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GREAT AUSTRALIAN BIGHT BASIN 1986

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SUMMARY

Late Cretaceous and younger sediments dredged from the upper continental slope and canyon walls in the Great Australian Bight Basin between 126° and 136°E broadly confirm the stratigraphy which had been established previously from scattered exploration wells. Late Cretaceous to Early Eocene marine and marginal marine terrigenous sediments are overlain by Middle Eocene and younger pelagic carbonate (fine limestone and calcareous ooze). The samples provide the first evidence of truly marine Maastrichtian sedimentation, with abundant calcareous nannoplankton, on the southern margin of the continent. Other samples of interest include Precambrian sheared granodiorite on the upper slope south of Eyre Terrace, Paleocene phosphatic sediment in 'Eucla' Canyon at 128°30'E, and terrigenous Early Miocene mudstone at 133°20' and 134°50'E. The mudstone is of note as an exception to the uniform pelagic carbonate wackestone and ooze which characterise Middle Eocene and younger sedimentation at all other sites. Fragments of alkali basalt lava of unknown age were recovered in 'Eucla' Canyon. Cores are mostly pelagic calcareous ooze, but those from submarine canyons include terrigenous turbidites.

INTRODUCTION

The objectives of *Rig Seismic* Cruise 11, BMR Survey 66, were to determine heat flow and collect geological samples from the Ceduna and Eyre Terrace region of the Great Australian Bight as a guide to petroleum prospectivity. The ship sailed from Port Lincoln, SA, on 12 November 1986 and berthed at Port Adelaide 26 days later, on 8 December. Eleven heat flow determinations were made and 14 dredge hauls and 20 cores collected.

This report presents a complete account of the geological results of the cruise. Willcox & others (1988) presented a summary of the geological data together with a discussion of heat flow, magnetic and seismic reflection data from this and the preceding cruise, *Rig Seismic* Cruise 10.

The shipboard scientific party comprised Davies and Stagg as co-chief scientists, T. Graham, D. Choi, M. Joshima (Geological Survey of Japan), M. Walton, Clarke (Flinders University), C. Conor (National Centre for Petroleum Geology and Geophysics), P. W. Haines (University of Adelaide), L. W. Miller, J. E. Stuart, K. Revill, R. McMahon, R. Schuler, M. O'Connor, N. Clark, D. Holdway, D. B. Pryce and J. Kossatz. The ship was under the command of Master D. Harvey and Chief Engineer was S. Johnson.

Acknowledgment

The authors thank other members of the scientific party and the ship's master and crew for willing and expert performance of all operations while at sea. Particular thanks are due to Second Engineer P. Pittiglio and Electrical Engineer P. Jiaer for their work in times of equipment failure, and the contribution to the scientific program of graduate students, Clarke, Conor and Haines, warrants special mention.

DREDGED ROCKS

The prime objective of the dredging program was to sample Mesozoic and Early Cainozoic sediments, the strata of most interest in terms of break-up history and petroleum prospectivity. The program was to concentrate on the shelf and slope at the junction of the Eyre and Ceduna Terraces, in the area gridded by Cruise 10 seismic reflection lines (127°-130°30'E; Willcox & others, 1988). However, this proved to be an area of gentle, sediment-covered slopes with few dredgeable targets. We found only one major canyon, here called 'Eucla' Canyon, on line 65/10, sampled in dredge hauls 1 and 3 (Fig. 1); other smaller canyons were dredged unsuccessfully, probably because the uppermost 200-300 m of sediment is too poorly lithified to be retained in the dredge chain bag. Because of the lack of targets, we moved operations eastward to between 130 30'E and Kangaroo Island, where terrace and slope are dissected by major canyons.

Targets were defined by recording bathymetric and some seismic profiles parallel to the slope in water depths of 2.5-3.5 km. The depth of dredging was limited because an accident prior to the cruise had reduced the length of dredge wire from 10 to 4.2 km. Probable Mesozoic targets at the base of the continental slope, which had been identified in pre-cruise planning, were beyond the depth limit. The program was further inhibited by several failures of the winch hydraulic system.

A total of 16 sites were occupied (Fig. 1, Table 1, Appendix 1). Two of these were unsuccessful with no indication that the dredge had touched bottom, probably because of excessive ship speed; in one of these cases the ship was

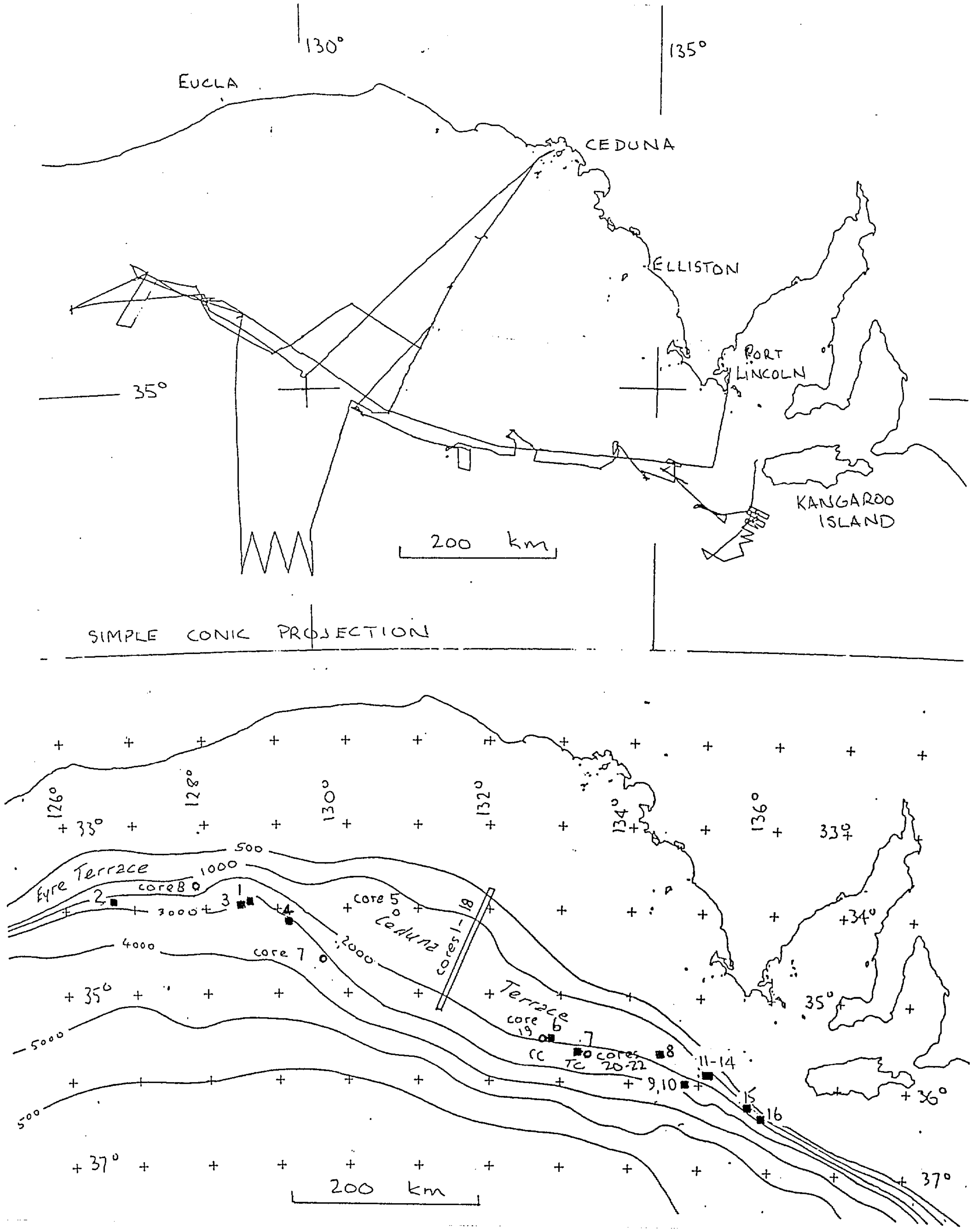

Figure 1: Maps showing ship track and dredge and core sites (solid and open symbols respectively). Isobaths in metres; CC Ceduna Canyon; TC 'Thevenard' Canyon.

TABLE 1: DREDGE LOCATIONS AND SAMPLE DESCRIPTIONS

DREDGE NO.	LOCATION ON, OFF	DEPTH (m)	MASS (kg)	DESCRIPTION OF TARGET AND SAMPLE
1	33°56.0' 128°38.3' -33°53.5' 128°37.0'	3280 2950	750	'Eucla' Canyon, NW slope, seismic line 65/10. Approximately equal proportions of Tertiary fine limestone and Maastr. to M Eocene siltstone, sandstone, etc. Also Paleocene phosphatic sediment and undated alkali basalt lava
2	34°01.5' 126°43.9' -33°59.8' 126°43.8'	2500 2070	50	Scarp S of Eyre Terrace, line 16/166. Precambrian granodiorite, part cataclastic; minor Eocene mudstone.
3	33°58.4' 128°36.6' -33°57.5' 128°34.7'	3535 3390	20	'Eucla' Canyon below DR1, near line 65/10. Equal quantities L Cretaceous mudstone, sandstone, conglomerate and Tertiary? siliceous carbonate. Minor alkali basalt lava.
4	34°09.5' 129°06.7' -34°09.2' 129°07.6'	3332 3095	0.2	Shallow canyon (140-300 m deep). Small piece of soft, friable siliceous wackestone, probably Early Tertiary.
5	35°14.0' 130°45.0' -35°12.0' 130°43.0'	3800 3200	0	Canyon intersects continental rise, lines 16/134 and 407-1. Dredge did not touch bottom (strong wind and drift).
6	35°34.0' 132°54.5' -35°33.5' 132°52.4'	2620 2015	50	W slope of Ceduna Canyon. E to L Oligocene fine pelagic wackestone.
7	35°42.0' 133°19.0' -35°42.1' 133°17.4'	2720 2200	20	W slope of 'Thevenard' Canyon. Equal amounts of L Cretaceous and L Paleocene to E Eocene mudstone/siltstone and Miocene interbedded wackestone and siltstone.
8	35°40.7' 134°26.0' -35°38.1' 134°24.7'	2826 2244	30	Small canyon, lines 16/72 and 66/11. Mostly L Paleocene to E or M Eocene gravelly siltstonee mudstone and some E and M Eocene wackestone.
9	36°00.1' 134°49.8' -36°00.5' 134°53.2'	3680 2982	2	'Platypus' canyons, line 16/70. Mostly Pliocene brown mudstone and white wackestone.
10	35°59.8' 134°50.8' -35°55.6' 134°47.6'	3614 2925	15	'Platypus' canyons. W slope, opposite DR 9, line 16/70. M Eocene and E Miocene wackestone.
11	35°49.7' 135°09.6' -35°50.1' 135°14.1'	3200 2141	40	'Platypus' canyons, up-canyon from DR 9 and 10, E slope. Mostly M-L Oligocene wackestone, some E Eocene pyritic, calcaeous sandstone, and L Cretaceous organic-rich muddy siltstone. Minor undated phosphatic, muddy quartz arenite.
12	35°54.8'	3670	120	'Platypus' canyons, down-canyon from DR 11.

	135°05.4' -35°56.0' 135°08.9'	 2720		Mostly wackestone of L Eocene and E Oligocene age. Minor L Paleocene and M Eocene organic-rich mudstone.
13	Near DR 14.			Dredge did not touch bottom.
14	35°58.3' 135°11.8' -35°58.0' 135°12.2'	3064 2627	35	'Platypus' canyons, line 16/68. M and L Eocene and E Oligocene wackestone. Minor E Eocene organic-rich mudstone. (First winch hydraulic failure.)
15	36°20.1' 135°40.1' -36°19.1' 135°36.3'	3394 2494	80	'Echidna' canyons, line 16/66. M Oligocene and E Miocene lime mudstone.
16	36°24.1' 135°51.3' -36°24.2' 135°50.9'	3302 3432	5	'Echidna' canyons (double canyon). Oligocene? dolomitic packstone and siliceous wackestone; some shows faulting. (Final winch hydraulic failure.)

Abbreviations: E Early; M Middle; L Late; Maastr Maastrichtian

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The largest dredge haul was about 750 kg of mixed sediment with some volcanics (dredge 1) and other hauls ranging from 2 to 250 kg (Appendix 1).

After the cruise, selected samples were examined for age-diagnostic foraminifera, nannoplanckton, and spores and pollen by B. McGowran, S. Shafik, and N. F. Alley, respectively (see Appendices). Petrographic descriptions and initial reports were prepared by Clarke and Davies, and minerals and volcanic glass were analysed by electron probe microanalyser by Davies.

The dredge, designed and constructed at the University of Sydney, had a rectangular mouth of soft steel plate, about 70 x 40 cm, with a scalloped leading edge, a chain bag 2 m deep, and a harness of two 2-m lengths of chain. A pipe dredge was suspended above the main dredge, and 100 kg of ballast was secured to the dredge wire a few metres up from the harness.

<u>Results</u>

The dredge hauls were dominated by two types of sediment: a) brown, weakly lithified, terrigenous mudstone, siltstone, muddy and gravelly sandstone, and minor peat of generally Late Cretaceous to Middle Eocene age, and b) white lithified and semi-lithified pelagic limestone (packstone and wackestone) of Early Eocene to Pliocene or Quaternary age. Other notable dredged samples included Precambrian, moderately sheared, pink granodiorite (dredge 2), Paleocene phosphatic sediment (dredge 1), fragments of alkali basalt lava (dredges 1 and 3), a fragment of solitary scleractinian coral limestone in dredge 7, a branching, tubular piece of hematite-cemented, gravelly quartz sandstone in dredge 8, and sharks' teeth in Late Cretaceous gravelly quartz sandstone and in Late Oligocene soft pelagic limestone in dredges 3 and 11, respectively (Clarke and N. Pledge, unpublished data). Unconsolidated Quaternary sediment in the pipe dredge was carbonate ooze and mud and, less commonly, sand.

Dredges 1 and 3 were directed at the northwestern wall of 'Eucla' Canyon, a structurally controlled canyon at the junction of Eyre and Ceduna Terraces which was discovered during Cruise 11 (Table 1, Figs 1 & 2). Dredge 1 climbed the northwestern wall and encountered Maastrichtian to Middle Eocene terrigenous marine sediment overlain by Eocene and younger carbonate. A possible boundary between the two rock types is indicated in Figure 2B. Dredge 3 traversed the floor and lower slope of the canyon and recovered Late Cretaceous terrigenous marine sediment and rounded, indurated boulders of Tertiary? siliceous and dolomitic wackestone.

Dredge 2 collected granodiorite from the relatively steep basement slope which bounds the Eyre Terrace on the south (Figs 1 & 3). Dredge 4 recovered small fragments of friable sediment from unlithified Neogene sediment on the east flank of a small canyon (Figs 1 & 4A), and dredge 5, in deeper water on the continental rise, failed to touch bottom (Figs 1 & 4B). Dredges 6 and 7, in Ceduna and 'Thevenard' Canyons (Figs 1 & 5), sampled Tertiary carbonate underlain, in 'Thevenard' Canyon, by organic-rich Late Paleocene to Early Eocene mudstone.

Dredge 8 collected Late Paleocene to Early or Middle Eocene gravelly siltstone and mudstone and Middle Eocene wackstone from an isolated canyon at 134°26'E (Fig. 6). Dredges 9-14, in the 'Platypus' group of canyons (Fig. 7) near Platypus exploration well, encountered Late Cretaceous, Late Paleocene, and Early and Middle Eocene organic-rich mudstone and Middle Eocene and younger wackestone. Dredges 15 and 16, in the 'Echidna' group of canyons (Fig. 8) near Echidna well, encountered only Oligocene and Miocene lime mudstone and minor dolomitic packstone and siliceous wackestone, some of which was faulted.

Brief descriptions of each dredge haul are given in Appendix 1 and the main rock types are discussed below.

Granodiorite

Moderately altered, finely jointed and locally cataclastic, coarse grained, pink hornblende-biotite granodiorite was collected in dredge 2 from a south-facing escarpment immediately south of Eyre Terrace. Plagioclase is dominant over perthite and microcline which latter are altered to clay and sericite; hornblende is partly altered to epidote. Minor talus-like sediment of fine angular granodiorite clasts, attached to the large blocks of granodiorite, has a hard limonite-cemented outer shell and is friable internally. The age of the granodiorite is not known but is presumed to be Precambrian.

Basaltic Lava

Fragments of amygdaloidal pillow lava were collected in dredges 1 and 3. In the largest sample in dredge 1 fine hyaloclastite breccia is attached to a curved pillow surface of chilled lava; the proportion and size of amygdules within the lava increase inward, away from the chilled surface. There are small euhedra of forsteritic olivine, Fo84, in the chilled rim. Glass from the rim is sodic phonotephrite (nomenclature of le Maitre, 1984), or undersaturated alkali basalt, with 8.35% total alkalis and 50.5% silica (Table 2). The abundance of large amygdules indicates eruption at relatively shallow depth.

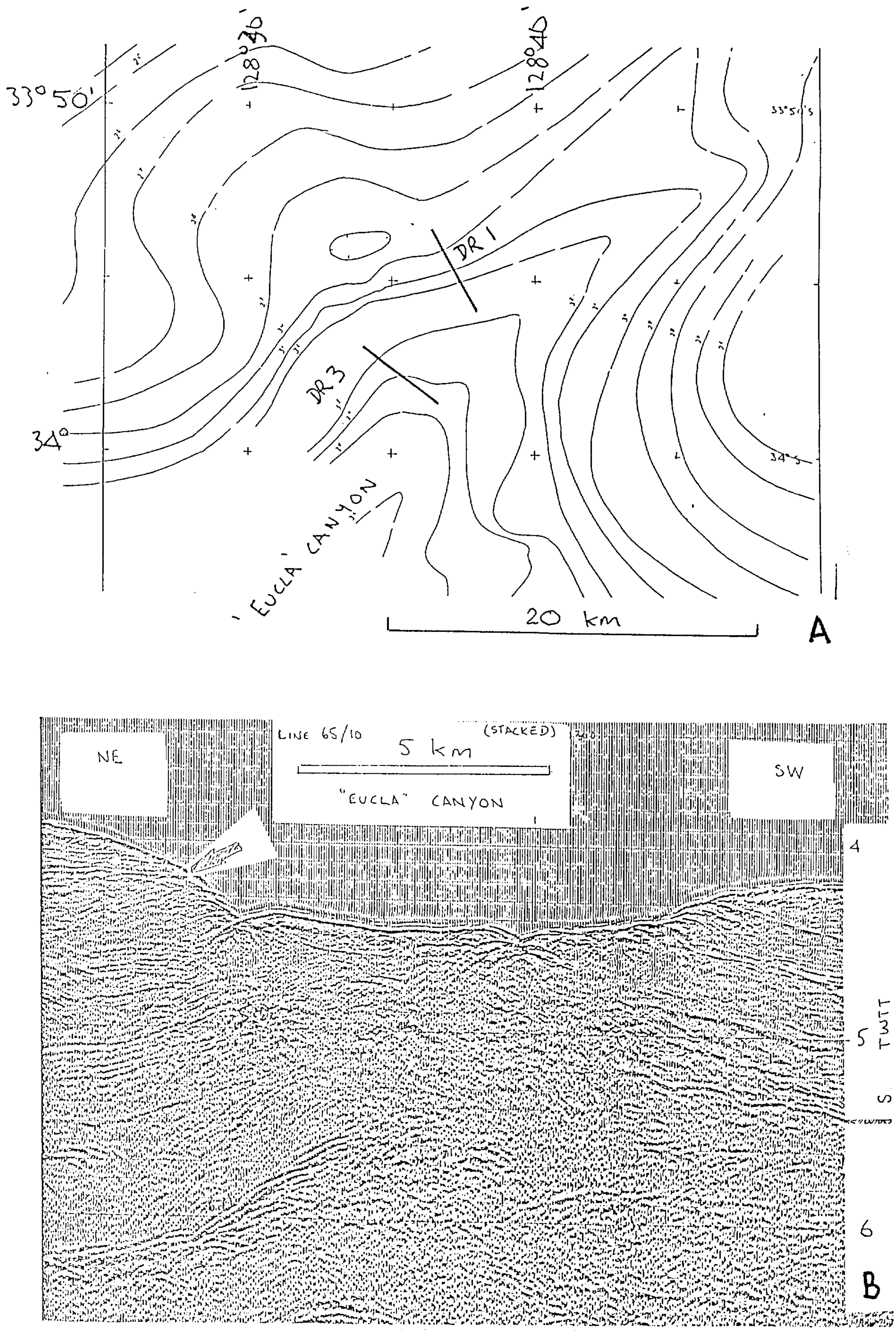


Figure 2: A. Plan view of 'Eucla' Canyon shows location of dredges 1 and 3.
B. Stacked multichannel seismic profile, part of line 65/10, shows 'Eucla' Canyon to coincide with the axis of a partly eroded anticline. Dredge 1 climbed the northeastern flank of the canyon and encountered Maastrichtian, Paleocene and Early to Middle Eocene terrigenous sediments overlain by Late Eocene and younger fine pelagic limestone. Arrow indicates the possible contact between the two rock groups.

