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STATOIL 15/9 - 10 NORWEGIAN NORTH SEA WELL: BIOSTRATIGRAPHY OF THE INTERVAL 2300m – 3291m T.D.

by

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II

INTRODUCTION

This report summarises the results of the micropalaeontological, palynological and stratigraphic analyses which have been carried out on material received from the section 2300m - 3291m T.D. from the Statoil 15/9-10 Norwegian North Sea Well under Project No. RRPS/812/A/10234.

The following analyses were carried out:
Lithology: 181 ditch cuttings, 17 sidewall core and 18 core samples from the entire section.
Micropalaeontology: 135 ditch cuttings and 8 sidewall core samples from the interval 2300m - 3024m.
Palynology: 21 ditch cuttings, 15 sidewall core and 18 core samples from the interval 2873m - 3291m.

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 the 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) and Larsen and Jaarvik (1981). 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:

John Church	-	Micropalaeontology
Jim Fenton	-	Palynology and Project Co-ordinator
Elizabeth Regnault	-	Lithologies
Paul Watson	-	Palynology
John Underwood	-	Lithologies
Rosemary Titterton	-	Micropalaeontology

SUCCESSION

Age		Tops
Late Palaeocene		2300m (top not seen)
Early Palaeocene	Danian	2620m
	----------Unconformity----------	
Late Cretaceous	Maastrichtian - late Campanian	2666m (log)
	early Campanian	2730m
	Santonian	2785m
	Coniacian? - ?Turonian	2825m
	Turonian	2873m (SWC)
	Cenomanian	2924m (log)
	Albian	2955m (log)
	early Albian - Aptian	2979m (SWC)
Early Cretaceous	early Aptian	2991m (SWC)
	----------?Unconformity----------	
	Barremian? - Neocomian	2992m (log)
	----------Unconformity----------	
	late - middle Volgian	3004m (log)
	----------Unconformity----------	
Late Jurassic	Kimmeridgian - middle Oxfordian	3021m (log)
	early Oxfordian - middle Callovian	3062m (SWC)
	early Callovian	3089m (core)
Middle Jurassic	Bathonian - Bajocian	3130m (log)
	----------Unconformity----------	
Triassic		3183m (log) - 3291m T.D.

This breakdown has been achieved by analysis of ditch cuttings, sidewall core and core piece samples. Electric logs (ISF/BHC/GR) were made available.

IV

LITHOSTRATIGRAPHY

Lithostratigraphic terminology used in this report is based on Deegan and Scull 1977, and Larsen and Jaarvik, 1981. Electric log information (ISF/BHC/GR) was available and proved of great assistance in determining the boundaries of the lithostratigraphic units. Turbo-drilling was carried out over the interval 2727m - 2980m and the lithology has been inferred largely from the log pattern and sidewall core evidence. Conventional core was taken within the Jurassic and core pieces were available for examination; sidewall cores were also available.

LITHOSTRATIGRAPHIC UNITS

ROGALAND GROUP: 2300m - 2410m (log); Age: Late Palaeocene.

Balder Formation: 2300m - 2334m (log).
The top of this unit was not seen in the studied section. The lithology consists of greenish grey and greyish red, moderately hard, non-calcareous shale, sometimes with bands of very finely crystalline pyrite. Tuffs and tuffaceous shales are also present and these are greenish grey with characteristic white mottling. Lower in the unit, hard, yellowish grey, finely crystalline limestone and chalky limestone occur as thin beds.

Sele Formation: 2334m (log) - 2410m (log)
This unit is identified by the log pattern. The lithology consists of moderately hard, banded shale and moderately hard, medium grey, occasionally pyritic and micromicaceous shale.

MONTROSE GROUP: 2410m (log) - 2666m (log); Age: Late Palaeocene to Danian.

Heimdal Formation: 2410m (log) - 2596m (log).
On the basis of lithology, this unit can be sub-divided:
2410m (log) - 2475m. This sub-unit consists of moderately hard, olive grey to olive black, non-calcareous shale, with hard, moderate yellowish brown, blocky

dolomite and chalky limestone at the top of the section. Finely disseminated pyrite is associated with the carbonate. This sub-unit probably equates to the undifferentiated part of the Montrose Group cited in Deegan and Scull (1977).

2475m - 2596m (log). This sub-unit consists of white, to very light grey, poorly sorted, fine to medium grained, mainly angular sand with occasional coarse and very coarse grains. These sands are interbedded with moderately hard, olive grey to olive black, non-calcareous shale. At the top of this sub-unit are significant amounts of white, chalky limestone which are considered, on log evidence, to represent either reworked clasts or thin interbedded limestones. Associated with the sands are spheres of yellowish grey calcite, clear pink grains of garnet and finely crystalline pyrite. Locally, the sandstone is calcareous and rarely slightly argillaceous.

Maureen Formation: 2596m (log) - 2666m (log); Age: Late Palaeocene to Danian.
The top of this unit has been placed below the sand of the overlying formation. The unit is characterised by an interbedded sequence of sands, shale and argillaceous limestones. The sand is white, very poorly sorted, fine to coarse grained, mainly sub-angular, with scattered greyish orange pink grains. The sand appears to be unconsolidated or weakly cemented. The shale is firm, medium dark grey and greenish grey, occasionally micaceous, and locally calcareous, and grades into firm to moderately soft, light grey, argillaceous limestone which is occasionally pyritic. The base of this unit in this well is marked by a bed of sandstone.

CHALK GROUP: 2666m (log) - 2955m (log); Age: Maastrichtian - late Campanian to Cenomanian.

Tor Formation: 2666m (log) - 2780m (log); Age: Maastrichtian - late Campanian to early Campanian.
The top of this unit is marked by a clearly defined log break, coincident with the incoming of white, chalky limestones. In this well there is no biostratigraphic evidence to suggest the presence of either Danian or late Maastrichtian carbonates, and therefore the Ekofisk Formation is considered to be absent. However, changes in log character occur at 2689m and 2710m (the latter associated with a change in log run) and the lithology consists

essentially of white, chalky limestones, with greyish pink limestones indicated below 2725m where they form a subordinate lithology. Brittle, greyish brown chert occurs in small amounts, probably as nodules within the limestones. Casing cement contaminates some samples and turbo-drilling commenced at 2737m. This has the effect of altering the rock cuttings to such an extent that only colour variations can be commented upon; the gross lithological characteristics are interpreted from the wireline log.

