

Biostratigraphic review of the Tertiary sequences from:  
UK Rockall Trough well 132/15-1, Erris Trough well 12/13-1, and  
the shallow boreholes 11/20-Sb01, 16/28-Sb01, 83/20-Sb01,  
83/24-Sb01 and 83/24-Sb-02, Irish Rockall Trough.

Prepared by:

Jake Jacovides

for the

Rockall Studies Group  
(RSG Project 00/4)

## **ABSTRACT**

In light of recent biostratigraphic analysis of five shallow boreholes from the Irish Rockall Trough the chronostratigraphic subdivisions, biozonal assignments and microfossil events for the Tertiary sequences penetrated in the wells 132/15-1 and 12/13-1A have been re-evaluated.

The micropalaeontological, palynological and nannofossil data for the five shallow boreholes has been integrated and provides a concise database for comparison with the wells drilled in the Erris Trough and southern UK Rockall Trough sector.

In general the palynological markers observed for the Neogene and Palaeogene of the West of Shetland and North Sea basins can be applied. At certain levels the micropalaeontological biozonation requires modification, most noticeably in the Palaeogene, where there is a marked degree of Tethyan influence and the marker fossils present are biased towards planktonic foraminifera. Nannofossil data available is restricted to the shallow borehole material and a modified version of the standard zonation scheme of Martini (1971) has been applied.

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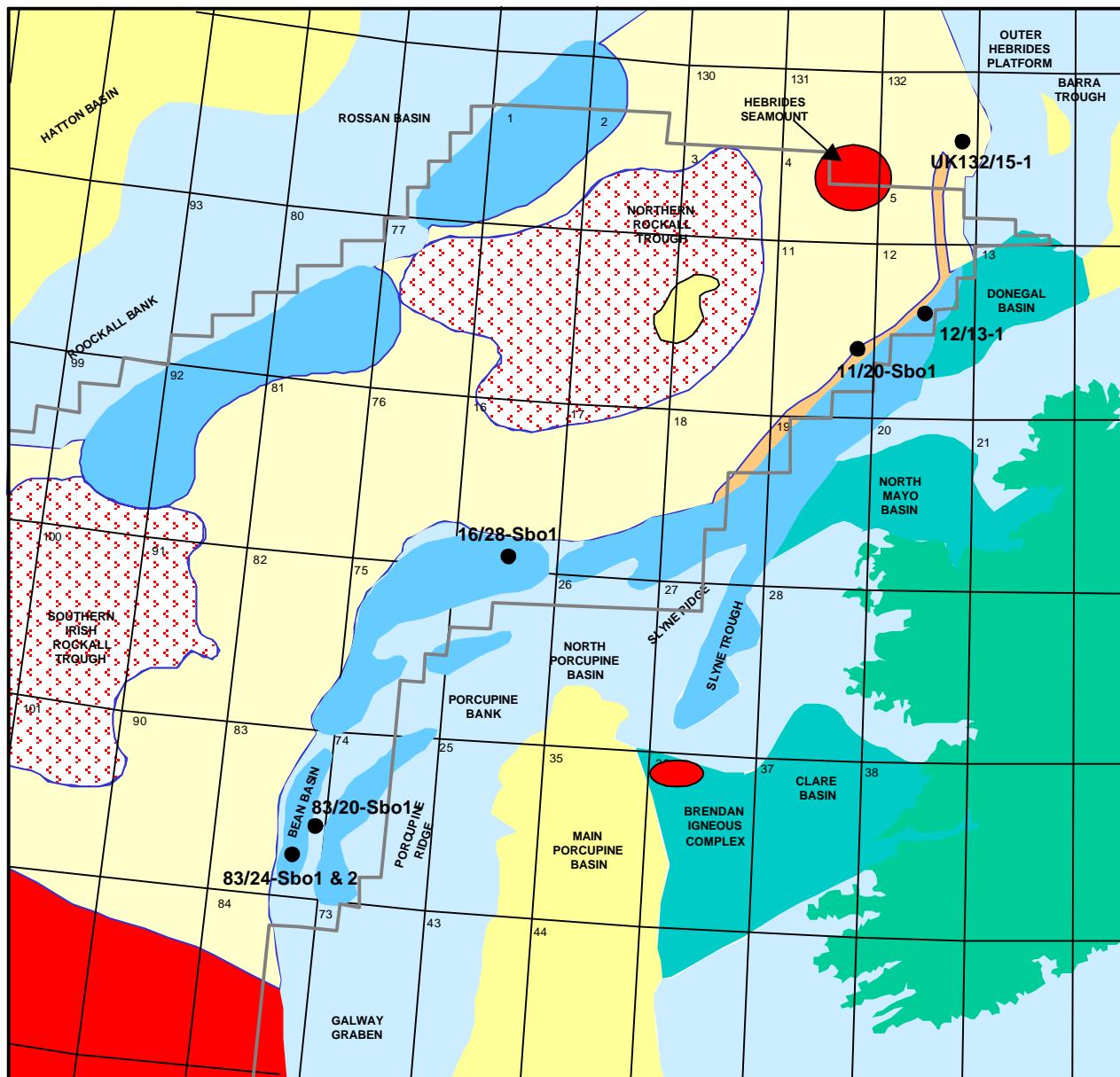


Figure 1. Location map

## 1. INTRODUCTION

### 1.1 Project objective

The main objective of this study has been to carry out a paper review of the biostratigraphy of the Tertiary sequences of the South Rockall well 132/15-1 and Irish well 12/13-1. The chronostratigraphic subdivisions, biozonal assignments and microfossil events in the above 2 wells have re-evaluated in light of recent work on Rockall Studies Group shallow boreholes 11/20-sb01, 16/28-sb01, 83/20-sb01, 83/24-sb01 and 83/24-sb02. Available palynological and micropalaeontological data from the Tertiary intervals in these wells is classified according to the in-house zonations of Millennia Ltd.

### 1.2 Previous work

The biostratigraphic data for 12/13-1 is limited, comprising a brief report and completion log (Church *et al.*, 1979). No palynological or nannopalaeontological analyses was contracted as part of that study. Microfaunal occurrence charts are available for examination.

Biostratigraphic data for 132/15-1 were made available in the form of two text reports and an annotated stratigraphic summary log (Wonder, 1991 and Ebdon *et al.*, 1992). No nannofossil analysis was undertaken and no microfossil occurrence charts or logging sheets were available for review.

Palynological data for the Rockall Studies Group boreholes were made available in the form of text and charts with fossil occurrence data (Harrington *et al.*, 2000), while micropalaeontological and nannopalaeontological data was derived from in-house Millennia Ltd. reports (Jacovides, 1999 and Zucchi, 2000).

### 1.3 Report content

A main results of the review are summarised in Section followed by the revised summarised stratigraphy for each well Sections 3 - 9.

Review work was undertaken by the following staff at Millennia Ltd:

P. Dodsworth - Palynology, and  
J. Jacovides – Micropalaeontology and project co-ordination.

### 1.4 Depth convention

Throughout the text of the report, all depths with the exception of well 12/13-1A are quoted in metres. Those for core samples are given to two decimal places while those for sidewall cores are given to one decimal place. Ditch cuttings sample depths are given as integers.

## 2. SUMMARY

The key microfossil components of the Tertiary sequences reviewed are outlined below. The main palynological taxa are similar to those in use in the North Sea and West of Shetland basins. There are however, some differences in the micropalaeontological components. Nannofossil markers observed in the shallow borehole material enable good correlation with the modified version of the standard zonation scheme of Martini (1971). Figures 2 and 3 illustrate the various zonation scheme discussed.

### 2.1 QUATERNARY

#### 2.1.1 Pleistocene

The youngest sediments identified are of Pleistocene age and occur in boreholes 11/20-Sb01, 16/28-Sb01, 83/24-Sb01 and 83/24-Sb02. Microfaunal assemblages are dominated by planktonic foraminifera and include the key marker *Globorotalia truncatulinoides*, which indicates the N22 to Recent Planktonic Foraminiferal Zone. This zone equates to the QM2 Microzone of Millennia Ltd.

Key Pleistocene nannofossil species and events observed include *Pseudoemiliania lacunosa* and *Helicosphaera inversa* (NN19a Nannozone) and the presence of small, superabundant *Gephyrocapsa* spp. (NN19b Subzone).

Borehole 16/28-Sb01 appears to directly rest on Palaeogene strata of Middle Eocene age.

