Department of Primary Industries and Energy
BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

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RIG SEISMIC RESEARCH CRUISE 7&8: SEDIMENTARY BASIN FRAMEWORK OF THE NORTHERN AND WESTERN EXMOUTH PLATEAU

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CHAPTER 1
INTRODUCTION

The Exmouth Plateau is a marginal plateau lying off northwest Australia (Fig.1). Water depths range from 800 m to 4000 m, and the area shallower than 2000 m is approximately 150,000 square kilometres. The plateau consists of rifted and deeply subsided continental crust, with a Phanerozoic sedimentary sequence about 10 km thick. It is separated from the Northwest Shelf by the Kangaroo Syncline, and is bounded to the north, west, and south by oceanic crustla.

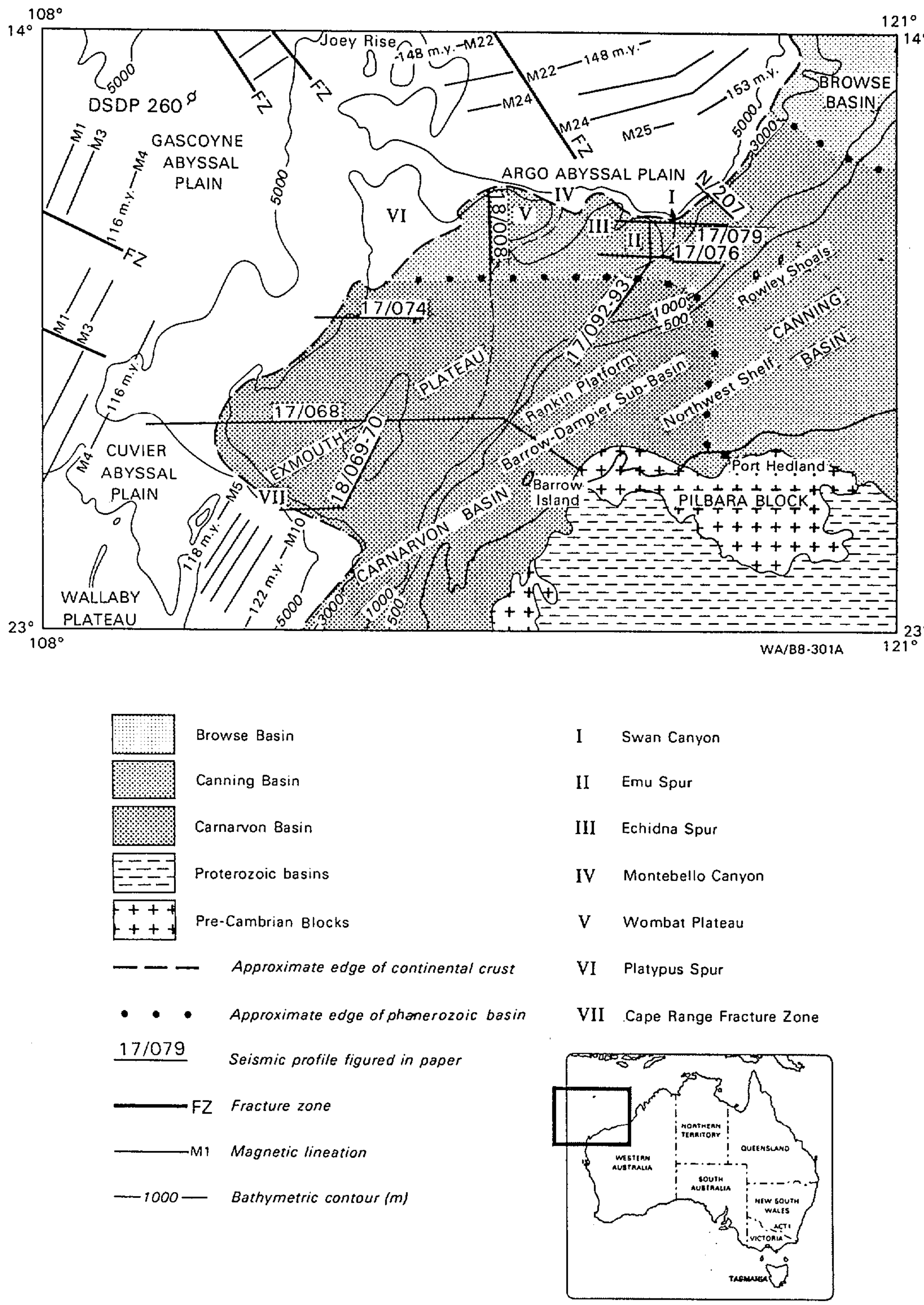
The plateau was first studied by BMR in the period 1974-1979, using 18,000 km of seismic profiles and some sample information, and results of the study were published, starting with Willcox & Exon (1976) and ending with von Rad & Exon (1983). The large fault blocks in the rifted Triassic and earliest Jurassic sequences, and the very large areal closures in the overlying Jurassic and Cretaceous sequences, encouraged petroleum exploration in the late 1970s and early 1980s. Some 30,000 km of high-quality multichannel seismic data were collected, and 14 exploration wells were drilled. The rifted section was shown to be largely gas-prone, and the overlying section to be largely immature. These results and the deep water over the plateau caused relinquishment of permits, except in the area surrounding the large Scarborough gas field discovered by Esso-BHP.

Because of the need to increase knowledge of this huge plateau, and to attempt to stimulate a second round of petroleum exploration over the plateau, BMR's Marine Division designed a three-phase research program for the plateau. The first phase was a short heatflow cruise, designed to ascertain present-day thermal gradients and hence maturation levels (Choi, Stagg et al., 1987). The second phase was a two-ship crustal structure study carried out with Lamont-Doherty Geological Observatory (Williamson, Falvey and others, 1988). The third phase was planned as a study of the northern and western margins of the plateau, using conventional geophysical and sampling methods.

This report deals with the third phase study; the work was carried out on the northern and western margins of the Plateau, and consisted of regional seismic profiling, site surveys for proposed Ocean Drilling Program holes, and dredging and coring, and one heatflow measurement to complete first phase data collection.

1.1 Crew of R.V. Rig Seismic

Master	D. Harvey
Chief Officer	R. Hardinge
2nd Officer	P. Moseley
Chief Engineer	C. de Souza
2nd Engineer	C. Shacks
Electrical Officer	W. Hansen
EA/AB	L. Clarke
Chief Steward-Cook	H. Dekker
Cook	G. LeMaire
Steward-Seaman	M. Cumner
2nd Steward-Seaman	S. O'Rourke



1. Regional and tectonic setting of the Exmouth Plateau (after Exon and others, 1981).

AB D. Kane
AB G. Pretsel
AB A. Scott

1.2 Acknowledgements

The enthusiasm, skill, and cooperation of the master and crew of the Rig Seismic are gratefully acknwoledged. They have made ma major contribution to the success of the cruise. The contribution of NATMAP personnel in providing the HIFIX radio navigation stations for this program is most gratefully acknowledged. Joan Brushett typed this report, and the BMR Drawing Office drew some critical figures.

CHAPTER 2
OBJECTIVES

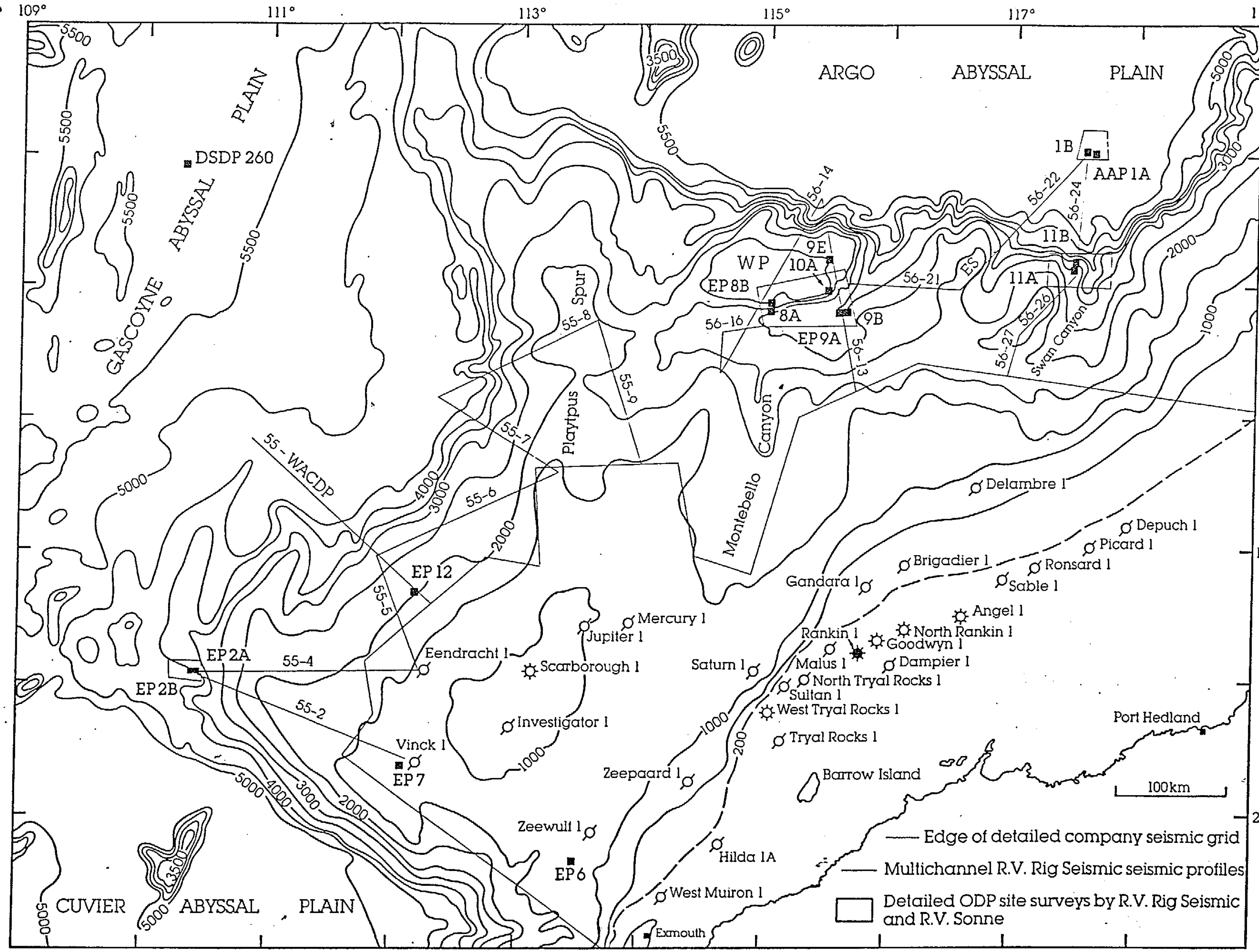
BMR's Exmouth Plateau program consists of three distinct research projects. The broad objectives of the program are: to define the history of basin subsidence; to define regional thermal history; to determine the structural and stratigraphic framework of the entire sedimentary basin, as well as the structure of the deep crust beneath the basin; to relate the evolution of the crust and basin to the formation of the surrounding oceanic crust of the abyssal plains; and finally to relate all these factors to the parameters governing petroleum potential. This report covers the results from the northern and western margin of the plateau obtained by underway geophysical methods and by geological sampling.

The northern margin of the plateau is clearly different from the central plateau and the other margins of Exmouth Plateau. It is separated from the central plateau by an east-west trending hinge line, which forms the southern slope of a half-graben. A series of highs north of the half-graben contain thick Jur ssic carbonate and coal measure sequences, not found on the central plateau. Breakup on this margin was in the Late Jurassic, about 20 m.y. earlier than elsewhere along the plateau's margins.

The objectives of the northern margin work were: to augment the northern seismic data base with high-quality seismic data for framework petroleum resource evaluation and to tie the central plateau to the Argo Abyssal Plain; to dredge and core steep slopes to obtain rock and sediment samples; to carry out site surveys of five small areas for geological dredging and proposed ODP drilling, which would provide invaluable additional information on the history of this unique starved passive continental margin.

The new data will be integrated with existing data to allow the development of a better geological understanding of the northern margin and its relationship to the central Plateau and the abyssal plain. The results would include an assessment of the petroleum potential of the northern margin and adjacent areas.

