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ROBERTSON RESEARCH INTERNATIONAL LIMITED

REPORT NO. 2724P/A

STATOIL 15/8 - 1 NORWEGIAN NORTH SEA WELL: BIOSTRATIGRAPHY OF THE INTERVALS 2400m – 2850m AND 3400m – 4303m T.D.

by

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SUMMARY

1. The youngest sediments examined in this well are tuffaceous shales, assignable to the Rogaland Group, of Late Palaeocene age.

2. Sands, with subordinate shales, of the Montrose Group accumulated during the Late Palaeocene and upper part of the Early Palaeocene, Danian.

3. Chalky limestone assignable to the Ekofisk Formation of the Chalk Group occurs in the lower part of the Early Palaeocene, Danian.

4. Interval 2850'-3400' was not examined.

5. Due to the use of the turbine-assisted drilling bit down into the Kimmeridge Clay Formation, age-diagnostic taxa within the Late Cretaceous - Late Jurassic, Kimmeridgian interval are lacking, thus preventing any detailed biostratigraphic analysis.

6. The Upper Cretaceous Chalk Group appears to rest conformably upon the Lower Cretaceous, Cromer Knoll Group.

7. Shales and limestones of the Cromer Knoll Group accumulated during the Lower Cretaceous.

8. The relationship of the Cromer Knoll Group to the underlying Humber Group is unknown, although they may be separated by a hiatus of unknown extent.

9. Shales of the Kimmeridge Clay Formation were deposited during the Ryazanian? - latest Oxfordian, and are underlain by the argillaceous Heather Formation.

10. The Heather Formation, of Oxfordian age, rests conformably upon the Hugin Formation, of Early Oxfordian - Callovian age.

11. During the late - middle Callovian, sands, shales and coals accumulated,whilst the early Callovian is essentially shales and silts with occasional sands.

12. The Hugin Formation is probably separated from the non-marine Fladen Group, of Middle Jurassic age, by a brief hiatus.

12. Shales, sands and coals of the Sleipner Formation rest upon a volcano-clastic sequence attributable to the Rattray Formation, within which the well terminated.

II

INTRODUCTION

This report summarises the results of the micropalaeontological, palynological and stratigraphic analyses which have been carried out on material received from the sections 2400m-2850m and 3400m-4303mT.D. from the Statoil 15/8-1 Norwegian North Sea Well under Project No. RRPS/812/A/10191. The interval 2850m-3400m was not examined on receipt of instructions from the client.

The following analyses were carried out:
Lithology: 536 ditch cuttings, 8 sidewall core and 12 core samples from the entire section.
Micropalaeontology: 162 ditch cuttings samples from the intervals 2400m-2850m and 3400m-3602m.
Palynology: 68 ditch cuttings, 7 sidewall core and 12 core samples from the interval 3400m-4298m.

The basic breakdown obtained by these analyses has already been communicated by telex and telephone and forms the framework of factual information on which this report is based. A summary of the sequence penetrated in this well can be seen on page 5.

All rock colour references in this report conform to the "Rock-Color Chart" distributed by the Geological Society of America. The lithological descriptions of sidewall cores can be seen in Appendix 1 whilst those of the core samples occur in Appendix 2.

It should be noted that the lithostratigraphic terminology is taken from Deegan and Scull 1977. The stratigraphic significance of the Rhaetian - Albian dinocyst zones is summarised in Appendices 3 and 4.

The prepared samples and recorded information are now filed and curated in the confidential records section of these laboratories.

We wish to acknowledge the continued co-operation and assistance received from the various members of Statoil with whom we have been associated during the course of this work.

Robertson Research staff involved in this study were:

Mark Capsey - Mesozoic Micropalaeontology
Paul Connell - Tertiary Micropalaeontology
Jim Fenton - Palynology and Project Co-ordinator
Elizabeth Regnault - Lithologies
Kevin Tooby - Palynology
John Underwood - Lithostratigraphy

III

SUCCESSION

Age		Tops (in feet)
Late Palaeocene		2400m (top not seen)
Early Palaeocene	Danian	2820m-2850m
	Interval 2850m-3400m not examined	
Late Cretaceous	-	3400m (top not seen)
Early Cretaceous	Albian - ?Neocomian	3435m(log)
----------?Unconformity----------		
Early Cretaceous? - Late Jurassic	Ryazanian? - Kimmeridgian	3535m(log)
Late Jurassic	(early Kimmeridgian - middle Oxfordian	3578m
	(early Oxfordian - middle Callovian	3632m
	(early Callovian	3833m
Middle Jurassic	Bathonian - Bajocian	3943m(log)-4303mT.D.

This breakdown has been achieved by analysis of ditch cuttings, sidewall core and core piece samples. Gamma, neutron, and density electric logs were supplied.

The poor biostratigraphic breakdown achieved over the interval 3400m-3578m is considered to result from the use of a turbine - assisted drilling bit.

IV

LITHOSTRATIGRAPHY

The lithostratigraphic terminology used in this report is based on Deegan and Scull (1977); further more detailed, information specific to this area is taken from Larsen and Jaarvik (1981). The descriptions of the lithologies is based upon ditch cuttings samples, sidewall cores and conventional cores. Turbo-drilling was carried out over the interval 2898m-3570m and the ditch cuttings samples from this interval are considered to be unrepresentative of the true lithology. Gamma ray, caliper, bulk density and neutron porosity logs at a scale of either 1:200 or 1:500 were available over the entire section. Lithostratigraphic boundaries are based on log evidence where possible.

LITHOSTRATIGRAPHIC UNITS

ROGALAND GROUP: 2400m-2406m(log). Age: Late Palaeocene.