### 2.2 NEOGENE

#### 2.2.1 Pliocene

Pliocene sediments are identified in boreholes 11/20-Sb01, 83/24-Sb01 and 83/24-Sb02, and are also represented by rich microfaunal assemblages dominated by planktonic foraminifera. Key taxa include *Neogloboquadrina atlantica*, *Neogloboquadrina pachyderma*, *Neogloboquadrina acostaensis* and *Globorotalia inflata*. Typical calcareous benthic taxa include *Bulimina marginata*, *Cassidulina laevigata* and *Melonis affine*. The planktonic foraminifera are typical of the N21 and N20 - N19 Planktonic Foraminiferal Zones, while the overall assemblage components are characteristic of the TM1 Microzone of Millennia Ltd.

The association of nannofossils *Discoaster triradiatus*, *Pseudoemiliania lacunosa* (common) and *Calcidiscus macintyrei* are typical of Late Pliocene sediments (NN18 - NN16 Nannozones).

Palynomorphs derived from the Late Pliocene sequence in borehole 83/24-Sb02 (sample 19.82m) comprise subtropical genera such as *Carya*, *Engelhardtia*, *Liquidamber*, *Nyssa*, *Sequoia* and *Taxodium*.

There is no conclusive evidence for the presence of Early Pliocene sediments in any of the wells studied. Boreholes 83/24-Sb01 and 83/24-Sb02 rest directly on Palaeogene sediments of Middle Eocene age, while in the borehole 11/20-Sb01 undifferentiated Palaeogene sediments underlie Pliocene sediments at 8.18m. Earliest Oligocene to Middle Eocene strata are first observed at 18.75m.

#### 2.2.2 Miocene

Miocene sediments were only encountered in the borehole 83/20-Sb01 and span the interval 35.73m - 86.10m. In general rich but long-ranging Neogene planktonic foraminifera (*Globigerina bulloides*, *Globigerina decoraperta* *Globoquadrina dehiscens* and *Globorotalia menardii*) and calcareous benthic taxa (*Uvigerina tenuipustulata*, *Plectofrondicularia advena* and *Valvulinaria mexicana*) are recorded. These assemblages are considered to equate to the Middle Miocene TM5 Microzone of Millennia Ltd. The co-occurrence of the planktonic foraminifera *Globorotalia mayeri* and *Globorotalia continuosa* indicates a zonal range of N14 - N6 and an age no younger than intra-Early Miocene for the base of the Neogene sequence encountered.

The nannofossils *Cyclicargolithus floridanus* and *Calcidiscus premacintyreai* are diagnostic of the Middle Miocene NN6 - NN4 Zones, while the co-occurrence of *Helicosphaera ampliaperta* and *Sphenolithus heteromorphus*, deeper in the section indicates penetration of the NN4 Nannozone of earliest Middle to Early Miocene age.

Rich dinocysts assemblages are present and include *Unipontidinium aquaeductum*, which indicates assignment to the Middle Miocene TP4b - TP5a Palynozones. . Also of note are rare to abundant occurrences of *Palaeocystodinium* sp. A and *Cannospaeropsis* sp. A (Costa & Downie, 1979). The presence of *Apteodinium spiridoides* (at 83.34m and 84.00m), signifies penetration of the TP5b Biozone and an Early Miocene age.

In borehole 83/20-Sb01 there is no evidence for the presence of Palaeogene strata, and a major unconformity marks the boundary with the underlying Mesozoic sequence at 86.22m

## 2.3 PALAEOGENE

Palaeogene sediments appear widespread and can be subdivided into Middle and Early Eocene, and Late and Early Palaeocene as defined in terms of the standard planktonic foraminifera (P Zones) and nannoplankton (NP Zones) zones. The presence of sporadic foraminifera, in the most northerly well 135/15-1 enables correlation with the richer planktonic foraminiferal assemblages recovered in the other wells.

With the exception of borehole 83/20-Sb01, all the other wells studied penetrated Palaeogene strata. However, there is no conclusive evidence for the presence of Oligocene strata. Only the sample at 8.18m, in the borehole 11/20-Sb01 is dated as Earliest Oligocene to Middle Eocene (Nannozones NP21 - NP15) but it is likely that the sediments in question are in fact Middle Eocene in age. In well 132/15-1 no drilling returns were collected from the sea bed down to 1706m, and no samples were analysed from the underlying interval (1706m - 1998m), for which the Early Oligocene to Eocene age assigned by Ebdon *et al.* (1992) is derived solely from regional seismic evidence.

Planktonic foraminifera are well represented in the well 12/13-1 and the boreholes 16/28-Sb01, 83/24-Sb01 and 83/24-Sb02 and form the basis of the biozonal framework. Many of the forms recorded are characteristic of Tethyan planktonic faunal associations.

Nannofossil data is limited to the boreholes drilled in the Irish Rockall Trough. The assemblages recovered are rich and diverse allowing high-resolution correlation with the standard NP Zones of Martini (1971).

Palynological data is available for all the wells with the exception of 12/13-1. There is a good degree of correlation with many of the standard zonal markers for the North Sea and West of Shetland basins.

### 2.3.1 EOCENE

Middle Eocene sediments are clearly identified in wells 132/15-1, 12/13-1 and boreholes 16/28-Sb01, 83/24-Sb01 and 83/24-Sb02. The youngest planktonic foraminiferal zone represented is P12 as indicated by the presence of *Hantkenina dutemplei* in 16/28-Sb01 and *Turborotalia cerroazulensis frontosa* in well 12/13-1. Other planktonic forms present in 16/28-Sb01 include *Truncorotaloides rohri* (P14 - P10), *Acarinina bullbrookii* (P14 - P9), *Hantkenina nuttalli* (intra-P11 - P10), frequent *Acarinina broedermannii* (P12 - P8), and abundant *Pseudohastigerina wilcoxensis* (intra-P12 and older), all indicating continued assignment to a Middle Eocene age. These faunas are considered to equate to the TM15 Microzone of Millennia Ltd. The records of "*Hastigerina bolivariana* (P11 - P9), *Truncorotaloides topilensis* (P14 - intra-P9), and *Acarinina pentacamerata* (P12 - P8), also in the borehole 16/28-Sb01 signify Middle - Lower Eocene sediments (TM15b - TM17).

Middle Eocene nannofossil assemblages are characterised by the presence of *Rhabdosphaera gladius* (Nannozone NP15 marker species), *Chiasmolithus gigas* (intra-NP15 Nannozone) in borehole 16/28-Sb01 and *Sphenolithus furcatolithoides*, *Reticulofenestra bisecta* and *Ellipsolithus lajollaensis* in borehole 83/24-Sb02.

Palynologically, the Middle Eocene strata encountered can be subdivided on the basis of the presence of the first downhole occurrence of *Cerebrocysta bartonensis* (the TP14b Palynozone), *Diphyes colligerum* (the TP15a Palynozone), *Diphyes ficusoides* (the TP16 Palynozone) and *Eatonicysta ursulae* (the TP17a Palynozone). The presence of the pollen *Spinizonocolpites echinatus* is significant. The Robertson Group regard this form as restricted to their late Early Eocene SE1 Biozone (Ebdon *et al.*, 1992), however this form is present in well dated Middle Eocene sediments in borehole 16/28-Sb01 and at a comparable level in well 132/15-1.

Early Eocene sediments are identified in the wells 132/15-1, 12/13-1 and the shallow boreholes 16/28-Sb01, and 83/24-Sb02. The microfaunal assemblages recovered are characterised by the presence of the planktonic foraminifera *Morozovella subbotinae* (intra-P8 - P6), *Morozovella marginodentata* (intra-P7 - P6), *Acarinina soldadoensis* (P9 - P6), and the longer ranging *Subbotinae linaperta*. The influx of abundant cenosphaerid radiolaria is a consistent feature of this interval. In well 132/15-1 the microfaunal assemblages recovered are initially characterised by a mixture of shallow water benthic taxa (*Assilina* and *Nummulites*) and deeper water planktonic and benthic foraminifera. These shallow water forms are considered to be derived from a coeval shallow water environment. Praebuliminids, chilostomellids and radiolaria characterise the underlying unit between 2583m and 2637m. Common *Subbotinae linaperta* distinguish the underlying unit. Similar faunal attributes are evident in the Early Eocene sequences in borehole 16/28-Sb01. The Early Eocene microfaunas equate directly to the TM18 and TM19 Microzones of Millennia Ltd.

Early Eocene nannofossil assemblages are encountered in boreholes 16/28-Sb01 and 83/24-Sb02, and are characterised by the presence of rich and diverse assemblages. Key taxa include *Chiphragmalithus barbatus* (NP12 Nannozone) and *Discoaster lodoensis*, *Discoaster kuepperi*, *Toweius* spp., *Tribachiatus orthostylus*.

