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ROCKALL CONTINENTAL MARGIN PROJECT
FINAL GEOLOGICAL REPORT

TECHNICAL REPORT WB/95/11C
VOLUME 2: APPENDIX 1
BOREHOLE DRILLING PROGRAMME 1994

M S Stoker

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CONTENTS

Cover Photograph: Two sections of core from an interbedded sequence of upper Paleocene-lower Eocene clastic sediments and fine-grained, basaltic, pillow lavas recovered in borehole 94/3. Three separate pillow lavas were penetrated by this borehole; see Volume 2, Appendix 1, Fig. 10 for stratigraphical details.

The left-hand section (207.87-207.99m) illustrates the contact between the uppermost pillow lava and overlying, shelly, marine sandstones, whilst the right-hand section (208.48-208.62m) shows the contact between the middle pillow lava and overlying, shelly, marine mudstones. In both sections, the outer part of the pillow lavas is cracked, locally fragmented, and partially altered to paler coloured smectite or chlorite. The infiltration of sediment into the cracks suggests that they may represent cooling cracks. The mottled texture of the mudstone (right-hand section) may be due, in part, to the decomposition of the pale coloured, altered, lava fragments enclosed within the sediment.

INTRODUCTION

Background

This report presents a description of the boreholes drilled in September 1994 by the British Geological Survey (BGS) as part of the Rockall Continental Margin Project. The drilling programme was funded by the members of the Rockall Continental Margin Consortium, consisting:

British Gas Exploration and Production
British Geological Survey
BP Exploration Operating Co Ltd
Conoco (UK) Ltd
E E Caledonia Ltd
Elf UK plc
Enterprise Oil plc
Esso Exploration and Production UK Ltd
Mobil North Sea Ltd

Drilling programme

The drilling programme successfully completed 7 of the proposed 10 borehole sites (cf. Hitchen and Stoker, 1994), including all of those in and adjacent to the detailed seismic grid (sub-area A), flanking Rockall Bank. The sites occupied (Fig. 1) and their respective borehole numbers are listed:

Original Plan No:	BGS Borehole No:
372	94/1
376	94/2
370	94/3
373	94/4
379	94/5
375	94/6
378	94/7

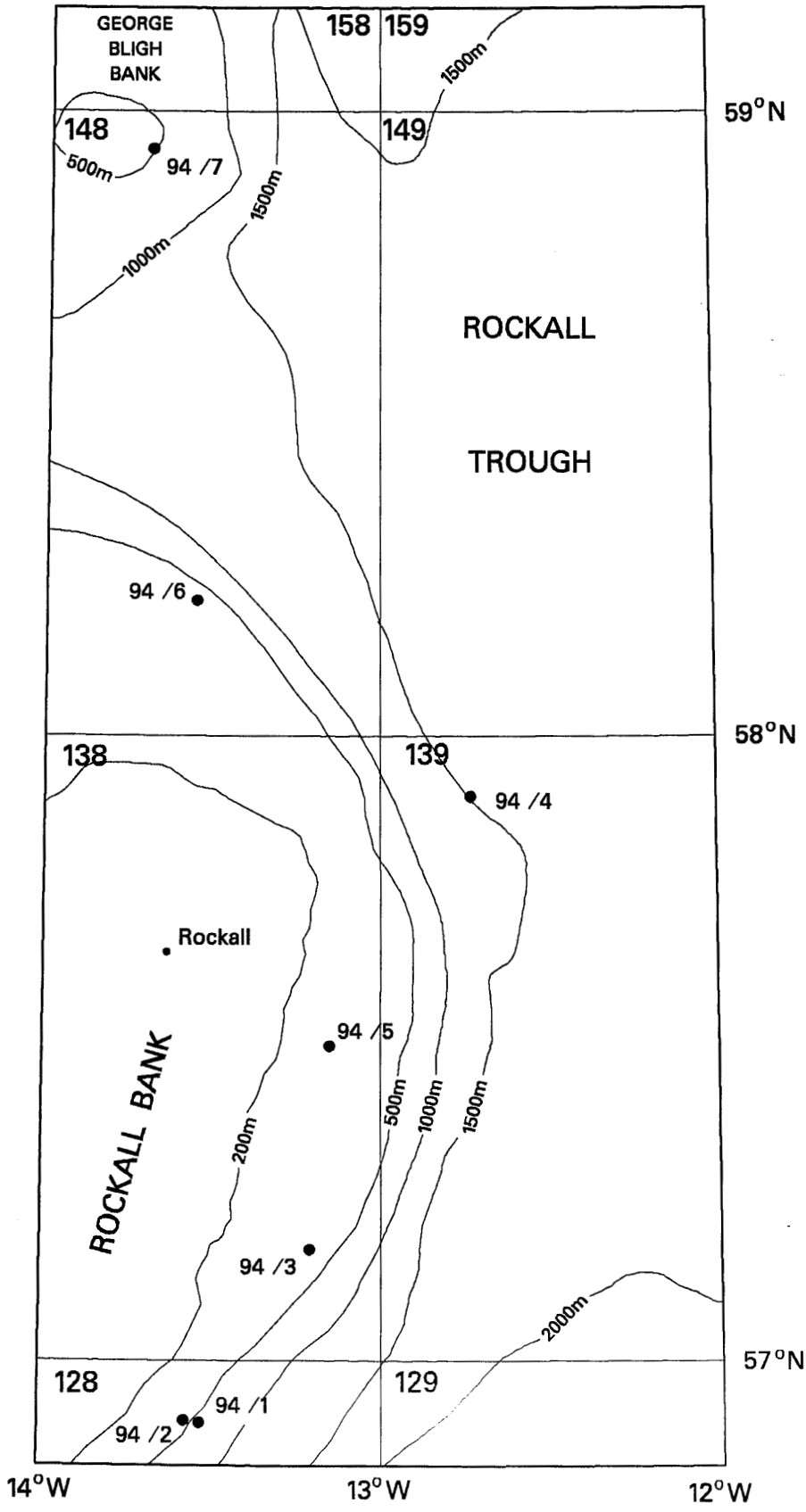


Fig. 1 Location of boreholes drilled during 1994 Rockall Continental Margin Project drilling programme

The rationale governing site selection was based on a combination of factors; geological priority, weather/sea-state, and on-going operational constraints within the time-interval of the cruise. A breakdown of the day-to-day activity, including drilling parameters, equipment performance and time-analysis has been presented elsewhere in the post-cruise operational report (Skinner and Gillespie, 1994).

Report

Each borehole is described separately in terms of its site details, objectives, drilling conditions and lithological characteristics, followed by a brief discussion on the implications of the results. Specialist palaeontological information, provided by the BGS and the University of Sheffield, is detailed in the relevant site chapters. These data have been partly reformatted by the author from the original biostratigraphical reports of Hine (1995a,b), Riding (1994) and Wilkinson (1995a-g). In addition, studies in organic geochemistry and petrography and igneous rock geochemistry were also undertaken by the BGS, the results of which are detailed in appendices 3 and 4 (see Volumes 4 and 5, respectively). Consequently, the shipboard geological observations and preliminary interpretations (Stoker and Gillespie, 1994) have been refined to take into account the results of these specialist studies. The stratigraphical range of the lithologies recovered in each borehole is summarised in Figure 2.

The seismic-stratigraphical setting of each borehole is illustrated in the relevant site chapter, whilst the borehole logs are presented in two forms:

1. Abbreviated summary logs in the site chapters.

2. Detailed composite logs in plastic wallets at the back of the report. All subsampled intervals are indicated on these logs.

All references cited in this report are listed at the back of the volume. This report compliments the geological summary presented in Volume 1.

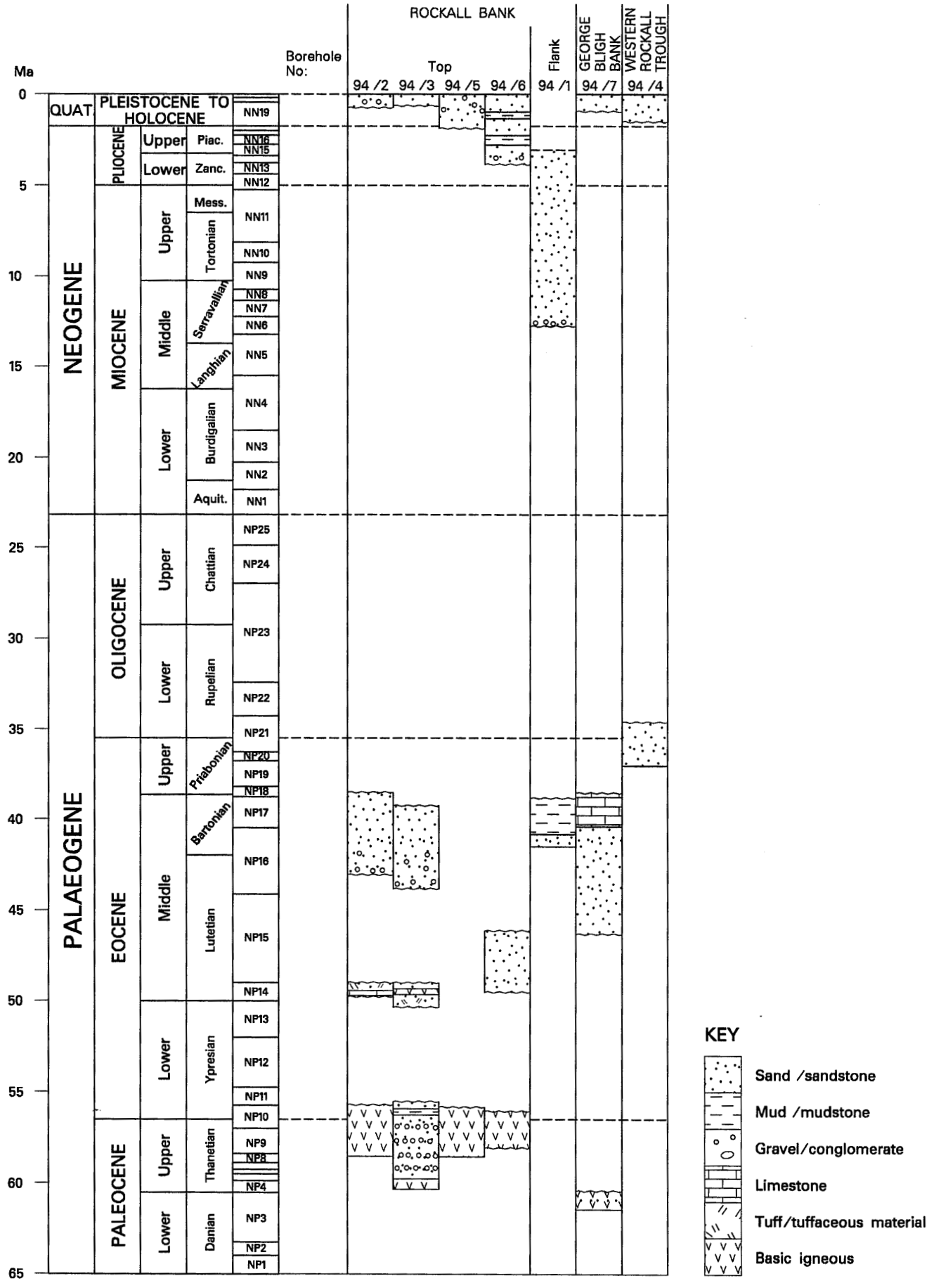


Fig. 2. Stratigraphical–range chart and generalised lithology (not to scale) of Cenozoic strata recovered in BGS boreholes during 1994 Rockall Continental Margin Project drilling programme

Explanatory notes for borehole logs

- All depths referred to on the logs and in the associated notes are in metres below sea bed.

- Each core run was up to a maximum of 6 metres penetration. Complete (100%) core recovery is rarely achieved. Consequently, by convention, all core depths have been measured up from the base of each core run - the maximum penetrated depth for each run. However, the drilling characteristics were constantly monitored and occasionally the positioning of the core in a particular run was modified on the basis of marked changes in the rate of drilling.

- The percentage of core recovery is indicated on the logs; recovered core intervals are shown graphically in black.

- The summary lithological descriptions included with the logs are based on shipboard estimates of grain-size, texture and composition from hand specimens and microscopic analyses.

- The sediments fall into three main lithological groups: siliciclastic, mixed siliciclastic/carbonate and carbonate. These have been further subdivided into textural groups on the basis of the relative proportions of three grain-size components: gravel, sand and mud. The size limits are those defined by Folk (1954). For the consolidated carbonate rocks, the textural classification is that of Folk (1962) which is based largely on the ratio of lime mud to spar forming the matrix.

- The hardness of muds is based on a field test code ranging from very soft (material exudes between fingers when squeezed in the fist) to firm (moderate finger pressure is required to mould) to very stiff (the material cannot be moulded). The suffix 'stone' is used to indicate hard or consolidated equivalents of the unconsolidated sediments.

- The descriptions of the igneous rocks has been greatly enhanced enhanced by post-cruise specialist petrographical study. This is detailed in Appendix 4 (Volume 5) which should be read in conjunction with this report.

- Symbols used to represent the various lithologies are shown in Figure 3.

- Bed thicknesses are defined according to Ingram (1954): laminae, less than 1cm; very thin beds, 1-3cm; thin beds, 3-10cm; medium beds, 10-30cm; thick beds, 30-100cm, and very thick beds, greater than 100cm.

- Sediment colour is most conveniently measured by comparison with a colour chart. The colour chart used in this study is the Munsell (1973 edition) soil colour chart. This is an international correlation tool based on common terms so defined as to obtain descriptive uniformity.

- Subsamples are indicated on the composite logs at their appropriate depth. The abbreviations are explained in Figure 3. The palaeontological subsamples are referenced by a CSC number, eg. CSC8979, which is an internal Marine Geology and Operations Group reference number. This allows for easy cross-reference between the borehole logs and the specialist palaeontological reports which retain this number.

Acknowledgements

The author would like to acknowledge the contributions made by all concerned in the drilling programme. The following people deserve special mention for their contributions to the final borehole report:

BGS

J B Riding and I P Wilkinson, micropalaeontology; R A Nicholson, C D Hughes and B P Vickers, organic geochemistry (Volume 4, Appendix 3); A C Morton, petrography and

Sediments


Mud/Mudstone


Limestone


Sand/Sandstone


Sporadic pebbles


Sand/Sandstone, pebbly


Shells/shell fragments


Gravel/Conglomerate


Plant/wood remains (organic material)

Igneous


Basic igneous


Tuff/tuffaceous material

Subsample abbreviations

MICROPAL: Micropalaeontology

MACROPAL: Macrofauna

CSC8915: BGS palaeontological sample reference number

PETROLOGY: Petrology

ORG GEOCHEM: Organic geochemistry

Fig. 3 Key to lithologic and other symbols used on both the summary and composite borehole logs.

igneous geochemistry (Volume 5, Appendix 4); S A Alexander, computing services; E J Gillespie, draughting and IT skills; D Evans for constructive comment.

External contributor

N M Hine (Industrial Palynology Unit, University of Sheffield), micropalaeontology.

BOREHOLE 94/1

SITE DETAILS

Dates of drilling: 10th-11th September, 1994

Latitude: 56°54.061'N; **Longitude:** 13°31.775'W

Location: Eastern slope of Rockall Bank, 78km south-south-east of Rockall Island

Map area: McCallien

BGS plan no: 372

Block no: 128/3

Water depth: 663m

Sea-bed conditions: Sandy

Total cored: 65.00m; **Recovered:** 12.97m (20%)

Oldest sediment cored:

Sub-bottom depth: 65.00m

Nature: Pebbly sandstone

Age: Mid-Eocene (NP16/17)

Basement: Not reached

Logging: None

SUMMARY

Borehole 94/1 is located on the eastern slope of Rockall Bank, close to the upslope feather-edge of the Feni Ridge sediment drift (Fig. 4). The borehole cored the following sedimentary succession:

0.0-33.45m. Middle Miocene to upper Pliocene (to Holocene*). Muddy sand on basal sandy gravel.

33.45-65.00m. Middle Eocene. Black organic-rich mudstone on pebbly sandstone.

* (Pleistocene and Holocene sediments recovered in adjacent BGS shallow core 56-14/13 (S24) - see Volume 3, Appendix 2).

OBJECTIVES

The primary objective of borehole 94/1 was to test the age and lithology of the sedimentary succession on the western margin of the Rockall Trough, in a location where several seismic-stratigraphical units could be penetrated, including the deeper levels of the Cenozoic succession (Fig. 4). The seismic-stratigraphical units to be tested consisted of the previously informally-named Rockall Trough sequences A and B and Transparent Zone of Hitchen and Stoker (1993). The latter unit is separated from the overlying, upslope-accreting sediment drift by a prominent angular unconformity; reflector C (revised seismic-stratigraphical scheme of this report) in Figure 4. An angular unconformity is also evident within the sediment drift, separating the uppermost draped sediments from the underlying, mainly onlapping strata. This may be equivalent to reflector A in the basin. Before drilling, the sediments below the main unconformity (reflector C) were inferred to be of Palaeogene age; a Neogene to Quaternary age was tentatively assigned to the overlying drift section.

DRILLING

The first attempt to drill this site ended with a twist-off and the loss of six drill collars. The reason for this was obvious upon recovery of the sea-bed template; a spud-in had not been achieved, the drill-bit having drilled through the entry cone and template. This explained the erratic torque throughout this initial attempt, ultimately causing the twist-off. After completion of repairs to the template, the site was re-occupied and spud-in was achieved. Penetration was slow but steady, and core recovery was very poor down to 30m. Despite deteriorating weather - wind speed increased to force 8 and heavy swell conditions - drilling continued to 65m, at which point the completion of the geological objectives and weather combined to terminate the borehole.

RESULTS

The stratigraphical succession cored at this site consists of 33.45 of middle Miocene to upper Pliocene (to Quaternary) sediments overlying middle Eocene strata. A

summary log is presented in Figure 4, and a detailed composite log is included at the back of this appendix.

Middle Miocene to upper Pliocene (to Quaternary)

This section is characterised by very poor recovery of predominantly muddy silty sand on a basal sandy gravel. In the best recovered section, between 22.35 and 23.0m, the sand is massive, very fine-grained, moderately to porly sorted, and carbonate-rich (>95%) with abundant foraminifera and sponge spicules, some of which appear glauconite stained. Scattered coarse to very coarse sand-grade shell fragments are also present. The sands appear bioturbated with some hints of burrows infilled with more terrigenous-rich sands. Traces of sand from higher in the section reveal a more variable siliciclastic/carbonate component, with terrigenous fragments occasionally exceeding 75% of the sand fraction. Sporadic pebbles, up to 6cm length, of siltstone and weathered igneous rocks, together with rare whole bivalve shells up to 2cm length, are also noted. The sands vary from dark olive-grey (5Y3/2) to paler olive (5Y6/3), and are firm to stiff below 20m depth.

An adjacent shallow core, 56-14/13 (S24) (see Volume 3, Appendix 2), recovered thin-to-medium-bedded sands and pebbly sands, with subordinate very thin-bedded muds, between sea bed and 2.1m depth.

The basal sandy gravel is massive and very poorly sorted. It consists of subrounded clasts up to cobble grade, including basic igneous rocks, mudstones and calcareous sandstones. It displays a clast-supported textural framework, the clasts being randomly orientated and disorganised. The matrix consists of olive-grey (5Y4/2), very poorly sorted, muddy, slightly gravelly sand of mixed siliciclastic/carbonate composition (about 40:60). The contact with the underlying Eocene strata is marked by a sharp erosive base and marked colour change.

Calcareous microfaunas (foraminifera and bolboformids) and radiolaria and dinoflagellate cysts suggest a mid-Miocene age (NN6-7) for the borehole section

between 17.0 and 33.45m, whereas calcareous nannofossil data favour a late Miocene to late Pliocene (NN10/12-15) age range. A mid-/late Pleistocene to Holocene age is indicated from the sediments in the adjacent shallow core, 56-14/13 (S24), on the basis of dinoflagellate cyst and calcareous nannofossil data (see Volume 3, Appendix 2).

The geometry of the sediment body as depicted on the seismic profile (Fig. 4), its predominantly fine-grained nature, and the palaeontology, are all consistent with a sediment drift accumulating in an open, deep-marine environment.

Middle Eocene

The middle Eocene sequence consists of 25.03m (33.45-58.48m depth) of mudstones overlying 6.52m (58.48- 65.00m depth) of pebbly sandstones. The mudstones are predominantly black (5Y2.5/2), massive, homogenous and structureless. They are largely siliciclastic in composition, terrigenous detritus forming 99% of the sediment with only rare foraminifera and shell fragments. The sediments are partly bioturbated with silt to very fine sand-filled *Planolites*-type burrows noted. Sporadic sandy intervals and parallel, colour-banded lamination are also observed; the latter marked by reddish-brown laminae, 5-20mm thick, alternating with the more typical black mudstone. The mudstones display a hackly fracture, have a waxy, greasy surface texture, and an aromatic (peaty) smell. Source rock evaluation indicates that they are potential gas-prone source rocks which are immature at this location (see Volume 1, Chapter 5: Prospectivity; and Volume 4, Appendix 3). Between 43.0 and 50.0m depth, thin vugs and fractures are present, infilled by calcite and pyrite. The contact with the underlying pebbly sandstones is sharp; the top of the sandstone section has a mottled yellow-brown to olive-grey colouration and may be a weathered surface.

The pebbly sandstones are very poorly sorted, predominantly fine- to medium-grained but with a silt to very fine-grained carbonate fraction, and common coarse- to very coarse-grained lithic grains and small pebbes. The mixed siliciclastic/carbonate composition is about 50:50, with lithic fragments (including ?glauconite) dominating the terrigenous component, whilst foraminifers are prominent in the carbonate fraction.

Pebbles up to 10mm length are disseminated throughout the section; they mostly display a matrix-supported, randomly-orientated and disorganised texture. Clast types include basic igneous rocks together with silty mudstone (as above), many of which are very well-rounded with have a smooth, shiny lustre. A mottled olive-grey (5Y4/2) colouration partially reflects sporadic bioturbation, which also includes subhorizontal tube-like burrows. The sandstones are variably soft to hard, and indurated.

Foraminiferal and radiolarian data suggest ages of early mid-Eocene and mid-Eocene, respectively, for the sandstone and mudstone sections. In contrast, the sandstones have been dated by dinoflagellate cysts as mid-Eocene (NP16/17) in age, whilst calcareous nannofossils favour an age of mid- to earliest late Eocene (NP16/17-18). An overall late mid-Eocene (NP16-18) age is inferred for the drilled section.

The palynofacies throughout the section is indicative of marine deposition, with abundant plant debris suggesting a nearshore marine setting. However, the recognition of a foraminiferal and radiolarian microfauna within the mudstones identical to that described as the *'Rhabdammina'* or 'flysch-type' biofacies in the North Sea implies that restricted water circulation may have prevailed during their deposition.

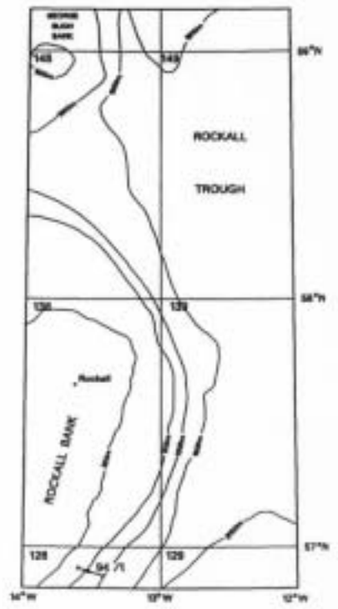
DISCUSSION

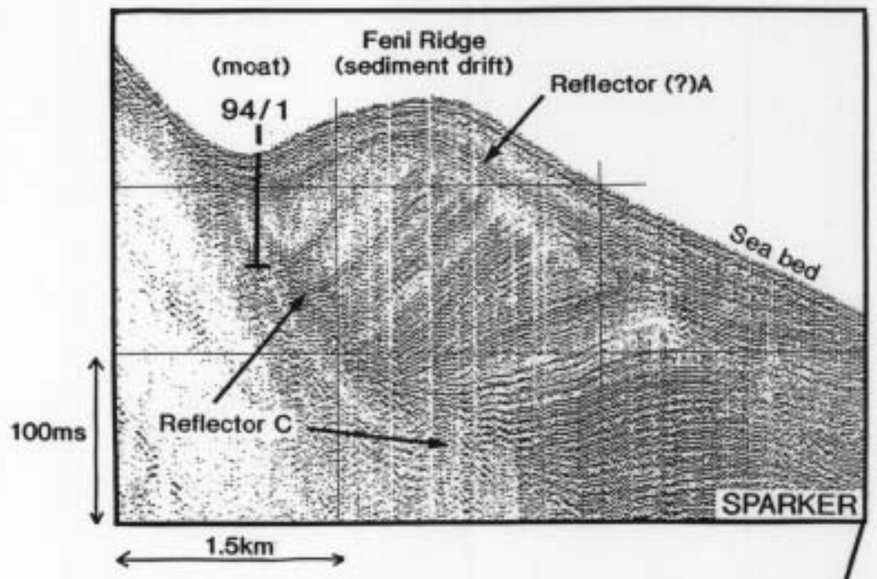
The marked angular unconformity penetrated at about 19m below sea bed may be equivalent to regional reflector A, which has been mapped widely throughout the Rockall Trough study area and can be traced farther to the north-east where it correlates with an intra-Langhian (mid-Miocene) unconformity in BP well 164/25-2 (see Volume 1, Chapter 3: Stratigraphy). On the western margin of the Rockall Trough, this unconformity tends to lose expression, and the overlying sediments are generally much thinner than in the basin. Shallow core data reveal that a post-middle Miocene sediment veneer is widely present on the basin margin, but it is usually beyond the limit of seismic resolution of the profiles collected. At this site, the age data are not inconsistent with the unconformity being equivalent to reflector A of the basin, although poor core recovery precludes a definitive dating of the event. Moreover, the

location of the borehole is at the upslope feather-edge of the Feni Ridge sediment drift, in the moated area which is predominantly an erosional zone. Erosion within the moat by bottom-current activity was concomitant with sediment accumulation on the basinward flank of the drift, hence the gradual upslope accretion. It is likely that some degree of reworking was preserved in Miocene and Pliocene sediments of the drift, as the drift axis migrated towards the slope.

The middle Eocene strata were deposited in a nearshore marine environment. This is incompatible with their present setting, which implies that a phase of post-mid-Eocene subsidence has affected these deposits. The top of the section at the borehole site correlates with reflector C, a prominent basin margin unconformity which is observed on both flanks of the Rockall Trough. At this particular site, the stratigraphy indicates that reflector C represents a hiatus of at least 20Ma.

In terms of the present bathymetric setting of the Rockall Trough, its main development is envisaged to post-date reflector C as all younger strata onlap this unconformity around the margin of the basin. However, the sediments in borehole 94/1 can be broadly correlated with sediments recovered in boreholes 94/2 and 94/3 on the adjacent Rockall Bank, and the increased thickness of sediment on the margin of the trough relative to the bank (Fig. 4) argues for some degree of penecontemporaneous subsidence within the basin, probably linked to the main basin-margin fault.





BOREHOLE 94 /1

STRATIGRAPHY		DEPTH (m)	LITHOLOGY	RECOVERY	SEISMIC REFLECTOR	LITHOLOGY
NEOGENE–QUATERNARY	? UPPER PLIOCENE TO HOLOCENE	10				0.0–33.45m Muddy silty SANDS. Very fine–grained, poorly sorted, mixed siliciclastic/carbonate composition, dark blue grey to pale olive, traces of mud and scattered pebbles. Basal sandy GRAVEL, massive, cobble–grade, very poorly sorted.
	MIDDLE MIOCENE TO UPPER PLIOCENE	20			(?)A	
		30			C	
PALAEOGENE	MIDDLE EOCENE	40				33.45–58.48m Silty MUDSTONE. Massive, structureless, siliciclastic, non–calcareous, black, organic–rich, waxy, greasy, aromatic odour.
		50				
		60	65.0m TD			58.48–65.00m Pebbly SANDSTONES. Massive, bioturbated, fine–medium–grained, very poorly sorted, mixed siliciclastic/carbonate composition, abundant glauconite (?), mottled olive grey.
		70				

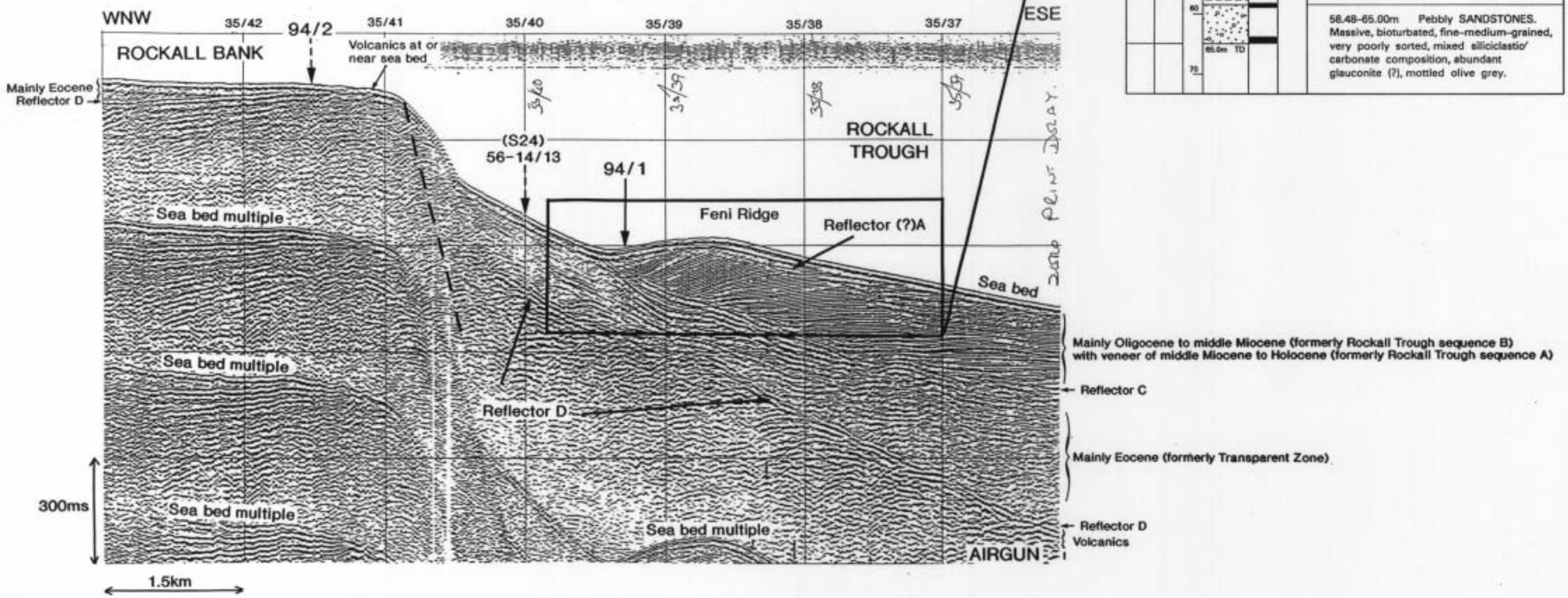


Fig. 4. Seismic-stratigraphical setting of borehole 94/1 with summary log (see text for details). Inset map shows location of borehole and seismic profile.