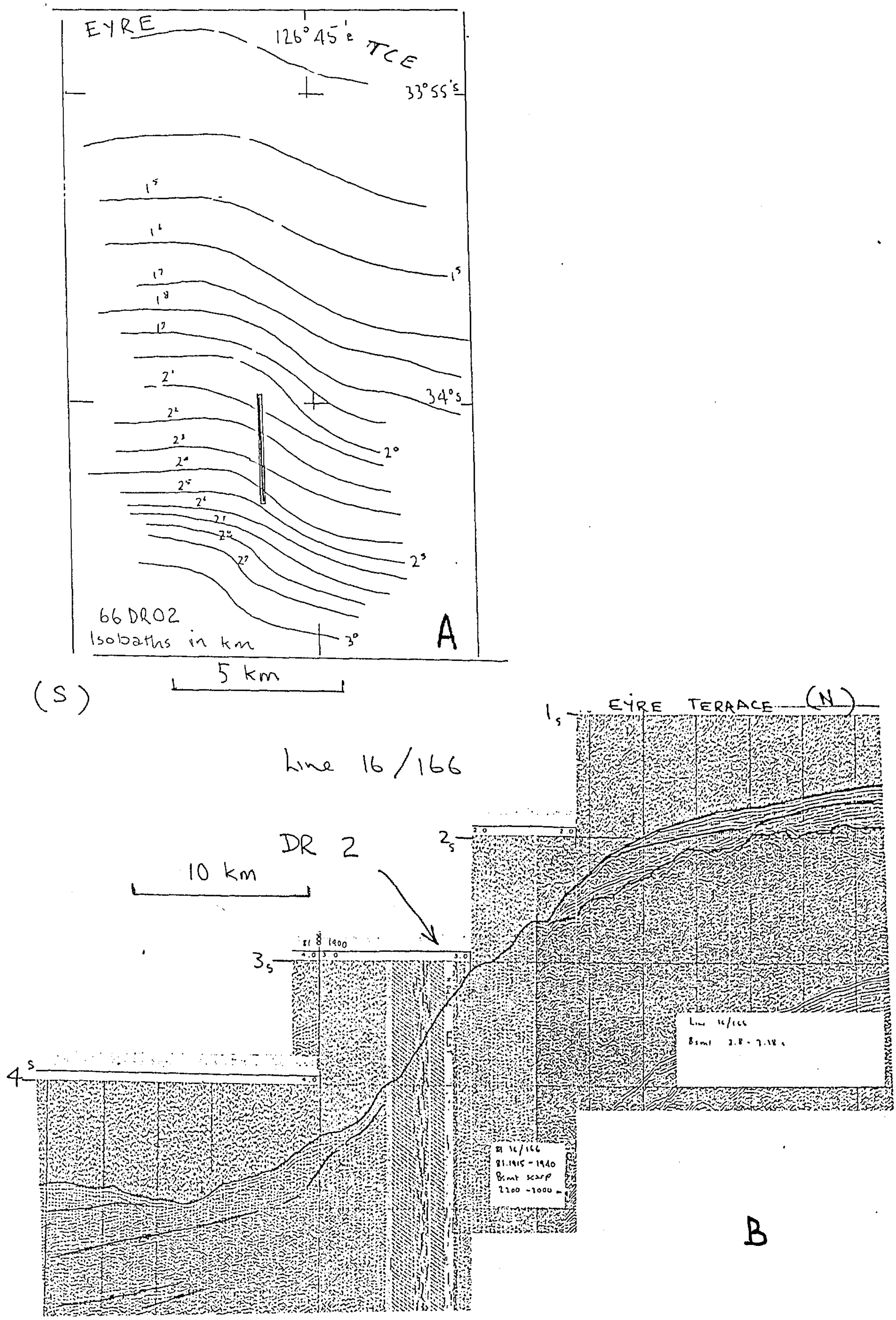
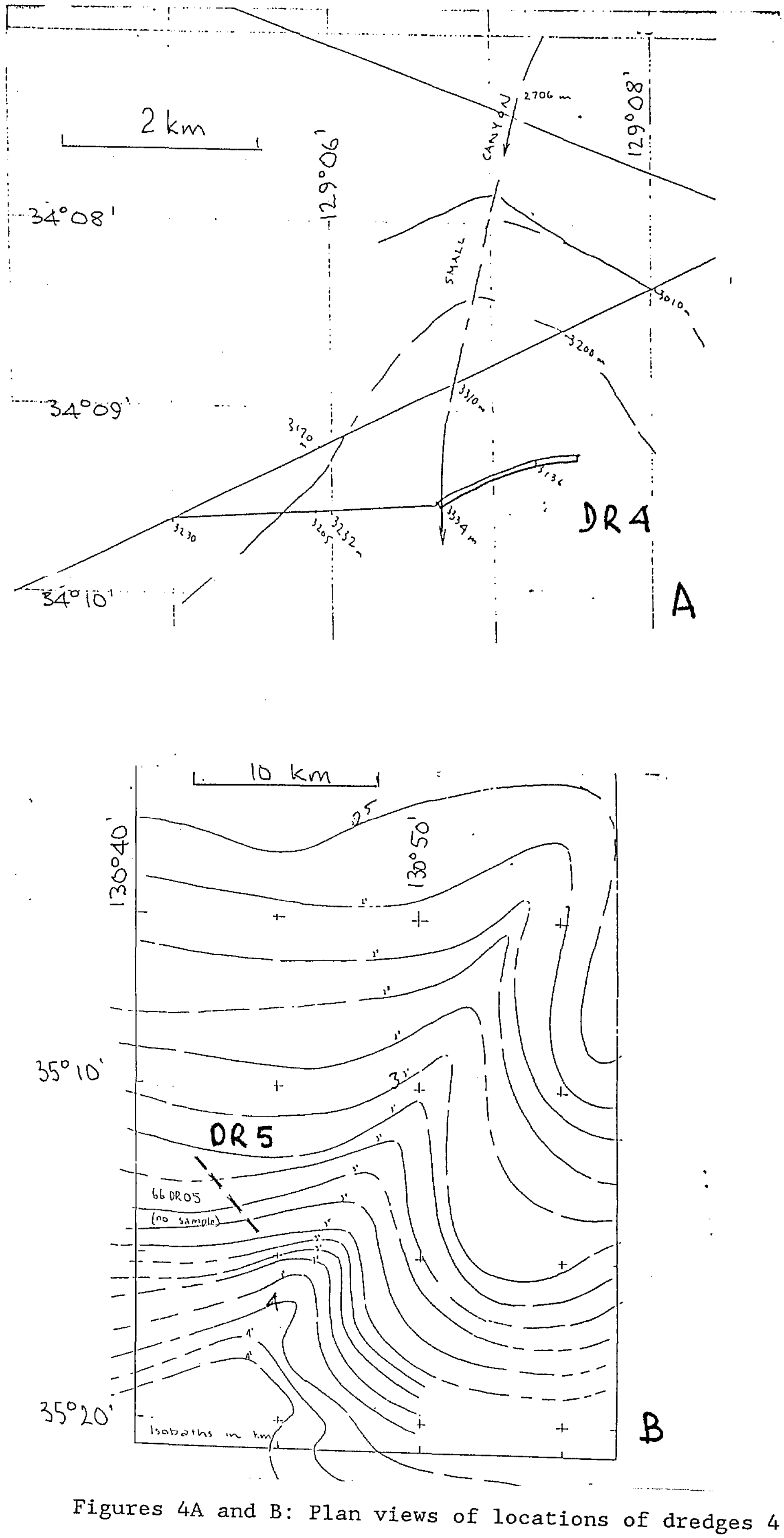
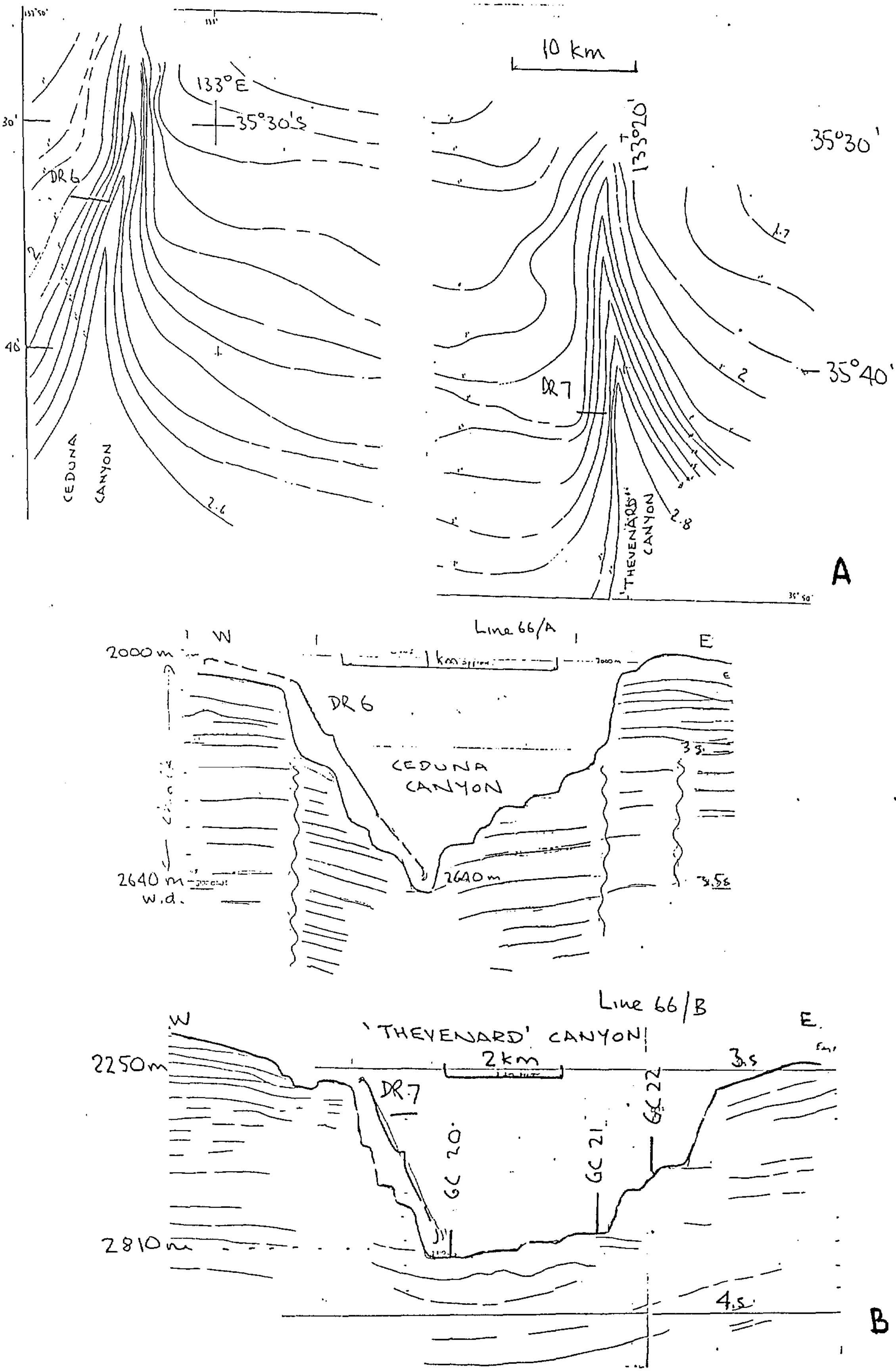


Figure 3A and B: Plan view and seismic profile over location of dredge 2. Precambrian granodiorite, partly sheared, was recovered from the escarpment.



Figures 4A and B: Plan views of locations of dredges 4 and 5.



Figures 5A and B: Plan views and line drawings of seismic profiles for dredges 6 and 7, in Ceduna and 'Thevenard' Canyons respectively. Dredge 7 recovered Late Cretaceous, Paleocene and Early Eocene terrigenous sediment and younger carbonate; dredge 6 recovered Oligocene pelagic limestone only. Location of gravity cores 20-22 in 'Thevenard' Canyon is shown.

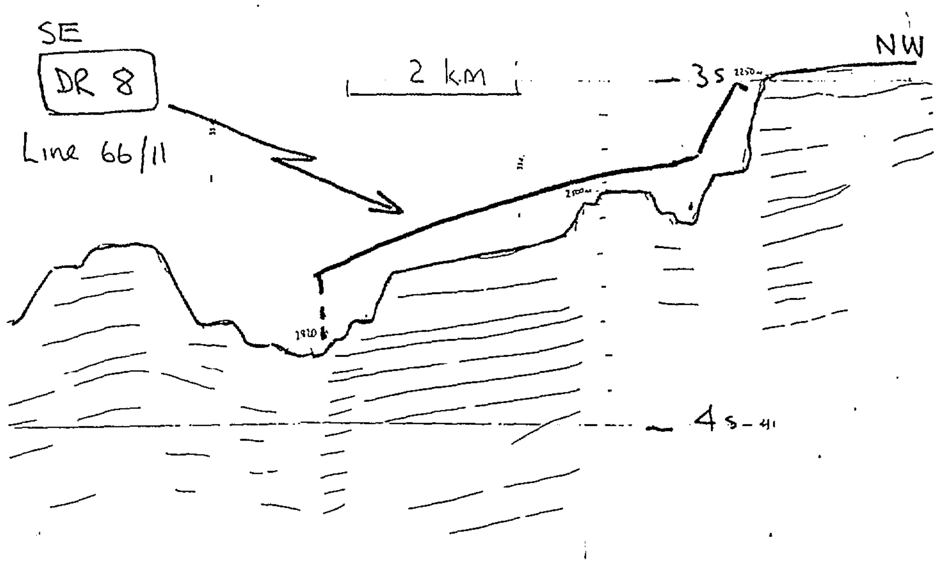
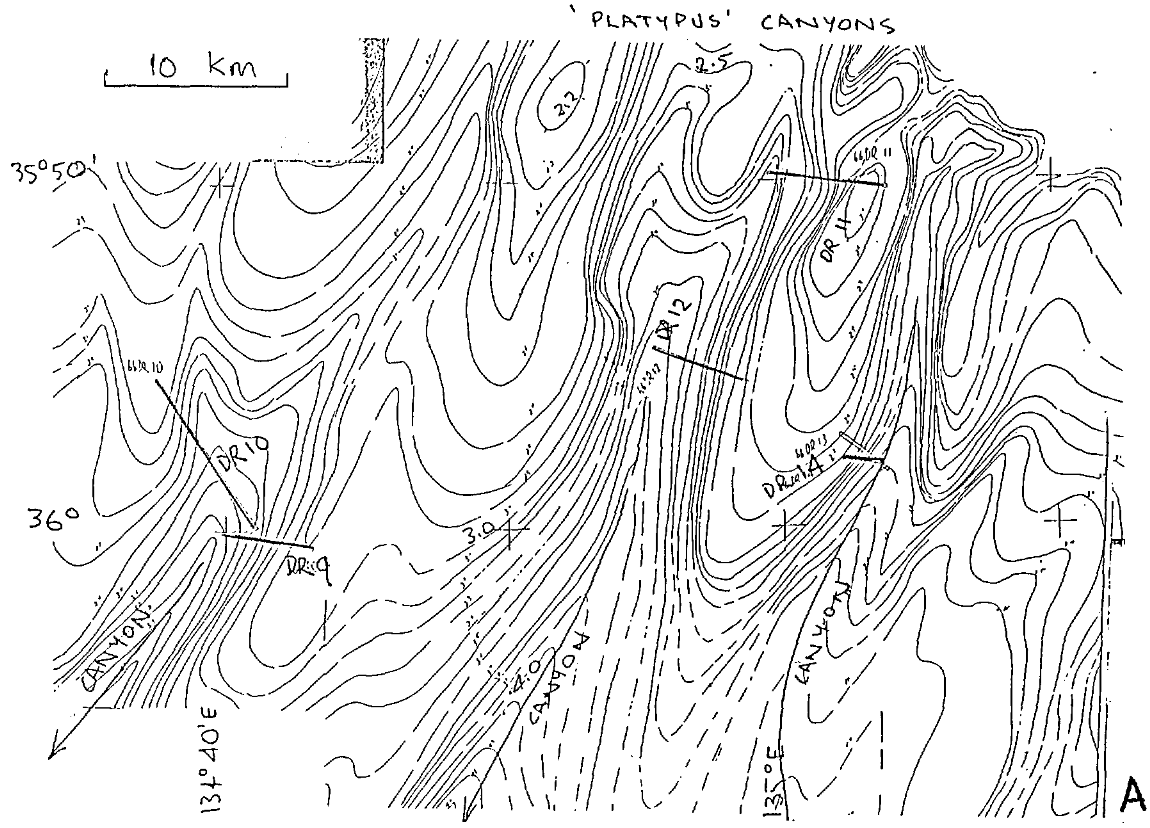


Figure 6: Line drawing of single-channel seismic reflection profile across location of dredge 8 which recovered Late Paleocene to Early or Middle Eocene gravelly siltstone and mudstone and some Early and Middle Eocene Pelagic limestone.



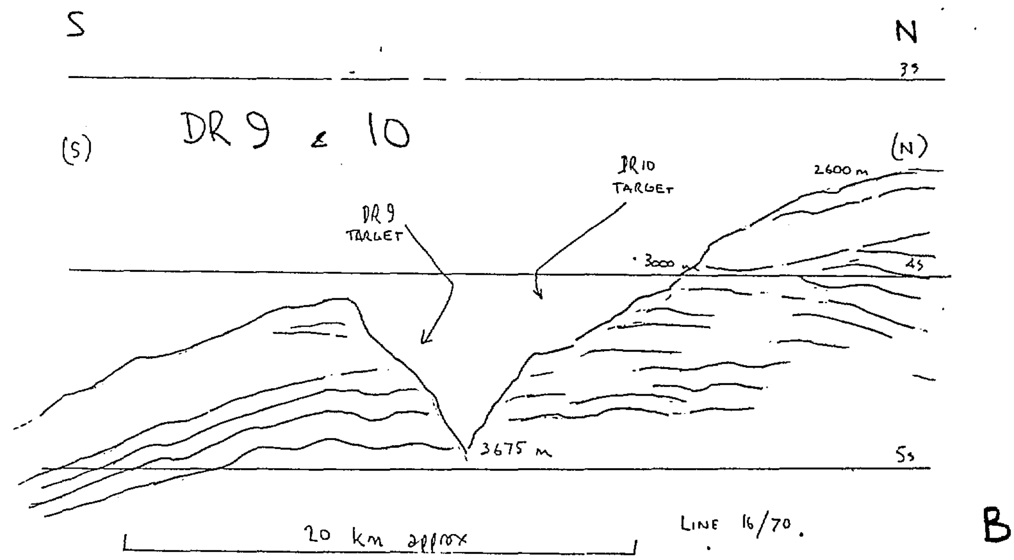
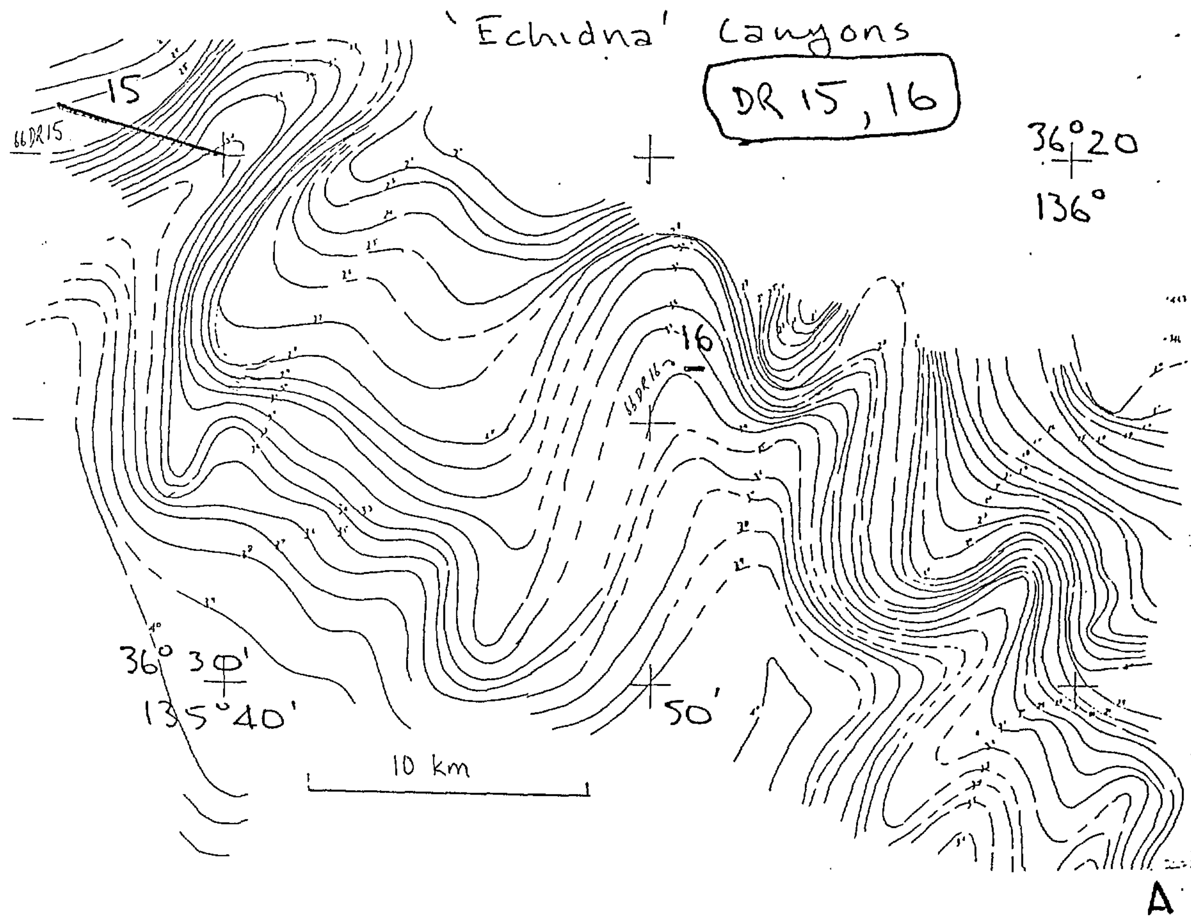


Figure 7: A. Plan view of the 'Platypus' group of canyons shows location of dredges 9-14. Dredge 13, near dredge 14, was unsuccessful. Dredges 11, 12 and 14 recovered Upper Cretaceous, Paleocene and Eocene organic-rich mudstone and siltstone as well as younger carbonate. Dredge 9 recovered Eocene and Miocene pelagic limestone.
B. Line drawing of north-south seismic profile across the canyon sampled by dredges 9 and 10.



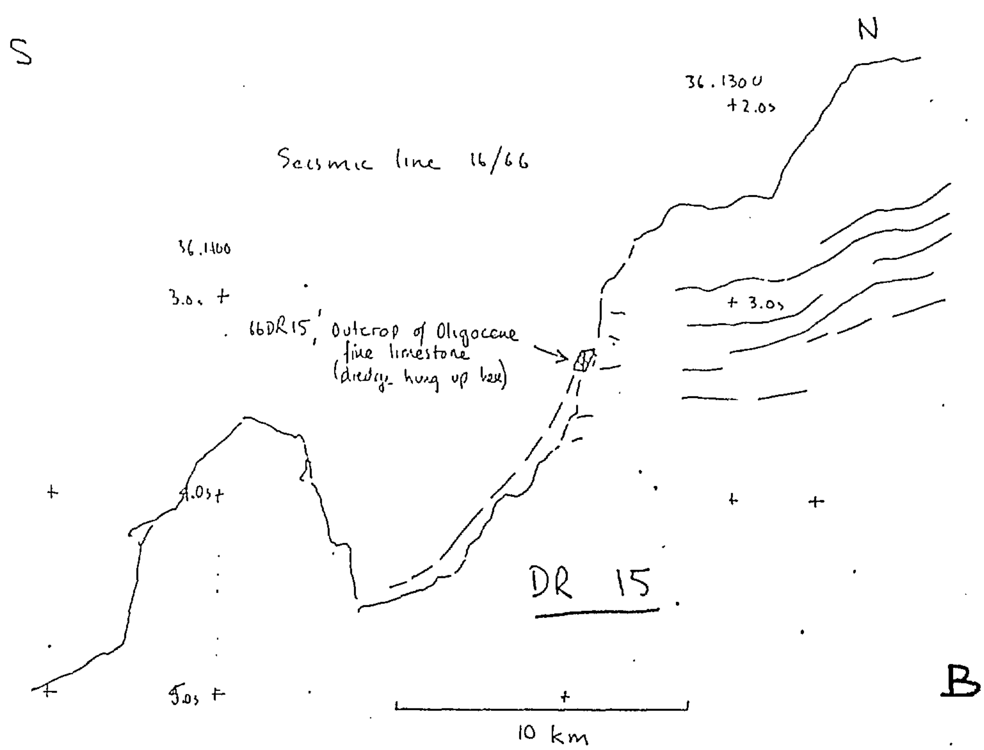


Figure 8: A. Plan view of locations of the 'Echidna' group of canyons showing the location of dredges 15 and 16. Both dredges collected Oligocene and younger fine limestone.
B. North-south seismic reflection profile across the slope from which dredge 15 was collected.

TABLE 2: CHEMICAL COMPOSITION OF GLASSY LAVA 66DR1J

	Wt %
SiO_2	50.6
TiO_2	2.25
Al_2O_3	16.2
FeO*	8.55
MnO	.13
MgO	5.01
CaO	8.07
Na_2O	5.07
K_2O	3.30
P_2O_5	.78
	99.96

Analysis of glassy selvage using Cameca electron probe microanalyser at Research School of Earth Sciences, Australian National University, 19 August 1987. Beam current 18 nA, rastering an area of 26 micron . Average of 7 analyses. If Fe 0 /FeO ratio is assumed to be 1:4, then SiO recalculates to 50.5% and other values are slightly reduced.

Total recalculated to sum to ~100, volatile free.

FeO* is total iron expressed as FeO

Terrigenous siliciclastic sediments

Siliciclastic, terrigenous, marginal marine and less commonly non-marine sediments are prominent in four dredge hauls (1,3,7 and 9; Fig. 1)) and present in five others (8, 11, 12, 14 and 15). Ages range from Late Cretaceous (Maastrichtian) to Early and Middle Eocene.

Most common are weakly indurated brown siltstones and mudstones, typically organic rich with small organic fragments and occasional coal or wood fragments, less common sponge spicules and foraminifera, and traces of glauconite in the form of small peloids. Measured total organic carbon contents are between about 0.2 and 2.0 percent (Table 3). The sediments commonly show wispy to parallel lamination with occasional burrows and cross lamination.

Coarser clastic sediments include fine to gravelly sandstones with angular to sub-rounded grains of intrusive and metamorphic provenance, some polycrystalline quartz and glauconite, and small amounts of chert, feldspar, volcanogenic quartz, reworked quartz-cemented sand grains, chamosite grains, intraclasts and fossils (predominantly foraminifera). The most common cement is poikiotropic ferroan calcite. Other common cements are clastic and carbonate muds. Minor cement types are phosphate, pyrite and meniscus iron oxides.

