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MOBIL NORWAY 33/9 - 9 WELL: BIOSTRATIGRAPHY OF THE INTERVAL 254m - 3100m

by

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CONTENTS

		Page No.
I	SUMMARY	1
II	INTRODUCTION	3
III	SUCCESSION	5
IV	TERTIARY	7
V	CRETACEOUS	18
VI	JURASSIC	24
VII	INDETERMINATE (?TRIASSIC)	37
VIII	PALAEOENVIRONMENTAL SUMMARY	39
IX	SELECTED BIBLIOGRAPHY	41
	APPENDIX 1: Core depths.	42
	APPENDIX 2: Core descriptions.	43
	APPENDIX 3: The Biostratigraphic Units of the Jurassic.	49
	APPENDIX 4: Norian - Barremian dinocyst zones.	50

Enclosures

Legend.

3 Biostratigraphical Charts.

Biostratigraphical Core Sample Chart.

Summary Log.

SUMMARY

1. A continuous sequence c.1590m thick of Tertiary deposits of Pliocene to Palaeocene age represents the youngest sediments examined in this well.

2. The absence of sediments of Danian age at the base of the Palaeocene indicates a stratigraphical hiatus between the Tertiary and Upper Cretaceous.

3. The underlying Upper Cretaceous is represented by a thick (c.543m) sequence of deposits of late Maastrichtian to late? Santonian age.

4. A stratigraphical hiatus exists between the Upper and Lower Cretaceous. Upper Cretaceous strata of Coniacian to Cenomanian age are absent.

5. A thin sequence of Lower Cretaceous deposits of Barremian age is recorded.

6. A marked stratigraphical hiatus exists between the Barremian, Lower Cretaceous and underlying Middle Jurassic. There are no Upper Jurassic sediments present.

7. The Middle Jurassic is characterised by a (93m thick) sequence of poorly sorted sands of ?Bathonian - early Bajocian (units ?t-v2) age i.e. the Brent Sand Formation.

8. Subdivisions of the Brent Sand Formation have been identified: (1) Fine to medium grained sands of the Upper Brent. (2) Shales silts, coals and sands of the Middle Brent. (3) The coarse basal sand of the Lower Brent. The massive sand member and micaceous sand member which usually lies between the Middle Brent and the basal sand were not identified with the material available for this study.

9. A complete sequence (c.200m thick) of deposits of Toarcian, Domerian, Carixian, and late Sinemurian age is recognised within the Lower Jurassic.

10. The incoming of coarse grained, angular sands thought to represent the Statfjord Sand Formation marks the penetration of sediments of ?early Sinemurian - ?Hettangian (unit ?z) age.

11. The oldest sediments penetrated in this well are a thick (c.336m) sequence of predominantly red shales, and coarse sandstones, of indeterminate (?Triassic) age. The predominance of red shales may suggest that Triassic deposits have been penetrated, but this is not considered to be conclusive evidence.

II

INTRODUCTION

This report summarises the results of the micropalaeontological, palynological and stratigraphical analyses which have been carried out on material received from the interval 254m - 3100m from the Mobil Norway 33/9-9 Norwegian North Sea Well under Project No. IIA/778/1142.

Under this project a total of 614 ditch cuttings and 43 core samples was analysed utilising standard micropalaeontological techniques. The results of well-site micropalaeontological analyses have also been included in this report. In addition 24 ditch cuttings samples and 34 core samples covering the interval 2396m to 3100m were treated palynologically. The core depths employed in this report are uncorrected for cores 1 - 16 and corrected for cores 17 - 23. A complete list of the core depths used is given in Appendix 1 whilst lithological descriptions of the core pieces can be seen in Appendix 2.

A summary of the determinations 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 in Table 1.

The Jurassic biostratigraphic units used in this report are those proposed in our study - "The Jurassic of Northwest Europe: Offshore Project". Their stratigraphical significance is summarised in Appendix 3.

The Norian - Barremian dinocyst zonation scheme used in this report is that proposed in our study - "The Inner Moray Firth Area of Scotland: Stratigraphy, Reservoir Rocks and Source Rock Potential of the Devonian to Lower Cretaceous sediments". The scheme is reproduced in Appendix 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 Mobil Exploration Norway Inc., with whom we have been associated during the course of this work.

The personnel who have been involved in this report are as follows:

Mark Capsey	-	Well Co-ordinator; Tertiary Micropalaeontology and Tertiary Lithologies.
Cyril Haskins	-	Ostracoda.
Kam Lam	-	Palynology.
Les Riley	-	Palynology.
Dave Shipp	-	Mesozoic Micropalaeontology.
John Underwood	-	Mesozoic Lithologies.

III

SUCCESSION

TABLE 1

System/Subsystem	Stage	Interval
Pliocene	-	254m - 506m
Upper Miocene	-	512m - 548m
Middle Miocene	-	554m - 905m
Lower Miocene	-	914m - 977m
Oligocene	-	986m - 1352m
Upper Eocene	-	1358m - 1388m
Middle Eocene	-	1394m - 1406m
Lower Eocene - Palaeocene	-	1412m - 1628m
Palaeocene	-	1634m - 1844m
- - - - - - - - - - - - UNCONFORMITY - - - - - - - - - - - -		
Upper Cretaceous	late Maastrichtian	1850m - 1856m
	Maastrichtian	1862m - 1922m
	early Maastrichtian - late Campanian	1928m - 2078m
	early Campanian - late? Santonian	2081m - 2393m
- - - - - - - - - - - - UNCONFORMITY - - - - - - - - - - - -		
Lower Cretaceous	Barremian	2396m

System/Subsystem	Stage	Interval
- - - - - - - - - - - -	UNCONFORMITY - - - - - - - - - - - -	
Middle Jurassic	?Bathonian (units ?t-v1)	2399m - 2417.7m
	earliest Bathonian - Bajocian (unit v1)	2422.2m - 2433m
	early Bajocian (unit v2)	2435.5m - 2492m
Lower Jurassic	late Toarcian (unit w)	2492.5m - 2519m
	early Toarcian (unit x1)	2522m - 2555m
	Domerian (unit x2)	2558m - 2597m
	Carixian - late Sinemurian (unit y)	2600m - 2693m
	?early Sinemurian - ?Hettangian (unit ?z)	2696m - 2762m
Indeterminate (?Triassic)	-	2764m - 3100m

IV

TERTIARY

INTERVAL 254m - 506m; PLIOCENE

The age assigned to this interval is based on the following:

- the presence of Cibicides lobatulus var. grossa at 254m.
- the subsequent occurrence of other age diagnostic foraminifera.

LITHOLOGY

Although cement contaminates many of the samples from this interval, the lithology appears to be a light grey clay, containing very fine to coarse sand, mica, rock fragments and shell debris.

MICROPALAEONTOLOGY

A Pliocene age is assigned to this uppermost interval on account of the presence of Cibicides lobatulus var. grossa in the top sample at 254m, and the subsequent occurrence of Bulimina elongata var. subulata (260m), and Cassidulina laevigata var. pliocarinata (476m).

The foraminiferal assemblages are poor to moderate in both abundance and diversity, and are almost exclusively dominated by calcareous benthonic forms. There is, however, a small but environmentally significant incoming of planktonic foraminifera towards the base of the interval, below 428m.

Some reworking of Palaeocene foraminifera is noted in the upper part of the interval.

ENVIRONMENT

The domination of the microfaunas by calcareous benthonic foraminifera, thought to be restricted to relatively shallow water conditions, suggests an inner shelf environment. This is supported by the presence of numbers of ostracoda.

The appearance of planktónic foraminifera towards the base of the Pliocene may indicate some slight deepening of the sea, and a probable improvement in open marine connections.

INTERVAL 512m - 548m; UPPER MIOCENE

The age assigned to this interval is based on the following:

- the presence of Pyrgo bulloides at 512m.

LITHOLOGY

As in the overlying interval light grey sandy and micaceous clays dominate the lithology. There is, however, an increase in the percentage of the fine to medium, clear to smoky, subangular to angular quartz fraction, as well as rock fragments and in particular coarse-grained micaceous sandstones.

MICROPALAEONTOLOGY

The presence of Middle Miocene foraminifera in Lower Pliocene sediments is probably due to reworking, and it is believed that in situ Miocene sediments are not penetrated until 512m, as indicated by the presence of the Upper Miocene index form Pyrgo bulloides.

The general character of the foraminiferal assemblages differs little from the Pliocene, Cibicides lobatulus var. grossa, Cassidulina laevigata and Elphidium spp. being the commonest forms. The microfaunas are moderate in abundance and diversity and still consist of mainly calcareous benthonic foraminifera, with small numbers of planktonic forms.

ENVIRONMENT

Inner shelf conditions, with open marine connections are again suggested for this interval.

INTERVAL 554m - 905m; MIDDLE MIOCENE

The age assigned to this interval is based on the following:

- the presence of Sigmoilina celata, and the first in situ occurrence of Pullenia sphaeroides at 554m.
- the subsequent occurrence of other diagnostic foraminifera.

LITHOLOGY

The in situ lithologies of this interval consist predominantly of light grey to light brown, sandy and micaceous clays. Between 686m and 698m, however, light brown sandy and micaceous claystones/shales with a poor fissility occur.