In addition, 1150 km of multichannel seismic data, recorded on the western plateau margin on the previous cruise, allows a comparison of the structural style of the northern and western plateau margins; and combined with existing industry data will enable a reevaluation of the petroleum exploration potential of the plateau:



2. Bathymetric map of Exmouth Plateau with key BMR seismic lines, area of detailed company seismic grid and proposed ODP sites.

CHAPTER 3
CRUISE PLAN

Scientific data collection planned for this phase of the Exmouth Plateau study consisted of two parts: firstly, 2750 km of multichannel seismic data and secondly, 7 days of geological sampling on the the northern plateau margin. Flexibility in adjusting Leg 1 and Leg 2 programme allowed the data collecting objectives of this phase to be achieved in spite of delays in the arrival of R.V. Conrad from 2 ship seismic work (Williamson, Falvey and others, 1988).

The seismic data collection phase included five long north-south regional seismic lines joining the central plateau's multichannel seismic grid to the Argo Abyssal Plain, and one cross-tie, and six long east-west regional seismic lines across the western margin. These add substantially to the regional data set. In addition six site surveys for proposed ODP holes and dredge locations were run near the regional lines. These were to be on the western plateau, the southern Wombat Plateau, in the Montebello Canyon nearby, on a ridge near Emu Spur, and on the Argo Abyssal Plain.

The remaining cruise time was allocated to dredging and coring at 20 stations in several areas on the northern margin. Much of this work would be aimed at sampling seismic sequences, thus providing constraints for the interpretation of the whole northern margin.

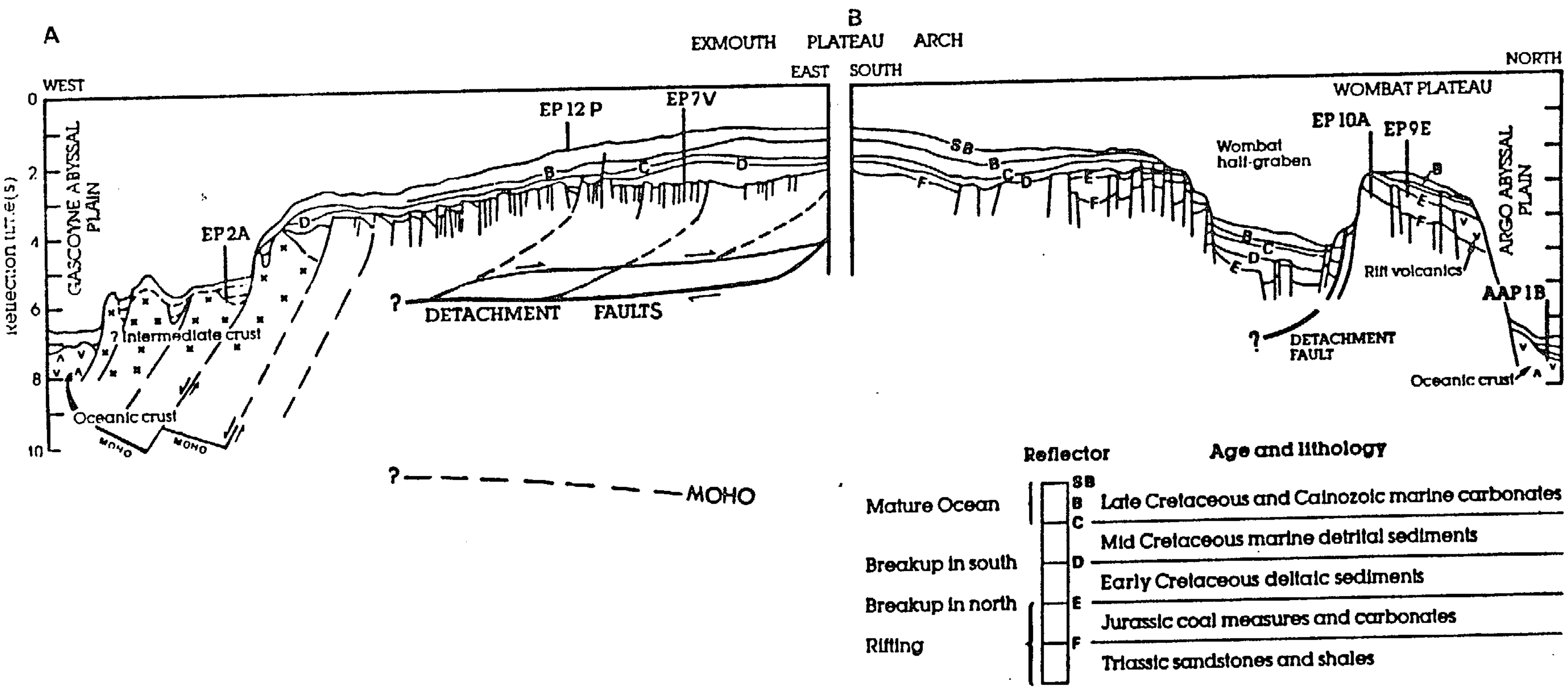
CHAPTER 4
BACKGROUND

The regional geological setting of the Exmouth Plateau is shown in Fig. 1 and its physiography in Fig. 2. The plateau is a continental block bounded on the north, west and south by oceanic crust forming the Argo, Gascoyne and Cuvier Abyssal Plains. The Canning and Carnarvon Basin sediments extend over the plateau from the east and abut the Pilbara Precambrian block. Pre-breakup, rift phase deposition has been identified on the plateau and beneath the shelf to the east (Fig. 1). The stratigraphic sequences in the region, shown in profile in Figures 3 & 4, consist of Tertiary limestones overlying Cretaceous to Permian clastics and Precambrian basement.

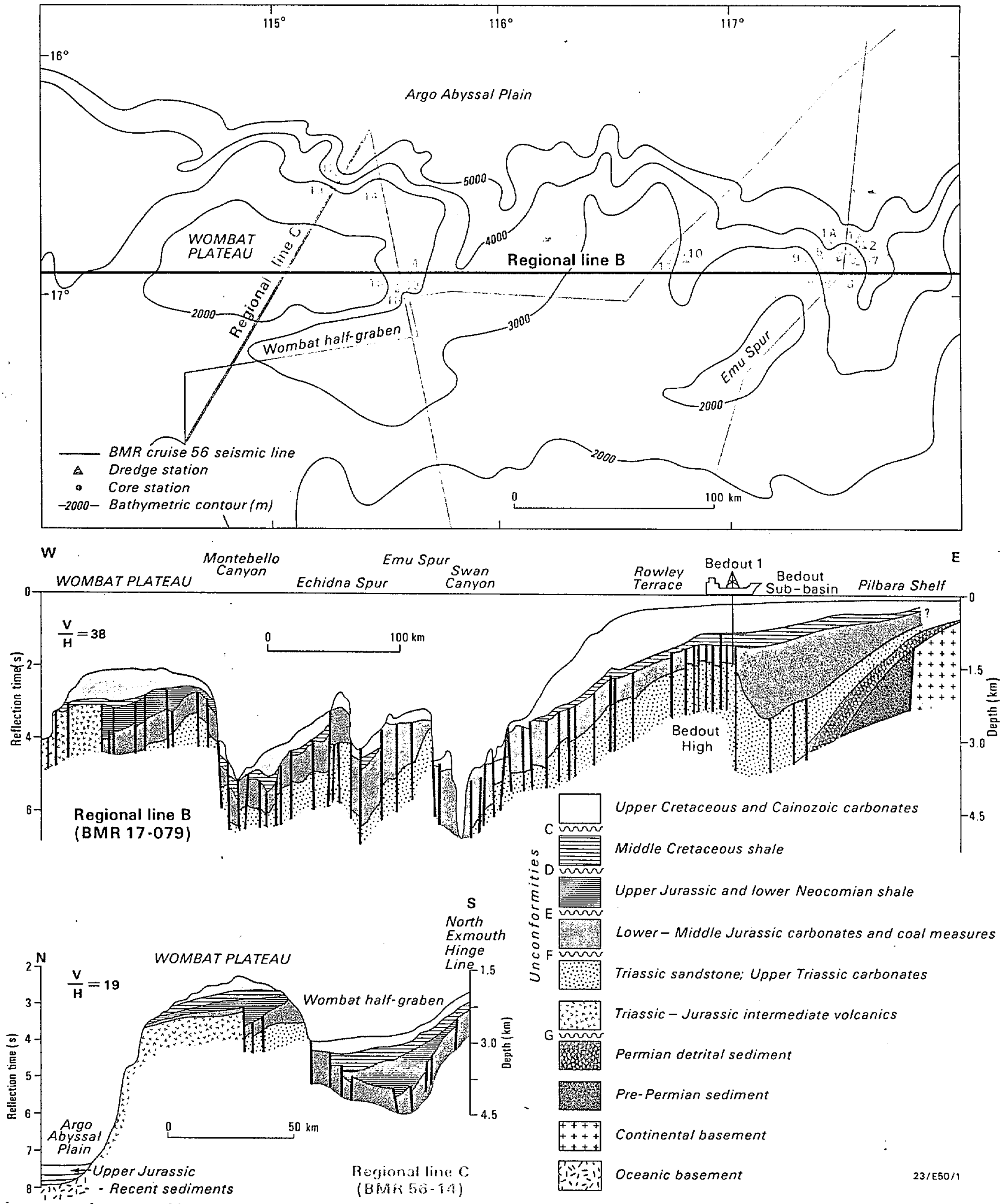
4.1 TECTONIC FRAMEWORK

The geological development of the Exmouth Plateau has been discussed by Falvey (1972b), Falvey and Veevers (1974), Veevers and Johnstone (1974), Exon and others (1975), Veevers and Cotterill (1976), Powell (1976), Willcox and Exon (1976), Exon and Willcox (1978, 1980), Wright and Wheatley (1979), Larson and others (1979), von Stackelberg and others (1980), Falvey and Mutter (1981), Willcox (1981), and von Rad and Exon (1983). The three margins abutting oceanic crust were compared and contrasted by Exon and others (1982).

The present structural configuration of the Exmouth Plateau region was initiated by rifting in Triassic to Middle Jurassic times



3. Schematic east-west and north-south cross-sections of Exmouth Plateau.



4. Schematic line drawings from seismic profiles and lithologies, northern Exmouth Plateau (after von Rad & Exon, 1988).

prior to seafloor spreading. The western margin has a normal rifted structure and the southern margin has a transform dominated structure. The complex northern rifted margin contains at least one crustal block of post breakup igneous origin.

The northern margin of the plateau (Figs. 1 & 2) formed in the Callovian (150m.y. ago), when seafloor spreading commenced in the Argo Abyssal Plain (anomaly M-25 time). The northeast-trending seafloor spreading anomaly pattern was initially described by Falvey (1972a), basin age was established by DSDP drilling (Veevers, Heirtzler and others, 1974), and magnetic lineations were mapped by Larson (1975), Heirtzler and others (1978), and Veevers and others (1986a). Throughout the Jurassic, pre-breakup rift tectonics affected the entire western margin (Falvey and Mutter, 1981). The initiation of rifting may be related to Triassic-Jurassic intermediate and acid volcanics (213-192 m.y. old) on the northern margin, which probably overlie a thick Triassic paralic sequence (von Stackelberg and others, 1980). Steady subsidence along the incipient northern margin, north of an east-west hinge line, allowed several thousand metres of Lower and Middle Jurassic carbonates and coal measures to accumulate before breakup (Exon and others, 1982). Breakup occurred along a series of rifted and sheared margin segments, the tectonic setting being further complicated by northeast trending Callovian horsts and grabens. The horsts were planed off in Late Jurassic and Early Cretaceous times, and the whole northern margin was covered by a few hundred metres of Upper Cretaceous and Cainozoic pelagic carbonates as it subsided steadily to its present average depth of 2000-5000 m.

The northeast-trending western margin of the Plateau (Figs. 1 & 2) formed by breakup in the Neocomian approximately 110m.y. ago as "Greater India" moved off to the northwest, and seafloor spreading anomalies started to form in the Gascoyne Abyssal Plain (Exon and others, 1982). Portions of the northeast trending seafloor spreading magnetic anomaly pattern of this and the Cuvier Abyssal Plain were initially described by Markl (1974) and Larson (1977), and have been integrated recently by Larson and others (1979), and Veevers and others (1985b). On the western margin of the Exmouth Plateau, normal faults parallel the margin. A thick Triassic paralic sequence is unconformably overlain by a thin, Upper Jurassic marine sequence indicating that the area was high in the Early and Middle Jurassic. Thin Upper Cretaceous and Cainozoic pelagic carbonates cover the western margin, which now lies more than 2000 m below sealevel.

