

RSG Project 97/50

Onsite biostratigraphic analysis of five boreholes from the Irish Rockall Trough



Prepared for

RSG Group

By

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1. INTRODUCTION

1.1 PROJECT SCOPE

During July 1999, five deep boreholes were drilled on the margins of the Irish Rockall Trough on behalf of the Rockall Studies Group. The British Geological Survey undertook the coring of these boreholes, while Millennia Ltd. provided an onboard palaeontologist to assist in the determination of the base Tertiary unconformity and to provide stratigraphic control through the underlying Mesozoic sequences at each site. This report provides a summary of the micropalaeontological data generated.

A full list of the samples studied at each location is presented in Appendices A to D.

The following personnel carried out sample analyses at wellsite and data interpretation:

J. Jacovides - wellsite micropalaeontology and project co-ordination.

1.2 REPORT FORMAT

Section 2 provides a summary of the stratigraphy encountered at each site, while the summarised stratigraphic succession for each site is detailed in Section 3. A full discussion of the biostratigraphic results obtained is given in Sections 4 - 8.

The interpreted stratigraphy and fossil occurrence data are detailed in enclosures 1 to 5.

A number of figures (1-10) are included in support of the report text and enclosures. Figure 1 (generated by Martyn Stoker of the BGS) summarises the stratigraphy encountered at each site. Figures 2 – 5 summarise the stratigraphy of Sites 3A, 2 and 1 as reported at wellsite. Note that no summary was prepared for Site 1A. Figures 6 – 10 represent the biozonation schemes referred to in the text.

1.3 DEPTH CONVENTION

Throughout the report, depths for the core samples are recorded to two decimal places.

1.4 GENERAL COMMENTS AND RECOMMENDATIONS

Microfaunal recovery throughout the Neogene, Palaeogene and Upper Cretaceous is of exceedingly high abundance and moderate to high diversity. Due to operational constraints only a limited amount of time could be given to the picking and logging of each sample. It is recommended that any further requirements for micropalaeontology studies be undertaken as a research project.

The following recommendations for future work are made:

Site 3: 11/20-Sb1

1. Undertake detailed thin section (5 samples) and palynological work to establish the presence of Palaeogene strata.

Site 2: 16/28-Sb1

1. Concentrate nannofossil (20 samples) and palynological analyses over Palaeogene and Cretaceous sections.

Site 1A: 83/20-Sb1

1. Concentrate nannofossil analysis (30 samples) over the Neogene, Palaeogene and Cretaceous sections where current microfaunal analyses have yielded good assemblages.
2. Utilise palynological analyses over the Palaeogene, Cretaceous and lowermost indeterminate sequences.

Site 1: 83/24-Sb1

1. Undertake detailed nannofossil analysis (10 samples) within the Eocene sequence.

Site 1: 83/24-Sb2

1. Undertake detailed nannofossil analysis (15 samples) within the Eocene and Cretaceous sequence.
2. Undertake palynology throughout the Mesozoic sequence.

2. SUMMARY

The aim of the boreholes was to test the age and lithologies encountered below the Tertiary unconformity on the Erris Ridge (Sites 3 and 2) and within the Brona Basin (Sites 1A and 1). In general, at each location, microfaunal recovery was exceptional in the Neogene and Palaeogene clays, muds and micritic limestones. Similarly, there was good microfaunal recovery and diversity in the Upper Cretaceous (Maastrichtian and Campanian) marls. In two of the boreholes (83/20-Sb01 and 83/24-Sb02) potentially older Mesozoic (?Jurassic) sediments were penetrated. After completion of the borehole programme, several samples were selected for palynology. The data from these results, which prove the presence of Upper Jurassic strata, appear as footnotes within this report.

2.1 Site 3 - 11/20-Sb01

A thin cover of Upper Pliocene mud was encountered down to 8m bsb. The sample analysed yielded a superabundant planktonic foraminiferal assemblage restricted to the N21 zone. The boundary with the underlying lithic/crystal tuff sequence represents a major unconformity, as there is some limited foraminiferal evidence to suggest a tentative Palaeogene age for this sequence.

2.2 Site 2 - 16/28-Sb01

The objective of this borehole was an unconformity estimated at 168m at the base of the Tertiary. After sampling thin Pliocene and thick Eocene sediments, this boundary was actually penetrated at 149.5m, and proved the presence of very thin Upper Cretaceous (Late Maastrichtian) marl. By comparison with the 83/20-Sb01 and 83/24-Sb02 boreholes, this unit is considered to rest unconformably on a thin coarse sandstone sequence, tentatively regarded as earliest Late Cretaceous in age. This unit was penetrated immediately overlying basalts of unknown age.

2.3 Site 1A - 83/20-Sb01

A thick Neogene sequence, considered to represent predominantly Miocene (Upper - Middle) sediments, is encountered between 35.73m and 86.10m. There is no evidence for the presence of Palaeogene strata in the samples studied and a major unconformity marks the boundary with the underlying Mesozoic sequence at 86.22m. The marls encountered between 86.22m and 102.87m yielded rich microfaunal assemblages, which represent Maastrichtian to Upper Campanian deposits and directly overlie glauconite rich sandstones, which ranges in age from Campanian or older (at 107.53m) to Cenomanian (131.11m). Microfaunal recovery through this latter unit was variable. The samples at 131.28m and 131.40m are tentatively assigned an undifferentiated Late Cretaceous age, the deeper comprising an ostracod assemblage similar to that observed at 147.17m in the 16/28-Sb01 borehole. Biostratigraphic resolution below 131.40m is poor with only the sample at 142.00m yielding a reasonable, but poorly preserved microfauna, which is considered to Middle Cretaceous (Cenomanian - Albion) in aspect. A tentative Cretaceous age can be inferred as deep as 161.33m but the nine samples studied below, between 166.50m and 177.40m proved to be barren and are of indeterminate age. Two samples were subsequently analysed for palynology. The sample at 177.26m yielded a palynomorph assemblage indicative of a Late Jurassic (Late Kimmeridgian) age, while the sample at 176.48m proved to be barren.

2.4 Site 1 - 83/24-Sb01

The first borehole drilled at Site 1 penetrated a 19.45m thick Neogene sequence, ranging in age from Pleistocene to Late Pliocene, resting unconformably on Palaeogene sediments of earliest Middle Eocene age. Due to bad weather conditions the borehole had to be terminated at 30.80m in Lower Eocene calcareous clays.