Palynologically, the top of the Early Eocene sequence encountered in well 132/15-1 is characterised by the presence of increased terrestrially-derived kerogen, regarded by Ebdon *et al.* (1992), as a positively-dated Early Eocene (Ypresian) event in the region. Underlying this unit characteristic Early Eocene events recorded include the first downhole occurrence of *Apectodinium quinquelatum/parvum* (TP17d Palynozone), *Areoligera cf. medusettiformis* (TP18b Palynozone), consistent *Deflandrea oebisfeldensis* (TP19a Palynozone), consistent *Alisocysta* sp. 2 Heilmann-Clausen (1985) (TP19b Palynozone), *Palaeocystodinium lidiae* (TP20a Palynozone), and consistent *Cerodinium wardenense* (TP20a Palynozone). In the

borehole 16/28-b01 the top of the Early Eocene is typical characterised by the presence of common/abundant *Eatonicysta ursulae* (TP17b - TP17d Palynozone). Other standard events recorded include *Dracodinium condylos* (TP17d - TP18 Palynozones), and *Dracodinium simile* (intra-TP18 Palynozone).

In well 132/15-1 the interval 2817m - 2865m is considered by Ebdon *et al.* (1992) to be Earliest Eocene to Late Palaeocene in age and equivalent to the Balder Formation as defined in the West of Shetlands and North Sea. The top of the formation has been chosen on the presence of a gamma spike at 2817m. The Balder Formation is normally constrained by the TP19b (influx of terrestrially derived taxa) and TP20a (*C. wardenensis*) Palynozones and the TM20 (*Coscondiscus* sp.1) Microzone. However, none of the diagnostic microfaunal elements were recovered in this or any of the other wells analysed and in 132/15-1 the interval is indeterminate for palynology.

### 2.3.2 PALAEOCENE

Palaeocene strata are well represented in wells 132/15-1 and 12/13-1 and can be subdivided into Late and Early Palaeocene units. There is limited evidence (micropalaeontology only) in borehole 16/28-Sb01 for the presence of undifferentiated Palaeocene sediments at 145.95m. It is recommended that nannofossil analysis is undertaken on this sample to provide further information.

A relatively thick Late Palaeocene sequence is encountered in well 132/15-1. The microfaunal assemblages recovered from the top of the interval (2883m - 2932m) are poor and lack characteristic markers. From 3019.0m micropalaeontological resolution improves and several zonal markers are identified. These include the influx of common *Cenodiscus lenticularis* (TM24a) and the presence of *Quadrrimorphina allomorphinoides* (TM24b), and the highest occurrence of *Globigerina pseudobulloides* (intra-TM24b Microzone). In well 12/13-1 the Late Palaeocene is characterised by moderately diverse planktonic and benthic foraminifera. Key taxa recorded include the first downhole occurrence of *Globigerina triloculinoides* (intra-P4 or older), *Planorotalites pseudomenardii* (P4 restricted) and *Planorotalites compressa* (P3 - intra-P1). These markers are indicative of the TM23 and TM24b Microzones of Millennia Ltd.

Palynologically the top of the Late Palaeocene in well 132/15-1 is also poorly defined. The presence of a questionable specimen of *Alisocysta margarita*, at 2865m, is tentative evidence for the penetration of Late Palaeocene strata (TP22a Palynozone) and it is not until the consistent occurrence of *Areoligera* spp., including *A. gippingensis* (TP22b Palynozone), at 2883m, that penetration of Late Palaeocene sediments is confirmed. However, below 2975m palynofloras are poor or barren for the remainder of the Late Palaeocene interval.

Diagnostic Early Palaeocene microfaunas are observed in well 132/15-1 between 3423m - 3552m and include the markers *Morozovella praeangulata* (TM25 Microzone) and *Globoconusa daubjergensis* (TM26 Microzone). The latter form is also noted in well 12/13-1. The key palynomorphs recorded in well 132/15-1 include common *Operculodinium centrocarpum* (TP25 Palynozone) and the first downhole occurrence of *Senoniasphaera inornata* (TP26 Palynozone).

### 3. WELL 132/15-1

#### 3.1 SUMMARISED STRATIGRAPHIC WELL 132/15-1

Depth / Interval	Age
1998m - 2250m	Middle Eocene
2340m - 2376m	?Early Eocene
2394m - 2854m	Early Eocene
2865m	?Late Palaeocene
2883m - 3393m	Late Palaeocene
3423m - 3552m	Early Palaeocene

#### 3.2. STRATIGRAPHY OF WELL 132/15-1

##### 3.2.1 Interval: 1998m - 2250m

**Age:** Middle Eocene.

**Palynozone(s):** TP14b (or older), TP15a (or older).

**Interval defined by:**

- the first downhole occurrence *Cerebrocysta bartonensis* at 1998m (the TP14b or older Palynozone) (highest sample analysed),
- the subsequent downhole occurrence of *Diphyes colligerum* at 2097m (the TP15a or older Palynozone).

**Palynological biostratigraphy:**

**TP14a (or older) Palynozone:** The sample at 1998m contains the dinocysts *Cerebrocysta bartonensis* and *Areoligera* spp. The presence of the former indicates an age not younger than early Bartonian (the TP14a Palynozone). Reworked Carboniferous spores were noted.

**TP15a (or older) Palynozone:** The sample at 2097m contains *Diphyes colligerum*, indicating the TP15a (or older) Palynozone. The dinocysts *Systematophora placacantha* and *Homotryblium oceanicum* were also recorded. The presence of a single specimen of the pollen *Spinozonocolpites echinatus*, more typical of sediments of Early Eocene or older age, may warrants a ranged age assignment of Middle - ?Early Eocene. The sample at 2250m contains no older indications. The presence of *Deflandrea phosphoritica* was noted at 2250m.

##### 3.2.2 Interval: 2340m - 2376m

**Age:** ?Early Eocene.

**Palynozone(s):** Unassigned.

**Interval defined by:**

- the significant downhole increase of terrestrially-derived kerogen from 2340m.

**Palynological biostratigraphy:**

**Unassigned Palynozone:** The samples at 2340m and 2376m contain a significant increase of terrestrially derived kerogen, including *Inapertuopollenites hiatus* (*Taxodiaceaeapollenites* spp. of Ebdon *et al.*, 1992) and, at 2376m, *Caryapollenites simplex* Group. According to Ebdon *et al.* (1992), the top of this event indicates positively-dated Early Eocene (Ypresian) sediments in the region.

**3.2.3 Interval: 2394m - 2854.0m**

**Age:** Early Eocene.

**Palynozone(s):** ?TP17d, ?TP18, TP19a, ?TP19b, ?TP20a, TP20a, Unassigned.

**Microzone(s):** TM18 or older.

**Interval defined by:**

- the presence of *Morozovella subbotinae* at 2394m (TM18 or older Microzone),
- the first downhole occurrence of *Apectodinium quinquelatum/parvum* at 2403m (the ?TP17d Palynozone),
- the subsequent occurrence of *Areoligera cf. medusettiformis* at 2457m (the ?TP18 Palynozone),
- the subsequent occurrence of consistent *Deflandrea oebisfeldensis* from 2601m (the TP19a Palynozone),
- the subsequent occurrence of consistent *Alisocysta* sp. 2 Heilmann-Clausen (1985) (the ?TP19b Palynozone),
- the subsequent occurrence of *Palaeocystodinium lidiae* at 2691m (the ?TP20a Palynozone),
- the subsequent occurrence of consistent *Cerodinium wardenense* from 2709m (the TP20a Palynozone), and
- the occurrence of impoverished/barren palynological assemblages from 2753m.

**Palynological biostratigraphy:**

**?TP17d Palynozone:** The sample at 2403m contains *Apectodinium quinquelatum / Apectodinium parvum* complex. Specimens of the former are not consistently recorded in sediments younger than late Early Eocene in the North Sea (the TP17d Biozone) while specimens of the latter are not recorded until older levels within the Early Eocene (i.e. the TP19b Biozone). The zonal assignment of TP17d is therefore queried here. No older indications are reported at 2430m. Reworked Jurassic and Carboniferous

taxa only are listed.

**?TP18 Palynozone:** The sample at 2457m contains *Areoligera cf. medusettiformis*. In the North Sea, an increase in a plexus of forms assignable to *Areoligera* spp. marks the penetration of the TP18a Biozone. An equivalent event is possibly indicated here. No older indications are reported at 2511m (*Adnatosphaeridium multispinosum*) and 2565m (*Apectodinium quinquelatum*, *Eatonicysta ursulae*). At 2592m, a questionable specimen of *Muratodinium fimbriatum* is supporting evidence for a queried TP18 zonal assignment.

**TP19a Palynozone:** The samples at 2601m and 2619m contain occurrences of *Deflandrea oebisfeldensis*, indicating penetration of the TP19a Biozone. Specimens of *Muratodinium fimbriatum* and *Cerodinium depressum* were also noted at 2619m.