DINOFLAGELLATE CYST ANALYSIS OF BOREHOLE 94/1

J.B. Riding

Introduction

Eight samples were taken from the borehole; all produced abundant acid-resistant residues and variably abundant palynofloras. Preservation is generally good. Sample details are as follows together with a summary of the palaeontological ages:

CSC No:	Depth (m)	Palaeontological Age
8908	17.00	? Mid-Miocene
8909	22.70-22.73	? Mid-Miocene
8910	33.40-33.41	? Mid-Miocene
8911	33.80-33.83	Undifferentiated Palaeogene
8912	44.97-45.00	Undifferentiated Palaeogene
8913	48.51-48.54	Undifferentiated Palaeogene
8914	58.90-58.92	Mid-Eocene
8915	64.90-64.93	Mid-Eocene

Results

? Mid-Miocene: CSC8908 to 8910

All of these samples yielded abundant and relatively diverse dinoflagellate cyst associations. Several key dinoflagellate cyst species are indicative of a mid-Miocene age. The most useful taxon is *Unipontidinium aquaeductum* (Piasecki 1980) Wrenn 1988, which is present in all three samples. This form is confined to the middle Miocene (Serravallian; calcareous nannoplankton zone NN5-NN6) according to Powell (1992). The consistent presence of *Achomosphaera andalousiensis* Jan du Chêne 1977 refines this dating to mid Serravallian, dinoflagellate cyst zone Aan of Piasecki (1980) and Powell (1992) and calcareous nannoplankton zone NN6 of Martini (1971). The occurrences of the following dinoflagellate cysts support this assessment: *Bitectatodinium tepikiense* Wilson 1973; *Hystrichosphaeropsis obscura* Habib 1972; *Labyrinthodinium truncatum* Piasecki 1980;

Operculodinium sp. of Piasecki (1980); *Palaeocystodinium golzowense* Alberti 1961; *Pentadinium* spp.; *Protoperidinium subinerme* (Paulsen 1931) Loeblich III 1969; *(=Selenopemphix nephroides* Benedek 1972 in the palaeontological literature); *Selenopemphix brevispinosa* Head *et al.* 1989 subsp. *conspicua* de Verteuil & Norris 1992; *Spiniferites pseudofurcatus* (Klumpp 1953) Sarjeant 1970 and *Sumatradinium* spp. (see Edwards, 1984; Powell, 1992; de Verteuil and Norris, 1992; Stover *et al.*, 1995). The assemblages encountered are broadly similar in species content and proportions to those reported from the Miocene of the Rockall Plateau by Edwards (1984). The high proportions of marine microplankton indicate deposition in an open marine setting.

Undifferentiated Palaeogene: CSC8911 to 8913

These three samples yielded residues dominated by light plant tissues; marine microplankton is relatively rare. The sparse dinoflagellate cyst floras are indicative of the Palaeogene/Neogene. Sample CSC8911 includes several rare forms reminiscent of the Neogene (e.g. *Impagidinium* sp., *Operculodinium centrocarpum* (Deflandre & Cookson 1955) Wall 1967 and *?Sumatradinium* sp). However, due to evidence of the Palaeogene from underlying samples (of the same genetic sequence), and the presence of typically Palaeogene forms such as *?Alisocysta* sp., sample CSC8911 is deemed to be of undifferentiated Palaeogene age. Sample CSC8912 did not produce any age-diagnostic dinoflagellate cyst taxa. Its position in the succession indicates a Palaeogene (undifferentiated) age. Sample CSC8913, by contrast, produced a relatively diverse dinoflagellate cyst flora. The occurrence of isolated operculae from the genus *Wetzeliella* is indicative of a Palaeogene age (Powell, 1992). The presence of large proportions of plant tissue, together with marine microplankton, points to a nearshore marine setting.

Mid-Eocene: CSC8914 and 8915

The oldest two samples from borehole 94/01 yielded relatively abundant and diverse dinoflagellate cyst associations of Eocene aspect. Sample CSC8914 was rich in plant debris, however, sample CSC8915 reflects the pebbly sandstone lithology in being rich in resistant mineral grains and having a relatively impoverished palynoflora. *Homotryblium*

tenuispinosum Davey & Williams 1966 was especially common in sample CSC8914. The dinoflagellate cysts indicate a late mid-Eocene (Bartonian) age. The crucial taxon in both samples is *Phthanoperidinium geminatum* Bujak in Bujak *et al.* 1980, which is confined to the Bartonian (calcareous nannoplankton zones NP16/NP17) (Powell, 1992). The presence of *Distatodinium ellipticum* (Cookson 1965) Eaton 1976, *Homotriblium tenuispinosum, Lentinia serrata* Bujak in Bujak *et al.* 1980, *Phthanoperidinium echinatum* Eaton 1976 and *Thalassiphora pelagica* (Eisenack 1954) Eisenack & Gocht 1960 is supportive of this mid-Eocene assessment. The palynofacies of both samples is indicative of marine deposition; the abundant plant debris in sample CSC8914 points to an inshore palaeoenvironment.

CALCAREOUS MICROFAUNAL ANALYSIS OF BOREHOLE 94/1

I.P. Wilkinson

Introduction

Eight samples (CSC8908-8915) from borehole 94/01 were submitted in order to provide a biostratigraphical age determination for the sequence, by means of calcareous microfossils. In addition to foraminifera, Bolboformids (an extinct group, questionably assigned to the calcareous algae) and radiolaria were present. Sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8908	17.00	? Mid-Miocene
8909	22.70-22.73	? Mid-Miocene
8910	33.40-33.41	? Mid-Miocene
8911	33.80-33.83	Mid Eocene
8912	44.97-45.00	Mid-Eocene
8913	48.51-48.54	Mid-Eocene
8914	58.90-58.92	Mid-Eocene
8915	64.90-64.93	Mid-Eocene

Results

? Mid-Miocene: CSC8908 to 8910

Sample CSC8908 contained a sparse, poorly preserved foraminifera of biostratigraphically non-diagnostic taxa. The Bolboformids, however, include *Bolboforma clodiusi* and *Bolboforma badensis*, both of which are indicators of the Miocene and the latter is particularly characteristic of the middle Miocene. Spiegler & von Daniels (1991) show the latter to be most common in nannofossil zones NN6 and NN7, planktonic foraminifera zone N10-12.

CSC8909 again contains Bolboformids, including *Bolboforma reticulata.* This species shows variability in its reticulation from its inception in the (?)latest Oligocene or earliest Miocene to its extinction level in the earliest part of the late Miocene. The morph recovered in the present sample is similar to that in the later part of its range. It is accompanied by the planktonic foraminifer *Orbulina universa*, which has its inception in the earliest mid-Eocene (planktonic foraminiferal zone N9) and *Uvigerina semiornata* is also present indicating an age no younger than the mid-Miocene. Sample CSC8910 is essentially similar to CSC8909.

Mid-Eocene: CSC8911 to 8915

A major change in the microfauna takes place below 33.45m, at the top of a silty, black, organic-rich mudstone. In sample CSC8911, the non-calcareous foraminifera *Psammosiphonella* gr. *discreta* is common together with rare *Reophax* sp, *Trochammina* sp and rare specimens of a large spherical radiolaria, *Cenosphaera* sp. This fauna is identical to that described as the "*Rhabdammina*" or "flysch-type" biofacies in the Labrador Sea, Norwegian Sea and North Sea (Gradstein & Berggren, 1981; King, 1989). It is entirely facies controlled, being indicative of low oxygen, high CO_2, levels at the sediment:water interface, resulting in reduced conditions that preclude the precipitation of $CaCO_3$. It is often, although not exclusively, related to restricted water circulation in areas of deep water.

The age of this interval is problematical, but falls within the mid-Eocene to the earliest part of the Early Oligocene. It is possibly mid-Eocene in age. Very rare specimens, tentatively assigned to *Cribrostomoides scitulus* (which ranges from the mid-Eocene to the Oligocene) were found in sample CSC8912 and 8913. In addition, there are similarities with the North Sea where a *Cenosphaera*-rich zone (NSP6) overlies a *Globigerina* sp. ex. gr. *linaperta* Zone (NSP5) (King, 1983; 1989). Although *Cenosphaera* is not common in the present borehole, the general trend is similar.

Calcareous microfaunas reappear in the top of the fine-medium grained, bioturbated sandstone below 58.48m. The planktonic species *Globigerina linaperta* was recovered

together with the mid- to late Eocene morph (sensu King, 1989) of *Vaginulinopsis decorata, Cibicidoides eocaenus, Quinqueloculina juleana, Uvigerina farinosa* and *Cribrostomoides scitulus.* Again, a mid-Eocene age is indicated.

The lowest sample examined, CSC8915, contains a similar, though more diverse fauna to that of CSC8914. *Vaginulina decorata* subsp. A of King was present, possibly indicating an early to early mid-Eocene age. *Heteropleura dutemplei praecinctus* (mid-Eocene to Oligocene), *Uvigerina spinicostata* (early Eocene to Oligocene) and *Globigerina linaperta* were also found. An early mid-Eocene seems likely. A single specimen of *Vulvulina colei,* which, according to Berggren (1974) is indicative of the Palaeocene, was also present, but in the present borehole it may be reworked.

CALCAREOUS NANNOFOSSIL ANALYSIS OF BOREHOLE 94/1

N.M. Hine

Introduction

Eight samples were submitted for calcareous nannofossil analysis; sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8908	17.00	? Late Miocene to early Pliocene
8909	22.70-22.73	? Late Miocene to early Pliocene
8910	33.40-33.41	? Late Miocene to early Pliocene
8911	33.80-33.83	(None)
8912	44.97-45.00	(None)
8913	48.51-48.54	(None)
8914	58.90-58.92	Mid-Eocene
8915	64.90-64.93	Mid-Eocene

Results

? Late Miocene to early Pliocene: CSC8908 to 8910

These assemblages are dominated by small *Reticulofenestra* and *Dictyococcites* spp. (such as *R. productella, D. antarcticus, R. minutula, R. pseudoumbilicus, R. gelida, R. haqii* and *R. minuta*). Other common species include *Coccolithus pelagicus, Ericsonia ovalis* and *Helicosphaera* spp. Accessory taxa include *Calcidiscus macintyrei, Sphenolithus neoabies, S. abies* and *Rhabdosphaera stylifer*. Six rayed Discoasters are recorded in CSC8908, but are too poorly preserved to be identified to species level. In CSC8910 they are identified as *Discoaster variabilis*.

The placoliths recorded from this sample are generally long-ranging Neogene forms. The mean size of placoliths (esp. *D. antarcticus*), which are medium-sized, may indicate an earliest Pliocene to latest Miocene age, supported by the occurrence of

sphenoliths (*S. abies* and *S. neoabies*). Rare specimens of *Cyclicargolithus floridanus* were recorded in CSC8908. This species has its last occurrence in the Miocene (ranging from the ?Palaeocene to NP6/7). It is here attributed to reworking. *Reticulofenestra reticulata* (NP15-19) was recorded in sample CSC8910 and is attributed to reworking also. There are abundant siliceous microfossils recorded in the smear slides in the form of diatoms and silicoflagellates.

Zonation :- Late Miocene to early Pliocene (NN10/12-15). The absence of short ranging discoasters prevents designation to a more precise biostratigraphic zone.

CSC8911 to 8913

Barren of calcareous nannofossils (no specimens recorded in more than 25 fields of view).

Zonation :- None.

Mid-Eocene: CSC8914 and 8915

These two samples yielded rich and diverse calcareous nannofossil assemblages. Both are dominated by *Reticulofenestra reticulata, R. scrippsae, R. minuta* and *R. bisectus.* Additional species include *R. umbilicus, R. hampdenensis, Blackites spinosa, Ericsonia obruta, Neococcolithes dubius* and *Zygrhablithus bijugatus.* These assemblages can be assigned to zones NP16-18. In addition, CSC8914 contains specimens of *Chiasmolithus grandis* (NP11-17) and *Helicosphaera* spp. (*Helicosphaera* cf. *bramlettei, H. lophata*) which enable it to be assigned to NP17-18. Sample CSC8915 contains *Discoaster barbadiensis.* Reworking of Palaeocene (?NP4-5) material including *Nechiastozygus saepes* and *Toweius* spp.(*T. selandianus*) occurs in both samples.

Zonation :- Eocene, NP 16/17-18 of Martini (1971).

BOREHOLE 94/2

SITE DETAILS

Dates of drilling: 11th-13th September, 1994

Latitude: 56°54.243'N; **Longitude:** 13°34.512'W

Location: Eastern flank of Rockall Bank, 77km south-south-east of Rockall Island

Map area: McCallien

BGS plan no: 376

Block no: 128/3

Water depth: 308m

Sea-bed conditions: Sandy/gravelly

Total cored: 22.15m; **Recovered:** 6.00m (27%)

Oldest sediment cored:

Sub-bottom depth: 20.94m

Nature: Calcilutite

Age: Early mid-Eocene (NP14)

Basement: Basalt

Logging: None

SUMMARY

Borehole 94/2 is located on the eastern edge of Rockall Bank, in an area where acoustic basement is at shallow sub-bottom depth (Fig. 5). The borehole cored the following succession:

0.0-4.81m. Quaternary. Interbedded gravel, muddy sand and gravelly sandy mud.

4.81-20.94m. Middle to lowest upper Eocene. Sandstone and pebbly sandstone with basal conglomerate erosively overlying tuffaceous sandstone on calcilutite with basaltic clasts incorporated at base.

20.94-22.15m. Palaeogene (?upper Paleocene to lowest Eocene). Basalt and thin interbedded tuff.

OBJECTIVES

Borehole 94/2 had two main objectives: 1) to ascertain the age and lithology of the sediments on Rockall Bank, and establish their relations with the slope succession as identified in borehole 94/1; and 2) to test the nature of the acoustic basement marked by reflector D (Fig. 5) on this part of the bank. The sedimentary section on Rockall Bank was previously informally-named the Rockall Bank sequence by Hitchen and Stoker (1993), who, on the basis of seismic-stratigraphical evidence, suggested that it was laterally equivalent to their Transparent Zone within the Rockall Trough. Prior to drilling, a Palaeogene age was envisaged for the sediments on the bank.

DRILLING

Following a period of several hours before a stable spud-in was achieved, slow but steady penetration ensued despite bad weather. Core recovery was poor down to 16.0m, but improved below that depth and a variety of sediments was recovered before basalt was encountered at 20.94m. Coring continued to 22.15m, at which point the torque became erratic and dangerously high, and could have led to a twist-off. As the geological abjectives had been achieved the borehole was terminated.

RESULTS

The stratigraphical succession cored at this site consists of 4.81m of Quaternary sediments unconformably overlying 16.13m of middle to lowest upper Eocene strata, which are partly intercalated with the eroded top of the underlying basalt. A summary log is presented in Figure 5, and a detailed composite log is included at the back of this appendix.

Quaternary

Despite the poor recovery, a varied lithology was proved with gravel overlying muddy sands and sandy muds. The gravel layer consists of two cobbles, up to 8cm diameter,

of subangular to subrounded, grey to pale grey, fine- to medium-crystalline carbonate rock and mottled pebbly sandstone. The latter is very similar to the middle Eocene sediments recovered in the basal part of borehole 94/1. The underlying muddy sands are very poorly sorted, predominantly fine-grained but with scattered medium- to very coarse-grained sand grains. They have a mixed siliciclastic/carbonate composition (about 50:50), with abundant black lithics which impart a dark greenish grey (5BG4/1) colouration to the sand. These are underlain by dark greenish grey (5G4/1), gravelly and sandy muds which are very poorly sorted, massive and bioturbated, with scattered matrix-supported lithic clasts. They are strongly calcareous and give off a H_2S odour. The contact between the sands and muds is sharp, possibly scoured and eroded. The contact between the muds and the underlying bedrock is similarly very sharp.

No micropalaeontological examination of these deposits was undertaken, but in the light of information from boreholes 94/3, 94/5 and 94/6, also on Rockall Bank, this unconsolidated, lithologically-variable veneer is tentatively assigned a Quaternary age. The poor recovery precludes any detailed palaeo-environmental interpretation.

Middle to lowest upper Eocene

The Eocene section can be subdivided into three units: 1) an upper unit of sandstone, pebbly sandstone and basal conglomerate between 4.81 and 19.33m; 2) a middle unit of pebbly muddy tuffaceous sandstone and sandy tuff between 19.33 and 20.81m; and, 3) a lower unit of calcareous mudstone (calcilutite) with basaltic clasts between 20.81 and 20.94m. A synoptic log showing the lower part of the section and the relationships of the three units is illustrated in Figure 6.

Unit 1 (4.81-19.33m): This unit displays an overall upward-fining structure from basal conglomerate through coarse-grained to predominantly medium- to fine-grained sandstones and pebbly sandstones, although very coarse grade sand grains, granules and small pebbles occur disseminated throughout the section. The basal conglomerate is poorly sorted and disorganised, with matrix-supported, subangular clasts, including material from the underlying pyroclastic deposits and shell fragments, set in a coarse-

grained, poorly sorted, mainly terrigenous sandstone matrix. The overlying sandstones and pebbly sandstones are massive to crudely bedded, the bedding depicted by discrete, very thin-bedded, shell-rich beds and partings defined by subhorizontally-aligned shell fragments. The sandstones have a predominantly terrigenous composition with well-rounded to angular quartz and lithic grains comprising 75-95% of the sediment. The lithic fragments include an abundance of weathered igneous grains; subordinate biogenic debris includes bivalves and foraminifera. The siliciclastic grains are locally set in a partially recrystallised carbonate matrix; the latter locally replaced by pyrite in the lower part of the unit. Above 16.62m, the sandstones are black (2.5YN2/) but become mottled olive-grey to dark olive-grey (5Y4/2-3/2) and dark greenish grey (5G4/1-5BG4/1) towards the base. The sediments at the base are hard and indurated. The contact with the underlying unit is relatively indistinct, although the presence of rip-up clasts suggests and erosional boundary.

Unit 2 (19.33-20.81m): This unit consists of dark grey (5Y4/1) to dark greenish grey (5GY4/1) and greenish grey (5BG6/1), muddy tuffaceous sandstones and sandy tuffs, which are massive, poorly sorted, medium- to fine-grained, with occasional randomly-orientated, matrix-supported pebbles. Pyroclastic fragments include common angular ash shards. Pyrite is abundant in the upper part of the unit, as disseminated crystals and discrete veins, whilst carbonate veining occurs near the base. Soft and friable in the upper part of the unit, the sediments become hard and indurated at the base. The contact with the underlying unit is sharp and appears as a ?loaded/partly scoured base.

Unit 3 (20.81-20.94m): This very thin basal unit consists of greenish grey (5BG5/1) to bluish grey (5B5/1) calcilutite, indurated but flaky, including some biogenic debris and cut by carbonate veins. In the lower part of the unit, carbonate sediment becomes intermixed with the eroded top of the underlying basalt; fragments of the latter being incorporated into the carbonate mud.

Foraminifera and calcareous nannofossils suggest a predominantly mid-Eocene age for unit 1, although the nannofossil data imply that the age range may extend into the early part of the late Eocene. Consequently, a mid- to late Eocene (NP16-18) age range is

assigned to this interval. By contrast, units 2 and 3 are assigned an early mid-Eocene (?NP14) age on the basis of the foraminiferal data; calcarous nannofossils are absent from these units. Sparse dinoflagellate cyst assemblages are present throughout the section and are consistent with an Eocene age, although their sparse nature renders them non-age-specific.

The palynofacies of the sandstones in unit 1 suggests marine sedimentation, which is consistent with the presence of shell-rich beds within these deposits. The erosive contact between units 1 and 2 is confirmed by the micropalaeontology as an unconformity surface. The sandstones of unit 2 have a distinct volcaniclastic component indicative of penecontemporaneous explosive volcanism in the area. The fossiliferous nature of the tuffaceous sandstones and the carbonate rocks of unit 3 suggest a shallow marine origin. In the latter unit, the occurrence of a *'Rhabdammina'* or 'flysch-type' biofacies of foraminifera and radiolaria, similar to the North Sea, may be indicative of restricted water circulation (?lagoonal) during its deposition.

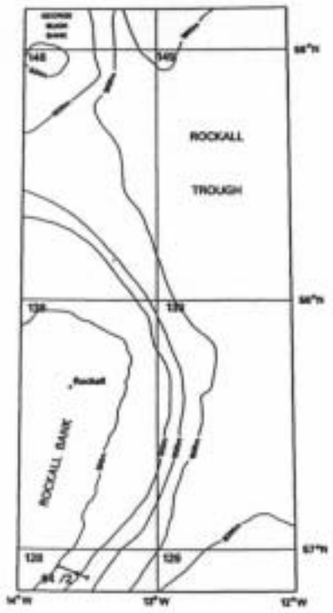
Palaeogene (?upper Paleocene to lowest Eocene)

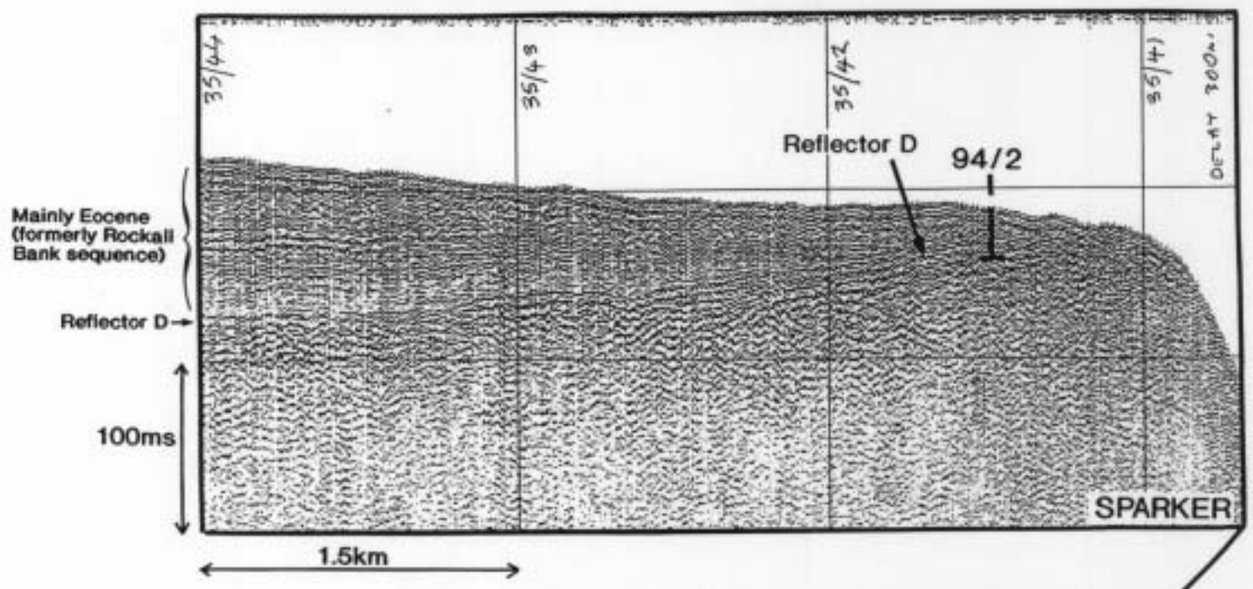
The borehole terminated in a sequence of basalts and interbedded tuffs (Figs. 5 & 6). The basalts are dark grey (N4/), finely crystalline, sparsely vesicular and amygdaloidal, cut by a criss-cross network of carbonate veins. Petrological analysis (see Volume 5, Appendix 4) indicates that the basalts are sparsely plagioclase-phyric, consisting of rare plagioclase phenocrysts set in a groundmass of plagioclase laths, finely-divided opaques and mafic phases, with green-brown ?smectite probably replacing interstitial glass. The basalts are interpreted as extrusive flows. Between 21.45m and 21.53m, a greenish grey (5GY6/1), fine-grained, lithic and crystal tuff is preserved between flows; this appears to be graded with a coarse-grained base and top. The tuffaceous material is set in a sparry carbonate matrix. Regional stratigraphical evidence from elsewhere on the Rockall Bank (see borehole 94/3 - this appendix - and shallow core 57-14/53 (S18) - Volume 3, Appendix 2) suggests a late Paleocene to earliest Eocene age for the basalts and the interbedded tuffs.

DISCUSSION

The Palaeogene record preserved in borehole 94/2 indicates three major phases of volcanism and sedimentation separated by erosional breaks, presumably in response to local tectonism: 1) late Paleocene to earliest Eocene basaltic extrusion and volcaniclastic activity; 2) early mid-Eocene carbonate and clastic marine sedimentation with continuing volcaniclastic activity; 3) mid- to earliest late Eocene clastic marine sedimentation. The timing of these events is directly comparable with similar events identified in borehole 94/3 (see Fig. 8) located about 40km farther to the north-east of borehole 94/2. In particular, there is good correlation of the timing of the main volcaniclastic phase at about late early to early mid-Eocene time. This inter-borehole correlation is significant in that despite the thickness variation of the sediment wedge along the edge of Rockall Bank (see Fig. 3.14 - Volume 1), the same erosional and depositional events are recognised in the cores, though not necessarily on the seismic profile (compare Figs. 5 and 7).

Borehole 94/2 has also demonstrated a correlation between the sediment wedge on the bank and the sediments preserved in the upper part of the Eocene section, at least, in the Rockall Trough. The latter was proved by borehole 94/1 to consist of sediments of late mid-Eocene (NP16-18) age; rocks of the same age comprise the uppermost Eocene unit (1) of borehole 94/2 (Figs. 5 and 6). In common with boreholes 94/3, 94/5, 94/6 and shallow core 57-14/53 (S18), borehole 94/2 has also proved that acoustic basement on the eastern flank of Rockall Bank is formed, at least in part, of volcanic rocks.





BOREHOLE 94/2

STRATIGRAPHY	DEPTH (m)	LITHOLOGY	RECOVERY	SEISMIC REFLECTOR	LITHOLOGY
PALAEOGENE: QUAT. TO HOL. / ? MIDDLE TO LOWER PLIST. / UPPER EOCENE	0				0.0–4.65m GRAVEL, subangular–subrounded cobbles of sparite and pebbly sandstone.
					4.65–4.81m MUDDY SAND, fine-grained, poorly sorted, calcareous, dark greenish grey, on, MUD, pebbly, bioturbated.
	20			D	4.81–19.33m SANDSTONES/PEBBLY SANDSTONES, on thin basal CONGLOMERATE. Massive to crudely bedded sandstone, upwards-fining, coarse to medium-fine-grained, shelly, predominently lithics and quartz set in recrystallised carbonate matrix. Soft and friable, becoming hard and indurated with depth. Black to olive grey to dark grey. Common disseminated pyrite. Basal conglomerate includes rip-ups of underlying strata.
? UPPER PALAEOCEN TO LOWER EOCENE	22.15m TD				19.33–20.94m PEBBLY MUDDY SANDSTONE (Pyroclastic flow?), massive, soft, fine-grained, very poorly sorted, includes ash shards, dark grey to dark greenish grey, on SANDY TUFF(?), hard, lithics, and crystals, carbonate matrix, greenish grey, on CALCILUTITE, hard, flaky, with biogenic debris, greenish-bluish grey, partly intercalated with brecciated top of underlying BASALT. Abundant pyritisation and carbonate veining.
	40				20.94–22.15m BASALT, finely crystalline, vesicular and amygdaloidal, carbonate veining. Thin interbedded TUFF(?), a/a, greenish grey.
	60				
	80				

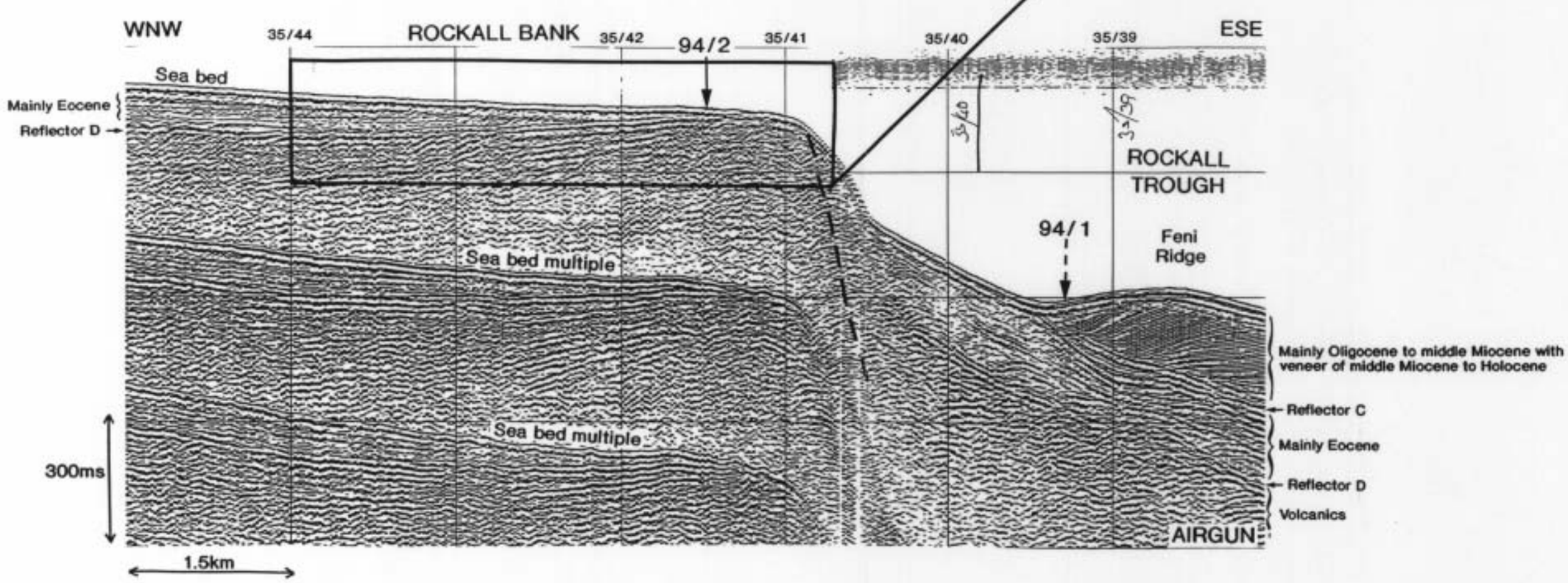


Fig. 5. Seismic-stratigraphical setting of borehole 94/2 with summary log (see text for details). Inset map shows location of borehole and seismic profile.