The fine to medium-grained, clear to smoky, angular to subangular quartz sand occurs consistently in abundances of between 20-30%. In addition, coarse, clear to milky quartz sand occurs in many of the samples, in particular at the base of the interval.

Minor in situ components of the lithologies include glauconite, pyrite, and shell debris. Throughout the interval coarse granules of igneous rocks and micaceous sandstones occur, but are believed to be present primarily as a result of caving.

MICROPALAEONTOLOGY

The top of the Middle Miocene is placed at 554m on the presence of Sigmoilina celata. In addition, Pullenia sphaeroides is thought to occur in situ for the first time at this depth, its higher occurrence being considered to be due to reworking.

Confirmation of the penetration of Middle Miocene sediments is afforded by the subsequent occurrence of other diagnostic forms, Globorotalia continuosa (560m), Angulogerina angulosa (590m), Planulina ariminensis (638m), Uvigerina hosiusi (764m), Listerella communis (830m), Eponides umbonatus (848m) and Sphaeroidina bulloides (869m).

Calcareous benthonic foraminifera continue to dominate the foraminiferal assemblages throughout the interval. Planktonic forms also

occur throughout much of the Middle Miocene, apart from a section over the central part of the interval. Agglutinating foraminifera appear for the first time in this interval, occurring intermittently down the section, though never in significant numbers.

The foraminiferal assemblages tend to be moderately abundant and diverse towards the top of the interval, and contain a number of new genera appearing for the first time, notably Bolivina and Uvigerina. Below this, the microfaunas exhibit a slight decrease in abundance and diversity. Then, at and below 786m, there is a significant increase in the numbers of Cibicides lobatulus var. grossa, Cassidulina laevigata and Nonion affine. There is also a general, overall increase in abundance and diversity of the microfauna. This feature is a useful aid for local correlation purposes since it is commonly recorded in the lower part of the Middle Miocene, in this part of the North Sea.

ENVIRONMENT

An inner - outer shelf environment is suggested by the overall increase in abundance and diversity of the dominantly calcareous benthonic foraminiferal assemblages. In support of these generally deeper water conditions is the occurrence of the outer shelf species Paromalina crassa (788m), and the presence of significant numbers of planktonic foraminifera.

INTERVAL 914m - 977m; LOWER MIOCENE

The age assigned to this interval is based on the following:

- the presence of Angulogerina gracilis var. tenuistriata at 914m.
- the presence of Angulogerina gracilis at 977m.

LITHOLOGY

The lithological character of the upper part of this interval from 914m to 932m, differs little from the overlying sediments. Apart from the presence of a pale green micaceous clay/shale at 914m, the light grey micaceous clays first seen in the Pliocene persist.

Below this at 941m, the character of the quartz sand component changes slightly by acquiring a yellowish tint. There also occurs at this level an

easily identifiable dark brown-grey micaceous shale, and which occurs again at 977m.

At and below 950m, there is a significant increase in the glauconite content of the samples. The in situ lithology of these horizons is believed to be a slightly calcareous, light brown-tan, sandy and glauconitic clay. As in younger intervals many of the samples contain igneous rock granules, again probably caved.

MICROPALAEONTOLOGY

Recognition of a Lower Miocene interval in this well is based on the occurrence of Angulogerina gracilis var. tenuistrata at 914m and the presence of Angulogerina gracilis in the basal sample at 977m.

Microfaunas in general, are similar in character to those of the lower part of the Middle Miocene, being abundant and diverse assemblages of dominantly calcareous benthonic foraminifera with smaller numbers of planktonic forms.

ENVIRONMENT

Inner to outer shelf conditions are again suggested for this interval. As in the overlying interval the presence of planktonic foraminifera also suggests a degree of open marine influence.

INTERVAL 986m - 1352m; OLIGOCENE

The age assigned to this interval is based on the following:

- the presence of Elphidium subnodosum at 986m.
- a significant reduction in abundance and diversity of the foraminiferal assemblages.
- the occurrence of large numbers of sponge spicules types A, B, and C at 1004m.
- the subsequent occurrence of other diagnostic forms.

LITHOLOGY

The dominant lithotypes of this interval are believed to be clays and soft shales with variable amounts of sand.

In the upper part of the section between 986m and 1040m light brown occasionally calcareous clays containing fine to coarse quartz sand, mica and glauconite occur. Below 1049m there is a reduction in the sand and glauconite fraction, and light grey-brown shales containing sand, mica and sponge spicules appear.

Although present throughout much of the interval glauconite again appears in abundance at 1112m, giving rise to some green-staining of clays and shales at and below 1121m. In the lower part of this glauconitic sequence, between 1148m and 1166m, medium grey micaceous shales occur, while at 1166m a fine-grained, medium brown limestone is present.

Below 1202m clays and shales, usually light brown to cream but sometimes green-stained, are predominant. Apart from a short section between 1244m and 1283m these sediments usually contain some 20-30% of fine to medium, subangular to angular, and coarse subrounded quartz sand, almost invariably clear to milky in colour. In addition pyrite and glauconite are important components.

Red-brown and dark brown dolomite/siderite occurs intermittently within the lower part of the interval. Towards the base of the Oligocene a calcareous glauconitic sandstone is present.

MICROPALAEONTOLOGY

The top of this interval is placed at 986m on the first occurrence of Elphidium subnodosum. In confirmation of the proposed penetration of Oligocene sediments, there is a distinct microfaunal break, which exhibits a significant reduction in foraminiferal abundance and diversity. Calcareous benthonic foraminiferal dominance of the assemblages is replaced by an influx of sponge spicules types A, B and C at 1004m.

The appearance of agglutinating foraminifera including Bathysiphon sp. (1130m), Sigmoilina tenuis (1166m) and Sigmoilina schlumbergeri (1211m) is noted at and below 1130m. Regionally, the first occurrence of significant numbers of agglutinating foraminifera may show some variation, and appears to be affected by facies considerations. However, within the immediate confines

of the 33/9 block, correlation seems to suggest that such an increase in numbers of agglutinating forms does reflect an Oligocene age.

The presence of other index foraminifera within the interval such as Cibicides dutemplei (1013m) and Globorotalia opima opima (1247m) lends additional support for the age assigned.

Small, round radiolaria occur intermittently below 1022m.

ENVIRONMENT

The decline in abundance of calcareous benthonic foraminifera down through the upper part of this interval probably reflects the existence of progressively deeper water conditions. Although planktonic foraminifera occur only rarely, the occurrence of small radiolaria below 1022m does suggest a degree of oceanic influence. In consequence a general shelf environment of mainly outer shelf depths is suggested for this part of the interval. The incoming of significant numbers of agglutinating foraminifera at and below 1130m may indicate somewhat deeper water conditions and an outer shelf - bathyal environment is proposed for the lower part of the Oligocene.

INTERVAL 1358m - 1388m; UPPER EOCENE

The age assigned to this interval is based on the following:

- the presence of Cyclammina challinori at 1358m.
- its stratigraphic position.

LITHOLOGY

Light grey-green, slightly sandy clay is the dominant lithotype of this interval. The clays are often pyritic and occasionally slightly silty. In addition, the occurrence of a light grey limestone with iron staining at and below 1364m, may be a useful lithotype for local correlation purposes. A hard, fine-grained, buff sandy dolomite is also recorded at 1364m.

MICROPALAEONTOLOGY

The penetration of Eocene sediments is indicated by the presence of Cyclammina challinori at 1358m. An Upper Eocene age is suggested by the stratigraphic position of this interval, which rests on sediments containing a Middle Eocene form.

Although relatively sparse, the assemblages are mainly agglutinating foraminifera, with a minor calcareous benthonic foraminiferal element which is probably caved. The increased abundance of some foraminifera, and the appearance of a number of new forms within the interval, mark the start of a limited, but easily identifiable faunal diversification down through the Eocene. This microfauna is characterised by an association which includes Cyclammina challinori, Bathysiphon sp. and Glomospira charoides.

ENVIRONMENT

An outer shelf to bathyal environment is proposed for this interval.

INTERVAL 1394m - 1406m; MIDDLE EOCENE

The age assigned to this interval is based upon:

- the presence of Acarinina pentacamerata at 1394m.

LITHOLOGY

Apart from the occurrence of a yellow calcareous sandstone at and below 1394m the lithologies of this interval differ little from the overlying Upper Eocene. The dominant lithotype is believed to be a grey-green clay/shale which contains minor amounts of silt and sand. Light grey limestone continues to occur but may be caved.

MICROPALAEONTOLOGY

The presence of a possible Middle Eocene interval is suggested by the occurrence of Acarinina pentacamerata at 1394m. Otherwise the interval differs little from the Upper Eocene, and although poor in character, contains mainly a microfauna dominated by the Cyclammina challinori, Bathysiphon sp., Glomospira charoides association.

ENVIRONMENT

An outer shelf to bathyal environment is again proposed for this interval.

INTERVAL 1412m - 1628m; LOWER EOCENE - PALAEOCENE

The age assigned to this interval is based on the following:

- the presence of Spiroplectammina spectabilis at 1412m.
- the subsequent occurrence of other diagnostic forms.
- the presence of large flat radiolaria at 1460m, and the incoming of a flood of small, round radiolaria at 1550m.