The northwest trending southern margin of the Plateau (Figs. 1 & 2) formed along an incipient transform in the Neocomian, about the same time as the western margin (Exon and others, 1982). It is cut by northeast trending normal faults, which formed in the Late Triassic and Callovian, and is paralleled by Neocomian and later normal faults. A thick Triassic paralic sequence is unconformably overlain by a thick Upper Jurassic and Neocomian delta. This suggests that the area was high in the Early and Middle Jurassic, but a depocentre before and afterwards. There was thermal uplift of more than 1000 m during the Neocomian. Igneous intrusions buttress the margin. Later normal faulting lowered the outermost margin, and turned the uplift into a marginal anticline trending northwest. The anticline had sunk beneath the sea by late in the Cretaceous, and thereafter this margin was covered by a thin sequence of pelagic carbonates, which now lie at a water depth of 1500 m.

Von Stackelberg and others (1980) have reported the results of 30 dredge hauls from the outer slopes of the Exmouth Plateau, mostly from the northern margin. More than half contained Jurassic and Triassic prebreakup shallow water sediments. Four dredges from the north also contained intermediate to acid volcanics dated at about the time of rift onset. This suggests limited continental crustal anatexis very near to the incipient continent-ocean boundary. These data also indicate that it is not valid to interpret the occurrence of volcanics on a marginal plateau slope as definitive evidence of non-continental crustal structure, either in whole or in part (Falvey and Mutter, 1981).

4.2 STRATIGRAPHY

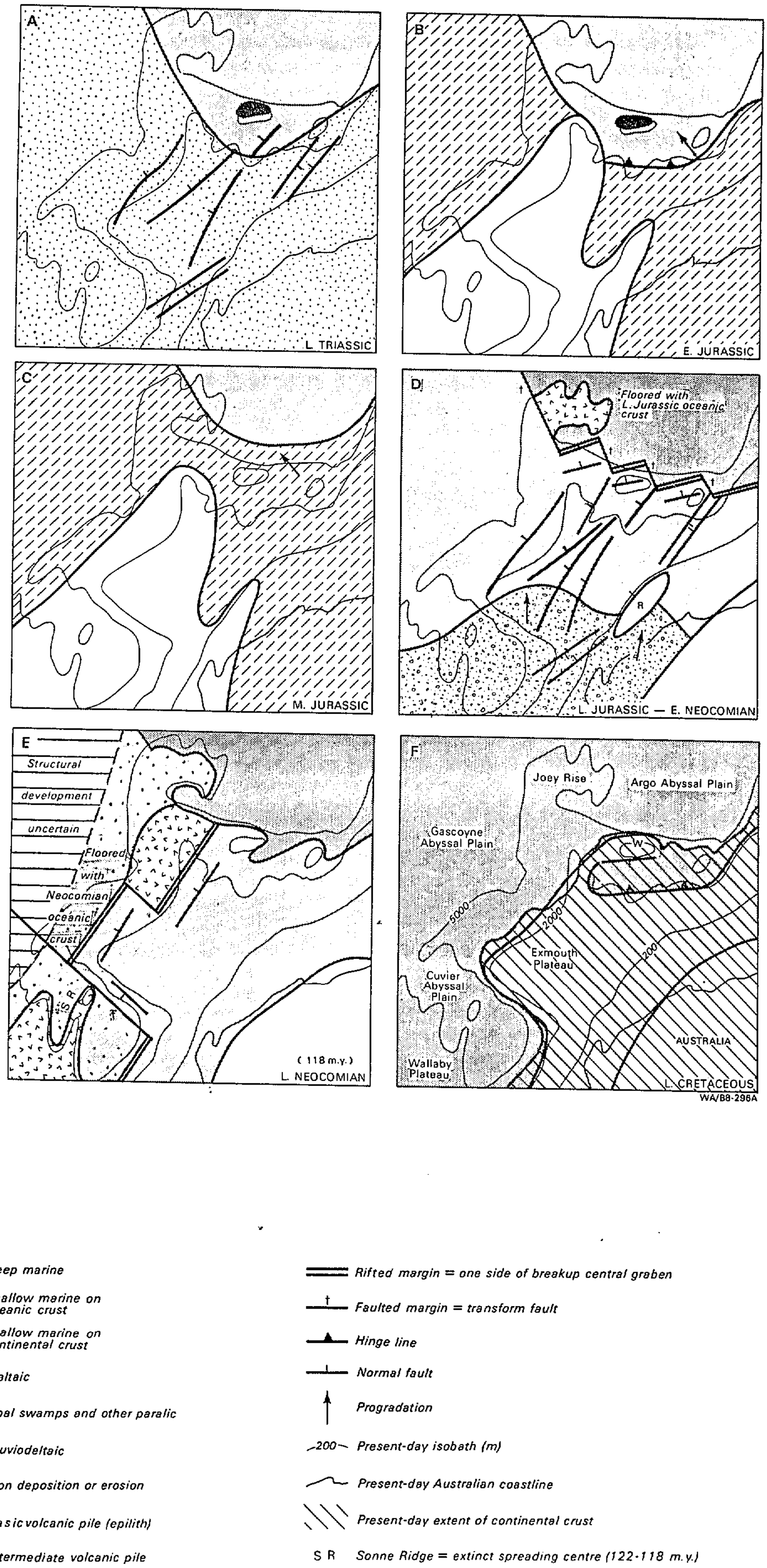
The paleogeographic evolution of the Exmouth Plateau is sketched in Fig. 5 and the stratigraphy is outlined in Figs. 6 and 7. Sediment starvation has led to a greatly reduced post breakup sequence on the continental margin. Thus, seismic profiling and drilling have been able to penetrate well into the pre-breakup sequence and resolve early stages of margin evolution (von Rad and Exon, 1983). Fourteen petroleum wells have been drilled and results from Phillips Jupiter No. 1, Saturn No. 1 and Mercury No. 1 have been published (Barber, 1982). Stratigraphic studies have been carried out by von Stackelberg and others (1980), Colwell and von Stackelberg (1981), and von Rad and Exon (1983), and palaeontological studies by Quilty (1980,1981) and Zobel (1984). Seismic control consists of 12,000 km of data from the 1972 BMR continental margin survey, 9300 kms of GSI seismic data collected in 1976 and 1977 (Wright and Wheatley, 1979) and 30,000 kms of subsequent petroleum industry seismic data.

Interpretation of seismic profiles indicates that up to 5000 m of Paleozoic strata and 5000 m of younger strata overlie basement. The sediments have been gently folded, and the pre-breakup section is affected by northeast trending faults.

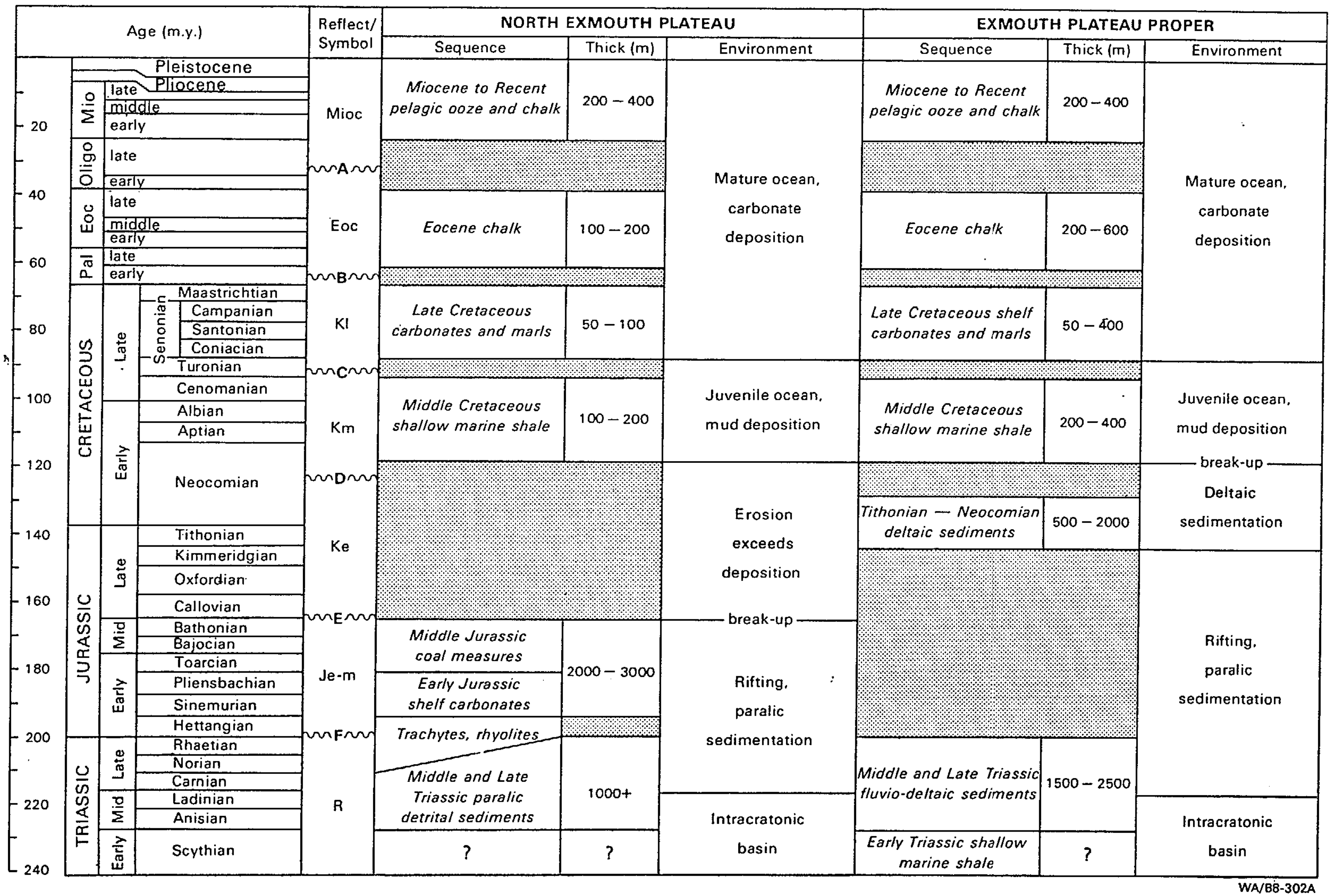
The sediments beneath Exmouth Plateau are considered to have been deposited in an extension of the Carnarvon Basin. This formed a north-facing Tethyan embayment in Gondwanaland and received detrital sediments from the south until early Cretaceous time. In the central Plateau region, at least 3000 m of mainly paralic and shallow marine detrital sediments were deposited from Permian to Middle Jurassic times. After the Late Triassic rifting, about 1000 m of shallow marine and deltaic detrital sediments, derived from the south and east, covered the block-faulted surface in Late Jurassic and Early Cretaceous times. About 200 m of terrigenous marine sediment was deposited in the Middle Cretaceous, and 500 to 1000 m of carbonate sediment in the Late Cretaceous and Cainozoic. The Exmouth Plateau Arch and Kangaroo Syncline probably warped to their present form in the Miocene (Exon and Willcox, 1978, 1980), by which time the central Plateau had subsided to bathyal depths (Barber, 1982). On the northern margin there are Early Jurassic shelf carbonates and Middle Jurassic coal measure sequences, perhaps 2000-3000 m thick in total (von Stackelberg and others, 1981).