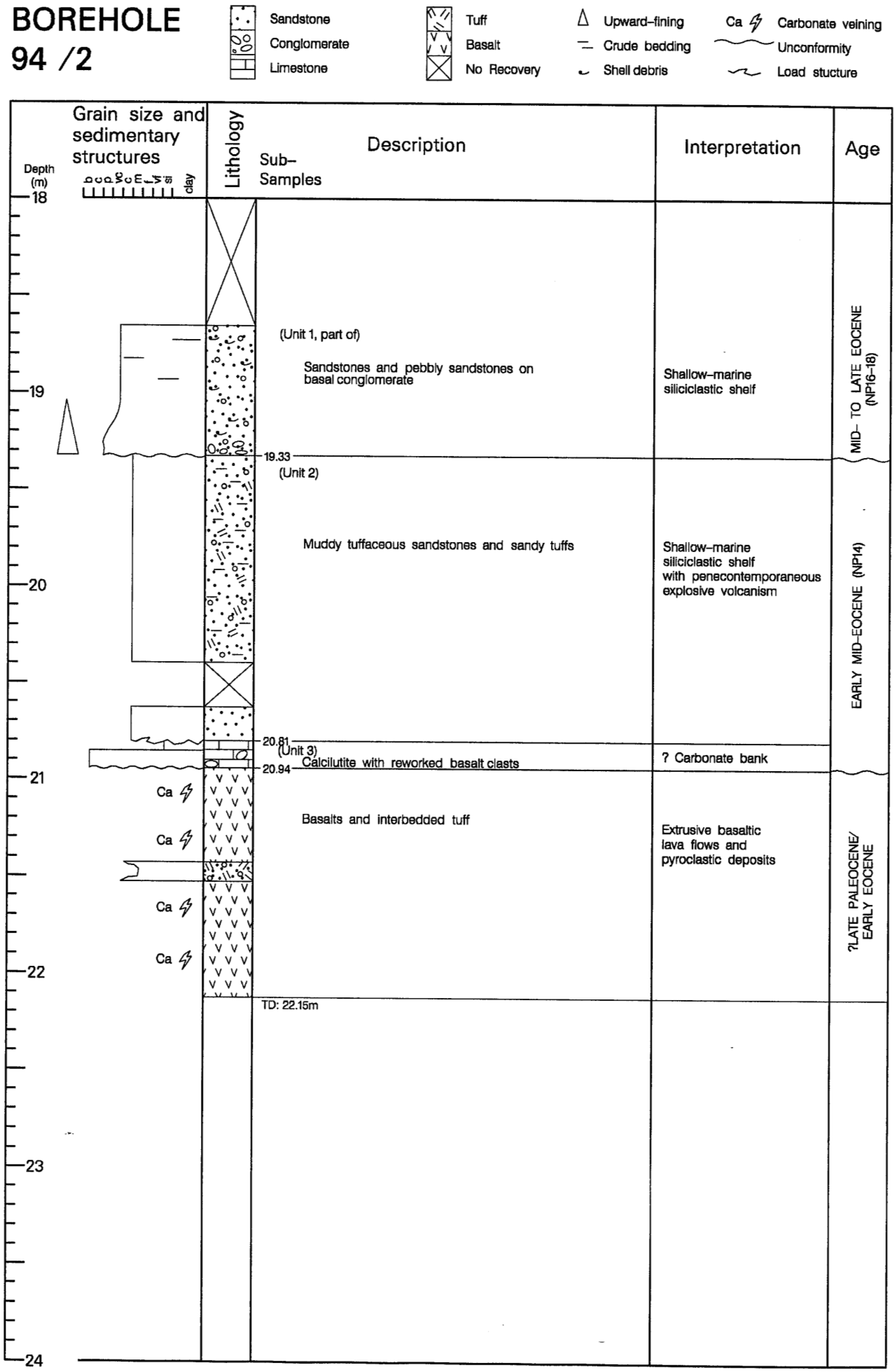


Fig. 6. Synoptic core log: lower part of borehole 94/2

DINOFLAGELLATE CYST ANALYSIS OF BOREHOLE 94/2

J.B. Riding

Introduction

All samples yielded extremely sparse acid-resistant residues and palynofloras; sandstones typically have low organic fractions. Resistant mineral grains and woody fragments are present in relatively high proportions. Sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8916	4.95-4.97	Eocene
8917	15.50-15.53	(Non-age diagnostic)
8918	17.32-17.33	(None)
8919	18.85-18.88	(Non-age diagnostic)
8920	19.69-19.71	(Non-age diagnostic)
8921	20.83-20.84	(Non-age diagnostic)

Results

? Eocene: CSC8916 to 8921

Samples CSC8916 and 8917 produced rare palynomorphs including sparse dinoflagellate cyst associations. Sample CSC8916 consisted of *?Areoligera* sp., *?Cribroperidinium* sp., *?Homotryblium tenuispinosum, ?Homotryblium* sp., indeterminate peridiniacean cyst, *?Operculodinium* sp. and *Spiniferites ramosus* (Ehrenberg 1838) Mantell 1854. This assemblage is most likely Eocene in age (Powell, 1992; Stover *et al.,* 1995); this remains tentative due to the sparsity and poor preservational state of the palynoflora. Sample CSC8917 included *?Protoperidinium* sp, *Spiniferites* sp., together with indeterminate skolochorate and gonyaulacacean forms. This sparse flora is not age diagnostic. Both samples suggest marine deposition. Sample CSC8918 was barren of palynomorphs, whilst samples CSC8919 to 8921 contained extremely rare, non-age diagnostic miospores.

CALCAREOUS MICROFAUNAL ANALYSIS OF BOREHOLE 94/2

I.P. Wilkinson

Introduction

Six samples (CSC8916-8921) were submitted from borehole 94/2 in order that an analysis of the calcareous microfossils could be undertaken to provide a biostratigraphical age determination for the section. In addition to foraminifera, radiolaria were occasionally present. Sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8916	4.95-4.97	Mid-Eocene
8917	15.50-15.53	Mid-Eocene
8918	17.32-17.33	Undifferentiated Eocene
8919	18.85-18.88	Undifferentiated Eocene
8920	19.69-19.71	Undifferentiated Eocene
8921	20.83-20.84	Early mid-Eocene

Results

Mid-Eocene: CSC8916-8921

Sample CSC8916 consisted of a sparse and poorly preserved fauna. Rare Quaternary specimens such as *Neogloboquadrina pachyderma*, *Cibicides lobatulus* and *Gyroidina* sp were present together with *Globigerina* ex gr. *linaperta*, *Bulimina* cf *aksuatica* and *Cibicidoides truncanus*. Whereas the *Bulimina* cf *aksuatica* ranges through much of the Eocene, *Globigerina* ex gr. *linaperta* occurs in the early and mid-Eocene, and *Cibicidoides truncanus* has been widely recorded from the mid- to late Eocene. A mid-Eocene age is therefore indicated for the fossilised part of the fauna, but the poor preservation may suggest that it is reworked.

Samples CSC8917 to 8920 also yielded, presumed, contaminants from the Quaternary together with a number of Eocene species. Sample CSC8917 included *Elphidium* cf. *hiltermanni*, *Globigerina linaperta*, *Uvigerina spinocostata*, *Bolivina cookei*, *Neoeponides karsteni* and *Planulina* cf. *costata*. Of these, King (1989) shows *N. karsteni* to be particularly significant in the North Sea where its range is restricted to the mid-Eocene. Its extinction level was used by King to define the top of NSB5a in the upper part of the Lutetian, a little above the base of Nannofossil Zone NP16. Faunas in samples CSC8918 to 8920 were very sparse and poorly preserved.

Although sample CSC8921 was almost barren, it yielded very rare specimens of the non-calcareous foraminifera *Psammosiphonella* gr. *discreta* and very rare specimens of a large spherical radiolaria, *Cenosphaera* sp. The "*Rhabdammina*" or "flysch-type" biofacies (Gradstein & Berggren, 1981; King, 1989) is probably indicated (see Borehole 94/1), although the sparse nature of the fauna precludes anything but a very tentative suggestion. By analogy with the North Sea, the earliest mid-Eocene may be indicated.

CALCAREOUS NANNOFOSSIL ANALYSIS OF BOREHOLE 94/2

N.M. Hine

Introduction

Six samples were submitted from borehole 94/2 for calcareous nannofossil analysis; sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8916	4.95-4.97	Mid- to late Eocene
8917	15.50-15.53	Mid-Eocene
8918	17.32-17.33	Mid-Eocene
8919	18.85-18.88	(None)
8920	19.69-19.71	Mid-Eocene
8921	20.83-20.84	(None)

Results

Mid- to late Eocene: CSC8916 to 8921

CSC8916: Nannofossils are very rare and badly preserved. Two groups of nannofossils form the assemblage: a late Miocene (?NN10) assemblage and a mid-Eocene assemblage characterised by *Cyclagelosphaera floridanus, Reticulofenestra minuta* and *R. reticulata.*

Zonation :- Mid- to late Eocene, NP16-18 (Martini, 1971).

CSC8917 and 8918: Nannofossils are far more abundant and diverse in sample CSC8917 but are very rare in sample CSC 8918. The assemblage is characterised by *Cyclagelosphaera floridanus, Reticulofenestra hillae, R. hampdenensis, R. pelycomorpha, R. coenura* and *R. dictyoda.* There are a number of large *Toweius* sp. and *Chiasmolithus* spp., but preservation is too poor to identify them to species level.

Zonation :- Mid-Eocene, *Discoaster tani nodifer* Zone, NP16 (Martini, 1971).

CSC8919: Barren of calcareous nannofossils (no specimens recorded in more than 25 fields of view).

Zonation :- None.

CSC8920: Nannofossils are very rare and poorly preserved. The assemblage is characterised by *Cyclagelosphaera floridanus, Reticulofenestra hillae, R. umbilicus, R. pelycomorpha* and *Chiasmolithus* sp..

Zonation :- Mid-Eocene, *Discoaster tani nodifer* Zone, NP16 (Martini, 1971).

CSC8921: Barren of calcareous nannofossils (no specimens recorded in more than 25 fields of view).

Zonation :- None.

BOREHOLE 94/3

SITE DETAILS

Dates of drilling: 12th-19th September, 1994

Latitude: 57°10.740'N; **Longitude:** 13°12.521'W

Location: Eastern flank of Rockall Bank, 54.5Km south-east of Rockall Island

Map area: Rockall Island

BGS plan no: 370

Block no: 138/24

Water depth: 280m

Sea-bed conditions: Sandy

Total cored: 209.65m; **Recovered:** 100.84m (48.1%)

Oldest sediment cored:

Sub-bottom depth: 208.6m

Nature: Mudstone

Age: Late Paleocene to earliest Eocene (NP4-10/11)

Basement: Interbedded pillow lava and sediment

Logging: None

SUMMARY

Borehole 94/3 is located on the eastern flank of Rockall Bank, in an area where the sediment wedge on the edge of the bank is acoustically well-defined (Fig. 7). The borehole cored the following succession:

0.0-@12.00m*. Quaternary. Siliciclastic, bioturbated muddy sand.

12.00-34.35m. Upper middle Eocene. Muddy sand on cobble gravel.

34.35-135.94m. Uppermost lower Eocene to middle Eocene. Interbedded mudstone, sandstone and conglomerate, tuffaceous in lower part of section, and with thin basalt flow near top of section.

*(Base of Quaternary may be as deep as 18.0m: see below for details)

135.94-207.94m. Upper Paleocene to lowest Eocene. Interbedded sandstone and conglomerate with occasional mudstone.

207.94-209.65m. Upper Paleocene to lowest Eocene. Interbedded submarine basalt (pillow lava) and shelly mudstone.

OBJECTIVES

Borehole 94/3 had several key objectives: 1) to ascertain the nature of the acoustic basement; 2) to test the age and lithology of the overlying prograding sediment wedge on the edge of Rockall Bank; and, 3) establish a Palaeogene stratigraphical framework for the western margin of the Rockall Trough. The latter would enable correlation across the Rockall Continental Margin, linking in with the established stratigraphical schemes on the Hebrides Slope and the south-west Rockall Plateau. The seismic-stratigraphical units to be tested included the previously informally-named 'pre-wedge' strata and overlying Rockall Bank sequence of Hitchen and Stoker (1993). Under the revised seismic-stratigraphical reflector notation, these units are represented, respectively, by the D (acoustic basement) -C_2 and the C_2-C (essentially sed bed) seismic intervals (Fig. 7); the latter is now further subdivided by the C_1 reflector. All of these units have been mapped on several adjacent seismic profiles crossing the eastern edge of the bank (see Volume 1, Chapter 3: Stratigraphy). Prior to drilling, a predominantly Palaeogene age was envisaged for the sediments of the prograding wedge.

DRILLING

The drilling operation began smoothly although progress was fairly slow, and at 44.5m depth penetration had all but ceased. In failing weather conditions, the hole was filled with heavy mud and the drill-string was tripped in a force 9 gale with heave reading 5 metres. The problem was the stratapax drill-bit which as completely balled-up and with many of the port discharges blocked. This was substituted with the BGS 4-cone roller-bit and the drill-string was re-run. However, a continuing force 9 gale and a 9m heave caused a temporary halt for 1.5 hours before an acceptable heave was monitored.

Running the drill-string recommenced and re-entry into the hole was achieved in force 8 wind conditions. The previous TD of 44.5m was successfully realised and subsequent drilling went smoothly with only occasional bit-blocking and torque affecting the drill-string. The borehole was drilled over a period of 7 days during which variable weather conditions were experienced, and at one stage the vessel had to turn through 200 degrees to head to the prevailing weather conditions. The borehole was terminated at 209.65m with the geological objectives having been achieved. Recovery in the lower part of the borehole was exceptionally good (Fig. 8).

RESULTS

The stratigraphical succession cored at this site consists of about 12m of Quaternary sediments overlying Palaeogene strata. The latter can be subdivided into four units - upper middle Eocene, upper lower Eocene to middle Eocene, upper Paleocene to lowest Eocene sediments, and upper Paleocene to lowest Eocene basalts - which are recognised both in the borehole and on the seismic profile. These units are separated by the reflectors C_1, C_2 and D; reflectors C_1 and C_2 represent unconformities within the sediment wedge, whilst reflector D is the acoustic basement (Fig. 7).

Due to the excellent recovery, particularly in the lower part of the borehole, summary lithological descriptions are presented in Figure 8, and in the composite log at the back of this appendix. In order to avoid a major repetition in the text, only the most salient characteristics of the succession are detailed below.

Quaternary

This section consists of very thin- to thick-bedded, poorly sorted, bioturbated, dark greenish grey (5G4/1) to dark olive-grey (5Y3/2) and black (2.5/2), muddy sands, which are composed predominantly of terrigenous material with subordinate scattered shell debris. Matrix-supported lithic clasts, up to 1cm length, include soft mudstone intraclasts. Bed thickness varies from 3 to 84cm; bed contacts vary from sharp to

gradational with upward-fining and -coarsening textures locally evident. Between 12m and 18m depth, the sands display a more massive texture.

Dinoflagellate cysts indicate a Quaternary age for the section down to about 12m. In contrast, the foraminifera suggest that Quaternary strata may extend down to 18m depth. Calcareous nannofossils indicate much reworking, with common late Paleocene species. This poor definition of the base of the Quaternary section is due partly to the poor recovery, which enhances the probability of downhole contamination within the samples that were recovered, and partly to the likely effects of reworking of the underlying strata due to the environmental setting. The borehole is sited on a wave-cut platform or terrace (Fig. 7), and the Quaternary sediments are likely to represent shoreline deposits derived, in part, from the underlying sediments. The platform/terrace is one of several that can be mapped along the edge of Rockall Bank, and are envisaged to have formed during low sea-level stands during the Quaternary. These features are complimented by the discovery of a shallow-marine sand bar or ridge on the top of the bank, proved in borehole 94/5 (this appendix).

Upper middle Eocene

This section extends from about 12m to 34.35m, the base of which is marked by reflector C_1. On the airgun profile in Figure 7, reflections within the upper middle Eocene unit appear to downlap onto the unconformity surface that is reflector C_1. Subsequent erosion during the Quaternary has cut into this unit forming the sub-horizontal wave-cut terraces or platforms.

Borehole 94/3 shows this unit to consist of dark grey (5Y3/1) to black (2.5/2), massive muddy sands on cobble gravel, although the entire interval is characterised by poor recovery. The sands are slightly pebbly and poorly sorted, and mainly terrigenous in composition. The gravel includes clasts of pebbly sandstone and basalt.

Diniflagellate cyst analysis indicates a late mid-Eocene (NP 16-17) age for this section, which is not inconsistent with the foraminiferal data. Calcareous nannofossils suggest

an older, Paleocene (NP6-8) age; however, the assemblages are low in numbers and diversity, and poorly preserved, and are probably reworked. The consensus of biostratigraphical data favours a mid-Eocene age. The palynofacies implies a nearshore-marine environment of deposition; the gravel may represent a beach deposit.

Uppermost lower Eocene to middle Eocene

This section extends from 34.35m to 135.90m, and represents the seismic interval C_2 to C_1 on Figure 7. Reflections within this unit vary from slightly irregular to shingled and prograding, with downlap onto the basal unconformity, reflector C_2. The latter is slightly irregular in form, and has cut into the underlying strata. Reflector C_2 may downlap onto reflector D (acoustic basement) at the edge of the bank where the underlying sediments have been eroded away.

Borehole 94/3 penetrated ten main lithological units within this section, primarily sandstones with variable mudstone, conglomerate and volcanic components (Fig. 8). With the exception of the uppermost silty sandstone unit, which contains scattered shell debris, the bulk of the sediments have a dominantly siliciclastic composition. Their immature character, together with locally common organic debris and sparse microfossils, suggest a fluctuating fluvio-deltaic to paralic depositional setting. The contact with the underlying sediments is marked by an erosive unconformity in the borehole (Fig. 9), which is correlated with reflector C_2. In the borehole, this contact is sharp and partly scoured, and separates fluvio-deltaic sediments above from shelly marine sandstones below.

The volcanic component includes common tuffaceous material in the lower part of the section, and a single, thin, extrusive basalt flow near the top of the unit. The tuffaceous material extends between about 90.0m and 135.9m, the base of this section. Indeed, the appearance of volcaniclastic material immediately above the unconformity surface of reflector C_2 (Fig. 9) marks the first indication of explosive volcanic activity in this area, as recorded in the borehole. Between 135.94m and 117.59m, the tuffaceous material occurs as common, soft, white, clayey grains disseminated throughout the

sediments or forming discrete laminae and very thin beds, which are commonly light and aerated. However, between 117.59m and 110.0m the clayey tuffaceous material is predominant forming a distinct, white to pale yellowish brown (2.5Y6/4) and greyish green (5G4/2), claystone interval with sporadic very thin- to thin-bedded sandstones. From 110.0m to about 90m, the tuffaceous material appears, again, as highly disseminated specks and thin beds. Petrological analysis (see Volume 5, Appendix 4) indicates that the volcaniclastic material consists largely of altered, highly vesicular and acidic volcanic glass, best described as pumice. These rocks probably resulted from explosive activity caused by the fragmentation of intermediate/acidic lavas flowing into water. Of particular note is their lack of resemblance, both in terms of texture and composition, to the tephras characteristic of the Balder Formation, and they are probably local in origin.

The thin basaltic flow occurs between 51.0m and 47.26m, and is black, finely crystalline, vesicular and highly fractured. Petrological analysis (see Volume 5, Appendix 4) indicates that it is aphyric, consisting of plagioclase laths, opaques and clinopyroxene set in a groundmass of brown smectite (replacing glass). The basalt lacks an obvious trachytic texture.

Foraminifera from near the base of this section indicate a late early Eocene to early mid-Eocene (NP13-14) age; this is not inconsistent with the dinoflagellate cyst data which includes early Eocene (?NP12) species.

Upper Paleocene to lowest Eocene

This section extends from 135.94 to 207.94, and represents the seismic interval D to C_2 on Figure 7. Reflections within this unit appear to downlap onto the acoustic basement and prograde towards the edge of the Rockall Bank. The top of the unit has been eroded (as described above).

Borehole 94/3 penetrated five main lithological units of this age, predominantly sandstones with variable conglomerate and mudstone components (Fig. 8). The upper

and lower sandstones are shelly and appear to represent shoreline and shallow-marine deposits. The top of the upper sandstone is stained yellow-brown to a depth of 30cm below the unconformity of reflector C_2, which may represent a zone of weathering and oxidation associated with the ensuing erosional hiatus.

The thickest unit within this section occurs between 153.5m and 188.75m, and consists of interbedded pebbly sandstones and sandy conglomerates. Sub-horizontally aligned clasts, together with parallel to ripple cross-laminated, locally graded beds, some with erosive scoured bases, indicate a predominantly waterlain origin. Patchy carbonate cementation, usually restricted to specific horizons, may reflect early diagenesis. Sporadic disorganised beds of massive conglomerate imply episodic mass-flow deposition. An alluvial origin is envisaged for this unit, perhaps a mid- to lower fan setting. A transitional change between the basal shallow-marine sandstones and this non-marine unit is an indication of the fluctuating environmental settings on the outer bank at this time. It also demonstrates a less-dramatic rate of change than that associated with the development of the unit-bounding unconformities.

The base of this section is inferred to rest on acoustic basement, interpreted to consist of interbedded volcanics and sediments.

Foraminiferal and dinoflagellate cyst assemblages yielded late Paleocene to earliest Eocene (NP10/11) species. In contrast, calcareous nannofossils suggest a slightly older, late Paleocene (NP4-8) age. An age range of late Paleocene to earliest Eocene (NP4-11) is tentatively assigned to this section.

Upper Paleocene to lower Eocene (acoustic basement)

The section between 207.94m and 209.65m is interpreted to represent the uppermost part of the acoustic basement marked by reflector D. On the seismic profile (Fig. 7), sub-parallel reflections are locally observed to shallow depth below reflector D, and may indicate an interlayered volcano-sedimentary section. On adjacent seismic profiles, reflector D locally separates strata with angular discordance.

Borehole 94/3 penetrated three basaltic pillow lavas interbedded with black to dark greenish grey (5GY4/1) shelly mudstones (Fig. 10). The top and base of each pillow is highly convoluted; the top is also partly brecciated, with lava clasts enclosed in the overlying sediment (see cover photograph), including the shelly sandstones interpreted to lie immediately above reflector D. This dramatic change from mudstone to sandstone sedimentation may indicate a sudden shallowing of the marine depositional environment, which may be responsible for the change in reflection character from parallel-bedded below reflector D to progradational in the overlying section.

Petrological analysis (see Volume 5, Appendix 4) indicates that the basalts are medium-grained, non-vesicular, and sparsely plagioclase-phyric. They consist of rare plagioclase phenocrysts set in a groundmass of plagioclase laths, opaques, clinopyroxene and smectite (replacing ?olivine and interstitial glass). The basalt has a well-defined trachytic texture. The interbedded mudstones are massive and bioturbated with sand-filled burrows. Shell debris is common. The lower bed has a distinct 'soapy' feel. Microfossil analysis is as reported for the overlying section (see above), and indicates a late Paleocene to earliest Eocene (NP4-11) age.

DISCUSSION

Borehole 94/3 provides an exceptionally good record of fluctuating early Palaeogene palaeo-environments associated with tectonism and volcanism on the Rockall Bank. The discovery of pillow lavas is the first unambiguous documentation of this style of subaqueous fissure extrusion on the margin of the Rockall Trough. The late Paleocene/earliest Eocene timing of this volcanism is comparable with that recorded elsewhere on the Rockall continental margin, including the Hebridean region, Hatton-Rockall Basin and south-west Rockall Plateau (cf. Hitchen and Ritchie, 1993; Stoker and Gillespie, 1994). Whilst the subsequent early to mid-Eocene volcanism - the volcaniclastic tuffs and extrusive basalt flow - is generally later than that recorded in the Hebridean region, volcanism persisted on the south-west Rockall Plateau into late mid-Eocene time. The closer location of Rockall Bank to the Iceland Basin spreading

axis at this time (cf. Stoker and Gillespie, 1994) may account for the slightly younger record of volcanism on the bank as compared to the more distant Hebridean region.

The punctuated record of sedimentation correlates well with the seismic profile, and indicates discrete phases of bank-edge progradation associated with the overall development of the outer bank sediment wedge. The unconformities which separate the main units reflect episodes of tectonism, in part, linked to volcanism. In particular, the first indications of explosive volcanism occur immediately above reflector C_2. Whilst the fluctuating palaeo-environments reflect changes in relative sea level, the combination of the seismic and borehole data suggest that such changes were most probably tectonically controlled along the edge of the bank. Boreholes 94/2 and 94/6, which penetrated smaller, separate depocentres on the eastern edge of the bank, also record phases of volcanism and sedimentation which correlate well with those preserved in borehole 94/3 (Fig. 8). This suggests that the bank may have been acting essentially as a single block during this interval, although the variable thickness between the different depocentres (see Volume 1, Fig. 3.14) implies some focusing of sediment deposition. Slightly different pulses of sedimentation and volcanism preserved on the south-west Rockall Plateau (cf. Stoker and Gillespie, 1994) supports the concept of tectonism as the major control on sequence deposition on the Rockall continental margin at this time.

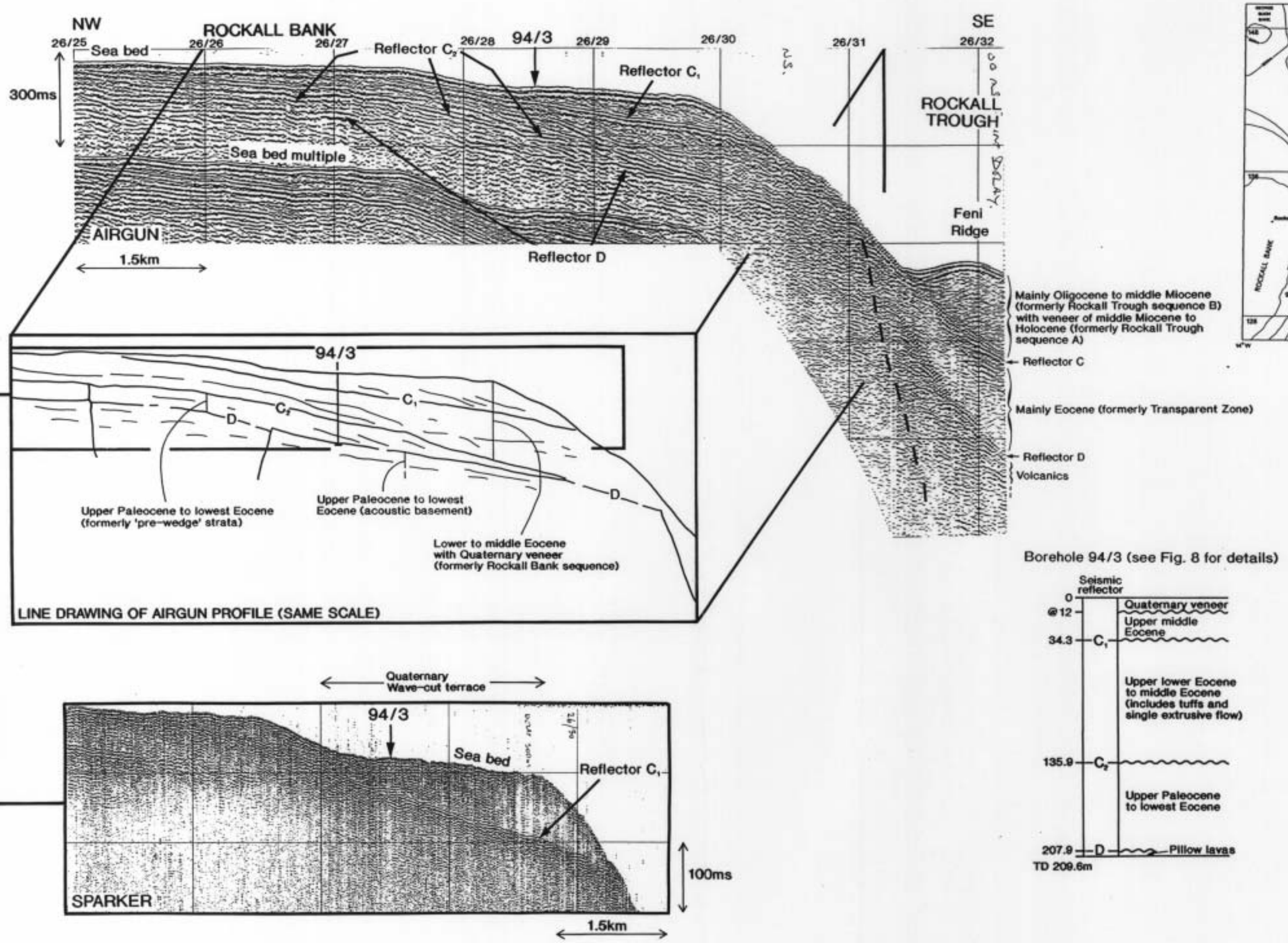


Fig. 7. Seismic-stratigraphical setting of borehole 94/3 with summary log (see text for details). Inset map shows location of borehole and seismic profile.

