BMR Record 1990/85

Stratigraphy of Australia's NW Continental Margin
(Project 121-26)

Post-cruise Report for BMR Survey 96

by

J.B. Colwell, T.L. Graham and others

Bureau of Mineral Resources, Geology & Geophysics

RECORD

BMR Record 1990/85

Stratigraphy of Australia's NW Continental Margin
(Project 121-26)

Post-cruise Report for BMR Survey 96

by

J.B. Colwell, T.L. Graham and others

Division of Marine Geosciences & Petroleum Geology

BMR Record 1990/85

Stratigraphy of Australia's NW Continental Margin (Project 121-26)

Post-cruise Report for BMR Survey 96

by

J.B. Colwell and T.L. Graham (Co-chief Scientists)

M. Bradshaw, S. Cadman, S. Shafik and P. Wells[1] (Scientific Staff)

H. Miller and R. Moshin (Systems Staff)

P. Butler, C. Lawson, T. McNamara, D. Pryce, G. Sparksman and J. Stratton (Science Technical Staff)

P. Golding, D. Holdway and J. Whatman (Electronics Technical Staff)

B. Dickinson, C. Dyke, C. Green and A. Radley (Mechanical Technical Staff)

[1] Geology Department, Australian National University

ABSTRACT

The geology of a significant part of the NW continental margin is relatively unknown. Survey 96 (August-September 1990) aimed to partly rectify this situation by addressing, through a program of coring and dredging, a number of problems on the margin, including :

(i) the nature of rift and immediately post-breakup sediments on the outer part of the Carnarvon Basin,

(ii) the composition and age of apparent Jurassic reefs on the northern central Exmouth Plateau,

(iii) the nature of pre-rift, rift and post-breakup sediments on the Rowley Terrace - southwestern Scott Plateau,

(iv) whether thermogenic hydrocarbons are leaking along a major fault in the Offshore Canning Basin, and

(v) the nature of dipping strata on the central part of the Wallaby Plateau.

Most work was concentrated on the continental slope in the area extending from the Carnarvon Terrace to Scott Plateau. Thirty four successful dredge hauls totalling 2.5 tonnes of rock, and 19.3 m of core were taken. Approximately 6000 km of bathymetric and magnetic data were collected on transits between the sampling areas.

The rocks recovered range considerably in type and age. They include :

- Early Cretaceous mudstones and marls from the Carnarvon Terrace;
- shelfal, mollusc-rich limestones from the central northern Exmouth Plateau;
- massive, crinoidal and peloidal limestones from the southern Rowley Terrace;
- lithic sandstones from the Scott Plateau margin;
- volcanics and dynamically metamorphosed rocks from the southwestern margin of the Exmouth Plateau; and
- basalts and basalt conglomerates from the central Wallaby Plateau.

None of the cores contained significant hydrocarbon gasses.

CONTENTS

FIGURES

INTRODUCTION

Although considerable exploration activity has been directed at the shallow-water (shelf) areas of the NW Australian continental margin, relatively little is known of the geology of the continental slope and of adjacent marginal plateaus such as the Wallaby and Scott. Rig Seismic Research Cruise 96 aimed at partly addressing this problem. The cruise sailed from Fremantle on 17 August 1990 and docked back in Fremantle on 11 September 1990.

Four major sedimentary basins occur on the NW Shelf part of NW continental margin : the Carnarvon, Offshore Canning, Browse and Bonaparte (Figs. 1 & 2). In places, these basins contain over 17,000 m of Phanerozoic sediments. Studies of the basins and adjacent areas have been undertaken by many workers including Powell (1976), Thomas & Smith (1976), Hocking & others (1987), Hocking (1988) - the Carnarvon Basin; Warris (1976), Forrest & Horstman (1986) - the Canning Basin; Allen & others (1978, 1979), Apthorpe (1979), Barter & others (1982), Willis (1988) - the Browse Basin; Laws & Brown (1976), Gunn (1988), Lavering & Ozimic (1988), MacDaniel (1988), Mory (1988) and Woods (1988) - the Bonaparte Basin; Exon & Willcox (1978) and Barber (1988) - the Exmouth Plateau; and Stagg & Exon (1981) - the Scott Plateau.

The tectonic development of the NW continental margin is the result of successive cycles of Palaeozoic and Mesozoic rifting, followed by latest Jurassic-Early Cretaceous breakup of the Gondwana supercontinent, and Tertiary collision and forearc development between Australia and Indonesia in the north. Marine and continental sediments of Early to Middle Palaeozoic age were deposited in and adjacent to a series of intracratonic rifts within the Gondwana supercontinent and were covered by Late Palaeozoic and Early Mesozoic marine and continental sediments (Bureau of Mineral Resources, 1988; Fig. 3). Late Triassic, Jurassic, Cretaceous and Cainozoic sediments were deposited during various stages in the margin's formation. Total sediment thicknesses range from 1000 m on the Wallaby Plateau to greater than 15,000 m in the major rifts (Falvey & Mutter, 1981; BMR, 1988).

Although the Late Triassic-Cainozoic section was divided into two parts separated by a breakup unconformity by Falvey & Mutter (1981), problems still remain in identifying the actual age of breakup along the margin. In general, it appears that breakup is older in the north

(possibly as old as Callovian in northern Carnarvon and Bonaparte Basins) than in the south (Neocomian in Perth Basin). On the Argo Abyssal Plain recent drilling during Ocean Drilling Program Leg 123 (Site 765) discovered sediments possibly ranging back to the Tithonian overlying the oldest oceanic crust (Gradstein, Ludden & Leg 123 Shipboard Scientific Party, 1990), thus giving a breakup age at the very end of the Jurassic. On the Gascoyne, Cuvier and Perth Abyssal Plains breakup appears to have occurred at much the same time (Neocomian) and in much the same direction (Fig. 4).

To date, most exploration activity in the region has been directed at Triassic to Cretaceous fault-block structures and anticlinal features (Falvey & others, 1990). Similar plays and wrench-related (pop-up) horst block plays may occur in deep water on parts of the margin. Stratigraphic and combined structurally stratigraphic traps have been tested in some areas, particularly on the southern NW Shelf and Exmouth Plateau. Untested stratigraphic plays in deep water include fans (NW4 on Fig. 3), and Triassic Reefs (NW5) such as that intersected at ODP Site 764 on the Exmouth Plateau (Williamson & others, 1989; Falvey & others, 1990).

OBJECTIVES

BMR's Survey 96, the operations side of BMR project 121.26 (NW Continental Margin Stratigraphy), aimed to provide geological information on a number of poorly-sampled areas on the NW continental margin (Colwell & Graham, 1990). The areas sampled (cored or dredged) include the Carnarvon Basin east of Wallaby Plateau and adjacent to the Exmouth Sub-basin, the NE Exmouth Plateau/Carnarvon Basin margin, Rowley Terrace, SW margin of the Scott Plateau, western margin of the Wombat Plateau, SW Exmouth Plateau margin, and the central part of the Wallaby Plateau (Figs 5 & 6); the ship's tracks are shown in Figure 7. Specific problems addressed by the sampling sites include :

(i) the nature of rift and immediately post-breakup sediments on the outer Carnarvon Basin (Sites A1-A3 and B0-B5; dredges 1-11; Table 1);

(ii) the composition and age of an apparent Jurassic reef on BMR line 55/13, central northern Exmouth Plateau (Site C1; dredges 29 & 30);

(iii) the nature of pre-rift , rift and post-breakup sediments on the Rowley Terrace (eastern) side of the Swan Canyon (Sites D1-D6 and RT1; dredges 12-18 & 28).
and on the western margin of the Scott Plateau (Sites E1-E9; dredges 19-27);

(iv) whether thermogenic hydrocarbons are leaking along a major, deep fault system in the Offshore Canning Basin (Sites F1-F11; cores 1-19);

(v) the nature of sediments and volcanics on the western margin of the Wombat Plateau (Sites G1 and G2; dredges 31-33);

(vi) the nature and age of volcanics and other rocks in the "rift/oceanic" transition zone on western Exmouth Plateau (Sites H1 and H2; dredges 34 & 35); and

(vii) the nature of strata on the central part of the Wallaby Plateau (Site I1; dredges 36-38).

GEOLOGICAL BACKGROUND TO SAMPLING AREAS

Areas A & B - Carnarvon Terrace/Basin

The Carnarvon Terrace is a physiographic feature which lies adjacent to the Exmouth and Gascoyne Sub-basins of the Carnarvon Basin in the north, and the northern Perth Basin in the south (Figs. 5 & 8). In general, the Carnarvon Basin can be divided at about 26^{o}N into two distinct parts : a southern, largely onshore, north-trending group of sub-basins which contain up to 7 km of mainly Palaeozoic sediments, and a northern, largely offshore, NE-trending group of sub-basins which contain up to 15km of Palaeozoic, Mesozoic and Cainozoic sediments (Hocking, 1988; Fig. 8). The generalised stratigraphy and depositional sequences of the basin are shown in Figures 9 and 10.

The Triassic-Late Cretaceous history of the offshore Carnarvon Basin largely reflects the development of a rift system between Australia and Greater India. Thick, pre-rift, trough-infill Triassic sediments were covered by Jurassic rift-valley deposits, and then by trough-infill and restricted-circulation strata of Cretaceous age (BMR 1988; Hocking, 1988). Marine carbonates were widely deposited in the Late Cretaceous and Cainozoic as the continental shelf prograded.

Areas C, D & H - Exmouth Plateau

The geology and tectonic development of the Exmouth Plateau (Figs. 1 & 11) have been discussed by a number of authors including Falvey & Veevers (1974), Powell (1976), Exon & Willcox (1978, 1980), Wright & Wheatley (1979), von Stackelberg & others (1980), Falvey & Mutter (1981), Barber (1982, 1988), von Rad & Exon (1983), Mutter & others (1989), and Haq & others (1990). The plateau is bounded by a sheared or transform margin to the south, a rift and thinned margin to the west, and a mixed rifted and sheared margin to the north (Exon & others, 1982; Fig. 4). It's stratigraphy is summarised in Figure 12.

The structural framework of the Exmouth Plateau region was initiated in Late Permian-Triassic to Jurassic time with the commencement of rifting between northwest Australia and Greater India. In latest Jurassic-earliest Cretaceous time, the northern margin of the plateau formed when seafloor spreading commenced in the Argo Abyssal Plain (Gradstein, Ludden & others, in press; ODP Leg 123). Several thousand metres of Upper Triassic to Middle Jurassic carbonates and coal measures accumulated before breakup along the incipient northern margin (Exon & others, 1982). Breakup occurred along a series of rifted and sheared margin segments which were later complicated by northeast-trending Callovian horsts and grabens. The whole margin subsided to its present water depths during the Cretaceous and Cainozoic and several hundred metres of pelagic carbonates were deposited (Haq & others, 1990).

During the Triassic and Jurassic, the plateau's western margin was affected by pre-breakup rift tectonics (Falvey & Mutter, 1981). Breakup occurred in the Neocomian as seafloor spreading began in the Gascoyne Abyssal Plain (Exon & others, 1982). A thick Triassic paralic sequence was deposited followed by a thin Upper Jurassic marine sequence and thin Upper Cretaceous and Cainozoic pelagic carbonates (Exon & others, op. cit.).

The southern margin formed along an incipient transform in the Neocomian (Exon & others, 1982). A thick Triassic paralic sequence was deposited followed by a thick lower Neocomian delta complex, the Barrow Delta. After Mid-Cretaceous time the margin was covered by a thin sequence of pelagic carbonates.

Prior to Survey 96, four major phases of geological work had been undertaken on the Exmouth Plateau. These are : dredging by the R/V Sonne in 1979 on the plateau's margins (von Stackelberg & others, 1980); exploration drilling by Phillips, Esso and BHP (Fig. 11; Barber, 1982, 1988); dredging and coring by the R/V Rig Seismic in 1986 (Exon & Williamson, 1988; von Rad & others, 1990); and ODP drilling in 1988 (Fig. 11; Haq & others, 1990).

Areas D, E and F - Rowley Terrace and Scott Plateau

The Rowley Terrace and adjacent Scott Plateau occur off the northern part of the Northwest Shelf (Fig. 1). The Scott Plateau forms the subsided western margin of the Browse Basin (Fig. 13). For much of the period between the Permian and Late Jurassic, the plateau appears to have been a topographic high with sediment shed from it into the Browse Basin to the east and the Rowley Sub-basin to the south (Stagg & Exon, 1981). With breakup between Australia and Greater India, the plateau began to subside to its present water depths. It is now covered by largely Late Cretaceous and Cainozoic sediments, mostly carbonates, averaging about 1 km thick (Fig. 14). Volcanics and other rocks (inc. Late Jurassic siltstones and sandstones) have been dredged by the R/V Valdivia from its western and northern margins (Hinz & others, 1978).

The southern Scott Plateau and Rowley Terrace are underlain by the Rowley Sub-basin (Fig. 13). This sub-basin trends east-northeast and contains mildly-deformed, largely Mesozoic sediments. It appears to contain at least 6 km of pre-breakup Mesozoic and Palaeozoic rocks, overlain by a post-breakup sequence with an average thickness of 1.5 to 2 km (Stagg & Exon, 1981). Sampling of the margin of the central part of the sub-basin during BMR Survey 95 yielded a wide variety of rock types including Jurassic marine and non-marine detrital sediments, Jurassic shelf carbonates, Triassic-Jurassic volcanics, and coral and algal boundstones of possible Triassic age (Exon & Ramsay, 1990).

Area I - Wallaby Plateau

The Wallaby Plateau (Figs. 4 & 5) is separated from the Carnarvon Terrace by the Wallaby Saddle. The plateau is broad and generally

smooth, with a crest in about 2200 m of water. It is separated from the Cuvier Abyssal Plain to the northeast by a low scarp and from the Perth Abyssal Plain to the southwest by the Wallaby-Zenith Fracture Zone.

The plateau has been considered to be of either continental (Symonds & Cameron, 1977) or oceanic/"epilith" origin (Veevers & Cotterill, 1978). Sampling carried out by the R/V Sonne in 1979 on the plateau's margins (Fig. 15) recovered a variety of volcanic and volcaniclastic rocks (von Stackelberg & others, 1980), adding weight to the oceanic or "epilith" theory. A minimum mid-Cretaceous K/Ar age of 89 Ma was obtained on an altered basalt sample from the plateau's southern margin.

Seismic profiles from the plateau show variations in seismic character beneath the main ?Neocomian "breakup" unconformity. Beneath the southern part of the plateau, seismic character varies from a faulted, south-dipping sequence of reflectors to vague north-dipping reflectors about 20 km east (Symonds, 1984). In some places, "true" basement appears to subcrop at the main unconformity, and in one area of the central plateau, reflectors dip to the north and south towards the centre of a 55 km wide "basin". In some processed profiles, the dipping basement is at least 2 seconds TWT thick (von Stackelberg & others, 1980).

The nature of the layered "basement" sequence is crucial to resolving the question of the origin of the plateau. If the sequence includes syn- or pre-rift rocks, then the plateau is at least partly of continental origin. If the sequence is volcanics, then the feature may either be an oceanic upgrowth formed by subaerial seafloor spreading, or represent late-stage rift volcanism on extended and highly-altered continental crust (Symonds, 1984).

OPERATIONS AND SYSTEMS REPORT

The ship sailed from Fremantle at 2100 hrs on 17 August 1990 and docked back in Fremantle at 0700 hrs on 11 September. During the intervening 23 days, 38 dredge hauls were attempted at 32 stations; 34 of the dredges were successful (Table 1 and Appendix 7). In addition, 11 cores totalling 19.3 metres were taken, and about 6000 km of

bathymetric and magnetic data were recorded (Fig. 7). All sites were selected on the basis of pre-existing seismic data, namely from BMR Surveys 17, 18, 55 and 56, Sonne (BGR) Survey SO-8, the Shell Petrel Survey, and JNOC's 1987 Offshore Canning Basin Study (Table 1).

Most work was concentrated on the continental slope between the Carnarvon Terrace and the Scott Plateau, areas A to F inclusive (Figs. 5 & 6). Transits between sampling areas were run at 12.5-13 knots and sited to fill in gaps in the regional bathymetric and magnetic data sets. Bathymetric data will be incorporated into the Offshore Resource Map series being produced within BMR.

In general, the systems on board the ship performed well. A list of the equipment used in the survey is given in Appendix 1.

Data Acquisition System (DAS)

The DAS, which handles the recording of the navigation, magnetic and bathymetric data, was operated for the duration of the survey. There were 28 breaks in data collection, resulting in 377 minutes of data loss. The problem was associated with memory control problems in the main DAS computer. A technician from Hewlett-Packard was called in on arrival at Fremantle to investigate the problem.

Navigation

Positioning of the ship was achieved using the Navstar Global Positioning System (GPS), backed up by dead reckoning (DR) using updates from the US Navy Navigation Satellite System (Transit System). As usual, all ship positions were calculated in the WGS72 coordinate system (as used by the Transit satellites) except for the on-board GPS receiver which calculated positions in the WGS84 coordinate system. The difference between WGS72 and WGS84 is of the order of a metre so no conversions were performed.

(i) Navstar Global Positioning System (GPS)

Magnavox T-set and Ashtech XII GPS receivers were used throughout the survey. For most of the time coverage was excellent and positional accuracy within 100 metres rms is believed to have been achieved. For

much of the survey, by using 2 satellite navigation for approximately 3 hours/day, almost continual coverage was attained.

(ii) Dead Reckoning System

Two systems incorporating a gyro compass, dual axis sonar-doppler and Transit Satnav receiver provided basic dead reckoning navigation for periods (up to four hours a day in the southernmost areas) when the GPS navigation system wasn't working satisfactorily.

Bathymetry

Bathymetric data were obtained from two Raytheon echo sounders, one operating at 12 KHz with 2KW maximum output and one at 3.5 KHz with 2KW maximum output. Transducers were replaced on both echo sounders prior to the survey. The 3.5 kHz echosounder gave particularly improved results, providing sub-bottom penetration even at transit speeds in 4000-5000 m of water.

Gravity

Prior to sailing a Bodenseewerk technician attempted to locate the problem which has plagued the gravity meter during the previous survey. He was not successful and at 237.0005 the gravity meter caged for the first of many times. The gravity meter spent so much time caged and being worked on that it is considered that there is no useable gravity data from this survey. The problem has now been solved.

Magnetics

Magnetic profiles were recorded during transits between sampling sites using a Geometrics G801 marine proton precession magnetometer. On day 230 a magnetometer head was lost in heavy seas. A second head was subsequently deployed.

Geology

All geological systems performed without problems. Approximately 800 metres of badly kinked cable was cut from the main coring winch during the survey. Another 800-1000 m is showing evidence of wear.

For the first time on any 'Rig Seismic' cruise a large number of thin sections were cut on board ship. This proved to be a very valuable aid to the shipboard descriptions.

PRELIMINARY RESULTS

A summary of the preliminary results (inc. shipboard descriptions) is given in Appendix 7. Although most of the marine and marginal-marine marine samples have been dated (see Appendices 5 and 6), much of the non-marine material is still to be dated using palynology. Consequently, this report doesn't attempt stratigraphic correlations.

Areas A & B - Carnarvon Terrace/Basin

Sites were selected on the Carnarvon Terrace to sample the oldest sediments exposed on this margin. Most sites were located in canyons on the continental slope in order to get below the regional Neocomian unconformity (Colwell & Graham, 1990; Figs. 5, 16 & 17).

Eleven dredge hauls (DR1-11) were successfully taken (Table 1). Rocks recovered include a variety of non-marine or deltaic sandstones and siltstones containing varying amounts of carbonaceous material, Early Cretaceous mudstones and marls, Tertiary marls and chalks, silicified siltstones, shales, and igneous rocks (Appendix 7). Detailed analysis of much of the material is still to be undertaken. However, it appears on broad lithological grounds that the rocks include equivalents of both the Barrow and Winning Groups, and "basement".

Area C - Exmouth Plateau

Two dredge hauls (DR29 & 30) were taken on the central northern Exmouth Plateau to sample an apparent Jurassic ?reefal buildup identified on BMR seismic line 56/13 (Figs. 6 & 18). Approximately 150 kg of hard, iron-stained, micritic and skeletal limestones (mollusc-rich in part) were recovered together with approximately 300 kg of Miocene limestone and clays (Appendix 7). The older limestones appear to be shelfal in nature.

Area D - Margin of the southern Rowley Terrace

Eight dredge hauls (DR12-18 and 28) were recovered in this area from eight sites, seven on the eastern side of the Swan Canyon (Figs. 6, 19-21) and one in a canyon to the northeast (Fig. 6). In general, the rocks obtained from the Swan Canyon are similar to those dredged previously by the Sonne and Rig Seismic from the western wall of the canyon (see Fig. 21). They typically consist of quartzose sandstones, mudstones, calcareous sandstones containing Inoceramus plates, carbonaceous siltstones and mudstones, shales, clays, chert, ironstones, and limestones (Appendix 7). They can be assigned to the following lithofacies associations defined from the northern Exmouth Plateau area by von Stackelberg & others (1980), von Rad & Exon (1983), Exon, Williamson & others (1988), and von Rad & others (1990) :

A. Delta plain/coal measures association
B. Ferruginous association
C. Shallow-water carbonate association
D. Marginal marine to bathyal claystone association
E. Pelagic marls and chalks
F. Chert and orthoquartzite association

The dredge haul located to the northeast of the Swan Canyon (DR28; Site RT1) was sited to sample an unnamed canyon from which a small piece of coralline reefal boundstone had been dredged during the Rig Seismic Triassic Reefs cruise (see Exon & Ramsay, 1990; Station 95/DR/07). The haul yielded a variety of rocks (commonly occurring as rounded boulders and cobbles) including crinoidal and peloidal limestones; calcarenites; a graded, chamositic, oolitic calcarenite/calcirudite; quartzose sandstones; siltstones; and silicified mudstones and chert (Appendix 7). Very little of the material has been dated at this stage.

Area E - Scott Plateau Margin

Dredging at nine sites on the western margin of the Scott Plateau dredges DR19-27; sites E1 to E9 Figs. 6 & 22) yielded basement volcanics, pumice, lithic sandstones containing mollusc casts, slightly carbonaceous siltstones, ?Jurassic to Early Cretaceous mudstones, chert and Miocene limestones. These dredge hauls fill in gaps between the

"Valdivia" sites in the north and BMR Survey 95 (Triassic Reefs) sites to the south (Fig. 6).

Area F - Rowley Terrace (Offshore Canning Basin)

A program of gravity coring in Area F (Fig. 6) was designed to test for thermogenic hydrocarbon gases thought to be possibly leaking along a major fault which extends on JNOC line 7 from deep in the basin to the surface (Fig. 23). Cores were sited in a radiating pattern away from the fault location as well as in a transect from just south of the Rowley Shoals to the Swan Canyon to establish background levels.

Only nine of nineteen cores attempted were successful because of difficulty in penetrating hardgrounds (inc. calcrete) on the seafloor. Sediments recovered consist mainly of Quaternary, carbonate-rich muddy sands (Appendix 7). Initial gas analyses show that only biogenic gas in low concentrations is present.

Area G - Western margin of the Wombat Plateau

Dredging in this area was aimed at sampling assumed latest Triassic-earliest Jurassic volcanics and the overlying sedimentary section. Three dredge hauls, DR31-33, were attempted at two sites, G1 & G2 (Figs. 6 & 24). Only moderate success was achieved because of widespread cover of Tertiary carbonates. Material recovered includes highly weathered volcanics, and a Miocene chalk (Appendix 7).

Area H - Southwestern margin of Exmouth Plateau

Two dredge hauls (DR34 & 35) were attempted in this area, one (DR34) inboard of ODP Site 766 and the other (DR35) on a seamount to the southwest on the transform margin (Figs. 5 & 25). DR34 was selected specifically to determine whether the volcanics in this area are rift related or oceanic. Rocks recovered include amygdaloidal basalts, veined porphyry and ?andesite. Geochemical work is still to be undertaken.

A variety of rock types (Appendix 7) was recovered in DR35 to the southwest of DR34. They include : igneous rocks (?basalt/andesite/gabbro); dynamically-metamorphosed (sheared)

siliceous mudstones and fault breccias/gouge related to the transform margin; and a very fine-grained, micaceous sandstone.

Area I - Wallaby Plateau

Three dredge hauls (DR36-38) were attempted at site I1 on the central Wallaby Plateau (Fig. 5). These hauls were aimed at sampling the only known exposure of dipping basement reflectors on the central part of the plateau, away from the plateau's margin (Fig. 26).

Two hauls were successful, recovering basalt and basalt conglomerate (Appendix 7). These rocks are similar to those dredged by the Sonne on the plateau's southern and eastern margins in 1979 (see Figs. 15 & 27), and support a volcanic origin for the entire feature.

Two cores (GC21 and 22) were successfully taken at Site I1 on the crest of the plateau (Fig. 5) to provide material for palaeoceanographic studies at ANU. The site was selected to be away from the influence of turbidity currents and above the Calcite Compensation Depth. Two approximately 2 metre lengths of Pleistocene-Holocene foram-rich ooze were recovered. The sediments are highly bioturbated.

ACKNOWLEDGEMENTS

The skill and professionalism of the ship's crew (Appendix 2) made a major contribution to the success of the cruise. We thank Pat Burrell for typing this report, particularly Appendix 7.

REFERENCES

Allen, G.A., Pearce, L.G.G., & Gardner, W.E., 1978 - A regional interpretation of the Browse Basin. APEA Journal, 18, 23-33.

Allen, G.A., Pearce, L.G.G. & Gardner, W.E., 1979 - Browse basin : regional interpretation. Oil & Gas Journal, 77 (10), 200-19.

Apthorpe, M., 1979 - Depositional history of the Upper Cretaceous of the Northwest Shelf, based on foraminifera. APEA Journal, 19, 74-89.

Barber, P.M., 1982 - Paleotectonic evolution and hydrocarbon genesis of the central Exmouth Plateau. APEA Journal, 22, 133-44.

Barber P.M., 1988 - The Exmouth Plateau deep water frontier : a case history. In : Purcell, P.G. & R.R. (Eds.), The Northwest Shelf, Australia. Proceedings of Petroleum Exploration Society Australia Symposium, Perth, 1988, 173-88.

Barter, T.P., Maron, P. & Willis I., 1982 - Results of exploration, Browse Basin, Northwest Shelf, Western Australia. In : Watson, S.T. (Ed.), Transactions Third Circum-Pacific Energy and Minerals Resources Conference, 105-15.

Bureau of Mineral Resources, Geology and Geophysics, 1988 - Australia's Petroleum Potential. In : Petroleum in Australia - the first century. Australian Petroleum Exploration Associaiton Limited, Sydney, 48-90.

Caron, M., 1985 - Cretaceous planktic foraminifera. In : Bolli, H.M., Saunders, J.B., & Perch-Nielsen, K. (eds). Planktonic stratigraphy. Cambridge University Press, 17-85.

Chaproniere, G.C.H., 1985 - Late Tertiary and Quaternary foraminiferal biostratigraphy and paleobathymetry of cores and dredge samples from cruise KK820316 Leg 2. In : Brocher, T.M. (ed). Geological investigations of the Northern Melanesian borderland, Circum-Pacific Council for Energy and Mineral Resources Earth Science Series V.3. Circum-Pacific Council for Energy and Mineral Resources, Houston, Texas, 103-122.

Colwell, J.B. & Graham, T.L., 1990 - Stratigitraphy of Australia's NW continental margin - research cruise proposal. BMR Record 1990/43.

Davies, H.L., Clarke, J.D.A., Stagg, H.M.J., Shafik, S., McGowran, B., Alley, N.F. & Willcox, J.B., 1989 - Maastrichtian and younger sediments from the Great Australian Bight. Bureau of Mineral Resources, Australia, Report 288.

Exon, N.F., Ramsay, D.C. and Shipboard Party, 1990 - Postcruise report for Survey 95, Triassic and Jurassic sequences of the Northern Exmouth Plateau and offshore Canning Basin. BMR Record 1990/57.

Exon, N.F., von Rad, U. & von Stackelberg, U., 1982 - The geological development of the passive margins of the Exmouth Plateau off northwest Australia. Marine Geology, 47, 131-52.

Exon, N.F. & Willcox, J.B., 1978 - Geology and petroleum potential of the Exmouth Plateau area off Western Australia. American Association ofPetroleum Geologists Bulletin, 62, 40-72.

Exon, N.F. & Willcox, J.B., 1980 - The Exmouth Plateau : Stratigraphy, structure and petroleum potential. Bureau of Mineral Resources, Australia, Bulletin 199.

Exon, N.F., Williamson, P.E. and others, 1988 - Sedimentary basin framework of the northern and western Exmouth Plateau. Rig Seismic Research Cruises 7 abd 8. Post-Cruise Report. BMR Record 1988/30.

Falvey, D.A. & Mutter, J.C., 1981 - Regional plate tectonics and the evolution of Australia's passive continental margins. BMR Journal of Australian Geology and Geophysics, 6, 1-29.

Falvey, D.A., Symonds, P.A., Colwell, J.B., Willcox, J.B., Marshall, J.F., Williamson, P.E. & Stagg, H.M.J., 1990 - Australia's deepwater frontier petroleum basins and play types. APEA Journal, 30, 23B-62.

Falvey, D.A. & Veevers, J.J., 1974 - Physiography of the Exmouth and Scott Plateaus, and adjacent north-east Wharton Basin. Marine Geology, 17, 21-59.

Forrest, J.T. & Horstman, E.L., 1986 - The Northwest Shelf of Australia - Geological review of a potential major petroleum province of the future. In : Halbouty, M.T. (Ed.), Future petroleum provinces of the world. Proceedings of the Wallace C. Pratt Memorial Conference, Phoenix 1984, American Associaiton of Petroleum Geologist Memoir, 40, 457-85.

Gradstein, F.M., Ludden, J. & Leg 123 Shipboard Scientific Party, in press - Proceedings ODP Leg 123. ODP Initial Report, 123, College Station, Texas.

Gunn, P.J., 1988 - Bonaparte Basin : evolution and structural framework. In : Purcell, P.G. & R.R. (Eds.), The Northwest Shelf, Australia. Proceedings of Petroleum Exploration Society Australia Symposium, Perth, 1988, 275-85.

Haq, B.U., von Rad, U., O'Connell, S., & Leg 122 Shipboard Scientific Party, 1990 - Proceedings ODP Leg 122. ODP Initial Report, 122, College Station, Texas.

Hinz, K., Beiersdorf, H., Exon, N.F., Roeser, H.A., Stagg, H.M.J. & von Stackelberg, U., 1978 - Geoscientific investigations from the Scott Plateau off northwest Australia to the Java Trench. BMR Journal of Australian Geology and Geophysics, 3, 319-40.

Hocking, R.M., 1988 - Regional geology of the northern Carnarvon Basin. In : Purcell, P.G. & R.R. (Eds.), The Northwest Shelf, Australia. Proceedings of Petroleum Exploration Society Australia Symposium, Perth, 1988, 97-114.

Hocking, R.M., Moors, H.T. & van de Graff, W.J.E., 1987 - Geology of the Carnarvon Basin, Western Australia. Geological Survey of Western Australia Bulletin 133.

Kennett, J.P. & Sprinivasan, M.S., 1983 - Neogene planktonic foraminifera. A phylogenetic atlas. Hutchinson Ross Publishing Company, Pennsylvania, 265 pp.

Lavering, I.H. & Ozimic, S., 1988 - Bonaparte Basin petroleum accumulations. In : Purcell, P.G. & R.R. (Eds.), The Northwest Shelf, Australia. Proceedings of Petroleum Exploration Society Australia Symposium, Perth, 1988, 331-7.

Laws, R.A. & Brown, R.S., 1976 - Petroleum geology of the southeastern Bonaparte Gulf Basin. In : Leslie, R.B., Evans, H.J. & Knight, C.L. (Eds.), Economic Geology of Australia and Papua New Guinea - 3, Petroleum. Australasian Institute of Mining & Metallurgy Monograph, 7, 200-8.

MacDaniel, R.P., 1988 - The geological evolution and hydrocarbon of the western Timor Sea region. In : Petroleum in Australia - the First Century Australian Petroleum Exploration Associaiton Limited, Sydney, 270-84.

Mory, A.J., 1988 - Regional geology of the offshore Bonaparte Basin. In : Purcell, P.G. & R.R. (Eds.), The Northwest Shelf, Australia. Proceedings of Petroleum Exploration Society Australia Symposium, Perth, 1988, 287-309.

Mutter, J.C., Larson, R.L. & NW Australia Study Group, 1989 - Extension of the Exmouth Plateau : deep seismic reflection/refraction evidence for simple and pure shear mechanisms. Geology, 16, 15-18.

Powell, D.E., 1976 - Dampier sub-basin, Carnarvon Basin. In : Leslie, R.B., Evans, H.J. & Knight, C.L., (Eds.). Economic geology of Australia and Papua New Guinea - 3, Petroleum. Australian Institute of Mining & Metallurgy Monograph, 7, 155-67.

Riegraf, W. & Luterbacher, H., 1984 - Jurassic foraminifera from the Mazagan Plateau, Deep Sea Drilling Project site 547, Leg 79 off Morocco. In : Hinz, K., Winterer, E.L. et al. (eds), Initial Reports of the Deep Sea Drilling Project, Vol. LXXIX. U.S. Government Printing Office, Washington, D.C., 671-705.

Shafik, S., 1990 - Late Cretaceous nannofossil biostratigraphy and biogeography of the Australian western margin. BMR Report, 295, 164 pp.

Shafik, S., 1991 - Upper Cretaceous and Tertiary stratigraphy of the Fremantle Canyon, South Perth Basin : a nannofossil assessment. BMR Journal of Australian Geology and Geophysics, 12, 65-91.

Shipp, D.J., 1989 - The Oxfordian to Portlandian (Upper Jurassic). In : Jenkins, D.G. & Murray, J.W., (eds.) Stratigraphical atlas of fossil foraminifera - 2nd edition. Ellis Horwood Limited, Chichester, 237-262.

Stagg, H.M.J. & Exon, N.F., 1981 - Geology of the Scott Plateau and Rowley Terrace off northwestern Australia. Bureau of Mineral Resources, Australia, Bulletin 213.

Symonds, P.A., 1984 - ODP drilling proposals for the Wallaby Plateau and Saddle. In :_Crook, K.A.W., Falvey, D.A. & Packham, G.H. (Eds.), Site proposals for scientific ocean drilling in the Australasian region. Consortium for Ocean Geosciences Publication 2, 173 p, Canberra.

Symonds, P.A. & Cameron, P.J., 1977 - The structure and stratigraphy of the Carnarvon Terrace and Wallaby Plateau. APEA Journal, 17, 30-41.

Thomas, B.M., & Smith, D.N., 1976 - Carnarvon Basin. In : Leslie, R.B., Evans, H.J. & Knight, C.L. (Eds.), Economic Geology of Australia and Papua New Guinea - 3, Petroleum. Australasian Institute of Mining & Metallurgy Monograph, 7, 126-55.

Thompson, P.B., Be, A.W.H., Duplussey, J.C. & Shackleton, N.J., 1979 - Disappearance of pink-pigmented Globigerinoides ruber at 120,000 yr BP in the Indian and Pacific Oceans. Nature, 280, 554-558.

Tourmarkine, M. & Luterbacher, H., 1985 - Paleocene and Eocene planktic foraminifera. In : Bolli, H.M., Saunders, J.B., & Perch-Nielson, K (eds). Planktonic stratigraphy. Cambridge University Press, 87-153.

Veever, J.J., & Cotterill, D., 1978 - Western margin of Australia - evolution of a rifted arch system. Bulletin Geological Society of America, 98, 337-55.

Von Rad, U. & Exon, N.F., 1983 - Mesozoic-Cenozoic sedimentary and volcanic evolution of the starved passive margin off northwest Australia. AAPG Memoir, 34, 253-81.

Von Rad, U., Schott, M., Exon, N.F., Quilty, P.G., Mutterlose, J. & Thurow, J.W., 1990 - Mesozoic sedimentary and volcanic rocks dredged from the northern Exmouth Plateau : petrography and microfacies. BMR Journal of Australian Geology and Geophysics, 11, 449-72.

Von Stackelberg, U., Exon, N.F., Von Rad, U., Quilty, P., Shafik, S., Beiersdorf, H., Seibertz, E. & Veevers, J.J., 1980 - Geology of the Exmouth and Wallaby Plateaus off northwest Australia : sampling of seismic sequences. BMR Journal of Australian Geology and Geophysics, 5, 113-40.

Warris, B.J., 1976 - Canning Basin, offshore, In : Leslie, R.E., Evans, H.J. & Knight, C.L., Economic Geology of Australia and Papua New Guinea - 3, Petroleum. Australasian Institute of Mining & Metallurgy, Monograph 7, 541.

Williamson, M.A. & Stam, B., 1988 - Jurassic/Cretaceous Epistominidae from Canada and Europe. Micropaleontology, 32, 136-158.

Williamson, P.E., Exon, N.F., Ul Haq, B., Von Rad, U. & Leg 122 Shipboard Scientific Party, 1989 - A Northwest Shelf Triassic reef play : results from ODP Leg 122. APEA Journal, 29, 328-44.

Willis, I., 1988 - Results of exploration, Browse Basin, North West Shelf, Western Australia. In : Purcell, P.G. & R.R. (Eds.), The Northwest Shelf, Australia. Proceedings of petroleum Exploration Society Australia Symposium, Perth. 1988, 259-72.

Woods, E.P., 1988 - Extensional structures of the Jabiru Terrace, Vulcan Sub-basin. In : Purcell. P.G. & R.R. (Eds.), The Northwest Shelf, Australia. Proceedings of Petroleum Exploration Society Australia Symposium, Perth, 1988, 311-30.

Wright, A.J. & Wheatley, T.J., 1979 - Trapping mechanisms and the hydrocarbon potential of the Exmouth Plateau. APEA Journal, 19, 19-29.

TABLE 1. DETAILS OF SAMPLING SITES

Area		Site	Seismic Line	Approx. Time/ Shot Point	Dredge/ Core
A	Carnarvon Terrace east of Wallaby Plateau	A1	17/052	35.1255-1300	DR3
		A2	17/052	35.1015-1022	DR2
		A3	18/004	04.0833-0842	DR1
B	Northern Carnarvon Terrace adjac. Exmouth Sub-basin and Cuvier Abyssal Plain	B0	Shell Petrel N300	s.p. 93144	DR4,5,7
		B1	"	s.p. 93135	DR6
		B2	"	s.p. 93000	DR8
		B3	17/058	38.1130-1140	DR9
		B4	"	38.1035-1040	DR10
		B5	56/?	108.0650-0715	DR11
C	Exmouth Plateau	C1	56/13	110.1505-1445	DR29,30
D	Rowley Terrace side of Swan Canyon	D1	S08-004	-?	DR14
		D2	S08-004	-?	DR15
		D3	17/079	65.1415-1350	DR12
		D3A	17/079	65.1355-1345	DR13
		D4	56/25B	?	DR16
		D5	56/25B	?	DR17
		D6	17/079	65.1135-1120	DR18
	Rowley Terrace	RT1	95/012 17/091	81.1310-1300	DR28
E	Western margin of Scott Plateau	E1	18/059	38.1250-1300	DR23
		E2	18/059	38.1245-1255	DR24
		E3	18/061	41.0910-0950	DR22
		E4	18/011	10.0735-0800	DR19

TABLE 1 (cont.)

	E5	18/064	41.2035-2050	DR20
	E6	18/063	41.1750-1815	DR21
	E7	18/064	42.0510-?	DR25
	E8	-	-	DR26
	E9	18/063	41.1920(top)	DR27
F Offshore Canning Basin (Rowley Terrace)	F1	JNOC-07	S.P. 1659-1678	GC1
	F2	Adjacent to JNOC-07	-	GC2,3
	F3	"	-	GC4,5
	F4	"	-	GC6,7
	F5	"	-	GC8
	F6	"	-	GC9,10,11
	F7	"	-	GC12,13
	F8	"	-	GC14,15
	F9	Transit to Area D	500m isobath	GC16
	F10	"	1000m "	GC17,18
	F11	"	2000m "	GC19
G Western margin of Wombat Plateau	G1	17/079	66.1640-1620	DR31
	G2	17/079	66.1725-1700	DR32,33
H SW margin of Exmouth Plateau	H1	55/04 17/068	75.0950-1005 44.1805-1815	DR34
	H2	17/067	44.1230 - 1300	DR35
I Wallaby Plateau	I1	17/048	32.0545-0600	DR36,37,38
	I2	18/073	55.1935	GC20,21,22
Transit, Perth Abyssal Plain	J1	-	-	GC23

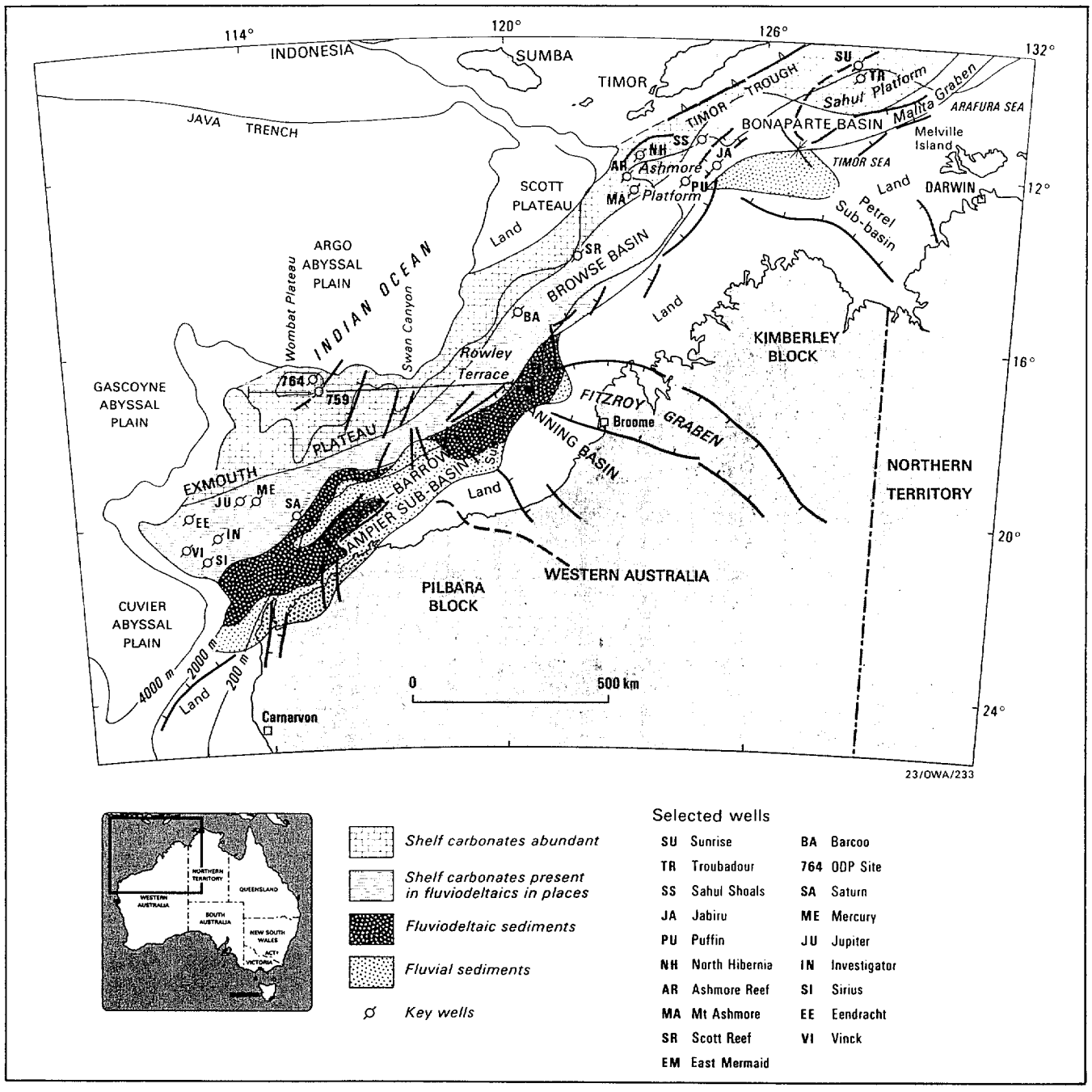


Figure 1. Major structural features of the Northwest Shelf region and predicted distribution of Upper Triassic shelf carbonates (from Falvey & others, 1990).