LITHOLOGY

As in overlying intervals clays and shales continue as the dominant lithotypes, although caving is common. A brown-buff glauconitic clay occurs at 1412m but appears to give way to grey-green clays below. These gradually adopt a more fissile nature as shales below 1502m. Other local colour variations in the clays and shales are also found, but are not persistent in occurrence.

Throughout the interval light grey, buff and brown limestones are common, often with a high argillaceous content, though their continued occurrence is probably due in part to caving.

Sand occurs as only a minor component of the lithologies in the upper part of the interval, and below this is rare. Pyrite occurs in many samples, but appears to be most significant at the very top and bottom of the interval.

MICROPALAEONTOLOGY

The top of this interval is placed on the occurrence of Spiroplectammina spectabilis at 1412m, and is confirmed as Lower Eocene - Palaeocene by the subsequent occurrence of other diagnostic foraminifera such as Acarinina soldadoensis (1430m) and Verneuilina subeocaena (1520m). The presence of

large, flat radiolaria at 1460m, and the incoming of a flood of small round radiolaria at 1550m, are also positive evidence in favour of the age assigned.

The foraminiferal assemblages are essentially poor in character and dominated mainly by agglutinating foraminifera, although with small numbers of calcareous benthonic and planktonic forms also present. It is, however, especially below 1550m, the radiolaria which are the most prominent microfaunal components.

Upper Cretaceous reworking is suggested by the occurrence of Pseudotextularia elegans elegans at 1580m.

ENVIRONMENT

An outer shelf to bathyal environment is proposed for this interval. The presence of both planktonic foraminifera and significant numbers of radiolaria, also suggests that there were good open marine connections at this time.

INTERVAL 1634m - 1844m; PALAEOCENE

The age assigned to this interval is based on the following:

- the occurrence of Coscinodiscus sp. 1 at 1634m.
- the occurrence at and below 1634m of volcanic lithotypes.
- the occurrence of a characteristic microfaunal assemblage which includes Bathysiphon sp., Ammodiscus incertus and Glomospira charoides.

LITHOLOGY

The dominant lithotypes within the Palaeocene are grey-green shales/claystones. These show white mottling, indicating volcanic activity, throughout the interval. Pyrite and siderite are common constituents of the lithologies, especially in the upper half of the interval.

Calcareous sediments, often caved, occur in many of the samples and

include limestones of variable character, while at and below 1814m white fibrous calcite occurs, probably as a result of veining within the shales.

MICROPALAEONTOLOGY

The top of this interval is placed at 1634m on the first occurrence of the pyritised diatom Coscinodiscus sp. 1. In addition, a Palaeocene age is also suggested by the occurrence at and below 1634m of volcanics in the form of mottled shales. Below 1700m, there is also the characteristic occurrence of a richer and more diverse, slightly green-stained assemblage which includes Bathysiphon sp., Ammodiscus incertus and Glomospira charoides.

The first occurrence of pyritised Coscinodiscus sp. 1 is at 1634m, however, there is a much richer influx of unpyritised forms at 1676m. Small round/ovate radiolaria are particularly abundant in the upper 30m of the interval, but are also present below 1700m.

The lack of any evidence for Danian microfauna and sediments suggests that a stratigraphic hiatus separates this interval from older, Upper Cretaceous rocks.

ENVIRONMENT

An outer shelf to bathyal environment affected by volcanic activity is proposed for this interval. Abundant radiolaria particularly towards the top of the interval, and planktonic foraminifera suggest that the area was also subject to open marine influences.

V

CRETACEOUS

INTERVAL 1850m - 1856m; UPPER CRETACEOUS, LATE MAASTRICHTIAN

The age assigned to this interval is based on the following:

- the appearance of Pseudotextularia elegans elegans, Pseudotextularia elegans fructicosa and Globotruncana contusa.

LITHOLOGY

The samples from this interval are dominated by considerable amounts of caved Tertiary shales and sand. The in situ lithology is thought to consist of firm, light grey, slightly silty shales.

MICROPALAEONTOLOGY

The occurrence of specimens of Pseudotextularia elegans elegans, Pseudotextularia elegans fructicosa and Globotruncana contusa at 1850m indicates that Upper Cretaceous, late Maastrichtian deposits have been penetrated. Other Upper Cretaceous forms which first appear in this interval include Praeglobotruncana citae, Heterohelix globulosa and Globigerinelloides asper.

The assemblages are moderately rich and are dominated by planktonic forms. Some caving from the Tertiary is evident and many of the agglutinating specimens recorded in this and the underlying interval may in fact be caved.

ENVIRONMENT

The predominance of planktonic specimens in the foraminiferal assemblages suggests an open marine, outer shelf environment.

INTERVAL 1862m - 1922m; UPPER CRETACEOUS, MAASTRICHTIAN

The age assigned to this interval is based on the following:

- the appearance of large numbers of Rugoglobigerina rugosa rugosa.
- a decline in the number of the late Maastrichtian forms seen in the overlying interval.

LITHOLOGY

Caved lithologies persist into this interval,but increasing amounts of light grey shale and limestone and traces of white chalk are present. Yellowish brown siderite and pyrite are present in small amounts in some samples.

MICROPALAEONTOLOGY

Large numbers of Rugoglobigerina rugosa rugosa occur throughout this interval, and this, coupled with the decline in late Maastrichtian forms (the few that continue to be recorded may well be caved) suggest that deposits of a more general Maastrichtian age have been penetrated.

Other significant forms first appearing in this interval include Abathomphalus mayaroensis, Biglobigerinella multispina, Globotruncana arca, Heterohelix costulata, Reussella szajnochae var., and Bolivina incrassata.

The assemblages are generally very rich and dominated by planktonic forms represented principally by Rugoglobigerina rugosa rugosa. Tertiary caving is again present.

ENVIRONMENT

An open marine, outer shelf environment is indicated by the large numbers of planktonic foraminifera.

INTERVAL 1928m - 2078m; UPPER CRETACEOUS, EARLY MAASTRICHTIAN - LATE CAMPANIAN

The age assigned to this interval is based on the following:

- a slight increase in the numbers of Rugoglobigerina rugosa rugosa.
- the appearance of Rugoglobigerina rugosa rotundata.
- the subsequent occurrence in the lower part of the interval of Globotruncana sp. 1 and Globotruncana cf. marginata.

LITHOLOGY

Light grey, weakly calcareous shale dominates this interval to approximately 1994m. Small amounts of white chalk are present at 1928m and 1940m, and yellowish brown siderite occurs in small amounts at 1950m and 1958m. Caved olive-grey shales, tuffs and sands are common. Between 1997m and 2018m cement occurs abundantly and below this point the samples are of poor quality and contain fairly high proportions of medium-grained sand which is not considered to be in situ.

MICROPALAEONTOLOGY

The appearance of Rugoglobigerina rugosa rotundata at 1928m in association with an increase in the numbers of Rugoglobigerina rugosa rugosa suggest that early Maastrichtian deposits are present. The occurrence of Globotruncana sp. 1 and Globotruncana cf. marginata in the lower part of this interval indicates the presence of late Campanian deposits. The top of the late Campanian cannot be clearly defined so an early Maastrichtian - late Campanian age has been assigned to this interval.

Assemblages are again rich and dominated by Rugoglobigerina rugosa rugosa, although agglutinating forms become gradually more significant towards the base of the interval. Caved forms are again present.

ENVIRONMENT

An open marine, outer shelf environment is again indicated, although the increase in agglutinating foraminifera may reflect slightly deeper water conditions.

INTERVAL 2081m - 2393m; UPPER CRETACEOUS, EARLY CAMPANIAN - LATE? SANTONIAN

The age assigned to this interval is based on the following:

- the appearance of a red shale yielding red-stained foraminifera at 2081m.
- the subsequent occurrences of Globorotalites cf. multisepta and Rzehakina epigona.
- the presence of palynomorphs as cavings in the underlying interval, most probably derived from the late? Santonian.

LITHOLOGY

This interval is dominated by light grey, weakly calcareous shale. In addition variable amounts of fine-grained, glauconitic sandstone are present between 2200m and 2372m. The sandstone probably occurs as thin beds within the shale. Medium grey limestone is present at 2375m and again at 2393m; at the latter depth pyrite is also present. Fine-grained pyrite is recorded at 2177m, 2189m and 2216m and yellowish brown, often finely crystalline siderite occurs frequently between 2276m and 2318m.

MICROPALAEONTOLOGY

The appearance of red-stained foraminifera at the top of this interval suggests the presence of early Campanian deposits. Further evidence of an early Campanian age is provided by the subsequent occurrences of Globorotalites cf. multisepta and Rzehakina epigona within the interval. The presence of Santonian deposits at the base of the interval is suggested by the occurrence of caved palynomorphs of probable late Santonian age in the underlying Barremian sample. No microfaunal evidence for the Santonian has been recorded.

The assemblages are again rich,but although planktonic foraminifera, represented mainly by Rugoglobigerina rugosa rugosa dominate the samples at the top of the interval, agglutinating forms, principally Bathysiphon spp. and Recurvoides spp., become increasingly significant through the unit until they dominate the assemblages below approximately 2150m.

There is no evidence for the presence of any Upper Cretaceous deposits older than the Santonian and consequently an unconformity is thought to occur between the base of this interval and the underlying Lower Cretaceous.