The presence of glauconite in nearly all the terrigenous rocks, and of marine fossils in some, indicates a predominantly marine environment. The low fossil content, abundant organic matter and occasional wood and coal fragments suggest a nearshore to marginal marine setting. Sand grains were derived from a predominantly intrusive and metamorphic source, most likely the uplifted margins of the Albany-Fraser and Gawler cratons, with a minor input of reworked sand grains from older sediments of the GAB Basin. The overall setting is of estuarine, lagoonal, deltaic and nearshore sedimentation, transitional to fluvial or, more commonly, offshore conditions. Some of the clean sands contain abundant glauconite and even chamosite suggesting low rates of deposition. The chamositic clasts in DR1E resemble replaced limestones, suggesting seafloor alteration of exposed carbonates.

TABLE 3: TOTAL ORGANIC CARBON IN SELECTED SAMPLES

Sample	Organic carbon as C, %	Lithology
66DR01G	.17	Maastrichtian calcareous silty organic mudstone.
66DR07E	2.00	Late Paleocene to Early Eocene organic-rich muddy siltstone.
66DR08F	1.70	Late Paleocene organic-rich, sandy, silty mudstone with plant fragments.
66DR09A	.70	Pliocene dark brown poorly lithified silty mudstone.
66DR11D	1.88	Organic-rich muddy siltstone, Maastrichtian with Miocene contamination.
66DR12D	1.60	Early to Middle Paleocene dark greyish brown mudstone with possible carbonaceous fragments.
66DR14F	1.50	Early Eocene dark greyish brown mudstone and muddy sandstone, soft and friable.

Data from AMDEL Report AC 2813/87 of 29 January 1987 (M. R. Hanckel).
Method: Z/Combustion

Diagenesis of the clastic sediments took place during burial, presumably by compaction and by cementation through carbonate and clay recrystallisation. The poikiotropic ferroan calcite cements were precipitated during deep burial from reducing pore waters (Choquette & James, 1987). An exception is sample DR12F, a mixed terrigenous clastic and carbonate sediment, which contains small fenestral cavities filled by drusy calcite, indicating a tidal flat environment with rapid cementation followed by meteoric phreatic diagenesis. In a few samples the matrix and cement have been replaced by other material. Examples of this are DR1I and DR11F where a calcareous matrix has been partly replaced by phosphate and DR7B where the matrix has been replaced by pyrite. In one sample (DR8G) there is a cement of meniscus haematite suggesting cementation in a soil horizon. In this sample the hematitic gravelly sandstone is in the form of a branching tubular concretion, perhaps indicating precipitation around a tree root.

<u>Carbonates</u>

Carbonate sediments are of four types: 'chalk', siliceous carbonate, non-pelagic limestone and dolomite. Chalks are most common and dolomites least common.

Chalks (lithified and semi-lithified fine pelagic limestones). These are composed of white, soft, fine-grained carbonate and range from lime mudstones to packstones. The grains are predominantly foraminifera and sponge spicules. The foraminifera are most commonly planktic but include arenaceous agglutinating forms. The sponge spicules represent calcisponges, hexactinallids and demosponges. Other fossils include echinoderm plates, ostracods and thin-walled molluscs, probably pteropods. Also present in some samples are small glauconitic, and less commonly calcareous, peloids. The matrix is white, microcrystalline carbonate, probably of coccoliths. Sedimentary structures include wispy laminae, thin winnowed beds, filled and unfilled burrows, and borings. Burrow fillings are chalky carbonate and, less commonly, glauconitic sediment. Some borings, in common with other exposed surfaces, are lined and coated with a crust of iron and manganese oxides. The crust ranges in thickness from a thin film to several mm.

Lithification is variable, ranging from unconsolidated ooze to relatively well indurated chalk. Lithification is generally due to compaction, the well compacted samples having presumably undergone some cementation by microcrystalline carbonate (Schlanger & Douglas, 1974). Some samples which show extensive evidence of seafloor exposure (borings, iron and manganese crusts) are more strongly lithified; this is interpreted to indicate sea floor case hardening. Such samples (DR6C, DR11G, DR12A & C, DR14C) show dissolution of molluscs and partial cavity fill by glauconite. In DR6C, spicules have been dissolved and replaced by manganese oxides. In most the fabric has become denser due to precipitation of microcrystalline carbonate; in these rocks the fabric may take on a clotted appearance.

Siliceous carbonates. These rocks appear to have originated as chalks and limestones which contained abundant siliceous sponge spicules and radiolaria. In one example volcanic glass shards may also have been present (DR3E). Silica is present as a cement, fossil fill, and replacing fossils; most is microcrystalline, and true cherty silica was seen in only one sample (DR15C). The pattern of silicification is commonly nodular with the boundary between nodule and surrounding sediment marked by limited dissolution of carbonate. Many of the siliceous carbonates are quite soft and are thus superfically similar to the more prevalent normal chalks and limestones. Glauconite is slightly more abundant in siliceous than in non-siliceous carbonates. Petrographically the siliceous carbonates resemble those of the Tortachilla, Blanche Point and Port Willunga Formations of the St Vincent Basin in South Australia (Cooper, 1979; Jones & Fitzgerald, 1986).

Non-pelagic limestones. These are rare. The most notable example is DR7G, an echinoderm coral floatstone, possibly boundstone, with solitary scleractinian coral. The rock contains bivalves, brachiopods and planktic foraminifera, and has a matrix of lime mudstone. Aragonitic and high magnesium calcite components have been dissolved away and the cavities lined by small drusy calcite crystals. Other limestones resemble impure chalks, and are commonly silty and glauconitic.

Dolomitic rocks. These include DR1C and DR3D, both of which are burrowed intraclastic silty wackestone with a weathering rind of iron oxide; probably they are from the one source. DR16A is a skeltal dolomitic packstone.

The carbonates were deposited in a range of environments. The chalks accumulated in a pelagic-dominated environment with very little input from shelf or continent. In this they resemble the Quaternary oozes recovered in our soft sediment cores (see Soft Sediment). They were therefore deposited in an environment similar to that prevailing today, on slope, terrace or possibly pelagic shelf. The limestones are thought to have been deposited in shallower shelf environments with varing degrees of pelagic influence. The coralline limestone presumably was formed in a shallow marine, low energy environment, possibly biohermal. The siliceous carbonates closely resemble the chalks and limestones and presumably were deposited in similar environment. The silicification appears to be due to later diagnesis rather than any depositional control, apart from the greater abundance of siliceous fossils and the possible presence in some of volcanic glass shards. The depositional environment of the dolomites in DR1 and DR3 is less clear. The fine grain size indicates a low energy environment, while the scarcity of fossils suggests restriction. The dolomite is very fine grained and therefore probably formed early. The most likely environment is a tidal flat.

Most of the carbonates have undergone very limited diagenesis. The chalks have been variably compacted and cemented, with greatest effects seen in those which have been exposed on the sea floor or have been silicified. The former are encrusted with rinds of iron and manganese oxides, have undergone dissolution of some fossils, and have cavities filled by glauconite or iron and manganese oxides. There has also been extensive case hardening through precipitation of microcrystalline carbonate resulting in a reduction of porosity and an increase in rock density. The coralline limestone has had a complex history. The preservation of moulds indicates rapid cementation either on the seafloor or soon after burial but before the formation of the moulds; dissolution is probably due to exposure to meteoric water; and the presence of thin cavity linings of drusy calcite indicates precipitation in a meteoric phreatic environment (James & Choquette, 1984). Other limestones have had a diagnetic history similar to that of the chalks. In the siliceous carbonates the pattern of silicification is petrographically similar to that which affects the Tertiary carbonates of the St Vincent Basin (Cooper, 1979), as described for the Blanche Point Formation by Jones and Fitzgerald (1984, 1986, 1987). Jones and Fitzgerald concluded that silica was mobilised from volcaniclastic material. In our samples, the scarcity of volcanogenic detritus and the abundance of siliceous organisms suggest a purely biogenic origin. A biogenic origin for silica in marine sediments has been argued by Wise and Weaver (1974) and Calvert (1974). The dolomites, if the tidal flat interpretation is correct, would have been cemented very early with synsedimentary dolomitisation. They appear to have undergone little subsequent diagensis apart from the formation of an iron-rich weathering rind during exposure on the sea floor.

Phosphates

The well-lithified Paleocene phosphatic sediment DR1I was examined and described by R. C. Garrison (personal communication, 1987). The rock is a laminated micrite and fine sandstone that includes a phosphorite interbed 25 mm thick . The sandstone laminae are mostly angular quartz grains with scattered glauconite, phosphate peloids, fish bone, carbonate skeletal fragments including ?bryozoa, carbonate peloids, pyrite, and disseminated organic matter. The micrite was formerly a lime mud or an accumulation of carbonate pellets. The phosphorite interbed is mostly a peloidal phosphorite with variable amounts (5-15%) of silt to fine sand size siliciclastic grains (mainly quartz) and minor glauconite. Later generations of phosphate, which bond the peloids, glauconite, and siliciclastic grains, are difficult to differentiate from first generation phosphate. In places, adjacent to the phosphate horizon, later phosphate appears to have replaced micritic carbonate. The laminated micrite and sandstone developed by passive accumulation of carbonate mud with periodic current-transported influx of silt to sand-size siliciclastic grains, perhaps by storms. The phosphorite horizon probably represents an interval of reduced rate of sediment accumulation, perhaps due to fluctuation in sea level, which permitted phosphatisation of peloids, reworking and winnowing, influx of some siliciclastic grains, and cementation, or replacement of micrite matrix, by phosphate.

DR11F is another mixed carbonate-siliciclastic sediment in which matrix has been partly replaced by phosphate and pyrite.

Discussion

The dredged rocks document a transition from generally terrigenous marine, and rarely non-marine, sedimentation in the Maastrichtian, Paleocene and Early to Mid Eocene, to accumulation of pelagic carbonate from the Middle Eocene through to the Quaternary. The only exceptions to this pattern are the Miocene mudstones with quartz detritus in dredges 7, 9 and 15 (Table 1, Appendix 1) The older samples provide the first record of truly marine Maastrichtian sediments with abundant calcareous nannoplankton in southern Australia. (A horizon in the Gippsland Basin with dinoflagellates also has been dated as Maastrichtian.) This is the first clear demonstration of a Maastrichtian marine connection from southern Australia to the Indian Ocean (*see* Appendix 2) although the concept of Late Cretaceous sea floor spreading between Australia and Antarctica is well established. The assemblages are remarkably well preserved and diverse, and are of value as a high palaeolatitude datum for Maastrichtian biogeography (see Appendix 2). Similarly, much of the microfaunal content of the Eocene samples is new and of biostratigraphic significance. Early Eocene sediments in dredges 8 and 14 are older than the oldest Eocene sediments intersected by DSDP drilling on the Naturaliste Plateau (Davies, Luyendyk, & others, 1974; Hayes, Frakes, & others, 1975).

The Cretaceous to Middle Eocene clastics, both fine and coarse grained, probably correlate with the Potoroo Formation and possibly the Wigunda and Platypus Formations. All of these are marginal marine (Robertson & others, 1979). The Cretaceous dolomites may correlate with those from the Wigunda Formation from the Ceduna Terrace (Robertson & others, 1979). The siliceous carbonates correlate with other Palaeogene siliceous carbonates common elsewhere on the Cainozoic rifted margins of Australia (Jones & Fitzgerald, 1986). The Eocene sandstones and carbonates correlate with the Nullarbor, Wilsons Bluff and Abrakurrie Formations of the Eucla Basin, and the coralline limestone may be a correlative of coralline limestones in the Nullabor Formation near Watson (Ludbrook, 1958). The Tertiary pelagic limestones which we encountered in almost all dredge hauls were not sampled in the various petroleum exploration wells and so have not been formally defined. They are time equivalents of the younger strata of the Eucla Basin.

SOFT SEDIMENT

A total of 41.16 m of soft Quaternary sediment was collected in 19 gravity cores and one piston core (Fig. 1, Table 4). Average core length was 2.08 m and longest core was 3.46 m. Three coring attempts encountered hard bottom and were unsuccessful. Seismic profiles over two of these sites (GC 1 on the Ceduna Terrace and GC 9 on the Eyre Terrace; Fig. 1) suggest that the sea floor may have been scoured of soft sediment by bottom currents; diffraction of seismic waves at the third site (GC 6) suggests an irregular, rough sea floor with little sediment cover. Soft sediment also was collected in the pipe dredge at each of the dredge stations.

Cores from terraces and upper slope were taken in conjunction with the heat flow program. These cores were predominantly pelagic calcareous ooze, but reworked pelagic sands were encountered in two cores from the upper slope off Ceduna Terrace (PC 1 and GC 7; Fig. 9). Cores from the floor of Ceduna and 'Thevenard' Canyons (GC 19 and 20) included terrigenous turbidite and debris-flow deposits beneath a blanket of pelagic calcareous ooze, and a pipe dredge sample from one of the 'Platypus' canyons (DR 14, Fig. 1) contained shelf-derived carbonate debris. Two attempts to core Neogene or older sediments which form benches on the eastern slope of the 'Thevenard' Canyon (GC 20 and 21) encountered only a cover of Quaternary pelagic calcareous ooze.

Pelagic calcareous ooze

Pelagic calcareous ooze is the dominant cored sediment (Fig. 9) and was also recovered in most pipe dredge hauls. The ooze is more than 60 percent very fine grained sediment, probably nannofossils such as coccoliths. A few samples, such as GC 10, 186-188 cm (Fig. 10), have a higher proportion of coarse grains, most of which are of pelagic or deep water origin, namely foraminifera with minor shell hash, siliceous and calcareous sponge spicules, and small aggregates; the only shelf-derived component is a small amount of terrigenous silt and perhaps some of the shell hash and sponge spicules. Typical ooze contains 15-20 percent of non-carbonate material as siliceous spicules and terrigenous silt (Table 5). In many of the cores a pale yellow or cream-coloured upper oxidised zone passes down core into a grey or green reduced zone. In core GC 10 the colour bands are repeated at intervals of 25-50 cm; this may be due to the corer having bounced on first impact with the result that cores from two or more localities are superposed. Grain-size analysis (Fig. 10) and measurements of carbonate content (Table 5; Fig. 9)

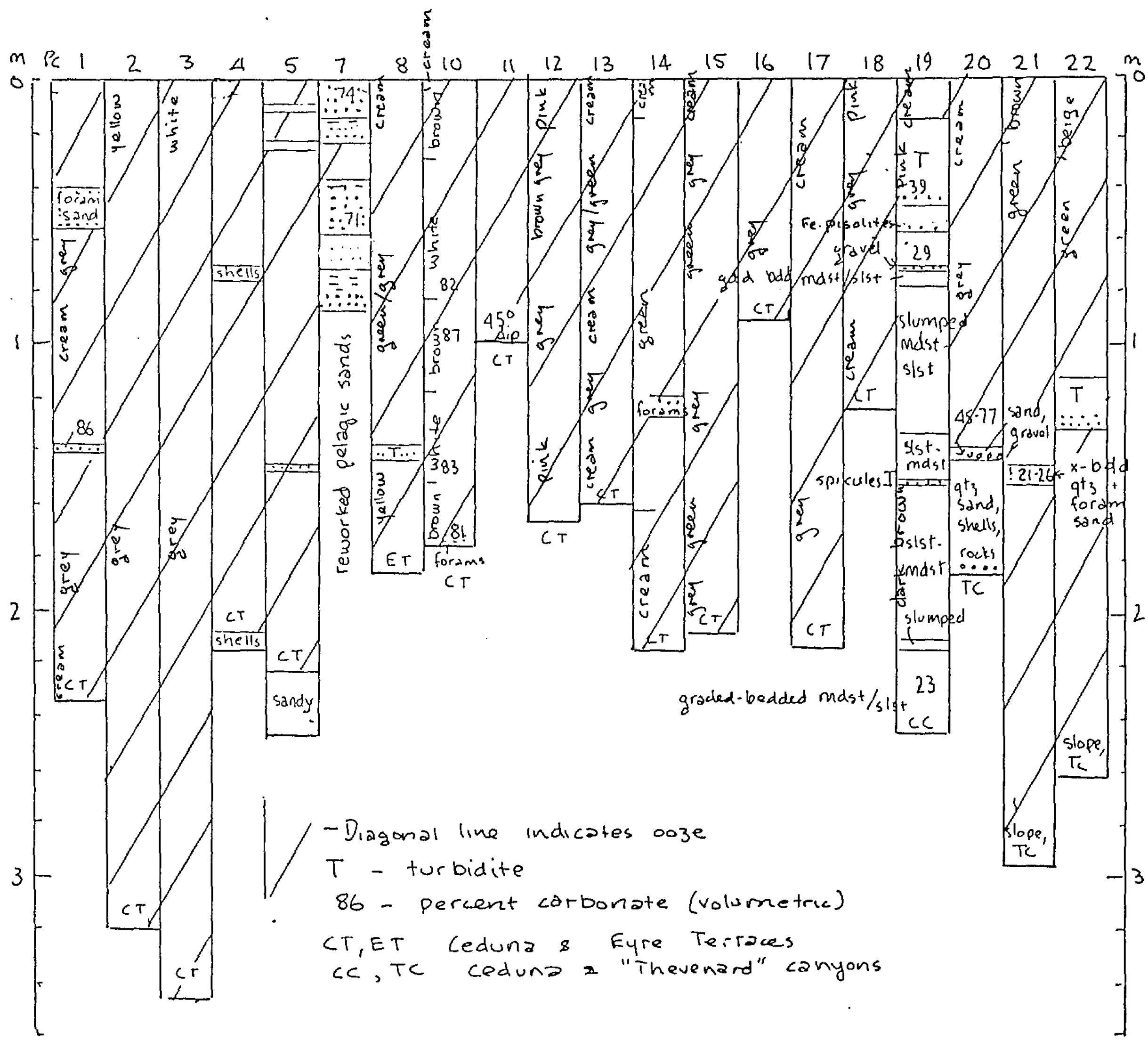


Figure 9: Summary graphic logs of all cores illustrate predominance of calcareous pelagic ooze on terraces and upper continental slope. Cores from canyons (GC 19-22) show turbidite and debris-flow deposits overlain by pelagic ooze. ET Eyre Terrace; CT Ceduna Terrace; CC Ceduna Canyon; TC 'Thevenard' Canyon. Core locations are summarised in Table 4.

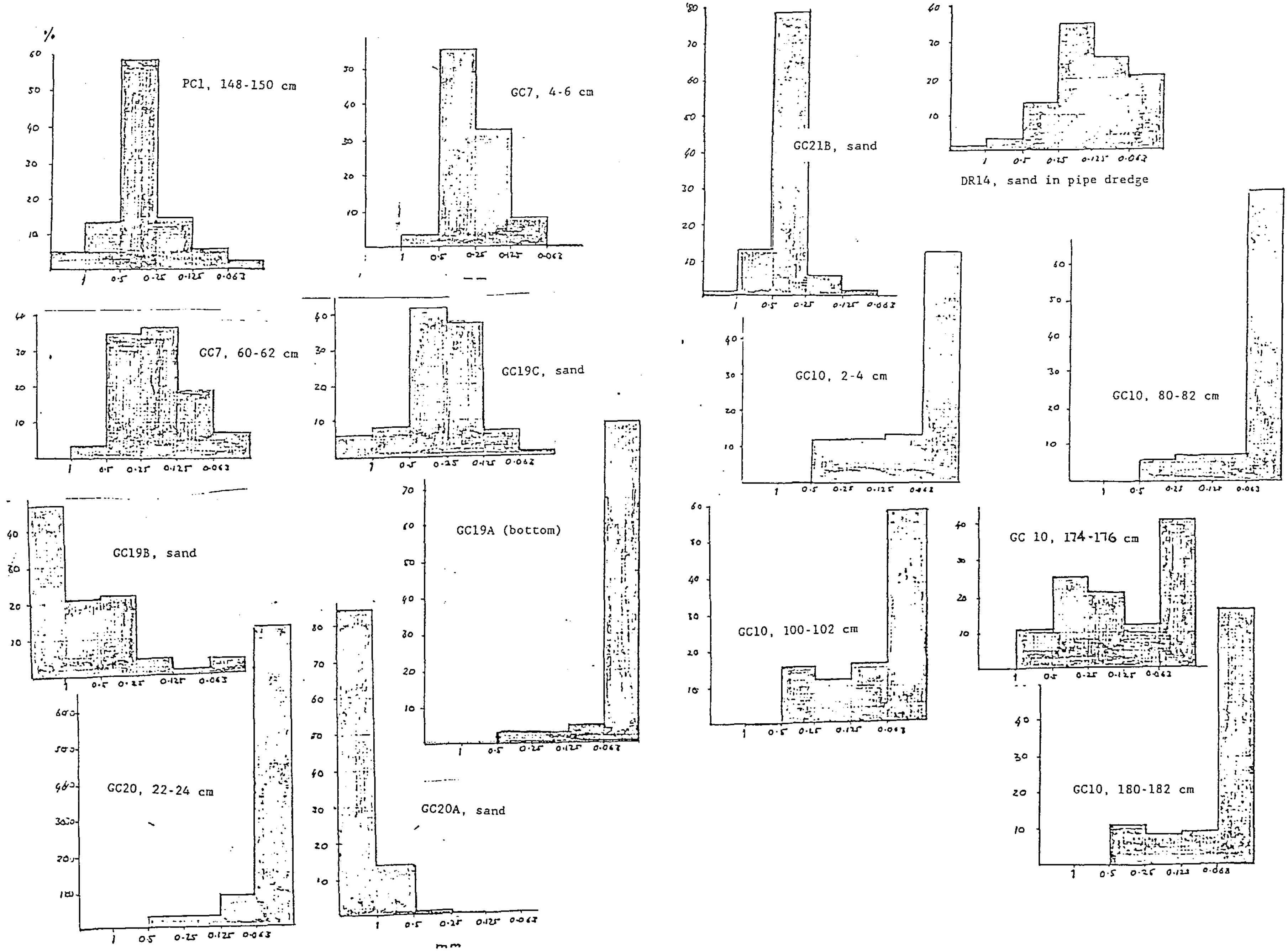


Figure 10: Grain-size distribution in selected samples. Ten histograms compare sandy horizons in cores PC 1 and GC 7, 19-21, and sand from dredge 14; five others compare the differently-coloured layers in core GC 10.