4.3 PETROLEUM EXPLORATION

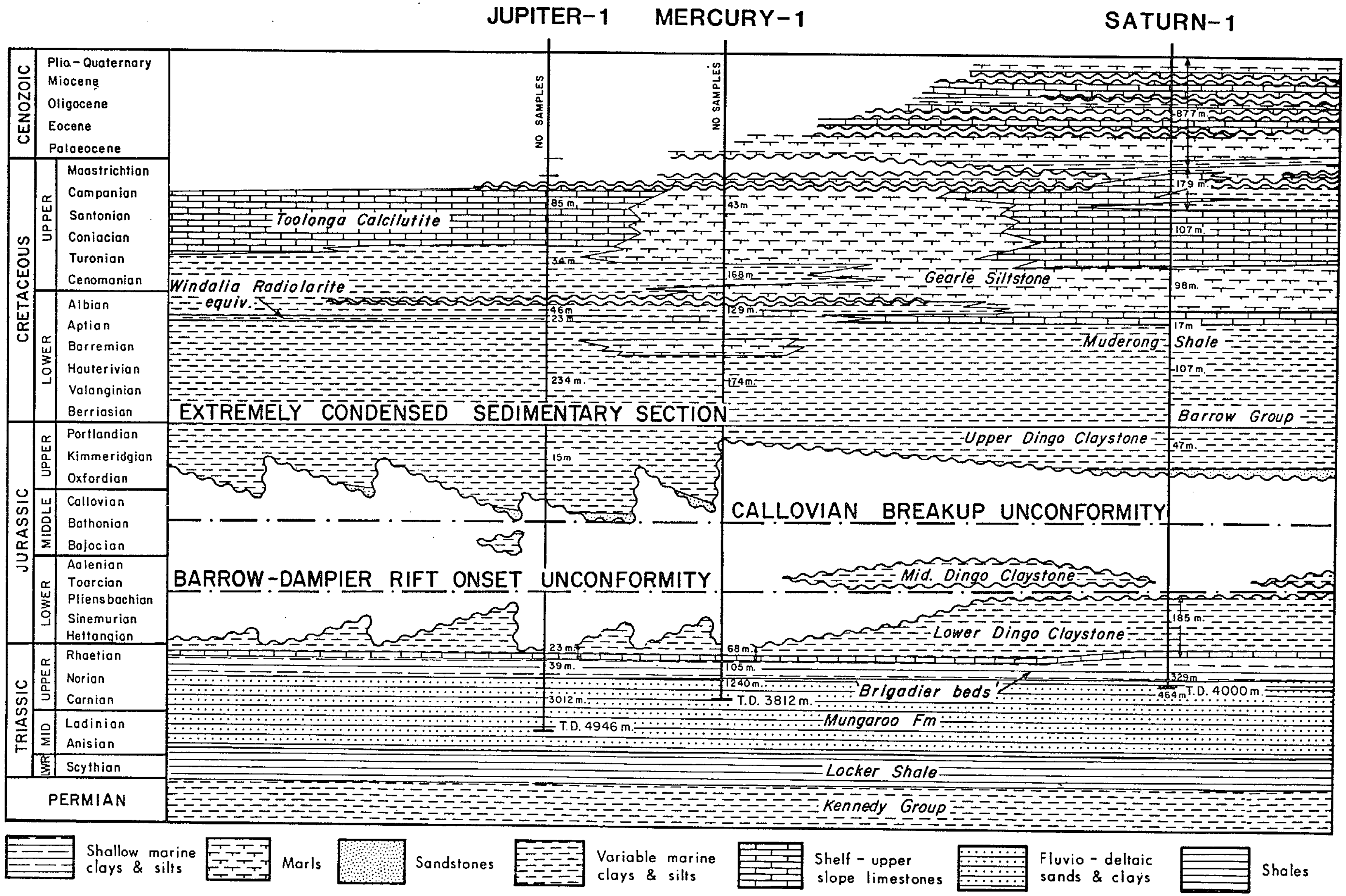
In the mid 1970's the Exmouth Plateau was regarded as having



5. Paleogeography of the Exmouth Plateau region (after Exon and others, 1981).



6. Simplified stratigraphy of the Exmouth Plateau (after Exon and others, 1981).



7. Lithostratigraphic correlation chart of the Exmouth Plateau (after Barber, 1982).

considerable petroleum potential. Reconnaissance surveys shot in the 1970's revealed the presence of large fault-bounded structures (Willcox and Exon, 1976; (Exon and Willcox, 1978; Wright and Wheatley, 1979) and the close proximity of major hydrocarbon accumulations on the Northwest Shelf and at Barrow Island in the Carnarvon Basin encouraged optimism. Five exploration permits divided up the Plateau in 1977 and 14 exploration wells were drilled in the central and southern areas (Fig. 2). These included three wells by the Phillips Group (British Petroleum, Gulf, Mount Isa Mines, Mobil and Phillips) in Permit WA-84-P on the central Exmouth Plateau (Barber, 1982). Several non-commercial gas shows were encountered as well as the Scarborough gas discovery that has been retained by Esso-BHP.

Early exploration concepts involved generation of oil from Upper Jurassic and Neocomian shales in the Kangaroo Syncline and subsequent migration into the Jurassic and Triassic tilted fault blocks on the Exmouth Plateau Arch. The lack of liquid hydrocarbons was attributed to unfavourable source rocks, unsuitable burial history and a low paleo-thermal gradient. For three wells (Phillips Saturn No. 1 , Jupiter No. 1 and Mercury No. 1) Upper Triasssic, Jurassic and Cretaceous sections were found to be imm ture and incapable of generating hydrocarbons. Most hydrocarbons so far encountered on the Exmouth Plateau are thought to have originated from deep (5 km or more) overmature gas source rocks, probably Lower Triassic and Permian shales, by deep tapping of source beds along faults bounding the tilted block structures, enabling the gas to migrate upwards (Barber, 1982).

The lack of success in finding oil in the major Exmouth Plateau structures has resulted in the dropping of all except part of one permit and the cessation of petroleum exploration on the plateau. Future petroleum exploration interest would appear to depend on demonstrating a marine oil-prone source at mature depths, either in Jurassic graben-fill sediments in the Kangaroo Syncline or local grabens, or in Triassic and Permian pre-rift sediments on the western or northern margins of the Plateau, along with suitably located trapping structures.

4.4 EVOLUTION OF THE EXMOUTH PLATEAU CONTINENTAL MARGINS

A great number of evolutionary schemes for passive continental margins have been proposed, both qualitative and semi-quantitative (e.g.Wegener, 1929; Du Toit, 1937; Heezen, 1960; Dewey and Bird, 1970; Bott, 1971; Falvey, 1974; Montadert and others, 1979; Watts and Steckler, 1979).

The mechanism of continental margin formation has been described in terms of models which usually relate cycles of uplift and subsidence to the thermal evolution of continental and oceanic lithosphere (Dewey and Bird, 1970; Sleep, 1971; Falvey, 1974). However, such tectonic models differ markedly, and appear strongly dependent on the type of continental margin chosen by a particular author for analysis. The emergence of a general continental margin model has been hindered by geological and structural complexity, and also by limited depth of penetration and resolution of relevant marine geophysical methods.

Advantages of the Exmouth Plateau as a study area for continental margin problems include:

1. The existence of three margin types around the plateau: a sheared or transform margin on the south, a rifted and thinned margin on the west, and a mixed rifted and sheared margin on the north.

2. The sediment-starved nature of the plateau after breakup, which enables detailed investigation of the pre-breakup sequences by seismic reflection techniques, drilling, dredging and coring.

3. Extensive oil search over the shallower parts of the plateau, coupled with government policy on public release of information, which provides a very large set of geophysical and well data.

CHAPTER 5
GEOPHYSICAL RESULTS

5.1 MULTICHANNEL REFLECTION SEISMIC PROFILES

5.1.1 Northern Margin

Previous extensive geophysical and geological studies of the northern margin established a regional framework, which this cruise was designed to augment, modify and improve. These previous studies were carried out largely by BMR and BGR (Exon and Willcox,1978; von Stackelberg and others,1980; Exon and others,1982; von Rad and Exon, 1983). They showed that:

(1) The margin is depressed overall compared to the central Exmouth Plateau.

(2) There are two directions of faulting, northeast trending and westerly trending. The former is believed to be Triassic to Late Jurassic in age, and the latter of Late Jurassic to Early Cretaceous age. The older faulting could be related to the Callovian breakup of the northern margin, and the younger faulting was probably related to the Neocomian breakup of the western and southern margins.

(3) The northeast trending faulting has cut the margin into a series of high blocks separated from each other by half-grabens dipping northwest. Displacement on the faults bounding the half-grabens on the northwest is of the order of 2000 m, and the half-graben width exceeds 100 km. The tops of the high blocks (Platypus Spur, Emu Spur, Wombat Plateau, Echidna Spur, Emu Spur) lie at 1500-2500 m, and the base of the intervening half-grabens lie at 3000-4000 m.

(4) The westerly trending faulting occurs along and north of a hinge line which underlies the 2000 m isobath along the northern edge of the central Exmouth Plateau. The hinge line extends westward from the south of Swan Canyon to the south of the Platypus Spur, a distance of 550 km. Seismic profiles show

that all the sequences above the F (top Triassic) reflector thin greatly across the hinge line. We here name this feature the "North Exmouth Hinge Line".

(5) North of the North Exmouth Hinge Line is a half graben which is best developed south of the Wombat Plateau and Platypus Spur. This half-graben is 100-200 km wide (Exon and others, 1982, Figs. 2 & 4) and has a displacement of up to 2000 m on the bounding faults to the north. This feature we here name the "Wombat Half-Graben".

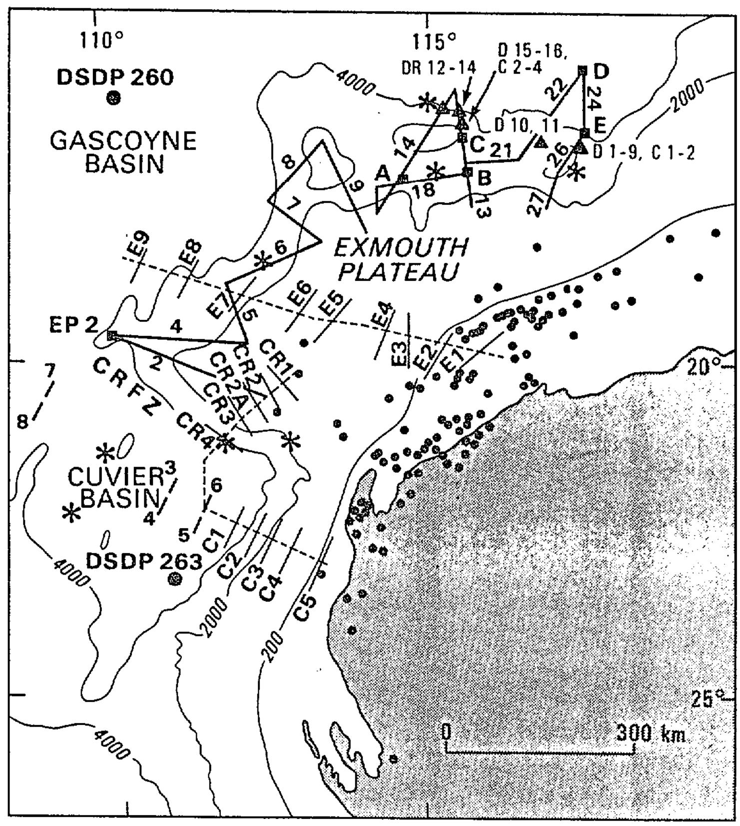
(6) The sequences of half-grabens and the high blocks appear to be quite similiar, at least until the Late Cretaceous. The contained sequences have similarities to and differences from the central Exmouth Plateau sequences (Fig. 6, and Chapter 6).

(7) On the high blocks there is a very marked almost flat Oligocene unconformity, which is underlain by rocks as old as Early Jurassic and incorporates the regional B,C and D unconformities (Fig. 6). Sampling of the scarps bounding the high blocks has yielded rocks as old as Triassic and helped date the regional unconformities.

(8) The northern margin of the plateau drops abruptly 3500 m to the Argo Abyssal Plain, which is underlain by Late Jurassic oceanic crust (Veevers, Heirtzler and others, 1974). There is a magnetic quiet zone on the southernmost Argo Abyssal Plain which Veevers and others (1985) believe lies north of the Continental/Ocean boundary. The crust has a similar appearance, on seismic reflection profiles, in the quiet zone and beneath the area of the magnetic anomalies further north.

(9) The northern margin of the plateau is buttressed by volcanic sequences of Triassic to lowermost Jurassic age which are clearly visible on the seismic profiles.