ENVIRONMENT

The upper part of the interval down to approximately 2150m where the assemblages are dominated by planktonic foraminifera is thought to have been deposited in an open marine, outer shelf environment. Below 2150m, however, the predominance of deepwater agglutinating foraminifera is thought to reflect deeper, outer shelf to bathyal conditions.

24073

SAMPLE ~~2396m;~~ LOWER CRETACEOUS, BARREMIAN

The age assigned to this sample is based on the following:

- the appearance of the diagnostic foraminifera Aulotortus (Spirillina) neocomiana, Trocholina infragranulata, Marssonella trochus and Globigerinelloides eaglefordensis.

This thin interval is considered to be bounded above and below by non-sequences.

LITHOLOGY

White chalky limestone and fine grained pyrite are present in the single sample from this interval.

MICROPALAEONTOLOGY

A marked change in the microfauna is noted at 2396m with a significant increase in the calcareous benthonic foraminifera of the assemblage. The presence of Marssonella trochus and Globigerinelloides eaglefordensis indicates that Lower Cretaceous deposits have been penetrated, while the additional occurrence of Aulotortus (Spirillina) neocomiana and Trocholina infragranulata further indicates that these deposits are Barremian in age.

PALYNOLOGY

A rich and diverse palynofloral assemblage dominated by dinocysts was recovered from the cuttings sample at 2396m. The majority of the dinocysts are, however, clearly Upper Cretaceous, accordingly, in the light of the available microfaunal evidence they must be interpreted as cavings. Odontochitina striatoperforata, Spiniferites ramosus and species of Palaeoperidinium, Exochosphaeridium and Oligosphaeridium figure prominently in association with Pseudoceratium ceratioides, Chlamydophorella discreeta and Cleistosphaeridium tiarum - a dinocyst assemblage which suggests derivation from a Santonian, possibly Upper Santonian, source.

Additional dinocysts recovered include forms which are known to range throughout the Cretaceous, but no Lower Cretaceous restricted elements were recovered. The occurrence of the miospore Cerebropollenites mesozoicus may, however, reflect the presence of Lower Cretaceous sediments as may the isolated occurrence of a caved dinocyst at 2399m which is tentatively attributed to Phoberocysta neocomica; conclusive evidence is, however, lacking.

ENVIRONMENT

The varied microfauna suggests a general, inner to outer shelf environment, though subject to less open marine influence than in the overlying intervals.

÷ 11.3

VI

JURASSIC

INTERVAL 2399m - 2417.7m; MIDDLE JURASSIC, ?BATHONIAN (unit ?t-v1)

The age assigned to this interval is based on the following:

- a lithological break between the cuttings samples at ~~2396m~~ and ~~2399m~~.
- the occurrence of impoverished Middle Jurassic palynofloras.

LITHOLOGY

The ditch cuttings samples from this interval consist of clean, medium grained, angular sand, with minor amounts of coarse, angular sand at ~~2406m~~. The core pieces examined consist of soft, friable, greenish black, poorly sorted, mainly medium grained, argillaceous sandstones. The sandstone exhibits good visible porosity at 2406.7m.

MICROPALAEONTOLOGY

The microfaunal assemblages from this interval consist essentially of caved material, and the only in situ foraminifera seen within the ditch cuttings and the core samples are rare, non-diagnostic agglutinating forms.

PALYNOLOGY

A mixed kerogen residue, similar to that seen at ~~2396m~~, is present in the material analysed from the cuttings sample at ~~2399m~~. There is, however, a minor palynofacies break (evidenced by an increase in amorphous sapropel and a reduction in sporopollenin) which may reflect a stratigraphic hiatus between 2396m and 2399m.

With few exceptions the palynomorphs seen at 2399m consist of Upper Cretaceous dinocysts which are interpreted as cavings. The occurrence of the dinocyst Mendicodinium groenlandicum in association with the miospore

Callialasporites trilobatus may, however, reflect the presence of Jurassic (?Middle) sediments at this depth.

The four core samples analysed from the interval 2404.5m to 2417.7m are, in contrast to the above cuttings sample, dominated by miospores. The dominant miospores are bisaccate pollen, species of Deltoidospora and elements of the Osmundacidites/Baculatisporites complex. This association of taxa is clearly facies controlled, but it is not atypical of assemblages reported in earlier studies from Middle Jurassic marginal marine/deltaic sediments in the Northern North Sea. Associated dinocysts recovered are few in number and include species of Mendicodinium, Chytroeisphaera, Cleistosphaeridium and Pareodinia. Age diagnostic taxa are lacking but the forms present favour a pre Dichadogonyaulax gochtii Subzone age. The absence of Nannoceratopsis gracilis does, however, suggest a post Nannoceratopsis spiculata Zone age.

Overall, the available data (albeit limited) favour a possible Bathonian age; on purely negative grounds, however, the possibility of earlier Bathonian or older Bajocian sediments being present cannot be entirely excluded.

ENVIRONMENT

The evidence available, both from lithological and palynological data indicates that deposition took place in a shallow-water, marginal marine, or deltaic environment.

INTERVAL ~~2422.2~~2433,5m - ~~2433m~~2444,3; MIDDLE JURASSIC, EARLIEST BATHONIAN - BAJOCIAN (unit v1)

The age assigned to this interval is based on the following:

- the first appearance of the dinocyst Nannoceratopsis gracilis at 2422.2m.

- the occurrence throughout, of diverse miospore assemblages characteristic of marginal marine Middle Jurassic sediments.

LITHOLOGY

Clear, mainly medium grained sand dominates the ditch cuttings samples from this interval. The core samples examined consist of brittle, greyish black to olive grey shale, medium dark grey, micaceous siltstone and, at 2424.8m and 2431m, black, brittle coal. Friable, fine grained sandstone occurs at 2426.2m.

MICROPALAEONTOLOGY

As in the overlying unit, the samples analysed micropalaeontologically from this interval yielded only rare, non diagnostic agglutinating foraminifera.

PALYNOLOGY

The dinocyst species Nannoceratopsis gracilis first appears in the core sample at ~~2422.2m~~ 2433.5m. This is a distinctive morphotype which ranges no younger than earliest Bathonian (Nannoceratopsis spiculata Zone), although it is more typical of Bajocian and older assemblages. Associated dinocysts include species of Pareodinia, Chytroeisphaeridia and Mendicodinium, morphotypes which, as in the overlying interval, occur only in very small numbers.

In marked contrast to the overlying core samples there is, however, a significant increase in miospore abundance and diversity at and below 2422.2m. Bisaccate pollen, species of Deltoidospora and elements of the Osmundacidites/ Baculatisporites complex remain as significant components of the assemblages, but Cerebropollenites mesozoicus, Perinopollenites elatoides and species of Lycopodiumsporites and Callialasporites attain some local numerical significance. Additional miospore taxa which serve to characterise this interval include Araucariacites australis and species of Klukisporites, Sestrosporites, Uvaesporites and Densoisporites.

The overall characteristics of the assemblages recovered from the interval 2422.2m to 2433m clearly reflect an age somewhere within the earliest Bathonian to Bajocian interval. This age proposal is based essentially on the occurrence of N. gracilis and the position of the sampled interval within the overall stratigraphical framework of the well.

Recycling of pre-Jurassic sediments during the deposition of these sediments is indicated by the occurrence of striate bisaccate pollen (Permo-Triassic) and dark, indeterminate spores (?Devonian/Carboniferous) at certain horizons.

ENVIRONMENT

Lithological evidence suggests deposition in a deltaic environment. The occurrence of marine phytoplankton (dinocysts) does, however, reflect marine influences; whereas the occurrence of coal may suggest the proximity of a delta top, coal-swamp environment. Close proximity to a source of coastal vegetation is indicated throughout by the dominance of miospores over microplankton and the taxonomic diversity and character of the miospore assemblages.

INTERVAL 2435.5m - 2492m; MIDDLE JURASSIC, EARLY BAJOCIAN (unit v2)

The age assigned to this interval is based on the following:

- an increase in numbers of the dinocyst Nannoceratopsis gracilis at 2435.5m.

- the occurrence throughout the interval of "typical Middle Jurassic miospore assemblages" which include species of Chasmatosporites and forms probably attributable to Cerebropollenites cf. thiergartii.

LITHOLOGY

The ditch cuttings samples from this interval consist almost entirely of fine to medium grained, angular sand and this is considered to be the dominant in situ lithology throughout the section.

The core pieces examined between 2462m and 2489m consist of friable, fine grained, angular sandstones, with the exception of the sandstone at 2462m which is very coarse to coarse grained and exhibits good visible porosity. Well-site work indicates that the top of this coarse sand, thought to correspond to the coarse member of the Brent sand, is at approximately 2455m. The sandstones are generally micaceous and non-calcareous, and may contain small streaks of shale and coal. At 2489.4m, 2491m and 2491.5m shale is present interbedded with the sandstone.

MICROPALAEONTOLOGY

Once again, the only in situ foraminifera seen in this interval are rare, non-diagnostic agglutinating forms.

PALYNOLOGY

The core sample at 2435.5m yielded a palynomorph assemblage which includes abundant specimens of the dinocyst Nannoceratopsis gracilis, a feature which is characteristic of Nannoceratopsis gracilis Zone of early Bajocian to Upper Liassic age. Associated palynomorphs which restrict this determination to early Bajocian (Polysphaeridium deflandrei Subzone) include varieties of N. gracilis which are characterised by a reticulate periphragm, Mendicodinium groenlandicum, Mendicodinium spp., Chytroeisphaeridia spp. and Pareodinia ceratophora.