This unit consists of medium bluish grey tuffs and tuffaceous shales which have a grainy texture and sometimes contain finely disseminated pyrite. Moderately hard, medium dark grey, waxy and occasionally non-calcareous claystones are also present. No attempt has been made to sub-divide this unit on the information available.

MONTROSE GROUP: 2406m(log)-2822m(log). Age: Late Palaeocene - Early Palaeocene, Danian.

Heimdal Formation

The top of this unit is placed at a clearly defined log break above a distinct sandstone bed. The sandstone is friable, with a weak calcareous cement, fine to medium grained, angular, with white, clear to opaque grains. Below the sand, moderately hard, light grey to light olive grey limestone occurs within a medium dark grey to medium grey claystone, which becomes more fissile with depth. Finely disseminated glauconite and pyrite occur throughout. Locally banded shale occurs in this section. At 2507m well cemented, predominantly fine grained, very calcareous sandstone, with occasional coarse grains, becomes

the predominant lithology with small amounts of moderately hard, greenish grey, non-calcareous claystone. Locally the sandstone is argillaceous, and minor amounts of limestone and dolomite occur, possibly as clasts within the sandstone.

Traces of brittle, black coal, probably reworked, are recorded at 2690m. Below 2715m the claystone and shale are greenish grey, dark greenish grey or medium dark grey, non-calcareous and waxy.

Maureen Formation: 2822m(log)-2846m(log). Age: Early Palaeocene, Danian.
This unit is defined on log criteria. The section consists of poorly sorted sandstone with varying amounts of argillaceous material, and minor calcareous cement.

CHALK GROUP: 2846m(log)-2850m. Age: Early Palaeocene, Danian.

Ekofisk Formation.
As only part of this section was studied the base was not seen and the full age range of the section was not determined. The lithology consists of soft, white to very light grey slightly argillaceous chalky limestone.

2850m-3400m. This interval was not studied.

CHALK GROUP: 3400m-3435m(log). Age: Late Cretaceous.

Plenus Marl Formation: 3400m-3410m(log).
This unit consists of turbo-drilled, light grey argillaceous limestones.

Hidra Formation: 3410m(log)-3435m(log).
Light olive grey, white and locally pinkish or red chalky limestone occurs within this unit. At the top of the unit the limestone is platy, glauconitic and micaceous and, at the base of the unit, argillaceous limestone is inferred from the log pattern.

CROMER KNOLL GROUP: 3435m(log)-3535m(log). Age: Early Cretaceous, Albian - ?Neocomian.

This unit has been identified by the log pattern, the lithology and the age assigned. Although turbo-drilling has occurred throughout the section the lithology commences with argillaceous limestones and calcareous shales. Amounts of argillaceous limestone decrease with depth and below 3500m red colouration becomes apparent.

HUMBER GROUP: 3535m(log)-3943m(log). Age: Early Cretaceous? - Late Jurassic to Late Jurassic, Ryazanian? - Kimmeridgian to early Callovian.

Kimmeridge Clay Formation: 3535m(log)-3604m(log). Age: Ryazanian? - Kimmeridgian to early Kimmeridgian - middle Oxfordian.
The top of this unit is placed at a clearly defined log break where the gamma ray value exceeds 150 A.P.I. units. The lithology consists of soft, fissile, olive black, non-calcareous shale which has been turbo-drilled. At 3570m turbo-drilling ceases, and the shale is very carbonaceous with common to abundant bone fragments. Thin stringers of dolomite and limestone are seen at 3555m and 3600m respectively.

Heather Formation: 3604m(log)-3643m(log). Age: early Kimmeridgian - middle Oxfordian to early Oxfordian - middle Callovian.
Shale persists throughout this unit, and olive black, micromicaceous non-calcareous shale is predominant. Traces of pyrite occur sporadically and thin limestones are seen at 3625m. The shale becomes sandy towards the base of the interval. This unit is fairly readily identified on log evidence.

Hugin Formation: 3643m(log)-3943m(log). Age: early Oxfordian - middle Callovian to early Callovian.
The top of this unit is based on a log break marking the incoming of sand. This unit has been included in the Humber Group in this instance and not in the Brent Group, as suggested in Larsen and Jaarvik (1981). This is because the Heather Formation is a lateral equivalent of the Hugin Formation in some areas.

Three cycles have been identified:

Cycle 3: 3643m-3662.5m.

The lithology consists of an interbedded sequence of moderately hard, mainly fine grained, locally medium and coarse grained, mainly angular, but also sub-rounded and rarely well rounded sand with local calcite and dolomite cement, and firm, waxy, olive black shale.

Cycle 2: 3662.5m-3900m.

This unit consists of interbedded sands, coals and shales. Part of the interval was cored, and the sand is seen to be similar to that described above; more detailed descriptions of the core pieces examined appear in Appendix 2 of this report. The shales seen in this unit are similar to those described in Cycle 3 although locally they become sandy. Carbonaceous fragments and relatively thick coal seams occur throughout, although coal is absent below 3785m. Hard, yellowish brown dolomite occurs as thin stringers or nodules, and pyrite as scattered euhedral crystals.

Cycle 1: 3900m-3943m.

This unit is characterised by a distinct coal bed capping the section. Medium and coarse grained, locally very waxy, coarse grained, occasionally argillaceous sandstone is predominant with subordinate firm, olive black to brownish black, locally carbonaceous, occasionally silty and sandy, non-calcareous shale.

FLADEN GROUP: 3943m(log)-4303mT.D. Age: Middle Jurassic, Bathonian - Bajocian.

Sleipner Formation: 3943m(log)-4157m(log).

