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A revised Cretaceous and Tertiary lithostratigraphic nomenclature for the Norwegian North Sea

Edited by
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Oljedirektoratet
Desember 1989

CONTENTS

INTRODUCTION

Background

Deegan & Scull (1977) published a lithostratigraphic nomenclature for the central and northern North Sea. In early 1980 an initiative was taken by the exploration group of NIFO (the Norwegian Industrial Federation of Operating Companies) to consider a revision of the existing lithostratigraphy. The intention was to revise all the periods, but later it was decided to postpone work on the Cretaceous and Tertiary until the committees working on the Triassic and Jurassic had completed their task. The revised nomenclature for the Triassic and Jurassic of offshore Norway was published in 1984 (Vollset & Dore 1984).

In May 1987 the Norwegian Petroleum Directorate (NPD) proposed that the Cretaceous and Tertiary nomenclature should be revised. Den norske stats oljeselskap, Statoil, Norsk Hydro a.s. and Saga Petroleum a.s. were invited to participate in the work. The reason for inviting only these three operators was to keep the committees to a reasonable size.

Participation

The working party was organised as two committees, both chaired by Dag Isaksen from NPD (Mobil Exploration from 1.9.88). Kjetil Tonstad from NPD joined the group when Dag Isaksen left NPD, and the groups were later chaired by Kjetil Tonstad and Dag Isaksen in cooperation.

Cretaceous:
Jon Einar Tellefsen (Esso Norge from 1.10.88) and Erik Holtar from Norsk Hydro, Per Audun Hole, Kjell Sigve Lervik and Thorbjørn Monsen from Statoil, Bjørn Thorleif Gunnar Wandås and Stein Nybakken from Saga Petroleum, Dag Isaksen and Kjetil Tonstad from NPD.

Tertiary:
Anne Strømmen Lycke and Erik Holtar from Norsk Hydro, Kjell Sigve Lervik and Gro Kyllingstad from Statoil, Thomas Hardt from Saga Petroleum, Dag Isaksen and Kjetil Tonstad from NPD.

Valuable help and comments have been received from other geologists in Saga Petroleum, Norsk Hydro, Statoil and the Norwegian Committee on Stratigraphy (Norsk Stratigrafisk Komité). Foreign operators have commented on the text. In addition we have enjoyed valuable cooperation with the Geological Survey of Denmark (Danmarks Geologiske Undersøgelse) with regard to the Lower Cretaceous.

Editorial statement

This paper proposes major changes to the lithostratigraphy in the Norwegian sector. However, some parts of the nomenclature proposed by Deegan & Scull (1977) remain unaltered or only modified, and the work of those authors has sometimes been almost directly quoted.

The introduction and general notes on the Cretaceous and Tertiary have been written by the editors on the basis of contributions from committee members. The authors of the formal descriptions are listed in alphabetical order at the beginning of each of the two main sections.

LITHOSTRATIGRAPHIC PROCEDURES

General

The lithostratigraphic nomenclature presented is based on the guidelines of the International Subcommission on Stratigraphic Nomenclature (Hedberg 1976) and "Regler og råd for navnsetting av geologiske enheter i Norge" (Nystuen 1986).

The criteria used for selecting type and reference wells are completeness of section, quality of wire-line logs and availability of cores. Reference wells are also used to illustrate different developments and boundaries of formations.

In this paper we have named most new formations from Norse mythology or after Norwegian "Viking" kings. Formations that are already formally defined retain their names. The overall nomenclature may thus therefore appear heterogeneous.

We have limited the nomenclature to two categories of lithostratigraphic units, namely group and formation. We have, however, found it necessary to suggest some additional informal subdivisions (see General lithostratigraphic notes).

Presentation of data

The groups and formations are defined under the following headings: name, well type section, well reference section, thickness, lithology, basal stratotype, characteristics of the upper boundary, distribution, age and depositional environment.

The vertical scale on well logs in this report is 1:2000. Depths are given on all figures. All depths quoted are from RKB. All units defined in the paper are listed alphabetically at the front. The lithological legend is given in Fig. 1.

Illustrations also comprise distribution maps, seismic profiles and cross sections.

CHRONOSTRATIGRAPHIC FRAMEWORK

Ages referred to in the text are at stage level for the Cretaceous and series level for the Tertiary (Fig. 2) Boreal terminology is adopted for the latest Jurassic - earliest Cretaceous stages, using the Volgian as the final Jurassic stage and the Ryazanian as the initial Cretaceous one.

STRUCTURAL NOMENCLATURE

The structural features referred to in this paper are outlined on Fig. 3. Their names are suggested by a commitee working on structural geology (Brekke et al., in prep.) to become formalised.

GEOLOGICAL INTRODUCTION

To understand the Cretaceous and Tertiary development of the North Sea requires familiarity with the pre-Cretaceous geological history. The geological history of the North Sea is therefore briefly reviewed in this introduction. For more details see P.A. Ziegler (1981) and W. H. Ziegler et al. (1986).

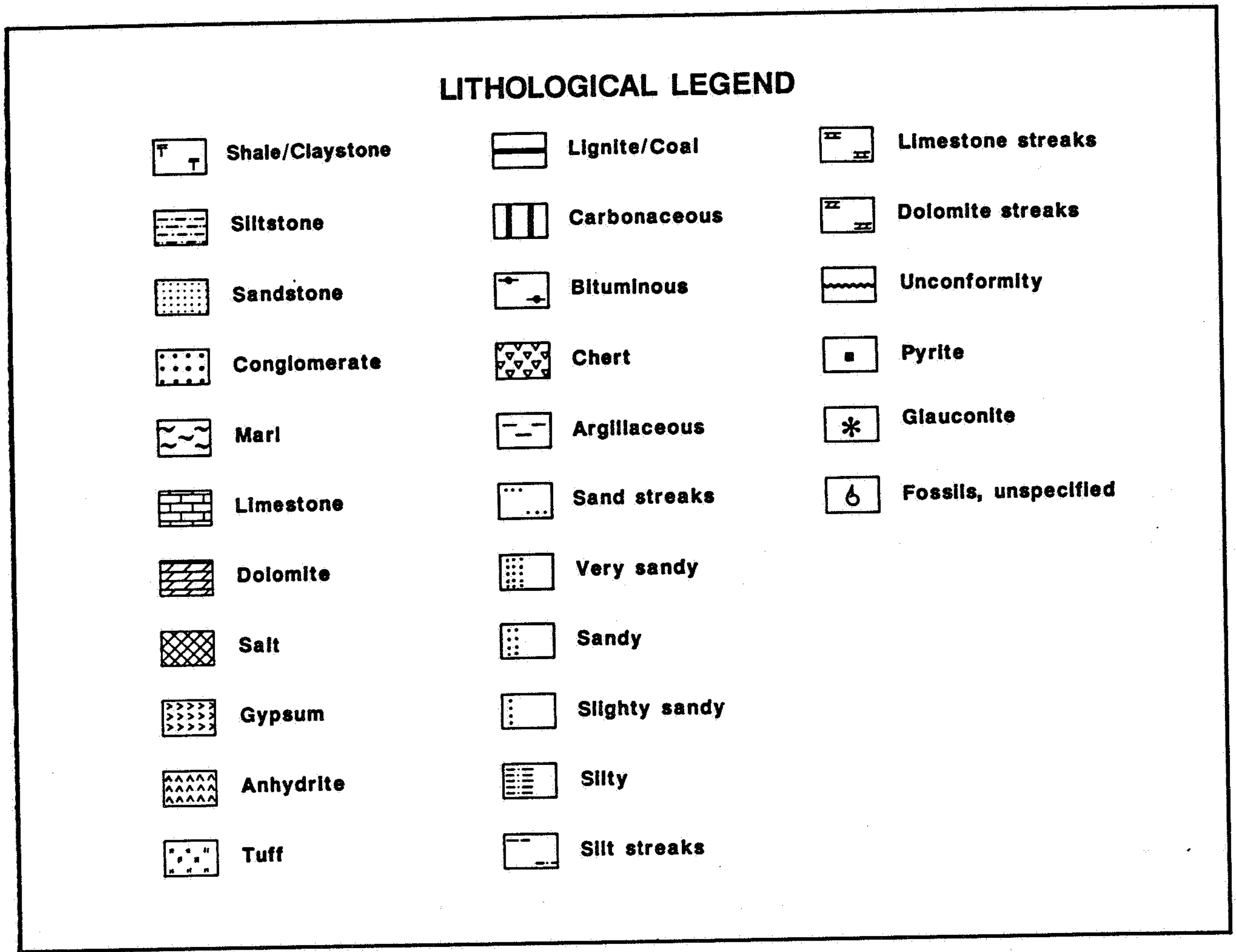


Fig. 1

CRETACEOUS

UPPER	MAASTRICHTIAN
	CAMPANIAN
	SANTONIAN
	CONIACIAN
	TURONIAN
	CENOMANIAN
LOWER	ALBIAN
	APTIAN
	BARREMIAN
	HAUTERIVIAN
	VALANGINIAN
	RYAZANIAN

TERTIARY/QUATERNARY

Quat	PLEISTOCENE
TERTIARY	PLIOCENE
	MIOCENE
	OLIGOCENE
	EOCENE
	PALEOCENE
	Danian

Stage nomenclature for Cretaceous and series nomenclature for the Tertiary and the Quaternary.

Fig. 2

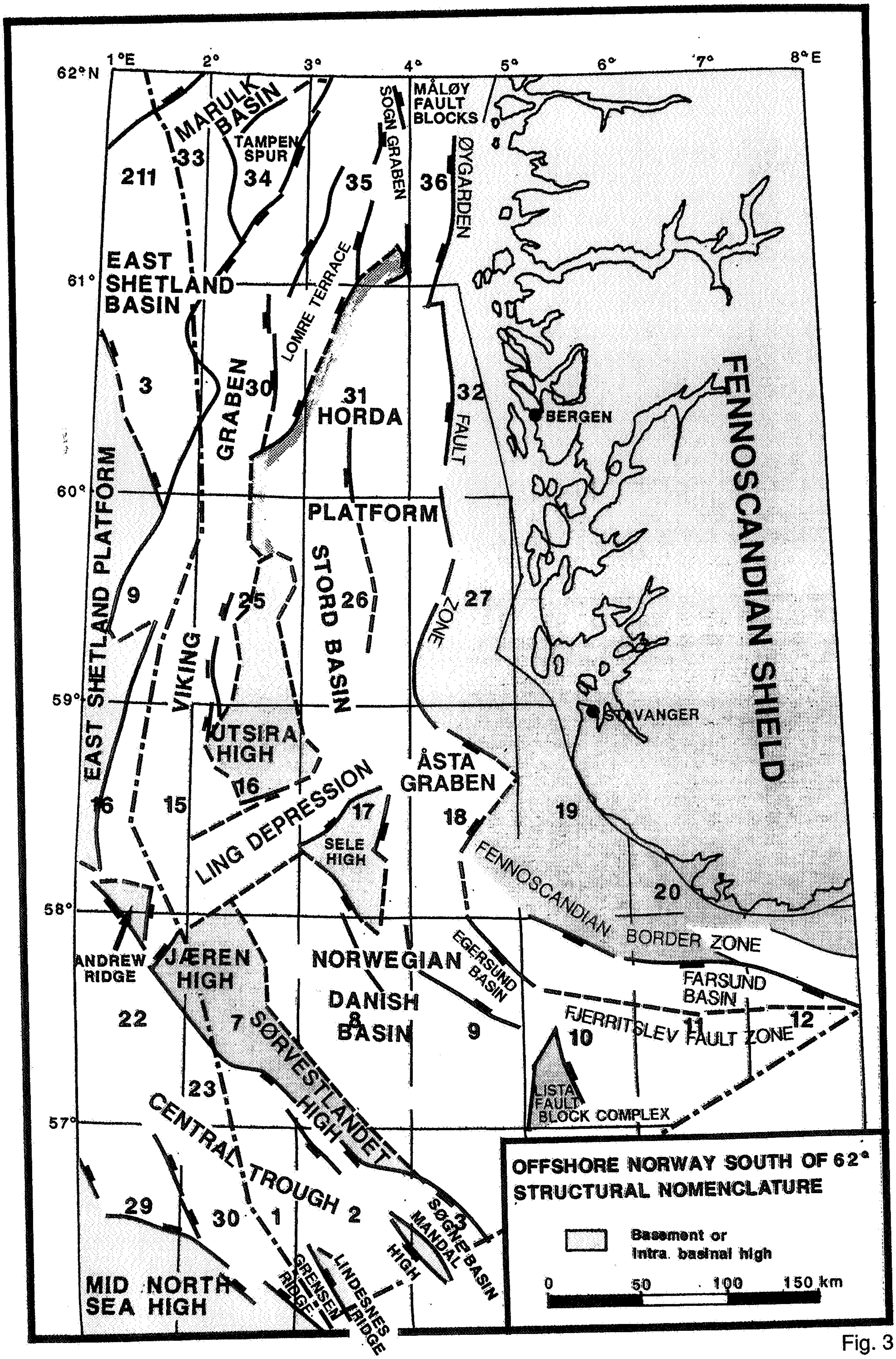

OFFSHORE NORWAY SOUTH OF 62°
STRUCTURAL NOMENCLATURE
Basement or
Intra. basinal high
0
50
100
150 km
MARULK BASIN
TAMPEN SPUR
SOGN GRABEN
MÅLØY FAULT BLOCKS
ØYGARDEN
EAST SHETLAND BASIN
LOMRE TERRACE
VIKING GRABEN
HORDA PLATFORM
FAULT ZONE
FENNOSCANDIAN SHIELD
BERGEN
STAVANGER
EAST SHETLAND PLATFORM
STORD BASIN
UTSIRA HIGH
ÅSTA GRABEN
LING DEPRESSION
SELE HIGH
FENNOSCANDIAN BORDER ZONE
ANDREW RIDGE
JÆREN HIGH
NORWEGIAN DANISH BASIN
EGERSUND BASIN
FARSUND BASIN
FJERRITSLEV FAULT ZONE
SØRVESTLANDET HIGH
LISTA FAULT BLOCK COMPLEX
CENTRAL TROUGH
SØGNE BASIN
MANDAL HIGH
GRENSEN RIDGE
LINDESNES RIDGE
MID NORTH SEA HIGH

Fig. 3

The Phanerozoic history can be divided into two major phases. The first phase is related to generation of the Pangaean supercontinent. In the North Sea region the Caledonian (Ordovician-Devonian) and Hercynian orogenies (Carboniferous-Permian) produced the major events during this phase.

During the Caledonian orogeny the collision between the Fennoscandian Baltic Shield and the Laurentian-Greenland Shield led to formation of compressional structural elements that were superimposed on older Precambrian structural trends. The Caledonian structural elements are typically directed northeast-southwest. They were reactivated during subsequent tectonic events.

The second major tectonic phase was associated with the break-up of the Pangaean supercontinent. In late Palaeozoic and early Triassic times tensional forces acted on the whole area and the supercontinent began to break up. The fragmentation culminated with the opening of the North Atlantic during the Tertiary. From Permian time onwards the area has been dominated by extension which produced grabens and other basins. Changes in sea level have been the main factor controlling the sedimentary processes.

A new and important structural feature developed in the North Sea during the Permian. The Mid North Sea High is a major east-west trending high dividing the North Sea area into a northern and a southern salt basin.

The Permian succession can generally be divided into a lower, sandy unit (Rotliegendes) and an upper unit (Zechstein) dominated by marine evaporites. These units can be recognised in the southern and central North Sea, but in the northern North Sea the nature of the Permian sediments is more uncertain. In the southern and central North Sea the salt sequences have been mobile since Triassic times, complicating the tectonic picture of the area.

In the Norwegian part of the North Sea the Triassic period was dominated by clastic sedimentation in a subsiding rift system. During the Jurassic and earliest Early Cretaceous the North Sea was affected by a series of earth movements in the Kimmerian tectonic episode. Rifting, with associated block faulting and erosion, took place in the later part of the Jurassic, and sedimentation was dominated by clastics.

CRETACEOUS

Basin evolution

A major phase of uplift and erosion producing the Late Kimmerian movements, took place across northwestern Europe during late Volgian to Ryazanian time. This resulted in widespread regression which formed isolated sedimentary basins where deposition took place under dominantly anaerobic, reducing bottom conditions (Rawson & Riley 1982). In these basinal areas sedimentation was continuous from Late Jurassic to Early Cretaceous. These sediments belong to the Draupne, Mandal and Flekkefjord Formations (Vollset & Doré 1984).

The regression culminated in the Middle-Late Ryazanian and affected the North Sea.

The Early Cretaceous was essentially a period of transgression with minor regressions. (Rawson and Riley 1982). The anaerobic conditions that dominated during the Late Volgian-Early Ryazanian regression ceased (Hesjedal & Hamar 1983). During the Valanginian to late Barremian times relatively quiet conditions dominated with sedimentation of shales and marls (Åsgard, Mime and Tuxen Formations, see Fig. 4).

During the transgression the sea covered progressively higher areas. Under these conditions condensed shallow-marine carbonates developed (Mime Formation). The present distribution of these limestones therefore reflects the subsidence pattern of the topographically higher features.

During Mid-Late Aptian times a regression occurred, which, together with movements along the North Sea rifts caused a change in lithology. In the basinal areas the claystones changed from calcareous rich to more organic rich (Sola Formation). Sandstones (Agat Formation and Ran sandstone units) were simultaneously deposited in some areas as submarine fans, due to erosion along the flanks of structural highs (Måløy Fault Blocks, Fladen Ground Spur/Andrew Ridge, Utsira High, Jæren High and Sele High).

The Mid-Late Aptian regressive event was followed by a regional transgression during Albian time. The sea flooded onto the structural highs, only the highest parts of which were exposed to erosion. Sandstone sequences (Agat Formation and Ran sandstone units) continued to be deposited along the flanks of structural highs as the sea encroached onto areas close to exposed Jurassic, Triassic or older sandy formations. The organic shales passed into a new fine-grained calcareous unit (Rødby Formation). The carbonate content continued to increase towards the end of the Albian.

A Late Albian-Early Cenomanian regressive event led to erosion and/or non-deposition of sediments along the flanks of structural highs. The Late Albian-Early Cenomanian sequences are very thin or absent in many wells.

The Upper Cretaceous sequence in the North Sea Basin was deposited in an open marine environment. In northwest Europe there was a general rise in relative sea level during the Late Cretaceous (Hancock & Kauffman 1979), although eustatic sea level on a global scale dropped overall during Turonian-Maastrichtian time (Haq et al. 1987). The Cretaceous subsidence in the Viking Graben and Central Trough has been related to lithospheric cooling after the Middle to Late Jurassic rifting phase (McKenzie 1978, Sclater & Christie 1980). This subsidence was increased by isostatic response to sediment loading (Beaumont & Sweeney 1978).

The Late Cretaceous was a quiet tectonic period. In the southern and central North Sea the supply of terrigenous material was reduced from the transition to the Cenomanian onwards, and pure carbonates were deposited (Shetland Group chalk facies).

In the northern North Sea the Late Cretaceous is dominated by a continuous, argillaceous and calcareous marine sequence (Shetland Group siliclastic facies).

It has been inferred that sedimentation rates somewhat exceeded the combined effects of subsidence and rising sea level in the Viking Graben (Ziegler 1982). Thus, water depth decreased gradually, though true shallow-water conditions were never established (Watts et al. 1980). During the Maastrichtian, the East

Shetland Basin and the Horda Platform were submerged and surrounding land areas comprised the Shetland Platform, Scotland, Norway and Greenland (Ziegler 1982, Hancock 1984).

General lithostratigraphic notes

The changes that have been made to the Cretaceous lithostratigraphy are documented in the group/formation definitions which follow. However, a brief summary of the principal revisions is given below.

Cromer Knoll Group:
The Valhall Formation, as defined by Deegan & Scull (1977), embraces all Lower Cretaceous sediments below the Rødby Formation in the Norwegian sector. The wealth of new data since the time of that publication allows several new formations to be separated from the Valhall Formation. Hesjedal & Hamar (1983) informally named some new formations (the Sola, Utvik, Klepp, Florø and Kopervik Formations) within the Valhall Formation. Jensen et al. (1986) formally defined two new formations (the Tuxen and Sola Formations), retaining the term Valhall Formation for the remnant of the original formation. In this report five formations are defined below the Rødby Formation: the Åsgard, Tuxen, Sola, Mime and Agat Formations. In addition the informal Ran sandstone units are described. An idealised development of the Cromer Knoll Group in the northern and central North Sea is shown in Fig. 4.

The Åsgard Formation consists of marly facies, and comprises the remainder of the original Valhall Formation after subdivision. According to Hedberg (1976), a previously established formation which is subdivided into new units must either be raised to group rank or abandoned. The old name should not be retained for any divisions of the original unit. Since the Cromer Knoll is well established as the group name for the Lower Cretaceous (also used on Haltenbanken by Dalland et al. 1988), we found it impractical to upgrade the Valhall Formation, and have therefore abandoned it.

The Sola Formation, which is part of the former Valhall Formation, was described and named, but not formally defined, by Hesjedal & Hamar (1983). Jensen et al. (1986) formally defined the formation. Even though the name conflicts with the rules laid down by Nystuen (1986), Sola being a village in Norway, it is retained in the Norwegian sector since the formation has already been defined in the Danish sector.

In their 1983 publication, Hesjedal & Hamar also informally named a basal limestone found in connection with structural highs, and called it the Utvik Formation. It is formally defined in this paper as the Mime Formation.

Sandstone intervals were developed in the vicinity of some structural highs at various times during the Early Cretaceous. Since it is uncertain how far they are related to each other we have found it expedient not to formally name individual sandstones. Their varying age also prohibits placing them as a member in one of the defined formations in the Cromer Knoll Group. We therefore propose to name them informally as the Ran sandstone units.

The Lower Cretaceous sandstones found in the Agat Field are thicker and can be correlated between wells. We have therefore given these sandstones formation status, the Agat Formation.

The Tuxen Formation defined by Jensen et al. (1986) is extended into the Norwegian sector.

Shetland Group:
The Shetland Group, as introduced by Deegan & Scull (1977), included the Upper Cretaceous siliciclastic sequence in the northern North Sea. The Shetland Group, as defined herein, has been expanded to include both the original Shetland Group and the former Chalk Group (Deegan & Scull 1977). There are several reasons for combining these Upper Cretaceous groups. The relationship between the Shetland and Chalk Groups was not properly established by Deegan & Scull (1977), owing to the limited data available at that time.

There is good correlation between the formation boundaries within the siliciclastic facies of the former Shetland Group in the northern North Sea and the chalk facies of the former Chalk Group in the central North Sea. Their boundaries are in chronostratigraphic accordance and there are great similarities in log patterns in the two regions despite the differences in lithological facies (Fig. 5).

Interfingering of the various lithologies and the presence of transitional lithologies have created difficulties in the transition zone between the two facies. Hence, it has been found most convenient to separate the facies on formation level. The previous formation subdivision has therefore been retained in the new Shetland Group.

With the amalgamation of the former Chalk and Shetland Groups, the term Chalk Group was discarded for two reasons. According to the rules for naming lithostratigraphic units, lithological terms should be avoided as unit names. The term Shetland Group was therefore chosen for the Upper Cretaceous sequence because it was already established in the northern North Sea and on the central and northern Norwegian Shelf (Dalland et al. 1988).

In the chalk facies area, no major changes have been proposed in the nomenclature used by Deegan & Scull (1977) except that the name "Plenus Marl Formation" has been changed to "Blodøks Formation", this name being used in both the chalk and siliciclastic facies areas. The term Plenus Marl Formation was renamed to accord with the rules for naming lithostratigraphic units, since fossil names should be avoided for stratigraphic units.

In the siliciclastic facies area, the informal subdivision proposed by Deegan & Scull (1977) has been formalised by defining the formations. The names Svarte, Blodøks, Tryggvason, Kyrre and Jorsalfare Formations have been introduced for the former Formations A, B, C, D and E. Formation D is equivalent to the Flounder Formation which is the name of the siliciclastic part of the former Chalk Group in the central part of the central North Sea (Fig. 6).

A new name, Hardråde Formation, has been introduced for the unit representing the Maastrichtian interval in the Shetland Group on the Horda Platform. The lower part of the group in this area is not formally subdivided. Although present in the Troll area, this lower part of the succesion has not been found in other wells on the Horda Platform. The development of the sequence here, also differs from that in the Viking

Idealised development of the Cromer Knoll Group in the Northern and Central North Sea.

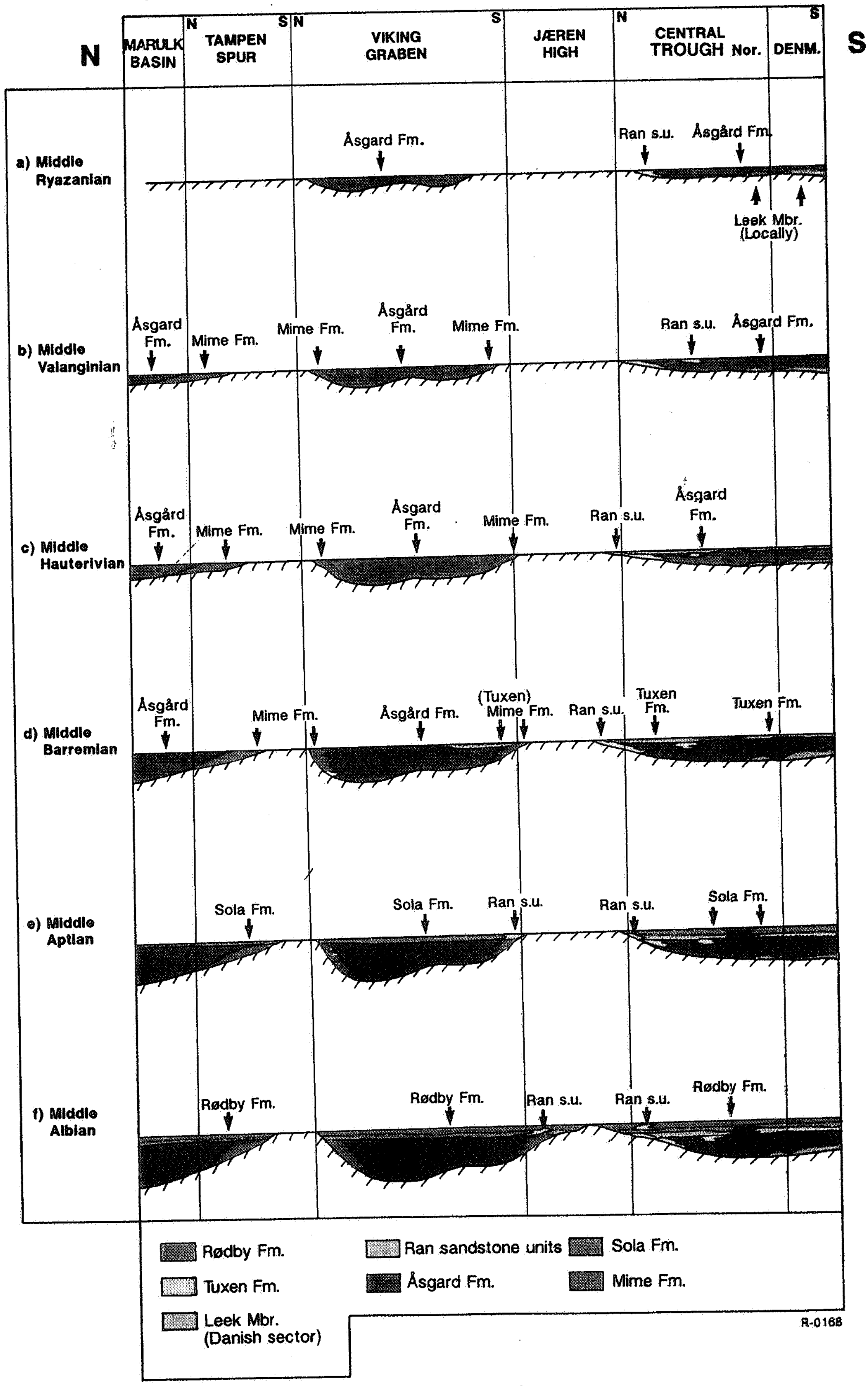


Fig. 4 **Development of the Cromer Knoll Group**

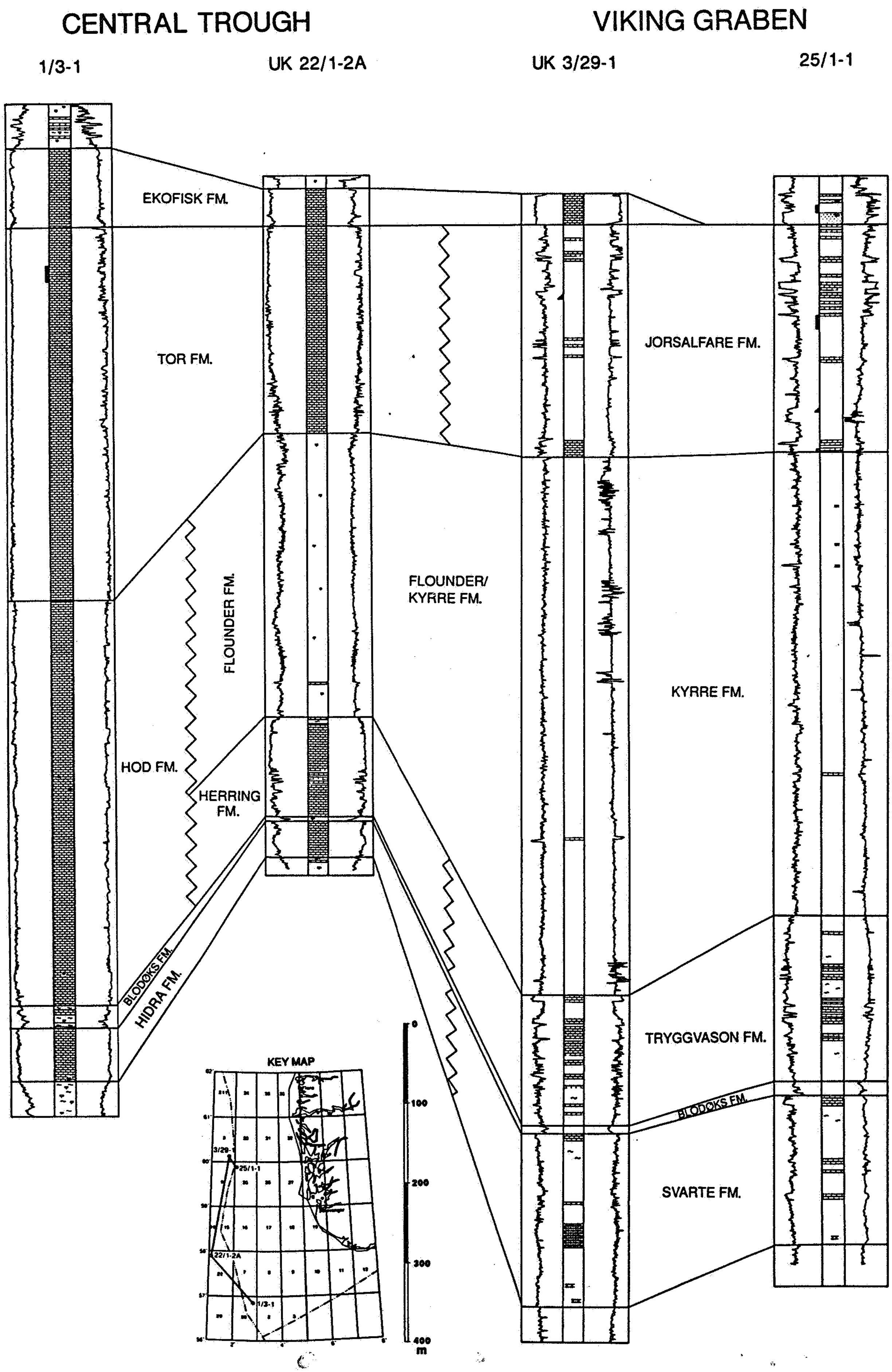


Fig. 5 **Well correlation in the Central trough and the Viking Graben**

SERIES	STAGE	Deegan & Scull (1977) Chalk Gp. W Central North Sea E	Deegan & Scull (1977) Shetland Gp. W Northern North Sea E	Present subdivision Shetland Gp. W Central North Sea E	Present subdivision Shetland Gp. W Northern North Sea E
Paleocene	Thanetian	Maureen Fm./ Unnamed unit		Lista / Våle / Maureen / Ty Fm.	
Paleocene	Danian	Ekofisk Fm.	Fm. F	Ekofisk Fm.	
Upper Cretaceous	Maastrichtian	Tor Fm.	Fm. E	Tor Fm.	Jorsalfare Fm. / Hardråde Fm.
Upper Cretaceous	Campanian	Flounder Fm. / Hod Fm.	Fm. D	Flounder Fm. / Hod Fm.	Kyrre Fm.
Upper Cretaceous	Santonian				
Upper Cretaceous	Coniacian				
Upper Cretaceous	Turonian	Herring Fm. / Hod Fm.	Fm. C	Herring Fm. / Hod Fm.	Tryggvason Fm. / Unspec.
		Plenus Marl Fm.	Fm. B	Blodøks Fm.	
Upper Cretaceous	Cenomanian	Hidra Fm.	Fm. A	Hidra Fm.	Svarte Fm. / Unspec.
L.Cret.	Albian	Valhall/Rødby Fm.	Unspec. unit	Rødby Fm.	