The zonal index, N. gracilis only occurs infrequently in the underlying core samples as do dinocysts in general - a feature which probably reflects local facies rather than time-stratigraphic controls. Rich and diverse miospore assemblages do, however, persist down to 2489.3m. Many of the component miospore elements and specific abundances are comparable with those recovered from the overlying interval; however, of note is the occurrence within this interval of species of Chasmatosporites and forms tentatively attributed to Cerebropollenites cf. thiergartii in association with clusters and localised abundances of small, sphaeroidal ?algal bodies - a feature not atypical of earliest Middle Jurassic assemblages.

Recycled striate bisaccate pollen derived from a Permo-Triassic source occur infrequently at certain horizons within this interval.

ENVIRONMENT

The overall lithological and palynological evidence suggests deposition in a marginal marine environment, lying in close proximity to a delta. The moderately rich and diverse miospore assemblages reflect deposition in close proximity to a terrestrial vegetative source. Fluctuations in the microplankton: miospore ratio seen throughout the interval may reflect changes in base-level, but conclusive evidence is lacking. Marine influences are, however, considered to have been more significant during the deposition of these sediments, than during deposition of the overlying Brent Sand sediments.

INTERVAL 2492.5m - 2519m; LOWER JURASSIC, LATE TOARCIAN (unit w)

The age assigned to this interval is based on the following:

- the appearance of Dunlin shale at 2492.5m in core 8 below the thin coarse sand horizon seen at the base of the Brent Formation (examined at the well-site).

- the reappearance of significant numbers of agglutinating foraminifera.

- the appearance of the ostracode Camptocythere cf. toarciana.

- the occurrence of common Nannoceratopsis gracilis, acanthomorph acritarchs and small, spheroidal algal bodies in association with species of Chasmatosporites and Cerebropollenites cf. thiergartii.

LITHOLOGY

The core pieces from this interval consist of fairly uniform, medium dark grey, micaceous, non-calcareous shale, with small amounts of carbonaceous debris at 2500.5m.

The ditch cuttings samples indicate the presence of sand, some of which is probably caved. At 2516m fine-grained, light orange siderite and light grey-green shale fragments occur in association with dominant, medium dark grey shale.

MICROPALAEONTOLOGY

The first microfaunal evidence for Lower Jurassic marine conditions is the appearance of the ostracode Monoceratina aff. vulsa at 2506m, in core 8. Other ostracodes and small, fine-grained agglutinating foraminifera also appear at the base of this core. The occurrence of the ostracode Camptocythere cf. toarciana (2513m) supports the late Toarcian age assigned, as does the occurrence of species of the foraminiferal genus Trochammina. The in situ foraminiferal assemblages consist entirely of agglutinating forms, although Tertiary and Cretaceous caved specimens are also present in this and the underlying intervals.

PALYNOLOGY

The Bajocian - Toarcian boundary is difficult to define using palynological criteria alone particularly since the palynofloral break at the

junction between the Brent Sand and the Dunlin Shale is essentially a response to facies rather than time controls. The occurrence of common Nannoceratopsis gracilis, acanthomorph acritarchs and small, sphaeroidal ?algal bodies seen in the core samples at 2499m and 2506.5m is, however, characteristic of late Toarcian assemblages. A pre-Bajocian age is,furthermore,indicated on negative criteria by the absence of such typical Middle Jurassic palynomorphs as Chytroeisphaeridia, Klukisporites and Densoisporites and on more positive criteria, the incoming of persistent Chasmatosporites.

ENVIRONMENT

Marine, inner shelf conditions are indicated by the reappearance of a rich microfauna below the Brent Sand. Fluctuations in the composition of the palynomorph assemblages seen in this and deeper Liassic intervals may, however, reflect changes in base level, perhaps associated with minor regressive and transgressive phases.

INTERVAL 2522m - 2555m; LOWER JURASSIC, EARLY TOARCIAN (unit x1)

The age assigned to this interval is based on the following:

- an influx of Nannoceratopsis gracilis at 2522m.
- a general decline in the numbers of agglutinating foraminifera.
- the presence of a distinctive lithological marker at 2522m.

LITHOLOGY

The ditch cuttings samples consist of dominant medium grey non-calcareous shale and persistent but subordinate fine-grained, angular sand and sandstone.

At 2522m light green-grey, chamosite ooliths, pyrite and siderite occur together; the ooliths occur both embedded in a grey-green, calcareous matrix and free within the sample.

MICROPALAEONTOLOGY

The assemblages continue to consist essentially of agglutinating foraminifera, though the numbers are less than in the overlying interval. Such a decline in the abundance of agglutinating foraminifera is frequently noted in early Toarcian sediments.

PALYNOLOGY

The cuttings sample at 2522m yielded a palynomorph assemblage which consists of a mixture of caved Middle Jurassic and in situ Lower Jurassic elements. The influx of N. gracilis seen at 2522m and its concurrence with Pareodinia ceratophora would suggests a Toarcian age perhaps in close proximity to the late/early Toarcian boundary. An influx of N. gracilis is typical of the early Toarcian, whereas P. ceratophora has yet to be recorded from pre-late Toarcian assemblages.

In many respects the remaining palynomorph assemblages are similar in that there is an admixture of in situ Liassic and caved Middle Jurassic elements. The occurrence throughout the cuttings samples analysed from this interval of common Nannoceratopsis gracilis and small, sphaeroidal ?algal bodies in association with localised influxes of Chasmatosporites, "Circumpolles", Cerebropollenites mesozoicus and less frequently C. cf. thiergartii is, however, not atypical of early Toarcian assemblages (?Sphaeromorphs/Spheripollenites Subzone).

ENVIRONMENT

An inner shelf marine environment is again indicated.

INTERVAL 2558m - 2597m; LOWER JURASSIC, DOMERIAN (unit x2)

The age assigned to this interval is based on the following:

- the appearance of the ostracodes Hungarella amalthei and Hungarella etaulensis at 2558m.

- the subsequent appearance of the ostracode Trachycythere tubulosa.

- an influx of calcareous benthonic foraminifera at 2570m.

LITHOLOGY

Medium grey, non-calcareous shale is considered to be the dominant in situ lithology, but approximately 30% of the samples consists of coarse and medium grained, angular sand which may not be in situ.

MICROPALAEONTOLOGY

The appearance of the ostracodes Hungarella amalthei and Hungarella etaulensis at 2558m indicates that sediments of Domerian age have been penetrated. This is confirmed by the subsequent appearance of the ostracode Trachycythere tubulosa.

Agglutinating foraminifera still dominate the microfauna, which is slightly richer than in the overlying interval. There is, however, an influx of calcareous benthonic foraminifera at 2570m, which includes such forms as Marginulina prima, providing additional support for a Domerian age.

PALYNOLOGY

The cuttings samples yielded moderately rich and diverse palynomorph assemblages, which in view of the microfaunal evidence must be considered to be dominated by caved elements. In this context it is noted that Nannoceratopsis gracilis occurs in considerable numbers - a feature which is atypical of Domerian assemblages. Of additional note is the occurrence of small numbers of tasmanitids and crassosphaerids a feature which has been encountered in earlier studies within or near the base of the Early Toarcian unit x1. A minor influx of Cerebropollenites cf. thiergartii, a reduction in numbers of the small, sphaeroidal ?algal bodies seen above, together with the presence of dinocysts tentatively attributed to Luehndea spinosa and Pareodinia "fusiformis" does, however, tentatively suggest that pre-Toarcian sediments have been penetrated.

ENVIRONMENT

Conditions are thought to be similar to those of the Toarcian, with deposition occurring in an inner shelf environment.

INTERVAL 2600m - 2693m; LOWER JURASSIC; CARIXIAN - LATE SINEMURIAN (unit y)

The age assigned to this interval is based on the following:

- the appearance of the ostracode Healdia mouhersensis at 2600m.
- the subsequent occurrence of Isobythocypris unispinata and Pontocyprella elongata.
- the presence of a more varied calcareous benthonic foraminiferal element which includes forms such as Dentalina terquemi, Dentalina cf. matutina and numerous Lenticulina varians.
- the presence of a distinctive lithological marker at 2633m.

LITHOLOGY

Light to medium grey shales are the dominant in situ lithology throughout this interval. Medium-grained, angular sand persists between 2603m - 2624m and white, fine-grained, angular sand becomes important at 2624m. Siderite and pyrite are recorded between 2624m and 2627m. At 2633m abundant, light grey or greenish grey, calcareous chamosite ooliths and coarse, angular, greenish grey sand grains are present. This distinctive lithological horizon frequently occurs in the Carixian - late Sinemurian. Below this horizon medium grey shale, which is slightly micaceous at 2648m, dominates the remainder of the interval, although thin sand beds are indicated at 2650m and 2681m.

MICROPALAEONTOLOGY

The appearance of the ostracode Healdia mouhersensis at 2600m indicates that pre-Domerian deposits have been penetrated, while the subsequent occurrences of Isobythocypris unispinata and Pontocyprella

elongata show that these deposits are Carixian - late Sinemurian in age. Ostracodes are common throughout this interval, with Hungarella and Healdia being the dominant forms.