The top of this unit is taken at a log break. The lithology consists of an interbedded sequence of firm, waxy, brownish grey shales, firm, olive grey, fine to coarse grained sandstones and common to abundant, vitreous, black coal seams. Pyrite, siderite and sphaerosiderite also occur.

Rattray Formation: 4157m(log)-4303mT.D.

The top of this unit has been placed at a log break and where volcanics are first seen in the ditch cuttings sample. It is not certain whether the upper part of the unit consists of reworked volcanics or whether the section contains thin volcanics interbedded with sediments. The section consists of friable, pale green, mottled vesicular volcanics which probably represent weathered and altered basalts, tuffs and agglomerates. At the base of the unit shales and coal are indicated on the electric log,although these lithologies were not seen in the ditch cuttings samples.

V

BIOSTRATIGRAPHY

V(1) TERTIARY

INTERVAL 2400m-2820m; LATE PALAEOCENE (top not seen)

Lithostratigraphic Units:
Rogaland Group 2400m-2406m(log);
Montrose Group (part);
Heimdal Formation 2406m(log)-2820m.

Environment: marine, outer shelf to upper bathyal.

The age of this interval is based on the following micropalaeontological criteria:

- the occurrence of the diatom Coscinodiscus sp. 1 between 2400m and 2470m.
- the subsequent occurrence of abundant spongodiscid radiolaria at 2740m and below.

MICROPALAEONTOLOGY

The diatom Coscinodiscus sp. 1 is common in the upper part of this interval and indicates a Late Palaeocene age. The pink coloured planktonic foraminifera Globigerina triloculinoides and G. linaperta group found at 2400m are presumed to be caved from the overlying Early Eocene.

Agglutinated foraminifera dominate the fauna and comprise species of Bathysiphon/Rhabdammina, Cyclammina, Haplophragmoides, Psammosphaera, Spiroplectammina and Glomospira, none of which are stratigraphically restricted to the Palaeocene.

Abundant spongodiscid radiolaria were first found at 2740m and their influx at this depth can be correlated with adjacent areas. This influx is indicative of an earliest Late Palaeocene age.

Reworked Late Cretaceous and Danian planktonic foraminifera were found throughout this interval.

INTERVAL 2820m-2850m; EARLY PALAEOCENE, DANIAN

Lithostratigraphic Units:

Montrose Group (part);

Heimdal Formation 2820m-2822m(log),

Maureen Formation 2822m(log)-2846m(log),

Chalk Group (part);

Ekofisk Formation 2846m(log)-2850m.

Environment: marine, outer shelf.

The upper limit and age of this interval are based on the following microfauna evidence:

- the occurrence at 2820m of Globigerina edita and Globorotalia pseudobulloides together with the subsequent appearance of Globorotalia cf. compressa and Globigerina trivialis at 2825m.

MICROPALAEONTOLOGY

The fauna is dominated by Danian planktonic foraminifera - G. edita, G. trivialis, G. compressa and G. pseudobulloides - together with calcareous benthonic foraminifera indicative of a Palaeocene age, e.g. Alabamina midwayensis, Pullenia americana and Anomalinoides midwayensis. The interval is assigned to zone P2 (Blow 1979) based on the uppermost occurrence of G. edita together with G. trivialis. Spongodiscid radiolaria continue to be abundant in the upper part of this interval.

V(2) CRETACEOUS

INTERVAL 3400m-3435m(log); LATE CRETACEOUS (top not seen)

Lithostratigraphic Units:
Chalk Group (part);
Plenus Marl Formation 3400m-3410m(log),
Hidra Formation 3410m(log)-3435m(log).

Environment: marine, outer shelf.

The age of this interval is based upon the following criteria:
- its stratigraphic position.
- regional considerations.

MICROPALAEONTOLOGY

The microfaunas within this interval consist exclusively of foraminifera which are obviously caved from higher in the well. The foraminiferal associations include Late Cretaceous and Tertiary calcareous benthonic and agglutinating forms, but are dominated by late Maastrichtian planktonics, notably members of the Rugoglobigerinia/Archaeoglobigerina complex, Pseudotextularia elegans elegans, P. elegans fructicosa, Globotruncana contusa and members of the Heterohelicidae.

The absence of in situ foraminifera is considered to reflect the use of a turbo-drill through this interval, so preventing a meaningful age determination.

PALYNOLOGY

The ditch cuttings sample from 3425m yielded an impoverished palynoflora, composed of taxa indicative of a Late Cretaceous, Maastrichtian - Campanian age. In view of the stratigraphic position of this interval the majority of the palynomorphs are considered to be caved.

INTERVAL 3435m(log)-3535m(log); EARLY CRETACEOUS, ALBIAN - ?NEOCOMIAN

Lithostratigraphic Unit:
Cromer Knoll Group.

Environment: marine, inner shelf.

The upper limit of the interval is defined by a log break.

The age of the interval is based upon the following criteria:
- regional considerations.
- its stratigraphic position.
- the occurrence of a late Albian restricted dinocyst within the interval.

MICROPALAEONTOLOGY

The microfaunas within this interval show no significant differences from those above and consist entirely of caved Tertiary and Late Cretaceous (no older than Campanian) forms.

There is no evidence for the presence of in situ forms, again reflecting the effects of turbo-drilling on ditch cuttings samples.

PALYNOLOGY

Impoverished in situ palynofloras were recovered from the ditch cuttings samples analysed in this interval. The palynofloras contain large numbers of caved taxa of Tertiary and Late Cretaceous ages. Few age diagnostic species have been recovered from this interval.