Fig. 6 **Comparison between the Deegan & Scull (1977) and the present subdivision.**

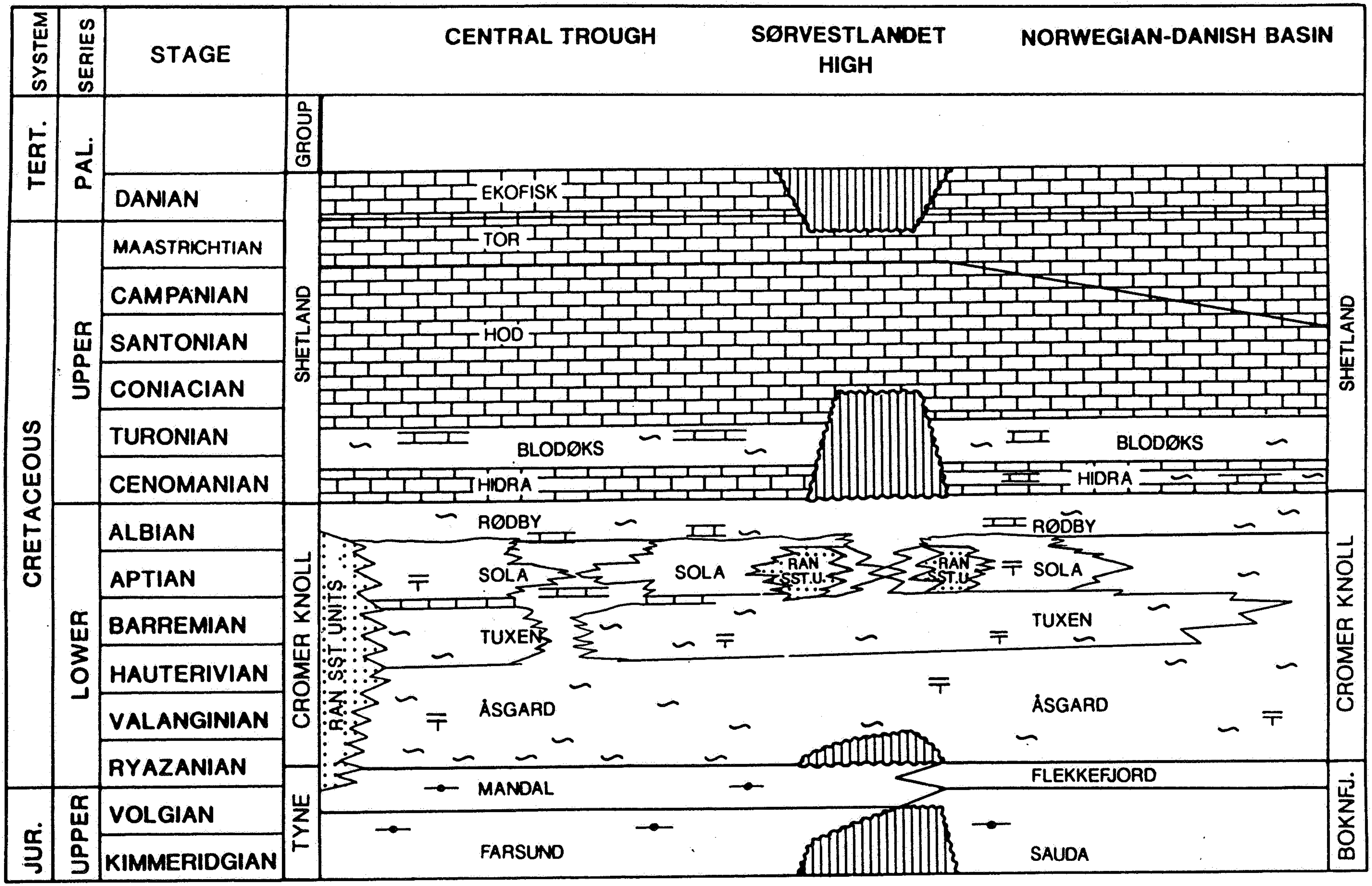


Fig. 7

CRETACEOUS LITHOSTRATIGRAPHIC NOMENCLATURE
NORWEGIAN NORTH SEA

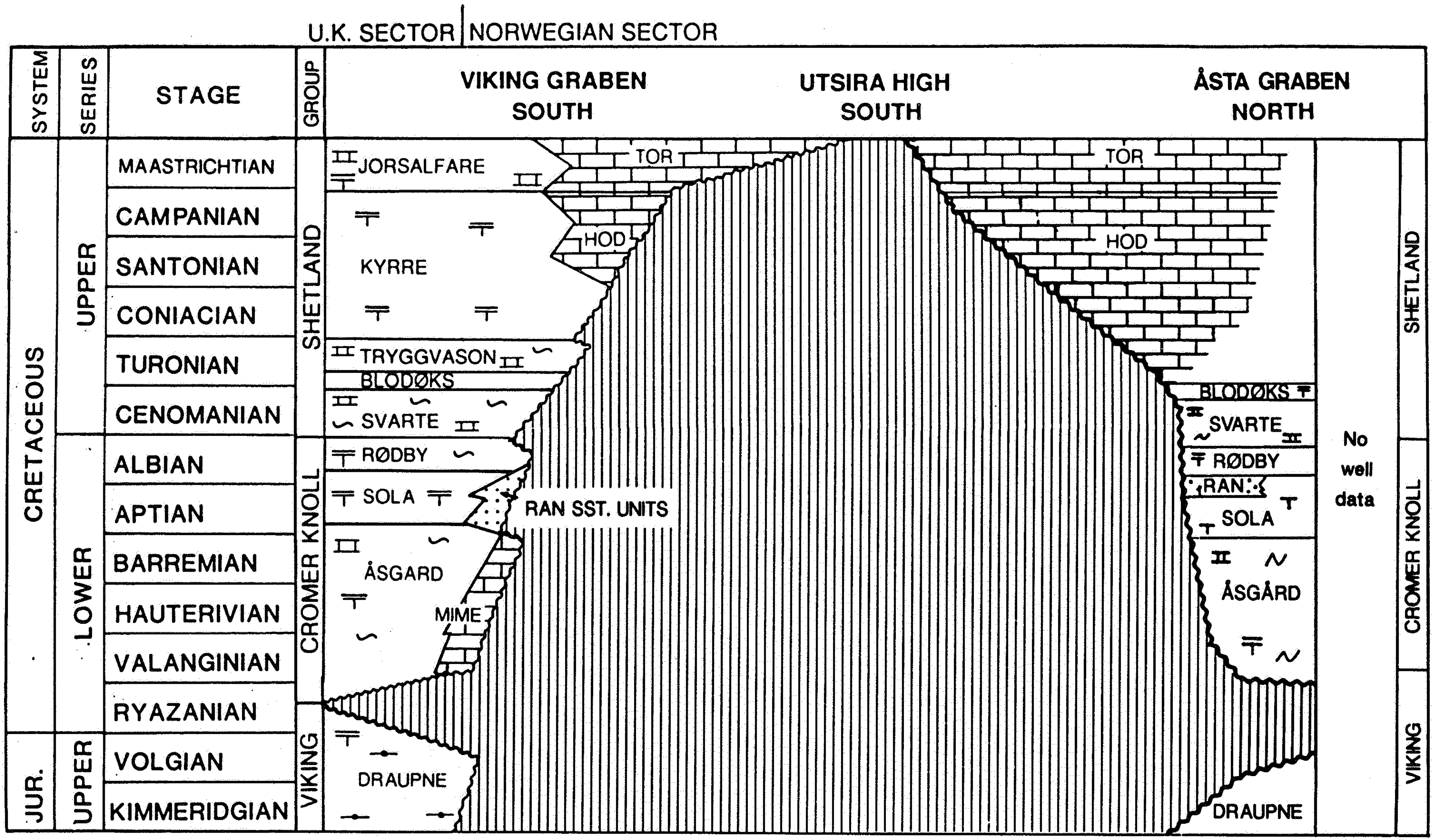


Fig. 8 CRETACEOUS LITHOSTRATIGRAPHIC NOMENCLATURE
NORWEGIAN NORTH SEA

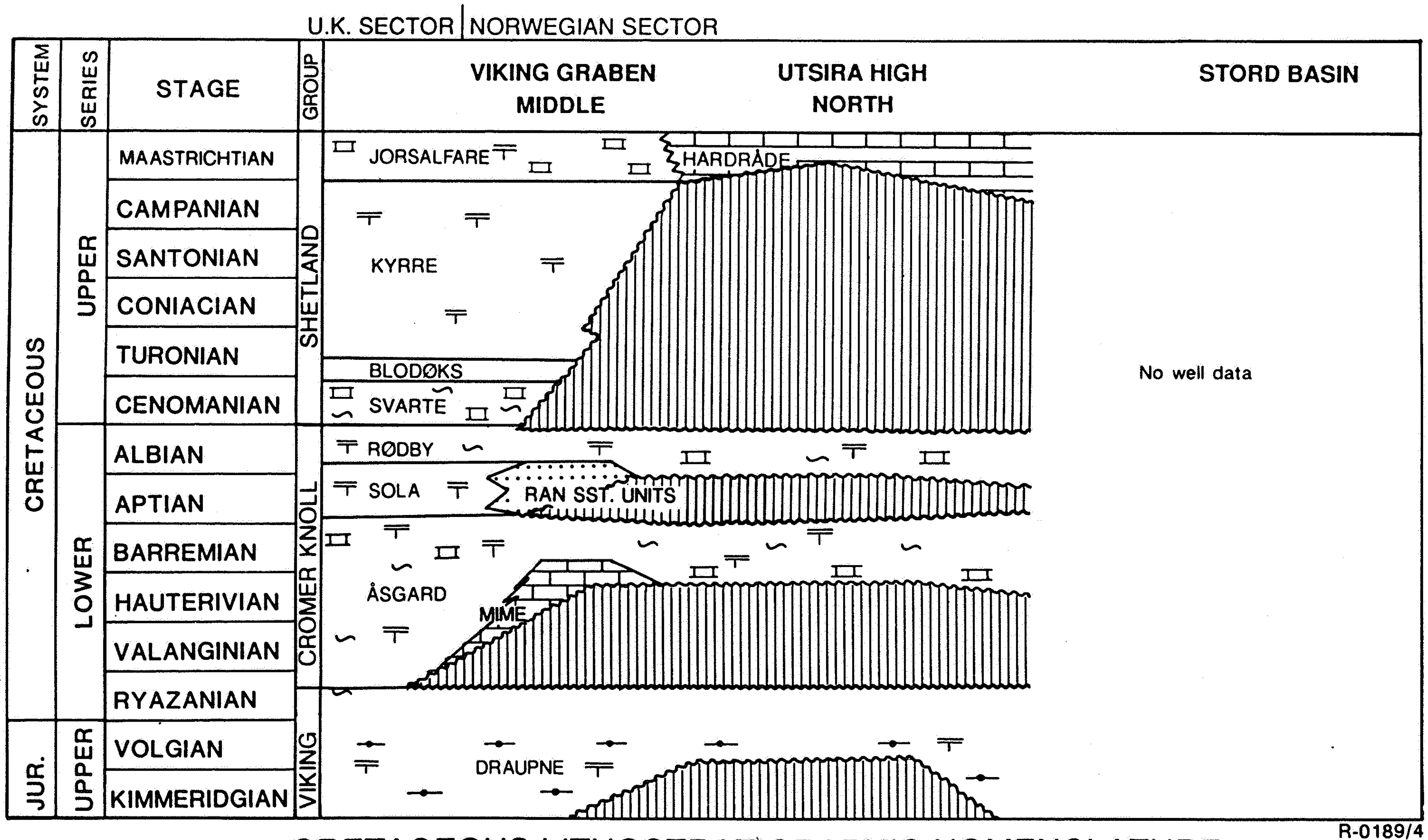


Fig. 9

CRETACEOUS LITHOSTRATIGRAPHIC NOMENCLATURE
NORWEGIAN NORTH SEA

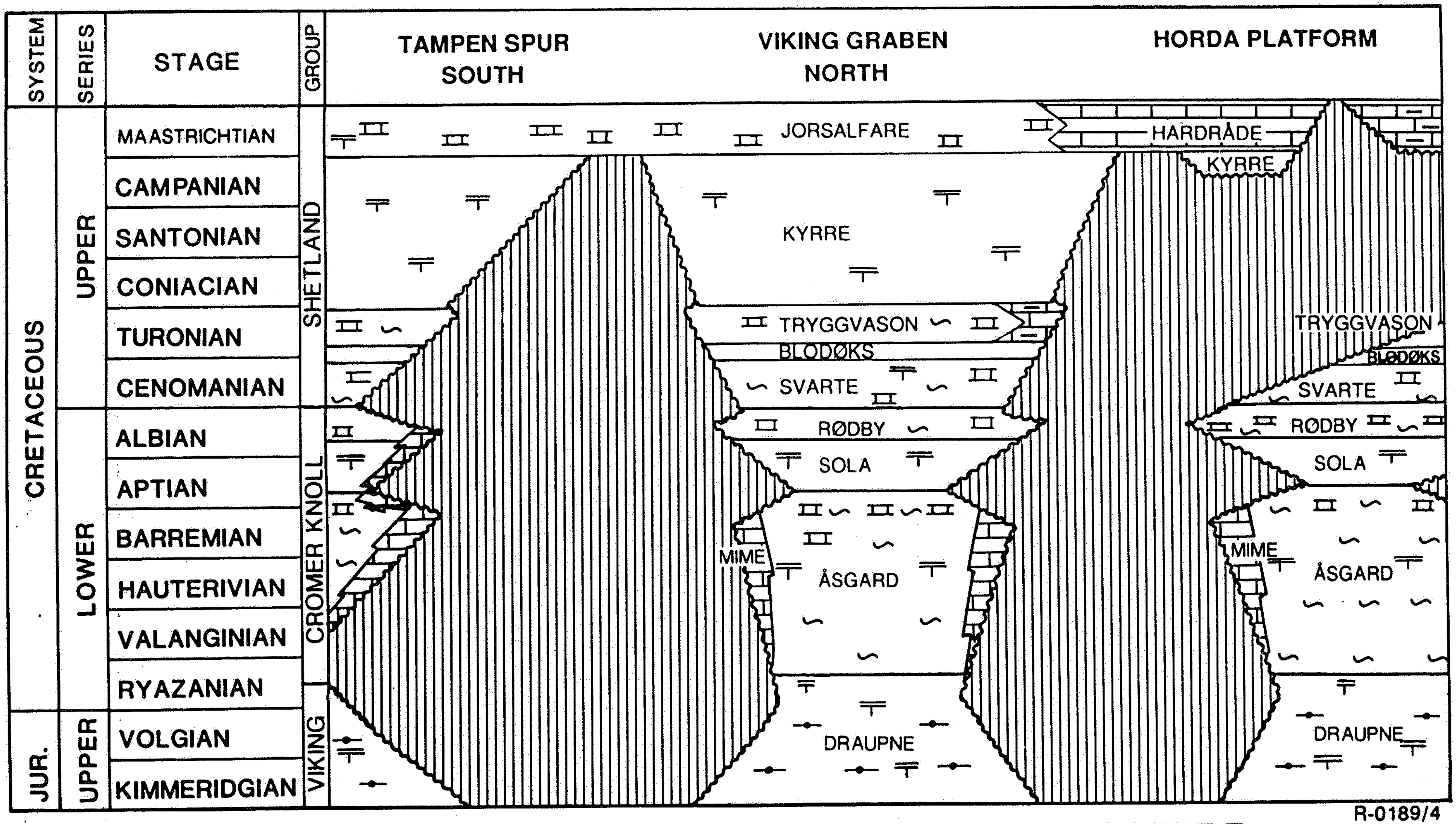


Fig. 10

CRETACEOUS LITHOSTRATIGRAPHIC NOMENCLATURE
NORWEGIAN NORTH SEA

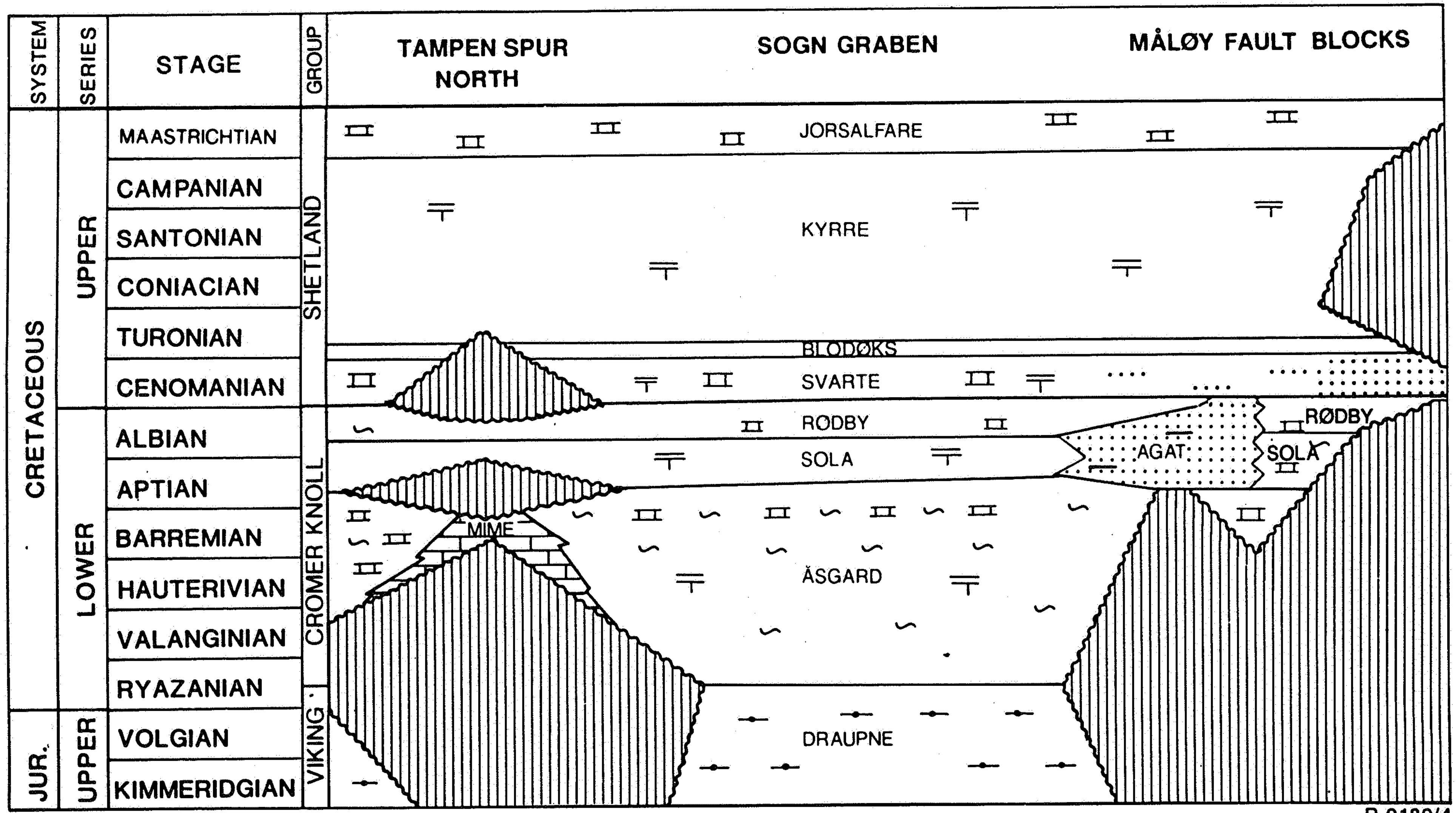


Fig.11 CRETACEOUS LITHOSTRATIGRAPHIC NOMENCLATURE
NORWEGIAN NORTH SEA

Graben and correlation is therefore difficult. More well data are needed before formal subdivision can be established.

REVISED CRETACEOUS LITHOSTRATIGRAPHY OF THE NORWEGIAN NORTH SEA
by P. A. Hole, E. Holtar, D. Isaksen, K. S. Lervik, T. Monsen, S. Nybakken, J. E. Tellefsen, K. Tonstad and B.T.G. Wandås.

Cromer Knoll Group (Cromer Knollgruppen)

Name:
From the Cromer Knoll buoy in the southern North Sea. Named by Deegan & Scull (1977).

Type area:
The type area is in the southern North Sea. Rhys (1974) used UK well 48/22-2 to illustrate a typical section of the group, and Deegan & Scull (1977) used UK wells 29/25-1, 22/1-2A and 3/29-1, and Norwegian well 2/11-1. The emphasis in this paper is on the Norwegian sector and the following Norwegian wells have been used to illustrate local developments of the group: 2/6-2, 2/7-15, 2/11-1, 7/3-1, 17/11-2, 34/10-18, 35/3-4, 35/3-5, 31/6-3, 24/12-2 and 17/4-1; the Danish well DK I-1 has also been used.

Thickness:
The thickness of the group varies considerably since the sediments were deposited in response to an active Late Jurassic tectonic phase. In the Viking Graben, the Åsta Graben and locally in the Central Trough the thickness is often more than 600 m, gradually thinning towards the basin margins. The group is 667 m thick in Norwegian well 2/11-1 and 643 m thick in Norwegian well 17/11-1. Seismic data indicate that the group is thickest in the Sogn Graben, where it probably reaches up to 1400 m.

Lithology:
The Cromer Knoll Group consists mainly of fine-grained, argillaceous, marine sediments with a varying content of calcareous material. Calcareous claystones, siltstones and marlstones dominate, but subordinate layers of limestone and sandstone occur. The claystones are generally light to dark grey, olive-grey, greenish and brownish, often becoming light grey, light greenish-grey and light olive-grey marlstones. Mica, pyrite and glauconite are common. Generally, marlstones become the more dominant lithology in both the upper and lower parts of the group.

Basal stratotype:
The lower boundary is usually well defined and is recognised by a distinct decrease in gamma-ray response and an increase in velocity when passing upward from the generally more organic-rich shales of the underlying Upper Jurassic formations (Figs. 12-14 and 22).

Characteristics of the upper boundary:
South of approximately 59° N (Fig. 32a), the upper boundary is the base of the chalk facies of the Shetland Group, defined by the onset of a decrease in gamma-ray response and an increase in velocity into the overlying carbonates (Figs. 12-15 and 22-28). The uppermost Rødby Formation of the Cromer Knoll Group often appears on logs as a transition between the overlying carbonates of the Shetland Group and the more argillaceous parts of the Cromer Knoll Group (Figs. 12 and 22). Further north, the upper boundary is the base of the siliclastic facies of the Shetland Group (Fig. 32a). This boundary is normally also shown by a decrease in gamma-ray response and an increase in velocity when passing into the overlying, generally more calcareous, Svarte Formation of the Shetland Group (Figs. 33 and 36). However, the opposite log response at the boundary is also observed (Fig. 37).

Distribution:
The group is widely distributed in the Norwegian sector of the North Sea. It is absent from the highest parts of the Mandal High, Jæren High, Utsira High and Lomre Terrace in the Troll area and locally from the Tampen Spur. (Figs. 7-11).

Age:
Ryazanian (usually late) to Albian/Early Cenomanian.

Depositional environment:
Open marine, with generally low energy.

Subdivision:
Six formations are defined within the group in the Norwegian sector (Figs. 7-11): the Åsgard (new), Tuxen (Jensen et al. 1986), Mime (new), Sola (Hamar & Hesjedal 1983; Jensen et al. 1986), Rødby and Agat (new) Formations. In addition we recognise a need to introduce the Ran sandstone units (new) (Figs. 7-11). Fig. 4 shows an idealised development of the Cromer Knoll Group in the northern and central North Sea.

Remarks:
The group was erected by Rhys (1974) to embrace three marine, arenaceous, argillaceous to marly formations of mainly Early Cretaceous age recognisable onshore and offshore. Deegan & Scull (1977) formally defined the group to include the sediments between the underlying Humber Group and Bream Formation and the overlying Shetland and Chalk Groups. Vollset & Doré (1984) replaced the Humber Group of the northern North Sea by the Viking Group, and the Bream Formation in the Central Trough and the Norwegian-Danish Basin by the Tyne and Boknfjorden Groups, respectively. The tops of the Draupne Formation of the Viking Group, the Mandal Formation of the Tyne Group and the Flekkefjord Formation of the Boknfjorden Group define the base of the Cromer Knoll Group.

The Cromer Knoll Group is partly equivalent to the Rijnland Group of the Dutch sector (NAM & RGD 1980, Crittenden 1982) and the Speeton Clay Formation together with the Red Chalk Formation of the UK sector (Rhys 1974). The subdivision in this paper can be used for the Danish sector (see also Jensen et al. 1986).

CRETACEOUS
WELL 2/11-1

REFERENCE WELL: ÅSGARD FORMATION, SOLA FORMATION, RØDBY FORMATION

(CROMER KNOLL GROUP)

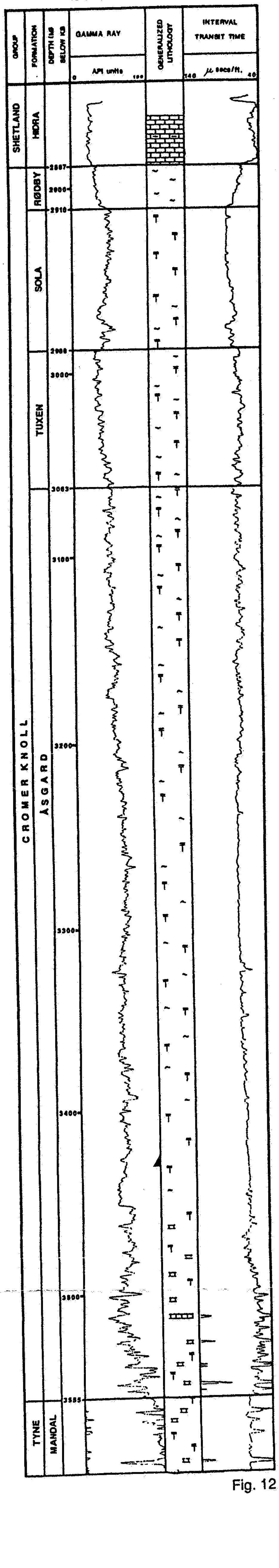


Fig. 12

CRETACEOUS
WELL 17/11-2

REFERENCE WELL: ÅSGARD FORMATION RAN SANDSTONE UNITS

(CROMER KNOLL GROUP)

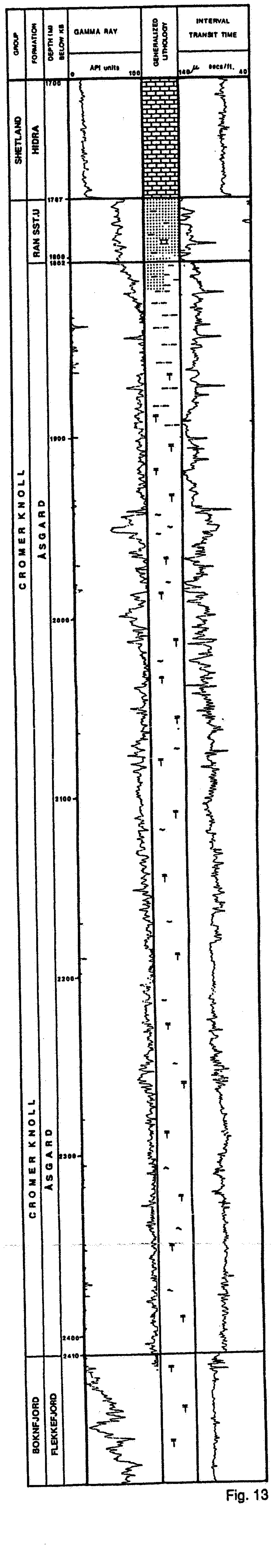


Fig. 13

CRETACEOUS
WELL DK I-1

TYPE WELL: SOLA FORMATION
TUXEN FORMATION

REFERENCE WELL : ÅSGARD FORMATION

(CROMER KNOLL GROUP)

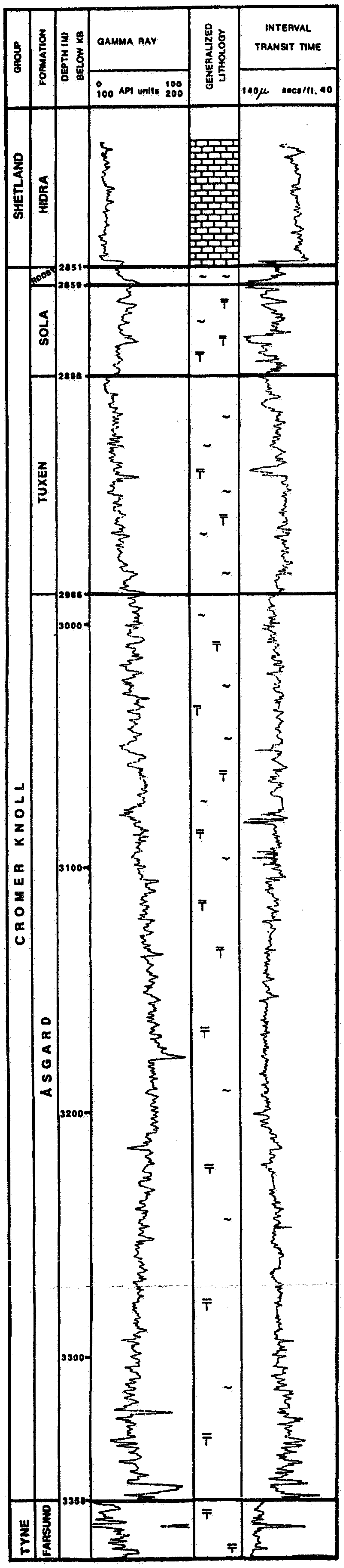


Fig. 14

CRETACEOUS
WELL 2/6-2

REFERENCE WELL: TUXEN FORMATION

(CROMER KNOLL GROUP)

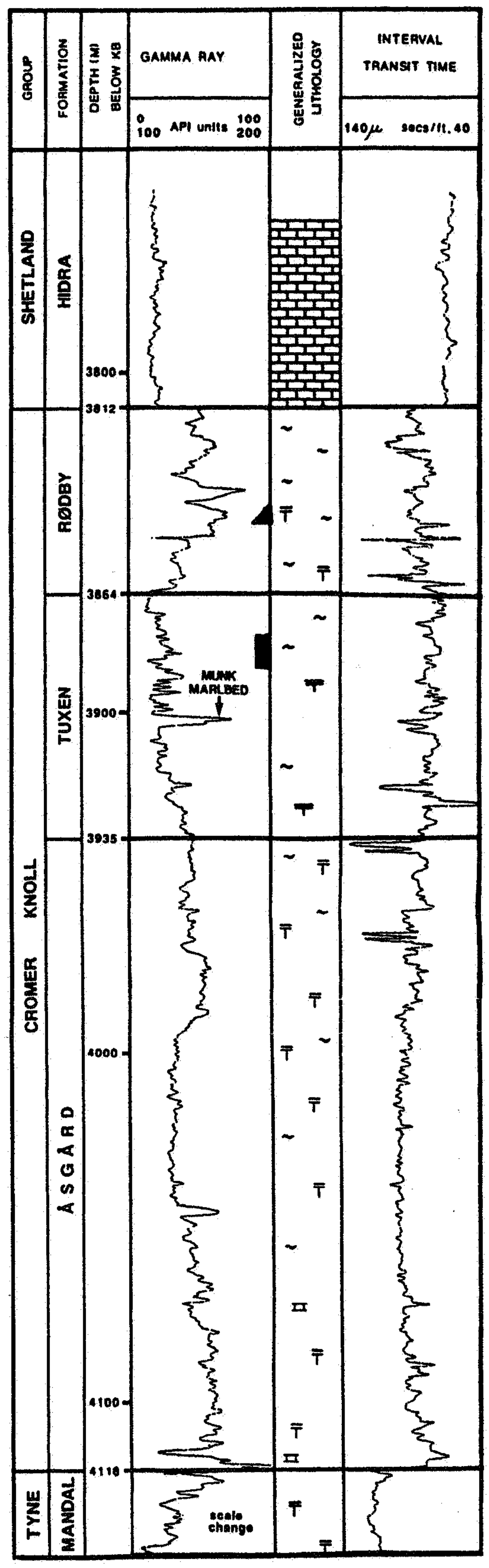


Fig. 15

Åsgard Formation (new) (Åsgardformasjonen)

Name:
Named from Norse mythology after the castle of the Norse gods, where Odin ruled.

Well type section:
Norwegian well 2/11-1 from 3555 to 3063 m, coordinates N 56°14'16.98", E 03°27'07.05" (Fig. 12). No cores.

Well reference sections:
Norwegian well 17/11-2 from 2410 to 1802 m, coordinates N 58°06'54.91", E 03°22'09.81" (Fig. 13). No cores.

Danish well I-1 from 3358 to 2986 m, coordinates N 56°03'10", E 04°14'60" (Fig. 14). No cores.

Thickness:
The formation is 492 m thick in the type well and 608 m thick in reference well 17/11-2. In the Central Trough area the thickness varies from a few metres to more than 500 m over short distances, showing the complex pattern of small, restricted Early Cretaceous basins. An even thicker sequence was penetrated in the Norwegian-Danish Basin, and especially in the Åsta Graben, where more than 700 m were encountered in well 17/12-3. The formation is thickest in the Sogn Graben where it is probably more than 1200 m, as indicated by seismic data.

Lithology:
The formation is dominated by light to dark grey, olive-grey, greenish and brownish, often calcareous claystones, and passes into light grey, light greenish-grey and light olivegrey marlstones and stringers of limestone. Mica, pyrite and glauconite are common. The claystones may be silty, and siltstones or very fine-grained sandstone layers or laminae are present. Where major sandstone layers occur they are regarded as belonging to the Ran sandstone units defined below. In a few Norwegian wells in the central North Sea (e.g. 1/9-3, 2/3-1, 2/7-2, 2/10-1, 2/11-1, 7/3-1, 7/8-2, 7/12-4, 7/12-5 and 8/1-1) a sequence of calcareous claystone, marlstone and limestone interbeds is recognised as the basal part of the Åsgard Formation (Figs. 12 and 14). This sequence is very difficult to correlate in the Norwegian sector, even over small distances, and is therefore regarded as representing local variations in the lowermost part of the Åsgard Formation. In the Danish sector this sequence is defined as the Leek Member (Jensen et al. 1986).

Basal stratotype:
The lower boundary is defined by a marked upward decrease in gamma-ray response and an increase in velocity in areas where the underlying sediments are slightly to non-calcareous, organic-rich claystones and shales, usually belonging to the Mandal, Flekkefjord, Tau or Draupne Formations (Figs. 15 and 22). Where the claystones and shales are less organic rich and more calcareous, the boundary may be more difficult to identify on logs.

Characteristics of the upper boundary:
The characteristics of the upper boundary vary with the overlying formations. Where the Tuxen Formation occurs, the boundary is defined by an upward decrease in the gamma-ray readings and an increase in velocity, reflecting slightly more calcareous claystones, marlstones and limestones compared with the underlying Åsgard Formation (Figs. 14 and 15). Where the Tuxen Formation is missing and the Sola Formation is deposited on the Åsgard Formation, the boundary is defined by an upward increase in gamma-ray readings and a decrease in velocity (Figs. 17, 18 and 23). If both the Tuxen and Sola Formations are missing, the boundary to the overlying Rødby Formation is defined by an upward decrease in gamma-ray readings and an increase in velocity. Locally, the Åsgard Formation is overlain by the Ran sandstone units (Fig. 22) and the Agat Formation (Figs. 19 and 20). This boundary is defined by an upward decrease in gamma-ray readings.

Distribution:
The Åsgard Formation is very widespread in the North Sea (Figs. 7-11), as are the partial equivalents in the Danish sector (Valhall Formation, Jensen et al. 1986; Vedsted Formation, Larsen 1966), British sector (Speeton Clay, Rhys 1974) and Dutch sector (Vlieland Shale Member, NAM & RGD 1980). In the Norwegian sector, the formation is absent from the highest parts of the Mandal, Jæren and Utsira Highs, the Lomre Terrace, the Troll area, Tampen Spur and locally over salt pillows and diapirs in the Central Trough and the Norwegian-Danish Basin.

Age:
Where the Tuxen Formation occurs, the Åsgard Formation ranges in age from Late Ryazanian to Late Hauterivian. In areas where neither the Tuxen nor Sola Formations are recognised, the Åsgard Formation represents a lateral equivalent and may reach Late Aptian to Early Albian age.

Depositional environment:
The formation was deposited in an open marine, low-energy shelf environment with well-oxygenated bottom water.

Remarks:
Deegan & Scull (1977) divided the Cromer Knoll Group into the Rødby and Valhall Formations. Several lithostratigraphic units have later been described in the Valhall Formation (Hesjedal & Hamar 1983, Jensen et al. 1986). The remaining claystones and marlstones of the originally defined Valhall Formation constitute the Åsgard Formation.

Tuxen Formation (Tuxenformasjonen)

Name:
Named by Jensen et al. (1986) from a bathymetric feature west of Blåvandshuk, the westernmost point of Jylland.

Well type section:
Danish well I-1 from 2986 to 2898 m, coordinates N 56°03'10", E 04°14'60" (Fig. 14). No cores.

Well reference sections:
Norwegian well 2/11-1 from 3063 to 2988 m, coordinates N 56°14'16.98", E 03°27'07.05" (Fig. 12). No cores.

Norwegian well 2/6-2 from 3935 to 3864 m, coordinates N 56°30'48.90", E 03°42'39.66" (Fig. 15). No cores.

Thickness:
The thickness of the formation varies from 1 m along structural highs to about 100 m in basinal areas. In the reference wells the thicknesses are 75 m (2/11-1) and 71 m (2/6-2). In the type well (I-1) the thickness is 88 m.

Lithology:
The formation is dominated by white to greyish-pink, calcareous claystones and marlstones. Along some of the structural highs the marlstones grade into purer limestones. Generally, the formation terminates vertically upwards with a chalk sequence containing subordinate marlstone layers. This chalk is white to pale orange or yellowish-grey, occasionally greenish and reddish. The marlstones are generally light grey to greenish-grey or olive-grey, but may be reddish-brown in some wells.

A 0.3-1 m thick, radioactive, marlstone bed is frequently encountered within the Tuxen Formation in the Danish sector where it is defined as the Munk Marl Bed (Jensen et al. 1986). This characteristic unit has also been recognised in some wells in the central Norwegian sector (e.g. 2/1-2, 2/1-3, 2/1-8, 2/6-2, 2/11-7, 6/3-1, 16/8-1 and 16/10-1), (see also Fig. 15). In the Norwegian sector, the Tuxen Formation above the Munk Marl Bed is often more calcareous than the rest of the sequence.

Basal stratotype:
The lower boundary is defined as the base of an upward decrease in gamma-ray readings and an increase in velocity, reflecting the passage from the slightly calcareous claystones of the underlying Åsgard Formation up into the more calcareous claystones and marlstones of the Tuxen Formation (Figs. 12, 14 and 15). The transition is generally gradual in basinal areas. Purer limestones were deposited along some structural highs, causing more distinct log breaks.

Characteristics of the upper boundary:
Upwards, the Tuxen Formation is generally in contact with the micaceous claystones and organic-rich shales of the Sola Formation (Figs. 12 and 14). This boundary is marked by an upward increase in gamma-ray readings and a decrease in velocity. Where the Sola Formation is missing, the Tuxen Formation is in contact with the marlstones of the overlying Rødby Formation (Fig. 15). The boundary is usually defined by an upward increase in gamma-ray readings.

Distribution:
The Tuxen Formation is widely distributed in the Norwegian and Danish sectors (Jensen et al. 1986). In the Norwegian sector it is developed in the Central Trough, along the Jæren High and in parts of the Norwegian-Danish Basin.

In basinal areas in the Norwegian sector it interfingers laterally with claystones and marlstones of the Åsgard Formation (Figs. 4 and 7).

CRETACEOUS
WELL 34/10-18

TYPE WELL: MIME FORMATION

(CROMER KNOLL GROUP)

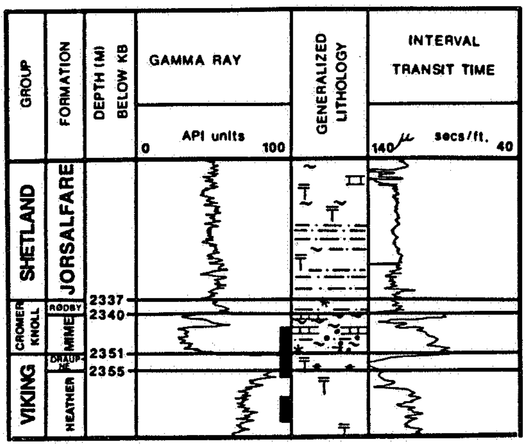


Fig. 16

CRETACEOUS
WELL 17/4-1

REFERENCE WELL: MIME FORMATION

(CROMER KNOLL GROUP)

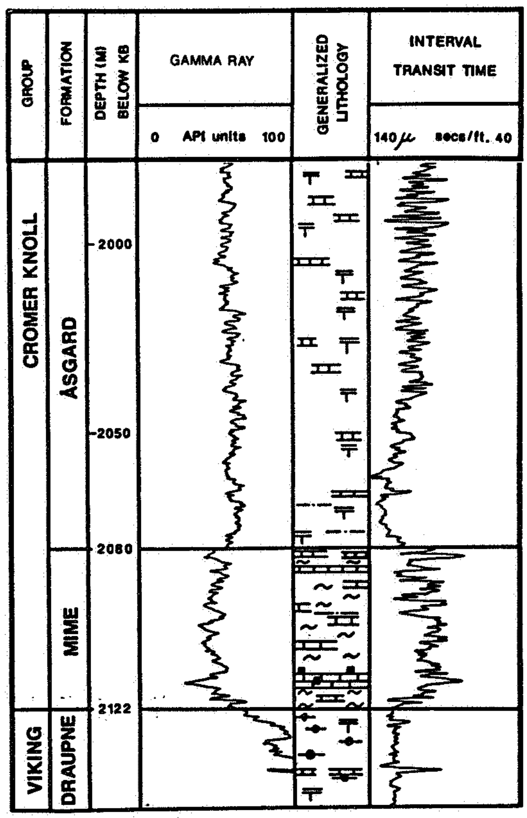


Fig. 17

Age:
Late Hauterivian to Late Barremian (Heilmann-Clausen 1987, Thomsen 1987).

Depositional environment:
Deposition was dominated by pelagic marl and chalk oozes, which covered large areas of the North Sea. The bottom waters were mainly well oxygenated (Jensen et al. 1986).

Mime Formation (new) **(Mimeformasjonen)**

Name:
Named after a god from Norse mythology who was considered to be very wise.

Well type section:
Norwegian well 34/10-18 from 2351 to 2340 m, coordinates N 61°14'22.48", E 02°03'18.83" (Fig. 16). Cores (lower half of the formation).

Well reference section:
Norwegian well 17/4-1 from 2122 to 2080 m, coordinates N 58°35'54.00", E 03°16'05.00" (Fig. 17). No cores.

Thickness:
In the type well the Mime Formation is 11 m, and in the reference well it is 42 m thick. Usually, the thickness varies between 5 and 20 m.

Lithology:
The formation is dominated by limestones and marls. It often contains impure carbonates that are reworked and mixed with smaller quantities of sand and silt. The formation is sometimes chalky. The matrix is usually very calcareous. Oolites are observed in some wells in the East Shetland Basin. The colour is usually white or light pink, but may vary slightly on account of the sand/silt mixture.

Basal stratotype:
In those wells where the Mime Formation is present it defines the lower boundary of the Lower Cretaceous, lying on the Upper Jurassic sediments or older rocks. This boundary is always an unconformity and can most often be seen on the logs as a decrease in gamma-ray readings and an increase in velocity upwards from the underlying Jurassic sediments.

Characteristics of the upper boundary:
The upper boundary is usually defined at the bottom of more or less calcareous shales in the Åsgard Formation. This boundary is reflected on the logs as an upward increase in gamma-ray readings and a reduction in velocity (Fig. 17). The upper boundary can also be defined by the overlying shales of the Sola or Rødby Formations. The boundary will normally be reflected on logs as described above (Fig. 16).