Hod Formation: 2780m (log) - 2862m (log); Age: early Campanian to Coniacian? - ?Turonian.
The top of this unit has been placed on a log break where the chalky limestones become slightly less pure and slightly less hard. However, as the section has been turbo-drilled, the lithology has been interpreted as very light grey to rarely pinkish grey, chalky limestone.

Plenus Marl Formation: 2862m (log) - 2924m (log); Age: Coniacian? - ?Turonian to Turonian.
The top of this unit has been placed on a log break where increasing gamma ray values and a decreased sonic value indicate the incoming of more argillaceous sediments. These are interpreted from the turbo-drilled ditch cuttings samples as being light grey limestones and argillaceous limestones, although the sidewall core samples within this unit are friable, fine to very fine grained, glauconitic sandstones.

Hidra Formation: 2924m (log) - 2955m (log); Age: Cenomanian.
The top of this unit is marked by a sharp, clearly defined log break. The turbo-drilled ditch cuttings samples are interpreted as being yellowish grey limestones with small amounts of fine grained, calcareous sandstone and glauconite grains.

CROMER KNOLL GROUP: 2955m (log) - 3004m (log); Age: Albian to Barremian? - Neocomian.
Part of this unit, down to 2980m, has been turbo-drilled; here the lithology is inferred to be light grey, calcareous shale, with some fine grained sandstone occurring in the sidewall core at 2956m and firm greyish red to blackish red, calcareous shale at 2979m. Red colouration is first seen in the ditch cuttings sample at 2975m, and greyish red shales persist throughout most

of the unit. Small amounts of fine grained sand occur scattered within the ditch cuttings samples. Light grey, argillaceous limestones occur towards the base of the unit and these are associated with sandy, silty, calcareous shales which contain very small grains of pale green chlorite. The sidewall core sample at 3002m consists of a firm, brittle, white, slightly pyritic, chalky limestone.

HUMBER GROUP: 3004m (log) - 3130m (log); Age: late - middle Volgian to early Callovian.

Kimmeridge Clay Formation: 3004m (log) - 3059m (log); Age: late - middle Volgian to Kimmeridgian - middle Oxfordian.
This unit can be divided into two:
3004m (log) - 3021m (log). This part of the Kimmeridge Clay Formation is characterised by an exceptionally high gamma ray value (in excess of 200 A.P.I. units) and a very low interval transit time. This unit is here termed the "Hot Shale" unit, an informal name given to sediments having a definitive log character. The lithology consists of very fissile, soft, olive black, carbonaceous, occasionally slightly silty and sandy, micromicaceous shale. Fish teeth and black carbonaceous bone fragments are abundant.

3021m (log) - 3059m (log). This section is characterised by gamma ray values which in this well are about 100 A.P.I. units. The lithology here differs little from the overlying "Hot Shale" unit, although the shale tends to be more silty and sandy. Locally, the sandy shale grades towards argillaceous sandstone, although this lithology is infrequent and probably forms very thin streaks. Carbonaceous debris persists in abundance.

Heather Formation: 3059m (log) - 3069m (log); Age: Kimmeridgian - middle Oxfordian to early Oxfordian - middle Callovian.
This unit is identified by the log pattern and the lithology. The section is predominantly olive black, sandy and silty shale with traces of pyrite. Carbonaceous material is also present. Olive grey, fine grained, angular sand is present in the ditch cuttings sample at 3060m, and firm, olive grey to olive black, weakly calcareous siltstone is seen in the sidewall core sample at 3062m. Core was cut between 3061m - 3062.4m and consists of sandy shale and fine to very fine grained, non-calcareous sandstone.

Hugin Formation: 3069m (log) - 3130m (log); Age: early Oxfordian - middle Callovian to early Callovian.

The term "Hugin Formation" is used in Larsen and Jaarvik, 1981, to describe the reservoir sandstone in the Sleipner area, and is used in this context for this report. The Formation is considered to be a lateral equivalent of the lower part of the Heather Formation. The lithology consists of interbedded sands, shales, coals and subordinate bedded dolomites. The sands are generally fine grained, angular, poorly cemented and occasionally slightly micaceous. The shales are firm, to moderately hard, brownish black, often micaceous, pyritic, and often with lenses of silt or fine to medium grained sand. The coals are brittle, vitreous, black or brownish black, and the dolomites, forming thin streaks or beds, are hard, yellowish brown and cryptocrystalline. Core 2 was taken between 3082m - 3100m.

FLADEN GROUP: 3130m (log) - 3183m (log); Age: Bathonian - Bajocian.

Sleipner Formation:

This Formation has been assigned to the Fladen Group and not, as in Larsen and Jaarvik, to the Brent Group. However, further study will probably elucidate the relationship between the respective groups and formations. The lithology consists of a predominantly sandstone sequence, with relatively thin interbeds of shale. The sandstone is olive grey to light olive grey, fine to very fine grained, angular, micaceous, occasionally argillaceous, locally becoming medium or coarse grained. Sphaerosiderite, pyrite and weak carbonate occur locally. Cores 3 and 4 were taken between 3137m - 3151m and 3153m - 3171m; Core 4 exhibits red and green quartz grains and also, at 3170.2m, clasts of greenish grey shale. The sandstone in Core 4 is pinkish grey in colour and probably represents reworking of Triassic deposits.

"TRIASSIC GROUP": 3183m (log) - 3285m; Age: Triassic.

Skagerrak Formation: 3183m (log) - 3241m (log).

The top of this unit is placed at a good log break, occurring within a sand sequence. This change in log character is associated with an increase in the number of green stained grains within the sand, which is essentially the same as that described for the lower part of the overlying interval. In addition,

finely crystalline pyrite is present in small amounts. Firm, dark reddish brown, non-calcareous, occasionally silty, waxy and micaceous shale occurs as very thin streaks and stringers down to the base of the unit.