An assemblage from 3506m contains a specimen of Muderongia cf. staurota and a questionable specimen of the Ellipsoidictyum imperfectum group. Both of these dinocysts become extinct in the Albian, and the latter does not occur in pre-Aptian sediments. The presence of sediments of late Albian age within this interval is indicated by the occurrence of Apteodinium grande at 3518m. This dinocyst is stratigraphically restricted to sediments of late Albian, A. grande Subzone (OIIB) of the Ovoidinium scabrosum Zone (OII) age. Due to the impoverished nature of the palynofloras, probably resulting from the use of the turbine-assisted drilling bit, the appearance of A. grande must be highly

questionable and its occurrence is almost certainly caved.

No positive palynological evidence is seen within this interval, or as cavings, for the presence of sediments of Barremian - Neocomian age. This results in the questionable oldest age assigned to the interval. The sharp log break at the base of the interval possibly reflects a hiatus between the Cromer Knoll Group and the underlying Kimmeridge Clay Formation. The absence of age-diagnostic microfossils unfortunately precludes definition of the stratigraphic extent of this hiatus.

V (3) CRETACEOUS? - JURASSIC

INTERVAL 3535m(log)-3578m; EARLY CRETACEOUS? - LATE JURASSIC, RYAZANIAN? - KIMMERIDGIAN

Lithostratigraphic Unit:
Humber Group (part);
Kimmeridge Clay Formation (part).

Environment: marine, inner shelf, with dysaerobic/anaerobic bottom conditions established beneath a ?partially stratified water column.

The upper limit of the interval is defined upon a log break.

The age is based upon the following criteria:
- the overall palynofloral content.
- its stratigraphic position.
- regional considerations.

MICROPALAEONTOLOGY

This interval proved to be barren of in situ microfaunas, probably as a result of the use of the turbine-assisted drilling bit.

PALYNOLOGY

Sparse in situ palynofloras were recovered from the ditch cuttings samples analysed within this interval. Assemblages are considerably modified by caved taxa of Tertiary and Cretaceous ages. Drilling mud additive is a significant kerogen component.

Regional evidence suggests that the appearance of Tasmanites spp. and Pterospermella spp. at 3542m indicates penetration of sediments attributable to the Kimmeridge Clay Formation. This formation may be as young as Early Cretaceous, Ryazanian although, in this case no positive evidence is available to accurately date the uppermost part and this may consequently be no younger than Volgian in age.

In situ evidence for the dating of the interval is lacking, although the occurrence of a caved specimen of Oligosphaeridium pulcherrimum sensu Ioannides et al. at 3662m indicates the presence of sediments of early Volgian - Kimmeridgian age. This dinocyst is considered not to occur in sediments older than the Gonyaulacysta cladophora Zone (X).

Positive evidence for penetration of early Kimmeridgian strata is not seen until 3578m. Due to the use of a turbo-assisted drilling bit down to 3570m, (with resultant poor palynological recovery) this top may be higher.

V (4) JURASSIC

INTERVAL 3578m-3632m; LATE JURASSIC, EARLY KIMMERIDGIAN - MIDDLE OXFORDIAN

Lithostratigraphic Units:

Humber Group (part);

Kimmeridge Clay Formation (part); 3578m-3604m(log),

Heather Formation (part); 3604m(log)-3632m.

Environment: marine, inner shelf, with strong terrestrial influence.

The top and age of the interval are defined upon the following palynological criteria:

- the appearance of Scriniodinium crystallinum at 3578m.
- the subsequent appearance of Adnatosphaeridium aemulum at 3614m.
- the overall palynofloral content.

MICROPALAEONTOLOGY

Although turbo drilling ended at 3570m, the microfaunas within this interval continue to consist of only caved Tertiary and Late Cretaceous forms.

PALYNOLOGY

Miospore dominated palynofloras were recovered from the ditch cuttings samples analysed from this interval. Assemblages are characterised by the common to abundant occurrences of undifferentiated bisaccates, Cerebropollenites mesozoicus and Perinopollenites elatoides.

A marked increase in the numbers of in situ palynomorphs is observed at and below 3578m, relative to the overlying intervals. This feature is accompanied by a reduction in numbers of caved taxa recorded.

An age no younger than the early Kimmeridgian, Scriniodinium crystallinum Zone (XI), is indicated at 3578m by the appearance of the zonal index taxon. Regional considerations suggest that the appearance of Adnatosphaeridium aemulum at 3614m indicates an Oxfordian age no younger than the Acanthaulax spinosissima Zone (XIII).

An increase in the proportion of structured vitrinite laths is seen at and below 3614m, relative to the assemblage.

The regionally identifiable late Oxfordian transgressive event, which results in the onset of shale deposition assignable to the Kimmeridge Clay Formation, is considered to be reflected by the log break at 3604m.

INTERVAL 3632m-3833m; LATE JURASSIC, EARLY OXFORDIAN - MIDDLE CALLOVIAN

Lithostratigraphic Units:
Humber Group (part);
Heather Formation 3632m-3643m(log),
Hugin Formation 3643m(log)-3833m.

Environment: upper part (3632m-3643m) marine, inner shelf with strong terrestrial influence; lower part (3643m-3833m) marginal marine to non-marine, deltaic.

The age and upper limit of this interval are defined upon the following palynological criteria:

- the appearance of Chytroeisphaeridia cerastes at 3632m.
- the occurrence of Wanaea fimbriata at 3641m.
- the subsequent appearance of the Lithodinia callomonii/decapitata plexus at 3713m.
- the overall palynofloral content.