**?TP19b Palynozone:** The samples at 2637m, 2655m and 2673m contain occurrences of *Alisocysta* sp. 2 Heilmann-Clausen (1985). The consistent presence of this taxon is evidence for a probable TP19b zonal assignment. A specimen of *Cerodinium wardenense* was noted at 2655m. This taxon can occur sporadically from the TP18 Biozone but only occurs consistently from TP20a.

**?TP20a Palynozone:** The sample at 2691m contains *Palaeocystodinium lidiae*, indicating possible penetration of the TP20a Biozone.

**TP20a Palynozone:** The samples at 2709m and 2718m contain occurrences of *Cerodinium wardenense*, indicating penetration of the TP20a Biozone. Specimens of *Alisocysta* sp. 2 Heilmann-Clausen (1985) and *Cerodinium speciosum* were also noted at 2718m.

**Unassigned Palynozone:** The samples analysed from 2753m, 2782m, 2793m, 2816m, 2823m and 2854m are impoverished or barren of palynomorphs, or contain taxa which do not permit zonal assignments over the interval, i.e. *Cerodinium speciosum* at 2782m and 2793m, and *Palaeocystodinium australinum* at 2823m.

#### **Micropalaeontological biostratigraphy:**

**TM18 (or older) Microzone:** The shallowest sample examined for micropalaeontology in this well was at 2394m. The microfaunas observed by Wonders (1991) are of limited stratigraphic significance, although the presence of the planktonic foraminifera *Morozovella subottinae* at 2394m and *Muricoglobigerina chasconana* at 2854.0m, restricts the age assignment of this interval to Early Eocene (Ypresian).

**Palaeoenvironment:** In general, in the upper part of this interval (2394m - 2583m), the microfaunas recorded comprise a mixed assemblage of shallow water foraminifera (*Nummulites* and *Assilina*) together with planktonic and calcareous benthic foraminifera. The faunas are considered to represent several coeval assemblages. As documented by Wonders (1991) the environment of deposition is considered to be outer shelf to upper slope. The predominance of buliminids, chilostomellids and *Baggina bismuthi* below 2583m represents a relatively deep water facies (?upper bathyal). The consistent occurrence of radiolaria (*Cenosphaera* spp.) from 2782m is good evidence for an upper bathyal setting.

**Stratigraphic comments:** As reported in Ebdon *et al* (1992), none of the biostratigraphical components normally associated with penetration of the

Balder Formation were recovered in this well.

### 3.2.4 Sample at:2865m

**Age:** ?Late Palaeocene.

**Palynozone(s):** ?TP22a.

**Interval defined by:**

- the occurrence of questionable *Alisocysta margarita* at 2865m (the ?TP22a Palynozone).

**Palynological biostratigraphy:**

**?TP22a Palynozone:** The sample at 2865m contains a questionable specimen of *Alisocysta margarita*, queried evidence for the penetration of strata of Late Palaeocene age (the TP22a Palynozone). Other taxa reported are *Cerodinium depressum*, *Cerodinium speciosum* and *Deflandrea denticulata*.

### 3.2.5 Interval: 2883m - 3393m

**Age:** Late Palaeocene.

**Palynozone(s):** TP22b, ?TP24 - ?TP25.

**Microzone(s):** Unassigned, TM24a, TM24b.

**Interval defined by:**

- the increase in *Areoligera* spp., including *A. gippingensis* (the TP22b Palynozone),
- the first sample analysed below *Areoligera gippingensis* at 3019.0m (the ?TP24 - ?TP25 Palynozone),
- the highest occurrence of common *Cenodiscus lenticularis* at 3019m (the TM24a Microzone),
- the influx of common calcareous benthic foraminifera including *Chilostomella* spp. at 3240m, and
- the highest occurrence of *Globigerina pseudobulloides* at 3393m (intra-TM24b Microzone).

**Micropalaeontological biostratigraphy:**

**Unassigned Microzone:** In general sparse microfaunas were recovered from this interval with limited age diagnostic or biozonal forms present. The reappearance of agglutinated taxa at 2883m may tentatively suggest penetration of the TM22 Microzone or older. Micropalaeontological recovery is particularly poor between 2943m and 3003m, and interval containing basalts.

**TM24a Microzone:** The presence of common *Cenodiscus lenticularis* at

3019.0m and 3240.0m is good evidence for the early Late Palaeocene ('early' Thanetian) Microzone TM24a. The presence of *Gyroidinoides subangulatus* is also a characteristic feature of the Late Palaeocene and occurs between 3033m and 3123m.

**TM24b Microzone:** The presence of common *Chilostomella* spp. at 3243m is taken as evidence for the earliest Late Palaeocene ('earliest' Thanetian) Microzone TM24b. Although the index taxon for this biozone (*Quadriflorina allomorphinoides*) was not observed the presence of *Chilostomella* spp. is significant as this form belongs to the same eco- and morphogroup and is often recorded in association with *Quadriflorina allomorphinoides*. Microfaunas are absent from the two sand prone samples examined at 3333m and 3363m. The subsequent highest occurrence of the planktonic foraminifer *Globigerina pseudobulloides* at 3393m is characteristic intra-TM24b event and confirms the biozonal assignment.

#### Palynological biostratigraphy:

**TP22b Palynozone:** The seven samples from 2883m - 2973m contain consistent occurrences of *Areoligera gippingensis* (A. 'regalis' of Ebdon et al., 1992), firm evidence for the penetration of strata of Late Palaeocene age. The increase in *Areoligera* spp., including *A. gippingensis*, reported by Ebdon et al. (1992), suggests the TP22b Palynozone. Other taxa reported from the interval are *Alisocysta margarita* at 2901m and 2955m, and reworked Jurassic/Carboniferous (*Gonyaulacysta jurassica* and *Lycospora pusilla*) at 2901m.

**TP24 - ?TP25 Palynozone:** The eight samples from 3019m - 3462m contain occasional occurrences of the Palaeocene (TP22 - TP25 Palynozones) marker *Alisocysta margarita* (3135m, 3252m). Other dinoflagellate cysts listed are *Hystrixosphaeridium tubiferum* at 3019m and *Palaeoperidinium pyrophorum* at 3462m. The occurrence of the samples below the last downhole record of *Areoligera gippingensis* is queried evidence for the TP24-?TP25 Palynozones.

**Palaeoenvironment:** Abundant radiolaria (*Cenosphaera* spp.) are recorded at 2883m, and together with the presence of buliminids and chilostomellids at 2932.0m point to an upper bathyal palaeoenvironment. The presence of common radiolaria in the upper part of the interval marks a period of upwelling. The subsequent occurrence of planktonic foraminifera and common calcareous benthic foraminifera suggests an well-oxygenated outer shelf to upper bathyal setting, although at several levels poorly oxygenated hemipelagic conditions existed.

#### 3.2.6 Interval: 3423m - 3552m

**Age:** Early Palaeocene (Danian).

**Palynozone(s):** TP25, TP26.

**Microzone(s):** TM25, TM26.

#### Interval defined by:

- the highest occurrence of *Morozovella praeanangulata* at 3423m (TM25 Microzone,
- the highest occurrence of *Globoconusa daubjergensis* at 3453m (TM26

- Microzone),
- the subsequent occurrence of common *Opercudolinium centrocarpum* from 3471m (the TP25 Palynozone), and
  - the first downhole occurrence of *Senoniasphaera inornata* at 3537m (the TP26 Palynozone).

#### **Palynological biostratigraphy:**

**TP25 Palynozone:** From 3471m - 3522m, common *Opercudolinium centrocarpum*, associated with common *Palaeoperidinium pyrophorum* and *Areoligera* spp., suggests probable assignment to the upper TP25 Palynozone and confirm penetration of Early Palaeocene (Danian) sediments as indicated by the microfaunal data.

**TP26 Palynozone:** The samples at 3537m and 3552m contain occurrences of *Senoniasphaera inornata*, indicating penetration of strata of Early Palaeocene (Danian) age (the TP26 Palynozone). A record of *Xenicodinium* sp. at the latter depth confirms the age assignment.

#### **Micropalaeontological biostratigraphy:**

**TM25 Microzone:** The highest occurrence of *Morozovella praeangulata* at 3423m is good evidence for the penetration of the TM25 Microzone and penetration of Early Palaeocene (Danian) sediments. This sample is documented in as comprising predominantly planktonic foraminifera including *Planorotalites ehrenbergi* and common subbotinids.

**TM6 Microzone:** The presence of abundant planktonic foraminifera including *Globoconusa daubjergensis* is characteristic the TM26 Microzone and the Early Palaeocene (Danian).