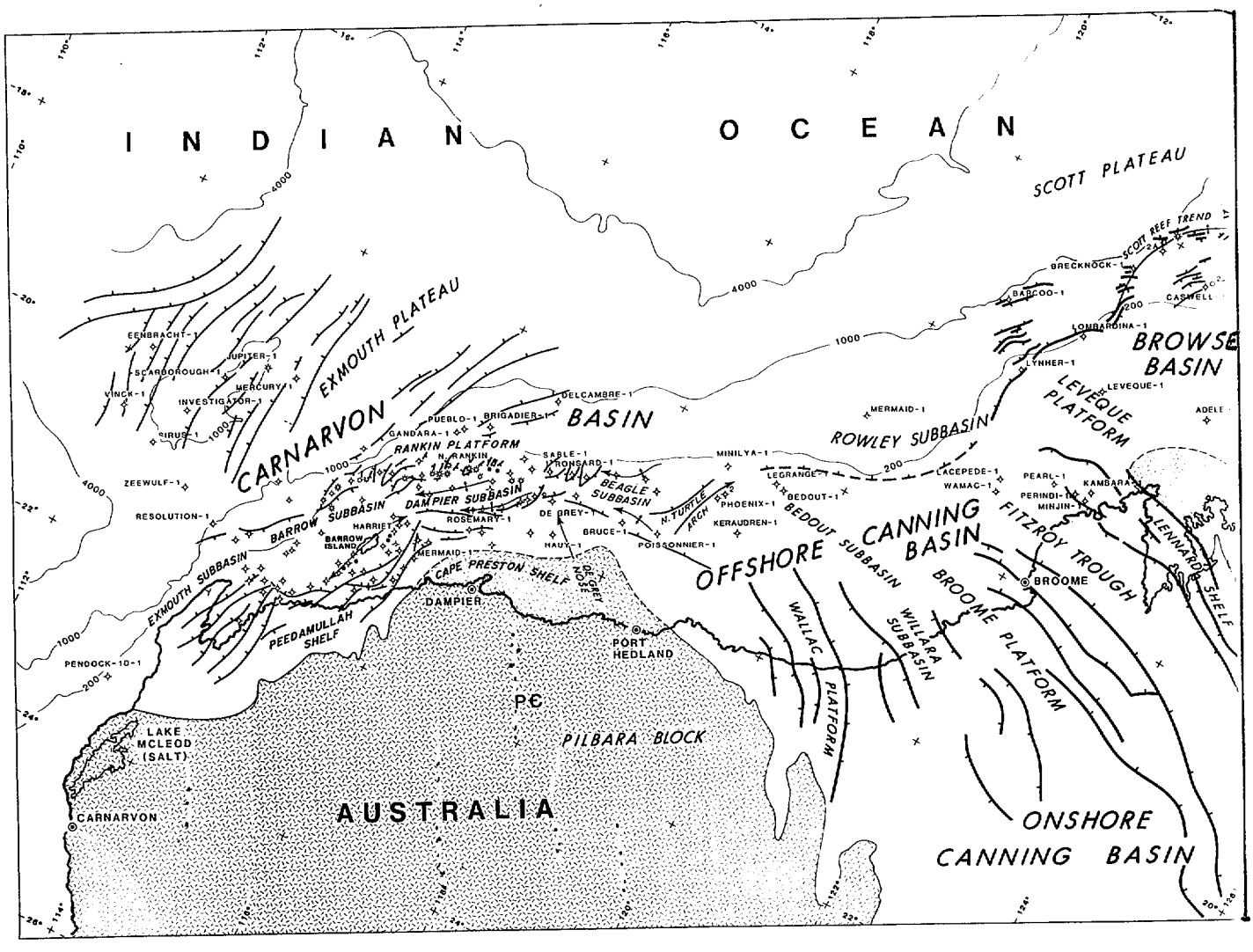


Figure 2. Tectonic elements of the western part of the Northwest Shelf (after Forrest & Horstman, 1986).

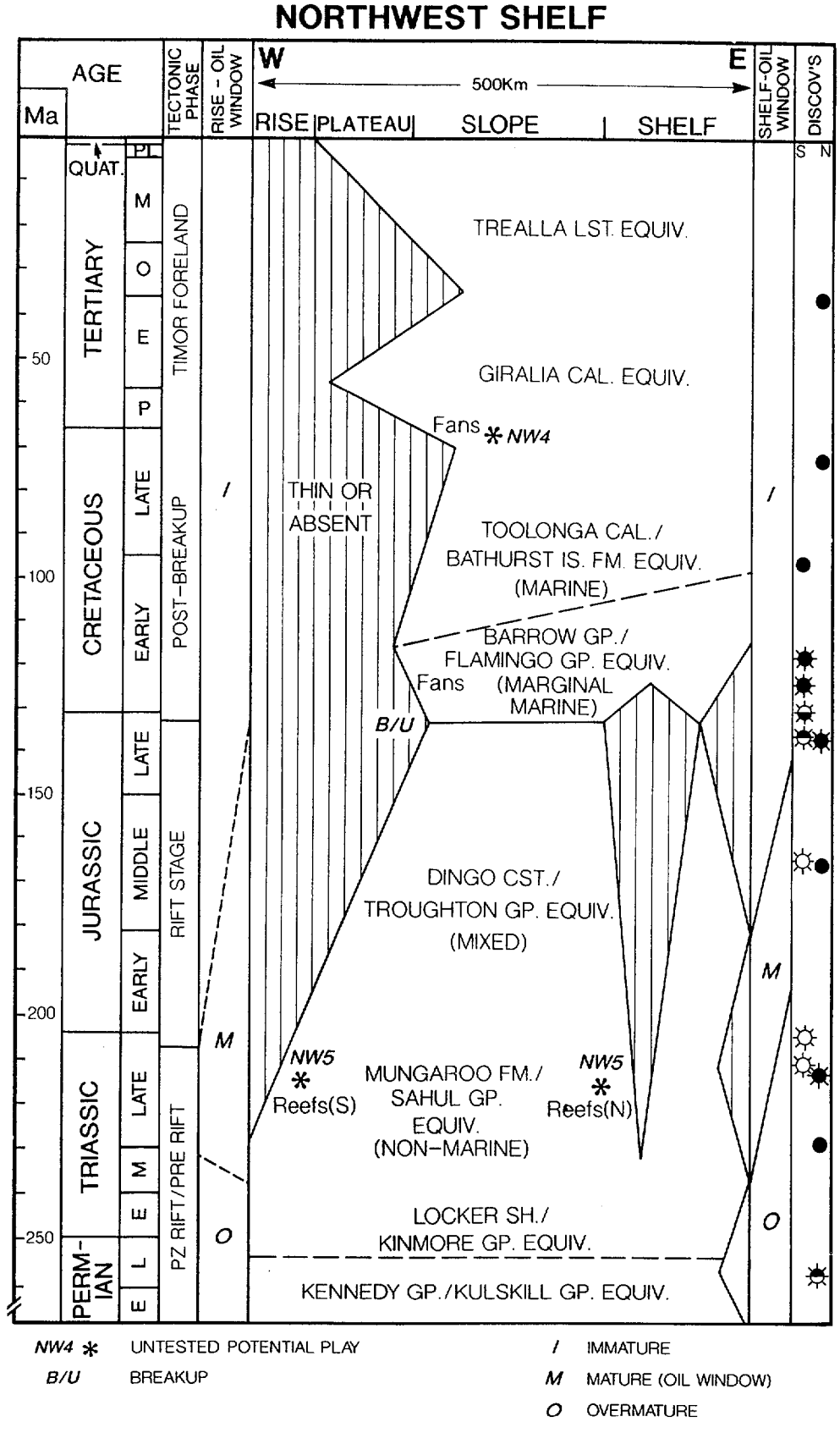


Figure 3. Generalised time-stratigraphic diagram for the Northwest Shelf region (from Falvey & others, 1990).

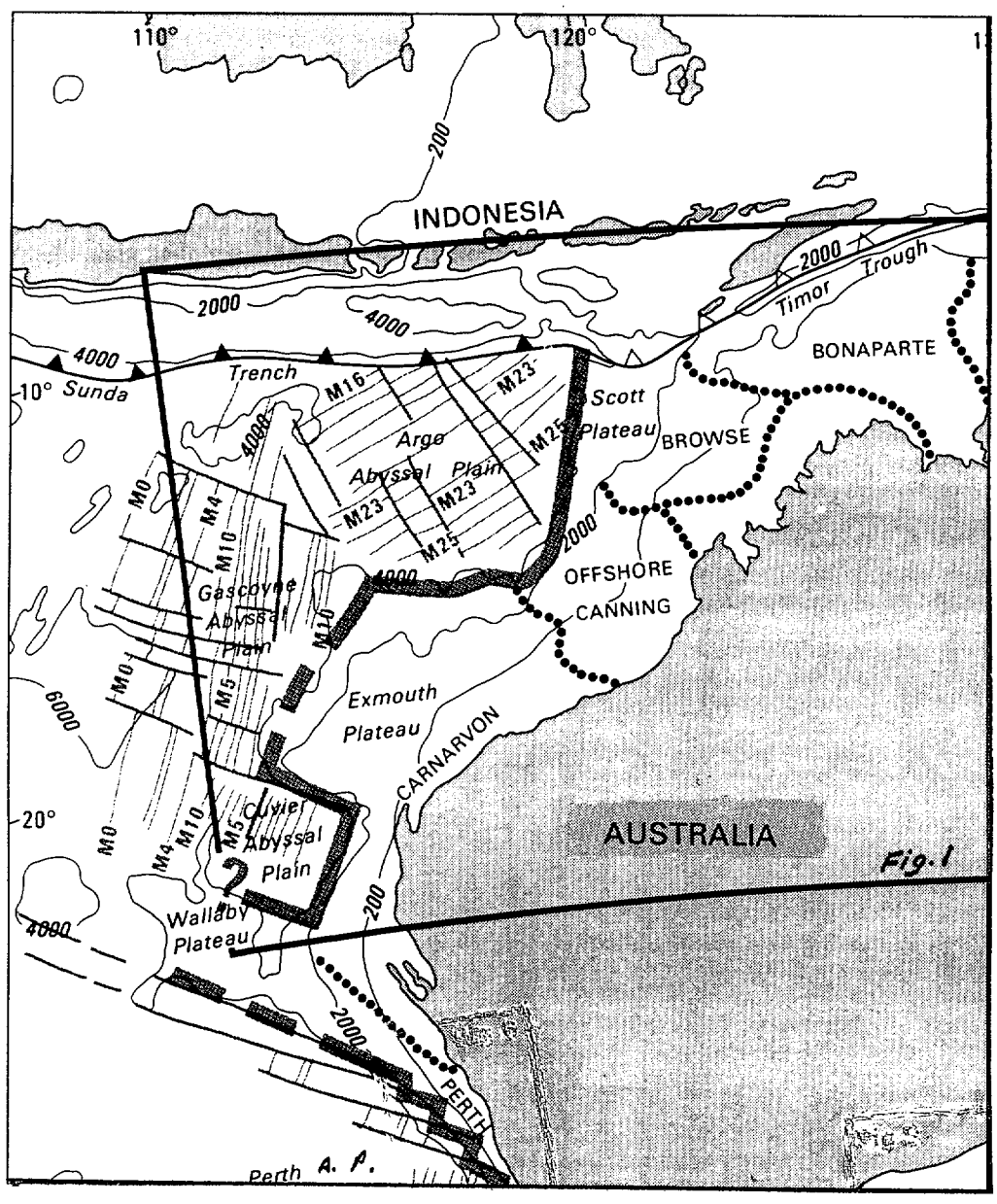


Figure 4. Generalised seafloor spreading anomalies off western Australia (after Falvey & others, 1990). Location of Figure 1 is shown by the box.

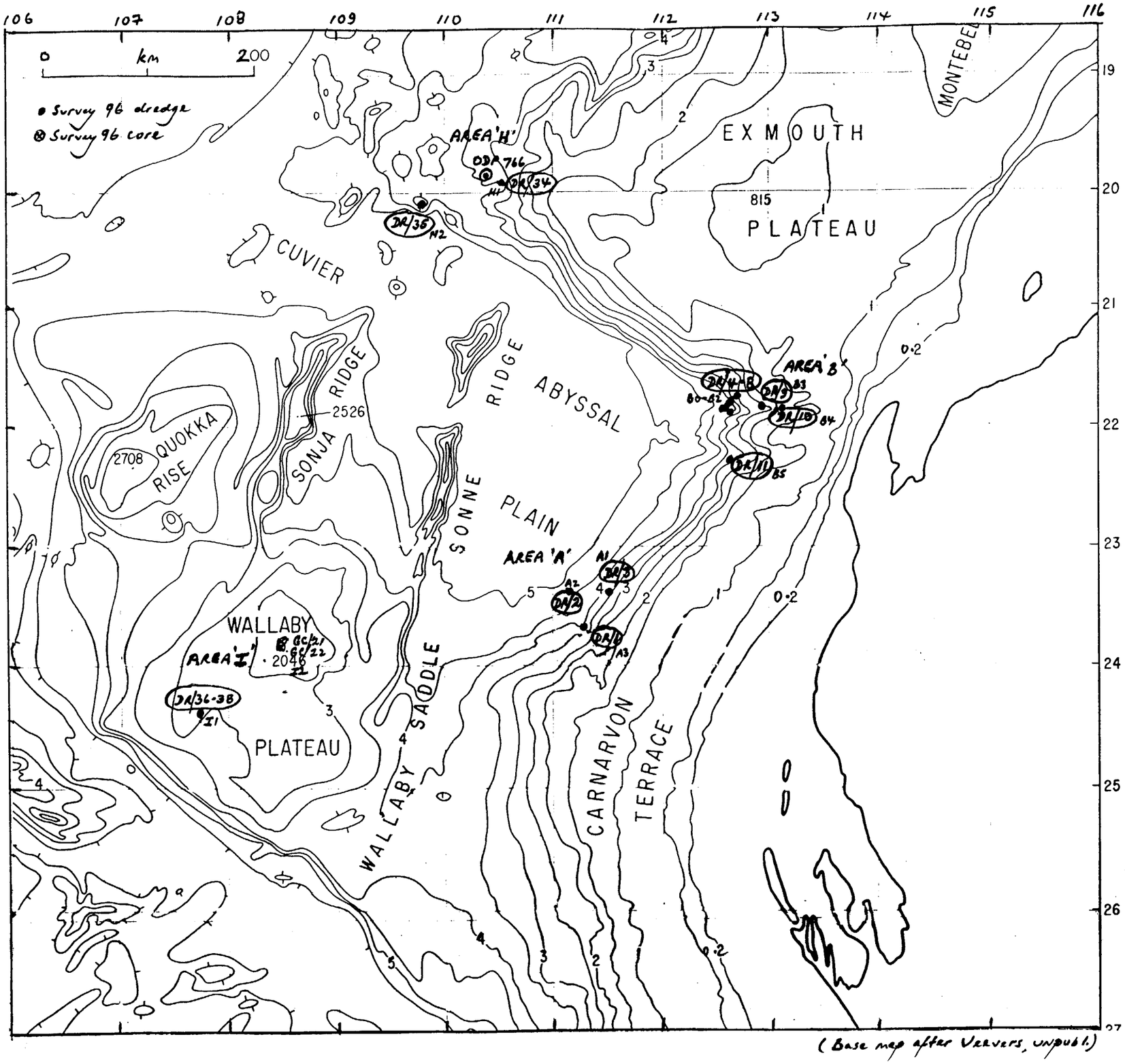


Figure 5. Location of sampling sites, southern part of the survey.

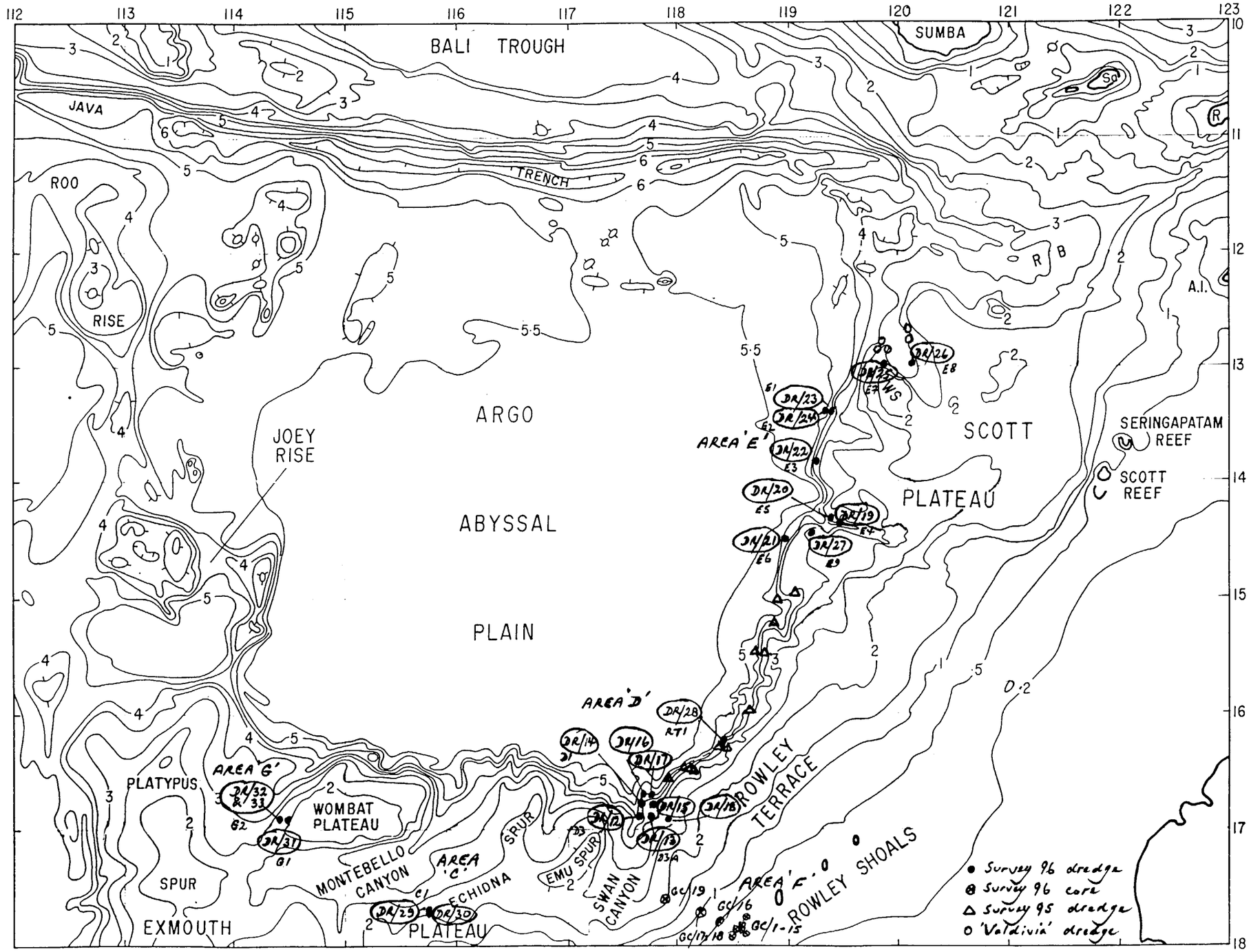


Figure 6. Location of sampling sites, northern part of the survey.

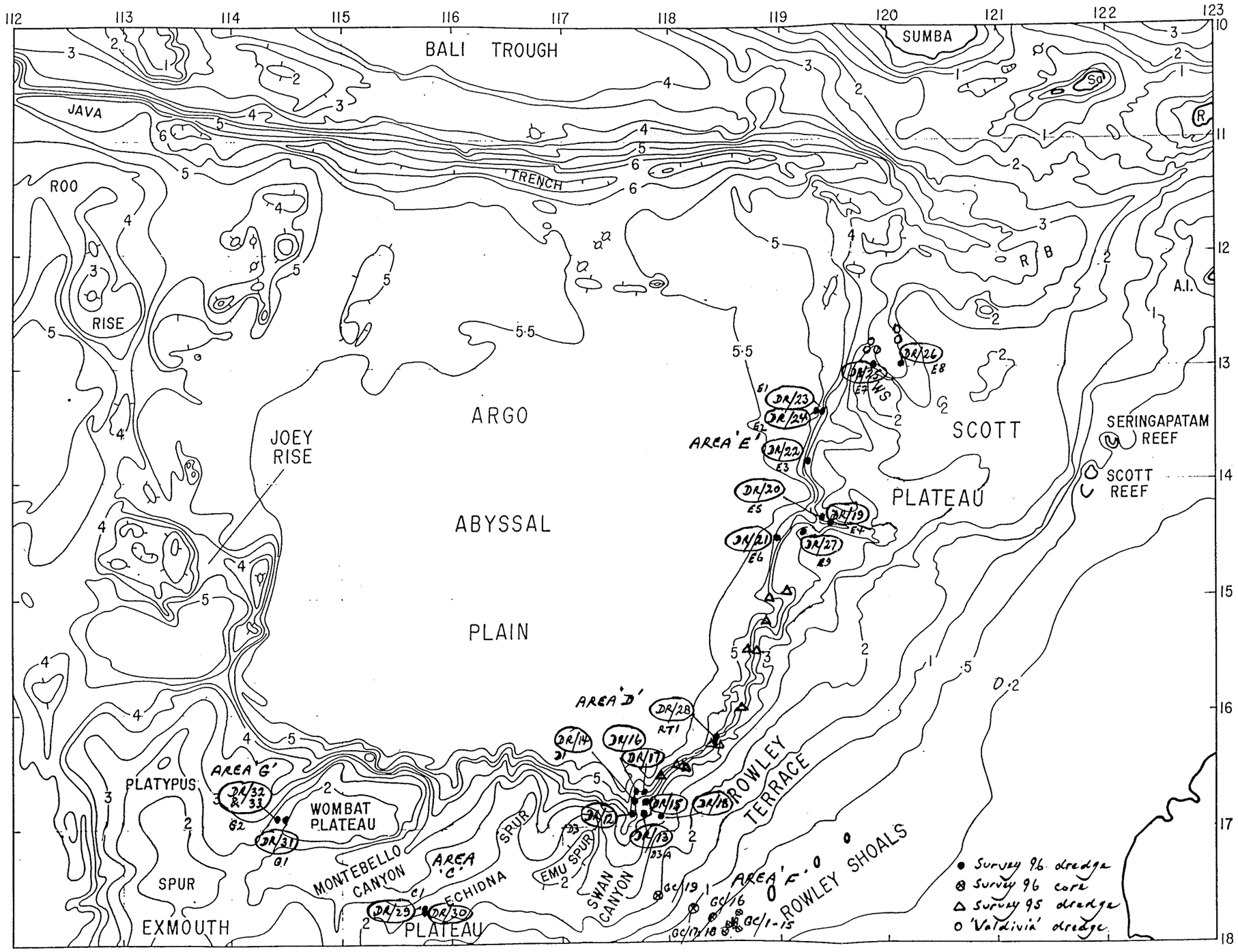
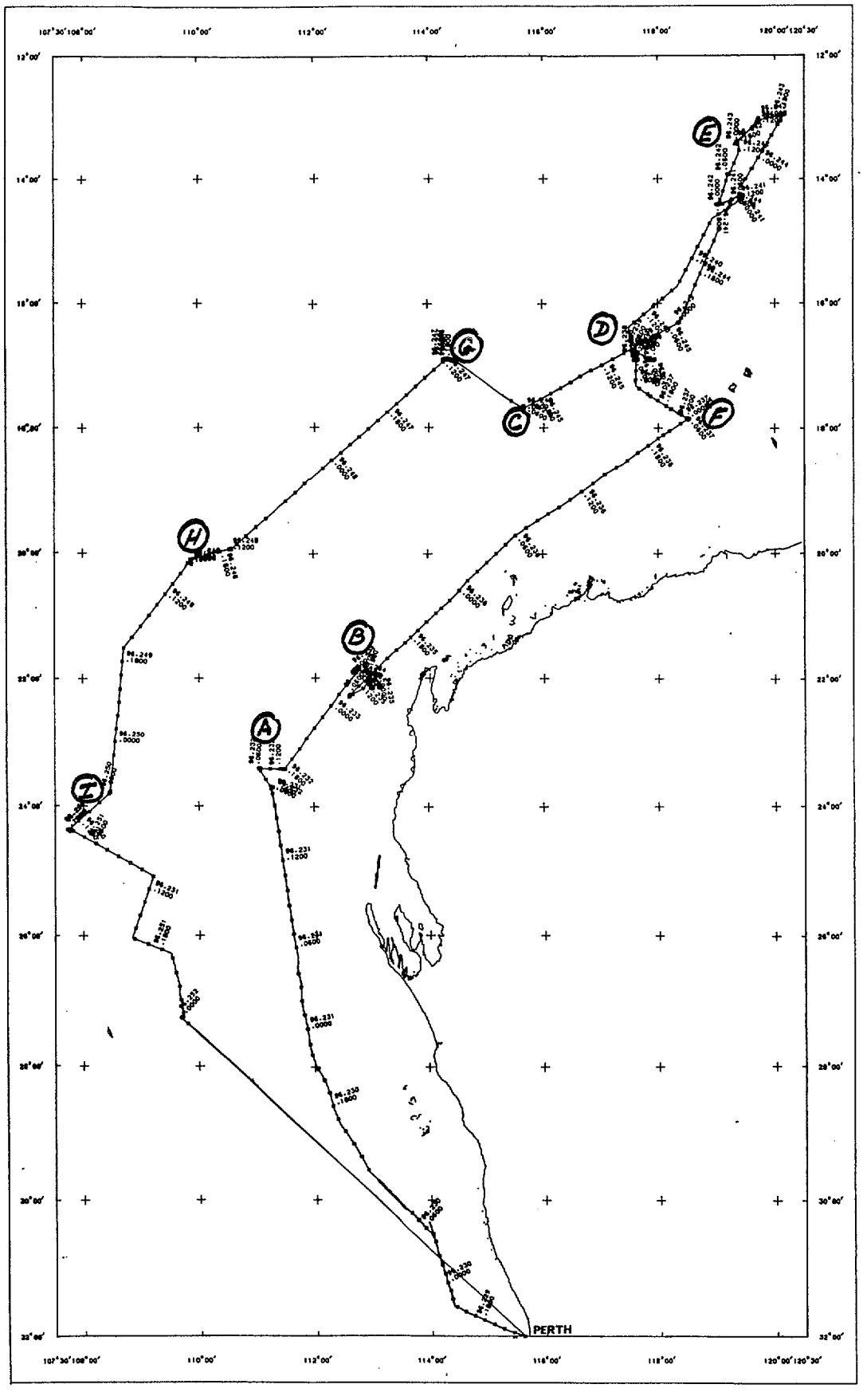


Figure 6. Location of sampling sites, northern part of the survey.

NTH WEST MARGIN STRATIGRAPHY

SCALE 1:6600001 NTH WEST SHELF WEST AUST EDITION OF 1990/09/09



WORLD GEODETIC SYSTEM 1972
UNIVERSAL MERCATOR (SPHERE)
WITH NATURAL SCALE CORRECT
AT LATITUDE 33 00

COMPUTER DRAWN AT THE DIVISION OF
MARINE GEOSCIENCES & PETROLEUM GEOLOGY

R.V. RIG SEISMIC
AUG-SEPT 1990

KILOMETRES
132 0 120 240 360 480
NAUTICAL MILES
60 0 60 120 180 240

NTH WEST MARGIN STRATIGRAPHY
NTH WEST SHELF WEST AUST
SURVEY 96

(A) Sampling areas, Survey 96

Figure 7. Trackmap.

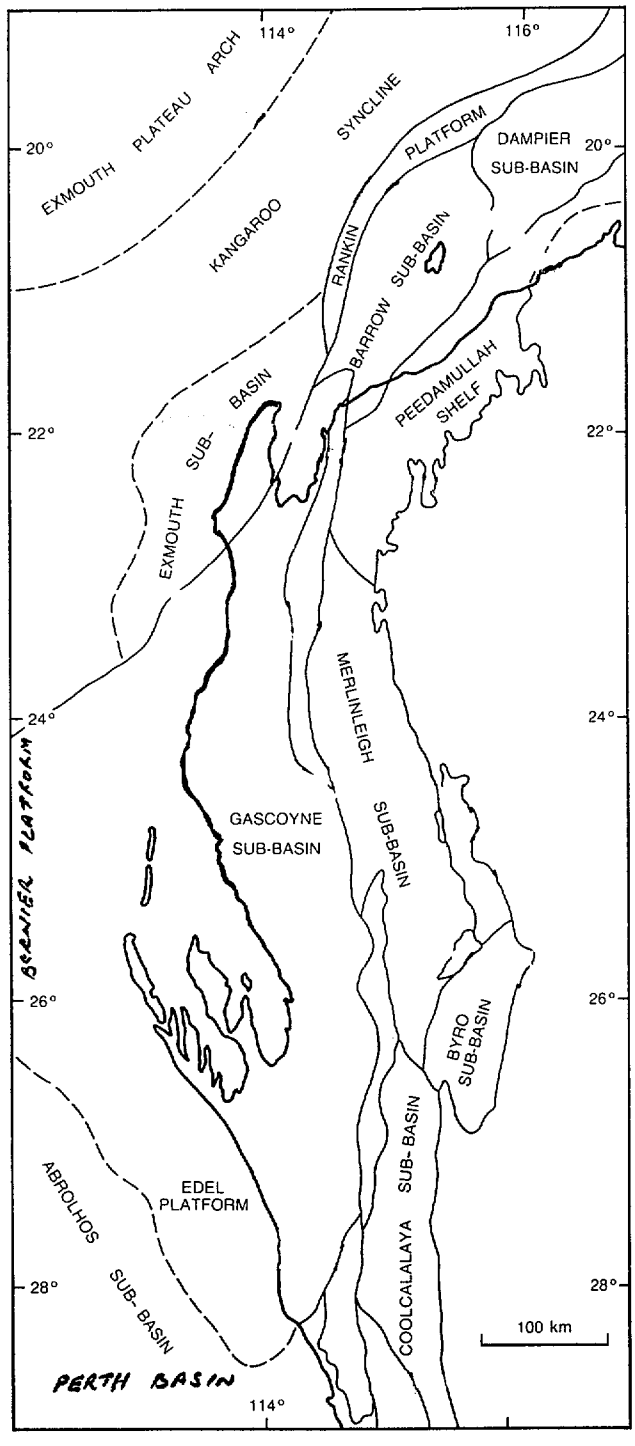


Figure 8. Location and major structural elements of the Carnarvon Basin (after Hocking, 1988).

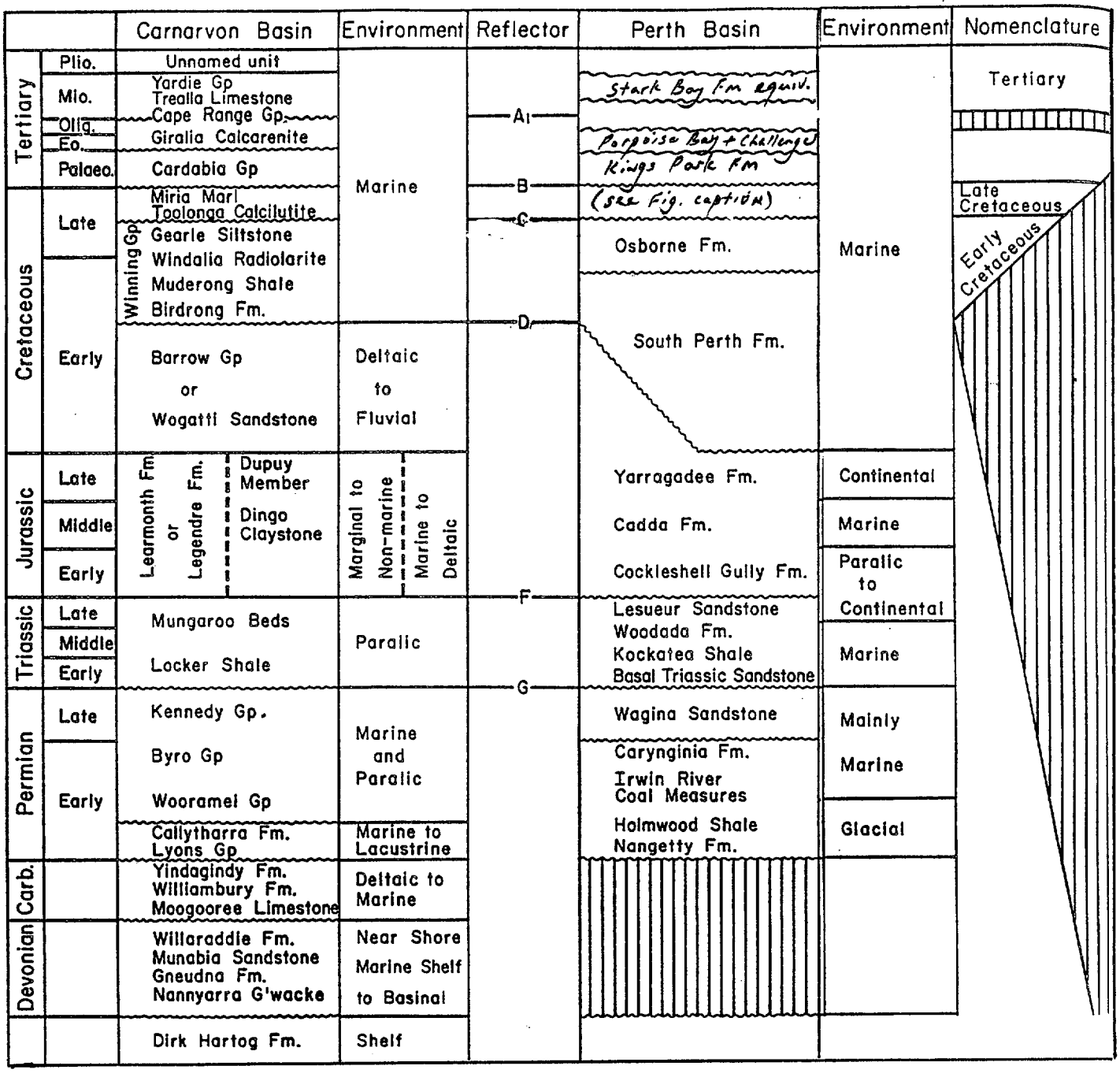


Figure 9. Generalised stratigraphy and principal seismic horizons for the Carnarvon and Perth Basins (after Symonds & Cameron, 1977). Recent work (Shafik, 1990) suggests that the Carnarvon Basin Late Cretaceous post-Winning Group carbonates can be divided into the Miria Marl (Late Maastrichtian), Korojon Calcarenite (Late Campanian-Early Maastrichtian), and Toolonga Calcilutite (Sartonian-Early Campanian). Perth Basin Tertiary stratigraphy after Shafik (1991). Late Cretaceous carbonates in the Perth Basin are the Breton Marl (Late Maastrichtian), and Gingin Chalk (Santonian-Early Campanian)(Shafik, 1990).

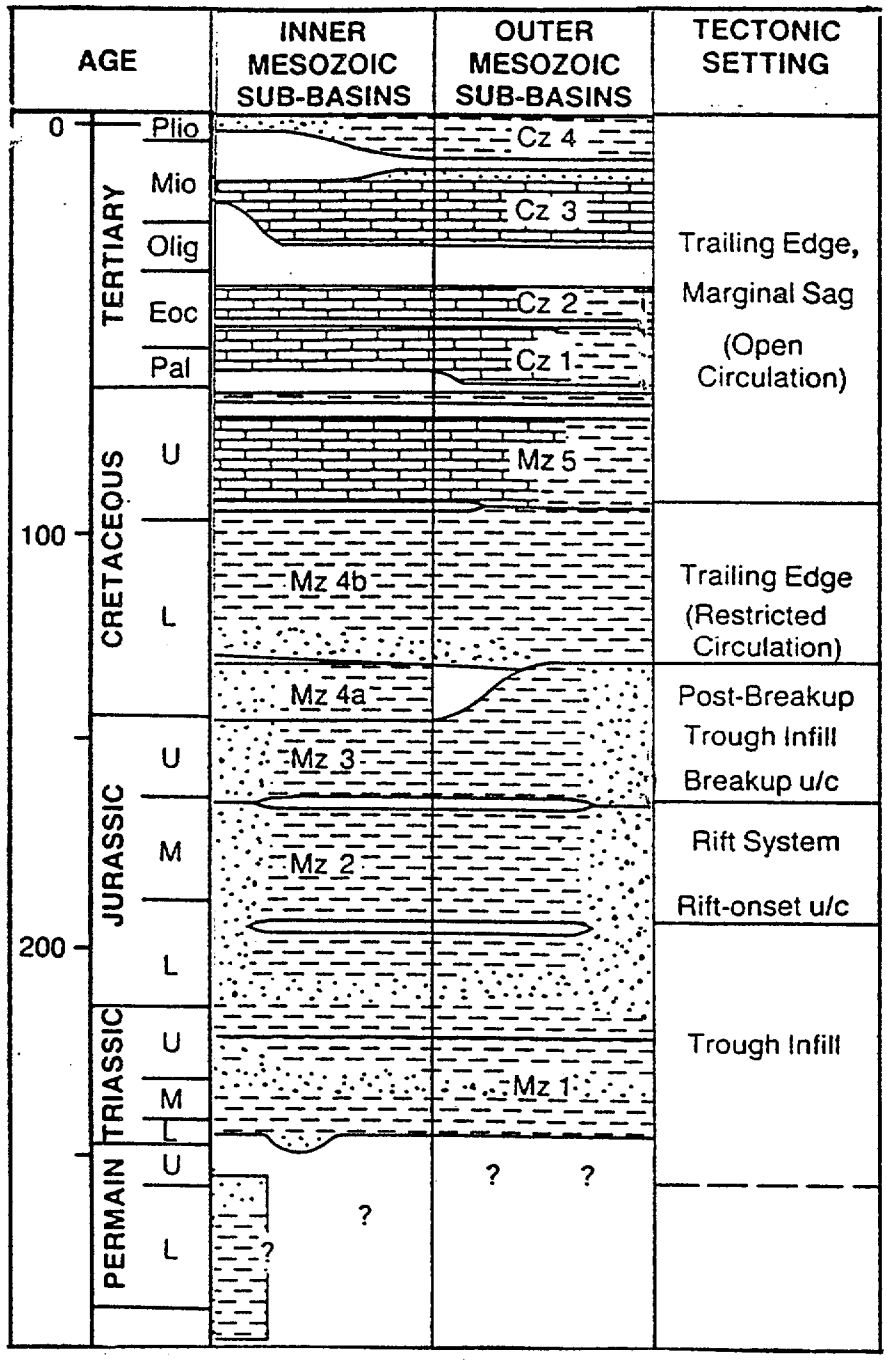


Figure 10. Depositional sequences in the Mesozoic sub-basins of the Carnarvon Basin (after Hocking, 1988).