Distribution:
The formation is found only as narrow zones along structural highs. On the flanks of the Viking Graben it may be seen almost continuously from approximately 58° to 62° N. It is also found as a thin carpet over most of the East Shetland Basin and along the Fladen Ground Spur, the Utsira High-Lomre Terrace, the northwest side of the Sele High, and the Jæren High. The formation is not encountered in the more central parts of the basins, and it is doubtful if it is present along the boundaries of the Fennoscandian Shield.

Age:
The formation is time-transgressive, and is dated to Late Valanginian to Albian. It is oldest in the deeper parts along the basin margins and becomes younger up along the flanks. In most of the East Shetland Basin, along the Utsira, Bergen, Sele and Jæren Highs, and along the flanks of the Viking Graben, it is usually of Barremian/Hauterivian age (Fig. 4).

Depositional environment:
Palaeontological investigations together with the observation of oolites indicate a transgressive, shallow marine, depositional environment.

Remarks:
Hesjedal & Hamar (1983) described the impure, reworked limestones resting directly on the Base Cretaceous unconformity over the structural highs, as the Utvik Formation. This formation is formally defined as the Mime Formation in this paper, since the name suggested was not in accordance with existing recommendations.

Sola Formation (Solaformasjonen)

Name:
Informally named by Hesjedal & Hamar (1983) after a village in southwestern Norway. Formally named by Jensen et al. (1986).

Well type section:
Danish well I-1 from 2898 to 2859 m. Coordinates N 56°03'10", E 04°14'60" (Fig. 14). No cores.

Well reference sections:
Norwegian well 2/11-1 from 2988 to 2910 m, coordinates N 56°14'16.98", E 03°27'07.05" (Fig. 12). No cores.

Norwegian well 24/12-2 from 4043 to 3985 m, coordinates N 59°12'00.75", E 01°52'53.34" (Fig. 18). No cores.

Thickness:
The thickness in the type well is 39 m, and in reference well 2/11-1 it is 78 m. It generally varies between 20 m and 200 m. The formation is thick in the Viking Graben and Åsta Graben, and thin in the East Shetland Basin and parts of the Fiskebank Sub-Basin.

Lithology:
The Sola Formation consists of shales interbedded with stringers of marlstone and limestone. The carbonate content is lower than that in the underlying Tuxen and Åsgard Formations and the overlying Rødby Formation. The colour is black or dark grey, but olive-grey, brown and red colours occur. The shales are finely laminated and often very pyritic.

Basal stratotype:
The lower boundary is usually placed on the Tuxen or Åsgard Formations (Figs. 12, 14, 17 and 18). Generally, the gamma-ray response increases and the velocity decreases from the calcareous and sandy sedi-

CRETACEOUS

WELL 24/12-2

REFERENCE WELL: SOLA FORMATION
(CROMER KNOLL GROUP)

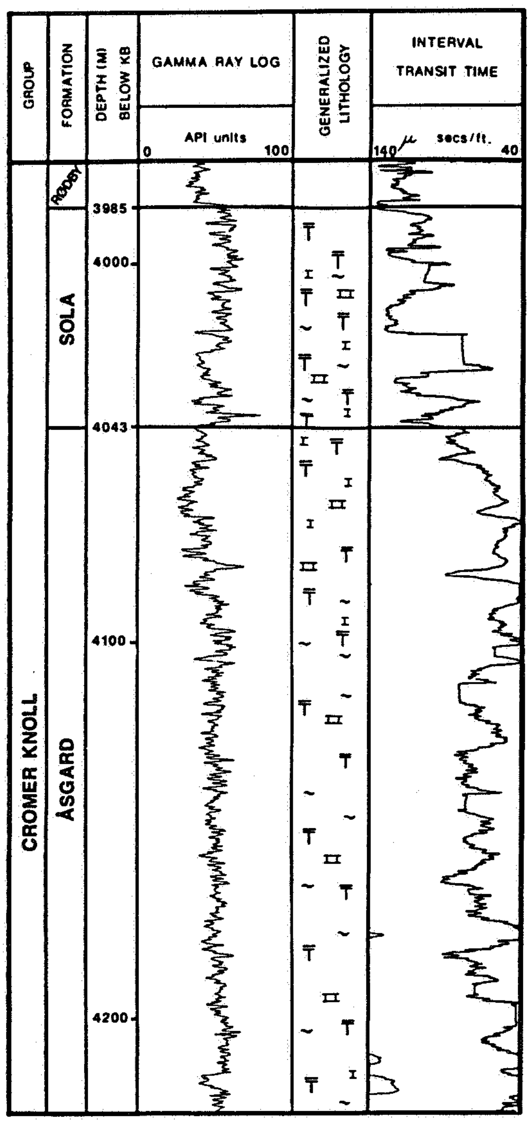


Fig. 18

ments up into the shaly and organic rich Sola Formation. In some wells in the east, on the Horda Platform, the gamma-ray response does not increase when the boundary from the Åsgard Formation up into the Sola Formation is crossed. In such wells, a lower, more stable velocity identifies the Sola Formation.

Characteristics of the upper boundary:
The upper boundary is most often placed where the carbonate content starts to increase rapidly into the overlying Rødby Formation (Figs. 12, 14, 18, and 22). In some areas where, the Sola Formation is overlain by the Ran sandstone units (Fig. 23), the boundary is defined by an upward decrease in gamma-ray response and an increase in velocity.

Distribution:
The formation is widespread in the North Sea. It is absent or thin on structural highs, salt-induced structures and in parts of the Central Trough and Norwegian-Danish Basin.

Age:
The Sola Formation is of Mid Aptian-Early Albian age. A possible Middle (Late) Barremian-Albian age is recorded from Danish wells (Heilmann-Clausen 1986).

Depositional environment:
The Sola Formation was deposited in a marine environment with alternating anoxic and oxic bottom conditions. Hesjedal & Hamar (1983) suggested that the formation was deposited during a regressive period, while Rawson & Riley (1982) held the opposite view.

Rødby Formation (Rødbyformasjonen)

Name:
Named by Larsen (1966) after a town on the island of Lolland in southern Denmark.

Well type section:
The Danish well Rødby-1 drilled on the island of Lolland (Larsen 1966).

Well reference sections:
Norwegian well 2/11-1 from 2910 to 2887 m, coordinates N 56°14'16.98", E 03°27'07.05" (Fig. 12). No cores.

Norwegian well 2/7-15 from 3419 to 3401 m, coordinates N 56°23'46.82", E 03°18'54.63" (Fig. 22). No cores.

Thickness:
In the well type section the thickness is 23 m. The thicknesses in the reference sections are 23 m in well 2/11-1 and 18 m in well 2/7-15. The formation generally ranges in thickness between 15 and 30 m. In the Viking Graben it may reach thicknesses of more than 200 m (Deegan & Scull 1977).

Lithology:
Mainly red-brown marlstones, but green and grey colours may occur. Glauconite and pyrite may be present. Sandstones and siltstones are known to be present locally.

Basal stratotype:
The lower boundary is placed on the Sola and Åsgard Formations and the Ran sandstone units, and represents an upward decrease in gamma-ray response and usually an increase in velocity into the Rødby Formation (Figs. 12, 22 and 23).

Characteristics of the upper boundary:
The upper boundary can be seen as an upward decrease in gamma-ray response and a increase in velocity when going into the more calcareous sediments of the Svarte Formation (Figs. 33-36). On the Horda Platform the Rødby Formation is more calcareous and has a lower gamma-ray response and a higher velocity than the overlying unspecified unit of the Shetland Group (Fig. 37). Where the chalk facies of the Shetland Group is present, the upper boundary is characterised by a distinct upward drop in gamma-ray readings and a marked increase in velocity (Figs. 12, 15, 22-28).

CRETACEOUS
WELL 35/3-4

TYPE WELL: AGAT FORMATION

(CROMER KNOLL GROUP)

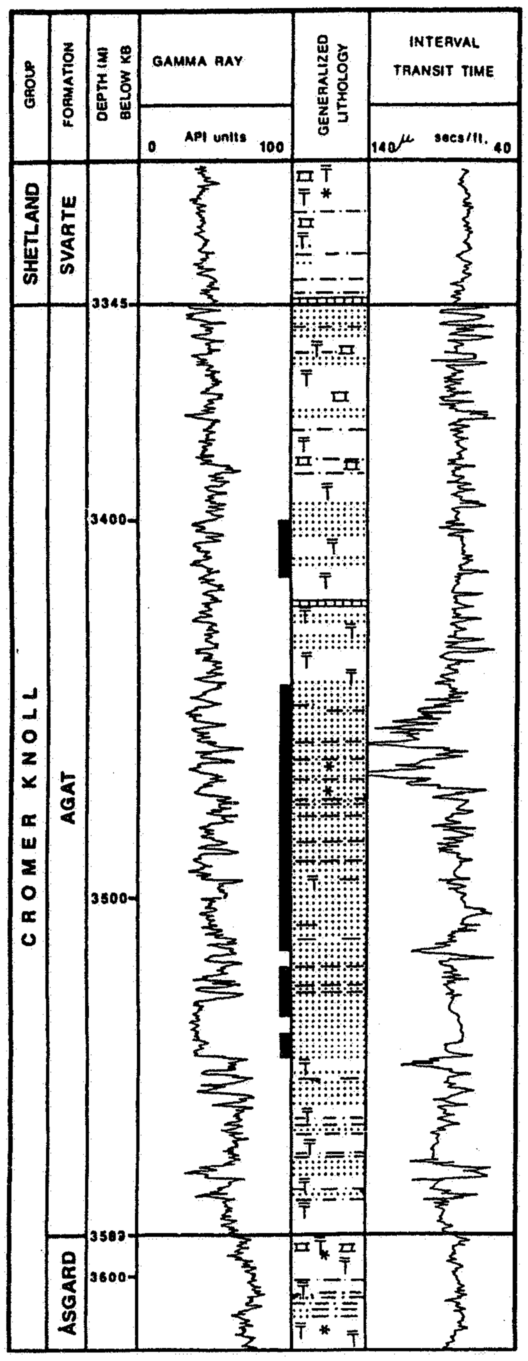


Fig. 19

CRETACEOUS
WELL 35/3-5

REFERENCE WELL: AGAT FORMATION

(CROMER KNOLL GROUP)

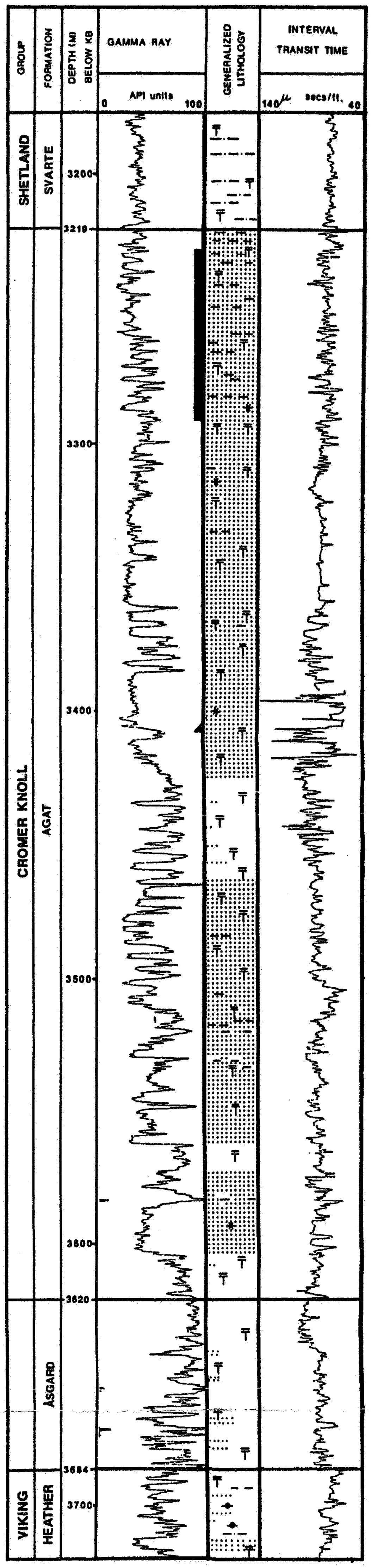


Fig. 20

Distribution:
The formation is widespread in the North Sea, but are missing locally on the Utsira, Jæren and Mandal Highs, Tampen Spur and Horda Platform on the Norwegian sector.

Age:
The formation is of Albian age (locally Early Cenomanian in the Danish sector (Jensen et al. 1986)).

Depositional environment:
The Rødby Formation was deposited as generally reddish sediments in an open marine, oxygenated environment with limited supply of clastics.

Agat Formation (new) **(Agatformasjonen)**
Name:
Named after the gas-condensate Agat Field in Norwegian block 35/3.

Well type section:
Norwegian well 35/3-4 from 3589 to 3345 m, coordinates N 61°51'54.54", E 03°52'26.99" (Fig. 19). 95 m of cores, mainly from the lower half of the formation.

Well reference section:
Norwegian well 35/3-5 from 3620 to 3219 m, coordinates N 61°47'46.71", E 03°54'44.01" (Fig. 20). 65 m of cores from the upper part of the formation.

Thickness:
In the type well the gross thickness of the formation is 244 m, and in the reference well 401 m. The gross thickness varies in that range in the 35/3 wells.

Lithology:
In the type well the formation consists of white to light grey, fine- to medium-grained, moderately to well-sorted sandstones alternating with grey claystones. The sandstones are usually micaceous and glauconitic and sometimes contain small amounts of pyrite. The sandstones in the type well are carbonate- and silica-cemented in zones. In the reference well, the upper part of the formation consists of medium- and coarse-grained to pebbly sandstones and conglomerates alternating with dark grey claystones. The conglomerates are both matrix- and grain-supported. The claystones are often found as 0.5-5 m thick layers between the sandstones. They are dark grey, usually calcareous and contain varying amounts of siltstone. They may occasionally pass into light grey, micaceous, calcareous and glauconitic siltstones.

Basal stratotype:
The lower boundary is defined where sandstones become the dominant lithology and is placed at the base of the first marked coarsening-upwards sandstone unit or distinct sand body. On logs it shows as an upward reduction in gamma-ray response (Figs. 19 and 20) and most often an increase in velocity (Fig. 20).

Characteristics of the upper boundary:
The upper boundary is placed at the top of the upper sandstone layer. This boundary is especially distinct on the gamma-ray log since the overlying sediments are dominated by calcareous shales with a low sandstone content. The overlying sediments are represented either by the Rødby Formation (well 35/3-1 and 2), or by the Svarte Formation (wells 35/3-4 and 5), (Figs. 19 and 20).

Distribution:
The formation is encountered in the area around the Måløy Fault Blocks in Norwegian blocks 35/3-36/1 (Fig. 21) and is expected to be present along the western boundary of the Fennoscandian Shield. It is assumed to pass into shales towards the west (Fig. 21).

Age:
Aptian-Albian (possibly Early Cenomanian).

Depositional environment:
Marine environment influenced by gravity flows of sediment.

Remarks:
Hesjedal & Hamar (1983) named the sand lobes and distal fandelta sands in the Agat Field, and a possible elongation (or similar development) along the Øygarden Fault Zone, as the Florø Formation. This formation is formally defined as the Agat Formation in this paper, since the name suggested does not conform with existing recommendations.

Ran sandstone units (new) **(Ransandsteinsenhetene)**
Name:
Ran was the wife of the sea god Gir in Norse mythology. She liked to drag sailors down to the depths with her net.

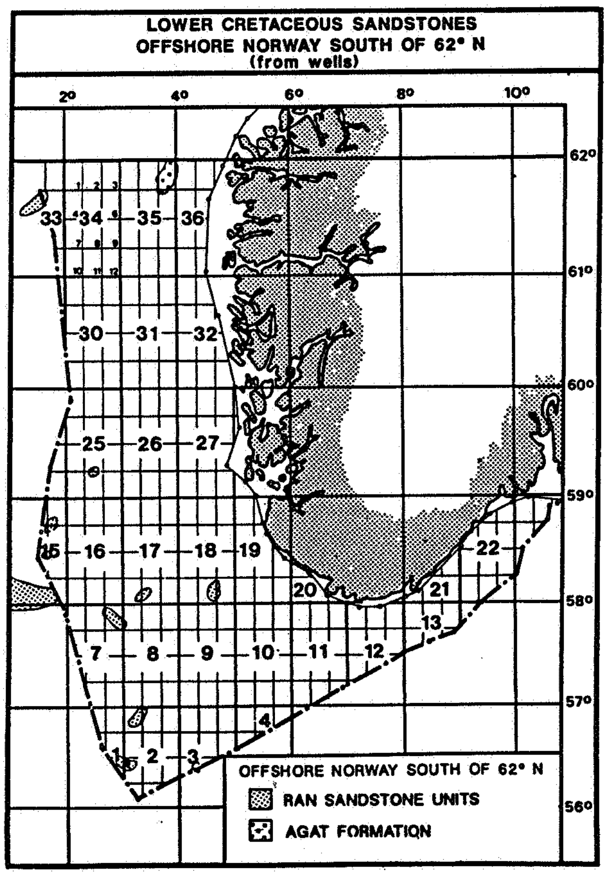


Fig. 21

Well type section:
None.

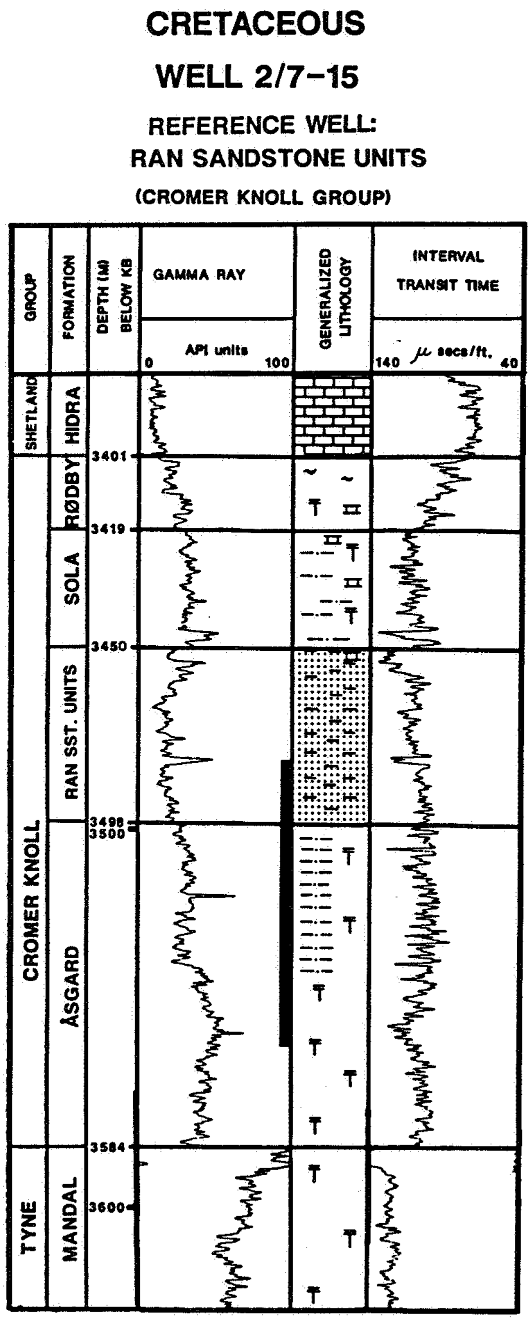


Fig. 22

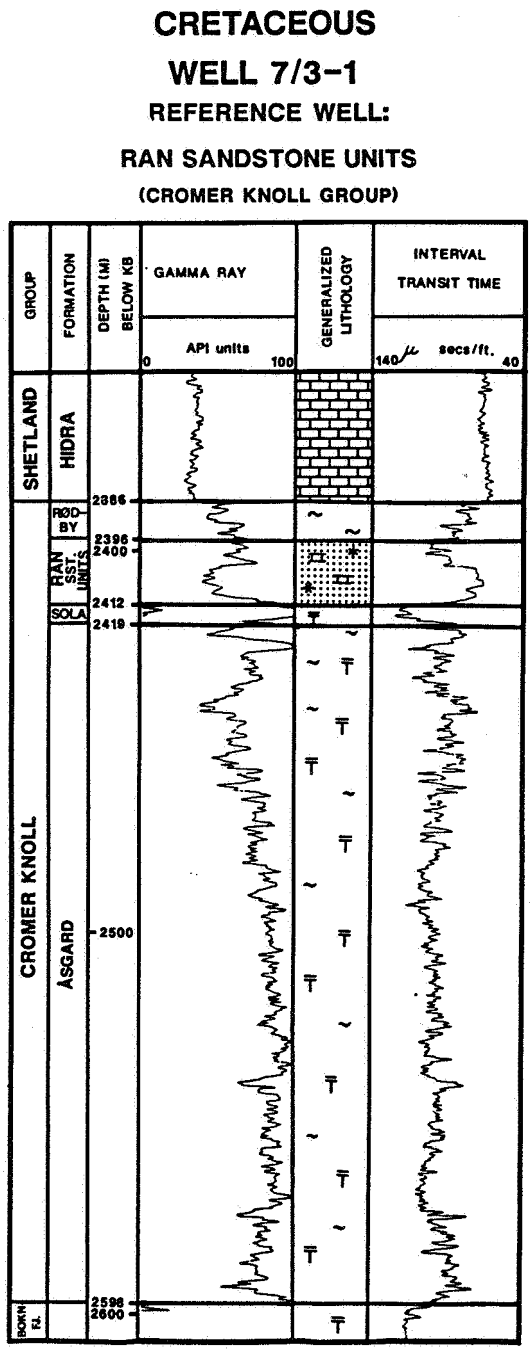


Fig. 23

Well reference sections:
Norwegian well 2/7-15 from 3498 to 3450 m, coordinates N 56°23'46.82", E 03°18'54.63" (Fig. 22). 16 m of cores in the lowermost part of the formation.

Norwegian well 7/3-1 from 2412 to 2396 m, coordinates N 57°50'35.25", E 02°44'55.61" (Fig. 23). No cores.

Norwegian well 17/11-2 from 1802 to 1767 m, coordinates N 58°06'54.91", E 03°22'09.81" (Fig. 13). No cores.

Thickness:
The gross sandstone thicknesses vary from a few metres up to approximately 100 m. The gross thicknesses in the reference wells are 48 m (2/7-15), 16 m (7/3-1) and 35 m (17/11-2). Up to 130 m (gross) of Aptian-Albian sandstone sequences are penetrated in block 16/27 in the UK sector (see Distribution).

Lithology:
The colour of the sandstones ranges from white to light grey, green and brown to reddish-brown. The sandstones are generally argillaceous, sometimes calcareous and glauconitic, and usually do not represent potential reservoir rocks in these wells.

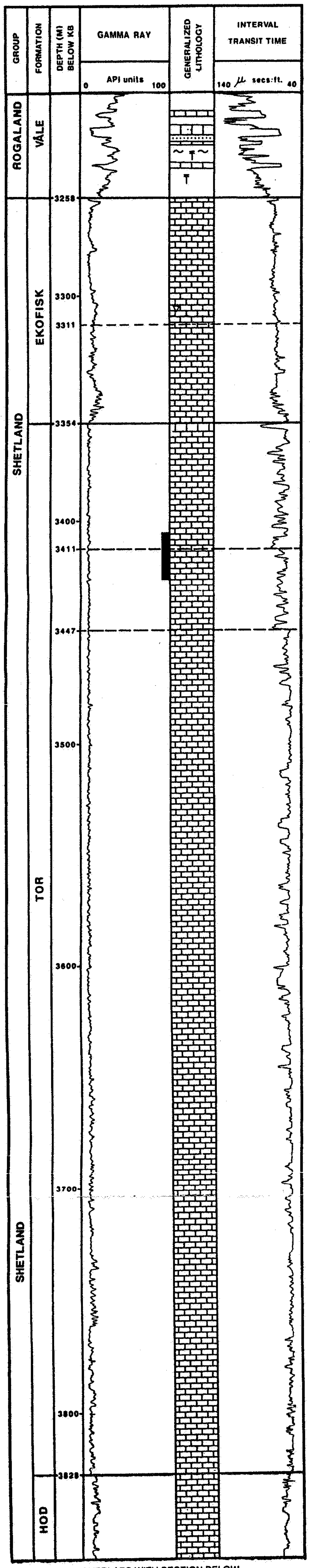
Basal stratotype:
The various sandstone units may appear in contact with the Åsgard, Tuxen, Sola and Rødby Formations (Figs. 4,7,8 and 9). Their lower boundaries are generally defined as the base of an upward decrease in the gamma-ray response when passing into the sandstone units (Figs. 22 and 23). The gamma-ray readings in the calcareous marlstones and chalks of the Tuxen Formation, especially its upper part, and the Mime Formation may be similar to those in the sandstones. The velocity curve is often less suitable for defining the lower boundary.

CRETACEOUS

WELL 1/3-1

TYPE WELL: HIDRA FORMATION
HOD FORMATION
TOR FORMATION
REFERENCE WELL: EKOFISK FORMATION
BLODØKS FORMATION

(SHETLAND GROUP)



OVERLAPS WITH SECTION BELOW

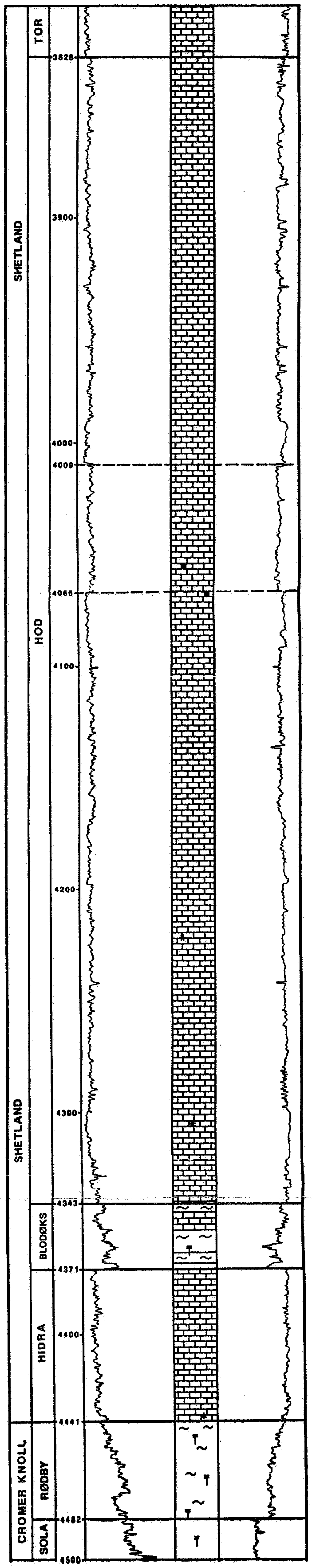


Fig. 24

Characteristics of the upper boundary:
The upper boundary can usually be identified as an upward increase in the gamma-ray readings (Fig. 22) and generally by a slight decrease in the sonic velocity.

Distribution:
The Ran sandstone units are encountered in only a few wells in the Norwegian sector (Fig. 21 and Remarks).

Age:
Ryazanian-Albian.

Depositional environment:
The sandstones that have been penetrated are described as shallow (Norwegian sector) and deep water (UK sector) submarine fans.

Remarks:
Hesjedal & Hamar (1983) recognised several scattered sandstone sequences which they described as the Kopervik and Klepp Formations in the Central Trough and Norwegian-Danish Basin, and the Florø Formation in the Agat Field in blocks 35/3 and 36/1. The Kopervik and Klepp Formations are here described as the Ran sandstone units. Since they consisted of several isolated sandstone bodies they should not have been given formation status, and the names did not conform with the existing recommendations. The Florø Formation is formally defined as the Agat Formation in this paper (see also General lithostratigraphic notes for Cretaceous).

In the UK sector (the Andrew Field), just south of the Andrew Ridge and Fladen Ground Spur, Aptian-Albian sandstone sequences (the Bosun Member) are encountered in many wells, among others UK wells 16/27-1 and 16/27a-2 (100-130 m gross), 16/28-1 (50 m gross) and 16/28-6 (90 m gross). The palaeogeographical position of these sandstones, i.e. basinal areas close to the subaerially exposed major structural highs mentioned above, may be quite similar to the palaeogeographical situation along the western margin of the Måløy Fault Blocks. Here, up to 400 m (gross) thick sandstone sequences of Aptian-Early Cenomanian age were deposited in Norwegian blocks 35/3 and 36/1, and are defined as the Agat Formation in this paper.

The Devil's Hole Formation (UK well 29/25-1) and the "Unnamed Formation" (UK well 14/20-5) in the UK sector are comparable to the Ran sandstone units.

Shetland Group (Shetlandsgruppen)

Name:
Named from the Shetland Islands off the north coast of Scotland (Deegan & Scull 1977). The group has now been expanded to include the formations of the former Chalk Group.

Type area:
The group is typically developed in the central and Northern North Sea. A chalk facies is developed in the central North Sea and a siliclastic facies in the Northern North Sea (Fig. 32 a). A typical section of the chalk facies in the central area is represented by Norwegian well 1/3-1 (Fig. 24), while Norwegian well 25/1-1 (Fig. 33) provides a typical section of the siliciclastic facies in the northern area. UK well 22/1-2A illustrates a section in the transition zone between the two facies (Figs. 5 and 25).

Thickness:
In well 1/3-1 the group is 1183 m thick, and in well 25/1-1 it measures 1284 m. Seismic interpretation and well data indicate that the thickness of the group ranges between 1000 and 2000 m in the graben areas. The group shows considerable thinning towards and in the platform areas.

Lithology:
The group consists of the chalk facies of chalky limestones, limestones, marls, and calcareous shales and mudstones. Chert (flint) occurs throughout the facies. The siliciclastic facies consists of mudstones and shales, partly interbedded with limestones. Minor amounts of sandstones are present in the lower part in the Agat Field area (block 35/3). The shales and sandstones are slightly to very calcareous. In the Maastrichtian sequence the quantity of limestones are generally higher on the Horda Platform than in the Viking Graben.

Basal stratotype:
Typically the lower boundary is the contact to the calcareous mudstones or marlstones of the Cromer Knoll Group. On structural highs like the Horda Platform, Tampen Spur, Sørvestlandet and Mandal Highs the lower part of the group is occasionally absent and the remainder rests unconformably on the Cromer Knoll Group, Jurassic or older rocks.

Characteristics of the upper boundary:
The group is overlain by Paleocene mudstones, marls or sandstones of the Rogaland Group.

Distribution:
The group is present throughout the Norwegian North Sea, being absent only locally on highs (e.g. 16/5-1, 31/2-9) and a few salt diapirs (e.g. 2/7-12). A transition between the chalk and siliciclastic facies of the group occurs relatively abruptly in the Norwegian sector along the Utsira High (Figs. 32a and b) and more gradually in the graben areas.

Age:
The group ranges in age from Cenomanian to Danian. The siliciclastic facies is restricted in age to the Late Cretaceous.

Depositional environment:
The Late Cretaceous sequence in the North Sea was deposited in an open marine environment during a general rise in sea level (Hancock & Kauffman 1979). The chalk facies formations were deposited as coccolith debris and other carbonate grains and sequences often show a cyclic pelagic sedimentation pattern termed periodite (d'Heur 1986). In the Central Trough, extensive subsidence resulted in the chalk facies being dominated by allochthonous, redeposited chalks which were transported downslope as major slides, slumps, debris flows, and proximal and distal turbidites. The siliciclastic facies is less well studied. The influx of siliciclastic mud was higher and the carbonate production probably lower than in the area with chalk facies.

Subdivision:
The Shetland Group is represented by four chalk facies formations: the Hidra, Hod, Tor and Ekofisk

Formations (all erected by Deegan & Scull 1977) and six siliciclastic facies formations: the Svarte (new), Blodøks (new), Tryggvason (new), Kyrre (new), Jorsalfare (new) and Hardråde (new) Formations.

Remarks:
The Herring and Flounder Formations in the UK sector (Deegan & Scull 1977) are regarded as equivalents of the lowermost part of the Hod Formation and of the Kyrre Formation, respectively (Fig. 5 and 6).

Hidra Formation (Hidraformasjonen)

Name:
Named by Deegan & Scull (1977) after the Hidra High in Norwegian blocks 1/3 and 2/1. The name Hidra is after the island of Hidra on the southern coast of Norway.

Well type section:
Norwegian well 1/3-1 from 4441 to 4371 m, coordinates N 56°51'21.00", E 02°51'05.00" (Fig. 24). No cores.

Well reference sections:
UK well 22/1-2A from 3783 to 3738 m, coordinates N 57°56'12.20", E 01°02'55.80" (Fig. 25). No cores.

UK well 29/25-1 from 2258.5 to 2228 m, coordinates N 56°18'10.00", E 01°51'48.80" (Fig. 26). No cores.

Danish well BO-1 from 2275.5 to 2220 m, coordinates N 55°48'8.22", E 04°34'18.66" (Fig. 27). Cored through the upper 35 m.

Thickness:
The formation is 70 m thick in the type well, 45 m in 22/1-2A, 30.5 m in 29/25-1 and 55.5 m in BO-1. Seismic interpretation suggests that the formation reaches a maximum thickness of about 150 m in the northwestern part of the Central Trough in the Norwegian sector.

Lithology:
In the type well the formation consists of white to light grey, hard chalks with thin interbeds of grey to black shale in the lower part of the formation. Locally the formation is more marly with interbedded marly chalk and marl. The chalks are occasionally softer with abundant glauconite and pyrite. The colour may be white, grey, green, brown or pink. At the base of the formation in UK well 22/1-2A, hard, black, carbonaceous and argillaceous limestones are present. Traces of pink waxy tuff occur in places. The formation is generally highly bioturbated.

Basal stratotype:
The formation usually shows a gamma-ray response that has constant low values and high velocities. These contrast sharply at the lower boundary with the higher gamma-ray response and lower velocity of the Åsgård and Sola Formations. The lower boundary is more gradational when the carbonate rich facies of the Rødby Formation is present beneath the Hidra Formation.

Characteristics of the upper boundary:
The upper boundary is defined by the stratotype of the Blodøks Formation. The boundary is characterised by a change from the chalk lithology to mainly mudstone. This is seen as an abrupt change to higher gamma-ray response and a decrease in velocity in the Blodøks Formation. The boundary shows as a glauconitised hardground in the core from Danish well BO-1.

Distribution:
The formation is found in the central and southern North Sea. In the Norwegian sector, it is missing above highs such as the Sørvestlandet, Mandal, Jæren, Utsira and Sele Highs, the Grensen Ridge, as well as many of the salt diapirs.

Age:
Cenomanian.

Depositional environment:
Open marine with a perioditic or turbiditic origin for the sediments.

Hod Formation (Hodformasjonen)

Name:
Named by Deegan & Scull (1977) from the Hod Field in Norwegian block 2/11. The name Hod derives from one of the twelve principal gods in Norse mythology. Hod was a son of Odin.

Well type section:
Norwegian well 1/3-1 from 4343 to 3828 m, coordinates N 56°51'21.00", E 01°51'05.00" (Fig. 24). No cores.

Well reference sections:
UK well 29/25-1 from 2225 to 2012 m, coordinates N 56°18'10.00", E 01°51'48.80" (Fig. 26). No cores.

Norwegian well 2/8-8 from 2601 to 2494 m, coordinates N 56°16'50.28", E 03°24'15.93" (Fig. 28). 36 m of cores discontinuously through the upper 78 m and lowermost 6 m of the formation.

Thickness:
The formation is 515 m thick in the type well, 213 m in UK well 29/25-1 and 107 m in Norwegian well 2/8-8. In the Norwegian sector, seismic interpretation indicates that the formation may reach a thickness of more than 700 m in the northwestern part of the Central Trough.

Lithology:
In the type well the formation consists of hard, white to light grey, crypto- to microcrystalline limestones which may become argillaceous or chalky in places. White, light grey to light brown, soft to hard chalk facies may dominate the formation or alternate with limestones. The limestones may be pink or pale orange. Thin, silty, white, light grey to green or brown, and soft, grey to black, calcareous clay/shale laminae are occasionally present. Pyrite and glauconite may occur throughout the formation and the latter may be common in the lower part.

Basal stratotype:
The lower boundary is usually marked by a distinct log break to a lower gamma-ray response and higher velocity from the Blodøks Formation to the Hod Formation (Fig. 24). The boundary may be less distinct when the Blodøks Formation is more calcareous (Fig. 31).