The number and variety of calcareous benthonic foraminifera increase through the interval, with Lenticulina varians becoming an especially prominent element of the microfauna. This and the appearance of forms such as Dentalina terquemi and Dentalina cf. matutina, provide further evidence of a Carixian - late Sinemurian age. The remains of macrofossils are also prominent in the samples and these include bivalves and gastropods, together with ophiuroid and echinoid debris.

PALYNOLOGY

The palynomorph assemblages recovered from the five cuttings samples analysed from this interval are in many respects similar to those recovered from the overlying unit. In view of the microfaunal evidence, many of the recovered elements, particularly the occurrence of common Nannoceratopsis gracilis seen in all of the samples, must be interpreted as cavings. The occurrence of isolated fragmentary dinocysts tentatively attributed to such Liassic taxa as Pareodinia "fusiformis" and Polysphaeridium does, however, suggest a late Sinemurian or younger age. Chasmatosporites, Osmundacidites/ Baculatisporites and Cerebropollenites cf. thiergartii figure prominently over this interval, but as such they only afford evidence of a general "upper" Liassic age.

Recycled striate bisaccate (Permo-Triassic) pollen occur at 2603m and 2668m, while the occurrence of a single miospore tentatively attributed to Kraeuselisporites reissingeri at 2648m may also be due to reworking.

ENVIRONMENT

The large number of ostracodes and macrofossils may indicate slightly shallower conditions than those suggested for the overlying intervals, although overall inner shelf conditions are still indicated.

INTERVAL 2696m - 2762m; LOWER JURASSIC, ?EARLY SINEMURIAN - ?HETTANGIAN (unit ?z)

The age assigned to this interval is based on the following:

- the appearance of the ostracode ?Hungarella cf. hagenowi at 2696m.

LITHOLOGY

Shale, as seen in the previous interval, is the dominant lithology, towards the top of this unit, however, at 2705m there is an influx of sand. The incoming of this sand sequence is thought to mark the penetration of the Statfjord Sand Formation. Core pieces as well as the cuttings have been examined from this interval which consists essentially of white to greenish grey, often fairly coarse-grained, angular sand with subordinate amounts of shale. This shale is light grey, greenish grey or medium dark grey and is sometimes silty and micaceous. Non-calcareous, brownish grey to olive-grey claystone is also present.

MICROPALAEONTOLOGY

The appearance of an ostracode tentatively assigned to Hungarella cf. hagenowi suggests that early Sinemurian to Hettangian sediments may have been penetrated. In the light of this and the similarly inconclusive evidence supplied by palynology a ?early Sinemurian - ?Hettangian age has been assigned to this unit.

The cuttings samples above the cored interval are rich in ostracodes and foraminifera represented mainly by Hungarella sp. B APOSTOLESCU and Lenticulina varians respectively. Samples analysed from cores 9 - 15 were barren of any diagnostic foraminifera or ostracodes.

PALYNOLOGY

The highest sample analysed from this interval, the cuttings sample at 2705m yielded a palynofloral assemblage of general Lower Jurassic aspect

which includes common (and presumably caved) Nannoceratopsis gracilis. A similar assemblage, again presumably considerably modified by caving, was recovered from the cuttings sample at 2831m.

In marked contrast to the cuttings samples above and below, the core samples analysed from the interval 2715.7m to 2826.2m are devoid of Nannoceratopsis gracilis - a feature which clearly reflects a pre-Domerian Lower Jurassic (Polysphaeridium langii Zone) age. On negative criteria the absence of such taxa as Pareodinia "fusiformis" may furthermore indicate a pre-late Sinemurian age. The in situ miospores recovered from the majority of core samples may only be used to infer a general early - middle Liassic age.

A particularly rich and diverse miospore assemblage was, however, recovered at 2739.8m. Osmundacidites/Baculatisporites, Cerebropollenites cf. thiergartii and forms comparable with Neoraistrickia cf. taylorii figure prominantly in association with such structurally simple microplankton as leiospheres and Mendicodinium spp. Abundances of Osmundacidites/ Baculatisporites and Cerebropollenites cf. thiergartii are known to figure prominently in sediments of unit z age, but additional and more conclusive palynological evidence as to the age of the sediments is lacking. The influx of miospores at this level may, however, be of local correlative value.

ENVIRONMENT

Inner shelf conditions are indicated for the section above the cored interval, while shallower, inner shelf to marginal marine or fluviatile conditions are suggested for the deposition of the more sandy lithologies of the core.

VII

INDETERMINATE

INTERVAL 2764m - 3100m; INDETERMINATE, (? TRIASSIC)

The identification of this interval is based on the following:

- the first appearance of red shales in the core sample at 2764m.
- the decline in the numbers of palynomorphs below this depth.

LITHOLOGY

Reddish brown shale is first seen at 2764m, and represents the dominant lithology below approximately 2825m.

In the upper part of the interval down to 2825m coarse sand, as seen in the overlying unit, continues to occur together with non-calcareous argillaceous siltstones, pink or greenish grey limestones and very fine grained sandstones.

Below this depth red-brown to purple non-calcareous shales dominate the lithology, but subordinate light grey, yellowish, light olive grey, greenish grey and variegated shales are also common. White or light grey sand is present between 2845m - 2885m, and in the ditch cuttings samples is often coarse grained. Yellowish brown sphaerosiderite occurs at 2891m and 2906m.

There is a lithological change at 2951m with the incoming of white, angular, medium and coarse grained sands in association with red brown, often micaceous shales. Below approximately 2981m red brown claystone is dominant and only subordinate amounts of white angular sand, light grey claystone and, at 3059m, soft, white anhydrite, occur. However, at 3092m small amounts of limestone are present.

The appearance of reddish shales may indicate that Triassic deposits have been penetrated, but as red shales can also occur in the Lias, and since conclusive fossil evidence is lacking an indeterminate, (? Triassic) age has been assigned to this unit.

MICROPALAEONTOLOGY

The core samples analysed from this unit failed to yield any diagnostic foraminifera while the cuttings contained only caved forms.

PALYNOLOGY

A decline in the number of palynomorphs yielded by the samples is noted in this unit which may possibly reflect a stratigraphic break, although no pre-Jurassic restricted palynomorphs were recovered.

The cuttings samples yielded a mixture of presumably caved elements, predominantly Lower Jurassic, although occasional Cretaceous forms were also encountered. The core samples yielded little in the way of structured palynomorphs. The few forms that were encountered are too poorly preserved to be of any taxonomic or stratigraphic value.

ENVIRONMENT

A terrestrial/fluviatile environment is suggested for that part of the interval dominated by red beds (below 2825m). Above this environmental determinations are more questionable and transitional conditions from terrestrial/fluviatile to sublittoral are indicated.

VIII

PALAEOENVIRONMENTAL SUMMARY

The oldest sediments penetrated in this well are of indeterminate (?Triassic) age, and consist of a sequence of terrestrial/fluviatile red shales and poorly sorted sandstones.

A transitional period with conditions ranging from terrestrial to inner shelf, is envisaged across the boundary between the indeterminate (?Triassic) unit and the overlying Lower Jurassic, ?Hettangian - ?early Sinemurian strata.

The Lower Jurassic above this consists of a thick sequence of sandy grey shales, ranging in age from ?Hettangian - ?early Sinemurian up to late Toarcian (units ?z-w). These were laid down in a shallow marine, inner shelf environment probably subject to minor regressive and transgressive phases.

The Lower Jurassic is overlain by a sequence of marginal marine and deltaic sand deposits of Middle Jurassic, early Bajocian - ?Bathonian (units v2-?t) age, i.e. the Brent Sand Formation.

Marked stratigraphical hiatuses exist between the Middle Jurassic and overlying thin Lower Cretaceous, and between the Lower Cretaceous and overlying Upper Cretaceous.

The Lower Cretaceous is represented by a white, chalky Barremian limestone laid down in an inner to outer shelf environment.

The overlying Upper Cretaceous is represented by deepwater grey shales of late? Santonian - early Campanian age, deposited in an outer shelf to bathyal environment. The rest of this and the overlying intervals up to the late Maastrichtian also consist of a sequence of grey shales, but are thought to have been deposited in a gradually shallowing outer shelf environment.

The absence of Danian sediments suggests a stratigraphical hiatus between the Upper Cretaceous and overlying Palaeocene strata.

A thick sequence of grey-green clays and shales of Palaeocene to

Eocene age was then deposited in a deep, outer shelf to bathyal environment. The Palaeocene is also characterised by the occurrence of volcanic lithotypes.

Grey green clays deposited in an outer shelf to bathyal environment continue into the Oligocene, but are replaced in the upper part of this interval by light brown clays containing coarse sand and glauconite horizons. These were deposited in a shallower, general shelf environment, though mainly of outer shelf depths.

Light grey - light brown sandy and micaceous clays with occasional igneous fragments, dominate the Miocene and Pliocene and represent the youngest strata examined in this well. An inner - outer shelf environment existed throughout the Lower and Middle Miocene, but gave way to shallower - inner shelf conditions during the Upper Miocene and Pliocene.

IX

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APPENDIX 1

CORE DEPTHS

Drilling depths employed in this report for cores 1 - 16 are uncorrected, those for cores 17 - 23 are based on corrected data (received 20/1/78). A list of these is given below.