Smith Bank Formation: 3241m (log) - 3291mT.D..

Firm, dark reddish brown, silty shale is the predominant lithology. Thin beds of sandstone, similar to that described above, are present in addition to stringers of non-calcareous siltstone.

V

BIOSTRATIGRAPHY

V(1) TERTIARY

INTERVAL 2300m - 2620m; LATE PALAEOCENE (top not seen)

Lithostratigraphic Units:
Rogaland Group: 2300m - 2410m (log);
    Balder Formation, 2300m - 2334m (log);
    Sele Formation, 2334m (log) - 2410m (log);
Montrose Group (part): 2410m (log) - 2620m;
    Heimdal Formation, 2410m (log) - 2596m (log);
    Maureen Formation (part), 2596m (log) - 2620m

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 at 2300m - 2305m.
- the subsequent occurrence of Spongodiscid radiolaria at 2535m.

MICROPALAEONTOLOGY

The occurrence of the pyritised diatom Coscinodiscus sp. 1 at 2300m - 2305m indicates a Late Palaeocene age. Towards the base of the interval, below 2535m, Spongodiscid radiolaria occur. This is a useful correlative feature in this area of the North Sea for sediments of early Late Palaeocene age.

The microfaunas throughout the interval are of low diversity and abundance, dominated by long ranging agglutinating foraminifera, notably species of Bathysiphon, Cyclammina, Haplophragmoides and Trochammina.

Reworked Early Palaeocene, Danian foraminifera were recorded near the base of the interval at 2570m and 2590m.

INTERVAL 2620m - 2666m (log); EARLY PALAEOCENE, DANIAN

Lithostratigraphic Unit:

Montrose Group (part);

Maureen Formation (part).

Environment: marine, outer shelf.

The upper limit and age of this interval are based on the following micropalaeontological criteria:

- the occurrence of Gavelinella vombensis and Globorotalia cf. compressa sensu BLOW at 2620m.
- the subsequent occurrence of Globigerina pseudobulloides and Nuttalides trumpyi at 2625m; Globigerina trivialis at 2635m; Globorotalia planocompressa at 2655m and Globigerina aff. trivialis sensu BLOW and Globigerina simplicissima at 2660m.

MICROPALAEONTOLOGY

The occurrence of Gavelinella vombensis and Globorotalia cf. compressa sensu BLOW at 2620m indicates that sediments of Early Palaeocene, Danian age have been penetrated. The occurrence of several diagnostic planktonic foraminifera allows the interval to be divided into two biostratigraphic zones (BLOW, 1979). Globorotalia cf. compressa sensu BLOW (2620m), Globigerina pseudobulloides (2625m), Nuttalides trumpyi (2625m) and Globigerina trivialis (2635m) are indicative of the P.2 Zone, whereas Globorotalia planocompressa (2655m), Globigerina aff. trivialis sensu BLOW (2660m) and Globigerina simplicissima (2660m) indicate the P.1 Zone.

At the top of the interval, agglutinating foraminifera continue to dominate the microfaunas, but are gradually replaced downwell by calcareous benthonic and planktonic foraminifera.

V(2) CRETACEOUS

INTERVAL 2666m (log) - 2730m; LATE CRETACEOUS, MAASTRICHTIAN - LATE CAMPANIAN

Lithostratigraphic Unit:
Chalk Group (part);
Tor Formation (part).

Environment: marine, outer shelf.

The upper limit of this boundary is placed in a log break at 2666m.

The one metre difference between the log break and the depth at which the first Cretaceous species occurs (ditch cuttings) is thought to be due to problems with the lag time.

The age of this interval is based in the following slender micropalaeontological evidence:

- the appearance of presumed in situ Late Cretaceous foraminifera at 2665m which include Heterohelix globulosa and a questionable specimen of Pseudotextularia elegans elegans.
- the subsequent incoming of Stensioina pommerana at 2685m, the Rugoglobigerina/Archaeoglobigerina complex at 2700m and ?Globotruncana marginata in 2715m.

MICROPALAEONTOLOGY

The microfaunas recovered from this interval are impoverished although, initially, significant numbers of presumed caved Danian forms are also present. In view of this, it is difficult to be certain whether the top of the Late Cretaceous is correctly chosen on the basis of the micofaunas. The confirmation is provided by the log information.

The appearance of Heterohelix globulosa, ?Pseudotextularia elegans elegans and the ?Rugoglobigerina/Archaeoglobigerina complex, in association with Inoceramus debris, suggests that, at 2665m, in situ Late Cretaceous microfaunas are present. Support for this conclusion is provided by the incoming of Stensioina

pommerana at 2685m. Additional evidence for a Late Cretaceous age can be seen at 2700m where the first positive specimens of the Rugoglobigerina/ Archaeoglobigerina complex appear. This feature could mark the top of the early Maastrichtian, although no positive identification is possible on the meagre microfaunas available. The identification of a questionable specimen of Globotruncana marginata at 2715m may suggest, that from this depth, sediments of late Campanian age occur.

On the basis of this slender microfaunal evidence, and the fact that the late Maastrichtian appears to be absent, a Maastrichtian to late Campanian age is assigned to this interval.

Some slight pink staining of the microfaunas is apparent at 2720m and 2725m.

INTERVAL 2730m - 2785m; LATE CRETACEOUS, EARLY CAMPANIAN

Lithostratigraphic Units:
Chalk Group (part);
Tor Formation (part); 2730m - 2780m (log).
Hod Formation (part); 2780m (log) - 2785m.

Environment: marine, outer shelf.

The upper limit and age assigned to this interval are based on the following slender micropalaeontological evidence:
- the appearance of Tritaxia tricarinata at 2730m.

Confirmation of this determination is provided by the subsequent incoming of Dorothia sp. 1 (2740m) and Tritaxia dubia at 2750m.