**Palaeoenvironment:** The presence of common to abundant planktonic foraminifera between 3423m and 3453m suggests an open marine, pelagic, probably upper bathyal setting, while the presence of an agglutinated component in the lower half of this interval suggests more restricted conditions prevailed.

#### 4. WELL 12/13-1

##### 4.1 SUMMARISED STRATIGRAPHIC WELL 12/13-1

Depth / Interval	Age
2830' - 3200'	Middle Eocene
3220' - 3290'	Early Eocene
3310' - 3440'	Late Palaeocene
3460' - 3510'	Early Palaeocene

##### 4.2. STRATIGRAPHY OF WELL 12/13-1

###### 4.2.1 Interval: 2830' - 3200'

**Age:** Middle Eocene (Lutetian).

**Microzone(s):** TM15 or older.

**Interval defined by:**

- the first downhole occurrence of *Turborotalia cerroazulensis frontosa* (TM15 Microzone) at 2830' (highest sample analysed), and
- the subsequent downhole occurrence of *Truncorotaloides* spp. at 2890'.

**Micropalaeontological biostratigraphy:**

**TM15 (or older) Microzone:** The sample at 2830' contains common planktonic foraminifera, which includes *Turborotalia cerroazulensis frontosa* (= *Globigerina boweri* of Church et al, 1979). This taxon suggests an age not younger than Middle Eocene (Lutetian) and indicates the penetration of the TM15 Microzone (or older). The subsequent downhole occurrence of the planktonic foraminifer *Truncorotaloides* spp., at 2890', is consistent with this age assignment. The microfaunal assemblages recorded in this interval also comprise mixed calcareous benthic and agglutinated foraminifera in relative abundance.

**Palaeoenvironment:** Marine, well oxygenated, outer shelf to upper slope with good open marine circulation.

###### 4.2.2 Interval: 3220' - 3290'

**Age:** Early Eocene (Ypresian).

**Microzone(s):** TM17, TM18-TM19.

**Interval defined by:**

- the first downhole occurrence of *Acarinina soldadoensis soldadoensis* at 3220' (the TM17 Microzone), and

- the subsequent highest downhole occurrence of *Morozovella subbotinae* (TM18 Microzone) and *Morozovella aequa* (TM19 Microzone) both at 3250'.

#### **Micropalaeontological biostratigraphy:**

**TM17 Microzone:** The highest occurrence of the planktonic foraminifer *Acarinina soldadoensis soldadoensis* (= *Globigerina soldadoensis* of Church et al, 1979) at 3220' signifies penetration of Early Eocene (Ypresian) sediments and assignment to the TM17 Microzone. The microfaunal assemblages recorded in this interval also comprise mixed calcareous benthic and agglutinated foraminifera in relative abundance.

**TM18 - TM19 Microzones:** The subsequent highest downhole occurrence of the planktonic foraminifera *Morozovella subbotinae* (= *Globorotalia rex* of Church et al, 1979) and *Morozovella aequa* (= *Globorotalia aequa* of Church et al, 1979), at 3250', are consistent with an Early Eocene age assignment but signify penetration of TM18 and TM19 Microzones respectively. Planktonic foraminifera, in particular *Subbotinae linaperta*, dominate this interval which further substantiates the age and biozonal assignments.

**Palaeoenvironment:** Marine, well oxygenated, outer shelf to upper slope with good open marine circulation.

#### **4.2.3 Interval: 3310' - 3450'**

**Age:** Late Paleocene (Thanetian).

**Microzone(s):** TM23, TM24b.

#### **Interval defined by:**

- the association and first downhole occurrences of *Globigerina triloculinoides* and *Planorotalites chapmani* at 3310',
- the highest downhole occurrence of *Planorotalites pseudomenardii* at 3330', and
- the subsequent downhole occurrence of *Planorotalites compressa* at 3450'.

#### **Micropalaeontological biostratigraphy:**

**TM23 Microzone:** The co-occurrences of *Globigerina triloculinoides* and *Planorotalites chapmani* (= *Globorotalia chapmani* of Church et al, 1979) at 3310' signifies penetration of a level within the Late Palaeocene (Thanetian) and assignment the TM23 Microzone. The subsequent downhole occurrence of *Planorotalites pseudomenardii*, at 3330', corroborates these assignments.

**TM24b Microzone:** The first downhole occurrence *Planorotalites compressa* (= *Globorotalia compressa* of Church et al, 1979), at 3450', signifies continued assignment to the Late Palaeocene (Thanetian) and penetration of the TM24b Microzone.

**Palaeoenvironment:** Marine, well oxygenated, outer shelf to upper slope with good open marine circulation.

#### 4.2.4 Interval: 3460' - 3510'

**Age:** Early Palaeocene (Danian).

**Microzone(s):** TM26b.

**Interval defined by:**

- the co-occurrence of *Globigerina pseudobulloides* and *?Globoconusa daubjergensis* at 3460'.

**Micropalaeontological biostratigraphy:**

**TM26 Microzone:** The co-occurrences of *Globigerina pseudobulloides* and *?Globoconusa daubjergensis* at 3460' signifies penetration of the Early Palaeocene (Danian) and assignment the TM26 Microzone.

**Palaeoenvironment:** Marine, well oxygenated, outer shelf to upper slope with good open marine circulation.

## 5. SHALLOW BOREHOLE 11/20-Sb01

### 5.1 SUMMARISED STRATIGRAPHIC WELL SHALLOW BOREHOLE 11/20-Sb01

Depth / Interval	Age
7.50m	Pleistocene or older
7.66m	Pliocene
----- stratigraphic break -----	
8.18m - 16.37m	Palaeogene undifferentiated
18.75m	Earliest Oligocene - Middle Eocene
18.88m - 20.75m	Eocene or younger

### 5.2. STRATIGRAPHY OF SHALLOW BOREHOLE 11/20-Sb01

#### 5.2.1 Sample: 7.50m

**Age:** Pleistocene or older.

**Nannozone(s):** Unassigned.

**Horizon defined by:**

- the presence of *Gephyrocapsa* spp. (small).

**Nannopalaeontology biostratigraphy:**

**Unassigned horizon:** Extensive Cretaceous and Palaeogene reworking dominates the assemblage. The presence of *Gephyrocapsa* spp. (small) only indicates a broad Pleistocene to Middle Miocene age. Other taxa recorded include *Reticulofenestra minuta* group and *Coccolithus pelagicus*.

#### 5.2.2 Sample: 7.66m

**Age:** Pliocene.

**Microzone(s):** TM1.

**Horizon defined by:**

- the presence of abundant *Neogloboquadrina atlantica*.

**Nannopalaeontology biostratigraphy:**

**TM1 Microzone:** The sample at 7.66m yielded a rich but low diversity microfauna dominated by planktonic foraminifera. The presence of *Neogloboquadrina atlantica* indicates an age no younger than Pliocene and assignment to the TM1 Microzone (N21 Planktonic 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.

**Palaeoenvironment:** Marine, slope/bathyal.

#### 5.2.3 Interval: 8.18m - 16.37m

**Age:** Palaeogene undifferentiated.

**Microzone(s):** Unassigned.

**Nannozone(s):** Indeterminate.

**Interval top defined by:**

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

**Micropalaeontological biostratigraphy:**

**Unassigned Interval:** 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.

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.

**Nannopalaeontology biostratigraphy:**

**Indeterminate horizon:** The sample examined at 9.68m was barren of nannofossils.

**Palaeoenvironment:** Marine, water depth uncertain.

#### 5.2.4 Sample: 18.75m

**Age:** Earliest Oligocene - Middle Eocene.

**Nannozone(s):** NP21 - NP15.

**Horizon defined by:**

- the occurrence of *Reticulofenestra bisecta* and *Ericsonia formosa*.

**Nannopalaeontology biostratigraphy:**

**NP21 - NP15 Nannozones:** The sample yielded a very sparse and poorly preserved assemblage. However, the co-occurrence of *Ericsonia formosa* and *Reticulofenestra bisecta* suggests earliest Oligocene to Middle Eocene age.

**5.2.5 Interval:** 18.88m - 20.75m

**Age:** Eocene or younger.

**Microzone(s):** Unassigned.

**Nannozone(s):** NP12 or younger.

**Interval top defined by:**

- the presence of sparse ?Palaeogene microfaunas within thin sections, and
- the occurrence of *Reticulofenestra* spp. at 20.75m.

**Micropalaeontological biostratigraphy:**

**Unassigned interval:** 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.

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. No age diagnostic forms were recovered, however nannofossil evidence suggests a continued Palaeogene age assignment.

**Nannopalaeontology biostratigraphy:**

**NP12 or younger Nannozone:** The sample examined at 20.75m yielded an impoverished assemblage. The presence of *Reticulofenestra* spp. only indicates an Eocene or younger age.