BOREHOLE 94 /3

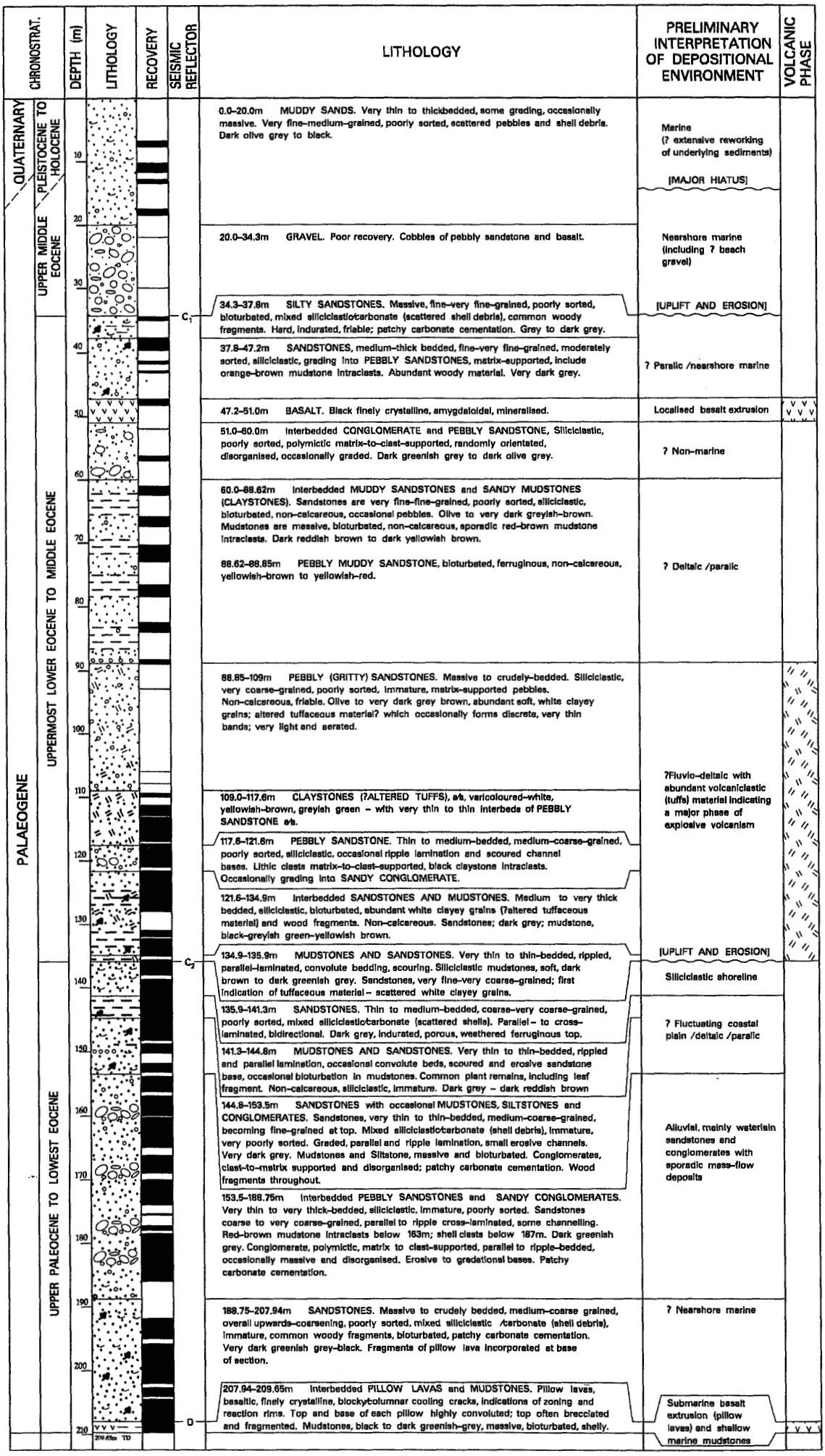


Fig. 8. Detailed summary log of borehole 94 /3

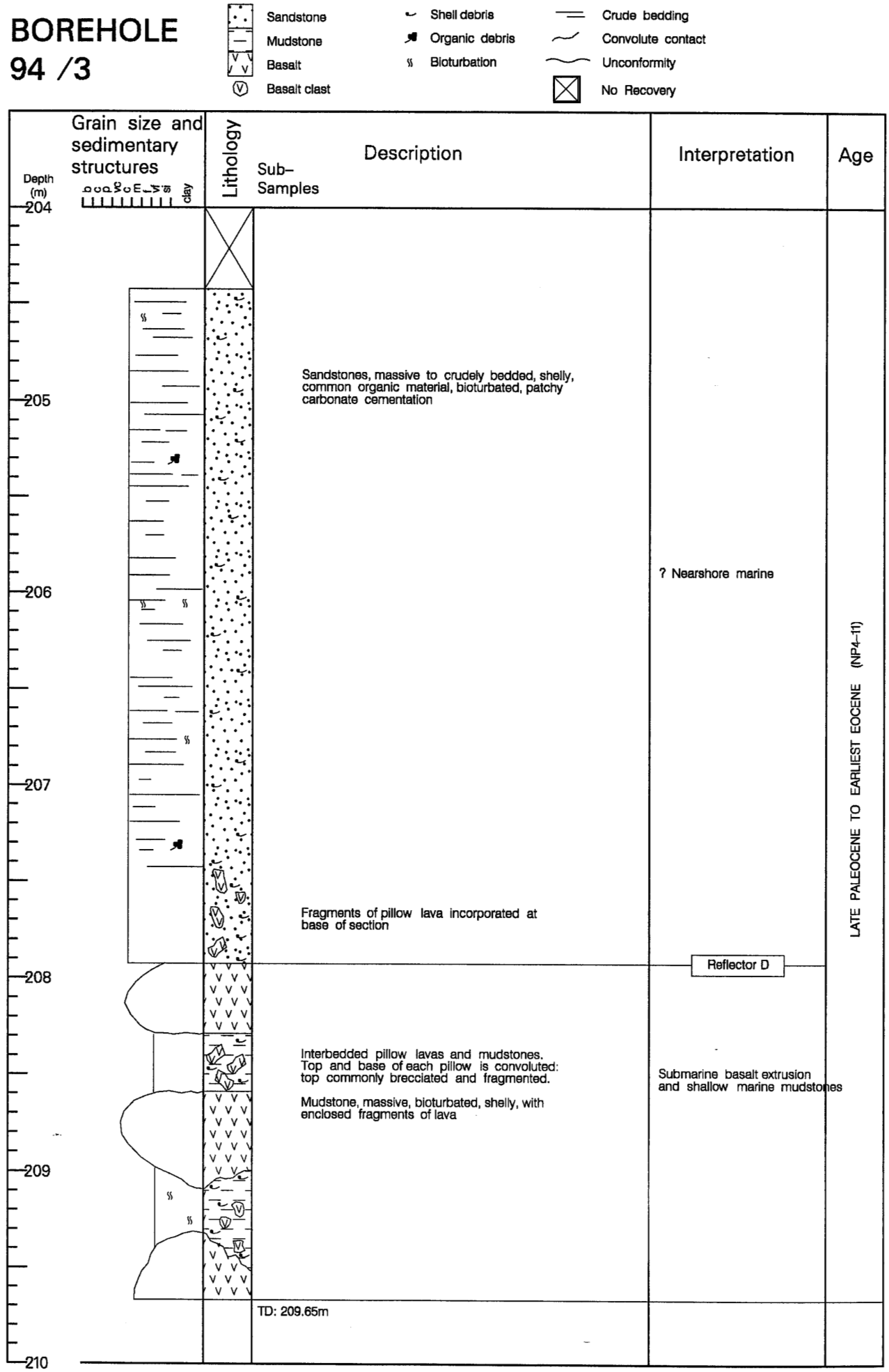


Fig. 10. Synoptic core log: borehole 94 /3 (204.41–209.65m)

Sediments


Mud/Mudstone


Limestone


Sand/Sandstone


Sporadic pebbles


Sand/Sandstone, pebbly


Shells/shell fragments


Gravel/Conglomerate


Plant/wood remains (organic material)

Igneous


Basic igneous


Tuff/tuffaceous material

Subsample abbreviations

MICROPAL: Micropalaeontology

MACROPAL: Macrofauna

CSC8915: BGS palaeontological sample reference number

PETROLOGY: Petrology

ORG GEOCHEM: Organic geochemistry

Fig. 3 Key to lithologic and other symbols used on both the summary and composite borehole logs.

DINOFLAGELLATE CYST ANALYSIS OF BOREHOLE 94/3

J.B. Riding

Introduction

Thirty-four samples were analysed for their palynology, and all produced highly variable residues and palynofloras. Most were dominated by varied, poorly-sorted plant tissue and wood fragments; this reflects the abundance of plant macrofossils present in the core and points to the relative proximity of a densely vegetated land area. Many of the sandstone horizons yielded sparse organic residues. Both terrestrially-derived and indigenous marine palynomorphs are present, albeit in relatively low numbers and diversities. Sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age	CSC No:	Depth (m)	Palaeontological Age
8922	7.30-7.33	Quaternary	8939	134.16-134.20	Early Eocene
8923	11.67-11.7	Late mid-Eocene	8940	136.36-136.40	(None)
8924	13.20-13.23	Late mid-Eocene	8941	139.37-139.40	(None)
8925	18.05-18.08	Late mid-Eocene	8942	142.42-142.45	Early Eocene
8926	21.92-21.93	Late mid-Eocene	8943	143.77-143.80	Early Eocene
8927	34.96-35.00	Late mid-Eocene	8944	148.17-148.20	Early Eocene
8928	38.70-38.72	Early Eocene	8945	152.38-152.40	Early Eocene
8929	42.80-42.83	(Non-age diagnostic)	8946	189.02-189.04	Early Eocene
8930	47.23-47.26	(None)	8947	190.39-190.42	Early Eocene
8931	62.02-62.04	(None)	8948	191.70-191.75	Early Eocene
8932	62.32-62.35	(None)	8949	192.31-192.36	Early Eocene
8933	66.14-66.17	(None)	8950	196.36-196.40	Early Eocene
8934	71.22-71.25	(None)	8951	199.28-199.34	(None)
8935	72.30-72.33	(None)	8952	203.55-203.60	Early Eocene
8936	83.60-83.65	(None)	8953	207.85-207.87	Late Paleocene to Early Eocene
8937	123.64-123.67	Early Eocene	8954	208.47-208.49	Early Eocene
8938	127.60-127.63	Early Eocene	8955	209.26-209.28	Early Eocene

Results

Quaternary: CSC8922

Sample CSC8922 produced a moderately abundant organic residue. Dark wood is common and foraminiferal test linings proved abundant. Other palynomorphs were relatively rare.

The dinoflagellate cyst flora is of mixed affinity. Several forms of Quaternary aspect are present. These include *Bitectatodinium tepikiense, Nematosphaeropsis labyrinthea* (Ostenfeld 1903) Reid 1974, *Protoperidinium* spp. (round brown cysts) and *Spiniferites* spp. Also present are species characteristic of the Palaeogene, for example *Areoligera* sp. and *Palaeoperidinium pyrophorum* (Ehrenberg 1838) Sarjeant 1967. *Palaeoperidinium pyrophorum* ranges from Late Cretaceous to the Palaeocene (Powell, 1992). This ambiguous association is deemed probably to be the result of contamination due principally to the ages of the underlying samples.

Late mid-Eocene: CSC8923 to 8927

These five samples yielded relatively abundant and diverse palynofloras. Plant tissue dominates the residues and all but sample CSC8925 produced common dinoflagellate cysts. The presence of such dinoflagellate cyst taxa as *Glaphyrocysta intricata* (Eaton 1971) Stover & Evitt 1978 (CSC8924), *Phthanoperidinium geminatum* (CSC8923), *Rhombodinium draco* Gocht 1955 (CSC8927) and *Rottnestia borussica* (Eisenack 1954) Cookson & Eisenack 1961 (CSC8926, ?8923) is indicative of a late mid-Eocene (Bartonian) age for the interval 11.67m to 35.00m. All these taxa characterise the Bartonian Stage (Powell, 1992). In particular, the range base of *Rhombodinium draco* is early Bartonian and the range tops of *Glaphyrocysta intricata, Phthanoperidinium geminatum* and *Rottnestia burussica* are coincident with the Bartonian-Priabonian boundary (Powell, 1992). These datums facilitate a correlation with the planktonic foraminiferal zones P13 and P14, calcareous nannoplankton zones NP16 and NP17 and dinoflagellate cyst zones Rdr to Wsi. The late mid-Eocene age of the interval is supported by the presence of species such as *Cerebrocysta* sp. (CSC8923), *Charlesdownia clathrata* (Eisenack 1938) Lentin & Vozzhennikova 1989 (CSC8923), *Cribroperidinium giuseppei* (Morgenroth 1966) Helenes 1984 (all samples) and *Deflandrea* spp. (CSC8924-8926). There is evidence of some intra-Eocene reworking, with occasional grains of forms such as *Wetzeliella lunaris* Gocht 1969 (CSC8924) and *Wetzeliella* cf. *meckelfeldensis* Gocht 1969 (CSC8923) present. The consistent presence of abundant plant tissue and marine microplankton points to a nearshore marine palaeoenvironment.

Early Eocene: CSC8928 to 8955

These samples are largely extremely sparsely paliniferous or entirely barren of palynomorphs. Sample CSC8953 produced a sparse dinoflagellate cyst assemblage including *Cordosphaeridium gracile* (Eisenack 1954) Davey & Williams 1966, *Microdinium* cf. *ornatum* Cookson & Eisenack 1960 of Heilman-Clausen (1985), Quaternary contamination and *Spiniferites* spp. *Microdinium* cf. *ornatum* of Heilmann-Clausen (1985) is typically late Thanetian to early Ypresian in age. This late Palaeocene to early Eocene age is supported by the presence of *Deflandrea oebisfeldensis* Alberti 1959 in sample CSC8938. This species has a Thanetian-Ypresian range (Powell, 1992). The early Eocene age of samples CSC8954 and 8955 (see below), together with the presence of *Wetzeliella* sp. in sample CSC8937, means that samples CSC8937 to 8953 are early Eocene (early Ypresian) age. The interval may be correlated with the calcareous nannoplankton zones NP10 to lowermost NP12 and the dinoflagellate cyst zones Gor to lowermost Ccl (Powell, 1992). Samples CSC8930 to 8936 inclusive are largely palynologically barren. The overlying and underlying dinoflagellate cyst assemblages are indicative of an Eocene age. Samples CSC8928 and 8929 did, however, yield sparse palynofloras. Although sample CSC8929 proved devoid of age-diagnostic taxa, dinoflagellate cysts in sample CSC8928 include *Cribroperidinium giuseppei* and *Hystrichokolpoma rigaudiae* Deflandre & Cookson 1955. Both these forms have early Eocene range bases; this is entirely consistent with samples CSC8928 to 8955 all being of early Eocene age. However, species indicating a detailed intra-Eocene minimum age are entirely absent.

The miospore associations from this interval, although not diverse, are typically Palaeogene. *Triatriopollenites triangulatus* Frederiksen 1979 / *Triatriopollenites subtriangulatus* (Stanley) Frederiksen 1979 was recovered from sample CSC8952. The *Caryapollinites simplex* (Potonié) Krutzsch 1961 group was recorded in sample CSC8948. Both these types range from the late Palaeocene to the earliest Oligocene. Additionally, the long ranging *Inaperturopollenites hiatus* (Potonié) Pflug & Thomson was observed from samples CSC8938 to 8948. Samples CSC8928, 8929, 8937, 8938, 8942, 8944, 8947 to

8950, 8952 and 8953 contain marine microplankton and thus are interpreted as representing marine deposition.

The two oldest samples, CSC8954 and 8955, produced sparse residues and palynofloras. Resistant mineral grains and woody fragments dominate both samples. Dinoflagellate cysts and miospores are, however, present. Skolochorate (spine-bearing) dinoflagellate cysts proved especially common; *Adnatosphaeridium* spp., *Cordosphaeridium* spp., *Homotryblium* spp. and *Spiniferites* spp. are prominent. The presence of *Adnatosphaeridium multispinosum* Williams & Downie 1966 (CSC8954, 8955) and *Adnatosphaeridium robustum* (Morgenroth 1966) de Coninck 1975 (CSC8955) indicates that this interval (208.47m to 209.28m) is of early Eocene age. *Adnatosphaeridium robustum* is confined to the Ypresian according to Eaton (1976). This assessment is supported by the presence of *Achilleodinium biformoides* (Eisenack 1954) Eaton 1976 in sample CSC8954 and the occurrence of *Achomosphaera alcicornu* (Eisenack 1954) Davey & Williams 1966 in sample CSC8955. The range bases of these distinctive forms are also Ypresian according to Powell (1992) and Eaton (1976) respectively. The presence of *?Homotryblium tenuispinosum* in sample CSC8954 is also consistent with an early Eocene age. Several forms suggestive of the Quaternary were observed in both samples, e.g. *Operculodinium* spp., *Spiniferites mirabilis* (Rossignol 1964) Sarjeant 1970. These grains are interpreted as being contaminants. Both samples are deemed to be of marine affinity due to the presence of common marine microplankton.

CALCAREOUS MICROFAUNAL ANALYSIS OF BOREHOLE 94/3

I.P. Wilkinson

Introduction

Thirty four samples were submitted from borehole 94/03 for calcareous microfaunal analysis in order to provide a biostratigraphical age determination for the section. In addition to foraminifera, radiolaria were occasionally present. Sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age	CSC No:	Depth (m)	Palaeontological Age
8922	7.30-7.33	Quaternary	8939	134.16-134.20	Late early Eocene
8923	11.67-11.7	? Quaternary	8940	136.36-136.40	Late Paleocene to early Eocene
8924	13.20-13.23	? Quaternary	8941	139.37-139.40	Late Paleocene to early Eocene
8925	18.05-18.08	? Mid-Eocene	8942	142.42-142.45	(None)
8926	21.92-21.93	? Mid-Eocene	8943	143.77-143.80	(None)
8927	34.96-35.00	Mid-Eocene	8944	148.17-148.20	(None)
8928	38.70-38.72	(None)	8945	152.38-152.40	(None)
8929	42.80-42.83	(None)	8946	189.02-189.04	(None)
8930	47.23-47.26	(None)	8947	190.39-190.42	(None)
8931	62.02-62.04	(None)	8948	191.70-191.75	(None)
8932	62.32-62.35	(None)	8949	192.31-192.36	(None)
8933	66.14-66.17	(None)	8950	196.36-196.40	Late Paleocene to earliest Eocene
8934	71.22-71.25	(None)	8951	199.28-199.34	Late Paleocene to earliest Eocene
8935	72.30-72.33	(None)	8952	203.55-203.60	Late Paleocene to earliest Eocene
8936	83.60-83.65	(None)	8953	207.85-207.87	Late Paleocene to earliest Eocene
8937	123.64-123.67	Early mid-Eocene	8954	208.47-208.49	Late Paleocene to earliest Eocene
8938	127.60-127.63	(None)	8955	209.26-209.28	Late Paleocene to earliest Eocene

Results

? Quaternary: CSC8922 to 8926

These samples yielded mainly Quaternary foraminifera, although samples CSC8925 and 8926 included very rare radiolaria and ?*Globigerina linaperta* indicative of the mid-Eocene. It is uncertain whether these Eocene specimens are reworked, hence the location of the Eocene/Quaternary boundary remains poorly defined. It should be

noted that evidence from the dinoflagellate cysts suggests that the boundary occurs at about 12m depth.

Mid-Eocene: CSC8927

This sample yielded very rare *Globigerina* ex gr. *linaperta*, rare specimens of the non-calcareous foraminifera *Psammosiphonella* gr. *discreta*, very rare *Trochammina* cf.*subvesicularis* and very rare specimens of a spherical radiolarian, *Cenosphaera* sp. The "*Rhabdammina*" or "flysch-type" biofacies (Gradstein & Berggren, 1981; King, 1989) is indicated (see Borehole 94/1). Very large specimens of dinoflagellate cysts were also present. A mid-Eocene age is indicated and by analogy with the North Sea, the early part of the mid-Eocene may be indicated.

CSC8928 to 8936

The plant-rich sandstone between 37.8 and 47.2m failed to yield foraminifera (except rare Quaternary to Recent contaminants) and the same is true for the muddy sandstones between 60.00 and 88.62m.

Late early Eocene to early mid-Eocene: CSC8937 to 8939

Sample CSC8937 yielded a very sparse fauna including very rare (?)*Neoeponides karsteni, Planulina costata, Globigerina linaperta*, diatoms and frequent lens-shape radiolaria (?compressed *Cenosphaera* sp). An age no younger than the early part of the mid-Eocene (early Lutetian) is implied and the earliest part of the mid-Eocene (earliest Lutetian) is a likely as the radiolaria may be compressed specimens of *Cenosphaera* sp. The first downhole appearance of the latter species defines the top of the NSP6 zone (within nannoplankton zone NP14 and basal part of planktonic foraminifera Zone P10) in the North Sea (King, 1989). Sample CSC8939 also yielded rare specimens of *Gaudryina hiltermanni* which becomes extinct at the top of NSB3b in the North Sea according to King (1989), who correlates this extinction to

Nannoplankton zone NP13 and planktonic foraminiferal zone P9 in the latest part of the Ypresian.

Late Paleocene to early Eocene: CSC8940 to 8955

The assemblage recorded from the shelly sand between 135.9 and 141.3m yielded a fauna quite unlike that of the North Sea. Lenticulina sp of Berggren (1974) is frequent and rare specimens of *Stomatorbina* sp, of Berggren (1974), *Anomalinoides howelli, Gyroidina* cf *subangulatus* and *Operculina* sp were recovered. This late Thanetian to early Ypresian fauna is comparable with that described from shallow water deposits of DSDP Site 117 on the western flank of the Rockall Bank (Berggren, 1974). Below this, samples yielded only a very sparse faunas, but in sample CSC8950,there was a return to this shallow water association.

Samples CSC8950 to 8954 contained common foraminifera. In sample CSC8950 the following are included in the fauna: *Operculina* sp, *Guttulina communis, Cibicides simplex, Nutallides truempyi* (?), *Stomatorbina* sp, *Anomalinoides howelli, Ellipsoglandulina* sp and *Pararotalia* sp. In sample CSC8952 *Quinqueloculina* sp and *Osangularia expansa* are added and in sample CSC8954 (?)*Nummulites* sp, *Nodosaria* sp, *Psammosiphonella* gr. *discreta,* and *Gavelinella danica* are also present. This essentially benthonic-rich, shallow water fauna can be related to the late Palaeocene and earliest Eocene faunas described by Berggren (1974). The absence of any North Sea influences is due to the barrier closing the connection between the North Atlantic and the Norwegian Sea/ North Sea during the late Palaeocene and early Eocene, shown by Gradstein *et al.* (1994, page77).

CALCAREOUS NANNOFOSSIL ANALYSIS OF BOREHOLE 94/3

N.M. Hine

Introduction

Thirty four samples were submitted from borehole 94/3 for calcareous nannofossil analysis; sample details and a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age	CSC No:	Depth (m)	Palaeontological Age
8922	7.30-7.33	? Late Paleocene	8939	134.16-134.20	(None)
8923	11.67-11.7	? Late Paleocene	8940	136.36-136.40	(None)
8924	13.20-13.23	? Late Paleocene	8941	139.37-139.40	(None)
8925	18.05-18.08	? Late Paleocene	8942	142.42-142.45	(None)
8926	21.92-21.93	? Late Paleocene	8943	143.77-143.80	? Late Paleocene
8927	34.96-35.00	? Late Paleocene	8944	148.17-148.20	Late Paleocene
8928	38.70-38.72	(None)	8945	152.38-152.40	(None)
8929	42.80-42.83	(None)	8946	189.02-189.04	? Late Paleocene
8930	47.23-47.26	(None)	8947	190.39-190.42	? Late Paleocene
8931	62.02-62.04	(None)	8948	191.70-191.75	? Late Paleocene
8932	62.32-62.35	(None)	8949	192.31-192.36	(None)
8933	66.14-66.17	(None)	8950	196.36-196.40	(None)
8934	71.22-71.25	(None)	8951	199.28-199.34	(None)
8935	72.30-72.33	(None)	8952	203.55-203.60	Late Paleocene
8936	83.60-83.65	(None)	8953	207.85-207.87	Late Paleocene
8937	123.64-123.67	(None)	8954	208.47-208.49	Late Paleocene
8938	127.60-127.63	(None)	8955	209.26-209.28	Late Paleocene

Results

? Late Paleocene: CSC8922 to 8927

Samples CSC8922 to 8926 yielded very rare, low diversity, poorly preserved assemblages. Sample CSC8927 yielded common nannofossils, but again of poor preservation. The assemblages are composed of *Prinsius dimorphosus, P. bisulcus. P. martinii*, *Toweius pertusus, T. selandianus, Toweius* sp., *Sphenolithus primus, Hornibrookina* cf. *australis*, *Neochiastozygus saepes*, *Chiasmolithus bidens* and other long ranging Cenozoic nannofossils. *Toweius* is, relative to the other genera, the most common element of the nannoflora. A single specimen of *Neococcolithes* cf. *dubius*

(NP12-18) and one resembling *Discoaster* cf. *megastypus* (NP8-9) were recorded from sample CSC8925, but are not considered to be in-situ.

Zonation :- Late Paleocene, NP6-8; Martini (1971).

CSC8928 to 8942

These samples were barren of calcareous nannofossils (no specimens recorded in more than 25 fields of view).

Zonation :- None.

Late Paleocene: CSC8943 and 8944

After extensive scanning of the slides one specimen of *Prinsius dimorphosus* (which ranges from NP2 to NP5/6) was recorded (CSC8943) suggesting a general Paleocene age designation. In contrast, sample CSC8944 yielded an assemblage of abundant and diverse but poorly preserved nannofossils. The assemblage is composed primarily of Paleocene forms however, an early Eocene component is also present. The Eocene material consists of species such as *Chiasmolithus grandis, Zygrhablithus bijugatus, Toweius magnicrassus* and fragments of *Discoaster* sp.. The Paleocene component is similar to that previously described from sample CSC8943 and provides an NP6-8 age assignment.

Zonation :- Late Paleocene, NP6-8; (Martini, 1971).

CSC8945

This sample was barren of calcareous nannofossils (no specimens recorded in more than 25 fields of view).

Zonation :- None.

Late Paleocene: CSC8946 to 8948

After extensive scanning of the slides one specimen of *Prinsius dimorphosus* was recorded in sample CSC8946, whilst one specimen of *Toweius* spp. was found in sample CSC8947; the latter genus ranges from NP5 to the mid-Eocene. In sample CSC8948, four nannofossil specimens were recorded: *Toweius* cf. *selandianus*, *Ericsonia ovalis*, *Prinsius martinii* and another small prinseacean.

Zonation :- Late Paleocene, ?NP5/6; Martini (1971).

CSC8949 to 8951

These samples were barren of calcareous nannofossils (no specimens recorded in more than 25 fields of view).

Zonation :- None.

Late Paleocene: CSC8952 to 8953

These samples yielded very rare, low diversity, poorly preserved assemblages. The assemblages are composed of *Prinsius dimorphosus, P. martinii*, *Toweius pertusus, T. selandianus, Toweius eminens, Sphenolithus primus, Semihololithus kerabyi, Placozygus sigmoides* and other long ranging Cenozoic nannofossils. *Prinsius*, relative to the other genera, is the most common element of the nannoflora.

Zonation :- Late Paleocene, NP4-6; Martini (1971).

Late Paleocene: CSC8954 to 8955

These samples yielded very rich and diverse nannofossil assemblages of moderate to good preservation. The assemblages are very mixed, being composed of material ranging from the early Paleocene through to the early Eocene. The Eocene material is

characterised by species such as *Zygrhablithus bijugatus, Toweius magnicrassus, Discoaster kuepperi, Discoaster* cf. *elegans* and *Chiasmolithus grandis* suggesting an early Eocene (NP11) age. This material is not considered to be *in-situ*. The Paleocene component is similar to those previously described from CSC8952 and 8953 being largely composed of species of *Prinsius* and *Toweius* suggesting an NP4-5/6 age.

Zonation :- Late Paleocene, NP4-5/6; Martini (1971).

BOREHOLE 94/4

SITE DETAILS

Dates of drilling: 20th-21st September, 1994

Latitude: 57°54.220'N; **Longitude:** 12°43.953'W

Location: Western Rockall Trough, 67km north-east of Rockall Island

Map area: Rockall Island

BGS plan no: 373

Block no: 139/2

Water depth: 1485m

Sea-bed conditions: Sandy

Total cored: 59.00m; **Recovered:** 15.40m (26.1%)

Oldest sediment cored:

Sub-bottom depth: 59.00m

Nature: Bioclastic sandstone

Age: Late Eocene to earliest Oligocene (?NP19-21)

Basement: Not reached

Logging: None

SUMMARY

Borehole 94/4 is located on the western margin of the Rockall Trough (Fig. 11). The borehole cored the following sedimentary succession:

0.0-26.00m. Quaternary. Slightly muddy, carbonate-rich sand.

26.00-59.00m. Upper Eocene to lowest Oligocene. Bioclastic sandstone.

OBJECTIVES

The primary objective of borehole 94/4 was to test the age and lithology of the sedimentary succession on the western margin of the Rockall Trough, in a location

where the deeper levels of the Cenozoic succession are accessible (Fig. 11). The stratigraphical unit to be tested consisted of the previously informally named Rockall Trough sequence C of Hitchen and Stoker (1993), sandwiched between their Transparent Zone (below) and Rockall Trough sequences A and B (above), and pinching-out basinwards. Under the revised seismic-stratigraphical scheme (this report), the base of this unit partly overlies reflectors D and C; its top, reflector B_0, is onlapped by reflector A. Prior to drilling, a late Palaeogene age was inferred for the unit.