CRETACEOUS
WELL UK 22/1-2A

REFERENCE WELL: HIDRA FORMATION
TOR FORMATION
EKOFISK FORMATION

(SHETLAND GROUP)

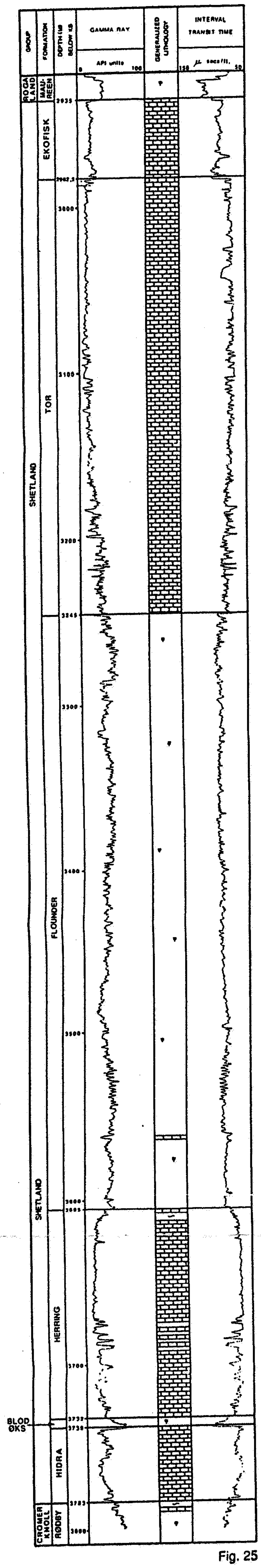


Fig. 25

CRETACEOUS
WELL UK 29/25-1

REFERENCE WELL: HIDRA FORMATION
HOD FORMATION
TOR FORMATION

(SHETLAND GROUP)

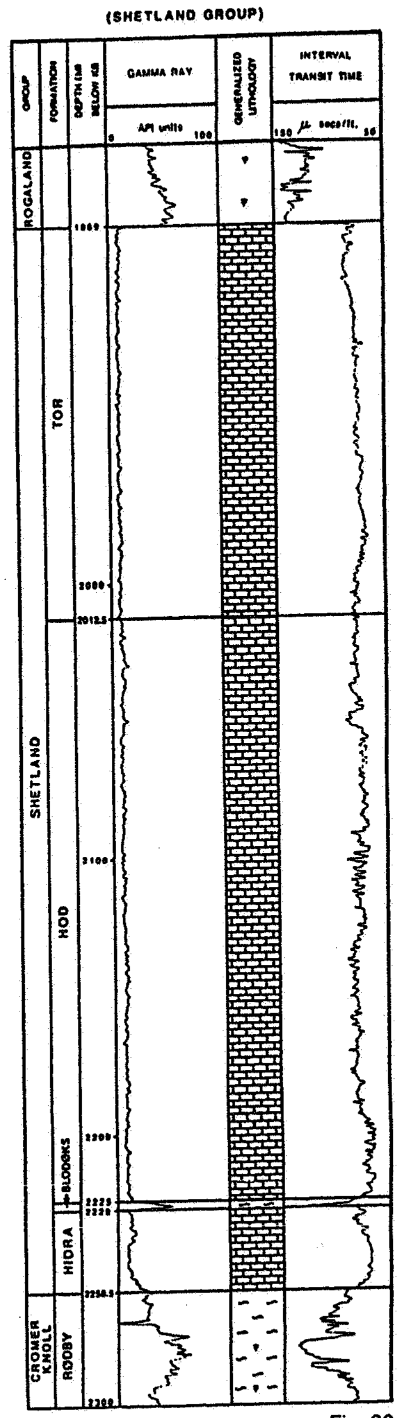


Fig. 26

CRETACEOUS
WELL DK BO-1
REFERENCE WELL: HIDRA FORMATION BLODØKS FORMATION
(SHETLAND GROUP)

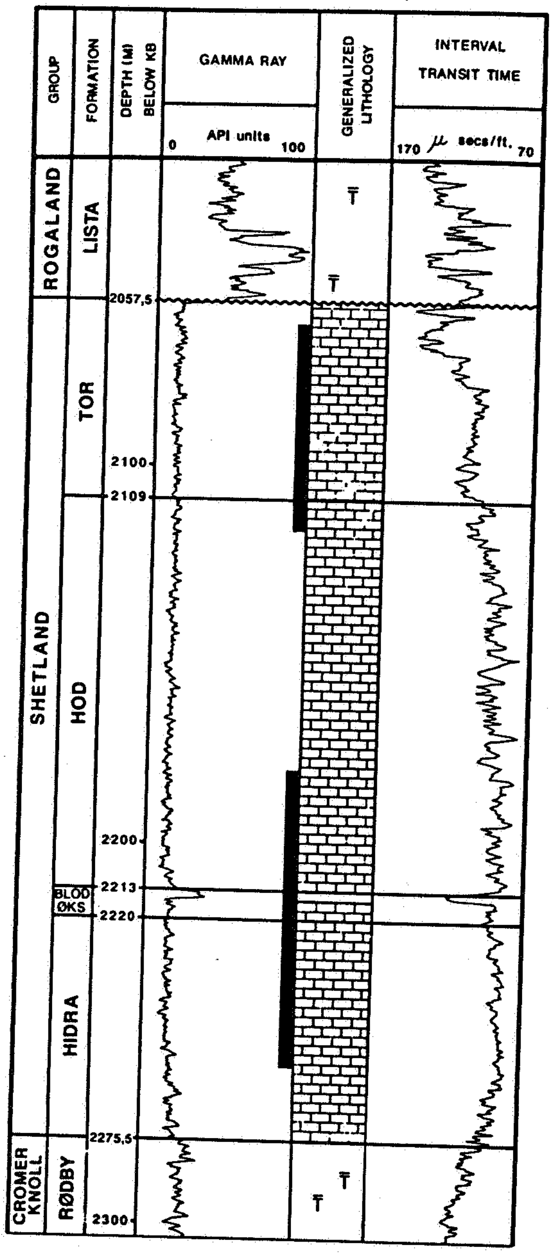


Fig. 27

Characteristics of the upper boundary:
The upper boundary towards the Tor Formation is generally marked by a change in gamma-ray readings to a more constant and slightly lower level, and also by higher velocity, (Figs. 24 and 31). The upper boundary may represent an unconformity in the Ekofisk area (e.g. Norwegian well 2/8-8, Fig. 28).

Distribution:
The formation is widely distributed in central and eastern parts of the central North Sea, passing laterally into sediments of the Herring and Flounder Formations to the west and the Tryggvason and Kyrre Formations to the northwest.

Age:
Turonian to Campanian.

Depositional environment:
Open marine with deposition of cyclic pelagic carbonates (periodites) and distal turbidites (Skovbro 1983 and d'Heur 1986).

Remarks:
An informal, tripartite subdivision of the Hod Formation into lower, middle and upper members is often possible in the southern part of the Central Trough in the Norwegian sector. The subdivision is based on the frequent presence of a higher clay content in the middle of the Hod Formation (Figs. 24, 28 and 29).

LOWER MEMBER OF THE HOD FORMATION:
This unit constitutes the largest part of the Hod Formation and is a sequence of bioturbated laminated chalks with a low clay content. It occurs in Norwegian wells 1/3-1 from 4343 to 4066 m, 2/8-8 from 2601 to 2538 m and 1/9-1 from 3648 to 3353 m.

MIDDLE MEMBER OF THE HOD FORMATION:
This is a sequence consisting mainly of periodites, which generally have a greyish colour reflecting a marked increase in terrigenous clay. It is shown on well logs as an increase in gamma-ray readings. It occurs in Norwegian wells 1/3-1 from 4066 to 4009 m, 2/8-8 from 2538 to 2518 m and 1/9-1 from 3353 to 3344 m.

UPPER MEMBER OF THE HOD FORMATION:
This unit constitutes another sequence dominated by periodites with minor allochthonous intercalations, but with a return to a low clay content. It occurs in Norwegian wells 1/3-1 from 4009 to 3828 m, 2/8-8 from 2518 to 2494 m and 1/9-1 from 3344 to 3312 m.

The Herring Formation of Deegan & Scull (1977) includes a similar lithology and was deposited at the same time as the Hod Formation. It is regarded here as the lower part of the Hod Formation. The Hod Formation is also equivalent in age to the Tryggvason and Kyrre Formations (Fig. 6).

Tor Formation (Torformasjonen)

Name:
Named by Deegan & Scull (1977) from the Tor Field in Norwegian blocks 2/4 and 2/5. Tor was a son of Odin, and one of the principal gods of Norse mythology.

Well type section:
Norwegian well 1/3-1 from 3828 to 3354 m, coordinates N 56°51'21.00", E 02°51'05.00" (Fig. 24). No cores.

Well reference sections:
UK well 22/1-2A from 3245 to 2982.5 m, coordinates N 57°56'12.20", E 01°12'55.80" (Fig. 25). No cores.
UK well 29/25-1 from 2212 to 1869 m, coordinates N 56°18'10.00", E 01°51'48.80" (Fig. 26). No cores.

Norwegian well 1/9-1 from 3312 to 3104 m, coordinates N 56°24'05.07", E 02°54'06.49" (Fig. 29). Cored through the formation.

Thickness:
The formation is 474 m thick in the type well, 262.5 m in 22/1-2A, 143 m in 29/25-1 and 208 m in 1/9-1. In the Norwegian sector, seismic interpretation indicates that the thickness of the formation may exceed 600 m in the northwestern part of the Central Trough.

Lithology:
In the type well the formation consists of white to light grey, tan to pink, hard, chalky limestones. The formation is generally homogenous, or consists of alternating white, grey or beige, moderately hard to very hard, rarely soft, mudstones or wackestones, rarely packstones, chalks, chalky limestones or limestones. Occasional fine layers of soft grey-green or brown marl occur and also rare stringers of grey to green calcareous shales.

Basal stratotype:
The lower boundary is generally marked by an upward change to a more constant lower level of gamma-ray response, and also by higher velocity (Fig. 24).

Characteristics of the upper boundary:
The upper boundary is marked by the end of the more constant low gamma-ray response with a return to a higher and more irregular gamma ray and a lower velocity in the overlying Ekofisk Formation (Fig. 24). The upper boundary represents an unconformity with a submarine hardground along the Lindesnes Ridge, and a change of deposition to clay-rich chalks or minor shales (Fig. 28).

Distribution:
The formation is present throughout the central North Sea (Fig. 32b). In the Norwegian sector it is very thin or absent on the Lindesnes Ridge and the Utsira High.

Age:
Late Campanian to Maastrichtian.

Depositional environment:
Open marine with deposition of calcareous debris flows, turbidites and autochthonous periodites.

Remarks:
In general the formation shows an upward increase in the intensity and thickness of allochthonous beds. 16 major correlative allochthonous units are recognised within the Central Trough area (Hatton 1986). The sequence of single or stacked mass flows with autochthonous periodite facies enables three separate members to be distinguished (d'Heur 1984, Hatton 1986, Figs. 24, 29, 30 and 31). The semi-regional distribution pattern of the allochthonous units shows that this subdivision is not valid throughout the area of the chalk facies.

Lower member of the Tor Formation:
The sequence is dominated by autochthonous periodite deposits interrupted by single or stacked minor debris flows. The sequence is present in Norwegian wells 2/5-1 from 3475 to 3235 m, 1/3-1 from 3828 to 3447 m and 2/4-5 from TD to 3283 m.

Middle member of the Tor Formation:
This unit shows a marked increase in slumps, slides, and stacked and single debris flows relative to intervening minor autochthonous beds. The unit is present in Norwegian wells 2/5-1 from 3235 to 3192 m, 1/3-1 from 3447 to 3411 m, 2/4-5 from 3283 to 3237 m and 1/9-1 from 3168 to 3137 m.

Upper member of the Tor Formation:
This unit generally consists of high porosity, homogenous chalks which represent stacked sequences of, often slumped, debris flows. The unit is present in Norwegian wells 2/5-1 from 3192 to 3132 m, 2/4-5 from 3237 to 3164 m and 1/3-1 from 3411 to 3354 m.

Ekofisk Formation (Ekofiskformasjonen)

Name:
Named after the Ekofisk Field in Norwegian block 2/4 (Deegan & Scull 1977).

Well type section:
Norwegian well 2/4-5 from 3164 to 3037 m, coordinates N 56°34'29.77", E 03°12'13.03" (Fig. 30). No cores.

Well reference sections:
Norwegian well 1/3-1 from 3354 to 3258 m, coordinates N 56°51'21.00", E 02°51'05.00" (Fig. 24). No cores.

UK well 22/1-2A from 2982.5 to 2935 m, coordinates N 57°56'12.20", E 01°02'55.80" (Fig. 25). No cores.

Norwegian well 2/5-1 from 3132 to 3041 m, coordinates N 56°38'19.95", E 03°21'07.94" (Fig. 31). Cored through the upper 78 m.

Thickness:
The formation is 127 m thick in the type well, 96 m in 1/3-1, 47.5 m in 22/1-2A and 91 m in 2/5-1. In the Norwegian sector, seismic interpretation indicates that a thickness of more than 150 m is found in the northwestern part of the Central Trough.

Lithology:
In the type well, the formation comprises white, tan or beige, hard, dense, sometimes finely crystalline limestones, although softer chalky textures are also present. The formation usually consists of white to light grey, beige to brownish, mudstones or wackestones with occasional packstones/grainstones and pisolitic horizons, often alternating with argillaceous chalks, chalky limestones or limestones. Thin beds of grey, calcareous, often pyritic shales or clays are most common in the lower part while brownish-grey cherts occur rarely to abundantly throughout the formation.

Basal stratotype:
The lower boundary is marked by a change in gamma-ray readings from a constant low level in the Tor Formation to a slightly lower level. The velocity may or may not show a corresponding increase. The lower boundary separates the Cretaceous and Tertiary chalks and may represent an unconformity (e.g. Norwegian well 1/9-1, Fig. 29).

CRETACEOUS
WELL 2/8-8

REFERENCE WELL: HOD FORMATION

(SHETLAND GROUP)

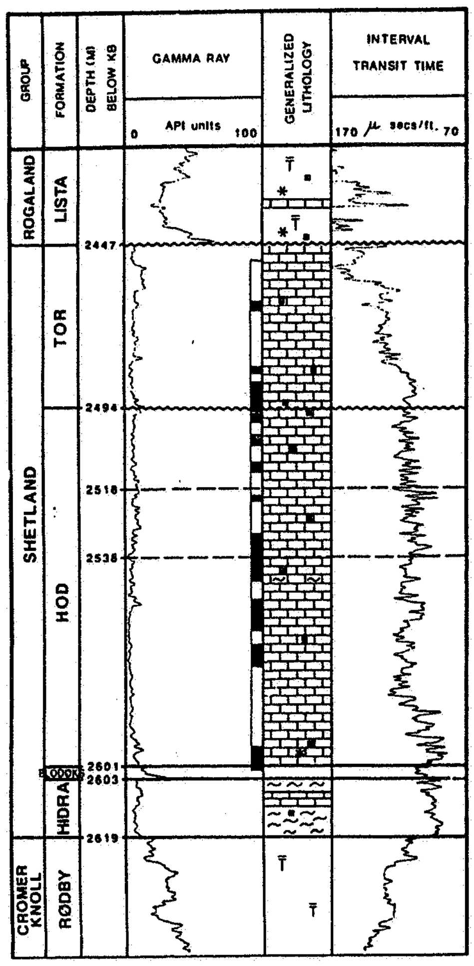


Fig. 28

CRETACEOUS
WELL 1/9-1

REFERENCE WELL: TOR FORMATION

(SHETLAND GROUP)

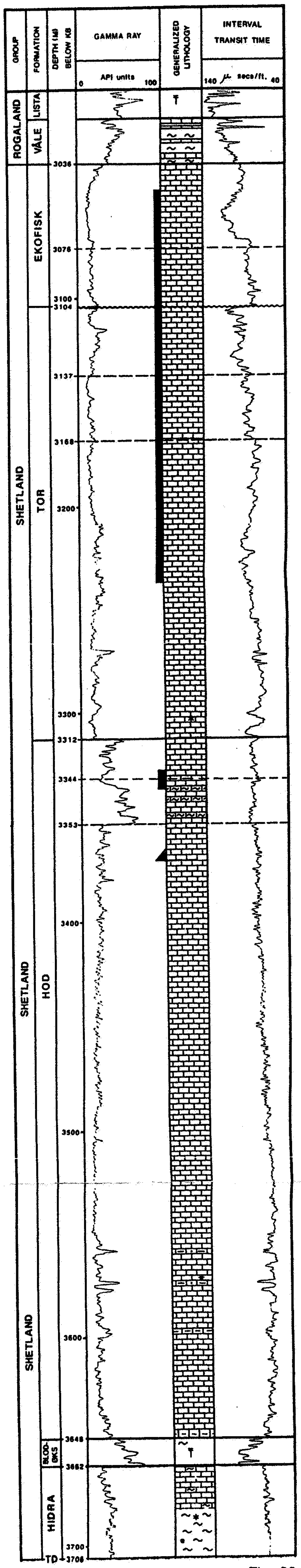


Fig. 29

CRETACEOUS
WELL 2/4-5

TYPE WELL: EKOFISK FORMATION
(SHETLAND GROUP)

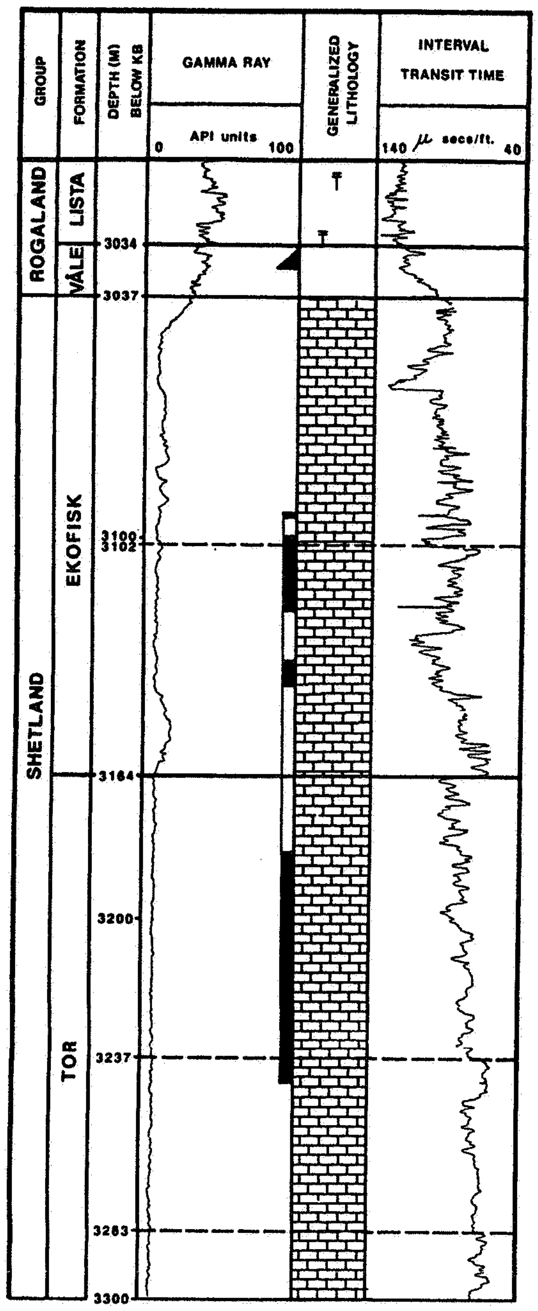


Fig. 30

CRETACEOUS
WELL 2/5-1

REFERENCE WELL: EKOFISK FORMATION
(SHETLAND GROUP)

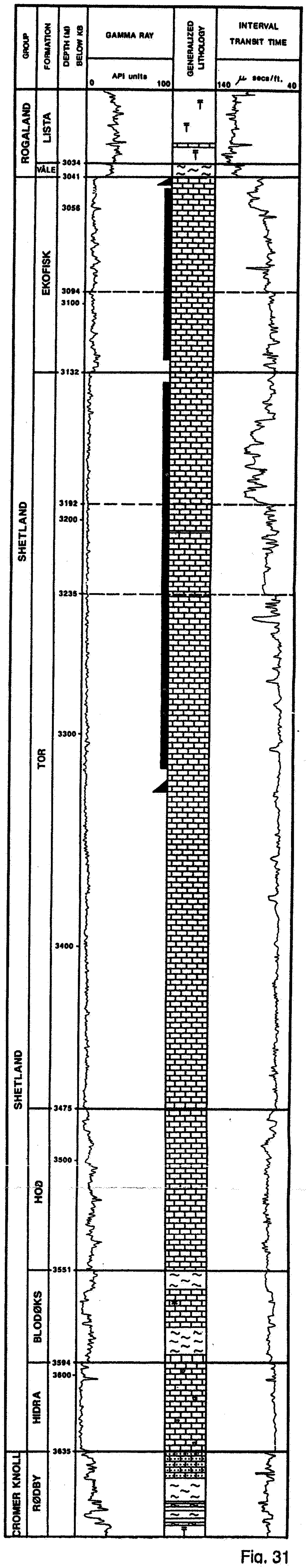


Fig. 31

Characteristics of the upper boundary:
The upper boundary is defined where the gamma-ray response increases and the velocity decreases towards the marly beds of the Våle Formation. Where the marl is not present the change is more abrupt (e.g. Norwegian well 2/8-8, Fig. 28).

Distribution:
The formation is widespread in the southern and central North Sea. In the Norwegian sector, it is missing from parts of the Sørvestlandet High and the Lindesnes Ridge.

Age:
Danian.

Depositional environment:
Open marine with deposition of calcareous debris flows, turbidites and autochthonous periodites (Skovbro 1983, d'Heur 1986, Hatton 1986).

Remarks:
Two zones of the formation are readily correlatable within the Central Trough area (Hatton 1986, Figs. 24, 29, 30 and 31).

LOWER MEMBER OF THE EKOFISK FORMATION:
The lowermost part consists of a low porosity to tight zone with a higher terrigenous clay content, and is informally termed the Ekofisk tight zone. The larger part consists of the informal Ekofisk reworked zone with mainly reworked Maastrichtian chalks (Tor Formation) deposited as various mass flows and periodite-facies chalks. This lower member is present in Norwegian wells 1/3-1 from 3354 to 3307 m, 1/9-1 from 3104 to 3072 m, 2/4-5 from 3164 to 3106 m and 2/5-1 from 3132 to 3099 m.

UPPER MEMBER OF THE EKOFISK FORMATION:
This zone is composed of mainly homogenous chalks with a low clay content, debris flows of reworked Danian chalks and minor turbidites. A lower tight to low porosity zone, informally termed the Tommeliten tight zone, is present in parts of the Central Trough. The zone is found in Norwegian wells 1/3-1 from 3311 to 3258 m, 1/9-1 from 3072 to 3036 m, 2/4-5 from 3102 to 3037 and 2/5-1 from 3094 to 3041 m.

Svarte Formation (new) (Svarteformasjonen)

Name:
Named after Halvdan Svarte, King of Ringerike, Norway about A.D. 850.

Well type section:
Norwegian well 25/1-1 from 3995 to 3807 m, coordinates N 59°53'17.40", E 02°04'42.70" (Fig. 33). No cores.

Well reference sections:
Norwegian well 35/3-2 from 3447 to 3207 m, coordinates N 61°51'05.98", E 03°46'28.22" (Fig. 34). No cores.

Norwegian well 24/9-1 from 3992 to 3804 m, coordinates N 59°16'09.48", E 01°47'31.18" (Fig. 35). No cores.

Approximate boundary between the Shetland Group. Siliclastic facies and chalk facies.

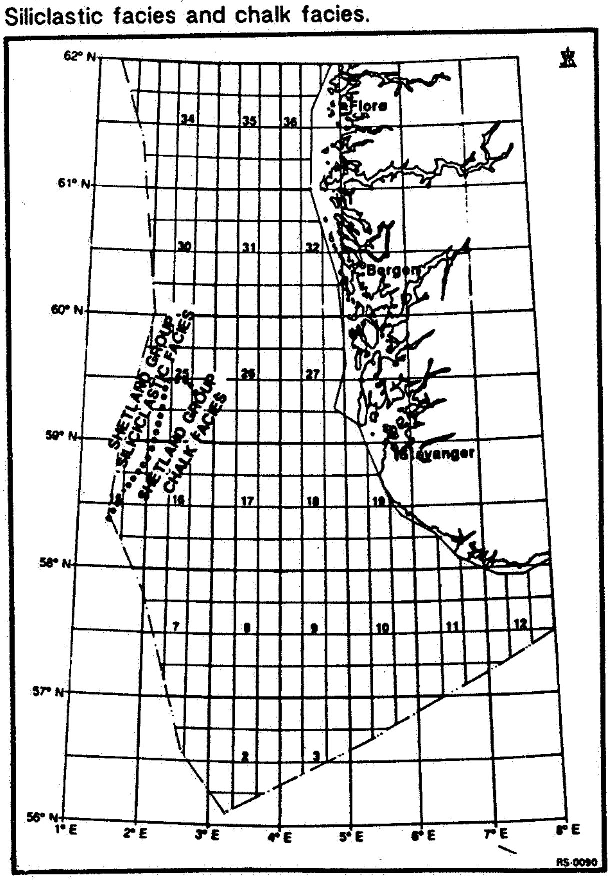


Fig. 32 a

Approximate boundary between the Jorsalfare, Hardråde and Tor Formations.

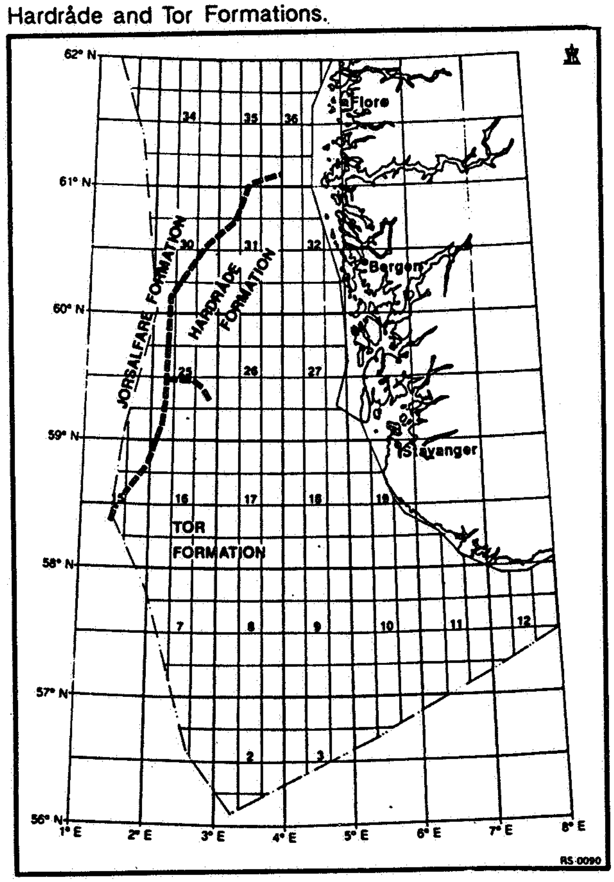


Fig. 32 b

Thickness:
In the Viking Graben, the formation is 188 m thick in the type well 25/1-1, 240 m in well 35/3-2 and 188 m in well 24/9-1.

Lithology:
The formation generally consists of mudstones interbedded with limestones. Sandstones occur in the Agat area. The content of limestones relative to mudstones is generally lower in the northern than in the southern part of the Viking Graben. The mudstones are medium to light grey, often calcareous, occasionally micaceous, glauconitic and pyritic. The limestones are mainly white to medium grey, argillaceous or sandy. The sandstones are clear to light grey and often cemented by calcite.

Basal stratotype:
The lower boundary shows a general upward decrease in gamma-ray intensity and an increase in velocity from the Cromer Knoll Group into the Svarte Formation (Fig. 34). This is due to a higher content of carbonate in the Svarte Formation.

Characteristics of the upper boundary:
The upper boundary is generally easily located, and is characterised by an increase in gamma-ray intensity and a distinct decrease in velocity from the Svarte Formation up into the Blodøks Formation (Fig. 33). This is caused by a lower carbonate content in the Blodøks Formation.

Distribution:
The formation is present in the Viking Graben and north of the Tampen Spur towards the Marulk Basin. It is, however, lacking on structural highs such as the Lomre Terrace (e.g. Norwegian wells 35/8-1 and 35/8-2), (Nybakken and Bäckstrøm, in press).

Age:
Cenomanian.

Depositional environment:
Open marine.

Remarks:
The Svarte Formation is time-equivalent with the Hidra Formation in the central North Sea and with the informal "formation A" of Deegan & Scull (1977) (Fig. 6).

Blodøks Formation (new) **(Blodøksformasjonen)**
Name:
Named after Eirik Haraldson Blodøks, a Norwegian king who reigned in Norway (A.D. 930-934) and in Northumberland (A.D. -954).

Well type section:
Norwegian well 25/1-1 from 3807 to 3790 m, coordinates N 59°53'17.40", E 02°04'42.70" (Fig. 33). No cores.

Well reference sections:
Norwegian well 35/3-2 from 3207 to 3190 m, coordinates N 61°51'05.98", N 03°46'28.22" (Fig. 34). No cores.

Norwegian well 1/3-1 from 4371 to 4343 m, coordinates N 56°51'21.00", E 02°51'05.00" (Fig. 24). No cores.

Danish well BO-1 from 2220 to 2213 m, coordinates N 55°48'02.22", E 04°34'18.66" (Fig. 27). Cored throughout.

Thickness:
The formation is 17 m thick in the type well (25/1-1), 17 m in well 35/3-2, 28 m in well 1/3-1 and 7 m in well BO-1. It rarely exceeds 20 m in thickness.

Lithology:
The formation consists of red, green, grey and black shales and mudstones which are non-calcareous to moderately calcareous. In the central North Sea the formation may show a varied influx of marls, limestones and chalky limestones.

Basal stratotype:
The lower boundary is generally characterised by a distinct log break with an upward increase in gamma-ray intensity and a distinct decrease in velocity from the Svarte Formation (Fig. 33) or Hidra Formation (Fig. 24) into the Blodøks Formation. This is due to the lower content of carbonate in the Blodøks Formation.

Characteristics of the upper boundary:
The upper boundary shows a decrease in gamma-ray intensity and an increase in velocity from the Blodøks Formation upwards into the more calcareous Tryggvason Formation (Fig. 34) or the chalky Hod Formation (Fig. 24).

Distribution:
The formation is present throughout the North Sea, lacking only on local highs such as the Sørvestlandet High, the Utsira, Mandal, Jæren and Sele Highs and the Grensen Ridje as well as above many salt diapirs.

Age:
Latest Cenomanian to early Turonian.

Depositional environment:
The formation was deposited during a period characterised by anoxic bottom conditions (e.g. Hart & Leary 1989). Presence of carbonates may indicate periods of more oxic conditions or supply of allochthonous limestones and chalks (e.g. Norwegian wells 1/3-1 and 2/5-1).

Remarks:
The Blodøks Formation is equivalent to the former Plenus Marl Formation and the informal "formation B" of Deegan & Scull (1977) (Fig. 6). A black shale of Early Turonian age is also widespread outside the North Sea, e.g. the Yorkshire Black Band in England (Jeffries 1963) and similar facies on Helgoland and in northwestern Germany (Schmid & Spaeth 1980).

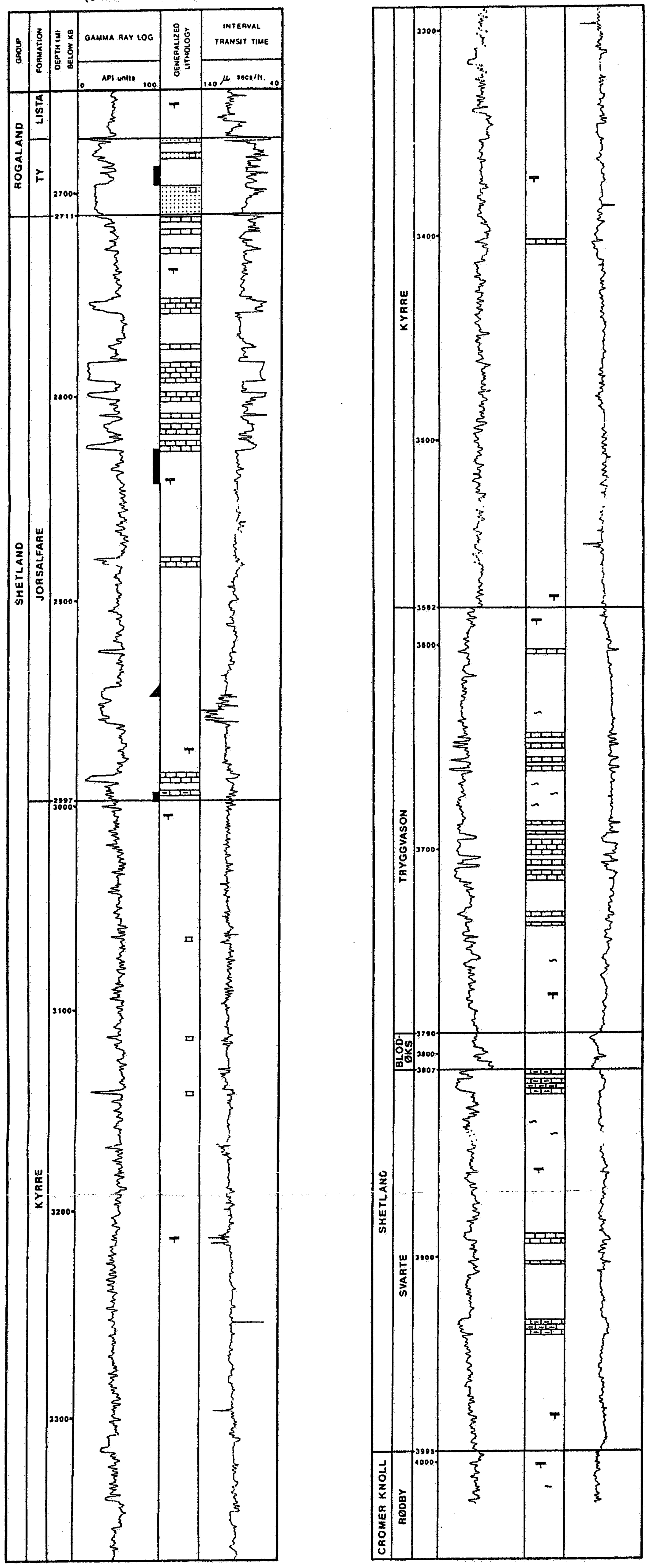
Tryggvason Formation (new)
(Tryggvasonformasjonen)
Name:
Named after Olav Trygvason, a Norwegian king (A.D 995-1000).

CRETACEOUS

WELL 25/1-1

TYPE WELL: SVARTE FORMATION
BLODØKS FORMATION
TRYGGVASON FORMATION
KYRRE FORMATION
JORSALFARE FORMATION

(SHETLAND GROUP)



OVERLAPS WITH SECTION BELOW

Fig. 33

CRETACEOUS

WELL 35/3-2

REFERENCE WELL: SVARTE FORMATION
BLODØKS FORMATION
TRYGGVASON FORMATION
KYRRE FORMATION
JORSALFARE FORMATION

(SHETLAND GROUP)

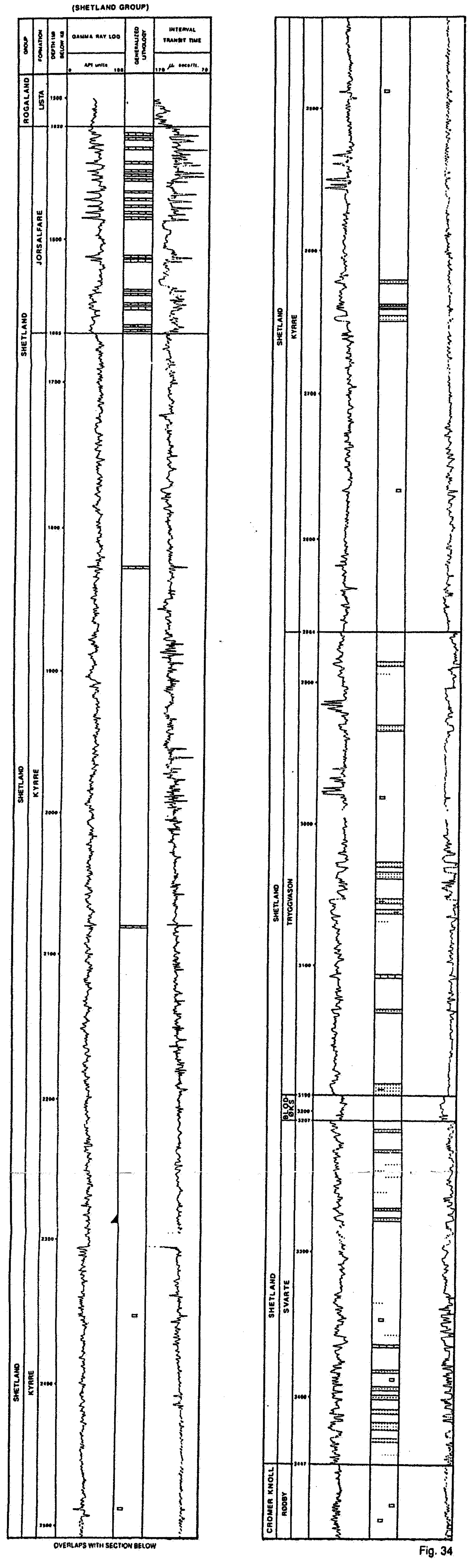


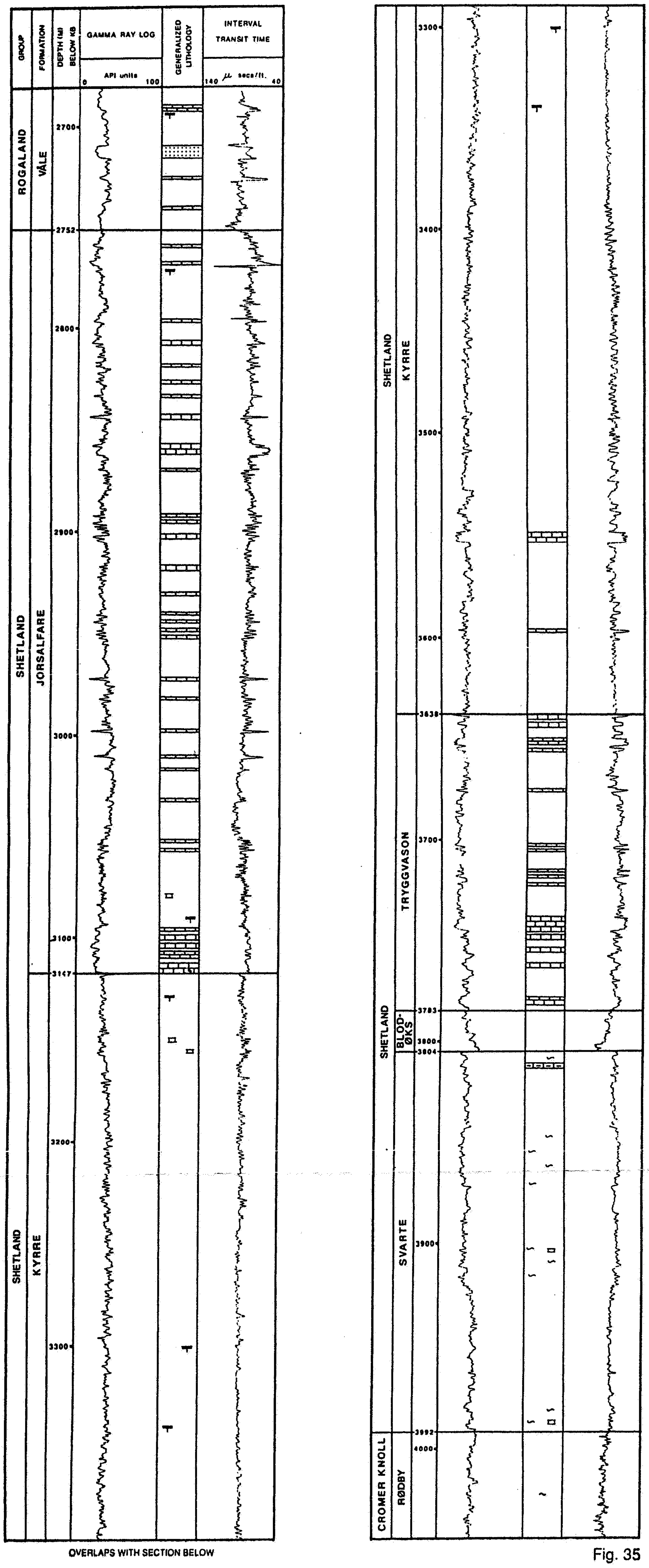
Fig. 34

CRETACEOUS

WELL 24/9-1

REFERENCE WELL: SVARTE FORMATION
TRYGGVASON FORMATION
KYRRE FORMATION
JORSALFARE FORMATION

(SHETLAND GROUP)



OVERLAPS WITH SECTION BELOW

Fig. 35

Well type section:
Norwegian well 25/1-1 from 3790 to 3582 m, coordinates N 59°53'17.40", E 02°04'42.70" (Fig. 33). No cores.