TABLE 4: CORE LOCATIONS AND DESCRIPTIONS

CORE NO.	WATER DEPTH (m)	LAT	LONG	LENGTH (cm)	BRIEF DESCRIPTION
Eyre Terrace					
8	1151	33°39.901	127 42.206	186	Pelagic calcareous ooze with one turbidite horizon
Ceduna Terrace, Line 65/2					
5	1134	34°02.305	130°41.483	247	Pelagic calcareous ooze with several sandy horizons
Slope below Ceduna Terrace, Line 65/2					
7	3662	34°35.438	129°31.716	90	Several beds of reworked pelagic sand, some ooze
Slope below Ceduna Terrace, Line 65/15					
1(PC)	2646	35°16.599	131°11.545	234	Pelagic calcareous ooze, minor foram sands
10	2643	35°16.668	131°10.897	176	Pelagic calcareous ooze with alternating colour bands
11	2326	35°12.156	131°13.597	100	Pelagic calcareous ooze
Ceduna Terrace, Line 65/15					
2	591	33°50.398	132°04.700	321	Pelagic calcareous ooze
3	600	33°51.069	132°05.308	346	Pelagic calcareous ooze
4	701	33°55.820	132°02.441	215	Pelagic calcareous ooze with two shelly horizons
12	2010	35°09.216	131°16.225	167	Pelagic calcareous ooze
13	1734	34°59.643	131°21.541	160	Pelagic calcareous ooze
14	1498	34°50.137	131°25.983	215	Pelagic calcareous ooze with colour banding, one horizon larger planktic forams
15	1376	34°41.721	131°33.056	207	Pelagic calcareous ooze
16	1253	34°32.528	131°39.272	91	Pelagic calcareous ooze
17	1186	34°24.251	131°44.095	213	Pelagic calcareous ooze
18	1247	34°16.234	131°49.083	124	Pelagic calcareous ooze
Ceduna Canyon					
19	2396	35°28.320	132°55.042	246	Sequence of terrigenous siltstone/mudstone and gravel overlain by pelagic calcareous ooze
'Thevenard' Canyon, floor					
20	2810	35°41.743	133°18.761	186	Shell hash, quartz sand, and rock fragments overlain by pelagic calcareous ooze
'Thevenard' Canyon, eastern slope					
21	2717	35°41.283	133°19.867	295	Pelagic calcareous ooze with one horizon X-bedded quartz and foram sand
22	2316	35°41.981	133°21.227	262	Pelagic calcareous ooze with one turbidite horizon of echinoid detritus

TABLE 5: CARBONATE CONTENT OF SELECTED SOFT SEDIMENT

Sample	% Carbonate	
PC 1 148-150 cm (sand)	86.1	All analyses were by volumetric techniques except GC 19B which used acid insoluble residue. GC 20 & 21 show considerable variation between runs due to coarse grained nature of sample.
DR 14 pipe dredge sand	85.2	
GC 7 4-6 cm (sand)	73.9	
GC 7 60-62 cm (sand)	70.8	
GC 10 4-6 cm	82.5	
GC 10 80-82 cm	81.5	
GC 10 100-102 cm	87.3	
GC 10 150-152 cm	83.1	
GC 10 174-176 cm	81.0	
GC 19C (sand)	38.7	
GC 19B (sand)	29.3	
GC 19A (silt at bottom)	23.2	
GC 20 22-24 cm	82.1	
GC 20 (sand)	44.8	
GC 20 (sand)	76.9	
GC 21 (sand)	20.8	
GC 21 (sand)	26.1	

show no correlation with colour banding. Almost certainly it reflects a transition from oxidising to reducing conditions just below the sea floor.

Ooze recovered in the pipe dredge is similar to that recovered in the cores and is essentially an unlithified foraminiferal wackestone with nannoplankton as the mud fraction. Other common components are siliceous spicules from demosponges and well-rounded quartz silt grains. Less common are molluscan hash, calcareous spicules, and possible radiolaria and ostracods.

Reworked pelagic sands

Reworked pelagic sand horizons in cores PC 1 and GC 7 (Fig. 9) have sharp top and bottom contacts, little or no grading, and are either massive or poorly cross bedded. The grains are mostly large foraminifera such as *Orbiculoides* with minor shell hash and spicules. Some of the foraminifera are yellow-brown in colour and probably have been reworked from older sediments. The sands are moderately to well sorted and contain only small amounts of mud. They are essentially winnowed and sorted pelagic material, without any obvious component of shelf origin.

Detrital sediment in canyons

Detrital sediment recovered from beneath the floors of Ceduna and 'Thevenard' Canyons, and dredged from one of the 'Platypus' canyons further to the east (DR 14; Fig. 1), are mixed terrigenous and carbonate sand, silt and mud. Detrital sediment at DR 14 has the highest carbonate content (85%), and that from Ceduna Canyon, the lowest (Fig. 9; Table 5). The carbonate detritus includes shelf-derived fragmented molluscs, bryozoans, brachiopods, corals and worms, and reworked pelagic fossils and lithoclasts of chalk. Terrigenous components included well-rounded quartz sand and gravel and abundant heavy minerals, including zircon, garnet and ilmenite. Core GC 19 from Ceduna Canyon also includes abundant ferruginous pisolites, possibly derived from erosion of lateritic soil profiles or pisolitic limestones similar to the Tortachila Limestone of the St Vincent Basin. The heavy minerals probably were derived from the igneous and metamorphic rocks of the Gawler Craton and Kanmantoo trough.

Typically the detrital sediments are medium to coarse-grained sands, but finer silt and mud dominate the lower part of core GC 19. The silt and mud are terrigenous and form fine graded sequences with sharp basal contacts. Probably they are fine turbidites. Parts appear to have been reworked by slumping, but some of this deformation may have been caused by contact with the core liner. The coarser deposits are generally unstratified or poorly stratified with either massive or cross bedding. In GC 19 the sands are very poorly sorted (Fig. 10) and may represent either turbidites or debris flow products. In GC 20 the detrital horizons have sharp boundaries and are probably grainflows rather than turbidites (Reineck & Singh, 1980, p.471), equivalent to the feeder channel sediments of Walker (1986, p.179). In GC 21, from a bench on the eastern slope of 'Thevenard' Canyon, there is a single, cross-bedded sand horizon which probably represents the migration of a single sand wave within an otherwise pelagic depositional setting.

Terrigenous dark brown and dark grey muds recovered in the pipe dredge from other canyons are unconsolidated to stiff and are composed of fine, well-rounded quartz grains in a clay matrix. Small black flecks of authigenic pyrite and organic matter are present in some, and rare fossils include mollusc fragments, sponge spicules and foraminifera. Some of the foraminifera are Miocene (Appendix 2).

In the cores from Ceduna and 'Thevenard' Canyons the detrital sequence is overlain by up to 1.2 m of pelagic calcareous ooze.

Discussion

The coring program demonstrated that the Eyre and Ceduna Terraces are regions of pelagic calcareous sedimentation, with little input from the landmass to north and east. Hard bottom in some areas, and evidence of scour on seismic profiles, indicate some erosion by bottom currents.

Reworked pelagic sands cored on the upper slope off the Ceduna Terrace are probably contourites or locally sourced grainflows. They lack the grading, poor sorting, and abundant matrix characteristic of turbidites (Stow & Lovell, 1979). Similar deposits on other continental slopes (MacIlreath & James, 1984) are attributed to grainflow (possibly storm generated), reworking of turbidites, storm deposits, and contour-hugging currents. The water depth of the sands in PC 1 and GC 7 precludes an origin as storm deposits, and the lack of shelf fauna argues against origin by grainflow from the shelf or upper slope. Contour currents are known to flow along the southern Australian margin, for example, the Leeuwin current, which follows the shelf break (Rochford, 1986). Such a shelf-following current would inhibit the movement of sediment down the slope, and thus would explain the apparent lack of shelf-source sediment on the southern margin slope. This contrasts with the slope off the Otway margin where there is much movement of shelf sediment down slope (Exon, Lee & others, 1987), possibly related to storm-driven on and off-shelf currents (Fandry, 1983).

The blanket of pelagic ooze encountered in the floor of the Ceduna and 'Thevenard' Canyons indicates that these are currently not active sediment channel ways. The presence of sand in the pipe dredge from the 'Platypus' canyon, on the other hand, may indicate active sediment transport. Presumably all canyons were active during intervals of lower sea level in the Neogene and Quaternary, and were conduits for the fine-grained shelf sands, aggregates and calcretised lithoclasts which now characterise the continental rise (Conolly & von der Borch, 1967). There was no evidence of down slope sediment transport in our cores and in the cores from the continental slope collected by Conolly and von der Borch. Du Couedic Canyon (136°30'E) currently carries saline outflow from the South Australian gulfs (Lennon & others, 1987).

REFERENCES

CALVERT, S.E., 1974 - Deposition and diagenesis of silica in marine sediments. *Special Publication of the International Association of Sedimentoligists*, 1, 273-99.

CHOQUETTE, P.W., & JAMES, N.P., 1987 - Diagenesis in limestones 3. The deep burial environment. *Geoscience Canada*, 14, 3-35.

CONOLLY, J.R., & von der BORCH, C.C., 1967 - Sedimentation and physiography of the sea-floor south of Australia. *Sedimentary Geology*, 1, 181-220.

COOPER, B.J., 1979 - Eocene to Miocene stratigraphy of the Willunga embayment. *South Australian Department of Mines Report of Investigation*, 50.

DAVIES, T.A., LUYENDYK, B.P., & others, 1974 - Initial Reports of the Deep Sea Drilling Project 26. *U.S. Government Printing Office, Washington, D.C.*

EXON, N.F., LEE, C-S., & others, 1987 - Preliminary post-cruise report, *Rig Seismic* research cruise 1987: Otway Basin and western Tasmania sampling. *Bureau of Mineral Resources, Australia, Record* 1987/11.

FANDRY, C.B., 1983 - Model for the three-dimensional structure of wind and tidal driven circulation in Bass Strait. In Imberger, J., (ed), Physical Oceanography in Australia. *CSIRO, Melbourne*, 121-42.

HAYES, D.E., FRAKES, L.A., & others, 1975 - Initial Reports of the Deep Sea Drilling Project 28. *U.S. Government Printing Office, Washington, D.C.*

JAMES, N.P., & CHOQUETTE, P.W., 1984 - Diagenesis 9. Limestones - the meteoritic environment. *Geoscience Canada*, 11, 161-94.

JONES, J.B., & FITZGERALD, M.J., 1984 - Extensive volcanism associated with the separation of Australia and Antarctica. *Science*, 226, 246-8.

JONES, J.B., & FITZGERALD, M.J., 1986 - Silica-rich layering at Blanche Point, South Australia. *Australian Journal of Earth Sciences*, 33, 529-51.

JONES, J.B., & FITZGERALD, M.J., 1987 - An unusual and characteristic sedimentary mineral suite associated with the evolution of passive margins. *Sedimentary Geology*, 52,45-63.

LE MAITRE, R.W., 1984 - A proposal by the IUGS Subcommission on the systematics of igneous rocks for a chemical classification of volcanic rocks based on the total alkali silica (TAS) diagram. *Australian Journal of Earth Sciences*, 31, 243-255.

LENNON, G.W., BOWERS, D.G., NUNES, R.A., SCOTT, B.D., ALI, M., BOYLE, J., CAI WENJU, HERZFELD, M., JOHANSSON, G., NIELD, S., PETRUSEVICS, P., STEPHENSON, P., SUSKIN, A.A., WIJFFELS, S.E.A., 1987 - Gravity currents and the release of salt from an inverse estuary. *Nature*, 327, 695-697

LUDBROOK, N.H., 1958 - The Eucla Basin in South Australia. In Glaessner, M.F., & Parkin, L.W., (eds), The Geology of South Australia. *Geological Society of Australia*, 127-135.

MACILREATH, I.A., & JAMES, N.P., 1984 - Carbonate slopes. In Walker, R.G., (ed), Facies Models. *Geoscience Canada Reprint Series, Second Edition*, 1, 245-58.

REINECK, H-E., & SINGH, I.B., 1980 - Depositional sedimentary environments. 2nd Edition. *Springer-Verlag, Berlin.*

ROBERTSON, C.S., CRONK, D.K., NICHOLAS, E., MAYNE, S.J., & TOWNSEND, D.G., 1979 - A review of petroleum exploration and prospects in the Great Australian Bight region. *Bureau of Mineral Resources, Australia, Record*, 1979/20.

ROCHFORD, D.J., 1986 - Seasonal changes in the distribution of Leeuwin Current waters off Southern Australia. *Australian Journal of Marine and Freshwater Research*, 37, 1-10.

SCHLANGER, S.O., & DOUGLAS, R.G., 1975 - The pelagic ooze-chalk-limestone transition and its implications for marine stratigraphy. *Special Publication of the International Association of Sedimentoligists*, 1, 117-48.

STOW, D.A.V., & LOVELL, J.P.B., 1979 - Contourites: their recognition in modern and ancient sediments. *Earth Science Reviews*, 15, 251-91.

WALKER, R.G., 1984 - Turbidites and associated coarse clastic deposits. *In*

Walker, R.G., (ed), Facies models. *Geoscience Canada Reprint Series, 2nd Edition*, 1, 171-188

WILLCOX, J.B., STAGG, H.M.J., & DAVIES, H.L., 1988 - *Rig Seismic* research cruises 10 & 11: structure, stratigraphy, and tectonic development of the Great Australian Bight region - preliminary report. *Bureau of Mineral Resources, Australia, Record*, 1988/13.

WISE, S.W., & WEAVER, F.M., 1974 - Chertification of oceanic sediments. *Special Publication of the International Association of Sedimentologists*, 1, 301-26.

APPENDIX 1: DESCRIPTION OF DREDGED SAMPLES

By H. L. Davies and J. D. A. Clarke

ABBREVIATIONS:

BM: Age determined from foraminifera by B. McGowran

SS: Age determined from nannoplankton by S. Shafik

NA: Age and environment determined from spores and pollen by N. F. Alley

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DREDGE 01 About 750 kg

All samples have prefix 66DR01

A. Fine, weakly lithified, white foram spicular wackestone; plastic, clay-like, when disaggregated, contains burrows 5-18 mm diameter. Comprises 45 percent of haul.
Age Early Oligocene (BM), Late Eocene (SS)
Composition: Carbonate. Fabric: Matrix supported. Structures: Borings, some manganese encrustation. Grains: Fossils. Grainsize: <1 mm. Sorting: Moderate. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams, siliceous and calcareous sponge spicules, ostracods. Cement: Microcrystalline carbonate. Depositional environment: Pelagic. Diagenesis: Compaction and cementation. Dissolution of some forams and encrustation of surfaces by manganese during seafloor exposure.

B. Pale grey-yellow poorly-sorted siliceous radiolarian wackestone; generally massive but some weak layering; minor chert-filled cavities; some fragments lenticular or lobate and rounded with iron oxide coating. Colour 5Y7/2. Comprises about 17 percent of haul. Somewhat similar to D, E and K.
Age: Eocene and Miocene mixture (BM).
Composition: Siliceous carbonate. Fabric: Matrix supported. Structures: Burrows and nodules. Grains: Fossils, glauconitic peloids. Grainsize: <0.25 mm. Sorting: Moderate. Roundness: Angular. Matrix: Siliceous micrite. Fossils: Radiolaria, siliceous sponge spicules, planktic forams, ostracods. Cement: Silica, microcrystalline carbonate. Other features: Calcareous fossils silicified. Depositional environment: Pelagic. Diagenesis: Formation of reworked glauconitic peloids, post depositional silicification and cementation resulting in nodular fabric. Note: 66DR01B may be part of a suite of Eocene siliceous carbonates together with DR1D, DR3E, F & G, DR14E, DR15C and DR16B. It is most similar to DR4A.

C. (i) Rounded nodule (15x10x10 cm) of opalline silica with limonitic rim (BMR sample). (ii) Dolomitic bioturbated intraclastic silty wackestone (Flinders University sample).
Age: Dinoflagellates in Flinders University sample indicate Late Cretaceous (Coniacian/Santonian).
Composition: Carbonate. Fabric: Matrix supported. Structures: Burrows, iron oxide rind on outside of sample. Grains: ?intraclasts, quartz silt, fossils. Grainsize: <5 mm (intraclasts), others <0.25 mm. Sorting: Poor Roundness: Subangular. Matrix: Dolomicrite. Fossils: Calcareous sponge spicules. Cement: Microcrystalline carbonate. Other features: Slight neomorphic recrystallisation.

D. Pale green-beige, poorly sorted, matrix supported siliceous, glauconitic, silty, spicular wackestone. Wilsons Bluff equivalent. Quartz grains fine to medium in size. Matrix silt/clay, similar to 66DR01B - distinguished from 66DR01B by colour, which may reflect presence of fine glauconite. 2 % of haul. Munsell colour 5Y 7/4.
Age: ?later Middle Eocene (BM)
Composition: Siliceous carbonate. Fabric: Matrix supported. Structures: Burrows, laminae. Grains: Quartz silt, glauconitic peloids, fossils. Grainsize: <0.25 mm. Sorting: Poor Roundness: Angular. Matrix: Micrite. Fossils: Demosponges, calcisponges, hexactinallids, forams. Cement: Microcrystalline carbonate. Other features: Localised silica precipitation and replacement. Some forams dissolved. Depositional environment: Pelagic shelf. Diagenesis: Minor dissolution of forams, cementation, silica precipitation. Note: This sample may form part of a siliceous carbonate suite along with DR1B, DR3E, F, & G, DR4A, DR14E, DR15C and DR16B of Eocene age.

E. Pale green-beige, poorly sorted, matrix supported, chamositic and glauconitic, intraclastic calcareous sandstone, similar to 66DR01D. Distinguished by granular olive green transported glauconite and chamosite, in places forming clots 1 cm in diameter. Munsell colour 5Y 6/3.
Age: later Middle Eocene (Wilsons Bluff type) (BM).
Composition: Calcareous sandstone. Fabric: Grain supported. Structures: Borings in some grains. Grains: Quartz sand, chamositic and glauconitic intraclasts, lithoclasts and peloids, fossils. Grainsize: 10-0.25 mm. Sorting: Moderate-well. Roundness: Angular-subrounded. Matrix: Calcareous mud. Fossils: Benthic arenaceous and calcareous forams, planktic forams. Cement: Microcrystalline carbonate. Other features: Large yellow grains of chamosite and glauconite in some cases replace earlier lithologies. Same material replaces or fills some fossils. Depositional environment: High energy shelf. Diagenesis: Seafloor boring and replacement of exposed carbonate lithologies by chamosite and glauconite, infill and replacement of fossils, burial cementation.

F. Pale green-beige, matrix supported silty sandstone and fine pebble conglomerate. Quartz grains, fine grained, granular ?glauconite. Contains fragments of other lithologies: (a) light green glauconitic and chamositic sandstone, similar to E, and (b) dark organic shale, similar to G-H, colours 5Y 7/2, 5Y 4/3.
Age: Maastrichtian (BM).
No systematic description.

G. Dark olive-green calcareous, organic, silty mudstone. Organic rich, fragmented nacrous portion of shells (<1 mm). Calcareous (?shelly debris). Paler green inclusions, ?disrupted layers and bioturbation. Soft. Munsell colour 5Y 4/3.
Age: Maastrichtian (BM); probably Maastrichtian to Early Paleocene, marine (NA).
Composition: Terrigenous. Fabric: Matrix supported. Structures: Laminae. Grains: quartz silt, glauconitic peloids, fossils. Grainsize: <0.125 mm. Sorting: Moderate. Roundness: Angular. Matrix: Organic rich clay and mud. Fossils: Echinoderms. Cement: Recrystallised clays, microcrystalline carbonate. Other features: Poorly lithified. Depositional environment: Low energy marginal marine. Diagenesis: Compaction and cementation.

H. Dark brown-black, organic-rich, soft silty mudstone.. Similar to G but with little or no quartz. Highly organic. Nacrous shelly debris, long spines (>2cm long). Bioturbated, with burrows (? marine). Munsell colour 5Y 4/1-3/2.
Age is Maastrichtian (BM) or Early Eocene, marine (NA)
Composition: Terrigenous. Fabric: Matrix supported. Structures: Laminae Grains: Quartz silt, glauconitic peloids. Grainsize: <0.125 mm. Sorting: Moderate-well. Roundness: Angular. Matrix: Organic rich clay and mud. Fossils: None. Cement: Minor carbonate, recrystallised clays. Other

features: Some peloids appear isotropic, ?phosphatic. Depositional environment: Low energy marginal marine. Diagenesis: Formation of glauconite, reworking and deposition, compaction and minor cementation.

(Notes: Samples G and H make up more than 50 percent of haul.)

I. Laminated, highly indurated, phosphatic, silty packstone/wackestone with 2 cm thick phosphate horizon. Portion of the rock contains sand sized quartz, graded, in a finely laminated calcareous matrix. One large boulder (subangular- subrounded) and two fist sized fragments.
<u>Age</u> Late Paleocene, marginal marine, *Lygistepollenites balmei* (NA).
Composition: Phosphatic silty carbonate. Fabric: Grain-matrix supported. Structures: Ripple cross laminae in lower part, grading up into parallel laminae in upper part, normally graded, phosphate band, calcite veins. Grains: Fine quartz sand, glauconitic and carbonate peloids. Grainsize: <0.25. Sorting: Moderate. Roundness: Angular-subangular. Matrix: Micrite. Fossils: None. Cement: Microcrystalline carbonate. Other features: Central bedding parallel band of granular collophane apatite partly replacing carbonate matrix. Depositional environment: ?shelf or upper slope. Bed may be a turbidite or storm bed. Diagenesis: Formation of glauconite and phosphate peloids, reworking and deposition, formation of phosphate band partly by replacement of carbonate matrix, fracturing and calcite veining.

J. Amygdaloidal sodic phonotephrite (undersaturated alkali basalt) lava, probably part of a pillow, with fine hyaloclastite in carbonate? matrix attached to glassy selvage. One larger sample (10 X 10 X 10 cm) and two smaller fragments. For major element analysis of glass see text Table 2) <u>Age</u> not determined; too altered and amygdale-rich for K-Ar age determination. Texture: Vesicular, microporphyritic. Crystals: 10-15% weathered ?olivine, 5% orthopyroxene, 1% plagioclase laths. Groundmass: Palagonite, dark brown and clay rich, fine mesh of plagioclase miocrolites. Other features: Vesicles lined with varying thicknesses of glass, some almost completely filled. Glass devitrified to silica spherulites.

K. Pale-green, soft, chamositic sandstone slab is contained within E or F type sediment.

L. Brown siltstone (Colour 10YR4/2 to 5YR3/2); L is interbedded with F.
<u>Age</u>: Maastrichtian (BM).

<u>Notes</u>: F and L, together with A, are the dominant rock types in the haul.

<u>DREDGE 02</u> 50 kg

<u>All samples have prefix 66DR02</u>

A. A small quantity of soft olive to dark olive-grey mudstone, to fine sandstone, slightly calcareous, some burrows. Wilsons Bluff type.
<u>Age</u>: ?later Middle Eocene (BM).

B-F. Strongly jointed and locally cataclastic-textured, moderately altered pink, equigranular, coarse-grained, hornblende-biotite granodiorite formed 98 percent of the haul; some clasts have sediment of fine angular granodiorite debris attached, with external limonitic cement, internally friable; alteration minerals are chlorite, epidote and clay minerals. Varieties of granodiorite were given sample identifications B-F. Chemical analysis in progress; hornblende and biotite + too altered for K-Ar age determination; U-Pb zircon age possible but probably not warranted.
<u>Age</u>: Presumed Precambrian, extension of Albany-Fraser Province.
Texture: Equicrystalline, some crystals poikioblastic. Crystals: Feldspars 60% (plagioclase 40%, perthite 15%, microcline 5%), amphiboles 10%, biotite

10% quartz 10%. Other features: Two generations of quartz, early generation of rounded to subrounded grains or crystals enclosed within feldspars, late generation of irregular crystals filling remaining spaces. Feldspars variably weathered, rock fractured with fracture fills of iron oxides.

DREDGE 03 20 kg

All samples have prefix 66DR03

A. Glauconitic, peloidal, silty mudstone. Dark brown, highly organic, fine grained shelly (nacrous) debris; 20 percent of sample; probably the most common rock type but difficult to recover; calcareous, soft.
Age: Maastrichtian (BM, SS). Palynology: mixed fauna Early Cretaceous to Early Eocene, pollen, spores and dinoflagellates (NA).
Composition: Terrigenous. Fabric: Matrix supported. Structures: Laminae Grains: Glauconitic and muddy peloids, quartz silt. Grainsize: < 1 mm. Sorting: Poor. Roundness: Angular. Matrix: Organic rich clay and mud. Cement: Recrystallised clays. Other features: Poorly lithified. Depositional environment: Low energy marginal marine. Diagenesis: Formation of glauconite. Reworking and deposition, compaction and limited cementation.

B. Glauconitic, calcareous, quartz sandstone. Poorly sorted, medium to very coarse grained . Subangular to subrounded. Low sphericity. Matrix 10 %, white, carbonate. Glauconite forms 5-10 % of grains. Porous, slightly calcareous and indurated.
Age: not known, presumed Cretaceous to Early Eocene.
Composition: Calcareous sandstone. Fabric: Grain supported. Structures: None. Grains: Quartz sand, large and small glauconitic grains. Grainsize: 2-0.25 mm. Sorting: Moderate-poor. Roundness: Angular. Matrix: None. Fossils: None. Cement: Poikiotropic ferroan calcite. Other features: Rare isotropic peloids, ?phosphatic. Depositional environment: High energy shallow marine. Provenance: Metamorphic. Diagenesis: Formation of glauconitic (? and phosphatic grains), reworking and deposition, deep burial cementation under reducing conditions by ferroan calcite.