DRILLING

The running-in of the drill-string took nine hours due to the water depth (1485m), but spud-in was smoothly achieved and few problems were encountered. Some sticking of the drill-string occurred below 15m sub-bottom depth, hence drilling mud was used to ease the operation. Core recovery was variable but the uniformity of the succession, particularly below about 26m, suggests that a representative section was cored.

RESULTS

The stratigraphical succession cored at this site consists of about 26m of Quaternary sediments unconformably overlying 33.0m of upper Eocene to lowest Oligocene sediments. A summary log is presented in Figure 11, and a detailed composite log is included at the back of this appendix.

Quaternary

This section is characterised by pale yellow (2.5Y7/4) to pale yellowish brown (2.5Y6/4), carbonate-rich sands, rich in foraminifera with subordinate shell fragments and terrigenous material. The sands are predominantly fine-grained but poorly sorted and slightly muddy, as shell fragments and terrigenous grains range from silt to small pebble grade. Some of the small lithic clasts are carbonate encrusted. A shallow core,

57-13/53 (S16) (see Volume 3, Appendix 2), was taken at the same site and recovered interbedded muds and sands from the uppermost 2.4m of the section.

Microfossil data suggest that the upper 25m of the borehole section is of Quaternary age, although problems of downhole contamination preclude a definitive correlation. Shallow core 57-13/53 (S16) proved lower Pleistocene strata at <3m below sea bed, therefore the base of the Quaternary may be shallower than 25m sub-bottom depth.

Upper Eocene to lowest Oligocene

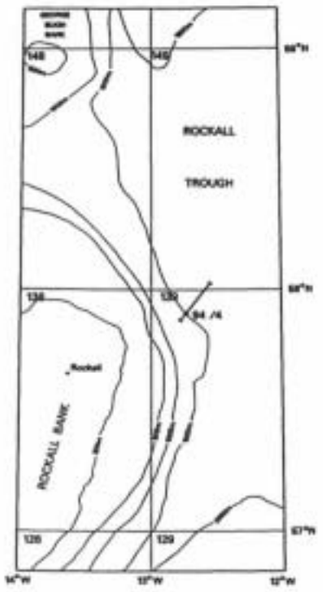
This section consists of pale yellow (2.5Y7/4-8/4), poorly sorted, medium- to coarse-grained, massive to crudely-bedded, clean, porous, bioclastic sandstone. The carbonate component is about 98%, consisting mainly of comminuted shell debris, including a few large gravel-grade shell fragments, and bryozoa. A subordinate terrigenous component consists of scattered, matrix-supported, lithic granules and small pebbles of basalt, granite, siltstone/fine-grained sandstone, and soft dark mudstone. The crude bedding is depicted mainly by the pervasive, sub-horizontal alignment of the shell fragments; the scale of the bedding is difficult to ascertain.

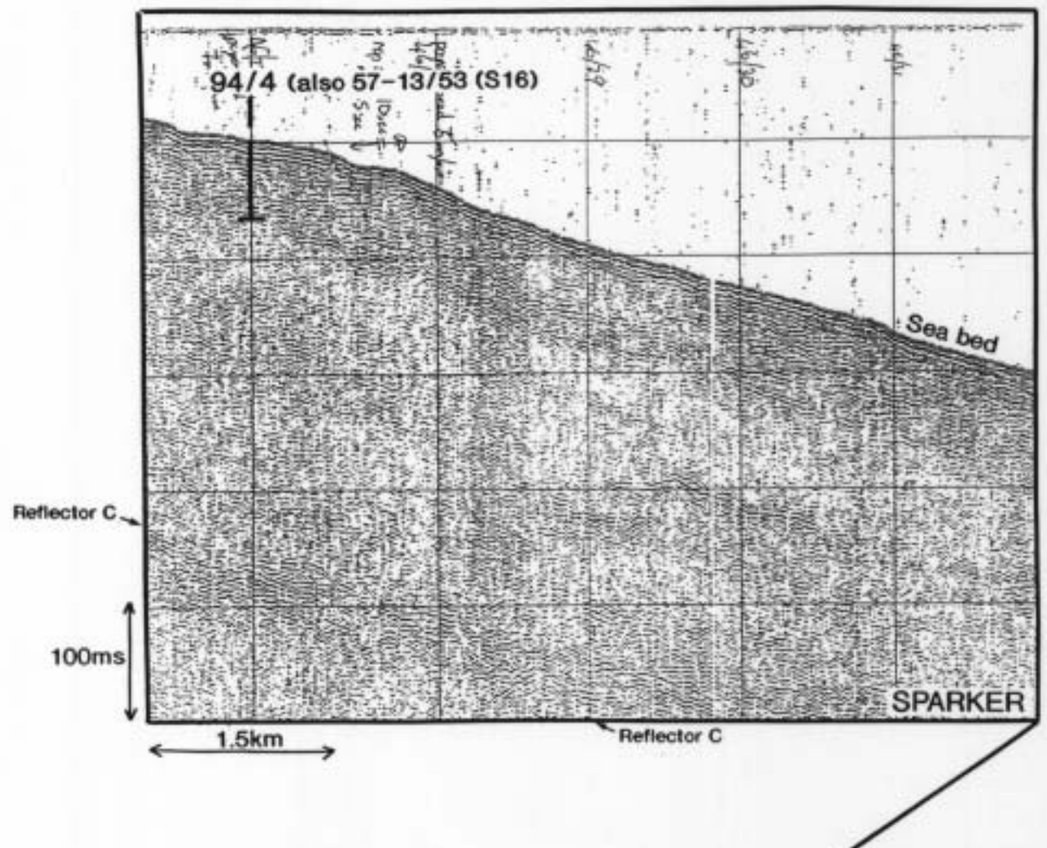
Foraminiferal data indicate a late Eocene to earliest Oligocene age; regional stratigraphical considerations suggest this age range spans biozones NP19-21 (see Volume 1, Chapter 3: Stratigraphy). Calcareous nannofossils support an Eocene-Oligocene age, although they are less specific in terms of age range.

DISCUSSION

The clean, porous, relatively coarse-grained nature of the upper Eocene to lowest Oligocene bioclastic sandstones suggests a high-energy, shallow-marine origin. However, their deep-water setting suggests redeposition as mass-flow sands on the slope during a subsequent lowstand of sea level. This is supported by the fan-like geometry of the sediment package which progrades into the basin, downlapping onto the underlying strata.

The proven occurrence of a Quaternary veneer, which is not easily distinguished even on high-resolution seismic profiles, highlights the need to combine such data with boreholes and shallow cores in order to ascertain the true nature and distribution of the shallower, near-sea-bed, geology. As noted earlier, the absolute thickness of the Quaternary veneer at this location remains poorly defined, and may be thinner than indicated in this report. The sediments appear to be largely reworked from the underlying sandstones, most probably by bottom-current processes.





BOREHOLE 94 /4

STRATIGRAPHY	DEPTH (m)	LITHOLOGY	RECOVERY	SEISMIC REFLECTOR	LITHOLOGY
QUATERNARY — PLEISTOCENE TO HOLOCENE	0				0.0–26.0m Bioclastic SANDS. Carbonate-rich, fine-grained, poorly sorted, rare scattered pebbles, pale yellow to pale yellowish-brown.
	20				
				B_Q	
PALAEOGENE — UPPER EOCENE TO LOWEST OLIGOCENE	40				26.0–59.0m Bioclastic SANDSTONE. Fine to coarse-grained, poorly sorted, @95% carbonate, mostly shell debris and foraminifera; subordinate, very poorly sorted, siliciclastic component, ranging from silt to small pebbles, scattered throughout. Crudely-bedded; pervasive subhorizontal alignment of shell fragments. Sandstone is clean, porous and friable. Pale yellow.
	60				
	59.0m TD				

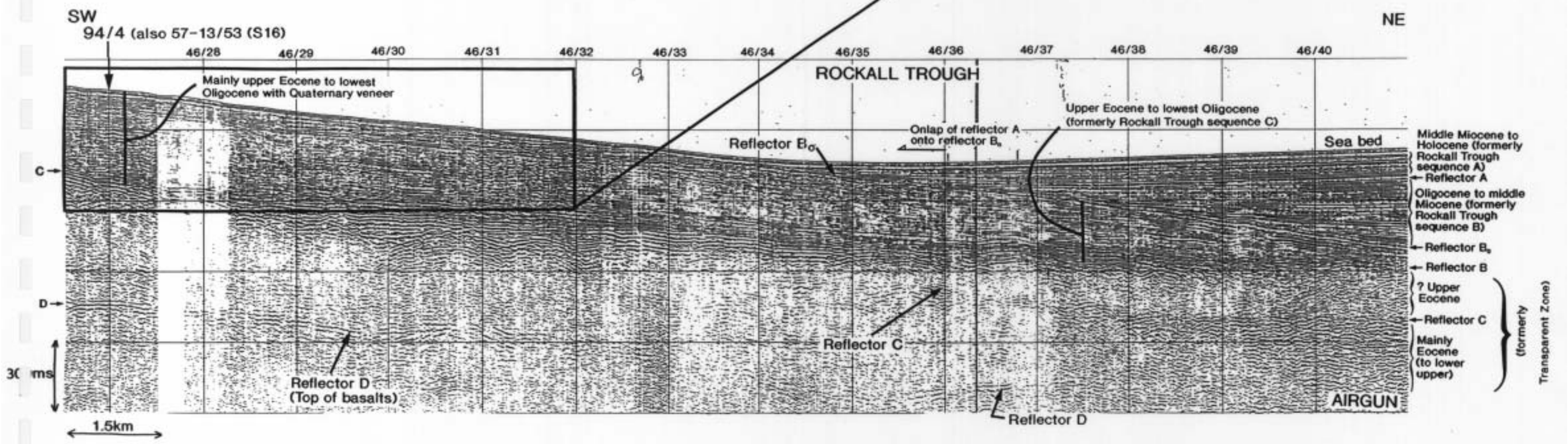


Fig. 11. Seismic-stratigraphical setting of borehole 94/4 with summary log (see text for details). Inset map shows location of borehole and seismic profile.

DINOFLAGELLATE CYST ANALYSIS OF BOREHOLE 94/4

J.B. Riding

Introduction

The 11 palynology samples generally yielded extremely sparse palynofloras and organic residues. The residues reflect the lithology in that the dominant constituent is resistant mineral grains with subordinate woody fragments. Sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8956	7.40-7.42	? Quaternary
8957	10.50-10.53	? Quaternary
8958	23.40-23.45	? Quaternary
8959	25.17-25.20	? Quaternary
8960	31.37-31.40	(Non-age diagnostic)
8961	40.25-40.32	(Non-age diagnostic)
8982	41.23-41.26	(Not analysed)
8962	42.42-42.45	(Non-age diagnostic)
8963	47.87-47.91	(Non-age diagnostic)
8964	53.27-53.31	(None)
8965	56.66-56.69	(Non-age diagnostic)
8983	58.57-58.60	(Not analysed)
8966	58.92-58.96	(Non-age diagnostic)

Results

? Quaternary: CSC8956 to 8959

The dinoflagellate cyst floras in these samples are of Quaternary aspect and the presence of *Spiniferites elongatus* Reid 1974 in samples CSC8956, 8958 and 8959 indicates (if the specimens are *in situ)* that the succession to 25.20m is probably mid-Pleistocene or younger (Harland, 1992). The productive samples are too sparse for meaningful statistical treatment, however, the dinoflagellate cyst associations are possibly suggestive of an interglacial palaeoclimate (Harland, 1992). This interpretation, however, is deemed to be tentative due

to the sparsity and the somewhat ambiguous palaeoecological signature of the floras. For example, *Bitectatodinium tepikiense* is indicative of cold, meltwater regimes and *Operculodinium centrocarpum* characterises interglacial phases (Harland, 1988; 1992). The presence of marine microplankton is indicative of an open marine depositional environment.

CSC8960 to 8966

Miospores and marine microplankton associations are sparse, often poorly preserved and of low diversity. Sample CSC8964 proved entirely palynologically barren. Whilst the assemblages are non-age diagnostic, the presence of marine microplankton in samples CSC8960 to 8963 is indicative of an open marine depositional environment.

CALCAREOUS MICROFAUNAL ANALYSIS OF BOREHOLE 94/4

I.P. Wilkinson

Introduction

Eleven samples (CSC 8956 to 8966) were originally sampled from borehole 94/4 in order to provide a biostratigraphical age determination for the section by means of calcareous microfossils. The great abundance of Quaternary foraminifera, which are partly regarded as down-hole contamination, however, swamped the pre-Quternary assemblages and thus obscured the age of the deposit. Two further samples (CSC8982 and 8983) were, therefore, examined and particular care was taken to remove the outer parts of the core in order to minimise contamination. Although the microfossil assemblages were found to be sparse, the sample size of CSC8982 and 8983 is sufficiently large to permit the recovery of several hundred foraminifera, given time. However, due to time constraints, only a preliminary examination could be made. Sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8956	7.40-7.42	? Quaternary
8957	10.50-10.53	? Quaternary
8958	23.40-23.45	? Quaternary
8959	25.17-25.20	? Quaternary
8960	31.37-31.40	(Non-age diagnostic)
8961	40.25-40.32	(Non-age diagnostic)
8982	41.23-41.26	Late Eocene to earliest Oligocene
8962	42.42-42.45	(Non-age diagnostic)
8963	47.87-47.91	? Eocene
8964	53.27-53.31	? Eocene
8965	56.66-56.69	? Eocene
8983	58.57-58.60	Late Eocene to earliest Oligocene
8966	58.92-58.96	(Non-age diagnostic)

Results

The eleven original samples (CSC8956-8966) of bioclastic sands and friable sandstone wre dominated by abundant, well preserved, Pleistocene to Recent taxa, although very rare, poorly preserved and probably reworked, Eocene specimens were found in the top 25.20m. In samples CSC8963 and 8965 rare specimens of *Pararotalia inermis* were found, also indicating the mid- to late Eocene, their preservation suggesting that they were possibly found *in situ.*

Late Eocene to earliest Oligocene: CSC8982 and 8983

Two further samples (CSC8982 and 8983) were examined in order to remove the problems associated with contamination from above. Sample CSC8982 yielded a sparse fauna that included rare *Pararotalia inermis* and *Cibicidoides trincherasensis,* together with very rare *Eponides sp. cf. alabamensis* and *Cibicides cf yazooensis* sensu Berggren & Aubert (1976), as well as rare specimens of the planktonic species *Globigerina eocaena* and *Globigerina angiporoides.* Sample CSC8983 contained a similar fauna, but in addition *Bolivina* sp and *Bolivina fastigia* were recorded. A late Eocene age is suggested , although the earliest Oligocene cannot be ruled out entirely. Planktonic foraminifera were rare and generally long-ranging forms, but planktonic foraminiferal zone P15 and younger (i.e. nannofossil zone NP18 and younger) is suggested. Although an upper limit cannot be given on the information available, it is unlikely to be younger than P19-20 (the lower part of nannofossil zone NP23).

CALCAREOUS NANNOFOSSIL ANALYSIS OF BOREHOLE 94/4

N.M. Hine

Introduction

Eleven samples were submitted from borehole 94/4 for calcareous nannofossil analysis; sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8956	7.40-7.42	Lower Quaternary
8957	10.50-10.53	Lower Quaternary
8958	23.40-23.45	Lower Quaternary
8959	25.17-25.20	Lower Quaternary
8960	31.37-31.40	Eocene to Oligocene
8961	40.25-40.32	Eocene to Oligocene
8982	41.23-41.26	(Not analysed)
8962	42.42-42.45	Eocene to Oligocene
8963	47.87-47.91	Eocene to Oligocene
8964	53.27-53.31	Eocene to Oligocene
8965	56.66-56.69	Eocene to Oligocene
8983	58.57-58.60	(Not analysed)
8966	58.92-58.96	Eocene to Oligocene

Results

Lower Quaternary: CSC8956 to 8959

Having removed the sandy component of the sample, a calcareous ooze residue remained. Calcareous nannofossils are abundant and include whole coccoliths. Key components of the flora include abundant *Gephyrocapsa* spp., common small *Reticulofenestra* spp. and rare *Pseudoemiliania lacunosa* (NN15-NN19). *G. caribbeanica* has its first occurrence in NN19, which co-occurring with P. lacunosa restricts the sample to NN19. This zonal assignment is supported by the absence of any

discoasters or sphenoliths. Cretaceous nannofossils are recorded from all samples in low numbers; these are here attributed to reworking. There is no evidence of any earlier Neogene material.

Zonation :- Lowermost Pleistocene; *Pseudoemiliania lacunosa* Zone, NN19 (Martini 1971).

Eocene to Oligocene: CSC 8960 to 8966

These samples are almost completely barren calcareous nannofossils (no specimens recorded in more than 25 fields of view). After extensive scanning of the slides a number of heavily overgrown specimes were recorded. Due to the poor state of preservation these were not identified to specific level but generally suggested a Tertiary age. Specimens of *Sphenolithus* (NP4-NN16), *Reticulofenestra* (NP12-NN21) and *Chiasmolithus* (NP1-NP25) were recorded. The concurrent ranges of these genera further restrict this sample to NP12-NP25.

Zonation :- Eocene-Oligocene, NP12-NP25 (Martini 1971).

BOREHOLE 94/5

SITE DETAILS

Dates of drilling: 22nd-23rd September, 1994

Latitude: 57°30.196'N; **Longitude:** 13°09.135'W

Location: Rockall Bank, 33.5km east-south-east of Rockall Island

Map area: Rockall Island

BGS plan no: 379

Block no: 138/15

Water depth: 232m

Sea-bed conditions: Sandy/gravelly

Total cored: 30.20m; **Recovered:** 2.60m (8.7%)

Oldest sediment cored:

Sub-bottom depth: 27.5m

Nature: Sand

Age: Quaternary

Basement: Basalt

Logging: None

SUMMARY

Borehole 94/5 is located on the top of Rockall Bank (Fig. 12). The borehole cored the following succession:

0.0-27.50m. Quaternary. Gravelly muddy sand, gravel and mud on interbedded muddy sand and gravel.

27.50-30.20m. Palaeogene (?upper Paleocene to lower Eocene). Basalt

OBJECTIVES

The primary objective of borehole 94/5 was to test the nature of the acoustic basement (reflector D of revised seismic-stratigraphical scheme - this report) on this part of the Rockall Bank. On high-resolution seismic profiles (Fig. 12), the top of the acoustic basement is clearly observable as a planar unconformity overlain by a thin sediment cover. South-eastward-dipping reflectors are evident within the basement. A subsidiary objective was to ascertain the age and lithology of the sediment cover, part of which has been moulded into a ridge which has been mapped on adjacent seismic profiles.

DRILLING

The drill-string was successfully spudded-in at the first attempt despite bad heave conditions which included excursions to 5m; however, conditions were workable. Although core recovery was very poor, drilling progressed smoothly until 18.5m sub-bottom when bit-blockage occurred and mud pressure increased. Subsequent little or no core recovery led to a phase of hammer coring in a bid to unblock the bit, and return the coring parameters to normal and establish renewed core recovery. Harder rock was recorded at 27.5m sub-bottom, and the hole as terminated at 30.2m with the geological objectives having been achieved.

RESULTS

The stratigraphical succession cored at this site consists of 27.5m of Quaternary sediments unconformably overlying Palaeogene basalt. A summary log is presented in Figure 12, and a detailed composite log is included at the back of this appendix.

Quaternary

On the sparker section in Figure 12, two informal seismic units, A and B, can be identified; these broadly correlate with a two-fold lithological subdivision of the Quaternary as established in borehole 94/5.

Unit A (0.0-c.13.5m): A lithologically variable unit consisting of gravelly muddy sands, gravels and muds. The gravelly muddy sands are olive-grey (5Y4/2), stiff to hard, and are composed of a poorly sorted admixture of gravel, shell fragments, sand and muddy sand. The sand fraction is fine- to medium-grained, very poorly sorted, predominantly siliciclastic (about 75%) with subordinate shell debris. The gravel consists of lithic clasts up to 5cm in diameter, and includes angular to subrounded basic igneous rocks, acidic gneiss, and soft, dark grey mudstone, together with broken shells. Some of the lithic clasts are carbonate encrusted. Discrete gravelly bands include granitic and quartzitic cobbles to about 8cm diameter. The muds are stiff to hard, very dark grey (5Y3/1), calcareous, massive and bioturbated, with sporadic matrix-supported lithic clasts and shell fragments, and scattered black sulphidic specks. On the sparker profile (Fig. 12), these sediments appear to drape the underlying deposits of unit B.

Unit B (c.13.50-27.50m): This unit consists predominantly of olive-grey (5Y4/2) to dark greenish grey (5GY4/1) muddy sand with interbeds of gravel in its upper part. The muddy sand is mainly fine grained, moderately to poorly sorted, with a mixed siliciclastic/carbonate composition. The terrigenous component dominates, generally ranging from 60-85%, although shell fragments are common and may depict a crude, flat-lying to rippled bedding. The sands are firm and compact but friable. Two discrete gravel layers were cored, and consist of cobbles including well-rounded grey siltstone and basic/metabasic rock. On the sparker profile (Fig. 12), this unit appears to pinch-out at right-angles to the ridge axis.

Microfossil data indicate a Quaternary age for both units. Poor recovery precludes any detailed palaeo-environmental assessment of unit A; unit B, however, clearly forms a distinct sandy and gravelly ridge, for which the dinoflagellate cyst assemblages indicate deposition in an open-marine setting. The ridge may have formed as a shallow-marine sand ridge or bar during a Quaternary low sea-level stand. The sands at the base of the ridge contain significant numbers of reworked Miocene and Eocene calcareous nannofossils.

Palaeogene (?upper Paleocene to lower Eocene)

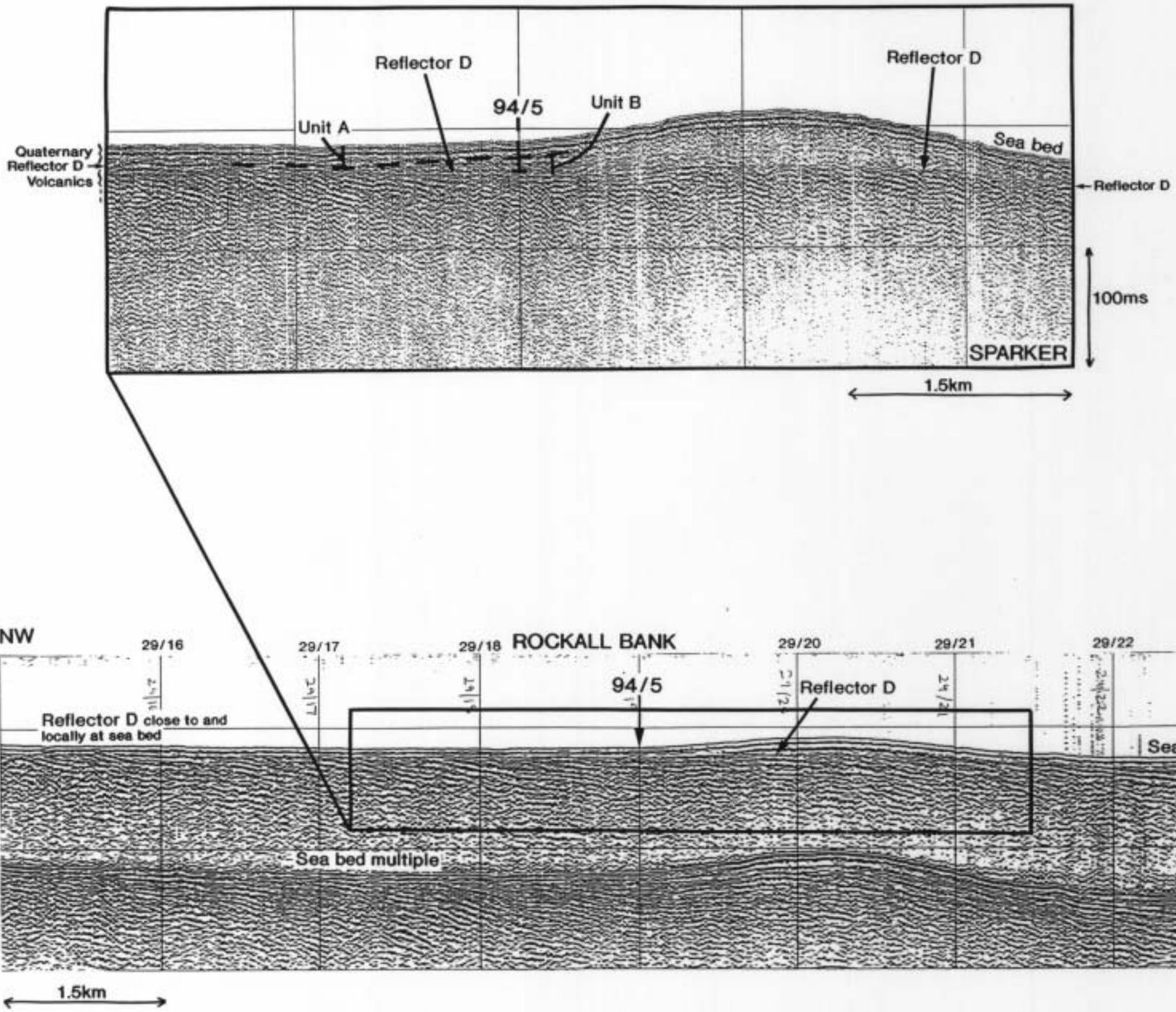
The borehole terminated in dark grey (N4/), finely crystalline basalt. Petrological analysis (see Volume 5, Appendix 4) indicates that the basalt is aphyric, consisting of plagioclase laths, clinopyroxene and rare altered ?olivine set in a highly altered oxidised groundmass. The basalt also contains partially resorbed, slightly coarser-grained basalt clasts which are sparsely vesicular.

Shallow core 57-14/53 (S18), which recovered basalts from a location about 12.5km to the north-west of borehole 94/5, yielded a K-Ar radiometric age date of 57.8±1.6Ma (late Paleocene to earliest Eocene). Consequently, this represents the maximum age for the basalt recovered in borehole 94/5, which is stratigraphically higher than that recovered in shallow core 57-14/53. The basalt is interpreted as an extrusive flow.

DISCUSSION

Borehole 94/5 compliments boreholes 94/2, 94/3, 94/6 and shallow core 57-14/53 (S18), which have recovered basalt and trachyte lava flows from the acoustic basement on Rockall Bank. Collectively, these sites prove that acoustic basement on the eastern and northern flank of the bank is formed, at least in part, of volcanic rocks.

The evidence of low Quaternary sea levels, proved by borehole 94/3 which sampled a wave-cut terrace or platform on the eastern edge of the Rockall Bank, is supported by the preservation of a Quaternary shallow-marine sand ridge or bar on the top of the bank. Unlike the eastern margin of the Rockall Trough, which has been modified during the Quaternary by slope-progradation and local fan development, the western margin of the trough has remained relatively unmodified during this interval. This is partly due to the absence of a significant sediment source area on the western side of the trough. This contrast may account for the preservation of the low-sea-level features on Rockall Bank.



BOREHOLE 94/5

STRATIGRAPHY	DEPTH (m)	LITHOLOGY	RECOVERY	SEISMIC REFLECTOR	LITHOLOGY
QUATERNARY — PLEISTOCENE TO HOLOCENE	0				0.0–13.5m Interbedded GRAVELLY MUDDY SAND and MUD. Very poorly sorted admixture of pebbles and cobbles, and fine–medium–grained muddy sand, mixed siliciclastic:carbonate (shell debris), olive–grey, with discrete interbeds of mud, massive, bioturbated, occasionally pebbly, stiff–hard, calcareous, monosulphide very dark grey. (Unit A)
	20				
PALAEOGENE — ? UPPER PALAEOCENE TO LOWER EOCENE	30	30.2m TD		D	13.5–27.5m SAND. Slightly muddy, very fine–grained, moderate–poorly sorted, mixed siliciclastic:carbonate (shell debris), firm and compact, calcareous, olive grey to dark greenish grey. Gravelly at top of section; also coarse shell fragments depict crude flat–lying to rippled bedding. (Unit B)
	40				27.5–30.2m BASALT. Finely crystalline, dark grey, vesicular.
	50				

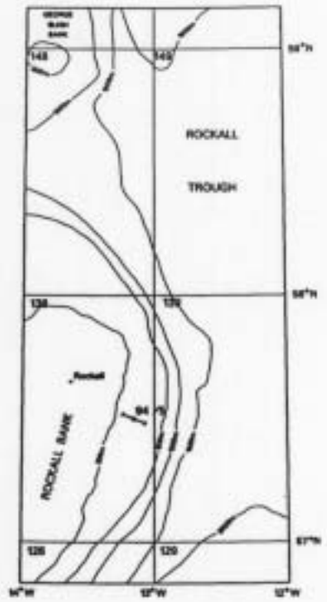


Fig. 12. Seismic-stratigraphical setting of borehole 94/5 with summary log (see text for details). Inset map shows location of borehole and seismic profile.

DINOFLAGELLATE CYST ANALYSIS OF BOREHOLE 94/5

J.B. Riding

Introduction

The seven palynology samples produced highly variable residues and palynofloras in terms of both productivity and relative proportions of kerogen types and palynomorphs. Sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8967	4.85-5.00	Quaternary
8968	8.40-8.43	Quaternary
8969	13.08-13.10	Quaternary
8970	13.30-13.35	Quaternary
8971	18.25-18.31	Quaternary
8972	20.50	Quaternary
8973	26.41-26.44	Quaternary

Results

Quaternary: CSC8967 to 8973

Samples CSC8967, 8971 and 8972 yielded relatively abundant palynofloras; the remainder were extremely sparse. The presence of *Protoperidinium avellana* (Meunier) Balech 1974 in samples CSC 8967 to 8971 means that the succession to 18.31m is probably no older than late Pleistocene (Harland, 1992). This dating is supported by the occurrences of *Protoperidinium conicoides* (Paulsen) Balech 1974, *Protoperidinium conicum* (Gran) Balech 1974, *Protoperidinium leonis* (Pavillard) Balech 1974 and *Protoperidinium pentagonum* (Gran) Balech 1974. Sample CSC8967 is dominated by *Bitectadinium tepikiense* and *Operculodinium centrocarpum;* it appears to represent an ameliorative episode, but with significant meltwater influence. Samples CSC8972 and 8973 yielded high proportions of round, brown, dinoflagellate cysts *(Protoperidinium* spp.) and

Bitectatodinium tepikiense. This configuration is indicative of cold, glacial conditions (Harland, 1992). The abundance of *Bitectatodinium tepikiense* strongly suggests significant meltwater influence and the *Protoperidinium* spp. are indicative of seasonal or more permanent sea-ice. The consistent presence of marine microplankton is indicative of an open marine depositional setting. Low proportions of Palaeogene and Neogene reworking were encountered in samples CSC 8969, 8971 and 8972.