Well reference sections:
Norwegian well 35/3-2 from 3190 to 2864 m, coordinates N 61°51'05.98", E 03°46'28.22" (Fig. 34). No cores.

Norwegian well 24/9-1 from 3783 to 3638 m, coordinates N 59°16'09.48", E 01°47'31.18" (Fig. 35). No cores.

Norwegian well 30/11-3 from 3207 to 3162 m, coordinates N 60°02'38.59", E 02°32'15.47" (Fig. 36). No cores.

Thickness:
In the Viking Graben, the formation is 208 m thick in the type well (25/5-1), 326 m in well 35/3-2 and 145 m in well 24/9-1. It is 45 m thick in well 30/11-3 on the western margin of the Horda Platform.

Lithology:
The Tryggvason Formation consists generally of mudstones with interbedded limestones. Interbedded sandstones are common in the Agat area. The content of limestones relative to mudstones is generally lower in the northern part of the Viking Graben (from blocks 30/2 and 30/3 northwards) than in the southern part. At the transition between the Viking Graben and the Horda Platform (e.g. block 30/11, Fig. 36) the formation consists of limestone. The mudstones are light to dark grey, often calcareous, occasionally micaceous, glauconitic and pyritic. The limestones are white to light grey or brownishgrey and argillaceous. The sandstones are clear to light grey, very fine to fine grained and cemented by calcite.

Basal stratotype:
The lower boundary is defined by a decrease in gamma-ray intensity and an increase in velocity from the Blodøks Formation into the Tryggvason Formation (Fig. 33 and 34). This is due to the difference in carbonate content.

Characteristics of the upper boundary:
The upper boundary shows an increase in gamma-ray intensity and a decrease in velocity from the Tryggvason Formation upwards into the Kyrre Formation (Fig. 33). This log change is due to the lower carbonate content of the Kyrre Formation.

Distribution:
The formation is present in the Viking Graben and northern Tampen Spur area towards the Marulk Basin.

Age:
Early to Mid Turonian.

Depositional environment:
Open marine.

Remarks:
The Tryggvason Formation is time-equivalent with the Herring Formation and the lower part of the Hod Formation in the central North Sea, and also with the informal "formation C" of Deegan & Scull (1977) (Fig. 6).

Kyrre Formation (new) (Kyrreformasjonen)

Name:
Named after Olav "Kyrre" Haraldson, a Norwegian king (A.D. 1067-1093).

Well type section:
Norwegian well 25/1-1 from 3582 to 2997 m, coordinates N 59°53'17.40", E 02°04'42.70" (Fig. 33). Part of one core (0.5 m), including the upper boundary.

Well reference sections:
Norwegian well 35/3-2 from 2864 to 1665 m, coordinates N 61°51'05.98", E 03°46'28.22" (Fig. 34). No cores.

Norwegian well 24/9-1 from 3638 to 3117 m, coordinates N 59°16'09.48", E 01°41'31.18" (Fig. 35). No cores.

Norwegian well 30/11-3 from 3162 to 2892 m, coordinates N 60°02'38.59", E 02°31'15.47" (Fig. 36). No cores.

Thickness:
The formation is 585 m thick in the type well (25/1-1), 1199 m in well 35/3-2, 521 m in well 24/9-1 and 270 m in well 30/11-3.

Lithology:
The formation consists of mudstones with occasional limestone beds. Some sandstone beds are found in parts of the Agat area. The mudstones are medium grey to grey, silty to calcareous, occasionally pyritic, glauconitic or micaceous. The sandstones are clear to white, and very fine to fine grained.

Basal stratotype:
The lower boundary is defined by an increase in gamma-ray intensity and a decrease in velocity from the Tryggvason Formation into the Kyrre Formation (Fig. 33) due to changes in carbonate content. The boundary is unconformable on structural highs, usually above the Cromer Knoll Group.

Characteristics of the upper boundary:
The upper boundary shows a decrease in gamma-ray intensity and an increase in velocity from the Kyrre Formation upwards into the Jorsalfare Formation (Figs. 33 and 34). This log change is also a result of the higher carbonate content and the presence of basal limestone beds in the Jorsalfare Formation.

Distribution:
With the exception of the Gullfaks area, the formation is present in the Viking Graben, on the Tampen Spur and the western margin of the Horda Platform.

Age:
Late Turonian to Campanian.

Depositional environment:
Open marine.

Remarks:
The Kyrre Formation is time-equivalent with the Flounder Formation in the western part of the central North Sea and the upper part of the Hod Formation in the eastern part (Deegan & Scull 1977). It is also equivalent with the informal "formation D" of Deegan & Scull (1977) (Fig. 6).

Jorsalfare Formation (new) (Jorsalfareformasjonen)

Name:
Named after Sigurd "Jorsalfare" Magnusson, a Norwegian king (A.D. 1103-1130).

Well type section:
Norwegian well 25/1-1 from 2997 to 2711 m, coordinates N 59°53'17.40", E 02°04'42.70" (Fig. 33). One core (17 m) in the middle of the formation and another (4 m) at the base.

Well reference sections:
Norwegian well 35/3-2 from 1665 to 1520 m, coordinates N 61°51'05.98", E 03°46'28.22" (Fig. 34). No cores.

Norwegian well 24/9-1 from 3117 to 2752 m, coordinates N 59°16'09.48", E 01°47'31.18" (Fig. 35). No cores.

Thickness:
The formation is 286 m thick in the type well (25/1-1), 145 m in well 35/3-2 and 365 m in well 24/9-1.

Lithology:
The formation generally consists of mudstones interbedded with thin limestone beds. The mudstones are light to medium grey, often calcareous. The limestones are white to light grey, fine grained, occasionally sandy and dolomitic.

Basal stratotype:
The lower boundary is defined by a decrease in gamma-ray intensity and an increase in velocity, reflecting an increase in calcareous content from the Kyrre Formation into the Jorsalfare Formation (Figs. 33 and 34). In the Tampen Spur area, however, the boundary may be difficult to identify due to small differences in calcareous content. The lower boundary may be unconformable above the Jurassic sequences (e.g. in the Gullfaks area).

Characteristics of the upper boundary:
The upper boundary may be towards the Våle, Lista or Ty Formations of the Rogaland Group. When the upper boundary is towards the shale of the Lista Formation it is usually characterised by an upward increase in gamma-ray intensity and a distinct drop in velocity (Fig. 34). When it is towards the Våle Formation it does not show the same distinct drop in velocity and increase in gamma-ray intensity, because the overlying lithology consists of limestones or calcareous mudstones (Fig. 35). Where the upper boundary is towards the Ty Formation it is identified as a change to sandstone (Fig. 33).

Distribution:
The formation is present in the Viking Graben and on the Tampen Spur. Its boundaries towards the Jorsalfare Formation in the Viking Graben, the Hardråde Formation on the Horda Platform and the Tor Formation on the Utsira High are illustrated in Fig. 32b.

The main characteristics that can be used to distinguish the three formations are:
a. The Jorsalfare Formation contains shales with thin limestone beds which are usually no thicker than 5 m.
b. The Tor Formation is dominated by limestones, and has a negligible shale content.
c. The Hardråde Formation contains thick limestone beds (10-60 m), as well as shales, except in the Troll area where it is thin and may consist of only a single bed of limestone or marly limestone.

Separation of these three formations may be difficult in transitional areas.

Age:
Late Campanian to Maastrichtian.

Depositional environment:
Open marine.

Remarks:
Hardråde and Tor Formations of the Shetland Group, and also with the informal "formation E" of Deegan & Scull (1977) (Fig. 6).

Hardråde Formation (new) (Hardrådeformasjonen)

Name:
Named after Harald "Hardråde" Sigurdsson, a Norwegian king (A.D. 1046-1066).

Well type section:
Norwegian well 30/11-3 from 2892 to 2601 m, coordinates N 60°02'38.59", E 02°32'15.47" (Fig. 36). No cores.

Well reference section:
Norwegian well 31/6-2 from 968 to 978 m, coordinates N 60°34'58.24", E 03°54'55.76" (Fig. 37). No cores.

Thickness:
The formation is 291 m thick in the type well (30/11-3) and 10 m in well 31/6-2. It is absent on tilted fault blocks in the Troll area (e.g. well 31/2-9).

Lithology:
The formation consists generally of interbedded limestones and mudstones, except in the Troll area where it is thin and consists of a single limestone bed. The limestones are white or pale, moderately hard to very hard. The mudstones are medium to light grey, often silty and calcareous.

Basal stratotype:
The lower boundary is towards the Kyrre Formation or an unconformity above older rocks. The boundary towards the Kyrre Formation is identified by the absence of relatively thick limestone beds in this formation and a lower content of calcareous material in the mudstone. This results in a decrease in gamma-ray intensity and an increase in velocity from the Kyrre Formation into the Hardråde Formation (Fig. 36). The formation has an unconformable lower boundary in the Troll area.

Characteristics of the upper boundary:
The upper boundary is towards the Rogaland Group. When it is towards the Lista Formation it is characterised by an upward increase in gamma-ray intensity and a distinct drop in velocity due to a transition from limestones to mudstones (Fig. 36). An upper boundary

CRETACEOUS
WELL 30/11-3

TYPE WELL: HARDRÅDE FORMATION

REFERENCE WELL: SVARTE FORMATION
TRYGGVASON FORMATION
KYRRE FORMATION

(SHETLAND GROUP)

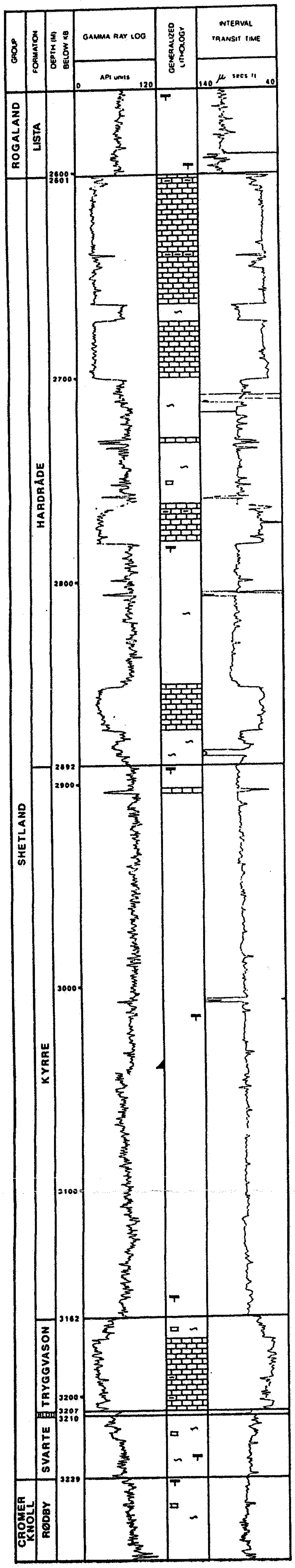


Fig. 36

CRETACEOUS
WELL 31/6-2

REFERENCE WELL: HARDRÅDE FORMATION
UNDIFF.SHETLAND GROUP
IN THE TROLL AREA

(SHETLAND GROUP)

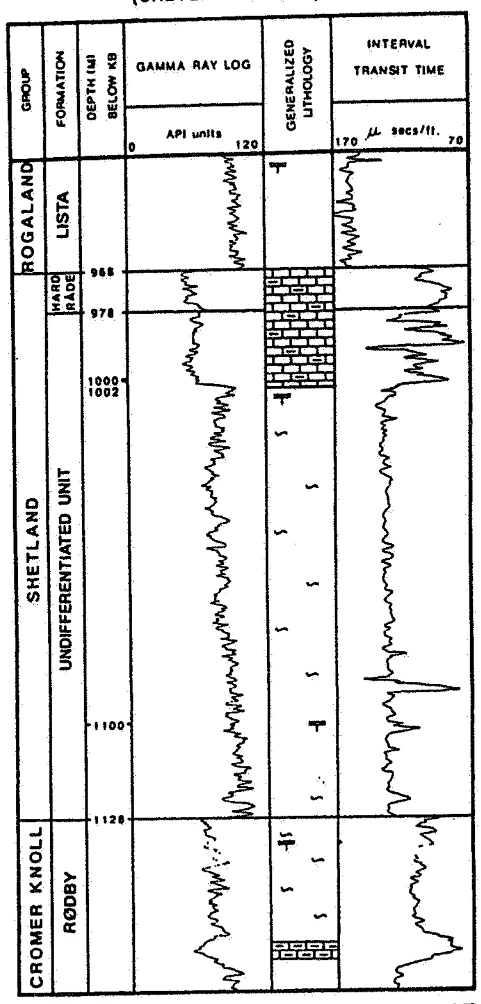


Fig. 37

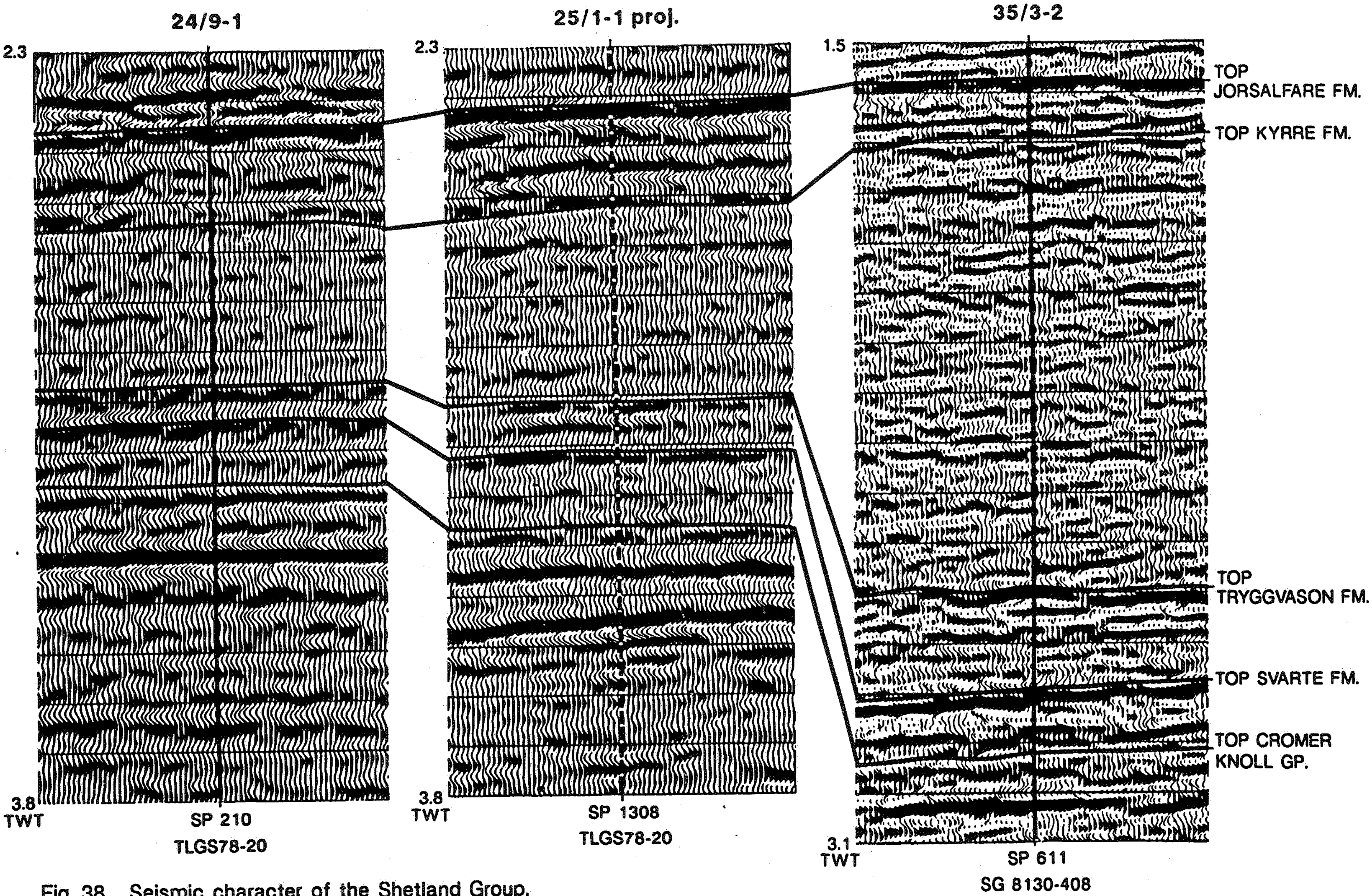


Fig. 38 Seismic character of the Shetland Group.

towards the Våle Formation lacks the distinct drop in velocity. This is due to the presence of limestones and a more marly facies in the Våle Formation. An upper boundary towards the Ty Formation is shown by a change to sandstone.

Distribution:
The formation is present on the Horda Platform (Fig. 32b).

Age:
Late Campanian to Maastrichtian.

Depositional environment:
Open marine.

Remarks:
The Hardråde Formation is time-equivalent with the Jorsalfare and Tor Formations of the Shetland Group (Fig. 6).

Undifferentiated Shetland Group in the Troll area (Udifferensiert Shetlandsgruppe i Troll-området).

General:
In the Troll area a part (probably the lower part) of the Shetland Group shows a different lithological development from that found in the type and reference wells. Hence, the subdivision based on the Viking Graben is not used there. Furthermore, because the proven lateral extent appears to be limited there is not defined any new stratigraphic unit. A description of the unit is, however, given below.

Reference well section:
Norwegian well 31/6-2 from 1128 to 978 m, coordinates N 60°43' 58.24", E 03° 54' 55.76" (Fig. 37). No cores.

Thickness:
In well 31/6-2 the thickness is 50 m, but the unit is absent from several wells in the area.

Lithology:
The unit generally consists of marly mudstones containing occasional limestone beds. In some wells, such as the type well, there is a relatively thick marly limestone bed uppermost. The mudstones are calcareous, medium to light grey, and the limestones are argillaceous, mainly white to medium grey.

Basal stratotype:
The lower boundary of the unit is towards the more carbonate rich Cromer Knoll Group. There is an increase in gamma-ray intensity and a distinct decrease in velocity across the boundary from the Cromer Knoll Group (Fig. 37).

Characteristics of the upper boundary:
The upper boundary is unconformable towards the limestones of the Hardråde Formation. This boundary can be difficult to detect on logs if the thick upper limestone bed is present (Fig. 37), but it is then defined by datings.

Distribution:
The unit is present in the Troll area.

Age:
Turonian to Cenomanian.

Depositional environment:
Open marine.

Remarks:
This unspecified unit is time-equivalent with the Svarte, Blodøks and Tryggvason Formations (Fig. 6).

TERTIARY

BASIN EVOLUTION

Early Tertiary time saw the culmination of a significant episode of rifting in the North Atlantic region. Oceanic crust was emplaced between Greenland and the Hebridean-Norwegian Margin during the Mid Paleocene (Gage & Dore 1986). In the context of this active rifting there was a late Early Paleocene tectonic event which was accompanied by a global drop in sea level.

This tectonic activity resulted in downwarping of the North Sea Basin, generally centred above the main Mesozoic rift system, complicated by intrabasinal uplift. The rapid subsidence of the Viking Graben and the Central Trough was accompanied by tilting of their flanks, in particular the East Shetland Platform and the Utsira High.

On the topographical highs, the Ekofisk Formation and sometimes the Tor Formation were eroded and redeposited in basinal areas by mass gravity flows (e.g. well 2/1-4, Fig. 51). This reworking is commonly observed along graben margins and intrabasinal highs, and close to rising salt diapirs.

The tectonic activity led to the production of coarse clastics derived from the faulted basin margins in the west. Associated tilting produced an easterly drainage pattern. The Shetland Platform was covered by a deltaic prism prograding towards the continental slope. The deep zones were gradually filled in by submarine fans (Maureen, Ty, Andrew, Heimdal, Forties and Hermod Formations) interbedded with hemipelagic sediments (Våle, Lista and Sele Formations).

Simultaneously, the uplifted intrabasinal areas were gradually submerged by the deepening sea, and covered by marine muds.

During the late Paleocene and early Eocene, progressive infill of the basin, combined with a drop in sea level in the early Eocene, the relatively shallow marine area changed to a non-marine shelf and deltaic environment. Sediments prograded eastwards. Sediments from the Shetland Platform were eroded to form a second depositional sequence - the Frigg Formation (Conort 1986).

At the end of the Paleocene, the general pattern of sedimentation was interrupted by ash-fall deposits (Balder Formation). These represent explosive volcanism, probably linked to an active rifting phase. The main eruption centres were probably the Møre Basin and the Faeroe-Shetland region (Malm et al. 1984), with an additional centre in the Skagerrak.

Further subsidence resulted in a major Early Eocene transgression. Marine muds (Hordaland Group) covered the Late Paleocene ash beds, except in marginal

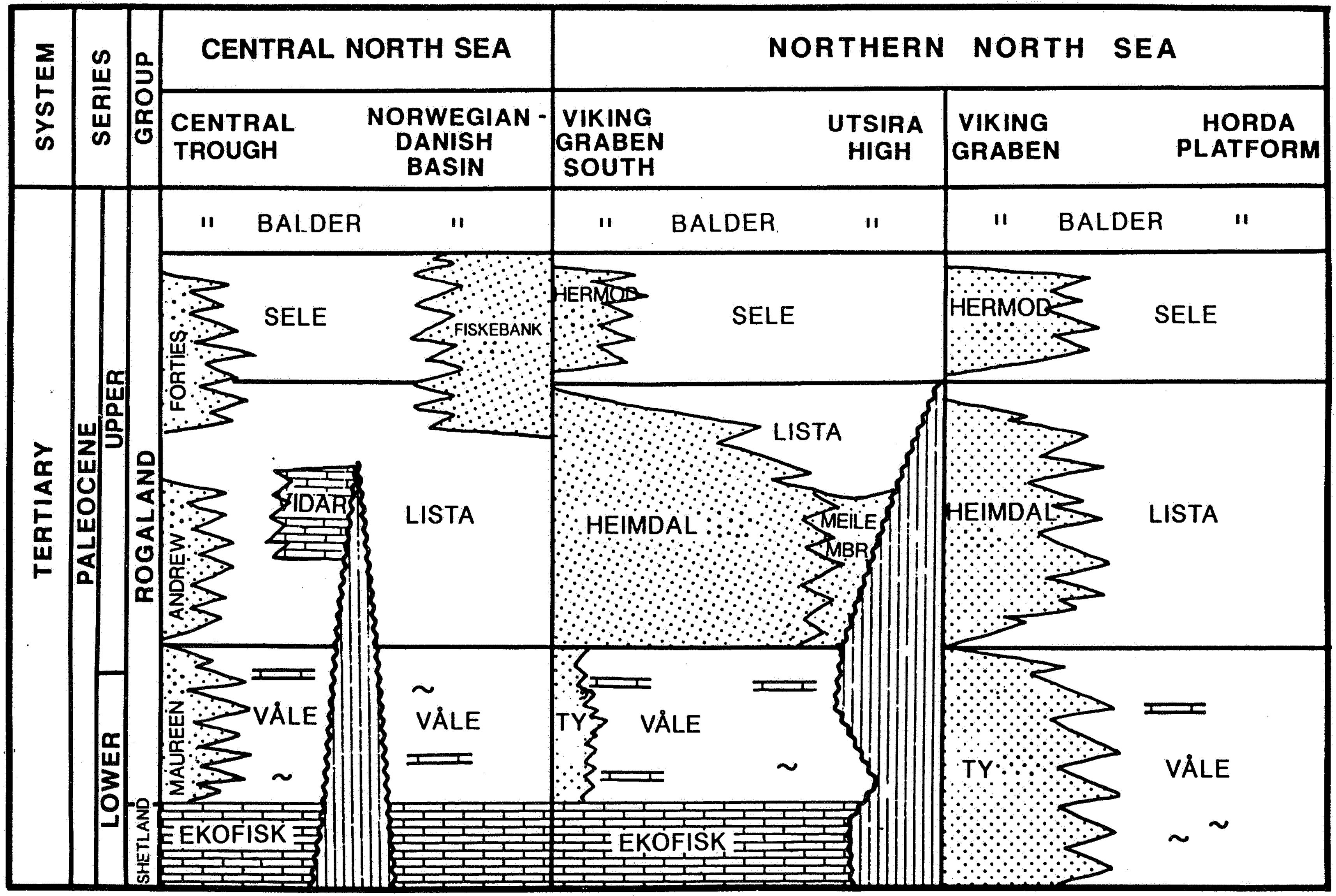


Fig. 39

PALEOCENE LITHOSTRATIGRAPHIC NOMENCLATURE, NORWEGIAN NORTH SEA.

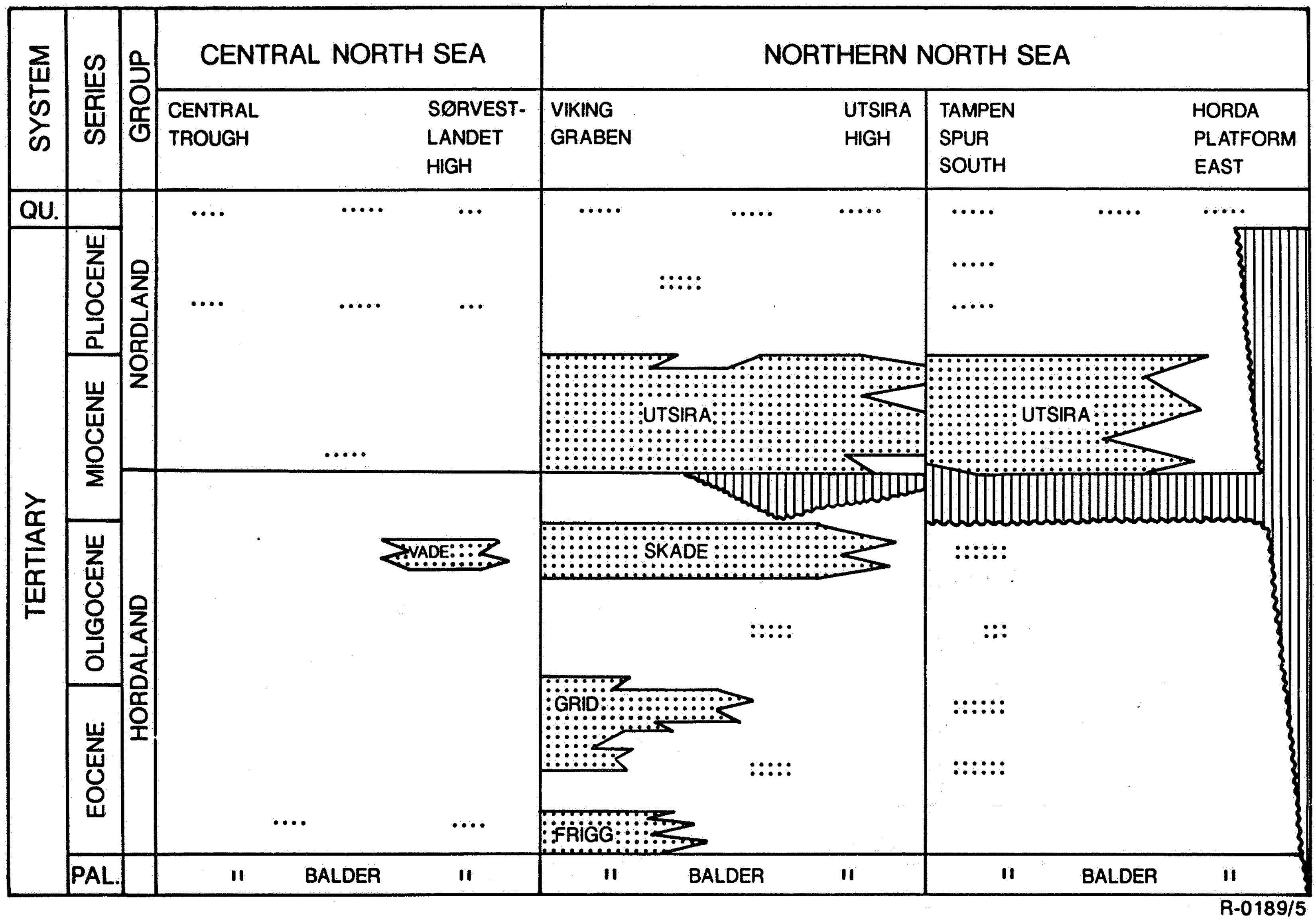


Fig. 40 **LITHOSTRATIGRAPHIC NOMENCLATURE IN THE HORDALAND AND NORDLAND GROUPS (TERTIARY)**
NORWEGIAN NORTH SEA

TERTIARY

WELL 1/3-1

TYPE WELL: VÅLE FORMATION
REFERENCE WELL: VIDAR FORMATION

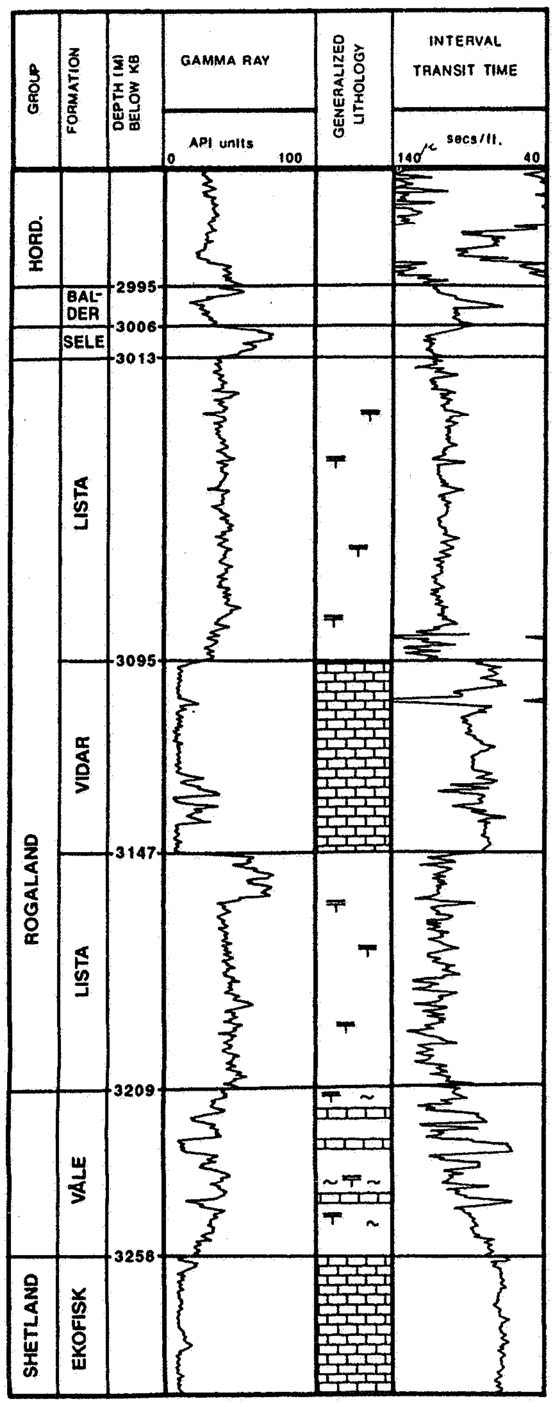


Fig. 41

TERTIARY

WELL 15/9-5

REFERENCE WELL: HEIMDAL FORMATION, VÅLE FORMATION

(ROGALAND GROUP)

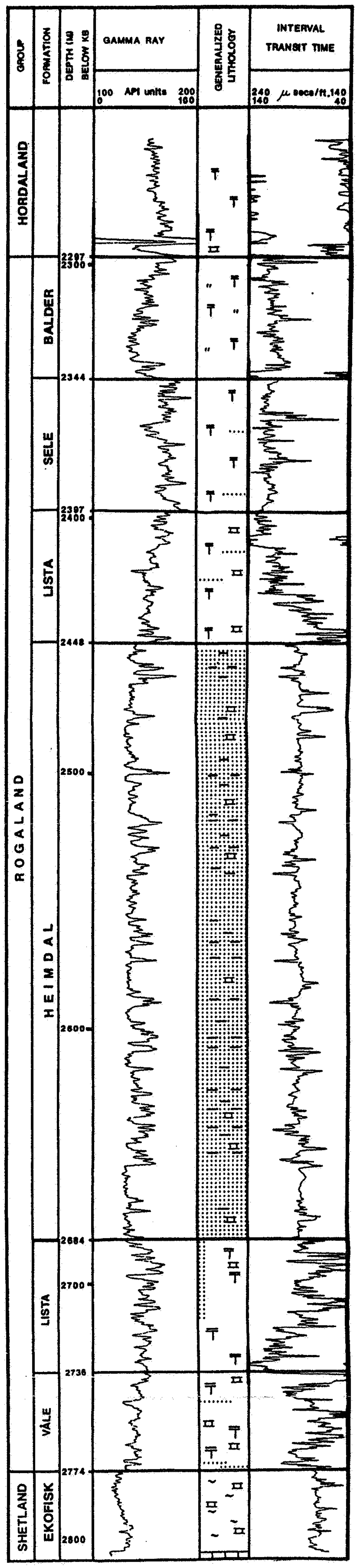


Fig. 42

areas around the East Shetland Platform where sands were locally deposited. Towards the end of the Eocene, the sea level dropped resulting in local erosion on highs and a hiatus. Sedimentation was continuous (Grid Formation) in basins.

Oligocene sediment was dominated by shales. Late in the period, however, the general pattern of sedimentation became dominated by deposition of sandstones (Skade Formation). The change in the sedimentation pattern was probably connected with a general lowering of the sea level.

From the Late Miocene, sedimentation was dominated by fine- grained marine clastics (Nordland Group). Local uplifts produced marginal, marine sands. In general, the period from Late Miocene to Recent is a regressive period. Sedimentation was affected by glacio-eustatic fluctuations of sea level.

During the Quaternary (Pleistocene), ice sheets advanced and retreated several times across the North Sea spreading a sheet of boulder clay, moraines and outwash sands across large areas of the North Sea Basin. Glaciomarine clays (Nordland Group) were deposited in front of the ice.

The Quaternary deposits vary in thickness, being up to 500 m in some areas and thin or absent elsewhere. The Pleistocene glacial deposits are often overlain by sheets of unconsolidated sand and gravel generated by the reworking action of present-day currents (Nordland Group).

General lithostratigraphic notes

Some changes to the nomenclature proposed for the Tertiary by Deegan & Scull (1977) have been made at group level, but all the formations are retained. Some new formations are defined for sections that were undifferentiated or unnamed by Deegan & Scull (1977).

Rogaland Group:
The strata deposited from the end of the Upper Cretaceous to the Balder Formation represent a genetical rock sequence deposited by gravitational forces as submarine fans interbedded with hemipelagic sediments. The sandstones grade into shales which are the distal representatives of the same sequence. When Deegan & Scull (1977) erected one group (the Montrose Group) containing the sandstone sequences and another group (the Rogaland Group) containing the shaly sequences they created a number of nomenclatorial problems. This division has therefore been abandoned, and the Rogaland Group now comprises all the formations from the earlier Montrose and Rogaland Groups.

Two new sandstone formations have been defined in the Rogaland Group. These were not identified or differentiated by Deegan & Scull (1977). They have previously been given informal names, the Ty Formation being called the '10/1-1 sand' and the Hermod Formation the 'Cod sand'. In addition, a new member, the Meile member, is informally named; it has previously been referred to as the 'Gamma sand on Sleipner'.

The distal equivalent of the Maureen Formation is formally named as the Våle Formation. The Lista and Sele Formations are distal representatives of those formations, and are unaltered from Deegan & Scull (1977).

Hordaland Group:
In the previously undifferentiated part of the Hordaland Group, three new, formally defined, formations (the Grid, Skade and Vade Formations) have been identified.

Nordland Group:
No changes from the existing nomenclature.

REVISED TERTIARY LITHOSTRATIGRAPHIC NOMENCLATURE FOR THE NORWEGIAN NORTH SEA
by T. Hardt, E. Holtar, D. Isaksen, G. Kyllingstad, K. S. Lervik, A. S. Lycke and K. Tonstad.

Rogaland Group (Rogalandsgruppen)

Name:
The Rogaland Group was named by Deegan & Scull (1977) after the county of Rogaland in southwest Norway.

Type area:
The group is developed in the northern and central North Sea. In this paper the Rogaland Group comprises all the formations allotted to the Montrose and Rogaland Groups by Deegan & Scull (1977). The division into the Montrose Group and the Rogaland Group is not retained. It was based on differences in proximal and distal parts of the same sedimentary system, and therefore caused numerous practical problems.

The Rogaland Group in the Norwegian sector consists generally of proximal sediments in the west which interfinger with more distal equivalents in the east. The proximal part is illustrated in UK wells 10/1-1A and 21/10-1 from the northern and central North Sea, respectively. The corresponding distal part of the sedimentary system is illustrated in Norwegian wells 31/2-6 and 2/7-1.

Thickness:
The group is 684 m thick in UK well 10/1-1A and 459 m in UK well 21/10-1. It thins eastwards and is 345 m and 112 m thick in Norwegian wells 31/2-6 and 2/7-1, respectively.

Lithology:
Dominant lithologies in the west are sandstones interbedded with shales. These sandstones form lobes which passes laterally into shales eastwards, and in most of the Norwegian sector the Rogaland Group consists of argillaceous marine sediments. The basal deposits frequently contain reworked limestones and marls. Towards the top of the group the shales become increasingly tuffaceous.

Basal stratotype:
The base of the Rogaland Group is placed at the contact with the underlying chalk or marl sequences of the Shetland Group. This boundary is defined by increasing gamma-ray response and reduced velocity, reflecting a reduction in carbonate content.

In the central North Sea, the lithology changes from the chalk facies of the Shetland Group to shales or marls of the Rogaland Group. In the western part of the area, calcareous sandstones may overlie the Shetland Group. In the northern North Sea, the boundary is reflected by a change from the calcareous shales of the Shetland Group to shales with a variable carbonate content. In the southwest, sandstones frequently overlie the Shetland Group.

Characteristics of the upper boundary:
The upper boundary of the Rogaland Group is marked by a change from laminated tuffaceous shales to more irregularly bedded sediments which are much less tuffaceous.

Distribution:
The Rogaland Group is widely distributed in the central and northern North Sea.

Age:
Paleocene - Early Eocene

Depositional environment:
The sediments of the Rogaland Group were deposited in a relatively deep marine environment characterised by submarine fans which built out from the west, and possibly from the southeast.