C. Glauconitic, calcareous, clay pellet, gravelly quartz arenite. Clasts 20 %, predominantly shale. Minor amounts of rounded quartz. One strange clast dark brown, waxy, relatively soft. Matrix 80%, fine to medium grained quartz, minor glauconite, some ?feldspar. Slightly calcareous.
Age probably Late Cret (younger than Turonian), although conceivably could be Tertiary (no Tertiary forms seen); marginal marine (NA).
Composition: Calcareous conglomerate. Fabric: Grain supported. Structures: None. Grains: Black clay pellets, quartz gravel and sand, glauconitic peloids, fossils. Grainsize: 10mm-0.25 mm. Sorting: Poor. Roundness: Angular-subangular. Clay pellets well rounded. Matrix: None. Fossils: Shark's tooth, mollusc fragments (pteropods?). Cement: Poikiotropic ferroan calcite. Other features: Authigenic pyrite replacing calcite. Depositional environment: Shallow, high energy marine. Provenance: Metamorphic. Diagenesis: Formation and reworking of glauconite, deposition, deep burial, cementation under reducing conditions by ferroan calcite, local replacement of calcite by pyrite.
Note: Compare 66DR03B.

D. Dolomitic silty wackestone. Fine grained, minor fine sand to silt sized quartz and glauconite grains. Marine.
Age: Late Cretaceous (NA).
Composition: Carbonate. Fabric: Matrix supported. Structures: Burrows, small wispy intraclasts, iron oxide rind on outside of sample. Grains: Carbonate intraclasts, quartz silt, peloids, fossils. Grainsize: Quartz silty <0.125 mm, intraclasts >3 mm. Sorting: Poor. Roundness: Angular. Matrix: Dolomicrite. Fossils: Calcareous spicules. Cement: Microcrystalline

carbonate. Other features: Slight neomorphism. Depositional environment: Shallow-marginal marine, low energy. Diagenesis: Cementation, contemperaneous dolomitisation and neomorphism. Note: Lithology is identical with sample 66DR01C.

E. Rounded cherty-looking boulder is spicular foraminiferal wackestone. Fine grained. Pale grey-beige. Very slightly calcareous. Moderately hard.
Age not known.
Composition: Siliceous carbonate. Fabric: Matrix supported. Structures: Burrows and borings. Grains: Fossils, quartz silt glauconitic peloids, possible glass shards. Grainsize: <0.5 mm. Sorting: Poor. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams, calcareous and siliceous spicules, rare ostracods, radiolaria. Cement: Microcrystalline carbonate, silica. Other features: partial silicification of some forams, growth of fibrous silica in pores and filling some fossils. Depositional environment: Pelagic. Diagenesis: Compaction, cementation, silica mobilization and precipitation. Note: May be part of a suite of Eocene siliceous carbonates together with DR1B & D, DR3F & G, DR4A, DR14E, DR15C and DR 16B.

F. Rounded cherty-looking boulder like 66DR03E is siliceous limestone. Pale grey, fine grained. Lighter coloured alteration rind.
G. Rounded cherty-looking boulder like E and F is siliceous limestone. Pale grey, fine grained. Paler and coarser than F. Small darker zone in centre is less altered core. Moderately hard.
Age not known.
Composition: Siliceous limestone. Fabric: Grain supported-matrix supported. Structures: Nodular. Grains: Fossils, quartz silt, peloids, ?devitrified shards. Grainsize: <0.5 mm. Sorting: Poor. Roundness: Angular. Matrix: Siliceous micrite. Fossils: Planktic forams, siliceous and calcareous spicules, radiolaria, echinoderms. Cement: Silica, minor microcrystalline carbonate. Other features: Extensive silica precipitation in fossils and replacing fossils, some overgrowths, solution of carbonate along nodule boundaries. Depositional environment: Pelagic-shelf. Diagenesis: Formation of glauconite, reworking and deposition, extensive silica mobilisation and precipitation forming fossil fills, overgrowths and replacing fossils. Nodule formation. Note: 66DR03E, F, and G may be part of a suite of Eocene siliceous carbonates with 66DR1B & D, 66DR04A, 66DR14E, 66DR15C, and 66DR16B.

H. Amygdaloidal black alkali basalt or phonotephrite, one piece 20 X 30 X 20 cm.
Age not known.
Texture: Amygdaloidal, porphyritic. Crystals: 10% weathered pyroxenes, 5% large plagioclase needles. Groundmass: Opaque minerals and plagioclase laths in a glassy matrix. Other features: Amygdules filled by cloudy blocky calcite and some fibrous silica. Quenched texture.

DREDGE 04 <250 g

Sample has prefix 66DR04

A. A single sample of grey-green, soft, friable siliceous, glauconitic, silty, spicular wackestone. External appearence massive. Large external boring about 1 cm in diameter and 3 cm deep. One burrow about 3 cm long and 0.5 cm wide filled by very soft green sediment. When cut showed wispy laminations and filled burrows. No obvious micro or macro fossils.
Age: Presumed to be Early Tertiary.
Composition: Siliceous carbonate. Fabric: Matrix supported. Structures: Wispy laminae, burrows. Grains: Quartz silt, fossils, glauconitic peloids. Grainsize: <0.25 mm. Sorting: Moderate. Roundness: Angular. Matrix: Siliceous micrite. Fossils: Planktic forams, radiolaria, calcareous and siliceous spicules, pteropods. Cement: Silica and carbonate. Other features:

Silicification of fossil fills, possibly minor phosphatic peloids. Depositional environment: Pelagic shelf. Diagenesis: Formation of glauconite, reworking and deposition, cementation and contemperaneous silica mobilisation and precipitation. Note: This sample probably forms part of the suite of siliceous carbonates.

DREDGE 06 50 kg

A. Very fine white 'chalk' (foraminiferal spicular wackestone), many borings by modern organisms (crustaceans, worms, etc.). Large burrow trace fossil *Zoophycus* in one block. 80 percent of haul.
Age: Eleven pieces are all Early Oligocene (BM).
Composition: Carbonate. Fabric: Matrix supported. Structures: Small burrows. Grains: Fossils. Grainsize: <0.5 mm. Sorting: Poor. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams, siliceous and calcareous spicules, ostracods, echinoderms. Cement: Microcrystalline carbonate. Other features: Poorly lithified and porous. Depositional environment: Pelagic. Diagenesis: Compaction and limited cementation.

B. Pale yellowish white, very fine grained 'chalk' (foraminiferal spicular wackestone), with many modern borings (crustaceans, worms, etc). More foraminifera and spicules than in A. 20 percent of haul.
Age: early Late Oligocene (BM).
Composition: Carbonate. Fabric: Matrix supported. Structures: None. Grains: Fossils. Grainsize: <0.25 mm. Sorting: Poor. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams, siliceous and calcareous spicules, ostracods. Cement: Microcrystalline carbonate. Other features: Soft, high porosity. Depositional environment: Pelagic. Diagenesis: Compaction and limited cementation.

C. Several small fragments of white limestone (foraminiferal spicular wackestone partly replaced by Mn oxides) with a ferruginous and manganiferous weathering crust (all from pipe dredge). Similar to A, but with distinct crust of Fe, Mn oxides.
Composition: Carbonate. Fabric: Matrix supported. Structures: None. Grains: Fossils. Grainsize: <0.25 mm. Sorting: Well. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams, calcareous and siliceous spicules. Cement: Microcrystalline carbonate. Other features: Manganese oxide filling spores and replacing some spicules. Well indurated, yellow colour. Depositional environment: Pelagic. Diagenesis: Burial cementation, seafloor exposure with dissolution of some spicules and fill of pores with manganese oxides. Possibly further cementation.

Pipe dredge was full of a yellowish brown ooze with scattered fragments of the above lithologies.

A, B, and C are lithified pelagic calcareous ooze.

DREDGE 07 20 kg

A. Partly consolidated (plastic), grey, gritty ooze (in both dredge and pipe). 10YR 8/1. Microfossils show contamination.
Age: ?Pliocene and younger (BM); ?Late Paleocene to ?Early Eocene, marine (NA)

B. Concretionary mass of pyritic, silty, quartz sandstone, roughly laminated. Composition: Pyritic sandstone. Fabric: Predominantly matrix supported. Structures: None. Grains: Quartz sand and silt. Grainsize: <0.5 mm. Sorting: Moderate. Roundness: Angular. Matrix: Pyrite. Fossils: None. Cement: Pyrite. Other features: Minor interstitial glauconite, relict muddy matrix, quartz grains eroded by pyrite. Depositional environment: Low energy marginal marine. Diagenesis: Compaction and cementation by glauconite and recrystallised clays, replacement of matrix by pyrite, now 95% complete.

C. Consolidated (plastic), white, smooth ooze/mud.
Age: Middle Miocene reworked into latest Miocene (BM).

D. Mixture of cream-coloured plastic mud with white mud (C) and dark brown mud. (i) Cream and white mud are a foraminiferal wackestone; (ii) dark brown mud is a glauconitic, organic-rich siltstone, colour 5Y 8/2. Mixing may be inherent or took place during dredging.
Age: earliest Middle Miocene (BM). Composition: (i) carbonate, (ii) terrigenous. Fabric: (i) matrix supported, (ii) grain supported. Structures: Sharp contact between lithologies (i) and (ii), (ii) laminated with laminae smeared round (i). Grains: (i) fossils, (ii) quartz silt and galuconitic peloids. Grainsize: <0.5 mm in both. Sorting: (i) poor, (ii) moderate. Roundness: Both angular. Matrix: (i) micrite, (ii) organic rich mud. Fossils: (i) planktic and benthic forams, some arenaceous. (ii) none. Cement: (i) microcrystalline carbonate, (ii) none? Other features: (ii) poorly lithified. Depostional environment: (i) pelagic, (ii) low energy marginal marine. Diagenesis: (i) compaction and cementation by microcrystalline carbonate; (ii) formation of glauconitic peloids, reworking and deposition, compaction and possibly limited cementation by clays.

E. Dark brown (10YR 2/1) organic-rich, muddy siltstone. Non-calcareous. Minute fragments, possibly of shelly debris. Contains fine grained quartz and minor forams. Carbonaceous and finely laminated. Similar to 66DR01L and 66DR03A. 50 percent of haul. Microfossils show contamination.
Age: Late Cainozoic? (BM); Late Paleocene to Early Eocene, marginal marine (NA). Degree of lithification suggests Paleocene-Eocene age for bulk of sample.
Composition: Terrigenous. Fabric: Matrix to grain supported. Structures: Silt poor and silt rich laminae. Grains: Quartz silt, muscovite flakes, glauconitic peloids, organic fragments. Grainsize: <0.125 mm. Sorting: Poor. Roundness: Angular. Matrix: Organic mud. Fossils: None. Cement: ?recrystallised clays and glauconite. Other features: None. Depositional environment: Low energy marginal marine. Diagenesis: Formation of peloids, reworking and deposition, compaction and cementation by interstitial glauconite and clay recrystallisation.

F. Red brown (2.5YR 3/2) plastic, calcareous glauconitic spicular siltstone.
Age: Middle Miocene or reworked (BM); ?Late Cretaceous (Campanian-Maastrichtian) dinoflagellates (NA).
Composition: Calcareous siltstone. Fabric: Grain supported. Structures: Parallel bedding. Grains: Large glauconitic grains, glauconitic peloids, quartz silt, fossils. Grainsize: <2 mm. Sorting: Poor. Roundness: Angular-sub angular. Matrix: Calcareous mud. Fossils: Planktic forams, calcareous and siliceous spicules, possible diatoms, calcispheres. Cement: Recrystallised clays, microcrystalline carbonate. Other features: Large glauconite grains orientated bedding parallel, glauconite also fills and replaces fossils. Calcareous sponge spicules leached. Depositional environment: Shallow marine-shelf. Diagenesis: Formation of glauconite grains, reworking and deposition, leaching of spicules, cementation.

G. Massive, porous, coralline limestone (2.5 Y 8/2), echinoderm coral floatstone, possibly a boundstone. Corals and bivalves preserved as internal and external moulds. Several generations of filled and unfilled borings. Infill of ?lime mudstone. No diagnostic microfossils.
Age: Probably Middle Miocene (BM).
Composition: Carbonate. Fabric: Matrix supported. Structures: Burrows. Grains: Fossils, minor quartz silt. Grainsize: Many >10 mm. Sorting: Poor. Roundness: Angular. Matrix: Micrite. Fossils: solitary scleractinian corals, echinoderms, bivalves, planktic forams, brachiopods. Cement: Microcrystalline

calcite, drusy calcite. Other features: Corals and bivalves preserved as moulds. Depositional environment: Shallow marine shelf, possibly biohermal. Diagenesis: Early seafloor cementation of mudstone (?seafloor), meteoric leaching of aragonitic components, mould cavity lining by drusy calcite in shallow phreatic environment. Note: This is one of only two samples which preserves evidence of exposure to meteoric waters. The other is DR12F.

H. Fine sandy muddy silt, cohesive but poorly consolidated and apparently unlithified; dark yellow brown (5YR 4/4) in colour. Most likely the source of the dark brown mud contaminating D. Found smeared round mouth of dredge. Similar to F.

<u>DREDGE 08</u> 30 KG

<u>All samples have prefix 66DR08</u>

A. Fine grained consolidated yellow-brown (5Y 6/3) calcareous interbedded mudstone/sandstone (glauconitic, spicular, foraminiferal packstone). Recent burrows.
<u>Age</u>: Early Eocene (BM).
Composition: Carbonate. Fabric: Grain supported. Structures: Mottled. Grains: Fossils, glauconitic peloids, quartz silt. Grainsize: <0.5 mm. Sorting: Moderate. Roundness: Angular. Matrix: Micrite. Fossils: Planktic foraminifera, calcareous spicules, Hexactinellid spicules (some still articulated). Cement: Microcrystalline carbonate and silica. Other features: Glauconitic fossil fills, some fossil fill by low birefringent, low-relief silica, very porous. Depositional environment: Moderate energy pelagic shelf. Diagenesis: Formation of glauconite grains, reworking, further glauconite formation as fossil fills, compaction, cementation and silica mobilisation. This sample shows some similarity to the siliceous suite but silica precipitation is very limited.

B. Fine grained consolidated pale yellow green (5Y 8/2) carbonate mudstone (spicular foraminiferal wackestone). Extensively burrowed.
<u>Age</u>: later Middle Eocene (BM).
Composition: Carbonate. Fabric: Matrix supported. Structures: Irregular bedding, borings and burrows. Grains: Fossils, glauconitic peloids, quartz silt. Grainsize: <0.5 mm. Sorting: Poor. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams, siliceous and calcareous spicules, molluscs. Cement: Microcrystalline carbonate. Depositional environment: Pelagic. Diagenesis: Formation of peloids, reworking and redeposition, compaction and cementation.

C. Brown (2.5y 4/4) mud-silt (glauconitic foraminiferal wackestone). Softer than D, E & F. From pipe dredge.
Composition: Carbonate. Fabric: Matrix supported. Structures: None. Grains: Fossils, peloids,. Grainsize: <1 mm. Sorting: Poor. Roundness: Angular. Matrix: Micrite. Fossils: Planktic and arenaceous forams, echinoderms, pteropods. Cement: Microcrystalline carbonate. Other features: Some fossils filled by glauconite. Depositional environment: Pelagic shelf. Diagenesis: Formation of glauconite, reworking and deposition, possible further glauconite precipitation, compaction and cementation.

D. Brown (10YR 4/4) gravelly, sandy, muddy siltstone. Recent burrows.
<u>Age</u>: Middle Eocene, Hampton facies (BM); palynology age Early Eocene, marginal marine (NA).
Composition: Terrigenous. Fabric: Grain supported. Structures: None. Grains: Quartz sand and silt (straight and undulose extinction quart dominates, minor amounts of polycrystalline quartz), small muddy intraclasts, muscovite flakes. Grainsize: <3 mm. Sorting: Very poor. Roundness: Sub rounded-well rounded. Matrix: Dark mud. Fossils: Very rare reworked

siliceous microfossils. Cement: Recrystallised clays. Other features: Mud matrix partly altered to sericite. Depositional environment: Non marine-marginal marine, rapid deposition. Palynomorphs indicate marine environnment. Provenance: Intrusive igneous with some metamorphic influence. Diagenesis: Compaction and cementation through neomorphism of clays.

E. Fine-grained muddy sandy siltstone. Irregular colour variation (2.5Y 7/4-2.5Y 4/2). Recent burrows, one sandy rim.
Age: Paleocene to Early Eocene, ?paralic (NA)

F. One large piece of organic-rich, sandy, silty mudstone with plant fragments; cross-laminated. Lower part yellow brown (2.5Y5/6). Upper part darker (5Y 2/2). Contains abundant muscovite <1.5 mm across. Also abundant black fragments of carbonaceous material, probably wood, although may be bone. One large piece 160 X 20 X 4 mm. Surface of lower, lighter coloured sediment appears brecciated and infilled by later, darker sediment. Lower sediment contains more clay, less plant debris, less mica and occasional forams. Black sediment is bio-turbated with de-watering structures and worm burrows.
Age: Late Paleocene, ?paralic (NA).
Composition: Terrigenous. Fabric: Matrix supported. Structures: Burrows, laminae. Grains: Quartz silt and sand, peloids, fossils. Grainsize: < 5 mm. Sorting: Poor. Roundness: Angular. Matrix: Slightly calcareous mud. Fossils: Wood and leaf fragments. Cement: Recrystallised clays and microcrystalline carbonate. Other features: Burrows filled by silt rather than mud, mud is sericitic. Depositional environment: Non-marine or marginal marine, predominantly low energy with higher energy episodes filling burrows. Possibly marsh, lagoon, delta or tidal deposit, paralic. Diagenesis: Recrystallisation of clays to form sericite, coalification of wood.

G. Branched concretionary hematitic gravelly quartz sandstone. Most of sample from main dredge with a few fragments from pipe dredge. Outer rind of goethite/limonite. Internally some semiconsolidated sand. Large (3-4 mm) quartz grains are rounded with moderately high sphericity; possible rizoconcretion.
Composition: Terrigenous. Fabric: Grain supported. Structures: Tubular branching concretion. Grains: Quartz gravel (polycrystalline quartz 20%, undulose quarts 40%, straight quartz 30%, reworked sedimentary quartz 10%), minor feldspar. Grainsize: 0.5-5 mm. Sorting: Moderate-well. Roundness: Angular to well rounded. Matrix: None. Fossils: None. Cement: Meniscus haematite. Other features: Some quartz grains have rounded quartz overgrowth indicating that they have been reworked from sandstones. Depositional environment: Fluvial. Diagenesis: Cementation by iron oxides in soil zone, possible rizoconcretion.

Lithologies C, D, E, and F make up most of the dredge haul.

DREDGE 09 2 kg

All samples have prefix 66DR09

A. 75 percent is dark brown (10YR 3/3) poorly lithified, wispy laminated mudstone with well developed bedding-parallel parting. Under microscope see fine silt-size quartz grains in brown clay matrix.
Age: Pliocene (BM).

B. 20 percent is soft, sticky, poorly lithified white spicular foraminiferal wackestone.
Age: Middle Miocene reworked into Pliocene (BM).
Composition: Carbonate. Fabric: Matrix supported. Structures: None. Grains: Fossils. Grainsize: <0.5 mm. Sorting: Poor. Roundness: Angular. Matrix:

Micrite. Fossils: Planktic forams, sponge spicules. Cement: Microcrystalline carbonate. Depositional environment: Pelagic. Diagenesis: Compaction and cementation.

C. 5 percent is dark brown (10YR 3/3) massive plastic mud (pyritic, organic-rich, silty mudstone).
Age: Mixed Early Tertiary, Miocene and Pliocene (BM); palynology age of one split is Late Paleocene to Early Eocene, marginal marine; and of another is mixture Early Cret to Early to Middle Eocene (NA).
Composition: Terrigenous. Fabric: Matrix supported. Structures: Wispy laminae. Grains: Quartz silt. Grainsize: <0.125 mm. Sorting: Moderate. Roundness: Angular. Matrix: Organic rich clay and mud. Fossils: None. Cement: Recrystallised clays. Other features: Pyrite framboids. Depositional environment: Low energy marginal marine or non marine. Diagenesis: Compaction, cementation through clay neomorphism, pyrite growth.

Pipe dredge contained gritty, cream-coloured, foraminiferal lime mud. Under microscope: abundant planktonic foraminifera and siliceous demosponge monoaxions, in a fine lime mudstone (nanno? ooze) matrix.

DREDGE 10 15 kg

Samples have prefix 66DR10

A. Fine grained pale limestone (foraminiferal wackestone). Poorly developed layering. Abundant fine grained glauconite. Microfossils include planktonic forms. Very little detrital component. Trace fossils include modern burrows.
Age: late Middle Eocene (BM).
Composition: Carbonate. Fabric: Matrix supported. Structures: Parallel laminae. Grains: Fossils, glauconitic peloids, quartz silt. Grainsize: <0.5 mm. Sorting: Poor. Roundness: Angular. Matrix: Micrite. Fossils: Planktic and arenaceous forams, siliceous spicules. Cement: Microcrystalline carbonate. Other features: Minor amounts of muscovite. Depositional environment: Pelagic. Diagenesis: Formation of glauconite, reworking and deposition, compaction cementation.

B. Very soft white fine grained limestone (wackestone?), all in pipe dredge.
Age: Earliest Miocene (BM).

Dredge also contained very pale, grey brown ooze.

DREDGE 11 40 kg

All samples have prefix 66DR11

A. White (with pale yellow-green tinge) compacted but unlithified chalky ooze (foraminiferal spicular wackestone). Under microscope: Very fine grained, abundant (> 25 %) siliceous spicules, commonly very small, and very small (> 10 %) well rounded silica grains (some may be radiolaria); rare forams; white carbonate mud matrix, probably nanno fossil ooze. The chalk forms angular blocks and can be broken into pieces by hand. Contains modern burrows, some containing worms. A large (5 cm) sharks tooth in one sample resembles modern teeth of the genus *Isurus* suggesting a Cenozoic age. Tooth was brown in colour altered to black along point due to exposure to seawater. This lithology grades into (B). 40 percent of haul.
Age: Oligocene (BM).
Composition: Carbonate. Fabric: Matrix supported. Structures: Burrows. Grains: Fossils. Grainsize: <0.25 mm. Sorting: Moderate. Roundness:

Angular. Matrix: Micrite. Fossils: Siliceous and calcareous spicules, planktic forams, radiolaria, pteropods, sharks teeth. Cement: ?None. Other features: Very porous. Depositional environment: Pelagic. Diagenesis: Compaction.

B. White chalky ooze (spicular wackestone), bored/burrowed, with borings/burrows still open and some lined by brown material (iron or manganese oxide). Partly lithified, forms rounded chunks, not easily broken by hand. Under microscope, more than 60 percent is probable nanno fossil ooze, with siliceous sponge spicules (commonly very small) and small planktonic foraminifera in equal amounts. Grades into (A). <30 percent of haul.
Age: Three fractions were Early Miocene, late Early Miocene, and early Late Oligocene (BM); palynology one fraction Early Miocene (NA).
Composition: Carbonate. Fabric: Matrix supported. Structures: Burrows, parallel laminae with winnowed spicule beds. Grains: Fossils. Grainsize: <0.125 mm. Sorting: Moderate-well. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams, calcareous and siliceous spicules. Cement: Microcrystalline carbonate. Other features: Spicules tend to be orientated parallel to bedding, especially in winnowed beds. Depositional environment: Pelagic, with local winnowing. Diagenesis: Compaction and limited cementation.

C. White chalky limestone (foraminiferal spicular wackestone) forming irregular rounded lumps with numerous burrows or borings; most are lined with iron or manganese oxides; this also coats some other surfaces. Solitary corals found attached to one; well lithified. 10 % of haul.
Age: early Late Oligocene (BM).
Composition: Carbonate. Fabric: Matrix supported. Structures: Burrows and borings. Grains: Fossils. Grainsize: <0.25 mm. Sorting: Moderate. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams, calcareous and siliceous spicules. Cement: Microcrystalline carbonate. Other features: Borings filled by planktic foram grainstone. Depositional environment: Pelagic. Diagenesis: Compaction and limited cementation.