2.5 Site 1 - 83/24-Sb02

The second borehole drilled at Site 1 penetrated a similar Neogene and Palaeogene sequence. The oldest Palaeogene sediments recorded were Early Eocene in age and resting unconformably on Upper Cretaceous ferruginous limestones. Microfaunal recovery and preservation in this latter sequence was limited and age determination poor. There is a major lithological break at 63.30m, with the penetration red clay. The sample analysed at 67.80m yielded a very poorly preserved (? non-marine) ostracod fauna either Early Cretaceous or Late Jurassic in aspect. The succeeding six samples analysed between 69.21m and 71.49m (T.D. depth) proved to be barren for microfauna. However, The sample at 71.23m was subsequently selected for palynological analysis and yielded a palynomorph assemblage indicative of a Late Jurassic (Early Portlandian - Kimmeridgian) age. Mass reworking was also observed, primarily of Late Carboniferous age.

3. SUMMARIZED STRATIGRAPHIC SUCCESSIONS

3.1 Site 3A

Borehole: 11/20-Sb01

Interval / top Age	
7.66m	Late Pliocene
-----	Unconformity -----
8.18m - 19.10m	?Palaeogene

3.2 Site 2

Borehole: 16/28-Sb01

Interval / top Age	
12.78m - 13.80m	Pleistocene - Late Pliocene
-----	Unconformity -----
14.50m - 44.00m	Middle Eocene
53.99m - 137.92m	Early Eocene
138.00m - 145.66m	Late Palaeocene
145.95m	Palaeocene (undiff.)
-----	Unconformity -----
146.00m	Late Maastrichtian
-----	Unconformity -----
147.17m - 147.23m	Late Cretaceous (undiff.)
147.30m	Sample not analysed

3.3 Site 1A

Borehole: 83/20-Sb01

Interval / top Age	
35.73m	?Pliocene
37.00m - 66.81m	Late - Middle Miocene

Interval / top Age	
86.10m	Middle Miocene
-----	Unconformity -----
86.22m - 100.00m	Maastrichtian
102.87m	Maastrichtian - Late Campanian
-----	?minor Unconformity -----
103.00m	Late Cretaceous (undiff.)
107.53m	Campanian or older
107.70m	Early Santonian or older
117.78m - 127.86m	Middle Turonian - Late Cenomanian
131.11m	Middle Cenomanian
131.28m - 138.00m	Late Cretaceous (undiff.)
142.0	Cenomanian - Albian
146.80m - 156.50	Indeterminate
161.33m	?no older than Early Cretaceous
166.50m - 177.40m	Indeterminate ¹

3.4 Site 1

Borehole: 83/24-Sb01

Interval / top Age	
9.30m - 19.18m	Pleistocene - Late Pliocene
19.38m	Late Pliocene
-----	Unconformity -----
19.50m - 20.00m	Earliest Middle Eocene
27.50m - 30.80	Early Eocene

¹ Two samples were selected for palynological analysis post drilling. The analysis, undertaken by Ken Higgs, indicates that the deeper sample of the two, at 177.26m yielded a palynoflora in which the presence of the dinocyst *Gochteodinia mutabilis* indicates that the assemblage is Late Jurassic in age, within the Upper Kimmeridgian interval. The shallower sample, at 176.48m proved to be barren.

3.5 Site 1

Borehole: 83/20-Sb02

Interval / top Age	
19.93m	Late Pliocene
-----	Unconformity -----
20.28m - 23.32m	Earliest Middle Eocene
30.75m - 38.10m	Early Eocene
-----	Unconformity -----
?Depth uncertain	Maastrichtian ²
-----	Unconformity -----
38.20m	?Late Cretaceous (undiff.)
38.82m - 40.60m	Indeterminate
45.41m	?Middle Cretaceous (undiff.)
58.90m - 63.20m	Indeterminate
-----	Unconformity -----
63.30m - 67.80m	?Late Jurassic
69.21m - 71.49m	Indeterminate ³

² Cavings examined at 58.70m yielded a rich and diverse Maastrichtian microfauna, which had not previously sampled in this borehole. It is most likely that this fauna occurs at the unconformity with the overlying Palaeogene sediments, somewhere between 38.10m and 38.13m.

³ Several samples were selected for palynological analysis. The sample at 71.23m, analysed by Ken Higgs, yielded a diverse palynoflora in which most of the dinocysts present are long ranging. However, the presence of *Senoniasphaera jurassica* and *Oligosphaeridium* sp. indicates that the assemblage is Late Jurassic in age, most likely within the range Kimmeridgian to Early Portlandian. Late Carboniferous reworking is also evident.

4. STRATIGRAPHY OF SITE 3A: 11/20-Sb01

4.1 Site 3: 11/20-Sb01.

4.1.1 Sample: 7.66m.

Age: Pliocene.

Microzone(s): N21 or older.

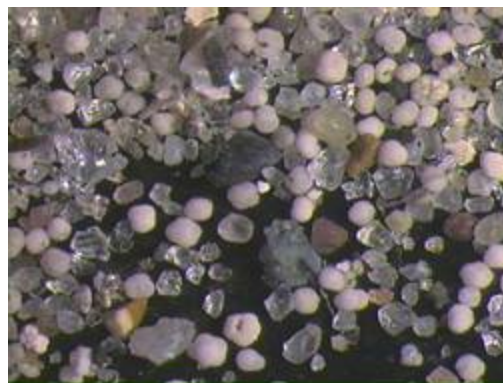
Horizon defined by:

- the presence of abundant *Neogloboquadrina atlantica*.

Micropalaeontological biostratigraphy:

N21 Planktonic foraminiferal

Zone: The sample at 7.66m yielded a rich but low diversity microfauna dominated by planktonic foraminifera. The presence of *Neoglobobulimina atlantica* indicates an age no younger than Pliocene (N21 Foraminiferal Zone). The other planktonic and calcareous benthic taxa recorded, such as *N. pachyderma*, *N. acostaensis*, *Bulimina marginata*, *Cassidulina laevigata* and *Melonis affine*, are longer ranging but consistent with a Pliocene age assignment.



Sample: 7.66m

Palaeoenvironment: Marine, slope/bathyal.

Lithology: Clay, mud, dark grey, soft to firm, sticky, fine sandy laminae.

4.1.2 Interval: 8.18m - 19.18m.

Age: ?Palaeogene.

Microzone(s): Unassigned.

Interval top defined by:

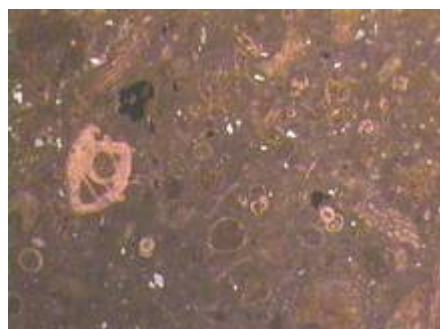
- the presence of sparse ?Palaeogene microfaunas within thin section.