**Palaeoenvironment:** Marine, water depth uncertain.

## 6. SHALLOW BOREHOLE 16/28-Sb01

### 6.1 SUMMARISED STRATIGRAPHIC WELL SHALLOW BOREHOLE 16/28-Sb01

Depth / Interval	Age
12.78m - 13.80m	Pleistocene
----- stratigraphic break -----	
14.50m - 88.55m	Middle Eocene
89.25m - 145.78m	Early Eocene
145.95m	Palaeocene (undifferentiated)

### 6.2. STRATIGRAPHY OF SHALLOW BOREHOLE 16/28-Sb01

#### 6.2.1 Interval: 12.78m - 13.80m

**Age:** Pleistocene.

**Microzone(s):** QM2.

**Nannozone(s):** NN19b.

**Interval top defined by:**

- the presence of the planktonic foraminifer *Globorotalia truncatulinoides*, and
- the presence in superabundance of the nannofossils *Gephyrocapsa* spp. (small) in the absence of Pliocene markers.

**Micropalaeontological biostratigraphy:**

**QM2 Microzone:** 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.

**Nannopalaeontology biostratigraphy:**

**NN19b Nannozone:** The sample examined at 13.00m yielded a rich, but low diversity assemblage. The co-occurrence of superabundant *Gephyrocapsa* spp. (small) and *Pseudoemiliania lacunosa*, in the absence of Pliocene markers, suggests an intra-Pleistocene age.

**Palaeoenvironment:** Marine, slope/bathyal.

#### 6.2.2 Interval: 14.50m - 88.55m

**Age:** Middle Eocene.

**Microzone(s):** TM15 - TM16.

**Nannozone(s):** NP15.

**Palynozone(s):** Indeterminate, TP16, and TP17a (*pars*).

**Interval top defined by:**

- the presence of the planktonic foraminifer the presence of abundant *Hantkenina dutemplei* at 14.50m,
- the occurrence of *Rhabdosphaera gladius* at 24.70m (the TM15 - TM16 Microzone),
- the subsequent occurrence of *Chiasmolithus gigas* at 34.00m (the NP15 Nannozone),
- the first downhole occurrence of *Diphyes ficusoides* at 87.75m (the TP16 or older Palynozone), and
- the subsequent occurrence of *Eatonicysta ursulae* from 88.55m (the TP17a or older Palynozone).

**Micropalaeontological biostratigraphy:**

**TM15 - TM16 Microzones:** 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 broedermannii*, common *Acarinina bullbrooki*, *Turborotalia frontosa*, frequent *Truncorotaloides rohri*, and abundant *Pseudohastigerina wilcoxensis*, all indicating continued assignment to a Middle Eocene age.

**TM15b - TM16a Microzones:** The subsequent occurrence, at 44.00m of "*Hastigerina*" *bolivariana*, *Truncorotaloides topilensis*, and *Acarinina pentacamerata* indicate Middle - Lower Eocene sediments.

**TM16b Microzones:** There is a major change in the composition of the microfaunal assemblages at 70.79m with the influx of abundant cenosphaerid radiolaria. This is a characteristic of the TM16b Microzone.

**Nannopalaeontology biostratigraphy:**

**NP15 Nannozone:** All the samples analysed from this interval yielded rich and diverse assemblages, dominated by *Reticulofenestra* spp. The continual occurrence of *Rhabdosphaera gladius*, marker species for the NP15 Nannozone, from 24.70m to 81.60m, indicates a Middle Eocene age, the subsequent occurrence of *Chiasmolithus gigas*, a marker restricted to the NP15 (intra) Nannozone, at 34.00 m and 60.55m, further supports this age interpretation. Other taxa consistent with this zonal assignment include *Sphenolithus furcatolithoides* at 34.00m, *Discoaster wemmelensis* and *Chiasmolithus grandis* at 42.00m, *Perma basquense* and *Cruciplacolithus vanheckae* at 52.70m and *Chiasmolithus solitus* throughout the interval.

**Palynological biostratigraphy:**

**Indeterminate interval:** The ten samples from 25.60m - 81.87m are barren of palynomorphs, while the sample at 82.72m yielded an impoverished palynological assemblage including *Areosphaeridium diktyoplokus*, confirming a broad Eocene age. The sample from 83.96m is barren of palynomorphs.

**TP16 (or older) Palynozone:** The three samples from 87.75m - 88.25m yielded diversified dinocyst assemblages, including *Diphyes ficusoides*, indicating an age not younger than Middle Eocene (the TP16 Palynozone). The dinocysts *Systematophora placacantha* (common), *Cerebrocysta bartonensis* and *Homotryblium oceanicum* were also recorded. *Spinozonocolpites echinatus* (*Nypa* spp. of Harrington *et al.*, 2000) was recorded consistently from 88.12m. This taxon is more typically recorded in sediments of Early Eocene or older age.

**TP17a Palynozone (pars):** The additional presence of *Eatonicysta ursulae* at 88.55m indicates penetration of the TP17a (or older) Palynozone.

**Palaeoenvironment:** Marine, slope/bathyal with good oxygenated water masses.

#### 6.2.4 Interval: 89.25m - 145.78m

**Age:** Early Eocene.

**Microzone(s):** TM18?

**Nannozone(s):** NP12 (intra).

**Palynozone(s):** TP17a (pars).

**Interval top defined by:**

- the occurrence of *Chiphragmalithus barbatus* at 89.25m and below,
- the abundant and superabundant counts of *Systematophora placacantha* at 89.51m and 89.91m,
- the first downhole occurrence of common/abundant *Eatonicysta ursulae* at 90.90m (the TP17b - TP17d Palynozone),
- the subsequent occurrence of *Dracodinium condylos* from 113.48m (the TP17d - TP18 Palynozones),
- the subsequent occurrence of *Dracodinium simile* from 130.00m (the intra-TP18 Palynozone), and
- the first sample analysed below the last downhole occurrence of *Systematophora placacantha* at 145.78m (the TP18/TP19 Palynozone).

**Micropalaeontological biostratigraphy:**

**?TM18 Microzone:** A significant 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 cenospaerid radiolaria, in superabundance at 129.55m, signifies a further change in faunal composition. At 138.00m there is a marked influx of superabundant

specimens of large cenosphaerid radiolaria. The presence of common specimens of the planktonic foraminifer *Subbotinae linaperta* is taken as evidence for continued evidence for assignment to the TM18 Microzone.

#### Nannopalaeontology biostratigraphy:

**NP12 Nannozone:** Rich assemblages, dominated by *Reticulofenestra minuta* group and *Coccolithus pelagicus* were recovered from this interval. The continual occurrence of *Chiphragmalithus barbatus* from 89.25m to 143.50m indicates an Early Eocene age and an intra NP12 zonal assignment. Other taxa consistent with this age determination include *Discoaster lodoensis*, *Discoaster kuepperi*, *Toweius* spp. and at 143.50m *Tribrachiatus orthostylus*.

#### Palynological biostratigraphy:

**TP17a Palynozone (pars):** The abundant and superabundant counts of *Systematophora placacantha* at 89.51m and 89.91m is indicative of an early Middle to late Early Eocene age assignment.

**TP17b - TP17d Palynozone:** The twenty-five samples from 90.90m - 112.98m yielded diversified dinocyst assemblages. From 90.90m - 91.73m, *Eatonicysta ursulae* is common/abundant, indicating the TP17b - TP17d Palynozone and penetration of Early Eocene sediments. The association with common *Homotryblium tenuispinosum* and common/abundant *Systematophora placacantha*, and the continued abundant occurrence of the latter down to 92.00m, confirms the zonal assignment. *Polysphaeridium subtile* is common/abundant down to 93.43m. Below this depth, from 94.13m - 112.98m, recovery is relatively poor. *Phthanoperidinium echinatum* is a prominent component of assemblages. No older age indications were encountered. At 112.98m, the first downhole occurrence of *Dracodinium varielongitudum* was noted. Among the angiosperm pollen (not zoned), occasional specimens of *Thomsonipollis magnificus* Group from 112.02m are consistent with penetration of older levels within the Early Eocene.

**TP17d - TP18 Palynozone:** The additional presence of *Dracodinium condylos* from 113.48m confirms a zonal assignment no younger than the TP17d Palynozone. The relatively sparse assemblages from the fifteen samples between this depth and 128.89m are dominated by *Phthanoperidinium echinatum* and, to a lesser extent, *Cerebrocysta bartonensis* Group. There is an increase in pollen from approximately 120.88m. *Inaperturopollenites hiatus* is frequent to common at and below this depth while *Spinozonocolpites echinatus* is common to abundant.