PALYNOLOGY

Assemblages recovered from the ditch cuttings and core piece samples within this interval are dominated by miospores. Palynofloras are characterised by the common to abundant occurrences of undifferentiated bisaccates, Cerebropollenites mesozoicus, Deltoidospora spp., Perinopollenites elatoides. Microplankton assemblages are characterised by the common occurrences of Adnatosphaeridium aemulum (3638m-3725m), Gonyaulacysta jurassica (3638m) and Polystephanephorus paracalathus (3773m).

An early Oxfordian age, no younger than the Gonyaulacysta areolata subzone (XIVA) of the Wanaea digitata Zone (XIV) is indicated at 3632m by the appearance of Chytroeisphaeridia cerastes. The subsequent common occurrences of A. aemulum at and below 3638m substantiates an early Oxfordian age. Acanthaulax spinosissima a taxon which achieves its numerical acme within the early Oxfordian, appears at 3638m and is relatively numerous. Penetration of sediments equivalent in age to the Wanaea fimbriata Subzone (XIVB) is indicated at 3641m by the occurrence of the subzonal index taxon.

A reduction in both numbers and diversity of microplankton is encountered at 3644m relative to 3641m. This event is associated with an influx of amorphous humic kerogen and an increase in physical degradation. Although positive evidence for the top of the Callovian is lacking, regional considerations suggest that the Oxfordian/Callovian boundary probably equates to the Heather Formation/Hugin Formation boundary.

Assemblages recovered from the ditch cuttings samples at 3650m and 3662m are considered to be significantly modified by cavings from the early Oxfordian. Specimens of the Lithodinia cristulata/caytonensis plexus, Dichadogonyaulax stauromatos and Kalyptea stegasta encountered at 3650m are considered to have been reworked into the basal Oxfordian and subsequently caved. Recycling of middle - lower Callovian sediments is also indicated.

A decrease in marine influence is seen at 3663.60m(core) relative to the sample at 3659.35m(core). This is reflected by a decrease in numbers and diversity of marine taxa, an increase in swamp spore diversity and plant cuticle. Marginal marine palynofloras are present at 3665.60m(core) and 3666.60m(core) with assemblages dominated by Dissiliodinium/Dichadogonyaulax sp.

Non-marine palynofloras were recovered from the core pieces between 3676m-78m and 3686.85m and age characterised by common to abundant occurrences of Deltoidospora spp.. Structured vitrinite (cortex) is the dominant kerogen component in these samples. Core piece samples between 3688.81m and 3703.25m yield marginal marine assemblages.

Ditch cuttings samples between 3713m and 3820m yielded relatively homogeneous palynofloras, consistently modified by caved Oxfordian taxa. In situ assemblages are considered to be of marginal marine origin.

An age no younger than middle Callovian is indicated at 3713m by the appearance of the Lithodinia callomonii/decapitata plexus. Due to the paucity of marine microplankton (however) the true top of the middle Callovian is probably higher. The common occurrence of P. paracalathus at 3773m substantiates an age no younger than middle Callovian. A feature of possible correlative value within the middle Callovian is the occurrence of Neoraistrickia gristhorpensis at 3686.65m(core), a miospore considered to have a stratigraphic top within the

middle Callovian.

A specimen of D. stauromatos encountered at 3638m is considered to be reworked from sediments of Callovian age. Permo-Carboniferous recycling is indicated at 3703.25m(core) and 3713m by the occurrences of Densosporites sp. and Lunatisporites sp..

Of interest is the occurrence of a cenosphere at 3703.25m(core), an artifact product of partial combustion of carbon. If in situ it would suggest the possibility of a forest fire.

INTERVAL 3833m-3943m(log); LATE JURASSIC, EARLY CALLOVIAN

Lithostratigraphic Unit:
Humber Group (part);
Hugin Formation (part).

Environment: marine, inner shelf to marginal marine, with strong terrestrial influence.

The age and upper limit of the interval are defined upon the following palynological criteria:

- the appearance of common to abundant specimens of Chytroeisphaeridia dictydia and Nannoceratopsis pellucida at 3833m.
- the overall palynofloral content.

PALYNOLOGY

Miospore dominated assemblages were recovered from the ditch cuttings samples within this interval, characterised by the common to abundant occurrences of undifferentiated bisaccates, Cerebropollenites mesozoicus and Perinopollenites elatoides. Relative to the overlying interval an increase in both numbers and taxonomic diversity of marine microplankton is observed at and below 3833m. Marine microplankton assemblages are characterised by the common to abundant occurrences of Chytroeisphaeridia dictydia, Valensiella spp., Adnatosphaeridium aemulum, Dichadogonyaulax stauromatos, Polystephanephorus paracalathus, Pareodinia ceratophora and Nannoceratopsis pellucida.

An age equivalent to the N. pellucida Subzone (XVB) is indicated at 3833m by the occurrence of abundant specimens of the subzonal index dinocyst. Regional considerations suggest that the simultaneous appearance of common specimens of C. dictydia indicates an age no younger than early Callovian. The last downhole occurrence of common specimens of N. pellucida at 3893m, tentatively suggests an age no older than the N. pellucida Subzone (XVB) of the P. paracalathus Zone (XV). Microplankton assemblages recovered from the remainder of the interval are of early Callovian aspect. An age no older than Callovian is indicated at 3941m by the common to abundant occurrences of C. dictydia, Valensiella spp., P. ceratophora and P. paracalathus, associated with the remainder of the dinocyst assemblage.

Of interest is the occurrence of large quantities of unstructured vitrinite (collinite) in the sample at 3905m. This kerogen component is normally the dominant type in allochthonous (drifted) coals within the Sleipner area, and suggests that the coal occurring between 3902m and 3904m is drifted in origin.

Reworking of Permo-Triassic sediments is indicated at 3833m by the presence of a striate bisaccate.