Micropalaeontological biostratigraphy:

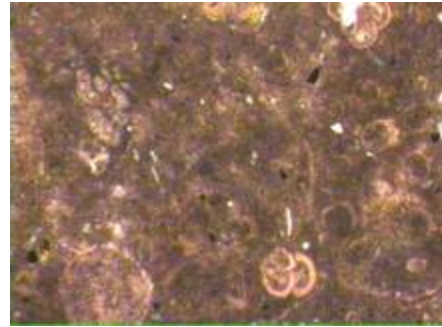
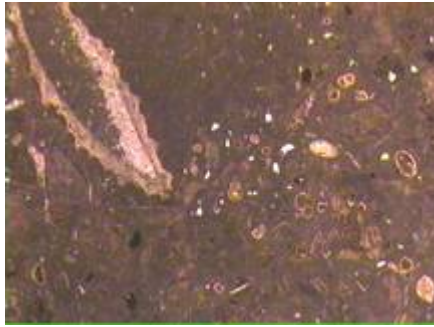
Unassigned Microzone: The samples at 8.18m and 9.45m were examined in thin section. The secondary limestones contained sparse ?Palaeogene planktonic foraminifera (*Turborotalia*) and calcareous benthic forms (*Anomalina*). The tuffs contained isolated specimens of benthic foraminifera and rare bivalves.



Sample: 8.18m (x6)

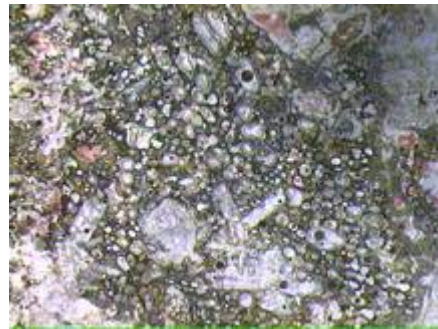


Sample: 9.45m (x15)

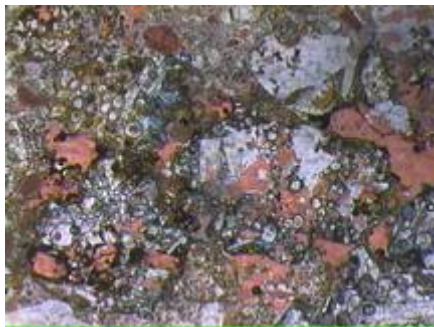


Sample: 9.45m (x13) Sample: 9.45m (x50)

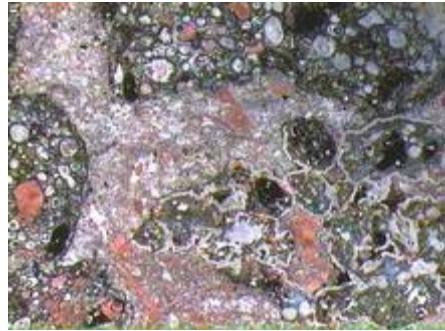
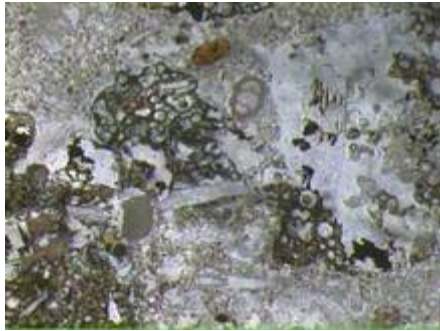
Thin sections were also made of eight core chips between 10.21m and 16.37m. These contained very sparse microfossils including rare ?Palaeogene planktonic and benthic foraminifera. Rare sponge spicules are present at 10.21m. Similar faunas have been recorded from Eocene sediments of the 16/28-Sb01. Rare miliolids were observed at 13.78m and 14.36m. These samples are also assigned an undifferentiated ?Palaeogene age.



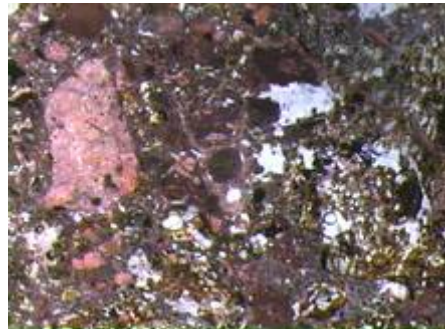
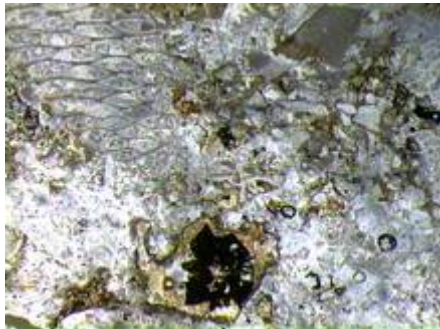
Sample: 10.21m (x20) Sample: 10.25m (x15)



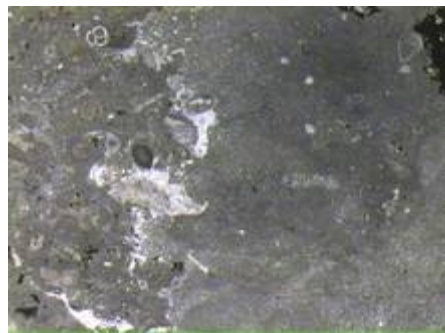
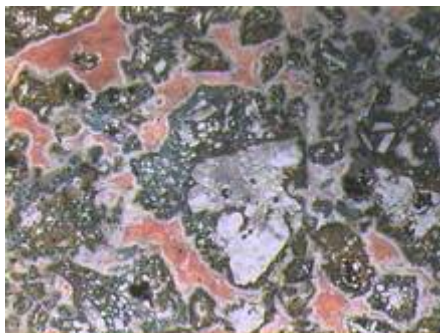
Sample: 11.09m (x18) Sample: 11.98m (x18)



Sample: 11.95m (x26) **Sample: 13.50m (x15)**

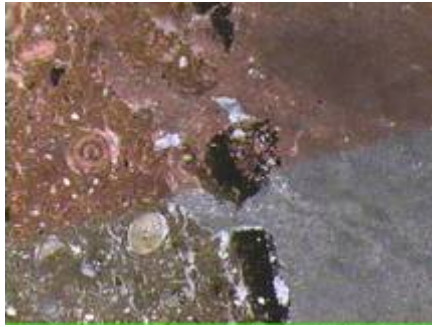


Sample: 13.78m (x25) **Sample: 14.36m (x14)**

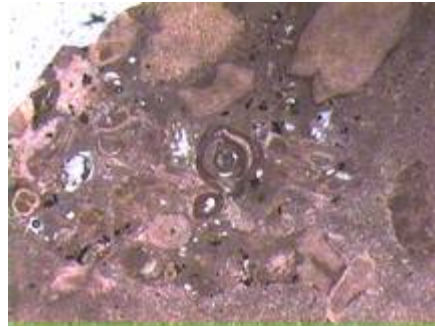


Sample: 16.37m (x12) **Sample**
18.88m (x14)

The thin section examined at 18.88m comprised a number of carbonate clasts containing rare Tertiary planktonic foraminifera and calcareous benthic taxa such as miliolids.