Core No.	Drilling Depths KB Metres
1	2402.7-2421.0
2	2421.0-2433.0
3	2433.0-2435.0
4	2435.0-2444.0
5	2444.0-2457.0
6	2457.0-2471.0
7	2471.0-2489.3
8	2489.3-2506.5
9	2707.7-2711.0
10	2711.0-2721.0
11	2721.0-2729.0
12	2729.0-2743.5
13	2743.5-2757.3
14	2757.3-2763.0
15	2763.0-2775.3
16	2775.3-2781.7
17	2793.0-2807.5
18	2807.5-2818.4
19	2818.4-2826.2
20	2826.2-2837.5
21	2837.5-2853.5
22	2853.5-2866.0
23	2866.0-2876.5

APPENDIX 2

Core Piece Descriptions

Depth in metres	Core No.	Type of Analysis		Description
2404.5	1	M	P	SANDSTONE: Soft, friable, greenish black, mainly medium grained, with fine, very fine and silt grains, occasional coarse grains, mainly angular to sub-rounded, with slightly frosted surfaces, argillaceous, slightly pyritic, oil odour.
2406.2	1		P	SANDSTONE: as 2404.5m, good visible porosity.
2410.2	1		P	SANDSTONE: as 2404.5m.
2417.2	1	M	P	SANDSTONE: soft, friable, light olive grey, poorly sorted, fine medium and coarse grained, angular to rarely well rounded, matrix weakly calcareous.
2422.2	2	M	P	SHALE: Waxy, brittle, greyish black, non-calcareous, and SILTSTONE. Firm, medium dark grey, very micaceous, slightly carbonaceous.
2424	2	M		SHALE: as 2422.2
2424.8	2		P	COAL: Brittle, black.
2426.2	2	M	P	SANDSTONE: Fairly friable, light olive grey to yellowish brown, fine to very fine grained, micaceous, with waxy olive grey SHALE laminae, ?flaser bedded.

Depth in metres	Core No.	Type of Analysis		Description
2431.0	2		P	SHALE: Brittle, waxy, olive-grey to brownish black, with black brittle coal laminae.
2431.2	2	M	P	SHALE: as 2431.
2432.8	2	M		SHALE: Brittle, waxy, brownish grey to medium dark grey.
2433.0	3	M		SHALE: Firm, olive-grey to brownish grey, micaceous, and SHALE soft, waxy, olive black to brownish black.
2435.5	4	M	P	SHALE: as 2432.8m.
2436.0	4	M		SHALE: Brittle waxy, olive grey.
2437.5	4	M	P	SHALE: as 2432.8m.
2441.5	4	M	P	SHALE: as 2432.8m.
2444.0	4	M	P	SHALE: as 2432.8m, micaceous.
2462.0	6	M	P	SANDSTONE: Friable, light yellowish brown, poorly sorted, very coarse, coarse, medium and fine grained, angular to sub-rounded, micaceous, with good visible porosity; also fine grained, angular, argillaceous, micaceous, sandstone.
2478.5	7		P	SANDSTONE: Friable, soft, fine grained, highly micaceous, with carbonaceous debris, and SHALE Firm, dark grey, to olive brown highly micaceous with carbonaceous debris, well stratified, grading towards coal.

Depth in metres	Core No.	Type of Analysis		Description
2482.7	7	M		SANDSTONE: Friable, light yellowish grey, to light olive grey, fine grained, micaceous, with thin dark grey shale streaks.
2485.3	7	M		SANDSTONE: Friable, dark olive grey, fine grained, micaceous, with dark olive grey shale streaks.
2488.4	7	M		SANDSTONE: Friable, dark yellowish brown, fine grained, angular, micaceous, argillaceous.
2489.3	7	M	P	SHALE: Fissile, dark grey, very highly micaceous.
2489.4	8	M		SHALE: as 2489.3
2491.0	8	M		SHALE: Firm, dark grey, micaceous, non-calcareous.
2491.5	8	M		SHALE: Firm, brownish black, slightly waxy, micaceous, non-calcareous.
2492.5	8	M		SHALE: Firm, medium dark grey, micaceous, non-calcareous.
2495.0	8	M		SHALE: as 2492.5, with light grey patch.
2499.0	8	M	P	SHALE: as 2492.5m.
2500.5	8	M		SHALE: as 2492.5, with carbonaceous debris.
2504.0	8	M		SHALE: as 2492.5m.
2505.0	8	M		SHALE: as 2492.5m.

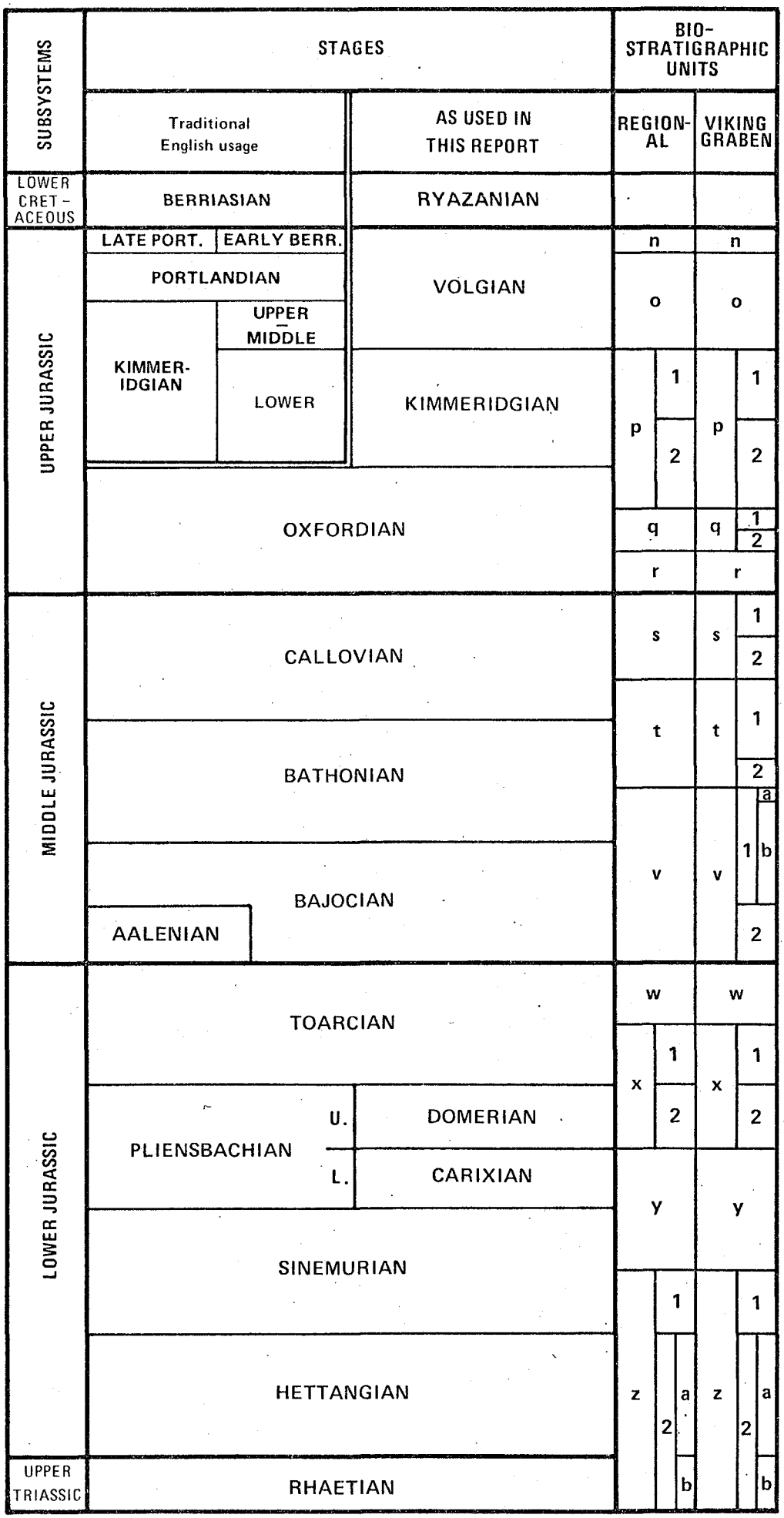
Depth in metres	Core No.	Type of Analysis		Description
2506.0	8	M		SHALE: as 2492.5m.
2506.5	8	M	P	SHALE: as 2492.5m.
2715.7	10		P	SANDSTONE: Hard, light grey, poorly sorted, mainly fine and medium, with light grey silty SHALE laminae, common carbonised plant impressions.
2716.3	10	M		SHALE: Fairly fissile, medium light grey to light olive grey, silty, micaceous, slightly carbonaceous, non-calcareous.
2723.5	11	M		SHALE: Fairly massive, medium light grey, mottled dark yellowish brown, slightly micaceous, non-calcareous.
2727.0	11		P	CLAYSTONE: Firm, brownish grey to olive grey, non-calcareous, with scattered sand grains.
2739.8/9	12		P	SHALE: Very fissile, medium grey to olive grey, to medium dark grey, locally carbonaceous.
2741.5	12	M		SHALE: Fairly fissile, medium dark grey, highly micaceous, slightly silty, non-calcareous.
2743.5	13		P	SHALE: Firm, fairly massive, dark grey, non-calcareous.
2757.5	14		P	SHALE/CLAYSTONE: Firm, massive, brownish grey, non-calcareous.
2769.5	15		P	SANDSTONE: Fairly firm, well cemented, light greenish grey, fine grained, angular, highly micaceous.