D. Very dark grey black massive silt (organic muddy siltstone); unlithified, but forms rounded cohesive lumps which can be broken up by hand only with some difficulty. Under microscope, fine sub-rounded quartz silt with black flecks of organic material or charcoal in a dark brown clay matrix; very rare sponge spicules. <10 percent of haul.
Age: Maastrichtian with Miocene contamination (BM).
Composition: Terrigenous. Fabric: Matrix-grain supported. Structures: Wispy laminae. Grains: Quartz silt, fossils, glauconitic peloids. Grainsize: <0.125 mm. Sorting: Well. Roundness: Angular. Matrix: Organic mud. Fossils: Wood fragments. Cement: Recrystallised clays. Other features: Poorly cemented. Depositional environment: Marginal marine. Diagenesis: Glauconite formation, reworking and deposition, compaction and limited cementation through clay neomorphism.

E. Dark grey rounded nodule of pyritic calcareous sandstone. Broken by dredge showing concentric colour zones (probably an oxidation effect). Strong sulphurous smell when cut by saw. Probable concretion. 5 percent of haul.
Age: (palynology) mixed Early Cretaceous to Early Eocene.

F. Nodule of hard calcareous siltstone (phosphatic muddy quartz arenite). Grey (N/5) colour. Contains small dark green/grey grains (possible glauconitic peloids). Filled burrows. 5 percent of haul.
Age: (palynology) Late Cretaceous to Tertiary, marginal marine.
Composition: Terrigenous. Fabric: Matrix supported. Structures: Nodules. Grains: Quartz sand and silt, minor peloids, rare microcline. Grainsize: 0.25-2 mm. Sorting: Poor. Roundness: Angular - sub rounded. Matrix: Slightly calcareous mud, locally phosphatic. Fossils: None. Cement: Recrystallised clays, microcrystalline carbonate, collophane phosphate. Other features: Locally, nodular collophane phosphate replaces matrix, minor

replacement of matrix by pyrite. Depositional environment: Shallow marine. Provenance: ?metamorphic. Diagenesis: Possible partial seafloor replacement of matrix by phosphate and pyrite.

G. Light grey (10YR 7/1) nodule of ?sandy calcareous limestone (spicular foraminiferal wackestone-packstone). <1 percent of haul.
Age: (early Late?) Oligocene and ? Early Tertiary (labelling problems) (BM).
Composition: Carbonate Fabric: Matrix-grain supported. Structures: Burrows. Grains: Fossils. Grainsize: <0.5 mm. Sorting: Moderate. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams, calcareous and siliceous spicules, ostracods, pteropods. Cement: Microcrystalline carbonate. Other features: Fossils usually fragmentary, pteropods leached to form moulds, minor glauconite. Depositional environment: Pelagic with some reworking. Diagenesis: Compaction and cementation, leaching of aragonitic components-possible seafloor exposure.

Pipe dredge contained two types of soft sediment:
(i) is an unconsolidated white gritty carbonate; under microscope, abundant siliceous sponge spicules, commonly very small, well rounded quartz silt and fine bioclastic debris; few foraminifera; matrix white mud, probably nanno fossil ooze.
(ii) is a stiff very dark grey (10YR 3/1) with a brownish tinge terrigenous mud. Under microscope, very fine-grained well-rounded quartz silt in a brown terrigenous clay matrix. Little or no biogenic or carbonate sediment.

DREDGE 12 120 kg

All samples have prefix 66DR12

A. 60 percent is white (N8/) fine-grained limestone (spicular wackestone with minor packstone and grainstone); well bored by modern organisms; many specimens have a thin black crust; small trace fossils (infilled burrows) common.
Age: Different fractions are Late Eocene (2), Eocene-Oligocene boundary (2), and Early Oligocene (2) (BM).
Composition: Carbonate. Fabric: Matrix supported. Structures: Burrows, parallel orientated fossils, winnowed beds. Grains: Fossils, minor peloids. Grainsize: >0.125. Sorting: Moderate-well sorted. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams, siliceous and calcareous sponge spicules. Cement: Microcrystalline carbonate. Other features: Some burrow fills slightly glauconitic. Depositional environment: Pelagic with episodic winnowing. Diagenesis: Compaction, cementation and glauconitic burrow fill.

B. Soft, white, fine grained limestone (foraminiferal spicular wackestone). Similar to but harder than lithogy C.
Age: Eocene-Oligocene boundary (BM).
Composition: Carbonate Fabric: Matrix supported. Structures: Rare burrows. Grains: Fossils. Grainsize: <0.25 mm. Sorting: Poor-moderate. Roundness: Angular. Matrix: Micrite. Fossils: Calcareous and siliceous spicules, planktic foraminifera.. Cement: Microcrystalline carbonate. Other features: Very poorly compacted and cemented. Depositional environment: Pelagic. Diagenesis: Limited compaction and cementation.

C. 35 percent is very soft white fine grained limestone or stiff ooze (weakly consolidated foraminiferal spicular packstone).
Age: Eocene-Oligocene boundary (BM).
Composition: Carbonate. Fabric: Grain supported. Structures: Burrows. Grains: Fossils, peloids, quartz silt. Grainsize: <0.5 mm. Sorting: Moderate-well. Roundness: Angular. Matrix: Micrite. Fossils: Planktic and arenaceous foraminifera, siliceous and calcareous spicules, echinoderms, molluscs. Cement: Microcrystalline carbonate. Other features: Minor solution

of mollusc fragments with glauconitic infill. Depositional environment: Pelagic? shelf. Diagenesis: Compaction, cementation, solution, glauconitic infill.

D. Very dark greyish brown mudstone; possible carbonaceous fragments. Age: Early Tertiary, Hampton-type, cf., 66DR08D (BM); palynology age is Early to Middle Paleocene, marginal marine (NA).

E. Woody pyritic siltstone, similar to D but more fissile. Iron oxide staining along bedding surfaces.
Age (palynology) Late Cretaceous to Paleocene (NA).
Composition: Terrigenous. Fabric: Grain supported. Structures: Parallel laminae. Grains: Quartz silt, fossils, glauconitic peloids. Grainsize: <0.125 mm. Sorting: Well sorted. Roundness: Angular. Matrix: Mud. Fossils: Wood fragments, arenaceous forams. Cement: Recrystallised clays, minor microcrystalline carbonate. Other features: Partially oxidised framboidal pyrite. Depositional environment: Shallow, low energy marginal marine. Diagenesis: Formation of glauconite, reworking and deposition, pyrite growth, oxidation of pyrite, possibly on seafloor.

F. Dark greyish brown, burrowed, calcareous, silty mudstone; similar to (D) but harder with central hard core (possibly pyritic) in each sample; small trace fossils (infilled burrows); small black fragments may be carbonaceous.
Age: Late Paleocene, marginal marine (NA).
Composition: Mixed carbonate and terrigenous. Fabric: Matrix supported. Structures: Nodules, small burrows, small filled cavities. Grains: Quartz silt, fossils, glauconitic peloids. Grainsize: <0.125 mm. Sorting: Poor. Roundness: Angular. Matrix: Calcareous mud. Fossils: Planktic forams, arenaceous forams. Cement: recrystallised clays and microcrystalline carbonate. Other features: Small cavities are lined with two generations of calcite, (a) drusy calcite, (b) blocky calcite. Depositional environment: Low energy marginal marine-peritidal with ?fenestral cavities. Diagenesis: Formation of glauconite, reworking and deposition, limited meteoric cementation, final burial cementation and void fill. Other than DR7G the only sample with clear evidence of meteoric diagenesis.

G. Similar to (F) but coarser grained in part; possibly pyritic; iron oxide crust on one side; spherical patches filled with ooze (several cm in diameter) represent weathered remains of some sort of concretion; infilled burrows; very dark greyish brown.
Age: Paleocene, non-marine (NA).

DREDGE 14 35 kg

All samples have prefix 66DR14

A. 70 percent of haul is light grey argillaceous limestone; microfossils include planktonic forams and siliceous sponge spicules; soft-bored by modern organisms; some specimens have a weak planar layering; occasional trace fossils (filled burrows).
Age: Different fractions are Eocene-Oligocene boundary (4), late Middle Eocene (2), latest Eocene and ?Middle Eocene (labelling problems) (BM).

B. Foraminiferal wackestone, very similar to (A) but white with common infilled burrows.
Age: Early Oligocene (BM).
Composition: Carbonate. Fabric: Matrix supported. Structures: Laminae. Grains: Fossils. Grainsize: <0.5 mm. Sorting: Poor. Roundness: Angular. Matrix: Micrite. Fossils: Planktic and arenaceous forams, calcareous and siliceous spicules, pteropods. Cement: Microcrystalline carbonate. Depositional environment: Pelagic shelf. Diagenesis: Compaction and

cementation.

C. Hard white limestone (foraminiferal lime mudstone); well bored; probably represents a hardground surface; iron and manganese staining on surface; stylolites and weak planar layering.
Age: Eocene-Oligocene boundary (BM).
Composition: Carbonate. Fabric: Matrix supported. Structures: Borings. Grains: Fossils. Grainsize: <0.125 mm. Sorting: Well. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams and rare pteropods. Cement: Microcrystalline carbonate. Other features: Faint clotted fabric, well cemented, poor porosity, minor manganese rind on surface, pteropods leached. Depositional environment: Pelagic. Diagenesis: Compaction and cementation, exposure on seafloor and resulting solution of aragonitic components, cementation and manganese encrustation forming hardground.

D. (1 rock only). Light brownish grey limestone (silty spicular foram wackestone); well developed planar layering disrupted by microfaulting.
Age: Late Eocene (BM); palynology age is possibly Late Cretaceous (unknown dinoflagellate assemblage) marine (NA).
Composition: Carbonate. Fabric: Matrix supported. Structures: Parallel fossil orientation. Grains: Fossils, quartz silt, glauconitic peloids. Grainsize: <025 mm. Sorting: Moderate. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams, calcreous and siliceous spicules. Cement: Microcrystalline carbonate. Other features: Fossils fragmentary. Depositional environment: Pelagic shelf. Diagenesis: Formation of glauconitic peloids, reworking and deposition, Compaction, cementation.

- E. Light brownish grey limestone or cherty spicular wackestone-packstone, probably closely related to D. Irregular central band of white limestone cut by infilled burrows and an irregular mass of olive chert; minor glauconite. (1 specimen only)
Age: Probably Early Oligocene (BM), unknown palynomorph assemblage (NA).
Composition: Cherty carbonate. Fabric: Matrix to grain supported. Structures: Nodular silicification, burrows, erosion surfaces overlain by normally graded beds, parallel laminae. Grains: Fossils, glauconitic peolids. Grainsize: <0.5 mm. Sorting: Moderate. Roundness: Angular. Matrix: Micrite. Fossils: Planktic and arenaceous formas, calcareous and siliceous spicules. Cement: Microcrystalline carbonate and silica. Other features: Non-disruptive chert replacement of fabric. Depositional environment: Pelagic shelf with reworking events (storms ?). Diagenesis: Formation of glauconite, reworking and deposition, compaction, cementation, silica mobilisation and precipitation.
This is possibly part of Eocene siliceous carbonate suite with DR1B & D, DR3E, F & G, DR4A, DR15C and DR16B.

F. Very dark greyish brown mudstone and muddy sandstone; coarser material is glauconitic and calcareous; some foraminifera; very soft and friable.
Age: Early Eocene (BM); palynology age is Late Paleocene to Late Eocene marginal marine (NA).

G. (1 small pebble). Pale yellow calcareous quartz sandstone; weak planar layering (from within pipe dredge).

Pipe dredge was largely filled with greenish medium to coarse sand composed largely of calcareous bioclastic material - shell fragments, bryozoans, foraminifera and spicules; sparse siliciclastic material; probably represents material from the floor of the canyon. Top of pipe dredge was filled with very pale brown ooze and rock fragments. Stiff pale brown ooze in jaws of dredge.

DREDGE 15 80 kg

All samples have prefix 66DR15

A. 85 percent is white (5Y8/1) with greenish tinge, soft friable foraminiferal lime mudstone; 10 percent siliceous (demosponge?) spicules in a matrix of white carbonate mud (probably nanno fossils); forms rounded blocks; small filled and unfilled burrows; exposed surfaces encrusted with manganese oxide and bored.
Age: Different fractions are Oligocene (3), Late Oligocene, and Oligocene-Miocene boundary (BM).
Composition: Carbonate. Fabric: Matrix supported. Structures: None. Grains: fossils. Grainsize: <0.25 mm. Sorting: Moderate-well. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams. Cement: ?None. Other features: Very porous. Depositional environment: Pelagic. Diagenesis: Limited compaction.

B. 10 percent is light greyish brown (10YR 8/2), soft, wispy laminated foraminiferal lime mudstone; moderate to well-rounded quartz silt 40 percent, brown calcareous mud 40 percent, some black flecks; exposed surfaces bored and borings lined with manganese oxide.
Composition: Mixed carbonate and terrigenous. Fabric: matrix supported. Structures: Laminae. Grains: Fossils, glauconitic peloids, quartz silt. Grainsize: <0.125 mm. Sorting: Moderate. Roundness: Angular. Matrix: Muddy micrite. Fossils: Planktic and arenaceous foraminifera, siliceous spicules. Cement: Microcrystalline carbonate, recrystallised clays. Depositional environment: Shelf. Diagenesis: Glauconite formation, reworking and deposition, compaction, cementation.

C. 5 percent is white (5Y 8/1, silty, intraclastic, siliceous, spicular foraminiferal wackestone), very similar to A except that it has a conchoidal fracture, is harder and less reactive with acid; 10 percent siliceous spicules (demosponges?), 5 percent foraminifera, in matrix of white nannofossil? ooze; probably a partly silicified equivalent of A.
Age: Oligocene (BM).
Composition: Carbonate. Fabric: Matrix supported. Structures: Burrows. Grains: Intraclasts, fossils, quartz silt, peloids. Grainsize: <0.125. Sorting: Moderate. Roundness: Angular-sub angular. Matrix: micrite. Fossils: Planktic and arenaceous forams, calcareous spicules. Cement: Microcrystalline carbonate. Other features: wispy chert lenses, small cavities with calcite fill, fossils fragmentary. Depositional environment: Shelf. Diagenesis: Formation of glauconite, reworking and deposition, compaction and cementation, silca mobilisation and reprecipitation. Possibly part of Eocene siliceous carbonate suite with DR1B & D, DR3E, F & G, DR4A, DR14E and DR16B.

D. Outcrop of A type, sawed through by dredge jaws.

Pipe dredge contained two different sediment types:
(i) a sloppy to stiff white gritty ooze: 20 percent siliceous spicules, 15 percent quartz silt, 5 percent foraminifera, 1 percent small fossil fragments.
(ii) a white muddy sandy carbonate: 20 percent siliceous spicules, 15 percent quartz silt, 5 percent foraminifera, 5 percent fossil hash.

DREDGE 16 5 kg

All samples have prefix 66DR16

A. A light grey (2.5YR 7/2) silty limestone (dolomitic skeletal packstone) grading into calcareous siltstone ; weak planar layering in some specimens; microfossils dominated by siliceous sponge spicules; some unidentified fossil

fragments and trace fossils.
Age: May be Oligocene (BM).
Composition: Carbonate. Fabric: Grain supported. Structures: Parallel bedding. Grains: Fossils, quartz silt, glauconitic peloids. Grainsize: <0.25 mm. Sorting: Well. Roundness: Angular. Matrix: Micrite. Fossils: Planktic forams, echinoderms. Cement: Microcrystalline carbonate. Other features: Fossils all fargmentary, neomorphism and partial dolomi- tisation. Depositional environment: intermediate shelf. Diagenesis: Formation of glauconite, reworking and deposition, compaction, cementation, neomorphism and dolomitisation.

B. Dark grey (5Y 4/1) siliceous limestone (siliceous spicular foraminiferal wackestone); similar to A on one side; bioturbated; some ?fossil fragments; small, irregular black patches; opal fills small fractures.
Age: May be Oligocene (BM); palynology age is possibly Mid-Cretaceous (unknown dinoflagellate assemblages) marine (NA).
Composition: Siliceous carbonate. Fabric: Grain supported. Structures: Parallel laminae. Grains: Fossils, quartz silt, peloids. Grainsize: <0.25 mm. Sorting: Well Roundness: Sub angular. Matrix: Siliceous micrite. Fossils: Planktic forams, siliceous spicules. Cement: Microcrystalline carbonate, silica. Other features: Spicules devitrified, fossils filled by microcrystalline silica. Depositional environment: Shelf. Diagenesis: Formation of glauconite, reworking and deposition, compaction, cementation, silica mobilisation and precipitation. Note: Probably forms part of Eocene-Miocene suite of siliceous carbonates with DR1B & D, DR3E, F & G, DR4A, DR14E and DR15C.

C. Material similar to (A) but appears to be part of a fault breccia, slickensided surfaces on some fragments; only a few small pieces.

APPENDIX 2: FORAMINIFERAL BIOSTRATIGRAPHY OF DREDGED SAMPLES

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INTRODUCTION

Samples are listed at the end of this appendix in order of numbering with ages determined using planktonic foraminifera. They are plotted according to age on two charts, where they are correlated with a standard foraminiferal-biostratigraphic zonation (the zones themselves are not recognized at high southern palaeolatitudes).

There are two general points to be made:

(i) The samples are a major addition to our knowledge of the stratigraphy of the southern continental margin. A Maastrichtian ingression is quite new, as are most of the microfaunal contents of two Eocene ingressions; and bathyal carbonates of Eocene, Oligocene, and Miocene age with species from an oceanic water column will bring new perspectives to the stratigraphy of neritic sections and their integration with palynobiostratigraphy.

(ii) However, it must be stressed that several prominent changes in the character of the assemblages are inferred to be of successional significance, whereas such changes can simply be observed in a sampled section. It is possible that some conclusions as to succession will turn out to be wrong. Also, there has been and is extensive reworking. Maastrichtian species are seen at several Eocene and younger horizons; and Eocene, Oligocene and Miocene species are recycled into the Pliocene and probably younger. As well, there is extensive contamination of many samples by Quaternary material, notwithstanding preliminary laboratory treatment to minimise this, and there is good evidence in several instances of downward contamination during the pre-Quaternary past. Thus, in a mixture of Maastrichtian and Miocene species, which is the "correct" age of the sample itself? Such problems of biostratigraphic mixing were expected and have come to pass, and the step from fossil age to sample age is taken hesitantly in some instances in this report.

MAASTRICHTIAN

The best preserved and most diverse planktonic assemblage occurs in DR03A:

Rugoglobigerina rugosa (including high-spired forms and others approaching *R. hexacamerata*)
Rugotruncana subpennyi
Rugotruncana aff. *circumnodifer*
Globotruncanella havanensis/petaloidea
cf. *Globotruncanella intermedia*
Globotruncana of the *arca/linneiana* group
Globigerinelloides prairiehillensis/multispinatus, and variants
Globigerinelloides subcarinata
Guembelitria (? *triseriata* not *cretacea*)
Heterohelix globulosa
Heterohelix glabrans
Gublerina reniformis
Pseudoguembelina excolata

There is a fairly diverse assemblage of benthic species. There is a (probably monospecific) swarm of high conical radiolarians. DR01F, 01H, 01G, 01 have the more common elements of the assemblage, as well as similar benthos and the radiolarian swarm, but are less well preserved. Well preserved, though less diverse, is sample DR01L.

There would seem to be little doubt that we have the same marine imgression at the two stations. The age is no older than Middle Maastrichtian and could be as young as Late Maastrichtian. The assemblages have a fair amount in common with the (Late Maastrichtian) Miria Marl in the Carnarvon Basin. They are a major discovery, in that:

(i) They represent the first truly marine record of Maastrichtian in southern Australia with an abundant calcareous plankton (an horizon in the Gippsland Basin with dinoflagellates has been dated as Maastrichtian); until now, a marine connection from the Indian Ocean to the southeast has been speculation only, although Late Cretaceous seafloor spreading is well established.

(ii) The assemblages, remarkably well preserved and diverse, are an important contribution from a high palaeolatitude to Maastrichtian biogeography.

(iii) The record of the ingression should in due course become an important datum in palynobiostratigraphy in southern Australia, which is insufficiently anchored by such ties to the global time scales.

EOCENE

<u>Early Eocene</u>

There are two samples with relatively good, biostratigraphically distinct planktonic assemblages:

(i) 66DR14F

Pseudohastigerina wilcoxensis (mostly *pseudoiota* form)
Planorotalites australiformis
Planorotalites pseudoscitula
Planorotalites cf. *imitata*
"*Turborotalia*" sp.
Acarinina nitida
Acarinina collactea
Subbotina spp. including *S. patagonica* and *S.* cf. *linaperta*
Chiloguembelina wilcoxensis

This assemblage differs from the Rivernook assemblage of the Otway Basin in the absence of *Morozovella aequa*, the abundance of *Planorotalites* and *Pseudohastigerina*, and in several changes among *Acarinina*. The Rivernook is correlated with Zone P6b; the presence in DR14F of *Ch. wilcoxensis* indicates that the assemblage probably correlates with Zone P7.

This is the best such assemblage in southern Australia at or near this level; it is either coeval with or very close to the Princetown ingression (in Otway Basin terms).

(ii) 66DR08A

Pseudohastigerina wilcoxensis (*pseudoiota* form)
Planorotalites australiformis
Planorotalites pseudoscitula
Acarinina coalingensis
Acarinina collactea
Acarinina cf. *densa*
Acarinina soldadoensis
Acarinina sp., cf. "*pre-quetra*"
Subbotina patagonica

Subbotina cf. *eocaena*
"Turborotalia" sp.

This assemblage is younger than that in DR14F. Although acarininids are common, *Acarinina primitiva* has not been found. At DSDP Site 264 on the Naturaliste Plateau, late Early Eocene (probably equivalent to Zone P9) is represented by an assemblage including *Morozovella caucasica* and *Acarinina primitiva*. The absence of the latter in DR08A is probably a sound criterion for assessing its age as somewhat older. Therefore, it squeezes into a level the equivalent to Zone P8.

This sample is more similar in biofacies and lithofacies to the offshore equivalents of the Wilson Bluff limestone than to the known Maastrichtian-Eocene marine ingressions in southern Australia. This is noteworthy because we have no record of calcareous sediments below the Wilson Bluff on the continental margin - i.e. in the interval spanned by the calcareous section on the Naturaliste Plateau.

<u>Middle Eocene</u>

A major benchmark in southern Australian stratigraphy is the Wilson Bluff transgression, the local manifestation of the Indo-Pacific Khirthar transgression at the Lutetian/Bartonian boundary. At the base of the section in the Eucla and Great Australian Bight Basins in the Hampton Sandstone.

A few samples of detrital lithology contain sparse microfaunas of uncertain status, in that it is unclear whether specimens are in place or reworked from older horizons (Maastrichtian specimens are present in the relatively well dated Early Eocene DR14F). Thus DR08D is of Hampton facies and DR14F and DR12D probably so.

<u>Deep water equivalents of Wilson Bluff Limestone</u>

(i) (DR01E or F) A poorly preserved assemblage of basal Wilson Bluff aspect, approximately equivalent to Zones upper P12-P13, with milky spicules and glauconitic moulds possible of radiolarians.

(ii) Bathyal benthic species with good planktonic assemblages including:

Globigerinatheka index
Subbotina linaperta
Chiloguembelina cubensis
Globorotaloides aff. *suteri*
Acarinina primitiva
Acarinina primitiva
Acarinina densa s.l.
Acarinina collactea

with strong variations between samples in the presence of:

Pseudohastigerina micra
Tenuitella aculeata
Tenuitella gemma
Tenuitella insolita
Guembelitria triseriata

Finally, there is a change from assemblages with prominent *S. linaperta* and *A. primitiva* to (presumably younger) assemblages with *Subbotina angiporoides* and *Turborotalia increbescens*. Variations are attributed to the instabilities of the later Eocene stratified ocean within the equivalent of Zone P14.