MICROPALAEONTOLOGY

Apart from the uppermost sample, the microfaunas recovered from this interval are extremely poor, presumably the result of the use of a turbine assisted drilling bit. The appearance of Tritaxia tricarinata at 2730m in a pink stained microfauna, suggests that the early Campanian has been penetrated. This determination is confirmed by the subsequent appearance of Dorothia sp. 1 (2740m) and T. dubia at 2750m.

INTERVAL 2785m - 2825m; LATE CRETACEOUS, SANTONIAN

Lithostratigraphic Unit:
Chalk Group (part);
Hod Formation (part).

Environment: marine, inner to outer shelf.

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

- the appearance of Stensioina praeexsculpta at 2785m.

MICROPALAEONTOLOGY

The microfaunas recovered from this interval are again impoverished and contain few forms of stratigraphic significance. The appearance of a solitary specimen of Stensioina praeexsculpta at 2785m, however, indicates that this interval is of Santonian age.

INTERVAL 2825m - 2873m (SWC); LATE CRETACEOUS, CONIACIAN? - ?TURONIAN

Lithostratigraphic Units:

Chalk Group (part);

Hod Formation (part); 2825m - 2862m (log)

Plenus Marl Formation (part); 2862m (log) - 2873m (SWC).

Environment: marine, outer shelf.

The upper limit and tentative age of this interval are based on the following slender micropalaeontological evidence:

- the more consistent occurrence of questionable and positive specimens of Globotruncana spp.

MICROPALAEONTOLOGY

It is difficult to identify the top of the Coniacian and Turonian in this well on the impoverished microfaunas that have been recovered. The rare but slightly more consistent occurrences of Globotruncana spp. and ?Globotruncana spp. over this interval suggests that a questionable Coniacian - Turonian age can be assigned to these sediments. The record, as a caved form, of Globotruncana linneiana coronata at 2965m indicates that deposits of Coniacian - Turonian age are present in this well.

The identification of the Plenus Marl Formation at the base of the interval suggests that, at least by 2862m (log), these deposits are no younger than the early Turonian.

INTERVAL 2873m (SWC) - 2924m (log); LATE CRETACEOUS, TURONIAN

Lithostratigraphic Unit:
Chalk Group (part);
Plenus Marl Formation (part).

Environment: marine, outer shelf.

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

- the appearance of Praeglobotruncana cf. stephani, in association with common Globotruncana imbricata, at 2873m (SWC).

MICROPALAEONTOLOGY

The microfaunas recovered from the ditch cuttings samples from this interval continue to be impoverished and contain few forms of stratigraphic significance.

However, the sidewall core at 2873m yielded a moderate, poorly preserved microfauna which includes common specimens of Globotruncana imbricata and Praeglobotruncana cf. stephani. This association indicates that the Praeglobotruncana cf. stephani Assemblage of Turonian age is present.

No additional evidence for a Turonian age, apart from the lithostratigraphy, has been recovered.

PALYNOLOGY

Impoverished palynofloras were recovered from the sidewall cores at 2873m and 2922m. No age-diagnostic taxa were encountered.

INTERVAL 2924m (log) - 2955m (log); LATE CRETACEOUS, CENOMANIAN

Lithostratigraphic Unit:
Chalk Group (part);
Hidra Formation.

Environment: marine, inner to outer shelf.

The upper limit of this interval is based on a log break at 2924m.

The age of these sediments is provided by the following slender microfaunal evidence:

- the more consistent occurrence of Hedbergella delrioensis in the ditch cuttings samples from 2930m.

MICROPALAEONTOLOGY

The microfaunas recovered from these sediments are impoverished and contain few forms of significance. The more consistent occurrence of Hedbergella delrioensis from 2930m does suggest that these deposits are of Cenomanian age. No index species have been recorded and so it is not possible to be certain of this age determination, although the identification of the Hidra Formation from the logs does support this conclusion.

INTERVAL 2955m (log) - 2979m (SWC); EARLY CRETACEOUS, ALBIAN

Lithostratigraphic Unit:
Cromer Knoll Group (part).

Environment: marine, inner to outer shelf.

The upper limit of this interval is based on the log break seen at 2955m.

The age of this interval is based on the following tentative microfaunal evidence:

- the more common occurrence of Hedbergella delrioensis from 2960m.

MICROPALAEONTOLOGY

The sparse microfaunas present in this section are similar to those recorded from the Cenomanian. However, an increase in numbers of Hedbergella delrioensis is noted from 2960m in the ditch cuttings samples and this, although by no means diagnostic, does suggest from our regional knowledge that these sediments are probably of Albian age.

PALYNOLOGY

A sparse, non age-diagnostic palynoflora was recovered from the sidewall core at 2956m.

INTERVAL 2979m (SWC) - 2991m (SWC); EARLY CRETACEOUS, EARLY ALBIAN - APTIAN

Lithostratigraphic Unit:
Cromer Knoll Group (part).

Environment: marine, inner to outer shelf.

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

- an influx of agglutinating foraminifera, including abundant Recurvoides spp. at 2979m (SWC).

Support for this determination is provided by the subsequent micropalaeontological evidence:

- the presence of abundant "Lingulogavelinella" gyroidinaeformis at 2985m.

MICROPALAEONTOLOGY

An influx of agglutinating foraminifera is noted in the sidewall core at 2979m. The presence of abundant Recurvoides spp., common Bathysiphon/Rhizammina, common aff. "Lingulogavelinella" gyroidinaeformis and Glomospira gordialis indicates that the Recurvoides/Glomospira Assemblage of early Albian - Aptian age is developed. Although the ditch cuttings sample at 2980m is impoverished and contains no diagnostic species, an influx of pink stained foraminifera is apparent at 2985m. The presence of abundant "Lingulogavelinella" gyroidinaeformis in this assemblage confirms the early Albian - Aptian age determination.

PALYNOLOGY

An impoverished palynoflora was recovered from the ditch cuttings sample at 2985m. No stratigraphically important, in situ palynomorphs were encountered. A caved specimen of Aptea polymorpha at 3010m indicates the presence of Aptian sediments in the well, as this dinocyst is considered to be restricted to deposits of Aptian age.

