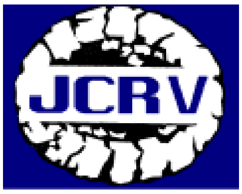
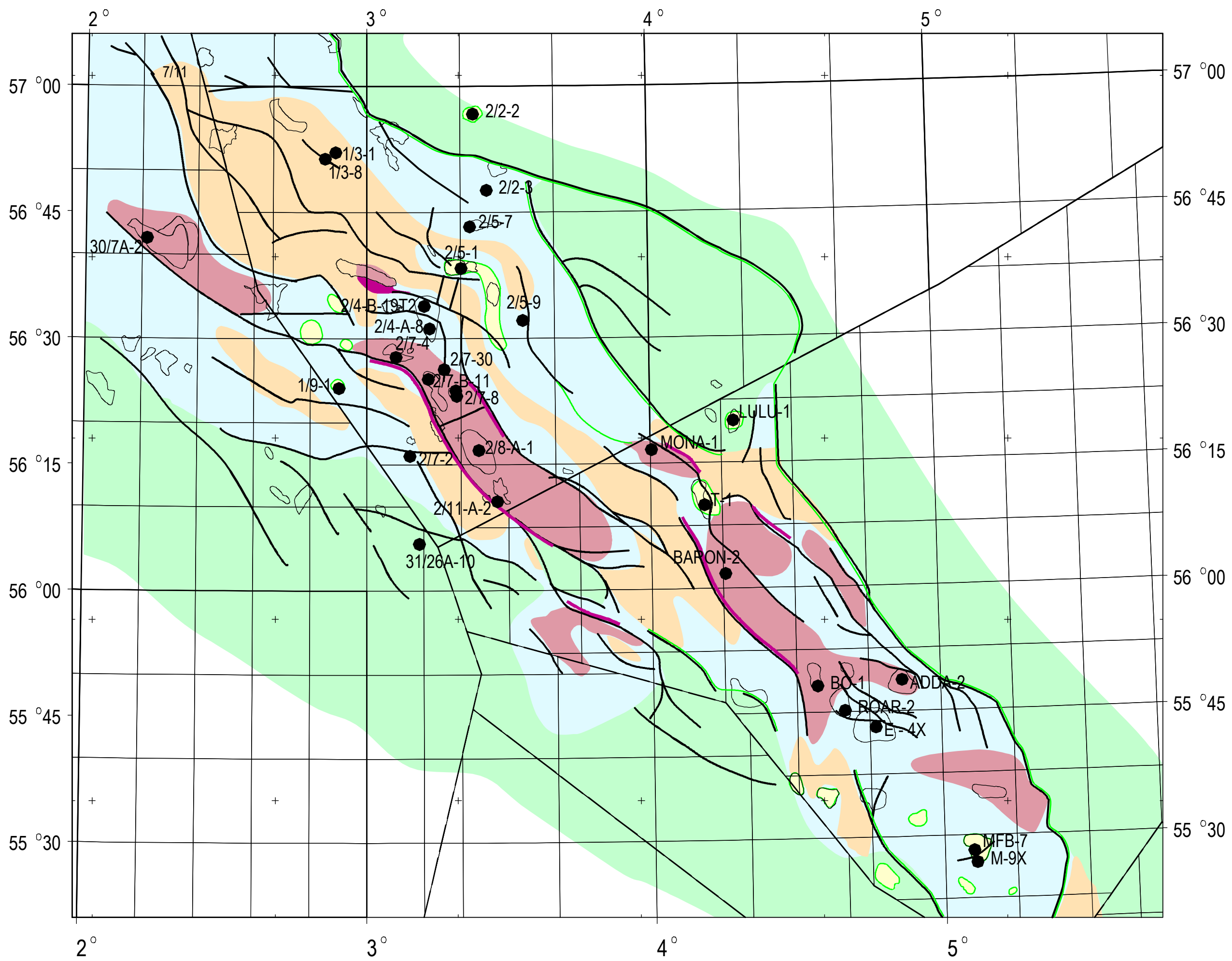


A JOINT CHALK STRATIGRAPHIC FRAMEWORK



Joint Chalk Research Phase V
December 1999

NPD

D E A

A JOINT CHALK STRATIGRAPHIC FRAMEWORK

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Joint Chalk Research Phase V
December 1999

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FOREWORD

In the Joint Chalk Research (JCR) Phase IV, 1995 - 1996, the project "Chalk Nomenclature" succeeded in establishing a standard JCR nomenclature for chalk core description and lithotype classification. The intention was to establish a common nomenclature for chalk stratigraphy as well, but as this task was found to be ambitious for the given time frame, it was postponed to the JCR phase V, commencing in 1997.

This report presents the results of the JCR Phase V project 1: A Joint Chalk Stratigraphic Framework. The report was compiled by a joint work group including geologists from the companies and agencies participating in JCR Phase V:

Amerada Hess Norge AS
BP Amoco
Elf Petroleum Norge AS
Total Fina
Norske Conoco AS
RWE-DEA AG
GEUS
Norwegian Petroleum Directorate (NPD)
Amerada Hess Danmark
Dansk Olie og Naturgas A/S (DOPAS)
Enterprise Oil Norge Ltd.
Mærsk Olie og Gas AS
Phillips Petroleum Company Norway
VEBA Oil Nederlands B.V.
Danish Energy Agency (DEA)

The contracted work was performed by Professor Bruce Sellwood (core descriptions/ sedimentology) and Network Stratigraphic Consulting Limited (biostratigraphy). Part of the seismic interpretation was contracted to Smedvig Technologies and financed by the NPD. Project management was performed by NPD.

Biostratigraphic analyses have comprised the majority of the project work, and the results were interpreted together with well logs, core description/chalk depositional facies and seismic data. Biostratigraphic nannoplankton and microfaunal distribution charts were made for all study wells, and chronostratigrahic "gapograms" display the presence and absence of the various chalk units. A joint biostratigraphic and lithostratigraphic framework for the chalks in the Central Graben is presented and discussed in the report. A revision of the formal Hod Formation into three new formations; Narve, Thud and Magne is proposed.

ACKNOWLEDGMENTS

The authors would like to thank the operators BP Amoco, Mærsk Olie og Gas AS, Phillips Petroleum Company Norway and Amerada Hess for release of well data (core data, biostratigraphic data, log data) and seismic data to this project. Special thanks are given to Mærsk for drafting all core descriptions, to the NPD for construction of the well composites and financing seismic interpretation, and to GEUS for it's significant contribution to this project. We also thank the NPD for being responsible for the master copy of the manual and the administration of copying. We are particularly grateful to all those who have contributed, technically and practically, in the final stages of this comprehensive report.

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1 INTRODUCTION AND SUMMARY

1.1 Original problem description

In over thirty years of exploration and production in the chalk formations of the North Sea Central Graben, many oil companies have developed their own local stratigraphic frameworks or nomenclatures in order to fit the well data from their license areas. The geologists having chalk experience based their methodology on the observations made from the fields within their respective areas. As a result, several nomenclature systems for chalk stratigraphic layering had been developed and used over the years. This practice complicated communication between oil companies and the regional understanding of the chalk facies.

Stratigraphic studies covering the Danish areas were undertaken in the early eighties (Lieberkind et.al 1982), but little later work has been published. The lithostratigraphic nomenclature for the Norwegian areas was published by Deagan and Scull (1977) and was later updated by Isachsen and Tonstad (1989). Since then, increased availability of released wells with core material has indicated the need for a revision. In addition, improved biostratigraphic techniques now enables better identification and dating of the two main stratigraphic challenges in chalk reservoirs, the "***time gaps"*** and the ***redeposition***.

"Time gaps" are defined as geologic time periods where no deposition took place, or where material deposited was later removed. Large time gaps are often observed in cores as hardgrounds or condensed sections. These may be important for the production performance of the field, since such sections often have a significant effect on vertical and total permeability. The lateral extent of these sections should be mapped, in order to correctly model and predict the production performance on the field. Also, tying of identified major time lines from wells to seismic data, would provide a better tool to map flank and basin areas, thus connecting chalk units across the Central Graben area and the Norwegian-Danish Basin area.

Redeposition of older chalk units within younger formations is now a well-known phenomenon in many chalk fields. The presence of such units often complicates traditional reservoir zonation and correlation, and has caused divergent nomenclatures to be developed between the oil companies. A better regional understanding of erosion and redeposition, and a common nomenclature to identify redeposited units, would therefore improve the reservoir modelling as well as mapping of flank and basin areas.

1.2 A common Stratigraphic Framework

The establishment and visualisation of a ***joint stratigraphic framework*** for the chalks in the Central Graben is the major result of the present project. Through the biostratigraphic analysis of 35 study wells in Norwegian, Danish and UK areas, combined with chalk lithofacies and seismic studies, joint biostratigraphic and lithostratigraphic nomenclatures have been agreed on. **Figure 1-1** is an overview to show the lithostratigraphic framework developed by this project, compared to other formal and informal nomenclatures.

The most important result is the proposed subdivision of the original formal Hod Formation into three new formations, Narve, Thud and Magne. This subdivision was based on the major stratigraphic breaks that were observed in the Hod Formation. These breaks were represented by time gaps of variable lengths in the biostratigraphic data, and often seen as hardgrounds in cores, and especially in wells located on structural highs. Also in the seismic data, the Hod Formation was seen to embrace two significant sequence boundaries that could be tracked over large distances. On basis of international stratigraphic rules (Hedberg 1976), such major sequence boundaries are not recommended within a formation. Consequently, the project work group decided to propose the split of the Hod Formation into three new formations. To avoid confusion with the existing informal lithological subdivision of the Hod into lower, middle and upper Hod, it was also decided to suggest unique names for the new units, following the tradition with names from the Norse mythology.

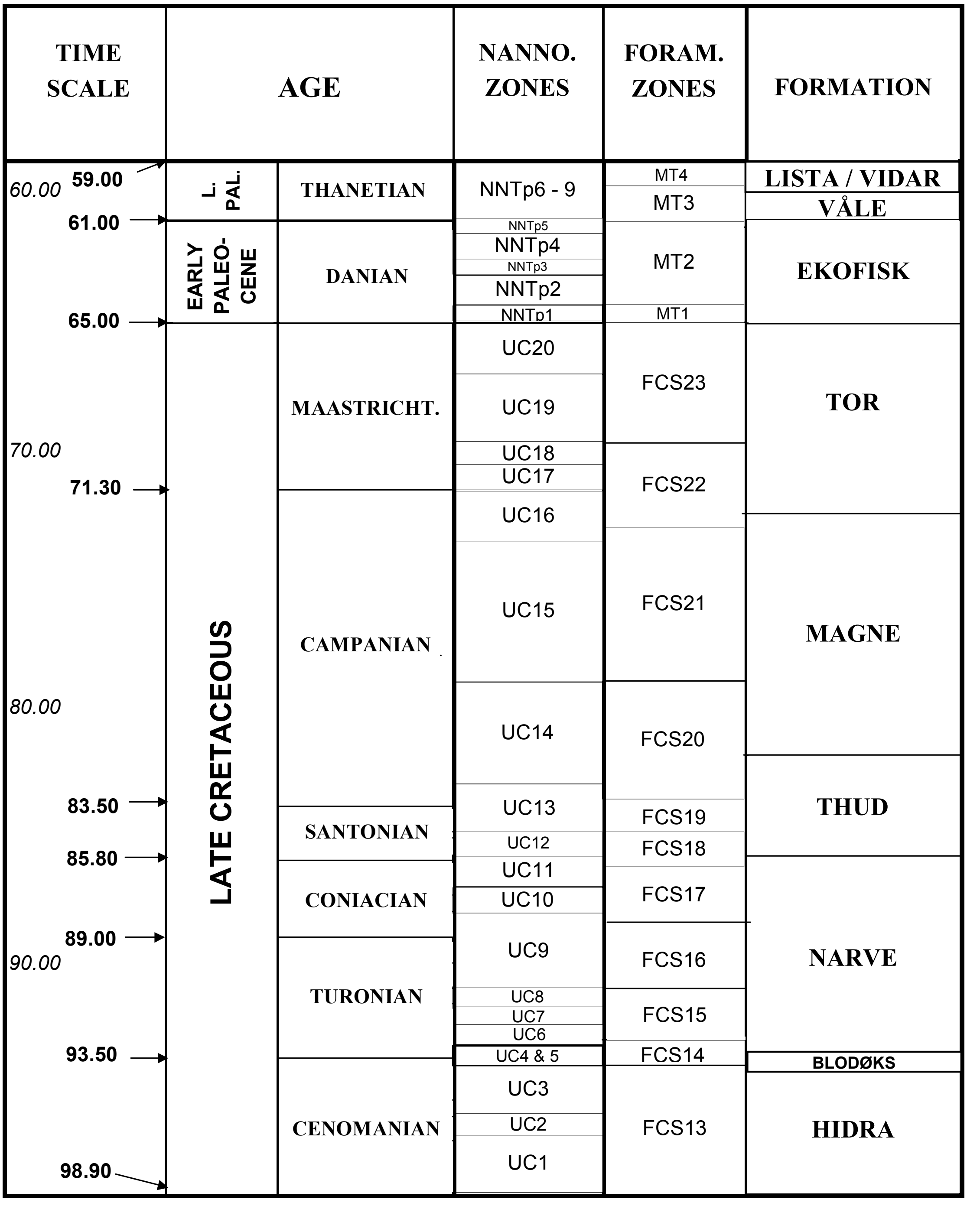

Figure 1-1: A joint JCR Stratigraphic Framework

This new common stratigraphic framework will hopefully improve the communication between the oil companies in both Norwegian and Danish areas, and ensure a standard basis for regional mapping and correlations between the various chalk fields and prospects. Also, following the improved regional understanding of deposition, erosion and redeposition of chalk, more reliable geological comparisons/correlations between fields and basins, as well as better control of seismic interpretation on and between fields will result from this project.

1.3 Project deliverables

In summary, this report includes:

1. **A joint biostratigraphic zonation nomenclature** for the chalk section of the Central Graben (Paleocene to Cenomanian), presented for each study well through range charts and stratigraphic summary logs.
2. **A suggested revised formal lithostratigraphic nomenclature** for the chalk section of the Central Graben/ Norwegian-Danish Basin, splitting the formal Hod Formation into 3 new units on formation level.
3. **Well log composite panels** for all study wells, showing the lithostratigraphic and biostratigraphic zonations together with logs and core lithofacies.
4. **Seismic interpretation** of formation boundaries across the Central Graben, and a map of the Late Cretaceous main structural elements, also illustrated by regional field - to - basin schematic cross-sections.
5. **Core descriptions** based on the JCR nomenclature for chalk description and classification.
6. **Gapograms** showing presence (primary deposition) and absence (time gaps, non-deposition/ erosion) of the lithostratigraphic units in a chronostratigraphic scale.
7. **Chalk facies distribution maps**, showing the main facies types in the cored study wells within the different formations.
8. **A standard nomenclature** for redeposited chalk units within younger formations.
9. **A digital biostratigraphic database** (based on the STRATABUGS software).

1.4 Project organisation

A work group drawn from participating companies performed much of the technical work. In addition, consultants were contracted to perform biostratigraphic analyses and core descriptions. The **work group**:

- decided on study area and study wells
- evaluated quality of existing documentation on wells and decided need of additional biostratigraphy, core description etc
- brought into the project all appropriate existing biostratigraphic, seismic, core and log data
- chose contractors
- interpreted seismic data
- organised core description and sampling practicalities
- performed drafting of core descriptions
- contributed to interpretation and conclusions
- decided the lithostratigraphic nomenclature
- produced the final report

The **contractors**:

- assisted in establishing a well database for the project
- described cores

- evaluated/reinterpreted, formatted and digitised existing biostratigraphy
- performed biostratigraphic analyses
- compiled data and presented a detailed biozonation and chronostratigraphical subdivision for each well
- constructed gapogram correlations
- reported the results
- delivered a database with all new and previous biostratigraphic data

Consultants reported to the Work Group and the Work Group reported progress to the JCR Technical Advisory Committee.

1.5 Method

A number of 35 wells from Norwegian, Danish and UK areas were chosen for the study. Existing original or reanalysed biostratigraphic data, well interpretations and core descriptions from these wells were made available from the companies. Cores and wireline logs were studied by the work group, and interesting or problematic intervals representing possible stratigraphic sequence boundaries, time gaps or redeposition were defined. Core descriptions were then performed, based on the JCR description system. More than 700 additional core samples were simultaneously collected for quantitative or semi-quantitative nannofossil- and micropaleontological analyses. Samples for palynology and thin section analyses were gathered where required. Regional seismic was interpreted to resolve stratigraphic surfaces between fields/key wells.

Figure 1-2 illustrates the workflow within the project, and the final main deliverables.

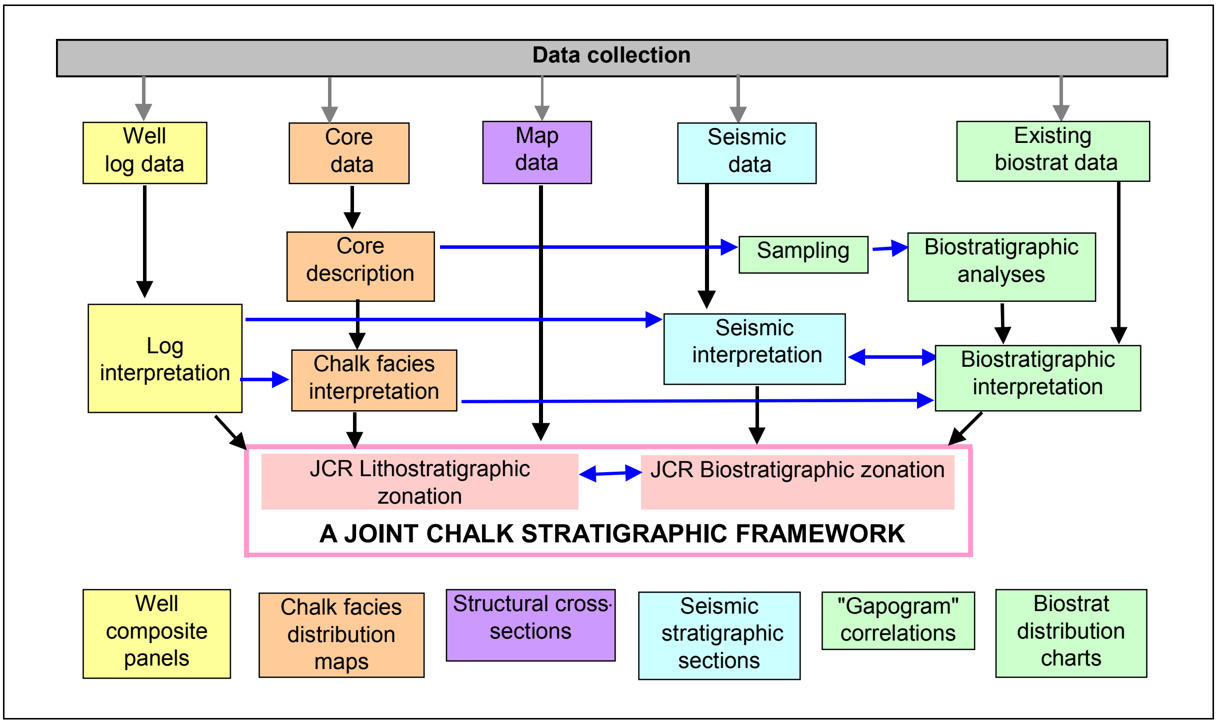

Figure 1-2: Project workflow and main deliverables

The following wells were analysed:

Norwegian wells:	Surface location Y=UTM north	Surface location X=UTM east	***Danish wells***	Surface location Y=UTM north	Surface location X=UTM east
1/3-1	6301489	490937	MFB-7	6150312	633274
1/3-8	6302911	493239	M-9X	6146726	633502
1/9-1	6250900	493939	Roar-2	6179956	604543
2/2-2	6311426	523099	Roar 2A	6179956	604543
2/2-3	6294616	526100	Baron-2	6210136	578413
2/4-A-8	6264216	513719	Lulu-1	6244143	580001
2/4-B-19	6269154	512527	Mona-1	6237463	562195
2/4- B-19A/T2	6269154	512527	E-4X	6176140	613195
2/5-1	6277379	520581	Adda-2	6186107	615630
2/5-7	6286564	522460	Adda-3	6185274	618515
2/5-9	6265939	534051	Bo-1	6185347	598533
2/7-2	6235934	509447	T-1	6228414	572675
2/7-4	6257918	506359			
2/7-8	6249195	519667		Surface location	
2/7-15	6250376	519456	***U.K. wells:***	Y=UTM north	X=UTM east
2/7-30	6255178	516880	30/7a-2	6284309	452067
2/7-B-11	6252893	513470	31/26a-10	6223622	503705
2/8-A-1	6237238	524493			
2/11-A-2	6225965	528571			
2/11-A-2 T2					
2/11-A-2 T3					

Table 1-1: Studied wells

Selection of the various study wells was based on various criteria, including:

- the well´s position regarding basin, continental margin or structural highs
- core data coverage
- existing biostratigraphic data
- the extent of main chalk formations and formation boundaries represented in the wells
- existing stratigraphic type wells, such as 1/3-1

Wells that had core coverage across a formation boundary were considered important, as were wells that appeared to have been drilled across major stratigraphic time breaks.

Figure 1-3 shows the study wells and the chalk fields in the North Sea Central Graben. Some of the study wells are not visible on the map because they are located close to another well, these are:

2/4-B-19 = 2/4-B-19T2
2/7-15 = 2/7-8
2/11-A-2 T2/T3 = 2/11-A-2
Adda-3 = Adda-2
Roar-2A = Roar-2

Well T-1 on the Svend Field is marked on the map, but due to few useful data, no logs or charts were constructed for this well in the study.

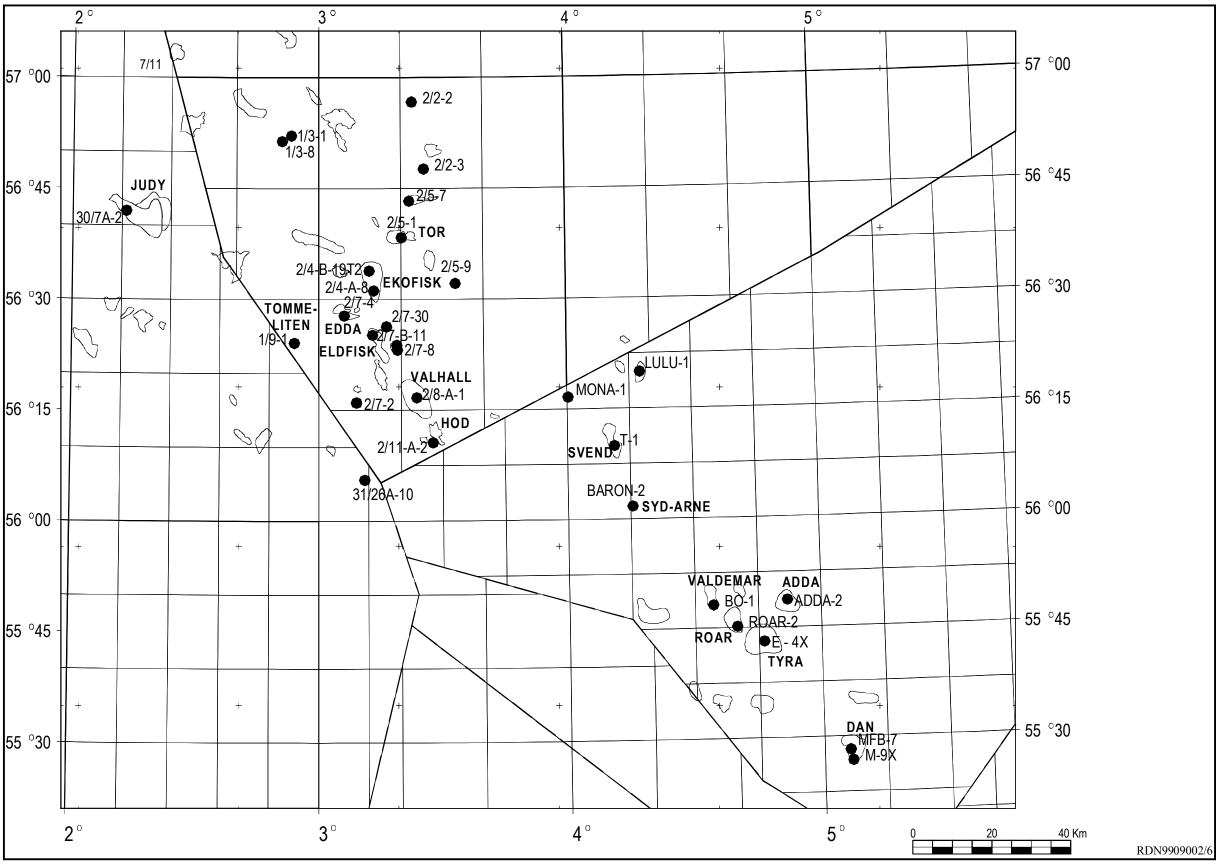

Figure 1-3: Location of the study wells and chalk fields

2 STRUCTURAL AND TECTONIC FRAMEWORK AND SEISMIC INTERPRETATION

The Central Graben was tectonically active during deposition of the chalk sequence. Graben subsidence, inversion structures and salt tectonics created a complex and changing pattern of basins and highs in the Late Cretaceous and Danian. It is important to see the chalk stratigraphy in the context of the structural elements that controlled the chalk deposition. As a part of the study, a set of regional 2D seismic lines, which tied the wells, were interpreted. There were three main objectives of the seismic interpretation:

- Identify main seismic sequence boundaries, in order to contribute to improve the stratigraphic subdivision
- Investigation of the change of seismic character between wells and different structural elements, in order to correlate facies changes.
- Tie reflectors between the studied wells in order to improve correlation based on logs and biostratigraphy

The seismic character of the chalk formations and their boundaries is an important attribute, which must be taken into account in their definition.

2.1 Main structural elements

The sketch map of the Central Graben and its main structural elements (**figure 2-1**) is based on Anderson (1995), Britze et al. (1995) and data from the Chalk Exploration Project (CEP), which were made available for JCR by PPCoN.

A major depocenter for the Cretaceous chalk was located in the northwestern part of the Central Graben, and it is penetrated by 1/3-1 and 1/3-8. These wells have a fairly complete chalk section, and they are important reference wells (**figure 2-10**). Additional depocenters with a chalk thickness exceeding 900 m were located in the deeper parts of the complex graben structure (**figure 2-1**). In general, there are few wells drilled in these depocenters, and those wells that have been drilled there were aimed at targets other than the chalk. Consequently, core and biostratigraphy data are sparse.

During chalk deposition, the Central Graben subsided along its major boundary faults towards the stable platforms (**figure 2-1**, **figures 2-3 to 2-7**). There were several episodes when the relatively uplifted platforms were eroded, and acted as source areas for redeposited chalk.

Salt tectonics and inversion tectonics added to the structural complexity of the Central Graben. Thick Zechstein salt was deposited in most of the Central Graben, except for a small area on both sides of the Denmark – Norway boundary. The timing of salt stock growth and withdrawal seems to correlate with the different tectonic phases. In **figure 2-1**, it is indicated which of the studied wells are located on major salt structures.

The inversion highs were formed by uplift and reverse movement along pre-existing faults in large areas of the Central Graben. The inversion highs were active at different occasions during and after chalk deposition, and the detailed timing of their activity may differ. They often represent a change in tectonic setting from a pre- Campanian trough to a Maastrichtian high.

2.2 Structural cross-sections

The structural/stratigraphic cross-sections shown in **figure 2-3 to 2-7** represent slices through a 3D geological layer model, which were prepared in the PL018 Chalk Exploration Project (CEP) and made available to the JCR by PPCoN. This model was based on 2D and 3D seismic interpretation of the Magne, Tor, Ekofisk and Balder Formations. The oldest horizon in the profiles is the Middle Hod reflector interpreted by the CEP. Over large areas, but not everywhere, this reflector coincides with the base of the Magne Formation, and there are a few discrepancies between the profiles and the corresponding JCR interpretation. In spite of these stratigraphic discrepancies, the profiles have been included in the project because they give useful overviews of the structural and stratigraphic setting of most of the northern study wells. Profile 1, Profile 2, Profile 3 and Profile 4 correspond to the "gapogram" correlation lines 1, 2, 4, and 6 (**figures 4-4, 4-5, 4-7 and 4-9),** respectively. **Figure 2-2** shows the location of the 5 structural profiles.

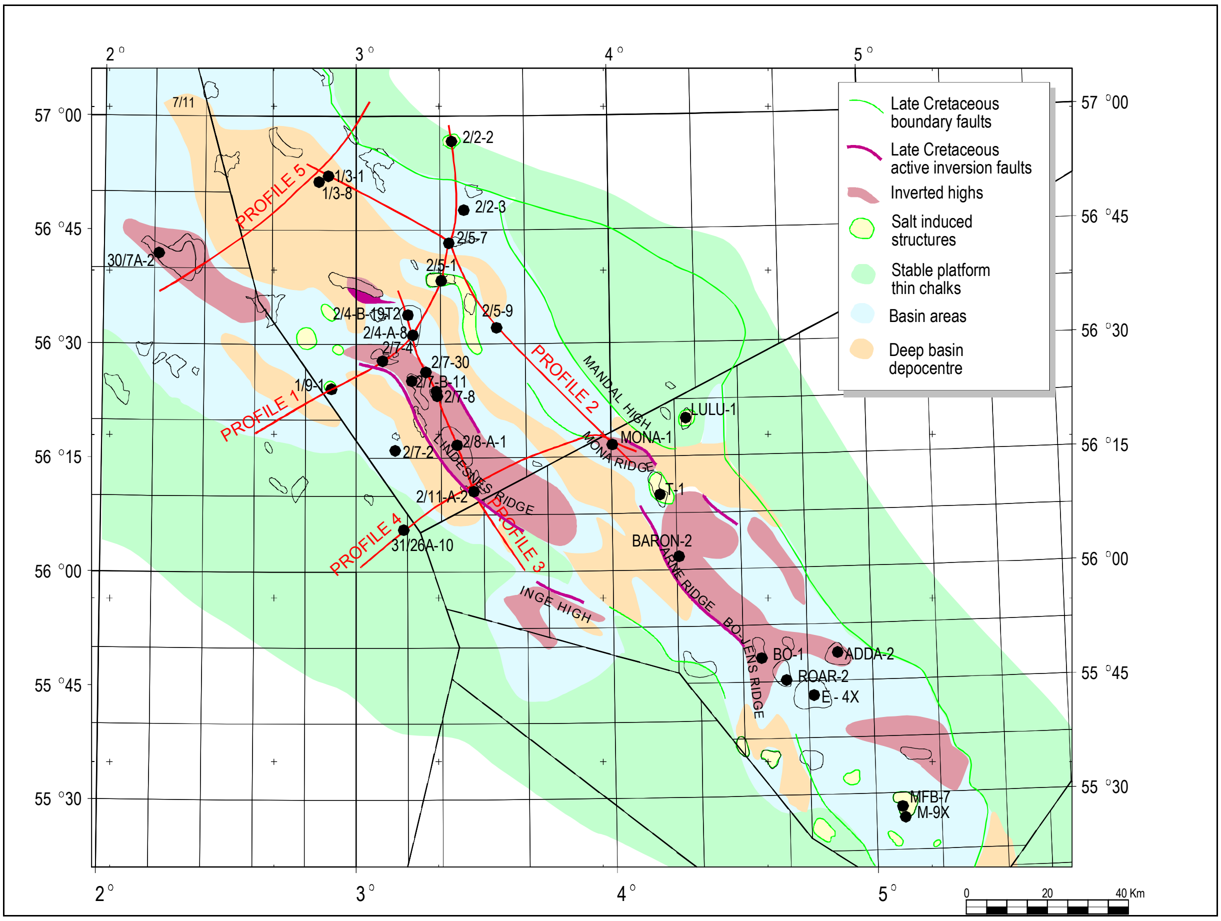

Figure 2-2: Index map of structural/stratigraphic profiles

2.3 Seismic interpretation

2.3.1 Data used

A base map of the seismic made available to the project is shown in **figure 2-8.** Highlighted lines represent the figures included in this section. On the Norwegian side, about 500 km of good quality 2D seismic data was available to be interpreted using Charisma software. There were 2 surveys involved; the bulk of the data being from the SGT8606 survey with the rest from the

CAST-90 survey. The 86 survey appeared to be better quality data on the workstation but the CAST-90 was better when paper sections were compared. This discrepancy was probably due to the differing display parameters used in the processing sequence.

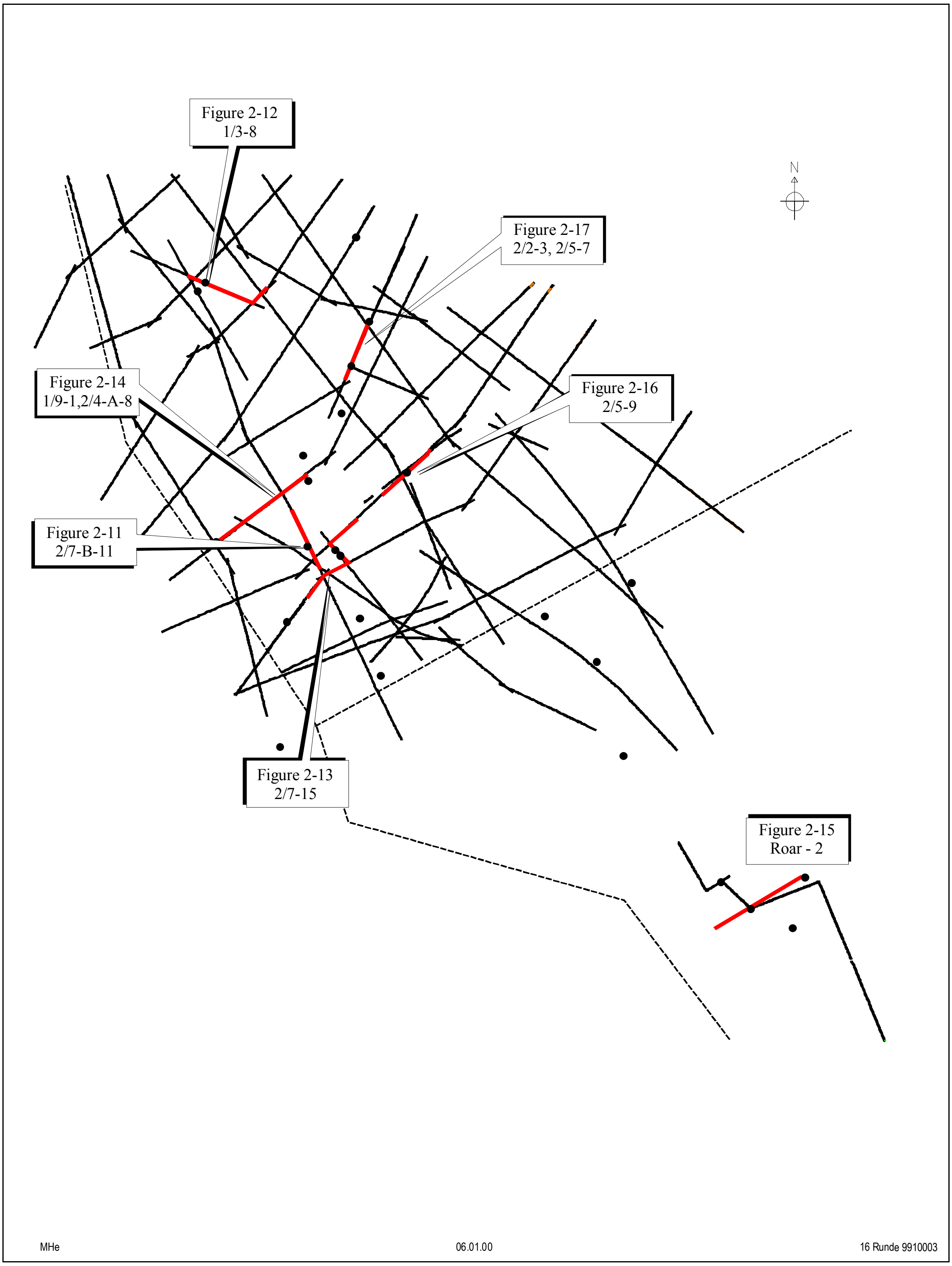

Figure 2-8: Base map showing location of seismic lines included as figures

Included as **enclosure 2-1** to **2-4** are regional seismic lines constructed from shorter lines.

Table 2-1 shows the seismic lines that are incorporated in the profiles.

Profile	Enclosure
Profile 1	
SGT8606-5404	**2-1 a**
SGT8606-4404	**2-1 b**
SGT8606-3404	**2-1 b**
SGT8606-2404	**2-1 b**
SGT8606-1404	**2-1 b**
SGT8606-404	**2-1 b**
Profile 2	
CAST-90-104B	**2-2**
Profile 3	
SGT8606-5202	**2-3**
SGT8606-4202	**2-3**
Profile 4	
SGT8606-2203	**2-4**
Profile 5	
CGG-92-08	**2-5 a**
IL1820_XL429	**2-5 a**
CGD-85-R-87	**2-5 b**
CGD-85-R-89	**2-5 b**
IL2090_XL3782	**2-5 c**

Table 2-1: Seismic lines included as enclosures.

Phillips also made available 4 random lines from 3D surveys in the area, and a few seismic lines were added in the 1/3 area to tie the wells better to the seismic grid.

On the Danish side, two long composite lines were provided from existing 2D and 3D surveys, in order to tie all the studied wells together. **Figure 2-9** shows the location of seismic profiles across the Danish sector. One of these lines is included as **enclosure 2-5.**

All the studied wells with logs and markers were loaded. Except for the UK wells, they are reasonably close to seismic lines in the database. There was a mis-tie of 10 to 20 ms between the two main seismic surveys of the Norwegian side. Several of the wells were drilled in areas of gas chimneys or very near to salt domes making correlation with the seismic difficult (**figure 2-11**).

2.3.2 Horizons picked

Seven sequence boundaries were interpreted to best determine the important seismo-stratigraphic events in the area, and are described below. These were,

- Blodøks
- Intra Middle Hod (imhod)

- Top Middle Hod (tmhod), equivalent to an important sequence boundary in the Campanian
- Top Hod (thod), a sequence boundary at or near to the base of the Maastrichtian,
- Top Tor (tor) at the top of the Cretaceous
- Top Ekofisk (tekofisk), at the top Danian
- Balder (balder), an important near Top Palaeocene event.

A possible sequence boundary within the Tor Formation (mtor) was interpreted in the depocenters in the northern part of the Norwegian sector, but its interpretation could not be extended to the south. In terms of the proposed lithostratigraphy, imhod can be correlated with top Narve in the northern part of the region. The reflectors tmhod and thod correlate with top Thud and Top Magne respectively.

2.3.3 Top Narve (imh, Intra middle Hod)

This event was picked on a weak peak only in the basinal areas in the north and west of the area. It represents a sequence boundary lying between the Blodøks and Top Middle Hod reflectors (**figure 2-12**). There is marked onlap onto this reflector at the basin margins and on the flanks of salt domes. Towards the east, and towards structural highs, the unit between the imhod and the tmhod pinches out (**figure 2-13, 2-14**).
In the Danish sector, a section of similar age as the Thud occurs in the Adda – Roar area. This section has an interesting seismic character, with mounded or channel-like features (**figure 2-15**). Significant internal downlaps are also observed. Thus, the seismic character of this section differs from the Norwegian sector. It is not possible to tie the two areas seismically, because of pinch-out of the units.

2.3.4 Top Thud (tmhod, Top middle Hod)

This event was generally picked on the lowest part of a poor quality peak doublet (**figures 2-12, 2-13, 2-14**). It did not have a consistent appearance throughout the area but sometimes separated a zone with stronger parallel reflectors above from a quieter zone beneath. On the platform margins and adjoining salt highs and inversion highs, marked onlap was visible onto the reflector. In certain more basinal areas both onlap onto and subcrop below the reflector could be recognised, probably indicating more localised tectonic activity, perhaps associated with underlying salt movements. The overall surface of the Middle Hod was broadly undulating and not always parallel to events below or above, even in flatter areas.

2.3.5 Top Magne (thod, Top Hod)

This event was generally picked as a diffuse peak at the base of the reflector separating a lower amplitude zone above from a zone below comprising stronger parallel reflectors (**figures 2-12 to 2-16**). In the structurally higher areas the reflector separates an overlying sequence of higher amplitude parallel reflectors from a lower amplitude zone below. This would imply that the Lower Tor sequence thickens considerably into the basinal areas particularly to the north and west around 1/3-1.

The overlying Tor formation could be seen to onlap the reflector in places at the platform edges and on the flanks of salt induced highs (**figure 2-16**). However in general the Tor sequence showed a greater areal extent than the Magne, extending up onto the platform and highs albeit as a much reduced sequence.

Well data indicate that the Magne Formation is developed as a hardground at some of the highs. The representative wells are all located within gas clouds, and the hardground has not been tied to seismic lines.

2.3.6 Intra Tor

This event was picked in the basinal northwestern part of the area (**figure 2-12**). The reflector represents a persistent sequence boundary within the Tor formation and is picked on a distinctive peak. Above the reflector strong parallel reflectors represent the Tor formation. Below the event, seismic events are less continuous and weaker in amplitude. The difference between the 2 zones can also be seen on the sonic logs in the wells eg. 1/3-1 but is not evident on the gamma logs. This event seems to have stratigraphic significance as subcropping reflectors can be seen in certain places. (JCRtiff10, SGT8606-1402 around sp. 1840). The event is only easily distinguishable in the basinal areas as the lower zone of the Tor thins markedly on the structurally higher areas. Tentative identification of this reflector in 2/5-7 would be as equivalent to the top of the Lower Tor as mapped by Phillips.

2.3.7 Top Tor

This event was picked at the base of a diffuse doublet, sometimes triplet peak below the strong Top Ekofisk reflector (**figures 2-12 to 2-16**). The reflector is very undulating and weak in nature showing local small-scale variations in sequence thickness. Overall the overlying Ekofisk sequence thickens into the basins and to the southeast in the Norwegian sector, showing marked thinning onto the platform and highs. Phase changes and anomalies are evident on some of the highs indicating hydrocarbon accumulations in the Ekofisk and Tor sequences.

The reflector becomes more defined and distinct towards the Danish sector as the overlying Ekofisk formation thickens and as the lithological nature of the Tor Ekofisk boundary changes. (JCRtiff5 and 6, SGT8606 4405 and SGT8606 5405).

2.3.8 Top Ekofisk

Zero-phase matching of surface seismic data to the regional well data normally results in a clear and unambiguous seismic identification of Top Chalk as also confirmed by the large well database existing in the region.

On the type of seismic sections used in this study, Top Chalk (top Ekofisk) is recognized as a seismic trough resulting from an increase in acoustic impedance (SEG reverse polarity standard) (**figures 2-13 to 2-16**). Presence of hydrocarbons or excessive high formation porosity may result in deviations from the normally expected seismic appearance with the top of the chalk formation show dimming or even phase reversal of the seismic signal.

The Ekofisk Formation is relatively thin, and internal events are weak. In the Ekofisk area, the extent of a redeposited event is marked by an irregular trough (**figure 2-14**). In the Northern sector the Top Ekofisk event becomes discontinuous and relatively weak. This is due to the effect on the seismic amplitudes of the overlying Vidar formation as well as by erosion of the Ekofisk. The Vidar lies within the overlying Rogaland Group and is marked by a series of very broad, often discontinuous, high amplitude events (**figure 2-12, 2-17**). The amplitudes are not as high and the effect on the Top Ekofisk is not as notable towards the margins of the area of Vidar occurrence. At the edges of the area of Vidar deposition the Vidar reflectors can be seen to downlap onto the Top Ekofisk. The Vidar events vary from being parallel to chaotic, implying differing sedimentation processes.

2.3.9 Top Balder

This event is picked on a trough, which is generally well defined although it becomes weaker and more discontinuous towards the basin margins. The reflector represents the widespread tuff marker at the top of the Balder formation.

2.4 Conclusions

The seismic interpretation indicates that the axes of deposition have changed during the period of chalk sedimentation. The older sequences (Narve and Thud) are generally thicker towards the west and northwest, while the younger sequences (Magne and Tor), thicken into several elongated depocenters within the Central Graben and onlap onto the highs. This pattern of depocenters and highs was caused by inversion in the Campanian and possibly Maastrichtian times. The overall picture is complicated by the occurrence of several salt piercement features, which have moved progressively in response to the tectonic influences giving rise to the various sequence boundaries.

The uppermost chalk sequence, the Danian Ekofisk Formation, shows small variation in thickness, although it thins towards the highs and tends to thicken towards the eastern part of the Central Graben. Apparently, most of the relief of the graben was filled in during the deposition of the Tor Formation.

Within basinal areas, several sequence boundaries, of varying degrees of importance, can be identified. The most important are the Top Magne and Top Thud boundaries, as well as the Top Narve where it exists.

3 DEPOSITIONAL FACIES

One major purpose of the Chalk Stratigraphic Framework project was to provide a better regional understanding of the deposition, erosion and redeposition of the Late Cretraceous chalk facies in the Central Graben. To obtain this, it was necessary to examine facies distribution in core, and use this information together with the biostratigraphic data, to map main reworked units as well as missing/eroded units.

Many, but not all, of the study wells had core material, and often there were cores only from parts of the chalk group**. Table 3-1** shows the availability of core material in the study wells.

3.1 Chalk description and classification nomenclature

In line with recommendations for all JCR projects, core material described for this project was based on the joint nomenclature developed for the JCR in 1996. Before that, several local nomenclatures for chalk description had been developed through the years. The main basis for the various nomenclatures was established when the re-deposition of chalk became a generally accepted idea in the early eighties, through subdividing the chalk lithology into pelagic (authochthonous) chalk and re-deposited (allochthonous) chalk. Phillips further developed this concept in a systematic and detailed nomenclature for use on the Ekofisk area fields (Siemers et. al. 1994).

In their work, however, Phillips recognised the abundance of floating boundaries and odd mixtures of chalk facies that did not fit the subdivision of in-situ or re-deposited chalk. Often it was not possible to define the depositional processes behind a specific chalk interval. From this perspective, the JCR description system was constructed on a pure common ***descriptive basis***, with no interpretive requirements that could cause subjective differences in classification (Crabtree et. al 1996).

In most cases when chalk cores are examined, additional features will be noted and interpreted, so that a succeeding evaluation of depositional facies and history can be made.

3.2 Core description and sampling method

Most of the Norwegian wells had previously been described using the Phillips chalk nomenclature system, see **table 3-1**, and it was considered unnecessary to re-log these cores. All other cores investigated for this project, were logged by Prof. B.W. Sellwood, at the same scale, and described according to the description and classification scheme agreed in JCR Phase IV, so that compatibility could be achieved. The descriptions were noted directly onto logging sheets as reproduced in **enclosure 3-1 to 3-9.** 2/8-A-1 had already been examined by him in previous studies so it was deemed unnecessary to re-log that core. Where cored intervals were found to be in a poor state of preservation, available core photographs (taken soon after the cores were archived) were used to provide additional information. Wherever core photos were available they were always used, in conjunction with the core itself. In nearly all cases the cores required thorough cleaning before examination could proceed.

All lithological interpretations on the cores were made using a hand-lens or the naked eye. The presence of accessory minerals (especially pyrite) was noted where large and obvious masses were seen to exist in the cores.

Well name	Location field	(Original) Operator	Feet of Chalk Core	Feet of core described this project	Comments
1/3-1	Basin / dry	Shell	10	0	*No core description performed*
1/3-8	Basin / dry	Amoco	0	-	
1/9-1	Tommeliten Alpha	Statoil	650	0	*Previous core description by T.Harland, Phillips*
2/2-2	Hidra Terrace	Saga	0	-	
2/2-3	Basin / dry	Saga	0	-	
2/4-A-8	Ekofisk	Phillips	638	0	*Previous core description by T.Siemers, Phillips*
2/4-B-19A	Ekofisk	Phillips	600	0	*Previous core description by Phillips, T.Siemers*
2/4-B-19	Ekofisk	Phillips	146	0	*Previous core description by Hydro*
2/5-1	Tor	Amoco	843	**843**	*JCR core description, B.Sellwood, this study*
2/5-7	Basin / dry	Agip	107	0	*Previous core description by Phillips, T.Harland*
2/5-9	Basin / dry	Amoco	0	-	
2/7-2	Basin / dry	Phillips	58	**58**	*JCR core description, B.Sellwood, this study*
2/7-4	Edda	Phillips	385	0	*Previous core description by T.Siemers, Phillips*
2/7-8	East Eldfisk	Phillips	0	-	
2/7-15	East Eldfisk	Phillips	0	-	
2/7-30	Slope / dry	Phillips	411	0	*Previous core description by Phillips, J.Brasher*
2/7-B-11	Eldfisk	Phillips	718	0	*Previous core description by T.Siemers, Phillips*
2/8-A-1	Valhall	Amoco	345	0	*B.Sellwood previous core description*
2/11-A-2	Hod	Amoco	248	0	*B.Sellwood previous core description*
2/11-A-2/T2	Hod	Amoco	194	0	*B.Sellwood previous core description*
2/11-A-2/T3	Hod	Amoco	0	-	
Total N: 21			5353	901	
MFB-7	Dan	Mærsk	628	**628**	*JCR core description, B.Sellwood, this study*
M-9X	Dan	Mærsk	300	**131**	*JCR core description, B.Sellwood, this study*
Roar-2	Roar	Chevron	122	**122**	*JCR core description, B.Sellwood, this study*
Roar 2A	Roar	Chevron	0	-	
Baron-2	Syd Arne	Hydro	341	**341**	*JCR core description, B.Sellwood, this study*
Lulu-1	Harald	Mærsk	325	**206**	*JCR core description, B.Sellwood, this study*
Mona-1	Inverted High	Mærsk	1029	**1029**	*JCR core description, B.Sellwood, this study*
T-1	Svend	Mærsk	400	0	*Core description not performed*
E-4X	Tyra	Chevron	321	0	*Core description not performed*
Adda-2	Adda	Chevron	-	-	
Adda-3	Adda	Chevron	-	-	
Bo-1	Valdemar	Chevron	-	-	
Total DK: 12			3466	2457	
30/7a-2		Phillips	664	**664**	*JCR core description, B.Sellwood, this study*
31/26a-10		Amerada	112	**112**	*JCR core description, B.Sellwood, this study*
Total UK: 2			776	776	
Total ft core:			9595	4134	

Table 3-1: Core availability and described cores in this project

Sampling procedures were determined depending on the degree of variability observed in the cored sections. If the rock succession was relatively uniform, then one sample was taken every metre. If, however, there were facies breaks, hardgrounds, conglomeratic, glauconitic or other features suggesting significant changes then more closely spaced samples were taken across the features observed in the cores. In this way it was hoped that a more refined biostratigraphic breakdown could be achieved.

Core depth shifts were recorded for many of the wells, as shown in **table 3-2** below. All core description sheets and all biostratigraphic data in the Chapter 4 distribution charts are in original core depths. Cores are only shifted to log depths on the well log composites (**enclosure 5-1 to 5-29**.). This means that ***the sample depths from cores, and hence zone boundaries, on the range charts and gapograms may not correspond to this depth on the log composites.***

Well name	Depth shift	
	Core interval	Log depth =
1/3-1	No core	
1/3-8	No core	
1/9-1	All intervals	No shift
2/2-2	No core	
2/2-3	No core	
2/4-A-8	All intervals	No shift
2/4-B-19	9755 - 9818 10180 - 10370	core - 16 ft core - 20 ft
2/4-B-19A/T2	All intervals	core + 10 ft
2/5-1	9995 - 10291 10292 - 10368 10369 - 10382 10383 - 10701 10702 - 10879	No shift core + 4 ft no shift core + 3 ft no shift
2/5-7	3303 - 3308 3312 - 3321 3326 - 3335 3339 - 3348	core - 1,5 m core - 2,3 m core - 5,3 m core - 1,7 m
2/5-9	No core	
2/7-2	All intervals	No shift
2/7-4	10360 - 10377 10381 - 10391 10405 - 10459 10460 - 10473	core + 6 ft core + 4 ft core + 2 ft core + 4 ft
2/7-8	No core	
2/7-15	No core	
2/7-30	All intervals	core + 20 ft (upper) core + 25 ft (lower)
2/7-B-11	9812 - 9849 9849 - 9999 10060 - 10649	core - 36 ft core - 12 ft core - 4 ft
2/8-A-1	All intervals	No shift

2/11-A-2	No logs in cored track	
2/11-A-2 T2	No logs in cored track	
2/11-A-2/T3	No Core	
MFB-7	All intervals	core - 4 ft
M-9X	All intervals	core + 1 ft
Roar-2	All intervals	core + 1 ft
Baron-2	2821 - 2847 2847 - 2871 2872 - 2900 2900 - 2926	core + 0.83 m core + 0,71 m core - 0,57 m core + 0,39 m
Lulu-1	9033 - 9065 9073 - 9117 9229 - 9358	core + 8 ft core + 6 ft no shift
Mona-1	All intervals	No shift
30/7a-2	9696 - 9766 10100 - 10115 10161 - 10225 10229 - 10252 10379 - 10498 10499 - 10599 10613 - 10721 10730 - 10846	core - 0,5 ft core + 9,5 ft core + 9,5 ft core + 12,5 ft core + 4,5 ft core +5,5 ft core + 7,5 ft core + 1,5 ft
31/26a-10	All intervals	No shift

Table 3-2: Core depth shifts

3.3 Sedimentological observations

Features such as burrows were identified to ichnogenus wherever possible. The presence of *Chondrites*, *Zoophycos*, and *Planolites* in otherwise structureless chalk was taken to indicate a pelagic mode of deposition. Obvious turbiditic layers are present as graded skeletal and peloidal grainstones and packstones (sometimes as rudstones). Large-scale overfolds were taken to mark the presence of slumps. Smaller scale overfolds were also logged as representing minor slumps, but such features may occur at the bases of very thick sediment packages, the folds giving way laterally to a variety of other features such as intraclastic wackestones generated through down-slope movement and localised shear-disruption. It is not possible to provide a refined interpretation of such features on the basis of core samples only a few centimetres in diameter, however. Thus few inferences about the thicknesses of slumped packages can be made. Debris flow units marked by chalk floatstones often have discrete bases and tops. Thick units can frequently be matched with a log motif on the wireline logs (as indicated for individual wells). Particular intervals dominated by re-sedimentation are organised by having discrete turbidites overlain by thick debris flows. This motif was noted in a number of wells and reflects individual emplacement events in which downslope movement was triggered, fast-moving grainy turbidites rushed immediately down slope, to be followed some time later by the more sluggish debris flow.

Massive units wholly lacking in definitive structures pose particular problems in interpretation. Total homogenisation may have been achieved through early post-depositional bioturbation. It may also have been produced through the sediment having been autosuspended and deposited essentially *in situ* (i.e. slurried), as for example through earthquake shock of a thixotropic (water-saturated) sediment. Massive units have been interpreted by association (i.e., as pelagic if found associated largely with obviously burrowed intervals etc.).

3.4 Main Chalk facies

For the composite well panels (**figures 5-12 to 5-41**), the core description summary logs (**figures 3-11 to 3-20**) and the chalk facies maps (**figures 3-21 to 3-25**), it was necessary to make a simplified interpretation of the main depositional facies as seen in the cores. In the JCR chalk classification system, a chalk lithotype is characterized by having a distinct combination of description codes. Lithotype is consequently a strictly descriptive unit and should not be confused with lithofacies. The “facies” term has historically been used in many different ways in the geological literature, guided by the purpose of the study. In our study, the depositional facies represent an interpretive grouping of the chalk units to reflect large scale or regional stratigraphic events that may be recognised between wells and fields. So, pelagic chalk has been separated out from the other facies characterised by higher energy origin, such as slumps, debris flows and turbidites. Also Hardgrounds are treated as separate facies. In addition, homogenous, massive chalk has been separated out, because this facies type may either be pelagic or allochthonous (mud flows).

Where the chalk constitutes thin interbeds of massive and laminated chalk mudstone, or interbedded bioturbated argillaceous chalk and thin turbidites or debris flows, it has been necessary to lump several depositional facies together in one. **Figure 3-1** and **table 3-3** shows the depositional facies used in the well correlation panels, and corresponding JCR lithotype descriptions. **Figure 3-1b** shows the facies key for the core summary logs.

Main chalk facies	Chalk lithotypes JCR nomenclature	Interpreted depositional chalk facies
Marl		
Mainly Pelagic chalk	• Laminated Chalk Mudstone • Laminated Argillaceous Chalk Mudstone • Burrowed Massive Argillaceous Chalk Mudstone • Burrowed Laminated Argillaceous Chalk Mudstone	• Pelagic/ authochthonous chalks • Periodites
Massive/ homogenous chalk	• Burrowed Massive Chalk Mudstone • Massive Chalk Mudstone	• Mudflows • Distal turbidites • Pelagic chalks
Reworked chalk	• Massive Pebbly Chalk Mudstone • Massive/Laminated Chalk Wackestone • Massive/Laminated Chalk Packstone • Massive/Laminated Chalk Grainstone • Graded Laminated Chalk	• Debris flows • Turbidites • Calcarenites

Slumped/ deformed chalk	• Deformed Chalk Mudstone • Deformed Pebbly Chalk Mudstone • Deformed Laminated Pebbly Chalk Mudstone • Deformed Chalk Wackestone	• Slides • Slumps • Shear deformation
Hardground	• Deformed Burrowed Wackestone	• Conglomerates • Erosion surfaces • Hiatus

Table 3-3: Main chalk facies, JCR lithotypes and depositional facies

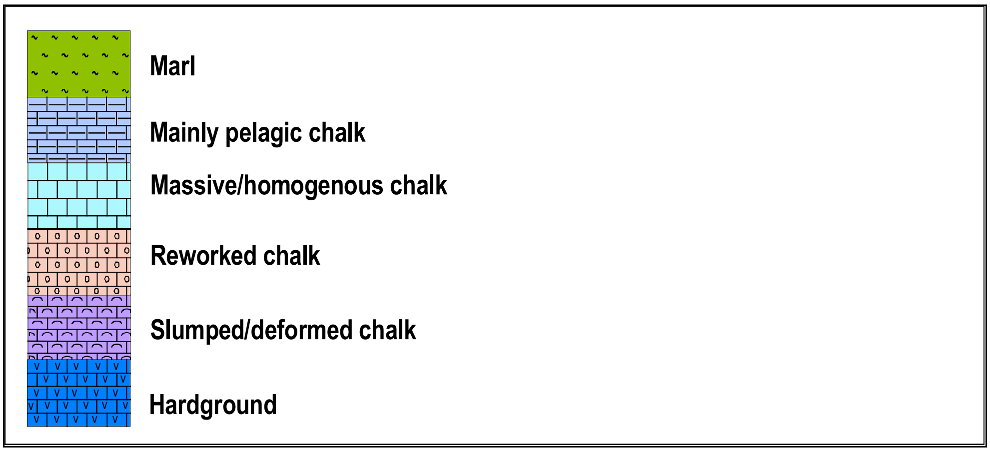

Figure 3-1: Index of main chalk facies

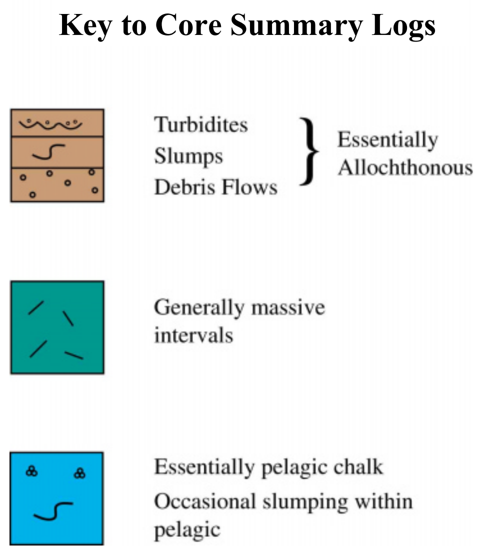

Figure 3-1b: Index of main chalk facies in core summary logs

Mainly pelagic chalk:

This facies type comprises all combinations of burrowed, laminated/massive and argillaceous chalk lithotypes expected to have been deposited in situ, such as laminated argillaceous chalk mudstone, burrowed massive chalk mudstone, or burrowed laminated chalk mudstone. Compared to the Phillips chalk facies nomenclature it includes argillaceous chalk, burrowed argillaceous chalk, burrowed laminated chalk and laminated chalk. In cases where originally pelagic chalk is observed deformed, such as slump folds, the latest event (slumping) is considered most important to our study.

Massive/homogenous chalk:

When there are no evidences of depositional processes in the chalk core, the chalk is classified to this facies group. In the Phillips system, homogenous chalk is interpreted to be deposited through sediment-gravity-flow from turbulent mud clouds or mud flows. However, it is also possible that such facies are purely pelagic in origin, and completely reworked by burrowing. In this study, burrowed homogenous/massive chalk mudstone is classified as pelagic, but if no trace fossils can be seen, it is classified as a massive chalk.

Reworked chalk:

This facies type was selected to represent chalk redeposited through mass-gravity flows, such as debris flows and turbidites. Thus, it comprises all combinations of pebbly mudstone and wackestone/packstone/grainstone. In the Phillips system, it is typically the pebble floatstone and calcarenites. In a regional stratigraphic setting, this facies type is believed to reflect the transport of semi-lithified or soft chalk material eroded or swept from basin margins or inversion ridges, and settled into the deeper basin areas.

Slumped/deformed chalk:

Slump folds and other deformation structures may represent semi-regional or local down-slope transport of semi-lithified - to soft chalk, or it may represent soft chalk deformation due to overlying sediment load. Considering the uncertain significance for regional chalk reworking, slumps were separated out from the reworked chalk group on the well composite logs. However, since the slumps often represent rather thin intervals, they were included together with debris flows and turbidites in the facies maps (**figures 3-21 to 3-25**).

Hardground

Hardgrounds and conglomerates are also thin intervals and very rare, but their significance as evidence for major stratigraphic breaks justified a separate facies group for these.