Poor assemblages in lithified matrix with milky spicules and radiolarians are also equivalents of the Wilson Bluff Limestone.

Late Eocene

Bathyal benthic species accompany planktonics showing rather more signs of corrosion than do either the Middle Eocene or Oligocene assemblages.

(i) (GC01A) Almost entirely large, thickly encrusted *Globigeroinatheka index* and *G. subconglobata luterbacheri* probably to be correlated with upper Zone P15.

(ii) (DR12A(5))

Globigerinatheka index
Globorotaloides suteri/testarugosa
Subbotina linaperta
"Globigerina" brevis
Chiloguembelina cubensis
Tenuitella insolita
Tenuitella gemma

This assemblage is correlated with upper Zone P16. Samples DR12A(4) and DR14D are less well preserved but are of about the same age.

LATEST EOCENE TO EARLY MIOCENE

All samples from latest Eocene age upwards to the Early Miocene are fine grained carbonates. Some disaggregated easily and yielded abundant specimens, usually well preserved; others are tighter (chalks) and did not give good assemblages. Most samples had at least traces of (clear) sponge spicules and many had them in abundance, in association with radiolarians and (in the Late Oligocene) diatoms. The presence of abundant biosilica in association with the benthic foraminifer *Bolivina* indicates high organic productivity. The lastest Eocene to Early Miocene samples fall into two groups, biostratigraphically, with a gap in the mid-Oligocene. Onshore successions, especially the Gambier Limestone on the Otway Basin, are three-part - lower and upper cherty sections separated by the relatively regressive non-cherty carbonates that span the "thirty million year event", the major drop in sea level in the Exxon curve and coeval global temperature minimum. Thus, there is at least a broad parallel between our onshore neritic sections and this first sampling of their bathyal equivalents.

Latest Eocene to earliest Oligocene

I suggest that good assemblages can be grouped biostratigracally as follows (inferred youngest on top):

(iv) *Subbotina angiporoides*, *Catapsydrax dissimilis*, *Chiloguembelina cubensis*, *"Globorotaloides" testarugosa*, *Tenuitella gemma*, and others.
(iii) *Subbotina angiporoides*, *"Globigerina" brevis*, *Chiloguembelina cubensis*, *"Globorotaloides" testarugosa*, and others.
(ii) *Subbotina linaperta*, *Subbotina angiporoides*, *Tenuitella aculeata* (abundant but sporadic), and others.
(i) *Subbotina linaperta*, *Turborotalia increbescens/ampliapertura*, and others.

Assemblage (i), the first assemblage above the disappearance of the genus *Globigerinatheka*, is considered to be latest Eocene in age, and assemblage (ii) may also be of Late Eocene age, with (iii) and (iv) in the Early Oligocene. However, this is tentative for two reasons: the consistent use of marker species such as *Subbotina linaperta*, *Cassigerinella chipolensis*, *Tenuitella aculeata* and *Guembelitria triseriata*, as in our onshore sections, is risky in the interslotting of geographically scattered grab samples; and, secondly, one has to correlate from a high southern palaeolatitude across watermass boundaries to the standard biostratigraphic and chronostratigraphic sections of the tropics and in the Northern Hemisphere.

Several samples dated as "Oligocene (?)" are likely to be of this age range.

Late Oligocene to Early Miocene

From the youngest downwards, samples are grouped as follows:

(iv) *Globigerinoides bisphericus, G. trilobus, Globigerina wood*; etc. Early/Middle Miocene boundary.
(iii) *Globigerina praebulloides, Globoguadrina dehiscens, Globigerinoides* aff. *altiaperturus, Globorotalia miozea, Globorotalia (Globoconella) panda, G. (G.) Zealandica*, etc. Early Miocene.
(ii) *Globoquadrina dehiscens* ("early" and "mature" forms), *Globorotalia (Jenkinsella) semivera*, occasional *Globigerinoides, Globigerina woodi, Cassigerinella chipolensis*, etc. Earliest Miocene; some may be latest Oligocene.
(i) *Globoquadrina* aff. *tripartita, Globoquadrina sellii, "Globigerina" euapertura, Globorotalia (Jenkinsella) semivera* group, etc. Late Oligocene.

MIDDLE MIOCENE AND YOUNGER

Samples DR09B and DR07C contain abundant *Globoquadrina dehiscens* and *Globorotalia (Globoconella)* and the *miozea/conoidea/conomiozea* group along with *Sphaeroidinellopsis disjuncta, Sph. seminulina, Globorotalia (Fohsella) peripheroronda* and *G. (Jenkinsella) mayeri, Orbulina and Biorbulina*. This could, with one or two problems, be an excellent Middle Miocene assemblage. However it is associated with abundant *Globorotalia (Menardella) menardii* group and (in other samples) *Globorotalia (Truncorotalia) crassaformis*, of Pliocene age. Indeed, Quaternary forms such as *Globorotalia (Truncorotalia) truncatulinoides* have a battered look, as if they are older than modern contaminants.

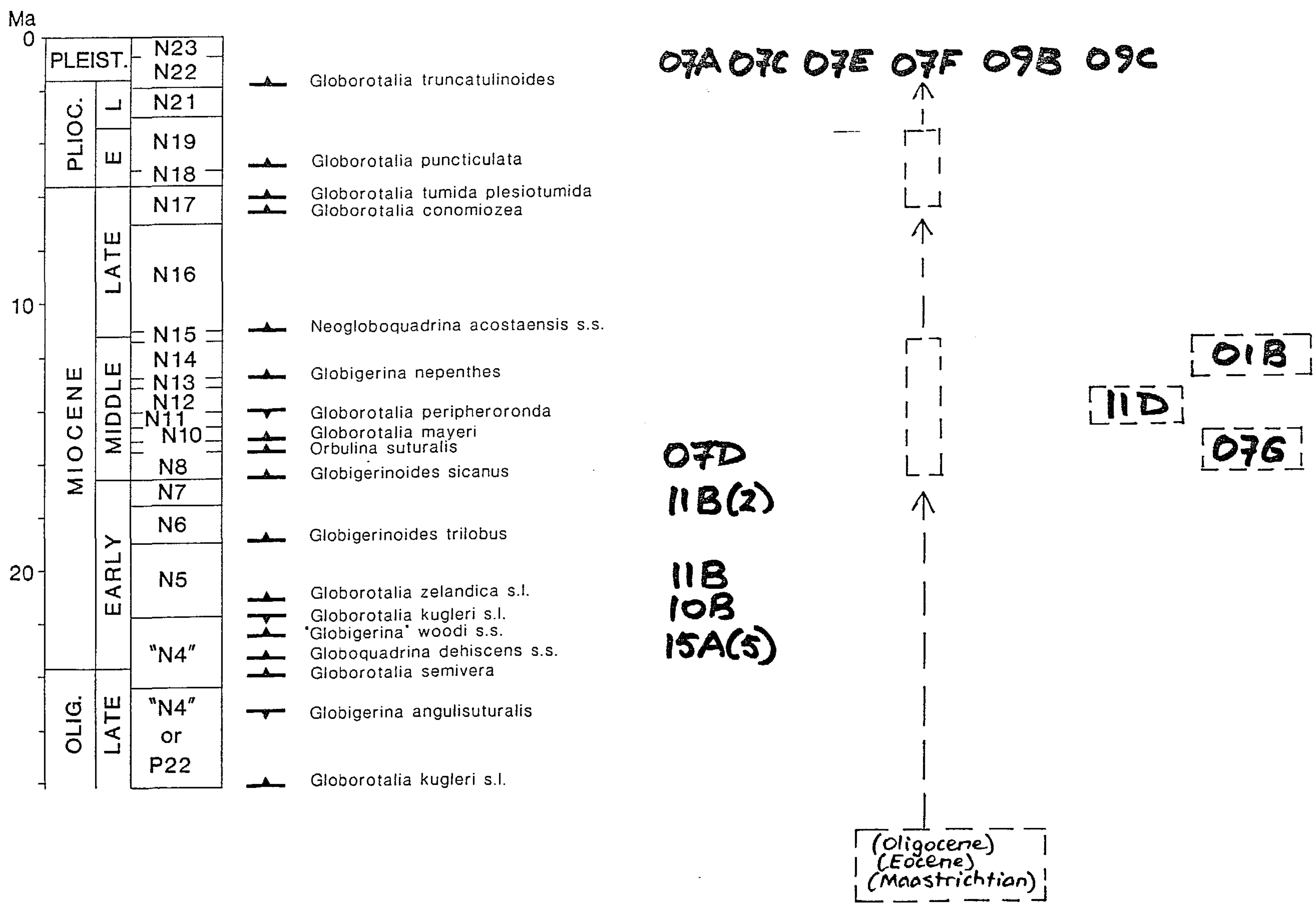
At this stage I believe that none of the samples younger than Early Miocene is older than Pliocene, and perhaps all of them are Quaternary. Some contain Oligocene, Miocene, and Pliocene as well as Quaternary species. This suggests that there has been reworking at each of the main sedimentary sequences as well as during the low stands of the Quaternary.

A particularly interesting mixture in DR01B consists of Eocene species, unsilicified, together with silicified Miocene species *(Globoquadrina dehiscens, Orbulina, Globoconella)*. This suggests a silicification coeval with silicification of the Nullarbor Limestone, with some Miocene limestones in the St. Vincent and Otway Basins and with the later Tertiary silcrete of the inland.

LIST OF SAMPLES EXAMINED FOR FORAMINIFERAL BIOSTRATIGRAPHY

GC01A		Late Eocene
DR01A		Early Oligocene
DR01B		Mixed Eocene and Miocene
DR01D		? later Middle Eocene
DR01E		later Middle Eocene
DR01E or F		later Middle Eocene
DR01F		Maastrichtian
DR01G		Maastrichtian
DR01H		Maastrichtian
DR01L		Maastrichtian
DR01?		Maastrichtian
DR02A		? later Middle Eocene
DR03A		Maastrichtian
DR06A	(1)	Early Oligocene
	(2)	Early Oligocene
	(4)	Early Oligocene

(7)	Early Oligocene
(8)	Early Oligocene
(9)	Early Oligocene
(10)	Early Oligocene
(11)	Early Oligocene
DR06B	early Late Oligocene
DR07A	? Pliocene, and younger
DR07C	Middle Miocene reworked into latest Miocene
DR07D	earliest Middle Miocene
DR07E	Late Cainozoic?
DR07F	Middle Miocene (or reworked)
DR07G	probably Middle Miocene
DR08A	Early Eocene
DR08B	later Middle Eocene
DR08D	Middle Eocene
DR08E or F	-
DR09A	Pliocene
DR09B	Middle Miocene reworked into Pliocene
DR09C	Mixed Early Tertiary, Miocene, Pliocene
DR10A	late Middle Eocene
DR10B	earliest Miocene
DR11A	Oligocene
DR11B	Early Miocene
DR11B (1)	early Late Oligocene
DR11B (2)	late Early Miocene
DR11C	early Late Oligocene
DR11D	Maastrichtian and Mikocene
DR11G	(early Late?) Oligocene and ?Early Tertiary (labelling confusion)
DR12A	Eocene/Oligocene boundary
DR12A (1)	Early Oligocene
DR12A (2)	Early Oligocene
DR12A (3)	Eocene/Oligocene boundary
DR12A (4)	Late Eocene (or reworked?)
DR12A (5)	Late Eocene
DR12B	Eocene/Oligocene boundary
DR12C	Eocene/Oligocene boundary
DR12D	Early Tertiary
DR14A	latest Eocene and ?Middle Eocene (labelling confusion)
DR14A (1)	Eocene/Oligocene boundary
DR14A (2)	Eocene/Oligocene boundary
DR14A (3)	Eocene/Oligocene boundary (with Miocene: contamination ?)
DR14A (4)	Eocene/Oligocene boundary
DR14A (5)	late Middle Eocene
DR14A (6)	late Middle Eocene
DR14B	Early Oligocene
DR14C	Eocene/Oligocene boundary
DR14D	Late Eocene
DR14E	(?Early) Oligocene
DR14F	Early Eocene
DR15A	(Late?) Oligocene
DR15A (1)	Oligocene
DR15A (2)	Oligocene
DR15A (3)	Oligocene
DR15A (4)	Late Oligocene
DR15A (5)	Oligocene/Miocene boundary
DR15C	Oligocene
DR16A	Oligocene
DR16A (1)	Oligocene ?
DR16A (2)	Oligocene ?
DR16B	Oligocene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"N4"
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or
P22
Globorotalia truncatulinoides
Globorotalia puncticulata
Globorotalia tumida plesiotumida
Globorotalia conomiozea
Neogloboquadrina acostaensis s.s.
Globigerina nepenthes
Globorotalia peripheroronda
Globorotalia mayeri
Orbulina suturalis
Globigerinoides sicanus
Globigerinoides trilobus
Globorotalia zelandica s.l.
Globorotalia kugleri s.l.
'Globigerina' woodi s.s.
Globoquadrina dehiscens s.s.
Globorotalia semivera
Globigerina angulisuturalis
Globorotalia kugleri s.l.
07A 07C 07E 07F 09B 09C
07D
11B(2)
11B
10B
15A(5)
01B
11D
07G
(Oligocene)
(Eocene)
(Maastrichtian)

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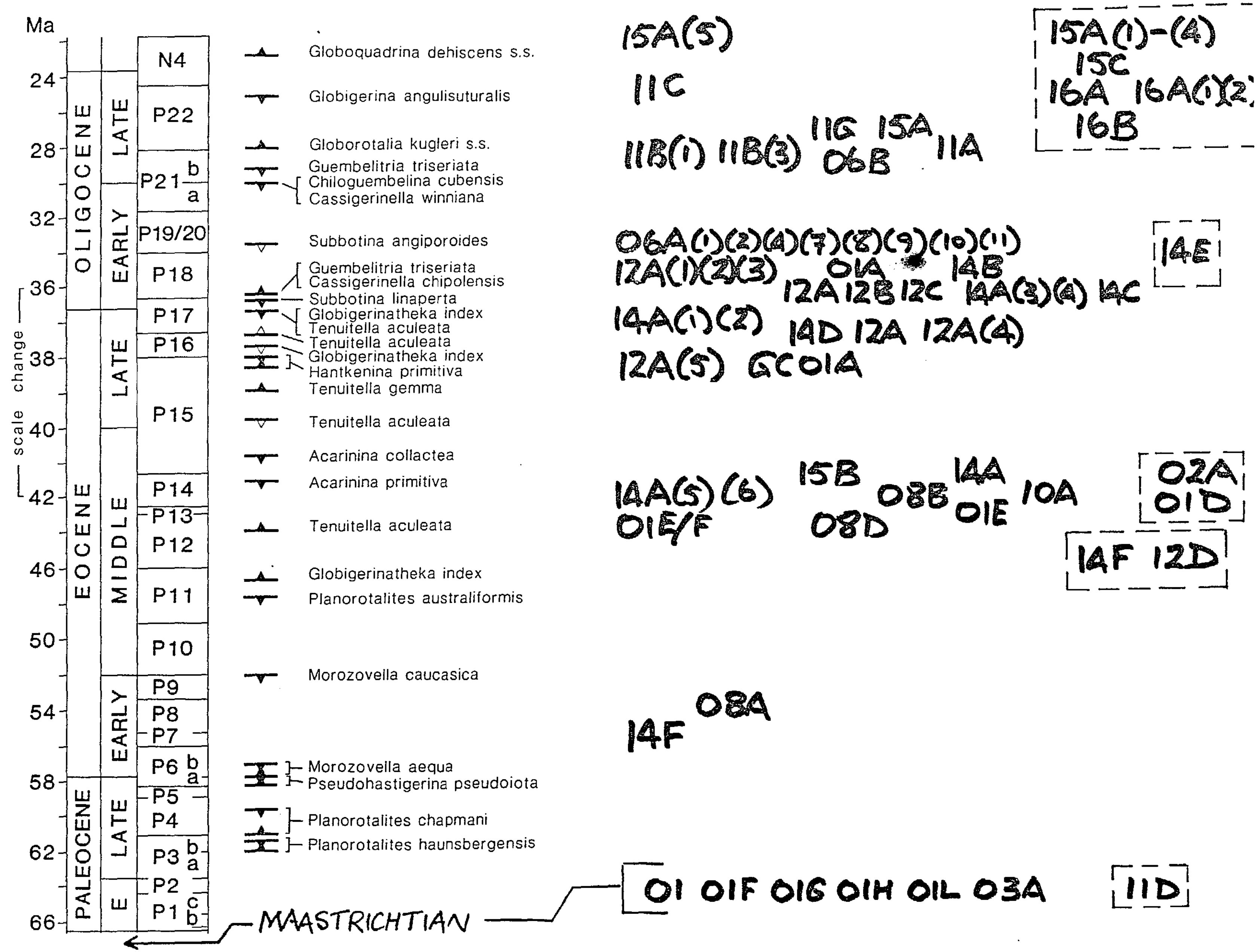
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scale change
OLIGOCENE
EOCENE
PALEOCENE
LATE
EARLY
LATE
MIDDLE
EARLY
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E
N4
P22
P21 b a
P19/20
P18
P17
P16
P15
P14
P13
P12
P11
P10
P9
P8
P7
P6 b a
P5
P4
P3 b a
P2
P1 c b
Globoquadrina dehiscens s.s.
Globigerina angulisuturalis
Globorotalia kugleri s.s.
Guembelitria triseriata
Chiloguembelina cubensis
Cassigerinella winniana
Subbotina angiporoides
Guembelitria triseriata
Cassigerinella chipolensis
Subbotina linaperta
Globigerinatheka index
Tenuitella aculeata
Tenuitella aculeata
Globigerinatheka index
Hantkenina primitiva
Tenuitella gemma
Tenuitella aculeata
Acarinina collactea
Acarinina primitiva
Tenuitella aculeata
Globigerinatheka index
Planorotalites australiformis
Morozovella caucasica
Morozovella aequa
Pseudohastigerina pseudoiota
Planorotalites chapmani
Planorotalites haunsbergensis
MAASTRICHTIAN
15A(5)
11C
11B(1) 11B(3) 11G 15A 06B 11A
15A(1)-(4) 15C 16A 16A(1)(2) 16B
06A(1)(2)(4)(7)(8)(9)(10)(11)
12A(1)(2)(3) 01A 14B
12A 12B 12C 14A(3)(4) 14C
14A(1)(2) 14D 12A 12A(4)
12A(5) GC01A
14E
14A(5)(6) 15B 08B 14A 10A
01E/F 08D 01E
02A 01D
14F 12D
14F 08A
01 01F 01G 01H 01L 03A
11D

APPENDIX 3: AGES OF SELECTED SAMPLES FROM CALCAREOUS NANNOFOSSILS

By Samir Shafik

Maastrichtian

Sediments of this age were dredged from two stations, DR01 and DR03, situated in a canyon between the Eyre and Ceduna Terraces (Fig. 1).

(A) Sample DR01H, a dark brown black highly organic mud, contains moderately preserved rare nannofossils representing a small number of taxa. This sample was collected from the same station as the highly fossiliferous sample DR01F (see below) where water depth ranges between 3288 and 2945 metres. Several smear slides were examined from DR01H because of the scarcity of fossils. The assemblage is dominated by three species: *Arkhangelskiella speciallata*, *Micula staurophora* and *M. concava*. Other species represented are *Prediscosphaera creacea* (frequent), *Markalius astroporus* (rare), *Cribrosphaerella daniae* (extremely rare), and ?*Kamtpnerius magnificus* (fragment). The age is considered Maastrichtian on account of the age of the associated, and lithologically similar, sample DR01F (discussed below). This is confirmed by the co-occurring foraminiferids which are Maastrichtian in age (see McGowran, 1988).

(B) Sample DR03A, a dark brown and highly organic mudstone, yielded moderately preserved and highly diversified calcareous nannofossil assemblage. This sample was dredged from water depths ranging between 3506 and 3285 metres. The assemblage included:

Acuturris scotus
Arkhangelskiella cymbiformis
Arkhangelskiella speciallata (rare)
Ahmuellerella octoradiata
Biscutum notaculum
Boletuvulum sp.
Chiastozygus litterarius
Cretarhabdus conicus
Cretarhabdus surirellus
Corollithion rhombicum
Corollithion exiguum
Cribrosphaerella daniae
Eiffellithus turriseiffeli
Gartnerago sp.
Grantarhabus camaratus
Cribrosphaerella ehrenbergii
Kamptnerius magnificus
Lapideacassis cornuta
Lithaphidites carniolensis
Lithraphidites praequadratus
Lithraphidites quadratus
Lucianorhabdus sp. cf. *L. cayeuxii*
Markalius astroporus
Micula concava
Micula staurophora
Microrhabdus belgicus

Nephrolithus corystus
Nephrolithus sp. aff. *N. frequens*
Placozygus fibuliformis
Prediscosphaera cretacea
Prediscosphaera grandis (very rare)
Prediscosphaera spinosa
Prediscosphaera stoveri
Rhagodiscus angustus
Rhagodiscus reniformis
Vekshinella elliptica
Scapholithus fossilis
Stephanolithion laffittie
Teichorhabdus ethmos
Tetrapodorhabdus decorus
Watznaueria barnesae

The key taxa *Nephrolithus corystus*, *Cribrosphaerela daniae* and *Arklhangelskiella cymbiformis* are particularly abundant, but *Lithraphidites quadratus* is rare. These taxa indicate a mid to late Maastrichtian age.

The overall aspect of the assemblage suggests high-latitude position and deposition in shallow-water environment: *Watznaueria barnesae* is extremely rare, whereas the taxa *Nephrolithus corystus*, *Cribrosphaerela daniae*, *Micula concava*, *Ahmuellerella octoradiata* and *Kamptnerius magnificus* are particularly abundant. The high-latitude position is reinforced by the total lack of distinctly low-latitude taxa (such as *Cribrocorona gallica*).

(C) Sample DR01F, a dark brown organic shale, contains another moderately preserved but less diversified nannofossil assemblage. This included:

Arkhangelskiella cymbiformis
Arkhangelskiella speciallata
Biscutum spp.
Chiastozygus litterarius
Cretarhabdus conicus
Cretarhabdus surirellus
Cribrosphaerella daniae
Cribrosphaerella ehrenbergii
Cyclogelosphaera reinhardtii
Eiffellithus turriseiffeli
Gartnerago sp.
Grantarhabdus camaratus
Kamptnerius magnificus
Lithraphidites carniolensis
Lithraphidites praequadratus
Lithraphidites quadratus
Markalius astroporus
Micula concava
Micula staurophora
Nephrolithus corystus (a single specimen)
Nephrolithus frequens
Placozygus fabuliformis
Prediscosphaera cretacea
Prediscosphaera grandis (very rare)
Prediscosphaera spinosa
Prediscosphaera stoveri
Teichorhabdus ethmos
Tetrapodorhabdus decorus

Watznaueria barnesae

Like the Maastrichtian assemblage of DR03A, this assemblage includes several elements indicative of deposition in shallow-water environment at high-latitude location; the shale of DR01F was collected from between 3288 and 2945 metres water-depths. The presence of typical *Nephrolithus frequens* suggests that it is late Maastrichtian and may be slightly younger than the assemblage of DR03A. Other differences between these two assemblages are worth mentioning: (a) *Arkhangelskiella speciallata*, frequent to common in DR03A, is very rare in DR01F, (b) *Nephrolithus corystus* is abundant in DR03A, but extremely rare in DR01F, and (c) *Teichorhabdus ethmos*, represented mainly by large specimens in DR03A, is much smaller in DR01F.

The assemblages of DR03A and DR01F compare with similar assemblages from the Perth Basin (Shafik, unpublished data). They differ from the Miria Marl assemblage of the Carnarvon Basin (Shafik, unpublished data) in containing elements suggestive of a more southerly location and in lacking low-latitude taxa such as *Micula murus* and *Cribrocorona gallica*.