INTERVAL 2991m (SWC) - 2992m (log); EARLY CRETACEOUS, EARLY APTIAN

Lithostratigraphic Unit:
Cromer Knoll Group (part).

Environment: marine, inner to possibly outer shelf depths.

The age and upper limit of this interval are based on the following micropalaeontological criterion:

- an influx of Hedbergella infracretacea in the sidewall core at 2991m.

MICROPALAEONTOLOGY

Although Hedbergella infracretacea is first recorded in the sidewall core at 2979m a significant influx does not occur until the sidewall core at 2991m. This latter development characterises the Hedbergella infracretacea Assemblage of early Aptian age.

The comparable microfaunal break is apparent in the ditch cuttings sample at 2990m, but the one metre depth discrepancy is considered to be due to lag time variations and so the sidewall core depth has been preferred.

PALYNOLOGY

The assemblage recovered from the sidewall core at 2991m is considered to be modified by drilling contamination. Contamination is considered to be from sediments of Ryazanian - Volgian age.

INTERVAL 2992m (log) - 3004m (log); EARLY CRETACEOUS, BARREMIAN? - NEOCOMIAN

Lithostratigraphic Unit:
Cromer Knoll Group (part).

Environment: marine, inner shelf.

The upper limit of this interval is based on a log break at 2992m.

The age of these sediments is provided by the following microfaunal evidence:

- an increase in calcareous benthonic foraminifera from 2995m, associated with the appearance of Uvigerinammina moesiana.
- the subsequent occurrence of Aulotortus (Spirillina) neocomiana and Marssonella hauteriviana at 3000m.

A tentative stratigraphic break is suggested at the top of this interval with part or all of the Barremian possibly missing.

MICROPALAEONTOLOGY

A slight increase in the calcareous benthonic element of the microfaunas is apparent at 2995m with the occurrence of Lenticulina cf. saxonica and common Lenticulina spp. This feature suggests that the Calcareous Benthonic/Ostracods Assemblage of Barremian - Neocomian age has been penetrated. This conclusion is supported by the appearance of Uvigerinammina moesiana at the same depth, and is confirmed by the incoming of Aulotortus (Spirillina) neocomiana, Thuranammina sp., Marssonella hauteriviana and common M. trochus at 3000m.

The sidewall core at 3002m produced an impoverished microfauna, although it is consistent with the Barremian? - Neocomian age assigned on the basis of the ditch cuttings evidence.

It is difficult to identify any missing sediments on the basis of the microfaunas in such a condensed sequence, but the general nature of the microfaunal association suggests that part or all of the Barremian may be absent and so a Barremian? - Neocomian age has been assigned. The implication is, therefore, that a possible stratigraphic break occurs at the top of the section.

PALYNOLOGY

The microflora recovered from the ditch cuttings sample at 2995m contains few age-diagnostic taxa, indicating only a general Early Cretaceous age.

V(3) JURASSIC

INTERVAL 3004m (log) - 3021m (log); LATE JURASSIC, LATE - MIDDLE VOLGIAN

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

Environment: marine, inner shelf, with anaerobic/dysaerobic bottom conditions and partial water stratification.

A log break defines the interval top. The age is based upon the following palynological criteria:

- the occurrence of common specimens of Gochteodinia villosa at 3005m (SWC).
- the subsequent appearance of Hexagonifera jurassica (3010m), Glossodinium dimorphum (3010m) and Dichadogonyaulax pannea (3015m).

MICROPALAEONTOLOGY

The single sidewall core examined from this interval proved to be devoid of foraminifera and so no stratigraphic conclusion is possible. The significant amount of bone fragments in this sample is consistent with the Kimmeridge Clay Formation.

PALYNOLOGY

Microplankton dominated palynofloras were recovered from the ditch cuttings samples and sidewall core sample analysed from this interval. Assemblages are characterised by the common to abundant occurrence of undifferentiated bisaccates, Sirmiodinium grossii, Hystrichodinium voigtii, Gochteodinia villosa, Tasmanites spp. and Pterospermella spp.

The sidewall core at 3005m yielded a palynoflora characterised by common specimens of G. villosa. Although this dinocyst may occur in sediments as old as latest middle Volgian, common specimens are more normally encountered in deposits of late Volgian, "I". villosa Zone (VI) age. Whilst the subsequent appearance of Glossodinium dimorphum at 3010m indicates penetration of middle Volgian sediments, the simultaneous appearance of Hexagonifera jurassica indicates an age no younger than the Dichadogonyaulax culmula Subzone (VIIB) of

the Muderongia sp. A Zone (VII). A middle Volgian age is confirmed by the appearance of Dichadogonyaulax pannea at 3015m.

Specimens of Oligosphaeridium pulcherrimum sensu IOANNIDES et. al. and Scriniodinium crystallinum at 3020m are considered to be reworked, being derived from sediments of Kimmeridgian age.

A hiatus is considered to be present at the base of this interval, with sediments of early Volgian and uppermost Kimmeridgian ages being absent. Regional considerations suggest that the base of this middle Volgian interval may be no older than the D. culmula Subzone (VIIB) of the Muderongia sp. A Zone (VII).

INTERVAL 3021m (log) - 3062m (SWC); LATE JURASSIC, KIMMERIDGIAN - MIDDLE OXFORDIAN

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

Environment: marine, inner shelf, bottom conditions initially aerobic, becoming progressively dysaerobic.

The upper limit of the interval is based upon a log break. The age is defined upon the following palynological criteria:

- the occurrence of numerous specimens of Gonyaulacysta jurassica and G. cladophora at 3024m (SWC).
- the subsequent appearances of Scriniodinium galeritum at 3056m (SWC) and Adnatosphaeridium aemulum (3060m).

MICROPALAEONTOLOGY

The sidewall core at 3024m was the only sample examined from this interval. The only in situ elements recovered consist of rare specimens of agglutinating foraminifera of no positive stratigraphic value.

PALYNOLOGY

Miospore dominated palynofloras were encountered throughout the interval. Assemblages are characterised by the common to abundant occurrences of undifferentiated bisaccates, Cerebropollenites mesozoicus, Callialasporites spp., microforaminiferal test linings and Gonyaulacysta cladophora.