3.5 Microfacies observations

In order to illustrate the various chalk facies types in one single well, microfacies photographs of thin-sections from well 2/4-A-8 on the Ekofisk Field are presented in **figure 3-2 to 3-10**. The main chalk facies index is shown in **figure 3-1**.

The well 2/4-A-8 was continuously cored from the Våle Formation, through the Ekofisk and most of the Tor Formations, a total of 690 feet of cored section. Approximately 150 samples were collected by NPD for thin section preparation in 1980, however no detailed core descriptions for these thin section samples exist. The thin section photographs shown in the present study were chosen amongst these preparations and the photographs were taken at DTI.

The photographs cover an area of the thin section measuring 1.9 mm x 1.4 mm. The same scale was used on all photos. Large variations in the size of foraminiferal tests can be observed. Chalk of Maastrichtian age with reworked foraminifera or abundant cenosphaere in small clasts can be observed in the Ekofisk formation.

The degree of dissolution or diagenesis can be indicated by the sharpness of the fossil tests. Along stylolites partly dissolved fossils can be observed.

The description on the thin sections are in accordance with the JCR nomenclature developed in 1996, as the chalk description scheme for depositional texture have been used.

3.6 Facies interpretations in wells

The simplified chalk facies distributions, in the individual cored wells that were described in this project, are given in **figures 3-11 to 3-20**, and summaries of the core descriptions are given in the back of this section.

2/8-A-1

The post-chalk claystones were deposited after a considerable time gap. The base is marked by an abrupt change to dark grey claystone above the underlying chalk intraclast conglomerate. The sediments represent deep-water clays that accumulated under generally well oxygenated conditions. The Ekofisk Formation is represented in this well by 3 meters of reworked chalk of Maastrichtian age, defined equivalent to the informally named Elle member (Sikora et. al. 1999). See also **figure 5-7.**

The Tor Formation is largely allochthonous in origin. Shear-fractured zones typical of locally-moved slide sheets are present and much of the sequence consists of conglomeratic chalks representing debris flows. The Tor/Magne boundary, as defined palaeontologically, occurs within a complex hardground interval a few metres thick (designated the “Dense Zone” in older reports, Magne in this study).

The Narve formation is largely represented by pelagic periodites with associated thin micro-turbidites. What evidence there is of tectonic activity, as reflected in re-sedimented units or slump-scars, is sparse. Slump-scars and intraclastic horizons occur at a very few horizons. At the base the sequence begins as a series of finely laminated chalks with associated clay and glauconitic interbeds. Initial chalk deposition coincided with the onset of tectonic activity. Sub-oxic and anoxic bottom waters gave way upwards to normally ventilated waters and burrowing becomes common away from the base.

The Blodøks Formation consists of laminated glauconitic claystones and laminated chalks, some slump-folded. The succession accumulated under anoxic to sub-oxic conditions, but more normal ventilation is reflected in the abundance of *Inoceramus* towards the top of the formation. Laminated claystones are sometimes kerogenic and the sediment could have minor source-rock potential.

The Hidra Formation accumulated as a regular pelagic periodite chalk. There are no signs of slumping or tectonic disturbance during deposition. Minor laminae may be micro-turbidites. The top of the Hidra is rich in shell material and may be a firmground rather than a hardground.

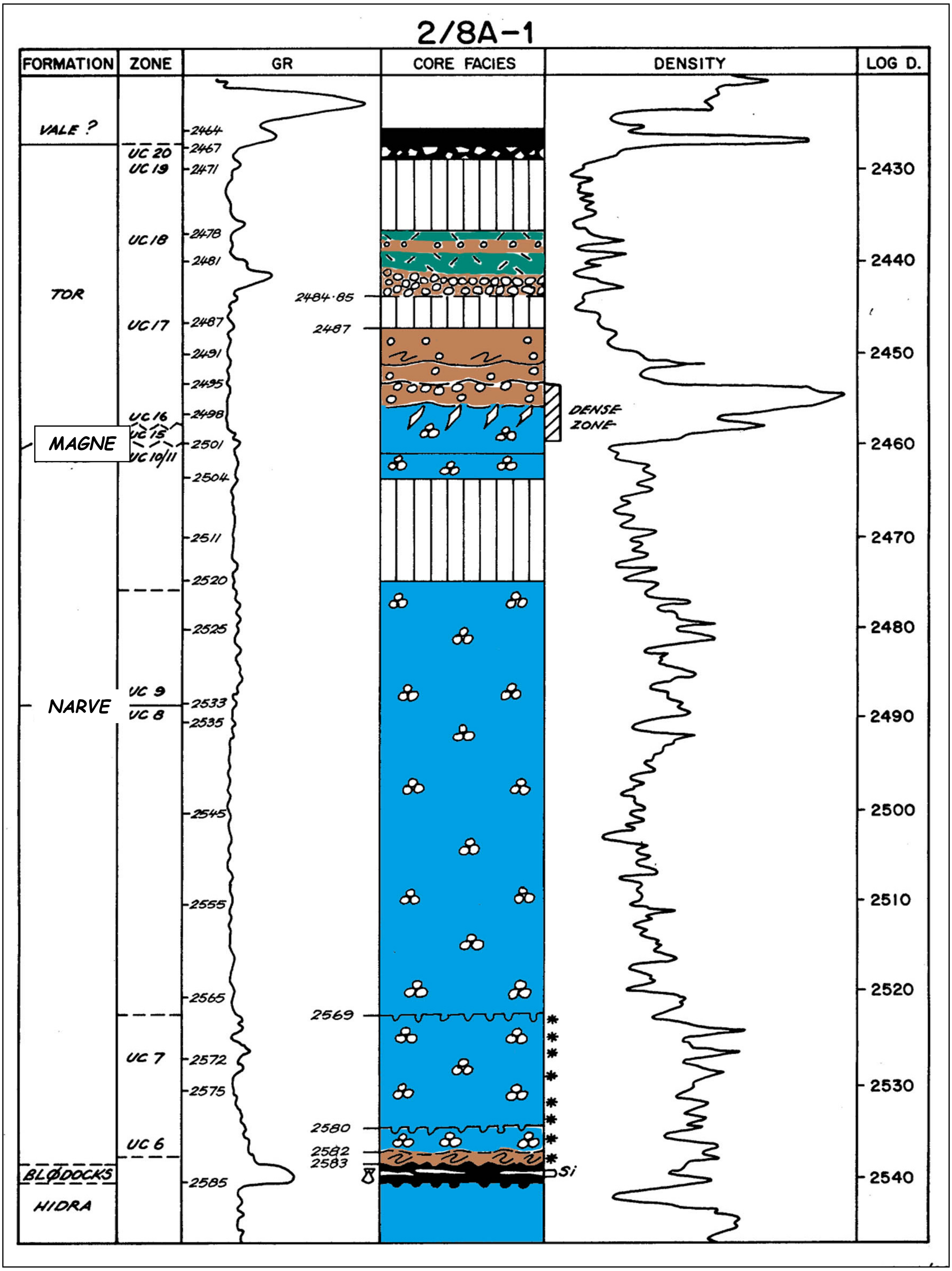

Figure 3-11: 2/8-A-1 core summary log

2/5-1

The Ekofisk Formation is predominantly pelagic chalks towards the top but has some redeposited intervals (mostly turbidites) in the middle and lower parts. The middle parts of the formation also exhibit rare slumps, as does the base, which is also silicified. The Tor Formation, represented by Zones UC 20 and UC 19, comprises some re-worked intervals of debris flows, slumps and turbidites emplaced within a background of pelagic sediments.

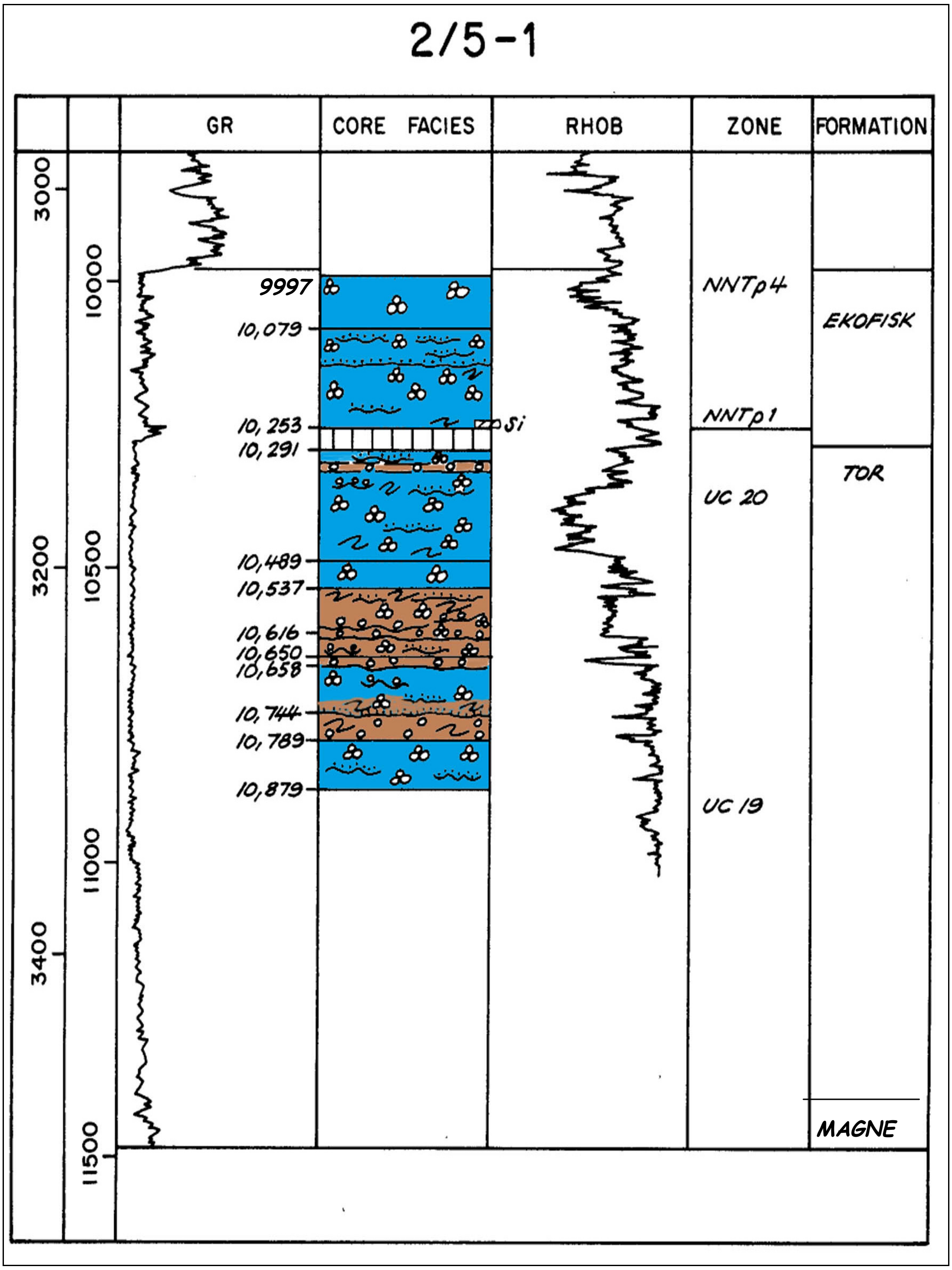

Figure 3-12: 2/5-1 core summary log

2/7-2

The Tor Formation is here represented by pelagic sediments only, the cored interval being entirely within Zone UC 20.

LULU-1

All of the cored section is in the Ekofisk Formation. Zone NNTp5 is represented by pelagic chalks. The underlying sediments (Zone NNTp4) consist of debris flows and slump overfolded wackestones and floatstones often rich in coarse skeletal debris. The Middle parts of the zone were not cored but where cored comprise essentially massive chalks with some evidence of both debris flow and slump activity. The lower parts of the cored section (base of Zone NNTp4 and Zones NNTp2 and NNTp1) are predominantly pelagics with rare slump overfolds, notably close to the base of the cored section.

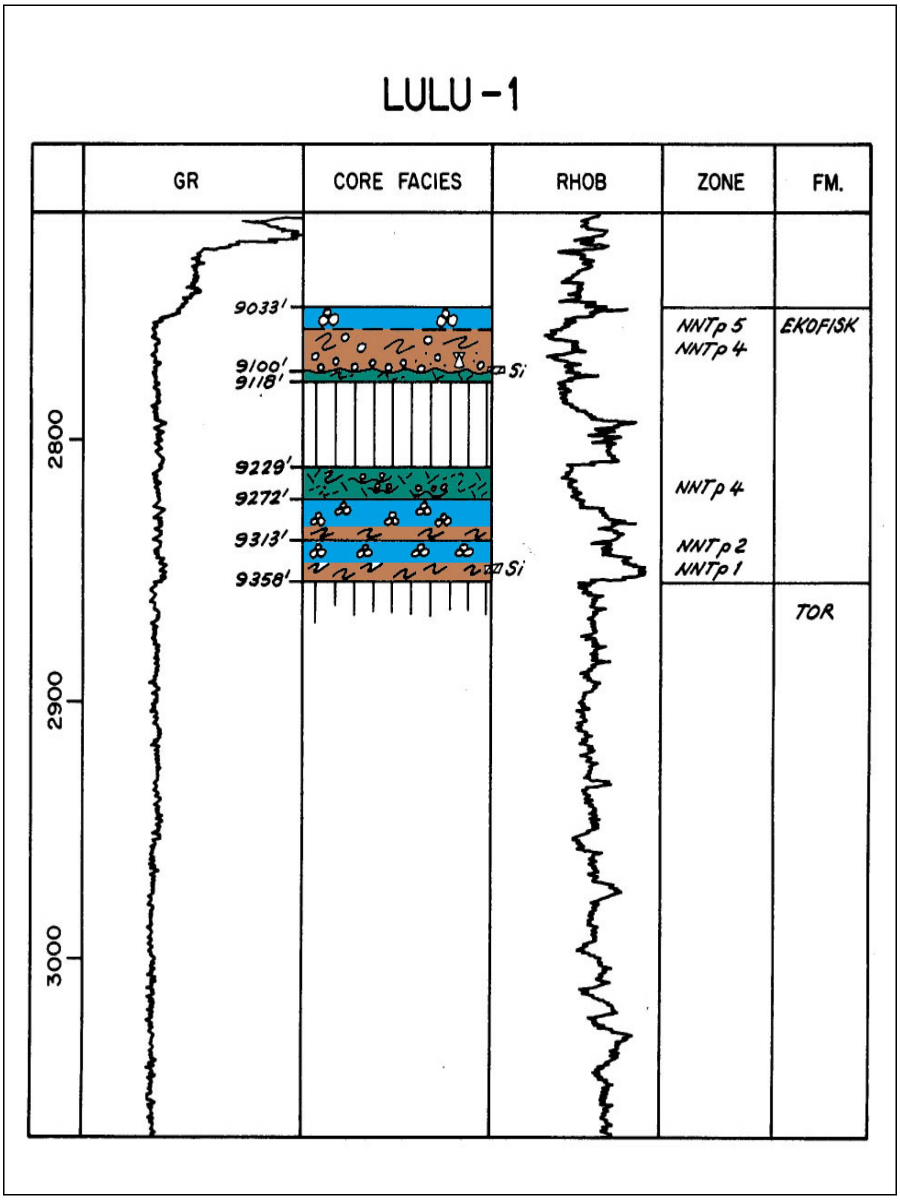

Figure 3-13: Lulu-1 core summary log

MONA-1

The Tor Formation was cored almost in its entirety (Zones UC 20, 19, 18, and 16 all being represented). UC 20 consists mostly of debris flows and slump-folded chalks with thin intervening pelagic units. UC 19 has pelagics with thin turbidites in its upper part and a major unit of debris flows in its lower. UC 18 is a predominantly pelagic interval with thin turbidites, and slumps and debris flows marking its base. UC 16 is represented by largely pelagic facies with rare turbidites. The contact with the underlying Magne formation is abrupt. The top of the Magne formation is a bored hardground above a red limestone, probably largely pelagic in origin. Below this, the Narve formation (zones UC 11 and 10) is an interval of debris flows and slumps in which the clasts are polymict and include non-chalk clasts set in a buff coloured micritic matrix. An abrupt change of facies marks the base. The Blodøks Formation is apparently not present in the well. Below this is a return to red micrites with chert bands (probably pelagic). This is dated as UC 3 Hidra Formation.

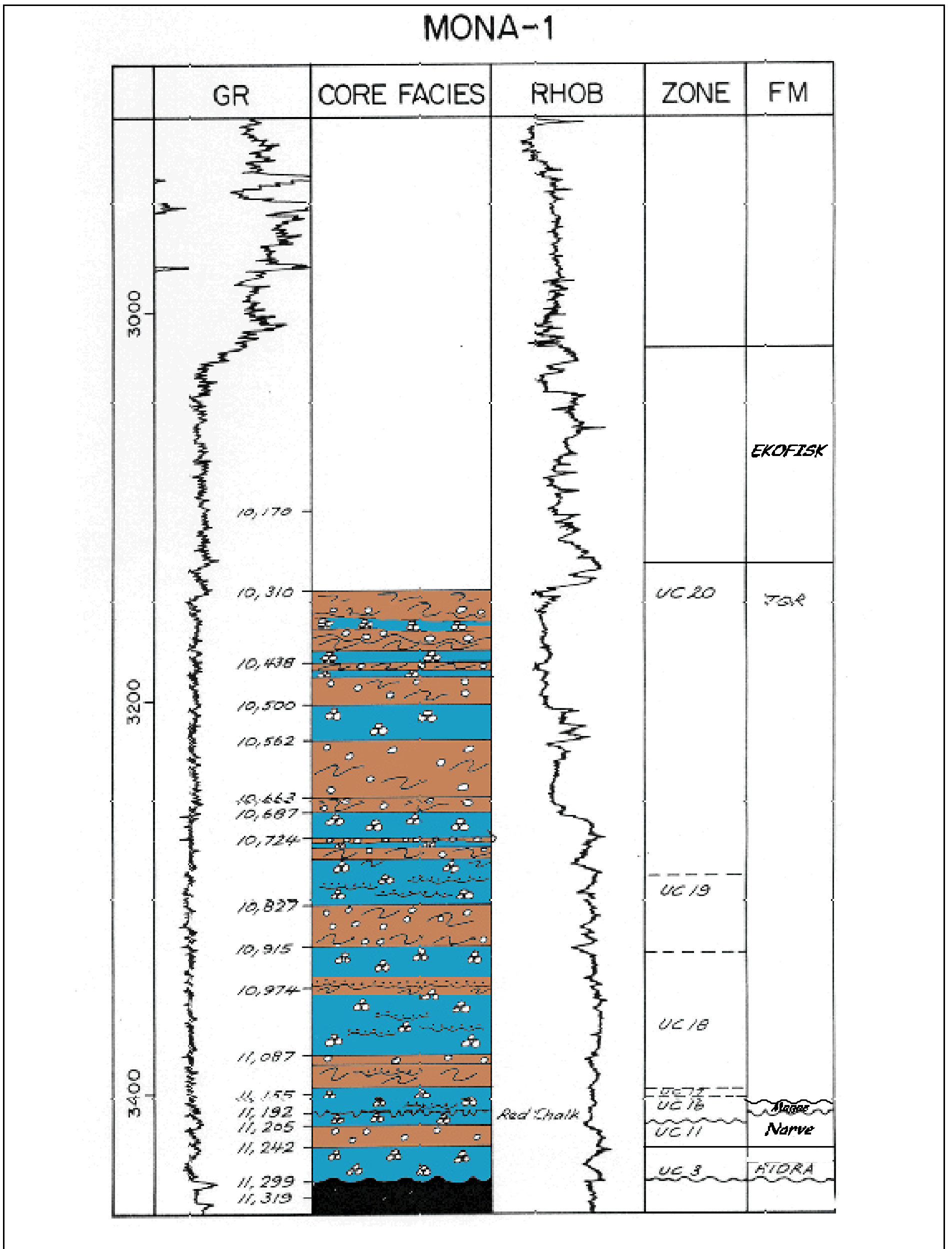

Figure 3-14: Mona-1 core summary log

BARON-2

Post-chalk (Våle Formation) is represented by deep-water calcareous claystones rich in *Zoophycos*. The contact with the underlying Ekofisk Formation is indistinct, being marked by an overall increase in the amount of carbonate and a corresponding decrease in the clay content. The Ekofisk Formation is represented by Zones NNTp4 to NNTp2. The upper and middle parts of Zone NNTp4 are predominantly pelagic sediments with rare slump-folded units. The lower parts have massive beds, slumps and rare silicified debris flows with intervening pelagics. Zones NNTp3 and NNTp2 are represented by essentially allochthonous (re-deposited) units as slumps and debris flows with rare pelagic intervals. The Tor Formation is absent in this well. The contact with the Magne formation (Zones UC 15 and UC 14) is abrupt, representing a bored hardground impregnated with a green mineral (? glauconite). Below this hardground, the Magne and Thud formations are represented by entirely pelagic chalks. The contact between these and the Narve formation (UC 11) pelagic chalks is a subtle clay seam with burrows.

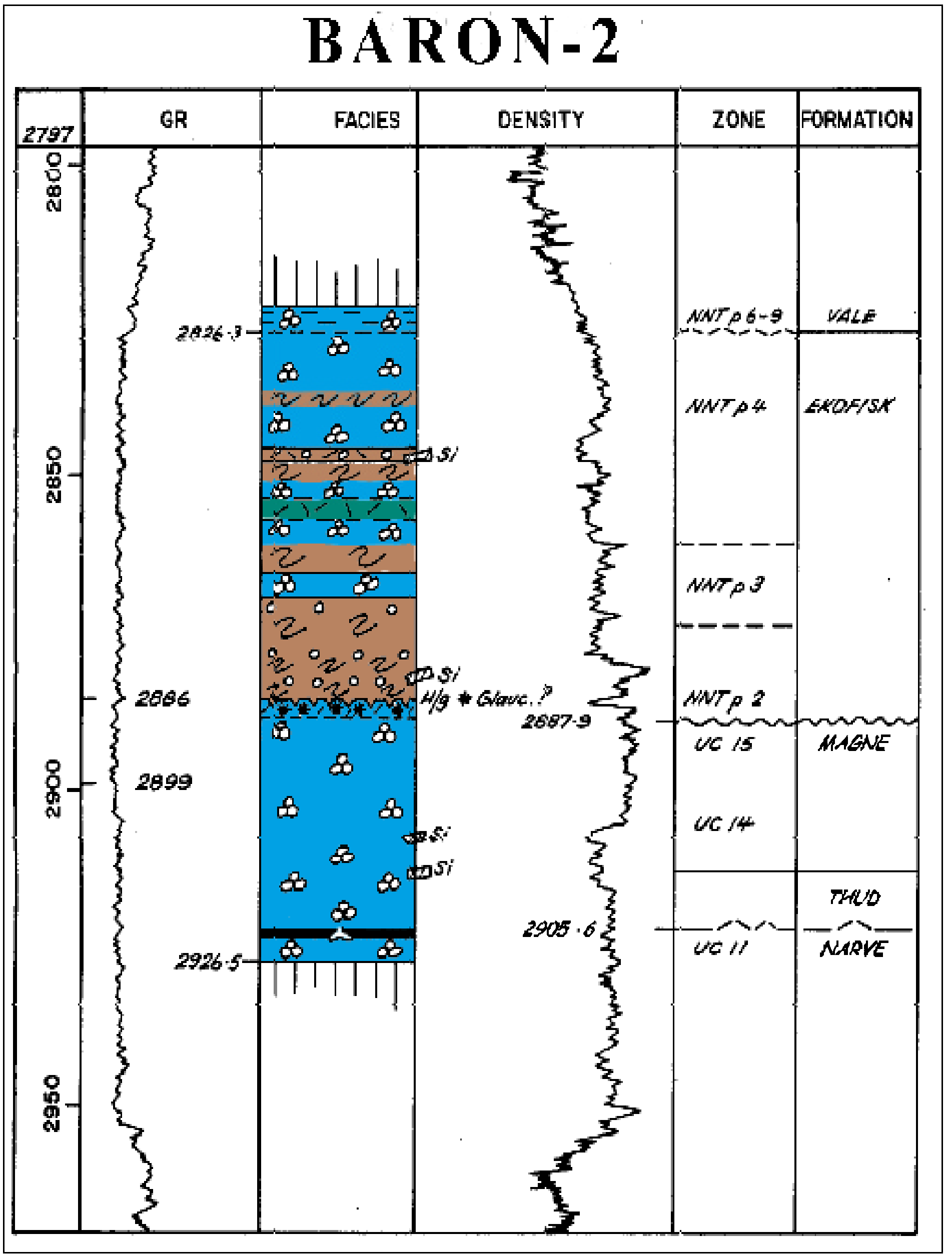

Figure 3-15: Baron-2 core summary log

ROAR-2

Post-chalk formations comprise dark brown and black claystones. Immediately overlying the chalk is a thin red-brown claystone.

The Ekofisk formation (Zone NNTp2) consists of pelagic chalks apart from a re-worked layer in the lower part.

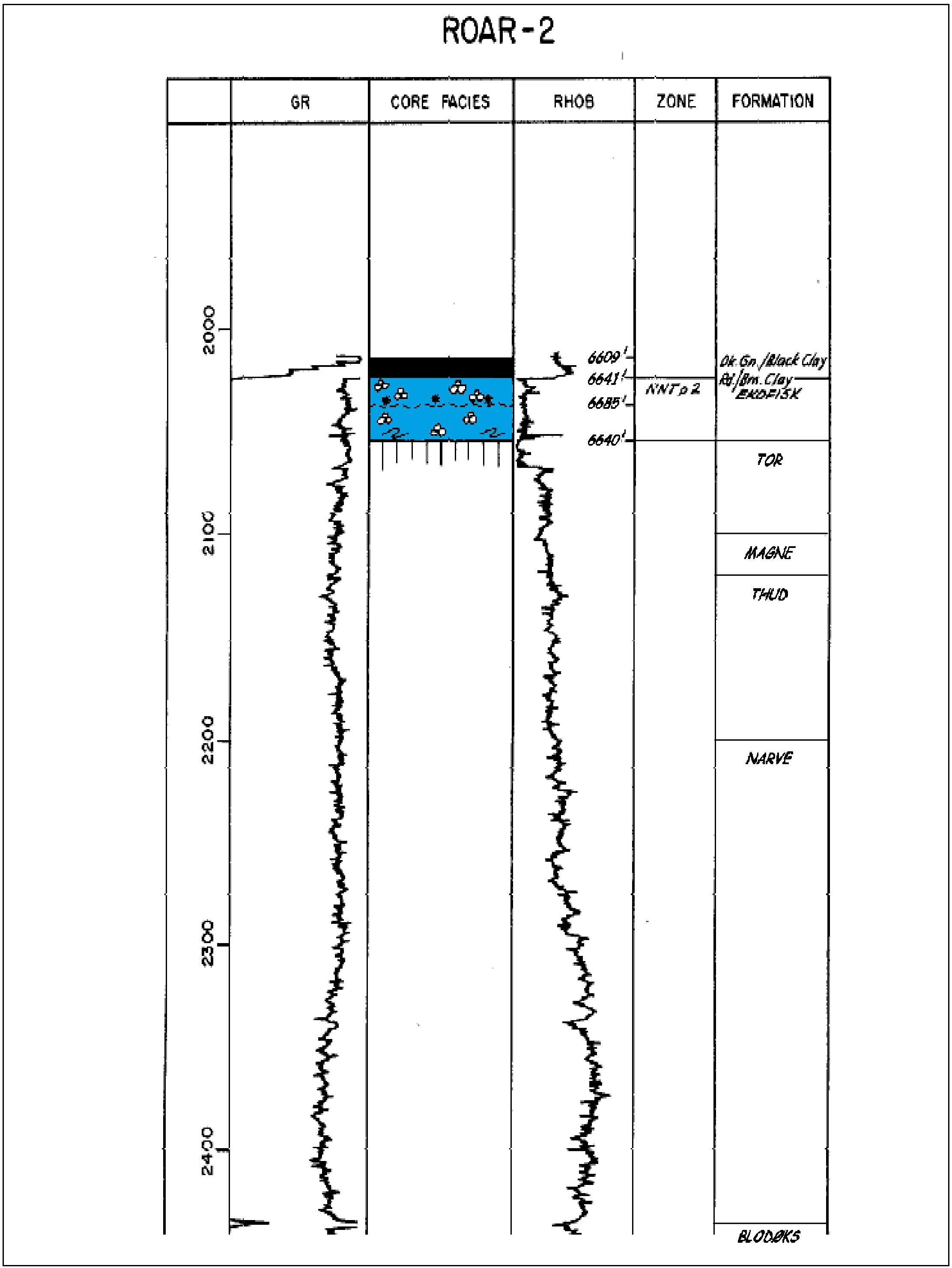

Figure 3-16: Roar-2 core summary log

MFB-7

The Ekofisk Formation (Zones NNTp4 to NNTp2) commences below an erosion surface at the top with predominantly pelagic material. It comprises largely pelagic chalks, but with discrete debris flow units and turbidites. The lower parts of the formation exhibit some flint bands. The base of the unit is a clay seam (possibly stylolitic) resting upon a glauconitised hardground at the top of the Tor Formation. Below the glauconitised top of Tor Formation, the rest (Zones UC 20 and UC 19) comprises essentially pelagic chalks.

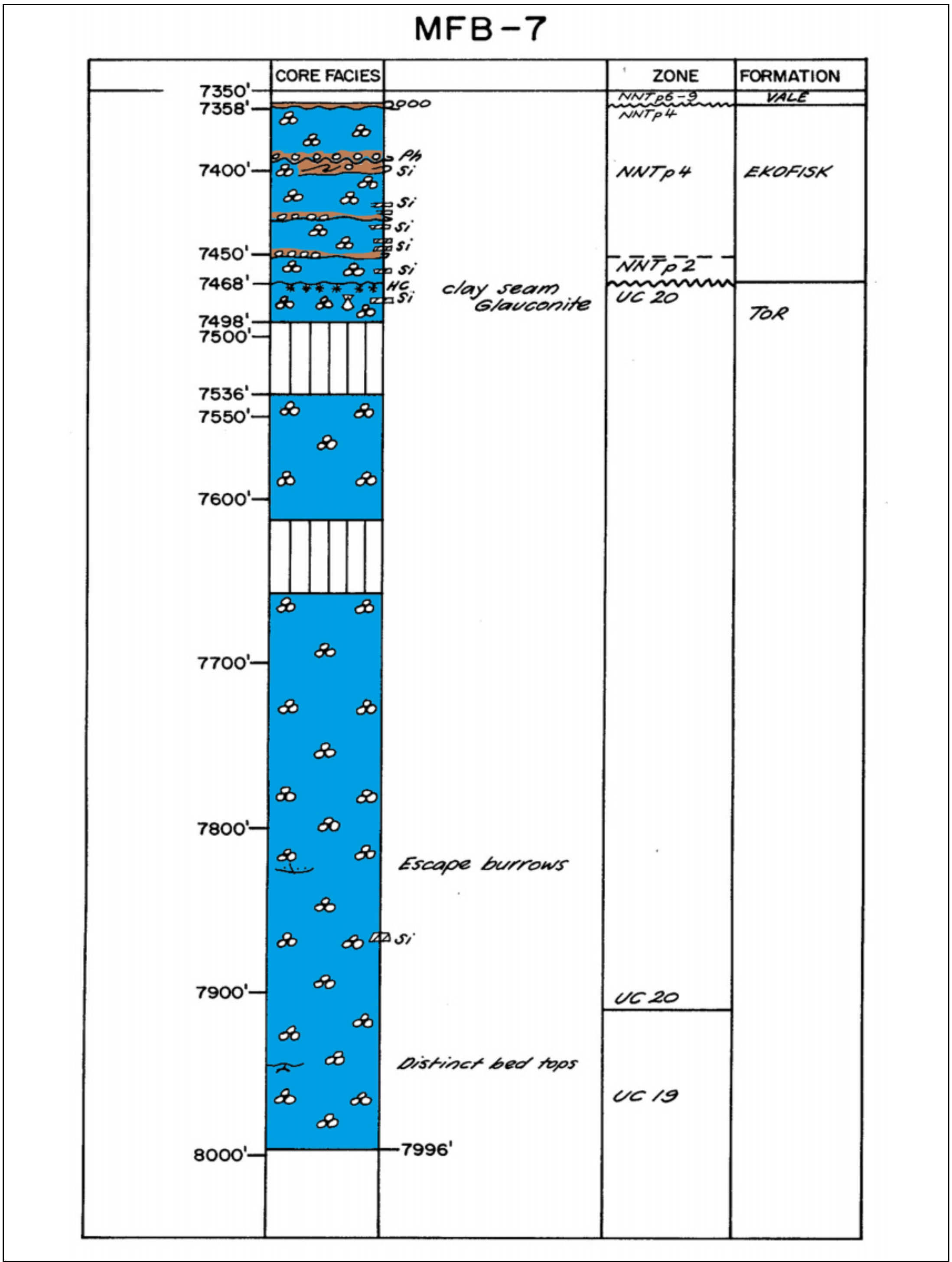

Figure 3-17: MFB-7 core summary log

M-9X

The Ekofisk Formation (Zone NNTp2) consists of pelagic chalks.

The Tor Formation (Zones UC 20 to UC 18) is also represented entirely in pelagic facies, with rare firm- or hardground surfaces.

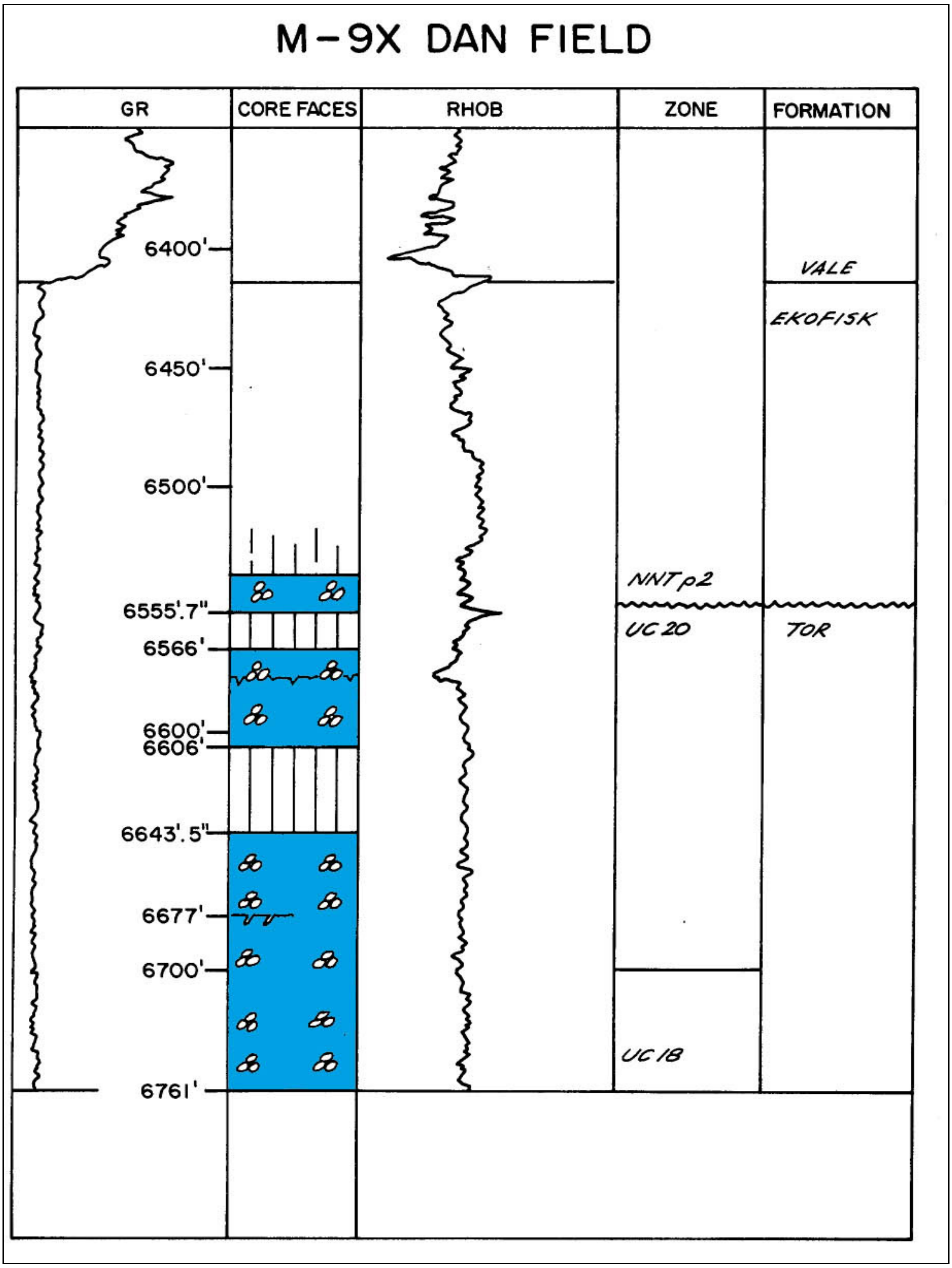

Figure 3-18: M-9X core summary log

30/7a-2

The Ekofisk Formation (Zones NNTp4 to NNTp2) is represented almost entirely by pelagic sediments. One debris flow unit occurs towards the top of the cored section and not far above a hardground. The Tor Formation (Zones UC 20 and UC 19) in bulk terms consists mostly of background pelagics, but there are a significant number of discrete debris flow units throughout the cored interval, some of which contain larger skeletal fragments. Some intervals are relatively structureless. The Narve formation(UC 9) is by wholly pelagic material.

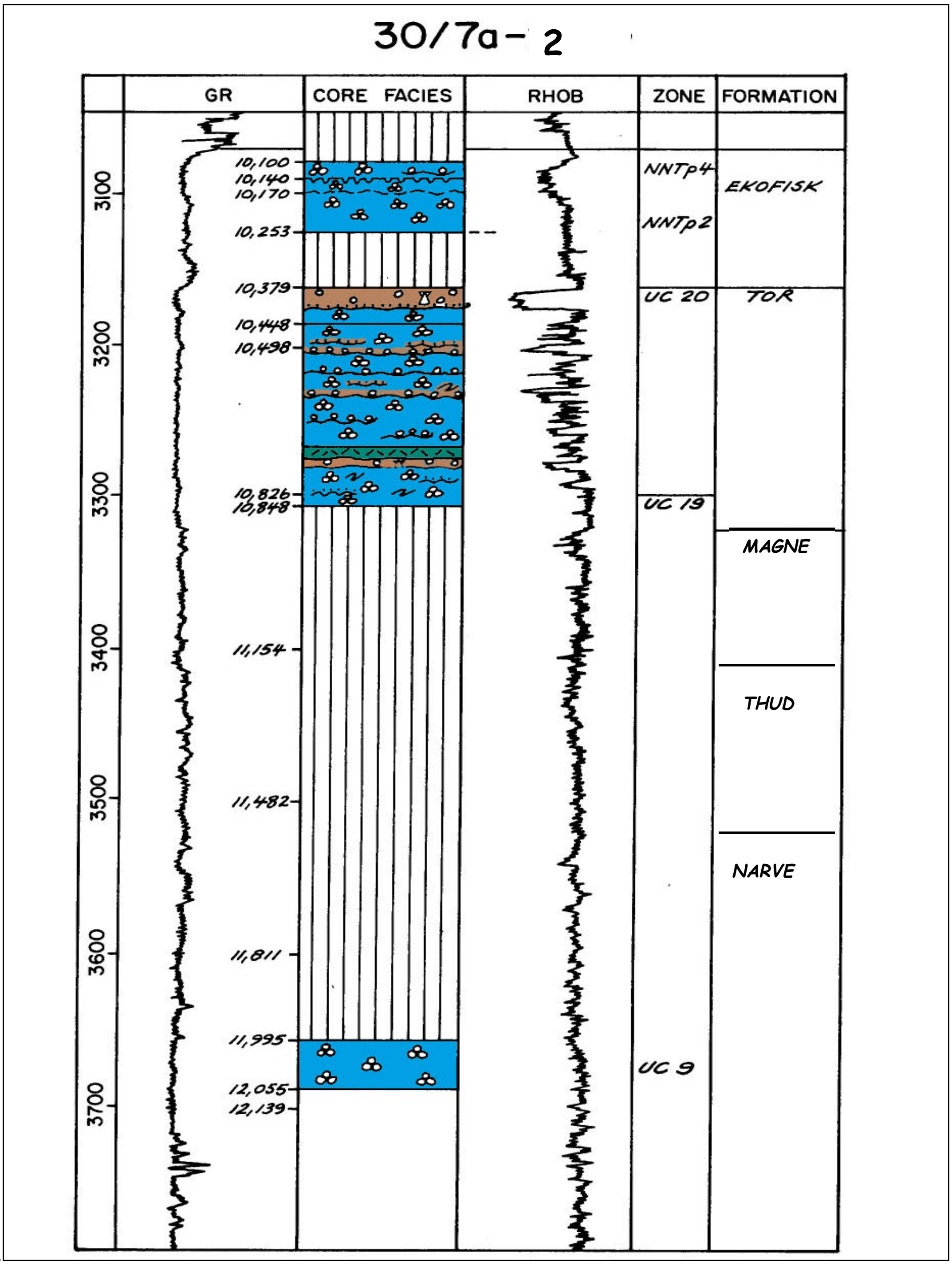

Figure 3-19: 30/7a-2 core summary log

31/26a-10

The Tor Formation (Zone UC 20) is represented mostly by pelagic chalks with thin (sometimes silicified) slumped layers. The deepest interval (also within Zone UC 20) is a slump-folded unit.

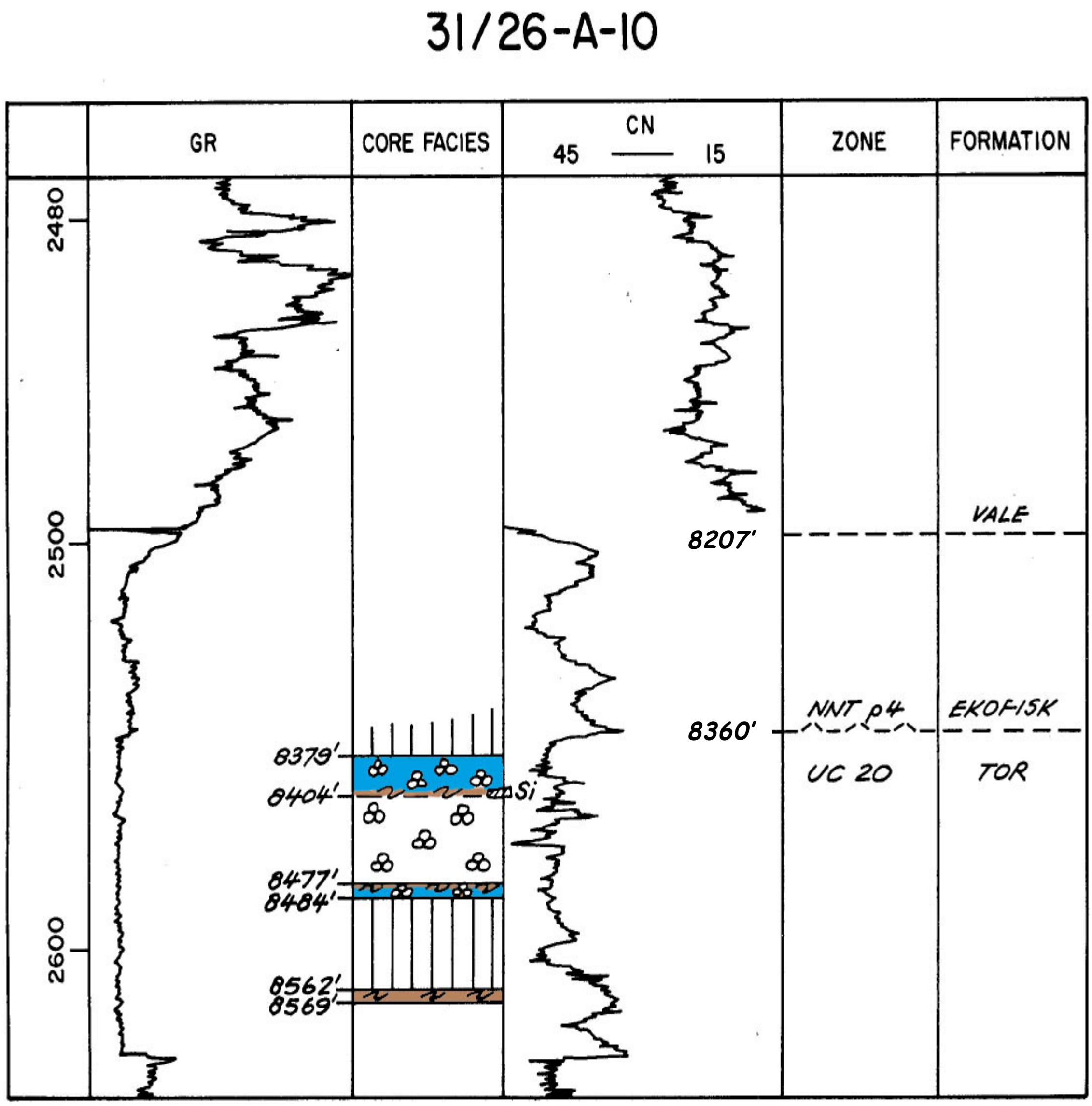

Figure 3-20: 31/26a-10 core summary log

3.7 Depositional facies distribution

The chalk facies in all cored study wells have been plotted on regional maps for each lithostratigraphic formation, in **figures 3-21 to 3-25.** These maps show the raw core description data interpreted into blocks of the simplified facies as defined in subchapter 3.4, and placed on top of the main Late Cretaceous structural elements. Each box represents the complete formation between the lower and upper formation boundaries, regardless of which biostratigraphic zones are present or absent within the formation, and regardless of the actual thickness of the formation. Empty intervals within the boxes represent non-cored sections. "No core" indicates that there were no core taken from that formation. Crossed-out box means that the formation is absent in the well location. An open well symbol with no connected box means that the well was not drilled down into the formation or that information about core availability is missing.

Narve formation (figure 3-21):

Wells were rarely drilled down to the Coniacian - Turonian sections, and only a few have core material within this formation. The wells along the Lindesnes ridge (2/11-A-2, 2/8-A-1 and 2/7-B-11) and the Arne ridge (Baron-2) show that mainly pelagic sedimentation took place on the inversion ridges by that time, with occasional hardgrounds. The exception from this is Mona-1, which has mainly reworked material.

Thud formation (figure 3-22):

The map shows that, of the few wells that were drilled through this formation, none have core material. This formation is also limited to the basin areas, thus missing in most wells in structural high positions.

Magne formation (figure 3-23):

Most wells were drilled into the Magne formation, but only few wells were cored. On the inversion ridges, this formation is mostly characterised by hardgrounds, conglomerates or condensed sections. Mona-1 was the site of red chalk deposition at this time.

Tor Formation (figure 3-24):

The southernmost area (wells MFB-7 and M-9x) was predominantly subjected to pelagic deposition, reflecting a general lack of both growth and disturbance. During late Campanian (UC16), non-depositional hiatuses occurred in a broad swathe running from 2/2-2 in the north, to Baron -2 in the south. Non-deposition, or even erosion, occurred over 2/5-1, 2/11-A-2 and Baron-2 (which has no Tor sediments at all), the general area of the Lindesnes Ridge. Slumping and mass flow movements appear to have been confined to the area adjacent and to the SW of the high centred on the site of 2/5-1.

In Maastrichtian, pelagics are interbedded with discrete slumps which, if contemporary with deposition and not just the “roots” of later disturbance events translated deep into the sediment, reflect a significant increase in the degree of tectonic activity. In addition, significant debris flow activity in Mona-1 occurred. In Baron-2 there is no Maastrichtian chalk present. Positive movements over the inversion ridges, either at this time or immediately later, manifests itself by the presence of many erosion/corrosion surfaces over a very broad area. Neither slumps nor significant breaks occur in the area of MFB-7 and M-9X, away from the main ridges.

Ekofisk Formation (figure 3-25):

Most wells have a significant break at the Tor/Ekofisk boundary, which probably reflects the combination of both sea level fall and more intense growth along the inversion ridges, from which slumping is assumed to have been triggered. The break in Baron-2 is marked by a major glauconitised hardground which may have formed over a very long time interval.

The Ekofisk Formation is generally absent in the central region embracing 2/8-A-1 and 2/11-A-2, except for a thin layer of reworked Maastrichtian chalk, named informally Elle Member by Sikora et. al. (1999). Erosion surfaces within the zone are also noted to the north of this central area. Most other wells contain pelagics and massive chalk with some slump disturbance, whereas areas to the east (Lulu) exhibit significant slumps. The southern area is dominated by pelagic chalks.

3.8 Summary of core descriptions

2/5-1

NNTp4 9995' - 10,079'	Essentially pelagic wackestones and mudstones with sparse burrowing including *Chondrites* and rarer *Planolites*. *Zoophycos* occurs sporadically. Burrows are dark-filled below clay layers. A questionable turbiditic (argillaceous and grainy) layer occurs at 9997'. The unit becomes thicker-bedded downwards and has bioturbated bed contacts. MUCH RUBBLED SECTION.
NNTp4 10,079' - 10,128'6"	Pelagic background chalk wackestones with *Chondrites* and *Planolites*. But there are interbeds of grainy graded turbidites (packstones and grainstones each around 6" thick) with undulose sharp bases and burrowed tops. Rare debris flow layers occur (e.g. at 10,079' - marking the top of the interval).
NNTp4 10,128'6" - 10,171'	Essentially interbedded pelagic chalk wackestones (with *Chondrites* and *Planolites*) and slump-folded units. RUBBLED BETWEEN 10,141 and 10,160'.
NNTp4 10,171' -10,195'	Essentially pelagic chalks with *Chondrites, Planolites* and occasional *Zoophycos*. *Zoophycos* becomes more common downwards.
NNTp4 10,195' - 10,232'	Pelagic chalk wackestones with *Chondrites, Planolites* and differing from the unit above by the presence of rare turbidites.
NNTp4/NNTp1 10,232' - 10,253'	Pelagic chalk wackestones with occasional thin (6" to 8" thick) slump packages. Silicified slump unit at base.
10,253' - 10,291'	GAP BETWEEN CORE 10 and CORE 11
UC 20 10,291' - 10,301'	Unit with essentially pelagic chalk at the top (with *Chondrites*) and thin intervening turbidites (at 10,297').
UC 20 10,301' - 10,314'	Thin chalk floatstone (debris flow unit) overlying a thicker slump-overfolded unit. POOR CORE PRESERVATION.
UC 20 10,314' - 10,489'	A largely rubbled succession but probably mostly comprising pelagic wackestones (with *Chondrites*), but with occasional turbidite packstones (10,387', 10,426'), debris flows (10,355') and slumps (10,363', 10,461' and 10,472').
UC 20 10,489' - 10,537'	Largely pelagic chalk wackestones with *Chondrites, Planolites* and occasional *Zoophycos.* Rare shear deformation also occurs. RUBBLED SECTION.
UC 20 10,537' - 10,616'	RUBBLED SECTION. Thin slumped succession (to 10,543') with thin intervening pelagics, passing down into a major series of chalk floatstones (debris flows), each separated by thin pelagic layers with *Chondrites, Planolites* and occasional *Zoophycos.*
UC 20 10,616' - 10,650'	Thicker-bedded pelagic intervals with thin intervening units of slumps and debris flows (each up to 3' thick) and with thin turbidites (each up to about 6" thick).

UC 20 10,650' - 10,658'	Thick chalk floatstone (debris flow) unit. Sparsely scattered well-rounded chalk clasts in chalk wackestone matrix.
UC 20 10,658' - 10,744'	Predominantly pelagic unit with *Chondrites, Planolites* and occasional *Zoophycos.* Thin debris flows and thin slumped intervals are present. A complex of turbidite, debris flow and slump layer is taken as the base of the unit.
UC 20 10,744' - 10,789'	The unit comprises a major succession of slump and associated debris flow units. This is probably a succession of debris flows each associated with a succeeding slump.
UC 19 10,789' - 10,879' (Base)	A largely pelagic interval comprising chalk wackestones with *Chondrites, Planolites* and occasional *Zoophycos.* Rare turbidite and debris flow layers occur (10,851-10,855'). The turbidite band at 10,841' has a silicified base.

2/7-2

UC 20 9876' - 9934' (Base)	Alternate units of parallel banded and massive (including obviously bioturbated) chalk wackestones. Largely pelagic, although parallel banded units may represent either micro-turbidites or undisturbed sapropelic chalks. Burrows mostly represented by *Chondrites*. Rare skeletal fragments are present.

LULU-1

NNTp5/NNTp4 9033' - 9051'	Badly rubbled section but available material suggests an essentially pelagic succession of Chondrites chalks.
NNTp4 9051' - 9100'	Sparse floatstones (chalk debris flows) with rounded chalk intraclasts set in a chalk matrix. Sometimes slump fold deformation is present and overprints the floatstone lithology. This suggests that the originally deposited debris flows were subsequently subjected to more plastic slump deformation. The base is abrupt and from 9082' to the base the matrix is grainy (well developed fine skeletal wackestone) with abundant skeletal debris including *Inoceramus*. Flint (apparent clasts) occurs at the base.
NNTp4 9100' - 9118'	Largely massive or vaguely banded chalk wackestones, rare grainier bands (fine skeletal wackestones). Banding locally cryptically folded (?slumped) and rarely silicified (flint bands and nodules).
9118' - 9229'	GAP - no core
NNTp4 9229' - 9272'	Relatively massive chalk with cryptic overfolding (very rare) and rare bands of scattered rounded chalk intraclasts. Stylolites and undulose surfaces are fairly common because burrows are entirely absent throughout. This evidence for slurry activity must be regarded as equivocal. A prominent pressure-solved clay seam is take as the base of the unit.
NNTp3/NNTp2 9274' - 9313'	Interbedded white chalk mudstones and thinner darker (argillaceous) chalks and thin clay seams. Burrows (dark-filled) descend from bed contacts (*Zoophycos,*

	Planolites and locally *Chondrites*). Essentially a pelagic unit (periodite) with possible cryptic re-sedimentation reflected by the presence of discrete massive beds.
NNTp2 9313' - 9345'	Essentially pelagic chalks with *Zoophycos* and *Chondrites.* Some *Chondrites* clay-filled and some more argillaceous seams.
NNTP1? 9345' - 9358' (Base)	Top of Unit is marked by a flint band that overprints a minor slumped layer. Remainer of succession comprises thin slump overfolded (cryptic) units (dm- to metre thickness) alternating with interbedded pelagics with *Chondrites*.

MONA-1

UC 20 10,310' - 10,424'	Many gaps occur in the cored succession. Unit appears to consist principally of slumps and minor debris flows with intervening disturbed pelagic intervals containing deformed *Zoophycos*, *Chondrites* and *Planolites*.
UC 20 10,424' - 10,438'	This in situ pelagic interval with undeformed *Zoophycos*, *Chondrites* and *Planolites*. Some burrows are dark-filled (i.e. clay present).
UC 20 10,438' - 10,450'	Mostly debris-flows but with a banded, slumped, unit at the top.
UC 20 10,450' - 10,459'	Regularly bedded pelagic interval with in situ *Chondrites* and *Planolites*.
UC 20 10,459' - 10,505'	Major unit of debris flows with thin slumps.
UC 20 10,505' - 10,562'	Regularly bedded pelagics dominated by *Chondrites* and *Planolites* but with occasional *Zoophycos*. Very rare *Inoceramus* present.
UC 20 10,562' - 10,663'	Major succession of debris flows and minor slumps, capped by a thin unit of slumps at the top. Most clasts consist of chalk but with occeasional *Inoceramus* remains.
UC 20 10,663' - 10,687'	Slump-bedded chalks with well developed overfolding. Matrix often chalk floatstones (debris-flows that have been subsequently deformed).
UC 20 10,687' - 10,724'	Pelagic chalks massively bioturbated with *Zoophycos*, *Chondrites* and *Planolites*. Some scattered skeletal material locally.
UC 20 10,724' - 10,726'	Major turbidite bed. Very coarse chalk clast conglomeratic base and graded top with parallel laminations and escape burrows.
UC 20 10,726' - 10,739'	Largely pelagic chalk with *Chondrites* and rare slump beds.
UC 20 10,739' - 10,759'	Major slump overfolded unit with rare debris flows.
UC 20/UC 19 10,759' - 10,832'	Predominantly pelagic interval. *Chondrites* burrows. Rare coarse grained turbidites, and slumps.
UC 19 10,832' - 10,915'	Cross bedded turbidite capping complex unit of slumps and debris flows. Matrix largely chalk floatstones which show slump overfolds.

UC 19/UC 18 10,915' - 10,974'	Predominantly pelagics with thin grainstone and packstone turbidites. There is a 5' thick stack of turbidites and minor slump beds at the base. *Chondrites* present.
UC 18 10,974' - 11,087'	Pelagic *Chondrites* and *Zoophycos* chalk. Very rare turbidites and eeven rarer debris flows.
UC 18 11,087' - 11,099'	Unit of sparse floatstones (debris flows with scattered chalk clasts).
UC 18/UC16 11,099' - 11,146'	Argillaceous unit dominated by slumps.
UC 16 11,146' - 11,192'	Buff coloured argillaceous unit, essentially pelagic, with *Chondrites* and *Planolites*, becoming pink in colour towards the base of the unit (below 11,182). Bored hardground marks the base of the unit.
UC 16 11,192' - 11,205'	Pink coloured pelagics with *Planolites* and capped by bored hardground representing major hiatus.
UC 15/UC 11/UC 10 11,205' - 11,242'	Polymict floatstones (debris flows), some pink and some grey in colour. Some slumping and overfolded bands, and cherts. Clasts comprise chalk, flints and shale.
UC 3 11,242' - 11,299'	Red micrites, pelagic, with irregularly spaced chert bands and nodules. Complex zone of faulting (11,284-11,288). *Zoophycos* abundant in lower parts of unit. Sharp undulose base to unit.

BARON-2

NNTp7/NNTp6 2821 - 2839 m	Grey bioturbated marls (argillaceous chalks), pyritic in places, with *Planolites*, *Zoophycos* and *Chondrites*. Some darker and lighter alternations (dm-scale) with scattered thin clay seams (accentuated by pressure dissolution). Subtle change to cleaner less clayey sediment at 2826m. A thin layer with slump overfolded deformation occurs at 2839 and is taken as the base of the unit.
NNTp4 2839 - 2843.5 m	Predominantly lighter grey chalks (generally less argillaceous than above). Occasional clay seams and darker argillaceous layers, argillaceous content is enhanced in these because of extensive pressure dissolution seaming. *Zoophycos* is present, and some slightly deformed by overfolding.
NNTp4 2843.5 - 2847 m	Massive chalk wackestone to mudstone, burrowed by *Planolites*, *Zoophycos* and *Chondrites*. An undulose flint band occurs towards the base containing intraclasts. This represents a thin silicified debris flow layer. At the base is a thin green claystone containing bright green clay clasts (?chloritic).
NNTp4/NNTp3/NNTp2 2847 - 2879.6m	The unit comprises slump overfolded intervals, very rare turbidites (i.e. at 2857.5m, 2860.3m and 2879m) and intervening intervals with undisturbed pelagic chalk wackestones/mudstones. The pelagic intervals contain *Chondrites* and zones with *Zoophycos* associated with minor clay seams. Locally undulose units with clay seams and pseudonodular chalks are present (e.g. at 2860m and 2878m). The slumped units exhibit discrete overfolded laminae, sometimes well developed but sometimes more cryptic but shown up by the presence of folded burrows such as *Zoophycos* (e.g. at 2874m).

NTp2 2879.6 - 2886.5m	The unit is intensely pyritic at the top and the topmost bed is cut by spar-filled fractures. Complex interval dominated by chalk floatstones (debris flows) comprising coarse, medium and fine-grained clasts (rarely also shale) set in a chalk matrix. Some massive floatstone units exhibit folded shear banding suggesting that they have been slump folded after their initial emplacement as debris flows. In places folded bands have been silicified and the unit contains several flint bands and nodules. The basal parts of the unit are discretely overfolded and rest on a well-marked glauconitized surface.
NNTp2/Gap/UC 15 2886.5 - 2887.5 m	Marker Bed. Major hardground comprising a glauconitic wackestone cut by truncated fractures descending from the top surface. Fractures contain green clay (?chloritic or glauconitic). Large burrow systems are present (?*Thalassinoides*), as are abundant fine skeletal grains (foraminiferans, molluscan, ?sponge). Burrows have multi-phase fillings. This bed represents a significant hiatus and I speculate that it could mark the Tor/Hod contact in this well.
UC 15/UC 14/UC13/UC 12/UC 11 2887.5 - 2926.5 m (Base)	Essentially a set of tight porcellaneous chalk mudstones with relics of *Planolites* and other burrows (including *Chondrites* and rare *Zoophycos*). Locally nodular and pseudonodular intervals are present, as are rare flints. One flint band appears to represent a silicified debris flow (at 2908.5m), but this layer is unique in this interval. Most of the succession is a pelagic one with some zones hinting at more regular alternations of clay richer and clay poorer bands on a dm-scale. Shear-fracturing, which is discrete, may reflect the stresses transmitted into the unit as a result of down-slope movements in the overlying Tor. Network note a break [Gap] at about 2922.6m and this may correspond with a relatively indistinct burrowed contact at 2923.25m. The pelagic chalks below this depth (to base of core) are dated as UC 11 by Network.