INTERVAL 3943m(log)-4303mT.D.; MIDDLE JURASSIC, BATHONIAN - BAJOCIAN

Lithostratigraphic Units:
Fladen Group;
Sleipner Formation 3943m(log)-4157m(log),
Rattray Formation 4157m(log)-4303mT.D.

Environment: non-marine, deltaic/fluviatile.

The upper limit of this interval is defined upon an electric log break:

The age of the interval is based upon the following palynological criteria:
- an influx of pteridophyte (swamp) spores at 3953m.
- the appearance of Parvisaccites enigmatus at 4073m.
- regional considerations.

PALYNOLOGY

Palynofloras recovered from the ditch cuttings and sidewall core samples within this interval are dominated by miospores, with pteridophyte (swamp) spores being the major component. Assemblages are characterised by the common to abundant occurrences of undifferentiated bisaccates, Cerebropollenites mesozoicus, Deltoidospora spp., the Baculatisporites/Osmundacidites group, Klukisporites variegatus, Todisporites spp., Densoisporites velatus, Callialasporites spp., Verrucosisporites spp. and Calamospora mesozoica.

A marked change in the palynofloras is observed at 3953m relative to the overlying interval. At and below this depth pteridophyte spores predominate, miospore diversity increases and kerogen becomes dominated by large grains of structured vitrinite (cortex). All these features reflect deposition within a variety of delta-top environments. A noticeable reduction in marine microplankton is associated with these features, and marine microplankton encountered between 3953m and 3989m are considered to be caved from overlying Callovian intervals. Marine microplankton are absent below 3989m, the only microplankton recorded being algae of freshwater origin, i.e. Botryococcus spp. and Schizophacus rugulatus.

Miospore assemblages encountered in the interval, in general, suggest only a general Callovian - Bajocian age. The appearance, however, at 4073m of Parvisaccites enigmatus suggests a Middle Jurassic age below this horizon, as this species is considered not to occur in post-Middle Jurassic deposits. Regional considerations suggest that the palynofloras encountered at and below 3953m are of Middle Jurassic, Bathonian - Bajocian age. No positive evidence has been seen for the presence of sediments of pre-Middle Jurassic age.

GEOLOGICAL HISTORY

Bajocian - Bathonian

The oldest sediments encountered in this well are an interbedded volcano-clastic sequence attributable to the Rattray Formation. The extrusive volcanics were probably derived from a major volcanic centre which lay to the southwest in the Outer Moray Firth area. Following cessation of volcanic activity, sediments assignable to the Sleipner Formation accumulated in a variety of non-marine, delta-top environments. This period was characterised by the formation of numerous coal seams.

Callovian - Kimmeridgian

Onset of sedimentation in a marine setting resulted from the regional Late Jurassic, early Callovian transgression. Deposition during the early Callovian occurred in marginal marine to inner shelf settings, with shales, silts and sandstones accumulating. The sandstones possibly represent washover deposits derived from the Sleipner Terrace to the east, where coeval bar sands were accumulating. A minor regressive (shallowing) phase within the early Callovian is indicated by the formation of a distinct allochthonous (drifted) coal.

A regressive phase ensued in the succeeding middle Callovian, with progradation of marginal marine, lagoonal or deltaic facies, probably from the south and/or southeast.

Within the later part of the middle Callovian or in the late Callovian a transgressive event resulted in deposition of a sandstone body in a marginal marine to inner shelf setting. Sand deposition was virtually eliminated by the succeeding early Oxfordian transgressive event. Shales with minor limestones, assignable to the Heather Formation, accumulated during the Oxfordian under aerobic bottom conditions. The regional late Oxfordian transgression resulted in the onset of dysaerobic bottom conditions and deposition of shales attributable to the Kimmeridgian Clay Formation, which continued into the Kimmeridgian.

Kimmeridgian - ?Ryazanian

Due to the paucity of age-diagnostic criteria the post-Kimmeridgian history is obscure. Shale deposition probably continued into the Early Cretaceous, Ryazanian, under progressively anaerobic bottom conditions, with partial water stratification.

Neocomian? - Late Cretaceous

The relationship of the Cromer Knoll Group to the preceding Humber Group is unknown due to the absence of age-diagnostic taxa. A hiatus, of unknown extent, may be present between the groups. Shales and limestones accumulated in shallow, inner shelf

	settings during the Early Cretaceous, with deposition probably continuing uninterrupted into the overlying Late Cretaceous, associated with an increase in water depth resulting in inner to outer shelf environments being established. This increase in water depth is associated with a marked decrease in terrigeneous input which resulted in the deposition of the Chalk Group. Following accumulation of the limestones of the Hidra Formation, an influx of argillaceous sediment resulted in the deposition of the Plenus Marl Formation.
Late Cretaceous	The post-Plenus Marl Formation to Tor Formation history is unknown, as the interval was not analysed.
Palaeocene	Deposition of chalk continued into the Early Palaeocene, Danian, before being abruptly terminated by an influx of arenaceous detritus probably due to basin tectonism. Sands, assignable to the Maureen Formation, were probably deposited as submarine debris flows in outer shelf to upper bathyal depths. Predominantly arenaceous deposition persisted into the Late Palaeocene, although shale interbeds became more numerous within the Montrose Group. Towards the end of the Late Palaeocene, sand deposition effectively ceased being replaced by shale sedimentation.

A marked phase of volcanic activity is evident towards the end of the Late Palaeocene, being associated with a period of rifting of the North Atlantic. The resultant tuffaceous shales are assigned to the Rogaland Group.