Subdivision:
The Rogaland Group is subdivided into twelve formations. The Våle (new), Lista, Sele and Balder Formations all represent a distal marine depositional environment. Arenaceous fans splaying from the East Shetland Platform are to varying extents interdigitated with the first three of these formations. These clastic sediments are defined as separate formations developed south and east of the Fladen Ground Spur, and other formations are developed east of the East Shetland Platform in the Viking Graben area. South and east of the Fladen Ground Spur, the Rogaland Group is subdivided into the Maureen, Andrew, Forties and Balder Formations, the first three having their approximate argillaceous equivalents in the Våle, Lista and Sele Formations.

In the southern Viking Graben, the Rogaland Group is subdivided into the Ty (new), Heimdal, Hermod (new) and Balder Formations, the first three having their argillaceous equivalents in the Våle, Lista and Sele Formations.

In the Norwegian-Danish Basin, the Fiskebank Formation replaces the Sele Formation and probably part of the Lista Formation.

Fig. 39 illustrates the relationship between these Paleocene formations.

Våle Formation (new) **(Våleformasjonen)**

Name:
Våle was a son of the Norse god Odin and his wife Rind. He was one of the twelve principal gods of Norse mythology.

Well type section:
Norwegian well 1/3-1 from 3258 to 3209 m, coordinates N 56°51'21.00", E 02°51'05.00" (Fig. 41). No cores.

Well reference sections:
Norwegian well 15/9-5 from 2774 to 2736 m, coordinates N 58°24'12.47", E 01°42'29.20" (Fig. 42). No cores.

Norwegian well 2/7-1 from 2934 to 2918 m, coordinates N 56°25'44.68", E 03°12'14.21" (Fig. 43). No cores.

TERTIARY

WELL 2/7-1

TYPE WELL: LISTA FORMATION

REFERENCE WELL: VÅLE FORMATION

(ROGALAND GROUP)

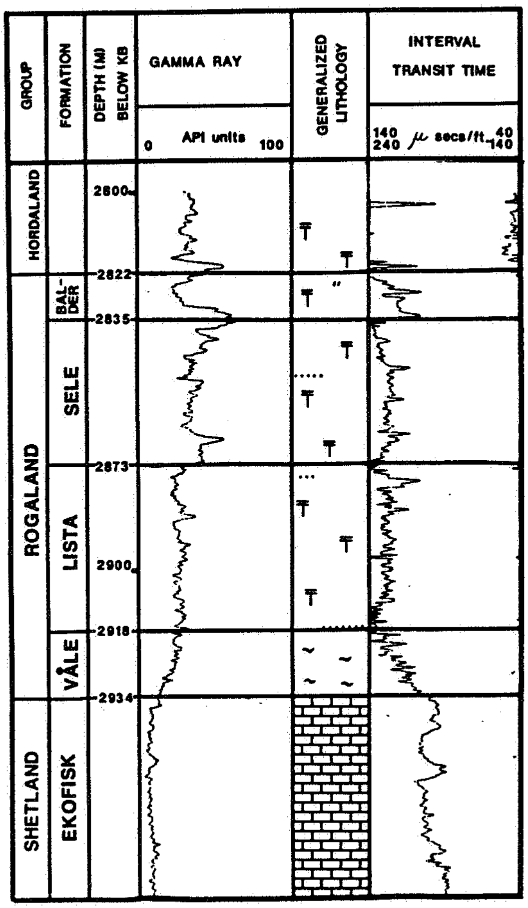


Fig. 43

Thickness:
In the type well, the Våle Formation is 49 m thick. The formation is generally of moderate thickness, normally less than 100 m. Its thickness decreases in central parts of the Central Trough and northwards in the Viking Graben.

Lithology:
The Våle Formation typically consists of marls and claystones interbedded with limestone beds and stringers of sandstone and siltstone. In the Central Trough, the formation is developed as a light grey marl, but locally has chalk and limestone interbeds probably eroded from rising diapirs. It also contains carbonate layers in the southern Viking Graben area.

Basal stratotype:
The Våle Formation rests on the Shetland Group, and the lower boundary is defined where the calcareous sediments grade into marl or shale. The boundary is placed at the upward increase in gamma-ray readings and decrease in velocity (Figs. 41 and 43). These trends may be interrupted by carbonate layers.

TERTIARY

WELL UK 21/10-1

TYPE WELL: SELE FORMATION
FORTIES FORMATION
MAUREEN FORMATION
REFERENCE WELL: ANDREW FORMATION

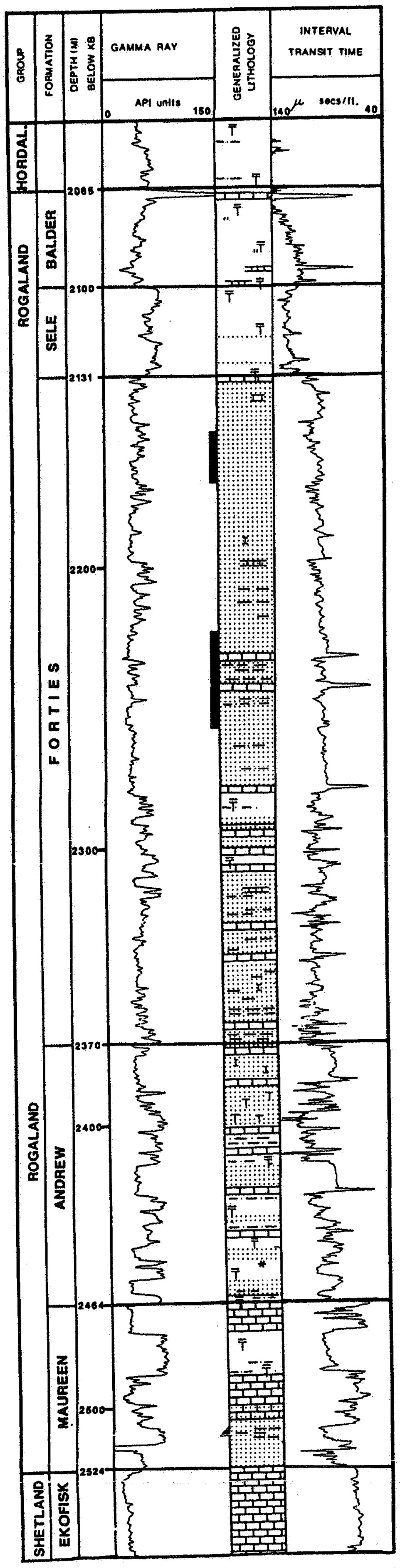


Fig. 44

TERTIARY

WELL UK 16/29-4

REFERENCE WELL : MAUREEN FORMATION

(ROGALAND GROUP)

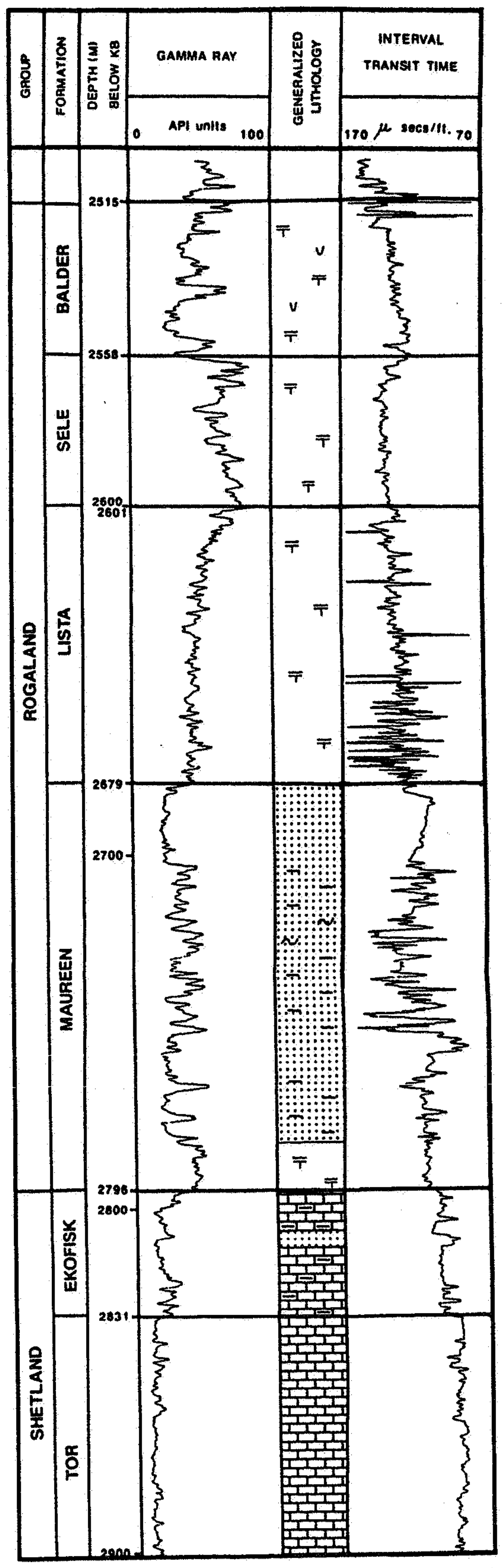


Fig. 45

Characteristics of the upper boundary:
The upper boundary is placed where the shales or marls of the Våle Formation give way to the shales of the Lista Formation. This boundary is defined by decreasing gamma-ray response and increasing velocity (Fig. 41). When the Våle Formation is overlain by sandstone-dominated formations, the upper boundary is marked by decreasing gamma-ray readings and higher velocity.

Distribution:
The Våle Formation is recognised in the central and northern North Sea, except for intrabasinal highs. In the northern part of the northern North Sea, the Lower Paleocene is very thin. The formation generally becomes coarser towards the west where it interfingers with the time-equivalent Maureen Formation in the Central Trough and Ty Formation in the Viking Graben.

Age:
Early Paleocene

Depositional environment:
The Våle Formation was deposited in a marine environment.

Maureen Formation (Maureenformasjonen)
Name:
Named by Deegan & Scull (1977) from the Maureen Field in UK block 16/29.

Well type section:
UK well 21/10-1 from 2524 to 2464 m, coordinates N 57°43'50.37", E 00°58'29.19" (Fig. 44). No cores.

Well reference sections:
UK well 16/29-4 from 2796 to 2679 m, coordinates N 58°05'20.90", E 01°39'15.10" (Fig. 45). No cores.
Norwegian well 7/11-1 from 3173 to 3069 m, coordinates N 57°04'15.60", E 02°26'24.40" (Fig. 46). No cores.

Thickness:
The Maureen Formation is thickest in the Witch Ground Graben in the UK sector of the central North Sea where it consists of as much as 400 m of mainly sandstones. It thins westwards and southwards, and is poorly developed in Norwegian waters, the maximum thickness in a well is found 7/11-1 where there are 104 m of sandstones and carbonates.

Lithology:
The Maureen Formation consists of sandstones that are slightly to very calcareous and often contain reworked limestones. The sandstones are interbedded with brown and dark grey shales, and are fine to medium grained, locally very coarse.
The type well established by Deegan & Scull (1977) represents a distal and somewhat atypical section. A more representative well from the Maureen Formation sandstones is UK well 16/29-4 (Fig. 45).
The formation pinches out distally and is replaced by the light grey marls and shales of the Våle Formation.

Basal stratotype:
The Maureen Formation rests on the Shetland Group.

TERTIARY
WELL 7/11-1
REFERENCE WELL : MAUREEN FORMATION
FORTIES FORMATION
(ROGALAND GROUP)

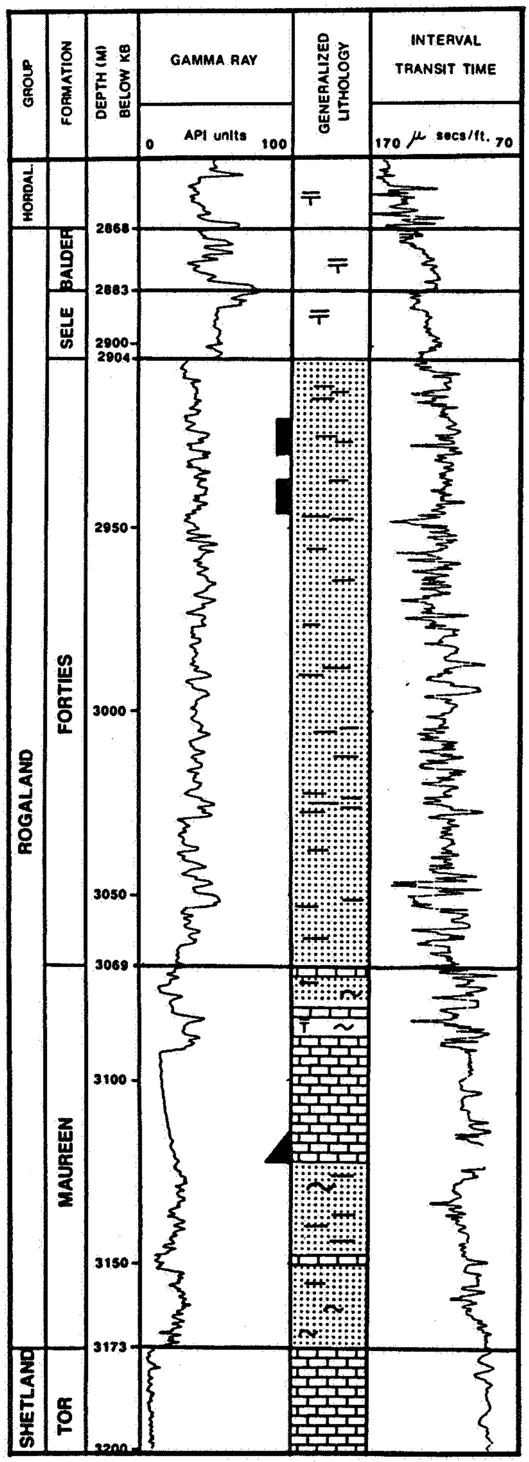
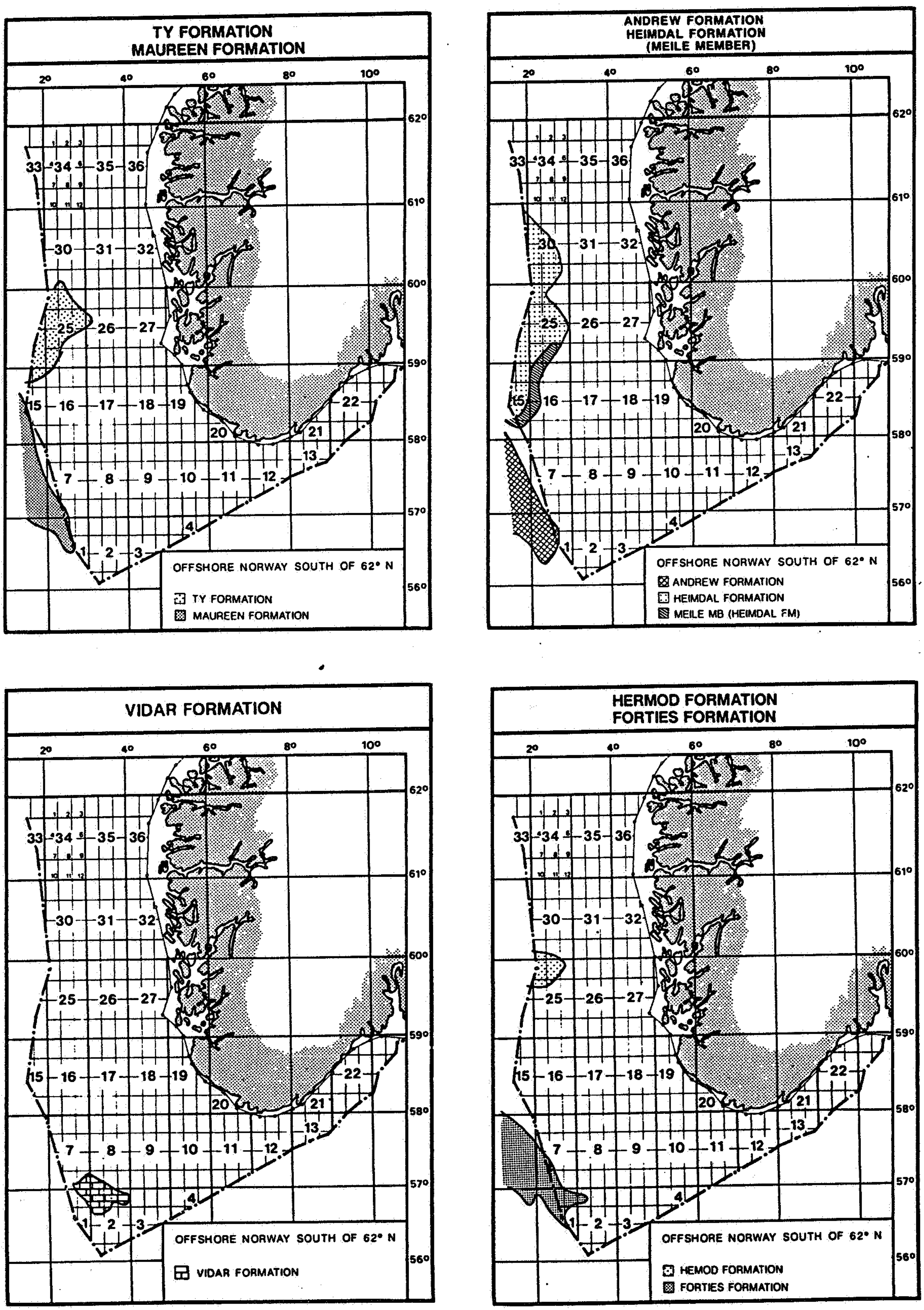


Fig. 46

The change from the primarily calcareous deposits of the chalk facies, or the calcareous mudstones of the siliciclastic facies, to the heterogeneous sandstones of the Maureen Formation is generally shown as an increasing and more irregular gamma-ray response (Fig. 45) and a decreasing velocity (Figs. 44 and 46).

APPROXIMATE DISTRIBUTION OF PALEOCENE FORMATIONS



RS-0061

Fig. 47

TERTIARY
WELL UK 10/1-1A

TYPE WELL: TY FORMATION
REFERENCE WELL: HERMOD FORMATION

(ROGALAND GROUP)

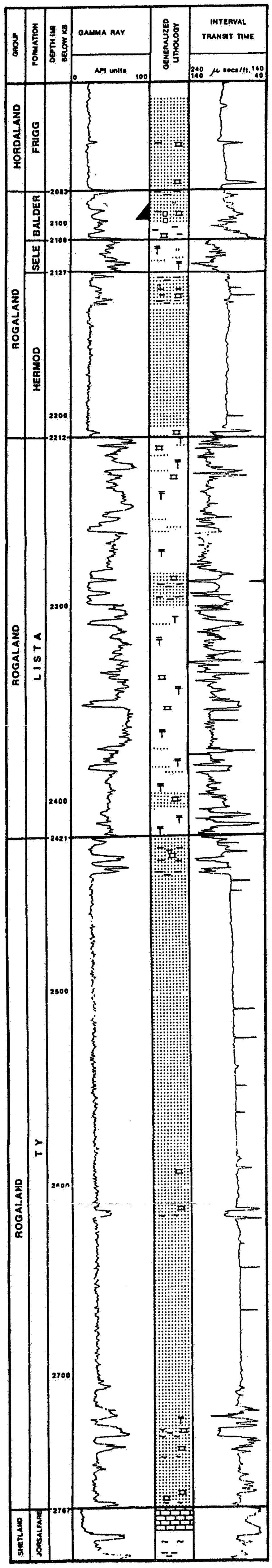


Fig. 48

TERTIARY
WELL 15/3-1

REFERENCE WELL: TY FORMATION

(ROGALAND GROUP)

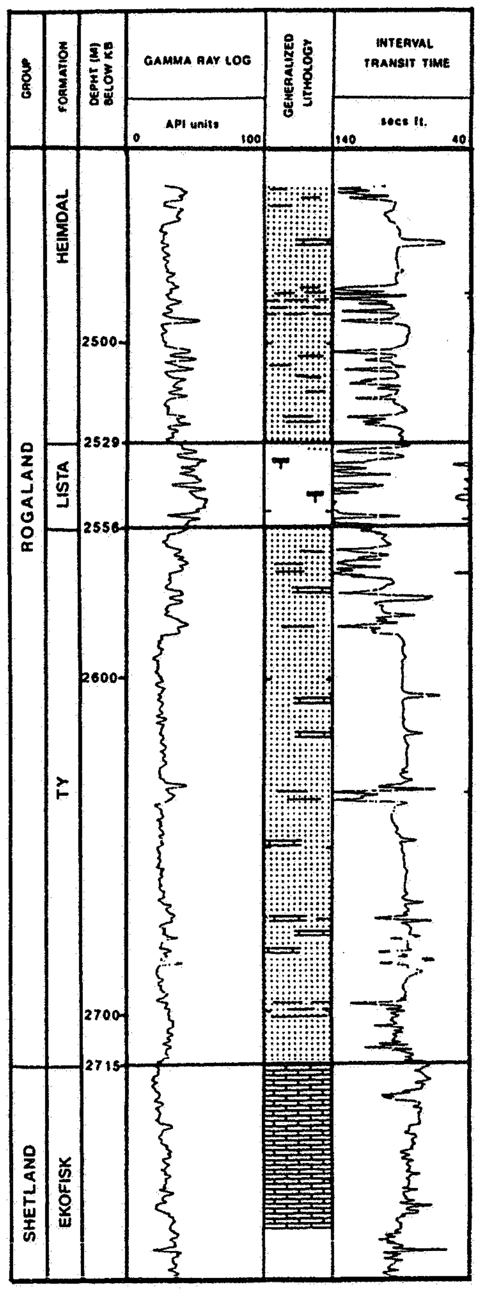


Fig. 49

Characteristics of the upper boundary:
The upper boundary is defined by the change from sandstones containing reworked limestone fragments and limestone beds, to the shales of the Lista Formation. The boundary is characterised by an upward increasing gamma-ray response (Fig. 45) and an overall decreasing velocity. Where the Andrew Formation rests on the Maureen Formation the transition is seen as an increase in gamma-ray readings and decrease in velocity (Fig. 44).

Distribution:
The coarse detrital facies of the Maureen Formation is developed in the central North Sea, in what is in general a lobe-shaped deposit trending from the East Shetland Platform southeast along the Central Trough. The formation thins towards the east and west, and grades into the Våle Formation. The Maureen Formation is not well developed in the Norwegian sector. Its approximate distribution on the Norwegian continental shelf is shown in Fig. 47.

Age:
Early Paleocene.

Depositional environment:
The Maureen Formation was deposited in an open marine environment dominated by sand influx from the northwest, together with local erosion of Danian and Cretaceous rocks.

Ty Formation (new) (Tyformasjonen)

Name:
Ty was a son of the Norse god Odin and was one of the 12 principal gods in Norse mythology.

Well type section:
UK well 10/1-1A from 2767 to 2421 m, coordinates N 59°50'10.50", E 02°00'33.60" (Fig. 48). No cores.

Well reference section:
Norwegian well 15/3-1 from 2715 to 2556 m, coordinates N 58°50'57.00", E 01°43'13.25" (Fig. 49). No cores.

Thickness:
The Ty Formation is 346 m thick in the type well. The formation has its depocenter west of the type well, and thins towards the east. It is 159 m thick in the reference well.

Lithology:
The Ty Formation consists of clean sandstones, generally massive and clear to light grey in colour. Distally the sandstones are interbedded with dark grey shales, but the sandstone bodies tend to be clean.

Basal stratotype:
The Ty Formation rests on the Shetland Group. The lower boundary represents a distinct change from calcareous sediments into clean sandstones with regular gamma-ray and velocity patterns. The log response changes from low gamma- ray readings and high velocity in the Shetland Group, to higher gamma-ray readings and lower velocity in the Ty Formation sandstones (Fig. 48). The boundary may be confused by interbedded shales in the Ty Formation, but the distinct drop in carbonate content distinguishes the formation from the underlying sediments.

Characteristics of the upper boundary:
The upper boundary is characterised by the transition into the shales of the Lista Formation with higher gamma-ray readings and lower velocity (Figs. 48 and 49). Where the Heimdal Formation overlies the Ty Formation, the boundary is recognised by the change to slightly more erratic log patterns. This boundary may be difficult to identify, but the two formations are normally separated by the Lista Formation.

Distribution:
The Ty Formation has been identified in the southern Viking Graben, especially in the northwestern part of quadrant 25 and the northernmost part of quadrant 15. Its approximate distribution on the Norwegian continental shelf is outlined in Fig. 47.

Age:
Early Paleocene.

Depositional environment:
The Ty Formation was deposited in a deep marine fan system which built out from the west.

Vidar Formation (Vidarformasjonen)

Name:
Vidar was a son of the Norse god Odin.

Well type section:
Norwegian well 2/1-4 from 3138 to 3075 m, coordinates N 56°54'39.82", E 03°04'02.25" (Fig. 50). No cores.

Well reference section:
Norwegian well 1/3-1 from 3147 to 3095 m, coordinates N 56° 51'21.00", E 02°51'05.00" (Fig. 41). No cores.

Thickness:
The Vidar Formation is 63 m thick in the type well and 52m thick in the reference well.

Lithology:
Homogenous limestone is the dominant lithology, but streaks of skeletal detritus and clasts of sandstone occur.

Basal stratotype:
The lower boundary represents a sharp transition from the claystones of the Lista Formation or the marl of the Våle Formation to the overlying limestones of the Vidar Formation. This is marked by a distinct decrease in gamma-ray readings and an increase in velocity (Figs. 41 and 50).

Characteristics of the upper boundary:
The upper boundary represents a transition to the claystones of the Lista Formation, characterised by a dramatic increase in gamma-ray readings and a decrease in velocity (Figs. 41 and 50).

Distribution:
The Vidar Formation is present in the Central Trough (Fig. 47). A similar limestone is found in well 16/1-1. This might be an equivalent to the Vidar Formation.

TERTIARY

WELL 2/1–4

REFERENCE WELL: VIDAR FORMATION

(ROGALAND GROUP)

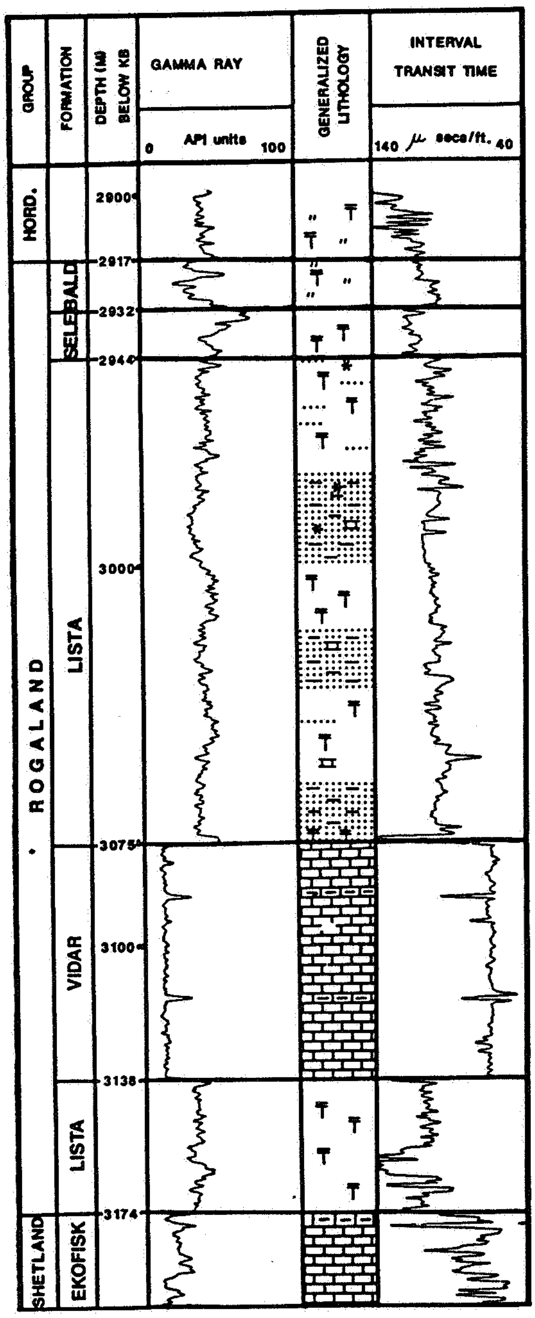


Fig. 50

Age:
Early Paleocene.

Depositional environment:
Presence of reworked Upper and Lower Cretaceous material indicates that the Vidar Formation represents reworked chalk from the Shetland Group chalk facies as well as reworked marls and claystones from the Cromer Knoll Group. Mass flows from each side of the Central Trough are the most probable transport mechanism for this reworked material.

Lista Formation (Listaformasjonen)

Name:
Named by Deegan & Scull (1977) after the Lista Spur structure (Lista Fault Block Complex on Fig. 3) in the Norwegian-Danish Basin.

Well type section:
Norwegian well 2/7-1 from 2918 to 2873 m, coordinates N 56°25'44.68", E 03°12'14.21" (Fig. 43). No cores.

Well reference sections:
Norwegian well 15/9-11 from 2386 to 2308 m, coordinates N 58°24'02.53", E 01°53'41.79" (Fig. 51). 10 m of cores from the lowermost part of the formation.

Norwegian well 16/8-1 from 1749 to 1708 m, coordinates N 58°27'24.80", E 02°25'56.80". No cores.

Thickness:
The Lista Formation is 45 m thick in the type well. In the Viking Graben its thickness varies between 100 and 200 m. There are two major depocentres, a northern one around the Beryl Field where thicknesses are up to 550 m, and a southern one at the northwestern edge of the Jæren High with a maximum thickness of approximately 350 m. Between these two depocentres the formation is thin (less than 50 m). The formation generally thins towards the highs where thicknesses are less than 50 m.

Lithology:
The Lista Formation consists of brown to grey-brown shales, which are generally non-tuffaceous and poorly laminated. Occasionally it contains stringers of limestone, dolomite and pyrite. Thin sandstone layers are locally developed. They are less than 5 m thick, and are most common in the lower part of the formation.

Basal stratotype:
In general, the lower boundary is marked by a transition into a lithology with higher gamma-ray and lower velocity readings than the underlying formations (Figs. 41, 48 and 50).

Characteristics of the upper boundary:
In areas where the Lista Formation is overlain by sandy Paleocene formations, the logs show the incoming of coarser clastics with a characteristic, blocky, gamma-ray and sonic log pattern (Figs. 48 and 52). Where the Sele Formation overlies the Lista Formation, the boundary is well defined on logs, without any distinct changes in lithology. The Sele Formation shows higher, and often smoother, gamma-ray readings and a very smooth, lower velocity pattern (Fig. 51). In some areas, both the Lista and Sele Formations contain sandstone beds, resulting in a poorly defined boundary based on log character. Where the Lista Formation is overlain by the Balder Formation, the boundary is defined by lower gamma-ray readings and higher velocity in the Balder Formation.

It is difficult to distinguish the Lista and Sele Formations in the Frigg area.

Distribution:
The Lista Formation is widespread in the Norwegian North Sea.

Age:
Late Paleocene.

Depositional environment:
The deposition of the Lista Formation shales took place in relatively deep water under low-energy conditions. Sandstone layers represent distal parts of sandy formations within the Rogaland Group.

Andrew Formation (Andrewformasjonen)

Name:
Named by Deegan & Scull (1977) after the Andrew Field in UK blocks 18/27 and 16/28.

Well type section:
UK well 14/25-1 from 2199 to 1897 m, coordinates N 58°01'11.40", E 00°00'56.40". No cores.

Well reference section:
UK well 21/10-1 from 2464 to 2370 m, coordinates N 57°43'50.37", E 00°58'29.19" (Fig. 44). No cores.

Thickness:
The Andrew Formation is 302 m thick in the type well and 94 m in the reference well, which represents the general thinning southwards from the East Shetland Platform. Close to the Fladen Ground Spur, the formation reaches thicknesses of approximately 1200 m.

Lithology:
The Andrew Formation consists of sandstones with claystone interbeds. The sandstones are generally very fine to medium grained and are composed of subangular to subrounded, clear to orange-stained quartz and feldspar grains. The sandstones are poorly sorted and often have a calcareous cement. Thin stringers of limestone occur.

Basal stratotype:
The Andrew Formation overlies the shales, marls and limestone interbeds of the Våle Formation, reflected by a higher gamma-ray level in the Andrew Formation. It may also rest on the Maureen Formation, and in that case the boundary is still seen as an increase in gamma-ray readings upwards into the less calcareous Andrew Formation (Fig. 44).

Characteristics of the upper boundary:
The Lista Formation usually overlies the Andrew Formation, and the boundary is characterised by higher gamma-ray readings and lower velocity upwards into the Lista Formation. Where the Forties Formation directly overlies the Andrew Formation, the boundary may be difficult to define, but the Forties Formation generally has a lower velocity than the Andrew Formation (Fig. 44). This boundary is very difficult to determine in the Norwegian sector.

Distribution:
The Andrew Formation was deposited as an elongated lobe trending southeastwards from the western part of the Fladen Ground Spur into the Central Trough. The formation is not well developed in the Norwegian sector, even though the distal parts of the lobe may be expected to occur. Its approximate distribution is shown in Fig. 47.

Age:
Paleocene.

Depositional environment:
The Andrew Formation was deposited as submarine fans.

Heimdal Formation (Heimdalformasjonen)

Name:
Named by Deegan & Scull (1977) after the Heimdal Field on the Norwegian continental shelf. Heimdal was a son of the Norse god Odin, and one of the principal gods in Norse mythology.

Well type section:
Norwegian well 25/4-1 from 2423 to 2067 m, coordinates N 59°34'27.30", E 02°13'22.60" (Fig. 52). 36 m of cores from the upper part of the formation, and 6.5 m from the lower part.

Well reference section:
Norwegian well 15/9-5 from 2684 to 2448 m, coordinates N 58°24'12.47", E 01°42'29.20" (Fig. 42). No cores.

Thickness:
The Heimdal Formation is 356 m thick in the type well and 236 m thick in the reference well. It thins rapidly east of these wells and south of well 15/9-5.

Lithology:
The formation is dominated by thick units of poorly sorted, fine to coarse grained, poorly cemented sandstones with variable amounts of mica, glauconite and detrital lignite. The sandstone units are interbedded with grey and black shales, limestones and sandy limestones. There is a wide range in number and thickness of interbedded lithologies. In general, the amount of carbonate increases towards the base of the formation.

Basal stratotype:
The lower boundary of the Heimdal Formation is usually marked by a transition from the Lista Formation into the interbedded sandstones of the Heimdal Formation. The log response is characterised by lower gamma-ray readings and higher velocities when entering the overlying Heimdal Formation (Fig. 52). The Heimdal Formation locally overlies the cleaner sandstones of the Ty Formation. In that case, the lower boundary is placed where clean sandstones give way to the interbedded sandstones of the Heimdal Formation. These formations are normally separated by the Lista Formation.

Characteristics of the upper boundary:
The upper boundary is usually defined by a transition into the Lista Formation shales and is then characterised by higher radioactivity and lower velocity (Fig. 52). Locally, the Heimdal Formation is overlain by the Hermod Formation, the upper boundary therefore being defined by a change into clean, "blocky" sand.

Distribution:
The sandstones of the Heimdal Formation are distributed in a broadly lobate pattern eastwards from the western margin of the Viking Graben. Their approximate distribution on the Norwegian continental shelf is shown in Fig. 47.

Age:
Paleocene.

Depositional environment:
In the westernmost areas (East Shetland Platform/Fladen Ground Spur), the Heimdal Formation was deposited on a shallow-marine shelf under high-energy conditions. In the Viking Graben, the formation was deposited as submarine fans derived from sand accumulations on the shallow shelf to the west. The shale layers consist partly of the fine fraction of the turbidity currents and of hemipelagic mud.

Remarks:
In a narrow belt extending from the eastern part of quadrant 15 (Fig. 47), the Heimdal Formation is developed as a clean sandstone without interbedded shales. This is described as the Meile member.

Meile member (new) **(Meileleddet)**

Name:
Meile was a son of the Norse god Odin. Little is told about him except that he was one of 3 messengers from the gods to save Balder from Hel (hell in Norse mythology).

Well reference section:
Norwegian well 15/9-11 from 2526 to 2386 m, coordinates N 58°24'02.53", E 01°53'41.79" (Fig. 51).

Thickness:
The Meile member is 140 m thick in the reference well. It has a relatively constant thickness.

Lithology:
The Meile member consists of clean, well-sorted sandstones, which are very fine to fine grained, friable to hard, and clear to white.

Basal stratotype:
The lower boundary of the Meile member is defined by the transition from the marly claystones of the Våle Formation. The gamma and sonic logs change from an erratic pattern in the Våle Formation to a smooth pattern with low gamma-ray readings when passing into the Meile member (Fig. 57). Where the Våle Formation is absent the Meile member rests directly on the calcareous deposits of the chalk facies of the Shetland Group. This boundary is characterised by upward increasing gamma-ray readings and decreasing velocity (Fig. 51).

Characteristics of the upper boundary:
The upper boundary is identified by a transition from clean sandstones into the shales of the Lista Formation. On the logs the upper boundary is seen as an increase in gamma-ray values and a change to a more erratic log pattern on both gamma and sonic logs (Fig. 51).

Distribution:
The Meile member is found in a narrow belt extending northnortheastwards from the eastern part of quadrant 15. Its approximate distribution on the Norwegian continental shelf is shown in Fig. 47.

Age:
Paleocene.

Depositional environment:
The clean sandstones of the Meile member may have been derived by winnowing of the Heimdal Formation sands by submarine currents acting along highs. The formation can also be interpreted in terms of high-density turbidites which source from well-sorted shelf sand.

Remarks:
The Meile member has earlier informally been referred to as the "Gamma sand on Sleipner". The Meile member is defined informally.

Sele Formation (Seleformasjonen)

Name:
Named by Deegan & Scull (1977) after the Sele High off the coast of southwest Norway.

Well type section:
UK well 21/10-1 from 2131 to 2100 m, coordinates N 57°43'50.37", E 00°58'29.19" (Fig. 44). No cores.

Well reference section:
Norwegian well 31/2-6 from 1225 to 1167 m, coordinates N 60°54'13.57", E 03°38'49.43" (Fig. 53). No cores.

Thickness:
The Sele Formation is 31 m thick in the type well and 58 m thick in the reference well. The thickness is variable, with a maximum of 80-90 m.

Lithology:
The Sele Formation consists 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.

Basal stratotype:
Where the Sele Formation directly overlies the Lista Formation, the boundary is defined by an upward increase in gamma-ray readings and a decrease in velocity (Figs. 44 and 58). Where the Sele Formation is situated directly above sandy formations, the boundary is defined by an upward increase in gamma-ray readings and a decrease in velocity (Figs. 46 and 48).

Characteristics of the upper boundary:
The upper boundary towards the Balder Formation is expressed by a reduced gamma-ray response and an increase in velocity (Fig. 44). It is difficult to distinguish the Lista and Sele Formations in the Frigg area.