"Rig Seismic" multichannel reflection profiles undertaken were designed to investigate the structure and stratigraphic thickness of the northern Exmouth Plateau margin. They also provide the first high quality regional tie lines for this area, in all about 950 km long. Profiles were collected in the areas of the Wombat Plateau, Echidna Spur, Emu Spur, Platypus Canyon, Montebello Canyon and onto the Argo Abyssal Plain (see Figs. 8 & 9). The seismic reflection results from this survey support the current beliefs on the geological history of the region. The Late Jurassic unconformity (E) is generally only two seconds (TWT) below the seafloor reflection. Below this unconformity dipping Jurassic and Triassic sediments are interpreted. In areas of high relief and slope, such as are found at plateau or spur terminations, the Jurassic outcrops or is covered by a very thin sedimentary pile. The major structural style is normal faulting in either horst-graben or half-grabens. There are numerous Jurassic and Cretaceous basinal sequences between the faulted blocks. The northernmost margin is heavily faulted with volcanic activity evident. The transition from oceanic crust through the magnetic quiet zone of the Argo Abyssal Plain to continental crust of the Exmouth Plateau is obscured by this volcanic activity. Given below is a preliminary interpretation of the regional lines over the northern margin, using the single channel monitor records. Survey lines are not sequential



23/OWA/60

Data generated in 1986

——— *BMR multichannel seismic*

——— *ESP location*

------- *WACDP*

■ *Site survey (ODP and/or geology)*

▲ *Dredge/core site*

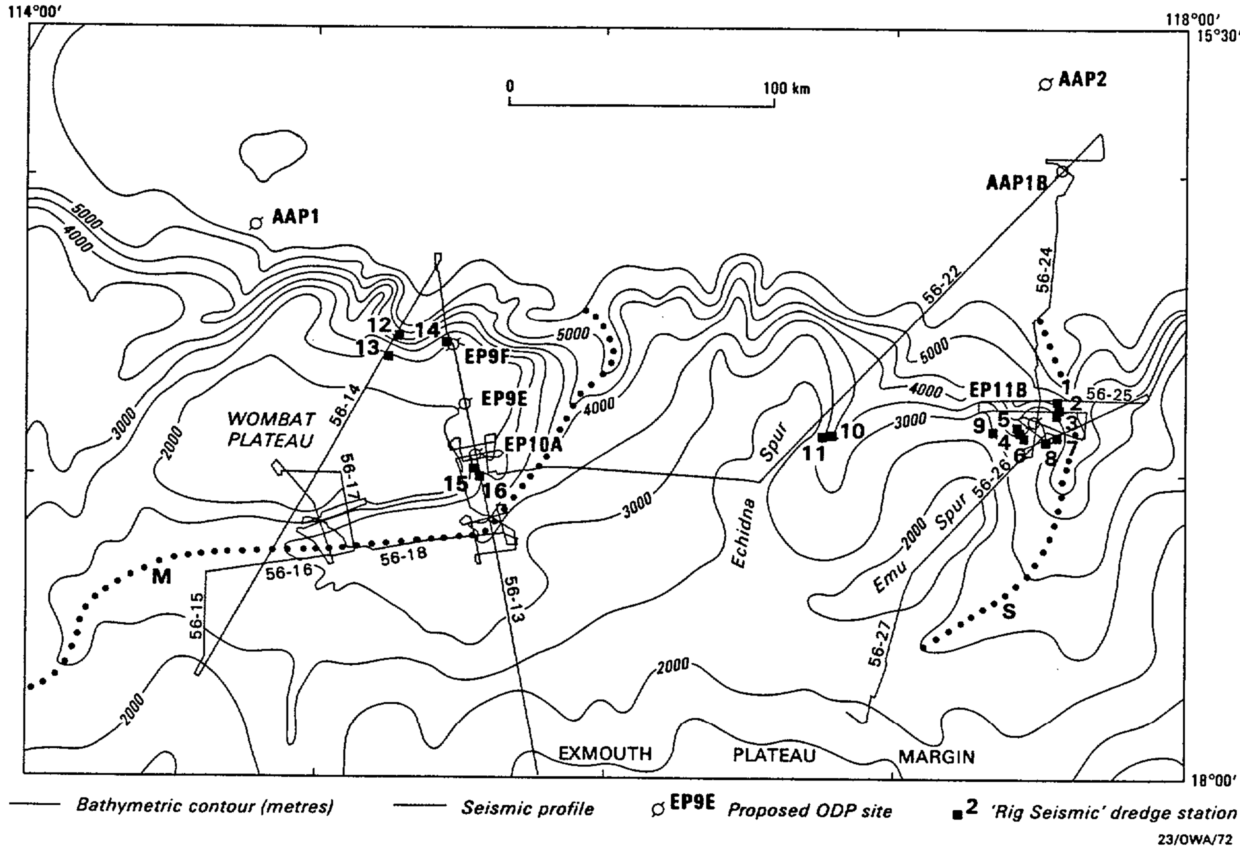
Previous data

— — *Refraction profiles from Larson & others (1979)*

• *Exploration well*

✱ *Dredge location*

8. Location map: BMR Cruises 55 and 56 (CRFZ = Cape Range Fracture Zone; bathymetry in metres).



9. Cruise BMR 56: Bathymetry, RIG SEISMIC seismic lines and sample locations on northern Exmouth Plateau.

as the profiling was interrupted by ODP and geological site surveys.

5.1.2 Emu Spur Area

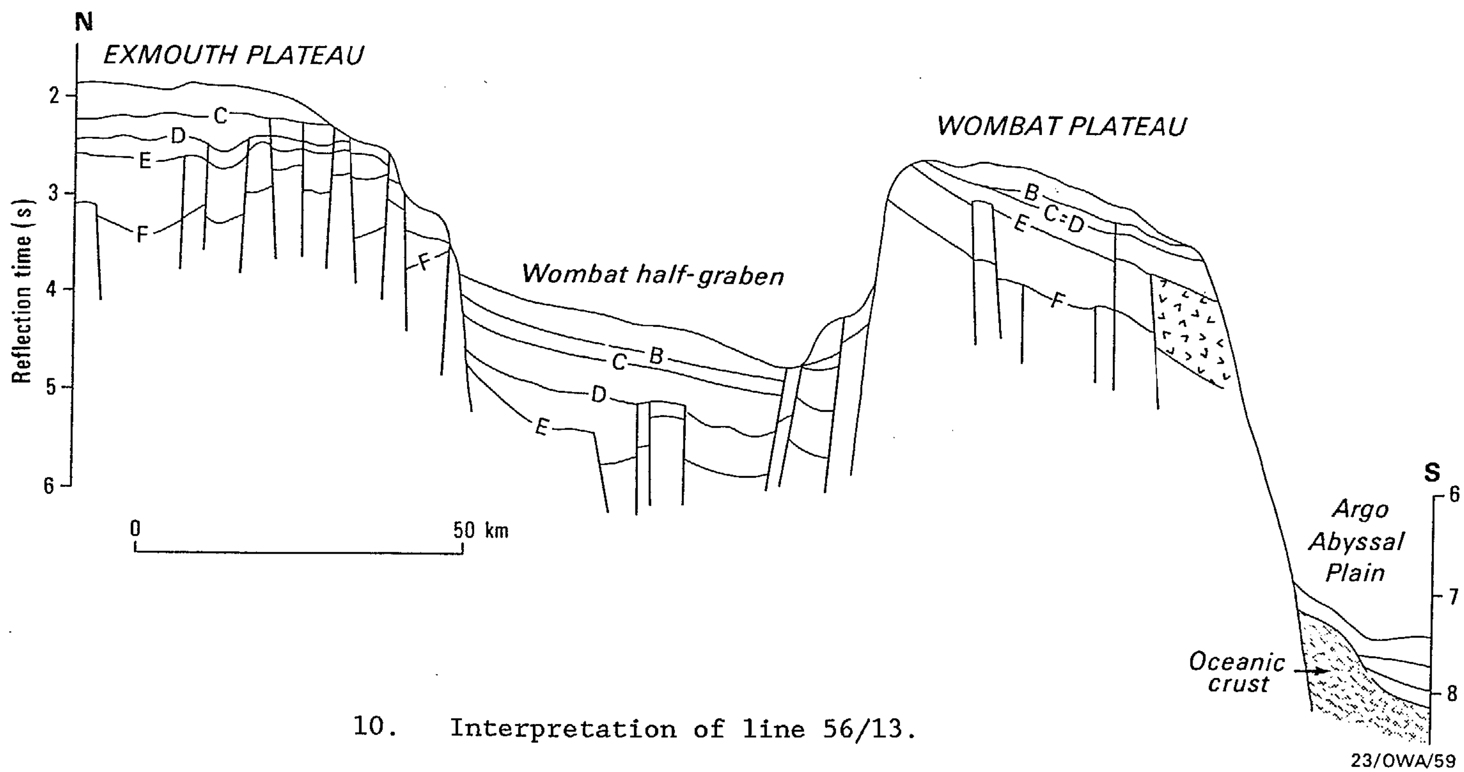
Three lines, 56/024, 025 & 026, are the most easterly 'Rig Seismic' lines (Fig. 9). Together the lines traverse from the Argo Abyssal Plain in the north to the 2000 m isobath on the North Exmouth Hinge Line. There is an intermediate terrace (Cygnet Spur, new name) on the rise from the abyssal plain to the Emu Spur. Cygnet Spur contains a thin pond of Cretaceous/Tertiary sediments. Emu Spur has the same characteristics as Echidna Spur, except for a slightly thicker Tertiary sedimentary column. Down faulting to form half-grabens separates Emu Spur from Cygnet Spur by a cumulative down-throw of 1500 m. From Cygnet Spur there are similar half-grabens leading down to the abyssal plain, 2000 m below. The Wombat Half-Graben is a depression of thick Jurassic to Tertiary sedimentation.

5.1.3 Wombat Plateau/Montebello Trough Region

Lines 56/013 and 56/014 (Figs 10 & 11, respectively) are regional south-north lines from the North Exmouth Hinge Line across the Wombat Plateau to the Argo Abyssal Plain. The profiles show the Wombat Plateau to be a planated block of Triassic to Cretaceous sediments with only a thin cover of Tertiary sediments. The presence of numerous diffractions on the northern margin suggests the occurrence of large volcanic bodies. This was later confirmed by geological sampling. The F (top Triassic) unconformity is the oldest reflector identified on the monitor records. It appears at depth only in regions of high topographic relief, such as the North Exmouth Hinge Line or the Wombat Plateau. The E (Callovian) unconformity is characterised by reflections atop tilted and eroded fault blocks. Some of these faults extend up to the D (Neocomian) unconformity. The Late Cretaceous/Oligocene (C+B) unconformity marks the top of the horst blocks. Sedimentation rates in the region declined as pelagic sedimentation became dominant in the Late Cretaceous.