CALCAREOUS MICROFAUNAL ANALYSIS OF BOREHOLE 94/5

I.P. Wilkinson

Introduction

Seven samples from Borehole 94/5 were submitted in order to provide a biostratigraphical age determination for the section, by means of calcareous microfossils. Sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8967	4.85-5.00	Quaternary
8968	8.40-8.43	Quaternary
8969	13.08-13.10	Quaternary
8970	13.30-13.35	Quaternary
8971	18.25-18.31	Quaternary
8972	20.50	Quaternary
8973	26.41-26.44	Quaternary

Results

Quaternary: CSC8967 to 8973

Abundant Pleistocene to Recent foraminifera and ostracoda were present in all samples.

CALCAREOUS NANNOFOSSIL ANALYSIS OF BOREHOLE 94/5

N.M. Hine

Introduction

Seven samples were submitted from borehole 94/5 for calcareous nannofossil analysis; sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8967	4.85-5.00	Quaternary
8968	8.40-8.43	Quaternary
8969	13.08-13.10	Quaternary
8970	13.30-13.35	Quaternary
8971	18.25-18.31	Quaternary
8972	20.50	Quaternary
8973	26.41-26.44	Quaternary

Results

Quaternary: CSC8967 to 8973

CSC8967: This sample yielded common nannofossils of low diversity and poor preservation. The assemblage is composed of a mixture of in-situ Quaternary material and reworked upper Cretaceous material. The in-situ assemblage is composed of *Gephyrocapsa aperta, Gephyrocapsa caribbeanica, Gephyrocapsa muellerae, Gephyrocapsa ericsonii, Coccolithus pelagicus, Calcidiscus leptoporus, Syracosphaera histrica* and small, closed *Reticulofenestra* spp. *Emiliania huxleyi*,the NN21 biomarker is recorded as occurring in low numbers in light microscope counts, the ratio of *Gephyrocapsa* to *Emiliania* being positive (ie. more *Gephyrocapsa* than *Emiliania*). This species is difficult to identify in light microscope and SEM analysis is necessary to confirm its identification.

The occurrence of *E. huxleyi* (first appearance datum, 266 ka; oxygen isotope stage 8) and the absence of *Pseudoemiliania lacunosa* (last appearance datum, LAD, 465 ka) restricts this sample to the late Quaternary *Emiliania huxleyi* Zone, NN21, of Martini (1971). There is no evidence of the *Coccolithus pelagicus* bloom which occurs in the early Holocene. The occurrence of *Gephyrocapsa ericsonii* (LAD 112 ka), further restricts this sample to either the lower part of the Transitional Zone or the *G. aperta* Zone of Hine, (1990).

Zonation :- Late Quaternary, *Emiliania huxleyi* Zone, NN21 (Martini, 1971); ?Transitional/*G. aperta* Zone (Hine, 1990).

CSC8968: This sample yielded only very rare nannofossils of poor preservation. The assemblage is composed of a mixture of in-situ Quaternary material and reworked upper Cretaceous material. The terrigenous component of the sample is high and there is an abundance of siliceous material (including centric and pennate diatoms). After scanning over 25 fields of view only seven specimens were recorded: *Gephyrocapsa aperta, Gephyrocapsa caribbeanica, Coccolithus pelagicus, Calcidiscus leptoporus* and small, closed *Reticulofenestra* spp. After extensive scanning there were still no records of *Emiliania huxleyi* (the NN21 biomarker), or of *Pseudoemiliania lacunosa* (the NN19 biomarker). The paucity of data makes assignment to a zone difficult, but in light of its general Quaternary character, and relationship to CSC8967, the sample is assigned a general Quaternary (NN20/21) age.

Zonation :- Quaternary, ?NN20/21; (Martini, 1971).

CSC8969 to 8971: The first two samples are very similar to CSC8968 and yielded extremely rare nannofossils of poor preservation. Although CSC8971 yielded similar nannofossils to the others, they are much more common and of moderate preservation. The assemblages are composed of a mixture of in-situ material and reworked upper Cretaceous material. The terrigenous components of the samples are high and siliceous material abundant. The following species were identified: *Gephyrocapsa caribbeanica, G. aperta, G.muellerae, Reticulofenestra productella* and *Coccolithus pelagicus.*

These suggest an early Pleistocene (NN19) age. *R. antarctica* and *Sphenolithus* cf. *abies* (LAD NP15) were also recorded. These are attributed to reworking of middle Pliocene material. One specimen of *Ericsonia* cf. *obruta*, a Late Miocene species, was recorded from CSC8969. This is again attributed to reworking. Due to the amount of reworked material and the generally poor preservation it is difficult to assign this sample to a nannofossil zone. Assuming the older material to be reworked, an early Pleistocene age is considered most probable.

Zonation :- Pleistocene, ?NN19; (Martini, 1971).

CSC8972 and 8973: These samples yielded very rare nannofossils of very poor preservation. The terrigenous components of the samples is very high and siliceous material has ceased to be abundant. The following species were identified: *Ericsonia ovalis, Pontosphaera sp., Reticulofenestra perplexa, R. antarcticus, Shenolithus abies* and other larger plugged *Reticulofenestra* spp.. The concurrent ranges of these species suggest a late Miocene (NN10/11) age. Sample CSC8973 yielded specimens of doubtful affinity (due to their poor preservation) which have here been assigned to *Reticulofenestra* cf. *scrippsae,* a mid-Eocene to late Oligocene species (NP16-25). This is attributed to reworking.

Zonation :- Miocene NN10/11*; (Martini, 1971).

(* On regional stratigraphical evidence, this is interpreted by M.S. Stoker to be a reworked assemblage: the most probable age is Quaternary).

BOREHOLE 94/6

SITE DETAILS

Dates of drilling: 23rd September, 1994

Latitude: 58°13.057'N; **Longitude:** 13°33.052'W

Location: Northern flank of Rockall Bank, 69.5km north-north-east of Rockall Island

Map area: George Bligh Bank

BGS plan no: 375

Block no: 148/23

Water depth: 373m

Sea-bed conditions: Sandy

Total cored: 21.90m; **Recovered:** 4.54m (20.7%)

Oldest sediment cored:

Sub-bottom depth: 17.86m

Nature: Sandstone

Age: Mid-Eocene (NP14/15)

Basement: Basalt

Logging: None

SUMMARY

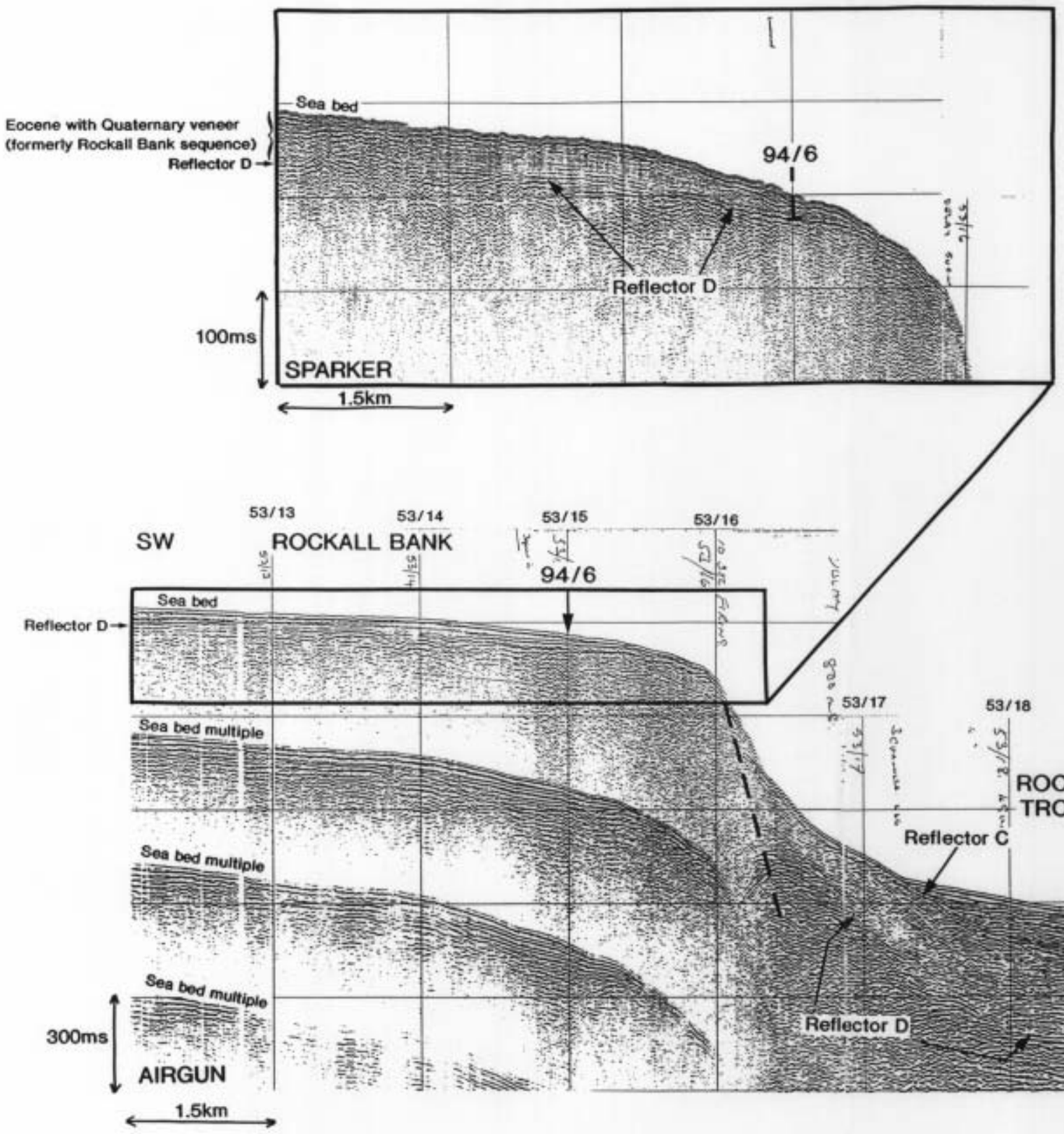
Borehole 94/6 is located on the northern edge of Rockall Bank (Fig. 13). The borehole cored the following succession:

0.0-8.94m*. Pliocene to Holocene. Interbedded bioclastic sands/muddy sands, calcareous muds/sandy muds, and gravels.

8.94-17.86m. Middle Eocene. Sandstone.

17.86-21.90m. Palaeogene (?upper Paleocene to lower Eocene). Basalt

* (Depth of lithological change based on change in drilling parameters).



BOREHOLE 94/6

STRATIGRAPHY	DEPTH (m)	LITHOLOGY	RECOVERY	SEISMIC REFLECTOR	LITHOLOGY
NEOGENE TO QUATERNARY / PLIOCENE TO HOLOCENE; PALAEOGENE / MIDDLE EOCENE TO ? UPPER PALEOCENE / LOWER EOCENE	0				0.0–8.94m Interbedded BIOCLASTIC SANDS / MUDDY SANDS, CALCAREOUS MUDS /SANDY MUDS, and GRAVELS. Sands and muddy sands, very thin to medium-bedded, medium to very fine-grained, @95% carbonate. Firm, compact. Varicoloured: olive brown, yellowish brown, grey and greenish-grey. Muds, very thin bedded, chalky, white.
	10				
	20			D	8.94–17.86m SAND /SANDSTONE Medium to thick-bedded, massive, very fine to fine-grained, poorly sorted, siliciclastic, immature, non-calcareous. Soft, weathered upper section; indurated lower section. Varicoloured: yellowish-brown to dark brown with yellowish-red mottling, to greenish-grey.
	21.9m TD				
	30				17.86–18.00m BASALT COBBLES. Rubbly /reworked top of lava.
	40				18.00–21.90m BASALT. Fine to medium crystalline, dark grey, jointed, highly vesicular and amygdaloidal above 21m; more massive below 21m. Carbonate veining and disseminated pyrite common below 21m.
	50				

Fig. 13. Seismic-stratigraphical setting of borehole 94/6 with summary log (see text for details). Inset map shows location of borehole and seismic profile.

OBJECTIVES

Borehole 94/6 had two main objectives: 1) to ascertain the age and lithology of the sediment cover on the northern edge of Rockall Bank; and, 2) to test the nature of the acoustic basement (reflector D of revised seismic-stratigraphical scheme - this report) on this part of the bank. The sediment cover forms part of the previously informallynamed Rockall Bank sequence of Hitchen and Stoker (1993), who, prior to drilling, tentatively assigned a Palaeogene age to the sequence. On the sparker profile (Fig. 13), these sediments overlie acoustic basement which is characterised by an irregular upper surface with sporadic, discontinuous to chaotic reflections within the basement, immediately below the surface.

DRILLING

The sloping and uneven, iceberg-scoured sea bed led to problems of setting-down the sea-bed template and spudding-in, as the angle of entry cone and pipe were so far off vertical as to cause unacceptable friction between the pipe and template. However, after several phases of lifting the template and moving the ships position, a successful entry into the template was achieved which did not involve pre-drill torque on the drill-string. Bad heave conditions and occasional blocking of the bit resulted in slow progress and poor recovery in the sediment section. However, acoustic basement was eventually reached and the borehole was terminated at 21.90m sub-bottom depth with the geological objectives successfully achieved.

RESULTS

The stratigraphical succession cored at this site consists of 8.94m of Pliocene to Holocene sediments unconformably overlying 8.92m of middle Eocene strata, which, in turn, unconformably overlies Palaeogene basalt. A summary log is presented in Figure 13, and a detailed composite log is included at the back of this appendix.

Pliocene to Holocene

Despite the poor recovery, a variable lithology was proved consisting of interbedded bioclastic sands/muddy sands, calcareous muds/sandy muds and gravels. The bioclastic sands and muddy sands range from very thin- to medium-bedded, are medium- to very fine-grained and poorly sorted, composed predominantly (about 95%) of broken shell fragments and foraminifera with subordinate quartz and lithics to small pebble grade. Rare bioturbation was noted. The sands are firm and compact, and varicoloured: pale olive-brown (2.5Y5/4), greenish grey (5GY6/1) and pale grey (5Y7/1). Contacts with the interbedded muds are sharp, with some mud rip-up clasts incorporated into the sands. The muds are very thin-bedded, and white and chalky in appearance. Two beds of cobble-grade gravel in the lower part of the section include clasts of igneous and metamorphic origin, up to 20cm in length.

Foraminifera and dinoflagellate cysts suggest a Quaternary age for these sediments. However, rich calcareous nannofossil assemblages from the calcareous muds suggest an older, early to late Pliocene (NN14-15) age. A general Pliocene to Holocene age range has been assigned to the section, and the palynofacies is indicative of an open-marine depositional environment.

The contact with the underlying middle Eocene strata was not observed, although an increase in the drilling rate concomitant with smoother drilling conditions was noted from about 8.94m, and this is interpreted as penetrating soft weathered sandstone.

Middle Eocene

The middle Eocene section consists of very fine-grained, medium to poorly sorted sandstone. It has a siliciclastic composition (about 95%) dominated by angular to rounded grains of quartz and lithics, with only rare carbonate fragments. The sandstone is predominantly massive with hints of bioturbation. The recovery was very poor, and in the upper part of the section the sandstone is soft and crumbly, becoming indurated at the base. It displays a variable colour ranging from dark yellowish brown

(10YR4/4) to dark brown (10YR3/3) with yellowish red (5YR4/6) mottling in the upper, weathered section to dark greenish grey (5BG4/1) in its lower part. The dinoflagellate cysts suggest a mid-Eocene (NP14/15) age, with sedimentation occurring in an open-marine environment.

Palaeogene (?upper Paleocene to lower Eocene)

The borehole terminated in dark grey (2.5YN4/), fine to medium crystalline basalt. In the upper part of the section, above 21.0m, the basalt is jointed, very vesicular and amygdaloidal; below 21.0m, it displays a more massive, less vesicular and amygdaloidal structure with abundant carbonate veining and scattered pyrite. The amygdales are filled by smectite and minor rhombic carbonate. The top of the section consists of several cobbles which may represent an erosional rubbly surface.

Petrological analysis (see Volume 5, Appendix 4) indicates that the basalt is aphyric, consisting of partially altered plagioclase laths, opaques and scarce clinopyroxene, with abundant green-brown smectite (replacing interstitial glass). In the lower part of the section, the plagioclase laths display a sub-trachytic texture.

The basalt is interpreted as an extrusive flow; the upper part probably represents the fine-grained vesicular zone near the flow top, whereas the lower part is the more-slowly cooled central part of the flow. Regional stratigraphical evidence, particularly with respect to borehole 94/3 and shallow core 57-14/53 (S18), suggests a late Paleocene to early Eocene age.

DISCUSSION

Borehole 94/6 compliments boreholes 94/2, 94/3, 94/5 and shallow core 57-14/53 (S18), which recovered basalt and trachyte lava flows from the acoustic basement on Rockall Bank. Collectively, these sites prove that acoustic basement on the eastern and northern flank of the bank is formed, at least in part, of volcanic rocks.

The middle Eocene strata are broadly correlatable with similar sections preserved in boreholes 94/2 and 94/3, both of which also sampled the sediment wedge on the edge of Rockall Bank. However, no tuffaceous material was recovered in the sandstones in borehole 94/6, and it may be that these rocks are slightly younger (NP14/15 as opposed to NP13/14 in 94/2 and 3) and post-date the volcaniclastic activity in this area.

DINOFLAGELLATE CYST ANALYSIS OF BOREHOLE 94/6

J.B. Riding

Introduction

Five samples were taken from borehole 94/6 for dinoflagellate cyst analysis; sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8974	3.14-3.16	Quaternary
8975	3.45-3.50	Quaternary
8976	8.57-8.64	Quaternary
8977	17.32-17.35	Mid-Eocene
8978	17.61-17.64	Mid-Eocene

Results

Quaternary: CSC8974 to 8976

Samples CSC8974 and 8975 proved virtually palynologically barren. Sample CSC8974 is dominated by resistant mineral grains with minor proportions of finely disseminated amorphogen. Whilst sample CSC8975 yielded a substantially similar acid-resistant residue, woody tissue is present and an indeterminate fungal spore was recognised. Sample CSC8976, however, is dominated by silicious microfossils, the principal forms being 'hooks' and 'rods.' Dinoflagellate cysts are commonly present, with the species spectrum dominated by *Operculodinium centrocarpum* (41.4%), and *Bitectatodinium tepikiense* (37.8%), with lesser proportions of *Nematosphaeropsis labyrinthea, Spiniferites* spp. and *Impagidinium* spp.. This association is of definite Quaternary aspect. However, all the species recorded have been reported from the Neogene (Harland, 1992: Powell, 1992). Due to the absence of typically Miocene/Pliocene taxa, a Quaternary age is preferred. The assemblage is somewhat ambiguous palaeoecologically; it is suggestive of interglacial conditions as *Protoperidinium* spp. are virtually absent. However, the high proportions of

Bitectatodinium tepikiense, low diversity and relative sparseness mitigates toward colder conditions (Harland, 1992). The presence of significant proportions of marine microplankton is indicative of open marine conditions.

Mid-Eocene: CSC8977 and 8978

Sample CSC8977 proved barren of palynomorphs, the residue comprises wood fragments, finely disseminated amorphogen and resistant mineral grains. Sample CSC8978 produced a relatively sparse palynoflora and residue, with wood, amorphogen and residual mineral grains prominent, but dinoflagellate cysts and miospores present in low proportions. The dinoflagellate cyst residue includes *Areoligera* spp., *?Cordosphaeridium gracile,* indeterminate skolochorate (spine-bearing) forms and *Spiniferites* spp. It is thus of Late Cretaceous/Palaeogene aspect. The presence of *Diphyes ficusoides* Islam 1983 restricts the range of this sample to mid-Eocene (Lutetian, calcareous nannoplankton zones NP14/NP15) (Powell, 1992). Small numbers of Neogene/Quaternary dinoflagellate cysts were observed (e.g. *?Achomosphaera andalousiensis* and *Spiniferites mirabilis*: these grains, by virtue of their rareity, are deemed to be contaminants. The occurrence of marine microplankton points to a marine depositional regime.

CALCAREOUS MICROFAUNAL ANALYSIS OF BOREHOLE 94/6

I.P. Wilkinson

Introduction

Five samples from Borehole 94/6 were submitted in order to provide a biostratigraphical age determination for the section by means of calcareous microfossils. Sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8974	3.14-3.16	Quaternary
8975	3.45-3.50	Quaternary
8976	8.57-8.64	Quaternary
8977	17.32-17.35	(Non-age diagnostic)
8978	17.61-17.64	(Non-age diagnostic)

Results

Abundant Pleistocene to Recent foraminifera and ostracoda were present in the samples CSC8974 to 8976, but only sparse faunas were recovered from samples CSC8977 and 8978. Pre-Quaternary taxa were not present.

CALCAREOUS NANNOFOSSIL ANALYSIS OF BOREHOLE 94/6

N.M. Hine

Introduction

Five samples from borehole 94/6 were submitted for calcareous nannofossil analysis: sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8974	3.14-3.16	Mid-Pliocene
8975	3.45-3.50	Early to mid-Pliocene
8976	8.57-8.64	Early to mid-Pliocene
8977	17.32-17.35	(None)
8978	17.61-17.64	(None)

Results

Early to mid-Pliocene: CSC8974 to 8976

CSC8974: This is highly productive sample. Having removed the sandy fraction of the sediment, a rich but low diversity assemblage remained. The assemblage is characterised by abundant small *Reticulofenestra* spp. (*R. productella, Reticulofenestra* sp.), rare *Gephyrocapsa aperta, Calcidiscus leptopora, Helicosphaera kamptneri* and *Sphenolithus neoabies*. There is no evidence of *Pseudoemiliania lacunosa* or *Discoaster* spp. Cretaceous nannofossils are recorded in low numbers and are attributed to reworking.

Zonation :- Mid-Pliocene; *Reticulofenestra pseudoumbilica* Zone, NN15 (Martini 1971).

CSC8975 and 8976: These samples yielded abundant but low diversity assemblages characterised by abundant small *Reticulofenestra* spp. (*R. productella, R. minutula,*

Reticulofenestra sp.), rare *Calcidiscus leptopora, Helicosphaera kamptneri* and *Sphenolithus neoabies*. There are no records of *Gephyrocapsa* which would suggest the assemblage is older than NN15 when the genus first evolved, however, rare specimens of a badly preserved form, assigned to *Pseudoemiliania lacunosa* are recorded, and so an NN14/15 age assignment is considered the most probable. There are no records of *Discoaster* spp. If the identification of *P. lacunosa* was incorrect, then an older NN13/14 zonation would be considered more consistent with the data.

Zonation :- Early to mid-Pliocene, NN14-15 (Martini 1971).

CSC8977 and 8978

These samples were barren of calcareous nannofossils (no specimens recorded in more than 25 fields of view).

Zonation :- None.

BOREHOLE 94/7

SITE DETAILS

Dates of drilling: 24th-25th September, 1994

Latitude: 58°56.420'N; **Longitude:** 13°41.640'W

Location: Top of George Bligh Bank, 149km north of Rockall Island

Map area: George Bligh Bank

BGS plan no: 378

Block no: 148/2

Water depth: 484m

Sea-bed conditions: Sandy

Total cored: 23.55m; **Recovered:** 2.90m (12.3%)

Oldest sediment cored:

Sub-bottom depth: 22.4m

Nature: Sandstone

Age: Paleocene

Basement: Interbedded basalts and sediments

Logging: None

SUMMARY

Borehole 94/7 is located on the top of George Bligh Bank, at the western edge of a sediment wedge overlying acoustic basement (Fig. 14). The borehole cored the following succession:

0.0-10.60m. Quaternary. Sand.

10.60-20.97m. Middle to lowest upper Eocene. Biosparite on bioclastic sandstone with basal gravel.

20.97-23.55m. Paleocene. Two basalt flows separated by a very thin sandstone layer.

OBJECTIVES

Borehole 94/7 had two main objectives: 1) to test the nature of the acoustic basement (reflector D of revised seismic-stratigraphical scheme - this report) on George Bligh Bank; and, 2) to ascertain the age and lithology of the overlying sediment wedge. The latter forms part of the previously informally-named George Bligh Bank sequence of Hitchen and Stoker (1993), who, prior to drilling, tentatively assigned a Palaeogene age to the sequence. The site also provided an opportunity for comparison of the Cenozoic development of the George Bligh Bank with the Rockall Bank to the south.

DRILLING

Despite a persistently heavy swell of 3 to 5m, no problems were encountered during the spud-in. Coring was relatively fast although recovery was very poor in the upper part of the hole; however, this improved with depth as harder material was encountered. Acoustic basement was reached at 20.91m sub-bottom depth, and the borehole was terminated at 23.55m, due partly to the objective being successfully achieved, but also influenced by the constant force 9 wind conditions and increasing swell to 5 to 6m.

RESULTS

The stratigraphical succession cored at this site consists of 10.60m of Quaternary sediments unconformably overlying 10.37m of middle to lowest upper Eocene strata, in turn, unconformably resting on weathered and eroded Paleocene basalt. A summary log is presented in Figure 14, and a detailed composite log is included at the back of this appendix.

Quaternary

Very poor recovery in this section is limited to traces of pale yellowish brown (2.5Y6/4), moderate- to well-sorted, fine-grained sand, rich in carbonate (@95%),

mostly foraminifera. This veneer of Quaternary sand is consistent with the results of an adjacent shallow core, 58-14/9 (S8) (see Volume 3, Appendix 2), which recovered 5.97m of stacked, thin- to thick-bedded, middle to upper Pleistocene, carbonate-rich sands.

Middle to lowest upper Eocene

Pale brownish grey (2.5Y6/2) biosparite on pale yellow (2.5Y7/4) to pale yellowish brown (2.5Y6/4) bioclastic sandstone was recovered at the top of this section. The biosparite is massive, medium to coarsely crystalline, partly recrystallised but with shell fragments still recognisable. Sporadic silt to medium-grained quartz and lithics are scattered throughout, and back manganese mineralisation is pervasive. The top of the sandstone is irregular and burrowed; the burrows infilled with sand and lithic clasts set in a white, recrystallised carbonate matrix. The top surface is also blackened with manganese.

The underlying bioclastic sandstone is carbonate-rich (about 95%), poorly sorted, predominantly fine- to medium-grained but with common very coarse- to granule-grade shell fragments. It is clean and porous with a framework-supported texture. A crude bedding is locally developed, defined by the sporadic alignment of shell fragments, particularly flat-lying bivalves.

The contact between the biosparite and the sandstone is irregular, variably sharp to diffuse, and appears sub-vertical in the core. Black manganese mineralisation is present at the contact. It is unclear whether contemporary jointing in the sandstone has been subsequently invaded by carbonate material, or whether some other explanation (eg. diagenetic) is necessary.

The base of this section is marked by a thin layer of sandy gravel overlying the jointed and weathered top of the underlying basalt. A grey sandstone cobble and very poorly sorted, coarse- to very coarse-grained, lithic sand and small pebbles comprise the

gravel; the finer fraction has also penetrated down into fractures within the basalt where it is bounded by a carbonate cement.

Calcareous nannofossil data indicate a mid- to earliest late Eocene (NP15-18) age for these sediments. Reworked specimens of Paleocene to earliest Eocene foraminifera are also present. Sedimentation probably occurred in a shallow-marine environment.

Paleocene

The borehole terminated in dark grey to very dark grey (2.5YN4/-N3/), medium crystalline basalt, which is highly fractured, slightly amygdaloidal, carbonate veined, and contains disseminated pyrite. Two separate extrusive flows have been penetrated, separated by a very thin layer (<1cm) of shelly sandstone resting on the weathered top of the lower flow. Petrological analysis (see Volume 5, Appendix 4) of the basalts indicates that they are aphyric, consisting of plagioclase laths and opaques, either ophiticallyenclosed by clinopyroxene or set in a groundmass of smectite (replacing interstitial glass). In the upper flow, the plagioclase laths define a strong trachytic texture; this is less well-defined in the lower flow. Near the top of the upper flow, xenoliths of finely crystalline, basic igneous rock and red sandstone have been incorporated into the flow.

The very thin sandstone is very fine- to very coarse-grained, very poorly sorted, with abundant shell debris and organic debris; the latter includes a leaf/wood impression cast on the base of the upper flow. The cellular structure of the leaf/wood fragment is very evident and partly pyritised. Large, robust fragments of the foraminifera *Operculina* sp are common, and a very shallow-water environment is envisaged for the deposition of the sandstone.