ROAR-2

Post-Ekofisk 6637' - 6640'	Green claystone with rare *Chondrites* and *Zoophycos* burrows, fossil fragments (including bryozoans and sponge) and rounded chalk clasts. Clayey debris flow at the base, which passes up into deep-water claystones.
NNTp3/NNTp2 6643' - 6665'	Massive and generally bioturbated chalk wackestone to mudstone with few distinct features except one band with molluscan fossils and a pseudonodular fabric (at 6656'). Rare *Chondrites* towards the base of the unit. The base is taken at a "scour-like surface" which has been enhanced by pressure dissolution (possibly a slump scar).
NNTp2 6665' - 6674'	*Chondrites* and *Zoophycos* in pelagic chalk wackestone to mudstone.
NNTp2 6674' - 6685'	Massive chalk wackestone with small patches of ?glauconite grains (possibly large burrow fills) and occasional pyrite-filled burrows up to 1' long. These chalks may be re-sedimented but emplaced as slurries rather than clast-rich debris flows.
NNTp2 6685' - 6734'	Essentially a *Zoophycos* (and *Chondrites*) pelagic chalk wackestone. *Zoophycos* are abundant. Rare undulose surfaces (e.g. at 6695') may reflect slump scars. Rare layers with slump overfolding are present (e.g. at 6709' and 6713'). A flint band occurs at the base.

MFB-7

NNTp6
7358' - 7361' — Bioturbated slightly calcareous claystone (marl) with floating chalk clasts close to the base. Basal debris flow and overlying deep-water clays.

NNTp5/NNTp4
7361' - 7393' — Chalk wackestones with rare scattered skeletal material. Essentially pelagic and containing Chondrites, Planolites and locally Zoophycos. Rare clay seams. ?Phosphatic intraclasts associated with undulose clay seam at the base.

NNTp4
7393' - 7420' — Massive and burrowed chalk wackestones. Chondrites, Planolites and rarer Zoophycos present. Undulose clay seams, scattered flint nodules (associated with rare, thin, discrete debris flow layers).

NNTp4
7420' - 7451' — Generally bioturbated and massive chalk wackestones but with more abundant flint bands and nodules than either the underlying or overlying units. Planolites, Chondrites and rarer Zoophycos are present throughout. Some more distinct flint bands are thicker than normal and appear to contain silicified chalk clasts (thin debris flow units, as at 7429'). Rare clay seams occur (as at 7451').

NNTp3/NNTp2
7451' - 7468' — Pelagic chalk with *Zoophycos* and *Planolites* burrows. Several flint bands are present (more abundant than above) and irregular undulose clay seams.

UC 20
7468' - 7469' — Very distinctive layer (<1' thick overall). A significant clay seam rest with an undulose contact upon a very hard and bioturbated wackestone/packstone, speckled with dark (?glauconite) grains. Hardground surface.

UC 20
7469' - 7492'3" — Massive and vaguely banded chalk wackestones with rare Zoophycos and articulated bivalve shells. Pelagic.

7492'3" - 7536' — GAP Between Core 4 and Core 5

UC 20/UC 19
7536' - 7996'4" (Base) — Parallel banded and regularly bedded pelagic chalk wackestones throughout with discrete burrows (*Planolites*, with rarer *Zoophycos* and *Chondrites*). *Zoophycos* becomes generally more abundant downwards, towards the base of the core. Banding and lamination may reflect either restricted oxygenation or micro-turbidite deposition. Scattered *Inoceramus* occur at various locations through the unit, as do rare flint nodules. Banding may be rhythmic in part but some parts of the succession are rubbled.

M-9X

NNTp2
6536' - 6550' — Massive to interbedded chalk wackestone, pelagic, with occasional clay seams and rare flint bands.

UC 20
6550' - 6555'7" — The flint band at 6550' is probably equivalent to the peak in the density log at about 6553' (log depth). This flint marks a subtle change of facies to more regularly bioturbated and flint-free pelagic chalks (below) by comparison with those above.

UC 20
6566' - 6606' — Pelagic chalk wackestones but with obvious Chondrites, Planolites and Zoophycos. Some burrows are dark-filled. The succession in interbedded (?rhythmic) on a 1' to 6" scale.

UC 20 6643'5" - 6715'	Essentially pelagic chalk wackestones as above but lacking in flints. Possible firmgrounds/hardgrounds occur at 6665', 6677' and 6690'. The firmground at 6677' (core depth) is probably equivalent to the subtle log change, which occurs at 6680' (log depth). That at 6690' (core depth) is equivalent to the log break at 6693' (log depth). Rubbled section occurs between 6703' and 6712'.

30/7a-2

NNTp4 10,100 - 10,140'	Generally massive pelagic chalk with clay-filled *Chondrites* and some units with indistinct Planolites. One rare floatstone unit at 10,120' (possible debris flow). *Zoophycos* more common towards base of unit.
NNTp4 10,140 - 10,161'	Top marked by sharp contact and a thin layer showing intersecting fractures and possible incipient break-up. This is probably a chalk hardground or firmground. Below, the succession is a Planolites, Zoophycos and, locally, *Chondrites* chalk, essentially pelagic in origin and with no signs of re-sedimentation. There is a minor log peak on the sonic possibly corresponding with the hardground.
NNTp4/NNTp3 10,161 - 10,253'	The unit is capped by a prominent set of undulose clay seams with relic lenticles of chalk. The bulk of the unit consists of *Zoophycos* chalk with local units rich in *Chondrites*, *Planolites* and ?*Thalassinoides*. Dark in colour locally and with some well-developed clay seams, this pelagic unit may be slightly more argillaceous than overlying units.
10,253 - 10,379'	GAP between Cores 5 and 6.
UC 20 10,379 - 10,409'	Massive chalk floatstone with abundant skeletal debris as well as chalk clasts all set in a chalk matrix. There is a downward increase in the diameter of chalk clasts and towards the base large skeletal fragments are visible including solitary corals. The base of the unit is marked by a thin but distinctive graded grainstone. The whole unit probably represents one catastrophically introduced deposit. Slope instability (possibly triggered by earthquake shock) caused pre-deposited carbonate sediment to begin its downslope movement. Coarser skeletal material moved swiftly downslope and formed an organised turbidity current. More consolidated material slipped more slowly as a disorganised debris flow. This unit has a distinctive low density character on the wireline log.
UC 20 10,409 - 10,448'	*Planolites*, *Chondrites* and *Zoophycos* chalk with occasional clay seams (all exaggerated by pressure dissolution). This is a pelagic interval.
UC 20 10,448 - 10,471'	*Chondrites* chalk with rarer *Planolites* and *Zoophycos*, it is differentiated from the overlying unit because of the paucity of clay seams. It is a pelagic unit.
UC 20 10,471 - 10,489'	Mostly pelagic chalk with *Chondrites*, but with discrete re-sedimented units: a thin turbidite penetrated by *Chondrites* at the top (at 10,471'-10,472'); a grainstone turbidite (at 10,476'); and deformed slump beds (at 10,477', and 10,478').
UC 20 10, 489 - 10,510'	At the top is a chalk floatstone unit with a thin graded grainstone at its base (at 10,499'6"), essentially a turbidite/debris flow couplet as described for the 10,379 - 10,409 interval, but with no skeletal debris in the matrix. Below this

	there is a slump-deformed layer and the rest of the unit is chalk floatstones with their tops penetrated by *Chondrites*.
UC 20 10.510 - 10,547'	Mostly Chondrites, Planolites and, rarer, Zoophycos chalks (pelagic) but with a discrete thin turbiditic grainstone at 10,536'6" and a thin slump at 10,524'.
UC 20 10,547 - 10,552'	Chalk floatstone with skeletal and chalk clasts set in a chalk matrix. Silicified overfolds occur at 10,550'. The base is marked by a thin grainy turbiditic wackestone.
UC 20 10,552 - 10,583'	Pelagic succession of *Chondrites* chalks with locally intense stylolite seams. A rare slump band occurs at 10,566'.
UC 20 10,583 - 10,592'	Debris flow unit with a coarser and more densely packed chalk wackestone turbidite at the base and a floatstone unit which becomes progressively more sparse with respect to clasts upwards.
UC 20 10,592 - 10,600'	Pelagic chalks with *Zoophycos* and *Chondrites*.
10,600 - 10,610'	GAP in Cored Section
UC 20 10,610 - 10,722'	Predominantly pelagic chalks with *Chondrites* and *Planolites* but with irregularly spaced interbeds of turbiditic grainstones (some very coarse, as at 10,680') and minor slump beds. Some parts of the succession consist of massive structureless chalk and it is not possible to tell whether these are pelagic or slurry deposits.
10,722 - 10,730'	GAP in Cored Section
UC 20 10,730 - 10,743'	Mostly massive chalks with rare burrows, some distinct and clay-filled. Probably a pelagic unit in large part.
UC 20 10,743 - 10,758"	Chalk floatstone with cm-scale chalk clasts and large (very coarse) skeletal clasts, deposited as a debris flow. The chalk clasts become sparser and there is an upward gradation to massive chalk. The top of the unit is taken at a significant stylolite.
UC 20/UC 19 10,758 - 10,848'6"	Predominantly pelagic chalks with Planolites, occasional Zoophycos and rarer Chondrites. Grainstone turbidites and micro-turbidites occur sporadically, as do minor slumped intervals.
10,848'6" - 11,995'	GAP in Cored Section
UC 10 11,995 - 12,055'	Essentially pelagic chalks with Zoophycos, Chondrites and Planolites. Zoophycos is locally so intense that it gives an apparent banding (pseudo-banding). Occasional flint nodules explain peaks on the sonic log corresponding with 11,997', 12,004', 12,008 - 09', and 12,019'. Possible turbidites occur at 12,001' and 12,009' but these are very cryptic and locally silicified.

31/26a-10

UC 20 8379 - 8404'	Essentially pelagic chalk mudstones with occasional flints towards the base of the unit. Burrows dominated bt *Planolites* and *Chondrites* with occasional intervals containing *Zoophycos*. Stylolites common. At 8404' is a shear-deformed (water-escape?) layer exhibiting a disrupted fabric now replaced by silica. This unusual band provides the only evidence that there may be a break at this depth.
UC 20 8404 - 8477'	Essentially pelagic chalk mudstones with occasional flints t. Burrows dominated bt *Planolites* and *Chondrites* with occasional intervals containing *Zoophycos* . Rare vertical burrows are also present. Stylolites common.
UC 20 8477 - 8484'	Deformed upper layers (?slumped) of chalk wackestone overlying a *Chondrites* (pelagic) chalk.
8484 - 8562'	LARGE GAP BETWEEN CORE 1 and CORE 2
UC 20/UC 19 8562 - 8569' (Base)	Slump-deformed chalk wackestones with disrupted *Planolites* burrows (slump-overfolds) associated with possible skeletal- and chalk-clast debris flow band at the base of the core.

4 BIOSTRATIGRAPHY

4.1 Introduction

4.1.1 Aim of the study:

To synthesise the biostratigraphic database available from the Chalk succession around the Central Graben "triple junction" (Norway, Denmark, U.K.) and to utilise this data to provide a chronostratigraphic framework for the sedimentation and structural development of the area.

4.1.2 Scope of the study:

The study divides into three discrete sections as follows:

1. The interpretation of new analyses to be carried out on selected samples.
2. The digital plotting of old biostratigraphic data into a unified format.
3. The interpretation and integration of both the above sets of data.

4.1.3 Database:

Biostratigraphic analyses of more than 4000 samples are included in the project database, as shown in **Table 4-1** below.

Well name	Existing data				New data this project			
	Nanno-plankton	Micro-palaeont	Palyno-morph	Total existing analyses	Nanno-plankton	Micro-palaeont	Palyno-morph	Total new analyses
1/3-1		14		14	20 dc			20
1/3-8	40	50		90	20 dc			20
1/9-1	25	133		158	18 c / 23 dc	5		46
2/2-2				0	13 dc		2 dc	15
2/2-3	50	50		100	14 dc		1 dc	15
2/4-A-8	48			48				
2/4-B-19	25	4		29	32 dc	3		35
2/4-B-19A/T2	129			129				
2/5-1	226	350		576	15 c / 13 dc	3c /ts		31
2/5-7	26	50		76	3	3		6
2/5-9	40	50		90				
2/7-2		200		200	4 c / 14 dc			18
2/7-4	63	59		122	7c			7
2/7-8	70	70		140	9 dc		1dc	10
2/7-15	125	103		228	33 dc		2 dc	35
2/7-30	84	33	33	150	19 dc			19
2/7-B-11	61	135		196	28 c			28

2/8-A-1	40	30	18	88				
2/11-A-2	25	31	9	65	2			2
2/11-A-2/T2	22	35	10	67	2	2		4
2/11-A-2/T3	37	56	10	103	3	3		6
MFB-7				0	74 c			74
M-9X		100		100	14 c			14
Roar-2		100		100	11c			11
Roar 2A	14	100		114				
Baron-2				0	41	21 ts	4	66
Lulu-1		100		100	24 c			24
Mona-1				0	129			129
T-1		10		10				
E-4X		100		100				
Adda-2		100		100				
Adda-3		10	35	35				
Bo-1		100		100				
UK 30/7a-2		100		100	67			67
UK 31/26a-10				0	15 c / 18 dc			33
TOTAL				3540	676	40	10	726

dc = ditch cutting c = core sample ts = thin section

Table 4-1: Biostratigraphic sample database for the present study

New Analyses:

Analyses have been carried out on selected samples from thirty-two wells, comprising nineteen in the Norwegian sector, eleven in the Danish sector and two in the U.K. sector of the North Sea Basin.

A total of 726 samples have been analysed comprising:

676 nannoplankton analyses
40 micropalaeontological analyses
10 palynological analyses.

Data re-plotting:

Much of the data available was in the form of old biostratigraphic reports (a total of sixty), some of which were almost thirty years old. These reports also originated from twelve different sources (exploration companies and consulting companies) and therefore existing formats were extremely variable and often of poor quality. It was therefore necessary to collate this database into a uniform format, which in this case was “Stratabugs”, the most accessible biostratigraphy format available within the industry at the present time.

Microfossil distribution data derived from different sources needed to be illustrated separately on the range charts. This application had to be developed during the course of this study.

Codes used to identify the sources of data are as follows:

AGP	=	Agip
AMO	=	Amoco Norway Oil Company/Amoco Houston
BST	=	Biostrat
EPA	=	Edelman, Percival & Associates (for Phillips, Bartlesville)
GEO	=	Geolab
GER	=	Gearhart Geoconsultants
GEU	=	Geus
NPD/NPD-N	=	Norwegian Petroleum Directorate
NSC	=	Network Stratigraphic Consulting Ltd.
PHIL	=	Phillips Petroleum Company Norway/Phillips Bartlesville
PSV	=	Paleoservices Ltd. and Paleo Services Ltd.
RRI	=	Robertson Research International
SIPM	=	Shell International Petroleum Maatschappij
SLB	=	Stratlab
SPT	=	Simon Petroleum Technologies

4.1.4 Data integration and interpretation:

In order to integrate data from the large number of sources available for this project several basic problem areas had to overcome before any interpretive work could be carried out.

i) Taxonomic variations: The age of the reports available meant that there was considerable variation between the report authors as to the taxonomic nomenclature used. It would be impossible to unify the whole of the taxonomy without recourse to the original slide/sample material, however it was decided to update fossil names where the new alternative was obvious (particularly for zonal index markers). Other, less stratigraphically important taxa would be left with their names unaltered.

In order to illustrate the zonal index markers used in this study, both microfaunal and nannofloral, a full list of available illustrations is given as an appendix.

ii) Zonal Schemes: It is extremely important in any study of this nature to use zonal schemes which are widely applicable across the whole region and not focussed on a small geographical area, or a particular producing field. Published zonal schemes, in common usage, were therefore used, these being that defined by King *et al.* (1989) for the microfauna and the recent schemes of Varol (1998) and Burnett *et al.* (1998) for the nannoflora.

Neither of these schemes is perfect for the purposes of this study, as they lack definition at the resolution available over certain stratigraphic intervals. There has been no attempt before this study to calibrate the microfaunal and nannofloral biomarker events, with the exception of the recent work of Bergen & Sikora (1999), which is concentrated on the southern Norwegian Chalk facies around the Valhall area and therefore lacks the wide scale applicability necessary in this study.

In order to increase the resolution of the zonal schemes, subzones have been added to the microfaunal scheme of King *et al.* (*op. cit*) and there has been some modification of the Burnett *et al.* (*op. cit.*) nannofloral scheme. Wherever possible direct comparison has been made between records of microfaunal and nannofloral zonal indices on the basis of occurrences in the same cored sections. Reference has also been made to unpublished research (Bailey *et al.*, in prep.) on the Coniacian to middle Campanian section at Seaford Head, Sussex where fully calibrated nannoplankton and foraminiferid distribution data were available at one metre intervals for the whole section.

Definitions of all zones and subzones used in this study are given in Section 2 of the Biostratigraphy. These are presented in descending order, despite much of the data being derived from cored intervals, as they are based on offshore well sections.
Some commonly used abbreviations have been incorporated into zonal definitions, these are as follows:

LAD - Last appearance datum
FAD - First appearance datum
LDO - Last downhole occurrence
FDO - First downhole occurrence

4.2 Stratigraphic zonations

Biostratigraphic zonation schemes used in this project are presented in **figure 4-1, 4-1b, 4-2** and **4-2b.**

4.2.1 NANNOPLANKTON ZONATION

4.2.1.1 PALEOCENE:

Zone and subzone definitions for the Paleocene broadly follow Varol (1989 & 1998) with reference to Van Heck & Prins (1987) and Perch Nielsen (1979) with minor amendments as discussed below:

Zone NNTp8:

Author: Varol (1998).

Age: Late Paleocene.

Definition: From the FDO (LAD) of common *Chiasmolithus edentulus* to the influx *Prinsius martinii* and/or common *Neochiastozygus perfectus*.

Comments: This zone has been recognised only rarely in the study area. This could be due to a number of factors, including, samples were selected for this chalk study below sediments of this age, non deposition of sediments of this age or sediments of this age are non calcareous and therefore barren of nannoplankton.

Distribution: This zone is recognised in the following well: 2/4-A-8 (below 10,076').

Zone NNTp7:

Author: Varol (1998).

Age: Late Paleocene.

Definition: From the influx *P. martinii* and/or common *N. perfectus* to the FDO (LAD) of common *Prinsius dimorphosus*.

Comments: This zone is only rarely recognised in this study. When recognised, sediments of this age are recovered from the Våle Formation and are characterised by low abundance and low diversity assemblages.

Larger forms of *Prinsius* spp. (including *P. martinii* and *P. bisulcus*) dominate the assemblages.

Distribution: This zone is recognised (undifferentiated) in the following well: 2/4-B-19 (9,760' - 9,775').

Within this zone the following subzones are recognised:

Subzone NNTp7B:

Author: Varol (1998), emended herein.

Age: Late Paleocene.

Definition: From the influx *Prinsius martinii* and common *Neochiastozygus perfectus* to the LDO (FAD) of *Toweius pertusus*.

Comments: Forms of *N. perfectus* recovered from sediments of this age are generally larger than older forms and are characterised by a slender, more elegant, morphology and a very low angle central area 'X'. Forms of *Toweius* spp. are often difficult to speciate in the light microscope in sediments of this age.

Toweius pertusus has been used an alternative for *Toweius selandianus* (Well 2/4-A-8) for the purposes of this study.

Distribution: This subzone is recognised in the following wells: 2/4-A-8 (above 10,090') & 2/7-B-11 (9,812' - 9,832').

Subzone NNTp7A:

Author: Varol (1998), emended herein.

Age: Late Paleocene.

Definition: From the LDO (FAD) of *Toweius pertusus* to the FDO (LAD) of common *Prinsius dimorphosus.*

Comments: Smaller, indeterminate, forms of *Toweius* spp. may still be found in this subzone, therefore making differentiation from the overlying subzone difficult in poorer quality sample material.

Distribution: This subzone is recognised in the following wells: 2/4-A-8 (below 10,100') & BARON-2 (2,820m).

Zone NNTp6:

Author: Varol (1998).

Age: Late Paleocene, "late" Danian to "early" Thanetian for the purposes of this study.

Definition: From the FDO (LAD) of common *P. dimorphosus* to the LDO (FAD) of common *N. perfectus.*

Comments: There is a conspicuous increase in the abundance of *P. dimorphosus* within this subzone, although larger forms such as *P. martinii* still dominate assemblages. Sediments of this age are constrained to the lower part of the Våle Formation in the study area.

Distribution: This zone is recognised in the following wells: 2/4-A-8 (above 10,110'), 2/4B-19 (below 9,780'), 2/4B-19A (below 9,839'), 2/5-7 (below 3,189'), 2/5-9 (3,252m - 3,258m), 2/7-30 (10,260' - 10,290'), 2/7-B-11 (9,840' - 9,843.5'), MFB-7 (7,360' - 7,361') & BARON-2 (2,823.2m - 2,826.3m).

Zone NNTp5:

Author: Varol (1998).

Age: Early Paleocene, informally termed "late" Danian for the purposes of this study.

Definition: From the LDO (FAD) of common *N. perfectus* to the influx of *P. dimorphosus.*

Comments: There is an increase in the abundance and diversity of nannofloral assemblages recovered through this zone, reflecting the increasingly calcareous nature of the sediment from the Våle Formation into the Ekofisk Formation.

Distribution: This zone is not recognised (undifferentiated) in any wells.

Within this zone the following subzones are recognised:

Subzone NNTp5B:

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the LDO (FAD) of common *N. perfectus* to the LDO (FAD) of *N. perfectus.*

Comments: The boundary between the Våle Formation and the Ekofisk Formation falls within this Subzone in the study area. Forms of *N. perfectus* appear smaller and more robust towards the base of their range and may be confused with *Neochiastozygus modestus*. The inception of the genus *Toweius* appears within this Subzone.

Distribution: This subzone is recognised in the following wells: 1/3-8 (3,385m), 2/4-A-8 (10,120' & 10,190'), 2/4B-19 (above 9,818'), 2/4B-19A (above 9,864' and below 9,870'), 2/5-1 (9,970'), 2/5-7 (above 3198m and below 3,189m), 2/7-8 (9,710'), 2/7-15 (below 3,000m and above 3,006m), 2/7-30 (10,300'), MFB-7 (7,362' - 7,362.58'), LULU-1 (9,033' - 9,040') & 30/7a-2 (below 10,101').

Subzone NNTp5A:

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the LDO (FAD) of *N. perfectus* to the influx of *P. dimorphosus.*

Comments: As sediments become less argillaceous downhole within this subzone, nannofloral abundance and diversity increases, together with the proportion of smaller forms of *Prinsius* (i.e. *P. dimorphosus*). *Chiasmolithus edentulus* and *Prinsius martinii* are still major assemblage constituents within this subzone.

Significant amounts of Late Cretaceous reworking are often noted within this subzone.

Distribution: This subzone is recognised in the following wells: 2/4B-19A (above 9,870'), 2/7-4? (10,224') & MFB-7 (7,364').

Zone NNTp4:

Author: Varol (1998).

Age: Early Paleocene, informally termed "late" Danian for the purposes of this study.

Definition: From the influx of *P. dimorphosus* to the LDO (FAD) of *Neochiastozygus eosaepes* and/or the FDO (LAD) of common *Prinsius tenuiculus*.

Comments: This zone occurs extensively throughout the study area and represents the majority of Ekofisk Formation sediments identified in the study area.

The lower part of this Zone (principally Subzones NNTp4C-A) may be characterised by massive re-deposition of Late Cretaceous sediments, forming the primary reservoir within the Ekofisk Formation. Sediments characterised by large scale re-deposition and reworking may be difficult to date due to effect of masking by the allochthonous taxa. As a result rare marker taxa may be difficult to find and abundance criteria becomes unreliable. Therefore, some of the sediment dated as "middle - "early" Danian, Zones NNTp3-2 may in fact be impoverished "late" Danian NNTp4 sediment masked by reworking.

The re-deposited sediments are commonly derived from the Late Maastrichtian, Tor Formation.

Distribution: This zone is recognised (undifferentiated) in the following well: 2/5-7 (3,205m).

Within this zone the following subzones are recognised:

Subzone NNTp4F:

Author: Varol (1998), emended herein.

Age: Early Paleocene.

Definition: From the influx of *P. dimorphosus* to the LDO (FAD) of common *Chiasmolithus edentulus* and/or common *P. martinii*.

Comments: Varol (1998) initially defined the base of this Subzone on the inception of *Chiasmolithus edentulus*. However, forms of *C. edentulus* are consistently recorded lower in the Danian and it is proposed that the LDO (FO) of common *C. edentulus* and *P. martinii* are events of better correlative utility within the study area.

Once again, Late Cretaceous reworking may be noted in the upper part of this Subzone. Sparse evidence for reworking of "middle - early" Danian age sediments may also be recorded in this subzone, particularly in the Eldfisk and Ekofisk fields, and primarily in the form of *Hornibrookina edwardsii* and *Prinsius tenuiculus*.

Distribution: This subzone is recognised in the following wells: 1/3-8 (below 3,400m), 1/9-1 (3,049.17m & 3,054.43m), 2/5-1 (below 10,005'), 2/5-9 (3,267m), 2/7-4 (10,231' - 10,261'), ?2/7-8 (9,730'), 2/7-15 (above 3,006m), MFB-7 (7,370.75') & 31/26a-10 (below 8,290').

<u>Subzone NNTp4E:</u>

Author: Varol (1998), emended herein.

Age: Early Paleocene.

Definition: From the LDO (FAD) of common *C. edentulus* and/or common *P. martinii* to the FDO of common *Neochiastozygus saepes* and/or *N. eosaepes.*

Comments: Assemblages throughout this interval may be characterised by low diversity and low abundance, dominated by *Thoracosphaera* spp. together with *Coccolithus pelagicus* and *Chiasmolithus inconspicuus*. Forms of *Neochiastozygus* spp. occur only rarely in this subzone (the informally termed *Neochiastozygus* “crisis”).

Rare evidence for reworking of "middle - early" Danian age sediments may be recorded herein, but Late Cretaceous reworking is reduced in comparison to other subzones.

Distribution: This subzone is recognised in the following wells: 1/3-1 (10,800' & 10,850'), 1/3-8 (above 3,430m), 2/4B-19A (9,870'), 2/7-4 (below 10,277'), 2/7-15 (below 3,011.42m), 2/7-30 (below 10,314'), 2/7-B-11 (below 9,852'), MFB-7 (7,377.58' - 7,389.19'), BARON-2 (2,838.2m - 2,851.8m), LULU-1 (9,050' - 9,116') & 30/7a-2 (above 10,140').

<u>Subzone NNTp4D:</u>

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the FDO of common *N. saepes* and/or *N. eosaepes* to the LDO (FAD) of *N. saepes* and/or *E. macellus*.

Comments: Nannofloral abundance and diversity is improved in this subzone relative to the overlying subzone. Forms of *Neochiastozygus*, particularly *N. saepes* become conspicuous assemblage constituents.

Distribution: This subzone is recognised in the following wells: 1/3-1 (10,850' - 10,950'), 1/3-8 (3,442m), 1/9-1 (3,060.56m & 3,066.88m), 2/4-A-8 (10,210' - 10,330'), 2/5-1 (above 10,082'), 2/7-4 (above 10,365'), 2/7-15 (above 3,014m), 2/7-B-11 (above 9,929'), MFB-7 (7,402.16' - 7,431.66'), LULU-1 (9,230' - 9,270'), 30/7a-2 (10,142' - 10,202') & 31/26a-10 (8,330').

Subzone NNTp4C:

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the LDO (FAD) of *N. saepes* and/or *E. macellus* to the LDO (FAD) of *P. martinii*.

Comments: *E. macellus* occurs very rarely within the study area, the inception of *N. saepes* is therefore a more reliable event regionally. The abundance of *Ericsonia* spp. may be seen to increase within this subzone.

Subzones NNTp4B and NNTp4C may be difficult to identify in ditch cuttings samples due to their reliance on inception events.

Overlying subzones within Zone NNTp4 are characterised by predominantly pelagic, autochthonous deposition, large scale Late Cretaceous reworking characterise this and the underlying subzones.

Distribution: This subzone is recognised in the following wells: 1/3-1 (11,000' & 11,050'), 1/9-1 (3,071.30m), 2/5-1 (10,088' - 10,200'), 2/5-9 (3,276m - 3,294m), 2/7-4 (10,368' - 10,369'), ?2/7-8 (9,810' - 9,870'), 2/7-30 (above 10,363'), 2/7-B-11 (below 9,943.5') & 31/26a-10 (8,350').

Subzone NNTp4B:

Author: Varol (1998).

Age: Early Paleocene.
Definition: From the LDO (FAD) of *P. martinii* to the LDO of *Neochiastozygus modestus.*

Comments: Large scale Late Cretaceous reworking is commonly recorded within this subzone, particularly on the Ekofisk Field structure.

Specimens of *N. modestus* have been recovered from more pelagic, autochthonous, horizons identified within and above re-deposited slumps derived from the Tor Formation and, therefore, prove that a major episode of slumping and re-deposition occurred within the North Sea Basin within this subzone.

Distribution: This subzone is recognised in the following wells: 1/9-1 (3,071.30m & 3,073.95m), 2/4B-19A (9,897' - 10,112'), 2/5-1 (10,216' - 10,248'), 2/5-9m (3,300m - 3,375m), 2/7-30 (10,372' - 10,523'), 2/7-B-11 (above 9,961.5'), BARON-2 (2,858.75m) & ROAR-2A (6,660'?).

Subzone NNTp4A:

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the LDO of *N. modestus* to the LDO (FAD) of *Neochiastozygus eosaepes* and/or the FDO (LAD) of common *Prinsius tenuiculus*.

Comments: This subzone may be difficult to identify in ditch cuttings samples as it relies on the recognition of inception events in sediment dominated by reworked Late Cretaceous material.

Distribution: This subzone is recognised in the following wells: 1/3-8 (3,445m), 2/4B-19A (10,117' - 10,134'), MFB-7 (7,440' - 7,451.58') & 30/7a-2 (10,214' - 10,226').

Zone NNTp3:

Author: Varol (1998).

Age: Early Paleocene, informally termed "middle" Danian for the purposes of this study.

Definition: From the LDO (FAD) of *N. eosaepes* and/or the FDO (LAD) of common *P. tenuiculus* to the FDO (LAD) of *Hornibrookina edwardsii*.

Comments: This distinctive zone is commonly observed in the Danish sector and on the Eldfisk Bravo structure in this study, but is typically absent on structural highs within the Norwegian sector of the study area such as the Ekofisk and Eldfisk Alpha fields.

Distribution: This zone is recognised in the following wells: 1/3-8 (3,460m), 2/4B-19 (below 10,179.50'), 2/7-4 (10,415'), 2/7-30 (10,568' -10,572.8'), 2/7-B-11 (9,978.5' - 9,989'), M-9X (6,545'), BARON-2 (2,860m - 2,867.6m), ROAR-2 (6,640' - 6,650'), ?ROAR-2A (6,680' - 6,720'), LULU-1 (9,280' - 9,300') & 30-7A-2 (10,238.16' - 10,250').

Zone NNTp2:

Author: Varol (1998).

Age: Early Paleocene, informally termed "early" Danian for the purposes of this study.

Definition: From the FDO (LAD) of *H. edwardsii* to the LDO (FAD) of *Cruciplacolithus primus*.

Comments: Sediments of "early" Danian age are well developed in the Danish section of the study area. Sediments of this age are rare on structural highs within the Norwegian section of the study area and where identified are complicated by reworked Late Cretaceous sediments. (*N.B.* these could in fact represent impoverished NNTp4 sediments - see discussion above).

The reliance on inception events for many of the subzones within this zone, Late Cretaceous reworking and a somewhat weaker database due to the paucity of sediments of this age within the study area, make sub-zonal attributions difficult within sediments of this age.

Distribution: This zone is not recognised (undifferentiated) in the wells.

Within this zone the following subzones are recognised:

Subzone NNTp2G:

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the FDO (LAD) of *H. edwardsii* to the LDO (FAD) of common *P. tenuiculus*.

Comments: The co-occurrence of moderately common *P. tenuiculus* and *H. edwardsii* enables this subzone to be readily identified in the study material.

The occurrence of smaller, sub-circular, forms of *P. dimorphosus* (perhaps confused with *P. tenuiculus*) in the "early" Danian may hinder positive identification of this and underlying subzones.

Distribution: This subzone is recognised in the following wells: 1/9-1 (3,080.69m - 3,094m), 2/4B-19 (above 10,179.50'?), 2/7-30 (10,578'), 2/7-B-11 (9,996.5' - 9,999'), MFB-7 (7,460' - 7,467.42'), BARON-2 (2,873.1m - 2,885.6m) & ROAR-2 (below 6,660').

Subzone NNTp2F:

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the LDO (FAD) of common *P. tenuiculus* to the LDO (FAD) of *Chiasmolithus danicus* and/or *H. edwardsii*.

Comments: The record of *H. edwardsii*, in association with *C. danicus*, in the absence of *P. tenuiculus* makes this subzone readily identifiable where sampled.

Distribution: This subzone is recognised in the following wells: 2/4-A-8 (below 10,340'), 2/5-9 (3,381m), 2/7-4 (below 10,421'), 2/7-15 (below 3,014m), 2/7-30 (10,578'), M-9X (6,550'), ROAR-2 (above 6,690') & LULU-1 (below 9,310').

Subzone NNTp2E:

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the LDO (FAD) of *C. danicus* and/or *H. edwardsii* to the LDO (FAD) of common *P. dimorphosus*.

Comments: Assemblages containing common *P. dimorphosus* (often smaller and more sub-circular in outline than in younger sediment) and no other younger marker species are assigned to this subzone.

Distribution: This subzone is recognised in the following wells: 1/9-1 (3,096.70m), 2/4-A-8 (above 10,354' and 10,510' & 10,520'), 2/4B-19A (10,207' & 10,209'), 2/5-7 (3,267m - 3,284m), 2/7-4 (above 10,429'), ?2/7-8 (9,880' - 9,920'), BARON-2 (2,885.9m - 2,886.3m), ROAR-2 (6,700' - 6,740') & LULU-1 (above 9,330').

Subzone NNTp2D:

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the LDO (FAD) of common *P. dimorphosus* to the LDO (FAD) of *P. dimorphosus*.

Comments: This is commonly the oldest positively dated subzone in the study area. The record of rare *P. dimorphosus* in very low diversity assemblages is recorded within or just below (in the Ekofisk Tight Zone) the major unit of reworking.

Distribution: This subzone is recognised in the following wells: 1/9-1 (below 3,100.62m), 2/4-A-8 (10,529.80' - 10,564'), 2/4B-19 (10,179.50' - 10,209.42'), 2/4B-19A (10,211' - 10,239'), 2/5-7 (3,294m - 3,345m), 2/7-15 (above 3,038m), 2/7-30 (below 10,584'), BARON-2 (2,886.6m - 2,887.4m) & LULU-1 (9,340').

Subzone NNTp2C:

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the LDO (FAD) of *P. dimorphosus* to the LDO (FAD) of *Coccolithus pelagicus.*

Comments: Rarely positively identified, the recognition of this subzone may be a function of poorly preserved, low diversity associations masked by reworking in some cases, although where recorded within the Ekofisk Tight Zone it is more likely to reflect pelagic deposition of "early" Danian age.

Distribution: This subzone is recognised in the following wells: 1/3-8 (3,472m - 3,484m), 1/9-1 (above 3,101.50m) & 2/7-30 (above 10,608').

Subzone NNTp2B:

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the LDO (FAD) of *C. pelagicus* to the LDO (FAD) of *Cruciplacolithus intermedius*.

Comments: Rarely positively identified, the recognition of this subzone may be a function of poorly preserved, low diversity associations masked by reworking.

Distribution: This subzone is recognised in the following well: 2/7-4 (10,435').

<u>Subzone NNTp2A:</u>

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the LDO (FAD) of *C. intermedius* to the LDO (FAD) of *C. primus*.

Comments: Very rarely positively identified, the recognition of this subzone may be a function of poorly preserved, low diversity associations masked by reworking.
Distribution: This subzone is recognised in the following well: 2/4B-19A (10,241' - 10,274').

<u>Zone NNTp1:</u>

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the LDO (FAD) of *C. primus* to the FDO (LAD) of *in situ* Late Cretaceous restricted species.

Comments: Assemblages recovered from sediments assigned to this zone are characterised by impoverished records dominated by *Thoracosphaera* spp., *Neocrepidolithus* spp. and *Biscutum* spp.

It was not possible to differentiate between Subzones NNTp1B and NNTp1A as defined by Varol (1998) during this study.

Distribution: This zone is recognised (undifferentiated) in the following wells: 2/4B-19 (10,216'?), 2/5-1 (10,252'?), 2/5-7 (3,346.5m - 3,347.5m), 2/7-4 (10,445' - 10,451.5') & LULU-1 (9,350'? - 9,358'?).

Within this zone the following subzones are recognised:

<u>Subzone NNTp1B:</u>

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the LDO (FAD) of *C. primus* to the LDO (FAD) of *Placozygus sigmoides*.

Comments: This subzone was not differentiated in the present study.

<u>Subzone NNTp1A:</u>

Author: Varol (1998).

Age: Early Paleocene.

Definition: From the LDO (FAD) of *Placozygus sigmoides* to the FDO (LAD) of *in situ* Late Cretaceous restricted species.

Comments: This subzone was not differentiated in the present study.

N.B. Sediments attributed to Zone NNTp1 have been identified at the base of the Ekofisk Formation both in this study and by numerous previous workers. Sediments assigned to Zone NNTp1 and the lower part of Zone NNTp2 appear to be coincident with the more argillaceous section (reflected by the higher gamma ray signatures of the Ekofisk Tight Zone) at the base of the Ekofisk Formation.

However, data generated during a detailed study of the Ekofisk structure reveals the occurrence of Paleocene restricted taxa within sediments previously identified as Late Maastrichtian age Tor Formation *below* the distinctive high gamma ray signatures and argillaceous limestones of the Ekofisk Tight Zone at the base of the Ekofisk Formation. These occurrences appear restricted to the northern part of the Ekofisk field.

The impoverished nature of sediments assigned to this Zone NNTp1 may be facies related and sediments attributable to Zone NNTp2 may occur below them, although complicated by reworking. (c.f. Elle Member described by Sikora *et al.* (1999).

A conglomeratic "lag" deposit may also be recorded at the base of the Ekofisk Formation, representing reworking and bioturbation between the Ekofisk and Tor Formations.

4.2.1.2 LATE CRETACEOUS:

Zone and subzone definitions for the Late Cretaceous broadly follow Burnett *et al.* 1998 with amendments as discussed below:

<u>Zone UC20:</u>

Author: Equivalent to Zone CC26 of Sissingh 1977.

Age: Late Maastrichtian ("latest" Maastrichtian)

Definition: From the FDO (LAD) of Late Cretaceous restricted taxa including common *Arkhangelskiella cymbiformis* and *Micula staurophora* to the LDO (FAD) of *Nephrolithus frequens*.

Comments: This zone has been emended for use in the North Sea Basin due to the paucity of *Lithraphidites quadratus* regionally.

This zone has been recognised in most of the wells studied. It is represented in some wells (indeed discrete areas) as thin laminated autochthonous, pelagic sediments (typically <5m thick) yielding diverse and well preserved assemblages (perhaps more distal to flows or on structural highs). More commonly it is represented as a thick allochthonous deposit (tens of metres thick) characterised by low diversity, poorly preserved assemblages dominated by more robust forms such as *M. staurophora, Lucianorhabdus cayeuxii, Prediscosphaera cretacea* and *A. cymbiformis* (perhaps more proximal to source and in basinal areas?). Evidence for intra Maastrichtian reworking within these allochthonous deposits can be seen in the rare occurrence of taxa characteristic of older zones such as *Gartnerago obliquum, Seribiscutum primitivum* (Zone UC19) and *Reinhardtites levis* (Zone UC18) within this zone. This zone is equivalent to Zones NK1 and NK2 of Mortimer (1987), but cannot be accurately calibrated to Zones KN1-4 of Bergen & Sikora (1999). Principally this is because the Bergen (1999) interpretation suggests that *N. frequens* ranges below the FDO (LAD) of *G. obliquum* and *S. primitivum* on the Valhall structure and may range into the Early Maastrichtian immediately to the North and East of the Valhall Field. Bergen & Sikora (1999) attributes this to diachronism in the range of *N. frequens* and to a preference for high latitudes. The results from this study, however, suggest no such pattern within this area other than within re-deposited sediments. The co-occurrence of *N. frequens* with *G. obliquum* and *S. primitivum* on the Valhall Field is related to reworking of Zone UC19 (or older) sediment into Zone UC20 sediment. The co-occurrence of *N. frequens* and *R. levis* observed by Bergen & Sikora (1999) to the North East of Valhall appears attributable to reworking of Zone UC18 (or older) sediment, a feature also seen to the South of Valhall (Gallagher & Hampton, herein).

In areas outside of the tectonic control of the Central Graben, the ranges of these taxa do not overlap (i.e. Western Approaches, Burnett *et al*. 1998). Gallagher & Hampton, herein suggest this overlap occurs primarily on the eastern flank of Valhall.

Distribution: This Zone has been recognised (undifferentiated) in the following well: 2/7-B-11 (10,060').

Within this Zone the following subzones are recognised:

Subzone UC20"iii":

Author: Equivalent to Zone NK1, Mortimer (1987).

Definition: From the FDO (LAD) of Late Cretaceous restricted taxa including *Arkhangelskiella cymbiformis* and *Micula staurophora* to the FDO (LAD) of *Nephrolithus frequens* and *Cribrosphaera daniae*.

Comments: This subzone is equivalent to Zone NK1 Mortimer (1987) and Zone KN1 Bergen & Sikora (1999). Assemblages recovered from the top of the Tor Formation (Late Maastrichtian age) are typically characterised by low diversity and poor preservation possibly related to re-crystallisation or hardground development at the top of the Tor Formation.

An alternative explanation is provided by Bergen & Sikora (1999) for the absence of *N. frequens* and *C. daniae*. It is attributed to a short period of climatic warming immediately prior to the end of the Cretaceous.

Distribution: This subzone is recognised in the following wells: 1/3-8 (3,940m), 2/4B-19A (10,920'), 2/2-3 (3,105m - 3,120m), 2/5-1 (10,290' & 10,294.50'), 2/5-7 (3,348.25m), 2/11A-2 T3 (3,372m), M-9X (6,553.6'), ROAR-2 (6,745' & 6,750'), BO-1 (6,787') and 30/7a-2 (10384.33').

Subzone UC20"ii":

Author: Gallagher & Hampton, herein.

Definition: From the FDO (LAD) of *N. frequens* and *C. daniae* to the LDO (FAD) of *C. daniae.*

Comments: Where present this subzone is typically characterised by diverse, moderately well to well preserved assemblages, often containing common to abundant *Lithraphidites* specimens and may reflect primarily autochthonous, pelagic deposition within the Late Maastrichtian.

Incredibly, the LDO (FAD) of *C. daniae* has not been employed as a subzonal index by Bergen & Sikora (1999) or other authors within the North Sea Basin, but was utilised by Burnett *et al*. (1998) to otherwise subdivide Zone UC20.

Distribution: This subzone has been recognised in the following wells: 1/3-1(11,100' - 11,150'), 1/9-1 (3,104m - 3107.5m), 2/4-A-8 (10,569' - 10,670'), 2/4B-19 (10,316'), 2/5-1 (10,301' - 10,496'), 2/5-9 (3,384m), 2/7-4 (10,455' - 10,473'), 2/7-30 (10,620' - 10,668'), 30/7-A2 (10,391' - 10,457.16'), 31/26-A10 (8,370' - 8,381.5'), MFB-7 (7,467.84' - 7,490'), M-9X (6,566' - 6,587'), ROAR-2A (6,739' - 6,773'), MONA-1 (10,310' - 10,410' and 10,420'? - 10,506'?) & 31/26a-10 (8,370' - 8,381.50').

Subzone UC20"i":

Author: Equivalent to Zone NK2 Mortimer (1987).

Definition: From the LDO (FAD) of *C. daniae* to the LDO (FAD) of *N. frequens*.

Comments: Despite the reliance of this subzone on LDO events it has been found to have particular utility when biosteering horizontal wells. LDO events are useful when the well bore is climbing up section stratigraphically, where for example the occurrence of *N. frequens* may indicate proximity to the over-pressured Lista Formation (*i.e.* Valhall Field) or penetration of the chert rich lower Ekofisk Formation (*i.e*. Ekofisk Field).

This subzone (and overlying subzones) are characterised by large morphotypes of *A. cymbiformis* (equivalent to *Arkhangelskiella maastrichtiana* of Burnett *et al*. 1998).

Distribution: This subzone is recognised in the following wells: 1/3-8 (3,496m - 3,520m), 1/9-1 (3110.5m - 3,173.13m), 2/4-A-8 (10,680' - 10,740'), 2/4B-19 (10,318' - 10,366'), 2/4B-

19A (10,292.5’ - 10,416.20’), 2/5-1 (10,516’ - 10,800’), 2/5-7 (3414.5m), 2/7-2 (9,880' - 9,950'), 2/7-4 (10,478’ - 10,580’ and 10,605'? - 10,699'?), 2/7-30 (10,679’ - 10,748’), 2/11-A2 T3 (3,378m & 3,384m), MFB-7 (7,540’ - 7,910’), M-9X (6,595’ - 6,702.75’), ROAR-2 (6,762’ - 6,780’), BO-1 (6,782’) and 31/26-A10 (8,400’ - 8,562’), 30/7-A2 (10,469’ - 10,808’) & MONA-1 (10,516’ – 10,785.66’).

Zone UC19:

Author: Burnett *et al.* 1998, emended herein

Age: Late Maastrichtian

Definition: From the LDO (FAD) of *N. frequens* to the FDO (LAD) of *Reinhardtites levis.*

Comments: Thick allochthonous sequences of this age have been recognised within the study area (particularly on the Eldfisk field and the MONA-1 well in Denmark), but it is commonly represented as a pelagic chalk with little reworking.

Distribution: This zone is recognised (undifferentiated) in the following wells: 2/7-30 (10,770') & 31/26a-10 (8,565'? - 8,600'?).

Within this Zone the following subzones are recognised:

Subzone UC19"iii":

Author: Equivalent to Zone NK3 of Mortimer (1987).

Definition: From the LDO (FAD) of *N. frequens* to the FDO (LAD) of *Seribiscutum primitivum* and/or *Gartnerago obliquum*.

Comments: This subzone is occasionally absent in the study area due to disconformities (e.g. Well 1/3-8 and Well 1/9-1) and may be difficult to identify due to reworking. Despite questions raised by many workers as to the validity of this subzone, it appears present and recognisable in core material and therefore of utility in this study area. This subzone is often the first subzone recognised upon penetration of the Tor Formation due to erosion or non-deposition of younger Late Maastrichtian sediments (particularly on parts of the Eldfisk Field).

Assemblages recovered from this subzone may appear similar to assemblages from Subzone UC20"iii". Subzone UC20"iii" assemblages, however, differ in the presence of common A. *maastrichtiana* (large *A. cymbiformis* morphotypes).

Extremely low diversity assemblages dominated by *M. staurophora* may be recorded within this subzone.

Distribution: This Subzone has been recognised in the following wells: 2/4B-19 (above 10,800'), 2/5-1 (10,808' - 10,990'), 2/7-B-11 (10,081' - 10,106'), 2/8-A-1 (2,478m) & ROAR-2 (6,800'? - 6,885’?).

Subzone UC19"ii":

Author: Equivalent to Zone NK4 of Mortimer (1987).

Definition: From the FDO (LAD) of *S. primitivum* and/or *G. obliquum* to the FDO (LAD) of *Zeugrhabdotus compactus* and/or *Calculites obscurus*. The unpublished *S. primitivum* Zone of R.R.I (1988 onwards) is equivalent to this subzone as is Zone KN4 of Bergen & Sikora (1999).

Comments: Large forms of *S. primitivum* (*B. magnum* or *S. primitivum grandis* of other authors) are conspicuous, but not necessarily common, in this subzone.

Distribution: This subzone has been recognised in the following wells: 1/3-1 (11,350', 12,300' & 12,340'), 1/3-8 (3,525m), 1/9-1 (3,184.32m - 3,288m), 2/4-A-8 (10,750' & 10,760'), 2/4B-19 (10,860' & 10,920'), 2/4B-19A (10,523' - 10,551'), 2/5-1 (below 11,050'), 2/5-9 (3,396m - 3,582m), 2/7-2 (10,000' - 10,130'), 2/7-4 (10,708'), 2/7-B-11 (below 10,117.50'), 2/8-A-1 (2,478.50m & 2,478.62m), MFB-7 (7,960' - 7,979.08'), MONA-1 (below 10,796'), BO-1 (6,812') & 30/7a-2 (10,820' - 10,847').

Subzone UC19"i":

Author: Equivalent to Zone NK5 of Mortimer (1987).

Definition: From the FDO (LAD) of *Z. compactus* and/or *C. obscurus* to the FDO (LAD) of *Reinhardtites levis*.

Comments: The FDO of *Z. compactus* (*Z. bicresenticus* of other workers) has proven to be a more reliable event than the FDO of *C. obscurus*, which occurs only very rarely and sporadically throughout the study area in this subzone.

Distribution: This Subzone has been recognised in the following wells: 2/4B-19 (10,980' - 11,100'), 2/5-1 (above 11,190'), 2/7-B-11 (above 10,380') & MONA-1 (above 10,930').

Zone UC18:

Author: Equivalent to Zone CC24 of Sissingh (1977) and Zone NK6 of Mortimer (1987).

Age: Early Maastrichtian.

Definition: From the FDO (LAD) of *R. levis* to the FDO (LAD) of *T. orionatus*.

Comments: The occurrence of *C. obscurus* appears more consistent within this zone and *R. levis* may become more conspicuous within it allowing sub-division (e.g. on the Valhall Field).

Specimens of *A. cymbiformis* show a general decreasing size trend within, and below, this Zone.

Distribution: This Subzone has been recognised in the following wells: 1/3-1 (12,430' & 12,480'), 1/3-8 (3,919m), 2/4B-19 (11,190' - 11,310'), 2/5-1 (11,200' - 11,440' and older), 2/5-7 (3,560m - 3,585m), 2/7-8 (9,950' - 10,050'), 2/7-30 (10,800' - 10,890'), 2/7-B-11 (10,390.50' - 10,408.50'), 2/8-A-1 (2,4783.62m - 2,487.42m), 2/11-A2 T3 (3,390m), MONA-1 (10,935' - 11,105.50') & BO-1 (below 6,827').

Zone UC17:

Author: Equivalent to Subzone CC23b of Sissingh (1977), and Zone NK7 of Mortimer (1987).

Age: Early Maastrichtian.

Definition: From the FDO (LAD) of *T. orionatus* to the FDO (LAD) of *Broinsonia parca constricta.*

Comments: This Zone has proven difficult to identify in the study area due to widespread disconformities and the very rare occurrence of *T. orionatus* (*T. phacelosus* of other workers).

Distribution: This zone has been recognised in the following wells: 1/3-1 (12,480' & 12,510') & 2/5-9 (3,584m - 3,726m or older).

Zone UC16:

Author: Equivalent to Subzone CC20b of Sissingh (1977) and Zones KN8-13 of Bergen & Sikora (1999).

Age: Late Campanian (current recommendation from the International Stage Boundary Subcommission).

Definition: From the FDO (LAD) of *B. parca constricta* to the FDO (LAD) of *Eiffellithus eximius*.

Comments: The boundary between the Tor and Magne Formations falls within the upper part of this Zone.

In some wells reworking of sediments (possibly from Zone UC11 or older) was observed in the upper part of this zone, (*i.e. E. eximius* and *H. trabeculatus*) within the lower part of the Tor Formation.

Distribution: This zone has been recognised (undifferentiated) in the following wells: 1/3-1 (12,510' & 12,550'), 2/5-7 (3,608m - 3,657m) & MONA-1 (above 11,116' - 11,204').

Within this Zone the following subzones are recognised:

Subzone UC16"iii":

Author: Equivalent to Subzone CC23a of Sissingh (1977) and Zones KN8-10 of Bergen & Sikora, 1999.

Age: Late Campanian.

Definition: From the FDO (LAD) of *B. parca constricta* to the FDO (LAD) of *Reinhardtites anthophorus*.

Comments: The FDO (LAD) of *B. parca constricta* is essentially coincident with the inception of the ammonite *Pachydiscus neubergicus* (Burnett, Hancock *et al*. 1992). The International Stage Boundaries Sub-Commission recommends this ammonite event as the defining criterion for the Campanian/Maastrichtian boundary. This definition (pending confirmation) is adopted in this study.

Within this subzone the abundance of *R. levis* is seen to increase. Very rare specimens of *Quadrum* sp. (c.f. *Q. gothicum/gartneri*?) may also be observed within this subzone. Occasional reworking of older sediments, principally in the form of *E. eximius* and *H. trabeculatus* may be observed in this subzone.

Distribution: This subzone has been recognised in the following wells: 1/3-8 (3,940m), 2/5-9 (3,741m - 3,772m), 2/7-15 (3,042m & 3,045m), 2/7-30 (10,920') & 2/11-A2 T3 (3,402m).

<u>Subzone UC16"ii":</u>

Author: Gallagher & Hampton, herein.

Age: Late Campanian.

Definition: From the FDO (LAD) of *Reinhardtites anthophorus* to the FDO (LAD) of *Broinsonia parca parca* and/or the FDO (LAD) of *Heteromarginatus bugensis*.

Comments: The extinction event of *R. anthophorus* is seen to occur later in the Central Graben than onshore U.K. (Burnett *et al*., 1998), perhaps reflecting the provincialism in the North Sea Basin during the Campanian.

Distribution: This subzone has been recognised in the following wells: 2/7-8 (10,070' or older), 2/7-15 (3,048m - 3,057m), 2/7-30 (10,950' - 10,980'), 2/7-B-11 (10,419' - 10,420') & 2/8-A-1 (2,487.50m - 2,498.20m).

<u>Subzone UC16"i":</u>

Author: Gallagher and Hampton, herein.

Age: Late Campanian.

Definition: From the FDO (LAD) of *Broinsonia parca parca* to the FDO (LAD) of *Eiffellithus eximius*.

Comments: The top of the Magne Formation within this study area commonly falls within this subzone.

The FDO (LAD) of *Monomarginatus quaternarius* also occurs within this subzone.

Distribution: This subzone is recognised in the following wells: 1/3-1 (12,690' & 12,720'), 1/3-8 (3,958m), 2/4B-19 (11,340') & 2/7-15 (3,060m - 3,066m).

Zone UC15:

Author: Emended from Burnett *et al*. (1998) herein for use in the North Sea, equivalent to Zones KN14-16 of Bergen & Sikora (1999).

Age: Late Campanian.

Definition: From the FDO (LAD) of *E. eximius* to the FDO (LAD) of *Saepiovirgata biferula.*

Comments: Correlation between the Central Graben and onshore sections proves difficult during the Campanian due to strong provincialism. The UC zonation has consequently been emended for use in the North Sea Basin to include endemic markers such as *Orastrum campanensis, Bifidalithus geminicatillus* and *Saepiovirgata biferula*. These taxa have been observed in North Norfolk (Gallagher & Hampton, in prep.), which may represent the southern limit of a 'northern' province.

The abundance of *A. cymbiformis* decreases within this zone. Taxa such as *C. obscurus, R. anthophorus*, *Lucianorhabdus* spp., *Prediscosphaera* spp. and *Watznaueria* spp. dominate assemblages.

Distribution: This zone is recognised (undifferentiated) in the following well: 2/8-A-1 (2,498.30m - 2,500.75m).

Within this zone the following subzones are recognised:

Subzone UC15"v":

Author: Equivalent to Subzone UC15eBP (Burnett *et al*., 1998).

Age: Late Campanian.

Definition: From the FDO (LAD) of *E. eximius* to the FDO (LAD) of *Orastrum campanensis.*

Comments: Occasional reworking of *E. eximius* into the base of the Tor Formation may complicate the accurate identification of this subzone.

Distribution: This subzone has been recognised in the following wells: 1/3-8 (3,964m - 4,003m) & 1/9-1 (3,297m - 3,315m).

Subzone UC15"iv":

Author: Equivalent to Zone NK9 of Mortimer (1987).

Age: Late Campanian.

Definition: From the FDO (LAD) of *O. campanensis* to the FDO (LAD) of *Helicolithus trabeculatus*.

Comments: *O. campanensis* is a distinctive boreal marker species and, although never common in assemblages, is usually conspicuous and readily utilised.

Distribution: This subzone has been recognised in the following wells: 1/3-8 (4,021m - 4,060m), 2/5-1 (11,460' - 11,800' and older), 2/7-30 (11,000' - 11,070'), 2/11-A2 T3 (3,441m & 3,468m), BARON-2 (2,887.90m - 2,899.20m) & BO-1 (above 6,827' - 6,842').

Subzone UC15"iii":

Author: Gallagher & Hampton, herein.

Age: Late Campanian.

Definition: From the FDO (LAD) of *H. trabeculatus* to the FDO (LAD) of *B. geminicatillus.*

Comments: The concept of *H. trabeculatus* used in this scheme includes all forms with a non-axial cross (*i.e*. X-shaped) greater than 7 microns in size.

The extinction event of *H. trabeculatus* is recorded in Early Campanian sediments in southern England, but is consistently seen in Late Campanian sediments in the North Sea Basin and North Norfolk.

Distribution: This subzone has been recognised in the following wells: 2/7-2 (10,900' - 11,090'), 2/7-B-11 (10,425.50' - 10,439.50') & MONA-1 (11,211').

Subzone UC15"ii":

Author: Gallagher & Hampton, herein.

Age: Late - Early Campanian.

Definition: From the FDO (LAD) of *B. geminicatillus* to the FDO (LAD) of *Cylindralithus biarcus* or *Lithastrinus grillii*.

Comments: *B. geminicatillus* is an extremely useful marker (although never common) in the North Sea basin and in North Norfolk coastal sections, although it is of limited utility outside of these areas (*i.e*. Southern England).

Distribution: This subzone has been recognised in the following wells: 1/3-8 (below 4,081m), 2/5-9 (below 3,783m), 2/7-15 (3,069m - 3,112m), 2/7-30 (11,080' & 11,100') & BARON-2 (2,899.55m & 2,903.20m).

Subzone UC15"i":
Author: Gallagher & Hampton, herein.

Age: Early Campanian.

Definition: From the FDO (LAD) of *C. biarcus* or *L. grillii* to the FDO (LAD) of *S. biferula.*

Comments: Both *C. biarcus* and *L. grillii* are very rare at the top of their range and for pragmatic purposes these events are deemed simultaneous.

Distribution: This subzone has been recognised in the following wells: 2/7-2 (11,190' or older), 2/7-30 (11,120' - 11,177'), 2/11-A2 T3 (below 3,479m) & BO-1 (6,857').

Zone UC14:

Author: Burnett *et al.* (1998), emended herein for use in the North sea Basin, equivalent to Zones KN17-21 of Bergen & Sikora (1999).

Age: Early Campanian.

Definition: From the FDO (LAD) of *S. biferula* to the LDO (FAD) of *B. parca parca.*

Comments: The top of this zone has been emended to coincide with the extinction of *S. biferula* (rather than the inception of *M. pleniporus*), providing greater utility in the North Sea Basin.

Due to the paucity of sediment of this age within the study area, the data set has been supplemented with reference to onshore sections in the U.K.

Sediments of Early Campanian to Santonian age (Thud Formation and basal Magne Formation) are not widely represented in the study material, as there has been a bias towards sampling from well locations on positive structures.

Distribution: This zone has been recognised (undifferentiated) in the following well: 2/5-9 (above 3,897m).

Within this Zone the following subzones are recognised:

Subzone UC14"iv":

Author: Gallagher & Hampton, herein.

Age: Early Campanian.

Definition: From the FDO (LAD) of *S. biferula* to the LDO (FAD) of *B. parca constricta.*

Comments: *S. biferula* is a very distinctive marker species within Early Campanian age sediments within the Central Graben but is not widely recorded from onshore sections (rare in North Norfolk).

Distribution: This subzone has been recognised in the following wells: 2/5-7 (3,961m - 3,970m or older), 2/7-8 (below 10,240'), 2/7-15 (below 3,115m), 2/7-30 (11,200' - 11,280'), 2/7-B-11 (below 10,443.50') & 2/11-A2 T3 (above 3,479m).

Subzone UC14"iii":

Author: Gallagher & Hampton, herein.

Age: Early Campanian.

Definition: From the LDO (FAD) of *B. parca constricta* to the LDO (FAD) of *Broinsonia enormis* or *Cylindralithus crassus*.

Comments: Our taxonomic concept of *B. parca constricta* is restricted to forms with a central area to rim ratio (b/a ratio) of less than 1 (*i.e.* the width of the central area is less than the width of the rim). We recommend the accurate measurement of specimens throughout sediments of this age, as this ratio may be deceptive.

Distribution: This zone is recognised in the following wells: 2/7-30 (11,280' - 11,360') & 2/7-B-11 (above 10,445').

Subzone UC14"ii":

Author: Gallagher & Hampton (herein)

Age: Early Campanian.

Definition: From the LDO (FAD) of *B. enormis* or *C. crassus* to the LDO (FAD) of *R. levis.*

Comments: Both *B. enormis* (taxonomic concept follows Thierstein, 1974) and *C. crassus* (see taxonomic concept of Stover, 1966) show biostratigraphic utility in sediments of this age. Their omission from previous schemes may be due to taxonomic uncertainty.

The boundary between the Magne and Thud Formations falls at, or near to, this level. However, due to a lack of data from this interval within the study area the exact relationships between lithostratigraphy and biostratigraphy cannot accurately be constrained. Due to the lack of section available in the study material data from onshore Germany and Southern England has been incorporated.

Distribution: This subzone has been recognised in the following wells: 2/4B-19 (11,370' & 11,400'), 2/7-8 (above 10,270' and below 10,280'), 2/7-15 (above 3,152m), BARON-2 (2,906m - 2,915.10m) & BO-1 (6,872').

Subzone UC14"i":

Author: Gallagher & Hampton, herein.

Age: Early Campanian.

Definition: From the LDO (FAD) of *R. levis* to the LDO (FAD) of *B. parca parca*.

Comments: Identification of this zone may prove difficult in poorly preserved material where badly preserved specimens of *Zeugrhabdotus biperforatus* can be mistaken for *R. levis*.