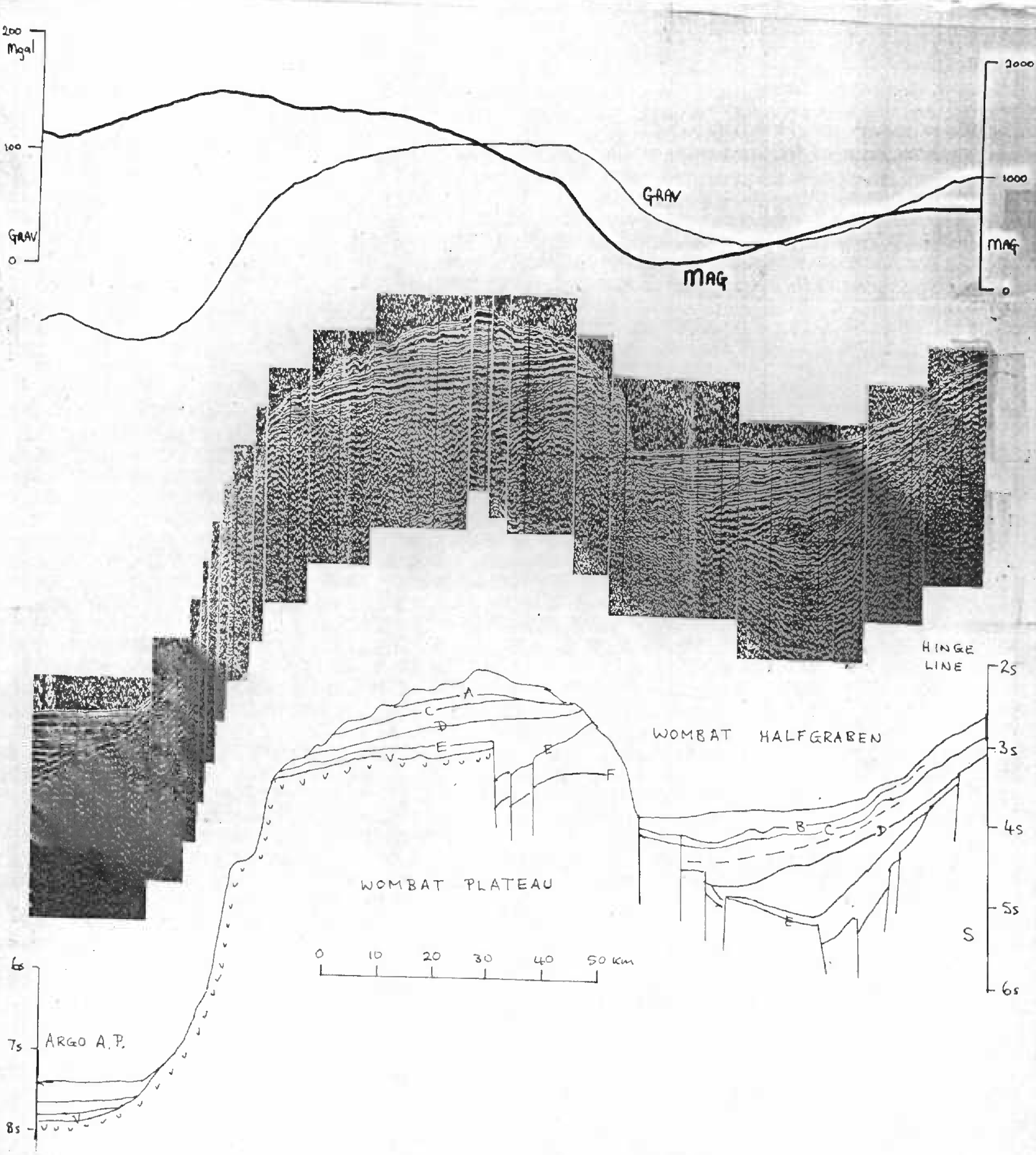
5.1.4 Platypus Canyon Region

Line 56/015 is a short line across Platypus Canyon (Fig. 8). Deep seated Jurassic blocks are interpreted from the reflection monitor. Line 56/016 along the Wombat Half-Graben shows a complex structure of small horsts and grabens, with an unusual structural 'high' or ridge which may be volcanic. To either side is a thickening sequence of Jurassic and Cretaceous sediments. Line 56/018 continues parallel to the axis of the Wombat Half-Graben. It shows a relatively thick, up to two seconds (TWT), sequence of Jurassic to Tertiary sediments, which pinch out to the east as the basement rises. Line 56/021 crosses the Montebello Canyon from the flanks of the Wombat Plateau to Echidna Spur. Large half-graben blocks occur at either end of the line with a subsequently more complex pattern of horsts and grabens in the centre. The monitors indicate the presence of two sub-basins on the western flank of Emu Spur, separated by a large horst block. Line 56/022 extends from Echidna Spur to the Argo Abyssal Plain to the northeast (Fig. 8). Echidna Spur shows the same structural style as Wombat Plateau, although it has a thicker Tertiary sedimentary sequence. Down faulting by 2500 m terminates the Echidna Spur against the Argo Abyssal Plain. There appears to be a very thin



10. Interpretation of line 56/13.

Line drawing, from RV *Rig Seismic* monitors, of the post-Late Jurassic sequences in the Exmouth Plateau, Wombat half-graben, and Wombat Plateau along line 13. Horizon B is Early Paleocene, C is early Late Cretaceous, D is the Neocomian unconformity, E is Late Jurassic, and F is the top of the Triassic; the chaotic-'V' symbol represents Upper Triassic–Lower Jurassic rift-phase (intermediate–basic) volcanics.



11. Seismic monitor and interpretation of line 56/14.

Tertiary sequence at the base of the spur, which has been ponded by a basement high. Further from the base and beyond this high, there is a thickening wedge of Late Jurassic to Tertiary sediments. The presence of numerous diffractions on the 'basement' below the Argo Abyssal Plain, could indicate oceanic crust. Sonobuoy information indicates that the crust beneath this area (possibly magnetic quiet zone) could be anomalously thick for oceanic crust. This suggests that the initial spreading in the Late Jurassic may have been slow, allowing a thick volcanic sequence to build up.

5.1.5 Platypus Spur Region

The Platypus Spur is an extension of the northwestern Plateau. It is separated by a bathymetric low and has an area of 4000 sq km at the 2000 m isobath. Lines 55/08 and 55/09 (Fig. 8) crossed this feature and investigated the nature of the Platypus Spur and the possible presence of substantial particularly Jurassic source rocks in the graben feature separating the Exmouth Plateau from the Spur.

Line 55/09 is presented to show the characteristics of the northwestern Plateau, the Spur and the intervening graben (Fig. 12). A thickening of graben fill sediments in the reentrant between the Spur and the Plateau was observed but the maximum depth of Jurassic sediments is 2.0 km which, at least on line 55/09, would not allow these sediments to be thermally mature for hydrocarbon generation even given the relatively high heatflow over the plateau (approx. 80 mW/sq.m.).

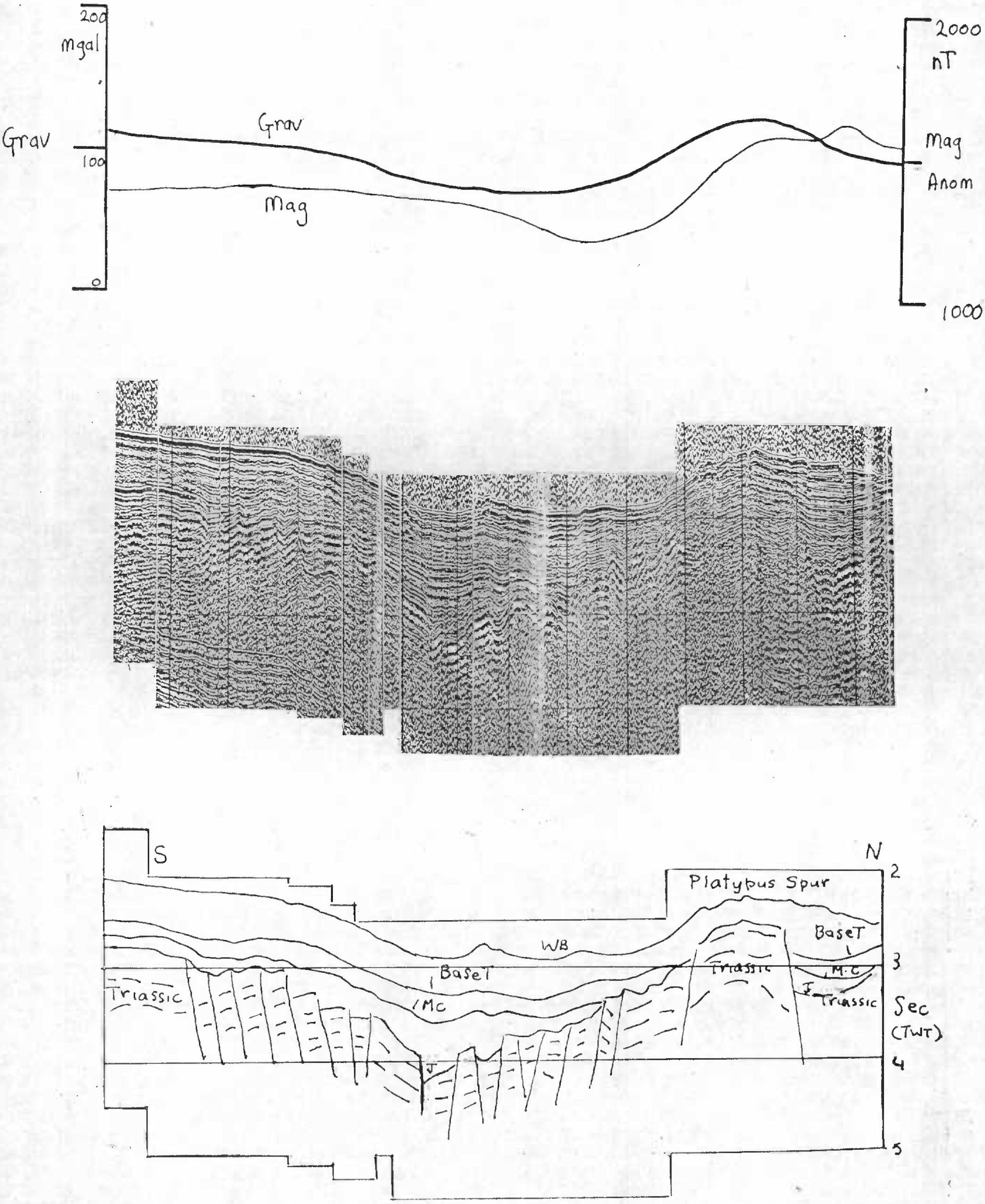
Seismic horizons representing a base Tertiary unconformity, the mid Cretaceous Base Gearle Siltstone and the rift onset unconform ty were tied from the Spur to the industry grid seismic on the Plateau. Thickening of sediments between the Spur and the Plateau were accommodated mainly in the thickening of pre-Tertiary strata. Triassic prerift strata exhibited rift graben topography with bedded Triassic sediments being evident on the Plateau itself.

Line 55/09 shows that the southern half of the Platypus pur is composed of an uplifted Triassic sedimentary block covered by 300 m of Tertiary and later sediments, and in its northern half by an accumulation of 2 km of post Triassic sediments. Th Spur is clearly continental and sedimentary in origin.

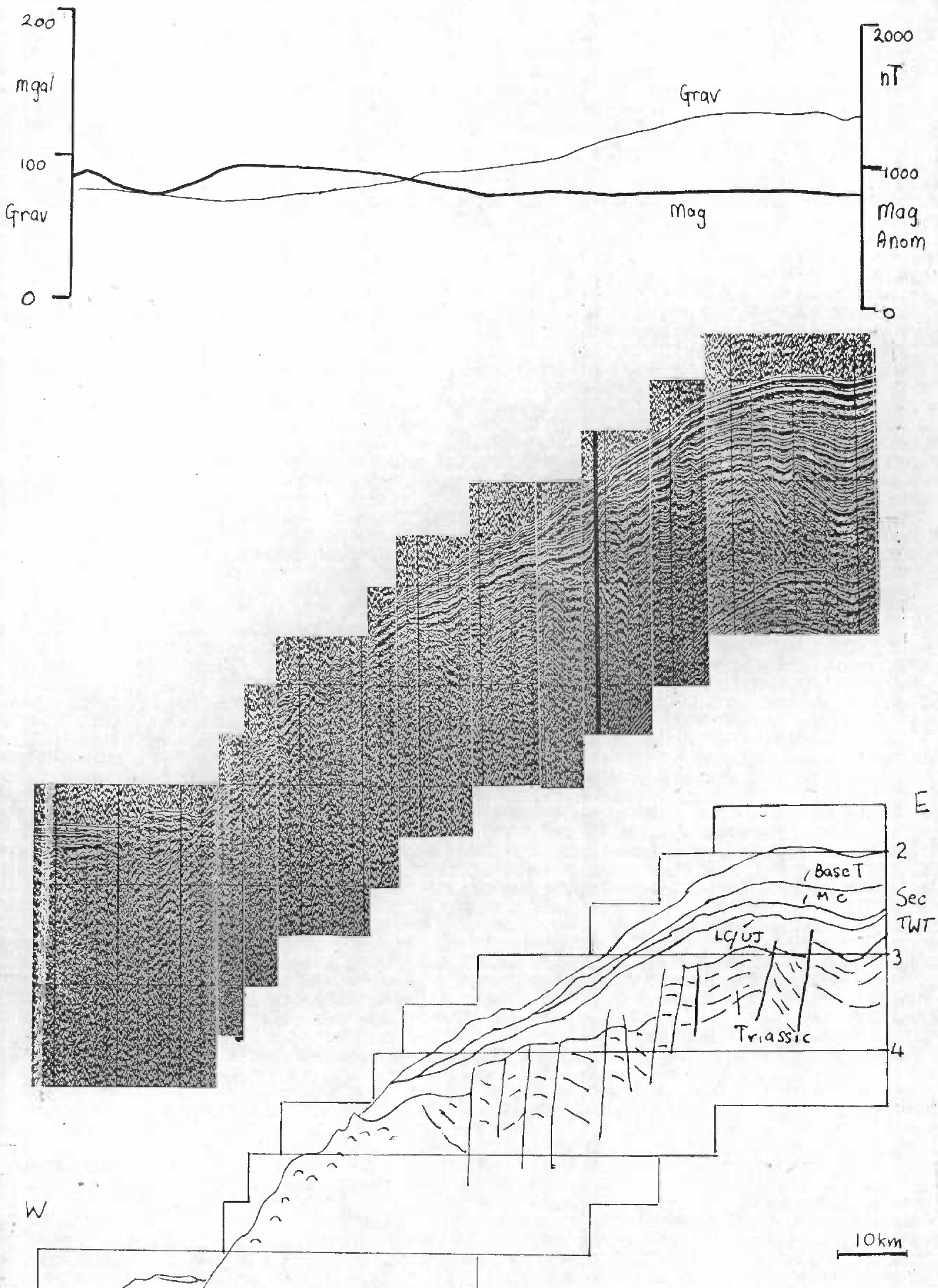
5.1.6 Northwestern Exmouth Plateau

The northwestern Plateau margin was traversed by line 55/07 (Figs. 8 & 13), which ties industry sesimic data on the Plateau crest northwest onto the continental rise. Jurassic and Lower Cretaceous Barrow Group sediments are less well developed on the northwestern Plateau than in the south, compatible with the provenance of the Barrow Group deltas on the Plateau being mainly from south of the Plateau in prebreakup time.