**Intra-TP18 Palynozone:** From 130.00m, the additional presence of *Dracodinium simile* indicates the penetration of older levels within the Early Eocene (the intra-TP18 Palynozone). The samples from 130.00m - 137.93m are comparable to those from the overlying palynozone, being characterised by common/abundant *Phthanoperidinium echinatum* and *Cerebrocysta bartonensis* Group, and abundant pollen, including common/abundant *Spinozonocolpites echinatus* and rare/frequent *Thomsomipollis magnificus* Group. There is an abrupt change at 143.38m, to dinocyst assemblages characterised by abundant *Operculodinium centrocarpum*, common to abundant *Adnatosphaeridium robustum*, *Dracodinium varielongitudum* (from 144.32m - 144.40m), *Deflandrea phosphoritica* (also from 144.32m - 144.40m), *Areoligera* spp. (from 145.46m - 145.69m) and *Dracodinium simile* (at 144.95m), common *Cordosphaeridium gracile*, and reduced pollen recovery. These assemblages, together with the continued presence of frequent/common *Systematophora placacantha* are typical of the intra-TP18

Palynozone. Specimens of *Palaeocystodinium lidiae*, recorded from 136.90m may be reworked.

**TP18/TP19 Palynozone:** The sample at 145.78m contains a comparable assemblage to the immediately overlying palynozone, including abundant *Opercudinum* spp. and common *Adnatosphaeridium robustum* and *Fibrocysta axialis*. However, *Systematopora placacantha* was not recorded, possibly indicating penetration of the TP19 Palynozone. The zonal marker for the latter, *Dracodinium solidum*, was not, however, recorded in the sample. The continued presence of frequent *Eatonicysta ursulae* indicates that the sample is no older than Early Eocene (the TP19 Biozone).

**Palaeoenvironment:** Marine, slope/bathyal, probably slightly restricted water circulation.

#### 6.2.5 Sample at: 145.95m

**Age:** Palaeocene (undifferentiated).

**Palynozone(s):** Indeterminate.

**Horizon defined 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.

## 7. SHALLOW BOREHOLE 83/20-Sb01

### 7.1 STRATIGRAPHY OF SHALLOW BOREHOLE 83/20-Sb01

Depth / Interval	Age
34.00m - 66.81m	Middle Miocene
67.00m - 83.32m	Earliest Middle Miocene - Early Miocene
83.34m - 86.10m	Early Miocene

### 7.2 STRATIGRAPHY OF SHALLOW BOREHOLE 83/20-Sb01

#### 7.2.1 Interval: 34.00m - 66.81m

**Age:** Middle Miocene.

**Microzone(s):** TM5?

**Nannozone(s):** NN6, NN5.

**Palynozone(s):** TP4b - TP5a, Unassigned.

**Interval defined by:**

- the first downhole occurrence of *Unipontidinium aquaeductum* at 25.60m (the TP4b - TP5a Palynozone),
- the occurrence of *Cyclicargolithus floridanus* at 34.00m, and
- the occurrence of *Sphenolithus heteromorphus* at 35.85m.

**Micropalaeontological biostratigraphy:**

**TM5? Microzone:** Long ranging Neogene planktonic and benthic foraminifera occur throughout this interval. No short ranging forms were observed. However, the assemblages present tend to suggest an age assignment no older than Middle Miocene.

**Nannopalaeontology biostratigraphy:**

**NN6 Nannozone:** An extremely rich assemblage, dominated by *Reticulofenestra minuta* group was recovered at 34.00m. The co-occurrence of *Cyclicargolithus floridanus* and *Calcidiscus premacintyrei*, if not reworked, would suggest a zonal assignment of NN6 - NN4, that can be further restricted to the NN6 Nannozone on the basis of the absence of *Sphenolithus heteromorphus*, marker species for the top of the NN5 Nannozone. The presence of common *Hayella aperta* is consistent with this age determination.

**Palynological biostratigraphy:**

**TP4b - TP5a Palynozone:** The five samples from 34.47m - 36.15m yielded comparable dinocyst assemblages characterised by common to abundant occurrences of *Unipontidinium aquaeductum*, *Operculodinium centrocarpum*,

*Spiniferites ramosus* Group and *Tectatodinium pellitum*. The consistent presence of *U. aquaeductum* indicates the TP4b - TP5a Palynozone and a Middle Miocene age. Also of note are rare to abundant occurrences of *Palaeocystodinium* sp. A and *Cannospaeropsis* sp. A (Costa & Downie, 1979). Possible reworking in the interval is represented by *Areosphaeridium arcuatum*, *Chiropteridium* cf. *mespilum* (Oligocene/Eocene) and cf. *Surculosphaeridium?* *longifurcatum* (Cretaceous).

**Unassigned Palynozone:** The three samples from 65.87m - 66.67m yielded sparse dinocyst assemblages including such longer ranging Middle - Early Miocene taxa as *Palaeocystodinium golzowense* and *Impagidinium patulum*.

**Palaeoenvironment:** Marine, slope/bathyal.

#### 7.2.2 Interval: 67.00m - 83.32m

**Age:** Earliest Middle Miocene - Early Miocene.

**Microzone(s):** TM5.

**Nannozone(s):** NN4.

**Interval top defined by:**

- the co-occurrence of *Helicosphaera ampliaperta* and *Sphenolithus heteromorphus*.

**Micropalaeontological biostratigraphy:**

**TM5 Microzone:** As in the overlying interval long ranging Neogene planktonic and calcareous benthic foraminifera continue to occur throughout this interval. However, no short ranging forms or zonal markers were observed.

**Nannopalaeontology biostratigraphy:**

**NN4 Nannozone:** The co-occurrence of *Helicosphaera ampliaperta* and *Sphenolithus heteromorphus* at 67.00m and below, indicates penetration of the NN4 Nannozone of earliest Middle to Early Miocene age. Other taxa consistent with this zonal assignment include, *Cyclicargolithus floridanus*, *Discoaster variabilis*, *D. deflandrei* and *Calcidiscus macintyrei*.

**Palaeoenvironment:** Marine, slope/bathyal.

#### 7.2.3 Interval: 83.34m - 86.10m

**Age:** Early Miocene.

**Microzone(s):** TM7a.

**Palynozone(s):** TP5b.

**Interval top defined by:**

- the first downhole occurrence of *Apteodinium spiridooides* at 83.34m (the TP5b Palynozone), and

- the co-occurrence of *Globorotalia mayeri* and *Globorotalia continuosa* at 86.10m.

**Micropalaeontological biostratigraphy:**

**TM7a Microzone:** The sample at 86.10m yielded a rich microfaunal assemblage dominated by the presence of the planktonic foraminifera *Globorotalia mayeri* and *Globorotalia continuosa*. The later form signifies an age assignment no older than Early Miocene.

**Palynological biostratigraphy:**

**TP5a-b Palynozone:** The four samples from 83.34m - 85.70m yielded dinocyst assemblages including *Apteodinium spiridoides* (at 83.34m and 84.00m), signifying penetration of the TP5b Biozone and an Early Miocene age. The continued presence of *Impagidinium patulum* down to 85.70m indicates an assignment to the TP5b Biozone to that depth. Abundant taxa in assemblages are *Spiniferites ramosus* Group, *Operculodinium centrocarpum* and *Tectatodinium psilatum*.

**Palaeoenvironment:** Marine, slope.

## 8. SHALLOW BOREHOLE 83/24-Sb01

### 8.1 STRATIGRAPHY OF SHALLOW BOREHOLE 83/24-Sb01

Depth / Interval	Age
9.30m - 19.18m	Pleistocene - Late Pliocene
19.30m - 19.38m	Late Pliocene
----- stratigraphic break -----	
19.50m - 30.80	Middle Eocene

### 8.2 STRATIGRAPHY OF SHALLOW BOREHOLE 83/24-Sb01

#### 8.2.1 Interval: 9.30m - 19.18m

**Age:** Pleistocene.

**Microzone(s):** QM2.

**Nannozone(s):** NN18 - NN16.

**Interval defined by:**

- the presence of *Globorotalia truncatulinoides*, *Globorotalia inflata* and *Neogloboquadrina pachyderma* at 9.30m,
- the co-occurrence of *Pseudoemiliana lacunosa* and *Helicosphaera inversa* at 9.40m, and
- the co-occurrence of superabundant *Gephyrocapsa* spp. (small) and *Gephyrocapsa caribbeanica* at 19.00m.

**Micropalaeontological biostratigraphy:**

**QM2 Microzone:** The samples between 9.30m and 19.18m are characterised the superabundance of planktonic foraminifera. The most significant occurrences observed are those of *Globorotalia truncatulinoides*, *Globorotalia inflata* and *Neogloboquadrina pachyderma*. The presence of *Globorotalia truncatulinoides* is consistent with a Pleistocene age and assignment to the QM2 Microzone.