Penetration of Kimmeridgian sediments is indicated at 3024m (SWC) by the appearance of Gonyaulacysta jurassica. An age no younger than the Gonyaulacysta cladophora Zone (X), however, is suggested by the simultaneous appearance of the zonal index taxon associated with Cleistosphaeridium tribuliferum and numerous specimens of G. jurassica.

The subsequent appearance of Scriniodinium galeritum at 3056m (SWC) indicates penetration of Oxfordian strata, probably no younger than the S. galeritum Zone

(XII), although this dinocyst may occur, albeit rarely, in sediments as young as the Scriniodinium crystallinum Zone (XI). An age no younger than the Acanthaulax spinosissima Zone (XIII) is indicated on regional grounds at 3060m, by the appearance of Adnatosphaeridium aemulum.

The regionally identifiable late Oxfordian transgression is considered to be reflected by the log break at 3059m which also marks the boundary between the Kimmeridge Clay and Heather Formations.

INTERVAL 3062m (SWC) - 3089m (core); LATE JURASSIC, EARLY OXFORDIAN - MIDDLE CALLOVIAN

Lithostratigraphic Units:
Humber Group (part);
Heather Formation (part);
Hugin Formation (part).

Environment: marine, inner shelf in upper part; marginal marine to deltaic in lower part.

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

- the appearance of Chytroeisphaeridia cerastes at 3062m (SWC).
- the simultaneous occurrence of Atopodinium prostatum.
- the presence of Acanthaulax spinosissima between 3061.00m - 3062.02m (uncorrected core depths).
- the presence of abundant specimens of Dichadogonyaulax stauromatos and Polystephanephorus paracalathus at 3082m (uncorrected core depth).

PALYNOLOGY

Rich and diverse palynofloras were recovered from the ditch cuttings, sidewall core and core piece samples analysed. Assemblages are characterised by the occurrence of common to abundant specimens of undifferentiated bisaccates, Deltoidospora spp., Cerebropollenites mesozoicus, Adnatosphaeridium aemulum (3061.50m - 3062.44m (core)), Gonyaulacysta jurassica (3062.00m - 3062.44m, (core)), Pareodinia ceratophora (3062.44m - 3085.16m (core)), Dichadogonyaulax stauromatos (3082m (core)), Polystephanephorus paracalathus (3082m (core)) and microforaminiferal test linings (3062.02m (core)).

Assemblages recovered from the core piece samples between 3061.00m and 3062.44m suggest that they are no younger than early Oxfordian in age, hence the samples from 3061.00m and 3061.50m are discussed in this interval. This discrepancy is due to a small difference between drillers and loggers depths in Core 1.

The appearances of Chytroeisphaeridia cerastes and Atopodinium prostatum at 3062m (SWC) indicate an early Oxfordian age, no younger than the Wanaea

digitata Zone (XIV). Dinocyst assemblages recovered from the core pieces between 3061.00m and 3062.44m also suggest an age no younger than early Oxfordian, being characterised by abundant Adnatosphaeridium aemulum, and numerous specimens of Acanthaulax spinosissima and Chytroeisphaeridia cerastes. The occurrence of A. spinosissima down to 3062.02m (core) indicates an age no older than the mid part of the Mendicodinium groenlandicum Subzone (XIVC). Specimens of Dichadogonyaulax stauromatos were recorded at 3061.50m (core), tentatively suggesting, if in situ, an age no younger than the late Callovian M. groenlandicum Subzone (XIVC). Regional considerations suggest that common specimens of Pareodinia ceratophora encountered in the core at 3062.44m may substantiate an age no younger than Callovian, although overall dinocyst content is more early Oxfordian in composition.

Relative to the assemblages described above, the palynofloras recovered at and below 3072.50m (SWC) are of restricted marginal marine to non-marine, deltaic origin. Kerogen from the coal at 3072.50m (SWC) is composed predominantly of unstructured vitrinite (collinite), a component which normally characterises allochthonous (drifted) coals in the Sleipner area. The drifted origin is substantiated by the presence of a specimen of the marine dinocyst Sentusidinium spp. within the assemblage. Low diversity, marginal marine palynofloras were recovered from the sidewall core at 3079m and core pieces at 3082.30m, 3083m, 3084.05m and 3085.16m, whilst a non-marine palynoflora was encountered at 3084.05m. The core piece from 3082m, however, yielded a relatively diverse marine microplankton assemblage, albeit still of marginal marine origin. The assemblage is characterised by abundant specimens of D. stauromatos and Polystephanephorus paracalathus, features of age diagnostic value, indicating an age no younger than the middle Callovian, P. paracalathus Zone (XV). Due to the paucity of age diagnostic taxa between 3062.44m (core) and 3082m (core), regional considerations suggest that the top of the middle Callovian is probably higher, possibly equating to the level of the log break at 3069m.

INTERVAL 3089m (core) - 3130m (log); LATE JURASSIC, EARLY CALLOVIAN

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

Environment: marine, marginal marine to inner shelf.

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

- the appearance of the Dichadogonyaulax gochtii/kettonensis plexus at 3089m (core).
- the simultaneous appearance of abundant specimens of Nannoceratopsis pellucida.
- the occurrence of Aldorfia aldorfensis at 3116.50m (SWC).
- the overall palynofloral content.

PALYNOLOGY

Ditch cuttings, sidewall core and core piece samples analysed from the interval yielded rich and diverse palynofloras. Assemblages are characterised by the common to abundant occurrences of undifferentiated bisaccates, Cerebropollenites mesozoicus, Deltoidospora spp., Perinopollenites elatoides, Pareodinia ceratophora, Nannoceratopsis pellucida, Polystephanephorus paracalathus, Valensiella spp., Sentusidinium cf. verrucosum, Chytroeisphaeridia dictydia, Dichadogonyaulax stauromatos and Wanaea acollaris.

A marked increase in marine influence is seen at and below 3089m (core), relative to the overlying interval 3072.50m (SWC) - 3085.16m (core).