VII

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APPENDIX 1

SIDEWALL CORES DESCRIPTIONS

Depth	Core No.	Rec.	Qual.	Type of Analysis	Lithology
4004m		15	Good	P	COAL: brittle, brownish black to black, sooty.
4015m		15	Good	P	CLAYSTONE: firm, blocky, yellowish grey, silty, micaceous and dolomitic.
4021m		20	Good	P	CLAYSTONE: as 4015m.
4051.5m		25	Good	P	CLAYSTONE: firm, waxy, yellowish grey to light greenish grey, weakly calcareous.
4109.5m		15	Good	P	SANDSTONE: friable, white to yellowish grey, fine to very fine grained, mainly angular, weakly calcareous.
4181m		25	Good	P	CLAYSTONE: firm, light greenish grey to greyish red, slightly micaceous, silty, sandy, moderately calcareous.
4241m		15	Good	P	VOLCANIC: firm to friable, medium dark grey, waxy, with chlorite and ?olivine crystals - possibly a weathered tuff, moderately calcareous.
4295m		25	Excel.		CLAYSTONE: waxy, reddish brown to greyish red, with white vein calcite - probably a weathered volcanic.

KEY

P = Palynology

Excel. = Excellent

APPENDIX 2

CORE PIECE DESCRIPTIONS

Depth	Core No.	Type of Analysis	Lithology
3659.35m		P	SANDSTONE: moderately hard, olive grey to light olive grey, fine to medium grained, with scattered coarse grains, mainly angular, with very thin, dark grey parallel argillaceous streaks; non-calcareous.
3663.60m		P	SHALE: hard, olive black, slightly micaceous, trace of carbonaceous debris, non-calcareous.
3665.60m		P	SHALE: hard, massive, dark grey, micromicaceous, non-calcareous.
3666.60m		P	SHALE: as 3665.60m, with very small pyritic traces.
3678.78m 'A'		P	SHALE: hard, dark grey, micromicaceous, weakly to non-calcareous.
3676-78m 'B'			SHALE: as 'A'.
'D'		P	COAL: brittle, black, vitreous.
3682.69 -3674m	4	P	SILTSTONE: moderately hard, fissile, olive black, argillaceous, slightly sandy, micaceous, rare traces of pyrite, minor carbonaceous debris, non-calcareous.
3686.65m		P	SANDSTONE: moderately firm, yellowish brown, fine to very fine grained, angular to sub-angular, slightly micaceous, argillaceous non-calcareous, locally grading to SHALE: firm, fissile, olive grey to olive black, silty sandy, carbonaceous, non-calcareous.
3688.75 -3688.81m	4	P	SHALE: moderately hard, sub-fissile, olive black, carbonaceous, micro-micaceous, non-calcareous.
3700.35m		P	COAL: brittle, vitreous, conchoidal fracture, black.

3701.37 -3701.43m	P	SANDSTONE: firm to friable, olive grey, mainly medium grained, sub-angular, non-calcareous, fair visible porosity.
3703.25m	P	SANDSTONE: moderately hard, light olive grey, mainly fine to medium grained, well sorted, angular to sub-angular, non-calcareous. COAL: as 3700.35m.

KEY

P = Palynology

APPENDIX 3

RYAZANIAN–ALBIAN DINOCYST ZONATION

GEOLOGICAL AGE			STANDARD AMMONITE ZONES	DINOCYST ZONATION	
				ZONES	SUBZONES
EARLY CRETACEOUS	Albian	late	*dispar*	*Ovoidinium scabrosum* OII	*Ovoidinium verrucosum* OIIA
			inflatum		*Apteodinium grande* OIIB
			cristatum		*Systematophora cretacea* OIIC
		middle	*lautus*		
			loricatus		
			dentatus		
		early	*mamillatum*		*Cauca parva* OIID
			tardefurcata		
	Aptian	late	*jacobi*	*Dingodinium albertii* OI	*Aptea polymorpha* OIA
			nutfieldensis		
			martinioides		*Cyclonephelium tabulatum* OIB
		early	*bowerbanki*		
			deshayesi		
			forbesi		
			fissicostatus		
	Barremian	late	*bidentatum*	*Sirmiodinium grossii* I	*"Astrocysta" cretacea* IA
		early – mid.	*rude-fissicostatum*		*Doidyx anaphrissa* IB
					Kleithriasphaeridium corrugatum IC
			rarocinctum		
	Hauterivian*	late	*variabilis*	*Subtilisphaera terrula* II	*Adnatosphaeridium vetusculum* IIA
			marginatus		*Canningia* cf. *reticulata* IIB
			gottschei	*"Oligosphaeridium" nannum* III	*Chlamydophorella trabeculosa* IIIA
			speetonensis		
		early	*inversus*		*Kleithriasphaeridium simplicispinum* IIIB
			regale		
			noricum		
			amblygonium		
	Valanginian	late	unnamed	*Phoberocysta neocomica* IV	*Muderongia extensiva* IVA
			pitrei		
			dichotomites		*Tubotuberella apatela* IVB
		early	*polyptychites*		*Endoscrinium pharo* IVC
			paratollia		
	Ryazanian	late	*albidum*	*Dingodinium spinosum* V	*"? Prolixosphaeridium" torynum* VA
			stenomphalus		*Dichadogonyaulax* spp. VB
			icenii		
		early	*kochi*		*Cannosphaeropsis* sp. A VC
			runctoni		

* The Barremian/Hauterivian boundary should now be placed at the top of the *marginatus* Zone (Rawson, in press).