**Nanopalaeontology:**

**NN19a Nannozone:** At 9.40m and 10.00m the co-occurrence of *Pseudoemiliana lacunosa* and *Helicosphaera inversa* suggests a Pleistocene age, restricted to the NN19a Nannozone.

**NN19b Nannozone:** At 19.00m the co-occurrence of *Pseudoemiliana lacunosa* and *Gephyrocapsa caribbeanica* suggests a zonal assignment of NN19, that can be restricted to the NN19b Subzone on the basis of the first downhole occurrence of superabundant *Gephyrocapsa* spp. (small).

**Palaeoenvironment:** Marine, slope.

**8.2.2 Interval:** 19.30m - 19.38m

**Age:** Late Pliocene.

**Microzone(s):** TM1.

**Nannozone(s):** NN19a, NN19b.

**Horizon defined by:**

- the occurrence of *Discoaster triradiatus* and *Pseudoemiliana lacunosa* (common) at 19.30m,
- the continued presence of *Globorotalia inflata* and *Neogloboquadrina pachyderma* at 19.38m.

**Micropalaeontological biostratigraphy:**

**TM1 Microzone:** 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.

**Nanopalaeontology:**

**NN18 - NN16 Nannozone(s):** The co-occurrence of *Discoaster triradiatus* and *Pseudoemiliana lacunosa* (common) at 19.30m indicates a Late Pliocene age. The first downhole occurrence of *Calcidiscus macintyreai* and *Helicosphaera sellii* is consistent with this age assignment.

**Palaeoenvironment:** Marine, outer shelf to upper slope.

**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.

**8.2.3 Interval:** 19.50m - 30.80

**Age:** Middle Eocene.

**Microzone(s):** TM15a (or older).

**Nannozone(s):** NP16 - NP15, NP15 (intra).

**Interval defined by:**

- the presence of *Globigerinatheka* spp. (abundant), *Acarinina broedermanni* (common), and *Pseudohastigerina wilcoxensis* (abundant) at 19.50m,
- the occurrence of *Sphenolithus furcatolithoides* from 19.57m, and
- the subsequent occurrence of *Chiasmolithus gigas* at 30.70m.

**Micropalaeontological biostratigraphy:**

**TM15a Microzone (or older):** 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 broedermannii* (common), and *Pseudohastigerina wilcoxensis* (abundant), indicating a biozonal assignment of TM15a or older, and an age of earliest Middle Eocene.

**Nanopalaeontology:**

**NP16 - NP15 Nannozones:** At 19.57m, the first downhole occurrence of *Sphenolithus furcatolithoides* indicates penetration of Middle Eocene sediments. Other taxa consistent with this age assignment include *Reticulofenestra bisecta*, *Chiasmolithus solitus* and *Reticulofenestra umbilica*.

**NP15 (intra) Nannozone:** The samples at 30.70m and 30.80m yielded rich but poorly preserved assemblages, dominated by *Reticulofenestra* spp. A zonal assignment of NP15 (intra) is based on the occurrence of the marker species, *Chiasmolithus gigas*. The presence of *Reticulofenestra umbilica* at 30.70 and *Pemma* spp. at 30.80m is consistent with this age determination.

**Palaeoenvironment:** Marine, outer shelf to upper slope.

## 9. SHALLOW BOREHOLE 83/24-Sb02

### 9.1 STRATIGRAPHY OF SHALLOW BOREHOLE 83/24-Sb02

Depth / Interval	Age
18.80m	Pleistocene
19.82m - 19.93m	Late Pliocene
----- Unconformity -----	
20.28m - 30.65m	Middle Eocene
30.75m - 38.10m	Early Eocene

### 9.2 STRATIGRAPHY OF SHALLOW BOREHOLE 83/24-Sb02

#### 9.2.1 Sample at: 18.80m

**Age:** Pleistocene.

**Nannozone(s):** NN19a, NN19b.

**Horizon defined by:**

- the co-occurrence of *Pseudoemiliania lacunosa* and *Helicosphaera inversa*,
- the co-occurrence of superabundant *Gephyrocapsa* spp. (small) and *Gephyrocapsa caribbeanica*.

**Nanopalaeontology biostratigraphy:**

**NN19a Nannozone:** At 9.40m and 10.00m the co-occurrence of *Pseudoemiliania lacunosa* and *Helicosphaera inversa* suggests a Pleistocene age, restricted to the NN19a Nannozone.

**NN19b Nannozone:** At 19.00m the co-occurrence of *Pseudoemiliania lacunosa* and *Gephyrocapsa caribbeanica* suggests a zonal assignment of NN19, that can be restricted to the NN19b Subzone on the basis of the first downhole occurrence of superabundant *Gephyrocapsa* spp. (small).

#### 9.2.2 Interval: 19.82m - 19.93m

**Age:** Late Pliocene.

**Microzone(s):** TM1.

**Nannozone(s):** NN18 - NN16.

**Palynozone(s):** Unassogned.

**Horizon defined by:**

- the presence of *Globorotalia inflata*, *Neogloboquadrina atlantica*, and *Neogloboquadrina pachyderma* at 19.93m, and
- the occurrence of subtropical and Quaternary pollen species at 19.82m.

#### **Micropalaeontological biostratigraphy:**

**TM1 Microzone:** The association of superabundant *Globorotalia inflata*, *Neogloboquadrina atlantica* (C), and *Neogloboquadrina pachyderma* (superabundant) signifies a Late Pliocene age assignment for this sample.

#### **Palynological biostratigraphy:**

**Unassigned Palynozone:** The sample at 19.82m yielded only terrestrially derived palynomorphs including subtropical genera such as *Carya*, *Engelhardtia*, *Liquidamber*, *Nyssa*, *Sequoia* and *Taxodium*. These taxa become regionally extinct at high latitudes in the latest Pliocene/Pleistocene. Harrington *et al.* (2000) state that the occurrence of these taxa together with Quaternary species suggests a Late Pliocene age for the assemblage.

**Palaeoenvironment:** Marine, outer shelf to upper slope.

**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.

#### **9.2.3 Interval: 20.28m - 30.65m**

**Age:** Middle Eocene.

**Microzone(s):** TM15 - TM16.

**Nannozone(s):** NP16 - NP15.

#### **Horizon defined by:**

- the occurrence of *Sphenolithus furcatolithoides* at 20.50m,
- the presence of *Globigerinatheka* spp. (abundant), *Acarinina broedermanni* (common), *Pseudohastigerina wilcoxensis* (abundant), and “*Hastigerina*” *bolivariana*, and
- the occurrence of *Reticulofenestra bisecta* and *Ellipsolithus lajollaensis* at 30.65m.

#### **Micropalaeontological biostratigraphy:**

**TM15 - TM16 Microzones:** 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 TM15 - TM16, and an age of Middle Eocene.

#### **Nanopalaeontology biostratigraphy:**

**NP16 - NP15 Nannozones:** The samples analysed from this interval yielded rich and moderately preserved assemblages. The occurrence of *Sphenolithus furcatolithoides* from 20.50m to 23.00m indicates a Middle Eocene age, while at 30.65m the age assignment is based on the occurrence of *Reticulofenestra bisecta* and *Ellipsolithus lajollaensis*. It is however, worth mentioning the presence at 30.65m of Early Eocene taxa (e.g. *Toweius occultatus* and *Toweius* spp.), that are here interpreted as reworked.

**Palaeoenvironment:** Marine, outer shelf to upper slope.

**9.2.4 Interval:** 30.75m - 38.10m

**Age:** Early Eocene.

**Microzone(s):** TM17/TM18.

**Nannozone(s):** NP14 (lower) - NP12.

**Horizon defined by:**

- the presence of *Morozovella marginodentata* and *Acarinina soldadoensis* at 30.75m,
- the co-occurrence of *Toweius* spp. and *Reticulofenestra minuta* group at 37.65m.

**Micropalaeontological biostratigraphy:**

**TM17/TM18 Microzones:** The penetration of Early Eocene carbonates is indicated by the presence of *Morozovella marginodentata* and *Acarinina soldadoensis* at 30.75m.

**Nanopalaeontology biostratigraphy:**

**NP14 (lower) - NP12 Nannozones:** The samples yielded moderately rich, but poorly preserved assemblage, dominated by *Reticulofenestra minuta* group and *Coccolithus pelagicus*. The co-occurrence of *Toweius* spp. and *Reticulofenestra minuta* group suggests an Early Eocene age, even if the more typical marker species are missing.

**Palaeoenvironment:** Marine, outer shelf to upper slope.

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