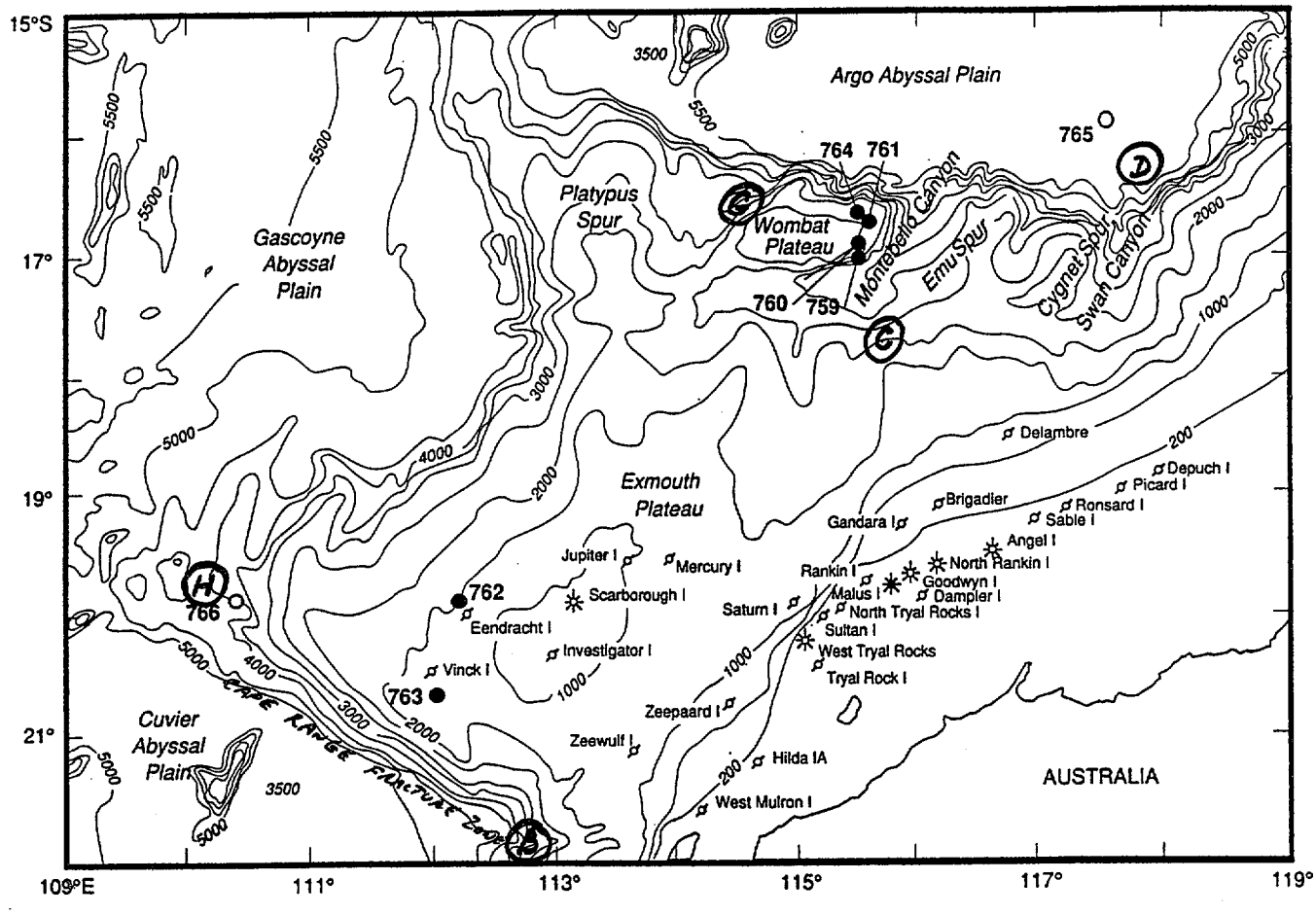


Figure 11. Bathymetric map of the Exmouth Plateau showing the location of ODP Sites (759-764 : Leg 122; 765 & 766 : Leg 123) exploration wells, and Survey 96 sampling areas (after Haq & others, 1990).

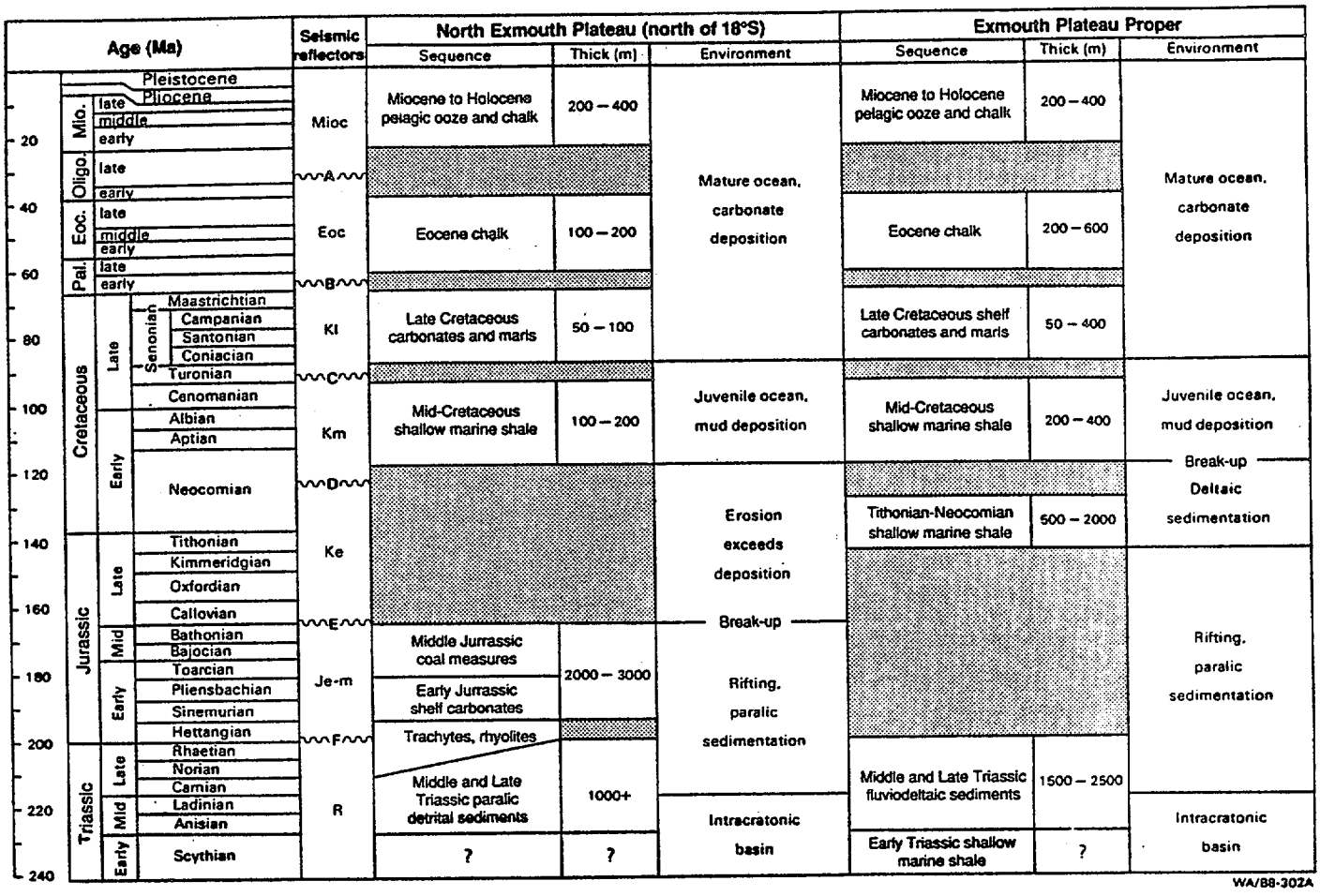
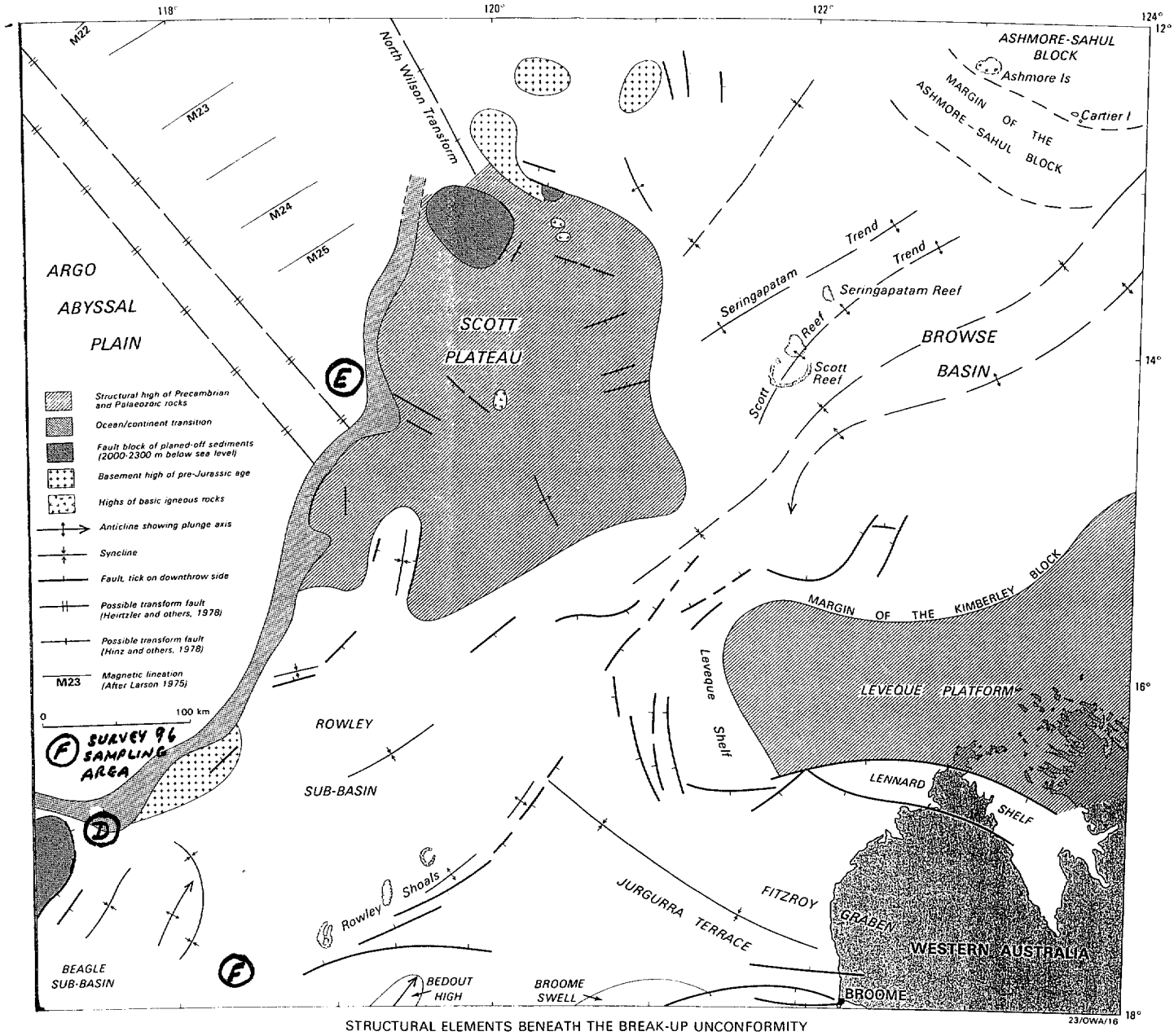


Figure 12. Simplified stratigraphy of the Exmouth Plateau (from Exon & others, 1982).



STRUCTURAL ELEMENTS BENEATH THE BREAK-UP UNCONFORMITY

Figure 13. Structural elements beneath the breakup unconformity in the Scott Plateau region (from Stagg & Exon, 1981).

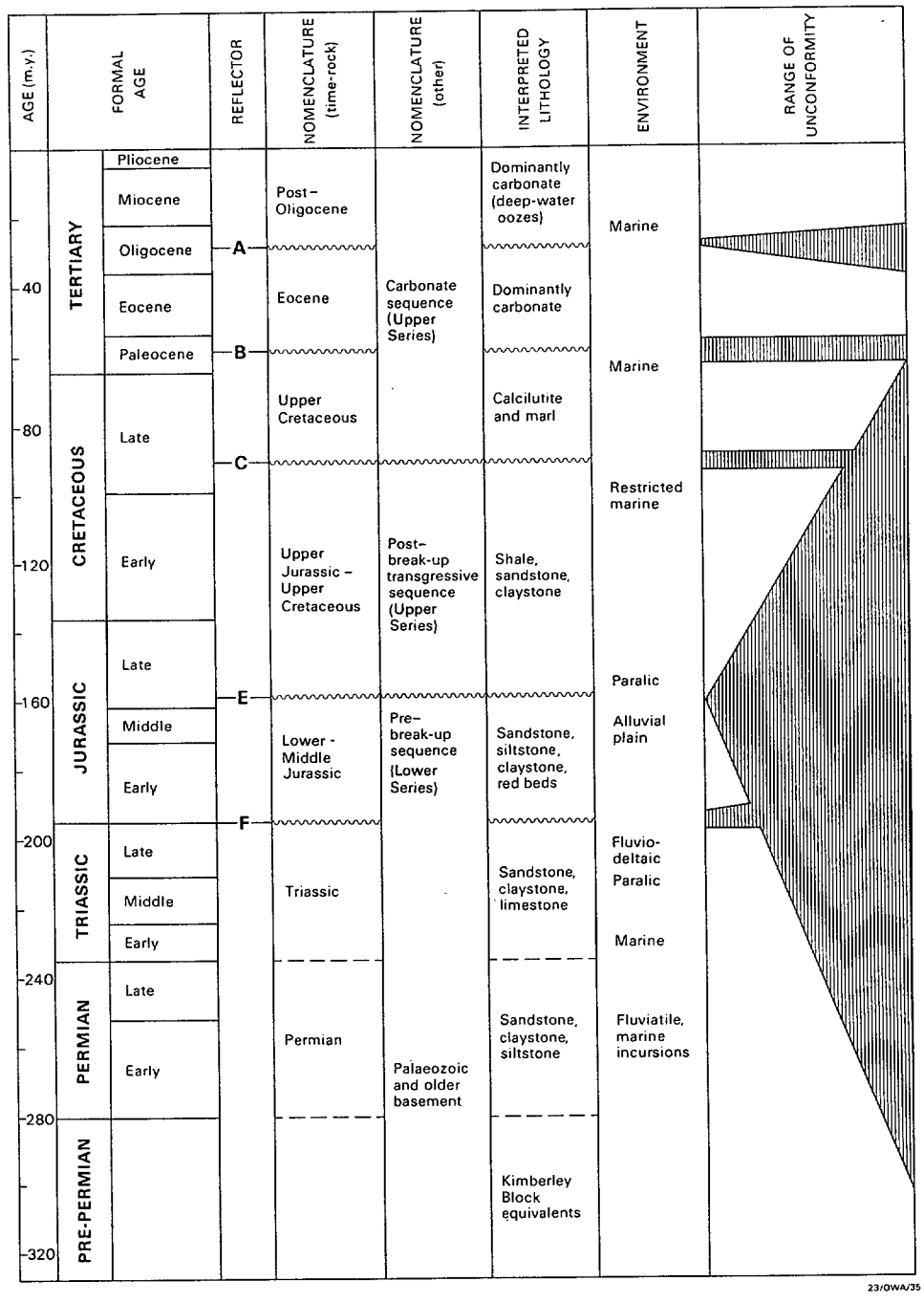


Figure 14. Interpreted stratigraphy of the Rowley Terrace and Scott Plateau (from Stagg & Exon, 1981).

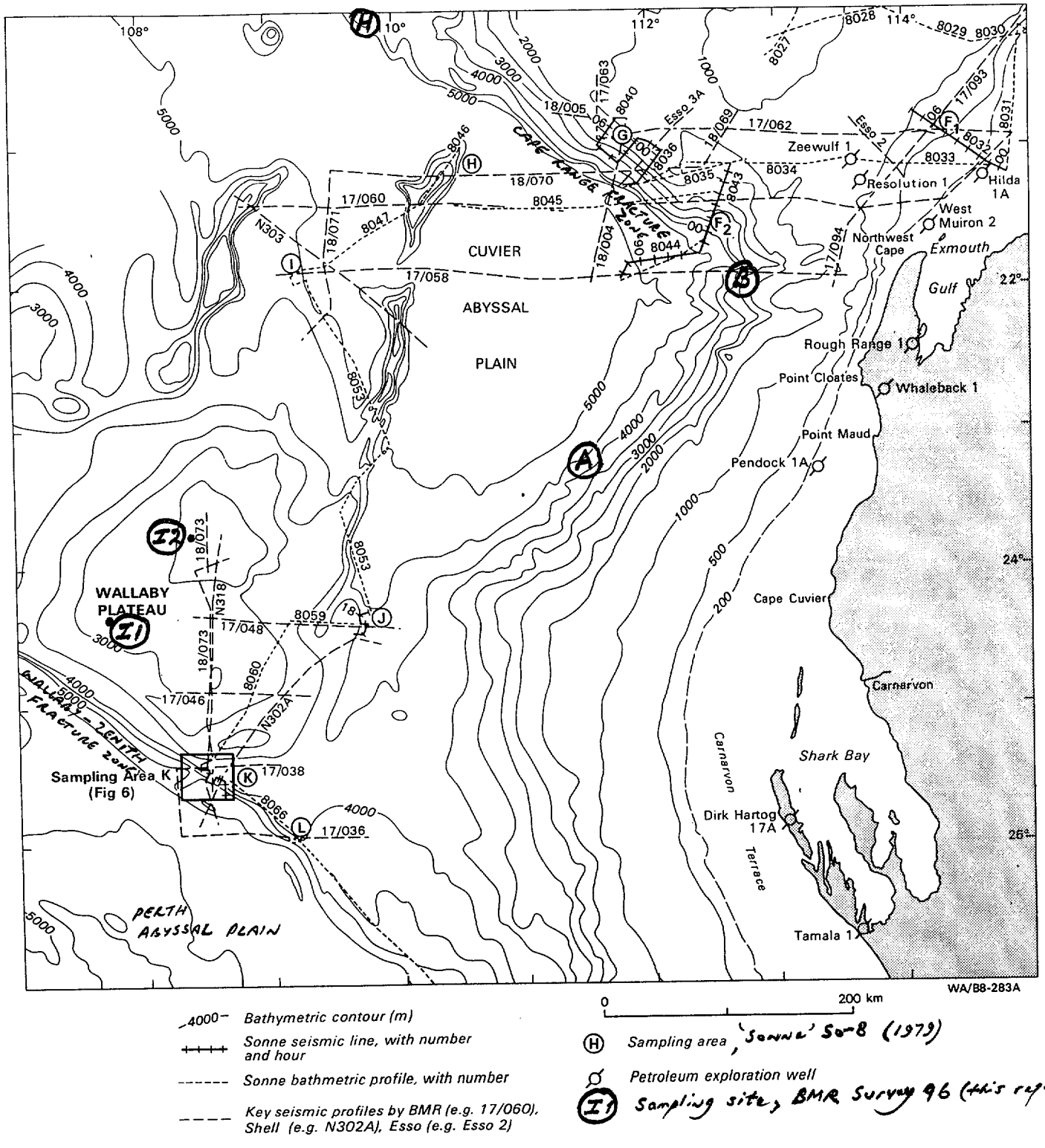


Figure 15. Detailed bathymetry of the Wallaby Plateau and adjacent Carnarvon Terrace regions (after Von Stackelberg & others, 1980) showing location of Survey 96 sampling areas.

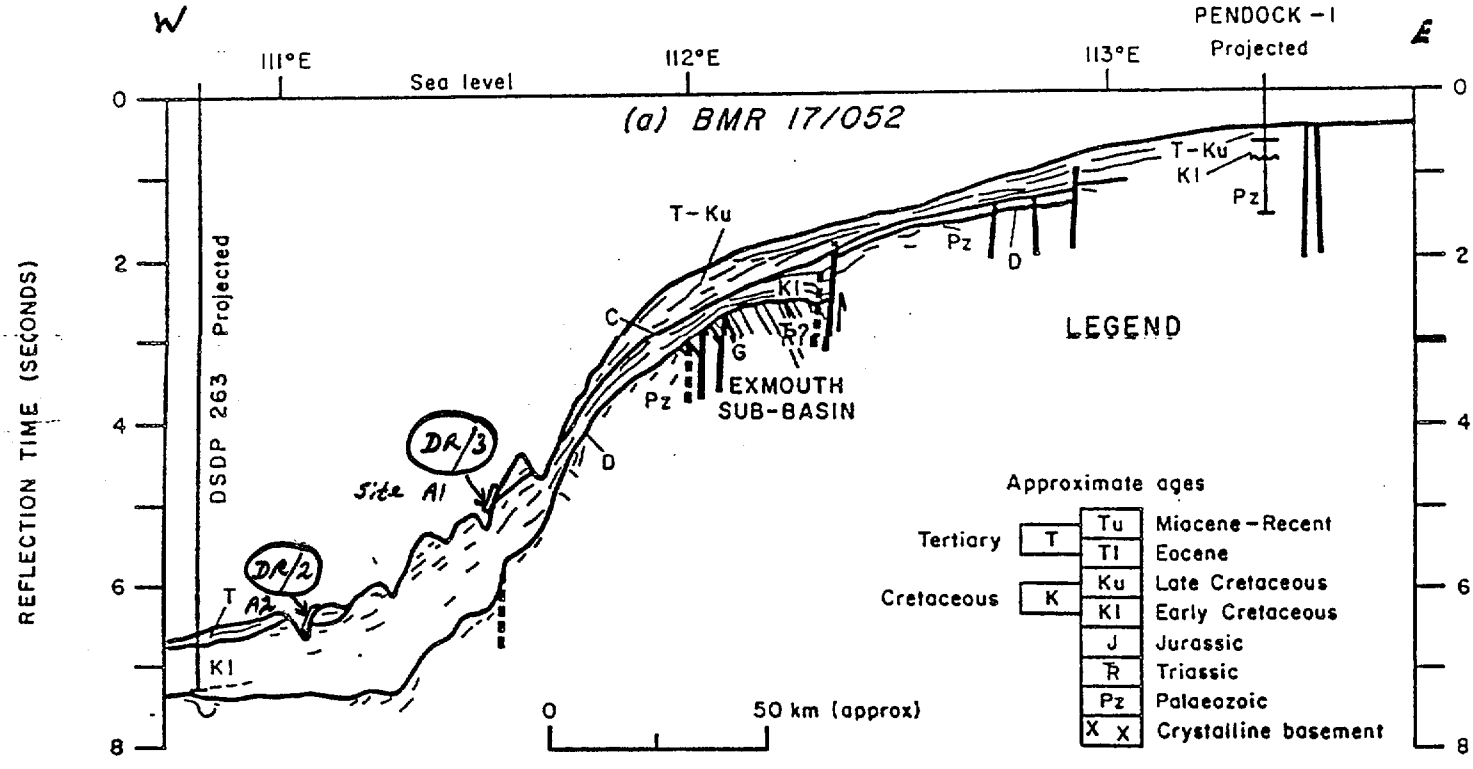


Figure 16. Line drawing of BMR line 17/052 (after Symonds & Cameron, 1977) showing the location of dredges DR/2 and 3 (sites A2 and A1), Carnarvon Terrace.

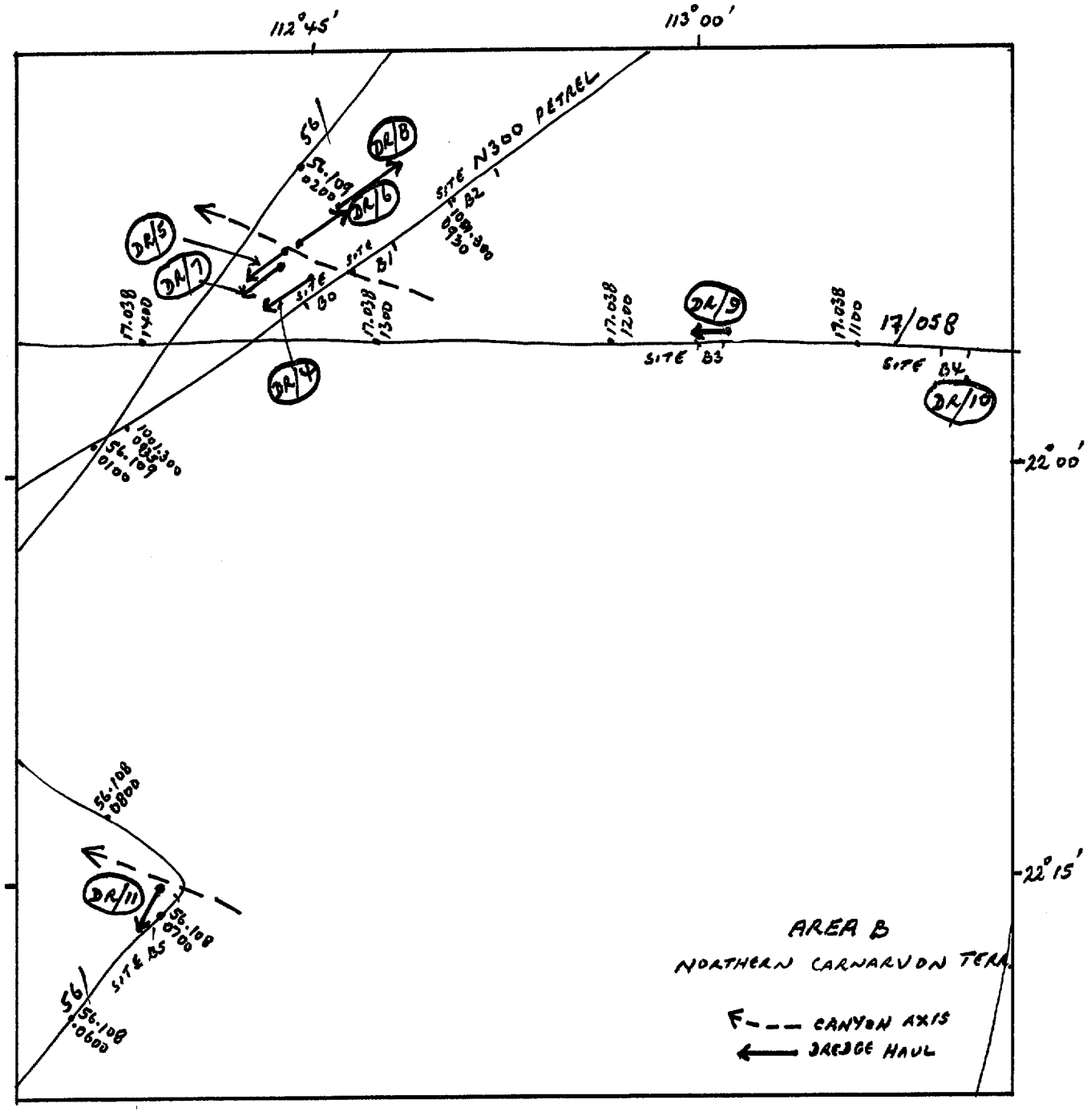


Figure 17. Location map of dredges DR/4-11 (sites B0 to B5), northern Carnarvon Terrace.

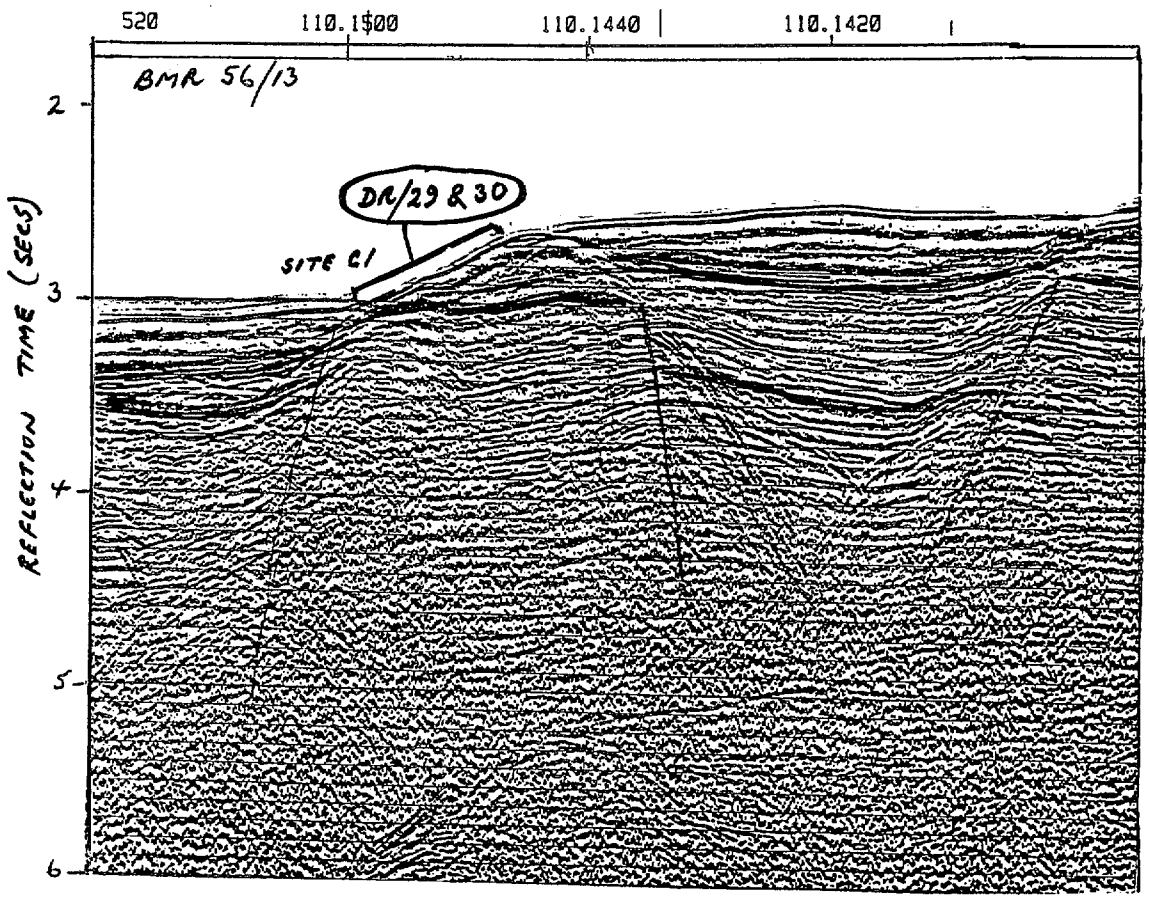


Figure 18. Location of dredges DR/29 and 30 (site C1), BMR line 56/13, central northern Exmouth Plateau.

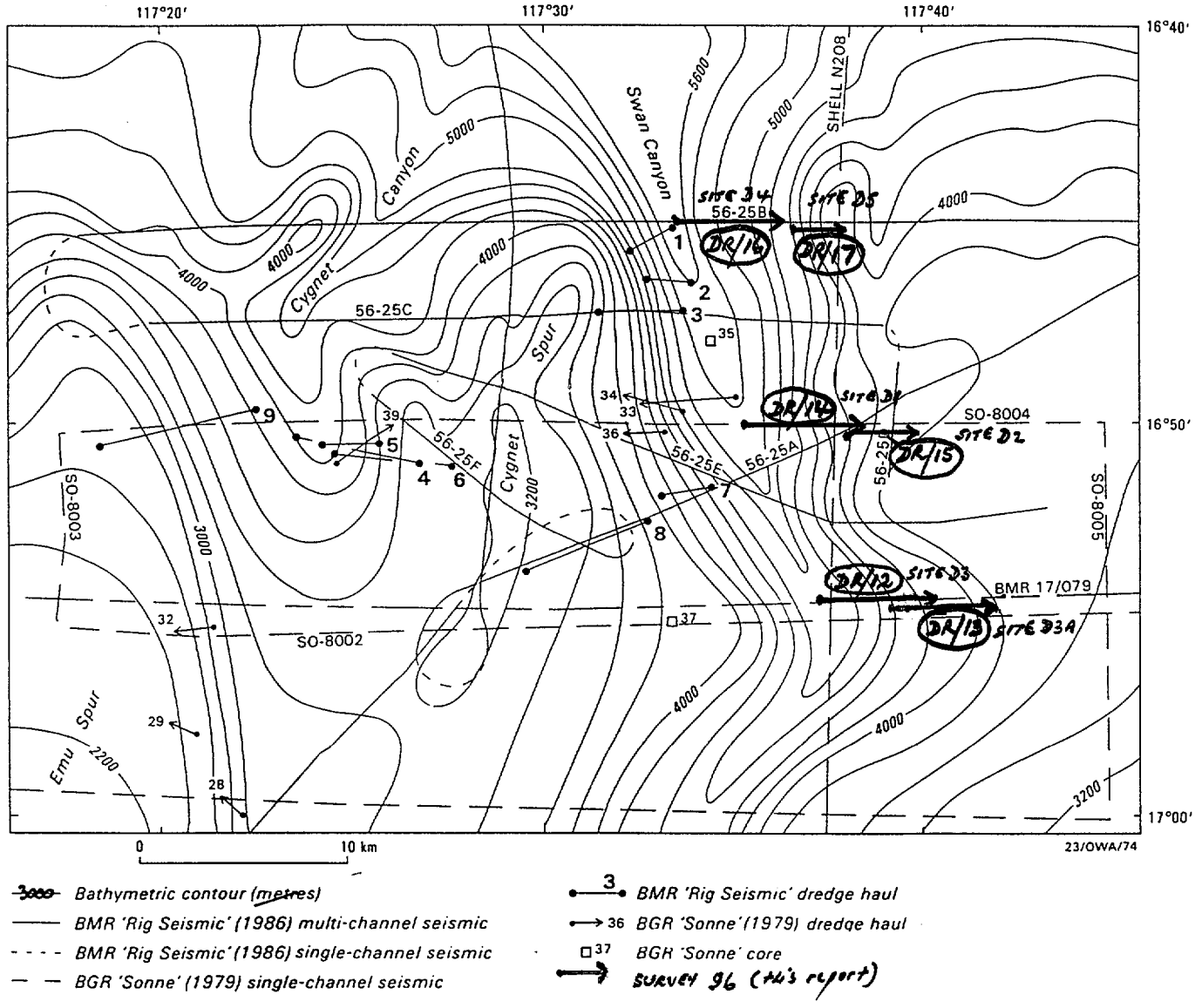
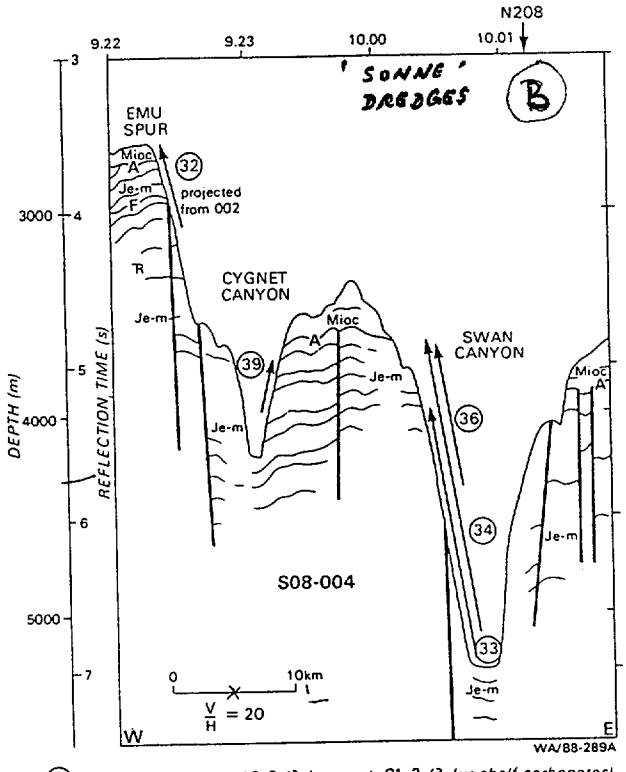


Figure 19. Location map of dredges DR/12-17 (sites D1-D5), Swan Canyon area. Base map from Von Rad & others (1990).



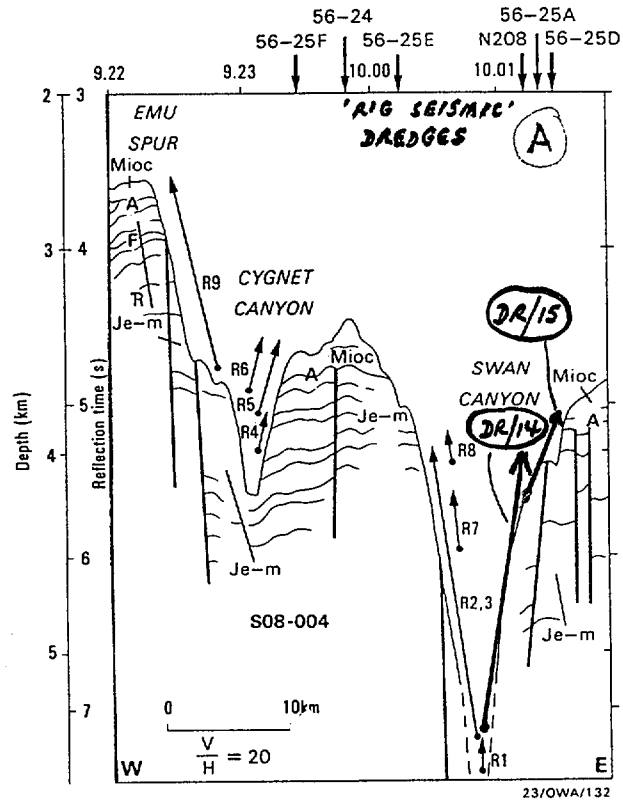
(32) E1 *(m. Mioc.chalk)*; A2,3 *(? Jur.c.m.)*; C1,2 *(? Jur.shelf carbonates)*

(33) E3,4 *(e. Apt chalk)*; A2,3 *(M. Jur c.m.)*

(34) A1-4 *(M. Jur.c.m.)*

(36) E2 *(l. Mioc.- e.Plioc.chalk)*; D2 *(l. Alb.- e.Cenom.shelf Clst)*; A1-4 & B1,2 *(M. Jur.c.m., some weathered)*

(39) D1 *(?Cret./Tertiary Clst)*; D2 *(l Alb - e. Cenom shelf Clst)*; B1-4 *(? Jur.terrest/littoral seds)*; A4,5 *(? Jur.c.m.)* C1,2,4,5 *(? E. Jur.shelf carbonates)*



Swan Canyon

R1: ? Jurassic coal measures (A2,3,4); ? Cretaceous marine clay (D3)
R2: Callovian coal measures (A2,3,4); ? Cretaceous marly clay (D2)
R3: ? Jurassic coal measures (A2,3,4)
R7: ? Early Cretaceous marine shale, sandstone (D3,4,6)
R8: ? Jurassic ironstone (B1,2,5); ? Cretaceous marine claystone, sandstone (D3,4,6)

Cygnet Canyon

R4: Callovian shelf carbonates (C2,3,4,8); ? Jurassic coal measures (A2) and ironstone (B1,2,3); ? Cretaceous marine claystone (D5)
R5: ? Jurassic coal measures (A2) and ironstone (B3)
R6: ? Jurassic ironstone (B3); Late Aptian and Cenomanian marine mudstone, sandstone conglomerate (D2,4,6)
R9: ? Oxfordian shelf carbonates (C1,3,4); ? Cretaceous marine sandstone, mudstone (D2,4,6,7)

Figure 20. Line drawing of Sonne line S08-004 (after Von Rad & others, 1990) showing the location of dredge hauls DR/14 and 15 (sites D1 and D2) on the eastern side of the Swan Canyon, with previous Sonne and Rig Seismic dredge hauls projected onto the line.

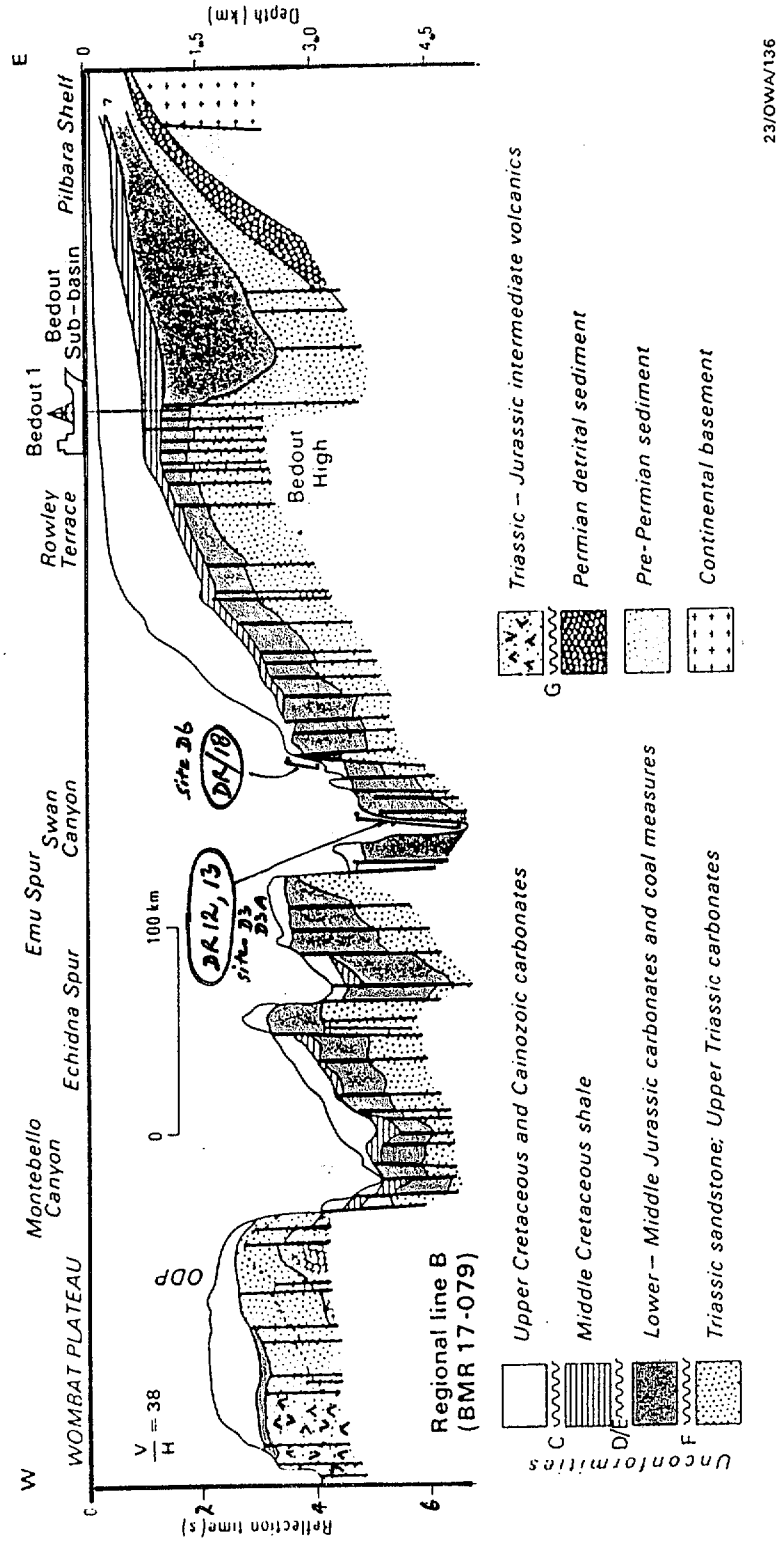


Figure 21. Location of dredges DR/12, 13 and 18 (sites D3, D3A and D6) on BMR line 17/79. Interpretation after Von Rad & others (1990).