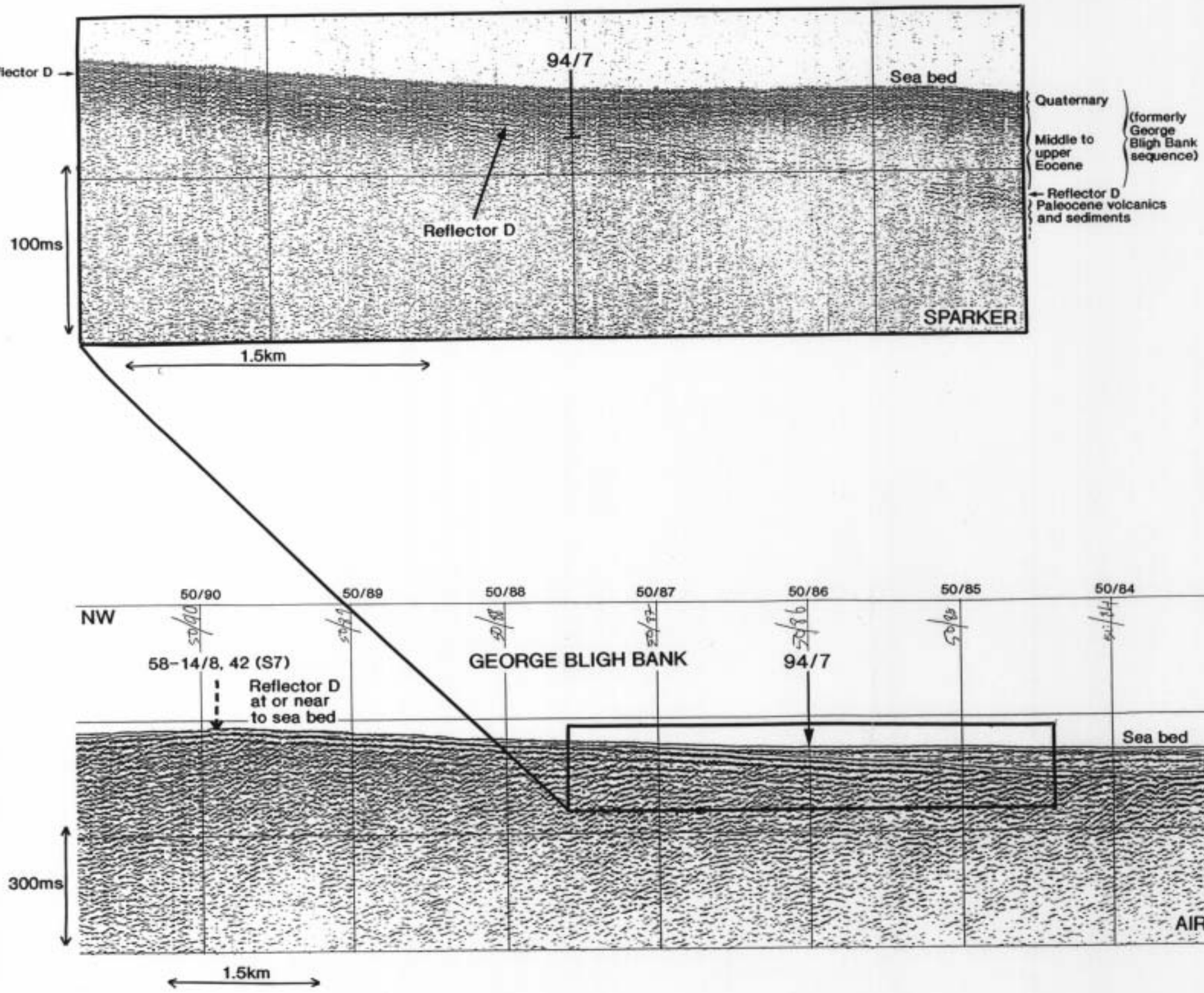
DISCUSSION

Shallow cores (58-14/10, 43 (S9), 58-14/11 (S10) and 58-14/55 (S40) - see Volume 3, Appendix 2) from the eastern flank of George Bligh Bank recovered sediments of late

Paleocene (NP6-9) age overlying acoustic basement. Borehole 94/7 has penetrated acoustic basement and proved basalt with a very thin interbed of Paleocene sandstone. These stratigraphical relationships suggest that the basalts are, at their youngest, late Paleocene in age, although an older Paleocene age cannot be discounted. In comparison to the late Paleocene to early Eocene basalts recovered in boreholes 94/2, 94/3, 94/5 and 94/6 on Rockall Bank, the basalts on George Bligh Bank may be slightly older.

Approximately 6km to the north-west of the borehole site, shallow core 58-14/8, 42 (S7) penetrated acoustic basement and recovered conglomerate overlying basalt (Fig. 14) (see Volume 3, Appendix 2). The conglomerate has been dated as Paleocene in age, entirely consistent with the findings of borehole 94/7. These data imply that the acoustic basement on George Bligh Bank is composed of an interbedded succession of volcanic and sedimentary rocks.

The middle to lowest upper Eocene sediments are correlatable with similar deposits recovered in boreholes 94/2 and 94/3 from the upper part of the sediment wedge on Rockall Bank. The section penetrated by borehole 94/7 also represents the upper part of the sediment wedge preserved on George Bligh Bank; lower sections within the wedge have been sampled by the shallow cores noted above. Although, unlike that on Rockall Bank, the entire wedge has not been sampled, the history of sedimentation and tectonism between these two banks seems broadly comparable.



BOREHOLE 94 /7

STRATIGRAPHY	DEPTH (m)	LITHOLOGY	RECOVERY	SEISMIC REFLECTOR	LITHOLOGY
QUATERNARY / PLEISTOCENE TO HOLOCENE; PALAEOGENE / MIDDLE TO UPPER EOCENE	10				0.0–10.60m Poor recovery. Traces of SAND, fine-grained, moderate-well-sorted, @95% carbonate, mostly forams. Pale yellowish brown.
PALAEOGENE / PALAEOCENE	20	23.55m- TD		D	10.60–12.0m BIOSPARITE on BIOCLASTIC SANDSTONE. Biosparite is medium to coarsly crystalline, partly recrystallised, massive, pale brownish-grey. Bioclastic sandstones are fine-coarse-grained, poorly sorted, clean, porous, framework-supported, crudely-bedded, depicted by shell alignment. Pale yellow to pale yellowish brown. Diffuse contact: depositional or diagenetic? Pervasive mineralisation attransition, black, ?Manganese. 12.0–20.91m No Recovery. 20.91–20.97m Gravelly sand overlying weathered top at basalt. 20.97–23.55m BASALT /BASIC IGNEOUS. Medium crystalline, dark grey, highly fractured, carbonate veining, disseminated pyrite, ?xenolith of red sandstone and finely-crystalline basic igneous rock, slightly amygdaloidal. Two flows separated at 22.4m by very thin shelly SAND with plant remains cast on base of overlying flow.
	30				
	40				
	50				
	60				

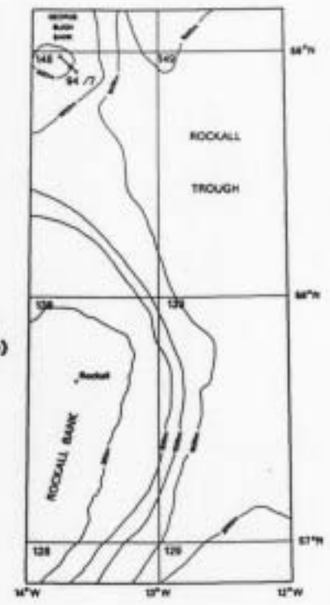


Fig. 14. Seismic-stratigraphical setting of borehole 94/7 with summary log (see text for details). Inset map shows location of borehole and seismic profile.

DINOFLAGELLATE CYST ANALYSIS OF BOREHOLE 94/7

J.B. Riding

Introduction

Three samples from borehole 94/7 were submitted for dinoflagellate cyst analysis; sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8979	10.87-10.88	(None)
8980	11.83-11.86	(None)
8981	22.40	(None)

Results

Samples CSC8979 and 8980 were both entirely barren of palynomorphs. Sample CSC8979 yielded a relatively sparse residue dominated by finely disseminated amorphogen and resistant mineral grains. The residue from sample CSC8980 proved similar, however, it also contained significant levels of dark, angular wood fragments. In sample CSC8981, the residue is again rather sparse and palynologically barren. The maceral types present are occasional woody fragments and finely divided amorphogen together with common resistant mineral grains. The barren nature of all of these samples means that an age/palaeoenvironmental assessment on palynological evidence is impossible.

CALCAREOUS MICROFAUNAL ANALYSIS OF BOREHOLE 94/7

I.P. Wilkinson

Introduction

Three samples from borehole 94/7 were submitted in order that an analysis of the calcareous microfossils could be undertaken to provide a biostratigraphical age determination for the sequence. Sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8979	10.87-10.88	(Non-age diagnostic)
8980	11.83-11.86	(Non-age diagnostic)
8981	22.40	Paleocene

Results

The only specimens considered to be *in situ* are from sample CSC8981 and tentatively placed in the late Paleocene. Abundant Pleistocene to Recent foraminifera were recovered from samples CSC8979 and 8980, and very rare specimens of *Operculina* sp, identical to those from the Paleocene to lowest Eocene samples in the lower part of Borehole 94/3, were also found in the latter sample. Whether or not this Paleocene species is *in situ* is not known, but no other fossil material was noted.

Paleocene: CSC8981

Sample CSC8981 contained common fragments of a large, robust species of foraminifera. Although no specimens could be satisfactorily removed from the sandstone matrix, they may be specimens of *Operculina* sp and a shallow water deposit of Paleocene age can be tentatively suggested by analogy with the findings of Berggren (1974).

CALCAREOUS NANNOFOSSIL ANALYSIS OF BOREHOLE 94/7

N.M. Hine

Introduction

Three samples from borehole 94/7 were submitted for calcareous nannofossil analysis; sample details together with a summary of the palaeontological ages are as follows:

CSC No:	Depth (m)	Palaeontological Age
8979	10.87-10.88	(Non-age diagnostic)
8980	11.83-11.86	Mid-Eocene
8981	22.40	(None)

Results

CSC 8979

No calcareous nannofossils were recorded in this sample from more than 25 fields of view. After extensive scanning of the slide a single specimen of *Cyclicargolithus floridanus* was recorded together with a single non-descript placolith. *C. floridanus* ranges stratigraphically from the mid-Eocene to the mid-Miocene (NP14-NN6).

Zonation :- None.

Mid-Eocene: CSC 8980

Nannofossils are very rare (8 specimens recorded in over 15 fields of view) and when recorded are of low diversity. The assemblage is composed primarily of *Reticulofenestra* spp. such as *R. scrippsae, R. bisecta, R. reticulata* and *R. minuta.* Additional species include *Chiasmolithus* spp., *Coccolithus pelagicus, Cyclicargolithus floridanus* and *Helicosphaera* cf. *reticulata.* The co-occurrence of

these species suggest a mid-Eocene age assignment. There is no evidence of any older reworked material.

Zonation :- Mid-Eocene, NP15 (?17)-18 (Martini, 1971).

CSC 8981

This sample was barren of calcareous nannofossils (no specimens recorded in more than 25 fields of view).

Zonation :- None.

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BRITISH GEOLOGICAL SURVEY

LOG OF BOREHOLE 94/1

BH NO. 94/1

APPROXIMATE POSITION	Eastern slope of Rockall Bank, approx 78km SSE of Rockall Island		
LATITUDE	56° 54.061'N	TOTAL DEPTH	728m
LONGITUDE	13° 31.775'W	WATER DEPTH	663m
NAVIGATION	Differential GPS	VESSEL	M/S Bucentaur
MAP AREA	McCallien	STATION KEEPING	Dynamic positioning
LICENCE BLOCK	128/3	DATES OF DRILLING	10th–11th September 1994
BGS PLAN NO.	372	GEOLOGISTS	M.S. Stoker

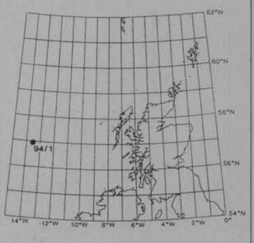
COMMENTS

Borehole 94/1 proved 33.45m of middle Miocene to Holocene sediments resting with angular unconformity on middle Eocene strata; the borehole was terminated at 65.00m. The middle Miocene to Holocene sediments comprise part of the Feni Ridge sediment drift which has developed by upslope–accretion and onlap onto older deposits on the western flank of the Rockall Trough. The angular unconformity penetrated by the borehole corresponds to regional seismic reflector C. Seismic reflector A, which occurs within the drift at about 19m depth, is less well–constrained, although a mid–Miocene age seems most likely.

LITHOLOGICAL KEY

- Clay/shale/mudstone
- Silt/siltstone
- Sand/sandstone
- Gravel/conglomerate
- Limestone/chalk
- Evaporites
- Extrusive igneous
- Intrusive igneous
- Basement
- Shells/shell frags

LOCATION MAP



STRATIGRAPHY	CORE RECOVERED	INTERPRETATION	DESCRIPTION	COMMENTS SUBSAMPLES
			Depths in metres below sea bed	
			0.00	
NEOGENE – QUATERNARY / ? Upper Pliocene to Holocene			Traces of muddy silty SAND: very fine–grained, moderate–poorly sorted, common fine–very coarse sand grains scattered throughout, mixed carbonate/terrigenous composition – abundant black lithics, common forams, unbroken single bivalve shell preserved, dark olive grey (5Y3/2), strongly calcareous.	Bag sample
			10.00	
			Traces of very poorly sorted mix of muddy silty very fine–grained SAND, poorly sorted, mostly terrigenous grains (>75%), scattered shell fragments; SAND, silty to medium–grained, terrigenous:carbonate approx 60:40, very poorly sorted, abundant quartz and lithics, common forams; occasional angular PEBBLES (up to 6mm), including ?siltstone and weathered igneous; MUD, soft, dark olive grey (5Y3/2).	Bag sample
			Traces of MUD: very soft, slightly silty, weakly calcareous, sporadic small pebbles, including black igneous, subangular–subrounded, 9mm, pale olive (5Y8/4).	17.0m MICROPAL Bag sample CSC8908
			20.00	
Middle Miocene to Upper Pliocene			Muddy silty SAND: massive, bioturbated, mostly very fine–grained with scattered fine–grade grains, moderate–poorly sorted, carbonate–rich (>95%), common forams and sponge spicules(partly glauconite stained), scattered coarse–very coarse grade shell fragments, common glauconite, firm to stiff, strongly calcareous, pale olive (5Y6/3).	22.7–22.73m MICROPAL CSC8909
			Sandy GRAVEL: massive, very poorly sorted. Clasts up to cobble grade, including basic igneous, subrounded, and intraformational carbonate–rich sandstone, fine to very fine–grained, and sandy gravel including mudstone clasts; clast–supported, randomly orientated, disorganised. Matrix consists of muddy, slightly gravelly sand,very poorly sorted, mixed terrigenous/carbonate composition approx 40:60, common forams, black lithics. Strong reaction HCl; olive grey (5Y4/2).	
			30.00	
			33.45 Sharp base colour change, rip–ups suggest some erosion	CSC8910 33.4–33.41m MICROPAL 33.8–33.83m MICROPAL CSC8911
			(33.45–58.48m) Silty MUDSTONES: massive, homogeneous, structureless, predominantly terrigenous composition (>99%), rare forams/shell fragments, black (5Y2.5/2), hard, hackly fracture, waxy–greasy; aromatic smell (peaty), non–calcareous.	37.65–37.7m ORG GEOCHEM
			40.00	
			Occasional parallel lamination: colour banded, reddish–brown (5YR4/3) alternating with black (a/e), laminae 5–20mm thick.	44.97–45.0m MICROPAL CSC8912
			Vugs/fractures, partly filled with calcite and ? pyrite.	
			Occasional hints of bioturbation; sand–filled burrows, becomes more dark olive grey (5Y3/2) in sandier intervals.	48.36–48.4m ORG GEOCHEM 48.51–48.54m MICROPAL CSC8913
			50.00	
			Occasional thin veins of calcite and pyrite noted.	
			Silty MUDSTONES a/e	
				53.77–53.8m ORG GEOCHEM
			Mottled, bioturbated texture	
			Dark olive grey (5Y3/2) – black (5Y2.5/2)	
PALAEOGENE / Middle Eocene			58.48 Sharp contact, ?weathered sst, yellow–brown	58.75–58.8m PETROLOGY 58.9–58.92m MICROPAL CSC8914
			(58.48–65.00m) Gravelly SAND/SANDSTONE: massive, bioturbated (including subhorizontal tubes) and mottled texture, mostly fine to medium–grained but with common coarse–very coarse sand grains and abundant small pebbles, very poorly sorted. Mixed terrigenous/carbonate composition approx 50:50, lithics dominate terrigenous component, including abundant black grains and ? glauconite, carbonate includes common forams.Strongly calcareous.	
			60.00	
			Pebbles up to 10mm diameter, predominantly matrix–supported, randomly orientated, disorganised, include basic igneous and intraformational silty mudstone (a/e), many pebbles are very well–rounded with smooth shiny surfaces. Variably soft to hard and indurated. Mottled olive grey (5Y4/2).	64.9–64.93m MICROPAL CSC8915
			65.00 TD	
			70.00	

BRITISH GEOLOGICAL SURVEY

LOG OF BOREHOLE 94/2

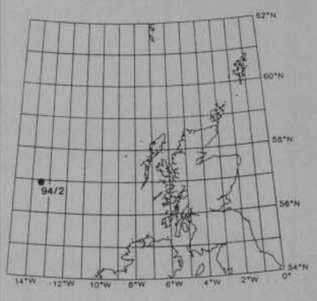
BH NO. 94/2

APPROXIMATE POSITION	Eastern flank of Rockall Bank, approx 77km SSE of Rockall Island		
LATITUDE	56° 54.243'N	TOTAL DEPTH	330.15m
LONGITUDE	13° 34.512'W	WATER DEPTH	308m
NAVIGATION	Differential GPS	VESSEL	M/S Bucentaur
MAP AREA	McCallien	STATION KEEPING	Dynamic positioning
LICENCE BLOCK	128/3	DATES OF DRILLING	11th–13th September 1994
BGS PLAN NO.	376	GEOLOGISTS	M.S. Stoker

COMMENTS

Borehole 94/2 successfully penetrated the distal–edge of the sedimentary wedge on the eastern flank of Rockall Bank, and encountered basalt (acoustic basement – seismic reflector D) at 20.94m. Regional stratigraphical evidence suggests that the basalt is probably late Paleocene to early Eocene in age. A thin section of calcilutite and tuffaceous sandstone of early mid–Eocene age rest unconformably on the basalt; these in turn, are unconformably overlain by an upwards–fining clastic sequence of mid– to late Eocene age. The latter forms the bulk of the sediment wedge which is capped by a Quaternary veneer.

LOCATION MAP



LITHOLOGICAL KEY

- Clay/shale/mudstone
- Silt/siltstone
- Sand/sandstone
- Gravel/conglomerate
- Limestone/chalk
- Evaporites
- Extrusive igneous
- Intrusive igneous
- Basement
- Shells/shell frags
- Ash shards

STRATIGRAPHY | CORE RECOVERED | INTERPRETATION | DESCRIPTION | COMMENTS SUBSAMPLES

Depths in metres below sea bed

QUATERNARY — Pleistocene to Holocene

PALAEOGENE — Middle to Upper Eocene

Lower Middle Eocene

? Upper Paleocene to Lower Eocene

0.00

(0–4.65m)
GRAVEL : cobbles(to 8cm), subangular–subrounded, including grey, fine–medium crystalline sparite and pebbly sandstone.

(4.65–4.81m)
Muddy SAND : fine–grained, very poorly sorted, 50% carbonate, dark greenish grey (5BG4/1) on gravelly sandy MUD, bioturbated, H2S odour, colour a/a.

CSC8916 4.95–4.97m MICROPAL and PETROLOGY

(4.81–19.33m)
SANDSTONES, PEBBLY SANDSTONES on thin basal CONGLOMERATE : overall upwards–fining from basal conglomerate through coarse–grained to predominantly medium to fine–grained sandstones and pebbly sandstones, although very coarse grains, granules and small matrix–supported pebbles occur throughout the sequence. Massive to crudely bedded, with discrete pebbly bands, shell–rich beds and partings defined by sub–horizontally aligned shell fragments. Predominantly terrigenous composition, >75–>90% quartz and lithics set in a partially recrystallised carbonate matrix. Abundance of weathered igneous grains, both rock and crystals; grain shapes vary from angular to well–rounded and lustrous. Subordinate biogenic debris includes bivalves and forams. Soft and friable in upper part of section, becoming hard and indurated towards base.

10.00

11.78–11.8m PETROLOGY

15.5–15.53m MICROPAL CSC8917

16.89–16.9m PETROLOGY

17.32–17.33m MICROPAL CSC8918

Black (2.5YN2/) above 16.62m ; mottled olive–grey to dark olive grey (5Y4/2–3/2) becoming dark greenish grey (5G4/1–5BG4/1) towards base. Abundant scattered pyrite in lower part of sequence.

18.85–18.88m MICROPAL CSC8919

19.69–19.71m MICROPAL CSC8920

20.00

Basal CONGLOMERATE is poorly sorted and disorganised, matrix–supported clasts including underlying material and shell fragments set in coarse sandstone matrix a/a.

20.83–20.84m MICROPAL CSC8921

21.74–21.76m PETROLOGY

22.15 TO

Indistinct base, possibly erosive (rip–ups)

(19.33–20.81m)
Pebbly muddy SANDSTONE : massive, soft, fine–grained, very poorly sorted, disorganised, mainly terrigenous (>90%) quartz and lithics, angular ash shards, scattered matrix–supported lithic clasts, angular to well–rounded, dark grey (5Y4/1) to dark greenish grey (5GY4/1) with abundant disseminated pyrite and discrete pyrite veins, on medium to fine–grained sand, TUFF(?),with coarse sand and granules of rock fragments and crystals set in a carbonate matrix. Very poorly sorted, hard and indurated, abundant pyrite and some carbonate veining. Greenish grey (5BG6/1).

30.00

Sharp contact : loaded/partly scoured ?

(20.81–20.94m)
Thin–bedded CALCILUTITE : indurated but soft and flaky, some biogenic debris, cut by carbonate veins, greenish grey (5BG8/9)/ bluish grey (5B5/1), on mix of brecciated BASALT ? and CALCILUTITE.

(20.94–22.15m)
BASALT : dark grey (N4/), fine–grained, vesicular and amygdaloidal, cut by criss–cross network of carbonate veins, with, thin interbedded TUFF ?, graded, coarse top and base, fine–grained, lithics and crystals, recrystallised carbonate matrix, greenish grey (5GY6/1).

40.00

50.00

BRITISH GEOLOGICAL SURVEY

LOG OF BOREHOLE 94/3

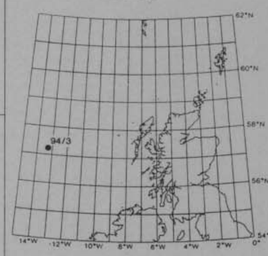
BH NO. 94/3

APPROXIMATE POSITION	Eastern flank of Rockall Bank, approx 54.5km SE of Rockall Island		
LATITUDE	57° 10.740'N	TOTAL DEPTH	489.65m
LONGITUDE	13° 12.521'W	WATER DEPTH	280m
NAVIGATION	Differential GPS	VESSEL	M/S Bucentaur
MAP AREA	Rockall Island	STATION KEEPING	Dynamic positioning
LICENCE BLOCK	138/24	DATES OF DRILLING	12th–19th September 1994
BGS PLAN NO.	370	GEOLOGISTS	M.S. Stoker

COMMENTS

Borehole 94/3 penetrated the entire prograding sediment wedge on the eastern flank of Rockall Bank, terminating in acoustic basement – seismic reflector D – at 209.65m. The acoustic basement is interpreted to consist of an interbedded sequence of basaltic pillow lavas and mudstones. Interbedded sediments of shallow marine,deltaic/paralic,siliciclastic shoreline and alluvial origin, together with tuffaceous deposits and a single lava flow,comprise the overlying +200m–thick section, which ranges from late Paleocene to late Eocene in age,with a Quaternary veneer. Seismic reflector C1 – an angular unconformity – was penetrated at @136m, above which the first indications of volcaniclastic activity are evident in this area.

LOCATION MAP



LITHOLOGICAL KEY

- Clay/shale/mudstone
- Silt/siltstone
- Sand/sandstone
- Gravel/conglomerate
- Limestone/chalk
- Evaporites
- Extrusive igneous
- Intrusive igneous
- Basement
- Shells/shell frags
- Plant/woody frags
- Tuff/tuffaceous material

STRATIGRAPHY | CORE RECOVERED | INTERPRETATION | DESCRIPTION | COMMENTS SUBSAMPLES

Depths in metres below sea bed

QUATERNARY

Pleistocene to Holocene

0.00

(@0–12m)
Very thin to thick–bedded MUDDY SANDS : mainly very fine to medium–grained, poorly sorted, scattered granules and pebbles (up to 1cm), matrix–supported, include soft mudstone intraclasts. Mottled and bioturbated, common sand–filled burrows, including ? planolites. Predominantly terrigenous composition, >90% quartz and lithics, but with scattered shell debris and foraminifera.
Beds vary from 3cm–84cm thick; bed contacts are sharp to gradational. Beds occasionally graded, upwards–fining and –coarsening. Upwards–fining to muds.
Very dark grey (5Y3/1)–dark olive grey (5Y3/2) to dark greenish grey (5G4/1), rarely black (2.5/).

7.3–7.33m MICROPAL CSC8922

10.00

11.67–11.7m MICROPAL CSC8923

12.00

(@12–20m)
Massive MUDDY SANDS : slightly pebbly, fine–grained, poorly sorted, matrix–supported granules and pebbles. Include mudstone intraclasts and well–rounded, lustrous, lithic pebbles, randomly orientated. Predominantly terrigenous a/a, subordinate shell debris, weak to non–calcareous, firm to stiff.
Dark olive grey (5Y3/2)–black (2.5/2) to very dark grey (5Y3/1).

13.2–13.23m MICROPAL CSC8924

18.05–18.08m MICROPAL CSC8925

20.00

(@20–34m)

COBBLE of medium–coarse grained, slightly pebbly sandstone.

21.92–21.93m MICROPAL CSC8926

Upper Middle Eocene

COBBLE of dark, finely crystalline basalt, and compacted ball of muddy, very fine–fine–grained sand.

30.00

(34.35–37.85m)
Massive SILTY SANDSTONE : fine–very fine–grained, poorly sorted, bioturbated and mottled, with silt–filled burrows, including planolites ? Predominantly terrigenous, >85% quartz and lithics set in a partly recrystallised carbonate cement, calcareous. Scattered shell fragments and occasional clasts of large shells including gastropod, common woody fragments. Hard, indurated, but friable.
Mottled grey (5Y6/1–5/1) to dark grey (5Y4/1).

34.96–35.0m MICROPAL CSC8927

37.85 [Indistinct base, possibly bioturbated]

(37.85–47.26m)
Medium to thick–bedded, slightly muddy SANDSTONES and PEBBLY SANDSTONES : sandstones are fine–very fine–grained, moderate to well–sorted, with scattered medium–coarse grains, predominantly terrigenous, >85–>95% quartz and lithics, rare shell debris (including gastropod and bivalve), partly carbonate cemented, but moderate to weakly calcareous, grading into pebbly sandstones, include intraclasts of carbonate–cemented sandstone and orange–brown mudstone (<1cm), matrix–supported, randomly orientated, occasional coarse–tail grading (upwards–fining). Abundant woody fragments scattered throughout.

38.7–38.72m MICROPAL CSC8928

40.00

CSC8929
42.8–42.83m MICROPAL
43.08–43.1m PETROLOGY

CSC8930
47.23–47.26m MICROPAL
47.75–47.8m PETROLOGY

47.26
Occasional bioturbation at 42.8–42.9m, with sand–filled subvertical (?skolithos) and horizontal burrows.
Bed contacts indistinct, ?transitional/ graded.
Very dark grey (5Y3/1) to black (5Y2.5/1), becoming grey (N5/) to dark grey (N4/) at base.
Hard and indurated.

50.00

51.00

51.81–51.85m PETROLOGY
51.91–51.95 (pebble)

47.26 [Contact not observed, probably sharp]

PALAEOGENE

(47.26–@51.0m)
BASALT : black (2.5YN2/), massive, finely crystalline, amygdaloidal (carbonate–filled), highly jointed with common mineralisation, thin carbonate veins and disseminated pyrite along the fracture planes.

51.00 [Contact not observed, but slow drilling to 51m]

(@51.0–60.0m)
CONGLOMERATE and PEBBLY SANDSTONE : poorly sorted, matrix to clast–supported, includes igneous and lithic clasts, (eg pebbly sandstone) to cobble grade (up to 8cm), angular to well–rounded, randomly orientated, disorganised to occasionally graded (upwards–fining), set in a fine–grained sandstone matrix, predominantly terrigenous (>95%) quartz and lithics, poorly sorted, non–calcareous.
Dark greenish grey (5GY4/1) to dark olive grey (5Y3/2).

60.00

CSC8931
62.02–62.04m MICROPAL
62.32–62.35m MICROPAL
CSC8932

60.00 [Contact not observed]

(@60.0–88.62m)
Interbedded MUDDY SANDSTONES and SANDY MUDSTONES (CLAYSTONES):
Muddy sandstones are very fine to fine–grained, moderate to poorly sorted, with scattered medium–coarse grains and occasional matrix–supported granules and small pebbles (including red–brown mudstone), randomly orientated, predominantly terrigenous composition, >95% quartz and lithics, rare scattered shell debris, bioturbated and mottled, with mud–filled burrows, occasional hint of parallel laminations (to 5mm thick), non–calcareous.

66.14–66.17m MICROPAL CSC8933

70.00

71.22–71.25m MICROPAL CSC8934

72.3–72.33m MICROPAL CSC8935

Sandy mudstones (claystones) are sandy largely through bioturbation (sand–filled burrows), massive with occasional hints of partially disrupted colour banding, hard, non–calcareous, sporadic red–brown mudstone intraclasts.
Dark reddish–brown (5YR3/1) to brown (10YR4/3) to dark yellowish brown (10YR4/4)

80.00

Beds range from thin to thick–bedded (4cm–95cm), occasional very thick sandstone beds (up to 1.88m); bed contacts vary from sharp to gradational, mostly showing some degree of bioturbation.

83.6–83.65m MICROPAL CSC8936

88.62 [Sharp contact, partly bioturbated]
(88.62–88.85m) PEBBLY MUDDY SANDSTONE : very poorly sorted, predominantly medium–grained with abundant lithic pebbles, commonly well–rounded and lustrous, matrix–to–clast supported, randomly orientated, highly disorganised. Bed is bioturbated with sand–filled burrows. Highly ferruginous, non–calcareous.
Yellowish brown (10YR5/6–5/8) to yellowish red (5YR4/6–5/8)

88.8–88.85m PETROLOGY

88.85 [Sharp contact]

90.00

(88.85–109.0m) Massive to crudely bedded PEBBLY SANDSTONES (GRITS) : very coarse–grained, poorly sorted, predominantly terrigenous, >99% lithics and quartz, with common matrix–(to clast) supported pebbles (to 2.5cm), sub–angular to rounded, sometimes lustrous, includes weathered igneous rocks, long axes display a crude sub–horizontal alignment. Sandstone matrix is similarly a mix of angular and rounded grains, very immature, non–calcareous, friable. Sandstones also contain disseminated white, soft clayey grains (altered TUFFACEOUS material ?), sometimes depicting a crude lamination, occasionally forms thin white sandy clayey beds, very light and aerated, and soft.
Olive to very dark grey brown (2.5Y3/2).