Distribution: This subzone has been recognised in the following wells: 1/3-8 (above 4,200m), 2/4B-19 (11,430'), 2/7-2 (11,290'?), 2/11-A2 T3 (3,486m - 3,498m) & BO-1 (6,887' - 6,932').

Zone UC13:

Author: Burnett *et al*. (1998) emended herein.

Age: "earliest" Campanian/Santonian.

Definition: From the LDO (FAD) of *B. parca parca* to the LDO (FAD) of *A. cymbiformis.*

Comments: Identification of this zone in ditch cuttings sample material may prove difficult as both the upper and lower boundaries are defined on inception events.

This zone was initially restricted to the Early Campanian (Burnett *et al*., 1998). However, *A. cymbiformis* is seen to occur in the Early Santonian in Germany, Southern England (Gallagher & Hampton, in Bailey *et al*., in prep.) and North East England (Burnett & Whitham, 1999). Therefore, this zone as emended, ranges into the Early Santonian (*M. coranguinum* echinoid Zone).

Distribution: This zone has been recognised (undifferentiated) in the following wells: 1/3-8 (below 4,303m), 2/4B-19 (11,460'? - 11,520'?), 2/5-7 (3,976m? - 3,979m?), 2/7-8 (above 10,360') & BARON-2 (below 2,916m).

Sediments representative of this zone are absent in most sections.

Within this zone the following subzones can be recognised:

Subzone UC13"iii":

Author: Equivalent to Zone CC17 of Sissingh (1977).

Age: "earliest" Campanian - Late Santonian.

Definition: From the LDO (FAD) of *B. parca parca* to the LDO (FAD) of common *C. obscurus.*

Comments: Within this subzone there is a conspicuous increase in Watznauriaceae diversity (possibly in response to an environmental signal?).

The first occurrence of *Orastrum campanensis* has been suggested by several authors to be of biostratigraphical utility at this level. However, in our studies, especially in Southern England, the recovery of this taxon is inconsistent. In the North Sea basin, this taxon is recorded in sediments as old as Turonian.

Distribution: This subzone was not differentiated in any of the study wells.

Subzone UC13"ii":

Author: Gallagher & Hampton, herein.

Age: Santonian.

Definition: From the LDO (FAD) of common *C. obscurus* to the LDO (FAD) of *C. crassus.*

Comments: The first downhole occurrence of *Z. 'floral'* may be used, if an increase in the abundance of *C. obscurus* cannot be seen (*i.e*. poor sample quality or in more oceanic settings).

Distribution: This subzone was not differentiated in any of the study wells.

Subzone UC13"i":

Author: Gallagher & Hampton, herein

Age: Santonian.

Definition: From the LDO (FAD) of *C. crassus* to the LDO (FAD) of *A. cymbiformis.*

Comments: The taxonomic concept of *C. crassus* used herein follows Stover (1966). The first occurrence of *C. crassus* is of utility in the Chalk Fields of the Central Graben and can be seen within the range of the planktic crinoid zonal index *U. socialis* in the North Downs and in Northern Germany.

The taxonomic concept of *A. cymbiformis* used herein is restricted to larger arkhangelskiellids with a wide central area plate and a single rim cycle visible in the light microscope.

Distribution: This subzone was not differentiated in any of the study wells.

Zone UC12:
Author: Burnett *et al*. (1998).

Age: Santonian.

Definition: From the LDO (FAD) of *A. cymbiformis* to the FDO (LAD) of *Quadrum eptabrachium.*

Comments: This is a difficult zone to identify due to the reliance on inception events and the relatively short amount of time that it encompasses.

The abundance of *Lucianorhabdus* spp. is seen to decrease with age through this zone.

Distribution: This zone has been recognised in the following wells: 1/3-8 (above 4,333m), 1/9-1 (3,318m), 2/7-15 (3,158m - 3,221m or older) & BARON-2 (above 2,925m?).

Zone UC11:

Author: Burnett *et al*. (1998).

Age: Early Santonian to Late Coniacian.

Definition: From the FDO (LAD) of *Q. eptabrachium* to the LDO (FAD) of *L. grillii*.

Comments: For the purposes of this study *Q. eptabrachium* includes all seven rayed polycylolithaceans without a central area diaphragm.

Assemblages throughout this Zone are dominated by *W. barnesae*, *G. obliquum*, *E. eximius* and *T. orionatus.*

Penetration of this zone is coincident with penetration of the Narve Formation.

There appears to be a regional stratigraphic break at this level. Sediment of the Tor and Magne Formations (Zones UC20 - UC14) commonly overlie sediment of Zone UC11 (Narve Formation) age. The absence of Thud Formation sediments on structure could be due to sea level fall and/or Wernigerode Phase tectonics.

Distribution: This zone was recognised (undifferentiated) in the following wells: 2/5-1 (11,820'?), 2/5-7 (3,983m - 4,065.5m or older) & 2/7-15 (3,231m - 3,249.17m).

Within this zone the following subzones are recognised:

Subzone UC11"iii":

Author: Gallagher & Hampton, herein.

Age: Early Santonian.

Definition: From the FDO (LAD) of *Q. eptabrachium* to the FDO (LAD) of common *H. trabeculatus*.

Comments: Pragmatically the base of this zone is coincident with the Santonian/Coniacian boundary. However, detailed analysis of onshore sections in England and Germany show this zonal boundary lies just above the Santonian/Coniacian boundary.

Distribution: This subzone has been recognised in the following wells: 1/3-8 (4,339m - 4,402m) & 1/9-1 (3,324m).

Subzone UC11"ii":

Author: Gallagher & Hampton, herein.

Age: Late Coniacian.

Definition: From the FDO (LAD) of common *H. trabeculatus* to the FDO (LAD) of *Tortolithus virginica*. (Used under the name of *W. virginica* in Bergen, 1999, and originally described as *T. caistorensis* “large” by the current authors).

Comments: The FDO (LAD) of common *H. trabeculatus*, first identified by Mortimer (1987), appears to be an event of good correlative value in the North Sea Basin and can be recognised in outcrop sections across Southern England and into Germany.

Bergen & Sikora (1999) regard the FDO (LAD) of *H. trabeculatus* to be diachronous across the Valhall structure (which is only a few kilometres across in diameter), however, our regional data plus data from onshore sections indicates that it is a reliable event.

Distribution: This subzone has been recognised in the following wells: 1/9-1 (3,326.15m - 3,329m), 2/4B-19 (11,580' - 11,820'), 2/7-2 (11,390' & 11,500') & BARON-2 (2,926.50m - 2,940m).

Subzone UC11"i":

Author: Gallagher & Hampton, herein.

Age: Late Coniacian.

Definition: From the FDO (LAD) of *T. virginica* to the LDO (FAD) of *L. grillii*.

Comments: Specimens of *Eprolithus floralis* and *Quadrum gartneri* become more conspicuous within this subzone.

Distribution: This subzone has been recognised in the following wells: 1/9-1 (3,329m - 3,326.20m), 2/4B-19 (11,880') & 2/8-A-1 (below 2,501.53m).

Zone UC10:

Author: Burnett *et al*. (1998).
Age: Late to Early Coniacian.

Definition: From the LDO (FAD) of *L. grillii* to the LDO (FAD) of *Micula staurophora.*

Comments: There is an increase in polycyclolithacean diversity through this zone.

Distribution: This zone is recognised (undifferentiated) in the following wells: 2/5-1 (11,820'?), 2/7-15 (below 3,258m), 2/8-A-1 (2,502m - 2,520.50m) & 2/11-A2 T3 (3,504m & 3,507m).

Within this zone the following subzones can be recognised:

Subzone UC10"ii":

Author: Burnett *et al*. (1998), emended herein.

Age: Late to Middle Coniacian.

Definition: From the LDO (FAD) of *L. grillii* to the FDO (LAD) of *Quadrum intermedium* and/or *Helicolithus turonicus (= H. valhallensis).*

Comments: The FDO of *H. turonicus* is noted above the LDO of *M. staurophora* in the North Sea Basin. It is recorded as below this event in onshore northern Europe sections (Burnett *et al*., 1998).

Distribution: This subzone has been recognised in the following wells: 1/9-1 (3,336m - 3,390m) & 2/8-A-1 (above 2,501.53m).

Subzone UC10"i":

Author: Mortimer (1987).

Age: Middle to Early Coniacian.

Definition: From the FDO (LAD) of *Q. intermedium* and/or *H. turonicus* to the LDO (FAD) of *M. staurophora*

Comments: For the purposes of this study and in general for industrial utility *H. turonicus* includes large forms of *Helicolithus* with the central area cross structure aligned more or less with the long axis of ellipse.

Distribution: This subzone has been recognised in the following wells: 1/9-1 (3,399m), 2/4B-19 (11,940' - 12,120'), 2/5-1 (11,970' - 12,070'), 2/7-2 (11,600' & 11,700'), 2/7-B-11 (10,460' - 10,473'), MONA-1 (11,215.16') & 30/7a-2 (below 11,995').

Zone UC9:

Author: Burnett *et al.* (1998), equivalent to Zones KN30-32 of Bergen & Sikora (1999).

Age: Early Coniacian to Middle Turonian.

Definition: From the LDO (FAD) of *M. staurophora* to the LDO (FAD) of *Q. eptabrachium.*

Comments: The LDO (FAD) of *M. staurophora* is coincident with the FDO (LAD) of *Retecapsa 'granulata'*, a large and distinct taxon with a "running track" outline, a retecapsid rim and large granular central area. This may be equivalent to *M. ficula* (Bergen & Sikora, 1999), although no central area cross could be identified in specimens observed in this study.

Distribution: This zone is recognised (undifferentiated) in the following well: 2/8-A-1 (2,521.50m - 2,533m).

Within this Zone the following Subzones can be identified:

Subzone UC9"ii":

Author: Equivalent to Subzone NK13D of Mortimer (1987) and Zone KN30 of Bergen & Sikora (1999).

Age: Early Coniacian.

Definition: From the LDO (FAD) of *M. staurophora* to the FDO (LAD) of common *Helicolithus turonicus.*

Comments: Specimens of *Retecapsa 'granulata'* appear consistently within this subzone, together with an increase in the abundance of *Prediscosphaera columnata* and *Marthasterites furcatus*.

Distribution: This subzone is recognised in the following wells: 2/4B-19 (12,150'), 2/11-A2 T3 (3,510m - 3,528m), BO-1 (below 7,156') & 30/7a-2 (above 12,055').

<u>Subzone UC9"i":</u>

Author: Gallagher & Hampton, herein.

Age: Late - Middle Turonian.

Definition: From the FDO (LAD) of common *H. turonicus* to the LDO (FAD) of *Q. eptabrachium.*

Comments: Many workers place the LDO (FAD) of *Marthasterites furcatus* within this subzone. However, rare specimens have been noted in older sediments within the study area (Gallagher & Hampton, herein) and we therefore question the utility of this as a marker event. *Q. eptabrachium* includes all seven rayed forms without a central area diaphragm.

Distribution: This subzone is recognised in the following wells: 2/4B-19 (12,180' & 12,210'), 2/7-B-11 (10,479.50' - 10,648.50') & 2/11-A2 T3 (below 3,544m).

<u>Zone UC8:</u>

Author: Burnett *et al*. (1998).

Age: Middle to Early Turonian.

Definition: From the LDO (FAD) of *Q. eptabrachium* to the LDO (FAD) of *E. eximius.*

Comments: A stratigraphic break is commonly seen (*i.e*. on the Valhall structure) at this stratigraphic level where sediment of Zone UC9 rests unconformably on Zone UC7/6 sediment.

Distribution: This zone is recognised (undifferentiated) in the following well: 2/7-15 (above 3,304.03m).

Within this zone the following subzones can be recognised:

Zone UC8"ii":

Author: Gallagher & Hampton, herein. Equivalent to Zones KN33/34 of Bergen & Sikora (1999).

Age: Middle Turonian.

Definition: From the LDO (FAD) of *Q. eptabrachium* to the LDO (FAD) of *Kamptnerius magnificus*.

Comments: The LDO (FAD) of *Retecapsa 'granulata'* appears coincident with the LDO (FAD) of *K. magnificus*.

Distribution: This subzone is recognised in the following wells: 2/8-A-1 (2,533.65m - 2,570m), 2/11-A2 T3 (above 3,557.50m) & BO-1 (above 7,216').

Subzone UC8"i":

Author: Mortimer (1987)

Age: Middle to Early Turonian.

Definition: From the LDO (FAD) of *K. magnificus* to the LDO (FAD) of *E. eximius*.

Comments: Particularly over the Valhall structure this subzone is often absent due to tectonism (perhaps the Early Ilsede phase).

Distribution: This subzone is recognised in the following wells: 2/11-A2 T3 (3,567m) & BO-1 (7,231').

Zone UC7:

Author: Mortimer (1987).

Age: Early Turonian.

Definition: From the LDO (FAD) of *E. eximius* to the LDO (FAD) of *Quadrum gartneri.*

Comments: The data set for sediment of this age is very reduced, particularly over the Valhall structure. This subzone is often absent probably due to tectonism (perhaps the Early Ilsede phase).

Distribution: This zone is recognised in the following wells: 2/7-15 (3,307m? - 3,359m?) & 2/8-A-1 (2,572m - 2,580.45m).

Zone UC6:

Author: Burnett *et al*. (1998).

Age: Early Turonian.

Definition: From the LDO (FAD) of *Q. gartneri* to the FDO (LAD) of *Helenea chiastia.*

Comments: An increase in the abundance of polycyclolithaceans is noted within this zone, together with the FDO (LAD) of *Rhagodiscus asper*.

Distribution: This zone is recognised in the following wells: 2/8-A-1 (2,580.50m - 2,581.30m), 2/11-A2 T3 (above 3,572m? - 3,605m?) & BO-1 (7,261' or older).

Zones UC5 and UC4 (undifferentiated):

Author: Burnett *et al*. (1998).

Age: Early Turonian to Late Cenomanian.

Definition: From the FDO (LAD) of *H. chiastia* to the LDO (FAD) of *C. biarcus.*

Comments: Due to the combination of extremely poor preservation and recovery, together with the scarcity of cored material from this interval, nannofloral resolution through this interval within this study is poor.

Distribution: This undifferentiated zonal grouping is recognised in the following well: BO-1 (7,276').

Zones UC3, UC2 and UC1 (undifferentiated):

Author: Burnett *et al*. (1998).

Age: Cenomanian.

Definition: From the LDO (FAD) of *C. biarcus* to the LDO (FAD) of *Corollithion kennedyi*

Comments: These zones can be found described in Burnett *et al.* (1998), but are not included within the scope of this study.

Distribution: This undifferentiated zonal grouping is recognised in the following wells: MONA-1 (11,277') & BO-1 (7,291' - 7,610').

4.2.2 MICROFAUNAL BIOZONATION

4.2.2.1 PALEOCENE

Zone MT7: (*Coscinodiscus* sp.7 Zone).

Author: Bailey, herein.

Age: "late" Thanetian.

Definition: Top defined on the highest occurrence of the diatom *Coscinodiscus* sp.7. This zone equates with the "unnamed" Zone NSP3 of King (1989).

Comments: This zone occurs within the lower part of the Sele Formation throughout the Central Graben area.

Distribution: This zone is recognised in the following well: 1/3-8 (3,136m).

Zone MT6: (*Spiroplectammina spectabilis* Zone).

Author: Bailey herein.

Age: "middle" Thanetian.

Definition: Top defined on the highest occurrence of the agglutinating foraminiferid *Spiroplectammina spectabilis,* within a microfauna dominated by agglutinating foraminiferids. This zone equates with Subzones NSB1c and 1b of King (1989).

Comments: This zone equates effectively with the Lista Formation throughout the study area and can be recognised on the basis of the data collated from various biostratigraphic reports. Where a Vidar Formation has been recognised in the 1/3-8 well, it is constrained within this zone.

Distribution: This zone is recognised in the following wells: 1/3-8 (at 3,145m & 3,301m – 3,340m) and 2/2-3 (2,910m – 2,940m).

Zone MT5: (*Cenodiscus lenticularis* Zone).

Author: Bailey herein.

Age: "early" Thanetian.

Definition: Top defined on the highest occurrence, often in abundance, of the radiolarian *Cenodiscus lenticularis.* This zone equates with Zone NSP2 of King (1989).

Comments: This zone is recognised throughout the Central Graben area as the *Cenodiscus* Claystone Member of various authors, occurring at the base of the Lista Formation. It is the lowest non-calcareous unit within the Paleocene succession.

Distribution: This zone is recognised in the following wells: 1/3-8 (3,355m), 2/2-3 (2,940m) and 2/7-30 (10,250')**.**

<u>Zone MT4:</u> (*Planorotalites compressa* Zone)

Author: Bailey herein.

Age: "early" Thanetian.

Definition: Top defined on the first appearance downhole (FAD) of the planktic foraminiferids *P. compressa, Globorotalia pseudobulloides, Subbotina triloculinoides* and, occasionally, *Planorotalites chapmani*. This zone equates with Subzone NSP1c as defined by King (*op. cit.*).

Comments: This zone marks the downhole penetration of calcareous sediments defined in this study as the Våle Formation, but referred to elsewhere as the Maureen Formation and/or the North Sea Marl.

Distribution: Definite Zone MT4 Våle Formation claystones have been recognised in the present study only in the well 2/7-B11 (at 9,812,core), although Våle Formation claystones, which could be as young as "early" Thanetian have also been recorded in the 1/9-1, 2/5-9, ADDA-2, E-4X, LULU-1 and MONA-1 wells.

Zone MT3: (*Globorotalia pseudobulloides* Zone)

Author: Bailey herein.

Age: "late" Danian.

Definition: Top defined by the occurrence of the planktic foraminiferid association described in Zone MT4, preserved within a chalk lithology.

Comments: This lithological change (at the Våle/Ekofisk formational contact) equates closely with the FAD of *Planorotalites chapmani* in this region and this zone effectively corresponds to Subzone NSP1b as defined by King (*op. cit.*). This species is only rarely recorded regionally making the recognition of the precise zonal top difficult.

Distribution: Definite Zone MT3 Ekofisk chalk has been recognised in the wells 2/7-2 (9,660'-9,700'), 2/7-8 (at 9,710'), M-9X (6,416',sc-6,470',sc), ROAR-2A (6,660'-6,690'), BARON-2 (2,812m,sc-2,839m,co)and BO-1 (at 6,750') and chalks which could be as young as this zone have also been recorded in the wells 1/9-1, 2/2-3, 2/5-1, 2/5-9, 2/7-4, ADDA-2, LULU-1, MONA-1 and ROAR-2.

Zone MT2: (*Globoconusa daubjergensis* Zone)

Author: Bailey herein.

Age: "late" – "early" Danian.

Definition: Top defined on the highest occurrence of *G. daubjergensis*, equating this zone with Subzone NSP1a as defined by King (*op. cit.*).

Comments: The top of this Zone also equates with the top of the *G. daubjergensis* Zone as illustrated by Bang (in Rasmussen, 1978). There is also limited evidence within the region that the zone might be subdivided on the occurrence of *G. daubjergensis gigantea*, which is known to occur in both the Norwegian and Danish sectors of the Central Graben area.

Distribution: This zone can be subdivided into two subzones in a limited number of wells and undifferentiated Zone MT2 Ekofisk sediments are recognised in wells 2/7-15 (2,990m-3,014m), 2/7-B11 (9,938',co-9,998',co), ROAR-2A (6,700'-6,735',co) and BO-1 (at 6,757',sc). Possible MT2 age sediments have also been recorded in wells 2/5-1, 2/7-4 and ROAR-2.

Two subzones can be recognised within this zone, these are defined as follows:

Subzone MT2b:

Author: Bailey herein.

Age: "late" – "middle" Danian.
Definition: Top defined on the highest occurrence of *G. daubjergensis*, with the base of the subzone taken at the FAD of *Planorotalites compressa*.

Comments: The precise dating at the base of this subzone is uncertain, however it frequently calibrates closely with the occurrence of the short-ranging "middle" Danian nannofossil *H. edwardsii*.

Distribution: Definite Subzone MT2b Ekofisk chalks have been recognised across the study area in both the Norwegian and Danish sectors, in wells 1/3-8 (3,385m-3,460m), 2/4-B19 (9,765',co-10,185'co), 2/7-2 (9,720'-9,840'), 2/7-30 (10,270'-10,l535',co), BARON-2 (2,843.70m,co-2,886.60m,co) and M-9X (6,472',sc-6,535'sc).

Subzone MT2a:

Author: Bailey herein.

Age: "early" Danian.

Definition: Top defined on the FAD of *Planorotalites compressa*, base coincident with a "flood occurrence" of the *Eoglobigerina* spp. group.

Comments: Recognition of this unit is extremely difficult, particularly on the basis of the database available in this study. In practical terms, it frequently covers Danian sediments which pre-date definite Subzone MT2b chalk.

Distribution: During the course of the present study this subzone has been combined with possible Zone MT1 sediments, as it has proved impossible to separate them due to the very limited microfaunal data. However, Subzone MT2a - ?MT1 chalks have been recorded in wells 1/9-1 (3,049.17m,co-3,098.50m,co), 2/4-B19 10,205',co-10,215',co), 2/5-9 (3,303m-3381m), 2/7-8 (9,730'-9,930'), ADDA-2 (6,902',sc-7,011',sc), LULU-1 (9,197',sc-9,360',sc), M-9X (6,540',co-6,550',co) and MONA-1 (9,976',sc-10,270').

Zone MT1: (*Planorotalites archeocompressa* Zone)

Author: Bailey herein.

Age: "early" Danian.

Definition: Top defined on the abundant occurrence of *Eoglobigerina* spp., normally recorded below the FAD of *Planorotalites compressa*. Rare records of the index taxon *P. archeocompressa* have been recorded in parts of the Central Graben, however this species is not noted in any of the study wells.

Comments: This is a very poorly represented unit throughout the study region and has only tentatively been identified on rare occasions. It may equate with the *Eoglobigerina eobulloides* assemblage Subzone identified by Bang (in Rasmussen, *op. cit.*).

Distribution: See comments for the overlying subzone.

4.2.2.2 CRETACEOUS

Zone FCS23: (*Pseudotextularia elegans* Zone).

Author: King *et al*. (1989).

Age: Late Maastrichtian.

Definition: Top defined on the "last appearance datum" (LAD) of *P. elegans*. (See King *et al*, 1989, for detailed discussion)

Comments: Bergen & Sikora (1999) clearly illustrate a comparison of this zone with the planktic foraminiferal distribution recorded over the Valhall and Hod fields within their Zone NCF1 and the top of Zone NCF2. Similar records of planktic taxa have not been observed with sufficient consistency within this study to make any valid comparisons.

Distribution: Widespread throughout the study area, undifferentiated FCS23 chalk has been recorded in 1/9-1 (3,106.5m,co-3,194.35m,co), 2/2-2 (2,510m-2,513m,sc), 2/5-1 (10,656',co-11,100'), 2/5-9 (3,426m-3,561m), 2/11-A2 T2 (3,378m-3,390m), 2/11-A2 T3 (3,378m – 3,384m), ADDA-2 (7,020',sc-7,090') and questionably in LULU-1 (9,590' – 9,830').

In several wells broadly dated Maastrichtian chalk was recognised ranging between Zones FCS23 and FCS22; these are 1/3-8 (3,535m-3,665m), 1/9-1 (3,199.5m,co-3,315m), 2/7-4 (10,605',co-10,610',co), M-9X (6,626',sc-6,770') & ROAR-2 (6,782',sc-6,864',co).

This zone has been divided into five subzones in the present study. These are as follows:

Subzone FCS23e:

Author: Bailey herein.

Age: Latest Maastrichtian.

Definition: Top and base defined by the abundant occurrence range of *Pseudotextularia elegans, Rosita contusa* and *Racemiguembelina fructicosa*.

Comments: This subzone equates closely with NCF1a of Bergen & Sikora (1999).

Distribution: This is a widely recognised subzone throughout the Central Graben area seen in 2/4-B19 (10,318',co-10,328'co), 2/5-1 (10,296',co-10,315',co), 2/7-4 (10,461',co - 10,465',co), M-9X (6,551',co-6,559',co), LULU-1 (at 9,363',sc) & MONA-1 (10,280'-10,300').

In several wells Subzones FCS23e-c cannot be differentiated and a combined subzonal unit is recognised; 2/5-9 (3,384m-3,411m), 2/7-30 (at 10,730',co), ROAR-2 (6,750',sc-6,780',sc) and 30/7a-2 (10,440'-10,700'). An undifferentiated FCS23e-d unit is recognised in the Tyra well E-4X (6,640'-6,665',co).

Subzone FCS23d:

Author: Bailey herein.

Age: Late Maastrichtian.

Definition: Top defined by the lowest abundant occurrence of the planktic foraminiferids listed above. Base defined by a regionally persistent acme occurrence of *Bolivinoides draco.*

Distribution: This subzone is recognised as a discrete unit in five wells: 2/7-4 (10,471',co-10,518',co), 2/11-A2 (at 3,368m), M-9X (6,563',sc-6,623',sc), LULU-1 (at 9,378',sc) & MONA-1 (at 10,313',sc). Undifferentiated Subzone FCS23d-c chalks were recognised in 2/4-B19 (10,347',co-10,366',co) and 2/5-1 (10,320'-10,648',co).

Subzone FCS23c:

Author: Bailey herein.

Age: Late Maastrichtian.

Definition: Top defined by the acme occurrence of *B. draco*. Base defined by the "first appearance datum" (FAD) in this region of *P. elegans*.

Comments: Bergen & Sikora (1999) regard the basal occurrence of *P. elegans* as being diachronous. No evidence has been recorded from the present study to confirm this and the event has proved a viable correlation marker.

Distribution: Discrete Subzone FCS23c chalk has been recognised throughout the study area in 2/7-2 (10,000'-10,180'), 2/7-4 (10,532',co-10,580',co), BO-1 (6,760',sc-6,770',sc), LULU-1 (9,382',sc-9,557'sc) & MONA-1 (10,340',co-10,386',sc). It has proved difficult to subdivide the early part of the Late Maastrichtian in two wells and an undifferentiated FCS23c-a unit is included in 2/11-A2 (3,380m,co-3,407.7m,co) & E-4X (6,670'-6,870').

Subzone FCS23b:

Author: Bailey herein.

Age: Late Maastrichtian.

Definition: Top defined by the FAD (LDO) of *P. elegans*. Base defined by the LAD (FDO) of *Gavelinella multipunctata* (this event has not been established throughout the whole study area and may be of more local significance in the Valhall and Hod area where is recognised with some consistency).
Comments: For practical purposes this subzone has been combined with the underlying unit in the present study.

Subzone FCS23a:

Author: Bailey, herein.

Age: Late Maastrichtian.

Definition: Top defined by the LAD of *G. multipunctata*. Base defined by the LAD of *Bolivinoides miliaris*.

Comments: The presence and possible thickness of this unit is largely dependant on the distribution of allochthonous chalk masses within well sections. It is thought that this and the overlying subzone represent thin locally reworked units within the Late Maastrichtian.

Distribution: An undifferentiated FCS23b/a Subzone is recognised in two Danish wells: BO-1 (6,780',sc-6,820',co) & ROAR-2A (6,776',sc-6,822',sc).

Zone FCS22: (*Bolivinoides miliaris* Zone).

Author: King *et al*, 1989.

Age: Early Maastrichtian – Late Campanian.

Definition: Top defined on the "last appearance datum" (LAD) of *B. miliaris*. (See King *et al*, 1989, for discussion).

Comments: The extinction point of *B. miliaris* has been identified close to the top of the Early Maastrichtian interval in several studies of standard onshore sections where the benthic foraminiferids are closely calibrated with the nannoplankton distribution and other stratigraphic criteria (Schönfeld & Burnett, 1991, Schönfeld *et al*, 1996). Occurrences of this taxon in younger sediments must be treated with caution due to the high levels of reworking through this part of the chalk.

Distribution: Sediments dated as an undifferentiated Zone FCS22 are recognised in 2/2-2 (2,560m-2,630m), 2/8-A-1(2,487.5m,co-2,489m,co), 2/11A-2 T2 (at 3,402m), 2/11A-2 T3 (at 3,395m), M-9X (6,780',sc-6,865')and ROAR-2A (6,822',sc-6,638'co) and tentatively in 2/5-9 (3,582m-3,768m) and 30/7a-2 (at 10,820').

This zone has been divided into four subzones in the present study, however recognition of these has proven difficult on the poor quality data available. For practical purposes, only two subzonal units have been recognised in the wells analysed. The subzones are defined as follows:

Subzone FCS22d:

Author: Bailey, herein.

Age: Early Maastrichtian.

Definition: Top defined on the LAD of *B. miliaris*. Base defined by the top of the underlying subzone.

Comments: This subzone has been combined with the underlying subzone for correlation purposes on the database from this study.

Distribution: A unit dated as Subzones FCS22d-c is recognised in the Danish wells E-4X (6,880',co-6,980') and LULU-1 (9,860'-9,946',sc).

Subzone FCS22c:

Author: Bailey, herein.

Age: Early Maastrichtian.

Definition: Top defined by the LAD of *Angulogavelinella bettenstaedti*. Base defined by the top of the underlying subzone. This subzone equates with Subzone FCS22b in King *et al.* (1989)

Comments: Bergen & Sikora (1999) rightly note that the index species for this subzone is extremely rare and logged only occasionally in Central Graben chalks, nevertheless it does occur and, when found, provides an extremely short-ranging marker event. It has therefore been maintained as a subzonal marker in the present study.

Distribution: See notes from overlying unit.

Subzone FCS22b:

Author: Bailey, herein.

Age: Early Maastrichtian.

Definition: Top defined by the acme occurrence of unkeeled planktic foraminiferids, particularly *Rugoglobigerina rugosa*, *Heterohelix globulosa* and *Globigerinelloides* spp. Base defined by the top of the underlying subzone.

Comments: Bergen & Sikora (1999) indicate a level of diachroneity for this Lower Tor marker event, however the abundant occurrence of unkeeled planktics is frequently logged by different analysts and therefore provides a useful subzonal index within the limits of the present study.

Distribution: A unit dated as Subzones FCS22b-a is recognised in the Danish wells E-4X (7,000'-7,200') and LULU-1 (9,980'-10,430').

Subzone FCS22a:

Author: Bailey, herein.

Age: Earliest Maastrichtian **-** Late Campanian.

Definition: Top defined by the highest common occurrence of *Aragonia aragonensis*. Base defined by the top of the underlying Zone.

Comments: This subzone is known to occur within the Valhall/Hod area and was originally identified in the onshore sections around Lägerdorf, in northern Germany (Schönfeld & Burnett 1991). Its potential use has therefore been maintained in the present zonation.

Distribution: Seen only in well 2/11-A2 (at 3,440m,core).

Zone FCS21 (*Bolivinoides decoratus* Zone).

Author: King *et al*., 1989

Age: Late – Early Campanian

Definition: Top defined by the LAD's (FDO's) of *Globotruncana* aff. *arca* and *Tritaxia capitosa*.

Comments: These events are equate closely with the abundance of *Reussella szajnochae szajnochae* used by King *et al.* (*op. cit.*) to define the top of this zone, however they appear to be more widespread and less prone to potential diachroneity. The zonal index, *B. decoratus*, is frequently recorded in the south of the study area (Danish wells), but is not common in the Norwegian sector and has therefore not been used to define the zone.

In the Norwegian sector of the Central Graben the top of this zone frequently equates with the "Upper Red Marker" as described by King *et al.* (1989). This event has been frequently used to define the top of the Late Campanian section in many reports, however current proposals by the International Stage Boundary Sub-commission (See discussion in Nannoplankton Zonation UC16iii) place this zone within the Late Campanian.

Distribution: Chalks dated as definite undifferentiated Zone FCS21 are recorded in wells 2/2-2 (at 2,670m), 2/5-7 (at 3,970m), 2/11A-2 (3,440m,co-3,485m,co), 2/11A-2 T2 (3,414m-3,485m), BO-1 (2,892.7m,co-2,902.95m,co), ROAR-2 (6,891',sc-6970'), ROAR-2A (6,842',co-6,940') & 30/7a-2 (10,920'-10,980'). Tentative FCS21 Zone sediments have been recorded in 1/3-8 (3,964m-4,048m), 2/5-1 (11,470'-11,600') & 2/7-30 (10,920'-11,040').

This zone has been divided into two subzones in the present study. These are as follows:

Subzone FCS21b:

Author: King *et al.*, 1989

Age: Late Campanian

Definition: Top defined on the LAD's (FDO's) of *G.* aff. *arca* and *T. capitosa*. Base defined by the top of the underlying subzone

Comments: This subzone is widely recognised throughout the study area, equating closely with the change in log response which defines the top of the Magne Formation.

Distribution: A discrete FCS21b subzonal unit has been recognised in four of the study wells; 2/2-3 (3,454m-3,460m), 2/5-9m (3,772m-3,825m), 2/7-15 (3,038m-3,063.1m) and LULU-1 (10,450'-10,605',sc). A unit ranging in age from Zone FCS22?-Subzone FCS21b is recorded in the well 2/7-8 (9,950'-10,070').

Subzone FCS21a:

Author: King *et al.*, 1989, amended Bailey, herein.

Age: Late - Early Campanian.

Definition: Top defined on the LAD of *Stensioeina granulata incondita*. Base defined by the top of the underlying Zone. King *et al.* (*op. cit.*) use *Gavelinella usakensis* to define this subzone, but as Bergen & Sikora (1999) point out, this taxon is extremely rare in the offshore area. An alternative event, noted by King *et al.* (*op. cit.*) as a supporting criterion for the subzonal definition, the FDO of *S. granulata incondita*, is therefore used here.

Distribution: This subzone is frequently only recognised as a very thin unit, however it is confirmed in wells 2/5-9 (3,843m-3,879m), 2/7-15 (at 3,075m), 2/7-B11 (at 10,450',co), LULU-1 (at 10,629',sc) & ROAR-2 (6,980'-6,990'). Sediments ranging in age from Zones FCS21a – FCS20 are recorded in 2/7-8 (10,090'-10,250') & E-4X (7,220'-7,500').

<u>Zone FCS20:</u> (*Stensioeina exsculpta gracilis* Zone).

Author: King *et al*., 1989.

Age: Early Campanian.

Definition: Top defined on the LAD of *S. exsculpta gracilis*. See King *et al.* (*op. cit.*) for discussion.

Comments: Sediments of this zonal age are very rarely recognised in the study area due to the erosive effects of mid Campanian Peine tectonism, however they are present in nine of the study wells.

Distribution: Undifferentiated Zone FCS21 chalk is recognised in wells 2/7-15 (3,081m-3,121.15m), 2/7-30 (11,090'-11,334',sc), 2/11A-2 (at 3,088m,co), ADDA-2 (at 7,110',sc), BO-1 (at 6,826',co) & 30/7a-2 (11,000'-11,100').

This zone has been divided into two subzones in the present study. These are as follows:

<u>Subzone FCS20b:</u>

Author: Bailey, herein.

Age: Early Campanian.

Definition: Top defined on the LAD of *S. exsculpta gracilis*. Base defined by the FAD (LDO) of *Stensioeina pommerana*.

Comments: The FAD of *S. pommerana* is difficult to recognise in offshore sections where only ditch samples are available. However, where cored sections are available it is possible to correlate the foraminiferid distribution used herein with the accurately dated onshore section at Seaford, U.K. (Bailey *et al.*, in prep.) where the inception of *S. pommerana* is calibrated with nannoplankton and macrofossil data.

Distribution: This unit can only be recognised in cored section and the only example recognised during the present study is in well 2/11A-2 T2 (at 3,088m,co).

<u>Subzone FCS20a:</u>

Author: Bailey, herein.

Age: Early Campanian.

Definition: Top taken at the FAD (LDO) of *S. pommerana*. Base defined by the top of the underlying zone.

Comments: See above.

Distribution: This subzone has not been differentiated during the course of the present study.

<u>**Zone FCS19:**</u> (*Stensioeina exsculpta exsculpta* Zone)

Author: King *et al*., 1989.

Age: Late – Middle Santonian.

Definition: Top defined on the LAD of *S. exsculpta exsculpta* King *et al.* (*op. cit.*).

Comments: Note the close relationship between this event and the highest occurrence on spherical radiolaria (*Cenosphaera* spp.). This has been confirmed in the present study and the radiolaria have been used as an alternative marker in the absence of the foraminiferal zonal index.

Distribution: This zone has been recorded in wells throughout the study area, however it is frequently very thin and truncated by an unconformable boundary with the overlying section. This is most likely the effect of the Late Santonian – earliest Campanian Wernigerode tectonic phase which may well have re-activated positive structures in the region Mortimore *et al.* (1998).

Chalk of Zone FCS19 age is recorded in wells 1/3-8 (4,297m-4,357m), 2/5-7 (at 3,979m), ROAR-2 (7,000'-7,060'), ROAR-2A (7,000'-7,080'), BARON-2 (at 2,916m), ADDA-2 (7,145'-7,166'), ADDA-3 (7,220'-7,237') & 30/7a-2 (at 11,120'). A tentatively dated FCS19 interval is noted at the base of the well 2/7-30 (11,390'-11,407',sc) and sediments ranging in age from FCS19 – FCS18 are recorded in 2/2-2 (at 2,730m) and 2/2-3 (3,472m-3,490m).

<u>**Zone FCS18:**</u> (*Stensioeina granulata polonica* Zone)

Author: King *et al*., 1989.

Age: Middle - Early Santonian.

Definition: Top defined on the highest common occurrence of *S. granulata polonica*.

Comments: There has been considerable doubt placed on the stratigraphic value of this taxon, as the LAD of the subspecies appears to be diachronous within the region (Bergen & Sikora, 1999). This diachroneity could be due to a number of factors including reworking, misidentification of this with other morphologically similar forms (e.g. *Gavelinella whitei, Stensioeina beccariiformis*) and the potential for this taxon having a longer range (i.e. becoming extinct later) in the deeper water areas of the Central Graben.

All of the above criteria have been recognised in the present study for the LAD of *S. granulata polonica*. However, the common occurrence of the taxon, which is thought to represent a widespread flooding event, is used to define the zone here. This appears to be a reliable stratigraphic datum when calibrated with the nannoplankton and is widely recognised by most practicing biostratigraphers working in the area. It has therefore been retained in the present study.

Distribution: The widespread occurrence of this zone over many of the structures present in the study area supports the view that it represents a major flooding event. It is present as a discrete zonal unit in wells 1/9-1 (3,318m-3,320m), 2/4-B19 (11,460'-11,520'), 2/5-1 (11,610'-11,820'), 2/5-9 (at 3,897m), 2/7-2 (11,240' –11,540'), 2/7-8 (10,270'-10,440'), 2/7-15 (3,158m-3,194m), 2/11-A2 (3,495m,co-3,503m), 2/11-A2 T2 (3,505.8m,co-3,515m,co), 2/11-A2 T3 (at 3,498m,sc), ADDA-2 (7,191,sc-7,274,sc), BO-1 (6,842,co-6,946m,co), ROAR-2 (7,090'-7,220') and ROAR-2A (7,090'-7,230'). Chalks dated with a zonal range of FCS18-FCS17 have also been recorded in wells 1/9-1 (3,324m-3,336.6m), 2/2-2 (at 2,750m) and 30/7a-2 (11,160'-11,490',sc).

<u>Zone FCS17:</u> (*Stensioeina granulata granulata* Zone).

Author: King *et al*., 1989.

Age: Late - Early Coniacian.

Definition: Top defined on the LAD of *S. granulata granulata*. See King *et al.* (*op. cit*.) for discussion.

Comments: Bergen & Sikora (1999) show the extinction point of *S. granulata granulata* within the Santonian (Zone NFC9) and the present author agrees that this taxon does occur sporadically to the mid Santonian. However, from a practical standpoint the majority of the records noted in the various biostratigraphic reports available have logged the common occurrence of the subspecies, which is restricted to the Coniacian Stage.

Distribution: A discrete FCS17 zonal unit is recorded in wells 1/9-1 (3,340m-3,400m), 2/7-8 (10,460'-10,520'), 2/8-A-1 (at 2,501.53m,co), ADDA-2 (7,280',sc-7,540'), BARON-2 (at 2,926.50m,co) and BO-1 (6,950',sc-7,075,sc). Longer ranging units covering sections from FCS17 – FCS16 are also recorded in wells 2/5-9 (3,903m-4,023m), 2/11A-2 (3,515m-3,548.5m), 2/11A-2 T2 (3,522m-3,538m,co) and 2/11A-2 T3 (3,504m-3,540m).

This zone has been divided into two subzones in the present study, recognisable principally in the Danish sector. These are as follows:

<u>Subzone FCS17b:</u>

Author: Bailey herein.

Age: Late Coniacian.

Definition: Top defined on the LAD of *S. granulata granulata*. Base defined by the highest common occurrence of *Marginotruncana marginata* and the LAD's of the radiolaria *Orbiculiforma vacaensis* and *Dictyomitra constricta*.

Distribution: This subzone is only recognised in two wells in the Danish sector: ADDA-3 (7,252',co-7,75',co) and ROAR-2 (7,240'-7,400').

Subzone FCS17a:

Author: Bailey, herein.

Age: Late - Early Coniacian.

Definition: Top defined on the highest common occurrence of *M. marginata* and the LAD's of the radiolaria *O. vacaensis* and *D. constricta*. Base defined by the top of the underlying Zone.

Comments: King *et al*. (*op. cit.*) mention the abundance of keeled planktic foraminiferids within Zone FCS17, but do not use this factor to divide the zone. However, this suggests that this marker event is of wider regional significance.

Distribution: This subzone is recorded as a discrete interval in three Danish sector wells: ADDA-3 (at 7,282',co), BARON-2 (at 2,940m,co) and ROAR-2 (7,420'-7,520'). The subzone is also recorded in the Norwegian sector in two wells, however in this area its' differentiation is less clear and in well 2/7-2 a FCS17a-FCS15 unit is recorded from 11,560'-11,920' and in well 2/7-15 Subzones FCS17a-FCS16a are recorded between 3,197m and 3,227m.

Zone FCS16: (*Stensioeina granulata levis* Zone)

Author: King *et al*., 1989.

Age: Early Coniacian – Middle Turonian.

Definition: Top defined on the LAD of *S. granulata levis*. See King *et al.* (*op. cit.*) for discussion.

Comments: Bergen & Sikora (1999) indicate that the index taxon for this zone occurs only rarely and sporadically and, whilst this is true, it is recorded more frequently in the data available from this study than the more recently defined planktic foraminiferids they suggest as alternative markers.

Distribution: A discrete FCS16 Zone is only recognised in ADDA-2 (7,545',sc – 7,640',sc), although the defining taxon is known to occur over the Valhall structure proving its' widespread distribution.

This zone has been divided into two subzones in the present study. These are as follows:

Subzone FCS16b:

Author: Bailey, herein.

Age: Early Coniacian – Late Turonian.

Definition: Top defined on the LAD of *S. granulata levis*. Base defined on a downhole abundance level of planktic foraminiferids including *M. marginata* and *Praeglobotruncana* cf.

stephani (This is an internal designation used in Robertson Research reports for a distinctive morphotype occurring at this level. It probably equates with the form designated *Dicarinella* cf. *oraviensis* by Bergen & Sikora (1999) which occurs at the same stratigraphic level).

Comments: This subzone is differentiated principally on the recognition of the underlying subzone. It is not recognised as a discrete unit in any of the present study wells.

Subzone FCS16a:
Author: Bailey, herein.

Age: Late - Middle Turonian.

Definition: Top defined on the abundant occurrence of *M. marginata* and the LAD of *P.* cf. *stephani*. The benthic form *Stensioeina granulata kelleri* has been recorded rarely within this subzone. In the usage of King *et al.* (*op. cit.*) this would define the top of Zone FCS15, however the rarity of this zonal index has made its use impractical during the present study. Base defined by the top of the underlying Zone.

Comments: The widespread distribution of the planktic foraminiferid abundance event aids its recognition throughout the study area, in spite of the large range of species names recorded at this level.

Distribution: Subzone FCS16a is recognised as a distinct unit in both the 2/5-9 (at 4,023m) and 2/8-A-1 (2,531.95m,co-2,569.19m,co). An interval defined on the top of FCS16a, but ranging into FCS15 is recorded in 2/7-8 (10,660'-10,780').

Zone FCS15: (*"Cenosphaera"* Zone).

Author: King *et al.* (*op. cit.*), amended Bailey, herein.

Age: Middle – Early Turonian.

Definition: Top defined on the high abundance and diversity level of radiolaria including *Cenosphaera* spp. and *Dictyomitra multicostata*.

Comments: There is some evidence to suggest that a non-sequence occurs within this zone in the study area. This is difficult to prove solely on the biostratigraphic data, but the evidence would support a stratigraphic break at this level.

Distribution: Undifferentiated Zone FCS15 chalk has been recognised in wells 2/5-9 (4,053m-4,059m), 2/7-15 (3,231m-3,300m), 2/8-A-1 (2,570m,co-2,576.75m,co), 2/11A-2 T2 (3,545m,co-3,598m) and 2/11A-2 T3 (3,559m-3,599m).

This zone has been divided into three subzones in the present study. These are as follows:

Subzone FCS15c:

Author: Bailey, herein.

Age: Middle Turonian.

Definition: Top defined on a high abundance and diversity level of radiolarian taxa, including *Cenosphaera* spp. and *D. multicostata*. Base defined on the LAD of *Stensioeina granulata humilis*.

Comments: It is only possible to differentiate this subzone in cored expanded sequences.

Distribution: In the present study the situation described above only occurs in the well 2/7-B-11 (10,595',co-10,649',co).

<u>Subzone FCS15b:</u>

Author: Bailey, herein.

Age: Middle - Early Turonian.

Definition: Top defined on the LAD of *Stensioeina granulata humilis*. Base defined on the downsection influx of common planktic foraminiferids, including *P. stephani, P. gibba* and *Dicarinella aumalensis*.

Comments: The index taxon for this subzone is only very rarely recorded in Central Graben wells and it has not been observed reliably during the course of the present study.

<u>Subzone FCS15a:</u>

Author: Bailey, herein.

Age: Early Turonian.

Definition Top defined on the downsection influx of common planktic foraminiferids, including *P. stephani, P. gibba* and *Dicarinella aumalensis*. This event may well equate with the top of Zone NCF13 as defined by Bergen & Sikora (1999) for the Valhall-Hod area. Base defined on the top of the underlying zone.

Comments: This planktic rich subzone represents a widespread flooding/transgressive event, as such it is easily recognised in several wells across the study area.

Distribution: This subzone is recorded in wells 2/5-1 (11,930'-12,050'), 2/7-8 (10,810'-10,887') ADDA-3 (at 7,617.42',co) and ROAR-2 (7,870'-7,960'). Undifferentiated FCS15a-FCS14 sediments are also recognised in 2/8-A-1 (2,580.45m,co-2,582.3m,co) and 30/7a-2 (12,360',sc-12,575',sc).

<u>Zone FCS14:</u> (*Praeglobotruncana stephani* Zone)

Author: King *et al.* (*op. cit.*), amended Bailey, herein.

Age: Early Turonian – Late Cenomanian

Definition: The FAD of the benthic foraminiferid *Lingulogavelinella globosa* and the common occurrence of the unkeeled planktic *Whiteinella archaeocretacea* have been used to define the top of this zone. The base is defined on the highest occurrence of *Rotalipora cushmani*.
Comments: This zone spans the Blodøks Formation and microfaunal recovery is consequently very poor. Zone FCS14 equates very closely to Zone NCF14 of Bergen & Sikora (1999).

Distribution: A discrete Zone FCS14 unit is only recognised in the well ROAR-2 (7,970'-8,000'). Other sections have combined FCS15a-FCS14 units (see above).

Zone FCS13: (*Rotalipora cushmani* Zone)

Author: King *et al.* (*op. cit.*).

Age: Cenomanian.

Definition: Top defined on the LAD of the planktic foraminiferid *R. cushmani*. See King *et al.* (*op. cit.*) for discussion.

Comments: Zone FCS13 spans most of the Cenomanian Stage and as such comprises at least two major transgressive/regressive cycles. In undifferentiated FCS13 intervals, it is unclear which cycle is represented on the basis of the foraminiferid data alone.

Distribution: Only a limited number of the wells studied were drilled through as complete Late Cretaceous sequence including the Hidra Formation. However sections of this age were recorded in wells 2/5-1 (12,150'-12,570'), 2/7-2 (12,200'-12,300'), 2/8-A-1 (2,585m,co-2,600.1m,co), ADDA-3 (7,672.42',co-7,679.33',co) & MONA-1 (11,272',co-11,280',co).

This zone has been divided into three subzones in the present study, the definitions of two of which, FCS13c and FCS13a, follow King *et al.* (*op. cit.)*. Definition of Subzone FCS13b has been modified here. Definitions for all three are as follows:

Subzone FCS13c:

Author: King *et al.* (*op. cit.*).

Age: Late – Middle Cenomanian.

Definition: Top defined on the LAD (FDO) of the planktic foraminiferid *R. cushmani*. Base defined on the FAD of *R. cushmani* and the LAD of the benthic *Lingulogavelinella ciryi inflata*.

Comments: The top of this subzone is clearly defined on the planktic event (FDO *R. cushmani*) but the contact with the underlying subzone is only poorly defined within the present study wells.

Distribution: A discrete Subzone FCS13c is recognised only in well 2/7-15 (at 3,377.18m). Units encompassing Subzones FCSD13c to 13b are recorded in the Danish wells BO-1 (7,282',co-7,490',co) & ROAR-2 (8,000'-8,300').

Subzone FCS13b:

Author: King *et al.* (*op. cit.*).

Age: Middle – Early Cenomanian.

Definition: Top defined on the FAD of *R. cushmani* and the LAD of the benthic *L. ciryi inflata*. Base defined on the LAD of the benthic species *Sigmoilina antiqua*.

Comments: Not recognised as a discrete unit within the scope of the present study

Distribution: A unit dated as Subzone FCS13b/a is recorded in the ADDA-2 well (7,650'-7,700',sc).

Subzone FCS13a:

Author: King *et al.* (*op. cit.*).

Age: Early Cenomanian.

Definition: Top defined on the LAD of *S. antiqua*. Base defined on the top of the underlying Zone (FCS12) which is of Late Albian age and falls outside the scope of the present study.

Comments: This subzone is only recognised where the Cenomanian interval is complete; in the present study this is in just two wells in the Danish sector.

Distribution: Discrete Subzone FCS13a sediments are recognised in wells BO-1 (7,500'-7,610',sc) and ROAR-2 (8,330'-8,390').

4.3 Biostratigraphic analyses

4.3.1 Sampling

Well selection criteria have been covered elsewhere in this report. One of the primary well selection controls was the availability of good quality core material for study. Of the thirty two wells studied, new core samples and old core data were available from eleven wells and old core data was available from a further twelve wells.

Core samples for biostratigraphy were collected by members of the JCR working group and despatched to Network Stratigraphic Consulting Ltd. for processing and analysis. For the other wells where only ditch cuttings samples were available, samples were selected from eight of these for new analyses.

4.3.2 Sample preparation

Micropalaeontology:

Only 40 new micropalaeontological analyses have been carried out during the course of this study, comprising the following:

- twenty thin sections cut from core samples from the BARON-2 well,
- sixteen ditch samples from four wells (1/9-1, 2/4-B19, 2/5-1, 2/5-7 & 2/11-A2 T3),
- four core samples (from the BARON-2: 1 sample & the 2/11-A2 T2 : 3 samples).

The ditch cuttings samples were simply rinsed carefully in detergent to remove fine "dust" from the microfossil specimens and the core samples were broken down for examination using the Glaubers Salts freeze/thaw technique. This requires subjecting the core samples to repeated freeze/thaw cycles, having first soaked the fragmented chalk in a saturated solution of Sodium sulphate ("Glaubers Salts").

Calcareous nannoplankton:

The "simple smear slide" technique as described by Bown & Young (1998) has been used for all samples analysed in the present study. This is as follows:

1. Trim all outer surfaces of the sample.
2. Scrape a small portion of sediment onto a glass cover-slip.
3. Add a drop of distilled water and make a thick sediment suspension using a flat sided tooth pick or plastic stirring rod.
4. Smear the suspension across the surface of the cover-slip with a tooth pick or plastic stirring rod and dry rapidly on a hot-plate.
5. Label a glass microscope slide and affix the cover-slip (smear side down) using (Norland optical adhesive) mounting medium.

Palynology:

All new sample preparations have been undertaken using standard palynological techniques involving treatment with Hydrofluoric acid and oxidation using Nitric acid. Palynomorphs have been stained where necessary using Safranin red.

4.3.3 Sample analysis

Micropalaeontology:
Semi-quantitative analyses were carried out on the washed sample residues of core and ditch cuttings samples, as well as on the thin sections examined from the BARON-2.

Calcareous Nannoplankton:
Semi-quantitative analyses have been carried out on all samples studied as part of this project.

Palynology:
New analyses have been undertaken on a semi-quantitative basis.

4.3.4 Data integration

All the results from the new micropalaeontological analyses were plotted directly into a digital format using "Stratabugs" software. Data derived from old reports on the same wells were re-plotted into the same format which allowed both new and old datasets to be incorporated onto the same finished diagrams.

It was also necessary to collate the pre-existing database into the same uniform format. This was done by initially transferring all the pre-existing microfossil distribution data into an "excel" format, which could then be easily imported into "Stratabugs".

Microfossil distribution data derived from different laboratories for the same wells and often samples from the same depths needed to be illustrated separately on the final range charts. The ability to produce this type of presentation format with sample data allocated to different analysts had to be developed during the course of this study.

In order to integrate data from the large number of sources available for this project, several basic problem areas had to be overcome before any interpretive work could be carried out.

The wide age range of the reports available meant that there was considerable variation between the data analysts as to the taxonomic nomenclature used. It would be impossible to unify the whole of the microfossil taxonomy without recourse to the original microfossil slides and sample material, however it was decided to update fossil names, particularly for zonal index marker taxa, where the new alternative was obvious. Other, less stratigraphically important taxa would be left on the revised charts with their names unaltered as given by the original analysts.

In order to provide reference to illustrations of the zonal index markers used in this study, both microfaunal and nannofloral, a full reference list of illustrations is given as an appendix (Appendix 1.).

Full microfossil distribution charts for both the microfauna and nannoflora are incorporated with this report for all the wells studied (Enclosures 4-35 to 4-104)

4.4 Biostratigraphic zonation of individual wells

Well 1/3-1

Existing data available:
SIPM (1968) Routine Biostratigraphy: very sparse data.
NSC (1996) Palynology: 10,080' - 10445': Paleocene.
NSC (1997) Nannoplankton: 10,170' - 10,320': Vidar Formation.

Existing data evaluation:
SIPM 1968: Report based on 119 ditch cuttings samples, 31 sidewall core samples and 1 core covering the interval 520' - 15,360'. Micropalaeontology, Nannoplankton and Palynology included. Stratigraphic succession is included, but the Upper Cretaceous is not differentiated. Recovery from cuttings was evidently very poor.

New analyses:
Micropalaeontology = 0
Nannoplankton = 20 dc
Palynology = 0.

All 20 ditch cuttings are of extremely poor quality and proved very difficult to work with. This is undoubtedly due to their age and the methodology employed at the time they were caught. These samples had to be soaked and rinsed several times in order to yield identifiable chalk grains and processed with great care (occasionally as individual grains) to ensure reliable slide preparations. Nevertheless, caving and mixing of lithologies remained a problem and assemblage quality is inevitably compromised. Significant sample gaps exist between 11,150' and 11,350' and between 11,350' and 12,300'.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
10,100’ – 10,140’	Lista	Late Paleocene	MT6

Comments: Diverse agglutinating foraminiferid fauna recorded at 10,140’, including *S. spectabilis.* Palynomorphs recovered from the sample at 10,100’ and 10,150’ are all the result of caving from latest Paleocene and younger sediments.

Depth	Formation	Age	Zone
10,157' - 10,326'	Vidar	Late Paleocene	Indeterminate

Comments: Large scale reworking of Late Cretaceous nannofossils in the sample at 10,175’. Reworking of Late Maastrichtian microfaunas present between 10,190’ and 10,320’. Coniacian/Turonian reworking also noted at 10,190’. Palynomorphs recovered from the sample at 10,290’ are all the result of caving.

Depth	Formation	Age	Zone
10,326' - 10,548'	Lista	Late Paleocene	Indeterminate

Comments: The samples examined at 10,350’ and 10,445’ only yielded sparse palynomorph assemblages, which are the result of caving

Depth	**Formation**	**Age**	**Zone**
10,548' - 10,686'	Våle	“early” Thanetian	Indeterminate

Comments: The interval is not zoned due to the poor quality of the microfaunal recovery, however a diverse planktic foraminiferid association at 10,620’ is consistent with an “early” Thanetian – “late” Danian age range.

Depth	**Formation**	**Age**	**Zone**
10,686' - 11,027'	Ekofisk	“late” Danian	NNTp4E-C

Comments: At 10,800’ down to 11,050’ nannoplankton subzones NNTp4E-C with varying amounts of reworking are recognised. This is based primarily on the occurrence of common *P. dimorphosus* and on the occurrence of *Neochiastozygus* spp. The LDO of *N. saepes* at 10,950’ is used with caution in ditch cuttings samples.

Depth	**Formation**	**Age**	**Zone**
11,027' - 12,549'	Tor	Late Maastrichtian - Late Campanian	UC20“ii”– UC16

Comments: The Ekofisk/Tor Formation boundary is estimated between 11,000’ and 11,050’ with Nannoplankton Subzone NNTp4C resting unconformably on Nannoplankton Subzone UC20 “ii” (based on the occurrence of *C. daniae)*. However, the occurrence of Danian taxa in the sample at 11,050’ is attributable to caving given the log pick for top Tor Formation at 11,027’. Samples at 11,350’ and 12,300’ indicate Nannoplankton Subzone UC19“ii” over this extensive interval, based on the occurrence of *G. obliquum* and *S. primitivum*. A large sample gap exists between 11,350’ and 12,300’.

Zones UC18, UC17 and UC16 are recognised at the base of the analysed interval between 12,430’ and 12,720’, based on the occurrences of *R. levis* and *T. orionatus* respectively.

Depth	**Formation**	**Age**	**Zone**
12,549' - 13,156'	Magne	Late Campanian	UC16“ii” or older

Comments: The sample at 12,690’ contains the FDO of common *R. levis* with *Broinsonia parca parca* and *R. anthophorus* in a red lithology.

Depth	**Formation**	**Age**	**Zone**
13,156' - 14,032'	Thud		

Comments: The sparse microfaunal data available from this interval is insufficient for age and zonal attributions.

Depth	**Formation**	**Age**	**Zone**
14,032' - 14,301'	Narve		

Comments: No biostratigraphic data.

Depth	Formation	Age	Zone
14,301' - 14,380'	Blodøks		

Comments: No biostratigraphic data.

Well 1/3-8

Existing data available:
BST (1997) Routine Biostratigraphy report.

Existing data evaluation:
Received only part of the existing report (Late Paleocene - Turonian) and distribution charts. Good quality palynology, micropalaeontology and nannoplankton data are provided throughout from samples of poor quality and low recovery.

New analyses:
Micropalaeontology = 0
Nannoplankton = 20 dc
Palynology = 0.

NSC 1999: All 20 ditch cuttings are of extremely poor quality and proved very difficult to work with. This is undoubtedly due to the methodology of drilling the chalk section in this well. These samples had to be rinsed several times in order to yield identifiable chalk grains and processed with great care (occasionally as individual grains) to ensure reliable slide preparations. Nevertheless, caving and mixing of lithologies remained a problem and assemblage quality is inevitably compromised.

Significant sample gaps exist between 3,525m and 3,919m.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
3,139m - 3,145m	Sele	“late” Thanetian	MT7

Comments: Good diatom recovery, including *Coscinodiscus* sp.7 at 3,139m

Depth	Formation	Age	Zone
3,145m - 3,202.5m	Lista	“middle” Thanetian	MT6

Comments: A marked downhole increase in agglutinating foraminiferid diversity occurs at 3,145m.

Depth	Formation	Age	Zone
3,205m - 3,281m	Vidar	“middle” Thanetian	MT6

Comments: Sporadic records of Danian, Late Maastrichtian and undifferentiated Late Cretaceous reworking between 3,211m and the ditch sample at 3,301m

Depth	**Formation**	**Age**	**Zone**
3,281m - 3,354.5m	Lista	"middle" Thanetian	MT6

Comments: Downhole re-appearance of agglutinating foraminiferids noted at 3,301m, with highest re-appearance of *Spiroplectammina spectabilis* at 3,316m.

Depth	**Formation**	**Age**	**Zone**
3,354.5m - 3,374m	Våle	" early " Thanetian	MT5

Comments: Abundant *Cenodiscus lenticularis* at 3,355m confirms both Zone MT5 and age.

Depth	**Formation**	**Age**	**Zone**
3,374m - 3,479.5m	Ekofisk	"late" Danian	NNTp5-4 MT3 - MT2b

Comments: Planktic foraminiferids (including *P. compressa*) are recorded from chalk lithologies at 3,385m confirming Zone MT3 within the "late" Danian. Zone MT2b is recorded below 3,400m on the occurrence of *G. daubjergensis*. Sporadic records of Maastrichtian – Campanian Tor reworking is noted within the unit.

The occurrence of *N. perfectus* at 3,445m is taken to indicate Nannoplankton Subzone NNTp5B. Subsequent samples contain common *P. dimorphosus* and *C. pelagicus* together with rare *Neochiastozygus* spp. (NNTp4E-F) in otherwise poor quality assemblages. Reworking is recorded in minor amounts. The LDO of *Neochiastozygus* spp. is tentatively used to indicate NNTp4A at 3,445m.

The presence of "middle - early" Danian sediments is based on the FDO of common *P. tenuiculus* at 3,460m (NNTp3), and the LDO of *P. dimorphosus* (tentatively NNTp2c at 3,472m). Late Cretaceous reworking is low throughout the Ekofisk Formation in this well, which is similar to that seen regionally on the Eldfisk Bravo Field, but differs markedly from the Ekofisk Field and Eldfisk Alpha Field.