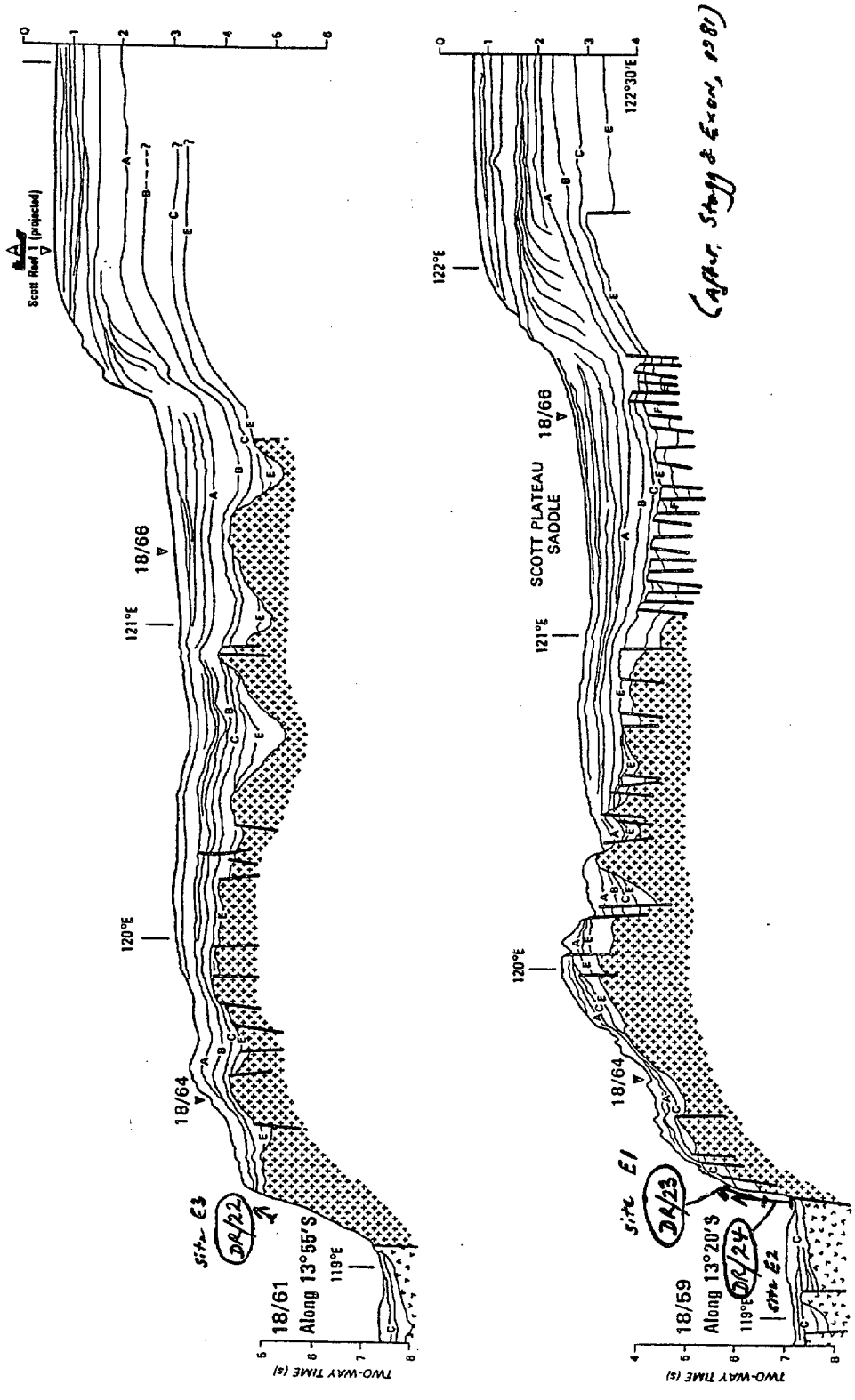


Figure 22. Location of dredges DR/22-24 (sites E1-E3) on BMR seismic lines 18/59 and 18/61. Line drawings and interpretations after Stagg & Exon (1981).

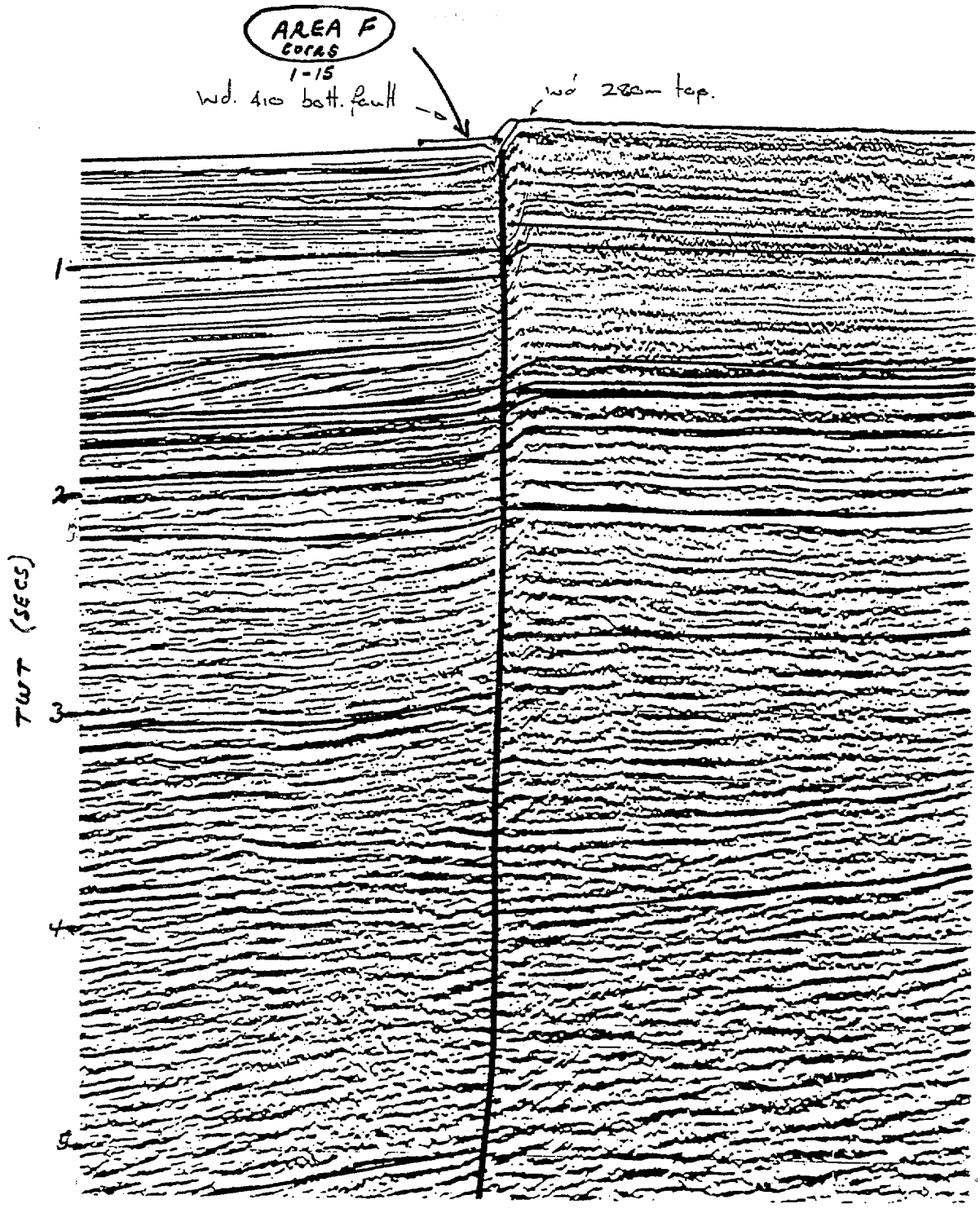


Figure 23. Segment of JNOC 1987 line JN-07 showing the major fault extending to the seabed in Area F.

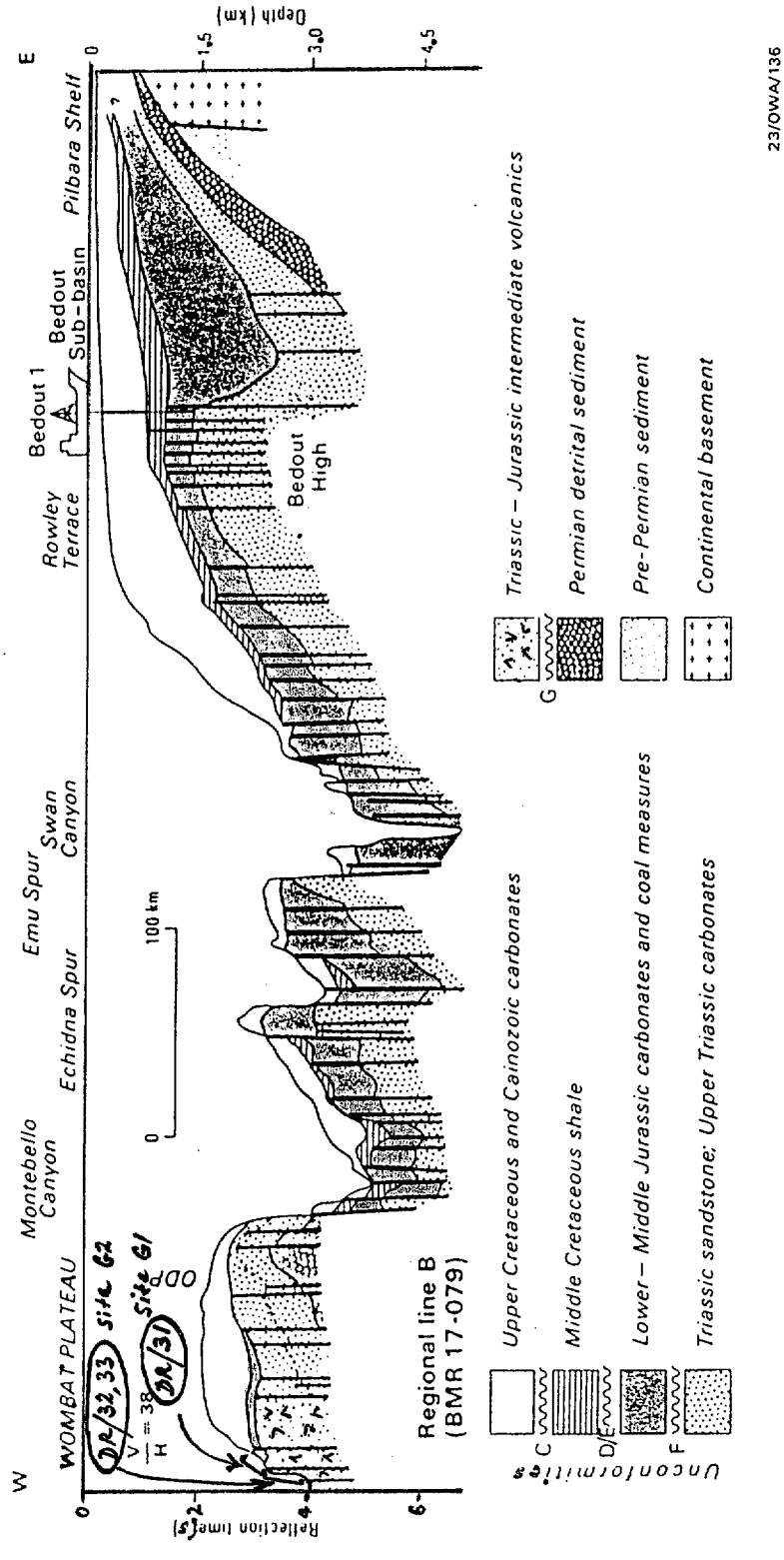


Figure 24. Location of dredges DR/31-33 (sites G1 and G2) on BMR line 17/79. Interpretation after Von Rad & others (1990).

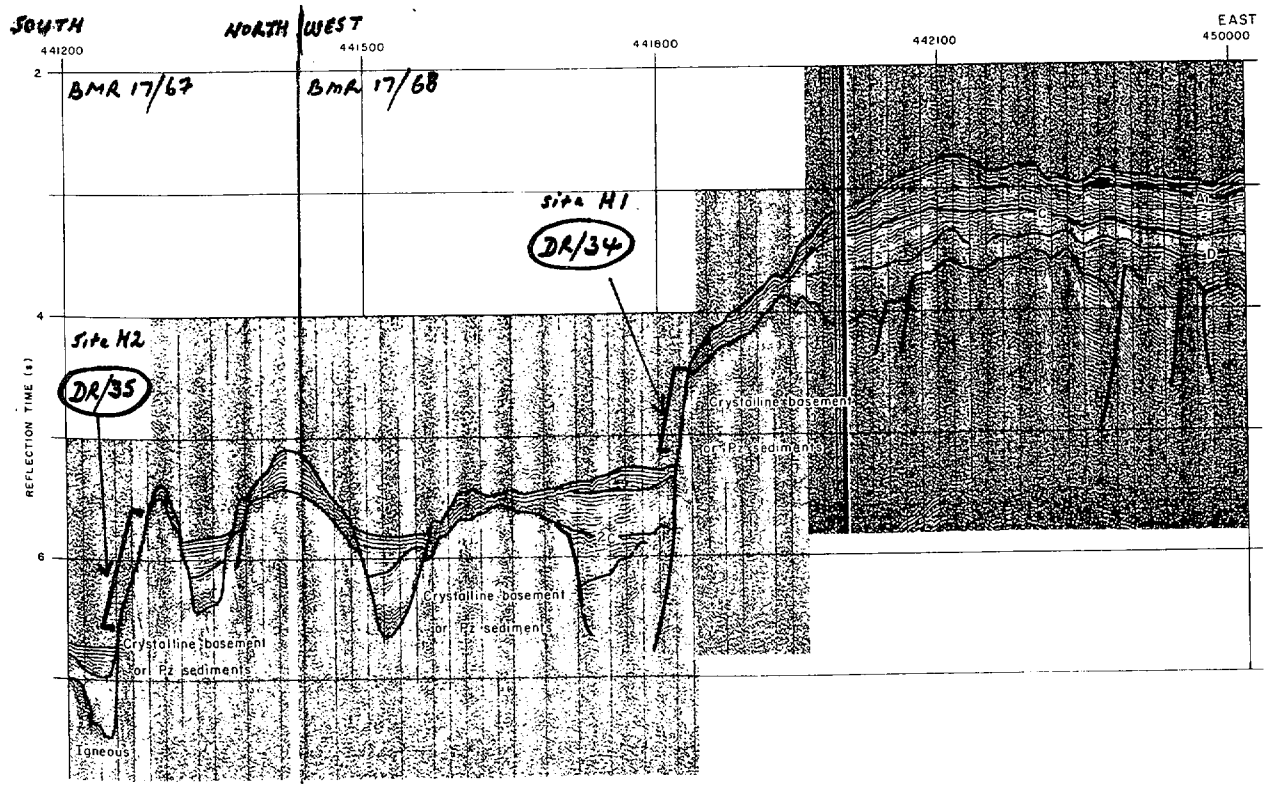


Figure 25. Location of dredges DR/34 and 35 (sites H1 and H2) on BMR line 17/67-68), south western Exmouth Plateau (after Exon & Willcox, 1980).

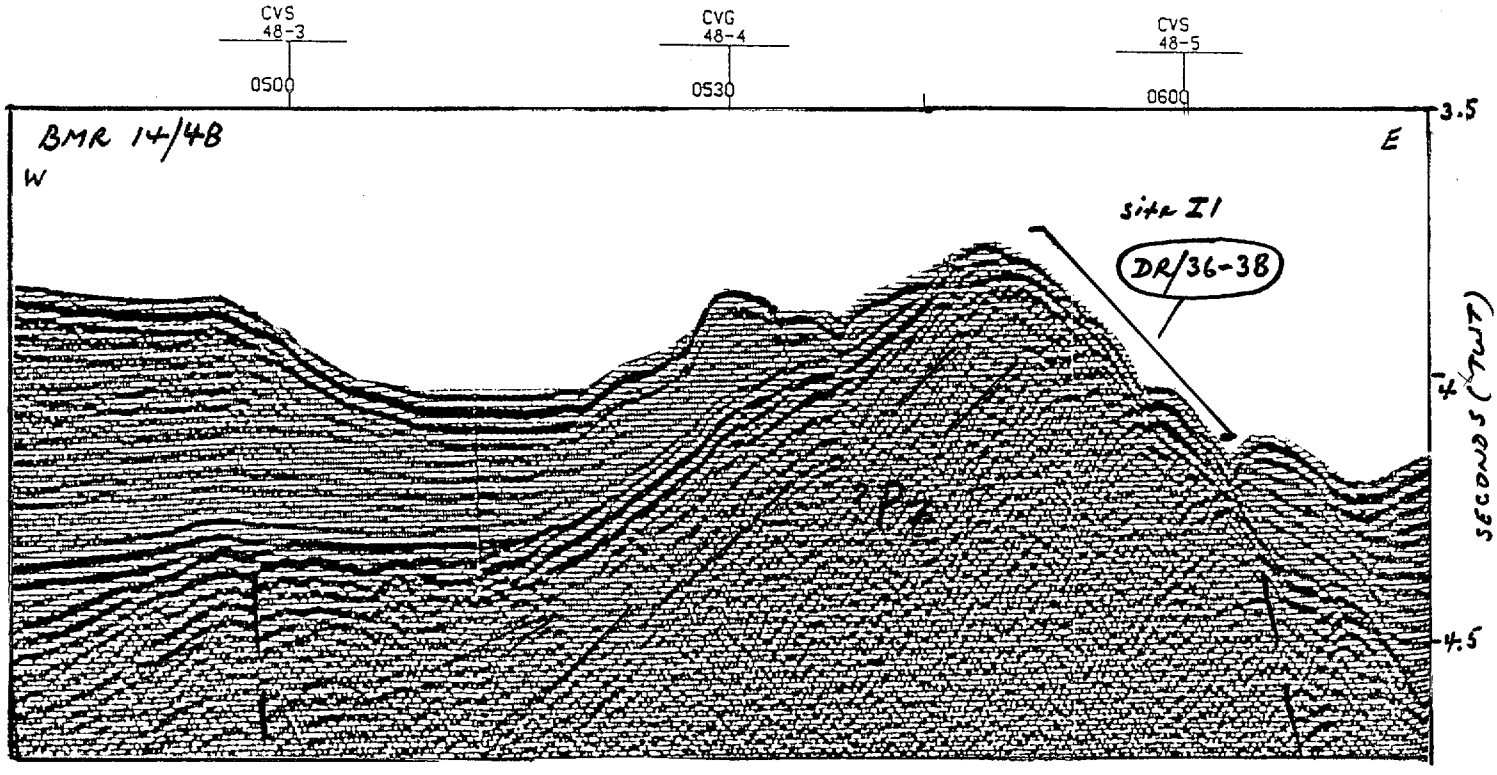


Figure 26. Location of dredges DR/36-38 (site I1) on BMR line 17/48, central Wallaby Plateau. Note the dipping basement reflectors.

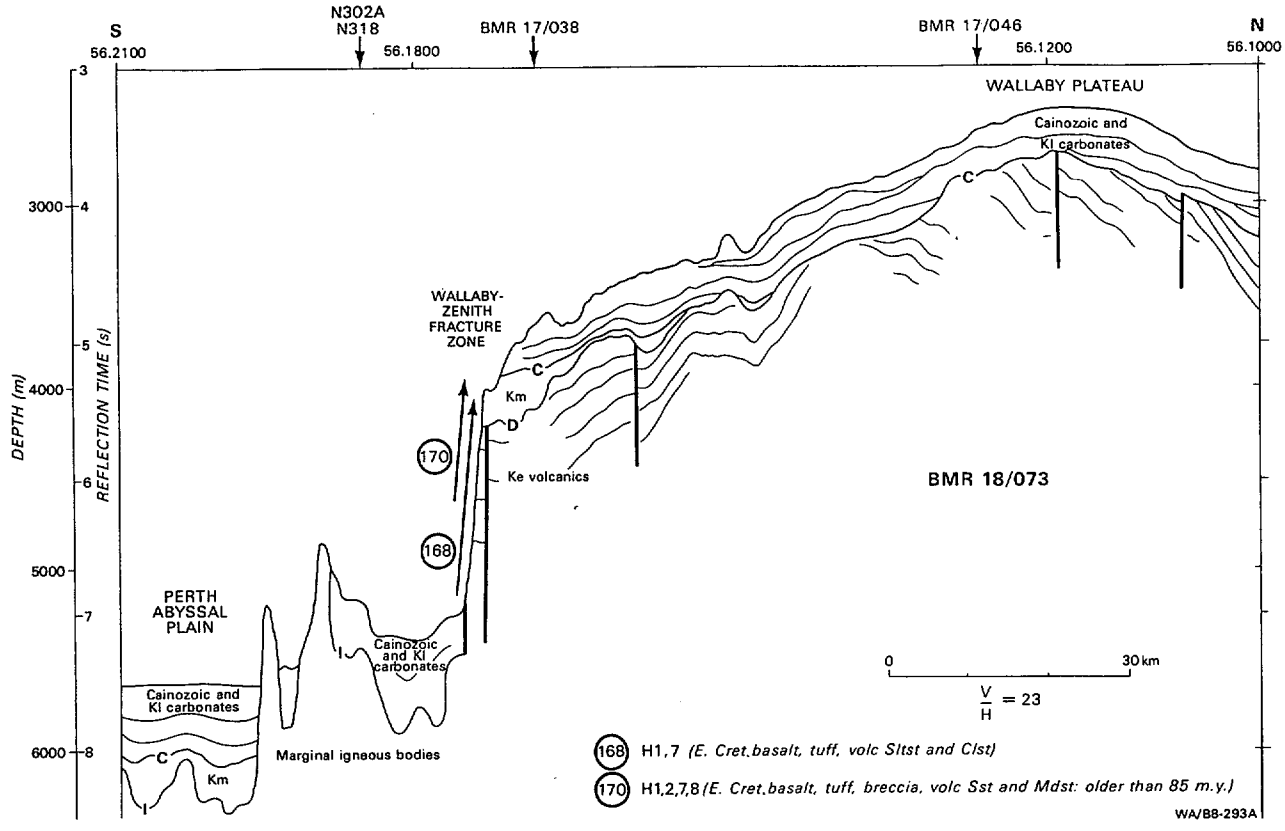


Figure 27. Line drawing of BMR line 18/73 across the southern margin of the Wallaby Plateau with seismic stratigraphy and R/V Sonne SO-08 dredge results (after von Stackelberg & others, 1980).

APPENDIX 1. EQUIPMENT LIST AND CHANNEL ALLOCATION

Navigation Systems

GPS Navigation System
- Magnavox T-set GPS navigator
- Ashtech XII GPS receiver

Prime Transit System
- Magnavox MX1107RS dual-channel satellite receiver
- Magnavox MX610D dual-axis sonar doppler speed log
- Sperry gyro-compass

Secondary Transit System
- Magnavox MX1142 single-channel satellite receiver
- Raytheon DSN450 dual-axis sonar doppler speed log
- Robertson gyro-compass

Bathymetric Systems

- Raytheon deep-sea echo-sounder, 2kW maximum output at 3.5 Hz
- Raytheon deep-sea echo-sounder; 2kW maximum output at 12 kHz

Magnetometer

- Geometrics G801 proton precession magnetometer

Geological Systems
- Deep-sea geological winch containing approx. 9000 m of 18 mm wire
- Chain-bag and pipe dredges
- Benthos time-depth recorders.

Data Acquisition System

- Data Acquisition System built around Hewlett-Packard 2117 F-series minicomputer, with tape drives, disc drives, 12" and 36" plotters, line printers, and interactive terminals.

- Data are saved on magnetic tape every minute in blocks of 128 x 6 floating point words. This represents 128 data channels of 6 records per block. The channels were allocated as follows :

1 Survey and day number (SS.DDD) from RTE clock
2 Acquisition GMT (.HHMMSS) from RTE clock
3 Acquisition GMT (.HHMMSS) from master clock
4 Latitude, best estimate (radians)
5 Longitude, best estimate (radians)
6 Speed, best estimate (knots)
7 Course, best estimate (degrees)
8 Magnetometer #1 (gammas)
9 Magnetometer #2 (gammas)
10 Depth from 3.5 kHz (metres)
11 Depth from 12.5 kHz (metres)
12 F/A Magnavox sonar doppler (3920 counts/nm)
13 P/S Magnavox sonar doppler (3920 counts/nm)
14 F/A Raytheon sonar doppler (195 counts/nm)
15 P/S Raytheon sonar doppler (195 counts/nm)
16 Paddle Log (7000 counts/nm)
18 S-G Brown gyro heading (degrees)
19 Robertson gyro heading (degrees)

20 Sperry gyro heading (degrees)
39 T-Set North Standard Deviation (metres)
40 T-Set East Standard Deviation (metres)
41 T-Set Satellite Numbers
42 T-Set Time (GMT seconds)
43 T-Set Dilution of Precision (DOP)
44 T-Set latitute (radians)
45 T-Set longitude (radians)
46 T-Set height above geoid (metres)
47 T-Set speed (knots * 10)
48 T-Set course (degrees *10)
49 T-Set frequency bias
50 T-Set GMT (hours, minutes, seconds)
51 Latitude from Magnavox Sonar Doppler (radians)
52 Longitude " " " " (radians)
53 Speed " " " " (knots)
54 Course " " " " (degrees)
55 Latitude from Raytheon Sonar Doppler (radians)
56 Longitude " " " " (radians)
57 Speed " " " " (radians)
58 Course from Raytheon Sonar Doppler (degrees)
59 Latitude from Spare Log (radians)
60 Longitude " " " (radians)
61 Speed " " " (knots)
62 Course " " " (degrees)
67 GMT from Magnavox MX1107 (seconds)
68 Dead reckoned time from MX1107 (seconds)
69 MX1107 latitude (radians)
70 MX1107 longitude (radians)
71 MX1107 speed (knots)
72 MX1107 heading (degrees)
73 GMT from Magnavox MX1142 (seconds)
74 Dead reckoned time from MV1142 (seconds)
75 MX1142 latitude (radians)
76 MX1142 longitude (radians)
77 MX1142 speed (knots)
78 MX1142 Heading (degrees)
79 Gravity (mGal x 100)
80 ACX (m/sec^2 x 10000)
81 ACY (m/sec^2 x 10000) 82 Sea state
83 AGRF magnetic anomaly #1
84 AGRF magnetic anomaly #2
88 Northerly set/drift (radians/10 seconds)
89 Easterly set/drift (radians/10 seconds)
111 Ashteck GPS latitude (radians)
112 Ashtech GPS longitude (radians)
113 Ashtech number of satellites
114 Ashtech velocity
115 Ashtech altitude (metres)
116 Ashtech P-dilution of precision (PDOP)
117 HDOP
118 VDOP
119 TDOP
120 Ashtech time of last fix

The Transit satellite fix information from both the MX1107 and MX1142 were saved in blocks of 20 floating point words when the fix data became available. The data from each Satnav was in a similar format, each being identified by the first word.

1	1107 or 1142
2	Day number (1107) or date (1142)
3	GMT
4	Latitude (radians)
5	Longitude (radians)
6	Used flag (0 = not used, 1 = used)
7	Elevation (degrees)
8	Iterations
9	Doppler counts
10	Distance from DR (natucical miles)
11	Direction from DR (degrees)
12	Satelite number
13	Antenna height (metres)
14	Doppler spread flags (1107 only)
.	" " "
.	" " "
20	" " "

APPENDIX 2. CREW LIST

(A) SCIENTIFIC AND TECHNICAL (BMR)

J. Colwell, Co-chief scientist
T. Graham, " "
M. Bradshaw, Geologist
S. Cadman "
P. Wells, Micropalaeontologist*
H. Miller, Systems scientist
R. Moshin " "
J. Stratton, Science technician
G. Sparksman " "
C. Lawson " "
D. Pryce " "
P. Butler " "
T. McNamara " "
D. Holdway, Electronics technician
J. Whatman " "
P. Golding " "
C. Green, Mechanical technician
C. Dyke " "
B. Dickinson " "
A. Radley " "

* Australian National University

(B) SHIP (DOT)

A. Codrington, Master
J. Finnie, Chief Engineer
W. McKay, Chief Officer
P. Mosley, Second Officer
D. Stewart, Second Engineer
P. Jiear, Electrician
L. Luscombe, A.B.
O. Harris, "
M. Stapleton, "
W. Fowler, Chief Steward/Cook
G. Conley, Cook
M. Cumner, Steward
S. O'Rourke, Steward, Seaman

APPENDIX 3. WAY POINTS

W.P.	Position		Site
1	Fremantle	)	
2	31°32.5', 114° 26.0'	)	
3	30° 28.0', 114°04.0'	)	Transit
4	29°34.0', 112°58.0'	)	
5	28°00.0', 112° 00.0'	)	
6	23° 40.80', 111°16.80'		A3 (top)
7	23° 23.91', 111°04.52'		A2 (top)
8	23°24.70, 111°30.72 '		A1 (top)
			Transit
9	21° 53.5', 112°45.0'		B0 (top)
10	21°52.0', 112°47.8'		B1 (top)
11	21°50.4', 112°50.3'		B2 (notch)
12	21°55.67', 112°59.49'		B3 (top)
13	21°56.05', 113°09.25'		B4 (top)
14	22°17.5', 112°36.5'		B5 (top)
			Transit
15	17°51.2', 118°32.76'		Area F cores and core transect
16	17°19.0', 117°38.0'		
17	16°54.4, 117°38.98		D3 (top)
18	16°54.4, 117°38.45'		D3A (bottom)
19	16°50.0', 117°38.4		D1 (top)
20	16°50.0', 117°40.1		D2 (top)
21	16°44.9, 117°33.7'		D4 (bottom)
22	16°44.88', 117°35.90'		D5 (bottom)
23	16°55.0', 117°52.5'	)	D6 (bottom)
24	16°44.9', 117°33.7'	)	
25	16°23.0', 117°31.0'	)	Transit
26	15°44.0', 118°22.0'	)	
27	14°39.0', 118°58.0'	)	
28	14°19.34', 119°29.58'		E4 (top)
29	14°16.50', 119°26.50'		E5 (top)
30	14°25.0', 119°07.5'		E6 (top)
31	13°55.62', 119°14.73'		E3 (top)
32	13°26.29', 119°23.7'		E1 (top)
33	13°26.26', 119°22.92'		E2 (top)
34	13°06.0', 119°45.0'		E7 (top)
35	12°57.5', 120°11.5'		E8 (top)
36	14°24.5', 119°17.0'		E9 (top)
			Transit
37	16°18.2', 118°24.3'		RT1 (top)
			Transit
38	17°39.50', 115°41.93'		C1 (top)
			Transit
39	16°54.28', 114°24.77'		G1 (top)
40	16°54.16', 114°20.08'		G2 (top)
			Transit
41	19°56.29', 110°35.57;		H1 (top)
42	20°06.0', 109°55.0'		H2 (top)
43	21°30.0', 108°45.0'		Transit
44	23°46.83', 108°30.23'		I2
45	24 °21.90', 107°47.55'		I1 (top)
46	25°05.0', 109°15.0'	)	
47	26° 02.0', 108°53.0'	)	Transit
48	26° 16.0', 109°33.0'	)	
49	26° 44.0', 109°42.0'	)	
50	27° 15.0', 109°46.0'		J1
51	Fremantle		

APPENDIX 4. ABRIDGED CRUISE NARRATIVE

The cruise left on schedule at 2100 hours on 17 August 1990. All equipment and systems were considered to be operational with the exception of the 3.5 kHz echo sounder which was to have new transducers installed during transit. Just prior to sailing it was discovered that the gravity meter used to do the gravity tie on land was malfunctioning. Consequently, no gravity tie was established.

Chronology

229.1200 : Departed Wharf 10, North Quay, Fremantle. Heavy seas. Collecting bathymetric data along the lower continental slope on route to first sampling area. 12 kHz echo sounder giving good results despite adverse sea conditions.

230.1400 : Completed bathymetric survey. Speed increased to 13 kts.

230.1700 : Loss of magnetometer readings. Magnetometer cable discovered to have parted at block in heavy seas. Redeployed using slightly different towing arrangement.

231.1750 : Arrived at first dredge site, A3. Only one substantial bite during dredging operations (DR/1). 8 kg of rock recovered.

232.0354 : Dredge (DR/2) deployed at site A2. Two substantial tension bites. 7 kg of rock recovered.

232.1300 : Dredge (DR/3) deployed at site A1. Low tension readings throughout. 5 kg of rock recovered.

232.1750 : Commenced transit to area B, northern Carnarvon Terrace.

233.0423 : Dredge (DR/4) deployed at site BO.

233.0709 : Large tension spike on wire resulted in the shear pin at the dredge breaking.

233.0948 : Dredge redeployed at site BO (DR/5). 30 kg of rock recovered.

233.1647 : Moved to northeast wall of canyon, site B1. Commenced dredge DR/6. Minor problems with power pack on winch. Approximately 40 kg of rock recovered.

233.2300 : Dredge DR/7 commenced targeting the top third of the slope dredged in DR/5 and overlying sequences. 25 kg of rock recovered.

234.0703 : Commenced dredge DR/8 at site B2. 50 kg of rock recovered.

234.1218 : Relocated to canyon system slightly to the east (site B3).

234.1433 : Commenced deploying dredge DR/9. Very few tension spikes. Approximately 30 kg of material recovered.

234.2054 : Commenced dredge DR/10 at site B4, slightly to the east of B3. Less than 1 kg of rock recovered.

235.0525 : Moved to canyon system to southwest. Commenced dredge DR/11. Very low tension readings. Only 0.5 kg of rock recovered.

235.1113 : Commenced transit to area F near Rowley Shoals.

235.1734 : Magnetometer retrieved with water in it. Serviced and redeployed at 235.2200.

236.2300 : Arrived at area F to begin a coring program south of Rowley Shoals for geochemistry. Nineteen cores attempted of which nine were successful. During day 237 the gravity meter began to cage for the first of many times.

237.1347 : Commenced core transit to head of Swan Canyon. Bathymetric profile run down the axis of the canyon.

238.0249 : Dredge (DR/12) deployed at site D3 on the eastern wall of the Swan Canyon. Approximately 25 kg of rock recovered.

238.0903 : Dredge (DR/13) deployed at site D3A to sample the upper part of the slope sampled in the previous dredge. NUmerous high tension readings. 300 kg of rock recovered.

238.1528-234.0600 : Five dredge hauls (DR/14-18) taken at sites D1, D2, D4, D5 and D6 in Swan Canyon area. Up to 400 kg of rock recovered at each site.

240.0620 : Commenced transit to area E running bathymetric profiles.

241.0108-241.1502 : Two dredge hauls (DR19 & 20) taken at sites E4 and E5 on the southwestern flank of the Scott Plateau. Up to 75 kg of material obtained.

241.1810 : Dredge (DR/21) deployed at site E6 to the west of sites E4 and E5. 50 kg of rock and manganese crusts obtained.

242.0454 : Commenced dredge DR/22 on the western margin of the Scott Plateau (site E3). Approximately 20 kg of rock recovered.

242.1313-243.0153 : Two dredges (DR/23 & 24) completed at sites E1 and E2 on the central western margin of the Scott plateau. 50 kg and 2 kg recovered, respectively.

243.0550-244.1059 : Three dredges (DR/25-27) taken in canyon on the northwestern flank of the Scott Plateau (sites E7-9). Two (DR/26 & 27) yielded 5 kg and 2 kg, respectively

244.1100 : Commenced transit south to site RT1 on the margin of the Rowley Terrace.

244.2250 : Dredge (DR/28) deployed at site RT1. Dredge hung up for several hours. 350 kg of rock recovered.

245.0501 : Commenced transit to area C on Exmouth Plateau.

245.2000 : Commenced dredge (DR/29) at site C1 on northern Exmouth plateau. Few tension spikes. 300 kg of rock recovered.

246.0151 : Redeployed dredge (DR/30) at site C1. Several moderate tension spikes. 150 kg of rock obtained.

246.0645 : Commenced transit to area G on the western margin of Wombat Plateau.

246.1453 : Dredge (DR/31) deployed at site G1. No tension spikes due to soft sediment cover. Zero recovery in chain-bag dredge.

246.2030 : Moved down slope to west in an attempt to sample slope beneath G1.

246.2152 : Dredge (DR/32) deployed at site G2. Zero recovery. Arms of dredge bridle bent.

247.0456 : Dredge (DR/33) redeployed at site G2. 10 kg of rock recovered.

247.1140 : Commenced transit at maximum speed to area H on southwestern margin of the Exmouth Plateau.

248.1054 : Dredge (DR/34) deployed at site H1. Approximately 30 kg of rock recovered.

248.1645 : Relocated slightly to the southwest to begin operations at site H2.

248.2100 : Dredge (DR/35) deployed at site H2. Hung up. Numerous tension spikes. 200 kg of rock recovered.

249.0710 : Commenced transit to area I. Ran bathymetric profiles part way down the axis of the Sonja Ridge.

250.0421-250.0846 : Coring program at site I2 on the crest of the Wallaby Plateau. Up to 2.0 metres of recovery.

250.0900 : Commenced transit to site I1.

250.1340-251.0320 : Three dredges (DR/36-38) taken at site I1 on the southwestern Wallaby Plateau. Up to 30 kg of rock recovered.

251.0320 : Commenced transit to Fremantle including bathymetric profiling to the southeast of the Wallaby Plateau.

251.2349 : Gravity core attempted on Perth Abyssal Plain to allow winch wire to be greased. Core unsuccessful due to failure of core catcher.

252.0205 : Underway at full speed to Fremantle.

253.0748 : Magnetometer off.

253.2215 : Vessel docked at Wharf 10, North Quay, Fremantle, 0715 hours on 11 September, 1990.

CALCAREOUS NANNOFOSSIL AGE DETERMINATION OF DREDGE SAMPLES, BMR CRUISE 96

I. Jurassic to Late Oligocene

by

Samir Shafik

ABSTRACT

The presence of Middle Jurassic horizons bearing calcareous nannofossils in the Rowley Terrace, described previously from material obtained during BMR Cruise 95, has been confirmed in this study. A large number of Early Cretaceous nannofossil assemblages have been recorded from the eastern side of the Swan Canyon (southern Rowley Terrace) and Carnarvaon Terrace. These indicate that surface waters over the area of the Swan Canyon were cool during the Late Rayazanian to Early Barremian (on account of *Crucibiscutum salebrosum* and *Tegumentum octiformis*), but a connection with the Tethyan during the Valanginian and Hauterivian did probably exist, allowing some warm-water species (such as *Cornusphaera mexicana*, *Cruciellipsis cuvillieri* and *Speetonia colligata*) into the area of the canyon. Surface waters over the Carnarvon Terrace during the following latest Barremian - Early Albian interval were similarly cool as evidenced by the presence of *Crucibiscutum salebrosum* (in pre-Ablian rocks), *Seribiscutum primitivum* and *Tegumentum octiformis*, and the later introduction of *Laguncula dorotheae* and *Sollasites falklandensis* (recorded in Lower Albian rocks only). Some warm-water influence over the area of the Carnarvon Terrace during the Early Albian has been suggested by the presence of *Nannoconus truitti truitti* in few assemblages.

Three mid Campanian to Late Maastrichtian assemblages, with abundant *Certolithoides aculeus*, have been identified from the Swan Canyon. Another three Late Cretaceous assemblages, indicating mixed water masses, have been described from the Carnarvon Terrace, albeit being displaced in younger sediments: a Late Campanian assemblage from a very small clast in a soft Oligocene marl, and Late Campanian and Late Maastrichtian assemblages displaced in Paleocene mudstones.

Several Paleocene and Eocene assemblages have also been recorded, indicating that the lower Tertiary sequences in the Swan Canyon and Carnarvon Terrace were sampled. The Paleocene assemblages pre-date the appearance of representatives of the genus *Discoaster* in these areas, and the Eocene assemblages post-date the (Early Eocene) *Discoaster sublodoensis* datum. Strong evidence for warm surface waters over the Carnarvon Terrace during the Late Eocene (*Isthmolithus recurvus* Zone) has been pointed out by the dominance of discoasters over chiasmoliths, the large number of species of *Helicosphaera* and the presence of both *Sphenolithus predistentus* and *S. pseudoradians*.

Three Oligocene assemblages have been described from the Carnarvon Terrace: an Early Oligocene highly-diversified one, and two mid to Late Oligocene assemblages containing large numbers of reworked Eocene species. A similar mid to Late Oligocene assemblage (with Eocene forms) has also been identified from material from the Exmouth Plateau. The mid to Late Oligocene assemblages included the key species *Cyclicargolithus abisectus*, *Helicosphaera recta*, *Sphenolithus distentus* and *S. aff. ciperoensis,* and have been correlated with other assemblages from the offshore Perth Basin and the Great Australian Bight Basin which also contained reworked Eocene species.

The top of the Oligocene sequence on the Carnarvon Terrace was apparently sampled. The assemblage recovered lacked *Sphenolithus distentus* and *S. ciperoensis* but contained abundant *Cyclicargolithus abisectus* associated with rare both *Helicosphaera recta* and *Triquetrorhabdulus carinatus*

INTRODUCTION

The study is based on optical microscopy of smear slides of dredges recovered from areas in the northwest corner of Australia. The dredges were obtained during BMR Cruise 96, aboard the R/V *Rig Seismic* (August- September 1990). The aim was to date the samples by their calcareous nannofossil contents. Only those dated as older than Early Miocene are discussed below; younger samples are the subject of part II of this appendix. Part III of this appendix summarises the results of examination of all samples supplied.

Assemblages from many of the samples were found to include nannofossils of different ages. This is interpreted as due to contaminations of soft sediments through mixing during

dredging, and/or due to reworking; nannofossils are prone to reworking in younger sediments because of their small size. In most cases it was difficult to determine whether the mixed assemblages are the result of (operational) mixing of samples during dredging, (original) reworking of the fossils, or both. Careful resampling of the soft sediments, where possible, was found to remove contaminants in many instances, pointing to mixing of the samples during dredging.

RESULTS

The assemblages discussed below are arranged chronologically, beginning with the oldest.

JURASSIC

Commonly-occurring but poorly-preserved calcareous nannofossils were recovered from sample 96DR028-16, a soft, plastic, dark grey mud/mudstone with some mica, which was dredged from the southern Rowley Terrace in water 4530-3500 m deep. These fossils include very rare (broken) *Carniolithus* sp., *?Crucirhabus primulus*, frequent *Discorhabdus striatus*, *Ethmorhabdus*, abundant *Lotharingius contractus*, *L. crucicentralis*, *L. velatus*, *Mitrolithus elegans*, *?Podorhabdus macrogranulatus*, frequent *Retecapsa incompta*, common *S. punctulata*, *Vekshinella quariarcullus*, *Watznaueria manivitella* and *Zygodiscus erectus*.