Distribution:
The Sele Formation is widely distributed throughout the North Sea. It probably has several local depo-

TERTIARY

WELL 15/9-11

REFERENCE WELL: LISTA FORMATION MEILE MEMBER, HEIMDAL FORMATION

(ROGALAND GROUP)

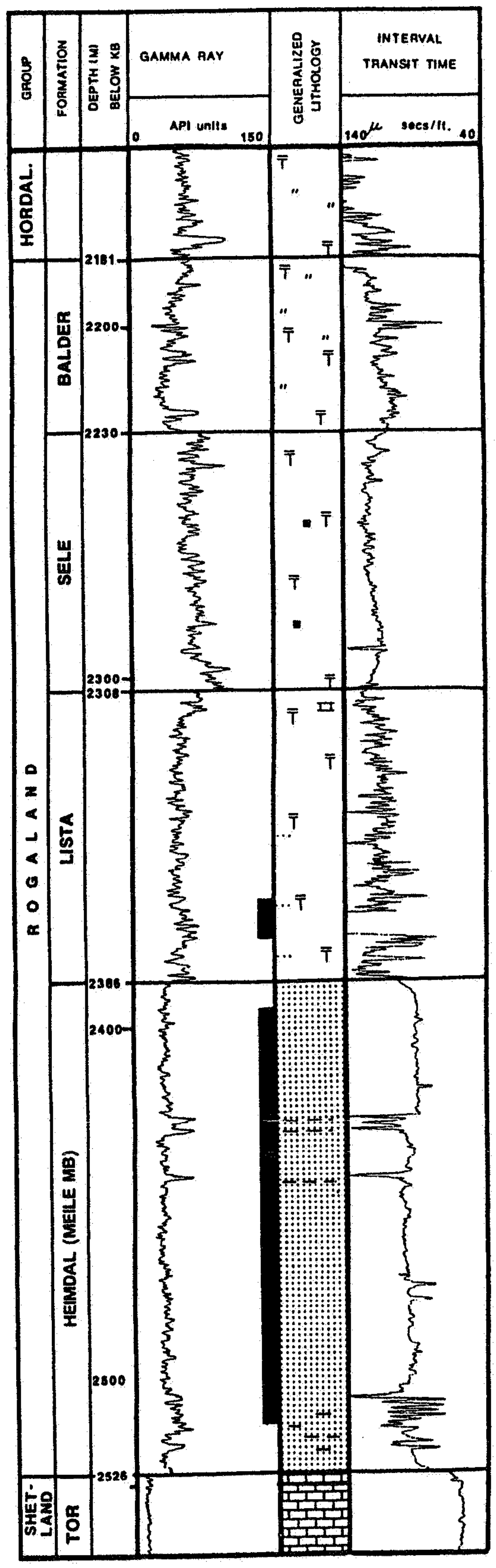


Fig. 51

TERTIARY

WELL 25/4-1

TYPE WELL : HEIMDAL FORMATION

(ROGALAND GROUP)

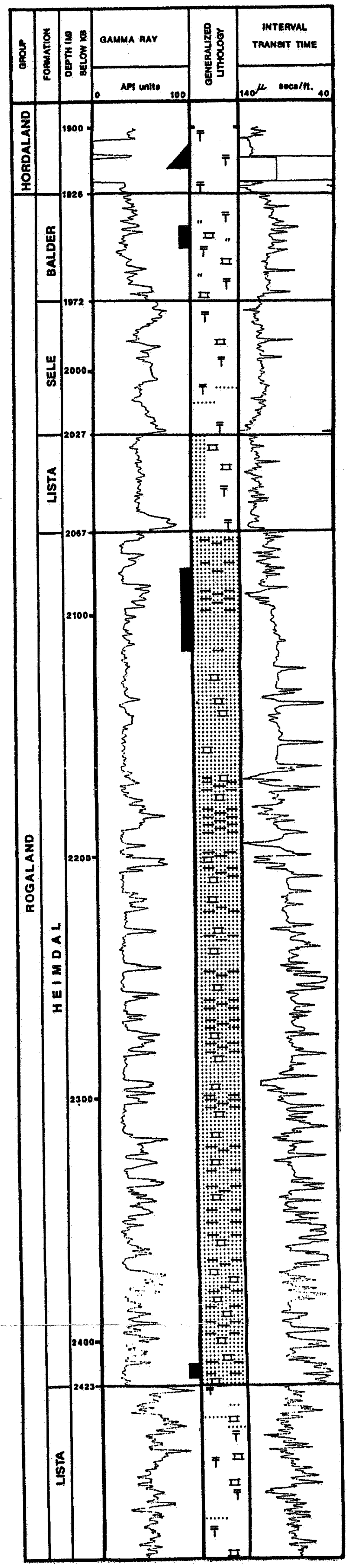


Fig. 52

TERTIARY
WELL 31/2-6

REFERENCE WELL: SELE FORMATION

(ROGALAND GROUP)

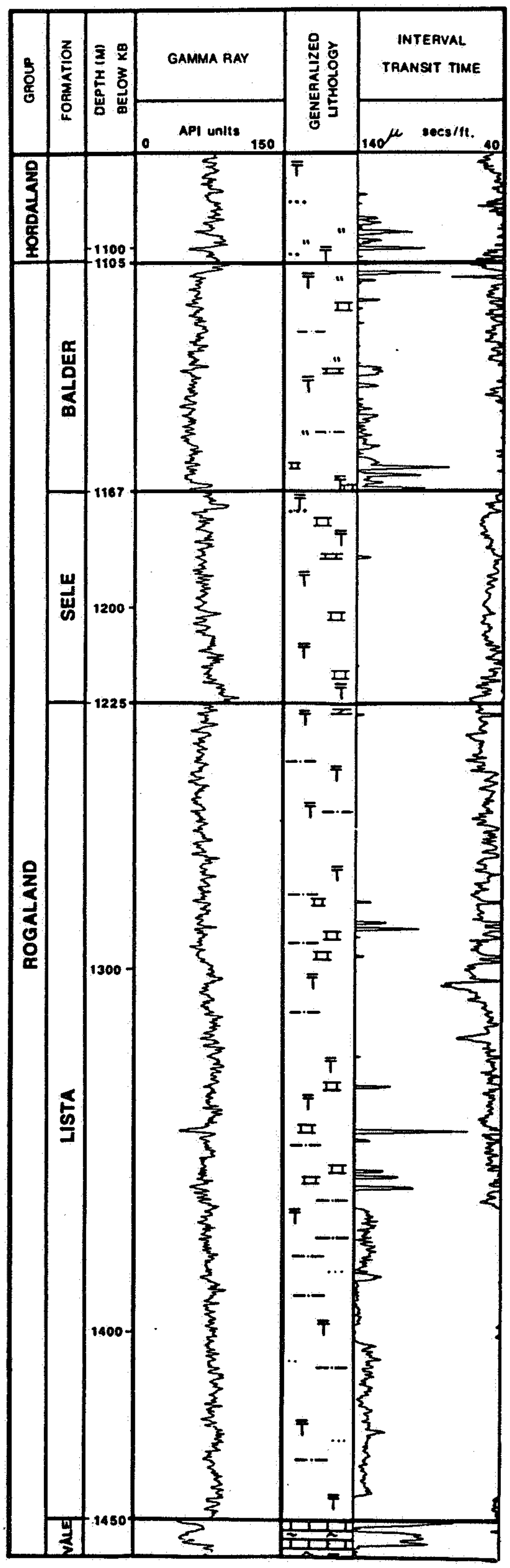


Fig. 53

TERTIARY
WELL 9/11-1

TYPE WELL: FISKEBANK FORMATION

(ROGALAND GROUP)

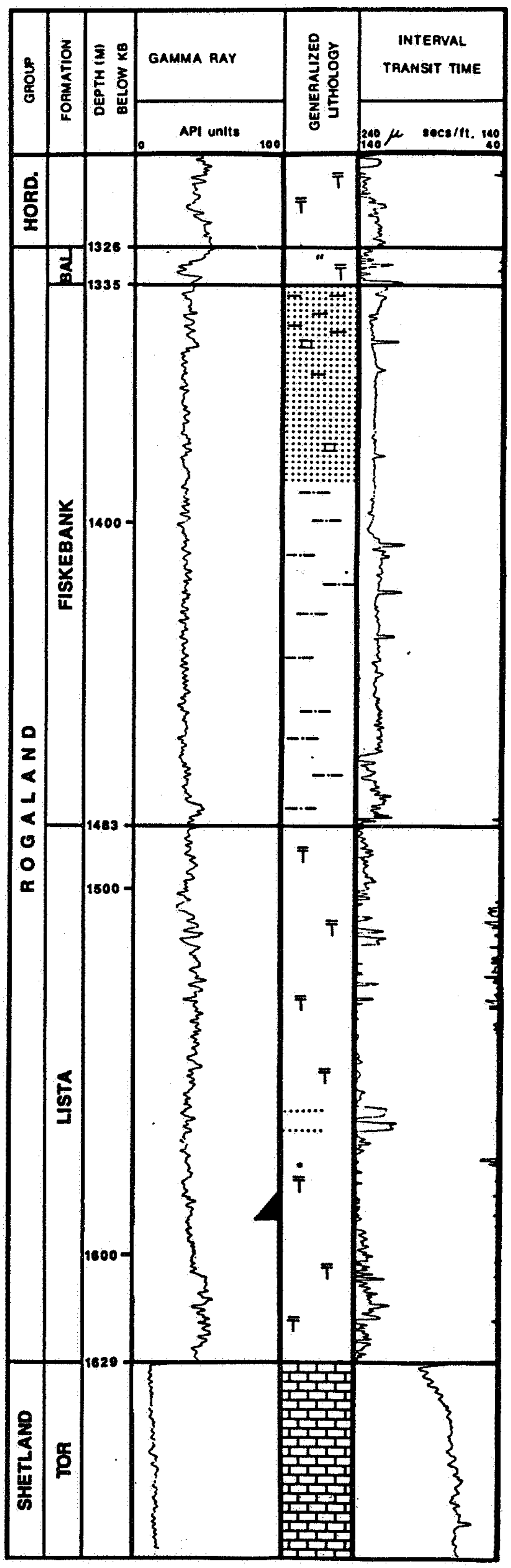


Fig. 54

centres on and near the flanks of the Viking Graben and the Central Trough. North of 60° N, the Sele Formation has only been penetrated in an area off Sognefjord. It is not found west of there, into the Viking Graben, where the Lista Formation alone is present. It does not occur on the Tampen Spur.

Age:
Late Paleocene.

Depositional environment:
The Sele Formation was deposited in a deep marine setting similar to that of the Lista Formation.

Fiskebank Formation (Fiskebankformasjonen)

Name:
From the Fiskebank (Fisher Bank), off the shore of southern Norway. Named by Deegan & Scull (1977).

Well type section:
Norwegian well 9/11-1 from 1483 to 1335 m, coordinates N 57°00'41.40", E 04°00'33.52" (Fig. 54). No cores.

Well reference section:
Norwegian well 8/9-1 from 1399 to 1307 m, coordinates N 57°26'27.28", E 03°51'03.48" (Fig. 55). No cores.

Thickness:
The formation is 148 m thick in the type well and 92 m thick in the reference well.

Lithology:
In the type section the major lithology is very fine grained, well sorted, slightly silty sandstone, which occasionally has calcareous cement.

Basal stratotype:
The basal contact of the Fiskebank Formation is defined by the boundary between the shales of the Lista Formation and the coarser sediments of the Fiskebank Formation. The difference between the two formations is not well defined on the logs. The boundary is placed where the gamma-ray readings decrease and the velocity increases somewhat upwards into the Fiskebank Formation (Figs. 54 and 55).

Characteristics of the upper boundary:
The Fiskebank Formation is overlain by the shales of the Balder Formation. The boundary is generally seen as an upward decrease in gamma-ray response and an increase in velocity (Fig. 55).

Distribution:
The formation is encountered in the Norwegian-Danish Basin.

Age:
Late Paleocene.

Depositional environment:
The formation is probably a basin-margin deposit, and appears to be mostly time-equivalent with the Sele Formation.

TERTIARY

WELL 8/9-1

REFERENCE WELL:
FISKEBANK FORMATION

(ROGALAND GROUP)

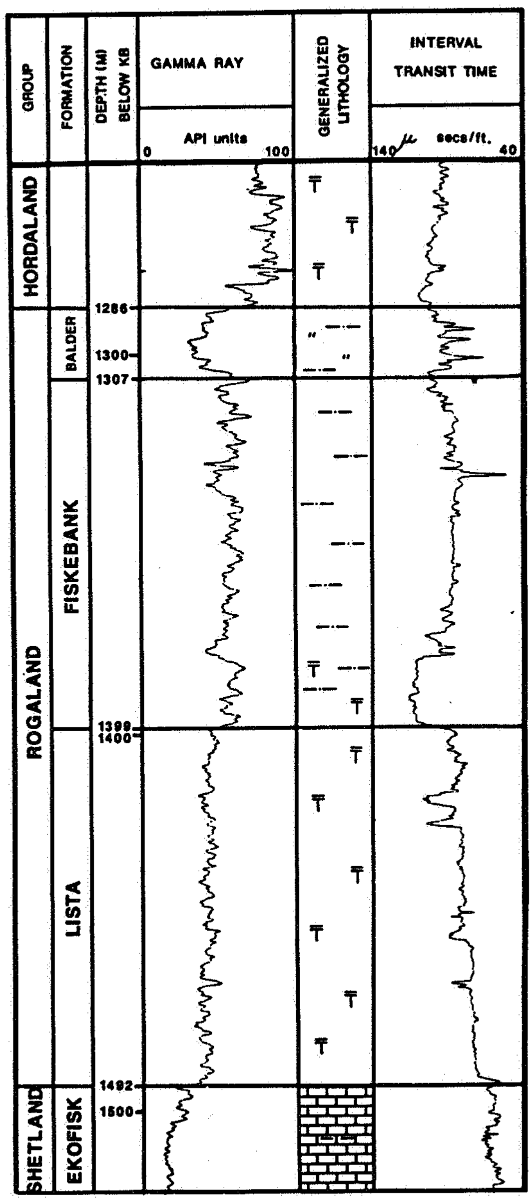


Fig. 55

Forties Formation (Fortiesformasjonen)

Name:
Named by Deegan & Scull (1977) from the Forties Field in UK block 21/10.

Well type section:
UK well 21/10-1 from 2370 to 2131 m, coordinates N 57°43'50.37", E 00°58'29.19" (Fig. 44). Cores.

Well reference section:
Norwegian well 7/11-1 from 3069 to 2904 m, coordinates N 57°04'15.60", E 02°26'24.40" (Fig. 46). No cores.

Thickness:
The Forties Formation is 239 m thick in the type well and 165 m thick in the reference well. The thickness decreases eastwards and southwards into the Norwegian sector.

Lithology:
The formation typically consists of interbedded sandstones, siltstones and claystones, becoming predominantly sandy higher in the section. The sand is fine to coarse grained, poorly to moderately sorted and contains minor amounts of lignite, pyrite, glauconite and mica. The sands encountered in the Norwegian sector were deposited distally in a lobe, and consist of very fine to fine, angular to subangular grains often with mica and a calcareous cement.

Basal stratotype:
Where the Forties Formation rests on the Andrew Formation Deegan & Scull 1977) its lower boundary is defined by a ecrease in velocity into the sandstones of the Forties ormation (Fig. 44). This boundary may be difficult to define on logs. Eastwards the Forties Formation overlies the argillaceous Lista Formation, and the boundary is haracterised by decreasing gamma-ray and increasing elocity readings into the Forties Formation.

Characteristics of the upper boundary:
The upper boundary is defined as the break between the Forties sandstones and the shales of the more or less time- equivalent Sele Formation. The log response changes from low gamma-ray readings and high velocity to higher gammaray readings and lower velocity in the Sele Formation (Fig. 44). As the Forties Formation passes into shales eastwards it may be enveloped by the Sele Formation.

Distribution:
The Forties Formation extends as a large lobe from the area south of the Halibut Horst to the northwestern part of the Central Trough. Its approximate distribution on the Norwegian continental shelf is shown in Fig. 47.

Age:
Late Paleocene.

Depositional environment:
The Forties Formation was deposited as submarine fans.

Hermod Formation (new) **(Hermodformasjonen)**
Name:
Hermod was a son of Odin, and was known as "the quick one".

Well type section:
Norwegian well 25/2-6 from 2361 to 2221 m, coordinates N 59°45'33.55", E 02°33'05.96" (Fig. 56). No cores.

Well reference section:
UK well 10/1-1A from 2212 to 2127 m, coordinates N 59°50'10.50", E 02°00'33.60" (Fig. 48). No cores.

TERTIARY

WELL 25/2-6

TYPE WELL: HERMOD FORMATION

(ROGALAND GROUP)

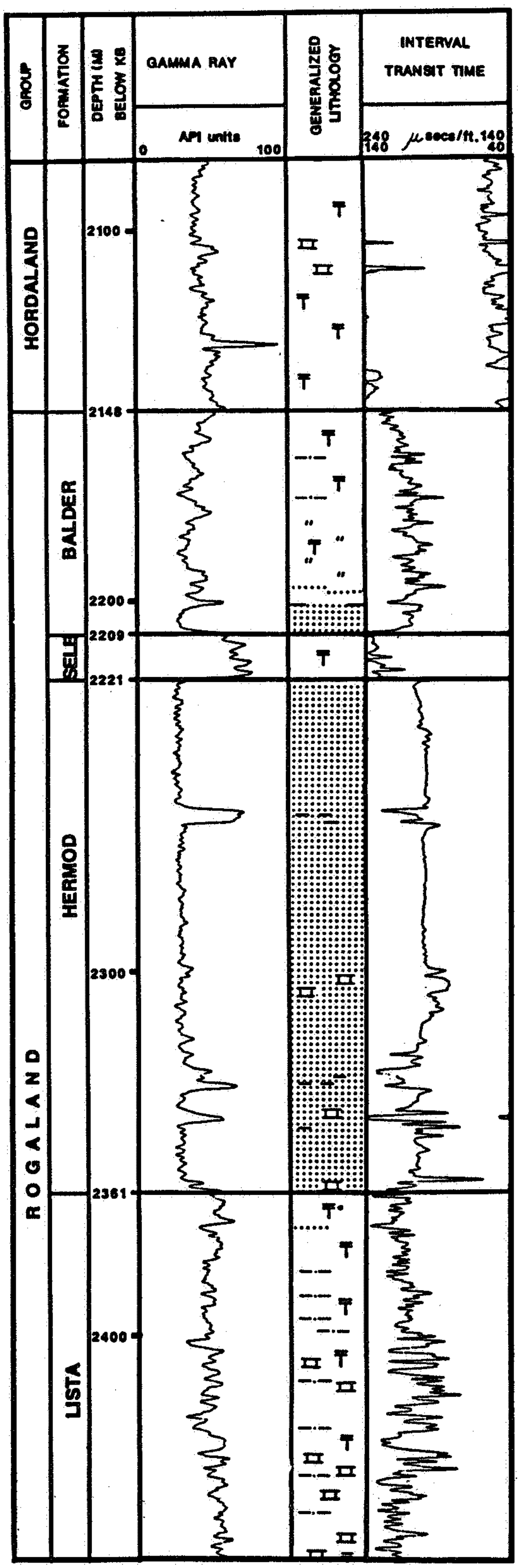


Fig. 56

Thickness:
The Hermod Formation is 140 m thick in the type well and 85 m thick in the reference well. It thickens towards the centre of its distribution area (Fig. 47).

Lithology:
The Hermod Formation consists of clean sandstones which are very fine to fine grained and clear to grey. The formation is to a limited extent interbedded with dark shales.

Basal stratotype:
The lower boundary of the Hermod Formation is identified by a transition from the shales of the Lista Formation. This boundary essentially represents the boundary between the Lista and Sele Formations, and the Hermod Formation may rest on shales of the Sele Formation. The log response in both cases is a sharp transition from the high gamma-ray readings and low velocity of the shales to the low and regular gammaray readings and higher velocity of the Hermod Formation sandstones (Fig 56). Where the Hermod Formation rests directly on the Heimdal Formation the boundary may be indistinct, but the log response changes from an erratic pattern in the Heimdal Formation to a smoother one, reflecting the more homogeneous sandstones of the Hermod Formation.

Characteristics of the upper boundary:
The Hermod Formation is overlain by the time-equivalent Sele Formation, and the boundary is an abrupt change from sandstones to dark shales. The gamma-ray response changes from low readings in the sandstones to significantly higher ones in the Sele Formation, and the velocity is lower in the Sele Formation (Fig. 56).

Distribution:
The Hermod Formation is found in the South Viking Graben, in the northwestern part of quadrant 25. It may also be found in other parts of the South Viking Graben. The main distribution area is outlined in Fig. 47.

Age:
Late Paleocene.

Depositional environment:
The Hermod Formation was deposited in submarine fan systems connected with the deltaic Moray Group in the west.

Balder Formation (Balderformasjonen)

Name:
Named by Deegan & Scull (1977) from the Balder Field in Norwegian blocks 25/10 and 25/11. Balder was a son of Odin, and one of the most famous gods in Norse mythology.

Well type section:
Norwegian well 25/11-1 from 1780 to 1705 m, coordinates N 59°10'57.39", E 02°24'28.18" (Fig. 57). Cores.

Well reference sections:
Norwegian well 30/2-1 from 1993 to 1917 m, coordinates N 60°52'05.42", E 02°38'49.16". Cores.

TERTIARY

WELL: 25/11-1

TYPE WELL: BALDER FORMATION

(ROGALAND GROUP)

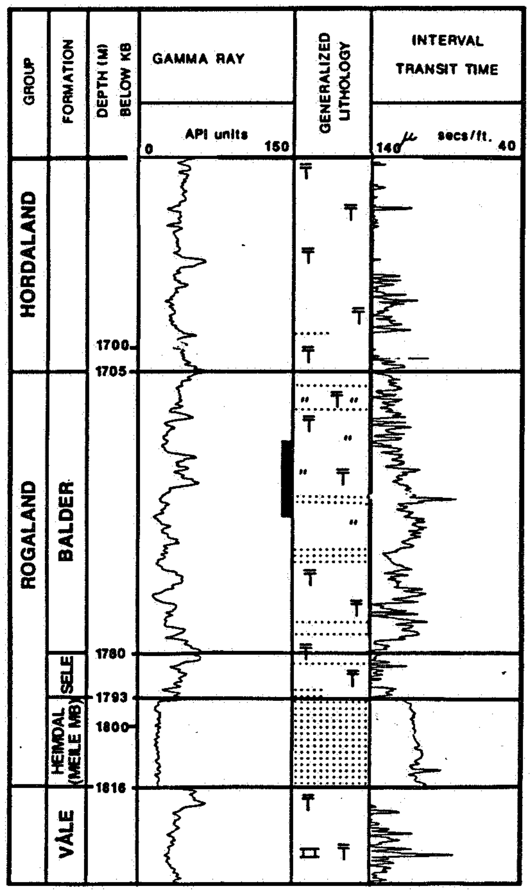


Fig. 57

Norwegian well 15/9-17 from 2253 to 2204 m, coordinates N 58°26'44.19", E 01°56'53.58" (Fig. 58). No cores.

Thickness:
The Balder Formation is 75 m thick in the type well. Generally its thickness varies from less than 20 m to more than 100 m. Normally it is between 40 and 60 m.

Lithology:
The Balder Formation is composed of laminated varicoloured, fissile shales with interbedded grey, green and buff, often pyritic, sandy tuffs and occasional stringers of limestone, dolomite and siderite. Sandstones are locally present, as shown in the type well (Fig. 57).

Basal stratotype:
The lower boundary to the Sele or Lista Formations is generally identified on logs as an upward decrease in gamma-ray response and an increase in velocity (Figs. 56 - 58). This probably reflects the increase in the tuffaceous component of the Balder Formation.

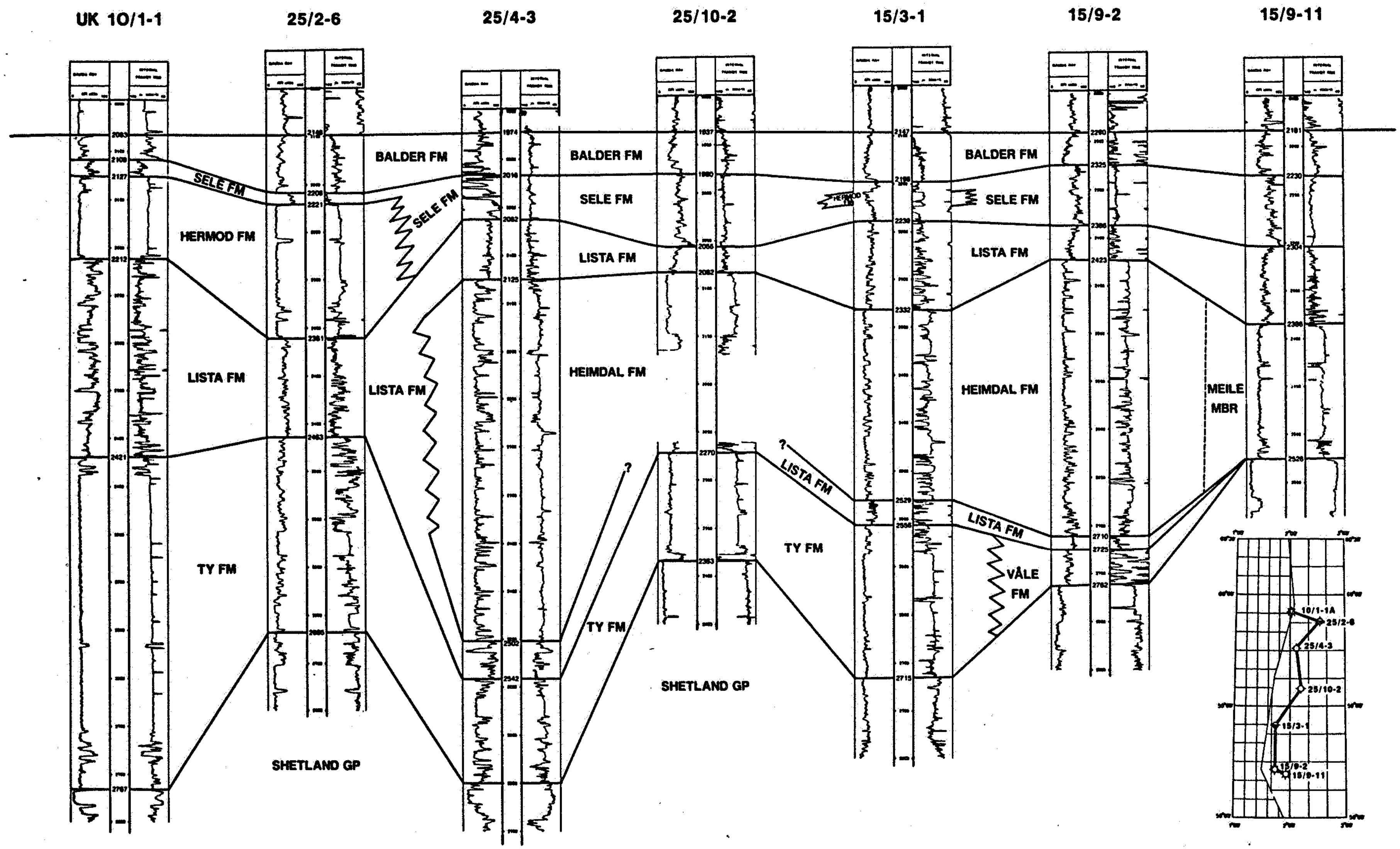


Fig. 59 Well correlation for some Paleocene wells.

TERTIARY

WELL 15/9-17

REFERENCE WELL: BALDER FORMATION

(ROGALAND GROUP)

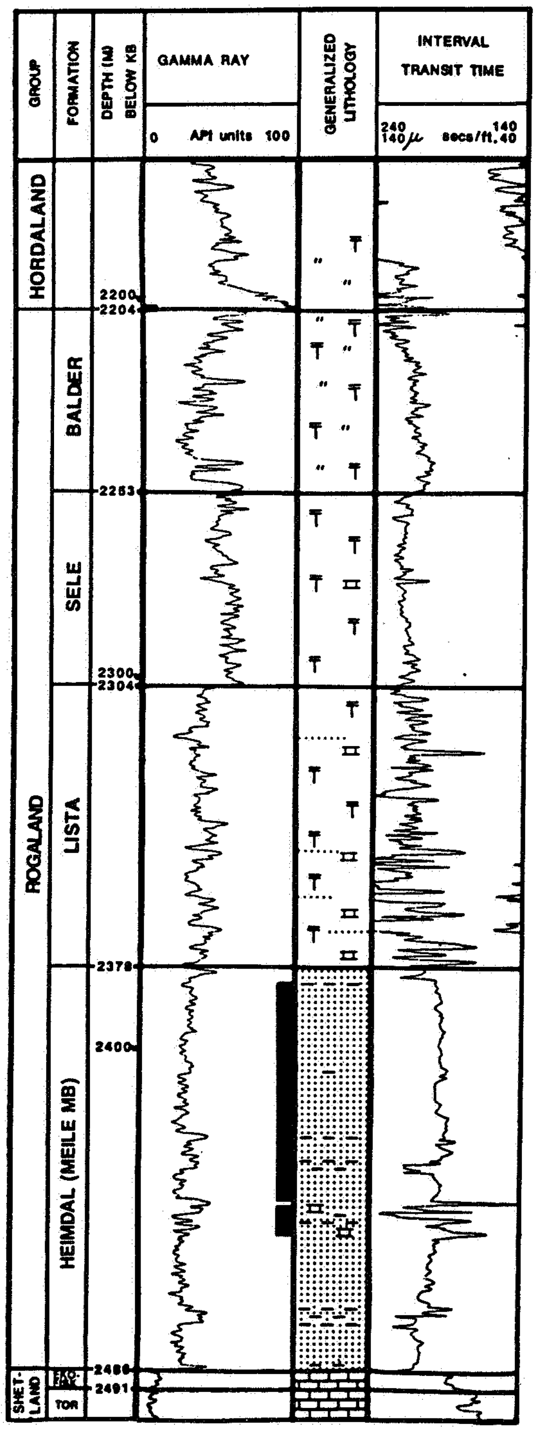


Fig. 58

Characteristics of the upper boundary:
The upper boundary is defined at the transition from the laminated shales of the Balder Formation to the-nonlaminated, often glauconitic, occasionally reddish, overlying sediments. On logs this can normally be seen as an upward reduction in gamma-ray response and a decrease in velocity Fig. 56). When the Balder Formation is overlain by the Frigg Formation the boundary is seen as a decrease in gamma-ray response and an increase in velocity into the Frigg Formation (Fig. 62). The log response of the Balder Formation is often described as bell-shaped (Fig. 58).

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

Age:
Paleocene - Early Eocene

Depositional environment:
The Balder Formation was deposited in a deep marine setting, mainly as hemipelagic sediments. Some turbiditic sands occur locally. There was probably more than one volcanic source.

Hordaland Group (Hordalandsgruppen)

Name:
The group was named by Deegan and Scull (1977) after the county of Hordaland in Norway.

Type area:
The type area is the North Sea Tertiary Basin. Typical sections through the group are shown in Norwegian wells 2/2-1 (Fig. 60) and 24/12-1 (Fig. 61). Fig. 69 shows a seismic section through the group in the Central Trough area. The lithostratigraphy is shown in Fig. 40.

Thickness:
The group has a thickness of 1060 m in well 2/2-1 and 1365 m in well 24/12-1. Its average thickness is around 1100-1200 m in the central and southern part of the Viking Grabens, but in the northern Viking Graben the group only reaches a thickness of a few hundred metres. Maximum thicknesses in the central and southern part of the Viking Graben are approximately 1300 m and 1400 m, respectively. The thickness decreases towards the basin margins.

Lithology:
The group consists of marine claystones with minor sandstones. The claystones are normally light grey to brown, fissile and fossiliferous. Red and green claystones sometimes occur at the base. Thin limestones and streaks of dolomite are present. Sandstones are developed at various levels in the group. These are generally very fine to medium grained, and are often interbedded with claystones.

Basal stratotype:
The lower boundary shows an increase in gamma-ray intensity and a decrease in velocity from the laminated tuffs of the Balder Formation into the claystones of the Hordaland Group (Fig. 56). Where the Frigg Formation is present at the base of the Hordaland Group the lower boundary normally shows a decrease in gamma-ray response and an increase in velocity from the Balder Formation into the Frigg Formation (Fig. 62).

WELL 2/2-1

TYPE WELL: VADE FORMATION

(NORDLAND GROUP)
(HORDALAND GROUP)

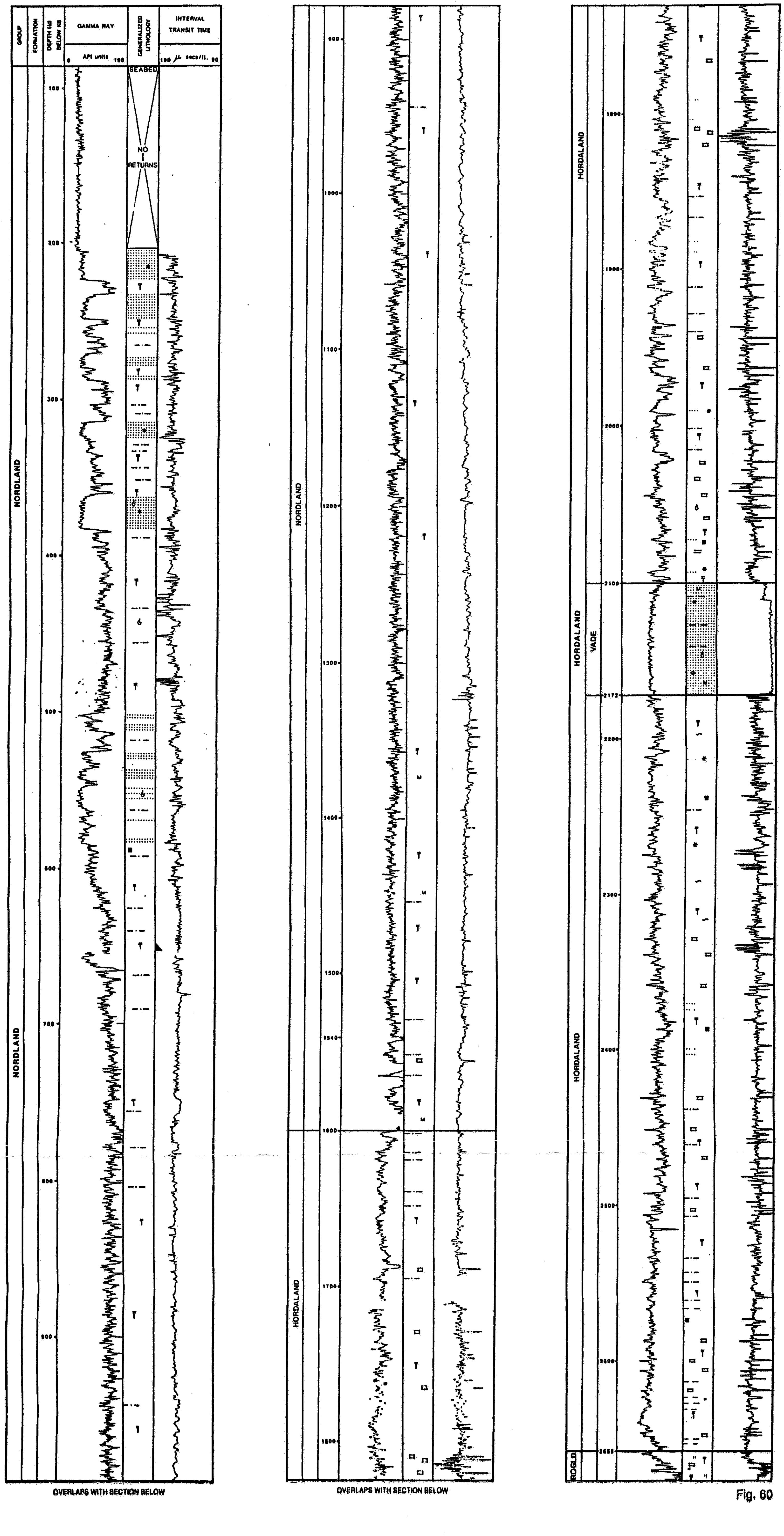


Fig. 60

TERTIARY

WELL 24/12-1

TYPE WELL: SKADE FORMATION
REFERENCE WELL: GRID FORMATION

(HORDALAND GROUP)

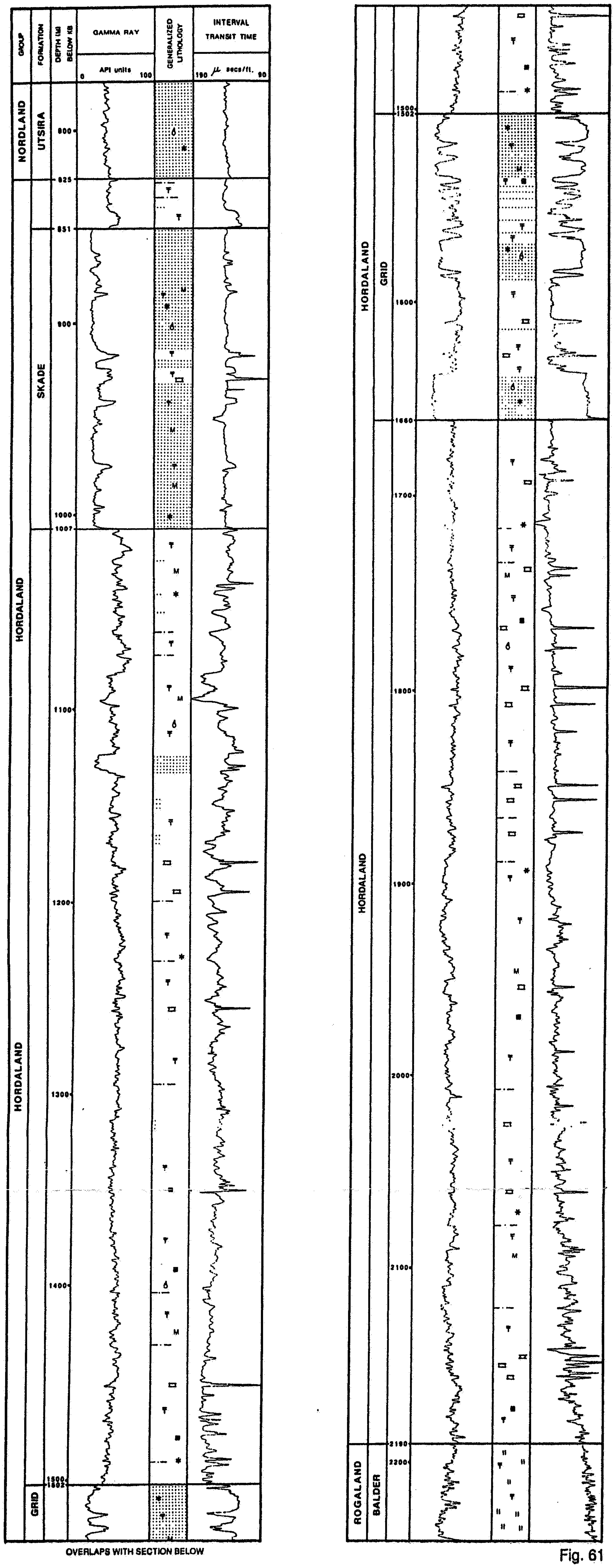


Fig. 61

Characteristics of the upper boundary:
The upper boundary is placed at the contact with undifferentiated grey to grey-brown claystones of the Nordland Group or sandstones of the Utsira Formation. It represents an unconformity of Early to Middle Miocene age, which may be difficult to identify in some wells.