Depth	**Formation**	**Age**	**Zone**
3,479.5m - 3,952m	Tor	Late Maastrichtian - Late Campanian	UC20"i"- UC16 "iii"

Comments: The Ekofisk/Tor Formation boundary is estimated between 3,484m and 3,496m, however, caving in the ditch cuttings samples is suspected with Nannoplankton Subzone NNTp2C resting unconformably on Nannoplankton Subzone UC20"i" (based on the occurrence of *N. frequens)*. The FDO of *G. obliquum* is at 3,525m indicating Nannoplankton Subzone UC19"ii". The remainder of the interval down to 3,910m is not positively zoned due to poor assemblage recovery and probable reworking.

The FDO of *R. levis* at 3,919m indicates Nannoplankton Zone UC18. Subsequently the FDO of *B. parca constricta* indicates Subzone UC16"iii" at 3,940m.

Microfaunal recovery was very poor throughout this well, which was logged at the wellsite. The occurrence of *S. pommerana* at 3,535m is used to indicate a general Maastrichtian age (Zones FCS23-22), supported by records of *Rugoglobigerina* spp. at 3,625m.

Depth	Formation	Age	Zone
3,952m - 4,125m	Magne	Late - Early Campanian	UC16“i”- UC14“i” ?FCS21

Comments: The FDO of *B. parca parca* is taken to indicate Subzone UC16“i” or older at 3,958m. The occurrence of *E. eximius* at 3,964m confirms penetration of Magne Formation sediments (Subzone UC15“v”). The effects of caving of the ditch cuttings samples may have suppressed these zonal tops. The FDO’s of *O. campanensis* and *B. geminicatillus* indicate the presence of Subzones UC15“iv” (4,021m) and UC15“iii” (4,081m).

A very tentative FCS21 date is applied to the section below 3,964m on the basis of a downhole increase in the recovery of *Rugoglobigerina* spp., with *Globotruncana linneiana* logged at 4,048m. Recovery is extremely poor.

Depth	Formation	Age	Zone
4,125m - 4,337m	Thud	Earliest Campanian - Santonian	UC13 – UC12 FCS19 – FCS18

Comments: The consistent occurrence of *Cenosphaera* spp. at and below 4,297m indicates a probable Santonian age below this depth, within the range of Zones FCS19-FCS18.
Identification of Thud Formation sediments is not possible with this nannoplankton data set due to the effects of caving and poor quality assemblages, although the weak assemblages recovered from 4,165m and 4,303m are consistent with a Zone UC13 -12 attribution.

Depth	Formation	Age	Zone
4,337m - 4,519m	Narve	“earliest” Santonian	UC11“iii”

Comments: The FDO of *Q. eneabrachium* at 4,339m confirms penetration of the Narve Formation (Nannoplankton Subzone UC11“iii”). Sample quality is poor throughout this interval.

Well 1/9-1

Existing data available:
RRI (1977) Routine Biostratigraphy;
RRI (1988) Selected core from three wells;
NPD (1980) Micropalaeontology Range Chart; NPD (1980?) Nannoplankton Range Chart.

Existing data evaluation:
RRI (1977) Micropalaeontology distribution charts only. Good quality data.
RRI (1988) Report based on 26 core samples over the relevant section covering the interval 3049.17m - 3336.20m. Micropalaeontology distribution charts. Good quality data.
NPD (1980) Micropalaeontology distribution chart only. 16 samples - Good quality data.
NPD (1980?) Nannoplankton distribution chart only. Moderate quality data.

New analyses:
Micropalaeontology = 5 dc
Nannoplankton = 18 c+23 dc
Palynology = 0.

All 18 ditch cuttings are of extremely poor quality and proved very difficult to work with. This is undoubtedly due to the age of the samples and the methodology employed when catching the samples. These samples had to be rinsed several times in order to yield identifiable chalk grains and processed with great care (occasionally as individual grains) to ensure reliable slide preparations. Nevertheless, caving and mixing of lithologies remained a problem and assemblage quality is inevitably compromised.

Good quality core samples were available for analyses.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
3,015m - 3,039m	Våle	"early" Thanetian - "late" Danian	MT4 – MT3

Comments: The highest record of common planktics at 3,025m confirms this interval within the range of Zones MT4 – MT3.

Depth	Formation	Age	Zone
3,039m - 3,103m	Ekofisk	Danian	NNTp4F - NTp2C/D MT2b - ?MT1

Comments: Sediments of "late" Danian age are represented by Subzones NNTp4F to NNTp4B between 3,049.17m and 3,073.95m. This is based on abundant *P. dimorphosus* and common *P. martinii* at 3,049.17m, an increase in *Neochiastozygus* spp. at 3,060.56m, the LDO of *N. saepes* at 3,066.88m, the LDO of *P. martinii* at 3,071.3m and the LDO of *N. modestus* at 3,073.95m.

Zone MT2b is indicated between 3,049.17m(core) to 3,087.8m (core) on the occurrence of *G. daubjergensis* down to the lowest *in-situ P. compressa*; below this, the precise dating is uncertain.

No sediments of "middle" Danian age NNTp3 were identified, however, a sample gap exists between 3,073.95m and 3,080.69m within which this Zone may be represented. The co-occurrence of *H. edwardsii* and common *P. tenuiculus* confirms the presence of Subzone NNTp2G at 3,080.69m. Subsequent subzones are based mainly on inception events in core. Pulses of Late Cretaceous reworking occur at 3,087.87m and 3,100.62m.

Depth	Formation	Age	Zone
3,103m - 3,297.2m	Tor	Late Maastrichtian	UC20"ii" – UC19"ii" FCS23

Comments: Definite Late Maastrichtian (FCS23) chalk between 3,103.95m(core) and 3,106.5m (core) marked by the highest occurrences of *R. fructicosa, B. draco* and *P. elegans.* The LDO of *P. elegans* at 3,194.35m (core) confirms Zone FCS23 to this depth.

Nannoplankton assemblages composed of Late Cretaceous restricted taxa, particularly *N. frequens* and *C. daniae* confirm penetration of Tor Formation sediments of Late Maastrichtian age (Subzone UC20“ii”). Subzone UC20”i” is present between 3,110.5m and 3,173.13m based on the occurrence of *N. frequens* in core material. Subzone UC19“ii” is present between 3,184.32m and 3,288m based on the FDO of *G. obliquum* and *S. primitivum*.

Depth	Formation	Age	Zone
3,297.2m - 3,314m	Magne	Campanian	UC15

Comments: The FDO of *E. eximius* is taken to indicate the presence of Magne Formation sediments of Campanian age (Subzone UC15“v”) at 3,297m.

Depth	Formation	Age	Zone
3,314m - 3,650m	Narve	Early Santonian - Coniacian	UC11-10 FCS18 – 17

Comments: *S. granulata polonica* is recorded at 3,318m, indicating the interpretation of the top Narve Formation within the basal part of this zone. The records of *S. granulata granulata* below 3,342m confirm the Coniacian age below this depth.

The FDO of *C. crassus* and *B. geminicatillus* indicate a Subzone UC14“ii” attribution or older at 3,318m. The presence of Narve Formation sediments of Late Coniacian Subzone UC11“ii” age is based on the occurrence of *Q. eptabrachium* and common *H. trabeculatus* at 3,324m. The FDO of *T. virginica* at 3,329m indicates Subzone UC11“i”. The Subzone UC10“ii” attribution at 3,357m is tentatively based on the absence of *L. grillii*. The occurrence of *Q. intermedium* at 3,399m confirms the presence of Subzone UC10“i”.

Well 2/2-2

Existing data available:
RRI (1983) Routine Biostratigraphy, but no distribution charts available.

Existing data evaluation:
RRI (1983) Succession page only - no additional data. Little microfaunal data of any stratigraphic value.

New analyses:
Micropalaeontology = 0
Nannoplankton = 15 dc
Palynology = 2 dc.

All 15 ditch cuttings are of moderate to poor quality and proved difficult to work with. This is undoubtedly due to the age of the samples and the methodology employed when catching the samples. These samples had to be rinsed in order to yield identifiable chalk grains and processed with great care (occasionally as individual grains) to ensure reliable slide preparations. Nevertheless, caving and mixing of lithologies remained a problem and assemblage quality is inevitably compromised.

Stratigraphic interpretation:

Depth	**Formation**	**Age**	**Zone**
2,490m – 2,510m	Rogaland	-	-

The ditch cutting samples examined at 2,490m and 2,510m for Palynology only yielded taxa derived as a result of caving from the Horda, Balder and Sele Formations.

Depth	**Formation**	**Age**	**Zone**
2,513.5m - 2,705.5m	Tor	Late Maastrichtian	UC(20/19)-UC16“iii”

Comments: The sporadic record of *N. frequens* (below 2,550m) in association with *S. primitivum* and *G. obliquum* (below 2,520m) and minor reworking (i.e. *R. levis* at 2,560m) in ditch cuttings samples of poor quality complicates the sub-division of the Tor Formation to the extent that only a broad Nannoplankton Zone UC20 – UC19 is applied. The FDO of *R. anthophorus* at 2,660m indicates Nannoplankton Subzone UC16“ii” in the Late Campanian.

A Zone FCS23 assignment is noted between 2,510m and 2,513m, just above the log pick for the top Tor; the difference is thought most likely to be caused by a minor log to sample discrepancy. The presence of *R. fructicosa* to 2,630’, if *in situ*, supports a Late Maawstrichtian date to this depth.

Depth	**Formation**	**Age**	**Zone**
2,705.5m - 2,753.5m	Magne	Campanian	UC15“iv”– UC14“iv”

Comments: The record of *O. campanensis* at 2,705m (slightly above the log break) and *S. biferula* at 2,725m indicate Subzones UC15“iv” and UC14“iv” respectively.

RRI record *T. capitosa* at 2,670m, considerably above the log pick for the top Magne. This discrepancy could be due to mis-identification of the taxon. An Early Campanian Zone FCS20 age is indicated at 2,730m on the occurrence of *S. exsculpta ?gracilis*, although this was also mis-identified as *S. exsculpta exsculpta* in the original report.

Well 2/2-3

Existing data available:
RRI (1983) Full report with charts and summary log

Existing data evaluation:
RRI (1983) Succession page only - no additional data.

New analyses:
Micropalaeontology = 0
Nannoplankton = 14 dc
Palynology = 1 dc

All 14 ditch cuttings are of moderate to poor quality and proved difficult to work with. This is undoubtedly due to the age of the samples and the methodology employed when catching the samples. These samples had to be rinsed in order to yield identifiable chalk grains and processed with great care (occasionally as individual grains) to ensure reliable slide preparations. Nevertheless caving and mixing of lithologies remained a problem and assemblage quality is inevitably compromised.

Stratigraphic interpretation:

Depth	**Formation**	**Age**	**Zone**
2,910m – 2,965m	Lista	"middle" Thanetian	MT6

Comments: RRI record common agglutinating foraminiferids at 2,910m, including *S. spectabilis*, thereby confirming the "middle" Thanetian Zone MT6 age at this depth. This zonal assignment is continued to 2,960m based on the relatively high agglutinating foraminiferid diversity to this depth. Common Danian reworking occurs through this unit.

Depth	**Formation**	**Age**	**Zone**
2,965m – 3,004m	Vidar	-	-

Comments: "Late" Danian, "early" Thanetian, plus Late Cretaceous reworked taxa dominate the nannoplankton assemblages recorded between 2,970m and 3,020m.

N.B. A single sample has been examined for palynomorph content at 3,010m. The assemblage is dominated by taxa derived from Horda, Balder and Sele Formations. No taxa which definitely prove a Danian age have been recorded.

Depth	**Formation**	**Age**	**Zone**
3,016.5m – 3,090.5m	Ekofisk	"late" Danian	NNTp4E/D

Comments: Abundant *P. dimorphosus* at 3,040m with *N. saepes* and *N. modestus*.

A broad Danian (Zone MT3/2) age is indicated by the record of *G. pseudobulloides* at 3,030m.

Depth	**Formation**	**Age**	**Zone**
3,090.5m – 3,400m	Tor	Late Maastrichtian - Late Campanian	UC(20/19)- UC16"ii"

Comments: There is an influx of Late Cretaceous species at 3,095m and sporadic records of *N. frequens* (below 3,095m) in association with *G. obliquum* (below 3,110m) and *S. primitivum* (below 3,125m). Minor reworking (i.e. odd occurrences of *R. levis* at, and below

3,125m in RRI data set) in ditch cuttings samples of poor quality complicates the sub-division of the Tor Formation to the extent that only a broad Nannoplankton Zone UC20 – UC19 is applied. The FDO of *T. orionatus* at 3,350m indicates Nannoplankton Zone UC17 and the FDO of *R. anthophorus* at 3,370 indicates Nannoplankton Subzone UC16"ii".

There are no zonal index microfaunal species recorded within the Tor, however the presence of *Rugoglobigerina* spp. at 3,110m and *B. incrassata gigantea* at 3,190m support the Maastrichtian dating.

Depth	**Formation**	**Age**	**Zone**
3,400m – 3,495m	Magne	Late Campanian	FCS21b UC16"ii" – UC15"iii"

Comments: An intra-Late Campanian age (Subzone FCS21b) is defined at 3,454m by the occurrence of *T. capitosa* and *G.* aff. *arca* in pink stained chalks. This event is normally coincident with the top Magne and the minor discrepancy between the two in this section is probably due to caving.

At 3,472m the FDO of *O. campanensis* with *E. eximius* and *H. trabeculatus* indicates an age within the range of Nannoplankton Subzones UC16"ii" – UC15"iii".

Well 2/4-A-8

Existing data available:
NPD (1976) chart with 48 samples; Data from NSC (1998) Ekofisk Field Study. Edelmann & Partners Micropalaeontology Report (1994) carried out for Phillips Petroleum.

Existing data evaluation:
NPD (1976) Moderate to poor quality data; Edelmann & Partners data had to interpreted with caution, as Danian–Late Cretaceous microfaunas included taxa normally described from Miocene, Oligocene and Early Cretaceous intervals: NSC (1998) Good nannofloral recovery from core samples.

New analyses:
Micropalaeontology = 0
Nannoplankton = 0
Palynology = 0.

Stratigraphic interpretation:

Depth	**Formation**	**Age**	**Zone**
10,076' - 10,113'	Våle	"early" Thanetian	NNTp8-6

Comments: Abundant *C. edentulus* and *N. perfectus* at 10,080'.

The presence of rare planktic foraminiferids at 10,087' (core) indicate Zone MT4 at this depth.

Depth	Formation	Age	Zone
10,113’ - 10,566’	Ekofisk	“late” Danian	NNTp5B - NNTp2D MT3-MT2b

Comments: The attribution of Zone NNTp5B is based on the occurrence of *N. perfectus*, however, a major increase in *P. dimorphosus* is noted at 10,150' and is used to define subzone NNTp4E/F.

The intra formational reworking makes zonal determination difficult in this well, however, the consistent occurrence of *N. eosaepes* from 10,210' suggests the presence of Zone NNTp4D.

A large increase in reworking (principally Late Maastrichtian) is noted between 10,220' and 10,230'.

The interval between 10,340' and 10,520' is tentatively attributed to Zone NNTp2E/F, suggesting an absence of Zones NNTp3 - 4C. However, this is based on the sparse *in situ* assemblage recovered and the absence of taxa indicative of a younger age.

The interval 10,340' to 10,564' is dominated by massive reworking of mainly Late Maastrichtian age sediments, indicated by both the nannofloral and microfaunal recovery.

An alternative interpretation is that the interval between 10,340’ and 10,520’ represents an impoverished Zone NNTp4A-C interval, masked by massive reworking.

Samples analysed between 10529.8' and 10564' suggest the presence of “early” Danian age sediments (NNTp2D) based on very low diversity assemblages with small varieties of *P. dimorphosus*. Moderate amounts of reworking are still present in what is equivalent to the Ekofisk Tight Zone.

The records of *G. pseudobulloides* at 10,122’ (core) and *G. daubjergensis* at 10,299’ (core) confirm Zones MT3 and MT2b respectively.

Depth	Formation	Age	Zone
10,566’ - 10,760’	Tor	Late Maastrichtian	UC20“ii” - UC19 FCS 23e-c

Comments: Tor Formation sediments are confirmed at 10,569' from an impoverished assemblage containing *N. frequens*. This supported by the recovery of *C. daniae* between 10,600' and 10,670'.

The *in situ* recovery of *P. elegans* below 10,575’ core, together with *B. draco* at 10,599’ (core) and common *R. fructicosa* recorded at 10,748’ (core).

Well 2/4-B-19

Existing data available:
NSC (1995) data from 4 samples only; NPD (1976?) Nannoplankton distribution chart. NSC (1998) Ekofisk Core Review study data set.

Existing data evaluation:
Good quality data.

New analyses:
Micropalaeontology = 3
Nannoplankton = 32
Palynology = 0.

All 32 ditch cuttings are of moderate quality and proved reasonable to work with. These samples were washed with repeatedly in order to yield identifiable chalk grains and processed with great care (occasionally as individual grains) to ensure reliable slide preparations. Nevertheless, caving and mixing of lithologies remained a problem and assemblage quality is inevitably compromised.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
9,711' – 9,777'	Våle	"early" Thanetian	NNTp7

Comments: The LDO of common *Toweius* spp. at 9,775'. The foraminiferid recovery at 9,765' is good and includes specimens referred to *G. pseudobulloides* and *G. daubjergensis*. The presence of the latter would suggest a "late" Danian age, but the nannoplankton data confirms the Våle Formation is of "early" Thanetian age at this level. There is considerable reworking present in the samples and the possibility that some of the Danian taxa have been reworked cannot be ruled out.

Depth	Formation	Age	Zone
9,777' – 10,212'	Ekofisk	Danian	NNTp5B – NNTp1?

Comments: Between 9,780' and 9,818' the occurrence of *N. perfectus* and common *C. edentulus* indicates Subzone NNTp6/5B.

The common occurrence of *P. tenuiculus* at 10,179.5' indicates Zone NNTp3.

Nannoplankton Subzone NNTp2D is based on rare *P. dimorphosus* and moderate amounts of reworking.

Danian chalks within Subzone MT2b are recognised to 10,195' on the presence of *P. compressa* to this depth.

Depth	Formation	Age	Zone
10,212' – 11,381'	Tor	Late Maastrichtian - Late Campanian	UC20"ii" – UC16"i"

Comments: A good Tor Formation sequence with the occurrence of *N. frequens* and *C. daniae* (10,316') indicating Subzone UC20"i". *N. frequens* persists down to 10,361'. A sample gap exists between 10,366' to 10,800'. The FDO of *G. obliquum* at 10,860' and *C. obscurus* (10,980') are used to sub-divide Zone UC19.

At 11,190’ the FDO of *R. levis* indicates Zone UC18 with reworking of *E. eximius* and *H. trabeculatus* complicating assemblages slightly.

The FDO of *R. anthophorus, M. quaternarius* and *B. parca parca* at 13,340’ indicates Subzone UC16“i”.

Depth	Formation	Age	Zone
11,381’ – 11,511’	Thud	Early Campanian - Santonian	UC14“iv/“ii” – UC12

Comments: The FDO of *S. biferula, B. geminicatillus* and *C. crassus* at 11,370’ indicates Subzone UC14“iv-ii”. The FDO of *Z. biperforatus* at 11,400’ confirms Subzone UC14“ii”.

The LDO of *B. parca parca* in the absence of *R. levis* in cuttings tentatively suggests Subzone UC14“i” at 11,430’.

Zone UC13 based on the occurrence of *A. cymbiformis* down to 11,490’ in cuttings and Zone UC12 below this.

The limited number of micropalaeontology analyses carried out between 11,460’ and 11,520’ contain both *S. granulata polonica* and *G. arnagerensis* indicating Zone FCS18 over this interval.

Depth	Formation	Age	Zone
11,511’ – 12,762’	Narve	Coniacian - Turonian	UC11“ii” – UC9“i”

Comments: At 11,700’ the increase in the abundance of *H. trabeculatus* indicates Subzone UC11“ii”. The FDO of *T. virginica* suggests Subzone UC11“i” at 11,880’.

The FDO of *Q. intermedium* at 11,940’ indicates Subzone UC10“i” with common *H. turonicus* indicating Subzone UC9“i” at 12,180’.

Depth	Formation	Age	Zone
12,762’	Blodøks	Earliest Turonian - Late Cenomanian	-

Comments: No analyses carried out.

Well 2/4-B-19A/T2

Existing data available:
PHI (1986) Report with taxa lists; AGP (1995) Report with diagrams and charts.

Existing data evaluation:
PHI (1986) Good quality data.

New analyses:
Micropalaeontology = 0

Nannoplankton = 0
Palynology = 0.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
9,836' – 10,279'	Ekofisk	Danian	NNTp5B – NNTp2A

Comments: The occurrence of *N. perfectus* with common P. dimorphosus at 9,839' indicates Subzone NNTp5B. The LDO of *N. perfectus* at 9,864' suggests Subzone NNTp5A-4F below this depth.

There is a significant sample gap between 9,870' and 9,897'.

Subzone NNTp4B at 9,897' is based on the LDO of *P. martinii*. This subzone includes pulses of reworking at 9,897', 9,967' and 9,993'. More significant reworking occurs between 10,159' and 10,204'.

Subzone NNTp2 at, and below, 10,209' based on the re-appearance of common *P. dimorphosus*, rare *P. dimorphosus* (10,211') and *C. primus* (10,241').

High amounts of reworking once again present in the Ekofisk Tight Zone at 10,270'.

Depth	Formation	Age	Zone
10,279' – 11,399'	Tor	Late Maastrichtian	UC20"iii" – UC19"ii"

Comments: There is an influx of Late Cretaceous restricted species at 10,290'. The occurrence of *N. frequens* between 10,292.5' and 10,416.2' indicates Subzone UC20"i".

The interval 10,416.2' – 10,523' is not zoned due to the record of "exotic" taxa quoted by previous authors.

At 10,523' *G. obliquum* indicates Subzone UC19"ii".

Well 2/5-1

Existing data available:
RRI (1990) Summary log (no raw data); RRI (1970) micropalaeontology chart and discussion; Paleoservices (1981) report and diagrams; Geolab (1990 chart).

Existing data evaluation:
RRI (1990) interpretation not possible to follow without raw data; Paleoservices (1981) and Geolab (1990) data set weak through Ekofisk Formation, but adequate through Tor Formation and very weak in the Magne Formation and below. Microfaunal recovery is poor from the well indurated chalk drilled in this well.

New analyses:
Micropalaeontology = 3
Nannoplankton = 15 c + 13 dc
Palynology = 0

Stratigraphic interpretation:

Depth	Formation	Age	Zone
9,970' - 10,276'	Ekofisk	Danian	NNTp5B – NNTp1?

Comments: Microfaunal recovery through the Ekofisk is very poor, but the recovery of rare *G. pseudobulloides* and *G. daubjergensis* at 9,970' confirm a "late" Danian age at this depth.

Data set weak through the Ekofisk Formation with varying amounts of reworked Late Cretaceous taxa. There is no evidence to support the RRI (1990) interpretation of a repeat sequence in the Ekofisk Formation from this data set.

The high relative abundance of *P. tenuiculus* at 10,025' in the RRI (1990) data set may be due to intra-formational reworking.

At 10,005' the FDO of influx *P. dimorphosus* indicates Subzone NNTp4F. Below 10,082' the absence of *N. saepes* suggests Subzone NNTp4C and below 10,200' the absence of *P. martinii* indicates Subzone NNTp4B.

There is tentative evidence for the presence of Zone NNTp1 at 10,252', and therefore a possible hiatus within the Ekofisk Formation.

Depth	Formation	Age	Zone
10,276' – 11,399'	Tor	Maastrichtian	UC20"iii" - UC18 FCS23 – FCS22

Comments: Poor recovery and low diversity assemblages from the top of the Tor Formation at 10,294.5', suggest the presence of Subzone UC20"iii". A more or less complete Late - Early Maastrichtian sequence (Zone UC20 to UC18) can be identified between 10,294.5' and 11,440'. However, the assemblages recovered from 11,430' and 11,440' are interpreted as caved given the log evidence for Magne Formation at 11,399'.

A definite latest Maastrichtian date (Subzone FCS23e) is confirmed by the records of *P. elegans* and *R. contusa* between 10,296'(core) and 10,315' (core). *P. elegans* is present in core to 10,636' confirming Subzone FCS23c to this depth. The recovery of the ostracod *Neocythere* cf. *virginea* to 11,030' supports a Late Maastrichtian (Zone FCS23) date.

The records of both *A. bettenstaedti* and consistent *Rugoglobigerina* spp. at, and below 11,300', confirm the Early Maastrichtian Zone FCS22 at this level.

Depth	Formation	Age	Zone
11,399' – 11,606'	Magne	Late Campanian	UC15"iv"

Comments: Assemblages (including *O. campanensis, R. anthophorus* and *B. parca parca*) characteristic of Subzone UC15"iv" at 11,460' support the log evidence for the presence of sediments belonging to the Magne Formation. Red coloured chalk is logged at 11,480' supporting the suggestion that this is close to the top of the Magne Formation.

The data from between 11,580' and 11,800' is very weak and therefore the age is indeterminate.

Depth	Formation	Age	Zone
11,606' – 12,060'	Narve	Early Santonian - Turonian	FCS18 – FCS16 FCS15a

Comments: Samples below 11,620' contain *Cenosphaera* spp. together with the planktic foraminiferids *G. bulloides* and *Whiteinella baltica*. These taxa are characteristic of Santonian to Coniacian chalks and, within the Narve, occur in basal Zone FCS18 to FCS16. The presence of common *Cenosphaera* spp. at 11,940'is used here to indicate Subzone FCS15a, within the Early Turonian.

The FDO of *E. floralis* at 11,820' indicates a broad Zone UC11/10. The Subzone UC10"i" attribution at 11,970' is considered caved.

Well 2/5-7

Existing data available:
Shell (1984) micropalaeontological report and diagrams (50 samples); Agip (1994) Nannoplankton report diagrams (26 samples).

Existing data evaluation:
Shell (1984) Micropalaeontological data unintelligible, very poor quality, very low diversity nannoplankton data; Agip (1994) Nannoplankton data of good quality.

New analyses:
Micropalaeontology = 3 dc
Nannoplankton = 3 dc
Palynology = 0.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
3,168.5m – 3,175m	Vidar	Indeterminate	Indeterminate

Comments: Minor late Cretaceous reworking in the nannoplankton assemblage at 3,172m.

Depth	Formation	Age	Zone
3,175m – 3,189.9m	Lista	Indeterminate	Indeterminate

Comments: No data available

Depth	Formation	Age	Zone
3,189.9m – 3,204m	Våle	“early” Thanetian - “late” Danian	NNTp6 – NNTp5B

Comments: The 1984 Shell data is of poor quality but suggests Subzones NNTp6-5B for the Våle Formation at 3,189.9m based on common *P. martinii*, common *C. edentulus* and common *P. bisulcus*. The LDO of *N. perfectus* is at 3,198m.

Depth	Formation	Age	Zone
3,204m – 3,347m	Ekofisk	Danian	NNTp4 - NNTp1?

Comments: Resolution beyond a general NNTp4 age for the Ekofisk Formation at 3,205m is not possible due to poor data quality.

A 62m sample gap exists between 3,205m and 3,267m, where Subzone NNTp2E is identified, once again confidence in this attribution is low due to poor data quality.

There is a major increase in Maastrichtian reworking at 3,284m, constrained to Subzone NNTp2E based on an impoverished *in situ* assemblage. Confidence in this data set is low. Reworked Late Maastrichtian assemblages continue to dominate down to 3,348m making zonal attribution extremely difficult.

Depth	Formation	Age	Zone
3,347m – 3,726m	Tor	Late Maastrichtian - Late Campanian	UC20“iii” - UC16

Comments: The impoverished assemblage recovered from 3348.25m is composed entirely of Late Cretaceous restricted taxa which suggests Subzone UC20“iii” at the top of the Tor Formation, however, confidence remains very low due to extremely poor data quality.

The isolated sample at 3,414.5m confirms Late Maastrichtian sediments to at least this depth (Subzone UC20“i” based on the occurrence of *N. frequens*). Age identification at samples 3,458m and 3,549m is not possible due to very poor data.

The subsequent occurrence of *R. levis* at 3,560m suggests the presence of Early Maastrichtian age sediments and the occurrence of *B. parca constricta* at 3,608m suggests Zone UC16 at this depth in otherwise poor assemblages.

Depth	Formation	Age	Zone
3,726m – 3,955.5m	Magne	Late Campanian	UC15 & UC14“iv-ii”

Comments: Confidence in this age attribution, based on the occurrence of *E. eximius* at 3,960m, remains low given the log evidence for top Magne Formation at 3,726m and the very poor quality of the nannoplankton data.
A Subzone UC14“iv-ii” attribution at 3,961m may be complicated by caving.

Depth	Formation	Age	Zone
3,955.5m – 3,983m	Thud	Santonian	UC13? FCS18 - ?FCS17

Comments: The Zone UC13? attribution at 3,979m (based on a low diversity assemblage) supports the log evidence for presence of sediments belonging to the Thud Formation.
The records of *S. granulata polonica* at 3,970m indicate a Middle-Early Santonian age at this depth and would equate with a level low in the Thud Formation. The age is further supported by records of *Cenosphaera* spp. and *S. exsculpta exsculpta* at 3,979m.

Depth	Formation	Age	Zone
3,983m	Narve	Coniacian	UC11

Comments: Narve Formation sediments of Zone UC11 or older are seen at, and below, 3,983m based on the occurrence of *E. floralis* (Agip report text).

Well 2/5-9

Existing data available:
STL (1992) Report and distribution charts; AMO (19XX) Distribution chart.

Existing data evaluation:

New analyses:
Micropalaeontology = 0
Nannoplankton = 0
Palynology = 0

Stratigraphic interpretation:

Depth	Formation	Age	Zone
3,250m – 3,259.9m	Våle	"early" Thanetian - "late" Danian	NNTp6

Comments: Moderately common *N. perfectus*, rare *P. dimorphosus* and common *P. martinii* at 3,252m. The LDO of *N. perfectus* is at 3,258m.

The occurrence of *G. pseudobulloides* at 3,252m indicates abroad "early" Thanetian – "late" Danian age range.

Depth	Formation	Age	Zone
3,259.5m – 3,380.4m	Ekofisk	Danian	NNTp4F - NNTp2F

Comments: The increased abundance of *P. dimorphosus* and common *C. edentulus* at 3,267m indicates Subzone NNTp4F. At 3,276m NNTp4C is suggested by the absence of *N. saepes*.

The LDO of *P. martinii* at 3,294m with *N. modestus* recorded down to 3,375m indicates Subzone NNTp4B.

An increase in the abundance of *P. tenuiculus* is noted at 3,357m, but is not utilised for zonal sub-division as it may be due to intra-formational reworking.

At 3,381m, the low diversity *in situ* assemblage and relatively high reworking component (Subzone NNTp2F) may in fact be part of the "lag" deposit between the Ekofisk and Tor Formations.

The FDO of *G. daubjergensis gigantea* at 3,300m confirms a level within Zone MT2 at this depth.

Depth	**Formation**	**Age**	**Zone**
3,380.4m – 3,745.7m	Tor	Late Maastrichtian - Late Campanian	UC20"ii" - UC16 FCS23e - ?FCS22

Comments: At 3,384m the FDO of *C. daniae* is used to define Subzone UC20"ii". Then assuming *N. gorkae* is equivalent to *N. frequens,* Subzone UC20"i" is recorded down to 3,584m. Reworking of Early Maastrichtian species is recognised at 3,584m.

Zone UC19 is assigned between 3,584m and 3,646m on the occurrence of *S. primitivum*. An increase in *C. obscurus* at 3,660m may indicate Subzone UC19"i".

The FDO of *R. levis* at 3,693m indicates Zone UC18 in the Early Maastrichtian and the FDO of *B. parca constricta* at 3,741m indicates Zone UC16.

The common occurrence of *P. elegans,* with *R. contusa*, between 3,381m and 3,411m confirms Subzones FCS23e-c between these depths. *P. elegans* continues in cuttings to 3,561m implying FCS23 to this depth. A broad ?FCS22 zonal date is indicated below this, but this is not confirmed until the FDO of *G. bulloides* at 3,717m.

Depth	**Formation**	**Age**	**Zone**
3,745.7m – 3,897m	Magne	Campanian	UC16 – UC14 FCS21b-a

Comments: The sample at 3,772m contains an increased agglutinating foraminiferid content, with *Dorothia retusa*, but lacking the zonal index *T. capitosa*. Nevertheless, the fauna present is characteristic of Zone FCS21. The dating is also supported by records of common *Rugoglobigerina* spp. at 3,783m and *Reussella szajnochae* at 3,807m. The FDO of specimens referred to *S. granulata incondita/perfecta* at 3,843m is used to define Subzone FCS21a. The specimens of *S. granulata polonica* at 3,861m are believed to be reworked.

Caving of Zone UC16 assemblages into the top of the Magne Formation is evident down to 3,772m.

B. geminicatillus, E. eximius and *O. campanensis* with *R. levis* at 3,783m indicates Subzone UC15"iii" or older.

Depth	Formation	Age	Zone
3,897m – 4,077.5m	Narve	Santonian – Turonian	UC11 or older FCS18 – FCS15

Comments: Consistent *S. granulata polonica* occurs below 3,897m indicating Zone FCS18. A complete sequence of zones is recorded, defined by the records of *Marginotruncana* spp. (below 3,903m - ?FCS17), with *M. pseudolinneiana* at 3,933m, *S. granulata granulata* at 3,951m (FCS17-16), common radiolaria including *D. constricta* and *D. multicostata* at 3,993m, *S. granulata kelleri* at 4,023m (FCS16a) and common *Cenosphaera* spp. at 4,053m (FCS15).

FDO of *Q. eneabrachium* at 3,993m indicates Zone UC11 or older. Assemblages above this depth are complicated by caving.

R. asper at 4,074m supports the Early Turonian age indicated by the microfauna.

Depth	Formation	Age	Zone
4,077.5m	Blodøks	-	-

Comments: Impoverished, non-age diagnostic nannoplankton assemblage at 4,086m**.**

Well 2/7-2

Existing data available:
RRI (1971) Micropalaeontological report with charts.

Existing data evaluation:
The core and ditch cuttings samples analysed for nannoplankton yield good to moderate assemblages.

New analyses:
Micropalaeontology = 0
Nannoplankton = 4c + 14 dc
Palynology = 0.

Reasonably clean core samples available for analyses. Moderately clean ditch cuttings samples available for analyses, however, minor mixing of lithologies meant care was necessary when selecting grains for preparation of nannoplankton slides.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
9,649' - 9,715'	Våle	“early” Thanetian - “late” Danian	MT3

Comments: Rare planktic foraminiferids, including *S. triloculinoides* and *G. pseudobulloides* occur below 9,660' indicating Zone MT3.

Depth	**Formation**	**Age**	**Zone**
9,715' - 9,856'	Ekofisk	Danian	MT2B

Comments: Definite "late" Danian chalks are present at 9,720', based on the FDO of *G. daubjergensis* at this depth. This zone is continued to 9,840' as *P.* cf. *compressa* is logged to this depth.

No sediments assignable to the Ekofisk Formation were selected for nannoplankton analyses.

Depth	**Formation**	**Age**	**Zone**
9,856' - 10,454'	Tor	Late Maastrichtian - Late Campanian	UC20"i" - UC19"ii" FCS23c - FCS22/?21

Comments: The highest definite Late Maastrichtian microfaunal date is provided by the FDO of *P. elegans* (Subzone FCS23c) at 10,000'. Microfaunal data below this is very sparse and it is only the consistent occurrence of *Rugoglobigerina rugosa* between 10,200' and 10,560' which permits the recognition of Zones FCS22 – FCS21.

Sediments of Subzone UC20"i" lie on sediments assigned to Subzone UC19"ii" between 10,000' and 10,130' based on the occurrence of *G. obliquum* and *S. primitivum*. There is a 50' sample gap between 9,950' and 10,000'. The core and ditch cuttings samples analysed in this interval contain good nannofloral assemblages.

No samples were selected for nannoplankton analyses between 10,130' and 10,900', below which samples were selected at 100' intervals

Depth	**Formation**	**Age**	**Zone**
10,454' – 11,220'	Magne	Campanian	UC15"iii" – UC15"i"

Comments: Log evidence for the presence of Magne Formation sediments at 10,454' is supported by the nannoplankton samples analysed between 10,900' and 11,090'. The occurrence of *E. eximius, H. trabeculatus* and *O. campanensis* suggests a Late Campanian, Subzone UC15"iii" age. Nannofloral recovery is slightly reduced through this interval.

The first downhole occurrence of *L. grillii* is taken to indicate the presence of Subzone UC15"i" or older of Early Campanian age at 11,190'.

Depth	**Formation**	**Age**	**Zone**
11,220' – 11,458'	Thud	Early Campanian - Santonian	UC14 ?FCS18

Comments: An influx of planktic foraminiferids at 11,240', including *G. linneiana*, is used to define the top of Zone FCS18, which implies a Santonian age. This dating is supported by the FDO of *Gavelinella ?arnagerensis* at 11,260'.
The presence of sediments of Early Campanian age in the well section is supported at 11,290' by the occurrence of *B. geminicatillus* and *C. biarcus*. The occurrence of *Z. biperforatus* at

this depth may suggest penetration of sediments assignable to Subzone UC14“ii”, supporting log evidence for penetration of the Thud Formation.

Depth	**Formation**	**Age**	**Zone**
11,458’ – 12,281’	Narve	Coniacian or older	UC11“ii” – UC10“i” FCS17a-FCS15

Comments: The occurrence of the planktic *M. marginata* between 11,560’ and 11,920’ is used here to indicate a zonal range of FCS17a – FCS15, i.e. Coniacian – Turonian. Microfaunal recovery is generally very poor, although it does improve considerably below 11,800’.

The RRI report includes records of the Cenomanian (or Albian) planktic form *Rotalipora* spp. below 12,200’. These are either mis-identified or reworked as they would occur well above the Blodøks Formation.

The increase in the abundance of *H. trabeculatus* and *W. barnesae* at 11,390’ indicate the presence of Subzone UC11“ii”, and the presence of sediments belonging to the Narve Formation of Late Coniacian age. The biostratigraphic pick occurs 68' above the log pick for the top of the Narve Formation.

Subzone UC10“i” is identified between 11,600' and 11,700' based on the occurrence of *Tortolithus virginica* and *Q. intermedium*.

Depth	**Formation**	**Age**	**Zone**
12,281’	Blodøks	-	-

Comments: No reliable biostratigraphic data available.

Well 2/7-4

Existing data available:
PHI (1991) Report with taxa lists; AGP (1995) Distribution chart; PHI (1994) Review of data.

Existing data evaluation:
PHI (1991) Good quality data; AGP (1995) Good quality data, but difficult to re-interpret; PHI (1994) Good quality data. Microfaunal identifications and taxonomy questionable without considerable caving/contamination.

New analyses:
Micropalaeontology = 0
Nannoplankton = 7 c
Palynology = 0

Reasonably clean core samples available for analyses.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
10,095' – 10,164'	Våle	Indeterminate	Indeterminate

Comments: Based on wireline log data only.

Depth	Formation	Age	Zone
10,164' – 10,458'	Ekofisk	Danian	NNTp5A-1 MT3-MT2

Comments: Nannofossil assemblages recovered from between 10,224' and 10,368' show an essentially complete sequence from Subzone NNTp5A (10,224') to NNTp4C (10,368').
Late Cretaceous reworking is recorded in trace amounts through this interval with the exception of the sample at 10,293', which is characterised by abundant Maastrichtian reworking.

Significant Maastrichtian microfaunal and nannofloral reworking is recorded between 10,327' and 10,388'.

An increase in the abundance of *in-situ* Paleocene restricted taxa, including abundant *P. tenuiculus* indicates the presence of "middle" Danian age sediments (Zone NNTp3).

Sediments of "early" Danian age are recorded between 10,421' (Subzone NNTp2E/F) and 10,451' (base NNTp1). Conspicuous Maastrichtian reworking is recorded within this interval.
The presence of a planktic association, comprising *G pseudobulloides* and *S. triloculinoides* (at 10,239, core) and *P. compressa* (at 10,248', core), confirms a Danian (Zones MT3 – MT2) age on the basis of the microfauna.

Depth	Formation	Age	Zone
10,458' – 10,881.4'	Tor	Late Maastrichtian	UC20"ii" - UC19"ii" FCS23e –FCS22

Comments: The Tor Formation sediments analysed in this well between 10,455' and 10,708' are all of Late Maastrichtian age (253' analysed), principally Subzone UC20"i" based on the occurrence of *N. frequens*. Subzone UC 20"ii" was identified at the top of the Tor Formation between 10,455' and 10,473'. Subzone UC19"ii" was identified in the bottom sample analysed at 10,708', based on the occurrence of *G. obliquum*.

The top Maastrichtian is indicated by the presence of *Heterohelix* spp. at 10,461'(core). The occurrence of abundant *P. elegans* at 10,465' indicates Subzone FCS23e at this depth. *B. draco* is recorded at 10,495'(core) supporting the FCS23d assignment and the occurrence of *P. elegans* and *R. fructicosa* to 10,580'(core) confirms FCS23c to this depth.
Below this level the microfaunal data is very sparse, with only the LDO of *B. draco* logged at 10,610'. This occurs within the range of zones FCS23 – FCS22.

Depth	Formation	Age	Zone
10,881.4'	Magne	-	-

Comments: No biostratigraphic data available.

Well 2/7-8

Existing data available:
RRI (1973) Micropalaeontological and Nannofloral report and charts.

Existing data evaluation:
RRI (1973) data suggests poor nannofloral recovery from ditch cuttings samples. Microfaunal data good, taxonomy considerably out of date.

New analyses:
Micropalaeontology = 0
Nannoplankton = 9 dc
Palynology = 1 dc

Moderately clean ditch cuttings samples available for analyses, however, mixing of lithologies meant great care was necessary when selecting grains for preparation of nannoplankton slides.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
9,744' - 9,943'	Ekofisk	Danian	NNTp5B – NNTp2E MT2

Comments: Weak assemblages recovered from the Ekofisk Formation, but they suggest a “late” Danian sequence between 9,718’ and 9,870’. Maastrichtian reworking increases below 9,790', dominating the assemblage between 9,810' and 9,890’. The LDO of *N. perfectus* is at 9,710’.

Sediments of “early” Danian age are identified between 9,880' and 9,930' (tentatively assigned to Subzone NNTp2E) once again based on sparse *in situ* Danian taxa amongst reworking.

“Late” Danian microfaunas were recorded below 9,710’, probably within the Våle interval. The interval is dominated by reworked Maastrichtian taxa.

Depth	Formation	Age	Zone
9,943’ – 10,273’	Magne	Late – Early Campanian	UC16“ii” - UC14 FCS22?- FCS20

Comments: The sample analysed at 9,950' appears to be of Early Maastrichtian age (Zone UC18). The nannoplankton evidence is supported by microfaunal data provided in the RRI report. No Late Maastrichtian age sediments (Zones UC20 and UC19) have been identified in this well.

The data from the sample at and below 10,010' is somewhat weak and the Zone UC18 attribution down to 10,050' is probably due to poor sample quality and/or caving given the log pick for top Magne Formation at 9,943’. Microfaunal data (top *T. capitosa*) at 10,050’ indicates Subzone FCS21b, within the Magne Formation. The Early Campanian Subzone FCS21a is indicated by the records of *S. exsculpta gracilis* at and below 10,090’

The Subzone UC16“ii” or older attribution at 10,070' is based on a single specimen of *R. anthophorus* in an otherwise impoverished assemblage.

Poor nannofloral recovery between 10,090' and 10,210' prohibits accurate zonal determination.

The occurrence of *B. parca parca, E. eximius, H. trabeculatus, O. campanensis* and *S. biferula in* slightly improved assemblages at 10,240' confirms the presence of sediments of Early Campanian age, Subzone UC14“iii/iv” in the Magne Formation.

The single ditch cutting sample examined for palynology from this interval, at 9,960’ yielded no in situ taxa.

Depth	**Formation**	**Age**	**Zone**
10,273’ – 10,460’	Thud	Early Campanian - Santonian	UC14“ii” - UC13 FCS18

Comments: The FDO of *B. enormis* at 10,280' indicates penetration of sediments of Subzone UC14“ii” or older, complimenting the log data for the presence of Thud Formation sediments at 10,273'.

The FDO’s of *S. exsculpta exsculpta* and *S. granulata polonica* at 10,270’ indicate an age within the Santonian, consistent with the Thud identification at 10,273.

Depth	**Formation**	**Age**	**Zone**
10,460’ – 10,887’	Narve	Coniacian – Turonian	FCS17 – FCS15a

Comments: An apparent complete succession is recorded through this interval on the basis of the microfaunal data presented in the RRI report. The FDO of *S. granulata granulata* at 10,460’ (FCS17) is coincident with the top of the Narve Formation Other zonal index markers are recorded throughout the interval.

The weak nannoplankton data set below 10,460' again prohibits accurate nannofloral zonal determination, however, the occurrence of *M. furcatus* at 10,650' and *E. floralis* at 10,730' is consistent with a Turonian/Coniacian age.

Well 2/7-15

Existing data available:
RRI (1980) Micropalaeontology and nannopalaeontological report and charts. IKU (1980) Micropalaeontology and nannopalaeontological report and charts.

Existing data evaluation:
1980 Nannoplankton data is relatively weak. However a good data set has been generated by the new analyses.

New analyses:
Micropalaeontology = 0
Nannoplankton = 33 dc
Palynology = 2 dc.

Reasonably clean ditch cuttings samples available for analyses, however, mixing of lithologies meant great care was necessary when selecting grains for preparation of nannoplankton slides.

Stratigraphic interpretation:

Depth	**Formation**	**Age**	**Zone**
2,983m - 3,004m	Våle	"late" Danian	MT3 –MT2

Comments: Planktic foraminiferids are recorded below 2,990m (MT3) with *G. daubjergensis* below 2,996m (MT2). These records are slightly out if phase with the lithostratigraphic picks; this being regarded as a log to sample discrepancy.

Depth	**Formation**	**Age**	**Zone**
3,004m - 3,038m	Ekofisk	Danian	NNTp5B – NNTp2D MT2 (in part)

Comments: Relatively thin "late" Danian sequence. Increased Maastrichtian reworking at 3,011.42m and 3,012m.

The LDO of *P. compressa* at 3,014m agrees with the nannoplankton data, implying only a thin "late" Danian section to this depth.

"Early" Danian age based on sparse *in situ* nannoflora amongst reworked Maastrichtian assemblages. Implies intra Danian hiatus.

Two ditch cutting samples, at 3000m and 3006m, have been analysed palynologically from this interval. Both assemblages included the dinocyst *Alisocysta reticulata* and that from 3000m *Spiniferites "magnificus"*. These taxa indicate a Late Danian age, Zone PT2.

Depth	**Formation**	**Age**	**Zone**
3,038m - 3,148m	Magne	Late -Early Campanian	UC16"i"- UC14"ii" FCS21b? – FCS20

Comments: The FDO of *T. capitosa* at 3,038m indicates an FCS21b or older age at this depth. This age is confirmed by the recovery of *Globotruncana stephensoni* at 3,048m. This species, recorded by IKU, is considered synonymous with *G.* aff. *arca*.

An Early Campanian data is recorded at 3,075m based on the FDO of *S. granulata incondita*. Further evidence for the age is provided by records of *S. exsculpta gracilis* (Zone FCS20) below 3,081m.

No evidence for Late Maastrichtian age sediments (comparable to Well 2/7-8). Occurrences of *B. parca constricta* (3,042m), *R. anthophorus* (3,048m), *M. quaternarius* and *B. parca parca* (3,060m) indicate Late Campanian (Subzone UC16"i").

The FDO *B. geminicatillus* (3,069m) indicates presence of Subzone UC15"ii" or older sediments. Nannofloral recovery reduced between 3,069m and 3,112m. Improved recovery together with the FDO *S. biferula* suggests Subzone UC14"iv" or older at 3,115m.

Specimens of *S. granulata polonica* recorded at and below 3,121.15m are regarded as being due to the diachroneity problem outlined for this taxon by Bergen & Sikora (1999) or simply due to reworking or mis-identification. In the absence of the original material, no check could be carried out.

Depth	Formation	Age	Zone
3,148m - 3,180m	Thud	Santonian	UC12 or older FCS18

Comments: Zone UC12 attribution tentative due to reliance on absences (i.e. *A. cymbiformis*) in assemblages recovered from ditch cuttings samples.
Consistent *S. granulata polonica* are recorded below 3,157.73m confirming Zone FCS18 at this depth.

Depth	Formation	Age	Zone
3,180m - 3,364m	Narve	Coniacian - Turonian	UC11 – UC7 FCS17a– FCS15

Comments: The common occurrence of *M. marginata* below 3,197m implies an age within the subzonal range FCS17a – FCS16a. A more definite Turonian (FCS15) age is indicated at 3,230.88m by the records of *Dicarinella* cf. *imbricata* and *D.* aff. *primitiva.*

FDO *Q. eptabrachium* indicates penetration of the Narve Formation (3,230.88m). Low confidence through this interval due to poor nannoplankton data. Assemblages consistent with a Coniacian -Turonian age.

Depth	Formation	Age	Zone
3,376m - 3,395m	Hidra	Late Cenomanian	FCS13c

Comments: The presence of *R. cushmani* and *R. reicheli* at 3,377.18m confirms the Late Cenomanian age (FCS13c).

Well 2/7- 30

Existing data available:
RRI (1995/6) Distribution Chart; NSC (1996) Distribution Chart and report.

Existing data evaluation:
RRI (1995/6) Good quality raw data from core, ditch cuttings and sidewall core samples. NSC (1996) Good quality raw data from core samples.

New analyses:
Micropalaeontology = 0
Nannoplankton = 19 dc
Palynology =0.

Moderate quality ditch cuttings samples available for analyses. Careful washing and preparation ensured reliable assemblage recovery.

Stratigraphic interpretation:

Depth	**Formation**	**Age**	**Zone**
10,200’ – 10,260’	Lista	“middle – early” Thanetian	PT4C & PT4B – PT3

Comments: The occurrence of abundant *Palaeoperidinium pyrophorum* at 10,200’ suggests a “middle” Thanetian, Zone PT4C age, whereas the subsequent occurrence of *Isabelidinium viborgense* and *Palaeocystodinium bulliforme* (RRI) is indicative of an “early” Thanetian age.

Depth	**Formation**	**Age**	**Zone**
10,269' - 10,335'	Våle	“early” Thanetian - “late” Danian	NNTp5B – NNTp6 MT4 – MT3 PT2

Comments: Nannofloral recovery includes common *N. perfectus* and *Toweius* sp. at 10,260’ and 10,290’. The record of a nannoflora characteristic of Zone NNTp6 apparently above the top of the Våle Formation is probably due to a sample to log depth discrepancy.

Planktic foraminiferid recovery at and below 10,270’ confirms a zonal range of MT4-MT3.

The records of *Spiniferites “magnificus”* at 10,270’ and *A. reticulata* at 10,302.00 (co) prove a “late” Danian, Zone PT2 age.

Depth	**Formation**	**Age**	**Zone**
10,335’ - 10,635’	Ekofisk	“late – early” Danian	NNTp4 –NNTp3 MT2b PT1

Comments: Relatively thick (>200’) “late” Danian sequence including Subzones NNTp4E-B. Subzone NNTp4F not recognised although a sample gap exists between 10,300’ and 10,314’. Major Maastrichtian reworking concentrated at 10,399’ and 10,463’. Age indeterminate at 10,551’ due to dominance of reworked Maastrichtian taxa.

The presence of common planktic foraminiferids, including *P.* cf. *compressa* to 10,472’, indicates an age no older than MT2b to this depth. Reworked microfaunas occur below this depth, dominating the assemblages recorded between 10,551’(core) and 10,605’(core)

The interval 10,568’ – 10,572’ is dominated by reworked Maastrichtian taxa. Age (Zone NNTp3) is based on increase in the abundance of *P. tenuiculus*.

"Early" Danian (Zone NNTp2) sediments identified on the occurrence of *H. edwardsii* at 10,578'.

The occurrence of a palynomorph assemblage with significant numbers of *Senoniasphaera inornata* at 10,578'(core) confirms an "early" Danian age at this depth (Zone PT1)

Depth	Formation	Age	Zone
10,635' - 10,920'	Tor	Late Maastrichtian - Late Campanian	UC20"ii" – UC16"ii" FCS23e-?c

Comments: The occurrence of *C. daniae* and *N. frequens* at 10,620' indicates the presence of Late Maastrichtian sediments assignable to Subzone UC20"ii". Subzones UC20"i" (10,679') and UC19 (10,770') are also present, suggesting at least 170' of Late Maastrichtian sediments.

Early Maastrichtian sediments (Zone UC18) are based on the occurrence of *R. levis* at 10,800' and *B. parca constricta* (Subzone UC16"iii") at 10,920' indicates penetration of Late Campanian. No evidence for Zone UC17 was identified implying a hiatus, however this may be a function of poor nannofossil recovery in the ditch cuttings samples. Subzone UC16"ii" is recognised at 10,950' based on FDO of *R. anthophorus*. This is considered caved given the log evidence for Magne Formation at 10,920'.

Definite Late Maastrichtian microfaunal elements are rare being restricted to *Osangularia navarroana* at 10,706'(core) and *P. elegans* at 10,730'(core) within an FCS23e-c range.

Depth	Formation	Age	Zone
10,920' - 11,201'	Magne	Campanian	UC15 ?FCS21

Comments: The presence of Magne Formation sediments is confirmed at 11,000' with the occurrence of *O. campanensis* together with *E. eximius* (11,010'). The subsequent occurrence of *B. geminicatillus* (11,080') and *L. grillii* (11,120') suggest the presence of sediments of Early Campanian (Subzones UC15"ii-i") age.

The top of ?Zone FCS21 is very tentatively based on the occurrence of common *R. rugosa* at 10,920'. The microfaunal distribution within this unit is difficult too interpret as RRI record Early Campanian – Santonian elements at 11,010'.

Depth	Formation	Age	Zone
11,201'	Thud	Early Campanian	UC14 FCS20 -?FCS19

Comments: A Subzone UC14"iv–iii" subzonal attribution for the Thud Formation in this interval is younger than other attributions for this Formation. This is considered to be due to caving of the ditch cuttings samples in this well.

Microfaunal recovery is very poor in this interval and a broad Early Campanian age is indicated only by the records of the FDO of *Whiteinella baltica* at 11,090' and the LDO of *Pullenia* spp. at 11,334'(swc). Abundant *Cenosphaera* spp. occur at 11,390' and

11,407'(swc), suggesting a possible Late Santonian (?FCS19 Zone) age between these depths, at the base of the Late Cretaceous sequence.

Well 2/7-B-11

Existing data available:
EPA (1994) Succession page with distribution chart; RRI (1982) Full report; NSC (1995) Report only; NPD (no date) Distribution chart only.

Existing data evaluation:
RRI (1982) Good quality data; NSC (1995) Good quality core data; NPD (no date) Moderate quality data. The EPA and RRI microfaunal data is frequently difficult to combine taxonomically and open to some duplication; some identifications are also very questionable.

New analyses:
Micropalaeontology = 0
Nannoplankton = 28 c
Palynology = 0.

Good quality core sample material available for all analyses.

Stratigraphic interpretation:

Depth	**Formation**	**Age**	**Zone**
9,754' - 9,805'	Våle	"early" Thanetian	NNTp7/6 MT4

Comments: Moderately common *P. martinii* and *N. perfectus* together with *Toweius* sp. in core samples down to 9,843.5' indicates the presence of sediments assignable to the Våle Formation (Subzones NNTp7B/6). This differs from the log interpretation which places samples at, and below, 9,805' within the Ekofisk Formation. This is attributed to a core to log shift of approximately 36'.

A sparse planktic foraminiferid (Zone MT4) assemblage, noted at 9,813', is believed to originate from this interval due to the core to log shift.

Depth	**Formation**	**Age**	**Zone**
9,805'- 10,056'	Ekofisk	Danian	NNTp4 – NNTp2 MT2

Comments: A sequence representative of Subzones NNTp4B-D can be identified in this interval. Subzone NNTp4F was not identified. Maastrichtian reworking is recorded in minor amounts – a feature which distinguishes the Eldfisk Bravo structure from Eldfisk Alpha and Ekofisk.

Zone NNTp3 is assigned based on the increase in the abundance of *P. tenuiculus* at 9,978.5'. This zone is commonly absent in the study area and its presence on this structure again differs from adjacent structures.

The FDO *H. edwardsii* confirms the presence of "early" Danian sediments (similar to Well 2/7-30) at 9,996.5'. There is a sample gap between 9,990' and 10,060'.

Microfaunal recovery from the top of this interval is poor, with the zonal species *G. pseudobulloides* and *P.* aff. *compressa* not recorded until 9,938'(core).

Depth	**Formation**	**Age**	**Zone**
10,056' - 10,413'	Tor	Maastrichtian	UC20 – UC18 FCS23

Comments: The influx of Late Cretaceous taxa is taken to indicate penetration of the Tor Formation. The presence of Subzone UC20"ii" is confirmed at 10,060' with the occurrence of *C. daniae* and *N. frequens*. Subzone UC19"iii" occurs at 10,081'. The first downhole occurrence of *S. primitivum* at 10,117.5' suggests Subzone UC19"ii", however, the occurrence of C. *obscurus* (NPD data) in some samples suggests Subzone UC19"i". Confidence in this assignment is low and the whole interval is given a Subzone UC19"ii/i" attribution. This is an uncharacteristically thick Zone UC19 section and confidence remains low due to the occurrence of Danian contaminants in the core samples analysed down to 10,126'.

Maastrichtian foraminiferids occur commonly below 10,060', but the FCS23 zonal index, *P. elegans*, is only recorded at 10,072'(core). The Early Maastrichtian species *A. bettenstaedti*, recorded below 10,126'(core) has been interpreted as being reworked, as has the record of *T. capitosa* at 10,238'(core).

At 10,390', the FDO of *R. levis* indicates Zone UC18 in the Early Maastrichtian. Reworking, in the form of *H. trabeculatus,* is also observed. This taxon occurs in Campanian and older sediments, but is common within Zone UC11 (Coniacian).

Depth	**Formation**	**Age**	**Zone**
10,413' - 10,460'	Magne	Campanian	UC16 – UC14 FCS21a

Comments: The FDO of *M. quaternarius* and *R. anthophorus* indicate the presence of Late Campanian sediments (Subzone UC16"ii") and implies an unconformity between the Tor and Magne Formation. This zone usually represents the basal zone in the Tor Formation, however log evidence at 10,413' suggests Magne Formation (due to core to log shift). Magne Formation sediments assignable to Subzone UC15"iii" (FDO *E. eximius, H. trabeculatus* and *O. campanensis*) at 10425.5'and Subzone UC14"iv-iii" (FDO *S. biferula*) at 10,443.5'.

Long-ranging taxa dominate the microfauna through this interval, although the LDO of *S. pommerana* at 10,444'(core) and the FDO of *Gavelinella stelligera* at 10,450'(core) are consistent with Subzone FCS21a at this level.

Depth	**Formation**	**Age**	**Zone**
10,460'	Narve	Coniacian-Turonian	UC10 - UC9 FCS15c

Comments: Narve Formation is confirmed at 10,460' with the FDO of *H. turonicus*, *E. floralis* and abundant *W. barnesae* indicative of Subzone UC10"i". The increase in the abundance of *H. turonicus,* in the absence of *M. staurophora,* at 10,479.5' is taken to indicate the presence of Subzone UC9"i" of Late Turonian age.
Despite the extensive microfaunal assemblage recorded by RRI and EPA through this section, few reliable or stratigraphically significant taxa are recorded. The downhole influx of *Cenosphaera* spp. between 10,595'(core) and 10,649'(core) has been used here to indicate the Middle Turonian Subzone FCS15c at these depths.

Well 2/8-A-1

Existing data available:
RRI (1982) Full report with summary log and distribution charts; PSV (1991) Report on 3 samples only; PSV (1993) Report with summary log; NSC (1997) Report on 18 samples; NSC (1998) Report on Overburden Section; KPN (1992) Distribution chart for 7 samples; AMO (1998) multidisciplinary Distribution chart

Existing data evaluation:
KPN (1992) Poor quality data set; PSV (1991) moderate quality data set; NSC (1997 & 1998) Good quality data sets; AMO (1998) Good quality data, but in house taxonomy and interpretations difficult to decipher.

New analyses:
Micropalaeontology = 0
Nannoplankton = 0
Palynology = 0.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
2,418m – 2,440m	Balder	"Earliest" Eocene	MT8, PT8

Comments: Palynological recovery at 2,418m(core) and diatoms recorded at 2,422m(core) confirm the Balder Formation at this level.

Depth	Formation	Age	Zone
2,440m – 2,447m	Sele	"late" Thanetian	PT7C

Comments: The influx of *Apectodinium* spp. at 2,440m(core) indicates Subzone PT7C, and the top Sele Formation.

Depth	Formation	Age	Zone
2,447m – 2,463m	Lista	"middle" Thanetian	MT6, PT5B

Comments: The abundant recovery of agglutinating foraminiferids at 2,447.0m(core), including *S. spectabilis,* indicates Zone MT6 at the top of the Lista Formation. An influx of

Areoligera gippingensis at 2,458.50m (core) indicates a level within the "middle" Thanetian, Zone PT5B.

Depth	**Formation**	**Age**	**Zone**
2,463m – 2,465.8m	?Våle	"early" Thanetian - "late" Danian	PT4B – PT2

Comments: The association of *I? viborgense* and *P. australinum* recorded at 2,463.0m(core) is characteristic of the "early" Thanetian Subzone PT4B whereas the occurrence of *A. reticulata* and *S. "magnificus*" at 2,465.8m (core) indicates a Zone PT2, "late" Danian age.

Depth	**Formation**	**Age**	**Zone**
2,467.2m - 2,470m	?Ekofisk	?Danian	Indeterminate

Comments: Based on log evidence – no direct evidence for Danian age in nannoplankton samples or in recorded microfauna, therefore assemblages recovered represent 100% Maastrichtian reworking.