Sample: 18.88m (x14)



Sample: 18.88m (x18)

At 19.18m the core sample taken was less compact and friable. Processed routinely, this sample yielded rare orange-pink stained *Lenticulina* spp., *Textularia* spp., and fish teeth and bryozoan debris.

Palaeoenvironment: Marine, water depth uncertain.

Lithology: Tuffs (see BGS Log for detailed lithological description). Limestone clasts are more evident at 18.88m and 19.18m.

5. STRATIGRAPHY OF SITE 2; 16/28-Sb01

5.1 Site 2, 16/28-Sb01.

5.1.1 Interval: 12.78m - 13.80m.

Age: Pleistocene - Late Pliocene.

Microzone(s): N22 - N21.

Interval top defined by:

- the presence of *Globorotalia truncatulinoides*.

Micropalaeontological biostratigraphy:

N22 - N21 Planktonic Foraminiferal Zones: The samples at 12.78m and 13.80m yielded superabundant microfaunas dominated by planktonic foraminifera. The presence of frequent to common specimens of *Globorotalia truncatulinoides* indicates an age range of Pleistocene - Late Pliocene. The presence of *Bulimina marginata* (12.78m) and superabundant *Globorotalia inflata* is consistent with this age assignment.



Sample: 12.78m



Sample: 13.80m

Palaeoenvironment: Marine, slope/bathyal.

Lithology: Foraminiferal sand, light olive brown - yellowish brown.

5.1.2 Interval: 14.50m - 44.00m.

Age: Middle Eocene.

Microzone(s): P12 - P10.

Interval top defined by:

- the presence of abundant *Hantkenina dutemplei*.

Micropalaeontological biostratigraphy:

P12 - P10 Planktonic Foraminiferal Zones: Superabundant microfaunas dominated by planktonic foraminifera and sponge spicules dominate this interval. The presence abundant *Hantkenina dutemplei*, at 14.50m, indicates a Middle Eocene age. The presence of *Turborotalia cerroazulensis*, *Truncorotaloides rohri* and *Acarinina bullbrooki*, also at this depth, supports this age assignment. Sponge spicules occur in superabundance at 24.70m. Also

present at this depth are rare *Hantkenina dutemplei*, *Hantkenina nuttalli*, frequent *Acarinina broedermanni*, common *Acarinina bullbrooki*, *Turborotalia frontosa*, frequent *Truncorotaloides rohri*, and abundant *Pseudohastigerina wilcoxensis*, all indicating continued assignment to a Middle Eocene age. The subsequent occurrence, at 44.00m of "*Hastigerina*" *bolivariana*, *Truncorotaloides topilensis*, and *Acarinina pentacamerata* indicate Middle - Lower Eocene sediments.



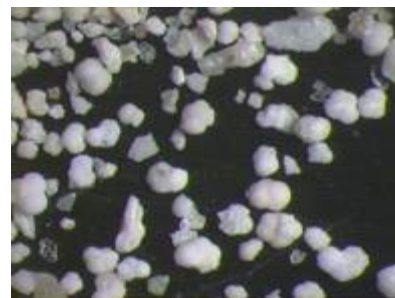
Sample: 14.50m



Sample: 14.50m



Sample: 24.70m



Sample: 44.00m

Palaeoenvironment: Marine, slope/bathyal.

Lithology: Clay, greenish grey, massive, glauconitic with abundant sponge spicules.

5.1.3 Interval: 53.99m - 137.92m.

Age: Early Eocene.

Microzone(s): P9 - P6.

Interval top defined by:

- the presence of *Acarinina soldadoensis* and *Morozovella subbotinae* at 53.99m.

Micropalaeontological biostratigraphy:

P8 - P6 Planktonic Foraminiferal Zones: Superabundant planktonic foraminifera continue to dominate. The presence of *Acarinina soldadoensis* and *Morozovella subbotinae* at 53.99m indicates the penetration of Lower Eocene sediments. There is a major change in the composition of the microfaunal assemblages at 70.79m with the influx of abundant cenosphaerid radiolaria. A further faunal break is noted at 92.00m with the decline in numbers and diversity of planktonic foraminifera, the absence of radiolaria, the greater diversity of calcareous benthic foraminifera, and the dominance of the assemblages by dwarf specimens of calcareous benthic and planktonic foraminifera. The

subsequent influx of small cenosphaerid radiolaria, in superabundance at 129.55m, signifies a further change in faunal composition.

Palaeoenvironment: Marine, slope/bathyal.

Lithology: Clay, dark greenish grey, massive.

5.1.4 Interval: 138.00m - 145.66m.

Age: Late Palaeocene.

Microzone(s): Unassigned.

Interval top defined by:

- the influx of large specimens of cenosphaerid radiolaria at 138.00m.

Micropalaeontological biostratigraphy:

Unassigned interval: The influx of superabundant specimens of large cenosphaerid radiolaria is taken as evidence for penetration of Upper Palaeocene sediments. The presence of common specimens of the planktonic foraminifer *Globigerina triloculinoides* confirms this assignment.

Palaeoenvironment: Marine, slope/bathyal.

Lithology: Clay, dark greenish grey, massive.

5.1.5 Horizon: 145.95m.

Age: Palaeocene (undifferentiated).

Microzone(s): Unassigned.

Horizon characterised by:

- the influx superabundant bryozoan debris at 145.95m.

Micropalaeontological biostratigraphy:

Unassigned sample: The sample at 145.95m yielded superabundant bryozoan debris in association with common *Gavelinella danica*, abundant *Cibicidoides* spp., and abundant poorly preserved *Globigerina* spp. This assemblage is considered to represent an undifferentiated Palaeocene age.

Palaeoenvironment: Marine, shelf.

Lithology: Mudstone, greenish grey.

5.1.6 Horizon: 146.00m.

Age: Late Maastrichtian.

Microzone(s): KM1.

Horizon characterised by:

- the influx of diagnostic Late Cretaceous planktonic foraminifera at. 146.00m.

Micropalaeontological biostratigraphy:

KM1 Microzone: Penetration of Upper Cretaceous, Upper Maastrichtian sediments is evidenced by the presence of the planktonic foraminifera *Abathomphalus mayaroensis* and *Rosita contusa*.

Palaeoenvironment: Marine, shelf.

Lithology: Siltstone, white, calcareous.

Stratigraphic comments: Evidence from the 83/23-Sb01 well suggests that this unit rests unconformably on the underlying sequence with the absence of Upper Cretaceous (Campanian - Cenomanian) sediments (Greensands).

5.1.7 Interval: 147.17m - 147.23m.

Age: Late Cretaceous (undifferentiated).

Microzone(s): Unassigned.

Interval top defined by:

- the influx a sparse microfauna dominated by *Bairdia* spp.