Eocene

Early Eocene

Sample DR08A contains abundant and moderately preserved calcareous nannofossils. This sample is a fine-grained, yellow brown interbeded mudstone/sandstone, dredged from the Ceduna Terrace. Taxa identified are:

Braarudosphaera bigelowii (very rare)
Campylosphaera dela
Chiasmolithus expansus
Chiasmolithus conseutus
Chiasmolithus eograndis (small, rare)
Chiasmolithus solitus
Clausicoccus cribellum
Coccolithus crassus
Coccolithus eopelagicus
Coccolithus magnicrassus
Cyclicargolithus gammation (very rare)
Coccolithus pelagicus
Cyclococcolithus protoannulus
Ellipsolithus lajolla
Ellipsolithus sp.
Holodiscolithus macroporus
Markalius astroporus/inversus
Micrantholithus vesper
Neococcolithes dubius
Neococcolites minutus
Pontosphaera pectinata
Pontosphaera versa
Blackites creber
Scapholithus fossilis
Semihololithus biskayae
Toweius callosus
Transversopontis pulcheroides
Sphenolitus primus
Sphenolitus radians

Lophodolithus reniformis
Lophodolithus mochlophorus
Lophodolithus nascens
Cyclococcolithus formosus
Pontosphaera plana
Tribrachiatus orthostylus
?Discoaster binodosus (very rare)
Discoaster lodoensis (very rare)
Discoasteroides kuepperi
Sphenolithus moriformis
Transversopontis pulcher
Zygodiscus adams
Zygrhablithus bijugatus

The association of *Tribrachiatus orthostylus*, *Discoaster lodoensis*, *Discoasteroides kuepperi*, *Chiasmolithus solitus*, *Cyclococcolithus formosus*, *Lophodolithus reniformis* and *Toweius callosus* in the absence of the key taxa *Tribrachiatus contortus* and *D. sublodoensis* indicates an early Eocene age, and a correlation with the foraminiferal zone P.8 according to data given by Martini (1971).

The occurrence of the taxa *Zygrhablithus bijugatus*, *Semihololithus biskayae*, *Holodiscolithus macroporus*, *Micrantholithus vesper* and species of *Pontosphaera* and of *Transversopontis* suggests deposition in shallow water environment -- nearshore or shelf. Present water depths at Station DR08 are 2823 to 2238 metres.

Middle Eocene

(A) Sample DR01D contains abundant and well preserved calcareous nannofossils in a pale green-beige poorly sorted sandstone. Taxa identified are:

Blackites creber
Blackites tenuis
Chiasmolithus gigas (frequent to common)
Chiasmolithus expansus
Chiasmolithus grandis
Chiasmolithus solitus
Clausicoccus cribellum
Coccolithus eopelagicus
Coccolithus pelagicus
Cyclicargolithus floridanus
Cyclococcolithus formosus
Cyclococcolithus protoannulus (very rare)
Discoaster barbadiensis
Discoaster bifax
Discoaster delicatus
Discoaster distinctus
Discoaster mirus (very rare)
Discoaster saipanensis
Discoaster tani
Gartnerago sp. (rare)
Helicosphaera sp. (rare)
Markalius astroporus/inversus
Nannotetrina cristata
Neococcolithes dubius
?Reinhardtites sp. (very rare)

Reticulofenestra dictyoda
Reticulofenestra umbilica (two sizes)
Transversopontis pulcher
Zygrhablithus bijugatus

Discoaster barbadiensis is appreciably more common than its sibling *Discoaster saipanensis*. A few specimens of *Reticulofenestra scissura* were encountered, but they are thought to be contaminants. The association of *Reticulofenestra umbilica, Discoaster bifax, Chiasmolithus grandis, C. solitus* and *Discoaster barbadiensis* suggests an early middle Eocene age, and a correlation with the foraminiferal zone P.11 of the tropics. This assemblage contains the obviously displaced Upper Cretaceous species of *Gartnerago* and *Reinhardtites*. Both *Chiasmolithus gigas* and *Nannotetrina* sp. could also be reworked from lower in the middle Eocene. Deposition was in shallow waters as indicated by the rare occurrence of *Transversopontis pulcher* and *Zygrhablithus bijugatus*. Present water depths at Station DR01 are 3288 to 2945 metres.

(B) Sample DR10A contains abundant and moderately preserved calcareous nannofossils in a fine-grained pale limestone. This was dredged from the Ceduna Terrace where water depths are 3565 to 2920 metres. Taxa identified are:

Blackites creber
Blackites spinulus
Chiasmolithus grandis
Chiasmolithus eograndis
Chiasmolithus expansus
Chiasmolithus solitus
Clausicoccus cribellum
Coccolithus eopelagicus
Coccolithus pelagicus
Cyclicargolithus floridanus
Cyclicargolithus reticulatus (rare & poorly preserved)
Cyclococcolithus formosus
Cyclococcolithus protoannulus
Daktylethra punctulata
Discoaster barbadiensis
Discoaster distinctus
Discoaster saipanensis
Discoaster tani
Helicosphaera seminulum/lophota
Markalius astroporus/inversus
Nannotetrina cristata
Neococcolites dubius
Pontosphaera multipora (very rare)
Reticulofenestra hampdenensis (small)
Reticulofenestra umbilica (two sizes)
Sphenolithus moriformis
Transversopontis pulcher
Trochaster simplex
Zygrhablithus bijugatus (very rare)

The rare occurrence of *Cyclicargolithus reticulatus* in association with *Chiasmolithus solitus* and *C. grandis*, in the absence of *Reticulofenestra scissura*, suggests a mid middle Eocene age, and a correlation with the foraminiferal early zone P.12.

Deposition was in shallow waters as indicated by the presence of *Daktylethra punctulata*, *Pontosphaera multipora* and *Zygrhablithus bijugatus*. Discoasters are relatively less abundant than in DR01D.

Sample DR15B, a light greyish brown calcareous siltstone from the Ceduna Terrace between 3393 and 2496 metres water depths, yielded a calcareous nannofossil assemblage similar to that of DR10A, except for the lack of *Nannotetrina cristata* and the presence of *Helicosphaera* sp. cf. *H. reticulata*, *Reticulofenestra oamaruensis* and *Orthozygus aureus*. *Cyclicargolithus reticulatus* is small in the DR15B assemblage, but undeniable.

(C) Sample DR14A(5), a light grey argillaceous limestone from the Ceduna Terrace, yielded calcareous nannofossils. These are abundant and moderately preserved overall, though their debris abounds. Taxa identified are:

Blackites spinulus (rare)
Chiasmolithus expansus
Chiasmolithus grandis
Chiasmolithus solitus
Clausicoccus cribellum
Coccolithus eopelagicus
Coccolithus pelagicus
Cyclicargolithus floridanus
Cyclicargolithus reticulatus
Cyclococcolithus formosus
Cyclococcolithus protoannulus
Discoaster barbadiensis
Discoaster nodifer
Discoaster saipanensis
Discoaster sp.
Helicosphaera sp. aff. *H. reticulata* (common)
Markalius astroporus/inversus (very rare)
Neococcolithes dubius
Pontosphaera multipora (poorly preserved, very rare)
Reticulofenestra hampdenensis
Reticulofenestra umbilica
Sphenolithus moriformis
Sphenolithus predistentus
Zygrahblithus bijugatus crassus (rare)

This assemblage is middle Eocene in age, based on the co-occurrence of *Cyclicargolithus reticulatus* and *Chiasmolithus grandis*, and the absence of *Reticulofenestra scissura*. It correlates with the foraminiferal late zone P.12 of the tropics. Abundant *C. reticulatus* suggests that the assemblage is slightly younger than the DR10A assemblage; the latter can probably be placed very close to the appearance (lowest occurrence) datum of *Cyclicargolithus reticulatus*, with the DR14A(5) assemblage being slightly higher up. The scarcity of *Pontosphaera multipora* and *Zygrhablithus bijugatus crassus* and the absence of other shallow-water indicators (such as *Lanternithus minutus*) suggests deposition in deeper waters, probably on the continental slope. Present water depths at Station DR14 are 3461 to 3064 metres.

(D) Sample DR08B, a fine-grained yellow green carbonate mudstone, contains abundant and moderately preserved calcareous nannofossils. Taxa identified are:

Blackites tenuis
Chiasmolithus expansus
Chiasmolithus grandis
Chiasmolithus solitus
Coccolithus eopelagicus
Coccolithus pelagicus
Cyclicargolithus floridanus
Cyclicargolithus reticulatus
Cyclococcolithus formosus
Cyclococcolithus protoannulus
Discoaster barbadiensis
Discoaster saipanensis
Discoaster tani
Lanternithus minutus (rare, poorly preserved)
Markalius astroporus/inversus
Neococcolites dubius
Reticulofenestra umbilica
Reticulofenestra scissura (small & rare)
Reticulofenestra scrippsae
Sphenolithus moriformis
Sphenolithus predistentus
Zygrahblithus bijugatus

The association of *Reticulofenestra scissura*, *Cyclicargolithus reticulatus* and *Chiasmolithus grandis* suggests a later middle Eocene age, and a correlation with the foraminiferal zone P.13. Deposition was in shallow waters as indicated by the presence of *Lanternithus minutus* and *Zygrhablithus bijugatus*; poor preservation (recrystallization) of *L. minutus* may account for its scarcity. Present water depths on the Ceduna Terrace at Station DR08 are 2823 to 2238 metres.

Sample DR14A(6), a light grey argillaceous limestone also from the Ceduna Terrace, but from between 3461 and 3064 metres water depths, yielded a nannofossil assemblage similar to that in DR08B: abundant *Cyclicargolithus reticulatus*, common *Helicosphaera reticulata* and rare small *Reticulofenestra scissura*.

Late Eocene

(A) Sample DR01A, a fine-grained white chalk, dredged from between the Eyre and Ceduna Terràces, yielded a rich nannofossil assemblage. This included:

Bramletteius serraculoides
Chiasmolithus altus
Chiasmolithus oamaruensis
Clausicoccus cribellum
Coccolithus eopelagicus
Cyclicargolithus floridanus
Cyclicargolithus reticulatus
Cyclococcolithus formosus
Discoaster barbadiensis (very rare)
Discoaster saipanensis (frequent)

Markalius inversus (very rare)
Reticulofenestra aragonensis
?Reticulofenestra hampdenensis
Reticulofenestra scissura
Reticulofenestra scrippsae
Reticulofenestra umbilica
Sphenolithus moriformis
and stems of *Blackites*

Based on the presence of *Bramletteius serraculoides*, *Chiasmolithus oamaruensis* and *Cyclicargolithus reticulatus* in the absence of *Isthmolithus recurvus*, the age of the assemblage is early late Eocene. A correlation with a low position within the foraminiferal zone P.15 of the tropics can also be made, based on the same evidence. Deposition was in deeper waters as suggested by the absence of the shallow-water indicators (such as *Lanternithus minutus*). Present water depths at Station DR01 are 3288 to 2945 metres.

(B) Sample DR12A(5), a fine-grained limestone, yielded a poorly preserved calcareous nannofossil assemblage which is characterised by the presence of the taxa:

Chiasmolithus altus
Chiasmolithus oamaruensis
Coccolithus pelagicus
?Cyclicargolithus reticulatus
Cyclococcolithus formosus
Discoaster saipanensis
Helicosphaera compacta
Isthmolithus recurvus
Markalius inversus
Pontosphaera
Reticulofenestra aragonensis
Reticulofenestra hampdenensis
Reticulofenestra scissura
Reticulofenestra umbilica
Sphenolithus moriformis
Transversopontis zigzag
Zygrhablithus bijugatus

The overlap in the ranges of *Cyclicargolithus reticulatus*, *Discoaster saipanensis* and *Isthmolithus recurvus* indicates a late Eocene age, and a correlation with the foraminiferal zonal interval late P.15 - early P.16. Deposition of DR12A(5) was in a nearshore or shelf environment as evidenced by the presence of species of *Pontosphaera* and *Transversopontis*. Present water depths at Station DR12 are 3622 to 2629 metres.

(C) Sample DR14D, light brownish grey limestone, yielded moderately preserved nannofossils, including:

Blackites tenuis
Chiasmolithus altus
Chiasmolithus oamaruensis
Clausicoccus cribellum
Coccolithus eopelagicus
Coccolithus pelagicus
Cyclococcolithus formosus

Discoaster barbadiensis
Discoaster nodifer (frequent)
Discoaster saipanensis
Discoaster tani
Helicosphaera sp. cf. *H. reticulata*
Holodiscolithus macroporus (very rare)
Isthmolithus recurvus
Leptodiscus larvalis
Markalius inversus
Pontosphaera multipora (single specimen, corroded)
Reticulofenestra aragonensis
Reticulofenestra hampdenensis
Reticulofenestra scissura
Reticulofenestra umbilica
Sphenolithus moriformis
Transversopontis zigzag
Zygrhablithus bijugatus

The presence of both *Discoaster barbadiensis* and *Isthmolithus recurvus* in the absence of *Cyclicargolithus reticulatus* suggests a late Eocene age and a correlation with the foraminiferal zone late P.16. Deposition was in shallow waters, nearshore or shelf environment. This is based on the presence of hemipelagic taxa such as *Holodiscolithus macroporus* and *Transversopontis zigzag*. Present water depths at Station DR14 are 3461 to 3064 metres.

Oligocene

Early Oligocene

(A) The assemblage extracted from sample DR14B, a white argillaceous limestone from the Ceduna Terrace, included:

Blackites spinosus
Blackites spinosus
Blackites tenuis
Chiasmolithus altus
Chiasmolithus oamaruensis (abundant)
Coccolithus pelagicus
Cyclococcolithus formosus
Discoaster tani
Helicosphaera lophota
Isthmolithus recurvus
Lanternithus minutus
Leptodiscus larvalis (Rare)
Pontosphaera multipora
Pontosphaera plana (Rare)
Reticulofenestra hampdenensis (Frequent to common)
Reticulofenestra oamaruensis (Rare)
Reticulofenestra scissura
Reticulofenestra scrippsae
Reticulofenestra umbilica
Sphenolithus moriformis
Transversopontis pulcher
Transversopontis pulcheroides
Zygrhablithus bijugatus.

This assemblage is early Oligocene in age, based on the co-occurrence of *Cyclococcolithus formosus*, *Isthmolithus recurvus*, *Lanternithus minutus* and *Reticulofenestra umbilica*, in the absence of the key Eocene taxa *Cyclicargolithus reticulatus* and *Discoaster saipanensis*. Deposition was in shallow waters as indicated by the presence of *Lanternithus minutus*, *Pontosphaera multipora* and *Zygrhablithus bijugatus*. Present water depths at Station DR14 are 3461 to 3064 metres.

(B) The assemblage recovered from sample DR06A, a fine-grained white chalk dredged from the Ceduna Terrace, included:

Chiasmolithus altus
Chiasmolithus oamaruensis
Clausicoccus cribellum
Coccolithus pelagicus
Pontosphaera plana
Reticulofenestra hampdenensis
Reticulofenestra oamaruensis
Reticulofenestra scissura
Reticulofenestra umbilica
Transversopontis pulcheroides
Zygrhablithus bijugatus.

The presence of *Reticulofenetra umbilica* in the absence of the key Eocene taxa *Discoaster saipanensis* and *Cyclicargolithus reticulatus* indicates an early Oligocene age. This assemblage is younger than that of DR14B because the latter contains *Cyclcococcolithus formosus*. Deposition of DR06A was in shallow waters because of the presence of *Pontosphaera plana*, *Transversopontis pulcheroides* and *Zygrhablithus bijugatus*. Present water depths at Station DR06 are 2493 to 2018 metres.

Mid Oligocene

Sample DR12B, a soft fine-grained white limestone dredged from the Ceduna Terrace, yielded a well preserved assemblage. This included:

Blackites spinosus
Blackites spinulus
Blackites tenuis
Blackites vitreus
Chiasmolithus altus
Coccolithus eopelagicus
Coronocylus nitescens
Coccolithus pelagicus
Cyclicargolithus floridanus
Discoaster
Helicosphaera intermedia
Helicosphaera obliqua
Lanternithus minutus (one poorly preserved specimen)
Orthozygus aureus
Pontosphaera multipora
Reticulofenestra scissura
Reticulofenestra scrippsae
Reticulofenestra spp.
Sphenolithus distentus
Sphenolithus moriformis

Sphenolithus predistentus
Transversopontis zigzag
Zygrhablithus bijugatus.

Based on the presence of the index species *Sphenolithus distentus*, in the absence of both *Sphenolitus ciperoensis* and *Cyclicargolithus abisectus*, the age of the assemblage is mid Oligocene. A correlation with the foraminiferal late zone P.19 of the tropics is made, based on data in Martini (1971). Deposition was in shallow waters, nearshore or shelf as evidenced by the presence of several hemipelagic taxa such as *Orthozygus aureus*, *Transveropontis zigzag* and *Zygrhablithus bijugatus*. Present water where DR12 was dredged range between 3622 and 2629 metres.

Late Oligocene

Sample DR06B, a fine-grained pale yellowish white chalk, dredged from Ceduna Terrace, yielded a late Oligocene assemblage which contains rare displaced Eocene elements:

Chiasmolithus altus
Chiasmolithus oamaruensis
Coccolithus eopelagicus
Coccolithus pelagicus
Coronocyclus nitescens
Cyclicargolithus abisectus
Cyclicargolithus floridanus
Discoaster deflandrei "group"
Discoaster tani
Helicosphaera euphratis
Helicosphaera recta
Reticulofenestra aragonensis
Reticulofenestra scissura
Reticulofenestra scrippsae
Reticulofenestra sp.
Sphenolithus ciperoensis
Sphenolithus moriformis
Zygrhablithus bijugatus
Discoaster saipanensis (displaced from Eocene)
Reticulofenestra hampdenensis (displaced from Eocene).
Reticulofenestra umbilica (displaced from Eocene).

The co-occurrence of *Helicosphaera recta*, *Sphenolithus ciperoensis* and *Cyclicargolithus abisectus*, in the absence of *Sphenolithus distentus*, indicates a late Oligocene age, and a correlation with the foraminiferal mid zone P.22. Deposition was in shallow waters as indicated by the abundant occurrence of *Zygrhablithus bijugatus*. Present water depths at Station DR6 are 2493 to 2018 metres.

References

McGowran, B., 1988 - Foraminiferal biostratigraphy of dredged samples. Appendix 2, this volume.

Martini, E., 1971 - Standard Tertiary and Quaternary calcareous nannoplankton zonation. *In* A. Farinacci (Ed.), Proceedings of the II Planktonic Conference, Roma, 1970. *Edizioni Tecnoscienza, Roma*, 739--785.

APPENDIX 4: PRELIMINARY PALYNOLOGICAL RESULTS

By N. F. Alley, Department of Mines & Energy, Adelaide.

The results for each sample are presented in the following order:

Palynological no. (SADME)
Rock sample no. (BMR)
Palynological zone
Age
Environment

S 6419, 66DR14E, unknown, unknown, marine.

S 4920, 66DR8E, unknown, Palaeocene to Early Eocene, ?paralic.

S 6421, 66DR7E, *Lygistepollenites balmei* to *Malvacipollis diversus* spore/pollen zone, Late Palaeocene to Early Eocene, marginal marine.

S 6423, 66DR1C, *Odontochitina porifera* to *Nelsoniella aceras* dinoflagellate zones, Late Cretaceous (Coniacian/Santonian), ?paralic.

S 6416, 66DR9C, this sample is a mixture of pollen, spores and dinoflagellates ranging in age from Early Cretaceous to Early/Middle Eocene.

S 6414, 66DR1G, unknown, probably Maastrichtian to Early Palaeocene, marine.

S 6413, 66DR11E, this sample contains a mixture of pollen, spores and dinoflagellates ranging in age from early Cretaceous to Early Eocene.

S 6412, 66DR1H, *Malvacipollis diversus*, Early Eocene, marine.

S 6400, 66DR3A, this sample contains a mixture of pollen, spores and dinoflagellates ranging in age from Early Cretaceous to early Eocene.

S 6415, 66DR8D, *Malvacipollis diversus* pollen zone, Early Eocene, marginal marine.

S 6417, 66DR7A, *?Lygistepollenites balmei* to *?Malvacipollis diversus* spore/pollen zones, ?Late Palaeocene to ?Early Eocene, marine.

S 6398, 66DR12G, *Tricolpites longus* to *Lygistepollenites balmei* pollen zones, Paleocene, nonmarine.

S 6399, 66DR8F, *Lygistepollenites balmei* zone, Late Palaeocene, ?paralic.

S 6404, 66DR12F, *Lygistepollenites balmei* zone, Late Paleocene, marginal marine.

S 6426, 66DR16B, unknown (only dinoflagellates present), possibly mid Cretaceous, marine.

S 6429, 66DR14D, unknown (mainly dinoflagellates), possibly Late Cretaceous, marine.

S 6432, 66DR8C, produced no palynomorphs.

S 6430, 66DR7F, unknown (mainly dinoflagellates), Late Cretaceous (Campanian/Maastrichtian), marine.

S 6454, 66DR12E, unknown, Late Cretaceous to Palaeocene, marine.

S 6449, 66DRD, unknown, unknown, marine.

S 6447, 66DR1I, *Lygistepollenites balmei*, Late Palaeocene, marginal marine.

S 6446, 66DR12D, *Tricolpites longus*, Early to Middle Palaeocene, marginal marine.

S 6445, 66DR11F, unknown, Late Cretaceous to Tertiary, marginal marine.

S 6444, 66DR9C, *L. Balmei* to *Malvacipollis diversus*, Late Palaeocene to Early Eocene, marginal marine.

S 6443, 66DR14F, *L. balmei* to *M. diversus*, L. Paleocene to E. Eocene, marginal marine.

S 6448, 66DR3C, unknown, probably Late Cretaceous (younger than Turonian) although an Early Tertiary age cannot be ruled out because the palynoflora is extremely poor. However, I observed no Tertiary forms. Marginal marine.

APPENDIX 5: GRAIN SIZE DATA FROM SELECTED CORE SAMPLES

By J. D. A. Clarke, Flinders University of South Australia (now Western Mining Corporation)

SAMPLE

Size Fraction	PC 1 148-150 cm	DR 14 (sand)	GC 7 2-4	GC 760-62
>1 mm	4.9%	1.6%	trace	trace
<1 >0.25 mm	13.4	3.3	3.2%	3.4%
<0.5 >0.25 mm	58.6	13.2	55.3	34.5
<0.25 >0.125 mm	14.6	35.2	33.4	36.2
<0.125 > 0.063 mm	6.1	26.2	8.1	19.0
<0.063 mm	2.4	20.5	0.0	6.9

	GC 10 2-4 cm	GC 10 80-82	GC 10 100-102	GC 10 150-152
>1 mm	0.0%	0.0%	0.0%	0.0%
<1 >0.5 mm	trace	trace	trace	trace
<0.5 >0.25 mm	11.8	5.8	14.9	11.2
<0.25 >0.125 mm	11.8	7.0	11.9	8.6
<0.125 > 0.063 mm	12.9	7.0	14.9	9.5
<0.063 mm	63.5	80.2	58.3	70.7

	GC 10 174-176	GC 19 A (bottom)	GC19B sand	GC 19C san??
>1 mm	trace	0.0%	46.8%	5.7%
<1 >0.5 mm	0.6%	trace	21.1	8.1
<0.5 >0.25 mm	25.2	3.3	21.4	41.8
<0.25 >0.125 mm	21.0	3.3	4.5	36.8
<0.125 >0.063 mm	12.0	4.9	1.3	6.9
<0.063 mm	41.2	88.5	3.9	1.2

	GC 20 22-24	GC 20 sand	GC 21 80-82	GC 21 sand
>1 mm	0.0	84.7%	0.0%	1.3%
<1 >0.5 mm	trace	14.0	trace	13.3
<0.5 >0.25 mm	3.6	1.0	4.5	78.5
<0.25 >0.125 mm	3.6	0.3	4.5	5.4
<0.125 >0.063 mm	9.6	0.0	9.2	1.3
<0.063 mm	83.2			

All samples were wet sieved except for the sands from GC 7, 19 C, 20, 21, PC1 and DR 14, which were dry sieved. Histograms are plotted separately.