In the Central Trough, a zone occurs which has high gamma-ray readings and usually a slightly lower velocity than the underlying and overlying claystones. The upper boundary of the Hordaland Group is placed at the base of this zone (Fig. 60). On seismic sections, the sediments below this horizon normally have a distorted signature whilst those above it have a smoother one. The boundary shows a very small angular unconformity; it is not clear whether a small hiatus is present. In the Viking Graben, the upper boundary is normally the base of the sandy Utsira Formation. The contact is then marked by an upward decrease in gamma-ray intensity (Fig. 70). Where the basal part of the Nordland Group is developed as claystone the boundary is placed at log breaks associated with a change in claystone colour.

Distribution:
The group is distributed over most of the North Sea Tertiary Basin. It is incomplete at the basin margins, owing to erosion or non-deposition. The Hordaland Group is also present on the Mid Norwegian Shelf (Dalland et al. 1988).

Age:
The group is of Eocene to Early Miocene age. Datings in wells 2/2-1, 2/2-2 and 2/2-3 indicate that the uppermost part of the group may be of Middle Miocene age in the Central Trough.

Depositional environment:
Open marine.

Subdivision:
The Frigg Formation was formally erected by Deegan & Scull (1977). Three additional sandstone formations are now recognised in the Hordaland Group, and are described here. Claystone intervals between the sandstones are not defined as formations and remain as unnamed units of the Hordaland Group. The Grid and Skade Formations are widely distributed in the Viking Graben area, whereas the Vade Formation, which is found in the Central Trough, has a limited distribution. Other sandstones, which cannot be assigned to the formations described here, are found in the Norwegian part of the North Sea Basin. Subregional work and further information from wells may enable more units to be formally erected in the future.

Remarks:
The boundary between the Hordaland and Nordland Groups in the Central Trough area may be slightly different from the position selected in well 2/7-1 by Deegan & Scull (1977). The boundary is difficult to identify in that well, owing to the borehole being damaged directly below the casing which is placed at 1591 m (5221 ft).

Frigg Formation (Friggformasjonen)

Name:
Named by Deegan & Scull (1977) after a Norse goddess, the wife of Odin.

Well type section:
Norwegian well 25/1-1 from 2115 to 1836 m, coordinates N 59°53'17.40", E 02°04'42.70" (Fig. 62). 42 m of cores (1868-1910 m).

Well reference section:
Norwegian well 30/7-6 from 1923 to 1783 m, coordinates N 60°29'29.82", E 02°03'26.14" (Fig. 63). No cores.

Thickness:
The formation has a thickness of 279 m in the type well and 140 m in the reference well. A depocentre with a maximum thickness of approximately 300 m lies in Norwegian block 25/1.

Lithology:
The formation consists of sandstones with some lenses and streaks of silty claystone. The sandstones are poorly consolidated, light brown to buff, micaceous and carbonaceous, and very fine to medium, occasionally coarse grained. Some layers have a calcareous cement. Traces of glauconite are present. The silty claystones are green to grey and carbonaceous.

Basal stratotype:
The lower boundary normally shows a decrease in gamma-ray intensity and an increase in velocity from the Balder Formation into the Frigg Formation (Fig. 62).

Characteristics of the upper boundary:
The top of the formation is placed where the sandstones give way to light grey to brown, occasionally green claystone of the Hordaland Group. The boundary is seen on logs as an increase in gamma-ray response and a decrease in velocity (Fig. 62).

Distribution:
The Frigg Formation is found in the southwestern part of quadrant 30, the northwestern part of quadrant 25, and in adjacent areas in the UK sector. The Frigg sands of the Beryl and Bruce Fields just extend into the Norwegian sector at about 59°30'N.

Age:
Early Eocene.

Depositional environment:
The Frigg Formation was deposited as submarine fans, by gravity flows. The mode of deposition led to the formation varying in thickness over short distances. The source was the East Shetland Platform to the west.

Grid Formation (new) (Gridformasjonen)

Name:
Named after a female giant in Norse mythology, who was one of the wives of Odin.

Well type section:
Norwegian well 15/3-3 from 1840 to 1470 m, coord-

TERTIARY

WELL 25/1-1

TYPE WELL: FRIGG FORMATION

(HORDALAND GROUP)

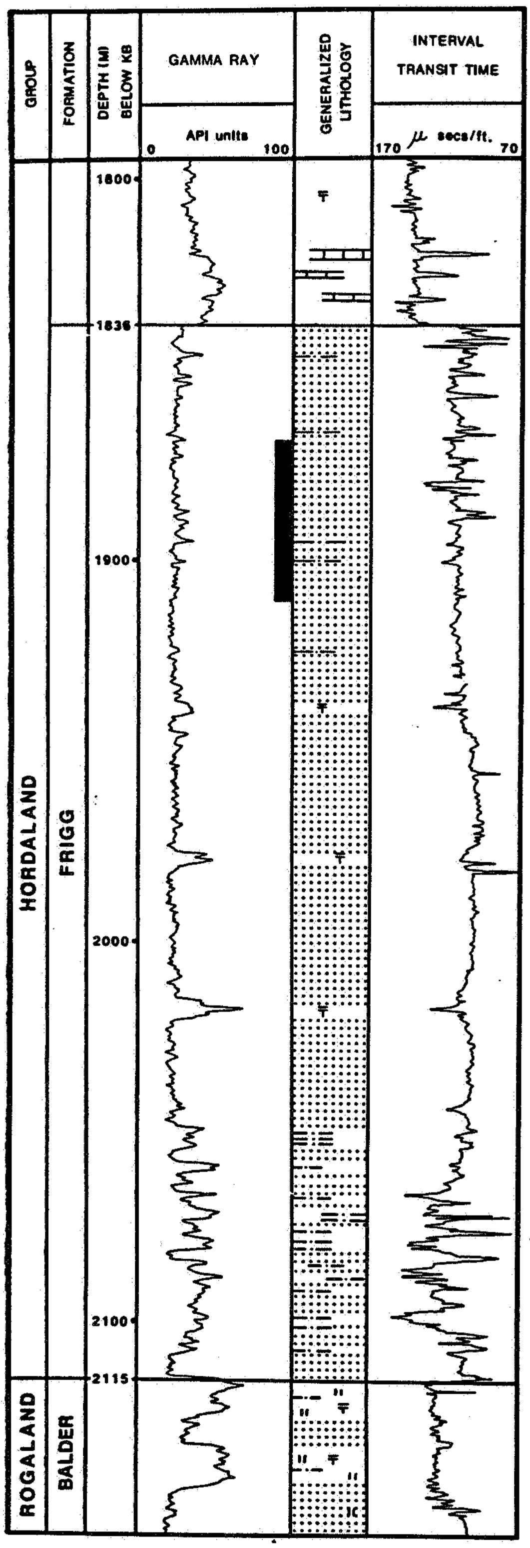


Fig. 62

TERTIARY

WELL 30/7-6

REFERENCE WELL: FRIGG FORMATION

(HORDALAND GROUP)

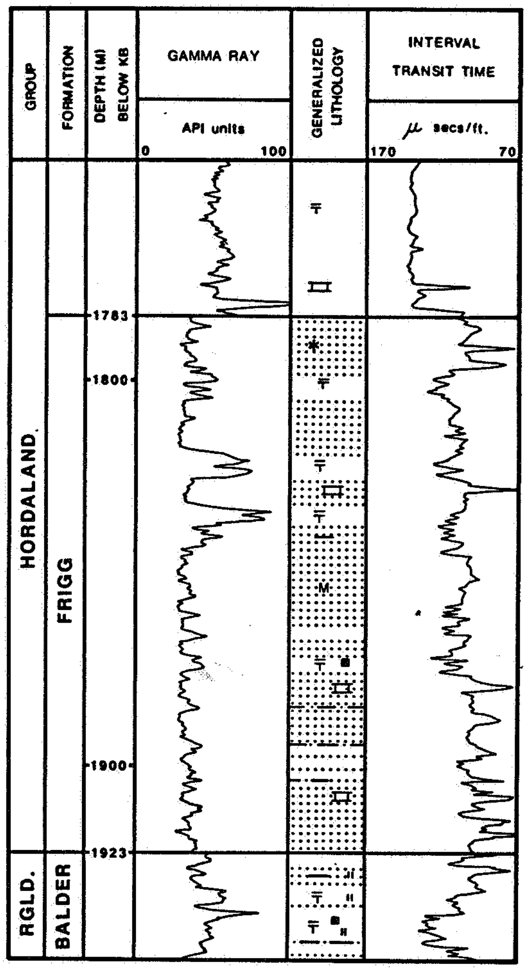


Fig. 63

inates N 58°52'31.25", E 01°46'46.24" (Fig. 64). No cores.

Well reference sections:
Norwegian well 24/12-1 from 1660 to 1502 m, coordinates N 59°02'29.80", E 01°52'57.93" (Fig. 61). No cores.

Norwegian well 24/12-2 from 1397 to 1282 m, coordinates N 59°12'00.75", E 01°52'53.34" (Fig. 65). No cores.

Thickness:
wells 24/12-1 and 24/12-2 it is 158 m and 115 m, respectively.

Lithology:
The formation consists of sandstones with interbeds of claystone and siltstone. The sandstones often have a massive, "blocky", appearance as illustrated by type well 15/3-3 (Fig. 64). Individual sandstone beds show little or no evidence of fining-upwards or coarsening-

TERTIARY
WELL 15/3-3

TYPE WELL: GRID FORMATION

(HORDALAND GROUP)

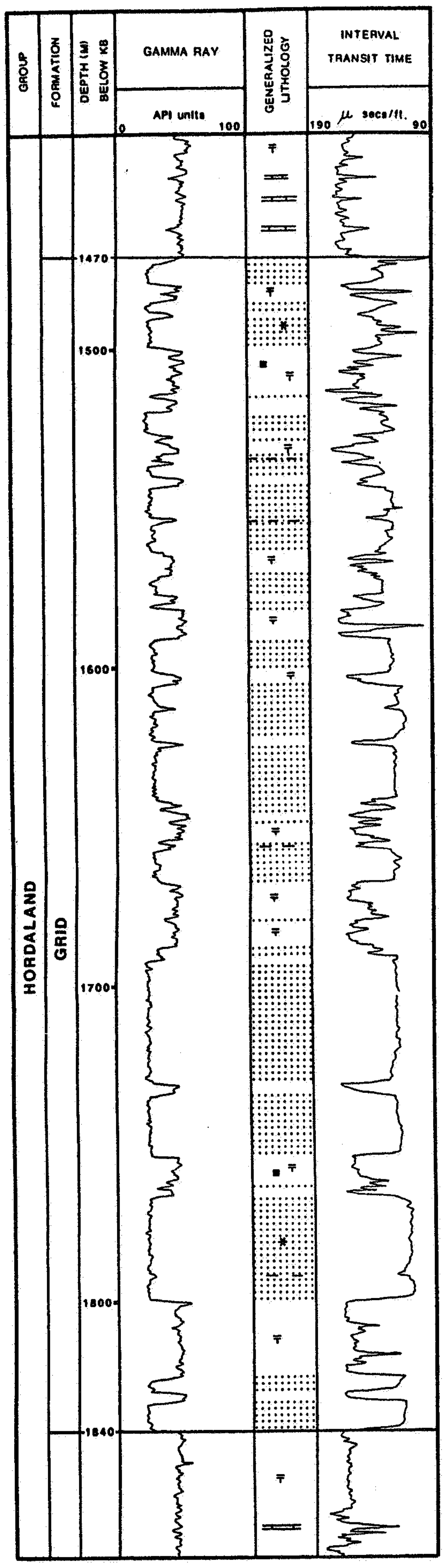


Fig. 64

TERTIARY
WELL 24/12-2

REFERENCE WELL: GRID FORMATION

(HORDALAND GROUP)

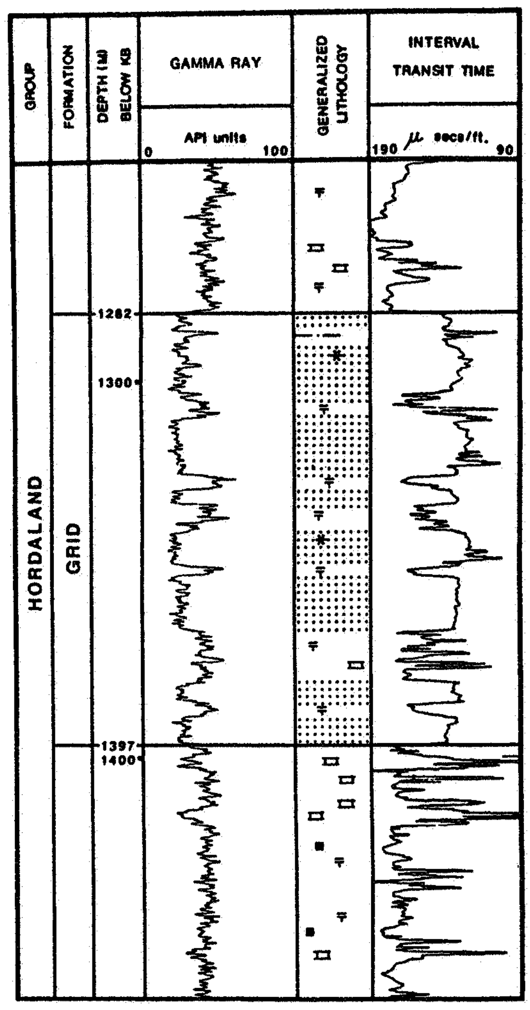


Fig. 65

APPROX. DISTRIBUTION OF THE GRID, SKADE AND VADE FORMATIONS

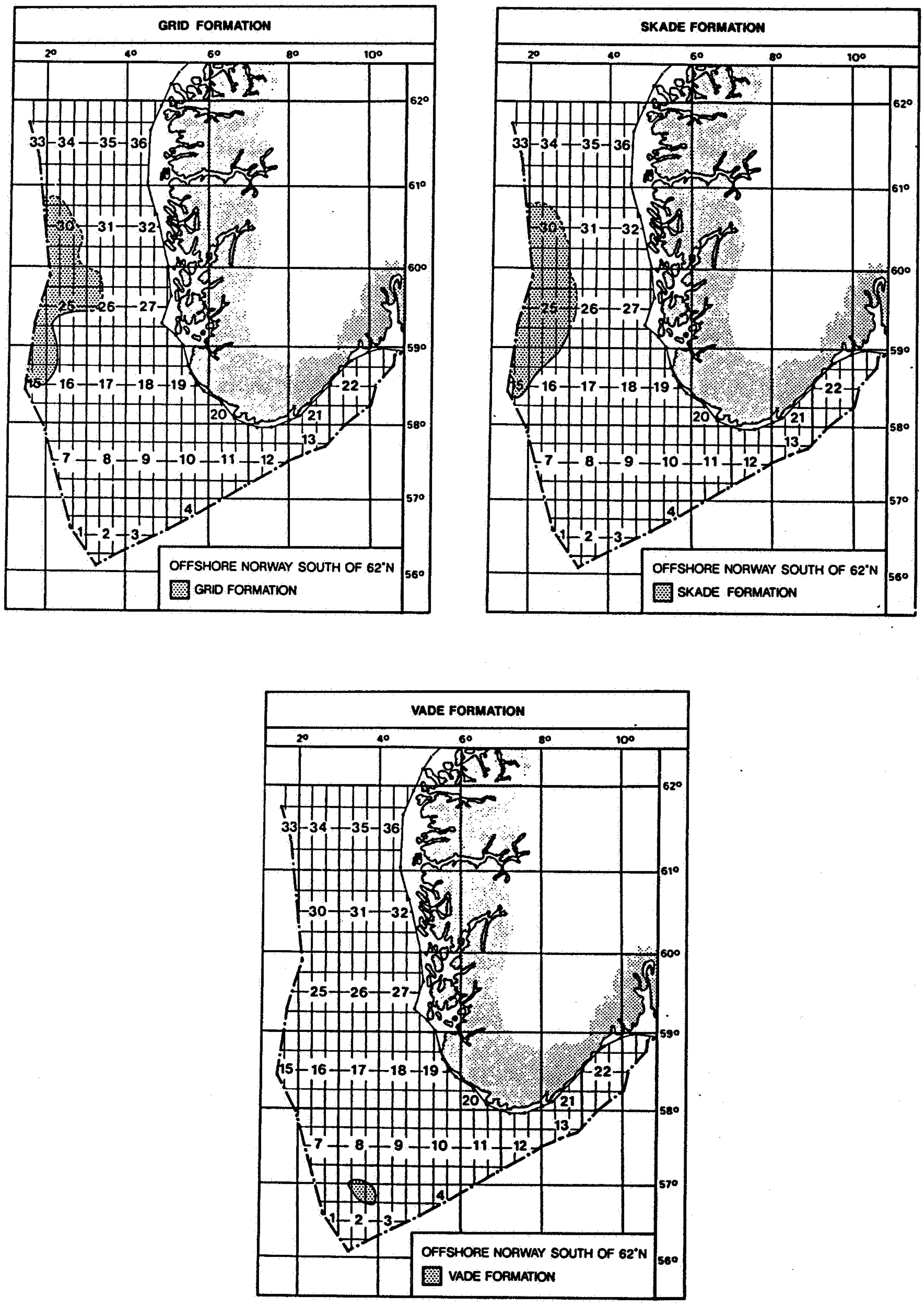


Fig. 66 Approx. distribution of the Grid, Skade and Vade Formations

upwards. The sandstones are very fine to fine, sometimes medium to coarse. Sorting is generally moderate to good. Traces of mica, pyrite, glauconite and fossil fragments are common. A higher argillaceous content is found in distal areas. Well 24/12-1 illustrates the interfingering of thicker claystone units of the Hordaland Group with the Grid Formation (Fig. 61) Further subdivision may be possible in the future (see Remarks).

Basal stratotype:
The lower boundary shows a decrease in gamma-ray response and an increase in velocity from the Hordaland Group into the sandstones of the Grid Formation (Fig. 64).

Characteristics of the upper boundary:
The upper boundary is characterised by an increase in gamma-ray readings and a decrease in velocity from the sandstones of the Grid Formation into the claystones of the Hordaland Group (Fig. 64).

Distribution:
The sandstones were probably derived from the East Shetland Platform and the formation is recognised in the Viking Graben area between 58°30'N and approximately 60°30'N (Fig. 66). A depocentre lies in Norwegian block 15/3 where the formation reaches a thickness of nearly 400 m. It thins eastwards and is not penetrated by wells on the Utsira High. It has been identified in some wells in the Oseberg area. In the Viking Graben north of 61° N, several sandstone bodies occur in the Hordaland Group at the same level, but it is uncertain whether they belong to the Grid Formation.

Age:
Middle to Late Eocene, but wells 25/6-1 and 24/12-2 have given an Early Oligocene age.

Depositional environment:
The formation is thought to have been deposited in an open marine environment during a regressive period. An eustatic fall in sea level in the Late Eocene is indicated by Haq et al. (1987).

Remarks:
The formation comprises a series of sand bodies which interfinger with claystones. There is a considerable increase in thickness from less than 200 m north of 59° N (e.g. wells 24/12-1 and 24/12-2) to nearly 400 m south of 59° N (e.g. well 15/3-3). This is not due to a general increase in thickness, but rather to sand deposition having started earlier in the south. This could give grounds for erecting two formal units, a lower one confined to the area south of 59° N and probably of Middle Eocene age, and an upper one. In some areas the lower unit is separated from the upper one by a sequence of claystones which is referred to informally as the Belton member in the UK sector. However, lithological uniformity renders such subdivision impractical at present.

Skade Formation (new) (Skadeformasjonen)

Name:
Named after a female giant in Norse mythology, the wife of the god Njord.

Well type section:

Norwegian well 24/12-1 from 1007 to 851 m, coordinates N 59°02'29.80", E 01°52'57.93" (Fig. 61). No cores.

Well reference section:
Norwegian well 15/9-13 from 1224 to 1143 m, coordinates N 58°22'25.96", E 01°56'02.86" (Fig. 67). No cores.

Thickness:
The Thickness is 156 m in the type welland 81 m in the reference well. It reaches nearly 200 m in Norwegian block 15/3, but is usually around 50-100 m. The formation shows a general eastward thinning.

Lithology:
The formation consists of marine sandstones with thin claystone interbeds. The sandstones are clear to light grey, usually fine to medium, occasionally coarse grained, with subrounded to rounded grains which are moderately to well sorted. Traces of fossils, shell fragments, mica and abundant glauconite occur. In some wells the sandstones are interbedded with silty claystones as illustrated by reference well 15/9-13 (Fig. 67). The formation often interfingers with the unnamed claystones of the Hordaland Group.

Basal stratotype:
The lower boundary shows a decreasing gamma-ray response from the underlying claystones into the sandstones of the Skade Formation. The velocity log usually records no distinct break (Fig. 61).

Characteristics of the upper boundary:
The gamma-ray response increases from the sandstones of the Skade Formation into the overlying claystones of the Hordaland Group. The velocity log usually records no distinct break (Fig. 61). Where the Skade Formation is directly overlain by the Utsira Formation the boundary is normally a break on the velocity log.

Distribution:
The formation has been identified in the Viking Graben area between 58° N and approximately 60°30' N (Fig. 66). Several sandstones occur in the upper part of the Hordaland Group in wells to the north and northeast of the known distribution area of the formation, and it may be present in these areas, but identification is difficult.

Age:
Late Oligocene.

Depositional environment:
The formation is thought to have been deposited in an open marine environment as a response to a fall in sea level. A globally low sea level during the late Oligocene is indicated by Haq et al. (1987).

TERTIARY

WELL 15/9-13

REFERENCE WELL: UTSIRA FORMATION
SKADE FORMATION

(NORDLAND GROUP)
(HORDALAND GROUP)

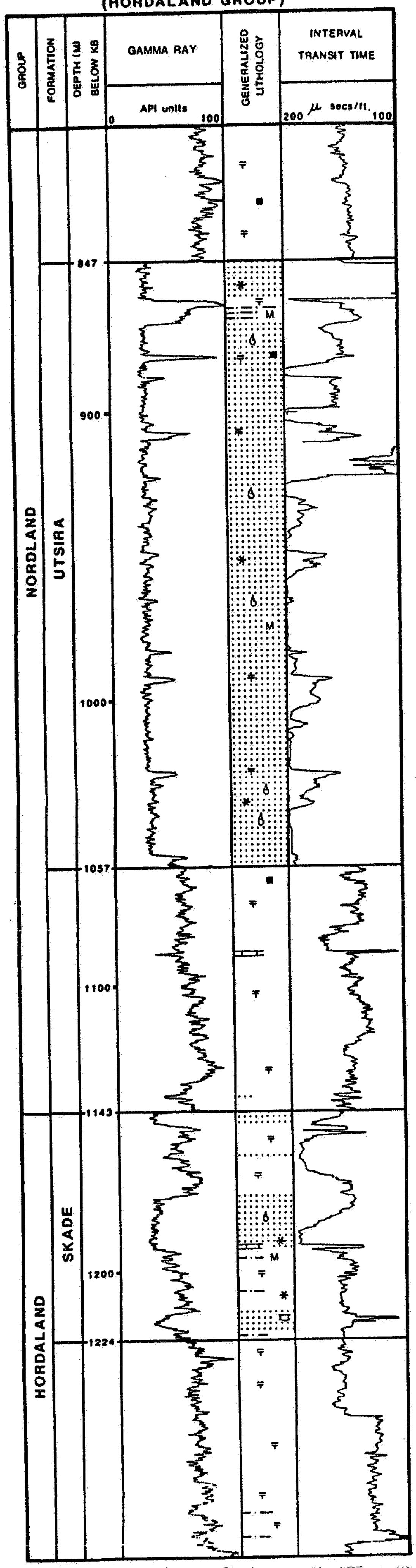


Fig. 67

TERTIARY

WELL 2/3-2

REFERENCE WELL: VADE FORMATION

(HORDALAND GROUP)

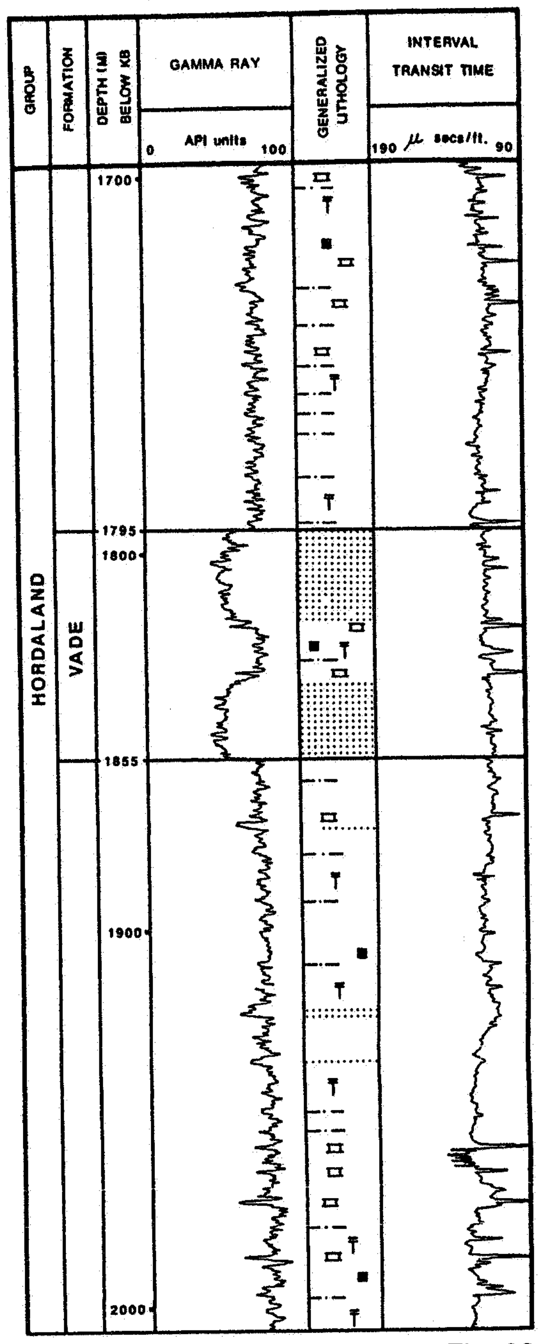


Fig. 68

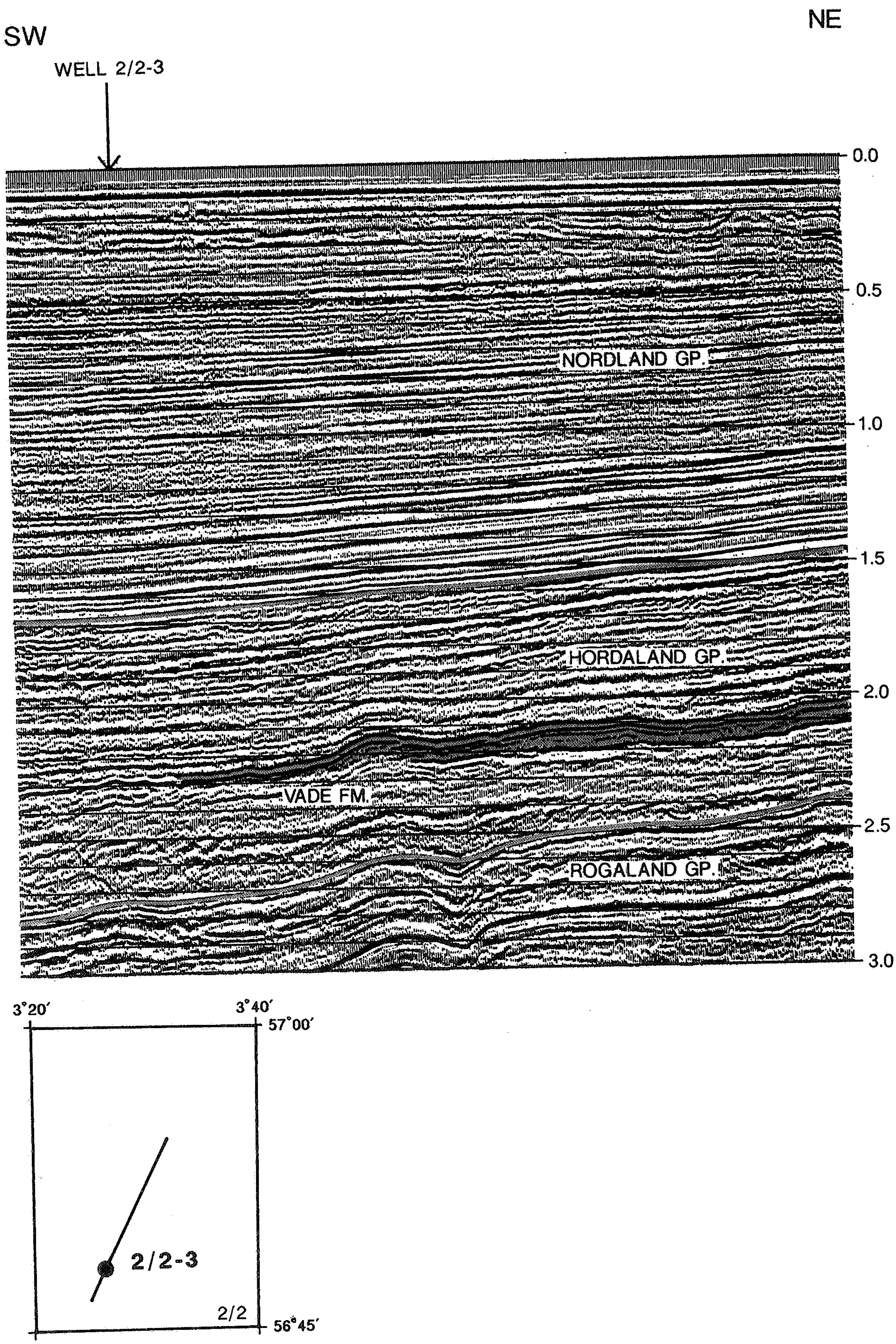


Fig. 69 Seismic section showing Hordaland Group with Vade Formation and Nordland Group.

Vade Formation (new) (Vadeformasjonen)

Name:
Vade is a giant from Norse mythology who wades across the fjords.

Well type section:
Norwegian well 2/2-1 from 2172 to 2100 m, coordinates N 56°47'15.69", E 03°38'15.62" (Fig. 60). No cores.

Well reference section:
Norwegian well 2/3-2 from 1855 to 1795 m, coordinates N 56°54'53.70", E 03°49'02.25" (Fig. 68). No cores.

Thickness:
The thickness is 72 m in the type well and 60 m in the reference well. Fig. 69 shows a seismic section through the Vade Formation which illustrates thinning to the southwest.

Lithology:
The formation consists of thinly interbedded, light green to grey, very fine grained sandstones and siltstones. These are glauconitic, slightly micaceous and well sorted. Fossils are present. Reference well 2/3-2 shows that the formation interfingers with the claystones of the Hordaland Group (Fig. 68).

Basal stratotype:
The lower boundary shows a decrease in gamma-ray intensity and an increase in velocity from the claystones of the Hordaland Group into the Vade Formation (Fig. 60).

Characteristics of the upper boundary:
The upper boundary is characterised by an increase in gamma-ray response and a decrease in velocity from the Vade Formation into the claystones of the Hordaland Group (Fig. 60).

Distribution:
The formation has only been penetrated in some wells in blocks 2/2 and 2/3. Its distribution is shown in Fig. 66.

Age:
Late Oligocene.

Depositional environment:
The sandstones were deposited in a shallow marine environment. Their deposition can be seen as a response to an eustatic fall in sea level or a tectonic uplift of the area. Regional considerations indicate a source area in the east or northeast.

Nordland Group (Nordlandsgruppen)

Name:
This group was named by Deegan & Scull (1977) after the county of Nordland in Norway.

Type area:
The type area is the North Sea Tertiary Basin. Typical sections through the group are seen in Norwegian well 2/2-1 (Fig. 60). Fig. 69 shows a seismic section through the group in the Central Trough area. The lithostratigraphy is shown in Fig. 40.

Thickness:
The group is 1514 m thick in well 2/2-1, but may exceed 1700 m in the Central Trough. It is approximately 1000 m thick in the Viking Graben area.

Lithology:
The Nordland Group is dominated by marine claystones. These are grey, sometimes greenish-grey and grey-brown, soft, locally silty and micaceous. The sandy Utsira Formation occurs in the lower part of the group in the Viking Graben area. The uppermost part of the group consists of unconsolidated clays and sands with glacial deposits uppermost.

Basal stratotype:
The base of the group occurs at the passage from the generally brown shales of the Hordaland Group into the more massive and blocky, generally grey, claystones of the Nordland Group. This contact is usually marked by a break on the logs which represents an unconformity of Early to Middle Miocene age. In the Central Trough the lower boundary is placed at the base of a claystone with high gamma-ray readings (Fig. 60). In the Viking Graben area the lower boundary is normally the base of the sandy Utsira Formation. In this case the contact is marked by a decrease in gamma-ray readings from the claystones of the Hordaland Group into the Utsira Formation. Where the basal part of the Nordland Group is developed as claystone the boundary is placed at log breaks associated with a change in claystone colour.

Characteristics of the upper boundary:
The upper boundary is the sea bed.

Distribution:
The group is distributed over most of the North Sea Tertiary Basin. It may be incomplete at the basin margins due to erosion or non-deposition. The Nordland Group is also present on the Mid Norwegian Shelf (Dalland et al. 1988).

Age:
Middle Miocene to Recent.

Depositional environment:
Open marine, with glacial deposits in the upper part in some areas.

Subdivision:
The Utsira Formation is the only formation defined in the Nordland Group at present. Additional units may be defined in the future from subregional work and further well information.

Utsira Formation (Utsiraformasjonen)

Name:
Named by Deegan & Scull (1977) after the Utsira High.

Well type section:
Norwegian well 16/1-1 from 1064 to 644.5 m, coord-

TERTIARY

WELL 16/1-1

TYPE WELL: UTSIRA FORMATION

(NORDLAND GROUP)

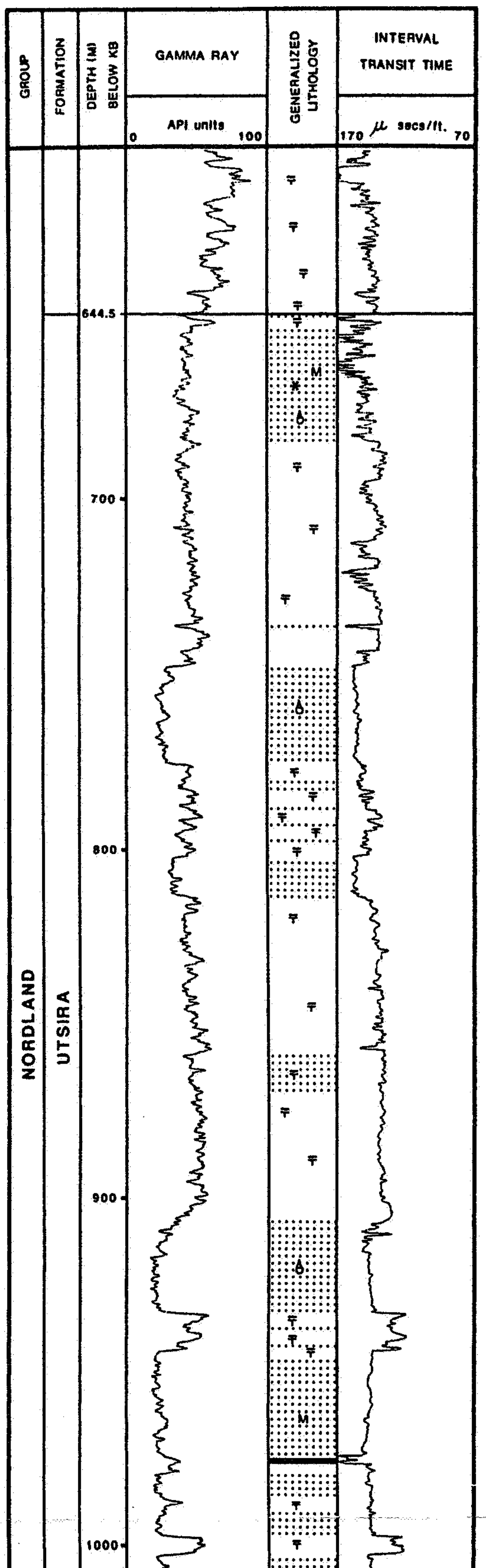


Fig. 70

inates N 58°59'18.38", E 02°02'02.97" (Fig. 70). No cores.

Well reference section:
Norwegian well 15/9-13 from 1057 to 847 m, coordinates N 58°22'25.96", E 01°56'02.86" (Fig. 67). No cores.

Thickness:
The thickness is 419.5 m in the type well and 210 m in the reference well.

Lithology:
The formation consists of marine sandstones and claystones. The sandstones are clear to white, often light greenish and normally very fine to fine grained, in places medium to very coarse grained. Occasionally rock fragments and lignite are found. The sandstones are separated by soft, plastic, light greenish claystones and minor siltstones. Glauconite and fossil fragments are common throughout.

Basal stratotype:
The lower boundary of the formation is normally well defined by a decrease in gamma-ray response from the underlying claystones into the sandstones of the Utsira Formation (Fig. 70). In wells where the formation directly overlies the Skade Formation the lower boundary may be more difficult to identify, but it is normally marked by a break on the velocity log.

Characteristics of the upper boundary:
The upper boundary is normally well defined by an increase in gamma-ray response into the overlying claystones (Fig. 70).

Distribution:
The formation is present in the Viking Graben area from about 580 N to the Tampen Spur. It pinches out in the northeast between the Oseberg and Troll Fields. General thinning and increase in clay content eastwards indicate that most of the sediment was derived from the west. However, local sources in the east are possible.

Age:
Middle to Late Miocene.

Depositional environment:
The formation probably represents shallow marine shelf sandstones.

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