Age. The presence of both *Lotharingius contractus* and *Watznaueria* suggests a maximum age of Bajocian (middle Jurassic) (see, e.g. Bown & others, 1988).

Remark. It is worth mentioning that other nannofossil assemblages of middle Jurassic age have been identified from the Rowley Terrace, during BMR Cruise 95 (see Shafik *in* Exon & others, 1990).

JURASSIC or CRETACEOUS

Three very poor assemblages were recovered from samples 96DR012-07B (pipe), 96DR012-03 and 96DR013-01 which were dredged from the Rowley Terrace (eastern) side of the Swan Canyon. These are assigned the broad Jurassic to Early Cretaceous age, because each is composed of a few long-ranging species.

(A) Extremely-rare, severely-corroded, single shields of placoliths probably belonging to

the genus *Watznaueria* were found in a piece of friable, carbonaceous sandstone with mica, which was found among the ooze of subsample 96DR012-07B (pipe). This piece of sandstone resembles rock type 1 and 2 recovered in the same dredge haul as sample 996DR012-07.

(B) Rare calcareous nannofossils were recovered from sample 96DR012-03, a very fine grained sandstone with abundant siliceous microfossils, which was dredged from water-depth of 5000-4005 m. These are *Cyclagelosphaera margerelii*, *Parhabdolithus embergeri*, *Watznaueria barnesae* and *Zygodiscus erectus*.

(C) Very rare, poorly-preserved nannofossils were recovered from sample 96DR013-01, a shelly sandstone with fragments of *Inoceramus*, which was dredged from water 4150-3600 m deep. These are *Cyclagelosphaera margerelii*, small *Cyclagelosphaera*, ? *Watznaueria britannica* and a large *Watznaueria*.

Remarks. The limited diversity of the assemblages and the lithology of the samples suggest shallow-water deposition. Water depths where the samples were recovered exceed 3000 m. A substantial subsidence must have occurred in the Swan Canyon area since the mid Mesozoic. Poor preservation of the nannofossils is probably a result of exposure to the cold bottom waters.

EARLY CRETACEOUS

Many Early Cretaceous assemblages were identified from the eastern side Swan Canyon and the Carnarvon Terrace. These are arranged in a chronological order below, beginning with the oldest.

(A) A moderately-preserved assemblage was extracted from subsample 96DR013-05A, a white mud/ooze, which was dredged from the Rowley Terrrace (eastern) side of the Swan Canyon in water 4150-3600 m deep. The assemblage is dominated by *Watznaueria barnesae*. Other species identified include rare *Cretarhabdus conicus*, *C. surirellus*, *Cretarhabdus* sp.1, frequent (small) *Crucibiscutum salebrosum*, *Cyclagelosphaera margerelii*, small *Cyclagelosphaera* sp., rare *?Eiffellithus windii*, *?Ethmorhabus hauterivianus*, *Haqius circumradiatus*, *Lithraphidites carniolensis*, *Manivitella pemmatoidae*, *Parhabdolithus embergeri*, *Rotelapillus laffittei*, *Tegumentum stradneri*, *Vekshinella crux*, *Vekshinella* spp., rare *Watznauera ovata* and *Zygodiscus erectus*.

rare *Watznauera ovata* and *Zygodiscus erectus*.

Age. The assemblage is assigned a Late Ryazanian to Early Barremian age. The lowest occurrence of *Crucibiscutum salebrosum* is Late Ryazanian in age according to Taylor (1982), and the highest occurrence of the same species is Early Barremian according to Jakubowski (1987).

Remarks. Another sample from the same dredge haul (as subsample 96DR013-05A), sample 96DR013-08 yielded a very poor assemblage which may correlate with the assemblage from subsample 96DR013-05A. Sample 96DR013-08 is a dusky yellow calcarenite limestone with abundant *Inoceramus*. It contains a poorly preserved assemblage dominated by three species of *Watznaueria*, namely *W. britannica*, *W. barnesae* and *W. ovata*. Extremely rare *Crucibiscutum salebrosum* was encountered after long search. This assemblage is regarded as Late Ryazanian to Early Barremian in age, on the presence of *Crucibiscutum salebrosum*.

Crucibiscutum salebrosum has been regarded as Boreal/Arctic/Austral species (see, Crux, 1989). The presence of this species in the assemblages from 96DR013-05A and 96DR013-08 suggests cool surface waters some time during the Late Ryazanian to Early Barremian interval in the area of the Swan Canyon.

(B) A poorly-preserved assemblage was recovered from sample 96DR013-03, a consolidated, light olive grey mudstone dredged from the Rowley Terrace (eastern) side of the Swan Canyon in water 4150-3600 m deep. The fossils are mostly corroded. The assemblage is dominated by *Watznaueria barnesae* and *W. ovata*. Other identifiable taxa are *Biscutum constans*, very rare *Cornusphaera mexicana*, rare *Cretarhabdus surirellus*, *Cretarhabdus* sp.1, frequent *Crucibiscutum salebrosum* , *Cruciellipsis cuvillieri*, *Cyclagelosphaera margerelii*, frequent *Eiffellithus windii*, ?*Ethmolithus gallicus*, rare *Haqius circumradiatus*, rare *Lithraphidites carniolensis*, *Manivetella pemmatoidea*, *Parhabdolithus embergeri*, *Retecapsa angustiforata*, *Rucinolithus*, *Rotelapillus laffittei*, *Sollasites*, *Speetonia colligata*, ?*Tubidiscus jurapelagicus*, *Vekshinella*, rare *Watznaueria britannica*, and *Zygodiscus erectus*.

Age and discussion. On account of *Eiffellithus windii*, *Cruciellipsis cuvillieri*, *Retecapsa angustiforata* and *Speetonia colligata*, the age of the assemblage is probably Valanginian. This association is usually found in the Valanginian *Calcicalathina oblongata* Zone (see

Barlower & others, 1989).

The frequent occurrence of *Crucibiscutum salebrosum* in the assemblage from sample 96DR013-03 confirms the conclusion advanced above regarding the surface waters above the area of the Swan Canyon being cool some time during the Late Ryazanian to Early Barremian interval. On the other hand, the species *Cornusphaera mexicana*, *Cruciellipsis cuvillieri* and *Speetonia colligata*, found in the assemblage from 96DR013-03, have been regarded elsewhere as Tethyan (see, Thierstein, 1976; Crux, 1989). This means that during the Valanginian, a connection between the Tethyan and the site of the Swan Canyon existed, allowing some warm surface waters into the latter.

(C) Three (broadly) coeval assemblages were identified from three samples which were recovered from the Rowley Terrace (eastern) side of the Swan Canyon at two stations. One sample from Station 96DR/014 where water is 5250-4005 m deep, and the other two samples from Station 96DR015 where water depth is 4200-3875 m.

(C1) A moderately-preserved assemblage was recovered from subsample 96DR014-08A, a soft, dusky yellow mudstone. The fossils are mostly corroded. The assemblage is dominated by *Watznaueria barnesae* and *Crucibiscutum salebrosum*. Other identifiable taxa are *Biscutum constans*, rare (short) *Cornusphaera mexicana*, *Cretarhabdus* sp.1, frequent *Cruciellipsis cuvillieri*, *Cyclagelosphaera deflandrei*, *C. margerelii*, small *Cyclagelosphaera*, *?Ethmolithus gallicus*, *Grantarhabdus meddii*, *Haqius circumradiatus*, rare *Lithraphidites carniolensis*, small *Manivitella pemmatoidea*, rare *Microstaurus chiastius*, *Parhabdolithus embergeri*, rare *Rotelapillus laffittei*, *Sollasites horticus*, *Speetonia colligata*, *Watznaueria britannica*, *W. ovata* and *Zygodiscus erectus*.

(C2) A moderately-preserved assemblage was recovered from sample 96DR015-06 (pipe), a soft, light olive grey mud. It is dominated by *Watznaueria barnesae*, *Zygodiscus erectus*. Other species are common *Axopodorhabdus* sp.1, *Biscutum*, *Cretarhabdus conicus*, *C. surirellus*, *Cretarhabdus* sp.1, frequent *Crucibiscutum salesbrosum*, rare *Cruciellipsis cuvillieri*, rare *Cyclagelosphaera deflandrei*, frequent *C. margerelii*, rare *Haqius circumradiatus*, rare *Grantarhabdus meddii*, very rare *Lithraphidites carniolensis*, *Manivetella pemmatoidea*, *Microstaurus chiastius*, *Polycostella senaria*, very rare *Rotelapillus laffittei*, rare *Speetonia collagata*, *Vekshinella*, very rare *Watznaueria britannica* and frequent *W. ovata*.

Age. Based on the co-occurrence of *Crucibiscutum salebrosum*, *Cruciellipsis cuvillieri* and

Speetonia colligata, the assemblages from 96DR014-08A and 96DR015-05 (pipe) are assigned a Late Ryazanian - Late Hauterivian age. The age of the lowest occurrence of both *Speetonia colligata* and *Crucibiscutum salebrosum* has been regarded elsewhere as Late Ryazanian (see Taylor, 1982), and the age of the extinction of *Cruciellipsis cuvillieri* has been given as Late Hauterivian by several authors (see, e.g. Barlower & others, 1987). The highest occurrence of *Speetonia colligata* is within the Lower Barremian according to Jakubowski (1987).

A finer biostratigraphic resolution is difficult because of the absence of certain key species (such as *Lithraphidites bollii*, *Eprolithus antiquus* and/or *Micrantholithus speetonensis*) which have been used elsewhere to subdivide the Late Ryazanian - Late Hauterivian interval.

(C3) A moderately-preserved assemblage was recovered from a sample 96DR015-01, a moderately hard, light olive grey mudstone. The assemblage is dominated by *Watznaueria barnesae*, *W. ovata* and *Cyclagelosphaera margerelii*. Other species present are very rare *Bidiscus*, rare *Biscutum*, very rare *Chiastozygus* sp. cf. *C. striatus*, frequent *Cretarhabdus conicus*, frequent *C. loriei*, rare *C. surirellus*, *Cretarhabdus* sp. 1, frequent *Crucibiscutum salebrosum*, rare *Cruciellipsis cuvillieri*, rare *Cyclagelosphaera deflandrei*, *Grantarhabdus meddii*, *Haqius circumradiatus*, rare *Eiffellithus* sp.1, *Manivetella pemmatoidea*, rare *Microstaurus chiastius*, very rare *Polycostella senaria*, *Retecapsa angustiforata*, *Rhagodiscus asper*, *Rotelapillus laffittei*, *Sollasites* sp.1, *Speetonia colligata*, very rare *Tegumentum octiformis*,*Vekshinella crux* and *Zygodiscus erectus*.

Age and remarks. The assemblage is Late Ryazanian to Late Hauterivian in age. This is based on the overlap in the ranges of *Speetonia colligata*, *Crucibiscutum salebrosum* and *Cruciellipsis cuvillieri* (discussed above). Narrowing of this age assignment seems possible, using other species from the assemblage.

Cretarhabdus loriei has been used as a zonal marker within the Lower Hauterivian (see Sissingh, 1977), and its presence in the assemblage of sample 96DR015-01 may be taken as an evidence of Hauterivian age. However, this species has been reported from the Upper Ryazanian (see Jakubowski, 1987, p. 109). Perch-Nielsen (1979, 1985) suggested *Chiastozygus striatus* as a substitute for *Cretarhabdus loriei* in the Lower Hauterivian of the Boreal region, and the presence of rare *Chiastozygus* sp. cf. *C. striatus* in the assemblage of sample 96DR/015-01 may, therefore, support its assignment a Hauterivian age. However, *Chiastozygus striatus*, similar to *Cretarhabdus loriei*, has been recorded from older rocks by

Jakubowski (1987); it was found in the Lower Valanginian at Speeton, Great Britain (see also Crux, 1989).

Tegumentum octiformis has been recorded from Lower Cretaceous sections in Great Britain, Germany and offshore Norway, and the base of its range seems to be a useful biostratigraphic evidence in the Lower Hauterivian (Crux, 1989). The presence of this species, though very rare, in the assemblage of 96DR015-01 is taken as a good evidence for its Hauterivian age.

Sollasite sp. is similar to *S. arcuatus* as illustrated by Jakubowski (1987), but differ from the holotype of the species (see Black, 1971, pl. 31, fig. 9) in having a much wider central area. The central structure in *Sollasites* sp. appears as a cross in optical microscopy. According to Jakubowski (1987), *S. arcuatus* has a short range at the top of the Ryazanian (see also Crux, 1989).

The broad age of Late Ryazanian - Late Hauterivian given to samples 96DR015-01 and 96DR015-06 and their lithological similarties suggest that they might have come from the same unit. Their assemblages differ in some respects. *Cretarhabdus loriei*, frequent in 96DR/015-01, seem to be absent from 96DR/015-06. *Crucibiscutum salebrosum* in 96DR/015-06 include a large variety not present in 96DR/015-01.

Discussion.*Tegumentum octiformis*, present in the assemblage from sample 96DR015-01, is probably a Boreal/Arctic/Austral species judging from its known geographic distribution (see Crux, 1989).

The frequent/common presence of *Crucibiscutum salebrosum* in the assemblages from samples 96DR015-01 and 96DR015-06 suggests cool surface waters, and the occurrence of rare *Cruciellipsis cuvillieri* and *Speetonia colligata* in the same suggests warm-water influence. *C. salebrosum* has been considered as Boreal/Arctic/Austral, and both *C. cuvillieri* and *S. colligata* have been regarded as Tethyan (see Crux, 1989).

Some time during the Late Ryazanian - Late Hauterivian (probably during the Valanginian and Hauterivian), warm surface waters, probably from the Tethyan, brought warm-water species to the area of the Swan Canyon, where the surface waters were generally cool. This conclusion is based on the assemblages recovered from samples 96DR013-03, 96DR014-08A, 96DR015-01 and 96DR015-06 where one or more of the warm-water species

Cornusphaera mexicana, *Cruciellipsis cuvillieri* and *Speetonia colligata* occur frequently in association with common *Crucibiscutum salebrosum*.

(D) A moderately-preserved assemblage was extracted from subsample 96DR013-05B, a white mud/ooze, which was dredged from the Rowley Terrrace (eastern) side of the Swan Canyon in water 4150-3600 m deep. The assemblage is dominated by *Watznaueria barnesae* and to a lesser extent by *Vekshinella matalosa*. Other species identified include rare *Cretarhabdus conicus*, *Cretarhabdus* sp.1, *Haqius circumradiatus*, *Lithraphidites carniolensis*, *Manivitella pemmatoidae*, *Parhabdolithus embergeri*, *Retecapsa angustiforata*, *Rhagodiscus asper*, *Rotelapillus laffittei*, *Vekshinella* spp., *Watznauera ovata* and *Zygodiscus erectus*.

Age. The abundant occurrence of *Vekshinella matalosa* suggests a (probably Late) Barremian to Late Aptian age. The minimum age (Late Aptian) is based on the absence of *Eprolithus floralis* and *Rhagodiscus angustus*.

According to Crux (1989), the lowest occurrence of *V. matalosa* in the Boreal region is Barremian in age. Earlier, Thierstein (1973, 1976) placed this biostratigraphic event at younger levels (within the Albian or Aptian). Recently, other authors regarded common occurrences of *V. matalosa* as an evidence for Early Aptian age (see, Haq, von Rad, O'Connel & others, 1990).

(E) A poorly-preserved (mostly corroded) assemblage was recovered from sample 96DR003-01, a light grey, consolidated, siliceous mudstone. The sample was dredged from the Carnarvon Terrace (area A, east of Wallaby Plateau) in water 3891-3700 m deep. It includes *Axopodorhabdus dietzmannii*, *Bidiscus*, *Biscutum*, *?Broinsonia signata* (some with stalk), *Bukrylithus ambiguus*, *Chiastozygus litterarius*, *Cretarhabudus conicus*, *C. loriei*, rare *Crucibiscutum salebrosum*, *Gephyrorhabdus coronadventus*, small *Manivitella pemmaroidea*, *Parhbabdolithus. embergeri*, *Placozygus sigmoides*, *Rhagodiscus pseudoangustus*, common *R. asper*, *Rotelapillus laffittei*, rare *Seribiscutum primitivum*, *Tetrapodorhabdus decorus*, *Tubidiscus*, common *Vekshinella matalosa*, *V.* spp., *Watznaueria barnesae*, *W. ovata*, *Zygodiscus bicrescenticus* and *Z. erectus*.

Age and discussion. This assemblage is dated as latest Barremian to Early Aptian on the presence of *Chiastozygus litterarius* in the absence of both *Eprolithus floralis* and *Rhagodiscus angustus* . The presence of *Vekshinella matalosa* and *Seribicutum primitivum* supports this age assignment. Thierstein (1976) considered the base of *Chiastozygus*

litterarius as latest Barremian in age.

The presence of both *Crucibiscutum salebrosum* and *Seribiscutum primitivum* suggests cool surface waters during the latest Barremian to Early Aptian interval on the southern part of the Carnarvon Terrace (area A, east of the Wallaby Plateau).

(F) Several well-preserved Albian assemblages were recovered from material dredged from the Carnarvon Terrace, at stations 96DR001 and 96DR003 in the area east of the Wallaby Plateau, and at station 96DR011 in the northern area adjacent to the Cuvier Abyssal Plain. In addition, two poor assemblages from stations 96DR002 and 96DR003, which were tentatively assigned an Albian age are discussed below.

(F1) A well-preserved assemblages was extracted from sample 96DR003-02, a soft, light olive brown mudstone, which was dredged from 3891-3700 m water depth. It included rare *Axopodorhabdus dietzmannii*, *Bidiscus rotatorius*, frequent *Biscutum ellipticum*, *B. constans*, very rare *Broinsonia signata*, *Bukrylithus ambiguus*, frequent *Chiastozygus striatus*, *Cretarhabdus conicus*, *C. loriei*, *Cretarhabdus* sp. 1, *C. surirellus*, common *Eprolithus floralis* (two types), frequent *Gephyrorhabdus coronadventus*, rare *Laguncula dorotheae*, common *Lithraphidites carniolensis*, rare *Octocyclus reinhardtii*, frequent *Parhabdolithus embergii*, very rare *Prediscosphaera columnata*, *Rhagodiscus angustus*, *R. asper*, abundant *Rotelapillus laffittei*, rare *Seribiscutum primitivum*, extremely rare *Sollasites falklandensis*, *Stoverius achlyosus*, extremely rare *Tegumentum octifomis*, *Tetrapodorhabdus decorus*, *Tubidiscus*, *Vekshinella* spp., abundant *Watznaueria barnesae*, common *W. britannica*, common *W. ovata* and *Zygodiscus erectus*.

(F2) A rich well-preserved was extracted from sample 96DR001-05, a pale olive mudstone, which was dredged from 4125-3700 m water depth. Taxa identified include *Axopodorhabdus dietzmannii*, *Biscutum*, *Broinsonia signata* (some specimens with stalk), *Chiastozygus litterarius*, *?Corolithion geometricum*, frequent *Cretarhabdus conicus*, *C. surirellus*, *Cretarhabdus* sp. 1, rare *Eiffellithus* sp.1, rare *Eprolithus floralis*, *Grantarhabdus meddii*, *Haqius circumradiatus*, *Helicolithus trabeculatus*, *Laguncula dorotheae*, *Lapideacassis fasciata*, abundant *Lithraphidites carniolensis*, frequent *Manivitella pemmatoidea*, frquent *Octocyclus reinhardtii*, rare *Prediscosphaera columnata*, rare small *P. spinosa*, *Rhagodiscus angustus*, *R. apser*, *R. splendens*, abundant *Rotelapillus laffittei* (two types), *Scapholithus fossilis*, rare *Seribiscutum primitivum*, *Sollasites falklandensis*, *Stoverius achylosus*, rare *Tegumentum octiformis*, *Tetrapodorhabdus decorus*, *Vekshinella matalosa*, *V.*

quadriarcullus, very rare *Watznaueria britannica*, common *W. barnesae*, very rare *W. biporta*, *W. ovata* and *Zygodiscus erectus*.

(F3) A rich nannofossil assemblage was recovered from sample 96DR/011-05 (pipe), a soft, light olive grey marl, which was dredged from 3700-3070 m water depth. Taxa indentified include *Bidiscus rotatorius*, *Biscutum*, *Broinsonia signata*, *Cretarhabdus conicus*, *C. surirellus*, *Crucicribrum angellicum*, *Cyclagelosphaera margerelii*, *Octocyclus reinhardtii*, *Eiffellithus dennisonii*, *Eprolithus floralis*, *Gephyrorhabdus coronadventis*, *Haqius circumradiatus*, *Helicolithus trabeculatus*, *Laguncula dorotheae*, *Lapideacassis cornuta*, *L. fasciata*, *Lithraphidites carniolensis*, *Manivitella pemmatoidea*, *Rhagodiscus angustus*, *R. asper*, *R. splendens*, abundant *Rotelapillus laffittei*, *Seribiscutum primitivum*, *Sollasites falklandensis*, *Tegumentum octiformis*, *Tetrapodorhabdus decorus*, *Vekshinella elliptica*, *V. matalosa*, *V. quadriarculla*, very rare *Watznaueria biporta*, *W. britannica*, common *W. barnesae*, *W. ovata* and *Zygodiscus erectus*.

(F4) A rich nannofossil assemblage was recovered from sample 96DR/011-03, a soft, medium olive grey marl. Taxa indentified include *Axopodorhabdus albianus*, *Bidiscus rotatorius*, *Biscutum*, *Broinsonia signata*, *?Chiastozygus litterarius*, *Corollithion geometricum*, *Cretarhabdus conicus*, *C. surirellus*, *Octocyclus reinhardtii*, *Eprolithus floralis*, *Gephyrorhabdus coronadventis*,*Grantarhabdus camaratus*, *Haqius circumradiatus*, *Laguncula dorotheae*, *Lapideacassis cornuta*, *L. fasciata*, *Lithraphidites carniolensis*, *Manivitella pemmatoidea*, *Nannoconus truitti truitti*, *Parhabdolithus embergeri*, very rare *Prediscosphaera columnata*, *P.* sp. (small, slightly elliptical with cross bars aligned with the major axes of the ellipse), *?Rhagodiscus angustus*, *R. asper*, *R. splendens*, *?Rucinolithus irregularis*, abundant *Rotelapillus laffittei* (two types), frequent *Seribiscutum primitivum*, *Sollasites falklandensis*, *Stoverius achlyosus*, *Teichorhabdus ethmos*, *Tetrapodorhabdus decorus*, *Tubidiscus* sp., *Vekshinella matalosa*, *V. quadriarcullus*, *Watznaueria barnesae*, *W. britannica*, *W. ovata*, *Zygodiscus bicrescenticus*, *Z.erectus* and *Z. sisyphus*.

(F5) A rich nannofossil assemblage was recovered from sample 96DR/011-02, a soft, light olive grey marl. Taxa identified include *Axopodorhabdus albianus*, *Bidiscus rotatorius*, *Biscutum*, *Broinsonia signata*, *?Chiastozygus litterarius*, *Corollithion geometricum*, *Cretarhabdus conicus*, *C. surirellus*, *Eprolithus floralis*, *Grantarhabdus camaratus*, *Haqius circumradiatus*, *Laguncula dorotheae*, *Lapideacassis fasciata*, *L. mariae*, *Lithraphidites carniolensis*, *Manivitella pemmatoidea*, *Parhabdolithus embergeri*, very rare *Prediscosphaera columnata*, *P.* sp. (small, slightly elliptical with cross bars aligned with the major axes of the

ellipse), ?*Rhagodiscus angustus*, *R. asper*, *R. splendens*, ?*Rucinolithus irregularis*, abundant *Rotelapillus laffittei*, rare *Seribiscutum primitivum*, *Sollasites falklandensis*, *Tetrapodorhabdus decorus*, *Vekshinella elliptica*, *V. matalosa*, *V. quadriarcullus*, *Watznaueria barnesae*, *W. ovata*, *Zygodiscus bicrescenticus*, *Z.erectus* and *Z. sisyphus*.

(F6) A rich nannofossil assemblage was recovered from sample 96DR/011-01, a firm, yellowish grey chalk/marl. Taxa identified include *Axopodorhabdus dietzmannii*, *Bidiscus rotatorius*, *Biscutum*, *Broinsonia signata*, *Chiastozygus litterarius*, *Corollithion geometricum*, *Cretarhabdus conicus*, *C. surirellus*, *Octocyclus reinhardtii*, *Eprolithus floralis* two types, *Grantarhbdus meddii*, *G. camaratus*, *Haqius circumradiatus*, *Laguncula dorotheae*, *Lapideacassis cornuta*, *L. fasciata*, *Lithraphidites carniolensis*, *Manivitella pemmatoidea*, *Nannoconus truitti truitti*, *Parhabdolithus embergeri*, rare *Prediscosphaera volumnata*, very rare *Prediscosphaera* sp. (small, slightly elliptical with cross bars aligned with the major axes of the ellipse), *Rhagodiscus angustus*, *R. asper*, *R. splendens*, ?*Rucinolithus irregularis*, abundant *Rotelapillus laffittei* (two types), *Seribiscutum primitivum*, *Sollasites falklandensis*, *Stoverius achlyosus*, *Teichorhabdus ethmos*, *Tetrapodorhabdus decorus*, *Tubidiscus* sp., *Vekshinella crux*, *V. matalosa*, *V. quadriarcullus*, *Watznaueria barnesae*, *W. briannica*, *W. ovata*, *Zygodiscus bicrescenticus*, *Z.erectus* and *Z. sisyphus*.

Age and Discussion. The assemblages (F1-F6) detailed above can be characterised by the association of the key species *Prediscosphaera columnata*, *Sollasites falklandensis* and *Seribiscutum primitivum.* This association indicates an Early Albian age. The presence of *S. falklandensis* and the absence of *Tranolithus orinatus* suggest that these assemblages are slightly older than the Toolebuc Formation of the Eromanga Basin. The later contains abundant *T. orionatus* and *Seribiscutum primitivum*, and lacks *S. falklandensis* (see Shafik, 1985)

The presence of *Laguncula dorotheae*, *Sollasites falklandensis*, *Seribiscutum primitivum* and *Tegumentum octiformis* in the assemblages from the Carnarvon Terrace (discussed above) suggests cool surface waters during the Early Albian there. On the other hand, the presence of *Nannoconus trutti trutti* (and probably ?*Rucinorhabdus irregularis*) in some of the assemblages suggests some warm-water influence.

(F7) Two poorly-preserved assemblages were extracted from subsample 96DR001-03A and sample 96R002-05. These assemblages are tentatively assigned an Albian age.

Subsample 96DR001-03A, a greyish olive, siltstone, yielded poorly preserved nannofossils. Dissolution effects are evident and nannossil debris abound. Dominating taxa are the solution-resistant species of *Watznaueria* (*W. barnesae* and *W. ovata*). other identifiable taxa include *Bidiscus*, *Cretarhabdus conicus*, *C. surirellus*, *Cretarhabdus* sp.1, *Eprolithus floralis*, *Hemipodorhabdus gorkae*, *Litharaphidites carniolensis*, *Octocyclus reinhardtii*, *Retecapsa angusiforata*, *Rhagodiscus angustus*, *?R. asper*, *Rotelapillus laffittei*, *Watznaueria biporta* and *Zygodiscus erectus*.

Sample 96DR002-05, a moderately-hard, pale to light olive mudstone boulder, dredged from the Carnarvon Terrace in water 4994-4720 m deep. Nannofossils recovered are rare and poorly-preserved, but the accompanying nannofossil debris is abundant. Identifiable species include *Broinsonia signata*, *Chiastozygus litterarius*, *Cretarhabdus conicus*, *Cretarhabdus* sp. 1, *Cyclagelosphaera margerelii*, *Lithraphidites carniolensis*, *Rhagodiscus angustus*, *R. splendens*, *Rotelapillus laffettei*, *Watznaueria barnesae* and *W. britannica*.

LATE CRETACEOUS

Five Late Cretaceous assemblages were identified from material dredged from the Rowley Terrace (eastern side of the Swan Canyon and the Carnarvon Terrace. The assemblages from the Carnarvon Terrace are displaced.

(A) Very poorly-preserved nannofossils were recovered from sample 96DR013-7, a greyish orange calcilutite, which was dredged from the Rowley Tarrace (eastern) side of the Swan Canyon in 4150-3600 m deep. Signs of dissolution are evident. Taxa identified include *Actinozygus regularis*, *Arkhangelskiella specillata*, small *A. cymbiformis*, *Biscutum*, abundant *Cretaolithoides aculeus* 'group', *Cretarhabdus conicus*, *Cribrosphaerella ehrenbergii*, *Cylagelosphaera margerelii*, *Cyclindralithus serratus*, *Eiffellithus turriseiffeli*, *Heterorhabdus sinuosus*, *Lithraphidites carniolensis*, *Manivitella pemmatoidea*, *Microrhabdulus decoratus*, *Micula concava*, *M. staurophora*, *?M. murus*, *Prediscosphaera cretacea*, *P. grandis*, *P. majungae*, *P. spinosa*, very rare *Reinharditites levis* and *Watznaueria barnesae*.

Age. Dissolution has probably drastically reduced the diversity of the assemblage. Species present are mostly solution-resistant. The assemblage is assigned a mid Campanian to Late Maastrichtian age. This is based on the presence of *C. aculeus*. While the absence of *Lithraphidites quadratus* and other Maastrichtian key species suggests the mid Campanian end of the age bracket, the absence of *Broinsonia parca* and *Eiffellithus eximius* favours a

Maastrichtian age. Foraminiferids are sparse dominated by small forms; rare specimens of *Globotruncana* and *Rygoglobigerina*.

(B) A very poorly-preserved assemblage was extracted from sample 96DR014-9, a pale yelowish orange mudstone, which was dredged from the Rowley Terrace (eastern) side of the Swan Canyon in water 5250-4005 m deep. Signs of dissolution abound and the identifiable specimens are few compared with abundant nannofossil debris. Taxa identified include *Arkhangelskiella specillata*, *Biscutum novaculum*, very rare *Broinsonia parca*, a very large *Biscutum* sp., *Ceratolithoides aculeus*, *Cribrocorona gallicus*, *Cribrosphaerella ehrenbergii*, *Cretarhabdus conicus*, *Cyclogelosphaera bergeri*, *Cyclindralithus serratus*, *Heterorhabdus sinuosus*, *Micula concava*, *M. staurophora*, *Prediscosphaera cretacea*, *P. grandis* and *P. spinosa*. *C. aculeus* is particularly abundant.

Age. The stratigraphic range of the key species *C. aculeus* is mid Campanian to Late Maastrichtian. Based on the occurrence of this species with *Broinsonia parca*, in the absence of *Quadrum trifidum* and *Lithraphidites quardatus*, the age of the assemblage is probably mid Campanian. The foraminiferal assemblage is poorly preserved, and lack planktic forms.

(C) A rich and well-preserved assemblage was recovered from sample 96DR014-4, a yellowish grey mudstone, which was dredged from the Rowley Terrace (eastern) side of the Swan Canyon. Taxa identified include *Actinozygus regularis*, *Acutturus scotus*, *Ahmuerella octoradiata*, *Arkhangelskiella specillata*, *Biscutum coronum*, *Broinsonia parca*, *Ceratolithoides aculeus*, *Crenulithus surirellus*, *Cribrosphaerella ehrenbergii*, *Cylindralithus serratus*, *Eiffellithus eximius*, *E. turriseiffeli*, *Gartnerago obliquum*, *Gephyrorhabdus coronadventus*, *Heterorhabdus sinuosus*, *Lapideacassis* sp. aff. *L. cornuta*, *Lithraphidites carniolensis*, *Lithastrinus grillii*, *Manivitella pemmatoidea*, *Markalius astroporus*, *Microrhabdulus belgicus*, *M. helicoides*, *Micula concava*, *Prediscosphaera cretacea*, *P. spinosa*, *P. stoveri*, *Quadrum gothicum*, *Q. gartneri*, *Reinhardtites anthrophorus*, *R. levis*, *Rotelapillus laffittei*, *Watznaueria barnesae*, *W. biporta*, and *Zygodiscus bicrescenticus*.

Age. On the account of *B. parca*, *C. aculeus*, and *Q. gothicum*, the assemblage is probably mid to Late Campanian in age. The presence of *E. eximius*, *R. levis* and *L. grillii*, and the absence of *Q. trifidum* seem consistent with this age assignment.

(D) A rich well-preserved assemblage was extracted from subsample 96DR011-4C (pipe), a

very small clast in the soft Oligocene marl of sample 96DR0011-04 (pipe) which was dredged from the Carnarvon Terrace in water 3700-3070 m deep. Taxa identified include *Ahmuellerella octoradiata*, *Arkhangelskiella specillata*, *Bipodorhabdus*, *Bidiscus*, *Biscutum* , *Broinsonia parca*, *Ceratolithoides aculeus*, *Chiastozygus litterarius*, *Cretarhabdus conicus*, *Cribrosphaerella ehrenbergii*, *Cylindralithus serratus*, *Eiffellithus turriseiffeli*, *Heterorhabdus sinuosus*, *Kamptnerius magnificus*, *Lithraphidites carniolensis*, *Microrhabdulus belgicus*, *M. decoratus*, *Micula staurophora*, *Prediscosphaera cretacea*, *P. spinosa*, *P. stoveri*, *Quadrum gothicum*, *Q. trifidum*, *decorus*, *spiralis*, *Reinhardtites levis*, *Watznaueria barnesae*, and *Zygodiscus bicrescenticus*.

Age. The association of *Q. trifidum*, *Q. gothicum*, *B. parca* and *C. aculeus* indicates that the assemblage is probably late Campanian in age. The vertical range of the key species *Q. trifidum* spans the late Campanian - early Maastrichtian interval, and *B. parca* has been known to become extinct at mid latitudes near the end of the Campanian. The presence of *R. levis*, and the absence of *Arkhangelskiella cymbiformis* seem to be consistent with this age assignment.

(E) Two mixed assemblages (with dominant Maastrichtian components) were recovered from two subsamples 96DR009-04B and 96DR009-05C which were obtained from the Carnarvon Terrace in water 2650-2200 m deep. Subsample 96DR009-04B is a soft, olive grey mud adhering to the Paleocene mudstone 96DR009-04A, and subsample 96DR009-05C is also a soft, dark olive grey mud present in the Paleocene mudstone 96DR009-05B. The Maastrichtian components include *Actinozygus regularis*, *Acuturris scotus*, *Arkhangelskiella cymbiformis*, *A. orthocancellata*, *A. specillata*, *Chiastozygus litterarius*, *Corollithion exiguum*, *Cribrosphaerela daniae*, *C. ehrenbergii*, *Cyclagelosphaera margerelii*, *Cylindralithus serratus*, *Eiffellithus eximius*, *E. turriseiffeli*, *Heterorhabdus sinuosus*, *Kamptnerius magnificus*, *Lapideacassis cornuta*, *Lithraphidites quadratus*, *Markalius astroporus*, *Marthasterites inconspicuus*, *Microrhabdulus belgicus*, *Micula concava*, *M. staurophora*, *Nephrolithus frequens*, *Placozygus fibuliformis*, *P. sigmoides*, *Prediscosphaera cretacea*, *P. majungae*, *P. spinosa*, *P. stoveri/bukryi*, *Quadrum aculeus*, *Q. gothicum*, *Reinharditites levis*, *Rhagodiscus splendens*, *Tetrapdorhabdus decorus*, *Thoracosphaera operculata*.

The assemblage of 96DR009-04B contains very rare Paleocene species. These are *Cruciplacolithus tenuis*, small *Cruciplacolithus* sp., *Chiasmolithus*, *Coccolithus robustus*, *Fasciculithus*, *Prinsius* and *Toweius pertusus*. Similarly, the assemblage of 96DR009-05C

contains very rare Paleocene forms. These are *Chiasmolithus danicus*, *Coccolithus robustus* and *Cruciplacolithus tenuis*.

Age and environmental considerations of the older components. The presence of the key species *Nephrolithus frequens* fixes the age as Late Maastrichtian. The association of *Cribrosphaerella daniae*, *Kamptnerius magnificus*, *Nephrolithus frequens*, *Quadrum aculeus* and *Q. gothicum* suggests a mixed water mass. The first three species are known to have prefered cool surface waters; abundant presence of these species has been used to identify the Austral Province during the Late Maastrichtian (see Shafik, 1990a). The other two species, namely *Quadrum aculeus* and *Q. gothicum*, are known to have favoured warmer surface waters.

EARLY PALEOCENE

A rich assemblage was extracted from subsample 96DR001-01A, a yellowish grey chalk/limestone, which was dredged from the Carnarvon Terrace in water 4125-3700 m deep. It is dominated by *Coccolithus* sp., *Placozygus sigmoides* and *Cruciplacolithus tenuis*. Other species present include *Chiasmolithus danicus*, *?C. inconspicuus*, *Cruciplacolithus asymmetricus*, *C. primus*, *C. platipons*, *Ericsonia subpertusa*, *Markalius astroporus*, *Micula staurophora*, *Neochiastozygus modestus*, *N.* sp. aff. *N. perfectus*, *N. denticulatus* and *Thoracosphaera crassus*.

Age and remark. The presence of *Neochiastozygus modestus* and the absence of species of *Fasciculithus* suggest an Early Paleocene age. On this evidence, *Micula staurophora* is considered as reworked from Upper Cretaceous sediments. Contaminations (such as specimens of *Gephyrocapsa*) from Pleistocene sediments were noted.

The assemblage in subsample 96DR001-01A (abundant Paleocene but rare Late Cretaceous species) contrasts sharply with that in subsample 96DR009-05C (abundant Late Cretaceous associated with very rare Paleocene forms). The Paleocene species in subsample 96DR009-05C
includes *Chiasmolithus danicus*, *Coccolithus robustus* and *Cruciplacolithus tenuis*.

LATE PALEOCENE

Five assemblages are identified. The Late Paleocene age is based on the presence of either

Fasciculithus spp., *Heliolithus kleinpellii* and/or *Chiasmolithus bidens*. In addition, very rare Late Paleocene species (*Cruciplacolithus tenuis*, small *Cruciplacolithus* sp., *Chiasmolithus*, *Coccolithus robustus*, *Fasciculithus*, *Prinsius* and *Toweius pertusus*) were identified from subsample 96DR009-04B which contains abundant Late Cretaceous forms.

(A) A poorly-preserved assemblage was recovered from sample 96DR015-03, a soft to firm, white to yellowish white chalk, which was dredged from the Rowley Terrace (eastern) side of the Swan Canyon in water 4200-3875 m deep. Nannofossil debris abounds. Species identified include *Ericsonia subpertusa*,*Toweius eminens*, *T. pertusus*, *T. tovae*, *Heliolithus* sp., *Coccolithus robustus*, *Chiasmolithus danicus*, *C. edentulus*, *C. consuetus*, *Cruciplacolithus tenuis*, *Fasciculithus involutus*, *F. pileatus*, *Placozygus sigmoides*.

(B) A poorly-preserved assemblage was extracted from sample 96DR015-05 (pipe), a white to yellowish white ooze; nannofossil debris abounds. Species identified include *Biantholithus sparsus*, *Toweius eminens*, *T. pertusus*, *T. tovae*, *Heliolithus* sp., *Coccolithus robustus*, *Chiasmolithus danicus*, *C. edentulus*, *C. consuetus*, *Cruciplacolithus tenuis*, *Fasciculithus involutus*, *F. janii*, *F. pileatus* and abundant *Placozygus sigmoides*.

(C) A nannofossil assemblage was recovered from subsample 96DR/009-05B, a consolidated, yellowish grey mudstone, which was dredged from the Carnarvon Terrace in water 2650-2200 m deep. Identified taxa included *Biantholithus sparsus*, ?*Chiasmolithus bidens*, *C. consuetus*, *C. edentulus*, *C. inconspicuus*, *Coccolithus robustus*, *Cruciplacolithus frequens*, *C. tenius*, *C. latipons*, *Ellipsolithus distichus*, *E. macellus*, *Ericsonia subpertusa*, *Fasciculithus involutus*, *F. tympaniformis*, rare *Lapideacassis*, *Markalius astroporus*, *Neochiastozygus junctus*, *Neocrepidolithus*, *Placozygus sigmoides*, *Prinsius bisulcus*, *Thoracosphaera operculata*, *Toweius pertusus*.

(D) A moderately-preserved assemblage was extracted from sample 96DR007-05, a firm, white chalk, which was dredged from the Carnarvon Terrace in water 3700-3150 m deep. This assemblage includes *Chiasmolithus bidens*, *C. consuetus*, *C. edentulus*, *Coccolithus robustus*, *Cruciplacolithus asymmetricus*, *C. frequens*, *C. tenuis*, *Ellipsolithus distichus*, *E. macellus*, *Fasciculithus involutus*, *F. tympaniformis*, *Heliolithus kleinpellii*, rare *Neochiastozygus denticulatus*, *N. modestus*, common *N. perfectus*, abundant *Placozygus sigmoides*, *Sphenolithus anarrhopus*, *Toweius eminens*, *T. pertusus*. In addition, very rare reworked Cretaceous forms (such as *Lithraphidites carniolensis*) were identified.

(E) A poor assemblage, with abundant reworked Late Cretaceous taxa, was extracted from sample 96DR007-09, a yellowish grey, glauconic chalk. The *in situ* species include *Chiasmolithus bidens*, *C. consuetus*, *C. edentulus*, *Coccolithus robustus*, *Cruciplacolithus tenuis*, *Ellipsolithus distichus*, *Fasciculithus involutus*, *F. tympaniformis*, *Heliolithus kleinpellii*, *Heliolithus*, *Markalius astroporus*, *Neochiastozygus modestus*, *N. perfectus*, *N. saepes*, *Placozygus sigmoides*, *Sphenolithus*, *Toweius eminens*, *T. pertusus* and*T. tovae*. The reworked taxa included *Arkhangelskiella cymbiformis*, *A. speciallata*, *Broinsonia parca*, *Cretarhabdus conicus*, *Cribrosphaerella ehrenbergii*, *Eiffellithus eximius*, *Heterolithus sinsosus*, *Kampnerus magnificus*, *Lapideacassis cornuta*, *Micula staurophora*, *M. swastika*, *Petrorhabdus copulatus*, *Prediscosphaera cretacea*, *Quadrum gothicum*, *Reinhardtites anthophorus*, *R. levis* and *Watznaueria barnesae*.