The occurrence of abundant to common specimens of N. pellucida and P. paracalathus at 3089m (core) suggests an age no younger than the N. pellucida Subzone (XVB) of the P. paracalathus Zone (XV). The simultaneous appearance of the Dichadogonyaulax gochtii/kettonensis plexus indicates an age no younger than early Callovian. The age assignment is substantiated by the subsequent occurrence of abundant D. gochtii/kettonensis plexus at 3093.50m (core) and appearance of common specimens of Valensiella spp. and C. dictydia at and below 3093.50m (core).

An age no younger than the D. gochtii Subzone (XVIA) of the P. ceratophora Zone (XVI) is tentatively indicated at 3116.50m (SWC) by the occurrence of Aldorfia aldorfensis and Leptodinium "arkellii". Both of these appearances are of potential correlative value, as is the occurrence of common specimens of Sentusidinium cf. verrucosum at 3100m (core).

INTERVAL 3130m (log) - 3183m (log); MIDDLE JURASSIC, BATHONIAN - BAJOCIAN

Lithostratigraphic Unit:
Fladen Group,
Sleipner Formation.

Environment: non-marine, initially fluvio-deltaic, becoming deltaic.

A log break defines the interval top. The age is based upon the following criteria:

- the occurrence of non-marine palynoflora of Bathonian age at 3131m (SWC).
- regional considerations.
- stratigraphic considerations.

PALYNOLOGY

Palynofloras recovered from the ditch cuttings samples in this interval are considerably modified by caved taxa from overlying intervals. Core piece samples from 3139m, 3149.50m and 3169m proved to be barren of palynomorphs, only rare grains of inertinite being recorded.

The sidewall core at 3131m, however, contained a rich and diverse non-marine palynoflora. The assemblage is characterised by the common occurrence of Kraueselisporites "hyalinus". The large numbers of this taxon, which occurs in strata of Callovian - Bathonian age, is considered to suggest a Bathonian age. Specimens of Verreticulatisporites giganteus support the age assigned, as this miospore is also considered not to occur in pre-Bathonian deposits. Rare colonies of Botryococcus reflect some freshwater input.

V(4) TRIASSIC

INTERVAL 3183m (log) - 3291m T.D.; TRIASSIC

Lithostratigraphic Units:

"Triassic Group"

Skagerrak Formation 3183m (log) - 3241m (log)

Smith Bank Formation 3241m (log) - 3291m T.D.

Environment: terrestrial, lacustrine/fluviatile.

A log break defines the interval top. The age is based upon the lithological and regional considerations.

PALYNOLOGY

Sidewall core samples from 3201m, 3224m and 3244m proved to be barren of palynomorphs, the only kerogen being abraded inertinite grains. Palynofloras recovered from the ditch cuttings samples proved to be barren of in situ taxa, assemblages containing palynomorphs derived entirely, via caving, from overlying intervals.

VI

GEOLOGICAL HISTORY

TRIASSIC	The oldest sediments encountered are vari-coloured shales, silts and sandstones of the Triassic Group. These are considered to have been deposited within a variety of fluvio-lacustrine environments, characterised by subaerial oxidation.
EARLY JURASSIC	ABSENT - due to deposition with subsequent erosion or non-deposition.
MIDDLE JURASSIC	Deposition resumed, probably in response to a basin-wide change in river base levels. A predominantly arenaceous sequence accumulated in a variety of non-marine, fluvio-deltaic settings.
CALLOVIAN - LATE VOLGIAN	The onset of marine conditions was due to the regionally identifiable early Callovian transgression. This initially resulted in the accumulation of sands and shales in inner shelf to marginal marine environments. The succeeding middle Callovian regression is reflected by a marked decrease in marine influence and increase in the frequency of coal seams. Deposition is envisaged within marginal marine-deltaic settings.
	During the later part of the middle Callovian or in the late Callovian inner shelf conditions were established, and led to the accumulation of shales under aerobic bottom conditions. Slow subsidence led to

a relatively thin sequence of early - middle Oxfordian age.

The regionally identifiable late Oxfordian transgression resulted in the onset of dysaerobic bottom conditions and accumulation of shales assignable to the Kimmeridge Clay Formation. An intraformational hiatus separates the middle Volgian from the Kimmeridgian, probably being a result of a regional phase of tectonism. Deposition resumed due to the ensuing middle Volgian event which resulted in basin isolation and stagnation, giving rise to anaerobic bottom conditions and water stratification.

NEOCOMIAN - MAASTRICHTIAN

Following a phase of non-deposition or deposition with erosion, sedimentation probably recommenced due to the regionally identifiable Hauterivian transgressive event. This led to accumulation of calcareous shales and limestones in a shallow, inner shelf setting. Following a brief hiatus, sedimentation recommenced due to the early Aptian transgressive event, with deposition continuing uninterrupted into the Late Cretaceous associated with a deepening to inner to outer shelf depths. Associated with this deepening was a reduction in terrigenous input which led to accumulation of the Chalk Group. An influx of argillaceous detritus within the Turonian resulted in the deposition of the Plenus Marl Formation.

PALAEOCENE

A marked phase of tectonism, associated with North Atlantic and basin margin rifting, resulted in an influx of arenaceous material, which rests unconformably upon the Late Cretaceous. Significant sand input continued into the Late Palaeocene, probably introduced via submarine grain flows. Sand input ceased during the Late Palaeocene resulting in accumulation of shales under outer shelf to upper bathyal conditions. Towards the end of the Late Palaeocene a widespread volcanic phase, associated with continued North Atlantic rifting, resulted in deposition of tuffaceous shales.