Depth	**Formation**	**Age**	**Zone**
2,470m - 2,497m	Tor	Late Maastrichtian - Late Campanian	UC19-UC16"ii" FCS22

Comments: No samples selected for analyses between 2,469m and 2,478m. The core sample at 2,478m contains an assemblage characteristic of Subzone UC19"iii". The subsequent FDO of *S. primitivum* at 2,478.5m(core) indicates Subzone UC19"ii".

Late Cretaceous microfaunal elements are recorded from 2,478.5m(core), including *R. rugosa* and *B. draco* (at 2,479.5m,core). The record of *B. miliaris* at 2,487.5m(core) confirms Zone FCS22 at this depth, within the latest Campanian.

Early Maastrichtian (Zone UC18) is based on the FDO of *R. levis* at 2,478.62m(core) (note this is an isolated occurrence and this taxon does not occur again until 2,486.93m,core, therefore confidence is low).

An intra Tor Formation hiatus is implied by the recognition of Subzone UC16"ii" at 2,487.5m(core) (FDO *R. anthophorus*) and the absence of section representing Zones UC17-16"iii". It is noteworthy that *B. parca* has not been recorded as part of this data set.

Depth	**Formation**	**Age**	**Zone**
2,497m - 2,501.5m	Magne	Campanian	UC15

Comments: Presence of sediments assignable to the Magne is supported by the FDO *E. eximius* at 2,498.3m. No significant microfauna recorded. No significant palynoflora recorded.

Depth	**Formation**	**Age**	**Zone**
2,501.5m - 2,581.5m	Narve	Coniacian - Turonian	UC11 – UC6 FCS17 – FCS14

Comments: An unconformity between Magne and Narve Formations can be identified in this well, effectively removing the Thud Formation (Nannoplankton Zones UC12-14).

Marker species recognised within this section include *Q. eneabrachium* and *H. turonicus* (2,502m) and *Q. intermedium* (2,526.04m) in association with the LDO of *M. staurophora* (2,520.5m), *M. furcatus* (2,533m), *E. eximius* and *K. magnificus* (2,570m).

A reliable sequence of microfaunal markers is recorded by RRI & Amoco between 2,502.5m(core) and 2,582.3m(core).

Relatively diverse assemblages of dinocysts are present in the limited number of core samples examined from this interval. The occurrence of *Stephodinium coronatum* at 2,531.6m (core) proves an age not younger than Turonian at this depth.

Depth	Formation	Age	Zone
2,581.5m – 2,583.5m	Blodøks	-	-

Comments: The sample analysed from the Blodøks Formation is barren of nannoplankton (2,582.3m).

Depth	Formation	Age	Zone
2,581.5m – 2,583.5m	Hidra	Cenomanian	FCS13

Comments: The records of abundant *Hedbergella* spp. below 2,585m(core) and the FDO of the agglutinant *Eggerellina mariae* at 2,590.6m(core) confirm a Cenomanian age, within Zone FCS13.

Well 2/11-A-2

Existing data available:
PSV (1991) Report and summary log; KPN (1992) Distribution chart only.

Existing data evaluation:
PSV (1991) Moderate quality data; KPN (1992) Poor quality data.

New analyses:
Micropalaeontology = 0
Nannoplankton = 2 c
Palynology = 0

Poor quality core material available for analyses.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
3,368m - 3,417m	Tor	Maastrichtian	UC20“ii” – UC18 FCS23a-d, FCS22a

Comments: The occurrence of *N. frequens* between 3,377m and 3,385m indicates the presence of Subzone UC20“i”. The occurrence of *G. obliquum* at 3,389m indicates Subzone UC19“ii” at this depth. No samples were analysed between 3,391m and 3,407m.

The attribution of Early Maastrichtian (Zone UC18) is based on the FDO of *R. levis* at 3,407.5m. The occurrence of *B. parca* (KPN 1992) is considered reworked or misidentified. No samples were analysed between 3,415m and 3,439.5m.
Late Maastrichtian chalks are indicated by *P. elegans, B. draco* and *Rosita walfischensis* at 3,380m(core). Below this depth microfaunal recovery is relatively poor, but at 3,440m(core) the occurrence of *Aragonia aragonensis* confirms the presence of the Early Maastrichtian - Late Campanian (basal Tor) Subzone FCS22a.

Depth	**Formation**	**Age**	**Zone**
3,439.5m - 3,503m	Magne	Campanian	UC15“v” – UC14

Comments: The FDO of *E. eximius* and *R. anthophorus* is taken to indicate penetration of Magne Formation sediments of Subzone UC15“v” age. The subsequent occurrence of *O. campanensis* (3,444m) indicates Subzone UC15“iv”, the occurrence of *H. trabeculatus* (3,464m) indicates Subzone UC15“iii” and *S. biferula* (3,494.65m) suggests Subzone UC14“iv-ii”. Data set relatively sparse for this interval.
Common *Rugoglobigerina* spp. at 3,460m(core) and the FDO of *T. capitosa* at 3,464m(core) are consistent with the Late – Early Campanian (Zone FCS21) date for this interval. The presence of *S. exsculpta gracilis* and *R. szajnochae praecursor* indicate an FCS20 date at 3,488m(core). Records of *S. granulata polonica* at 3,494.15m(core) and 3,495.0m(core), within the Early Campanian Magne Formation are interpreted as reworked in this instance (See Bergen & Sikora, 1999 for discussion)

Depth	**Formation**	**Age**	**Zone**
3,503m – 3,509m	Thud	Santonian	UC12 or older FCS18

Comments: The record of *S. granulata polonica* at 3,503m(core) is taken to be *in situ*, thereby indicated an earliest Santonian (basal FCS18 Zone) age at this level.

From the data it would appear that the nannofloral recovery is very poor from this sample and therefore the interpretation remains tentative. The assemblage recovered (particularly in the absence of *A. cymbiformis*) is consistent with a Zone UC12 or older attribution.

Depth	**Formation**	**Age**	**Zone**
3,509m – 3,548m	Narve	Coniacian - Turonian	UC10“i”or older FCS17-16

Comments: The FDO of *S. granulata granulata*, together with *M. marginata* at 3,515m, defines the top of a unit broadly dated as Zones FCS17 – FCS16.
The FDO of *Q. eptabrachium* and *H. valhallensis* (*H. turonicus*) at 3,509m confirm the presence of sediments belonging to the Narve Formation, Subzone UC10“i” or older.

No samples were analysed for nannoplankton between 3,521m and 3,542m.

Well 2/11-A-2 T2

Existing data available:
PSV (1991) Report and summary log.

Existing data evaluation:

PSV (1991) Moderate quality data.

New analyses:
Micropalaeontology = 2
Nannoplankton = 2 c
Palynology = 0

Moderate quality core material available for analyses.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
3,378m - 3,444m	Tor	Maastrichtian - Late Campanian	UC20"i" – UC16"ii" FCS23 – FCS21

Comments: The occurrence of *N. frequens* in this interval is taken to indicate the presence of sediments of Late Maastrichtian age, Subzone UC20"i" through this interval.

The FDO of *R. levis* at 3,396m confirms the presence of Zone UC18 in the Early Maastrichtian. A Subzone UC16"ii" attribution is based on the FDO of *B. parca* at 3,420m.

A broad Late Maastrichtian (Zone FCS23) age is indicated at 3,378m, based on a very sparse microfauna. The recovery of both *G.* aff. *arca* and *T. capitosa* at 3,414m was originally interpreted as Zone FCS21, however subsequent interpretation suggests that these occurrences may be due to reworking. Common *T. capitosa* at 3,438m, together with *A. aragonensis* suggests a more definite top FCS21 Zone at this level.

Depth	Formation	Age	Zone
3,456m - 3,495m	Magne	Late Campanian	UC15 FCS21

Comments: Sediments belonging to the Magne Formation are confirmed at 3,456m based on the occurrence of *O. campanensis*, supported at 3,462m by the occurrence of *E. eximius*. This suggests a Subzone UC15"iv" (Late Campanian) subzonal attribution and provides correlation with 2/11A-2.

Depth	Formation	Age	Zone
3,495m - 3,505.8m	Thud	Early Campanian	UC14 or older FCS20

Comments: This interval represents a thin sequence of sediments belonging to the Thud Formation based on the FDO of *B. enormis* and the LDO of B. parca parca at 3,500.8m. The weak assemblage recovered from the ditch cuttings sample at 3,504m is consistent with a Zone UC13 attribution based on the presence of *A. cymbiformis.*

The core samples at 3,495m and 3,498m contain extremely "mixed" microfaunas, including specimens *of S. granulata incondita, S. exsculpta gracilis, S. exsculpta exsculpta, S. granulata polonica* and *Gavelinella arnagerensis*. Given the Early Campanian Thud interpretation for this very condensed section, at least the last two of these are most likely reworked.

Depth	**Formation**	**Age**	**Zone**
3,505.8m- 3,598m	Narve	Santonian - Turonian	UC11 – UC8 FCS18 – FCS15

Comments: The FDO of *L septenarius* (*Q. eptabrachium*) at 3,510m and subsequent increase in the abundance of H. *trabeculatus* (3,512m) is taken to indicate the presence of Narve Formation sediments of "earliest" Santonian – Late Coniacian age (Zone UC11). A stratigraphic succession through the Narve Formation is revealed by the FDO *H. valhallensis (H. turonicus*) together with the inception of *M. staurophora* at 3,516.7m (Subzone UC10"i"), an increase in the abundance of *H. turonicus* at 3,540m (UC9"i" or older) and the LDO of *K. magnificus* at 3,581m. The data set provided from both core and ditch sample in this interval is relatively weak.

The presence of *Cenosphaera* spp. at 3,505.8m indicates a Santonian age, probably within Zone FCS18. As in the mainhole section, the highest occurrence of *S. granulata granulata* can be recognised at 3,522m, defining the top of the FCS17 – FCS16 zonal interval. The abundance of radiolaria below 3,545m supports a Zone FCS15 date below this depth; with *S. granulata humilis* present at 3,598m suggesting a possible FCS15b date at this depth.

Well 2/11-A-2 T3

Existing data available:
PSV (1991) Report and summary log.

Existing data evaluation:

PSV (1991) Moderate quality data.

New analyses:
Micropalaeontology = 3 dc
Nannoplankton = 3 dc
Palynology = 0

Trace chalk only in samples received (mixed lithologies).

Stratigraphic interpretation:

Depth	Formation	Age	Zone
3,372m – 3,378.5m	Ekofisk?	Danian	Indeterminate

Comments: The occurrence of *G. pseudobulloides*, *C. danicus* and *E. cavus* in the sample at 3,372m suggests the presence of a “lag” deposit on top of the Tor Formation of Danian age.

Depth	Formation	Age	Zone
3,378.5m - 3,427.4m	Tor	Late Maastrichtian - Late Campanian	UC20“i” – UC16“iii” FCS23 – FCS22/21

Comments: The occurrence of Late Cretaceous restricted taxa at 3,378.5m is taken to indicate the presence of Tor Formation sediments. The occurrence *N. frequens* confirms a Late Maastrichtian age (Subzone UC20“i”).

The FDO of *R. levis* indicates penetration of the Early Maastrichtian (Zone UC18), This together with the record of the benthic foraminiferid *A. aragonensis* at 3,395m (Zone FCS22), provide good correlation points with Wells 2/11A-2 and 2/11A-T2.

Based on the FDO of *B. parca* at 3,402m Subzone UC16“iii” is assigned. An increase in the numbers of *Rugoglobigerina* spp. at 3,408m supports the Early Maastrichtian to Late Campanian dating.

The data from 3,414m and 3,426m does not provide sufficient information to date these samples.

Depth	Formation	Age	Zone
3,427.4m - 3,486m	Magne	Campanian	UC15

Comments: The presence of Magne Formation is confirmed by the occurrence of *O. campanensis* at 3,441m (UC15“iv”). The subsequent occurrence of *L. grillii* (3,479m) suggests penetration of Subzone UC15“i” of Early Campanian age. Again, confidence is low due to a weak database. Very poor microfaunal recovery throughout this interval.

Depth	Formation	Age	Zone
3,486m – 3,498m	Thud	Early Campanian	UC14

Comments: Zone UC14 – UC12 is based on the continued occurrence of *B. parca parca*. However, the age attribution is very tentative due to the weak nature of the data in this interval. Santonian microfaunal elements recorded at 3,486m are regarded as reworked.

Depth	Formation	Age	Zone
3,498m - 3,605m	Narve	Coniacian - Turonian	UC10 – UC6 FCS18 – FCS15

Comments: The occurrence of *T. virginica* and common *H. trabeculatus* at 3,498m is interpreted as Subzone UC11“i” in the Narve Formation.

The FDO of *H. valhallensis* at 3,504m supports the log evidence for the presence of Narve Formation sediments. The succession through the Narve Formation is generated primarily on the microfaunal data. Nannofloral data supports this although it is reliant upon inception events through this interval.

Common *Cenosphaera* spp. are recorded at 3,498m indicating an earliest Santonian or older age at this depth (cf. 2/11A-2 T2). The presence of *S. granulata granulata* together with *M. marginata* at 3,504m is used to define the top of the Coniacian – Turonian (Zones FCS17-FCS16) interval, as seen in the other two comparable wells. Likewise, a downhole increase in the radiolarian abundance, recognised in this well at 3,559m, is taken to indicate the top of the Turonian Zone FCS15.

Well MFB-7

Existing data available:
None.

Existing data evaluation:

New analyses:
Micropalaeontology = 0
Nannoplankton = 74 c
Palynology = 0

Good quality core samples available for analyses.

Stratigraphic interpretation:

Depth	**Formation**	**Age**	**Zone**
7,331' - 7,357'	Våle	"early" Thanetian	NNTp6

Comments: There is a minor discrepancy between log and biostratigraphic data, possibly attributable to a small core to log shift. Occurrence of *Toweius* sp. together with moderately common *N. perfectus* at 7,360' indicates the presence of Våle Formation sediments.

Depth	**Formation**	**Age**	**Zone**
7,357' - 7,464'	Ekofisk	Danian	NNTp5B – NNTp2G

Comments: "Late" Danian sequence between 7,362' and 7,431.66' (NNTp5B-4D), with only rare Maastrichtian reworking recorded. Occurrence of NNTp4A at 7,440' implies a minor intra Danian unconformity, although a 9' sample gap exists between 7,431.66' and 7,440'.

The occurrence of *H. edwardsii* and common *P. tenuiculus* at 7,460' indicates the presence of a thin "early" Danian sequence (Subzone NNTp2G). Again, an unconformity is only tentatively implied due to a sample gap between 7,451.58' and 7,460'.

Depth	Formation	Age	Zone
7,464’	Tor	Late Maastrichtian	UC20“ii” – UC19“ii”

Comments: The minor discrepancy between core samples and log depth may be attributable to a small core to log shift. A Late Maastrichtian age for the top of the Tor Formation is indicated by the occurrence of *N. frequens* at 7,467.84’. The occurrence of *C. daniae* down to 7,490’ suggests a Subzone UC20“ii” attribution to this depth although a sample gap exists between 7,490’ and 7,540’. Between 7,540’ and 7,910’ an extensive interval dated as Subzone UC20”i” on the occurrence of *N. frequens* in core samples. Intra Maastrichtian reworking may account for the thickness of this subzone. The absence of *N. frequens* at, and below, 7,920’ may be taken to indicate the presence of sediments attributable to Zone UC19, supported at 7,960 with the FDO of *G. obliquum* (Subzone UC19“ii”). No samples were analysed below 7,979.08’.

Well M9-X

Existing data available:
RRI (1985) Report on 5 core samples; PSV (1980) Report with summary log and distribution charts.

Existing data evaluation:
PSV data of moderate quality.

New analyses:
Micropalaeontology = 0
Nannoplankton = 14 c
Palynology = 0

Good quality core samples available for analyses.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
6,416.0' - 6,550’	Ekofisk	Danian	NNTp3 MT3 – MT2b

Comments: *G. pseudobulloides* is recorded from chalk sample sat 6,416’(swc), indicating a “late” Danian Zone MT3 age. The presence of *G. daubjergensis* at and below 6,478’ indicates the top of Subzone MT2b, which is continued to the LDO of *P. compressa*, recorded at 6,535’(swc).

The occurrence of *P. tenuiculus* at 6,545’ indicates the presence of Zone NNTp3 of “middle” Danian age.

An “early” Danian age is implied at 6,550’, based on the absence of *C. danicus* and *P. tenuiculus* which occur in the overlying sample. This date is supported by the record of consistent *Eoglobigerina* spp. below 6,545’.

Depth	Formation	Age	Zone
6,550' – 6,865'	Tor	Maastrichtian	UC20 FCS23e – FCS22

Comments: The occurrence of a Late Cretaceous restricted assemblage at 6,553.6' confirms penetration of Tor Formation sediments assignable to Subzone UC20"iii". The subsequent occurrence of *C. daniae* down to 6,587' confirms the presence of a well developed Subzone UC20"ii". *N. frequens* occurs in core sample down to 6,702' providing another example of a thick Subzone UC20"i".

The records of *R. contusa* and *R. fructicosa* between 6,551' and 6,559'(swc) define the latest Maastrichtian Subzone FCS23e. The LDO of *P. elegans* at 6,623'(swc) confirms Subzone FCS23c to this depth. Below this, the microfauna is less age restricted and it is only the common occurrence of *R. rugosa* at 6,780'(swc) and *Aragonia* sp. at 6,580', which indicate the Early Maastrichtian Zone FCS22 at this level.

Well E-4X

Existing data available:
PSV (1976) Report with summary log and distribution charts.

Existing data evaluation:
PSV data of moderate quality only; taxonomy out of date.

New analyses:
Micropalaeontology = 0
Nannoplankton = 0
Palynology = 0

Stratigraphic interpretation:

Depth	Formation	Age	Zone
6,490.0' - 6,630'	Ekofisk	Danian	MT4? – MT1?

Comments: *G. pseudobulloides* and *S. triloculinoides* are both recorded from the sample at 6,490' indicating a "late" Danian (Zone MT3) age, although it could be as young as "early" Thanetian. The interval has been given a broad Danian dating based on the very limited microfaunal data recorded.

Rare traces of Late Campanian (Magne) reworking are noted at 6,625'(core).

Depth	Formation	Age	Zone
6,640' – 7,200'	Tor	Maastrichtian - Late Campanian	FCS23e – FCS22

Comments: A definite latest Maastrichtian (Subzones FCS23d-e) interval is recorded between 6,640' and 6,665'(core); the LDO of *P. elegans* is at 6,665'. A general late

Maastrichtian (FCS23c-a) date is applied to the section 6,670' – 6,870', supported by records of A*bathomphalus mayaroensis* at 6,710'(core) and the FDO of *R. rugosa* at 6,810'.

The FDO of *B. miliaris* at 6,880'(core) is used to define the top Early Maastrichtian (Subzones FCS22c-d) interval. An interval within Subzones FCS22a-b is also recognised at 7,000', based on the common occurrence of *R. rugosa* at this depth. This unit extends to 7,200', the dating being supported at 7,180' by the highest occurrences of *G. bulloides* and *R. szajnochae*.

Depth	Formation	Age	Zone
7,220' - 7,500'	Magne	Late – Early Campanian	FCS21 – FCS20

Comments: Definite Late Campanian aged Magne sediments (top Zone FCS21) are noted at 7,220', based on the FDO of *T. capitosa*. The PSV report includes records of *S. exsculpta* at this depth, but the identification of this is questioned given the other taxa present. *R. szajnocha*e is logged as common at 7,260' supporting the Late Campanian dating. This interval is continued without any significant change to 7,500', the well TD.

Well ROAR-2

Existing data available:
PSV (1980) Report with summary log and distribution charts.

Existing data evaluation:
PSV (1980) Report - Good quality, detailed database.

New analyses:
Micropalaeontology = 0
Nannoplankton = 11c
Palynology = 0

Good quality core samples available for analyses.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
6,638' - 6,650'	Ekofisk	"middle - early" Danian	NNTp3 – NNTp2 MT3 – MT2

Comments: The presence of *G. pseudobulloides* in chalk core at 6,638' indicates an age within the zonal range MT3 – MT2.

The first sample selected for nannofloral analysis at 6,640' is characterised by abundant *P. tenuiculus* indicating a "middle" Danian, Zone NNTp3 age. It is unusual for the top of the Ekofisk Formation to be as old as this in the study area.

The occurrence of H. *edwardsii* (6,660') is taken to indicate the presence of sediments of "early" Danian age (NNTp2F/G). The subsequent LDO of *H. edwardsii* (6,690') and *C.*

danicus (6,710') suggests penetration of stratigraphically older sediments within the "early" Danian (Subzones NNTp2E).

Late Cretaceous reworking is identified in minor amounts throughout this interval.

Depth	Formation	Age	Zone
6,740' - 6,878'	Tor	Late Maastrichtian	UC20"i" – UC19"iii" FCS23e – FCS22

Comments: The recovery of dominantly Late Cretaceous restricted taxa in the cuttings sample at 6,740', (including *N. frequens*) confirms the presence of Late Maastrichtian age sediments (Subzone UC20"i"). The absence of this taxon at and below 6,800' suggests penetration of Subzone UC19"iii".

An influx of Maastrichtian taxa is recorded at 6,740', in agreement with the lithostratigraphic data. *P. elegans, R. contusa* and *R. fructicosa* all occur at 6,750' and *P. elegans* is noted in sidewall core samples down to 6,780', giving a subzonal range of FCS23e-c down to this depth. The micropalaeontological recovery between 6,782' and 6,864' is dominated by calcispheres, typical of the lower part of the Tor in this area. This facies was described from the Danish area as the "Skjold" Member (Svendsen, 1979).

The recovery of both *B. miliaris* and common *Rugoglobigerina* spp. at 6,870' indicates a definite Early Maastrichtian (Zone FCS22) age at this depth.

Depth	Formation	Age	Zone
6,878' - 6,990'	Magne	Late – Early Campanian	FCS21

Comments: The microfaunal recovery at the top of the Magne (6,878') comprises mainly taxa which range across the Maastrichtian – Campanian boundary. However, the presence of *Gavelinella monterelensis* at 6,880' indicates a Late Campanian age, probably within Zone FCS21. This is supported by the recovery of *Bolivinoides decoratus* at 6,891'(swc).

Definite Early Campanian dates are provided by records of *Bolivinoides strigillatus* and *S. granulata incondita* at 6,980', supported by *R. szajnochae praecursor* at 6,970'.

Depth	Formation	Age	Zone
6,990' - 7,218'	Thud	Santonian	FCS19 – FCS18

Comments: The FDO of *S. exsculpta exsculpta* at 7,000' provides strong evidence for a Late – Middle Santonian (FCS19) age at this level. This dating is supported by the recovery of *Cenosphaera* spp. at the same depth. A Middle – Early Santonian (FCS18) age is indicated at 7,090' by the FDO of *S. granulata polonica.*

Depth	Formation	Age	Zone
7,218' - 7,979'	Narve	Earliest Santonian - Turonian	FCS17b - FCS14 (in part)

Comments: This section provides probably the best, most complete example of the Narve Formation in the study area. The succession of biostratigraphic marker events allows recognition of virtually all the micropalaeontological zones defined. These comprise FDO *S. granulata granulata* at 7,240' (FCS17b), abundant *Cenosphaera* spp. at 7,420' (FCS17a), common *M. marginata* at 7,550' (FCS17a – FCS15), *P. gibba* at 7,870' and *P. praehelvetica* at 7,880' (FCS15a) and abundant *Cenosphaera* spp. at 7,970' (top FCS14).

Depth	Formation	Age	Zone
7,979' – c,8000'	Blodøks	Earliest Turonian - Late Cenomanian	FCS14 (in part)

Depth	Formation	Age	Zone
c,8000'	Hidra	Cenomanian	FCS13

Comments: Full Cenomanian Stage present, FCS13b-c marked by *R. cushmani* (8,000') and Subzone FCS13a by *L. jarzevae* (8,330').

Well ROAR-2A

Existing data available:
PSV (1980) Report with summary log and distribution charts.

Existing data evaluation:
PSV (1980) Report - Good quality, detailed database.

New analyses:
Micropalaeontology = 0
Nannoplankton = 0
Palynology = 0.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
6,660' – 6,739'	Ekofisk	"late - middle" Danian	NNTp4B – NNTp3 MT3 – MT2

Comments: The occurrence of *N. modestus* at 6,660' suggests a "late" Danian age (Subzone NNTp4B) for this sample, although data from this sample is weak. This dating is supported by the foraminiferid data (FDO *G. pseudobulloides* – MT3) at 6,660'.

The FDO of abundant *P. tenuiculus* at 6,680' is taken to indicate the presence of "middle" Danian Zone NNTp3. This interpretation remains tentative, as data quality is poor.

The highest occurrence of *G. daubjergensis* at 6,700' indicates top Zone MT2, which is of "late – middle" Danian age.

Depth	**Formation**	**Age**	**Zone**
6,739' - 6,838'	Tor	Late Maastrichtian	UC20“ii” FCS23c – FCS22

Comments: The occurrence of Late Maastrichtian taxa, including *N. frequens* at 6,739’, confirms penetration of the Tor Formation. The occurrence of *C. daniae* at 6,754’(core) confirms a Late Maastrichtian Subzone UC20“ii” age attribution. Data quality at, and below, 6,801’ is poor and prohibits age determination.

The in-situ occurrence of *P. elegans* between 6,764’(swc) and 6,774’(swc) defines Subzone FCS23c within the Late Maastrichtian. Below this depth, the assemblages are dominated by calcispheres of the “Skjold” Member as described in the ROAR-2.

The FDO of B. *miliaris* at 6,822’(swc) indicates a definite Early Maastrichtian interval at the base of the Tor Formation.

Depth	**Formation**	**Age**	**Zone**
6,840' - 6,990'	Magne	Late – Early Campanian	FCS21- FCS20

Comments: The FDO of *B. decoratus* at 6,482’ (core) has been used here to define the top of Zone FCS21. This species provides a good alternative to *T. capitosa* and *G.* aff. *arca* which are more characteristic of deeper water chalks.

The top of the Early Campanian Zone FCS20 has been taken at the FDO’s of *S. exsculpta gracilis* and *R. szajnochae praecursor* (both at 6,950’), although the FDO’S of *S. granulata incondita* and *B. strigillatus* at 6,980’ probably compare more closely to the zonal pick in the ROAR-2.

Depth	**Formation**	**Age**	**Zone**
7,000' - 7,080'	Thud	Santonian	FCS19 – FCS18

Comments: The top Santonian FCS19 Zone is defined here on the FDO of *S. exsculpta exsculpta* at 7,000’ and this dating is supported at 7,010’ by the FDO of *Cenosphaera* spp. The record of the FDO of the planktic *Globigerinelloides rowei* at 7,050’ is a useful marker as this species, although infrequently recorded can be no younger than Late Santonian (c.f. Bailey *et al*., 1983).

Depth	**Formation**	**Age**	**Zone**
7,090' - 7,230'	Narve	Early Santonian	FCS18 (in part)

Comments: The precise top for the Narve formation is not known in this well, but it is likely to occur within the FCS18 Zone as defined here. The presence of *G. arnagerensis* at 7,210’ confirms an age no younger than earliest Santonian at this depth.

Well BARON-2

Existing data available:
SPT (1992) Report with summary log and distribution charts

Existing data evaluation:
Good to moderate data quality.

New analyses:
Micropalaeontology = 1 + 20 ts
Nannoplankton = 41 c
Palynology = 4.

Good quality core samples available for all analyses.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
2,812m - 2,826.5m	Våle	"early" Thanetian -"late" Danian	NNTp6-7 MT4

Comments: Based on the occurrence of common planktic foraminiferids typical of Zone MT4 at 2,812m(swc), with *T. pertusus* present at 2,820m and both *C. edentulus* and moderately common *N. perfectus* in the core sample at 2,826.3m.

A "late" Danian age is confirmed at 2,823.2m (core) by the presence of *A. reticulata* and *S. "magnificus"*.

Depth	Formation	Age	Zone
2,826.5m - 2,868.5m	Ekofisk	Danian	NNTp4E – NNTp2 MT3

Comments: The FDO of *G. pseudobulloides*, recorded by RRI at 2,830m(core), provides a top for Zone MT3 within the "late" Danian. The FDO of *G. daubjergensis* has been logged at 2,843.7m(core) with a downhole influx of radiolaria. This event defines the top of Subzone MT2b, which ranges through the "late-middle" Danian to 2,886.6m(core) the LDO of *P. compressa*. Very large scale reworking of Maastrichtian foraminiferids was recorded between 2,880m(core) and 2,887.4m(core).

No samples were analysed for nannoplankton between 2,826.3m and 2,838.2m. The occurrence of assemblages including abundant *P. dimorphosus,* common *C. pelagicus*, rare *C. edentulus* and rare *Neochiastozygus* spp. suggests a NNTp4E attribution between 2,838.2m(core) and 2,851.8m(core). A sample gap exists between 2,851.8m and 2,858.75m(core). The LDO of *N. modestus* at 2,858.75m suggests an age no older than NNTp4B at this depth.

The occurrence of common *P. tenuiculus* at 2,860m indicates the presence of sediments of "middle" Danian age (Zone NNTp3).

The occurrence of *H. edwardsii* at 2,873.1m and 2,885.6m confirms the presence of "early" Danian sediments (NNTp2G). Danian restricted taxa are only recorded in minor amount between these depths, as samples are dominated by reworked Maastrichtian and Campanian restricted taxa. The LDO of *H. edwardsii* (2,885.6m), the LDO of *C. danicus* (2,885.9m) and the LDO of common *P. dimorphosus* (2,886.3m) all indicate passage through "early" Danian sediments (Subzones NNTp2E-D). The sample at 2,887m is characterised by poor recovery and reworked Late Cretaceous taxa.

The three core samples (2,879.55m, 2,885.15m and 2886.60m) examined for palynology only yielded fragments of pyritised radiolaria and sponge spicules.

N.B. A minor core to log shift explains the apparent discrepancy between the core data and wireline log data at the Magne – Ekofisk boundary.

Depth	**Formation**	**Age**	**Zone**
2,886.5m - 2,904.8m	Magne	Campanian	UC15"iv-ii" FCS21

Comments: The occurrence of assemblages composed of Late Cretaceous taxa including *O. campanensis* suggests penetration of Magne Formation sediments assignable to Subzone UC15"iv" of Late Campanian age. This indicates a significant unconformity between the Magne and Ekofisk Formations, effectively removing the whole of the Tor Formation. The occurrence of *B. geminicatillus* at 2,899.55m suggests the presence of Subzone UC15"ii".

Microfaunal recovery in the Magne Formation is not good and the highest occurrence of *Globotruncana bulloides*, with the FDO of *R. szajnochae szajnochae* at the same depth has been used to indicate a Campanian date, within Zone FCS21.

Depth	**Formation**	**Age**	**Zone**
2,904.8m - 2,926.5m	Thud	Campanian - Santonian	UC14 – UC12? FCS19

Comments: The occurrence of *B. enormis* at 2,906m is taken to indicate the presence of Subzone UC14"ii". The Zone UC13 attribution between 2,916m and 2,925m is based on the absence of *B. parca parca* and the continued occurrence of *A. cymbiformis* in core samples. However, the occurrence of *A. cymbiformis* is flagged as questionable in this interval, which may suggest an age as old as Santonian Zone UC12.

A Santonian (FCS19) age is indicated at 2,815m, on the basis of the radiolarian assemblage recorded by RRI, together with the planktic *G. linneiana*.

Depth	**Formation**	**Age**	**Zone**
2,926.5m – 2,953.5m	Narve	Late Coniacian	UC11 FCS17

Comments: The occurrence of *Q. eptabrachium* in association with common *H. trabeculatus* (2,625m; core shift of approximately 1m) confirms the presence of Narve Formation sediments of Late Coniacian Subzone UC11"ii" age.

The Coniacian age is supported by records of *M. marginata, M. pseudolinneiana* and *D.* cf. *imbricata* down to 2,940m.

Well LULU-1

Existing data available:
PSV (1980) Report with summary log and distribution charts.

Existing data evaluation:
Good quality micropalaeontology data only.

New analyses:
Micropalaeontology = 0
Nannoplankton = 24 c
Palynology = 0.

Good quality core samples available for analyses.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
9,028' - 9,360’	Ekofisk	Danian	NNTp5B – NNTp1? MT4/3 –MT1?

Comments: The highest occurrence of *G. pseudobulloides* and *S. triloculinoides* at 9,025’(swc) provides a reliable top for the Ekofisk chalk. A “late-middle” Danian (Subzone MT2b) age is confirmed at 9,197’(swc) by the FDO of *G. daubjergensis*.

The NNTp5B attribution is based on the LDO of *N. perfectus* at 9,040’. However, the assemblage as a whole looks more like Zone NNTp4 based on high abundance of *P. dimorphosus*, *C. inconspicuus* and *C. pelagicus*. The presence of Subzone NNTp4E is confirmed at 9,050’ by the absence of *N. perfectus* in weak assemblages dominated by *P. dimorphosus* and *C. pelagicus*. Samples between 9,060’ and 9,080’ are dominated by reworked Late Cretaceous taxa. No samples or data was made available between 9,116’ and 9,230’. An increase in the abundance of *Neochiastozygus* spp. in improved quality assemblages is taken to indicate the presence of Subzone NNTp4D. The LDO’s of *N. modestus*, *N. saepes* and *P. martinii* all occur in the same sample at 9,270’ possibly implying a minor unconformity at the base of Subzone NNTp4D.

The occurrence of *P. tenuiculus* at 9,280’ is taken to indicate the presence of Zone NNTp3. The occurrence of moderately common *P. dimorphosus* and *C. danicus* suggests an age no older than Subzone NNTp2E at 9,330’. The assemblages recovered between 9,340’ and 9,358’ are impoverished. The continued occurrence of *P. dimorphosus* at 9,340’ suggests an age no older than “early” Danian age NNTp2 at this depth. The impoverished assemblages at and below 9,350’ are consistent with an NNTp1 attribution below the inceptions of *Prinsius* spp. and *Cruciplacolithus* spp.

Depth	Formation	Age	Zone
9,360' - 10,466'	Tor	Late Maastrichtian- Late Campanian	FCS23e – FCS22

Comments: The Late Maastrichtian chalk is recognised at 9,360' on the basis of a very poor microfauna. However, at 9,366' the FDO of P. elegans provides a good marker event for Subzone FCS23d. This dating is supported at 9,378'(swc) by the record of *B. draco.* Both *P. elegans* and *R. fructicosa* are recorded *in situ* to 9,557'(swc) defining Subzone FCS23c to this depth. Below this depth a general Late Maastrichtian date is implied on tentative data.
The FDO of *B. miliaris* at 9,860' defines the top of the Early Maastrichtian Subzones FCS22c-d, and below this, at 9,980', common *R. rugosa* confirm Subzones FCS22a-b, which range into the Late Campanian.

Depth	Formation	Age	Zone
10,466' – 10,629'	Magne	Late Campanian	FCS21

Comments: The FDO of *T. capitosa* at 10,480' provides a reliable marker for Subzone FCS21b, which equates closely with the top Magne Formation. PSV record *S. granulata perfecta* in the basal sample examined at 10,629'(swc), however it is considered more likely that the specimens observed were the related form *S. granulata incondita*. If so, this event would indicate the basal Late Campanian Subzone FCS21a at the base of the Late Cretaceous chalk section.

Well MONA-1

Existing data available:
PSV (1983) Report with summary log and distribution charts.

Existing data evaluation:
Good quality micropalaeontology data. No nannoplankton data.

New analyses:
Micropalaeontology = 0
Nannoplankton = 129 c
Palynology = 0.

Good quality core samples available for all analyses.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
9,873' - 9,908'	Våle	"early" Thanetian -"late" Danian	MT5/4

Comments: The records of *Cenosphaera* spp. at 9,880' possibly represent *C. lenticularis* and therefore the "early" Thanetian MT5 Zone. However, as no material was available for reexamination this could not be confirmed. The presence of the foraminiferids *G. pseudobulloides* and *P. compressa* at 9,900’ confirm Zone MT4 at this depth.

Depth	**Formation**	**Age**	**Zone**
9,908' - 10,278'	Ekofisk	Danian	MT4/3-?MT1

Comments: Planktic foraminiferids dominate the assemblages recorded throughout the Ekofisk Formation, with the FDO of *G. daubjergensis* at 9,976’(swc) indicating Subzone MT2b at this depth. High levels of Late Maastrichtian reworking are present between10,036’ and 10,080’. Microfaunal recovery is poor towards the base of the interval and it is impossible to provide a precise dating.

Depth	**Formation**	**Age**	**Zone**
10,278' - 11,195’	Tor	Late Maastrichtian - Late Campanian	UC20“ii” – UC16 FCS23 – FCS22

Comments: The Tor Formation in this well is characterised by an expanded Late Maastrichtian sequence (>600’). The occurrence of *C. daniae* down to 10,506’ suggests Subzone UC20“ii” down to this depth, although this lowest occurrence of this taxon is flagged as questionable and occurs 86’ below the previous occurrence. The remainder of the Late Maastrichtian sequence is represented by Subzone UC20“i” between 10,516’ and 10,785.66’(core), based on the occurrence of *N. frequens* together with some intra Maastrichtian reworking. Subzone UC19“ii” is recorded between 10,796’ and 10930’ on the occurrence of *G. obliquum.*

The FDO of *R. levis* at 10,935’ is taken to indicate the presence of Early Maastrichtian age sediments (Zone UC18). The subsequent occurrence of *B. parca parca* at 11,116’ is taken to indicate penetration of Late Campanian age sediments (Zone UC16), although nannofloral recovery was not of sufficient quality to sub-divide this interval further.

The Late Maastrichtian dating is confirmed at 10,280’ by the FDO of *P. elegans* (Subzone FCS23e). The record of *R. fructicosa* with *B. draco* at 10,290’ is considered to define Subzone FCS23d and the LDO of *P. elegans* at 10,386’(swc) marks the base of Subzone FCS23c. Below this depth microfaunal recovery was very poor from the core, although the FDO of *Globotruncanella havanensis* at 10,850’(core) indicates a Maastrichtian age. The common occurrence of *R. rugosa* at and below 11,120’ indicates an Early Maastrichtian (Subzones FCS22b/a) age.

Depth	**Formation**	**Age**	**Zone**
11,195' - 11,212’	Magne	Campanian	UC15“iii” or older

Comments: Nannofloral recovery is very poor in this and adjacent samples. However, the FDO of *E. eximius* and *H. trabeculatus* at 11,211’ supports the presence of Magne Formation sediments and is taken to indicate Subzone UC15“iii” or older.

Depth	**Formation**	**Age**	**Zone**
11,212' – 11,242’	Narve	Coniacian and older	UC11 – UC10

Comments: The occurrence of Q. *gartneri, E. floralis* and *L. grillii,* in association with increased *W. barnesae* and *M. staurophora* (at 11,213.33'), suggests penetration of Zone UC11 and Narve Formation sediments. Analysis of a clast recovered from the core at this depth reveals an Albian origin for this reworked material. The recovery of *H. turonicus* and *T. virginica* at 11,215.16' suggest penetration of stratigraphically older sediments (Subzone UC10"i") of Late Coniacian age. The recovery of *M. staurophora* in core samples down to 11,242' suggests an age no older than Zone UC10. Samples below this depth are characterised by poor recovery and therefore they are age indeterminate.

Depth	**Formation**	**Age**	**Zone**
11,242' - 11,299.5'	Hidra	Cenomanian	UC3 or older

Comments: The recovery of *G. nanum* and *R. asper* at 11,277' in an otherwise impoverished interval suggests Zone UC3 or older of Cenomanian age and the presence of sediments assignable to the Hidra Formation. Core samples examined for microfauna yielded a planktic assemblage dominated by *Whiteinella baltica*.

Depth	**Formation**	**Age**	**Zone**
11,299.5'	Rødby	Albian	BC27

Comments: Penetration of the Early Cretaceous Cromer Knoll Group (Rødby Formation) is confirmed at 11,299.5'(core) with the occurrence of *G. praeobliquum*.

Well ADDA-2

Existing data available:
PSV (1981) Report with summary log and distribution charts.

Existing data evaluation:
PSV data of moderate quality only.

New analyses:
Micropalaeontology = 0
Nannoplankton = 0
Palynology = 0.

Stratigraphic interpretation:

Depth	**Formation**	**Age**	**Zone**
6,840' - 7,011'	Ekofisk	Danian	MT3 – MT1?

Comments: *G. pseudobulloides* is recorded from the chalk sample at 6,840' indicating a "late" Danian (Zone MT3) age at this depth. This date is supported below 6,844'(swc) by records of *S. triloculinoides*. Rare traces of Late Cretaceous reworking are also noted at 6,844'(swc).

The FDO of *G. daubjergensis* at 6,902'(swc) indicates the top of the "late-middle" Danian Subzone MT2b. This interval has been extended to a questionable MT1 zonal date, but there is no definite evidence to confirm this.

Depth	**Formation**	**Age**	**Zone**
7,020' – 7,090'	Tor	Maastrichtian	FCS23

Comments: Definite Late Maastrichtian (Zone FCS23) chalk is recorded between 7,020' and 7,090' based on the FDO of *P. elegans* and *S. pommerana* at 7,020'. *P. elegans* occurs to 7,050' (swc) implying Subzone FCS23c to this depth. No evidence for Early Maastrichtian or Late Campanian chalks is recorded.

Depth	**Formation**	**Age**	**Zone**
7,090' - 7,166'	Magne	Early Campanian - Late Santonian	FCS20 – FCS19

Comments: Early Campanian Magne sediments are noted at 7,110'(swc), based on the FDO of *S. exsculpta gracilis. G. bulloides* and *Rugoglobigerina* spp. were noted in a very sparse microfauna from this sample. A Late Santonian age (Zone FCS19) is indicated at 7,145'(swc) by the FDO of *S. exsculpta exsculpta*; this dating is supported by the records of abundant *Cenosphaera* spp. at the same depth.

Depth	**Formation**	**Age**	**Zone**
7,170' - 7,260'	Thud	Early Santonian	FCS18

Comments: The presence of *Stensioeina granulata polonica* at 7,191'(swc) suggests the presence of a thin, ?basal, Thud Formation unit. The Zone FCS18 date is supported by the abundance of planktic foraminiferids logged at 7,228'(swc).

Depth	**Formation**	**Age**	**Zone**
7,260' – 7,640'	Narve	Earliest Santonian - Late Turonian	FCS18 – FCS16

Comments: The top of the Narve Formation occurs within microfaunal Zone FCS18, giving the top of the unit an earliest Santonian dating. A Late Coniacian date is provided at 7,274'(swc) by the highest record of *S. granulata granulata*, which is coincident with the LDO of *S. granulata polonica* is the same sample. Several occurrences of the Early Coniacian marker *S. granulata levis* are recorded in this well, providing a reliable top for Zone FCS16 at 7,545'(swc). This dating is supported by common records of *M. marginata* at the same depth.

There is no evidence of Middle Turonian to Late Cenomanian sediments is the well and a major unconformity is thought to exists between the Narve and Hidra Formations.

Depth	**Formation**	**Age**	**Zone**
7,650' – 7,700'	Hidra	Middle - Early	FCS13b/a Cenomanian

Comments: Consistent records of the benthic foraminiferid *Lingulogavelinella ciryi inflata* below 7,650’ indicate a Middle – Early Cenomanian (Subzones FCS13b/a) date for the section down to 7,700’. Late Albian (Rødby Formation) foraminiferids were noted in the PSV report at and below 7,720’.

Well ADDA-3

Existing data available:
GEUS (1998) Report on the “Microfaunal and Nannofloral analysis of the Cretaceous of the ADDA-3 well”. GEUS (1997) Report on the “Palynological analysis of the Upper Cretaceous of the ADDA-3 and BO-1 wells.

Existing data evaluation:
Very limited micropalaeontological raw data; some conflicting microfaunal data. No nannoplankton distribution data. Extensive Palynological distribution charts; but data of limited value.

New analyses:
Micropalaeontology = 0
Nannoplankton = 0
Palynology = 0

Stratigraphic interpretation:

Depth	Formation	Age	Zone
6,931' - 6,946’	Våle?	“late” Danian	MT4

Comments: A “late” Danian age, Zone PT2 is indicated by the occurrence of *A. reticulata* at 6,931.0m (core). Common indeterminate planktics were logged at 6,931’(core), suggesting Zone MT4 or older, consistent with the “late” Danian age indicated by the palynological data.

Depth	Formation	Age	Zone
7,220' - 7,237'	Magne?	Late Santonian	FCS19

Comments: No definite lithostratigraphy is available for this well. The presence of *S. exsculpta exsculpta*, together with *S. exsculpta gracilis* at 7,220’(core), suggests a Late Santonian (Zone FCS19) age, very close to the Santonian/Campanian stage boundary. The age is supported by a diverse planktic association recorded at 7,237’(core) which includes abundant *Cenosphaera* spp., used elsewhere to mark Zone FCS19. Planktic foraminiferids recorded include important zonal index species rarely, if ever, previously logged in North Sea wells. The presence of these taxa, whilst indicating a Late Santonian age, is unverified in the present study.

A significant discrepancy exists in the age interpretation between the Geus palynological and microfaunal reports on this well. The palynological data from this interval is interpreted by Geus as indicating a Late Campanian age. Without examination of the original material, this difference cannot be resolved.

Depth	Formation	Age	Zone
7,252' - 7,617.42’	Narve	Con iacian - Turonian	FCS17 & FCS15a

Comments: The FDO of *S. granulata granulata* at 7,252’(core) provides a Coniacian (Subzone FCS17b) age at and below this depth. Microfaunal recovery is noted as poor below 7,262’(core), although records of a diverse radiolarian association at 7,282’(core), including *D. constricta*, imply Subzone FCS17a, still within the Middle Coniacian.

A lower radiolarian abundance event occurs at 7,617.42’(core), including common *Cenosphaera spp*.; this event is used elsewhere in this study to define the Early Turonian Subzone FCS15a.

The two core samples examined by Geus from the upper part of this interval (7,252.0’ and 7,262.0’) are considered by them to contain palynofloras which indicate a Late Campanian age based on the occurrence of *Cassiculosphaeridia intermedia.* The differences between this interpretation and that presented here cannot be resolved without recourse to the original material

Palynomorph recovery improves markedly at and below 7,439.17’ (core). An influx of *Odontochitina* spp. at this depth is consistent with the micropalaeontological dating for this interval.

Depth	Formation	Age	Zone
7,672.42’ – 7,679.33’	Hidra	Cenomanian	FCS13

Comments: The presence of abundant *Hedbergella* spp. at 7,672.42’(core), together with the benthic species *Gavelinella cenomanica* and *G. baltica* confirms a Cenomanian (Zone FCS13) age at this level. The palynomorph assemblages recorded between 7,682.75’ and 7,684.33’ are characterised by the presence of *Litosphaeridium siphoniphorum*. This is consistent with the micropalaeontological dating of the interval.

Well BO-1

Existing data available:
PSV (1977) Report with summary log and distribution charts. GEUS (1997) Report on the Microfaunal and Nannofloral analysis of the BO-1, with nannoplankton distribution data. GEUS (1997) Report on the “Palynological analysis of the Upper Cretaceous of the ADDA-3 and BO-1 wells.

Existing data evaluation:
The datasets are of good quality, although distribution charts were not available for the GEUS nannoplankton and microfaunal report. Microfaunal events are therefore taken from the report text.

New analyses:
Micropalaeontology = 0
Nannoplankton = 0
Palynology = 0.

Stratigraphic interpretation: It is important to acknowledge in this well that the microfaunal data recorded by both PSV and GEUS conflicts with the nannoplankton distribution recorded by GEUS. Inter-formational reworking is also a possible problem in this well. The stratigraphic interpretation presented here therefore represents a "best fit" based on the data available.

Depth	Formation	Age	Zone
6,750' - 6,760'	Ekofisk	"late – middle" Danian	MT3 – MT2

Comments: A very condensed Ekofisk unit is present in this well with *G. pseudobulloides* at 6,750' indicating Zone MT3 and *G. daubjergensis* at 6,754'(swc) indicating Zone MT2.

Depth	Formation	Age	Zone
6,760' - 6,816'	Tor	Late Maastrichtian	UC20 – UC19 FCS23

Comments: The top of the Tor Formation (Subzone FCS23c) is defined microfaunally by the FDO of *B. draco* at 6,760'. The LDO of an assemblage including *B. draco, B. incrassata* and *Globigerinelloides multispina* at 6,770'(swc) is used here to define the base of this subzone.

The sample at 6,767' contains evidence for intra Late Cretaceous reworking in the form of *B. parca.* The occurrence of *N. frequens* confirms a Subzone UC20"i" attribution at 6,782'. The occurrence of *G. obliquum* at 6,812' is taken to indicate the presence of Subzone UC19"ii".

The palynological data recorded from three productive core samples examined from this interval agrees with the Late Maastrichtian age interpretation based on the nannoplankton and microfauna.

Depth	Formation	Age	Zone
6,816' - 6,872'	Magne	Campanian	UC15 FCS20

Comments: An Early Campanian (Zone FCS20) date is recorded at 6,826'(core) on the presence of *S. exsculpta gracilis*. The microfaunal assemblages recorded at this depth and in the samples at 6,842'(core), 6,857'(core) and 6,866'(core) include several taxa which are considered to be reworked from the underlying Thud Formation.

Penetration of the Magne Formation is confirmed in the nannoplankton sample analysed at 6,842' based on the FDO of *O. campanensis* and *R. anthophorus* (Subzone UC15"iv") and the subsequent FDO of *L. grillii* at 6,857' (Subzone UC15"i").

Depth	Formation	Age	Zone
6,872' - 6,955'	Thud	Early Campanian	UC14

Comments: The presence of sediments belonging to the Thud Formation is implied by the occurrence of *B. enormis* at 6,872' (Subzone UC14"ii") and supported by the LDO of *R. levis* in the same sample. Nannofloral recovery from 6,945' was not sufficient to accurately date although the assemblage is consistent with a Zone UC13-12 attribution. No nannofloral data was provided for the interval 6,945' to 7,156'.

The single productive sample recovered from this interval yielded a sparse dinocyst assemblage which does not allow a precise age determination.

Depth	**Formation**	**Age**	**Zone**
6,955' - 7,260'	Narve	Earliest Santonian - Turonian	UC9 - UC6 FCS18 – FCS15/14

Comments: The FDO of *S. granulata granulata* is recorded at 6,950'(swc) and the last *in situ* downhole occurrence of *S. granulata polonica* is recorded at 6,994'(swc). These two taxa only co-exist within earliest Santonian chalks (c.f. Koch, 1977) implying that this interval represents Zone FCS18. Below the LDO of *S. granulata polonica,* the section is dated as "late-middle" Coniacian (Zone FCS17) on the presence of *S. granulata granulata* down to 7,080'(swc).

Microfaunas below 7,080' are relatively poor and a general Coniacian- Turonian age is indicated. However, at 7,242'(core) the FDO of *W. archaeocretacea* indicates a level either very low in Zone FCS15 or into FCS14. This interpretation would suggest the possibility of a non-sequence with the lower part of the Narve Formation.

Nannofloral data is very sparse through this interval suggesting poor recovery, although assemblages are consistent with a Zone UC9 - UC6 attribution.

The occurrence of a restricted dinocyst assemblage dominated by *Eurydinium saxoniense* at 7,241.0' (core) is typical regionally of sediments of earliest Turonian – latest Cenomanian age.

Depth	**Formation**	**Age**	**Zone**
7,260' - 7,262'	Blodøks	Early Turonian - Late Cenomanian	-

Comments: The "flood" occurrence of *Cenosphaera* spp. recorded at 7,261'(core) is characteristic of the Blodøks Formation.

Depth	**Formation**	**Age**	**Zone**
7,262' – 7,610'	Hidra	Cenomanian	UC5 – UC3 FCS13

Comments: The sparse planktic foraminiferid association recorded between 7,282'(core) and 7,450' supports a Late Cenomanian (Subzone FCS13b-c) age to this latter depth. Microfaunal recovery remains poor through the rest of the Late Cretaceous section, although the records of *L. jarzevae* below 7,500' and *S. antiqua* below 7,520' indicate an Early Cenomanian (Subzone FCS13a) age.

The FDO of *R. asper* is taken to indicate penetration of Zone UC5, the FDO of *G. theta* at 7,291' and *G. nanum* at 7,351' confirms a Cenomanian age (Zone UC3 or older).

Relatively rich and diverse dinocyst assemblages are present through this interval and are typical of the Cenomanian with *L. siphoniphorum* having its highest occurrence at 7,280.0' (core).

Well 30/7a-2

Existing data available:
RPS (1994) Correlation panel; GER (1983) Report and Summary log with distribution charts.

Existing data evaluation:
GER micropalaeontology of moderate to good quality.

New analyses:
Micropalaeontology = 0
Nannoplankton = 67 c
Palynology = 0

Good quality core samples available for all analyses.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
10,066' - 10,087'	Våle	"early" Thanetian	MT4

Comments: The occurrence of both *G. pseudobulloides* and *S. triloculinoides* at 10,080' indicates an "early" Thanetian (Zone MT4) age.

Depth	Formation	Age	Zone
10,087' - 10,377'	Ekofisk	"late - middle" Danian	NNTp5B -NNTp3

Comments: The recovery of *Toweius* sp. in an otherwise weak assemblage tentatively suggests Subzone NNTp5B. The occurrence of abundant *P. dimorphosus* at, and below, 10,111.8' in assemblages containing common *C. inconspicuus* and rare *Neochiastozygus* spp. is taken to indicate Subzone NNTp4E of "late" Danian age. Late Cretaceous reworking is recorded in only minor amounts. The LDO of *P. martinii* at 10,142' suggests NNTp4D below this depth. Further penetration of the wellpath through "late" Danian sediments is implied by the LDO of *Neochiastozygus* spp. at 10,202' suggesting NNTp4?A below this.

Zone NNTp3 in the "middle" Danian is based on the occurrence of common *P. tenuiculus* at 10,238'. No samples were examined for nannoplankton between 10,250' and 10,384.33'.

Only long-ranging Danian microfaunas are recorded.

Depth	Formation	Age	Zone
10,377' - 10,897'	Tor	Late Maastrichtian	UC20"iii" – UC19"ii" FCS23

Comments: An assemblage composed of Late Cretaceous restricted taxa at 10,384.33' characteristic of Late Maastrichtian Zone Subzone UC20"iii". Intra Late Cretaceous reworking is also noted in this sample (coincidently comparable to Well BO-1). The occurrence of *N. frequens* at 10,391' and *C. daniae* at 10,403' confirm the presence of Subzone UC20"ii". Subzone UC20"i" is again represented as a thick sequence between 10,469' and 10,808'. The LDO of *N. frequens* is at 10,808'. The FDO of *S. primitivum* at 10,820' is taken to indicate penetration of Subzone UC19"ii". No evidence for Subzone UC19"iii" was observed.

The FDO of *P. elegans* at 10,440' is used to define the top of a Subzonal unit from FCS23e – c; this is continued to the LDO of both *P. elegans* and *R. contusa* at 10,700' (in ditch cuttings).

A questionable Early Maastrichtian date is recorded at 10,820' on the occurrence of *Globotruncana bulloides*, however this uncorroborated record could be due to reworking.

Depth	Formation	Age	Zone
10,897' - 11,154.7'	Magne	Campanian – Late Santonian	FCS21 – FCS19

Comments: The FDO of *G.* aff. *arca* at 10,920', together with abundant *Rugoglobigerina* spp. at the same depth, provide reliable markers for the Late Campanian Zone FCS21. An Early Campanian interval is recognised at 11,040' based on the FDO of *S. exsculpta gracilis*. Towards the base of the Magne at 11,120' common *Cenosphaera* spp. occur together with *S. exsculpta exsculpta* indicating the presence of a thin Late Santonian (FCS19) interval.

Depth	Formation	Age	Zone
11,154.7' - 11,512'	Thud	Middle Santonian - Late Coniacian	FCS18

Comments: The total range of *S. granulata polonica* in this well (11,160' – 11,460') equates closely with the Thud Formation. An Early Santonian (Zone FCS18) age is indicated

Depth	Formation	Age	Zone
11,512' - 12,555.8'	Narve	Coniacian - Turonian	UC10 – UC9 FCS17 – FCS14

Comments: No samples or data were provided for nannoplankton between 10,847' and 11,995'. The occurrence of *H. turonicus* in assemblages dominated by *W. barnesae* suggests Subzone UC10"i" or older. The occurrence of a questionable specimen of *M. staurophora* at 12,052' may restrict this to Subzone UC10"i", but given the uncertainty of the identification the interval may be as old as Zone UC9 (Early Coniacian).

Microfaunal evidence for the age of this interval is very poor and it is dated as Zones FCS17 – FCS16 by its stratigraphic position below the LDO of *S. granulata polonica* and on the occurrence of *M. marginata* to 12,000'. The record of *Gavelinella praeinfrasantonica* at 11,690'(swc) is consistent with this dating.

Abundant *Hedbergella* spp. recorded at 12,360' are consistent with an Early Turonian (FCS15) or older date, but this is very tentative.

Depth	Formation	Age	Zone
12,575' - 12, 912'	Hidra	Cenomanian	FCS13

Comments: The planktic foraminiferid assemblages recorded at and below 12,600' (i.e. first sample below the Blodøks) include consistent *Hedbergella delrioensis* implying a Cenomanian (Zone FCS13) age. This date is confirmed at 12,800' by the FDO of the agglutinant *Arenobulimina* cf. *advena*.

Well 31/26a-10

Existing data available:
SPT (1983) Report with summary log.

Existing data evaluation:

New analyses
Micropalaeontology = 0
Nannoplankton = 18 dc + 15 c
Palynology = 0

All ditch cuttings received are of very poor quality (heavily contaminated with LCM) and proved difficult to work with. This is undoubtedly due to the methodology employed when catching the samples. Only 18 of the 26 available could be prepared for nannoplankton. These samples had to be rinsed in order to yield identifiable chalk grains and processed with great care (occasionally as individual grains) to ensure reliable slide preparations. Nevertheless caving and mixing of lithologies remained a problem and assemblage quality is inevitably compromised.

Stratigraphic interpretation:

Depth	Formation	Age	Zone
8,148' - 8,207'	Våle	"early" Thanetian	

Comments: Common *N. perfectus* and common *P. martinii* in the sample at 8,180' are consistent with a Våle Formation assignment.

Depth	Formation	Age	Zone
8,207' - 8,360'	Ekofisk	"late" Danian	NNTp4

Comments: Interpretation of assemblages through this interval is complicated by caving from overlying sediments. However, the assemblages recovered are characterised by dominantly *P. dimorphosus* together with *C. pelagicus*, *C. inconspicuus* and rare *Neochiastozygus* spp. suggesting Subzones NNTp4F-D. The basal occurrence of *N. saepes* at 8,330' tentatively suggests NNTp4C at 8,350'. Late Cretaceous reworking was recorded in only minor amounts. No samples were examined for nannoplankton between 8,350' and 8,370'.

Depth	**Formation**	**Age**	**Zone**
8,360' - 8,617'	Tor	Late Maastrichtian	UC20 "ii"

Comments: This influx of Late Cretaceous restricted taxa at 8,370' is taken to indicate penetration of the Tor Formation and an absence of "middle" to "early" Danian sediments. The sample is complicated by caving from overlying sediments. The occurrence of *C. daniae* at 8,380' and 8,380.5' confirms the presence of Subzone UC20"ii". A thick section equivalent to Subzone UC20"i" is recognised between 8,400' and 8,562' on the continued occurrence of *N. frequens*.

Samples at, and below, 8,565' are somewhat difficult to interpret. If the occurrence of *G. obliquum* in the absence of *N. frequens* at this depth in core is taken as *in situ*, then the occurrence of *N. frequens* in subsequent ditch cuttings samples can be interpreted as caved. This would indicate a Subzone UC19"ii" attribution. However, it has been regionally recognised that *G. obliquum* can be reworked into Zone UC20, although this would be difficult to interpret in ditch cuttings and an alternative explanation for this interval would date it as Subzone UC20"i" with intra Maastrichtian reworking.

Depth	**Formation**	**Age**	**Zone**
8,617' - 8,963'	Magne	-	-

Comments: *R. levis* has its FDO at 8,620' in Magne Formation according to logs.

Depth	**Formation**	**Age**	**Zone**
8,963'	Blodøks	-	-

4.5 Reworking

4.5.1 Introduction

This section deals primarily with the reworking of Late Cretaceous calcareous nannoplankton into the Early Paleocene Ekofisk Formation, although important new evidence for intra formational reworking within all the Chalk Group formations, utilising both microfauna and nannoflora, has been recorded and will be discussed.

The extent of Late Cretaceous reworking within the Ekofisk Formation, its provenance, effect on the stratigraphy within that formation and implications for hydrocarbon recovery have rarely been investigated in published literature. The recent paper by Lottaroli and Catrullo (in press) and the proprietorial work by Young (PPCoN) are the only two sources showing an appreciation for the importance this reworking plays in reservoir characterisation and stratigraphic interpretation.

Reworked Late Cretaceous taxa may account for up to 100% of the assemblage recovered in certain sections representing tens of metres in vertical thickness. These sections often represent the best reservoir zones within the Ekofisk Formation.

Methodology: Calcareous nannoplankton suffered a dramatic extinction event at the Cretaceous/Tertiary boundary. The resultant radiation and bloom in nannoflora through the Paleocene gave rise to taxa that were morphologically very distinct from Late Cretaceous forms. As a result the *in situ* Tertiary restricted component of the assemblage can be readily distinguished from the reworked Late Cretaceous component. Accurate identification of the *in situ* Paleocene restricted flora allows the timing of the reworking to be constrained and a zonal attribution applied (according to the Paleocene scheme utilized in this study, **figure 4-1**).

It must be stressed, however, that a zonal attribution determined from the *in situ* component of the assemblage may not be possible in assemblages which are dominated by (in some cases by 100%) reworked Late Cretaceous taxa. In this instance the timing of the reworking is constrained to an age range determined by overlying and underlying *in situ* assemblages. In some cases, particularly on the Ekofisk Field, thick sequences of redeposited Late Cretaceous sediments often contain thin pelagic horizons containing increased abundances of *in situ* Paleocene restricted taxa.