EOCENE

Four Eocene assemblages from four different stratigraphic levels are identified. Arranged in a chronological order, these assemblages are discussed below beginning with the oldest. In addition, a mixed assemblage, dominated by elements indicative of a Middle Eocene age is discussed.

(A) A poorly-preserved assemblages was extracted from sample 96DR013-02, a pale orange limestone, which was dredged from the Rowley Terrace (eastern) side of the Swan Canyon in water 4150-3600 m deep. Signs of dissolution, such as loss of central cross in *Camplyosphaera*, are evident. Taxa identified included common *Cyclicargolithus gammation*, *Coccolithus formosus*, *C. eopelagicus*, *C. pelagicus*, abundant *Sphenolithus radians*, common *Discoaster lodoensis*, *D. barbadiensis*, *D. sublodoensis*, *D. tanii tanii*, *Discoasteroides kuepperi*, frequent *Chiasmolithus grandis*, *Helicosphaera lophota*, very rare *Orthostylus tribrachiatus*, *Calcidiscus protoannulus*, abundant *Campylosphaera dela*, and common *Zygrhablithus bijugatus crassus*.

Age. The presence of *D. sublodoensis* indicates the *D. sublodoensis* Zone. The age is late Early Eocene age. A correlation with the foraminiferal late zone P9 can be made. The Early Eocene *D. sublodoensis* Zone has been recognised from many parts of the world (see, e.g. Martini, 1971).

Very minor reworking from Cretaceous and Paleocene sediments was detected. Rare *Chiasmolithus californicus* and *Cruciplacolithus latipons* were identified as displaced from

Paleocene sediments. Reworked Late Cretaceous as well as Paleocene foraminiferids of zone P5 were found (see Wells, this report).

(B) A poorly-preserved assemblage was extracted from sample 96DR/013-09 (preparation MFN-4820), a stiff, pale yellowish orange mud, which was dredged from the same station as the above-mentioned sample. Signs of dissolution effects abound. Taxa identified include *Discoaster barbadiensis, D. bifax, D. lenticularis, D. saipanensis,* rare *D. sublodoensis, D. tanii tanii, Calcidiscus protoannulus, Campylosphaera dela, Chiasmolithus consuetus, C. grandis, C. solitus, Clausicoccus cribellum, Coccolithus eopelagicus, C. formosus, Cyclicargolithus floridanus, Helicosphaera,* very rare *Nannotetrina fulgens, N. pappii, Pseudotriquetrorhabdulus inversus,* common *Reticulofenestra dictyoda,* common *R. umbilicus,* common *Sphenolithus furcatolithoides, S. moriformis* and rare *Zygrhablithus bijugatus bijugatus* .

Age and remarks. Based on the association of *Reticulofenestra umbilicus, Sphenolithus furcatolitoides* and *Discoaster bifax,* the age is Middle Eocene and a correlation with the foraminiferal P12 zone is possible. These key species have been used in the definition of two Middle Eocene zone. Gartner (1971) used *Reticulofenestra umbilicus* to describe the *R. umbilica-S. furcatolithoides* Zone from the Middle Eocene of the Blake Plateau (off the east of Florida, USA). Bukry (1973) used *Discoaster bifax* to subdivide his Middle Eocene *R. umbilica* Zone.

Some reworking from older Eocene levels is apparent by the presence of *Discoaster sublodoensis* and *Nannotetrina fulgens.*

Another preparation (MFN4620) from the same sample yielded a similarly poorly-preserved nannofossil assemblage indicating a Middle Eocene age. Signs of dissolution effects abound. The composition of the assemblage is similar to that listed above except for the lack of *Discoaster bifax, D. sublodoensis* and *Nannotetrina fulgens,* and the presence of *?Cyclicargolithus reticulatus, Markalius astroporus, Pedinocyclus larvalis, Sphenolithus obtusus, S. radians.*

(C) A mixed assemblage was recovered from subsample 96DR029-08B (pipe), a pale yellowish grey sand dredged from the central northern Exmouth Plateau in a water 2280-1995 m deep. The presumably allochthonous elements of the assemblage are chiefly late Tertiary in age. The Eocene forms include abundant *Campylosphaera dela, Chiasmolithus*

grandis, rare *C.solitus*, frequent *Coccolithus eopelagicus*, *C. formosus*, rare *Cyclicargolithus floridanus*, common *C. gammation*, frequent *Discoaster barbadiensis*, frequent *D. lodoensis*, *Discoasteroides kuepperi*, *Helicosphaera lophota*, *H. seminulum*, rare small *Nannotetrina fulgens*, frequent *Pseudotriquetrorhabdulus inversus*, rare *Reticulofenestra umbilicus*, common *Sphenolithus furcatolithoides*, rare *S. predistentus*, frequent *S. radians* and *Zygrhablithus bijugatus crassus*. The late Tertiary and Quaternary forms include *Calcidiscus leptoporus*, *C. macintyrei*, *Ceratolithus cristatus*, rare *Cyclicargolithus abisectus*, frequent *Discoaster asymmetricus*, *D. brouweri*, *D. pentaradiatus*, *D. surculus*, *D. tamalis*, *Gephyrocapsa* spp., *Helicosphaera kamptneri* and *Pesudoemiliania lacunosa*.

Age of the older components. The assemblage includes Early and Middle Eocene elements. The age is probably mid Middle Eocene on account of *Sphenolithus furcatolithoides* and *Reticulofenestra umbilicus*.

(D) A moderately rich nannofossil assemblage was recovered from sample 96DR/009-02 (preparation MFN-4617), a light grey marl dredged from the Carnarvon Terrace in water 2650-2200 m deep. identified include rare *Bramletteius serraculoides*, *Calcidiscus protoannulus*, *Chiasmolithus grandis*, *Coccolithus eopelagicus*, *C. formosus*, *Clausicoccus cribellum*, *Cyclicargolithus floridanus*, abundant *C. reticulatus*, *Discoaster saipanensis*, *Helicosphaera dinesensii*, *H. lophota*, *H. seminulum*, *Lanternithus minutus*, *Neococcolithes dubius*, *Reticulofenestra orangensis*, *R. scrippsae*, *R. scissura*, *R. umbilicus*, and *Zygrhablithus bijugatus bijugatus*.

Age. The presence of *Bramletteius serraculoides*, *Chiasmolithus grandis* and *Reticulofenestra scissura*, suggests that the age of the assemblage is a later Middle Eocene. Based on material from the Blake Plateau, Gartner (1971) used *B. serraculoides* to define a Middle Eocene zone, bearing its name. This zone has been correlated with the foraminiferal P13 Zone.

(E) A moderately-preserved assemblage was extracted from sample 96DR/010-01, a very light grey mudstone, which was dredged from the Carnarvon Terrace in water 2420-2100 m deep. Taxa identified include rare *Blackites spinulus*, rare *Braarudosphaera bigelowii*, rare *Brameletteius serraculoides*, frequent *Calcidiscus protoannulus*, very rare *Chiasmolithus grandis*, rare *C. oamaruensis*, *Coccolithus eopelagicus*, *Coccolithus formosus*, *C. germanicus*, *Cyclicargolithus floridanus*, ver rare *C. reticulatus*, common *Discoaster barbadiensis*, common *D. distinctus*, *D. tanii nodifer*, frequent *D. saipanensis*, frequent *Helicosphaera compacta*,

rare *H. heezenii*, frequent *H. lophota*, rare *H. papillata*, rare *H. reticulata*, frequent *H. seminulum*, rare *H. wilcoxonii*, rare *Holodiscolithus solidus*, frequent *Isthmolithus recurvus*, (recrystalised) abundant *Lanternithus minutus*, *Pedinocyclus larvalis*, poorly-preserved *Pontosphaera multipora* and rare *P. plana*, *Reticulofenestra scissura*, *R. scrippsae*, *R. umbilicus*, *Sphenolithus predistentus*, *S. pseudoradians*, very rare *Transversopontis pulcheroides*, and common *Zygrhablithus bijugatus bijugatus*.

Age and remarks. The association of *Isthmolithus recurvus*, *Discoaster barbadiensis*, *D. saipanensis* and *Cyclicargolithus reticulatus* indicates a Late Eocene age. This association is typical of the Late Eocene *I. recurvus* Zone of several authors (e.g. Martini, 1971; Gartner, 1971; Shafik, 1973).

I. recurvus is a neritic species which preferred cool surface waters, but there is a strong evidence of warmer water in the assemblage. Specimens of *Discoaster* are condiderably more abundant than specimens of *Chiasmolithus*, indicating warm surface waters. Similarly, the large number of species of the genus *Helicosphaera* and the presence of both *Sphenolithus predistentus* and *S. pseudoradians* also indicate warm surface waters. Species suggesting neritic environment include *Braarudosphaera bigelowii*, *Holodiscolithus solidus*, *Lanternithus minutus*, *Pontosphaera* spp., *Transversopontis pulcheroides* and *Zygrhablithus bijugatus bijugatus*.

The presence of *Chismolithus grandis* may suggest a minor reworking from oldèr Eocene levels.

EARLY OLIGOCENE

A well-preserved assemblage was recovered from subsample 96DR009-05A, a soft, greyish white mudstone dredged from the Carnarvon Terace in water 2650-2200 m deep. Species identified include *Blackites spinulus*, *Brameletteius seraculoides*, *Calcidiscus protoannulus*, *Chiasmolithus oamaruensis*, *Coccolithus formosus*, *Clausicoccus cribellum*, *Cyclicargolithus floridanus*, *Discoaster tanii nodifer*, *Helicosphaera compacta*, *H. heezenii*, *H. seminulum*, frequent *Isthmolithus recurvus*, *Lanternithus minutus*, *Pontosphaera multipora*, *P. plana*, *Reticulofenestra hampdenensis*, *R. oamaruensis*, *R. scissura*, *R. scrippsae*, *R. umbilicus*, *Sphenolithus moriformis*, frequent *S. predistentus*, rare *S. pseudoradians*, *Transversopontis pulcher*, *Zygrablithus bijugatus bijugatus* and *Z. bijugatus crassus*.

Age. The association of *Chiasmolithus oamaruensis*, *Coccolithus formosus* and *Isthmolithus recurvus*, in the absence of the key Eocene species *Discoaster barbadiensis* and *D. saipanensis* suggests an Early Oligocene age.

MID TO LATE OLIGOCENE

Three assemblages of mid - late Oligocene age are identified, two from stations on the Carnarvon Terrace in area B, and one from the central northern Exmouth Plateau where water depth is 2280-1995 m. These assemblages include a large number of reworked Eocene species. Coeval assemblages, also with reworked Eocene species, have been recorded previously from other areas on the Australian western and southern margins (see, Shafik, 1990b, 1991)

(A) A mixed flora was recovered from subsample 96DR011-04A (pipe), a soft, yellowish grey marl from the Carnarvon Terrace (area B) (water depth 3700-3070 m). Dominant among this mixed assemblage are the elements which suggest mid Oligocene age. Species identified include very rare *Coccolithus formosus*, *Discoaster saipanensis*, *Cyclicargolithus reticulatus*, *Helicosphaera compacta, H. lophota, H. seminulum, H. wilcoxonii*, *Lanternithus minutus*, *Pendinocyclus larvalis*, and *Reticulofenestra umbilicus* which are mostly reworked from the Eocene. The mid Oligocene taxa include common to abundant *Helicosphaera recta*, *H. euphratis*, *H. obliqua*, *Sphenolithus predistentus*, *S. distentus*, *S.* sp. aff. *S. ciperoensis*, *Cyclicargolithus floridanus*, *C. abisectus*, *Discoaster deflandrei*, *Coronocyclus nitescens*, *Chiasmolithus altus* and *Triquetrorhabdulus carinatus*. Other taxa identified are known from both Eocene and Oligocene sediments. These include *Calcidiscus protoannulus*, *Clausicoccus cribellum*, *Coccolithus eopelagicus*, *C. pelagicus*, *Pontosphaera plana*, *P. multipora*, *Sphenolithus moriformis*, and *Zygrhablithus bijugatus bijugatus*. Also a very minor amount of Late Cretaceous taxa such as *Cribrosphaerella ehrenbergii* and *Micula staurophora* were also encountered.

(B) A mixed assemblage was extracted from sample 96DR029-08 (pipe), a pale yellowish brown, calcareous sand, which was dredged from the central northern Exmouth Plateau in water 2280-1995 m deep. The Eocene and Eocene/Oligocene species are more abundant than the mid Oligocene ones. The mainly-Eocene species include *Brameletteius serraculoides*, *Campylosphaera dela*, *Chiasmolithus grandis*, *C. solitus*, *Coccolithus formosus*, *Discoaster barbadiensis*, *D. nodifer*, *D. tanii*, *Cyclicargolithus reticulatus*, *Helicosphaera compacta*, very rare *Lanternithus minutus*, poorly-preserved and rare *Neococcolithes dubius*,

Pseusotriquetrorhabdulus inversus and *Sphenolithus furcatolithodes*. The mainly-Oligocene species identified include *Discoaster deflandrei* (group), *Helicosphaera recta*, *H. euphratis*, *Sphenolithus distentus*, *S.* sp. aff. *S. ciperoensis*, *Cyclicargolithus abisectus*, *Coccolithus pelagicus*, *Discoaster deflandrei*, and *Coronocyclus nitescens*. Other taxa identified are known from both Eocene and Oligocene sediments. These include *Calcidiscus protoannulus*, *Clausicoccus cribellum*, *Coccolithus eopelagicus*, *C. pelagicus*, *Cyclicargolithus floridanus*, severely-corroded *Pontosphaera plana*, *Sphenolithus moriformis*, *Reticulofenestra scissura, R. scrippsae*, *R. umbilicus*, *Sphenolithus predistentus*, *S. pseudoradianus*, and *Zygrhablithus bijugatus bijugatus*.

Age and remark. The association of the key species *Cyclicargolithus abisectus, Helicosphaera recta, Reticulofenestra scissura, Sphenolithus distentus* and *S.* sp. aff. *S. ciperoensis* in the assemblages from 96DR011-04A (pipe) and 96DR029-08 (pipe) suggests a mid (late early) Oligocene age. According to data in Martini (1971), and in the light of revised correlation by Berggren & others (1985), some elements of this association suggest correlation with the foraminiferal zone P21a.

A similar mid Oligocene assemblage, with abundant reworked Eocene elements, has recently been reported from the offshore South Perth Basin (Shafik, 1991).

(C) A rich assemblage was recovered from sample 96DR007-04 (subsamples 007-04A & 007-04B), a soft, yellowish grey chalk, which was dredged from the Carnarvon Terrace in water 3700-3150 m deep. Age-diagnostic species pointing to a mid to Late Oligocene age are rare and the key sphenoliths, in particular, are somehow poorly preserved. Most of the other species (which range from Eocene into Oligocene) are more frequent and excellently preserved. The mid to late Oligocene species included *Coronocyclus nitescens*, *Cyclicargolithus abisectus*, *Helicosphaera euphratis*, *H. recta*, *Sphenolithus distentus*, *S. dissimilis*, *?S. ciperoensis* and *Triquetrorhabdulus carinatus*. Other species identified include some which are known to have originated in the Eocene and range into the Oligocene (or younger levels). These are very rare *Bramletteius serraculoides*, very rare *Chiasmolithus expansus*, very rare *C. oamaruensis*, *Coccolithus eopelagicus*, *C. cribellum*, *Cyclicargolithus floridanus* , rare *C. reticulatus*, *Discoaster deflandrei*, *D. nodifer*, *Helicosphaera bramlettei*, abundant *H. compacta*, *H. seminulum*, *H. wilcoxnii*, very rare *Isthmolithus recurvus*, rare *Markalius inversus*, *Pedinocyclus larvalis*, very rare *Pontosphaera multipora*, abundant *Reticulofenestra scissura*, very rare *R. umbilicus*, abundant *Spenolithus moriformis*, common *S. predistentus*, very rare *S. pseudoradians*, very rare *S. radians* and *Zygrhablithus bijugatus*

bijugatus.

Age and remarks. Based on the presence of the key species *Helicosphaera recta* and *Sphenolithus distentus*, the age of the assemblage is mid to late Oligocene. The maximum age limit of mid Oligocene is based on the presence of *Cyclicargolithus abisectus*, *Sphenolithus distentus* and *Helicosphaera recta*. The latter species together with *Reticulofenestra scissura* and *Zygrhablithus bijugatus bijugatus* are known to range to the top of the Oligocene. *Triquetrorhabdulus carinatus* is known to range from latest Oligocene to Early Miocene.

This assemblage is probably younger than those from 96DR011004B (pipe) and 96DR029-08 (pipe) on account of *Triquetrorhabdulus carinatus*. Those from 96DR011-04A (pipe) and 96DR029-08 (pipe) contain strong evidence of reworking from middle or upper Eocene sources. The evidence of reworking in sample 96DR007-04 suggests a mainly lower Oligocene source. In this regard, the assemblage from 96DR007-04 resembles another recorded recently from the Great Australian Bight Basin (see Shafik, 1990b).

LATEST OLIGOCENE

An assemblage composed of predominantly Oligocene taxa, but includes some reworked Eocene species as well, was recovered from sample 96DR/008-07. This sample is a greyish yellow chalk, which was dredged from the Carnarvon Terrace (area B) in water 3550-3180 m deep . The dominant species in the assemblage are *Coccolithus pelagicus*, *Cyclicargolithus abisectus*, *C. floridanus*, *Discoaster deflandrei* (group), *Sphenolithus moriformis* and *Zygrhablithus bijugatus bijugatus*. Common species include *Clausicoccus cribellum*, *Coccolithus eopelagicus*, *Coronocyclus nitescens*, *Helicosphaera euphratis*, *H. intermedia* and *H. obliqua*. Rare species are *Chiasmolithus* sp., *Helicosphaera recta*, *Reticulofenestra scissura* and *Triquetrorhabdulus carinatus*.

Rare specimens of *Cyclicargolithus gammation*, *C. reticulatus*, *Reticulofenestra umbilicus* and *Sphenolithus radians* were noted in the assemblage. They are considered reworked from Eocene sediments.

Rare specimens of the Neogene species *Calcidiscus leptoporus* were also noted in the assemblage.

Age and comments. The assemblage is tentatively assigned a latest Oligocene age, on account of the association of *Helicosphaera euphratis*, *H. intermedia*, *H. recta*, *Reticulofenestra scissura* and *Zygrhablithus bijugatus bijugatus*. The vertical range of *H.euphratis* is Late Oligocene - Early Miocene, but *H. recta* is a typical mid to Late Oligocene species. Also, *Reticulofenestra scissura* and *Zygrhablithus bijugatus bijugatus* are known to disappear at or near the top of the Oligocene; these two species could be reworked from the Eocene similar to the associated reworked Eocene species (e.g. *Reticulofenestra umbilicus*), however. *Calcidiscus leptoporus* is known to first appears during the Early Miocene, and is probably a contaminant.

REFERENCES

Barlower, T.J., Monechi, S., Thierstein, H.R., 1989 - Calcareous nannofossil zonation of the Jurassic-Cretaceous boundary interval and correlation with the geomagnetic polarity timescale. *Marine Micropaleontology*, **14**, 153-235.

Berggren, W.A., Kent, D.V. and Flynn, J.J., 1985 - Jurassic to Paleogene: Part 2 Paleogene geochronology and chronostratigraphy. *In* Snelling, N. J. (Ed.), The Chronology of the Geological Record. *The Geological Society, Memoir* **10**, 141-195.

Black, M., 1971 - Coccoliths of the Speeton Clay and Sutterby Marl. *Proceedings of the Yorkshire geological Society*, **38**, 381-424.

Bown, P.R., Cooper, M.K.E. & Lord, A.R., 1988 - A calcareous nannofossil biozonation scheme for the early to mid Mesozoic. *Newsletters in Stratigraphy*, **20** (2), 91-114.

Bukry, D., 1973 - Low-latitude coccolith biostratigraphic zonation. *In* Edgar, N.T., Saunders, J.B. & others, *Initial reports of the Deep Sea Drilling Project*, **15**, Washington (U.S. Government Printing Office), 653-711.

Crux, J.A., 1987 - Boreal Cretaceous nannofossil biostratigraphy (Ryazanian - Barremian), *INA Newsletter*, **9** (2), 48-49.

Crux. J.A., 1989 - Biostratigraphy and palaeogeographical implications of Lower Cretaceous nannofossils from north-western Europe. *In* Crux, J.A. & van Heck, S.E.

(Eds.), *Nannofossils and their applications*, Ellis Horwood Ltd., 143-211.

Exon, N.F., Ramsay, D.C. & others, 1990 - Triassic and Jurassic sequences of the northern Exmouth Plateau and offshore Canning Basin. *BMR Record* 1990/57, 76pp.

Gartner, S., 1971 - Calcareous nannofossils from the *JOIDES* Blake Plateau cores, and revision of Paleogene nannofossil zonation, *Tulane studies in Geology and Paleontology*, **8** (3), 101-121.

Haq, B.U., von Rad, U., O'Connel, S. & others, 1990 - *Proceedings of Ocean Drilling Programe, Initial Reports*, **122**, College Station, Texas (Ocean Drilling Programe), 826 pp.

Jakubowski, M., 1987 - A proposed Lower Cretaceous calcareous nannofossil zonation scheme for the Moray Firth area of the North Sea. *Abhandlungen der Geologischen Bundesanstalt*, **39**, 99-119.

Martini, E., 1971 - Standard Tertiary and Quaternary calcareous nannoplankton zonation. *In* Farinacci, A. (Ed.), *Proceedings of the 2nd Planktonic Conference,* Roma 1970. Edizioni Tecnoscienza, Roma, 739-785.

Perch-Nielsen, K., 1979 - Calcareous nannofossils from the Cretaceous between the North Sea and the Mediterranean. *Aspekte der Kreide Europas*. IUGS Series A, **6**, 223-272.

Perch-Nielsen, K., 1985 - Mesozoic calcareous nannofossils. *In* Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K. (Eds.), *Plankton Stratigraphy*. Cambridge Earth Science Series, Cambridge University Press, 329-426.

Shafik, S., 1973 - Eocene-Oligocene nannoplankton biostratigraphy in the western and southern margins of Australia. *Abstracts, 45th Congress, Australian and New Zealand Association for Advancement of Science, Section* **3**, 101-103.

Shafik, S., 1985 - Calcareous nannofossils from the Toolebuc Formation, Eromanga Basin, Australia. *BMR Journal of Australian Geology & Geophysics*, **9**, 171-181.

Shafik, S., 1990a - Late Cretaceous nannofossil biostratigraphy and biogeography of the

Australian western margin. *Bureau of Mineral Resources Report* 295, 164pp.

Shafik, S., 1990b - Maastrichtian and Early Tertiary record of the Great Australian Bight Basin and its onshore quivalents on the Australian southern margin: a nannofossil study. *BMR Journal of Australian Geology & Geophysics*, **11**, 473-497.

Shafik, S., 1991 - Upper Cretaceous and Tertiary stratigraphy of the Fremantle Canyon, South Perth Basin: a nannofossil assessment. *BMR Journal of Australian Geology & Geophysics*, 12, 65-91.

Sissingh, W., 1977 - Biostratigraphy of Cretaceous calcareous nannoplankton. *Geologie en Mijnbouw*, **56**, 37-65.

Taylor, R.J., 1982 Lower Cretaceous (Ryazanian to Albian) calcareous nannofossils. *In* Lord, A.R. (Ed.), *A stratigraphic index of calcareous nannofossils*, British Micropalaeontological Society Series, 40-80.

Thierstein, H.R., 1973 - Lower Cretaceous nannoplankton biostratigraphy. *Abhandlungen der Geologischen Bundesanstalt*, Wein, **29**, 1-52.

Thierstein, H.R., 1976 - Mesozoic calcareous nannoplankton biostratigraphy of marine sediments. *Marine Micropaleontology*, **1**, 325-362.

CALCAREOUS NONNOFSSIL AGE DETERMINATION OF DREDGE SAMPLES, BMR CRUISE 96

II. Neogene

by

Samir Shafik

ABSTRACT

Several Neogene calcareous nannofossil assemblages have been recorded from material dredged during BMR Cruise 96; their biostratigraphy has been discussed. The Early Miocene *Discoaster druggii* Subzone (Bukry, 1973) has been identified from the central northern Exmouth Plateau by a mixed assemblage, containing reworked Eocene and Oligocene forms. Assemblages assignable to the Middle Miocene *Sphenolithus heteromorphus* Zone (Martini, 1971; Bukry, 1973) have been identified from the southern Rowley Terrace, and from the central northern Exmouth, the Scott and the western margin of the Wombat Plateaux; evidence of reworking from Tertiary sources is particularly strong in the assemblage from the Exmouth Plateau. Other Middle Miocene assemblages have been identified from the Carnarvon Terrace and the Scott Plateau, but these are largely mixed. A younger assemblage, assignable to the Early Pliocene *Discoaster asymmetricus* Subzone (Bukry, 1973) has been recorded from the central northern Exmouth Plateau.

INTRODUCTION

Most of the assemblages identified here are mixed calcareous nannofloras which often include, in addition to obvious reworked species, others whose stratigraphic ranges are not separated by large gaps. Consequently, distinction between autochthonous and allochthonous species (which are either a result of contaminantion from younger soft material and/or reworking from older sediments) has not always been easy. This meant that precise age determination was not possible in some instances.

Neogene zones described by Martini (1971), and Bukry (1973) which have been given code numbers by Okada & Bukry (1980), were used where possible.

RESULTS

The assemblages discussed below are arranged in a chronological order, beginning with the oldest.

EARLY MIOCENE

A moderately-preserved mixed assemblage was extracted from sample 96DR029-04, a greyish orange clay, which was dredged from the central northern Exmouth Plateau in water 2280-1995 m deep. The list of species identified is long and includes a large number of displaced species which were found to be rare in the smear slides examined. Autochthonous species include rare *Coronocyclus nitescens*, *Cyclicargolithus abisectus*, *C. floridanus*, *Discoaster deflandrei*, *D. druggii*, *D.* sp. cf. *D. variabilis*, *Helicosphaera euphratis*, *Orthorhabdus serratus*, *Sphenolithus delphix*, *S. dissimilis* and *Triquetrorhabdulus challengeri*.

Evidence of reworking from Eocene and Oligocene sources is overwhelming (e.g. *Bramletteius serraculoides*, *Chiasmolithus oamaruensis*, *Coccolithus formosus*, *Reticulofenestra scissura*, *R. umbilicus* and *Sphenolithus predistentus*). The reworked typical Eocene forms (*Discoaster saipanensis*) are not as diversified as the typical Oligocene ones (e.g. *Sphenolithus ciperoensis* and *Helicosphaera recta*).

Biostratigraphic assignment and age. The presence of both *Discoaster druggii* and *Orthorhabdus serratus* indicates the Early Miocene *Discoaster druggii* Subzone of Bukry (1973) (=CN1c Subzone of Okada & Bukry, 1980). The overlap in the stratigraphic ranges of *Sphenolithus disimilis*, *S. delphix*, *Triquetrorhabdulus challengeri* and *T. carinatus* supports the Early Miocene age, and suggests an assignement to the NN1 Zone of Martini, 1971. However, the discoasters, although dominated by the *Discoaster deflandrei* group i.e. consistent with NN1 Zone placement, include rare specimens of free-armed species (such as *D. variabilis*) which suggest a younger level within the Lower Miocene. Also, the presence of *Calcidiscus macintyrei* suggests a younger level than NN1 Zone. It was not possible to determine whether or not the rare occurrences of these younger species (*D. variabilis* and *C. macintyrei*) are a result of contamination.

MIDDLE MIOCENE

(A) A moderately to poorly-preserved assemblage was extracted from sample 96DR018-03, a soft, greyish yellow chalk, which was dredged from the Rowley Terrace (eastern) side of the Swan Canyon in water 3360-2980 m deep. It is dominated by *Sphenolithus heteromorphus* and *Cyclicargolithus floridanus*. Other species present such as *Calcidiscus leptoporus*, *C. macintyrei*, *Coronocyclus nitescens*, *Hayaster perplexus*, *Helicosphaera kamptneri*, *Reticulofenestra* sp. cf. *R. gartneri* are frequent, and *Scyphosphaera* spp. are rare. The discoasters include *Discoaster exilis*, *D. deflandrei*, *D. moorei*, *D. signus* and *D. variabilis*.

Biostratigraphic assignment and age. *Helicosphaera ampliaperta*, a useful species for discriminating the older part of the range of the key species *Sphenolithus heteromorphus*, was not encountered; the latter species is abundant in the assemblage. This is consistent with the common occurrence of *Calcidiscus macintyrei*, *Hayaster perplexus*, *Helicosphaera kamptneri* and *Discoaster variabilis* in the assemblage. This evidence suggests the early Middle Miocene (*Sphenolithus heteromorphus*) NN5 Zone of Martini (1971) or the CN4 Zone of Okada & Bukry (1980).

(B) A moderately-preserved assemblage was recovered from sample 96DR029-01, a soft, white to yellowish grey limestone, which was dredged from the central northern Exmouth Plateau in water 2280-1995 m deep. Reworked taxa from Paleocene (*Toweius pertusus*), Eocene (*Chiasmolithus solitus* and *Sphenolithus furcatolithoides*) and Oligocene (e.g. *Helicosphaera recta* and *Sphenolithus ciperoensis*) sources are scarce but undeniable. The *in situ* species include *Calcidiscus leptoporus*, common *C. macintyrei*, *Coccolithus miopelagicus*, *C. pelagicus*, *Coronocyclus nitescens*, *Cyclicargolithus floridanus*, *Discoaster deflandrei*, rare *D. druggii*, *D. exilis*, *D. moorei*, *D.* aff. *D. challengeri*, *Helicosphaera euphratis*, common *Reticulofenestra pseudoumbilicus*, rare *Sphenolithus heteromorphus* and rare (three-ridged) *Triquetrorhabdulus challengeri*.

Biostratigraphic assignment and age. The assemblage is readily assignable to the early Middle Miocene (*Sphenolithus heteromorphus*) NN5 Zone of Martini (1971) or CN4 Zone of Okada & Bukry (1980). This is based on the record of the nominate species without the association of *Helicosphaera ampliaperta*.

The presence of three-ridged *Triquetrorhabdulus challengeri* in the assemblage may be a

result of some reworking from a basal Miocene source since this species is currently known as being restricted to NN1 and NN2 Zones (see Biolzi & others, 1981; Perch-Nielsen, 1985).

(C) A poorly-preserved assemblage was extracted from sample 96DR026-03, a soft, pale orange mudstone, which was dredged from the Scott Plateau in water 3050-2710 m deep. Signs of dissolution abound. Discoasers are diversified and include *D. variabilis, D. signus, D. exilis, D. formosus, D. moorei, D. challengeri*, and *D. deflandrei*. The key species *Sphenolithus heteromorphus* is present, in association with *Calcidiscus leptoporus, C. macintyrei, C. protoannulus, Reticulofenestra pseudoumbilicus, Cyclicargolithus floridanus, Helicosphaera kamptneri, H. granulata, Coronocyclus nitescens, Hayaster perlexus, Sphenolithus moriformis*, very rare *Orthorhabdus serratus, Triquetrorhabdulus carinatus, T. milowii* (with one ridge), and species of *Scyphosphaera*.

Biostratigraphic assignment and age. Based on the presence of *Sphenolithus heteromorphus*, in the absence of *Helicosphaera ampliaperta*, the assemblage is assigned to the NN5 Zone of Martini (1971) or to the CN4 Zone of Okada & Bukry (1980). The presence of *Discoaster formosus* supports this zonal assignment. This species has been recorded from the three major oceans and the Arabian Sea as being confined to the *Sphenolithus heteromorphus* Zone (=CN4 Zone) (see Bukry, 1974). The age is early Middle Miocene.

Very little evidence of reworking from Eocene (*Pseudotriquetrorhabdulus inversus*) and Upper Oligocene/Lower Miocene (*Triquetrorhabdulus carinatus*) sediments is detected.

(D) A moderately-preserved assemblage was recovered from sample 96DR033-02, a pale orange to white chalk, which was dredged from the western margin of the Wombat Plateau in water 3050-2470 m deep. The species *Calcidiscus leptoporus, C. macintyrei, Discoaster variabilis, Helicosphaera kamptneri, Reticulofenestra* sp. cf. *R. gartneri, R. pseudoumbilicus, Sphenolithus abies* and *S. moriformis* are abundant. The key species *Sphenolithus heteromorphus* is present, but extremely scarce. Other species present include rare *Discoaster deflandrei, D. exilis, Hayaster perplexus, Helicosphaera granulata, Scapholithus fossilis*, (rare and probably displaced) *Triquetrorhabus milowii* and *T. rugosus*.

Biostratigraphic assignment and age. The rarity of *Sphenolithus heteromorphus*, together with the common occurrence of *Calcidiscus macintyrei* and *Reticulofenestra*

pseudoumbilicus, and the absence of *Cyclicargolithus floridanus*, places the assemblage high within the NN5 Zone of Martini (1971) or CN4 Zone of Okada & Bukry (1980). The age is early Middle Miocene.

MIXED (UNDIFFERENTIATED) MIDDLE MIOCENE

(A) A moderately to poorly-preserved assemblage was recovered from sample 96DR001-01C, a yellowish grey limestone, which was dredged from the Carnarvon Terrace (area A) in water 4125-3700 m deep. Signs of dissolution are evident and nannofossil debris abound. The assemblage is dominated by *Cyclicargolithus floridanus*, *Reticulofenestra pseudoumbilicus*, *Calcidiscus macintyrei*, *Coronocyclus nitescens* and the *Discoaster variabilis* and *D. deflandrei* groups. The *D. variabilis* group includes a very large form (somehow resembles the Pliocene *D. decorus*) occurring frequently. Also present *Calcidiscus protoannulus*, *Coccolithus pelagicus*, *Cyclicargolithus abisectus*, *Discoaster moorei*, *Hayaster perplexus*, *Helicosphaera granulata*, *Orthorhabdus serratus*, *Sphenolithus abies*, *S. moriformis*, *Triquetrorhabdulus milowii* and *T. rugosus*.

Orthorhabdus serratus is probably reworked from older Miocene level. Reworking from Upper Oligocene/Lower Miocene is also suggested by the presence of *Cyclicargolithus abisectus* ; the vertical range of this species coincides with part of the range of *C. floridanus*. Very little evidence of reworking from Eocene source (very rare *Chiasmolithus grandis*) is detected.

(B) A moderately to poorly-preserved assemblage was recovered from a sample 96DR001-01B. It includes abundant *Cyclcicargolithus floridanus*, *Calcidiscus macintyrei* and several long-armed discoasters, such as *D. challengeri*, *D. exilis* (including a large variety), *D. variabilis* (including a very large variety) and *D.* sp. cf. *D. brouweri*. Rare occurrences of *Discoaster druggii*, *Orthorhabus serratus* and *Triquetrorhabdulus carinatus* suggests minor reworking from Lower Miocene source. Very rare evidence of reworking from Eocene sediments (very rare *Discoaster barbadiensis*) is detected.

(C) A similar assemblage to that extracted from sample 96DR001-01B was identified from sample 96DR001-02, a pale orange chalky ooze, which was dredged from the same station as sample 96DR001-01B. *Discoaster* sp. cf. *D. kugleri* and *D. brouweri* were noted in the sample from 96DR001-02.

Discussion. The samples 96DR001-1C, 96DR001-1B and 96 DR001-02 have probably come from the same stratigraphic unit. Their lithologies and nannofossil assemblages are generally similar. *Discoaster brouweri* occurs in 96DR001-02 but not in 96DR001-01C, however.

(D) A moderately-preserved assemblage was recovered from sample 96DR008-01, a pale orange chalk, which was dredged from the northern part of the Carnarvon Terrace (area B) in water 3550-3180 m deep. This assemblage is somewhat similar to that from 96DR001-02. Several *Scyphosphaera* species are present, and *Discoaster brouweri* is more abundant than in 96DR001-02. Evidence of reworking from Eocene sediments is more substantial than in the Middle Miocene at Station 96DR001. This includes the rare occurrences of *Coccolithus formosus*, *C. eopelagicus*, *Chiasmolithus grandis*, *Discoaster lodoensis*, *Reticulofenestra umbilicus* and *Sphenolithus radianus*.

(E) A poorly-preserved assemblage was recovered from sample 96DR026-01, a pale orange limestone, which was dredged from the Scott Plateau in water 3050-2710 m deep. Signs of dissolution abound. The assemblage includes frequent *Calcidiscus macintyrei*, rare *C. leptoporus*, frequent *Coccolithus pelagicus*, rare *Coronocyclus nitescens*, *Hayaster perplexus*, frequent *Helicosphaera granulata*, *H. kamptneri*, *Reticulofenestra pseudoumbilicus*, *Scyphosphaera*, *Sphenolithus abies*, *S. moriformis*, frequent *Triquetrorhabdulus rugosus* Discoasters are abundant, being dominated by *Discoaster variabilis*. Other discoasters present include *D. moorei, D. exilis, D. challengeri* and *D. deflandrei.*

EARLY PLIOCENE

A moderately-preserved assemblage was recovered from sample 96DR029-07 (pipe), a very pale orange ooze, which was dredged from the central northern Exmouth Plateau in a water 2280-1995 m deep. The nannofossils are abundant. Discoasters are well preserved, but most ceratoliths are overgrown with calcite. Very little evidence of reworking from older sediments is detected. Important members of the assemblage are *Discoaster asymmetricus*, *D. brouweri*, *Reticulofenestra pesudoumbilicus*, *Calcidiscus macintyrei* and *Sphenolithus* spp. Also present are *Discoaster decorus*, *D. pentaradiatus*, *D. surculus*, *D. tamalis*, *D. triradiatus*, *Calcidiscus leptoporus*, *Ceratolithus armatus*, *C. rugosus*, *Helicosphaera kamptneri* and several species of *Scyphosphaera*.

Rare reworked species (such as *Sphenolithus heteromorphus* from Miocene sources) were

detected.

Biostratigraphic assignment and age. Based on the abundant occurrence of *Discoaster asymmetricus*, in the presence of *Reticulofenestra pseudoumbilicus* and *Sphenolithus abies*, the assemblage is assigned to the (*Discoaster asymmetricus*) CN11b Subzone of Okada & Bukry (1980). According to Bukry (1973), *Discoaster decorus* and *D. tamalis* first appear within the *D. asymmetricus* Subzone; the presence of these species in the assemblage is consistent with its assignment to the CN11b Subzone. The age is late Early Pliocene, probably between 3.5 and 3 Ma.

REFERENCES

Biolzi, M., Perch-Nielsen, K. & Ramos, I., 1981 - *Triquetrorhabdulus* - an Oligocene/Miocene calcareous nannofossil genus. *INA Newsletter*, **3** (2), 89-92.

Bukry, D., 1973 - Low-latitude coccolith biostratigraphic zonation. *In* Edgar, N.T., Saunders, J.B. & others, *Initial reports of the Deep Sea Drilling Project*, **15**, Washington (U.S. Government Printing Office), 653-711.

Bukry, D., 1974 - Coccolith stratigraphy, Arabian and Red Seas, Deep Sea Drilling Project Leg 23. *In* Whitmarsh, R.B., Weser, O.E., Ross, D.A. & others, *Initial reports of the Deep Sea Drilling Project*, **23**, Washington (U.S. Government Printing Office), 1091-1093.

Martini, E., 1971 - Standard Tertiary and Quaternary calcareous nannoplankton zonation. *In* Farinacci, A. (Ed.), *Proceedings of the 2nd Planktonic Conference,* Roma 1970. Edizioni Tecnoscienza, Roma, 739-785.

Okada, H. & Bukry, D., 1980 - Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). *Marine Micropaleontology*, **5** (3), 321-325.

Perch-Nielsen, K., 1985 - Mesozoic calcareous nannofossils. *In* Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K. (Eds.), *Plankton Stratigraphy*. Cambridge Earth Science Series, Cambridge University Press, 329-426.

CALCAREOUS NANNOFOSSIL AGE DETERMINATION OF DREDGE SAMPLES, BMR CRUISE 96

III. Summary

by

Samir Shafik

CARNARVON TERRACE

Eleven stations were occupied and successfully dredged along the Carnarvon Terrace between 23° 42.24' and 21° 49.85'. Based on the nannofossils extracted, the fossiliferous part of the stratigraphic sequence of the Carnarvon Terrace includes units of Cretaceous and Palaeogene age. These units are arranged below in a descending order.

- Middle Miocene limestone and chalky ooze at Station 96DR001 in the south (area A, east of the Wallaby Plateau);
- Upper Oligocene chalk at Station 96DR008 in the north (area B, adjacent to the Exmouth Sub-basin and Cuvier Plain);
- Upper Oligocene marl with very small clasts bearing Late Cretaceous nannofossils at Station 96DR011 in the north (area B);
- Lower Oligocene mudstone at Station 96DR009 in the north (area B);
- Upper Eocene mudstone at Station 96DR010 in the north (area B);
- Middle Eocene marl at Station 96DR009 in the north (area B);
- Upper Paleocene marl and chalk at Station 96DR007 and mudstones at Station 9 in the north (area B). There is mud bearing Late Maastrichtian nannofossils associated with the Paleocene mudstones at Station 96DR009;
- Lower Paleocene limestone at Station 96DR001 in the south (area A);
- Lower Cretaceous mudstones and siltstone at Stations 96DR001, 96DR002 and 96DR003 in the south (area A) and marls at Station 96DR011 in the north (area B).

The Lower Cretaceous mudstones, siltstone and marls include levels dateable as latest

Barremian - Late Aptian and Early Albian. The available data suggest that the Lower Albian sediments are widely spread, having been sampled from at least three widely-spaced stations along the terrace.

EASTERN SIDE OF SWAN CANYON

Seven stations were occupied and successfully dredged along the Rowley Terrace (eastern) side of the Swan Canyon between 16° 55.0' and 16° 44.88'. As indicated by their nannofossils, Cretaceous, Paleocene, Eocene and Miocene units were sampled. These are arranged in a descending order.

- Middle Miocene chalk at Station 96DR018;
- Middle Eocene stiff mud at Station 96DR013;
- Lower Eocene limestone at Station 96DR013;
- Upper Paleocene chalk and ooze at Station 96DR015;
- Upper Cretaceous mudstones at Station 96DR014 and limestone at Station 96DR013;
- Lower Cretaceous mud, mudstone and limestones at Station 96DR013, mudstone at Station 96DR014 and mud at Station 96DR015.