VII

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APPENDIX 1

SIDEWALL CORE DESCRIPTIONS

Depth	Core No.	Rec. (mm)	Qual.	Type of Analysis	Lithology
2873m	29	10	G	M P	SANDSTONE: firm to friable, yellowish grey, fine to very fine grained, angular, slightly micaceous, traces of glauconite, slightly calcareous.
2922m	28	20	G	M P	SANDSTONE: firm to friable, to soft, fine to very fine grained, angular, micaceous, calcareous, argillaceous, grading to SANDY CLAYSTONE.
2956m	25	10	G	M P	SANDSTONE: firm to friable, greenish grey, fine grained, angular, micaceous, argillaceous, glauconitic, highly calcareous.
2979m	22	35	Ex	M	SHALE: firm, greyish red to blackish red, micromicaceous, moderately calcareous.
2991m	19	25	G	M P	SHALE: as 2979m.
3002m	17	15	G	M	CHALKY LIMESTONE: firm, brittle, white, slightly pyritic.
3005m	16	30	Ex	M P	SHALE: firm, black to brownish black, non-calcareous.
3024m	15	30	Ex	M P	SHALE: firm to hard, brittle, olive black, non-calcareous.
3056m	14	Fgs	G	P	SHALE: firm, fissile, brownish black, micaceous, silty with scattered fine sand grains, non-calcareous.
3062m	13	15	G	P	SILTSTONE: firm, olive grey to olive black, weakly calcareous.
3072.50m	12	Fgs	G	P	COAL: brittle, vitreous, brownish black.
3079m	10	30	Ex	P	SHALE: firm, brownish black, micaceous, non-calcareous.
3116.50m	9	25	Ex	P	SHALE: as 3079m.

3131m	9	15	G	P	SANDSTONE: soft, olive grey to light olive grey, fine to very fine grained, angular, micaceous, argillaceous, silty, traces of carbonaceous debris, non-calcareous.
3201m	4	30	G	P	SANDSTONE: friable, white to yellowish grey, fine to medium grained, angular to sub-rounded, slightly micaceous, with rare orange and greenish grains, non-calcareous.
3224m	3	10	G	P	SANDSTONE: firm to friable, olive grey, fine to very fine grained, micaceous, moderately calcareous.
3244m	2	15	G	P	SHALE: firm, dark reddish brown, silty, grading to SILTSTONE friable, dark reddish brown, micaceous and silty, with streaks of white siltstone; non-calcareous.

KEY

M = Micropalaeontology

P = Palynology

Ex = Excellent

G = Good

Qual. = Quality

Rec. = Recovery

APPENDIX 2

CORE PIECE DESCRIPTIONS

Depth	Core	Type of Analysis	Lithology
3061.00m	1	P	SANDSTONE: hard, medium grey, very fine grained, quartzitic, very weakly calcareous.
3061.25-3061.50m	1	P	SANDSTONE: hard, weakly fissile, dark grey, micaceous, carbonaceous, fine to very fine grained, non-calcareous.
3061.75-3062.00m	1	P	SANDY SHALE/ARGILLACEOUS SANDSTONE: as 3061.50m.
3061.92-3062.02m	1	P	SHALE: hard, quite fissile, dark grey to brownish black, micaceous, pyritic (?burrow infill), carbonaceous and silty to sandy (in pockets and lenses).
3062.25-3062.44m	1	P	SANDY SHALE/ARGILLACEOUS SANDTONE: as 3061.50m.
3082m	2	P	SHALE: moderately hard, brownish black, with common medium sand grains, sub-angular to sub-rounded (brown stained). Micaceous, with streaks of SANDSTONE: moderately hard, light brownish grey, sub-angular, non-calcareous.
3082.25-3082.30m	2	P	SHALE: as above but highly carbonaceous with COAL lenses, black, brittle, vitreous.
3083m		P	SHALE: fissile, waxy, brownish black, micaceous, carbonaceous, non-calcareous.
3084.00-3084.05m	2	P	SANDSTONE: moderately hard, weakly cemented to friable, yellowish grey to light olive grey, fine grained, angular, highly carbonaceous and pyritic.
3085.09-3085.16m	2	P	COAL: quite hard, brittle, vitreous black.
3089m	2	P	SANDSTONE: hard, yellowish brown, fine grained, slightly carbonaceous and pyritic, weakly calcareous.

3089.42-3089.46m	2	P	ARGILLACEOUS SANDSTONE: hard, quite well cemented, olive grey, very fine to fine grained, with angular grains set in argillaceous matrix, pyritic, carbonaceous.
3093.50m	2	P	SANDSTONE: as 3089m.
3095.54-3095.57m	2	P	SHALE: hard, fissile, dark grey to brownish black, micromicaceous, scattered small carbonaceous flecks.
3100m	2	P	SANDSTONE: friable, yellowish grey, fine to very fine grained, angular to sub-rounded, with thin dark argillaceous streaks.
3139m	3	P	SANDSTONE: moderately hard, white, fine to very fine grained, angular, with very thin, parallel, micaceous laminae, non-calcareous.
3149.50m	3	P	SANDSTONE: moderately hard, white, fine to medium grained, occasional coarse grains, angular to well rounded, weakly calcareous matrix. Thin streak of SHALE: fine, greenish grey, sandy, micaceous, non-calcareous.
3169m	4	P	SANDSTONE: friable, pinkish grey, medium to coarse grained, occasionally very coarse grained, sub-rounded to well rounded, with occasional orange and greenish grains, non-calcareous, good porosity.

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		
		middle	*lautus*		*Systematophora cretacea* OIIC
			loricatus		
			dentatus		
		early	*mamillatum*		*Cauca parva* OIID
			tardefurcata		
	Aptian	late	*jacobi*	*Dingodinium albertii* OI	*Aptea polymorpha* OIA
			nutfieldensis		*Cyclonephelium tabulatum* OIB
			martinioides		
		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).

APPENDIX 4

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		
			Pavlovia sp.	*Pareodinia mutabilis* VIII	*Gonyaulacysta pennata* VIIIA
		early	*pectinatus*		*Gonyaulacysta jurassica* VIIIB
			hudlestoni	*Gonyaulacysta longicornis* IX	*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		
		middle	*morrisi*		*Gonyaulacysta filapicata* XVIC
			subcontractus		
			progracilis		
		early	*zigzag*	*Nannoceratopsis spiculata* XVII	
	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*		"Sphaeromorphs" XVIIIC
			bifrons		
		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).