Micropalaeontological biostratigraphy:

Unassigned interval: The sample examined at 147.17m yielded a low diversity, low abundance microfauna dominated by poorly preserved specimens of the ostracod *Bairdia* spp. An undifferentiated Late Cretaceous age is tentatively assigned to this interval.

Palaeoenvironment: Marine, shelf.

Lithology: Sandstone, dark yellow – brown, cU-mL, subangular – subrounded.

Stratigraphic comments: An equivalent unit was observed in the 80/23-Sb01 well, at 138.00m, immediately below Middle Cenomanian sediments.

5.1.8 Horizon: 147.30m.

Basalt was penetrated at 147.30m. The sample was not analysed.

6. STRATIGRAPHY OF SITE 1A: 83/20-Sb01.

6.1 Site 1A: 83/20-Sb01.

6.1.1 Horizon: 35.73m.

Age: ?Pliocene.

Microzone(s): N21 or older.

Horizon characterised by:

- the presence of long ranging planktonic foraminifera including superabundant *Globigerina bulloides*, *Globigerina decoraperta* and *Globorotalia menardii*.

Micropalaeontological biostratigraphy:

N21 or older Planktonic Foraminiferal Zone: The sample at 35.73 yielded a rich microfaunal assemblage dominated by planktonic foraminifera. No short ranging forms are observed. However, the presence of the long ranging Neogene planktonic foraminifera, including superabundant *Globigerina bulloides*, *Globigerina decoraperta* and *Globorotalia menardii* may suggest a Pliocene age assignment. The presence, at this depth, of the calcareous benthic foraminifera *Cibicides lobatulus grossa*, *Siphonina reticulata*, and *Uvigerina peregrina* is consistent with this interpretation.



Sample: 35.73m

Palaeoenvironment: Marine, slope.

Lithology: Clay, greenish grey, sandy, fine-grained.

6.1.2 Interval: 37.00m - 66.81m.

Age: Late - Middle Miocene.

Microzone(s): N17 - N15 or older.

Interval top defined by:

- the presence of *Uvigerina tenuipustulata*, *Plectofrondicularia advena* and *Valvulinaria mexicana*.

Micropalaeontological biostratigraphy:

N17 - N15 Planktonic Foraminiferal Zones: Long ranging Neogene planktonic foraminifera continue to the samples studied in this interval. Calcareous benthic foraminifera also form a significant element of the microfaunal assemblage, and the co-occurrence of *Uvigerina tenuipustulata*, *Plectofrondicularia advena* and *Valvulinaria mexicana*, at 37.00m is considered to signify the penetration of Upper - Middle Miocene sediments. The subsequent sample at 66.52m yielded abundant specimens of the Miocene planktonic form, *Globoquadrina dehiscens*, which would suggest a zonal assignment to the N17 Zone or older.



Sample: 37.00m

Palaeoenvironment: Marine, slope.

Lithology: Clay, greenish grey, sandy, fine-grained.

6.1.3 Horizon: 86.10m.

Age: Middle Miocene.

Microzone(s): N14 or older.

Horizon characterised by:

- the presence of *Globorotalia mayeri* and *Globorotalia contiuousa*.

Micropalaeontological biostratigraphy:

N14 or older Planktonic Foraminiferal Zone: The sample at 86.10m yielded a rich microfaunal assemblage dominated by the presence of the planktonic foraminifera *Globorotalia mayeri* and *Globorotalia contiuousa*. These forms signify assignment to the N14 Zone or older and an age no younger than Middle Miocene.



Sample: 86.10m

Palaeoenvironment: Marine, slope.

Lithology: Silty clay, light greenish grey, sandy, fine-grained.

Stratigraphic comments: Due to the long core run between 67.00m and 86.60m, the exact depth of the unconformity between the Neogene and Cretaceous is uncertain. However, there was a drilling break at 72.00m, that correlates with an unconformity surface on the sparker record at 90msec (TWT), assuming a velocity of 1600m/sec. Thus, the actual depth of the unconformity is most probably at about 72.00m below seabed.

6.1.4 Interval: 86.22m - 100.00m.

Age: Maastrichtian.

Microzone(s): KM1 - KM3.

Interval top defined by:

- the presence of *Rosita fornicata*, *Rosita contusa*, *Globotruncana arca*, and *Globotruncana orientalis*.

Micropalaeontological biostratigraphy:

KM1 – KM3 Microzones: There is a major faunal change at 86.22m with the influx of planktonic and benthic foraminifera indicating the penetration of Upper Cretaceous, Maastrichtian marls. Key forms include the planktonic forms *Rosita fornicata*, *Rosita contusa*, *Globotruncana arca*, and *Globotruncana orientalis*, while diagnostic benthic taxa include *Stensioeina pommerana*, *Reussella szajnochae*, and *Neoflabellina rugosa*. Similar assemblages are recorded at 86.60m, and include in addition the records of *Racemiguembelina fructicosa* and *Bolivina incrassata*. The downhole co-occurrence, at 100.00m, of the agglutinated foraminifer *Vernuilina muensteri* and the calcareous benthic taxon *Bolivinoidea decoratus* signifies an Early Maastrichtian or older age assignment.



Sample: 86.22m



Sample: 86.60m



Sample: 100.00m

Palaeoenvironment: Marine, slope.

Lithology: Marl, pale grey - yellow, massive.

6.1.5 Horizon: 102.87m.

Age: Maastrichtian - Late Campanian.

Microzone(s): KM3 or older.

Horizon characterised by:

- the presence of *Globotruncanella havanensis* and *Globorotalites hiltermanni*.

Micropalaeontological biostratigraphy:

KM3 or older Microzone: A moderately rich and diverse microfaunal assemblage is recorded at 192.87m. The co-occurrence at this depth, of *Globotruncanella havanensis* and *Globorotalites hiltermanni*, is taken to signify an age range of Maastrichtian to Late Campanian.



Sample: 102.87m

Palaeoenvironment: Marine, slope.

Lithology: Marl, pale grey – yellow, massive.

6.1.6 Horizon: 103.00m.

Age: Late Cretaceous (undifferentiated).

Microzone(s): Indeterminate.

Horizon characterised by:

- the absence of microfossils.

Micropalaeontological biostratigraphy:

Indeterminate horizon: There is a major lithological break with the penetration ferruginous and glauconitic sandstones. No microfossils were recovered from the sample analysed at 103.00m.



Sample: 103.00m x6



Sample: 103.00m x9

Palaeoenvironment: Marine, slope.

Lithology: Sandstone, dark brown, cU-fL, poorly sorted, subangular - subrounded, rich in glauconite.

6.1.7 Horizon: 107.53m.

Age: Campanian or older.

Microzone(s): KM6 or older.

Horizon characterised by:

- the presence of *Globorotalites micheliniana*.

Micropalaeontological biostratigraphy:

KM6 or older Microzone: The sample at 107.53m yielded a low diversity, low abundance microfauna characterised by the presence of *Inoceramus* debris and the calcareous benthic foraminifera *Globorotalites micheliniana* suggesting an Campanian or older age assignment.