The Lower Cretaceous mud, mudstones, siltstone and marls include levels dateable as Late Ryazanian - Late Hauterivian, Valanginian, Hauterivian and Late Barremian - Late Aptian.

OTHER AREAS

Mesozoic sediments on the southern Rowley Terrace were sampled: Middle Jurassic mudstone at Station 96DR028, and undifferentiated Jurassic/Cretaceous sandstones at Stations 96DR012 and 96DR013. Mid Oligocene calcareous sand, Middle Miocene limestones and clays, and Lower Pliocene ooze were recovered from the central northern Exmouth Plateau at Station 96DR029. A Middle Miocene chalk was sampled at Station 96DR033 on the western margin of the Wombat Plateau, and Middle Miocene limestone was recovered at Station 96DR026 on the Scott Plateau. Other pre-Quaternary samples dredged from the Exmouth, Wombat and Scott Plateaux were found to be barren of calcareous nannofossils.

Summary: Age of samples from BMR Cruise 96.

Sample	Age
96DR001-01A	Early Paleocene
96DR001-01B	Middle Miocene
96DR001-01C	Middle Miocene
96DR001-02	Middle Miocene
96DR001-03A	Early Albian
96DR001-03B	indeterminable (barren)
96DR001-03C	indeterminable (barren)
96DR001-04	indeterminable (barren)
96DR001-05	Early Albian
96DR002-02	Quaternary
96DR002-03	Quaternary
96DR002-05	Early Albian
96DR002-06	Quaternary
96DR003-01	Latest Barremian to Early Aptian
96DR003-02	Early Albian
96DR004-01	indeterminable (barren)
96DR004-02	indeterminable (barren)
96DR004-05	indeterminable (barren)
96DR004-04	Quaternary
96DR004-06	indeterminable (barren)
96DR004-07	indeterminable (barren)
96DR005-01	indeterminable (barren)
96DR005-02	indeterminable (barren)
96DR005-03	indeterminable (barren)
96DR005-07	Quaternary
96DR005-08	Quaternary
96DR005-09	indeterminable (barren)
96DR006-01	indeterminable (barren)
96DR006-02	indeterminable (barren)
96DR006-03	Quaternary
96DR007-04A	Mid to Late Oligocene
96DR007-04B	Mid to Late Oligocene (with reworked Eocene)
96DR007-04C	Early Miocene
96DR007-05	Late Paleocene
96DR007-06	indeterminable (barren)
96DR007-07	indeterminable (barren)
96DR007-08	indeterminable (barren)
96DR007-09	Late Paleocene
96DR007-11	indeterminable (barren)
96DR008-01	Middle Miocene
96DR008-02	indeterminable (barren)
96DR008-03	indeterminable (barren)
96DR008-04	indeterminable (barren)
96DR008-05	indeterminable (barren)
96DR008-06	indeterminable (barren)
96DR008-07	Latest Oligocene
96DR008-09	Middle Miocene
96DR009-01	Late Paleocene
96DR009-02	Middle Eocene
96DR009-04A	Paleocene
96DR009-04B	Late Maastrichtian (with rare Paleocene forms)
96DR009-05A	Early Oligocene
96DR009-05B	Late Paleocene
96DR009-05C	Late Maastrichtian (with rare Paleocene forms)
96DR010-01	Late Eocene
96DR011-01	Early Albian
96DR011-02	Early Albian
96DR011-03	Early Albian
96DR011-04A (pipe)	Mid Oligocene
96DR011-04C (pipe)	Late Campanian
96DR011-05 (pipe)	Early Albian
96DR012-03	Mesozoic
96DR012-04	indeterminable (barren)
96DR012-05	indeterminable/barren

Sample	Age
96DR012-07B (pipe)	Mesozoic
96DR013-01	Mesozoic
96DR013-02	late Early Eocene
96DR013-03	Valanginian
96DR013-04	indeterminable (barren)
96DR013-05A	Late Ryazanian to Early Barremian
96DR013-05B	Late Barremian to Late Aptian
96DR013-07	Mid Campanian to Late Maastrichtian
96DR013-08	Late Ryazanian to Early Barremian
96DR013-09	Middle Eocene
96DR014-04	Mid to Late Campanian
96DR014-06	indeterminable (barren)
96DR014-08A	Late Ryazanian to Late Hauterivian
96DR014-09	Mid Campanian to Late Maastrichtian
96DR015-01	Late Ryazanian to Late Hauterivian
96DR015-02	indeterminable (barren)
96DR015-03	Late Paleocene
96DR015-04	indeterminable (barren)
96DR015-05 (pipe)	Late Paleocene
96DR015-06 (pipe)	Late Ryazanian to Late Hauterivian
96DR017-05	indeterminable (barren)
96DR018-01	indeterminable (barren)
96DR018-03	early Middle Miocene
96DR018-05	indeterminable (barren)
96DR019-02	indeterminable (barren)
96DR019-04	Quaternary
96DR020-02	indeterminable (barren)
96DR021-05	indeterminable (barren)
96DR021-06	indeterminable (barren)
96DR023-03	indeterminable (barren)
96DR026-01	Middle Miocene
96DR026-03	early Middle Miocene
96DR027-01	indeterminable (barren)
96DR028-01A	indeterminable (barren)
96DR028-08	indeterminable (barren)
96DR028-10	indeterminable (barren)
96DR028-11A	indeterminable (barren)
96DR028-14	indeterminable (barren)
96DR028-15	indeterminable (barren)
96DR028-16 (pipe)	Middle Jurassic
96DR029-01	early Middle Miocene
96DR029-02	Middle Miocene
96DR029-03	Early Miocene
96DR029-04	Early Miocene
96DR029-05	indeterminable (barren)
96DR029-07	Early Pliocene
96DR029-08A	Quaternary (with reworked Eocene, Oligocene & late Tertiary)
96DR029-08B	Middle Eocene (with rare late Tertiary contaminants)
96DR029-08	Mid Oligocene
96DR029-09	Quaternary
96DR030-01	indeterminable (barren)
96DR033-02	early Middle Miocene
96DR033-03	Middle Miocene
96DR033-04	Middle Miocene
96DR033-05	Quaternary
96DR034-05	Quaternary
96DR035-03	indeterminable (barren)
96DR035-05	Quaternary

APPENDIX 6.

Foraminiferal biostratigraphy, BMR Cruise 96.

P. Wells, Geology Department, Australian National University.

Jurassic, Cretaceous and Tertiary to Recent foraminiferal faunas were obtained from dredge and gravity cores during Cruise 96. Sample ages were determined using planktic foraminifera in all samples younger than Jurassic age.

All soft rocks were sampled, and treated by soaking in hydrogen peroxide solution before washing through a 63 micron sieve. Strew slides were made of the >63 micron residue of samples with abundant foraminiferal faunas : samples with sparse faunas were handpicked into small recessed slides.

Age-distribution of Mesozoic and Tertiary samples

Pleistocene	51 samples (plus 10 gravity cores)- see text.
Middle Miocene	DR01-1B, DR01-2, DR08-1, DR26-1, DR26-3, DR29-1, DR32-2, DR33-2 to 4.
Early Miocene	DR08-7, DR08-9, DR29-4
Oligocene	DR07-4
Eocene	DR09-2#, DR10-1, DR13-2**, DR13-9.
Paleocene	DR01-1A, DR07-5**##, DR07-9**, DR09-5##
Late Cretaceous	DR09-4, DR14-4
Early Cretaceous	DR01-5, DR03-1, DR11-2, DR11-3, DR11-5
Jurassic	DR28-15, DR28-16.
?Jurassic-?E.Cret.	DR02-4, DR13-5, DR14-8, DR15-4, DR19-2, DR19-4
Mixed-age	DR02-2, DR02-3, DR07-1, DR09-1**, DR09-5, DR11-4P**#, DR13-7** DR18-3, DR29-2, DR29-3, DR29-7.
Undatable	63 samples - see text.

** with reworked Cretaceous material
# with reworked Paleocene material
with Eocene material.

Many samples contained faunas of mixed ages. Burrowing and other surface reworking was commonly observed in the Tertiary rock samples, resulting in mixed-age faunas. Down-slope transport and reworking, as well as mixing of very soft clays during dredging also contributed to mixing of different aged lithologies. Pleistocene contamination was also common, usually indicated by a sparse fauna of large, broken specimens. Age assignment to such mixed-age faunas is sometimes difficult, and the problem has been discussed in previous cruise reports (e.g. McGowran, in Davies et al., 1989). For example sample DR07-9 is dominated by Late Cretaceous planktics, yet contains a distinctive Late Paleocene fauna : has the Paleocene assemblage been introduced into the Cretaceous rock through burrowing or sampling contamination? or has the Late Cretaceous material been reworked in Paleocene time?

Jurassic

Dark grey mudstones from the Rowley Terrace (sample DR28-16) contain a very well preserved, abundant and diverse benthonic foraminiferal fauna dominated by minute specimens of Miliolidae, including *Ophthalmidium strumosum* (Gumbel) and *Massilina* sp., together with *Lenticulina* spp., *Astacolus* spp. and rare epistiminids, including ornamented (*E. mosquensis* Uhlig) and smooth forms (*E. caracolla* (Roemer) and *E. nuda* Terquem). A Middle to Late Jurassic age is indicated, using the epistominid biostratigraphy of Williamson & Stam (1988). This epistominid assemblage is inferred to have accumulated in a shallow marine (inner shelf) environment, judging from the fine-grained lithology, the dominance of small agglutinated forms, the abundance of *Ophthalmidium* spp. (Riegraf et al., 1984; Shipp, 1989), and the presence of smooth epistiminids (Williamson & Stam, 1988). Sample DR28-15 contains a sparse fauna of large, worn specimens of epistominids (including *E.hechti*). It occurs in a similar lithology to DR28-16 but lacks the diverse fauna of miliolid and other benthonic foraminifera of that sample, and may be a reworked assemblage (and therefore of younger age).

A sparse fauna of (mainly) agglutinated foraminiferal species was observed in a number of samples; the most common species present are-

Genus/species	Dredge Number	02 4	13 5	14 8	15 4	19 2	19 4
Glomospira spp.		*	*	*	*	-	-
Nodosaria sp., *N.regularis*		-	-	*	*	*	*
Hyperammina sp.		*	-	-	-	-	-
Textularia sp.		*	-	-	-	-	*
Spirillina sp.		*	-	*	-	-	-
Dentalina sp.		-	-	*	-	-	*
Lingula sp.		-	-	-	-	*	-
Lingulina sp.		-	-	-	-	*	*

Very rare genera seen in individual samples include - *Lagenammina* (DR19-4), *Astacolus, Lenticulina* and *Palmula* (DR13-4), smooth-shelled *Lenticulina* sp. (DR13-5) and trochammids (DR15-4) and saccamminids (DR02-4). An undifferentiated Jurassic to Early Cretaceous age is tentatively assigned to these samples, in the absence of well preserved, age-diagnostic planktonic or benthic species. There were no distinctive Late Cretaceous species observed in these samples, and no early Cretaceous species could be identified. However, samples DR01-3 DR13-3, DR13-5 and DR14-8 contain a number of specimens of some of the genera listed above (*Glomospira* sp., *Nodosaria* sp., *Hyperammina* sp., *Textularia* sp. *Lingula* and *Dentalina* sp.), together with a nannofossil flora indicating an early Cretaceous age (S.Shafik, this report), so it is possible that a number of the samples listed above may also be of this age. In addition, samples DR02-4 and DR19-4 contained a component of Quaternary material, considered to be contamination.

This agglutinated assemblage appears to have lived in a shallow-water, medium to high-energy, restricted-marine to brackish environment, judging from the small speciman size, lack of species diversity and the sandy mud matrix.

Cretaceous

The planktic biostratigraphy of Caron (1985) was used to determine the age of Cretaceous samples.

Samples DR01-5, DR03-1A, DR11-2, DR11-3 and DR11-5 contain sparse foraminiferal faunas characterised by the predominance of *Hedbergella* spp., including forms similar to *H.delrioensis* and *H.planispira,* which, in the absence of keeled planktic forms characteristic of Late Cretaceous assemblages, suggests an Early Cretaceous age for these rocks (this age was initially determined by nannofossils (Shafik, this report)).

Late Cretaceous planktic foraminifera are present in samples DR09-4 and DR14-4. Samples DR07-5, DR07-9, DR09-1, DR11-4, DR13-2 and DR13-7 contain Late Cretaceous faunas mixed/reworked into younger material (discussed in Paleocene and Mixed-age sections).

Sample DR14-4, from yellowish grey mudstones of the Rowley Terrace side of the Swan Canyon, contains an abundant, poorly to moderately-well preserved planktic foraminiferal fauna of late Campanian to earliest Maastrichtian age. The assemblage includes

Archaeoglobigerina cretacea
Globotruncana spp., *G. arca, G.linneiana, G.bulloides*
Rugoglobigerina rugosa
Globotruncanella havanensis
Globigerinelloides praerihillensis
Heterohelix spp., *H. striata, H.globulosa*
Hedbergella holmdelensis.

The abundance of plankic specimens, many of which are affected by dissolution, together with abundant benthic forms suggests deposition at bathyal depths.

Sample DR09-4, from light olive grey mudstone of the Northern Carnarvon Terrace, contains a sparse fauna of Campanian to Maastrichtian age, dominated by minute planktic forms, with

Hedbergella holmdelensis (abundant)
Abathomphalus sp.
Heterohelix spp.
Rugoglobigerina rugosa,
Pseudoguembelina palpebra.

The small size of the majority of the specimens of the assemblage suggests that it accumulated in a restricted marine environment.

Early Tertiary

The planktic biostratigraphy of Tourmarkine & Luterbacher (1985) has been used in the following Early Tertiary age determinations.

Paleocene

Yellowish grey chalks of the Northern Carnarvon Terrace (sample DR7-9) contains a Late Paleocene - Late Cretaceous mix. The Paleocene fauna is sparse. Planktic species present include

Globorotalia pseudomenardii
Morozovella conicontruncata, M. pseudobulloides
and *Globigerinoides triloculinoides.*

This assemblage occurs together with an abundant assemblage of large Late Cretaceous planktics. Late Maastrichtian species identified include

Globotruncana arca, G. falsostuarti, G. linneiana
Rugoglobigerina rugosa, R. hexacamerata
Abathomphalus mayaroensis
Globotruncanella petaloidea, G. citae,
Heterohelix spp., *H. reussi* and *H. pulchra.*

A Paleocene age is assigned to the sample on the basis of the dominant nannofossil content (Shafik, this report).

Samples DR07-5 and DR09-5 contained a mix of Late Paleocene and Eocene-aged forams. Small subsplits of the rock-sample yielded good Late Paleocene nannofossil floras (Shafik, this report)
Sample DR07-5 contains middle Eocene planktics (*Acarinina primitiva, A. spinuloinflata, Morozovella lehneri,* and *Turborotalia cerroazulensis*), mixed in with Late Cretaceous planktics (*Globotruncana* spp. and *Rugoglobigerina* spp.); fragmented Late Paleocene species (*Globorotalia pseudomenardii*) and Miocene planktic species (*Catapsydrax parvulus, Globigerina falconensis* and *Globoquadrina baroemoenensis).*
Sample DR09-5 consists predominantly of siliceous material. The sparse foraminiferal fauna contains abundant, minute, globigerinid forms, and include species distinctive of both Paleocene and Eocene age. Identified middle to late Eocene species include *Hantkenina alabamensis* (rare), *Morozovella* spp (common), *Globigerina eocaena,* and *G. cryptomphala.*; good specimens of the Paleocene planktic *Morozovella conicotruncata* are also present, though rare.

Sample DR01-1A contains abundant minute globigerinid forms, including *Planorotalites compressa* and forms intermediate between *P. compressa* and *P. chapmani,* as well as *Morozovella trinidadensis.* Absence of the distinctive Middle to Late Paleocene *M. velascoensis* group, as well as the genus *Pseudohastigerina* suggests an Early Paleocene age for the sample. The common presence of Late Tertiary and Quaternary planktics suggests some reworking has occurred.

Eocene

Eocene foraminiferal faunas are present in the pale grey mudstone (samples DR09-2 and DR10-1) of the Northern Carnarvon Terrace and pale yellowish orange limestone and mud (DR13-2 and DR13-9) from the Rowley Terrace area.
Sample DR10-1 contains abundant *Pseudohastigerina micra* and common *Turborotalia cerroazulensis-cerroazulensis,* which, together with the absence of Early to Middle Eocene genera *Morozovella* and *Acarinina,* indicate a Late Eocene age.
Sample DR13-2 contains a sparse but diverse planktic fauna containing

Pseudohastigerina wilcoxensis
Morozovella caucasica, M. aragonensis
Acarinina bullbrooki, A. soldadoensis soldadoensis
A. broedermanni
Globigerina eocaena
Globigerinoides higginsi
and no *Globigerinatheka* spp., indicating a late Early Eocene (P9) age.
Some minor contamination by Late Cretaceous material is present. The foraminiferal fauna is predominantly planktic and probably accumulated at bathyal depths.

Sample DR13-9 contains a middle Eocene assemblage dominated by small forms : *Acarinina* spp., *A. bullbrooki, Globigerinatheka* spp., *G. subconglobata Globigerina cryptomphala* and *G. eocaena.* This middle Eocene fauna is mixed in with Late Tertiary forms - *Globorotalia menardii, G. tosaensis, Globigerina sacculifer,* and *Pulleniatina* spp., which are considered to be contaminants. The planktic species of this sample are frequently fragmented and with the sparse benthic content suggest that deposition occurred at bathyal depths, near or below the C.C.D.

Sample DR09-2 was from a bored/burrowed rocktype similar to DR09-5. A mixed-age assemblage is present, with common Late Paleocene *Globorotalia pseudomenardii* mixed in with a Middle Eocene fauna containing *Clavigerinella eocanica* (rare), *Morozovella* spp. (common), *M. spinulosa, Acarinina* aff. *broedermanni* and common large globigerinids such as *G. eocaena* and *G. cryptomphala.*

Sample DR29-8 contains rare specimens of *Hatkenina* spp., reworked into Miocene and Pleistocene material containing *Dentoglobоquadrina altispira, G.truncatulinoides, Sphaeroidina dehiscens* etc.

Late Tertiary (Neogene)
The tropical planktic foraminiferal biostratigraphy of Kennett & Srinivasan (1983) has been used to determine the age of Miocene and younger assemblages.

Oligocene-Early Miocene

A Late Oligocene to Early Miocene age is indicated for sample DR07-4 (yellow-grey chalks from the northern Carnarvon Terrace) by the presence of

Cassigerinella chipolensis
Globoquadrina praedehiscens,
Catapsydrax unicavus,
Globigerina praebulloides, G. angulisuturalis,
and *G.angustiumbilicata.*
Most of these species have a time range from Oligocene into Early Miocene. The distinctive Early Miocene species *Globoquadrina dehiscens* was not observed, but rare specimens of *Dentoglobigerina altispira* are present.

Early Miocene

Early Miocene faunas are present in light-yellowish grey chalks from the Northern Carnarvon Terrace (samples DR08-7, and DR08-9) and the Exmouth Plateau (sample DR29-4).
Samples DR08-7 and DR29-4 contain essentially the same fauna:

Globigerina ciperoensis,
G. angulisuturalis, G. triloba
Catapsydrax unicavus
Globoquadrina binaiensis
G. dehiscens, G. praedehiscens
Globigerinoides immaturus, G. ruber and *Globorotalia obesa.*

The assemblage is inferred to be of early Miocene age (N4B-N5) and to have accumulated in deep water, near or below the C.C.D., judging from the abundance of planktic forms and the fragmented nature of many of the specimens.

Sample DR08-9 contains a sparse but distinctive fauna of Early Miocene species (*Globoquadrina binaiensis* and *Catapsydrax unicavus*), mixed in with occasional younger (Middle Miocene) forms (*Globigerinoides ruber, Globigerina triloba,* and *Globorotalia obesa*).

Middle Miocene

An early Middle Miocene (N9) age is indicated for sample DR08-1 (orange chalk from the Carnarvon Terrace) and samples DR29-1 and DR33-2 to 4) (pale orange marls from the western margin of the Wombat Plateau) by the presence of

Praeorbulina glomerosa glomerosa, P.o.curva,
Orbulina bilobata, O. universa,
Sphaeroidinellopsis disjuncta,
Globigerina decoraperta.

A younger, Middle Miocene age is inferred for samples DR01-1B, DR01-2, DR26-1, DR26-3 and DR32-2. Samples DR01-1B and DR01-2 are from bored rocks and contain a mix of Middle Miocene and younger Miocene to Quaternary planktics. Middle Miocene species identified include

Globigerinoides sicanus,
Praeorbulina glomerosa,
Sphaeroidinellopsis disjuncta,
Catapsydrax parvulus,
Globorotalia archaeomenardii,
Dentoglobigerina altispira ssp.

Younger Middle Miocene species present in sample DR01-2 include *Globigerinoides extremus* and *Globorotalia fohsi fohsi ; G.f. peripheroronda* and *G.f. peripheroacuta* are present in DR01-1B.

Samples DR26-1 and DR26-3, from orange limestones and mud of the western margin of the Scott Plateau, contain a Middle Miocene (N10-12) fauna :

Globoquadrina praedehiscens, G. dehiscens
Dentoglobigerina altispira, D.a. conica
Globorotalia fohsi fohsi
G.f. peripheroronda, G.f. peripheroacuta
G.obesa, G. continuosa
Globigerinoides sacculifer, G. quadrilobatus, and
Sphaeroidinellopsis disjuncta.

Burrowing within the chalk has introduced younger Tertiary contaminants.

Sample DR32-2, from white chalks of the western margin of the Wombat Plateau contain many species in common with DR26-1 and 3, with older species of the Fohsella lineage replaced by *Globorotalia fohsi lobata* and *G. f. fohsi,* indicating a N12 age. As with the previous samples, later Tertiary forms have been mixed into the older rock by burrowing.

Pleistocene

The yellow-brown to grey muds to oozes listed below were collected in the pipe dredge (P) and contain Pleistocene faunas, characterised by the presence of *Globorotalia truncatulinoides.* Where *G. truncatulinoides* was not observed in the sample (#), the presence of various combinations of *Globigerinella calida calida, Globiorotalia tumida flexuosa, Sphaeroidinella dehiscens excavata, Pulleniatina obliquiloculata finalis* and *Globorotalia crassaformis hessi* were used to indicate a Pleistocene age (after Chaproniere, 1985). The presence of *Bolliella adamsi* (*) indicates a latest Pleistocene to Holocene age.

DR01-6P, DR02-2P*, DR02-3P*, DR02-6P, DR03-3P, DR04-3P, DR04-4P*, DR05-7P, DR05-8P, DR06-3P, DR07-3P, DR08-12P, DR10P, DR11-6P, DR12-6P, DR13-10P#, DR14-11P, DR15-6P#, DR15-7P*, DR16-3P, DR17-18P, DR18-4P*, DR19-3P#, DR19-5P*, DR20-3P, DR20-4P, DR21-7P, DR22-4P*, DR23-11#, DR23-12P#, DR24-3P, DR25-1*, DR26-2*, DR26-4P*, DR26-5P*, DR27-

2P*, DR27-3P*, DR28-17P, DR29-8, DR29-9*, DR30-3P*, DR31-1P*, DR32-1P*, DR33-5P, DR35-5P, DR35-6P, DR36-5P, DR36-6P, DR37-1P, DR37-2P, DR38-3P.

Further age differentiation of these pipe samples samples was not attempted, as such material is unlikely to have come from a single time interval.

A Pleistocene age was indicated for the base of the ten gravity cores collected. The Pleistocene foraminiferal biostratigraphy of Chaproniere (1985) was used to differentiate the age of these core-base samples: this stratigraphy subdivides the Pleistocene (N22) zone into a *Globorotalia crassaformis viola* subzone (early N22) and a *G. crassaformis hessi* subzone (late N22). In this report the latest Pleistocene (N23) zone has been divided into a *Globigerinella calida calida* subzone and a *Bolliella adamsi* (Holocene) subzone. Core GC19 terminated in early N22 sediment, indicated by the presence of *Globigerinoides fistulosus* and *Globorotalia truncatulinoides* : Cores GC03, GC10, GC16 and GC22 terminated in *G. hessi* subzone (upper N22) sediment, the remainder (GC05, GC11, GC13, GC18) terminated in latest Pleistocene (early to middle N23 ; pre-*adamsi*) sediment.
The bottom 10 cm of GC21 appears to be a repeat-sampling section, as the section at 193.5cm (e-m N23) is younger than the overlying interval (N22 at 185cm), judging from the proportion of pink *Globigerinoides ruber* in samples taken at 185cm and 193.5 cm. Over fifty percent of the *G. ruber* population is pink at 185cm, whereas there are no pink forms of that species at 193.5 cm. According to Thompson et al (1979), this indicates a >120 Ky age for the upper sample and a <120 ky age for the lower sample.

Mixed-age assemblages
Important age-indicative species present include-

DR07-1(pipe):- Late Miocene-Pliocene forms *Globigerinoides extremus* (N16-21), *G. sacculifer, G. conglobatus, Sphaeroidinellopsis kochi* (N10-19) and Pleistocene forms (*Globorotalia truncatulinoides*).

DR09-1(ooze in burrows of DR09-2): Predominantly Late Tertiary-Quaternary planktic material (*G.truncatulinoides, G. ruber, G.dutertrei* and *G.rubescens*), with a small amount of Late Cretaceous material (*Hedbergella* spp., *Racemiguembelina fructicosa*, and *Guembelitria* spp.)

DR09-5(pipe):- mostly long-ranging Oligocene-Miocene species- *Globigerina woodi, G. glutinata, G. quinqueloba, G. humilis, G. falconensis* and *Cassigerinella chipolensis*, together with Early Miocene species (*Catapsydrax parvulus*) and Late Pliocene - early Pleistocene species (*Globorotalia tosaensis).*

DR11-4:- A mix of Late Cretaceous (late Campanian to Maastrichtian) species *Rugoglobigerina rugosa, R.hexacamerata, Globotruncana linneiana, G.arca, Globotruncanella havanensis, G. citae, G petaloidea, Globigerinelloides praerihillensis, Allomorphina cretacea* and *Pseudotextularia elegans*, together with an abundant fauna of minute globigerinids, and larger, Early Tertiary planktics (*Turborotalia* spp., *Globigerina cryptomphala, Globigerinatheka subconglomerata, Catapsydrax unicavus, C. dissimilis* and *Dentoglobigerina altispira* ssp.) and large Late Tertiary species (e.g. *Globorotalia tosaensis, G. menardii, G. crassaformis G. hexagona, Globigerina dutertrei*).

DR13-7:- Late Cretaceous (Maastrichtian) species (*Globotruncana* sp., *Rugoglobigerina rugosa* and *R. hexacamerata*), mixed in with a sparse fauna of small benthics and rare, minute Tertiary globigerinids.

DR18-3 (a three coloured clay mix):- A mix of early Miocene forms (*Sphaeroidinellopsis disjuncta, Globoquadrina dehiscens, Praeorbulina glomerosa*, middle Miocene (*Globorotalia fohsi peripheroronda, G.f.lobata*) and common Late Miocene-Pleistocene forms.

DR29-2 and DR29-3 (bored and burrowed clays):- *Catapsydrax dissimilis, C. unicavus, Globoquadrina praedehiscens, G.binaiensis, Globorotalia fohsi kugleri* (Oligocene-Early Miocene); *Globigerina triloba, G. immaturus*, (long-ranging Miocene), *Sphaeroidinellopsis seminulina, S. paenedehiscens* (late Miocene); *Globigerina nepenthes* (late Miocene - Pliocene).

Samples unable to be dated

The following samples were processed, but could not be dated, either due to lack of foraminifera (apart from those species considered to be contaminants), or which contained a fauna lacking age-indicative species (*)

DR01-3*, DR01-4, DR03-2*, DR04-1, DR04-2, DR04-5, DR04-6, DR05-1, DR07-2, DR07-6, DR07-7, DR07-8, DR07-11, DR07-12, DR11-1*, DR12-2, DR12-4, DR12-5, DR12-07*, DR13-1*. DR13-3*, DR13-6, DR13-8*, DR14-1, DR14-2, DR14-6, DR14-9*, DR15-1*, DR15-2, DR15-3, DR15-5*, DR16-1, DR16-2, DR17-2, DR17-3, DR17-5, DR17-6, DR17-10, DR17-12, DR17-16, DR17-17, DR17-19, DR17-20, DR18-2, DR18-5, DR18-6, DR19-1, DR21-5, DR21-6, DR22-1, DR22-3, DR23-1, DR23-2, DR24-4, DR27-1, DR28-1, DR28-3, DR28-8, DR28-10, DR28-14, DR29-5, DR30-1A, DR34-3.

References

CARON, M., 1985 - Cretaceous planktic foraminifera. *In* Bolli, H.M., Saunders, J.B., & Perch-Nielson, K. (eds). Planktonic stratigraphy. *Cambridge University Press, England,* 17-85.

CHAPRONIERE, G.C.H., 1985 - Late Tertiary and Quaternary foraminiferal biostratigraphy and paleobathymetry of cores and dredge samples from cruise KK820316 Leg 2. *In* Brocher, T.M. (ed). Geological investigations of the Northern Melanesian borderland, Circum-Pacific Council for Energy and Mineral Resources Earth Science Series V.3. *Circum-Pacific Council for Energy and Mineral Resources, Houston, Texas,* 103-122

DAVIES, H.L., CLARKE, J.D.A., STAGG, H.M.J., SHAFIK, S., McGOWRAN, B., ALLEY, N.F., & WILLCOX, J.B., 1989 - Maastrichtian and younger sediments from the Great Australian Bight. *Bureau of Mineral Resources, Australia, Report* 288, p.27.

KENNETT, J.P., & SRINIVASAN, M.S., 1983 - Neogene planktonic foraminifera. A phylogenetic atlas. *Hutchinson Ross Publishing Company, Pennsylvania,* 265 pp

SHIPP, D.J., 1989 - The Oxfordian to Portlandian (Upper Jurassic). *In* Jenkins, D.G., & Murray, J.W., (eds.) Stratigraphical atlas of fossil foraminifera - 2nd edition. *Ellis Horwood Limited, Chichester, England,* 237-262.

TOURMARKINE, M., & LUTERBACHER, H., 1985 - Paleocene and Eocene planktic foraminifera. *In* Bolli, H.M., Saunders, J.B., & Perch-Nielson, K (eds). Planktonic stratigraphy. *Cambridge University Press, England,* 87-153.

THOMPSON, P.B., BE, A.W.H., DUPLUSSEY, J.C., & SHACKLETON, N.J., 1979 - Disappearance of pink-pigmented *Globigerinoides ruber* at 120,000 yr BP in the Indian and Pacific Oceans. *Nature,* 280, 554-558.

RIEGRAF, W., & LUTERBACHER, H., 1984 - Jurassic foraminifera from the Mazagan Plateau, Deep Sea Drilling Project site 547, Leg 79 off Morocco. *In* Hinz, K., Winterer, E.L. et al.,(eds), Initial Reports of the Deep Sea Drilling Project, Vol LXXIX. *U.S. Government Printing Office, Washington, D.C.,* 671-705.

WILLIAMSON, M.A., & STAM, B., 1988 - Jurassic/Cretaceous Epistominidae from Canada and Europe. *Micropaleontology,* 32, 136-158.

Summary : Age of samples from BMR Cruise 96 (foram dates)

Sample	Age
DR01-1A	Early Paleocene
DR01-1B	Middle Miocene
DR01-2	"
DR01-3	indeterminate
DR01-4	- (barren)
DR01-5	Early Cretaceous
DR01-6P	Pleistocene
DR02-2P	Pleistocene
DR02-3P	"
DR02-4P	?Jurassic -?E.Cret. (+Quat.**)
DR02-6P	Pleistocene
DR03-1	Early Cretaceous
DR03-2	indeterminate
DR03-3P	Pleistocene
DR04-1P	- (barren)
DR04-2P	"
DR04-3P	Pleistocene
DR04-4P	Pleistocene - Recent
DR04-5P	- (barren; (+Pleistocene**))
DR04-6P	"
DR05-1	- (barren)
DR05-7P	Pleistocene
DR05-8P	"
DR06-3P	Pleistocene
DR07-1P	mixed age (Pliocene + Pleistocene)
DR07-2	- (barren)
DR07-3P	Pleistocene
DR07-4	Oligocene - Early Miocene
DR07-5	mixed age (L.Paleoc.+ Eocene)(+Cret.**)
DR07-6	- (barren)
DR07-7	"
DR07-8	"
DR07-9	L.Paleocene (+Cretaceous*)
DR07-11	- (barren)
DR07-12	"
DR08-1	early Middle Miocene (N9)
DR08-7	Early Miocene (N4B-6)
DR08-9	Early-Middle Miocene
DR08-12P	Pleistocene
DR09-1	mixed age (L.Cret + Tertiary)
DR09-2	M.Eocene (+Paleocene*.)
DR09-4	L. Cretaceous (Camp.- Maast.)
DR09-5	mixed age (Paleocene/Eocene)
DR09-5P	mixed age (Oligocene - Recent)
DR10-1	Late Eocene
DR10P	Pleistocene
DR11-1	indeterminate
DR11-2	Early Cretaceous
DR11-3	"
DR11-4	mixed age (L.Cret + Tertiary)
DR11-5	Early Cretaceous
DR11-6P	Pleistocene

Sample	Age
DR12-2	- (barren)
DR12-4	"
DR12-5	"
DR12-6P	Pleistocene
DR12-7P	indeterminate
DR13-1	"
DR13-2	Early Eocene (+Cret.*)
DR13-3	indeterminate
DR13-5	?Jurassic -? E.Cretaceous
DR13-6	- (barren)
DR13-7	mixed age (Cret.+Tertiary)
DR13-8	indeterminate
DR13-9	Middle Eocene
DR13-10P	Pleistocene
DR14-1	- (barren)
DR14-2	"
DR14-4	L.Cretaceous
DR14-6	- (barren)
DR14-8	?Jurassic - ?E.Cretaceous
DR14-9	indeterminate
DR14-11P	Pleistocene
DR15-1	indeterminate
DR15-2	- (barren)
DR15-3	"
DR15-4	?Jurassic - ?E.Cretaceous
DR15-5P	indeterminate
DR15-6P	Pleistocene
DR15-7P	Pleistocene to Recent
DR16-1	- (barren)
DR16-2	"
DR16-3P	Pleistocene
DR17-2	- (barren)
DR17-3	"
DR17-5	"
DR17-6	"
DR17-10	"
DR17-12	"
DR17-16P	"
DR17-17	"
DR17-18P	Pleistocene
DR17-19	- (barren)
DR17-20	"
DR18-2	"
DR18-3P	Mixed Miocene
DR18-4P	Pleistocene
DR18-5P	- (barren)
DR18-6P	"
DR19-1	"
DR19-2	?Jurassic - ?E.Cretaceous
DR19-3P	Pleistocene
DR19-4P	?Jurassic _ ?E.Cretaceous
DR19-5P	Pleistocene - Recent

DR20-3P	Pleistocene
DR20-4P	"
DR21-5	- (barren)
DR21-6	"
DR21-7P	Pleistocene
DR22-1	- (barren)
DR22-3	- (barren)
DR22-4P	Pleistocene - Recent
DR23-1	- (barren)
DR23-2	"
DR23-11	Pleistocene
DR23-12P	"
DR24-3P	Pleistocene (eN22)
DR24-4P	- (barren)
DR25-1P	Pleistocene - Recent
DR26-1	Mid. Miocene
DR26-2	Pleistocene - Recent
DR26-3P	M.Miocene (N10-12)
DR26-4P	Pleistocene - Recent
DR26-5P	"
DR27-1	- (barren)
DR27-2P	Pleistocene-Recent
DR27-3P	"
DR28-1	- (barren)
DR28-3	"
DR28-8	"
DR28-10	"
DR28-14	"
DR28-15	Jurassic
DR28-16	Jurassic
DR28-17P	Pleistocene
DR29-1	early Middle Miocene (N9)
DR29-2	mixed age (Early+L Miocene)
DR29-3	"
DR29-4	Early Miocene (N4-5)
DR29-5	- (barren (+ Pleist.**))
DR29-7P	Miocene - Pliocene mix
DR29-8	Pleistocene (+Eocene*)
DR29-9	Pleistocene-Recent
DR30-1A	indeterminate
DR30-3P	Pleistocene - Recent
DR31-1P	"
DR32-1P	"
DR32-2P	Middle Miocene (N12)
DR33-2	early Middle Miocene
DR33-3	"
DR33-4	"
DR33-5P	Pleistocene
DR34-3	- (barren)
DR35-5P	Pleistocene
DR35-6P	"
DR36-5P	"
DR36-6P	"
DR37-1P	"
DR37-2P	"
DR38-3P	"

Gravity Cores

GC03	Pleistocene (late N22)
GC05	Pleistocene (N23)
GC10	" (N22)
GC11	" (N23)
GC13	" "
GC16	" (N22)
GC18	" (N23)
GC19	" (eN22)
GC21(185cm)	" (lN22)
GC21(194cm)	" (e-mN23)
GC22	Pleistocene (lN22)

DR = Dredge sample
GC = Gravity core bottom sample
P = Dredge pipe sample
barren = contained no forams
indeterminate = no age-diagnostic forams.
* reworked
** contamination

AREA A - CARNARVON TERRACE

Station *	Site	Lat. & Long. (start)	Lat. & Long (finish)	Water Depth Range (m)	Head'g dredge run	Rock	Type +	D or P #	Shipboard Description	Age (Foram)	(Nanno)
DR/01 (8 kg)	A3	23°42.24' 111°16.50'	23°40.13' 111°17.08'	4125-3700	NNE	1	(50%)	D	LMST/CHALK Yellowish grey (5Y7/2), burrowed, mod. consolidated	E. Pal. + M. Mio.	E. Pal. + M. Mio.
						2	(5%)	D	CHALK/LMST v. pale orange (10yr8/2), burrowed, mod. consolidated.	M. Mio.	M. Mio.
						3	(20%)	D	SILTSTONE Greyish olive (10y4/2), slightly sandy, siliceous, minor carb.	(indet.)	E. Cret.
						4	(20%)	D	SANDSTONE Mod. olive brown. ?glaucon., fine grained, mod. indurated	-	-
						5	(5%)	D	MUDSTONE Pale olive (10y6/2)	E. Cret.	E. Cret.
						6		P	MUDDY SAND Light brown (5yr 6/4) Ooze? Foraminiferal	Pleistocene	
DR/02 (7 kg)	A2	23°23.94' 111°03.40'	23°23.95' 111°04.48'	4994-4720	E	1	(60%)	D	MUDSTONE (boulders) Dark grey (N3), hard, highly siliceous, qtz veinlets & infills.	-	-
						2		P	MUD Pale yell.brown (10yr6/2) - lt olive grey (5y5/2), soft, plastic.	Pleisto.	Quater.
						3		P	MUD Pale yell brown (10yr6/2), very soft, plastic.	Pleisto.	Quater.
						4		P	MUDSTONE Dark greenish grey(5GY4/1) burrowed, soft to firm, ?carbonaceous specks.	?Jur.-?E. Cret.	
						5	(40%)	D	MUDSTONE (boulder) Pale to light olive (10y5.5/3), mod. hard, siliceous, calc. on outside.	-	E. Cret.
						6		P	MUD Greyish olive pink-light brown, very soft, plastic	Pleisto.	Quater.
DR/03 (5 kg)	A1	23°24.75' 111°28.89'	23°24.69' 111°30.60'	3891-3700	E	1		D	MUDSTONE Light grey (N7), burrowed mottled, well consolidated, partly siliceous	E. Cret.	E. Cret.
						2		D	MUDSTONE Light olive brown (5y5/6), soft calcareous	(indet.)	E. Cret.
						3		P	SANDY MUD Greyish orange pink (5yr7/2) to light brown (5yr6/4)	Pleistocene	

* Recovery in chain-bag dredge shown in brackets.
\# D: chain-bag dredge, P: pipe dredge.
\+ Percentage of each rock type in chain-bag dredge.