Depth in metres	Core No.	Type of Analysis		Description
2777.3	16	M	P	ARGILLACEOUS SILTSTONE: Firm, light olive grey, micaceous, non-calcareous.
2780.5	16		P	SHALE: Fissile, to earthy, dark reddish brown to purplish, slightly sandy, non-calcareous.
2798.5	17		P	SHALE: Fissile, medium grey, very slightly micaceous, non-calcareous.
2800.5	17	M		SHALE: Firm, light grey to olive-grey, micaceous, non-calcareous.
2813.4	18		P	SANDSTONE: Firm, light green grey, fine-grained, angular, micaceous, argillaceous.
2813.9	18	M		SHALE: Firm, medium dark grey, silty, micaceous, non-calcareous.
2815.5	18	M		SHALE: Firm, earthy, greyish red to reddish brown, very slightly micaceous, non-calcareous.
2823.2	19	M		ARGILLACEOUS SANDSTONE: Firm, brownish grey to purplish, medium to fine grained, sub-angular to sub-rounded, very weakly calcareous.
2826.2.	20		P	LIMESTONE: Hard, light grey, yellowish grey, to pale yellowish brown, mottled, crystalline patches.
2827.2	20	M		SHALE: Firm to earthy, brownish grey, with scattered coarse, sometimes well rounded, red stained sand grains, non-calcareous.

Depth in metres	Core No.	Type of Analysis	Description
2830.7	20	M	SANDSTONE: Fairly friable, light olive-grey to olive-grey, very poorly sorted, fine to coarse grained, angular to sub-angular, micaceous, argillaceous, non-calcareous.
2833.7	20	P	SHALE: Firm, greyish green to locally pale red, non-calcareous.
2839.0	21	M	CLAYSTONE: Firm, greyish red to reddish brown, slightly sandy and micaceous, non-calcareous.
2845.5	21	M	SHALE/CLAYSTONE: Firm, greyish red to reddish brown.
2847.0	21	P	SHALE: Fairly fissile, light greyish green, very micaceous, slightly silty, non-calcareous.
2852.5	21	M	SHALE/CLAYSTONE: Firm, waxy, medium dark grey, non-calcarous.
2857.5	22	P	SHALE: Fairly firm, greenish grey with dark green patches, slightly micaceous, non-calcareous.
2871.0	23	P	SANDSTONE: Moderately friable, white to light greenish grey, fine grained, angular, micaceous, non-calcareous.
2874.0	23	M	SHALE: Firm to earthy, reddish brown, micaceous, non-calcareous.
2876.0	23	P	SANDSTONE: as 2871m.

Key: M - Micropalaeontology

P - Palynology



THE BIOSTRATIGRAPHIC UNITS OF THE JURASSIC AS ESTABLISHED BY ROBERTSON RESEARCH INTERNATIONAL LIMITED

JAN.1977

APPENDIX 4 NORIAN – BARREMIAN DINOCYST ZONES
(In part from Riley, 1977)

GEOLOGICAL AGE		"STANDARD" AMMONITE ZONES	SPEETON CLAY LITHO-UNITS	DINOCYST ZONATION	
				ZONE	SUBZONE
BARREMIAN	L		UPPER B	SIRMIODINIUM GROSSI I	ASTROCYSTA CRETACEA IA
	M		CEMENT BEDS		DOIDYX ANAPHRISSA IB
	EARLY		LB1 LB2 LB3 LB4 LB5 A-D		KLEITHRIASPHAERIDIUM CORRUGATUM IC
HAUTERIVIAN	LATE	SIMBIRSKITES BEDS	LB5 E LB6 C1 C2 C3 C4 C5 C6 C7	SUBTILISPHAERA TERRULA II	ADNATOSPHAERIDIUM VETUSCULUM IIA
					CANNINGIA cf. RETICULATA IIB
				OLIGOSPHAERIDIUM NANNUM III	CHLAMYDOPHORELLA TRABECULOSA IIIA
	EARLY	ENDEMOCERAS BEDS	C8 C9 C10 C11 D1 D2 A-D		KLEITHRIASPHAERIDIUM SIMPLICISPINUM IIIB
VALANGINIAN	L		BASAL D2 D	PHOBEROCYSTA NEOCOMICA IV	MUDERONGIA EXTENSIVA IVA
	E		D2 E D3 D4 D5		TUBOTUBERELLA APATELA IVB
					ENDOSCRINIUM PHARO IVC
RYAZANIAN	L	ALBIDUM STENOMPHALUS	D6 - D7 A-E	DINGODINIUM SPINOSUM V	? PROLIXOSPHAERIDIUM TORYNUM VA
		ICENII			DICHADOGONYAULAX SPP. VB
	E	KOCHTI RUNCTONI			CANNOSPHAEROPSIS SP. A. VC
VOLGIAN	L	LAMPLUGHI PERICOMPHALUS PRIMITIVUS OPPRESSUS		IMBATODINIUM VILLOSUM VI	EGMONTODINIUM SP. A VIA
					unnamed subzone VIB
	M	GIGANTEUS GOREI ALBANI EPIPALLASICERAS SP. ROTUNDA SP. PALLASIOIDES PAVLOVIA SP.		MUDERONGIA SIMPLEX VII	DICHADOGONYAULAX PANNEA VIIA
					DICHADOGONYAULAX CULMULA VIIB
					GLOSSODINIUM DIMORPHUM VIIC
				PAREODINIA MUTABILIS VIII	GONYAULACYSTA PENNATA VIIIA
					GONYAULACYSTA JURASSICA VIIIB
	E	PECTINATUS HUDLESTONI WHEATLEYENSIS SCITULUS ELEGANS		GONYAULACYSTA LONGICORNIS IX	EGMONTODINIUM POLYPLACOPHORUM IXA
					FROMEA WARLINGHAMENSIS IXB
KIMMERIDGIAN		AUTISSIODORENSIS EUDOXUS MUTABILIS CYMODOCE		GONYAULACYSTA CLADOPHORA X	
		BAYLEI		SCRINIODINIUM CRYSTALLINUM XI	LEPTODINIUM EGEMENII XIA
					STEPHANELYTRON REDCLIFFENSE XIB
OXFORDIAN	LATE	PSEUDOCORDATA DECIPIENS CAUTISINGRAE TRANSVERSARIUM PLICATILIS	?	SCRINIODINIUM GALERITUM XII	
				ACANTHAULAX SPINOSISSIMA XIII	
	E	CORDATUM MARIAE		WANAEA DIGITATA XIV	GONYAULACYSTA SCARBURGHENSIS XIVA
					WANAEA FIMBRIATA XIVB
CALLOVIAN	L	LAMBERTI ATHLETA			MENDICODINIUM "EGALITUM" XIVC
	M	CORONATUM JASON		POLYSTEPHANEPHORUS PARACALATHUS XV	KALYPTEA STEGASTA XVA
					NANNOCERATOPSIS PELLUCIDA XVB
	E	CALLOVIENSE MACROCEPHALUS			DICHADOGONYAULAX GOCHTI XVIA
BATHONIAN		DISCUS ASPIDOIDES RETROCOSTATUM MORRISI SUBCONTRACTUS PROGRACILIS ZIGZAG		PAREODINIA CERATOPHORA XVI	WANAEA ACOLLARIS XVIB
			?		GONYAULCYSTA FILAPICATA XVIC
BAJOCIAN	L	PARKINSONI GARANTIANA SUBFURCATUM		NANNOCERATOPSIS SPICULATA XVII	
	M	HUMPHRIESIANUM SOWERBYI			
	E	CONCAVUM MURCHISONAE SCISSUM OPALINUM		NANNOCERATOPSIS GRACILIS XVIII	POLYSPHAERIDIUM DEFLANDREI XVIIIA
TOARCIAN		LEVESQUEI THOUARSENSE VARIABILIS BIERONS FALCIFERUM TENUICOSTATUM			unnamed subzone XVIIIB
					SPHAEROMORPHS / SPHERIPOLLENITES XVIIIC
PLIENSBACHIAN	L	SPINATUM MARGARITATUS			LUEHNDEA SPINOSA XVIIID
	E	DAVOEI IBEX JAMESONI		POLYSPHAERIDIUM LANGII XIX	unnamed subzone XIXA
SINEMURIAN	L	RARICOSTATUM OXYNOTUM OBTUSUM			PAREODINIA 'FUSIFORMIS' XIXB
	E	TURNERI SEMICOSTATUM BUCKLANDI			unnamed subzone XIXC
HETTANGIAN		ANGULATA LIASICUS PLANORBIS	?		DAPCODINIUM PRISCUM XIXD
RHAETIAN ?				RHAETOGONYAULAX RHAETICA XX	CLEISTOSPHAERIDIUM MOJSISOVICSII XXA
NORIAN	L	SUESSI			SVERDRUPIELLA SPP. XXB
	M	COLUMBIANUS RUTHERFORDI MAGNUS			unnamed subzone XXC
	E	DAWSONI KERRI			