Three seismic horizons were tied to the industry grid on the Plateau and grid data were in turn tied back to the Phillips Mercury No. 1 well. These horizons were base Tertiary unconformity, base Middle Cretaeous Gearle Siltstone (breakup unconformity for the central, western and southern Plateau) and the top Triassic rift onset unconformity. An horizon probably representing the top Barrow Group



12. Seismic monitor and interpretation of line 55/09.



13. Seismic monitor and interpretation of line 55/07.

appears down-flank of the crest of the Plateau. On the Plateau crest it is replaced by the Muderong Shale. The reappearance of the Barrow Group towards the Plateau margin would relate to the erosion of uplifted areas prior to breakup on the western margin of the Plateau, producing a more proximal facies differing from the partly time equivalent Muderong Shale. The Triassic horst and graben topography under the rift onset unconformity progressively approaches the sea floor towards the Plateau edge and down the Plateau lower slope. This is accommodated largely by thinning of post Middle Cretaceous strata. The seismic ccharacter of the prerift lithology becomes chaotic towards the Plateau margin and it is likely that pre-Triassic sediments, basement or igneous material occur beneath the rift onset unconformity on the edge of the Plateau, on the Plateau lower slope and rise. At the base of the escarpment they are covered by a zone of chaotic mounded sediments. This mounded zone is approximately 5 km wide and 750 m in thickness. An unconformity similar in seismic character to the mid Cretaceous base Gearle Siltstone is identified towards the top of these mounded sediments. West of the mounded zone a thinner (400 m) representation of the same sediments is horizontally layered and an event interpreted on seismic character as equivalent to the top Barrow Group is recognised below the mid Cretaceous event. That event is not observed in the mounded region due to the chaotic nature of the sediments.

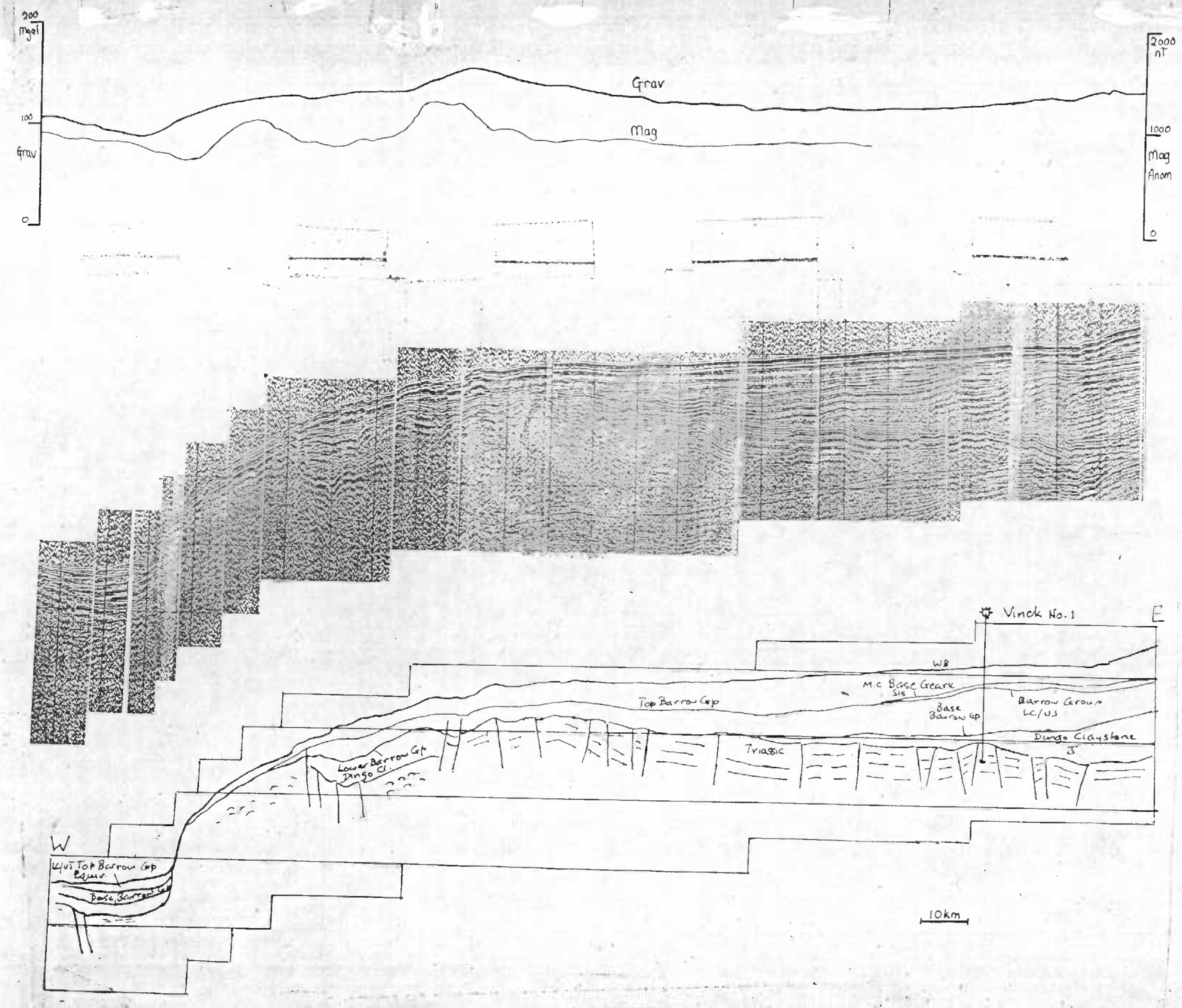
The thinning of overburden above pre-Jurassic source rocks towards the western Plateau margin in general could result in a zone west of the Central Dome where the Lower Triassic or Permian source rocks, thermally overmature at the crest could be less mature and produce oil rather than thermal gas.

5.1.7 Southwestern Exmouth Plateau

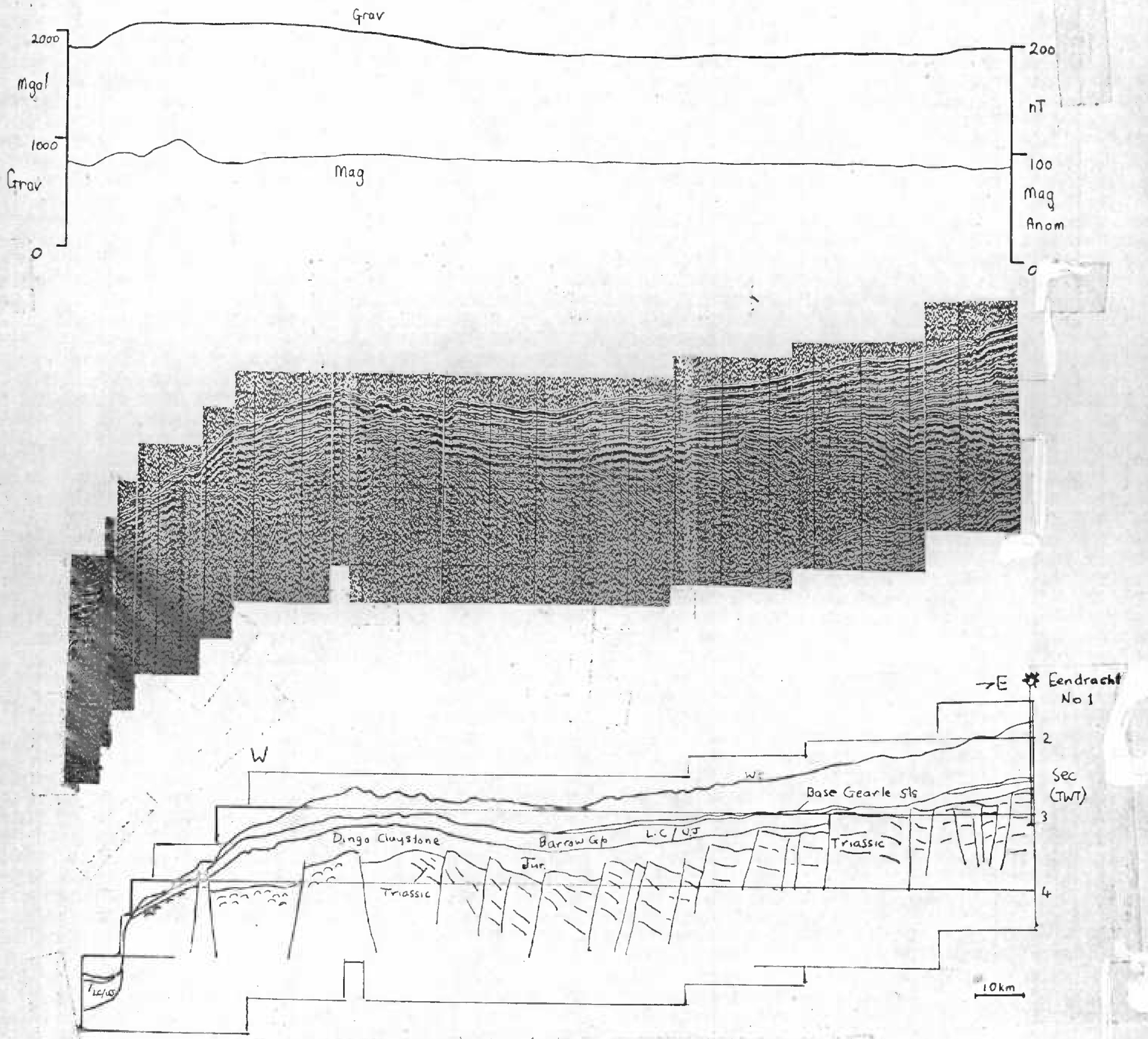
Line 55/02 (Figs. 8 & 14) ties Esso Vinck No. 1 petroleum exploration well and extends WNW to the base of the Plateau lower slope and the area of the ODP EP-2 site survey.

Horizons interpreted on line 55/02 are tied to Vinck No. 1, which encountered 677 m of Jurassic deltaic sediments of the Barrow Group underlying 105 m of the Albian/Aptian Gearle Siltstone and 56 m of the Aptian/Neocomian Muderong Shale. The Barrow Group overlies a thin Upper Jurassic Dingo Claystone unit which rests unconformably on tilted fault blocks composed of Triassic sediments (rift onset unconformity).

Horst and graben rifted structures in the Triassic are overlain by post Triassic sediments, which progressively thin towards the Plateau margin. A relic shelf edge is preserved in an upper delta of the Barrow Group at the east of the line and seismic character is consistent with more distal facies west of this feature. A further change in seismic character from opaque to alternating reflectors argues for the facies of the Barrow Group again becoming more proximal further west around a Plateau edge high at the rift onset unconformity surface, which presumably was emergent above sealevel during the period of deposition of the Barrow Group and was eroded to source the local Barrow Group sediments. The clearly sedimentary character of the strata below the rift onset unconformity changes westward unitl at the the Plateau edge the seismic character is consistent with that of



14. Seismic monitor and interpretation of line 55/02.



15. Seismic monitor and interpretation of line 55/04.

basement or igneous rock types.