Palaeoenvironment: Marine, slope.

Lithology: Sandstone, dark brown, cU-fL, poorly sorted, subangular – subrounded, rich in glauconite.

6.1.8 Horizon: 107.70m.

Age: Early Santonian or older.

Microzone(s): KM9 or older.

Horizon characterised by:

- the presence of *Whiteinella paradubia* and *Reussella kelleri*.

Micropalaeontological biostratigraphy:

KM9 or older Microzone: The sample at 107.70m also yielded a low diversity, low abundance microfauna. The co-occurrence of *Whiteinella paradubia* and *Reussella kelleri* is good evidence for an Early Santonian or older age assignment.



Sample: 107.70m

Palaeoenvironment: Marine, slope.

Lithology: Sandstone, dark brown, cU-fL, poorly sorted, subangular - subrounded, rich in glauconite.

6.1.9 Interval: 117.78m - 127.86.

Age: Middle Turonian - Late Cenomanian.

Microzone(s): KM12 - KM14.

Interval top defined by:

- the presence of *Praeglobotruncana gibba*, *Rotalipora ?cushmani*, *Dicarinella hagni*, *Dicarinella imbricata*, *Lingulogavelinella globosa*, and *Gavelinella cenomanica*.

Micropalaeontological biostratigraphy:

KM12 - KM14 Microzones: A rich and diverse microfauna comprising planktonic and benthic foraminifera is recovered at 117.78m. The co-occurrence at this depth of *Praeglobotruncana gibba*, *Rotalipora ?cushmani*, *Dicarinella hagni*, *Dicarinella imbricata*, *Lingulogavelinella globosa*, and *Gavelinella cenomanica* signifies a Middle - Early Turonian age. Similarly rich assemblages occur at 118.00m and 127.86m. Also present at 127.86m is the calcareous benthic form *Gavelinella cenomanica*, which suggests a range into Upper Cenomanian or older strata.



Sample: 117.78m



Sample: 122.80m x12



Sample: 127.86m x26

Palaeoenvironment: Marine, slope.

Lithology: Interbeds of soft, muddy and hard sandstone, dark greenish grey, vfl, poorly sorted, rich in glauconite.

6.1.10 Horizon: 131.11m.

Age: Middle Cenomanian.

Microzone(s): KM15.

Horizon characterised by:

- the presence of *Lingulogavelinella ciryi inflata*.

Micropalaeontological biostratigraphy:

KM15 Microzone: The sample at 131.11m yielded a sparse microfauna. The most significant form recorded is the calcareous benthic taxon *Lingulogavelinella ciryi inflata* indicating a Middle Cenomanian age.



Sample: 131.11m x3

Palaeoenvironment: Marine, slope.

Lithology: Interbeds of soft, muddy and hard sandstone, dark greenish grey, vfl, poorly sorted, rich in glauconite.

6.1.11 Interval: 131.28m - 138.00m.

Age: Late Cretaceous (undifferentiated).

Microzone(s): Unassigned.

Interval top defined by:

- the presence of *Bairdia* spp. at 131.40m.

Micropalaeontological biostratigraphy:

Unassigned Interval: There is a marked decline in microfaunal recovery. The sample at 131.28m is effectively devoid of microfauna, while the sample at 138.00m yielded rare ostracods of the genus *Bairdia*. A similar assemblage was recorded in ?Late Cretaceous sediments in the borehole 16/28Sb1. The remaining samples analysed from this were either barren or lacking in age diagnostic taxa.



Sample: 131.40m x6



Sample: 133.00m x10



Sample: 133.00m x30



Sample: 138.00m x9

Palaeoenvironment: Marine, shelf.

Lithology: Limestone, olive yellow, hard. Sandstone, olive yellow, friable, cU-mL, subangular - subrounded, common brown glauconite.

6.1.12 Horizon: 142.00m.

Age: Cenomanian - Albian.

Microzone(s): Unassigned.

Horizon characterised by:

- the presence of ?*Globigerinelloides bentonensis*

Micropalaeontological biostratigraphy:

Unassigned Microzone: The sample at 142.00m yielded a sparse and very poorly preserved microfaunal assemblage comprising both benthic and planktonic microfossils. The presence of questionable specimens of *Globigerinelloides bentonensis* is considered to indicate the presence of Middle Cretaceous sediments, probably within the range of Cenomanian - Albian.



Sample: 142.00m x15

Palaeoenvironment: Marine, ?middle - outer shelf.

Lithology: Limestone, fine grained, recrystallised, slightly sandy with common green glauconite.

6.1.13 Interval: 146.80m - 156.50m.

Age: Indeterminate.

Microzone(s): Indeterminate.

Interval top defined by:

- the absence of age diagnostic microfossils.

Micropalaeontological biostratigraphy:

Unassigned interval: The samples analysed within this interval were either barren or lacking in age diagnostic forms.



Sample: 146.80m x12



Sample: 150.90m x8



Sample: 156.50m x12

Palaeoenvironment: Marine, shelf.

Lithology: Interbeds of friable or indurated sand, with glauconite and locally common shell fragments.

6.1.14 Horizon: 161.33m.

Age: ?no older than Early Cretaceous.

Microzone(s): Unassigned.

Horizon characterised by:

- the presence of rare ostracods.

Micropalaeontological biostratigraphy:

Unassigned horizon: The sample at 161.33m yielded a sparse microfaunal assemblage dominated by ostracods including *Bairdoppilata* spp., *Cytherella* spp., and *Paracypris* spp. Although long ranging and lacking in age diagnostic forms this assemblage is considered to indicate an age no older than Early Cretaceous.



Sample: 161.33m x6

Palaeoenvironment: Marine, shelf.

Lithology: As above, interbeds of friable or indurated sand, with glauconite and locally common shell fragments

6.1.15 Interval: 166.50m - 177.40m.

Age: Indeterminate.⁴

Microzone(s): Indeterminate.

Interval top defined by:

- the general absence of microfossils.

Micropalaeontological biostratigraphy:

⁴ Two samples were selected for palynological analysis post drilling. The analysis, undertaken by Ken Higgs, indicates that the deeper sample of the two, at 177.26m yielded a palynoflora in which the presence of the dinocyst *Gochteodinia mutabilis* indicates that the assemblage is Late Jurassic in age, within the Upper Kimmeridgian interval. The shallower sample, at 176.48m proved to be barren.

Indeterminate interval: The samples analysed in this interval were generally barren or yielded shell debris.



Sample: 166.50m x6



Sample: 169.70m x9



Sample: 169.90m x8



Sample: 172.00m x9



Sample: 176.29m x11



Sample: 176.48m x10



Sample: 176.78m x9



Sample: 177.35m x14



Sample: 177.40m x9

Palaeoenvironment: Marine, shelf.