92.91–92.96m PETROLOGY

100.00

(@109–110m)
Pebbly sandstones and white clays (?altered tuffs) becoming increasingly interbedded, clayey beds 5mm–5cm thick.

109.00

(@110–117.59m)
Predominantly soft, sandy CLAYS (altered TUFFS?) with very thin to thin interbeds of slightly pebbly, coarse–grained SANDSTONE a/a.

109.97–110.0m PETROLOGY

Claystones are soft and change in colour from white at the top of the sequence, becoming light yellowish brown (2.5Y6/4) to greyish–green (5G4/2) towards the base.

112.5–112.54m PETROLOGY

117.59 [Sharp contact]

115.76–115.8m PETROLOGY

(117.59–121.57m)
Thin–to–medium bedded PEBBLY SANDSTONES : medium to coarse–grained, poorly sorted, wholly terrigenous, quartz and lithics, abundant matrix–to–clast–supported lithic fragments, including common soft black claystone intraclasts. Beds occasionally display scoured, channelled bases and ripple laminations.
Sandstone occasionally grades into SANDY CONGLOMERATE, matrix–to–clast–supported. Rare very thin (<1cm) black mudstone/ claystone bed at @120m.

117.59

118.59–118.63m PETROLOGY

120.00

121.57

121.57 [Indistinct contact, core broken up]

123.64–123.67m MICROPAL CSC8937

(121.57–134.94m)
Interbedded medium to very thick beds of SANDSTONES and MUDSTONES :
Sandstones are very fine to fine–grained, moderately sorted, predominantly terrigenous, occasionally pebbly, including dark grey and black mudstone and very soft white claystone intraclasts, matrix–supported, randomly orientated. Beds appear mostly massive with bioturbational mottling, occasional hint of lamination (5mm–2cm) picked out by pebble bands and organic debris, latter disseminated throughout. Non–calcareous, friable.
?Tuffaceous.
Dark grey (N4/) to very dark grey (5Y3/1).

127.6–127.63m MICROPAL CSC8938

130.00

Mudstones (claystones), predominantly massive and bioturbated, occasional hint of banding (up to 3cm), partly colour banded at top of section, occasionally sandy, common altered ?tuffaceous material in upper part of section, some discrete white clayey bands near base, scattered woody fragments throughout. Bioturbation includes ?chondrites and ?skolithos (long vertical pipes up to 7cm long).
Varicoloured : black, very dark grey, greyish green and yellowish brown.
Bed contacts vary from sharp to transitional, occasionally erosive and scoured, occasionally bioturbated.

134.16–134.2m MICROPAL CSC8939

134.94

135.94

136.36–136.4m MICROPAL CSC8940

139.37–139.4m MICROPAL CSC8941

140.00

134.94 [Sharp contact]

141.33

(134.94–135.94) Very thin to thin–bedded MUDSTONES and SANDSTONES: rippled,parallel–laminated, occasional convolutions, mudstone intraclasts. Mudstones are soft, dark brown(7.5YR4/2)–dark greenish grey (5G4/1). Sandstones vary from very fine to very coarse–grained, dark greenish grey to yellow brown, occasional scoured bases. Basal sandstone bed contains first indications of ?TUFFACEOUS material.

142.42–142.45m MICROPAL CSC8942

143.77–143.8m MICROPAL CSC8943

144.85

135.94 [Sharp, irregular, partly channelised base]

(135.94–141.33) Thin to medium–bedded SANDSTONE : coarse to very coarse–grained, poorly sorted, abundant shell fragments, sand mostly terrigenous, >85% quartz and lithics, grains angular–rounded, immature. Beds display horizontal and cross–bedded lamination (bi–directional),foresets partly depicted by shell fragments. Carbonate debris includes bivalves and ? serpulid worm tubes. Top 30cm is yellowish–brown te–stained, also an influx of mudstone intraclasts and reduction in shell debris.
Mainly dark grey, hard, indurated, porous.

148.17–148.2m MICROPAL CSC8944

150.00

152.38–152.4m MICROPAL CSC8945

153.50

141.33 [Sharp contact]

(141.33–144.85) Very thin to thin bedded MUDSTONES with very thin, immature, terrigenous, SANDSTONE beds, rippled to parallel laminated,occasional convolutions, mudstone and sandstone intraclasts, base of sandstone beds is generally sharp and erosive, some brecciation of mudstones, strongly bioturbated in certain horizons, including ?chondrites, ?planolites, ?skolithos, ?escape structures; common scattered organic debris, including leaf. Non–calcareous. Mudstones, dark grey (N4/) to dark greyish brown (5YR3/2).

156.94–156.97m PETROLOGY

160.00

144.85 [Sharp contact]

(144.85–@153.5m)
Very thin to thin–bedded SANDSTONES, with occasional thin to medium–bedded MUDSTONES, SILTSTONES and CONGLOMERATES.
Sandstones predominantly medium to coarse–grained, becoming fine–grained towards top of section, very poorly sorted, mainly terrigenous composition but common scattered shell fragments (including bivalves, bryozoan nets and worm–tube casts), common woody material. Grain–size changes appear gradational, upwards–coarsening and –fining. Bedding mostly parallel laminated, occasional ripple laminations, some of bed contacts are erosive (base of small channels) mostly gradational. Occasional bioturbation. Some lithic granules in coarser beds; include mudstone intraclasts.
Very dark grey.

164.11–164.13m PETROLOGY

170.00

170.19–170.23m PETROLOGY

171.17–171.2m PETROLOGY

172.23–172.26m PETROLOGY

Mudstones, massive and bioturbated (including ?chondrites), very dark grey, eroded tops of beds. At ~148m mudstone grades into siltstone, pale grey, and back into mudstone.

Conglomerate, very poorly sorted, clast–to–matrix–supported, lithic clasts include sandstone and dark grey–black mudstone, also well–rounded and lustrous quartzo–feldspathic rock, randomly orientated, disorganised, much shell debris and woody fragments. Beds are partly carbonate–cemented; bases sharp and planar to erosive and scoured.

180.00

153.5 [Contacts not observed,probably transitional]
(153.5–188.75m)
Interbedded very thin to thick–bedded PEBBLY SANDSTONES and SANDY CONGLOMERATES:
Pebbly sandstones predominantly coarse to very coarse–grained, very poorly sorted, immature, wholly terrigenous composition, non–calcareous. Mostly thin to very thin–bedded; long axes of grains and clasts are aligned subhorizontal, parallel to ripple cross–laminated, occasionally graded,rarely massive, occasional erosive and scoured bases to beds. Graded beds occur within sandstone section and occasionally grade into very thin granule conglomerates.
Clasts are predominantly matrix–supported, include soft red–brown mudstone intraclasts below @163m; also shelly intraclasts present below @183.5m.
Dark (to very dark) greenish grey (5BG4/1).

188.75

189.02–189.04m MICROPAL CSC8946

190.00

190.39–190.42m MICROPAL CSC8947

191.7–191.75m MICROPAL CSC8948

192.31–192.36 MICROPAL CSC8949

Sandy conglomerates, very poorly sorted, matrix–to–clast supported, mostly very thin to very thick–bedded with subhorizontal, occasionally rippled, clast alignment, but sporadic disorganised beds present with randomly orientated clasts (eg 161.5–161.97m,170.35–171.72m).
Polymictic, mostly metamorphic/meta–igneous pebbles and cobbles, occasional red–brown mudstone intraclasts; basaltic clasts noted in disorganised beds. Clast shapes vary from angular to rounded, are up to 13cm. Bedding mostly flat–lying, occasionally rippled/foreset lamination. Base of beds range from scoured and erosive into sandstones, to gradational with occasional upward–fining both into sandstones and finer grade conglomerate.
Patchy carbonate cementation, often restricted to specific horizons; not pervasive.

196.36–196.4m MICROPAL CSC8950

199.28–199.34 MICROPAL CSC8951

200.00

[Transitional contact ; upwards–coarsening with loss of organic and shell fragments]

203.55–203.6m MICROPAL CSC8952

(188.75–207.46m)
Massive to crudely bedded SANDSTONES : overall upwards–coarsening, medium to coarse–grained, poorly sorted,predominantly terrigenous composition (>85%), immature, angular–well rounded quartz and lithics, common shell debris scattered throughout, including fragments of coral and large foraminifera (?Hummulites), and occasionally concentrated in discrete bands, depicting a crude bedding, mostly flat–lying, occasional hint of foreset bedding; subhorizontal bedding fabric best depicted near base of section; occasional massive beds, fine–medium grained, lacking shell debris. Common scattered woody fragments, occasional bioturbation, including vertical–subvertical tubes infilled by sediment and shell debris. Rare matrix–supported lithic clasts; patchy carbonate cementation.
Hard, occasionally friable.
Very dark grey–very dark greenish grey–black.

207.46

207.85–207.87m MICROPAL CSC8953

207.94

208.12–208.15m PETROLOGY
208.47–208.49m MICROPAL*
208.7–208.71m PETROLOGY
208.72–208.73m PETROLOGY
209.11–209.13m PETROLOGY
209.28–209.28m MICROPAL**
209.57–209.58m PETROLOGY

* CSC8954
** CSC8955

209.65
TD

207.46 [Transition : mixed zone]

Brecciated top of lava or fragments of pillow detached from flow and incorporated into sandstone (a/a). Sediment has percolated into cracks within the fragments. Lava fragments display reaction rims at contact with sediment.

220.00

207.94 [Top of uppermost pillow lava]

(207.94–209.65m TD)
Interbedded PILLOW LAVAS and MUDSTONES

Pillow lavas, basaltic, black, finely crystalline with sporadic feldspar phenocrysts. Indications of zoning and reaction rims within pillow, and columnar/ blocky jointing/cooling cracks, some thin carbonate veins along fractures. Top and base of each pillow is highly convoluted, suggests mobile contact; top often highly brecciated with lava clasts enclosed within overlying sediment.

230.00

Mudstones, black to dark greenish grey (5GY4/1), massive, bioturbated (including ?planolites) with sand–filled burrows, common shell debris. Lower bed has a 'soapy' feel. Sediment infiltrates cracks in underlying pillow.

240.00

BRITISH GEOLOGICAL SURVEY

LOG OF BOREHOLE 94/4

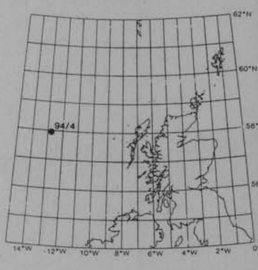
BH NO. 94/4

APPROXIMATE POSITION	Western Rockall Trough, approximately 67km NE of Rockall Island		
LATITUDE	57° 54.220'N	TOTAL DEPTH	1544m
LONGITUDE	12° 43.953'W	WATER DEPTH	1485m
NAVIGATION	Differential GPS	VESSEL	M/S Bucentaur
MAP AREA	Rockall Island	STATION KEEPING	Dynamic positioning
LICENCE BLOCK	139/2	DATES OF DRILLING	20th–21st September 1994
BGS PLAN NO.	373	GEOLOGISTS	M.S. Stoker

COMMENTS

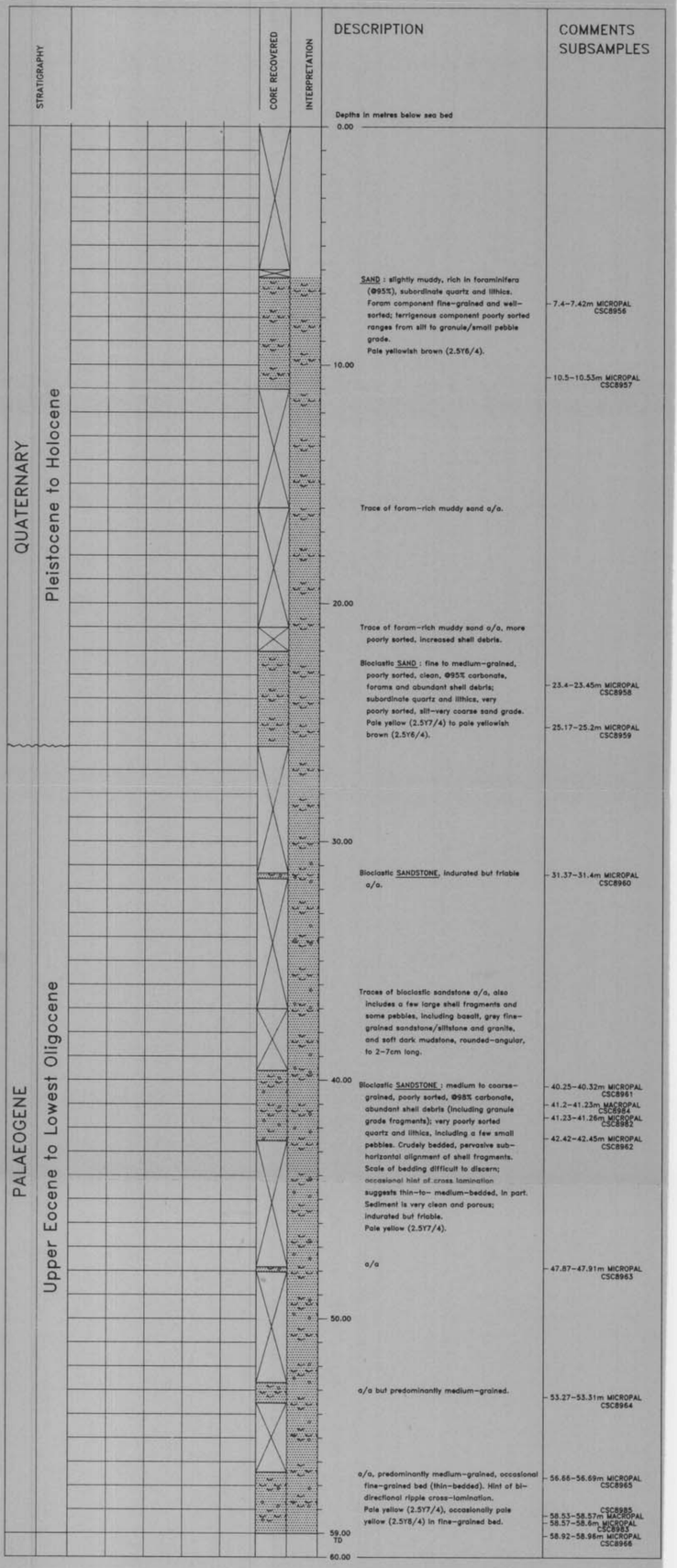
Borehole 94/4 proved about 26m of Quaternary on upper Eocene to lowest Oligocene strata. The latter represent part of seismic interval B–B_0 which forms a discrete downlapping wedge on the eastern slope of the Rockall Trough. The clean, porous, relatively coarse–grained nature of the bioclastic sediments implies a high–energy, shallow–water origin. However, their deep–water setting suggests redeposition as mass–flow sands on the slope during a subsequent lowstand. This section rests unconformably on seismic reflector C and is itself progressively onlapped by deep–water sediments of seismic intervals B–A and A–sea bed. The Quaternary cover appears to largely constitute reworked elements of the underlying deposits.

LOCATION MAP



LITHOLOGICAL KEY

- Clay/shale/mudstone
- Silt/siltstone
- Sand/sandstone
- Gravel/conglomerate
- Limestone/chalk
- Evaporites
- Extrusive igneous
- Intrusive igneous
- Basement
- Shells/shell frags
- Pebbles



BRITISH GEOLOGICAL SURVEY

LOG OF BOREHOLE 94/5

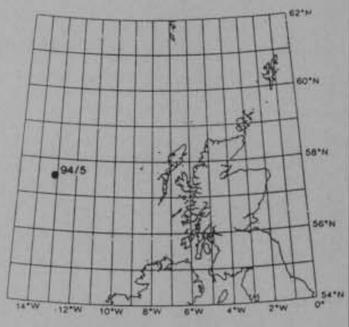
BH NO. 94/5

APPROXIMATE POSITION	Rockall Bank, approximately 33.5km ESE of Rockall Island		
LATITUDE	57° 30.196'N	TOTAL DEPTH	262.2m
LONGITUDE	13° 09.135'W	WATER DEPTH	232m
NAVIGATION	Differential GPS	VESSEL	M/S Bucentaur
MAP AREA	Rockall Island	STATION KEEPING	Dynamic positioning
LICENCE BLOCK	138/15	DATES OF DRILLING	22nd–23rd September 1994
BGS PLAN NO.	379	GEOLOGISTS	M.S. Stoker

COMMENTS

Borehole 94/5 successfully tested the acoustic basement – seismic reflector D – on Rockall Bank, and proved basalt at about 27.5m. Regional stratigraphical evidence suggests that the basalts are of late Paleocene to early Eocene age. The overlying sediments were proved to be of Quaternary age, consisting of sands associated with a discrete sediment ridge (?nearshore sand bar), in turn overlain by a drape of muds and gravelly muddy sands.

LOCATION MAP



LITHOLOGICAL KEY

- Clay/shale/mudstone
- Silt/siltstone
- Sand/sandstone
- Gravel/conglomerate
- Limestone/chalk
- Evaporites
- Extrusive igneous
- Intrusive igneous
- Basement
- Shells/shell frags
- Pebbles

STRATIGRAPHY: QUATERNARY; Pleistocene to Holocene; ?Upper Paleocene to Lower Eocene; PALAEOGENE

CORE RECOVERED

INTERPRETATION

DESCRIPTION

Depths in metres below sea bed

0.00

(4.85–5.0m)
GRAVELLY SAND/MUDDY SAND : poorly sorted admixture of gravel, shell fragments, sand and muddy sand. Sand is fine to medium–grained, very poorly sorted, mixed (@75:25) siliciclastic/carbonate (forams) and shell debris. Gravel includes lithic clasts to 5cm, angular–subrounded, basic igneous, acidic gneiss, soft dark grey mudstone. Abundant broken shells,include bivalves. Some of lithic clasts carbonate encrusted. Olive–grey (5Y4/2) sand/muddy sand.

4.85–5.0m MICROPAL CSC8967

(8.25–8.5m)
Granitic COBBLE : subangular–subrounded, to 8cm, on MUD : stiff to hard, very poorly sorted, bioturbated (sand–filled burrows), scattered matrix–supported lithic pebbles and shell fragments. Strongly calcareous. Very dark grey (5Y3/1).

8.4–8.43m MICROPAL CSC8968

10.00

(13.08–13.3m)
Very poorly sorted admixture of SANDY MUD, PEBBLES and SHELLS, stiff–hard, calcareous, disturbed through drilling ?, very dark grey,
on (13.3–13.5m)
MUD : massive, bioturbated, scattered small shell fragments, calcareous, very dark grey,scattered black monosulphidic streaks.

CSC8969
13.08–13.1m MICROPAL
13.3–13.35m MICROPAL CSC8970

13.50 BASED ON SEISMIC DATA

(18.13–18.5m)
? interbedded GRAVEL and MUDDY SAND : Gravel includes two cobbles (6.5–7.5cm) of well–rounded grey siltstone and basic/ metabasic rock. Sand is muddy, very fine–grained, poorly sorted, mixed (85/15) siliciclastic/carbonate (shell fragments up to 1cm), shell debris depict crude bedding, flat–lying to rippled ? Samples may be partly disturbed by drilling : uncertain if interbedding is real or not. Dark greenish grey (5GY4/1).

18.25–18.31m MICROPAL CSC8971

20.00

20.50m MICROPAL CSC8972

20.5m Hammer sample : MUDDY SAND a/a Olive–grey (5Y5/2).

(26.3–26.5m)
SAND : slightly muddy, very fine–grained, moderate–poorly sorted, mixed (60/40) siliciclastic/carbonate (very fine shell fragments and forams). Firm and compact but friable. Olive–grey (5Y4/2) to dark greenish grey (5GY4/1).

26.41–26.44m MICROPAL CSC8973

27.50

29.21–29.25m PETROLOGY

30.00
30.20 TD

27.5 ROCKHEAD AS SUGGESTED BY DRILLING RATE/STYLE

(28.56–30.2m)
BASALT : finely crystalline, dark grey (N4/), vesicular.

40.00

BRITISH GEOLOGICAL SURVEY

LOG OF BOREHOLE 94/6

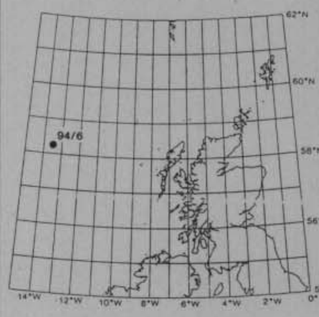
BH NO. 94/6

APPROXIMATE POSITION	Northern flank of Rockall Bank, approx 69.5km NNE of Rockall Island		
LATITUDE	58° 13.057'N	TOTAL DEPTH	394.9m
LONGITUDE	13° 33.052'W	WATER DEPTH	373m
NAVIGATION	Differential GPS	VESSEL	M/S Bucentaur
MAP AREA	George Bligh Bank	STATION KEEPING	Dynamic positioning
LICENCE BLOCK	148/23	DATES OF DRILLING	23rd September 1994
BGS PLAN NO.	375	GEOLOGISTS	M.S. Stoker

COMMENTS

Borehole 94/6 successfully tested acoustic basement – seismic reflector D – on the northern edge of Rockall Bank, and proved basalt at about 18.0m. Regional stratigraphical evidence suggests that the basalt is probably of late Paleocene to early Eocene age. The basalt is unconformably overlain by middle Eocene sandstones which form part of the clastic wedge fringing the eastern and northern flanks of the bank. The section is capped by a mixed carbonate–siliciclastic sequence of ?late Pliocene to Holocene age.

LOCATION MAP



LITHOLOGICAL KEY

- Clay/shale/mudstone
- Silt/siltstone
- Sand/sandstone
- Gravel/conglomerate
- Limestone/chalk
- Evaporites
- Extrusive igneous
- Intrusive igneous
- Basement
- Shells/shell frags

STRATIGRAPHY | CORE RECOVERED | INTERPRETATION | DESCRIPTION | COMMENTS SUBSAMPLES

PALAEOGENE – NEOGENE – QUATERNARY

?Upper Paleocene to Lower Eocene | Middle Eocene | ?Lower Pliocene to Holocene

Depths in metres below sea bed

0.00

(3.0–3.5m)
Interbedded BIOCLASTIC SANDS and CALCAREOUS MUDS/SANDY MUDS :
Bioclastic sands, very thin to medium-bedded, predominantly medium to very fine-grained, very poorly sorted, grains range from silt to very coarse grade. Mixed (95/5) carbonate/siliciclastic composition, mostly broken shell fragments and forams. Occasional white sandy mud intraclasts. Firm to compact. Pale olive brown (2.5Y5/4) to pale yellowish brown (2.5Y6/4). Muds/sandy muds, very thin bedded, soft–firm, white (2.5Y8/2),strongly calcareous/chalky. Bed thickness ranges 1–2.5cm; bed contacts sharp, slightly irregular and wavy.

CSC8974
3.14–3.16m MICROPAL
3.45–3.5m MICROPAL
CSC8975

8.57–8.64m MICROPAL
CSC8976

10.00

(8.5–8.94m)
Interbedded GRAVEL and BIOCLASTIC SAND/MUDDY SAND :
Thin-bedded, greenish grey (5GY6/1) bioclastic sands and pale grey (5Y7/1) chalky muddy sand, a/a. Rare lithic pebble in muddy sand. Firm–hard, compact. Gravel, cobble grade, including subangular igneous rock, two 'drilled' cobbles of gneiss (up to 20cm long), and grey, very fine-grained sandstone.

Increased drilling rate

(8.94–17.86m) Increased, faster drilling rate interpreted as due to penetrating soft, weathered SANDSTONE, described below.

CSC8977
17.32–17.35m MICROPAL
17.61–17.64m MICROPAL
CSC8978

(17.26–17.86m)
SAND/SANDSTONE : upper part of section is soft and crumbly, ?weathered; indurated (in part) below @ 17.5m. Medium to thick-bedded, massive, occasionally ? bioturbated. Very fine to fine-grained, poorly sorted, siliciclastic, immature, rounded–angular quartz and lithic grains, non–calcareous. Varicoloured : dark yellowish brown (10YR4/4) to dark brown (10YR3/3) with yellowish–red mottling (5YR4/6) in upper part of section; dark greenish grey (5BG4/1) in lower part of section.

20.00

20.12–20.19m PETROLOGY

21.83–21.84m PETROLOGY

21.90
TD

17.86 Sharp Contact

(17.86–18.0m)
BASALT COBBLES : rubbly top of lava ?

(18.0–21.9m)
BASALT : fine–medium, crystalline, dark grey (2.5YN4/), jointed, very vesicular and amygdaloidal in upper part of section (above 21m), very open structure; becomes less amygdaloidal and vesicular (below 21m) in lower section, more massive. Amygdales consist siliceous material ?, material altered to chlorite/talc ? (very soft and soapy). Carbonate veining below 21m, together with disseminated pyrite.

30.00

40.00

BRITISH GEOLOGICAL SURVEY

LOG OF BOREHOLE 94/7

BH NO. 94/7

APPROXIMATE POSITION	Top of George Bligh Bank, approximately 149km N of Rockall Island		
LATITUDE	58° 56.420'N	TOTAL DEPTH	507.55m
LONGITUDE	13° 41.640'W	WATER DEPTH	484m
NAVIGATION	Differential GPS	VESSEL	M/S Bucentaur
MAP AREA	George Bligh Bank	STATION KEEPING	Dynamic positioning
LICENCE BLOCK	148/2	DATES OF DRILLING	24th–25th September 1994
BGS PLAN NO.	378	GEOLOGISTS	M.S. Stoker

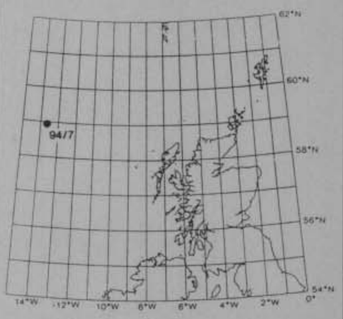
COMMENTS

Borehole 94/7 successfully tested acoustic basement – seismic reflector D – on top of George Bligh Bank, and proved basalt at 20.97m. Two lavas were cored, separated by a very thin shelly sand of Paleocene age. Organic (plant) remains are preserved as casts on the base of the upper flow. The basalts are unconformably overlain by middle to upper Eocene bioclastic sandstone and biosparite, in turn, unconformably overlain by a sandy Quaternary cover.

LITHOLOGICAL KEY

- Clay/shale/mudstone
- Silt/siltstone
- Sand/sandstone
- Gravel/conglomerate
- Limestone/chalk
- Evaporites
- Extrusive igneous
- Intrusive igneous
- Basement
- Shells/shell frags
- Wood/plant remains

LOCATION MAP



STRATIGRAPHY: QUATERNARY (?Pleistocene to Holocene); PALAEOGENE (Middle to Upper Eocene; Paleocene)

CORE RECOVERED

INTERPRETATION: UPPER FLOW; LOWER FLOW; TD

DESCRIPTION

Depths in metres below sea bed

0.00

Traces of SAND : fine–grained, moderate–well sorted, @95% carbonate, mostly foraminifera. Pale yellowish–brown (2.5Y6/4).

(10.6–10.65m) Weathered top of biosparite. Irregular, some of hollows filled with sand and lithic clasts (to 1cm) set in a white recrystallised carbonate matrix. Also partly filled with bioclastic sandstone, as below. Top surface is blackened.

(10.65–10.97m) BIOSPARITE : medium–coarsely crystalline, poorly sorted. @95/5 carbonate/siliciclastic (scattered quartz and lithics). Partly recrystallised but shell debris still very recognisable. Massive. Pervasive black (?manganese) mineralisation.

10.00

(10.97–11.3m) Diffuse contact. Irregular. Some solution of underlying bioclastic sandstone. Pervasive mineralisation a/a. Contact appears subvertical, sharp to diffuse. ? Sedimentary (i.e. depositional) or diagenetic.

(11.3–12.0m) BIOCLASTIC SANDSTONE : fine to coarse–grained, poorly sorted, @95/5 carbonate/siliciclastic a/a. Clean and porous, framework–supported texture. Massive to crudely–bedded, sporadic alignment of shell debris. Occasional large bivalves (1–2cm) observed. Pale yellow (2.5Y7/4) to pale yellowish brown (2.5Y6/4).

20.00

20.97

(20.91–20.97m) Grey, recrystallised sandstone cobble and lithic coarse to very coarse–grained sand/fine gravel overlying weathered, jointed top of basalt, also filtering down fractures; some carbonate cementation in fractures.

20.97 SHARP CONTACT

(20.97–22.4m) BASALT/BASIC IGNEOUS : medium crystalline, dark grey to very dark grey (2.5YN4/–N3/), highly fractured, carbonate veining, fine basic igneous and red sandstone XENOLITHS (?) near top.

23.55 TD

(22.4m)
? Weathered fractured top of lower flow; very thin shelly SAND layer (<1cm) filtered into fracture. Sand is very fine to very coarse–grained, very poorly sorted, includes abundant shell debris and organic material. Base of upper flow has ? WOOD/LEAF impression; cellular structure very evident, partly pyritised.

30.00

(22.4–23.55m TD) BASALT/BASIC IGNEOUS a/a slightly amygdaloidal, highly fractured, disseminated pyrite, carbonate veining.

40.00

COMMENTS SUBSAMPLES

CSC8979
10.87–10.88m MICROPAL
11.07–11.13m PETROLOGY
11.83–11.86m MICROPAL CSC8980

21.07–21.10m PETROLOGY
22.40m MICROPAL CSC8981
22.52–22.57m PETROLOGY
23.20–23.25m PETROLOGY