Accurate age determination of reworking within the Ekofisk Formation is also limited by the nature of the zonation scheme. The Danian calcareous nannoplankton scheme utilises both changes in abundances and the presence of sometimes rare index fossils. In sections where the *in situ* assemblages are ‘diluted’ by allochthonous taxa, abundances and apparent absences of markers cannot be relied upon to give an accurate zonal attribution.

There are serious limitations in the interpretation of the reworking when utilising data generated by workers who have clearly not recorded it, those with different taxonomic concepts or when using older data generated before some of the more recent advances in nannofossil biostratigraphy (i.e. Varol 1989 & 1998 and van Heck and Prins 1987).

Certain floral and faunal associations within the reworked assemblages have also been used in development studies (particularly when biosteering horizontal wells) to further divide the reworked units. These associations may be related to discrete slumps or flow deposits, perhaps representing material from different sources.

A discussion of the mechanisms of mass redeposition and slumping and the determination of proximity and direction of source is not within the scope of this study and warrants a detailed study of its own.

The results and interpretations generated in the course of this study are intended to act as an introduction to the potential of a detailed study into the reworking within the chalks of the Central Graben, as this is by no means a conclusive investigation. These results are limited by many sample gaps, the use of old data and sample bias (many samples were selected to answer specific questions unrelated to a reworking study).

4.5.2 Results

During the course of this and other studies on core samples recovered from the Ekofisk Formation within the Central Graben of the North Sea Basin, the amount, type and the lateral and vertical distribution of reworking has been carefully recorded.

Generally the reworked Late Cretaceous assemblages recovered are dominated by large robust taxa such as *Arkhangelskiella cymbiformis, Kamptnerius magnificus, Lucianorhabdus cayeuxii, Micula staurophora* and *Prediscosphaera cretacea.* However, marker taxa key to the provenancing of this material are also recorded. The majority of reworked Late Cretaceous sediments within the Ekofisk Formation are derived from sediments of Late Maastrichtian age, as indicated by the recovery of *Cribrosphaera daniae* and, more commonly, *Nephrolithus frequens*. Late Campanian to "early" Late Maastrichtian age reworking has also been identified to a lesser degree, based on the occurrence of taxa such as *Seribiscutum primitivum, Gartnerago obliquum, Broinsonia parca constricta*, *Reinhardtites anthophorus, Reinhardtites levis, Eiffellithus eximius and Orastrum campanensis.*

The results are represented on **figure 4-3**. Where recorded the reworking is represented as a yellow block, the thickness of the block is proportional to the amount of reworking recorded.

Very little evidence for reworking of sediments derived from the Magne, Thud and Narve Formations into the Ekofisk Formation has been observed during the course of this study. Within the study area, redeposition of Late Cretaceous age sediments is concentrated in five distinct/separate horizons/phases which in descending stratigraphic order are designated Zones A - E for pragmatic purposes:

ZONE A: Includes the Våle Formation as recorded in this study and the uppermost Ekofisk Formation (Zones NNTp6 - NNTp8).

ZONE B: Between the upper part of Subzone NNTp4F and Subzone NNTp5B, ("late" Danian).

ZONE C: Between Subzones NNTp4A and the lower part of Subzone NNTp4E, ("late" Danian).

Significant reworking is not typically recorded in Zone NNTp3, a known pelagic horizon lacking allochthonous input (except well ?2/7-30, but this may be due to *H. edwardsii* not being identified).

ZONE D: Between Subzones NNTp2D and NNTp2G.

ZONE E: Between Subzones NNTp1A and NNTp2C, associated with argillaceous sediments at the base of the Ekofisk Formation.

Distribution of Zone A:

Well	Depth range	Zones	Percentage	Age range
2/4-A-8	10076'-10110'	NNTp8-6	up to10%	Late Maastrichtian
2/4-B-19	9760'	NNTp7	Trace	Late Maastrichtian
2/5-7	3189m-3198m	NNTp6-5B	Trace	Early Maastrichtian
2/5-9	3258m	NNTp6	25%	Maastrichtian
2/7-15	2983m-2983.99m	Våle(unzoned)	50%	Late Campanian
2/7-30	10260'-10290'	NNTp6	10%	Late Campanian
2/7-B-11	9812'-9843.5'	NNTp7B-6	Up to 10%	Late - Early Maastrichtian
2/8-A-1	2467m-2469.3m	Unzoned (As lag deposit)	Up to 100%	Late Maastrichtian
2/11-A-2T3	3372m-3378m	Unzoned ?(As lag deposit)	Up to 100%	Late Maastrichtian
MFB-7	7360’-7361’	NNTp6	Up to 10%	Late Maastrichtian
BARON-2	2820’-2826.3’	NNTp6-7	Trace	Maastrichtian

Only limited data is available for Zone A (within the Våle Formation) within this study.
The conglomeratic lag deposit present on the Valhall structure is interpreted as “late” Danian – “early” Thanetian in age and possibly represents an on structure, locally higher energy, lateral equivalent of the Vale Formation.

Distribution of Zone B:

Well	Depth range	Zones	Percentage	Age range
1/3-8	3385m-3430m	NNTp5B-4E	5%-20%	Late Cretaceous (Undifferentiated)

2/2-3	2970m-3020m	NNTp5B	30%-50%	Maastrichtian - Late Campanian
2/4-A-8	10120'-10190'	NNTp5B - NNTp4E/F	Up to 10%	Late Maastrichtian - Late Campanian
2/4-B-19	9790'	NNTp5B	Up to 10%	Late Maastrichtian
2/4-B-19A	9839'-9846'	NNTp5B - NNTp4F	10%-30%	Maastrichtian - Campanian
2/5-1	9970'-10008'	NNTp5-4F	20%	Late Maastrichtian
2/7-4	10224'-10261'	NNTp5A-4F	Trace	Maastrichtian - Late Campanian
2/7-8	9710'-9730'	NNTp5B-4F	Trace	Maastrichtian
2/7-15	3000m-3006m	NNTp5B-4F	Up to 20%	Maastrichtian
2/7-30	10300'	NNTp5B	15%	Late Campanian

This phase of reworking, recognised in the upper part of the Ekofisk Formation ('Zone B'), appears to be centered around and to the North of the Ekofisk and Eldfisk structures.

Late Cretaceous taxa recovered from this phase do not typically comprise more than 30% of the assemblage. Reworked "early" Danian taxa may also be recorded within this Zone.

Significant reworking in 'Zone B' has not been recognised in the Danish Sector wells selected for this study.

Distribution of Zone C:

Well	**Depth range**	**Zones**	**Percentage**	**Age range**
1/3-1	10950' - 11050'	NNTp4C-D	25%-50%	Late Maastrichtian
1/3-8	3442m-3445m	NNTp4D-C	Trace	Maastrichtian
1/9-1	3060.56m-3073.95m	NNTp4D-B	Trace	Maastrichtian
2/2-3	3050m-3085m	NNTp4D/E	Minor Trace	Maastrichtian
2/4-A-8	10210'-10330'	NNTp4D	Minor Trace (50% 10210')	Late Maastrichtian - Late Campanian
2/4-B-19A	9897' - 10134'	NNTp4B-A	Sporadic peaks (50%-100%)	Maastrichtian - Campanian

2/5-1	10088'-10248'	NNTp4B-4D	Sporadic peaks (40%-100%)	Late Cretaceous (Undifferentiated)
2/5-9	3279m-3375m	NNTp4C-4B	Isolated peak @3279m(50%)	Maastrichtian
2/7-4	10277'-10409'	NNTp4D/E-NNTp4C	Sporadic peaks (up to 80%)	Late Maastrichtian-Late Campanian
2/7-8	9770'-9870'	NNTp4C?	Increasing (up to 80%)	Maastrichtian
2/7-15	3011.4m-3012m	NNTp4D/E	50%	Late - Early Maastrichtian
2/7-30	10314'-10523'	NNTp4E/C-D	Sporadic peaks (up to 90%)	Maastrichtian
2/7-B-11	9852'-9961.5'	NNTp4E/D - NNTp4B/C	Minor	Maastrichtian
BARON-2	2838.2m-2867.6m	NNTp4E-4B	Minor	Maastrichtian
LULU-1	9050’-9116’	NNTp4E	Up to 90%	Late Maastrichtian
30/7a-2	10143’-10238.16’	NNTp4D-A	Trace	Maastrichtian
31/26a-10	8290’-8350’	NNTp4F-4C	Trace	Late Maastrichtian-Late Campanian

Significant Zone C reworking is again concentrated mainly in the Norwegian wells in the Greater Ekofisk area. Zone C reworking is not typically noted in the Danish wells selected for analysis (with the exception of LULU-1, potentially due to its location close to the Norwegian sector and therefore influenced by the same reworking phase as the Greater Ekofisk area) or in the British Sector wells selected (perhaps reflecting their location on the Graben margin).

Distribution of Zone D:

Well	Depth range	Zones	Percentage	Age range
1/3-8	3460m	NNTp3	Trace	Early Maastrichtian
1/9-1	3080.69m-3101.5m	NNTp2G - NNTp2C/D	Up to 60% (Variable)	Late Maastrichtian - Late Campanian
2/4-A-8	10340' - 10520'	NNTp2E/F	70%-100% (massive)	Late Maastrichtian
2/4-B-19A	10159'-10209'	NNTp2E	90%-100% (massive)	Late Maastrichtian

2/5-7	3267m-3345m	NNTp2E-2D	Up to 100% (massive)	Late - Early Maastrichtian
2/5-9	3281m	NNTp2F	70%	Maastrichtian
2/7-4	10421'-10423'	NNTp2E/F	25%	Maastrichtian
2/7-8	9880'-9920'	NNTp2E	40%-90%	Early Maastrichtian
2/7-15	3014m - 3038.86m	NNTp2F-2D	Up to 100%	Late - Early Maastrichtian
2/7-30	10551'-10608'	NNTp3? - NNTp2C/D	Up to 60%	Late Maastrichtian
M-9X	6545'-6550'	NNTp3-2E/F	10%	Maastrichtian
ROAR-2	6640'-6740'	NNTp3-2E	Sporadic 10%-20%	Late Maastrichtian - Late Campanian
BARON-2	2878.3m-2885.15m	NNTp2G	Up to 100% (massive)	Late Maastrichtian – Late Campanian

This Zone can be identified in both the Norwegian and Danish sectors and represents the best reservoir within the Ekofisk Formation.

Sediments attributable to this zone generally occur as thick allochthonous sequences/slumps when well developed.

Distribution of Zone E:

Well	**Depth range**	**Zones**	**Percentage**	**Age range**
1/3-8	3472m-3484m	NNTp2C	up to 25%	Late Maastrichtian
2/4-A-8	10529.8'-10564'	NNTp2D	30%-50%	Late Maastrichtian
2/4-B-19	10200'-10216'	NNTp2D - NNTp1	Up to 30%	Late - Early Maastrichtian
2/4-B-19A	10211'-10274'	NNTp2A-D	30% (up to 100% at base)	Late Maastrichtian
2/5-1	10245' - 10270'	NNTp1	Up to 60%	Late Cretaceous (Undifferentiated)
2/5-7	3346m-3348m	NNTp1	Up to 70%	Late Maastrichtian
2/7-4	10435'-10451.5'	NNTp2B-1	Up to 80% (Peaks)	Late Maastrichtian

LULU-1	9340’-9358’	NNTp2D-1	Up to 10%	Late Maastrichtian

Generally associated with argillaceous sediments, previously assumed to be entirely "pelagic" in their depositional character, at the base of the Ekofisk Formation.

Initial results from our on-going research in the Greater Ekofisk Area suggests that a previously assumed NNTp1 age for these argillaceous sediments is a function of the impoverished assemblages recovered and this argillaceous facies may be diachronous. There appears to be evidence for sediments of younger NNTp2 age characterised by massive Late Maastrichtian reworking below this argillaceous unit.

4.5.3 Intra Formational reworking within the Chalk.

Throughout the course of this study evidence for intra formational reworking was recorded within the chalk. The true extent of intra formational reworking may be difficult to ascertain due to presence of dominantly longer ranging taxa (a reworked long ranging taxon cannot be distinguished from an *in situ* long ranging taxon). The percentage of intra formational reworking may therefore be higher than recorded.

The best evidence for intra formational reworking within the Ekofisk Formation is in the form of *H. edwardsii* and *P. tenuiculus*. These are typically “middle” to “early” Danian taxa and may be seen reworked into “late” Danian sediments (e.g. Well 2/4A-8), Zones NNTp4D-5A.

Reworking in the Late Maastrichtian Tor Formation is discussed in the Zonation scheme (see Chapter 4.1.2.1). Reworking was also recorded near the base of the Tor Formation, commonly in the form of *E. eximius* and *H. trabeculatus*. This may be due to reworking of Magne Formation sediments or more likely assignable to reworked Narve Formation sediments within which these taxa occur commonly.

4.6 "Gapograms"

4.6.1 "Gapogram" construction

A shorthand format of illustrating the majority of the wells included in this study has been developed by cross-plotting the individual well sections against the integrated biozonations developed during the study. The zonations themselves are plotted against absolute time (Gradstein *et al*., 1994 & 1995 and Gradstein & Ogg, 1996). Therefore, by calibrating the age of each formation against this timescale, using the biostratigraphic content, it is possible to indicate the timing of unconformities and their duration by high lighting the amount of missing section in each well.

The emphasis on the missing section for each well gives rise to the "Gapogram" title used in this study. "Gapograms" have been produced to coincide with eight of the seismic lines re-interpreted across the Central Graben. These diagrams are included as **Figures 4-4** to **4-11** of this report. The lines of section correlated are as follows:

Line 1
1/9-1 - 2/7-4 - 2/4-A-8 - 2/4-B-19A - 2/5-1 - 2/5-7 - 2/2-3 - 2/2-2

Line 2
1/3-1 - 1/3-8 - 2/5-7 - 2/5-9 - Mona-1

Line 3
31/26a-10 - 2/7-2 - 2/7-B-11 - 2/7-30 - 2/7-15 - 2/7-8 - 2/5-9

Line 4
2/4-B-19A - 2/4-A-8 - 2/7-30 - 2/7-15 - 2/7-8 - 2/8-A-1 - 2/11-A-2 T3

Line 5
2/7-4 - 2/7-B-11 - 2/8-A-1 - 2/11-A-2 T3

Line 6
31/26a-10 - 2/11-A-2 T3 - Mona-1 - Lulu-1

Line 7
30/7a-2 - 1/3-1 - 1/3-8 - 2/2-2

Line 8
Mona-1 - Baron-2 - Roar-2 - MFB-7 - M-9X

Figure 4-12 shows the location of the gapogram correlations.

The "Gapograms" have been produced in colour in order to indicate where good quality biostratigraphic data exists. For those intervals tightly constrained by biostratigraphic data the formation represented is shown in its' true colour. However, in contrast to this, where chalk lithologies exist, but their age is not tightly constrained, then the lighter version of the colour is used on the figure.

Depths are given for the top and bottom of each biostratigraphic unit recognised, normally on the basis of either nannofloral of microfaunal criteria. Where there is alternative information available to indicate depths for particular boundaries, these are indicated as log depths (log), sedimentological data (sed), microfaunal evidence (mic) or nannofloral evidence (nan).

On a number of occasions in wells where only ditch samples were available, log data has been used in preference to the biostratigraphic data. This has resulted in the latter being out of place because of caving and this is indicated on the diagrams (cav).

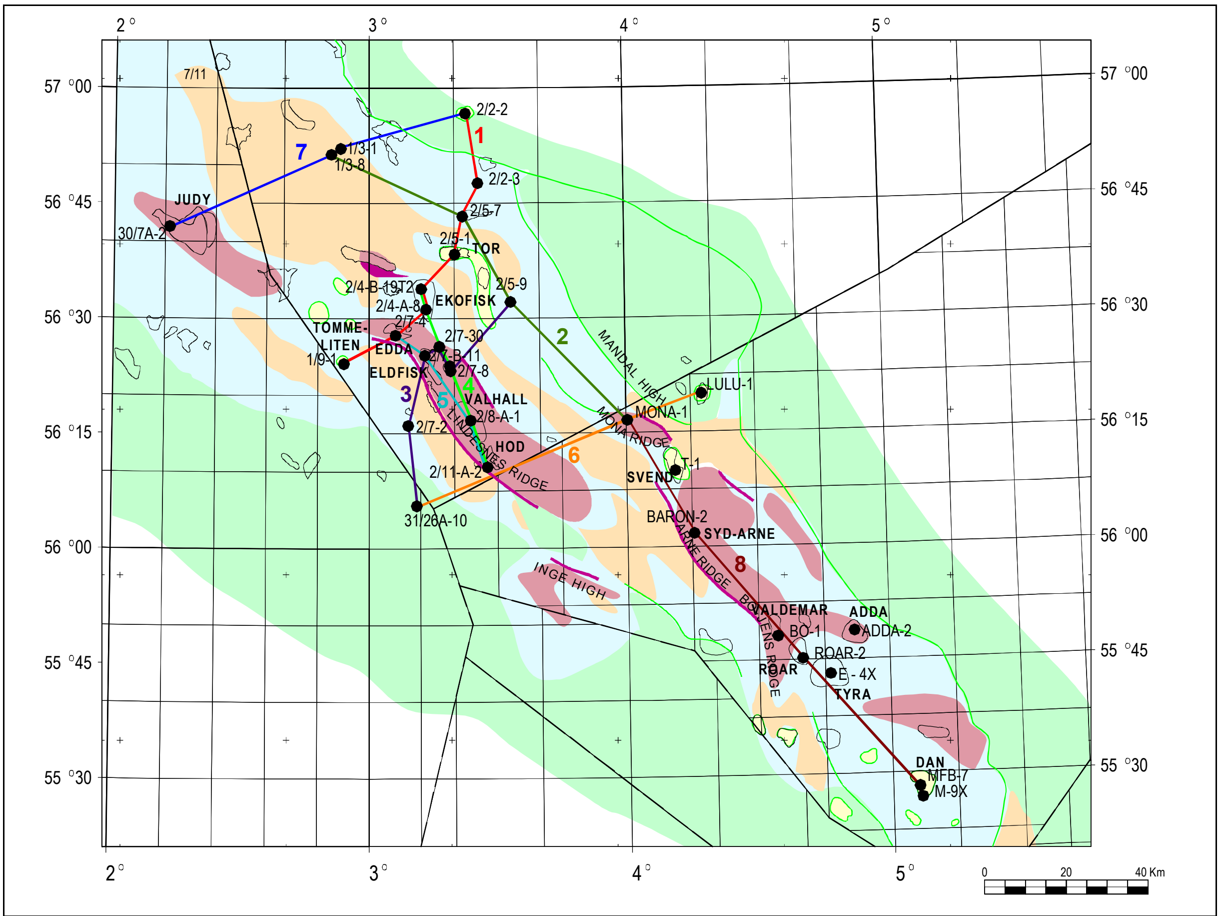

Figure 4-12: Index map of gapogram correlations

4.4.2. "Gapogram" Interpretation

A considerable amount of research carried out over the last two decades has emphasised the importance of eustatic changes during the Late Cretaceous, particularly the progressive rise in sea level from the end Turonian through the Late Campanian (Hancock & Kauffman 1979). If this were the case then it would be logical to expect that carbonate sedimentation would have been broadly continuous across the region, particularly within the Central Graben basinal area. This is clearly not the case from the evidence provided by the "Gapograms" and an alternative explanation has to be sought to explain the preservation of the sedimentary packages identified.

In none of the wells studied is there a "complete" Late Cretaceous - Danian succession preserved. This is perfectly understandable in that the majority of hydrocarbon exploration wells are located by choice on present day positive structures that are likely to have been active for a considerable time; certainly as far back as the Early Cretaceous. Despite the present study wells being selected largely on the basis of their "off-structure" locations, none of them is in a basinal location which received an uninterrupted supply of sediment during the deposition of the Chalk.

Many of the structures on which the wells are located may be solely the result of tectonic controls, whereas there is evidence, particularly in the Danish sector to indicate that some of this positive structures are at least in part halokinetically induced. In this latter case, salt movements will also have been induced by more regional tectonic activity.

Within the Late Cretaceous period, it is possible to identify episodes which are very poorly represented in the columns of sediment preserved. Not only this, but the hiatuses in sedimentation frequently fall at broadly synchronous times. For example on Line 3 it is evident that very little sediment of the Thud Formation is preserved, and that the top of this formation recorded from two of the wells is based primarily on log rather than biostratigraphic evidence.

It is apparent that no Santonian to Early Campanian chalks are preserved in these wells, despite the likelihood that carbonate deposition was continuous across the region. Any sediment deposited during this period would have been eroded prior to the onset of the next phase of deposition. In order to do this on such a wide scale it is reasonable to suspect that a regional phase of uplift occurred within the Early Campanian which stripped any chalk deposits off these positive structures.

Recent work by Mortimore & Pomerol (1997) and Mortimore *et al.* (1998) has indicated major periods of tectonic activity which can be identified within the onshore sections of the Anglo-Paris Basin and Northern Germany. It is the contention here that these same major tectonic phases were instrumental in the activation and re-activation of fault lines within the Central Graben region which delineated the structures within the study area.

The phases identified by Mortimore *et al*.(*op. cit*.) are:

Early Ilsede	-	Late Turonian - Early Coniacian
Main Ilsede	-	Mid/Late Coniacian - earliest Santonian
Wernigerode	-	Late Santonian
Peine	-	Mid Campanian

To these can be added several smaller tectonic episodes known to occur during the Early Maastrichtian and identified in North German sections, which precede the onset of the main "Laramide" tectonics which resulted in considerable tectonism and uplift during the Late Maastrichtian up to and including the Cretaceous/Tertiary boundary section.

The example cited above from Line 4 illustrates the lack of sediment preserved in the area representing the mid Santonian to Early Campanian interval. Given the timing of the Wernigerode and Peine tectonic phases, it is most likely that any sediment deposited during this time were likely to be rapidly eroded as a result of uplift caused at the end Santonian or during the mid Campanian.

The same Line 3 also shows evidence from at least three of the wells studied for a similar break in sediment preservation over the latest Early - Middle Turonian interval. The timing of the early phase of the Peine tectonic episode may well account for uplift along these structures resulting in sediment erosion prior to the subsequent onset of deposition during the latest Turonian.

Additional periods of regional non-preservation of sediments can also be recognised on the "Gapograms" across the Cretaceous/Tertiary boundary and possibly close to the Campanian/Maastrichtian Stage boundary, although the latter is only identified positively in a very limited number of wells. Certainly, during the Maastrichtian and Danian, there is well established evidence for the allochthonous re-deposition of chalks by mass-flow and turbidity current mechanisms. These could easily have been initiated by the tectonic pulses which are known to have occurred during this period of time.

The systematic analysis of Chalk sequences such as that carried out using the "Gapogram" technique can clearly be used as an interpretive tool in the regional evaluation of Late Cretaceous sediments. It emphasises the importance of detailed biostratigraphic analysis in order to establish the accurate stratigraphy for individual wells. The identification of discrete "packages of sediment" can then be utilised in the broader sequential interpretation of the region and the seismic mapping carried out as part of this overall study.

4.7 List of illustrations for zonal index taxa and selected stratigraphically important species

4.7.1 Microfaunal Markers

Angulogavelinella bettenstaedti Hofker	Fig. 6, Pl. XXXVIII, in Hanzlikova (1972)
Aragonia aragonensis (Nuttall)	Fig. 11, Pl. 13, in Koch (1977)
Bolivinoides draco (Marsson)	Figs.2 & 3, Pl. 12, in Koch (1977)
Bolivinoides miliaris (Hiltermann & Koch)	Fig.4, Pl. 12, in Koch (1977)
Dictyomitra constricta	
Eoglobigerina aff. trivialis	
Globoconusa daubjergensis (Brönnimann)	Figs.6 - 8, Pl. 7, in Koch (1977)
Globorotalites pseudobulloides(Plummer)	Figs.3 & 4, Pl. 7, in Koch (1977)
Lingulogavelinella ciryi inflata Malapris-Bizouard	Figs. 10 & 11, Pl8.2, in King *et al.* (1989).
Lingulogavelinella globosa (Brotzen)	Figs.8-10, Pl.7.18, in Hart *et al.* (1989).
Marginotruncana marginata (Reuss)	Figs. 1& 2, PL.63, in Robaszynski *et al.* (1979).
Orbiculiforma vacaensis (Pessagno)	Figs. 1-6, Pl.17 in Pessagno (1973)
Praeglobotruncana aumalensis (Sigal)	Fig.1, Pl.42, in Robaszynski *et al.* (1979).
Praeglobotruncana gibba Klaus	Figs.1 & 2, Pl.44, in Robaszynski *et al.* (1979).
Praeglobotruncana stephani (Gandolfi)	Figs.1- 3, Pl.48, in Robaszynski *et al.* (1979).
Planorotalites archaeocompressa	
Planorotalites compressa (Plummer)	Fig. 5, Pl. 7, in Koch (1977).
Pseudotextularia elegans (Rzehak)	Figs.5 & 6, Pl. 15, in Koch (1977).
Racemiguembelina fructicosa (Egger)	Fig. 9, Pl. XXIV, in Hanzlikova (1972).
Rosita contusa (Cushman)	Figs.1 & 2, Pl.37, in Robaszynski *et al.* (1984).
Rotalipora cushmani (Morrow)	Figs.1& 2., Pl.8, in Robaszynski *et al.* (1979).
Rugoglobigerina spp. Brönnimann	Figs.1 - 8, Pl.49, in Robaszynski *et al.* (1984).

4.7.2 Nannofloral Markers

Toweius pertusus (Sullivan 1965) Romein 1979	Fig. 20, Pl. 7.2, in Varol (1998)
Chiasmolithus edentulus van Heck & Prins 1987	Fig. 13, Pl. 1, in van Heck & Prins (1987)
Prinsius martinii (Perch Nielsen 1969) Haq 1971	Fig. 18, Pl. 7.2, in Varol (1998)
Neochiastozygus perfectus Perch Nielsen 1981	Fig. 23, Pl. 7.1, in Varol (1998)
Prinsius dimorphosus (Perch Nielsen 1969) Perch Nielsen 1977	Fig. 24, Pl. 7.2, in Varol (1998)
Neochiastozygus eosaepes Perch Nielsen 1981	Fig. 20, Pl. 1, in van Heck & Prins (1987)
Neochiastozygus saepes Perch Nielsen 1971	Fig. 19, Pl. 7.1, in Varol (1998)
Neochiastozygus modestus Perch Nielsen 1971	Fig. 15, Pl. 1, in van Heck & Prins (1987)

Ellipsolithus macellus (Bramlette & Sullivan 1961) Sullivan 1964
Fig. 6, Pl. 7.5, in Varol (1998)
Neocrepidolithus fossus (Romein 1977) Romein 1979
Fig. 15, Pl. 7.1, in Varol (1998)
Prinsius tenuiculus (Okada & Thierstein 1979) Perch Nielsen 1984
Fig. 28, Pl. 7.2, in Varol (1998)
Hornibrookina edwardsii Perch Nielsen 1977
Fig. 5, Pl. 7.1, in Varol (1998)
Chiasmolithus danicus (Brontzen 1959) ex van Heck & Perch Nielsen 1987
Fig. 7, Pl. 12.3, in Varol (1989)
Coccolithus pelagicus (Wallich 1871) Schiller 1930
Fig. 7, Pl. 7.3, in Varol (1998)
Cruciplacolithus intermedius van Heck & Prins 1987
Fig. 13, Pl. 7.3, in Varol (1998)
Cruciplacolithus primus Perch Nielsen 1977 Fig. 12, Pl. 7.3, in Varol (1998)
Placozygus sigmoides (Bramlette & Sullivan 1961) Romein 1979
Fig. 3, Pl. 7.3, in Varol (1998)
Nephrolithus frequens Górka 1957 Fig. 12, Pl. 6.5, in Burnett *et al.* (1998)
Cribrosphaera daniae Perch Nielsen 1973 Fig. 9, Pl. 6.5, in Burnett *et al.* (1998)
Seribiscutum primitivum (Thierstein 1974) Filewicz in Wise & Wind 1977
Fig. 9, Pl. 6.6, in Burnett *et al.* (1998)
Gartnerago obliquum (Stradner 1963) Noël 1970
Fig. 3, Pl. 6.9, in Burnett *et al.* (1998)
Zeugrhabdotus compactus Fig. 12, Pl. 6.2, in Burnett *et al.* (1998)
(= *Z. bicrescenticus* (Stover 1966) Burnett in Gale et al. 1996)
Calculites obscurus (Deflandre 1959) Prins & Sissingh in Sissingh 1977)
Fig. 2, Pl. 6.11, in Burnett *et al.* (1998)
Reinhardtites levis Prins & Sissingh in Sissingh 1977
Fig. 9, Pl. 6.2, in Burnett *et al.* (1998)
Tranolithus orionatus (Reinhardt 1966a) Reinhardt 1966b
Fig. 7, Pl. 6.2, in Burnett *et al.* (1998)
Broinsonia parca (Stradner 1963) Bukry 1969 ssp. *constricta* Hattner et al. 1980
Fig. 15, Pl. 6.8, in Burnett *et al.* (1998)
Reinhardtites anthophorus (Deflandre 1959) Perch Nielsen 1968
Fig. 10, Pl. 6.2, in Burnett *et al.* (1998)
Broinsonia parca (Stradner 1963) Bukry 1969 spp. *parca*
Fig. 13, Pl. 6.8, in Burnett *et al.* (1998)
Heteromarginatus bugensis (Górka 1957) Crux in Crux *et al*. 1982
Fig. 5, Pl. 6.1, in Burnett *et al.* (1998)
Eiffellithus eximius (Stover 1966) Perch Nielsen 1968
Fig. 22, Pl. 6.3, in Burnett *et al.* (1998)
Orastrum campanensis (Cepek 1970) Wind & Wise in Wise & Wind 1977
Fig. 18, Pl. 6.11, in Burnett *et al.* (1998)
Helicolithus trabeculatus (Górka 1957) Verbeek 1977
Fig. 29, Pl. 6.3, in Burnett *et al.* (1998)
Bifidalithus geminicatillus Varol 1991 Fig. 22, Pl. 6.11, in Burnett *et al.* (1998)
Cylindralithus biarcus Bukry 1969 Fig. 23, Pl. 6.4, in Burnett *et al.* (1998)
Lithastrinus grillii Stradner 1962 Fig. 9, Pl. 6.13, in Burnett *et al.* (1998)
Saepiovirgata biferula Varol 1991 Fig. 16, Pl. 6.11, in Burnett *et al.* (1998)

Broinsonia enormis (Shumenko 1968) Manivit 1971	
	Fig. 18, Pl. 6.8, in Burnett *et al.* (1998)
Cylindralithus crassus Stover 1966	Fig.11, on Fig.71 in Perch Nielsen (1985)
Arkhangelskiella cymbiformis Vekshina 1959	
	Fig. 3, Pl. 6.8, in Burnett *et al.* (1998)
Lucianorhabdus cayeuxii Deflandre 1959	Fig. 16, Pl. 6.10, in Burnett *et al.* (1998)
Quadrum eptabrachium Varol 1992	Fig. 4, Pl. 7, in Varol (1992)
Tortolithus "virginica" Bergen 1999	Fig. 21, Pl. 6.9, in Burnett *et al.* (1998)
	(= T. caistorensis Crux in Crux *et al.* 1982*)*
Quadrum intermedium Varol 1992	Fig. 3, Pl. 7, in Varol (1992)
Helicolithus turonicus Varol & Girgis 1994	Fig. 30, Pl. 6.3, in Burnett *et al.* (1998)
Micula staurophora (Gardet 1955) Stradner 1963	
	Fig. 25, Pl. 6.13, in Burnett *et al.* (1998)
Lithastrinus septenarius Forcheimer 1972	Fig. 7, Pl. 6.13, in Burnett *et al.* (1998)
Kamptnerius magnificus Deflandre 1959	Fig. 15, Pl. 6.9, in Burnett *et al.* (1998)
Retecapsa ficula (Stover 1966) Burnett 1998b	
	Fig. 8, Pl. 6.7, in Burnett *et al.* (1998)
Quadrum gartneri Prins & Perch Nielsen in Manivit *et al.* 1977	
	Fig. 12a, Pl. 6.13, in Burnett *et al.* (1998)
Helenea chiastia Worsley 1971	Fig. 14, Pl. 6.7, in Burnett *et al.* (1998)
Lithraphidites acutus Verbeek & Manivit in Manivit *et al*. 1977	
	Fig. 14, Pl. 6.12, in Burnett *et al.* (1998)
Gartnerago segmentatum (Stover 1966) Thierstein 1974	
	Fig. 7, Pl. 6.9, in Burnett *et al.* (1998)
Corollithion kennedyi Crux 1981	Fig. 16a, Pl. 6.4, in Burnett *et al.* (1998)

5 A JOINT CHALK STRATIGRAPHIC FRAMEWORK

5.1 North Sea Central Graben formal chalk lithostratigraphic nomenclature

The first formal lithostratigraphic nomenclature for the central and northern North Sea was published by Deegan & Scull in 1977. The Cretaceous and Tertiary for Norwegian areas was later revised by Isaksen and Tonstad (1989). Lieberkind *et al.* published an informal nomenclature for the chalks in the Danish Central Graben in 1982. For UK North Sea, Knox and Cordey published a revised lithostratigraphy in 1993. In the JCR Chalk Monograph compiled by Andersen (1995), North Sea chalk lithostratigraphy is summarized. The stratigraphic nomenclature for chalk formations in the Central Graben used in the JCR Phase IV is shown in **figure 5-1** below.

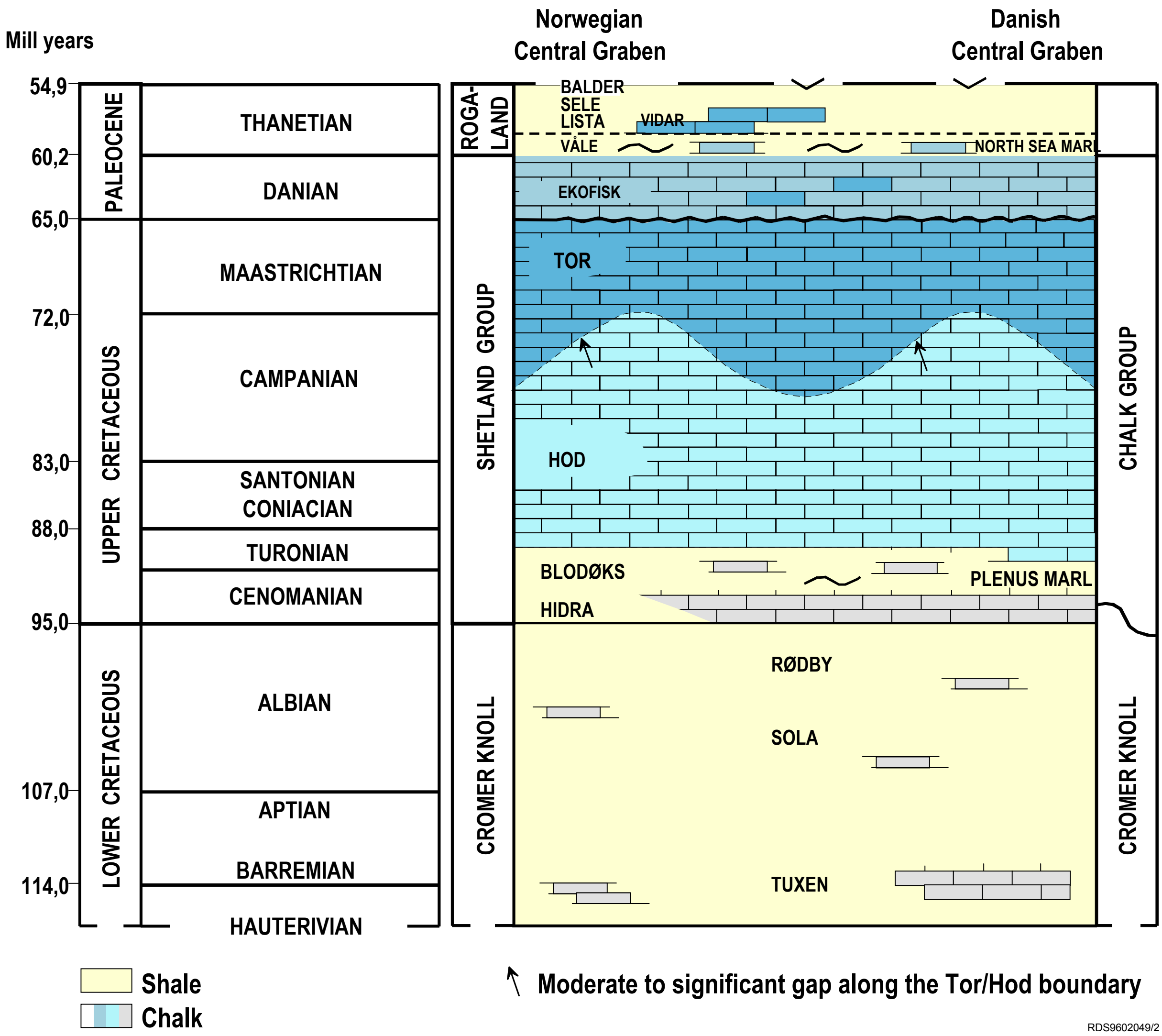

Figure 5-1: Cretaceous and Paleocene historical lithostratigraphy

This formal lithostratigraphic nomenclature 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). Type and reference wells are selected based on completeness of section, quality of electrical logs and availability of cores. The Norwegian formations are named from Norse mythology or after Norwegian "Viking" kings. The nomenclature is limited to two categories of lithostratigraphical subdivision; groups and formations. Some additional informal local subdivision is also suggested. Ages referred to are of stage level for the Cretaceous and series level for the Tertiary.

Table 5-1 illustrates the correlation between the lithostratigraphic chalk formations and the age of the chalk, as presented by Isachsen and Tonstad (1989). As shown, the Ekofisk and Vidar formations may constitute reworked chalk of older age, causing potential confusion about the formal lithostratigraphic name of the chalk.

Group	Formation	Age	Origin of chalk in Norwegian and northernmost Danish Central Graben	Origin of chalk in Danish Central Graben
Rogaland	Vidar	Late Paleocene	Reworked late Cretaceous, mainly Maastrichtian chalk	Not present
Shetland	Ekofisk	Danian	Reworked Maastrichtian, pelagic and reworked Danian chalks	Pelagic and intra-formational reworking
Shetland	Tor	Late Campanian-Maastrichtian	Pelagic and intra-formational reworking	Pelagic and intra-formational reworking
Shetland	Hod	Turonian-early Campanian	Pelagic and intra-formational reworking	Pelagic and intra-formational reworking

Table 5-1: Formal Chalk formations in the Central Graben area

In addition to reworking of the chalk, the biostratigraphic data have revealed the presence of time gaps, representing non-deposition, erosion or faulting out, between or within the chalk formations.

The lithostratigraphic nomenclature relevant for the oil and gas reservoir sections of the chalk fields in the North Sea Central Graben has been adopted almost completely in the Norwegian sector and to some extent in the Danish sector. It has for some years been recommended to use the chalk formation names, e.g. Hod, Tor, Ekofisk and Vidar on all chalk fields in the North Sea Central Graben, and to keep a strict separation between these lithostratigraphic formation names and the chronostratigraphic age names, such as Maastrichtian and Danian.

5.2 A proposed revised Chalk lithostratigraphic nomenclature

The present study, based on the compilation of more than 4000 biostratigraphic sample analyses from 35 study wells in both Norwegian, Danish and UK sectors, represents the most thorough stratigraphic study ever performed on the North sea chalks. Conclusions and recommendations from the study will be presented to the national stratigraphic committees, in order to influence forthcoming revisions of the lithostratigraphic nomenclatures. In the following sections, the lithostratigraphic formations or units are discussed on basis of biostratigraphy, seismic data and depositional facies. **Figure 5-2** shows the various published lithostratigraphical nomenclatures for the North Sea Central Graben, in comparison to the stratigraphic framework suggested in this study, and **figure 5-2 b** gives the detailed reference to the biostratigraphic zonal scheme.

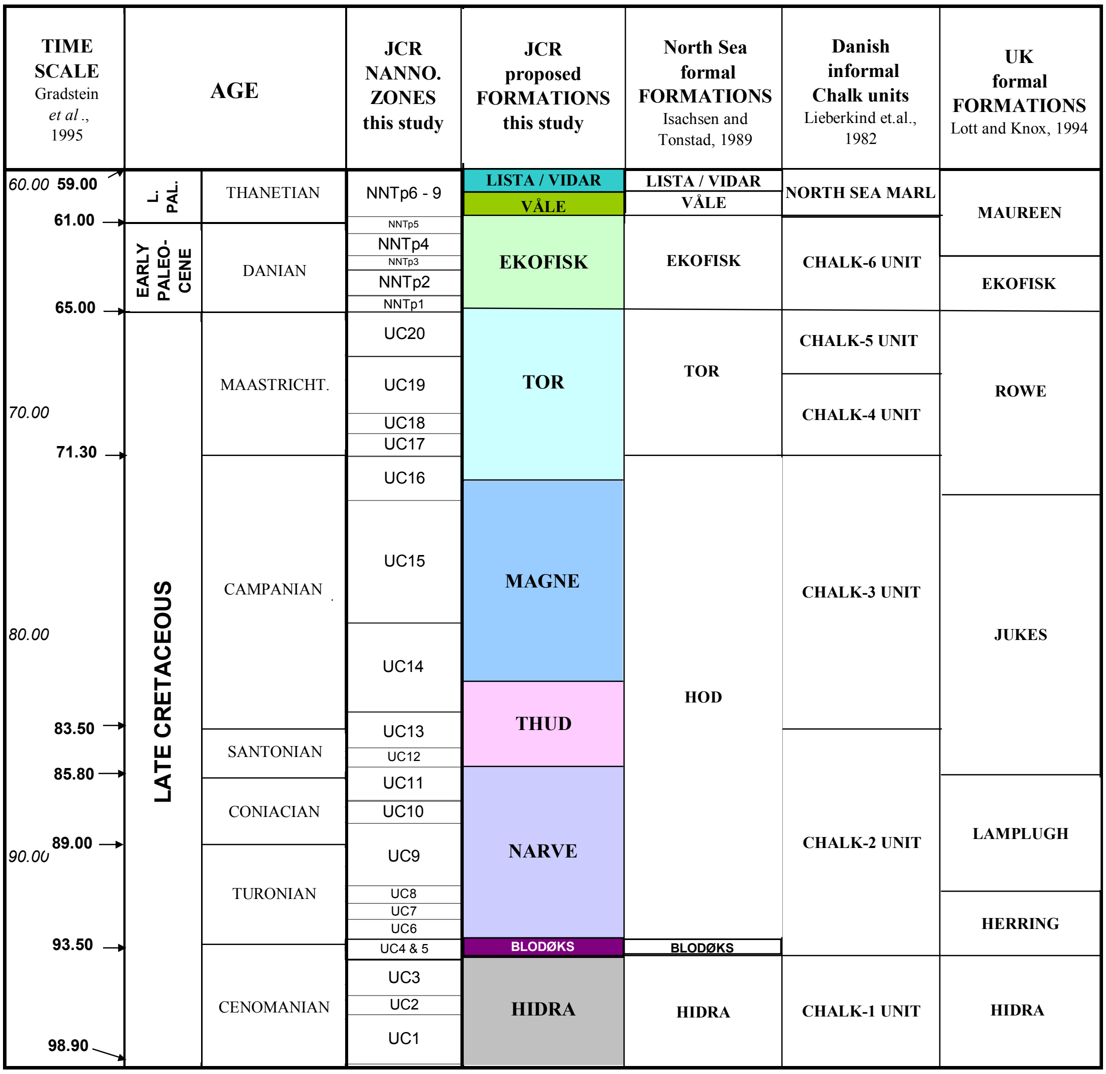

Figure 5-2: North Sea Central Graben stratigraphic framework

Table 5-2 shows the formation boundary picks in the individual study wells. Some wells are marked with NA (Not Available) in cases where missing logs and insufficient biostratigraphic evidence make boundary picks uncertain. NP (Not Present) means that the formation is not positively recognised from logs or biostratigraphic data. Depths are shown in feet or meters according to original logs or in both to facilitate comparison with nearby wells.

well	Top-Base Vidar	Top Våle	Top Ekofisk	Top Tor	Top Magne	Top Thud	Top Narve	Top Blodøks
1/3-1	10157-10326' 3096-3147,5m	10548' 3215m	10686' 3257m	11027' 3360,9m	12549' 3825m	13156' 4010 m	14032 4277m	14301' 4359m
1/3-8	10507-10764' 3202,5-3281m	11006' 3354,5m	11070' 3374m	11416' 3479,5m	12966' 3952m	13533' 4125m	14229' 4337m	14829' 4520m
1/9-1	NP	9892' 3015m	9970' 3039m	10180' 3103m	10818' 3297,2m	NP	10905' 3324m	11976' 3650,5m
2/2-2	NP	NP	NP	2513,5m	2705,5m	NP	NP	NP
2/2-3	2965-3004m	NP	3016,5m	3090,5	3400m	NP	NP	NP
2/4-A-8	NP	10076'	10113'	10566'	NP	NP	NP	NP
2/4-B-19	NP	9711'	9777'	10212'	NP	11381'	11511'	12762'
2/4-B-19A/T2	NP	9767'	9836'	10279'	NP	NP	NP	NP
2/5-1	NP	NP	9977' 3041m	10276' 3132m	11399' 3474,5m	NP	11606' 3537,6m	12 060' 3676m
2/5-7	3168,5-3175m	3189,9m	3204m	3347m	3726m	3955,5m	3983m	NP
2/5-9	NP	3250m	3259,5m	3380,4m	3745,7m	NP	3897m	4077,5m
2/7-2	NP	9649'	9715'	9856'	10454'	11220'	11458'	12281'
2/7-4	NP	10095'	10164'	10458'	10881,4'	NP	NP	NP
2/7-8	NP	NP	9744'	NP	9943'	10273'	10460'	NP
2/7-15	NP	9788'	9856'	NP	9967'	10328'	10433'	11037'
2/7-30	NP	10269'	10335'	10635'	10 920'	11201'	NP	NP
2/7-B-11	NP	9754'	9805'	10056'	10413'	NP	10460'	10925'
2/8-A-1	NP	NP	2467m	2470m	2497m	NP	2501,5m	2581,5
2/11-A-2	NP	NP	3373m	3378,5	3427.4m	3486m	3498m	3607,5m
2/11-A-2T2	NP	NP	3373m	3378,5	3427.4m	3486m	3498m	3607,5m
2/11-A2-T3	NP	NP	3373m	3378,5	3427.4m	3486m	3498m	3607,5m
MFB-7	NP	7331'	7357'	7464'	NP	NP	NP	NP
M-9X	NP	NP	6416'	6550'	NP	NP	NP	NP
E-4X	NP	NP	NA	6635'	7207'	NP	NP	NP
Roar-2	NP	NP	6641' 2024,2m	6740' 2054,4m	6878' 2096,5m	6990' 2130m	7218' 2200m	7979' 2432 m
Roar-2A	NP	NP	6641' 2024,2m	6740' 2054,4m	6878' 2096,5m	6990' 2130m	7218' 2200m	7979' 2432 m
Adda-2	NA	NA	NA	7015'	7092'	7170'	7260'	7640'
Adda-3	NA	NA	NA	NA	NA	NA	NA	NA
BO-1			6750'	6760'	6816'	6872	6955'	7260'
Baron-2	NP	NP	2826,5m	NP	2886,5m	2904.8m	2926m	2953,5m
Lulu1	NP	8940'	9028'	9360'	10466'	NP	NP	NP
Mona-1	NP	9873'	9908'	10278'	11195'	NP	11212'	NP
30/7a-2	NP	10066'	10087'	10377'	10897'	11154.7'	11512'	12 555.8'
31/26a-10	NP	8148'	8207'	8360'	8617'	NP	?	8963'

Table 5-2: Formation tops (in Measured Depth) in study wells

Figure 5-4 shows the JCR proposed formations in a sequence stratigraphic framework in the type/reference well 1/3-1.

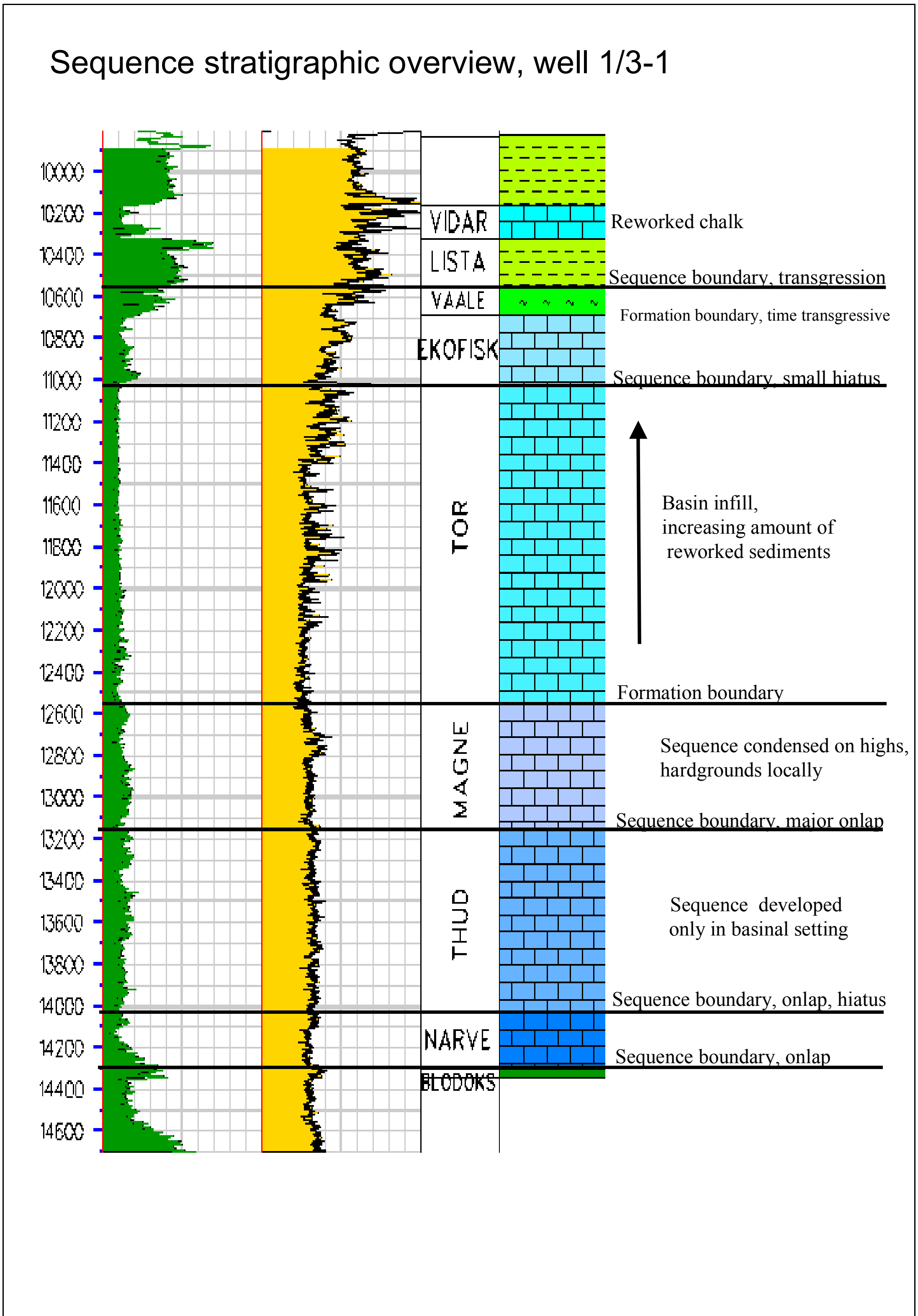

Figure 5-4: Well reference section 1/3-1

5.3 Turonian to Campanian chalk stratigraphic framework

The original Hod Formation (cf. Deegan and Scull, 1977) was informally split into a Lower, Middle and Upper unit (Isaksen and Tonstad, 1989). In this study, an alternative subdivision of the Turonian-Campanian section is presented, proposing three new formation names, Narve, Thud and Magne, stratigraphically placed between the Blodøks Formation and the Tor Formation, see **figure 5-2**.

5.3.1 A proposed new "Hod" lithostratigraphy

Recent seismic evidence shows that sediments assigned to the formal Hod Formation actually represent three genetically unrelated units, such that the original concept of the formation (Deegan and Scull, 1977, Isaksen & Tonstad, 1989) is no longer tenable. We herein propose the new names Narve (oldest), Thud (intermediate) and Magne (youngest) formations for these units, which are in effect seismic sequences. The geometrical relationships between the units are shown in geoseismic cartoon form on **figure 5-3**. The criteria for defining their boundaries on seismic, biostratigraphic and well log evidence are described below and summarised in **table 5-3.** Thickness and distribution, lithology and facies, and biostratigraphic and age data pertaining to the proposed units are also discussed below, with further details to be found elsewhere in the text (seismic sequence boundary definitions and thickness and distribution data in Section 2, lithology and facies data in Section 3, and biostratigraphic and age data in Section 4). Boundary picks are tabulated in **table 5-2**. Individual well composite logs honouring these picks are given in **figures 5-12 to 5-41**.

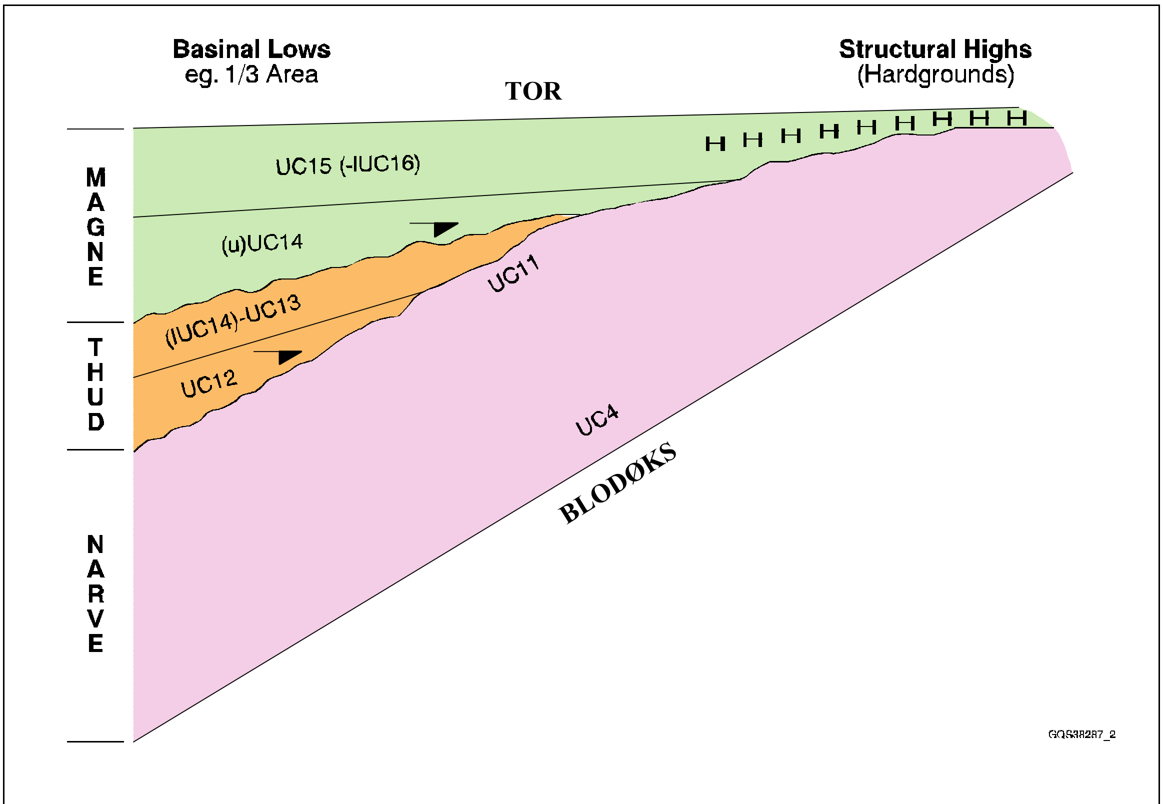

Figure 5-3: Schematic presentation of the sequence stratigraphic relationships between the Narve, Thud and Magne formations

Formation/ boundary	Boundary definition		
	Seismic *+/- few tens of metres (depth conversion)*	**Biostrat** *+/- few metres (sampling)*	**Logs** *+/- one metre (tool resolution)*
Tor			
Tor / Magne boundary	**Poorly imaged**	**intraUC 16**	**Uphole gamma increase**
Magne			
Magne / Thud boundary	**Onlap surface**	**intraUC 14**	
Thud			
Thud / Narve boundary	**Onlap surface**	**UC 11**	
Narve			
Narve / Blodøks boundary	**Base chalk reflector**	**UC 3**	**Downhole gamma increase**
Blodøks			

Table 5-3: Summary of formation boundary definitions according to the various criteria

5.3.2 Narve formation

Name:
Narve formation (proposed). After the Norse god Narve, who was the son of Loke and Sigyn (Sturluson, 1954).

Well Type Section:
1/3-8, 4520-4337 m MD. **Figure 5-13** shows the formation present in well 1/3-8.

Well Reference section:
2/8-A-1, 2581,5 - 2501,5 m MD.

Lower Boundary Characteristics:
Picked primarily on biostratigraphic and log criteria. The biostratigraphic criterion is penetration of microzone FCS13 or nannozone UC3. The log criterion is a downhole gamma increase indicating penetration of the shales of the Blodøks Formation.

Upper Boundary Characteristics:
Picked primarily on seismic and biostratigraphic criteria. The seismic criterion is an onlap surface (**figure 5-4**). The biostratigraphic criterion is penetration of nannozone UC11.

Thickness and Distribution throughout Study Area:
The thickness of this formation ranges from zero to a few hundred metres in the study wells. It is absent in the 2/2 wells in the Norwegian Sector and in the Lulu-1 well in the Danish Sector. It is thin (typically less than 100m thick) in wells on structural highs such as Valhall-Hod and Tor in the Norwegian Sector, and thickest in wells in basinal lows such as that in the Roar area in the Danish Sector, and in the northern and western depocenters in the Norwegian sector.

Lithology, Main Depositional Facies and Environments:
Lithofacies associated with the crestal biofacies on the Valhall Megastructure (see below) are typically (textural) mudstones and wackestones. Those associated with the "shallow water" pelagic biofacies are varied, though typically bioturbated to laminated chalks or interlaminated chalks and clays indicative of slow sedimentation. Those associated with the "deep water" pelagic biofacies are typically massive chalks. Recognition of allochthonous as against autochthonous chalks is rendered difficult by the poor bathymetric resolution afforded by the rare benthonic foraminifera.

Lithofacies in core from the 2/8-A-1 well include bioturbated chalks with *Chondrites, Planolites* and *Zoophycos*, and also allochthonous debris flows and slumps with micritic matrices and polymict/non-chalk clasts (see also Section 3), indicating affinity with the "shallow water" and "deep water" pelagic biofacies of the Valhall Megastructure respectively (see below). Allochthonous chalks are also observed in core from Mona-1.

Biofacies and interpreted environments on the Valhall Megastructure include the following (Sikora *et al.,* in Jones & Simmons, 1999):

Low Productivity Crestal Biofacies.- Characterised by low diversity, but often high abundance assemblages of unkeeled planktonic foraminifera and radiolaria, and by rare benthonic foraminifera. This is the shallowest, most crestal biofacies seen, though probably still comparatively deep (below storm wavebase).

"Shallow Water" Pelagic Biofacies.- Characterised by moderate abundance and diversity assemblages of unkeeled and, locally, keeled planktonic foraminifera and radiolaria, and by rare benthonic foraminifera. This biofacies is generally centred on the crest-flank transition, and intergrades with the low productivity crestal biofacies up-dip and the "deep water" pelagic biofacies down-dip.

"Deep Water" Pelagic Biofacies.- Characterised by high abundance and diversity assemblages of (epipelagic) unkeeled and (bathypelagic) keeled planktonic foraminifera and radiolaria, and by rare benthonic foraminifera (including deep water forms such as *Stensioina* and *Osangularia*). This biofacies is generally centred on the flank or flank-basin transition, though it is also represented on the crest-flank transition and crest (at times of maximum flooding).

Biostratigraphic Characterisation:
Microzones FCS14-FCS18pp; nannozones UC4-UC11 (see **figure 5-2 and figure 5-3**; see also Chapter 4).

Log pattern:

The Narve formation has been penetrated in quite many wells in the Valhall area (Lindesnes Ridge) and in the Ål basin to the west of the ridge. The gamma log patterns of these wells correlate well in this area, and a detailed correlation of different subzones is possible. A zone of clean chalk with consistently low gamma values, overlain by a gamma spike, is situated in the middle of the Narve formation. This zone (informally named Hod4 by BPAmoco) constitutes an important reservoir in the Valhall Field (see **figure 5-29**), and it can easily be recognised on the logs. However, its biostratigraphic age is not consistent between the wells, and it is possible that the "Hod4" subzone is diachronous.

Age:
Latest Cenomanian-earliest Santonian (for practical purposes, Turonian-Coniacian).

Remarks:
Eroded on crests of structures.

5.3.3 Thud formation

Name:
Thud formation (proposed). After an alternative name for the Norse god Odin (Sturluson, 1954). Thud means "thin one".

Well Type Section:
1/3-8, 4337-4125 m MD, see **figure 5-13**.

Lower Boundary Characteristics:
Picked primarily on seismic and biostratigraphic criteria. The seismic criterion is an onlap surface (see Chapter 2). The biostratigraphic criterion is penetration of nannozone UC11.

Upper Boundary Characteristics:
Picked primarily on a seismic criterion (onlap surface: see Chapter 2), corresponding to the original informal middle Hod sequence boundary.