Lithology: As above, interbeds of friable or indurated sand, with glauconite and locally common shell fragments. From 169.70m limestone, grey, fossiliferous with corals and shell debris. From 176.29m interbedded mudstone/claystone, grey, laminated, silty, sandy, and sandstone, grey, very fine grained, pyritic.

7. STRATIGRAPHY OF SITE 1: 83/24-Sb01.

7.1 Site 1: 83/24-Sb01.

7.1.1 Interval: 9.30m - 19.18m.

Age: Pleistocene - Late Pliocene.

Microzone(s): N22 - N21.

Interval top defined by:

- the presence of *Globorotalia truncatulinoides*, *Globorotalia inflata* and *Neogloboquadrina pachyderma*.

Micropalaeontological biostratigraphy:

N22 - N21 Planktonic Foraminiferal Zones: The samples between 9.30m and 19.18m are characterised by the superabundance of planktonic foraminifera. The most significant occurrences observed are those of *Globorotalia truncatulinoides*, *Globorotalia inflata* and *Neogloboquadrina pachyderma* signifying an age range of Pleistocene - Late Pliocene. Calcareous benthic foraminifera form a minor element throughout this interval.



Sample: 9.30m x12



Sample: 9.70m x30



Sample: 10.00m x28



Sample: 19.00m x25

Palaeoenvironment: Marine, slope.

Lithology: Clay, light grey, silty. Pale yellow below 19.18m.

7.1.2 Horizon: 19.38m.

Age: Late Pliocene.

Microzone(s): N21.

Horizon characterised by:

- the continued presence of *Globorotalia inflata* and *Neogloboquadrina pachyderma*.

Micropalaeontological biostratigraphy:

N21 Planktonic Foraminiferal Zone: The continued presence of *Globorotalia inflata* (abundant) and *Neogloboquadrina pachyderma* (superabundant) and absence of *Globorotalia truncatulinoides* signifies a Late Pliocene age assignment for the sample at 19.38m.



Sample: 19.38m x22

Palaeoenvironment: Marine, slope.

Lithology: Clay, light grey, silty.

Stratigraphic comments: There is good biostratigraphic evidence for a major unconformity between 19.38m and 19.50m with Late Pliocene clays resting directly on earliest Middle Eocene micritic limestones.

7.1.3 Interval: 19.50m - 20.00m.

Age: Earliest Middle Eocene.

Microzone(s): P12 or older.

Interval top defined by:

- the presence of *Globigerinatheka* spp. (abundant), *Acarinina broedermanni* (common), and *Pseudohastigerina wilcoxensis* (abundant).

Micropalaeontological biostratigraphy:

P12 Planktonic Foraminiferal Zone: There is a marked faunal change at 19.50m with the influx of Eocene foraminifera. The most significant forms observed include *Globigerinatheka* spp. (abundant), *Acarinina broedermanni* (common), and *Pseudohastigerina wilcoxensis* (abundant), indicating a biozonal of P12 or older, and an age of earliest Middle Eocene.



Sample: 19.50m x20



Sample: 20.00m x40

Palaeoenvironment: Marine, upper slope.

Lithology: Limestone, pale yellow, and micritic.

7.1.4 Interval: 27.50m - 30.80m.

Age: Early Eocene.

Microzone(s): P9/P8.

Interval top defined by:

- the presence of *Morozovella marginodentata* and *Acarinina soldadoensis* at 27.50m, and the subsequent occurrence of *Morozovella subbotinae* at 30.80m.

Micropalaeontological biostratigraphy:

P9/P8 Planktonic Foraminiferal Zones: The association of *Morozovella marginodentata* and *Acarinina soldadoensis* at 27.50m is taken as evidence of penetration of Lower Eocene carbonates. The subsequent occurrences of *Morozovella subbotinae* and *Morozovella pentacamerata*, at 30.80m, substantiate this age assignment and allocation to the P9/P8 Zones.



Sample: 27.50m x20



Sample: 30.80m x40

Palaeoenvironment: Marine, upper slope.

Lithology: Limestone, pale yellow, and micritic.

8. STRATIGRAPHY OF SITE 1: 83/20-Sb02.

8.1 Site 1: 83/24-Sb02.

8.1.1 Horizon: 19.93m.

Age: Late Pliocene.

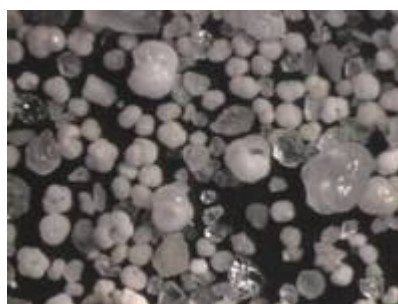
Microzone(s): N21.

Horizon characterised by:

- the continued *Globorotalia inflata* and *Neogloboquadrina atlantica*, and *Neogloboquadrina pachyderma*.

Micropalaeontological biostratigraphy:

N21 Planktonic Foraminiferal Zone: The association of superabundant *Globorotalia inflata*, *Neogloboquadrina atlantica* (C), and *Neogloboquadrina pachyderma* (superabundant) signifies a Late Pliocene age assignment for this sample. Calcareous benthic foraminifera form a minor element of the assemblage and include *Bulimina aculeata* and *Uvigerina peregrina*.



Sample: 19.93m x27

Palaeoenvironment: Marine, slope.

Lithology: Clay, light grey, silty.

Stratigraphic comments: Biostratigraphic evidence indicates a major unconformity between 19.93m and 20.28m with Upper Pliocene clays resting directly on lowermost Middle Eocene micritic limestones.

8.1.2 Interval: 20.28m - 23.32m.

Age: Earliest Middle Eocene.

Microzone(s): P12 - P10.

Interval top defined by:

- the presence of *Globigerinatheka* spp. (abundant), *Acarinina broedermanni* (common), *Pseudohastigerina wilcoxensis* (abundant), and "*Hastigerina*" *bolivariana*.

Micropalaeontological biostratigraphy:

P12 - P10 Planktonic Foraminiferal Zone: There is a marked faunal change at 20.28m with the influx of Eocene foraminifera. The most significant forms observed include *Globigerinatheka* spp. (abundant), *Acarinina broedermanni* (common), *Pseudohastigerina wilcoxensis* (abundant), and "*Hastigerina*" *bolivariana*, indicating a biozonal assignment of P12 - P10, and an age of earliest Middle Eocene. Sponge spicules occur in superabundance at 23.32m.



Sample: 20.28m x30



Sample: 23.22m x32

Palaeoenvironment: Marine, upper slope.

Lithology: Limestone, pale yellow, and micritic.

8.1.4 Interval: 30.75m - 38.10m.

Age: Early Eocene.

Microzone(s): P9/P8.

Interval top defined by:

- the presence of *Morozovella marginodentata* and *Acarinina soldadoensis* at 30.75m.