AREA B - CARNARVON TERRACE

Station	Site	Lat. & Long. (start)	Lat. & Long (finish)	Water Depth Range (m)	Head'g dredge run	Rock Type		D or P	Shipboard Description	Age (Foram)	Age (Nanno)
DR/04 (shear pin broke)	A1	21°53.056′ 112°44.942′	21°52.87′ 112°43.34′	4200-3540	SW	1		P	SANDSTONE Dark yellowish brown (10yr4/2), soft, f.-v.fine grained, rare glauconite and carbonaceous fragments. Trace mica. Clayey.	-	-
						2		P	SANDSTONE Light olive brown (5y4/6). Soft, f.-v.fine grained, trace glauconite, rare carbonaceous fragments, mica.	-	-
						3		P	OOZE Pale yellowish brown (10yr6/2)	Pleistocene	
						4		P	OOZE Light olive grey (5y5/2), calcareous	Pleistocene-Recent	
						5		P	MUD Moderate-dark reddish brown (10yr3/6), very soft, silty and sandy, some mica. (degraded Type 1 lithology?)	-	-
						6		P	MUD Dark yellowish brown (10yr4/2) very soft, silty and sandy (degraded Type 1 lithology?)	-	-
						7		P	MUD Dark olive brown (5y3/4), soft, silty and sandy (degraded Type 1 or 2?)	-	-
DR/05 (30 kg) repeat DR/04	BO	21°52.12′ 112°43.75′	21°52.92′ 112°42.28′	4200-3150	SW	1	(40%)	D	SANDSTONE Dusky yellowish brown (10yr2/2), very fine grained, flagstone, carbonaceous in places, glauconite, Fe stained	-	-
						2	(15%)	D	SANDSTONE similar to type 1. Bored, MN & Fe stained, v.fine grained. quartz sandstone. Micaceous.	-	-
						3	(5%)	D	SILTSTONE Yellowish grey (5y7/2), sandy, flaggy, ?carbonaceous flecks	-	-
						4	(2%)	D	SANDSTONE Pale yellowish brown (10yr6/2), very fine grained, some secondary calcite cement.	-	-
						5	(1%)	D	SANDSTONE Medium grey (N5), carbonaceous, glauconitic.	-	-
						6	(35%)	D	SANDSTONE Medium & dark grey (N5/N3), mottled, fine grained, slightly carbonaceous, Fe cemented rind.	-	-
						7		P	MUD/OOZE Dark yellowish brown (10yr4/2) sandy, foraminiferal	Pleisto.	Quaternary

AREA B (contd)

Station	Site	Lat. & Long. (start)	Lat. & Long (finish)	Water Depth Range (m)	Head'g dredge run	Rock	Type	D or P	Shipboard Description	Age (Foram)	Age (Nanno)
						8		P	MUD/OOZE Pale yellowish brown (10yr6/2), foraminiferal.	Pleisto.	Quater.
						9	(1%)	D	SANDSTONE Medium to light grey (N6/N5), very fine grained, carbonaceous, calcareous	-	-
DR/06 (40 kg)	B1	21° 52.1′ 112° 43.8′	21° 51.49′ 112° 45.88′	4100-3340	NE	1	(2%)	D	MUDSTONE Grey (N3-N6), hard, ?silicified, Mn-stained, ?chert.	-	-
						2	(98%)	D	SHALE Black to grey (N1-N3), slate-like (platey), burrowed in places, hard, non-calcareous.	-	-
						3		P	MUD/OOZE Pale yellowish brown (10yr6/2), sandy. Foraminiferal	Pleisto.	Quater.
DR/07 (25 kg)	B0 (top part)	21° 52.66′ 112° 43.11′	21° 53.04′ 112° 41.19′	3700-3150	SW	1		P	OOZE very pale orange (10yr8/2), calcareous, foraminiferal	Plio. + Pleist (mixed)	(indet.)
						2		P	SAND Dusky brown (5yr2/2), soft, silty (?degraded Type 6 lithology)	-	-
						3		P	OOZE Light brown (5yr5/6), very soft, calcareous.	Pleisto.	
						4	(40%)	D	CHALK Yellowish grey (5y8/1), soft, occasional burrow	Olig-E. Mio. M-L. Oligo.	
						5	(7%)	D	CHALK White (N9), firm, clean	L. Pal. + Eo. (mixed)	L. Palaeo.
						6	(30%)	D	SANDSTONE Dusky brown (5yr2/2), soft to firm, very fine grained grading to siltstone, occasional carbonaceous frag., mica and glauconite. Fe stained. Bored in part	-	-
						7	(15%)	D	SILTSTONE Dark grey (N3), firm to soft, occasional glauconite, micaceous, carbonaceous	-	-
						8	(2%)	D	SANDSTONE Dark yellowish brown (10yr4/2), soft to firm, very fine to fine grained, ?carbonate cement, occ. glauconite, rare organic material.	-	-

AREA B (cont.)

Station	Site	Lat. & Long. (start)	Lat. & Long (finish)	Water Depth Range (m)	Head'g dredge run		Rock Type	D or P	Shipboard Description	Age (Foram)	Age (Nanno)
						9	(1%)	D	CHALK Yellowish grey (5y8/1), speckled, soft to firm, glauconitic, minor qtz.	L. Paleo.	L. Paleo.
						10		P	SANDSTONE Dark grey (N3), very hard, siliceous and ?carbonate cement, very f. to fine grained, common glauconite, occasional carb. frag.	-	-
						11		P	SANDSTONE Mod. olive brown (5y4/4), soft, fine-v.fine grained, common glauconite, occas. mica, rare carbonaceous fragment.	-	-
						12	(5%)	D	SILTSTONE/MUDSTONE Olive grey (5y4/1), hard to v.hard, carbonaceous frags, occas. glauconite & mica, Fe rind, sandy in places.	-	-
DR/08 (50 kg)	B2	21° 50.93' 112° 45.69'	21° 49.85' 112° 47.30'	3550-3180	NE	1	(5%)	D	CHALK Very pale orange (10yr8/2), soft	e.M. Mio.	M. Mio.
						2	(5%)	D	SILTSTONE Brownish black (5yr2/1), soft-firm, very glauconitic, non-calcareous, sandy in part. 'Greensand'.	-	-
						3	(5%)	D	SILTSTONE Greyish black (N2), soft, common mica, occ. glauconite, non-calcareous.	-	-
						4	(10%)	D	SILTSTONE Very dark yellowish brown (10yr3/2), firm, common mica, occ. occ. glauconite, minor carbonaceous specks, clayey.	-	-
						5	(5%)	D	SANDSTONE Dark greyish olive (10y3/2), soft to firm, silty in part, v.fine grained, occ. glauconite, occ. carbonaceous frags	-	-
						6	(10%)	D	SANDSTONE Medium dark grey (N4), hard, calcareous, very fine grained, occ. glauconite and mica.	-	-
						7	(10%)	D	CHALK Greyish yellow (5y8/4), mod. hard, foram rich.	E. Mio.	L. Oligo.

AREA B (cont.)

Station	Site	Lat. & Long. (start)	Lat. & Long (finish)	Water Depth Range (m)	Head'g dredge run	Rock Type	D or P	Shipboard Description	Age (Foram)	Age (Nanno)
						8 (5%)	D	MUDSTONE Dark grey (N3), very hard, extremely siliceous, qtz veinlets.	–	–
						9 (15%)	D	CHALK Yellowish grey (5y7/2), soft, slightly marly.	E.-M. Mio.	M. Mio.
						10+ (15%) 10A	D	IGNEOUS ROCKS At least two varieties varying from ?granite to ?gabbro. Free quartz in 10 at least.	–	–
						11+ (10%) 11A (2%)	D	SHALE Dark grey to greyish black (N3-N2), hard to very hard, siliceous.	–	–
						12	P	OOZE Mod. yellowish brown (10yr5/4)	Pleistocene	
DR/09 (30 kg)	B3 21°55.74′ 113°01.32′	21°55.85′ 113°00.06′	2650-2200	W	1	(<1%)	D	MUD/OOZE Light brown (5yr6/4); foraminiferal	L. Cret+Tert. (mixed)	L. Paleo.
					2	(70%)	D	MUDSTONE (marl-lst). Very light grey (N8), calcareous, burrowed, slight Mn staining.	M. Eoc.	M. Eoc.
					3	(<10%)	D	LIMESTONE Light olive grey (5y5/2) and olivie grey (5y3/2), crystalline, ?recrystallised version of Type 2 grainstone-packstone.	–	–
					4	(<10%)	D	MUDSTONE Light olive grey (5y5/2), soft, calcareous.	L. Cret.	L. Cret. + Pal. (mixed)
					5	(<10%)	D	MUDSTONE Yellowish grey (5y7/2), calcareous, consolidated.	Pal.+Eoc. (mixed)	E. Olig + L. Pal (mixed) + Cre
							P	OOZE Pale brown (5yr5/2), foraminiferal		
							P	MUD Very light grey (5yr5/2), calcareous.	Olig-Recent (mixed)	
DR/10 (<1 kg)	B4 21°56.288′ 113°09.669′	21°56.95′ 113°07.94′	2420-2100	W	1		D	MUDSTONE Very light grey (N8), calcareous.	L. Eoc.	L. Eoc.
							P	MUD/OOZE Light brown-pale yellowish brown (5yr6/4-10yr6/2). Calcareous. Agglutinated worm tubes made up of forams.	Pleistocene	

AREA B (cont.)

Station	Site	Lat. & Long. (start)	Lat. & Long (finish)	Water Depth Range (m)	Head'g dredge run	Rock Type		D or P	Shipboard Description	Age (Foram)	Age (Nanno)
DR/11 (0.5kg)	B5	22° 14.84′ 112° 38.08′	22° 16.73′ 112° 37.19′	3700-3070	SSW	1	(60%)	D	CHALK/MARL Yellowish grey (5y6/2) firm, occ. burrow.	(indet.)	E. Cret.
						2	(40%)	D	MARL Light olive grey (5y5/2), soft.	E. Cret.	E. Cret.
						3		P	MARL Medium olive grey (5y4/2), soft.	E. Cret.	E. Cret.
						4		P	MARL Yellowish grey (5y7/2), soft.	mixed	{M. Olig. + L. Cret.
						5		P	MARL Light olive grey (5y5/2), soft, ? same as Type 2.	E. Cret.	E. Cret.
						6		P	OOZE Moderate yellowish brown (10yr5/4), calcareous.	Pleistocene	

AREA D - MARGIN OF SOUTHERN ROWLEY TERRACE

Station	Site	Lat. & Long. (start)	Lat. & Long. (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type		D or P	Shipboard Description	Age (Foram)	Age (Nanno)
DR/12 (25kg)	D3	16°54.50' 117°36.08'	16°54.37' 117°38.72'	5000-4005	E	1	(80%)	D	SHALE/MUDSTONE Dark grey to black (N3-N2), very carbonaceous, plant fragments, interbedded in part with Type 2 sst.	-	-
						2	(15%)	D	SANDSTONE Light olive grey (5y5/2) - mod. yell. brown (10yr5/4), v. fine grained, micaceous, quartzose, argillaceous in part, carbonaceous.	-	-
						3	(2%)	D	MUDSTONE Mod. yell. brown (10yr5/4) to dusky yellow (5y6/4), hard, very siliceous (rads and diatoms).	-	Mesozoic
						4	(1%)	D	MUDSTONE Mod.brown (5yr3/4), firm non-calcareous, carbonateous, occ. mica.	-	-
						5	(2%)	D	MUDSTONE Med dark grey (N4), soft to firm, common fine mica and carbonaceous specks, non-calcareous	-	-
						6		P	OOZE/MUD Light olive grey (5y6/1), soft, calcareous, foram-rich	Pleistocene	
						7		P	OOZE/MUD Dark yellowish brown (10yr3/2), soft, contaminated with type 6 lithology.	(indet.)	Mesozoic contam.
DR/13 (300kg)	D3A	16°54.40' 117°38.45'	16°54.31' 117°40.55'	4150-3600	E	1	(2%)	D	SHELLY SANDSTONE Mod brown (5yr4/4)- mod. reddish brown, friable, current bedded, shell fragments 30-50% of rock, Inoceramus frags abundant. Patches similar to Type 8 lithology. Coquina.	(indet.)	Mesozoic
						2	(2%)	D	LIMESTONE Very pale orange	E. Eoc.	l. E. Eoc.
						3	(2%)	D	MUDSTONE Light olive grey (5y5/2), well consolidated, calcareous	(indet.)	E. Cret.
						4	(30%)	D	SILTSTONE Olive grey (5y3/2) & greyish olive (10y4/2), carbonaceous non-clacareous, quartz, mica, ferruginous in part.	-	-

AREA D (CONT.)

Station	Site	Lat. & Long. (start)	Lat. & Long. (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type		D or P	Shipboard Description	Age (Foram)	Age (Nanno)
						5	(20%)	D	D LIMESTONE Yellowish grey (5y7/2) & medium light grey (N6) mottles. Well indurated. Similar to Type 2. Rare forams.	?Ju-?E.Cr.	E. Cret.
						6	(3%)	D	D SILTSTONE Brownish black (5yr2/1), soft, micaceous, carbonaceous, non-calcareous. Similar to Type 4.	–	–
						7	(2%)	D	LIMESTONE Greyish orange (10yr7/4), calcilutite.	Cret.+Ter. (mixed)	L. Cret.
						8	(30%)	D	CALCARENITE LST (GRAINSTONE) Dusky yellow (5y6/4). Abundant Inoceramus plates (Inoceramus grainstone), bivavle moulds etc.	(indet.)	E. Cret.
						9	(8%)	D	MUD Pale yellowish orange (10yr8/6) yellowish brown (10yr6/2), stiff	M. Eoc.	M. Eoc.
						10		P	MUD Mod yellowish brown (10yr5/4) calcareous (forams etc)	Pleistocene	
DR/14 (200 kg)	D1	16°50.02′ 117°35.22′	16°49.89′ 117°38.61′	5250-4005	E	1	(8%)	D	SANDSTONE Dark yellowish orange (10yr6/6), Fe and Mn staining, quartzose, well sorted, fine grained, friable.	–	–
						2	(15%)	D	SANDSTONE Light grey (N7), fine-grained, well sorted, cross-bedded in places, some mica.	–	–
						3	(1%)	D	LIMESTONE/? White (N9), indurated knobbly calcrete?	–	–
						4	(5%)	D	MUDSTONE Yellowish-grey, calcareous.	L. Cret.	L. Cret.
						5	(15%)	D	SILTSTONE/SANDSTONE Interbedded. Predom. siltstone with sand stringers. Sandstone is fine-grained, slightly micaceous, some burrows. Siltstone micaceous, brownish black.	–	–
						6	(35%)	D	SILTSTONE Med. light grey (N6)-med grey (N5). Soft, non-calcareous, burrowed, Fe crusts (box-work), slightly micaceous, grading into T10	–	–

AREA D (cont.)

Station	Site	Lat. & Long. (start)	Lat. & Long. (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type		D or P	Shipboard Description	Age (Foram)	Age (Nanno)
						7	(5%)	D	CRUSTS Fe and Mn crusts & concretions.	–	–
						8	(<1%)	D	MUDSTONE Dusky yellow (5y6/4), slightly calcareous, soft, bored, textularian forams.	?Ju-?E.Cr.	E. Cret.
						9	(<1%)	D	MUDSTONE Pale yellowish orange (10yr8/6), calcareous, burrowed.	(indet.)	L. Cret.
						10	(15%)	D	CLAYSTONE/SILTSTONE Brown (10yr6/2)-brownish grey (5yr6/1). Interbedded. Graded bedding, non calcareous, burrowed, micaceous. Gradational with Type 6.	–	–
						11		P	SAND Quartz-foram-glauconite. Qtz derived from sandstones	Pleistocene	
						12		P	SANDSTONE Very coarse-granular, quartzose, poorly-sorted, indurated with Fe oxides	–	
						13		P	SHALE Black, very micaceous + carb.	–	
DR/15 (30kg)	D2	16°50.01' 117°37.98'	16°50.01' 117°39.76'	4200-3875	E	1	(80%)	D	MUDSTONE Light olive grey (5y5/2) - light olive brown (5y5/6), mod. hard-hard, mod. calcareous, abundant fine mica, bored.	(indet.)	E. Cret.
						2	(15%)	D	MUDSTONE Olive grey (5y4/1) - dark greenish grey (5GY4/1), firm, v. fine mica, ?forams	–	–
						3	(3%)	D	CHALK White to yellowish white (5y9/1), soft to firm, clean, common borings	–	L. Palaeo.
						4	(2%)	D	MUD Dark reddish brown (10r3/4) - dusky red (5r3/4), soft, plastic, very silty, non-calcareous. Contains texturian (agglutinated) forams made up of qtz sand.	?Jur-E.Cr.	–
						5		P	MUD/OOZE white (N9) - yellowish white (5y9/1), soft, plastic, chalky, calcareous.	(indet.)	L. Palaeo.
						6		P	MUD Light olive grey (5y6/1) to olive grey (5y4/1), soft, mod calcareous.	Pleisto.	E. Cret. (contam.)
						7		P	MUD yellowish brown (10yr5/4), soft, calcareous, abundant siliceous microfossils.	Pleisto-Recent	

AREA D (cont.)

Station	Site	Lat. & Long. (start)	Lat. & Long. (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type		D or P	Shipboard Description	Age (Foram)	Age (Nanno)
DR/16 (7 kg)	D4	16°44.9′ 117°33.7′	16°44.86′ 117°35.58′	5612-4675	E	1	(85%)	D	SANDSTONE Light olive grey (5y5/2) - light olive brown (5y5/6), friable, very fine grained quartzose, common mica. Occasional carbonaceous laminae and fragments.	—	—
						2	(15%)	D	SHALE/MUDSTONE Greyish black (N2), carbonaceous, non-calcareous interbedded with siltstone	—	—
						3		P	OOZE Dark yellowish brown (10yr3/2) very soft, non-calcareous?	Pleistocene	
DR17 (400 kg)	D5	16°44.88′ 117°35.90′	16°45.03′ 117°37.68′	4500-3910	E	1	(35%)	D	SANDSTONE dark yell. orange (10yr6/6)- pale brown (5yr5/2)- white. Fe-stained, med. grained, Cross bedded, trace mica rare carbonaceous frags, abun. lithics.	—	—
						2	(10%)	D	SANDSTONE Pale yell.brown (10yr6/2), fine grained, massive, quartzose.	—	—
						3	(5%)	D	SANDSTONE Light brown (5yr4/1), quartzose orange, fine-grained, crossbedded.	—	—
						4	(5%)	D	CONGLOMERATE. Brownish grey (5yr4/1), soft, claystone clasts in clayey micaceous sand.	—	—
						5	(15%)	D	CLAYSTONE/SHALE Greyish black (N2), micaceous, grades into silty shales and clayey siltstones.	—	—
						6	(15%)	D	SANDSTONE/SILTSTONE/SHALE Inter-bedded.	—	—
						7	(<2%)	D	SILTSTONE brownish black (5yr2/1), well indurated.	—	—
						8	(<2%)	D	SANDSTONE Medium grey (N5) to light brown (5yr5/6). Coarse grained, mod. sorting.	—	—
						9	(1%)	D	CARBONACEOUS SANDSTONE/SILTSTONE/ CLAYSTONE. Some leaf impressions. Strings.	—	—

AREA D (cont.)

Station	Site	Lat. & Long. (start)	Lat. & Long. (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type	D or P	Shipboard Description	Age (Foram)	Age (Nanno)
						10 (<2%)	D	SILTSTONE Brownish grey (5yr4/1), micaceous, burrowed.	—	—
						11 (5%)	D	INTERLAMINATED SILTST/CLAYSTONE/ SANDSTONE. Micaceous, intergrades with Type 12.	—	—
						12 (<5%)	D	SANDSTONE Pale brown (5yr5/2). v.fine grained, massive.	—	—
						13 (<1%)	D	CLAYSTONE Moderate brown (5yr4/4), silicified, hard.	—	—
						14 (<1%)	D	CLAYSTONE Greyish-orange (10yr7/4), soft, non-calcareous, intensively burrowed & bored.	—	—
						15 (<1%)	D	IRONSTONE NODULE Grey (N6), clay in nodule.	—	—
						16	P	CLAY Brownish grey (5yr4/1) - mod. yellowish brown (10yr5/4), calcareous.	—	—
						17	P	SAND Pale yell. brown (10yr6/2) fine grained, quartzose.	—	—
						18	P	OOZE/CLAY Light brown (5yr6/4), calcareous, forams.	Pleistocene	
						19	P	MUDSTONE Black, soft, carbonaceous, micaceous, grades with Type 5.	—	—
						20	P	MUD Greyish brown, soft	—	—
DR/18 (3kg)	D6	16°55.0′ 117°52.5′	16°54.11′ 117°58.30′	3360-2980	E-NE	1 (90%)	D	CHERT Moderate brown (5YR4/4-5YR3/4), very hard.	—	—
						2 (10%)	D	SANDSTONE/SILTSTONE Light grey (N7) to light olive brown (5y5/6), v. fine grained, clean, quartzose	—	—
						3	P	CHALK Greyish yellow (5y8/4), soft, clean	Mixed Mio.	e. M. Mio.
						4	P	OOZE Pale yellowish brown (10yr8/2) foram-rich.	Pleistocene	
						5	P	SILTSTONE Light grey (N7), soft, quartzose, micaceous	—	—
						6	P	MUDSTONE Medium dark grey (N4) to dark grey (N3), carbonaceous, micaceous, non-calcareous	—	—

AREA E - SCOTT PLATEAU MARGIN

Station	Site	Lat. & Long (start)	Lat. & Long. (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type		D or P	Shipboard Description	Age (Foram)	Age (Nanno)
DR/019 (75kg)	E4	14°19.51′ 119°26.51′	14°19.30′ 119°29.51′	4370-3705	E	1	(80%)	D	SANDSTONE/SILTSTONE Olive grey (5y3/2) to olive brown (5y3/4), very fine gr-silt, poor-mod. sorted, litharenite, mollusc casts and fragments in places..	—	—
						1A	(5%)	D	SANDSTONE Light olive grey (5y5/2) to mod.yell. brown (10yr5/4), fine-med. grained largely volcanologenic litharenite. In part, abundant Inoceramus, mollusc casts & frags. Grades into Type 1.	?	?
						2	(15%)	D	MUDSTONE Light olive grey (5y5/2), firm, non-calcareous, burrowed.	?Ju-E.Cr.	—
						3		P	OOZE Dark yellowish brown (10yr4/2), soft, foram-rich.	Pleist.	
						4		P	MUD Dark yellowish brown (10yr4/2), soft, slightly calcareous, contaminated witht Types 2 and 3	?Ju-E.Cr (contam.)	Quaternary
						5		P	OOZE Medium olive grey (5y5/1), calcareous, foram-rich.	Pleistocene-Recent	
DR/020 (15kg)	E5	14°20.06′ 119°25.57′	14°17.54′ 119°25.86′	4600-3620	NNE	1	(5%)	D	PUMICE One well rounded piece, lgt olive grey (5y5/2)	—	—
						2	(80%)	D	SANDSTONE Olive grey (5y3/2), v fine fine gr., poorly sorted, well cemented, litharenite (largely volcanogenic).	—	—
						2A	(10%)	D	CONGLOMERATE Olive grey (5y3/2), poorly sorted, hard, volcanogenic pebbles and granules. Grades into Types 2 & 2B	—	—
						2B	(5%)	D	MUDSTONE Greyish brown (5yr3/2), mod hard, non calcareous, inter-grading Types 2A & 2.	—	—
						3		P	OOZE Light olive grey (5y6/1), very soft, calcareous, foram-rich.	Pleistocene	
						4		P	MUDST/OOZE Pale yellowish brown (10yr6/2).	Pleistocene	

AREA E (cont.)

Station	Site	Lat. & Long. (start)	Lat. & Long. (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type		D or P	Shipboard Description	Age (Foram)	Age (Nanno)
DR/021 (50kg)	E6	14° 25.29′ 119° 02.25′	14° 24.99 119° 05.56′	4700-3650	E	1	(2%)	D	MN CRUSTS	—	—
						2	(2%)	D	CHERT Pale brown (5yr5/2) - greyish red (5R4/2), very hard.	—	—
						3	(25%)	D	?BASALT Mn crusts up to 5cm thick. Weathered.	—	—
						4	(25%)	D	VOLCANIC CONGLOM./BRECCIA Some matrix similar to Type 5	—	—
						5	(5%)	D	CLAYSTONE Mod soft volcanic weathering product? Greyish orange pink (5y7/2).	—	—
						6	(40%)	D	CLAYSTONE Yellowish grey (5y7/2), non-calcareous, bored & burrowed. Similar dredge 27 Type 1. Friable.	—	—
						7		P	MUD Mod yellowish brown (10yr5/4), abundant forams	*Pleistocene*	
DR/022 (20kg)	E3	13° 55.67′ 119° 13.71′	13° 55.52′ 119° 15.95′	4100-3685	E	1	(95%)	D	MUDSTONE Olive grey (5y3/2) -dk olive brown (5y3/4), hard, siliceous, faintly mottled (?burrowing), massive, recent borings.	—	—
						2	(5%)	D	MUDSTONE BRECCIA Light olive grey (5y5/2) - dk yell. brown (10yr4/2), well cemented, predom. calc. matrix	—	—
						3		P	MUDSTONE Med. dk grey (N4), soft to firm, non-calcareous.	—	—
						4		P	OOZE Mod. yell brown (10yr5/4), very soft, calcareous, foram-rich.	*Pleist.-Recent*	
DR/023 (50kg)	E1	13° 26.17′ 119° 22.25′	13° 26.01′ 119° 23.72′	5200-4385	E	1	(25%)	D	SILTSTONE Pale brown (5yr5/2), soft clayey, non-calcareous.	—	—
						2	(15%)	D	SILTSTONE-V.F.SST Mod. brown (5yr4/4) - pale brown (5yr5/2), soft, mod. hard, Gradational with Type 1. ?Plant fossil	—	—
						3	(<5%)	D	CLAYSTONE Med. bluish grey (5B5/1), mod hard, slicken sides, non-calc.	—	—
						4	(20%)	D	BASALT with Mn crusts	—	—
						5	(10%)	D	BASALT Weathered	—	—
						6	(<2%)	D	BASALT Porphyritic	—	—
						7	(15%)	D	VOLCANIC BRECCIA Clasts up to few cm across.		—

AREA E (cont.)

Station	Site	Lat. & Long. (start)	Lat. & Long. (finish)	Water Depth Range(m)	Head'g dredge run	Rock	Type	D or P	Shipboard Description	Age (Foram)	Age (Nanno)
						8	(5%)	D	WEATHERED? VOLCANIC/CLAYSTONE Dark yellowish brown (10yr4/2). Mod. hard, weathered Type 9?	—	—
						9	(<2%)	D	AMYGDALOIDAL BASALT	—	—
						10	(<2%)	D	PORPHYRITIC BASALT	—	—
						11	(<1%)	D	MUD Pale yellowish brown (10yr6/2) forams, off chain bag.	Pleistocene	
						12		P	MUD Mod. brown (5yr4/4), foram-rich.	Pleistocene	
DR/024 (2kg)	E2	13°26.18′ 119°21.66′	13°25.86′ 119°22.86′	5320-4650	E	1	(100%)	D	?BASALT Partly weathered	—	—
						2		P	MN CRUSTS	—	—
						3		P	OOZE Light olive grey (5y6/1), foram-rich, sandy.	Pleistocene	
						4		P	MUD Dark yell. brown (10yr4/2), non-calcareous.	—	—
DR/025 (0kg)	E7	13°00.99′ 119°45.02′	13°05.61′ 119°45.01′	2820-2530	S	1		P	OOZE Light olive grey (5y6/1) to (5y5/2), foram-rich	Pleistocene-Recent	
DR/026 (5kg)	E8	12°57.52′ 120°09.95	12°57.63′ 120°11.66′	3050-2710	E	1	(60%)	D	LIMESTONE Very pale orange (10yr8/2) burrowed.	M. Mio.	M. Mio.
						2	(40%)	D	MUD Pale yellowish brown (10yr6/2), calcareous, abundant forams.	Pleist - Recent	
						3		P	MUDSTONE Very pale orange (10yr8/2), calcareous, soft.	M. Mio.	e M. Mio.
						4		P	MUD Pale yell. brown (10yr6/2), calcareous, abundant forams.	Pleist. - Recent	
						5		P	MUD Light olive grey (5y6/1), calcareous, common forams.	Pleist. - Recent	
DR/027 (2 kg)	E9	14°21.75′ 119°17.78′	14°23.45′ 119°17.02	4350-3660	SW	1	(100%)	D	CLAYSTONE Yellowish grey (5y7/2) - greyish yellow (5y8/4), non-calcareous, friable. Same as DR21/5,6	—	—
						2		P	OOZE Mod.yell brown (10yr5/4), soft calcareous, foram-rich. Contam. with Type 3.	Pleist.-Recent	
						3		P	Mod. brown (5yr3/4), soft, calcareous, foram-rich. Contam. with Type 2.	Pleist.-Recent	

AREA D (cont.)

Station	Site	Lat. & Long. (start)	Lat. & Long. (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type	D,or P	Shipboard Description	Age (Foram)	Age (Nanno)
DR/028 (350 kg)	RT1	16°18.496′ 118°23.419′	16°18.00′ 118°24.70′	4530-3500	E	1 (10%)	D	LIMESTONE Yellowish grey (5y7/2), hard (well-cemented), massive, peloidal in part, ?micritic. Some crinoid and bivalve fragments. 1A has large ammonite.	—	—
						2 (10%)	D	LIMESTONE Grey (N7), hard, massive, crinoid-rich. Grades into Type 3.	—	—
						3 (30%)	D	LIMESTONE Grey (N6.5) massive, hard. Includes some finegrained skeletal debris. 3A - weathered (clayey) version.	—	—
						4 (<1%)	D	LIMESTONE BRECCIA. Hard, white lst fragments in dk grey micritic matrix.	—	—
						5 (<1%)	D	?CALCRETE/LMST Greyish orange pink (5yr7/2), hard, banded	—	—
						6 (2%)	D	QTZOSE CALCARENITES-CALCARENITES Pale olive (10y6/2) to yellowish grey (5y7/2), hard, flaggy, varying proportions of components, carbonate cement.	—	—
						7 (1%)	D	SANDSTONE Greyish olive green (5gy3/2), calcareous, coarse-grained ?glauconitic, poorly sorted, oolitic, sim. Type 9.	—	—
						8 (10%)	D	?DOLOMITE Olive grey (5y3/2), very massive, with 2-4mm thick Fe crusts ("boxstone" like). Ammonite cast in 8A.	—	—
						9 (10%)	D	CALCARENITE/CALCIRUDITE Hard, greenish grey (5G6/1) to medium bluish grey (5B5/1), subround to angular fragments of ?chamositic, spastolithic, oolitic limestone set in a pale, hard, carbonate matrix. Graded bedding.	—	—

AREA D (cont)

Station	Site	Lat. & Long. (start)	Lat. & Long. (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type	D,or P	Shipboard Description	Age (Foram)	Age (Nanno)
						10 (<1%)	D	SANDSTONE Light grey (N7) to medium light grey (N6), soft to firm, v.f. to f. grained, mod. sorted, quartzose, slightly argillaceous in places, occ. slightly calcareous (cement), occ. fine micaceous laminae. ?Grades in Type 11. Lithics common.	—	—
						11 (<1%)	D	SILTSTONE Medium grey (N5), hard, calcareous (cement), finely laminated N4 mudstone and mica, lithics common.	—	—
						11A (<1%)	D	SILTSTONE Medium grey (N5), hard to very hard, siliceous, clean, occ. dark grey (N3) mod. micaceous mudstone laminae.	—	—
						11B (<1%)	D	SILTSTONE Dark greenish grey (5gy4/1), mod hard, massive, non-calcareous, occ. very fine micaceous laminae.	—	—
						12 (<1%)	D	SANDSTONE Very light grey (N8), hard, non-calcareous, medium-coarse grained, mod. poorly sorted, common lithic fragments.	—	—
						13 (<1%)	D	SILICIFIED MUDSTONE/CHERT Greyish brown (5yr3/2), hard, non-calcareous ferruginous.	—	—
						14 (<1%)	D	SILTSTONE Medium light grey (N6), mod. hard, mod. well cemented (silica) non-calcareous, some Mn veining outlining siltstone clasts (?intraclasts).	—	—
						15 (2%)	D	MUDSTONE Dark grey (N3), firm to mod hard, calcareous, very carbonaceous in part.	Jurassic	—
						16 (20%)	D	MUD/MUDSTONE Dark grey (N3), soft, plastic, dissem. mica, some carbonate (?forams).	Jurassic	M. Jur.
						17	P	OOZE Dark yellowish brown (10yr4/2) calcareous, abundant forams.	Pleistocene	

AREA C - EXMOUTH PLATEAU

Station	Site	Lat & Long (start)	Lat & Long (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type	D, M or P	Shipboard Description	(foram)	(Nanno)
DR/029 (300 kg)	C1	17°37.38′ 115°41.5′	17°40.43′ 115°41.93′	2280-1995	SSE	1 (50%)	D	LIMESTONE White-yellowish grey (5y8/1), mod. soft, intensely bored, Mn stained, foram-rich. 1A-?Holocene encrusting bryozoan	E.M. Mio.	E.M. Mio.
						2 (<5%)	D	CLAY Yellowish grey (5y7/2), stiff, plastic, calcareous, burrowed.	E.+L. Mio. (mixed)	M. Mio.
						3 (<5%)	D	CLAY Greyish orange (10yr7/4), massive, burrowed, sticky, calc., grades into Types 2 and 4.	E+L. Mio. (mixed)	E. Mio.
						4 (20%)	D	CLAY Greyish orange (10yr7/4), calc., bored and burrowed. Sim. to Type 2.	E. Mio.	E. Mio.
						5 (20%)	D	CLAY Dark yellowish orange (10yr6/6), laminated, slightly calcareous.	-	-
						6 (<1%)	D	MN CRUSTS AND CONCRETIONS	-	-
						7	P	OOZE Very pale orange (10yr8/2), foram-rich.	Mio-Plio (mixed)	E. Plio.
						8	P	SAND Pale yellowish brown (10yr6/2), foram rich.	Pleist.	Quater. +M. Eoc.+ M. Olig.
						9	P	OOZE Pale yellowish brown (10yr6/2), sandy, foram-rich.	Pleist. -Recent	Quat.
						10	P	Washings, Mn crusts, echinoid spines etc	-	-
DR/030 (150kg) Repeat of DR/029	C1	17°37.65′ 115°41.41′	17°40.05′ 115°42.00′	2300-2000	SSE	1 (30%)	D	LIMESTONE Greyish orange (10yr7/4) - dk yellowish orange (10yr6/6), hard, bored, Mn coatings, mollusc-rich, fine-grained, calcarenite grading into hard limestone of Types 1A & 1B.	-	-
						1A (20%)	D	LIMESTONE Dark yellowish orange (10yr6/6) hard, bored, Mn coated, limestone with v.f. grained skeletal debris. Grades into Type 1.	(indet.)	-
						1B (20%)	D	LIMESTONE Greyish orange, hard, bored, Mn stained, v.f. grained.	-	-

AREA C (cont.)

Station	Site	Lat. & Long. (start)	Lat. & Long. (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type	D. or P	Shipboard Description	Age (Foram)	Age (Nanno)
						1C (25%)	D	?LIMESTONE BRECCIA Greyish orange (10yr7/4), to very pale orange (10yr8/2) hard, clasts of types 1A & 1B (some ironstained), bored, Mn staining on surfaces.	—	—
						2 (5%)	D	MN CRUSTS. In some cases on pieces of Type 1 limestones. 2A Mn oxide worm tube casts.	—	—
						3	P	OOZE Greyish orange pink (5yr7/2) soft, calcareous, foram-rich.	Pleistocene - Recent	

AREA G - WESTERN MARGIN OF WOMBAT PLATEAU

Station	Site	Lat. & Long. (start)	Lat. & Long. (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type	D, P or C	Shipboard Description	Age (Foram)	Age (Nanno)
DR/031 (0 kg)	G1	16°54.27′ 114°22.42′	16°54.34′ 114°25.79′	2510-2310	E	1	P	OOZE Greyish orange pink (5yr7/2), calcareous, foram-rich.	Pleist-Recent	
DR/032 (0 kg)	G2	16°54.27′ 114°16.54′	16°54.11′ 114°20.52′	3100-2560	E	1	P	OOZE Greyish orange pink (5yr7/2), soft, calcareous, foram-rich	Pleist.-Recent	
						2	P	chalk White (N9), clean, soft, burrowed.	M. Mio.	
						3	P	VOLCANICS Weathered fragments. Fine vesicles infilled with calcite. Brown (5yr5/6 - 5yr4/4)	-	-
DR/033 (10kg) Repeat of DR/032	G2	16°54.1′ 114°16.8′	16°53.89′ 114°20.59′	3050-2470	E	1 (20%)	D	?BASALT Highly weathered, brown, same as DR32 Type 3. Abundant vesicles and occasional vugs infilled with calcite.	-	-
						2 (25%)	D	CHALK white (N9) - very pale orange (10yr8/2), firm, clean. 2A - encrusting bryozoan.	e. M. Mio.	e. M. Mio.
						3 (30%)	D	CHALK very pale orange (10Yr8/2) soft, v. slightly marly	e. M. Mio.	M. Mio.
						4 (25%)	D	CHALK Very pale orange (10yr8/2), very soft, v. slightly marly.	e. M. Mio.	M. Mio.
						5	P	OOZE Greyish orange pink (5yr7/4), very soft, calcareous, foram-rich.	Pleistocene	Quater.

AREA H - SOUTHWESTERN MARGIN OF EXMOUTH PLATEAU

Station	Site	Lat & Long (start)	Lat & Long (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type	D or P	Shipboard Description	Age (foram)	Age (Nanno)
DR/034 (30kg)	H1	19° 56.27′ 110° 34.07′	19° 56.03′ 110° 35.62′	3950-3410	E	1 (10%)	D	?AMYGDALOIDAL BASALT	—	—
						2 (30%)	D	WEATHERED ?BASALT	—	—
						3 (5%)	D	VEINED PORPHYRY	—	—
						4 (55%)	D	?BASALT/ANDESITE	—	—
						5	P	OOZE Light brown (5yr6/4), calcareous, foram-rich.		Quater.
DR/035 (200kg)	H2	20° 10.87′ 109° 54.85′	20° 06.46′ 109° 55.01′	5025-4050	N	1 (40%)	D	?SILICEOUS MUDSTONES Dark grey (N2-N3), hard,slickensides in part, dynamically metamorphosed (sheared), quartz veins in part. 1A-Dk grey (N4), siliceous mudstone, hard to mod. hard.	—	—
						2 (40%)	D	FAULT BRECCIA/GOUGE Dark grey (N3.5) - mod. greenish yellow (10y7/4), friable, conglomeratic in part, poorly sorted clasts (?most Type 1 lithology) set in chlorite-rich clay matrix. Occasional slickensides. A few well-rounded igneous pebbles.	—	—
						3 (5%)	D	SANDSTONE Dusky yellow (5y6/4), very fine grained, well sorted, slightly micaceous, mod. hard.	—	—
						4 (15%)	D	IGNEOUS ROCKS - ?BASALTS/ANDESITES/ GABBRO	—	—
						5	P	MUD Yellowish grey (5y7/2), very soft, calcareous, contam. with Type 6.	Pleistocene	Quater.
						6	P	MUD/OOZE Moderate brown (5y4/4), very soft, calcareous, foram-rich.	Pleistocene	

AREA I - WALLABY PLATEAU

Core	Site	Lat. & Long.	Water Depth (m)	Recovery (m)		Shipboard Description	Basal Age (Foram)	(Nanno)
GC21	I2	23°46.63′ 108°30.04′	2100	1.95	C	MUD/OOZE Greyish orange (10yr7/4)-pale yellowish brown (10yr6.5/3), soft calcareous, foram-rich, bioturbated.	Pleist. (e-mN23)	
GC22	I2	23°46.82′ 108°30.22′	2106	2.04	C	MUD/OOZE very pale orange (10yr8/2) greyish pink (5yr8/1), bioturbated soft, calcareous, foram-rich.	Pleist. (1N22)	

Only cores with recovery listed. (CC20 no recovery, did not hit bottom)

TRANSIT

GC23	J1	27°15.259′ 109°45.786′	5600	0 (core catcher failed)				

Station	Site	Lat. & Long. (start)	Lat. & Long (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type	D or P	Shipboard Description	Age (Foram)	(Nanno)
DR/036 (30kg)	I1	24°21.81′ 107°49.70′	24°22.13′ 107°46.85′	3120-2850	W	1 (80%)	D	BASALTIC CONGLOMERATE Mod.yellowish brown (10yr5/4), poorly sorted, friable, most clasts mod. well rounded. Thick Mn crust.	—	—
						2 (10%)	D	MN CRUSTS	—	—
						3 (8%)	D	BASALT Mod.yellowish brown (10yr5/4) dark yell. brown (10yr4/2), highly weathered.	—	—
						4 (2%)	D	?AMYGDALOIDAL BASALT Moderate brown, highly weathered.	—	—
						5	P	OOZE greyish orange pink (5yr7/2), soft, calcareous, foram-rich.	Pleistocene	
						6	P	OOZE Greyish orange pink (5y7/2), soft, calcareous, foram-rich, more clay than Type 5.	Pleistocene	

AREA I (cont.)

Station	Site	Lat. & Long. (start)	Lat. & Long. (finish)	Water Depth Range(m)	Head'g dredge run	Rock Type	D or P	Shipboard Description	Age (Foram)	Age (Nanno)
DR/037 (0 kg)	I1	24° 22.60′ 107° 49.28′	24° 22.65′ 107° 48.23′	3200-3010	W	1	P	OOZE Greyish orange pink (5y7r/2), soft, calcareous, foram-rich.	Pleistocene	
						2	P	OOZE Greyish orange pink (5yr7/2), soft, calcareous, foram-rich.	Pleistocene	
DR/038 (5 kg) repeat DR/036	I1	24° 21.90′ 107° 49.64′	24° 21.56 107° 49.31	3120-2980	W	1 (60%)	D	BASALTIC CONGLOMERATE. Dark yellowish orange (10yr6/6) - light brown (5yr5/6) Bimodal clasts, clasts subround, mod. consolidated. Same as Type 1 in DR/36	—	
						2 (40%)	D	BASALT Dk.yell. orange - grey (10yr6/6-5yr3/42).Highly weathered.	—	
						3	P	OOZE Greyish orange pink (5yr7/2), foram-rich.	Pleistocene	

AREA F - ROWLEY TERRACE (OFFSHORE CANNING BASIN)

Core	Site	Lat. & Long.	Water Depth	Recovery (m)	Shipboard Description	Basal age (Foram)	Basal age (Nanno)
GC02	F2	17° 51.08′ 118° 32.77′	330	-	Calcrete + shell fragments (30 gms)		
GC03	F2	17° 51.08′ 118° 32.75	350	2.90	MUDDY SAND Pale olive (10y6/2) shell grit in upper 20 cm, carbonate rich.	Pleist.	(lN22)
GC05	F3	17° 50.88′ 118° 33.22′	360	0.93	MUDDY SAND Pale olive (10y6/2), carbonate-rich (forams, pteropods etc)	Pleist.	(N23)
GC10	F6	17° 51.47′ 118° 32.36′	380	0.69	MUDDY SAND. Pale olive (10y6/2), foram-rich, carbonate-rich	Pleist.	(N22)
GC11	F6	17° 51.37′ 118° 32.33′	370	0.66	MUDDY SAND, Pale olive (10y6/2), carbonate-rich (forams, pteropod frags etc)	Pleist.	(N23)
GC13	F7	17° 50.98′ 118° 32.33	360	0.46	MUDDY SAND Pale olive (10y6/2) carbonate-rich	Pleist.	(N23)
GC16	F9	17° 46.94′ 118° 25.72′	500	3.45	SANDY MUD Light olive grey (5y6/1), calcareous, common foram, pterpod & shell material.	Pleist.	(N22)
GC18	F10	17° 40.95′ 118° 14.96′	1000	2.60	MUD Yellowish grey (5y7/2) at top, pale olive (10y6/2) below. calcareous.	Pleist.	(N23)
GC19	F11	17° 28.15′ 117° 53.36	2000	3.45	MUD Pale yellowish brown (5yr5/6) - greenish grey (5GY6/1). Sandy in part. Carbonate-rich (mainly skeletal).	Pleist.	(eN22)

* Only cores with recovery listed. GC 1, 4, 6, 7, 8, 9, 12, 14, 15, 17 no recovery due to hard ground