Thickness and Distribution throughout Study Area:
The thickness of this formation ranges from zero to a few hundred metres in the study wells. It is absent in the 2/2 wells and in wells on structural highs, such as Valhall-Hod and Eldfisk in the Norwegian Sector and in the Lulu-1 well in the Danish Sector. It is thickest in wells in basinal lows, such as those in the 1/3 area in the Norwegian Sector and the Roar area in the Danish Sector.

Lithology, Main Depositional Facies and Environments:
Poorly constrained owing to the lack of core coverage. Biofacies in cuttings samples from some wells are characterised by moderately abundant and diverse planktonic foraminifera and radiolaria and generally rarer calc-agglutinated and calcareous benthonic foraminifera, indicating an affinity with the open marine platform or "shallow water" pelagic biofacies of the Valhall Megastructure.

Biostratigraphic Characterisation:
Microzones FCS18pp-FCS20pp; nannozones UC12-UC14 pp (see **figure 5-2 and figure 5-3**; see also Chapter 4).

Log pattern:
A complete Thud formation has been penetrated in few wells, because of its basinal setting. In the northern part of the region, the gamma values in 1/3-1 and 1/3-8 (see **figure 5-12** and **5-13)** indicate a clay content that is higher than in the Magne Formation. The relatively argillaceous chalks seem to alternate with clean chalks, giving rise to a "box-shaped" pattern of the gamma log. The time equivalent to the Thud Formation in the Roar-2 well (**figure 5-33** and **enclosure 5-1**) in the Danish sector has developed a different log and seismic pattern (chapter 2.3.3), and is described in chapter 2.4.

Age:
Late Early Santonian to earliest Campanian (for practical purposes, Santonian).

Remarks:
Laps on to Narve formation on flanks of structures.

5.3.4 Magne formation

Name:
Magne formation (proposed). After the Norse god Magne, who was the son of Tor, and who supported him after his great fight with the giant Hrungnir (Sturluson, 1954).

Well Type Section:
1/3-8, 4125-3952 m MD, see **figure 5-13**.

Well Reference section:
2/11-A-2 T2, 3486 - 3427,4 m MD, see **figure 5-30**.

Lower Boundary Characteristics:
Picked primarily on a seismic criterion (onlap surface: see Chapter 2).

Upper Boundary Characteristics:
Picked on seismic, biostratigraphic and log criteria. The seismic criterion is a reflector (which may also locally be an onlap surface) separating a lower amplitude interval below from a higher amplitude interval above, at least in structurally higher areas (see Chapter 2). The biostratigraphic criterion is penetration of microzone FCS21. The log criterion is a downhole gamma increase (the Magne is more clay-rich than the overlying Tor).

Thickness and Distribution throughout Study Area:
The thickness of this formation ranges from zero to a few hundred metres in the study wells. It is absent in the 31/26A-10 well in the United Kingdom Sector, thin (typically less than 100 m thick) on structural highs such as Valhall-Hod, Eldfisk and Tor in the Norwegian Sector,

and thickest in wells in basinal lows such as those in the 1/3 and, locally, 2/5 areas in the Norwegian Sector.

Lithology, Main Depositional Facies and Environments:
Lithofacies associated with the crestal biofacies on the Valhall Megastructure (see below) are typically (textural) mudstones and wackestones. Those associated with the open marine platform, high productivity upper slope and basinal biofacies are typically bioturbated argillaceous wackestones and chalks or interbedded chalks and claystones (sometimes referred to as periodites), indicative of slow sedimentation or, in the case of the basinal biofacies, incipient hardgrounds, indicative of extremely slow sedimentation (sediment starvation). Those associated with the eutrophic sub-biofacies are bioturbated, those associated with the dysoxic sub-biofacies are laminated (i.e., non-bioturbated) pyritic chalks.

Biofacies and interpreted environments on the Valhall Megastructure include the following (Sikora *et al.,* in Jones & Simmons, 1999):

Low Productivity Crestal Biofacies.- As in the case of Narve formation (see above), characterised by low diversity, but often high abundance assemblages of unkeeled planktonic foraminifera and radiolaria, and by rare benthonic foraminifera. This is the shallowest, most crestal biofacies seen, though probably still comparatively deep (below storm wavebase).

Open Marine Platform Biofacies.- Characterised by moderate abundance and diversity assemblages of planktonic foraminifera (and calcispheres) and calcareous benthonic foraminifera (the latter including *Gyroidinoides, Globorotalites, Reussella, Bolivinoides*, nodosariids and frequent but never common deep water *Stensioina*). This biofacies is generally centred on the crest-flank transition, though it is also represented on the crest (at times of maximum flooding).

Upper Slope High Productivity Biofacies.- Characterised by high abundance and diversity assemblages of (epipelagic) unkeeled and, especially, (bathypelagic) keeled planktonic foraminifera, and by rarer benthonic foraminifera (including deep water forms such as *Stensioina* and *Eponides*). This biofacies is generally centred on the flank.

Basinal Biofacies.- Characterised by high abundance and diversity assemblages of planktonic and benthonic foraminifera (the latter including deep water forms such as *Stensioina, Cibicidoides, Aragonia, Alabamina, Gavelinella, Dorothia, Spiroplectammina, Pullenia* and *Osangularia*, and very deep water forms such as *Nuttallides truempyi* and *Nuttallinella florealis,* which probably indicate middle-lower slope depths). This is the deepest, most basinal biofacies seen.

Carbonaceous Biofacies.- Carbonaceous (eutrophic and dysoxic) sub-biofacies of the upper slope and basinal biofacies are locally recognisable. The eutrophic sub-biofacies is characterised by a high incidence of infaunal taxa such as *Bolivina incrassata, Coryphostomum plaitum, Neobulimina* and *Praebulimina,* probably indicating a high organic carbon content in the sediment. The dysoxic sub-biofacies is characterised by a dominance of the epifaunal taxon *Stensioina*, especially *S. granulata polonica,* probably indicating borderline anoxia in the sediment.

Biostratigraphic Characterisation:
Microzones intraFCS20pp-intraFCS22; nannozones intraUC14pp-intraUC16pp (see **figure 5-2 and figure 5-3**; see also Chapter 4).

Age:
Late Early to early Late Campanian (for practical purposes, Campanian).

Remarks:
Onlaps Thud and oversteps on to Narve (?) on flanks of structures. Generally absent or thin on crests (characterised by hardground development).

5.4 Turonian-Campanian stratigraphy in Danish Central Graben

The formal lithostratigraphy of the Chalk Group in the North Sea (Deegan & Scull 1977) was only tentatively correlated to an informal log stratigraphy established in the Danish Central Graben by Lieberkind et al. (1982). Later, seismic sequences, log motifs and biostratigraphy were integrated as a basis for correlation and subdivision of the Chalk Group in the northern part of the Danish Central Graben by Nygaard *et al*. (1990), but a correlation further to the north was not considered.

In recent publications, the informal log units of Lieberkind *et al*. (1982) and also the formal formations of Isaksen & Tonstad (1989) established for the Norwegian sector have rarely been used for the Cenomanian – Danian carbonates in the Danish Central Graben.

In the present study progress has been made to establish a link between the Turonian – Campanian carbonates of the Norwegian type area and a Danish reference area represented by the Roar-2 well.

5.4.1 Log stratigraphy of the Chalk Group

In the Danish sector of the Central Graben the Chalk Group of Deegan & Scull (1977) was subdivided by Lieberkind *et al*. (1982) into six informal log units, the Chalk-1 Unit to Chalk-6 Unit, see **figure 5-2**. The units were primarily defined by the gamma ray and sonic velocity (GR / DT log) responses. The boundaries between the six units are *diachronous* except for the Chalk-1 / Chalk-2 Unit boundary. The Chalk-2 Unit, excluding the lowermost part and the Chalk-3 Units were tentatively correlated to the Norwegian Hod Formation. The lowermost part of Chalk Unit-2 is represented by a shale assigned a Turonian age (no biostratigraphic or other evidence for this age was given in the text), and it was suggested that the shale interval probably could be equivalent to the lower part of the Plenus Marl Formation. The Chalk-3 / Chalk-4 Unit boundary is of Campanian age and might be equivalent to the Hod / Tor boundary of Deegan & Scull (1977). The type sections for the informal Chalk-2 and Chalk-3 Units are in the wells E-1 and V-1, respectively, while the reference sections for the two units are in the wells V-1 and Q-1, respectively. None of these wells are included in the present study. Lieberkind *et al*. (1982) further subdivided the Danish Central Graben into six depositional zones reflecting different subbasin and high areas. They found the most complete Cenomanian – Campanian chalk sequence in the deposit zones in the eastern part of Danish Central Graben, and suggested that only the three youngest units of Late Campanian to Danian ages are present over the whole of the Danish Central Graben.

5.4.2 Integrated correlation and subdivision of the Chalk Group

Nygaard et al. (1990) recognized six seismic sequences in the Chalk Group in the northern part of the Danish Central Graben. The area is characterized by considerable thickness variation and by a number of inversion zones, which have been active in separate phases during Late Cretaceous times, Vejbæk & Andersen (1987). The lower four sequences are of Turonian – Campanian ages, and the most complete section of these sequences is seen in the Gert-1 (DK) and Karl-1 (DK) wells, neither of which are included in the present study.

5.4.3 Turonian – Campanian stratigraphy in Danish wells

Turonian – Campanian carbonates are only present in few of the Danish wells selected for the present study i.e. in Roar-2, Baron-2 and Lulu-1, and none of these three wells are included in the previous stratigraphic studies (cited above) in the Danish sector. In the Roar-2 well, 336m of Late Cenomanian – Early-Late Campanian carbonates are present. In the Baron-2 well, 52m of Late Coniacian – Late Campanian carbonates are recorded and most of that interval is cored. In the Lulu-1 well, 55m of Late Campanian carbonates are present, and finally in the Mona-1 well, 23 m of Middle Coniacian - Late Campanian carbonates are cored.

Reference section:
The **Roar-2** (DK / 1981) well has a rather complete section of the late Cenomanian – Early-Late Campanian carbonates in the interval 2436 – 2100 m MD. During the late Cenomanian – Campanian times the setting at the well location shifted from a basin setting to a flank setting – high setting.

Reference area:
The Roar-2 (DK / 1981) well appraised an anticlinal structure at top chalk level in the northwestern part of the Tyra – Igor Ridge; see Britze et al. (1995). The structure lies on an end-Cretaceous and Tertiary, predominantly Miocene, structural inversion (Megson 1992); see also seismic reference section through the Roar-2 well in **figure 2-15.**

Boundaries:
The lower boundary is at the top of a claystone layer (Plenus Marl), which is well defined with high GR and sonic log responses.
The upper boundary is picked based on biostratigraphy between carbonates determined to the FCS21- and FCS22a-b zones. No characteristic changes in the trends of the GR and sonic log responses are seen at the upper boundary.

Thickness and distribution:
The thickness of the Turonian – Campanian carbonates, i.e. approximately the thickness of the Chalk-2 and Chalk-3 Units, varies from about 50 – 400m in the wells studied by Lieberkind *et al*. (1982), while the thickness in the Karl-1 well, drilled in a basin setting between the Mona Ridge and the Mandal High, is more than 850m. The Roar-2 reference well has a rather complete 336m thick section of Turonian – Campanian carbonates and is considered representative for the local sub-basin of the reference area.

Lithology and depositional facies:
The Turonian – Campanian carbonates have only been cored in few wells in the Danish (and Norwegian) Sector(s), and most of these cores only have an incomplete or condensed section of the carbonates i.e. the cored Coniacian – Late Campanian section in the Baron-2 and Mona-1 wells. Therefore a tight integration of log-, seismic- and biostratigraphic data has been compiled in efforts to characterise, correlate and subdivide the Turonian – Campanian carbonates.

A log derived characterisation of the lithology in the Cenomanian – Danian carbonates has been applied in the Roar-2 well, amongst others. The characterisation roughly defines the clay content in non-clean carbonates and the porosity in clean carbonates. The log-derived lithology is primarily from the gamma and the sonic logs, respectively, and is here called the

GR/DT-lithology. The GR/DT-lithology identify six different lithologies on the basis of three GR-Base Line values and two DT-Base Line values, see Table below. The Base Line concept is a part of a lithological interpretation tool used in the log analysis application of Landmark Stratworks.

1. – 3. GR Base Line Values	< 1.			> 1. & < 2.	> 2. & < 3.	> 3.
1. - 2. DT Base Line Values	> 1.	< 1. & > 2.	< 2.			
Chalk / Limestone	Clean			Slightly Clayey	Clayey	Clay-rich
Approximate Porosity's	> 25%	25 - 15%	< 15%			
Display colour of Lithology	Yellow	Green	Blue	Light Brown	Dark Brown	Red

Table 5-4: GR/DT-lithology of the Cenomanian – Danian carbonates

In the Turonian – Campanian carbonates several orders of distinct cycles with clayey carbonates - clean carbonates can be defined on the basis of the combined pattern of the GR and DT logs. The cycle thickness ranges from a few metres to around hundred metres.

In the Roar-2 well (**enclosure 5-1**) three major cycles have been defined constrained by seismic markers and biostratigraphy i.e. a Late Cenomanian – Coniacian cycle between Top Upper Cretaceous Cycle (T. UCC 03 and 04, 2445 – 2324m MD), a Coniacian cycle between T. UCC 04 and 05 (2324 – 2232m MD) and a Santonian cycle between T. UCC 05 and 06 (2232 – 2131m MD. The lowermost of these cycles is characterised by several chert layers. Before defining these major cycles, an analysis of the combined GR/DT-log response revealed eleven more or less developed cycles, where the GR-log response change from low frequency - low values near the top of a cycle to higher frequency - higher values in the lower part of the overlying cycle, i. e. from a relatively clean carbonate interval in the uppermost part of a cycle to a more clay-rich interval in the lower and / or middle part of a cycle; see the track to the right in **enclosure 5-1**.

Most cycles show a decrease in GR values through a cycle, from maximum values at the base or higher in the cycle, to the top of the cycle. The corresponding DT-log response throughout a well-developed cycle is one of lower sonic velocities in the more clay-rich part and higher sonic velocities in the clean carbonates at the top of the cycle. Two of the combined GR/DT-log responses can mask or make the identification of cycles difficult. First log response, which here will be designated a GR/DT-hardground with glauconite, is where a higher GR pick value corresponds to a high sonic velocity pick, and the second, is where a very low GR pick correspond to a very high sonic velocity, a response which could be caused by a chert layer.

The final definition of the three major cycles involves an evaluation of the position of the seismic markers and of the biostratigraphy, as well as the uncertainties of the log-, the seismic- and the biostratigraphic data. When comparing the thickness of these major cycles with equivalent cycles in the Norwegian well 1/3-8, se **enclosure 5-2**, it appears that the section in the Roar-2 well is very complete. This is also supported by the biostratigraphy. The Campanian carbonates in the Roar-2 well are very thin, 2131 – 2100 m MD.

A correlation of the major cycles in the Roar-2 well with selected wells in the Norwegian sector is shown in **enclosure 5-3**, and seismic profiles across Roar-2 are shown in **figure 2-15** and **enclosure 2-5.**

5.5 Tor Formation

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 (**figure 5-12**) is the type well for the Tor Formation (Tonstad and Isaksen 1989).

Well Reference Sections:
The Mona-1 well is chosen as a one of two reference sections for the Tor Formation. The Tor Formation interval in this well is from 3133 to 3412mMD. The stratigraphic sequence in Mona-1 is relatively complete with individual zones being represented by a significant thickness. Except for the very top the Tor Formation is cored throughout this well, as seen in **figure 5-5 - 5-6** and in **figure 5-36**.

Discovery well for the Tor Field, well 2/5-1, is chosen as a second reference section for the Tor Formation. Only the upper half of the Tor Formation is cored but the 2/5-1 well has all Tor zones well developed, as seen in **figure 5-5** - **5-6** and in **figure 5-20**. The Tor Formation interval in 2/5-1 is from 3132 to 3474.5mMD.

Age:
The age of the Tor Formation has in this study been decided to encompass all of the Maastrichtian, i.e. nannofossil zones UC17 through 20 and intra microfossil zone FCS22 through FCS23. At the detailed level the top of zone UC16, which is of late Campanian age, cannot in all wells be brought to coincide with well defined log breaks. This is a problem that remains even after careful integration of all data. UC17 and 18 are Early Maastrichtian. UC19 and 20 are Late Maastrichtian.

Lower Boundary Characteristics:
35 wells are included in this project. 27 of those are represented with log data. In four of these the lower boundary of the Tor Formation is not covered by logs (2/4-B-19, 2/4-A-8, MFB-7, M-9X). The Baron-2 and 2/7-15 wells contain no Tor Formation. The log characteristics described below most often apply to a stratigraphic level within the UC16 zone.

In general the lower Tor boundary is difficult to pick on logs. A decrease in the GR level, small or large, is common, though quite often no change of the GR level is observed. This is contrary to findings by Lieberkind et al (1982), who noted no change or a small increase in the GR level upon entering the Tor Formation/Chalk-4 Unit. Wells studied are not the same, though, and Lieberkind et al's observations concerns the Danish Central Graben area only. Figure 5.9a,b shows six wells from the present study, selected to represent the variation in boundary characteristics observed.

In the stratigraphically more complete wells there seems to be a regional element to the log characteristics. In the northern basin wells the sonic log shows an increase in velocity upon entering the Tor Formation from Magne below. This is associated with either no change or a slight increase in the density reading, i.e lower porosity. From 2/7-B-11 on the Lindesnes

Ridge and southeastwards the sonic log shows a decrease in velocity crossing from Magne to Tor Formation. This is associated with either no change or a slight decrease in the density reading, i.e higher porosity. Where nannozones UC16-18 are thin or missing a change to lower porosity associated with an increase in velocity is observed at the boundary. These are observations of a general nature and exceptions can be found.

The resistivity logs to some degree mirror the sonic and density logs in water bearing chalk. Where the velocity and density go up an increased resistivity is often seen, reflecting a more dense rock, and vice versa. Exceptions are wells, where the bottom part of the Tor Formation is porous and oil-bearing, e.g. 2/7-B-11. Here a decrease in velocity and density is accompanied by an increase in resistivity.

The lower boundary either coincides with the boundary between biozones UC16 and 18 (UC17 is only scarcely present) or is placed midway in UC16. In wells 2/2-2, 2/7-15 and Mona-1 most of UC16 is shown as belonging to the Tor Formation. There is often a discrepancy between the biostratigraphy and the log picks, such that the log picks tend to be deeper placed than than the top of nannozone UC16.

Upper Boundary Characteristics:
In general the Top Tor is of the same age over the study area. The duration of the Tor/Ekofisk hiatus mostly depends on how much is missing from the Ekofisk Formation. Locally all of the Ekofisk is missing due to later inversion as seen on the crestal parts of the Hod and Valhall Fields. Here the Tor Formation, or reworked Tor Formation, is overlain by Paleocene shales (2/8-A-1).

The GR shows a gradual or well defined (though mostly minor) increase, more rarely an abrupt increase. In a few wells there is no change in the GR level across the boundary (Dan Field wells and 2/5-9). The Top Tor pick is usually put right at the start of the increase. A reliable determination of the boundary requires other logs in addition to the GR and above all biostratigraphy to establish the overall frame.

In accordance with a shift to lower porosities in the bottom part of the Ekofisk Formation the velocity shows a clear increase at Top Tor. Alternatively the Top Tor shows up as a high density peak right at the boundary and the porosity at either side of the peak is about the same value (the 2/5 wells). In this case the Top Tor pick should be just above the high density peak. The uppermost part of the Tor Formation can be well cemented and as a result appear exactly like the Ekofisk on density and velocity logs. In the absence of good biostratigraphic data the usual slight increase in GR should enable an accurate log pick, though.

Where the Top Tor is represented by nannozone UC19 a decrease in velocity and density is seen (2/2-2 and 2/7-8).

A relative decrease in resistivity across the Tor/Ekofisk boundary is seen. This picture is consistent even though the resistivity in the top part of the Tor Formation is affected by pore fluids (water, oil or gas).

Thickness and Distribution:
Tor thicknesses in the study wells vary from 0m in Baron-2 to 472m in 1/3-8. The arithmetic average of the study wells is 198m. The thickness variations in the study wells are not

representative of the North Sea Basin Chalk/Tor Formation distribution as most wells are drilled on structural highs. Regional thickness maps based on seismic interpretation show a general thickening of the Upper Cretaceous package from southeast to northwest in the Central Graben system (Britze et al, 1995, Ziegler, 1990, Japsen, 1998). This general observation has an overprint of local east or west depocentres going from north to southeast along the Graben axis (This study). This pattern is confirmed by the study wells also for the Tor Formation alone.

Seismic character:
A general description of the reflectors can be found in section 2.3. The Tor Formation seismic package is characterised by well defined continous reflectors in the upper half, while the lower half most often show less distinct reflectors. This difference is most pronounced in the northern part of the study area, where the formation is also the thickest. It is probable, that the lower half is simply better developed to the north and that these deeper layers has a very thin development southeastwards in the basin resulting in more pronounced reflectors. Neither the Base nor the Top Tor boundary are seismically distinct reflectors and would be difficult to pick without well-tie. Onto the Lindesnes Ridge a major part of the Tor package disappears. The 2/7 and 2/8 wells show that the missing part is from top down. The same generalisations cannot be made for the Arne/Bo-Jens inversion ridge.

Lithology and Depositional Facies:
15 of the study wells are more or less well represented by core in the Tor Formation. Nannozone UC20 is described in core material from all fifteen wells, UC19 from ten wells and UC18 from four wells. Zone UC17 has not been cored.

All depositional modes identified in the core descriptions are present in the Tor Formation. There seems to be no systematic correlation between reservoir quality and depositional mode. Statistically the tightest intervals/beds are pelagic (nine of fifteen examples), while the most porous intervals can be either depositional facies (pelagic, homogeneous, reworked or slumped).

The Tor Formation is in general very clean with a low content of insolubles (<5%). The clean nature of the chalk is reflected in the light colour and the evidence of pressure solution in the form of dental stylolites. Dental stylolites are typical for clean chalk, while the pressure solution in the more dirty chalks appears as horsetails solution seams.

The Tor formation is composed of mixed pelagic and allochthonous chalks. There is a gradual upward increase in the amount of allochthonous material in the Mona-1 type well and in well 2/5- 1 on the Tor Field. A similar distribution is observed in wells drilled on Ekofisk, West Ekofisk and Albuskjell.

The distribution of sedimentary facies is driven by paleotopography, so that what is seen today is the combined result of primary deposition and secondary processes in the form of reworking and diagenesis. Therefore, to understand the depositional facies, the location of the individual wells with respect to regional structural features (basinal axis, margins and inversion ridges) and more local halokinetic structures, is critical (**figure 2-1**, **table 3-1**).

The Late Campanian UC16 nannozone is described here, since the topmost part is often included in the Tor Formation. The UC16 zone is absent from Baron-2, situated on an inversion ridge and from 31/26a-10, located on the western margin of the basin. The sparse core information from this zone shows a variety of sedimentary facies. In the Mona-1 well all of the UC16 is pelagic, owing to this wells sheltered position on a gentle local high some distance from basin margins. The three remaining wells with UC16 cored (2/7-B-11, 2/8-A-1, 2/11-A-2) show a more condensed section represented by slumped and reworked chalk. These three wells are located on the Lindesnes inversion ridge in the Norwegian sector.

Zones UC17 and 18 are of Early Maastrichtian age. No cores are available from the UC17 zone The UC18 is cored throughout in the Mona-1 well, where this zone is developed as predominantly pelagic chalk with intermittent slumped and reworked sections.

The cores from wells 2/7-B-11 and 2/8-A-1 show a relatively thin UC18 of a homogeneous or reworked appearance. The 2/7-B-11 well with complete Tor core coverage is remarkable in that only one facies is described – a homogeneous chalk. This well is located on the Eldfisk structure which was affected by inversion and halokinesis, and depositional facies may be totally dominated by intense/continous reworking. The Tor Formation in the 2/8-A-1 well in the Valhall Field shows many unconformities and condensed sections as a result of being located on the Lindesnes inversion ridge. The reworked Tor Fm chalks on the Lindesnes Ridge are often preserved in local sub basins, and the allochthonous chalks are in general difficult to correlate between the fields on the ridge.

Zones UC19 and 20 are of Upper Maastrichtian age. Both are relatively well represented by core. The most extensive core coverage of zone UC19 is in wells 30/7a-2, 2/5-1, 1/9-1, 2/7-B-11 and Mona-1. Cores of the top part of zone 19 only is available from wells 2/4-A-8, 2/7-4, 2/11-A-2, M-9X and MFB-7. This zone is mostly characterised by pelagic or homogeneous chalk with only few, thin intercalactions of reworked material in the form of wackestones and grainstones. Strangely enough, the Mona-1 well is an exception in that the major part of UC19 here is a thick package of grainstones/debris flows. There is also a thick package of reworked chalk in the upper part of UC 19 in the Ekofisk Field. This is not immediately obvious from material presented here (wells 2/4B-19/ 2/4-19B is not positively cored through UC19), but reworking can be inferred from other well data from the Ekofisk Field (Kennedy, 1985).

Since the Late Maastrichtian was a time of global high sea level with high chalk production and sedimentation rates, the basin margin/slope areas were prone to redistribution of unstably accumulated chalk ooze. The high chalk sedimentation rates served to drape existing structures in the central parts of the basins (pelagic and/or homogeneous turbidites). In all wells the top part of UC19 comprise pelagic or homogeneous chalk.

The UC20 zone is cored in 15 of the study wells. It is always pelagic at the bottom, suggesting a tectonically quiet period around the UC19/20 boundary. Up through UC20 the cores show increasing complexity of facies in the Norwegian and northern part of the Danish sector. The southernmost Danish wells are, however, pelagic throughout. A line running ENE-WSW from the Ringkøbing-Fyn High to the Mid-North Sea High separates the Southern Salt Dome Province ("all pelagic") from the rest of the study area.

The top section of UC20 is also dominantly pelagic, except for 2/4-A-8, 2/4B-19, 2/7-4, 30/7a-2 and 2/7-B-11, which have a reworked or slumped section at the top.

Based on log characteristics the UC20 biozone is the most porous zone, particularly in the upper half. The internal contrasts in porosity are most pronounced in the westernmost wells (30/7a-2, 1/3-8, 1/3-1, 2/7-4, 2/7-2, 31/26a-10). In these wells a much more bedded appearance is seen compared to the easternmost and Danish wells, where any development in porosity is more gradual with less contrasts and much thicker bed-composites. In this respect the Tommeliten alpha well 1/9-1, though located quite far west looks more like the eastern wells. These variations can be ascribed to the different source areas for reworked chalks. The Hidra High and Lindesnes ridge are two important source areas for allochthonous chalk in UC19/20 whose position and contribution have changed over time.

Biostratigraphic Characterisation:
Biostratigraphically, the Tor Formation encompasses the upper part of nannoplankton Zone UC16 through to Zone UC20 and the two foraminiferid Zones FCS22 and FCS23, both of which have been further divided into subzones as part of the present study (see Chapter 4).

Both the nannofloral and microfaunal assemblages used to define the zonal schemes compare closely to similar assemblages from latest Campanian to Maastrichtian chalk sections described from the adjacent onshore regions of Denmark (Surlyk & Birkelund, 1977, Stenestad, 1979), North Germany (Schönfeld & Burnett, 1991) and the north Norfolk area of East Anglia, U.K (Hart et al., 1989). These comparisons allow a high confidence level in the zonal dates applied to the offshore sections examined.

There is considerable biostratigraphic evidence for intra-formational reworking within the Tor throughout the study region. Several wells contain sections where Late Campanian and Early Maastrichtian Tor sediments have been re-deposited during the Late Maastrichtian (e.g. 2/5-1, 2/7-4, 30/7a-2 and Mona-1). There is also evidence of reworking within the Late Maastrichtian, which can be proven by presence of restricted Zone UC19 nannofloral markers co-existing with the restricted Zone UC20 species *Nephrolithus frequens*. Despite the frequent presence of stacked allochthonous chalk units within the Tor, the ages of individual units can be ascertained on the basis of the characteristic nannofloral and microfaunal associations.

Many of the well sections examined include very thin and condensed Late Campanian to Early Maastrichtian intervals (Foram. Zone FCS22, Nannoplankton Zones UC16 - UC18), suggesting active structural growth during this period. Although occasional reworking within lower Tor sediments is recognised with Campanian or older taxa present within Early Maastrichtian (Zone UC18) chalks (e.g. wells 2/4B-19, 2/11A-2 T3 and Mona-1), the maximum phase of allochthonous chalk deposition is during the Late Maastrichtian resulting in considerable variation in formation thickness across the region.

Subdivisions:
It has been decided not to propose any formal subdivision of the Tor Formation. As mentioned in the section on seismic character the North-western end of the study area suggests potential for subdivision here. Many Norwegian companies have previously subdivided the Tor Formation in Quadrant 2 into TA (top), TB and TC, corresponding to Unit 4 and 5 in the Danish Sector (Lieberkind et al., 1982, correlation in Andersen, 1995). TC is the basin infill facies. TB and TA correspond to upper UC19 and UC20 in well 2/5-1.

5.6 Ekofisk Formation

A schematic diagram illustrating the stratigraphic framework of the Ekofisk Formation is shown in **figure 5-7**. Note that the diagram is based on well data only, the internal seismic resolution of the Ekofisk Formation does not permit regional subdivision of the unit, and the exact erosional/depositional relationship is uncertain. Also, regional variations exist, and the diagram is not meant to illustrate the exact stratigraphy in a certain area, but just to give an approximate picture of the regional variations from basinal settings to structural highs.

A figure illustrating typical wells from the south to the north is shown in **figure 5-8**.
Figure 5-9 shows the presence of the various biozones in the study wells.

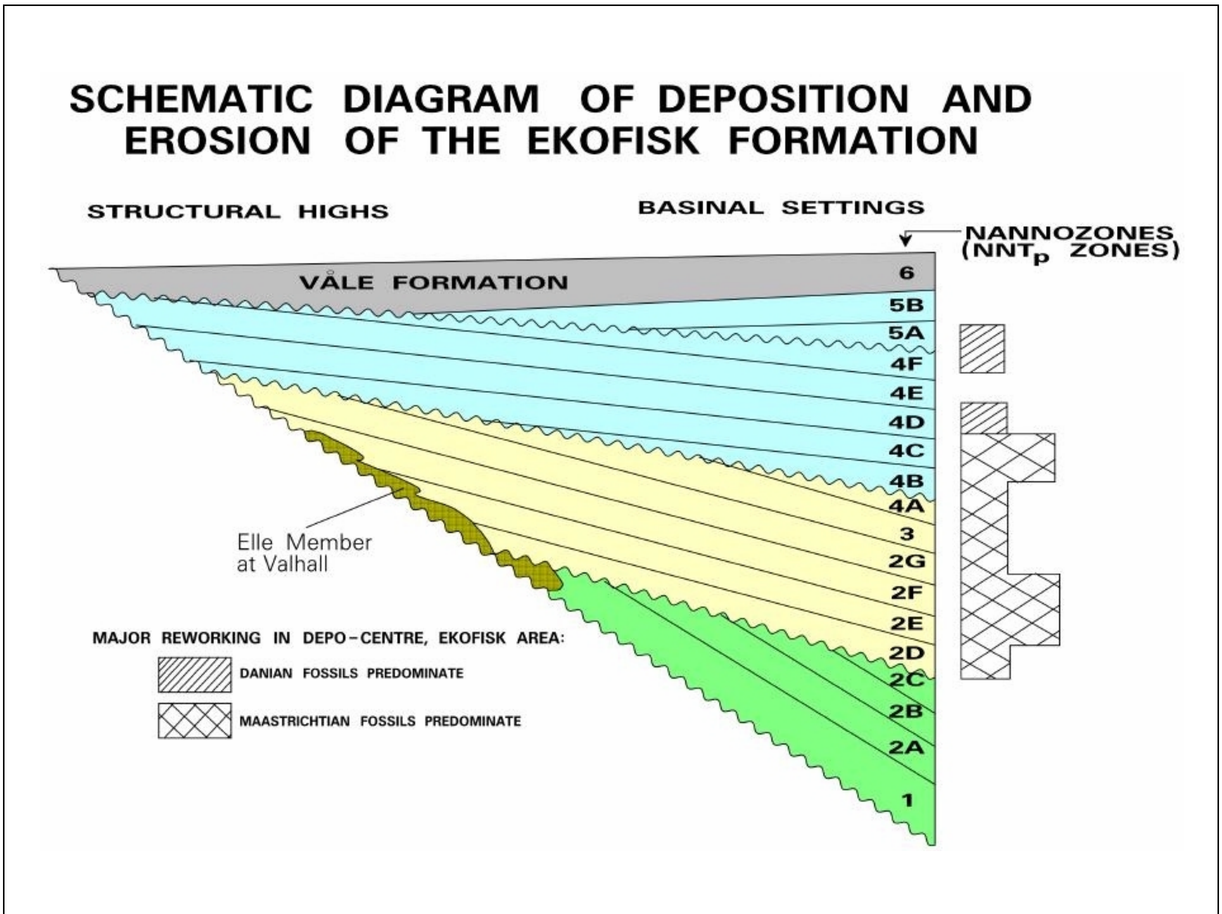

Figure 5-7: Schematic diagram of deposition and erosion of the Ekofisk Formation

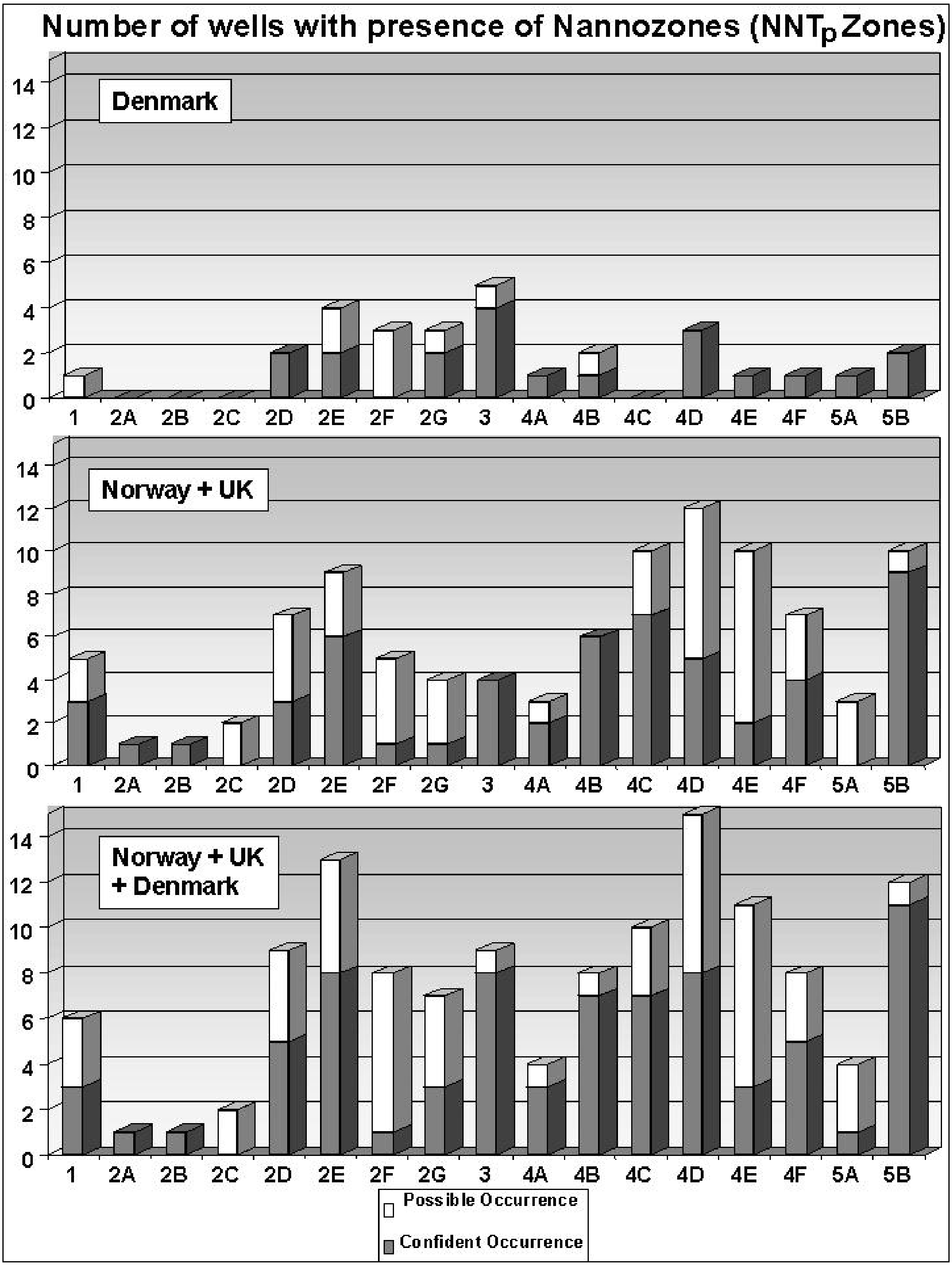

Figure 5-9: Ekofisk Formation biostratigraphic zones presence

Name:
From the Ekofisk field, Norwegian Block 2/4.

Well Type Section:
2/4-5, 3164-3037 m MD (Deegan and Scull, 1977).

Well Reference Sections:
1/3-1, 3354-3257 m MD.
UK 22/1-2A, 2982.5-2935 m MD.
2/5-1, 3132-3041 m MD. (This well was added by Isaksen and Tonstad, 1989).

Age:
Danian. Nannoplankton zones NNTp1-NNTp5B.

Lower contact characteristics:
The lower contact of the Ekofisk Formation is defined by the distinct stratigraphic unconformity at the Cretaceous-Tertiary boundary over most of the study area. Based on lithology, the recognition of the contact may, especially in the central parts of the Danish sector, be difficult due to low contrast in physical properties between the adjacent formations, as seen for example in the Roar-2 well (**figure 5-8**). In the southern and northern part of the Danish area, the lower section of the Ekofisk Formation is influenced by chert and clay in contrast to the pure chalk of the underlying Tor Formation. Most typical for the contact is, however, the erosional hardground at the top of the Tor Formation (see Chapter 5.4 and well MFB-7, **figure 5-8**).

Recognition from wireline logs is less clear than for the upper contact. In the wells in the Danish sector south of the Rinkøbing-Fyn High, there is no distinct break on the Gamma Ray. The erosional hardground on the top of the Tor formation is reflected by an increase on the density log in most wells. In the Baron-2 well, where the Tor formation is absent, the contact between Ekofisk and Hod is marked by a similar break on the density log (**figure 5-8**).

In the Norwegian sector, in the axial part of the Central Graben the contact is conformable, or with a minor hiatus, such as in the Ekofisk field. The lower contact is often marked by an increase of the Gamma Ray signal into a zone comprising argillaceous chalk in the lowermost Ekofisk Formation, informally known as the Ekofisk tight zone, for example in well 2/4-A-8 (**figure 5-8**). In some areas this zone is less well developed, and in wells in the Danish sector south of the Rinkøbing-Fyn high there is no distinct break on the Gamma Ray log.

On the flanks of the Central Graben and on the Lindesnes Ridge the contact is marked by an unconformity, and the lower part of the Ekofisk Formation is generally absent (**figure 5-7**). Here the lower contact is typically marked by a basal hard ground (well 2/2-3, **figure 5-8**). In some places, the Ekofisk Formation is very thin or absent, such as in the Hod and Valhall fields, where the Tor Formation is locally overlain by Paleocene shale.

The contact is in most cases easily recognized from biostratigraphy, although reworking of Maastrichtian fossils into younger deposits occasionally occur.

Upper contact characteristics:
The upper contact is characterized by an upward distinct change in lithology from the pure chalk of the Ekofisk Formation to massive layered shale. In some cases, a marl-dominated layer is found in between. In some areas, both in the Danish and the Norwegian sector, there is a gradual transition into the overlying marl, which may make it difficult to pick the exact top (Baron-2, **figure 5-8**).

The upper contact is observed on several of the wireline logs. It is most distinct on the Gamma Ray log, where the contact often is expressed as a very sharp break, which, however, is more gradual when marl is present at the contact. (Compare Baron-2 and MFB-7, **figure 5-8**.) The sonic log shows a similar response.

The density log is also showing a clear change as a consequence of the porosity contrast between the adjacent layers. The change on the neutron log is not as distinct as it is modified by the presence/absence of hydrocarbons/water in the pore spaces, but there is usually a distinct break in the neutron-density separation across the boundary (2/4-A-8, **figure 5-8**).

The contact is always recognisable biostratigraphically.

Formation thickness and distribution across study area:
The thickness of the Ekofisk Formation varies throughout the study area. In the southern end of the Danish sector, the thickness is some 30 to 40 meters whereas in the central area (Roar-2, Bo-1), the upper part or all of the Ekofisk Formation is absent and the thickness may be reduced significantly, down to a few meters.

Further north, the thickness increases again (61 m, Baron-2) to more than 100 meters in Mona-1 and Lulu-1. Cores from the Ekofisk formation in Lulu-1 show significant influence from turbidites and this may also be the case in Mona-1, which displays a similar log pattern.

The depositional centre for the Ekofisk Formation extends along the axis of the Central Graben from the Mona area past the Ekofisk area, with thicknesses reaching about 170 m (139 m in 2/4-A-8, **figure 5-8**). Major reworking is observed in this depositional centre.

On the east and northeast flank of the Central Graben the Ekofisk Formation thins and is locally absent, as for example in well 2/2-2. On the western flank of the Central Graben, in the border area between the Norwegian and UK sectors, the thickness generally varies between 50 -100 m (e.g. 31/26a-10 and 1/9-1), reflecting an environment dominated primarily by pelagic deposition and debris flows.

Due to inversion along the Lindesnes Ridge the Ekofisk Formation thins rapidly onto the ridge and is locally absent in the Hod and Valhall fields.

Lithology, main depositional facies and environment:
In general, the lowermost part (Nannofossil zones NNTp1 and NNTp2B/C) of the Ekofisk Formation is absent from the study wells in the Danish sector. This may reflect the erosion on the Tor-Ekofisk boundary continuing into the Danian. Indications of occurrence of the oldest zone (NNTp1) are reported from Lulu-1. The environment of the Ekofisk Formation in the southern part of the Danish sector is dominated by pelagic deposition of a laminated, bioturbated mudstone (MFB-7, **figures 3-17** and **5-8**). The lower parts are often argillaceous

and chert bearing. Only minor reworking of mainly Late Maastrichtian species occurs. The pelagic strata are occasionally interrupted by debris flows, in several cases marking the contact between adjacent biozones.

In the central part of the Danish sector a similar environment is found (Roar-2, **figures 3-16** and **5-8**). However, slumps are more common compared to the southern part. In addition, the youngest part of the formation is absent. The chalk is less argillaceous and chert is rare. Continuing northwards, slumps and turbidites dominate the lower part of the Ekofisk Formation in Baron-2, whereas the upper part is dominantly pelagic laminated, bioturbated mudstone (**figures 3-15** and **5-8**). Like in Roar-2, the youngest part of the formation is absent.

Approaching the Norwegian sector, the thickest and stratigraphically most complete Ekofisk succession in the Danish sector is found in Lulu-1 (**figure 3-13**). The coring of the Ekofisk Formation is, however, incomplete in this well such that the cores cover the upper and lower part but the central part (approximately 34 m) is uncored. Lulu-1 is the only of the Danish study wells where the oldest nannofossil biozone (NNTp1) is observed. The lowest part of the section is dominated by an argillaceous massive to laminated chalk mudstone. The argillaceous content shows a cyclic variation but generally the density of clay seams increase upward. The section is dominantly pelagic and slumps are rare, mainly occurring in the deepest part. The section above is dominated by massive pelagic mudstone. Clay is less common than below but stylolites are numerous. Slumps are rare and mainly present toward the top of the lower part of the cored sections. The section uncored in Lulu-1 is known from offset wells to be dominated by reworked chalk. The base of the upper part of the cored sections is dominated by pelagic massive chalk mudstones and wackestones. To the top of nannofossil biozone NNTp4D, slumps and debris flows dominate and reworked chalk thus forms a significant part of this section. In the uppermost part, white pelagic chalk becomes dominant, represented by nannofossil biozone NNTp5B. This late Danian biozone is only found in Lulu-1 and in MFB-7 in the southernmost part of the Danish sector.

The most complete Ekofisk Formation is found in the Ekofisk field area in the Norwegian sector. The lowermost part is generally formed by argillaceous, pelagic chalk belonging to nannofossil biozone NNTp1 and the lower part of NNTp2, up to NNTp2D/E (2/4-A-8, **figure 5-8**). In the upper part of this “Ekofisk tight zone” some reworked layers may occur. Upwards the section is dominated by a thick, heavily reworked unit comprising predominantly Maastrichtian fossils. Dating is problematic due to the extensive reworking, but the zone seems to correspond mainly to the upper part of NNTp2 and the lower part of NNTp4 (see **enclosure 4-48**). The unit consists mainly of massive, homogenous chalk and pebble floatstone interpreted as slides, slumps and debris flows, occasionally with thin pelagic layers in between. The upper part of the Ekofisk Formation is also variably reworked, but less extensively than the lower part, and generally consists of slumped, deformed chalk and debris flows with interbeds of pelagic chalk. Reworking took place especially within zone NNTp4D, but also in the uppermost part of zone NNTp4 and during NNTp5A. The uppermost part, belonging to zone NNTp5B is predominantly pelagic and grades into the overlying marl of the Våle Formation, with no sharp transition.

The source area for the reworked zones is believed to be mainly the Lindesnes Ridge to the southwest, but also with some contribution from the east and northeast. Further away from the Lindesnes Ridge, in Block 2/5, the reworking seems to be less penetrative, and the Ekofisk

Formation is dominated by interbedded pelagic chalk and thin turbidites with occasional thicker debris flows (Well 2/5-1, **figure 3-12**).

In the Valhall Field on the Lindesnes Ridge, the Maastrichtian chalk was reworked through shallow-water shoaling and winnowing across the central crest, feeding coarser-grained debris flows down the flank (Elle Member; Bergen and Sikora, 1999). This reworked unit seems to correlate at least in part to the lower reworked Maastrichtian deposits at the Ekofisk Field (**Figure 5-7**). A major flooding event at about 63 Ma BP terminated the reworking at Valhall, and younger Danian chalk is a highly condensed, stratigraphically discontinous, deep-water autochthonous deposit (Sikora et al., 1999).

On the flanks of the Norwegian part of the Central Graben, as well as in the wells from the UK sector, the lower part of the Ekofisk Formation is generally absent. Pelagic chalk with thin turbidites dominate, with occasional thicker reworked zones (i.e. 30/7a-2, **figure 3-19**).

In summary, the Ekofisk Formation comprises a highly varied range of deposits, with pelagic chalk dominating in the southern and western part of the study area, but in the area around the Ekofisk field, where the thickest and most complete section is found, reworked chalk dominates. The main stratigraphic breaks appear at the base and top of the formation.

Seismic characteristics:
On the type of seismic sections used in this study Top Chalk is recognised as a clear seismic trough resulting from an increase in acoustic impedance (SEG reverse polarity standard). In areas where there is a gradual transition from the Ekofisk Formation to the overlying marls the top may be difficult to pick exactly.Presence of hydrocarbons or excessive high formation porosity may result in deviations from the normally expected seismic appearance with the top of the chalk formation show dimming or even phase reversal of the seismic signal.

Where thick enough to be resolved, the internal seismic character of the Ekofisk Formation tends to be chaotic, and internal units can only be interpreted locally. See also Chapter 2.3.

Biostratigraphic characteristics:
All study wells with cores from the Ekofisk formation have been analysed to identify diagnostic nannofossil assemblages. In the present study, some 17 nannofossil zones have been identified (**figure 5-9**). In the wells in the Danish sector up to seven of these were found in individual wells and four were not observed at all. As core coverage is incomplete, these are minimum numbers. However, the stratigraphic breaks seem to occur at some distinct levels, namely the lowermost zones NNTp1 to NNTp2C/D, the intermediate zones NNTp4A/B/C and the upper zones NNTp4E/F and NNTp5A/B. These zones are either sparsely represented or absent.

The wells in the southernmost part of the Danish sector (MFB-7, **figure 5-8**, and M-9X) are showing the largest diversity in terms of biozones present. This is in agreement with the dominantly pelagic depositional environment as interpreted from the cores. Although the interval is cored, the oldest zones have not been identified in these wells. This may be due to absence or condensing of the zones. Also, in these wells, reworking of fossils of Maastrichtian age is observed, even in the shallowest samples. The wells in the central part of the Danish sector (Roar-2 and Baron-2, **figure 5-8**) show a pattern similar to the southern part except that the upper biozones are absent. This follows generally the observations from logs.

Although the number of biozones present is low, the formation is relatively thick (30-60 m). This is at least partly caused by significant reworking of older strata especially in the lowest Ekofisk, where Maastrichtian fossils dominate. Reworking is observed continuously upwards through the formation and fossils as old as Campanian are found. The occurrence of such old fossils at this level is linked to the Tor formation being thin or absent in this area.

The thickest Ekofisk section in the Danish sector is found in the Lulu-1 and Mona-1 wells. Nevertheless, reworking seems, in the studied cores, to be insignificant (**figures 3-13 and 3-14**). Some reworking is found in the upper part of the formation and, as mentioned above, the uncored central section is known to be dominated by reworked chalk. Note, however, that the same biozone (NNTp4D) is observed immediately below and above the uncored section. This biozone is more than 65 m thick in Lulu-1. The same zone is respectively 0 and 20 m in the central wells Roar-2 and Baron-2. It is the youngest zone in the Ekofisk Formation found in these wells, which may be due to erosion of the younger zones. However, in the pelagic-dominated MFB-7, the zone is 12 m thick. The Lulu-1 deposits are therefore likely to represent a combination of *in situ* deposits and a significant volume of redeposited (older) sediments.

In the Norwegian sector, a fairly complete stratigraphic section is found in the axial part of the Central Graben, where all 17 nannofossil zones have been identified. Up to approximately ten zones have been found in individual wells. The stratigraphic breaks that were noted in the Danish wells mentioned above can also be observed in the Norwegian wells, although somewhat shifted in position (**figure 5-9**). In the depocentre in the Ekofisk area, deposition took place resulting from erosion further south, associated with some of the above mentioned stratigraphic breaks, but also here biostratigraphic breaks can be observed in individual wells.

Zone NNTp1 has been found in some wells in the axial part of the Central Graben. Zones 2A-2C is sparsely represented in the data, even in the depocentre. A significant erosional episode took place within zone NNTp2, eroding into the Maastrichtian deposits on the Lindesnes Ridge and depositing a thick reworked unit in the basin, particularly during zones 2E-F. A thin Danian unit comprising mainly reworked Maastrichtian chalk has also been described at the Valhall Field (Bergen and Sikora, 1999). The datings correspond approximately to zones NNTp1 and at least part of zone 2, and the unit probably represents the erosional remains left behind on the ridge (Figure 5.10). Zones NNTp2G/3/4A are again less frequently represented in the data, and the amount of erosional deposits is less marked. These zones, in particular zone 3, are more common in the more pelagically-dominated Danish wells. A flooding event took place on the Lindesnes Ridge at about this time, and the younger Danian chalk is represented by a thin, condensed deep-water section (Sikora et al., 1999). A new significant erosional/depositional pulse of Maastrichtian material seems to have taken place within zones NNTp4B-4C. In the wells from the areas flanking the depositional centre, both on the Norwegian and the UK sector, most of the section up through the lower part of zone NNTp4 is missing (2/2-3, **figure 5-8**).

A change in deposition can be seen in the Ekofisk area in the middle part of zone NNTp4, approximately zone 4D, when there is a marked reduction in reworking, and especially in influx of Maastrichtian material. This is associated with a more widespread deposition of the Ekofisk Formation over the structurally high areas, with less erosion of the underlying Tor

Formation. Significant slumping and debris flow continued, however, although less than in the section below.

Higher up in the section, pelagic deposits are more dominating, but a new episode with reworking occurred in the upper part of zone NNTp4 and lower part of zone NNTp5 (NNTp4E/F-5A), approximately coinciding with a stratigraphic break observed both in the Danish and Norwegian/UK wells (**Figures 5-7 and 5-9).**

Zone NNTp5B is widespread in the Norwegian study area, but has not been identified in the UK wells. It is dominated by pelagic deposits, with a gradational transition into the overlying marls.

Subdivision:
In this project it was decided that no subdivisiun of the Ekofisk Formation will be performed, implying that each company continues their own nomenclature for zonation. However, see subchapter 5.8 for recommendations on naming of reworked zones.

5.7 Late Paleocene chalk units: Vidar Formation

Reworked chalk of Early Paleocene to Late Cretaceous age are observed in the late Paleocene section. Chalk beds varying from only a few cm thick and up to beds of 70 metres thick are common. Only one formation has been named, the Vidar Formation.

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

Well type section:
Norwegian well 2/1-4 from 3138 to 3075 m. No cores.

Well reference section:
Norwegian well 1/3-1 from 3147 to 3095 m. No cores.

Lower Boundary Characteristics:
The lower boundary represents a sharp transition from the claystone 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. **Figure 5-10** shows the presence of the Vidar Formation in wells 1/3-8, 2/2-3 and 2/5-7.

Upper Boundary Characteristics:
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. The upper boundary can be picked seismically.

Thickness and distribution throughout Study Area:
The thickness varies from less than a few m to about 70 m in the study area. Where the Vidar Formation is well developed, it is easily identified on the seismic lines, as strong reflections with poor continuity, indicating an increase in acoustic impedance (**figure 2-12**). Based on the seismic interpretation, the Vidar Formation is restricted to the northern part of the Central Graben (**figure 5-11**), and it is found in the following of the studied wells: 1/3-1, 1/3-8, 2/2-3 and 2/5-7 (**figure 5-10)**.

Lithology, main Depositional Facies and Environments:
Homogeneous limestone is the dominant lithology. Thin shales occur within the chalk beds. The chalk beds of the Vidar Formation may occur at different levels in the Lista Formation. Presence of reworked chalk of early Palaeocene and late Cretaceous age indicates that the Vidar Formation Chalk originates from the Shetland Group. Mass flows from each side of the Central Graben are the most probable transport mechanism for this reworked unit.

Biostratigraphic Characterisation:
All chalks of the Vidar formation are reworked Danian or Late Cretaceous of age.

Age:
Late Paleocene, consisting of reworked chalk mainly of Danian and Maastrichtian age.

5.8 A Joint lithostratigraphic nomenclature for reworking

The formal lithostratigraphic formations in the various chalk fields are usually subdivided by the operator into informal sub-zones, based on chalk lithotypes or other stratigraphic information. A detailed description of the sub-zones in the Tor and Ekofisk formations on the Ekofisk field was published by Pekot and Gersib (1987), and Jørgensen (1992) has published a subdivision of the Dan field. This local sub-zonation within the various chalk fields, combined with the biostratigraphic and lithostratigraphic complexity of the chalk formations, makes intraformational or zonal correlation between the fields difficult.

For this study, it has been agreed that it will not be possible, and not even attractive, to develop a joint and common nomenclature for lithostratigraphic sub-formation layering. Sub-formation layering may have many different purposes, from the pure sedimentological / sequence stratigraphy and to pure petrophysical / porosity guided layering. The layer boundaries would therefore not follow the same lines in the various cases. Using the joint JCR biostratigraphic nomenclature and the lithostrat formations as a common basis, it is always possible to see if the actual model layer as an example belongs to the upper Ekofisk or the lower Ekofisk.

However, for reworked chalk units, it will be a general advantage to be able to identify their presence and their origin as close as possible. For this purpose, the following nomenclature has been agreed:

Once a reworked unit has been identified through biostratigraphic analysis, it is given an additional nametag, consisting of two parts. The first part of the nametag tells which lithostratigraphic formation is the host for the unit, i.e. within which formation it is physically present today. The other part of the name tells the age origin of the guest chalk unit, i.e. in which geologic time was it originally deposited. **Table 5-5** illustrates the point. This name tagging will often help understanding the reservoir characteristics of specific layers, not only from the fact that the chalk has been transported and thus changed its original texture, but also from the fact that the size of nannofossils has changed over time. Maastrichtian coccoliths were generally larger than Danian coccoliths, thus having different capillary and porosity /permeability properties.

Formation	Example of old zonation	Example of new zonation	Explanation
VIDAR FM	V1	Vr-Dan	*Chalk of Danian age redeposited within Vidar Fm*
		Vr-LMaa	*Chalk of Late Maastrichtian age redeposited within Vidar Fm*
VÅLE FM	V2		
EKOFISK FM.	E1		
	E2	**Ek-Dan**	*Chalk of Danian age redeposited within Ekofisk Fm*
	E3	**Ek-EMaa**	*Chalk of Early Maastrichtian age redeposited within Ekofisk Fm*
		Ek-LMaa	*Chalk of Late Maastrichtian age redeposited within Ekofisk Fm*
	E4		
TOR FM.	T1		
		Tr-LCmp	*Chalk of Late Campanian age redeposited within Tor Fm*
	T2		
	T3	**Tr-EMaa**	*Chalk of Early Maastrichtian age redeposited within Tor Fm*

Table 5-5: Examples of nomenclature for reworked units

In this study, wherever reworking has been identified in the biostratigraphic analyses, the nomenclature for reworking has been applied in a separate column in the biostrat range charts (**enclosures 4-35 to 4-104)**.

Nametags used in the study wells are:

- **Vr-Dan:** Chalk of Danian age redeposited within the Vidar Formation, as seen in well 1/3-8.
- **Vr-LMaa:** Chalk of Late Maastrichtian age redeposited within the Vidar Formation, as seen in wells 1/3-1 and 1/3-8.
- **Ek-Dan**: chalk of Danian age, reworked and finally deposited within the Ekofisk Formation, as seen in well 2/4-A-8.

- **Ek-LMaa**: chalk of Late Maastrichtian age, reworked and finally deposited within the Ekofisk Formation , as seen in many of the wells in the study area (1/9-1, 2/4-B-19/A, 2/4-A-8, 2/5-7, 2/7-4, 2/7-B-11, Mona-1, MFB-1)
- **Ek-Emaa**: chalk of Early Maastrichtian age, reworked and finally deposited within the Ekofisk Formation , as seen in wells 2/7-15 and 2/7-8.
- **Ek-LCmp**: chalk of Late Campanian age, reworked and finally deposited within the Ekofisk Formation, as seen in wells 2/7-4, 2/5-9, 2/4-B-19A, 2/4-A-8.
- **Ek-Con/Tur**: chalk of Coniacian or Turonian age, reworked and finally deposited within the Ekofisk Formation, as seen in wells 2/7-30 and 2/4-B-19.
- **Tr-Lmaa:** chalk of Late Maastrichtian age, reworked and finally deposited within the Tor Formation, as seen in wells 1/9-1, 30/7a-2 and M-9X.
- **Tr-Emaa:** chalk of Early Maastrichtian age, reworked and finally deposited within the Tor Formation, as seen in wells 2/11-A-2, 2/5-1, 30/7a-2 and Roar-2.
- **Tr-LCmp**: chalk of Late Campanian age, reworked and finally deposited within the Tor Formation, as seen in wells 2/7-4, 2/4-B-19, 1/9-1 and 30/7a-2.
- **Tr-Cen:** chalk of Cenomanian age, reworked and finally deposited within the Tor Formation, as seen in well 2/4-B-19.
- **Mg-Con:** chalk of Coniacian age, reworked and finally deposited within the Magne Formation, as seen in well Baron-2.

5.9 Well composites

Figures 5-12 to **5-41** are composite log, core and stratigraphic panels showing the key well logs together with lithostratigraphic formations, biostratigraphic zones and main chalk facies from core descriptions. The panels document the lithostratigraphic interpretation and give a useful overview of how the different data sets correlate. The panels also document the limitations of biostratigraphic resolution in the different wells. Discrepancies between the lithostratigraphic interpretation and biostratigraphic zones are often caused by sampling and data quality. The guidelines for the compilation of the panels are listed below.

- Core- to log depth shifts were performed on the main chalk facies columns according to **table 3-2**. The biostratigraphic data collected from core samples have been depth shifted as far as possible in the composites. Biostratigraphic zones may therefore appear slightly off scale compared to the biostratigraphic zone boundaries in the distribution charts of Chapter 4, in wells with significant depth shifts. Where obvious misties occur between the biostratigraphic zones and the lithostratigraphic formation boundaries, this is most likely due to the biostratigraphic data originating from ditch cuttings or from short non-shifted core sections.

- Apparent misties between biostratigraphy and lithostratigraphy can be seen in the upper section of some of the well composites, where a Danian age is defined for sediments well above the Ekofisk Formation. This is due to thin stringers of reworked limestone that frequently occur above the Våle Formation. These limestones are regarded as time equivalent to the Vidar Formation, originally derived from Danian age sediments. In these cases, the biostratigraphy is overruled by the lithostratigraphic interpretation.

- The biostratigraphic zone codes are generally simplified and do not include the sub-zones.

- Wells 2/11-A-2, 2/11-A-2 T2 and 2/11-A-2 T3 are treated as separate wells in the biostratigraphic chapter, with separate biostratigraphic summary logs and distribution charts, whereas the 3 well tracks are combined into one composite well panel. The logs and the depth scales represent 2/11-A-2 T3. In spite of the tracks being very close in space, depths are not exactly the same. Consequently, the biostratigraphic zones in the two other tracks appear somewhat shifted compared to the formation boundaries. Further, the cores were recovered partly from 2/11-A-2 (248 ft) and partly from 2/11-A-2 T2 (194 ft), but in the well composite the cores are combined into one section, with depths representing 2/11-A-2. Biostratigraphic data in 2/11-A-2 T3 are from ditch cuttings and are not depth shifted to the cores in the other tracks.

- Wells Roar-2 and Roar-2A are treated as two separate wells in the biostratigraphic chapter, but since Roar-2A had no available digital wireline logs, the two wells are combined into one composite well panel. There are only minor depth differences.

- Missing digital wireline logs is also the reason that no well composites were made for E-4X and Adda-3. These wells are included with biostratigraphic distribution charts in Chapter 4.

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