Micropalaeontological biostratigraphy:

P9/P8 Planktonic Foraminiferal Zones: The penetration of Early Eocene carbonates is indicated by the presence of *Morozovella marginodentata* and *Acarinina soldadoensis* at 30.75m.



Sample: 30.73m x30



Sample: 38.10m x16

Palaeoenvironment: Marine, upper slope.

Lithology: Limestone, pale yellow, and micritic.

Stratigraphic comments: Cavings examined at 58.70m yielded a rich and diverse Late Maastrichtian microfauna, which has not been observed in the routine examination of this borehole. It is likely that this fauna occurs at the unconformity with the overlying Palaeogene sediments between 38.10m and 38.13m.

8.1.5 Horizon: 38.20m.

Age: Late? Cretaceous, (undifferentiated).

Microzone(s): Unassigned.

Horizon characterised by:

- the presence of a single specimen of *Whiteinella* spp.

Micropalaeontological biostratigraphy:

Unassigned Horizon: The presence of a single specimen of the planktonic foraminifer *Whiteinella* indicates a broad Late Cretaceous age, probably within the range Early Santonian to Late Cenomanian.



Sample: 38.20m x18

Palaeoenvironment: Marine, shelf.

Lithology: Limestone, yellow - brown, friable with brown, glauconite.

8.1.6 Interval: 38.82m - 40.60m.

Age: Indeterminate.

Microzone(s): Indeterminate.

Interval defined by:

- absence of microfossils.

Micropalaeontological biostratigraphy:

Indeterminate interval: The interval is characterised by the absence of microfossils.



Sample: 38.82m x12



Sample: 40.60m x8

Palaeoenvironment: Marine, shelf.

Lithology: Limestone, yellow - brown, friable with brown, glauconite.

8.1.7 Horizon: 45.51m.

Age: Middle? Cretaceous, (undifferentiated).

Microzone(s): Unassigned.

Horizon characterised by:

- the presence of single specimens of *Rotalipora* sp. and *Gavelinella* sp.

Micropalaeontological biostratigraphy:

Unassigned Horizon: The presence of single specimens of *Rotalipora* sp. and *Gavelinella* sp. indicates a Middle Cretaceous age, probably within the range Cenomanian - Albian.



Sample: 45.51m x8

Palaeoenvironment: Marine, shelf.

Lithology: Limestone, yellow - brown, friable with brown.

8.1.8 Interval: 58.90m - 63.20m.

Age: Indeterminate.

Microzone(s): Indeterminate.

Interval top defined by:

- absence of diagnostic microfossils.

Micropalaeontological biostratigraphy:

Indeterminate intervals: The absence of diagnostic microfossils.



Sample: 58.90m x11



Sample: 63.20m x12

Palaeoenvironment: Marine, shelf.

Lithology: Limestone, yellow - brown, friable with brown.

Stratigraphic comments: There is good biostratigraphic evidence to indicate the presence of an unconformity between 63.20m and 63.30m.

8.1.9 Interval: 63.30m - 67.80m.

Age: ?Late Jurassic.

Microzone(s): Unassigned.

Interval top defined by:

- the presence of rare agglutinated foraminifera at 63.30m and non-marine ostracods at 67.80m.

Micropalaeontological biostratigraphy:

Indeterminate intervals: Specimens of the agglutinated foraminifer *Bathysiphon* spp. are recorded at 63.30m. Of more significance is the presence of poorly preserved non-marine ostracods at 67.80m. Specimens are decalcified and identification tentative but a few specimens resemble *Bisulcocypis* spp. indicating either an Early Cretaceous or more likely Late Jurassic or older age.



Sample: 63.30m x1

Palaeoenvironment: Non - Marine.

Lithology: Clay, brick red.

8.1.10 Interval: 69.21m - 71.49m.

Age: Indeterminate.⁵

Microzone(s): Indeterminate.

Interval top defined by:

- the absence of age diagnostic microfossils.

Micropalaeontological biostratigraphy:

Indeterminate interval: The samples between 69.21m and 71.23m were devoid of microfossils, while the sample at 71.49m yielded rare specimens of *Bathysiphon* spp. No direct age assignment can be made



Sample: 69.21m x11



Sample: 70.82m x11

Palaeoenvironment: Marginal marine?

Lithology: Siltstone, light grey, non-calcareous.

⁵ Several samples were selected for palynological analysis. The sample at 71.23m, analysed by Ken Higgs, yielded a diverse palynoflora in which most of the dinocysts present are long ranging. However, the presence of *Senoniasphaera jurassica* and *Oligosphaeridium* sp. indicates that the assemblage is Late Jurassic in age, most likely within the range Kimmeridgian to Early Portlandian. Late Carboniferous reworking is also evident.

APPENDIX A**SAMPLE LIST: Site 3A, 11/20Sb01**

7.68	M	10.50	T*	13.70	M	18.00	M
8.18	MT	11.09	MT	13.78	T	18.88	T
2.45	MT	11.90	M	14.36	MT	19.10	MT
10.21	MT	11.98	T	16.37	MT		
10.25	MT	13.50	MT	17.00	M		

APPENDIX B**SAMPLE LIST: Site 2, 16/28-Sb01**

12.78	M	60.80	M	114.00	M	146.00	M
13.80	M	70.79	M	121.00	M	147.17	M
14.50	MT	83.92	M	126.60	M	147.23	M
24.70	M	88.35	M	129.55	M	147.24	T*
24.94	MT	92.00	M	137.92	M		
33.39	M	98.00	M	138.00	M		
44.00	M	102.00	M	145.66	M		
53.99	M	109.86	M	145.95	M		

APPENDIX C**SAMPLE LIST: Site 1A, 83/20-Sb01**

35.73	M	103.00	M	131.40	M	169.70	M
37.00	M	107.53	M	133.00	M	169.90	M
66.52	M	107.70	M	138.00	M	172.00	M
66.81	M	117.78	M	142.00	M	176.29	M
86.10	M	118.00	M	146.80	M	176.48	M
86.22	M	122.88	M	150.90	M	176.78	M
86.60	M	127.86	M	156.50	M	177.35	M
100.00	M	131.11	M	161.33	M	177.40	M
102.87	M	131.20	M	166.50	M		

APPENDIX D**SAMPLE LIST: Site 1, 83/24-Sb01**

9.30	M	19.00	M	19.50	M	30.80	M
9.70	M	19.18	M	20.00	M		
10.00	M	19.38	M	27.50	M		

APPENDIX E**SAMPLE LIST: Site 1, 83/24-Sb02**

19.93	M	38.20	M	63.20	M	71.00	M
20.28	M	38.82	M	63.30	M	71.04	M
23.22	M	40.60	M	67.80	M	71.23	M
30.73	M	45.51	M	69.21	M	71.49	M
38.10	M	58.90	M	70.82	M		

M = sample analysed for microfossils

T = thin section prepared

T* = thin section lost to petrothin