RHAETIAN–VOLGIAN DINOCYST ZONATION

GEOLOGICAL AGE			STANDARD AMMONITE ZONES	DINOCYST ZONATION	
				ZONES	SUBZONES
LATE JURASSIC	Volgian	late	*lamplughi*	*"Imbatodinium" villosum* VI	*Egmontodinium* sp. A VIA
			preplicomphalus		*Kleithriasphaeridium* sp. A VIB
			primitivus		*Systematophora* spp. VIC
			oppressus		
		middle	*giganteus*	*Muderongia* sp. A VII	*Dichadogonyaulax pannea* VIIA
			gorei		*Dichadogonyaulax culmula* VIIB
			albani		
			Epipallasiceras sp.		*Glossodinium dimorphum* VIIC
			rotunda		
			pallasioides	*Pareodinia mutabilis* VIII	*Gonyaulacysta pennata* VIIIA
			Pavlovia sp.		*Gonyaulacysta jurassica* VIIIB
		early	*pectinatus*	*Gonyaulacysta longicornis* IX	
			hudlestoni		*Egmontodinium polyplacophorum* IXA
			wheatleyensis		
			scitulus		*Scriniodinium luridum* IXB
			elegans		
	Kimmeridgian		*autissiodorensis*	*Gonyaulacysta cladophora* X	
			eudoxus		
			mutabilis		
			cymodoce		
			baylei	*Scriniodinium crystallinum* XI	*Leptodinium egemenii* XIA
	Oxfordian	late	*pseudocordata*		*Stephanelytron redcliffense* XIB
			decipiens	*Scriniodinium galeritum* XII	*Scriniodinium oxfordianum* XIIA
			cautisnigrae		*Compositosphaeridium costatum* XIIB
		middle	*transversarium*		
			plicatilis	*Acanthaulax spinosissima* XIII	
		early	*cordatum*	*Wanaea digitata* XIV	*Gonyaulacysta areolata* XIVA
			mariae		*Wanaea fimbriata* XIVB
	Callovian	late	*lamberti*		*Mendicodinium groenlandicum* XIVC
			athleta		
		middle	*coronatum*	*Polystephanephorus paracalathus* XV	*Kalyptea stegasta* XVA
			jason		*Nannoceratopsis pellucida* XVB
		early	*calloviense*	*Pareodinia ceratophora* XVI	*Dichadogonyaulax gochtii* XVIA
			macrocephalus		
MIDDLE JURASSIC	Bathonian	late	*discus*		*Wanaea acollaris* XVIB
			aspidoides		
			retrocostatum		*Gonyaulacysta filapicata* XVIC
		middle	*morrisi*		
			subcontractus	*Nannoceratopsis spiculata* XVII	
			progracilis		
		early	*zigzag*		
	Bajocian	late	*parkinsoni*		
			garantiana		
			subfurcatum		
		middle	*humphriesianum*	*Nannoceratopsis gracilis* XVIII	*Polysphaeridium deflandrei* XVIIIA
			sauzii		
			laeviuscula		
			discites		
		early	*concavum*		
			murchisonae		
			opalinum		
EARLY JURASSIC	Toarcian	late	*levesquei*		*Mancodinium semitabulatum* XVIIIB
			thouarsense		
		middle	*variabilis*		
			bifrons		"Sphaeromorphs" XVIIIC
		early	*falciferum*		
			tenuicostatum		
	Pliensbachian	late	*spinatum*		*Luehndea spinosa* XVIIID
			margaritatus		
		early	*davoei*	*Polysphaeridium langii* XIX	Unnamed subzone XIXA
			ibex		
			jamesoni		
	Sinemurian	late	*raricostatum*		*Liasidium variabile* XIXB
			oxynotum		
			obtusum		
		early	*turneri*		Unnamed subzone XIXC
			semicostatum		
			bucklandi		
	Hettangian		*angulata*		*Dapcodinium priscum* XIXD
			liasicus		
			planorbis		
LATE TRIASSIC	Rhaetian			*Rhaetogonyaulax rhaetica* XX	

LITHOLOGIES

Clay
Shale/mudstone
Siltstone
Sand/sandstone, very fine to medium grained
Sand/sandstone, coarse grained to granules
Conglomerate (with sand matrix)
Conglomerate (without sand matrix)
Coal/lignite
Breccia
Limestone (undifferentiated)
Dolomitic limestone
Calcareous dolomite
Dolomite
Chalk
Chert
Anhydrite
Salt (halite)
Potassium salts
Concretions/nodules
Igneous rocks, undifferentiated
Basement, undifferentiated
Granite

Qualifiers

Argillaceous
Silty/sandy
Pebbly
Carbonaceous
Calcareous
Dolomitic
Red sediments (red)

Accessories

Calcite C
Ironstone (ferruginous) ..... Fe
Glauconite ..... Gl
Kaolinite ..... K
Phosphate ..... Ph
Pyrite ..... Py
Siderite/sphaerosiderite ..... S
Silica ..... Si

GRAIN TYPES

Oolith
Fossils in general
Bioclastic debris
Mudflakes

BIOSTRATIGRAPHIC SYMBOLS

Fossil Abundances:
- Present ..... o
- Common ..... ●
- Abundant ..... ■

Diagnostic forms ..... *
Caved forms C
Reworked forms ..... R
Incoming of
Outgoing of
Unconformity/stratigraphic hiatus
Late ..... LT., lt.
Middle ..... M., m.
Early ..... EY., ey.

Other symbols

Sample gap
Lost circulation material ..... lcm
Cement ..... cmt
Turbo drilling or diamond bit drilling ..... tu
(Samples unsuitable for good stratigraphic analysis)
Casing point
Core
Sidewall core
Sidewall core (no recovery)

FIGURE 1 – Legend (edited from Robertson Research Standard Legend).