Ponded sediments occur at the base of the outer slope of the Plateau on the western end of line 55/02 in the region of the proposed ODP location EP-2. Correlation of seismic character suggests that most of the 700 m of ponded sediments overlying the rift onset unconformity in that region is composed of Lower Cretaceous and Jurassic time equivalents of the Barrow Group and Dingo Claystone.

Line 55/04 (Figs. 8 & 15) runs aproximately east-west north of line 55/02. It ties the Eendracht No. 1 well to the EP-2 location. Eendracht No. 1 has a similar post rift sedimentary thickness to Vinck No. 1 but greatly reduced Lower Cretaceous and Jurassic sequences. The Lower Cretaceous/Upper Jurassic Barrow Group is 149 m thick in Eendracht No. 1, compared to 677 m at Vinck No. 1; the mid Cretaceous Gearle Siltstone is 25 m thick compared with more than 105 m and the underlying Munderong Shale is 11 m thick, compared with 56 m, respectively.

Basic features of line 55/04 are similar to those of line 55/02 except that the westward transition in the prerift reflection events from sedimentary to basement or igneous character is more clearly seen, and pronounced ponding of Lower Jurassic Dingo Claystone is observed landward of a Plateau edge high. A more proximal facies of these sediments occurs over an uplifted rifted feature suggesting lateral sourcing from an area of still higher relief.

5.2 OCEAN DRILLING PROJECT SITE SURVEYS

5.2.1 Introduction

Given the excellent chance of Ocean Drilling Program (ODP) holes being drilled in this region if adequate site surveys were prepared, we took the opportunity of surveying six areas in some detail, for this purpose and also to seek good sampling sites.

The areas selected (Fig. 2) were the western margin of the Exmouth Plateau, the southern margin of the Wombat Plateau (area A), the Wombat Half-graben (area B) and the southeastern margin of the Wombat Plateau (area C), the Argo Abyssal Plain (area D), and the Emu Spur (area E). Tentative drill sites had already been proposed for most of these areas by Exon and von Rad (1985). Proposals for all six areas were assembled aboard ship, and forwarded to ODP (von Rad et al., 1986).

The first choice holes for each area were:

A. EP2 : Cainozoic to "Triassic target.
B. EP8A : Early Cretaceous and Jurassic target.
C. EP9B : Cainozoic to Early Cretaceous target.
D. EP10A : Jurassic target.
E. AAP1B : Cainozoic to Callovian to oceanic crust target.
F. EP11B : Jurassic target.

Of these wells EP10A and AAP1B were regarded as of the highest priority by us. EP9B was important in that it was complementary to

EP10A. Extracts from all first choice site proposals are given below.

5.2.2 Proposed site EP2 (western Exmouth Plateau)

The site survey for this proposal (Fig. 16) lies on the westernmost extremity of the Exmouth Plateau on regional tie lines 55/002 and 55/004. Bathymetrically the area slopes south-southwest in water depths of around 4000 m. The seabed is gently terraced , each step downwards probably representing progressive erosion of Tertiary and Cretaceous sediments, perhaps by boundary currents along the plateau slope. Both proposed sites, EP2A and EP2B, lie on BMR line 55-02 and appear to be safe as regards lack of petroleum traps. Site EP2A is illustrated in Figure 16, on BMR line 55-03E.

5.2.3 Proposed site EP8A (Area A)

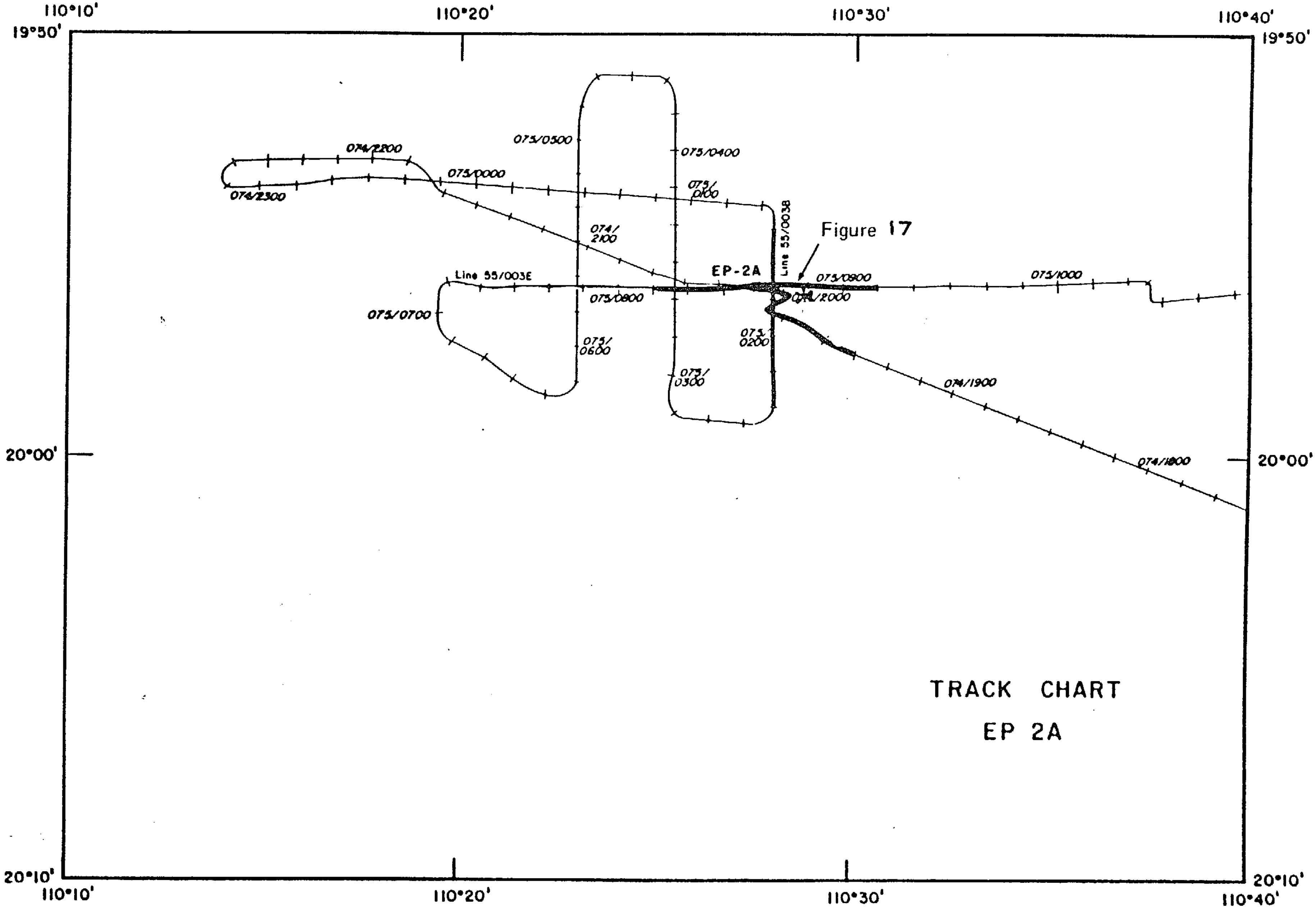
The site survey of Area A (Fig. 18) lies on the southern flank of the Wombat Plateau on regional tie line 56/014 (Fig. 11). Bathymetrically the area consists of the fairly flat Wombat Plateau, a steep south-facing scarp, and the flat floor of the Wombat Half-graben. The plateau and scarp are cut by a small canyon running southwest. Site EP8A is on the top of the scarp in an area which structure contours on the C and D horizon show has a regional dip to the northwest. Despite some faulting, the site appears safe as regards lack of petroleum traps.

5.2.4 Proposed site EP9B (Area B)

The site survey of Area B (Fig. 19) lies on the floor of the Wombat Half-graben off the southeast corner of Wombat Plateau, on regional tie line 56/013 (Fig. 10). Bathymetrically the area is rather flat. Structure contours of the C horizon (Fig. 20) indicate that EP9B is on the northwest flank of an anticlinal structure, and an east-west cross-section shows how the Cretaceous and younger strata thin onto the anticline. A north-south cross-line indicates that the area is cut by east-west faults, but altogether the data show the site is safe, at least above the D horizon (Neocomian). At the level of the E horizon (Fig. 21) the structure is complex.

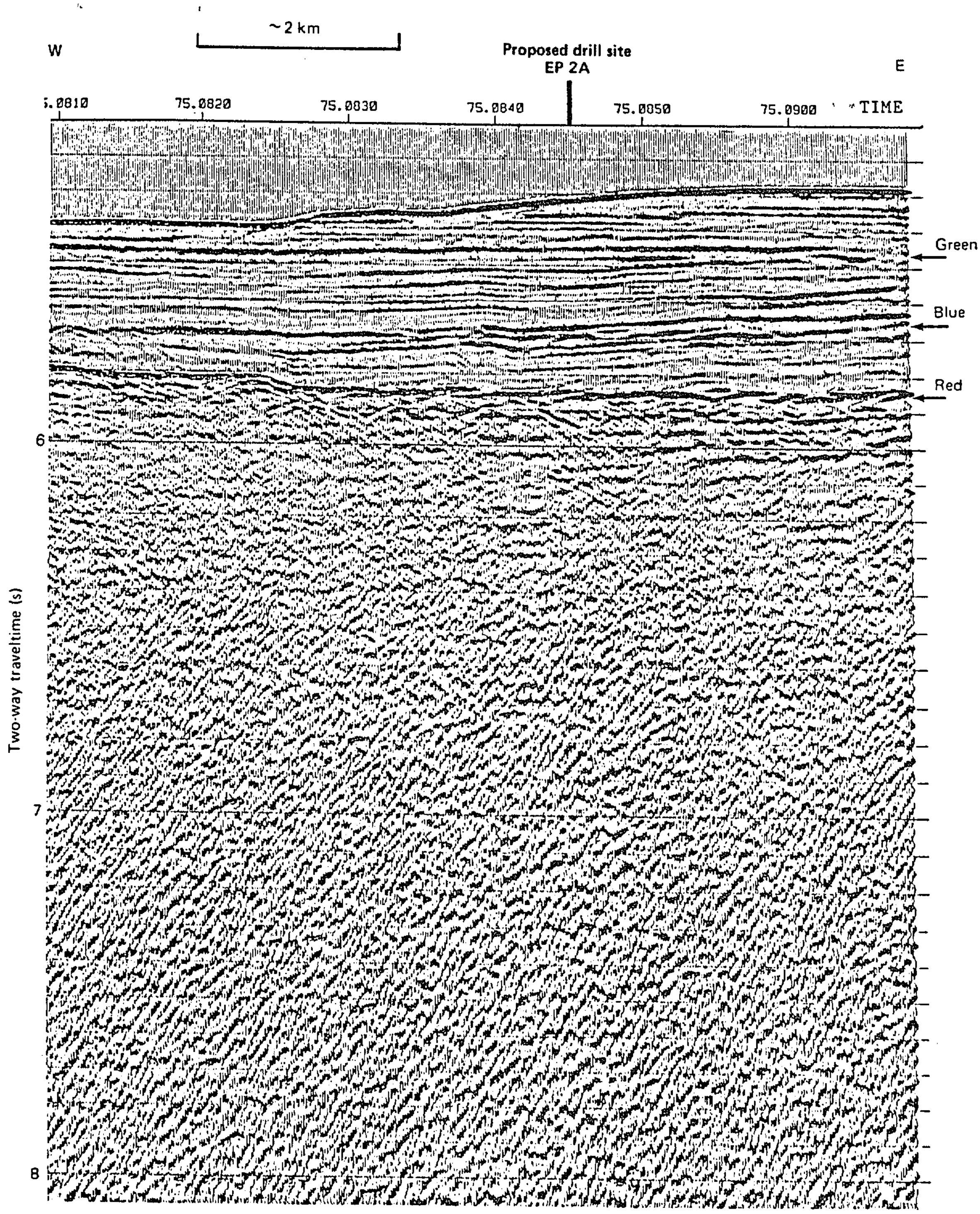
5.2.5 Proposed site EP10A (Area C)

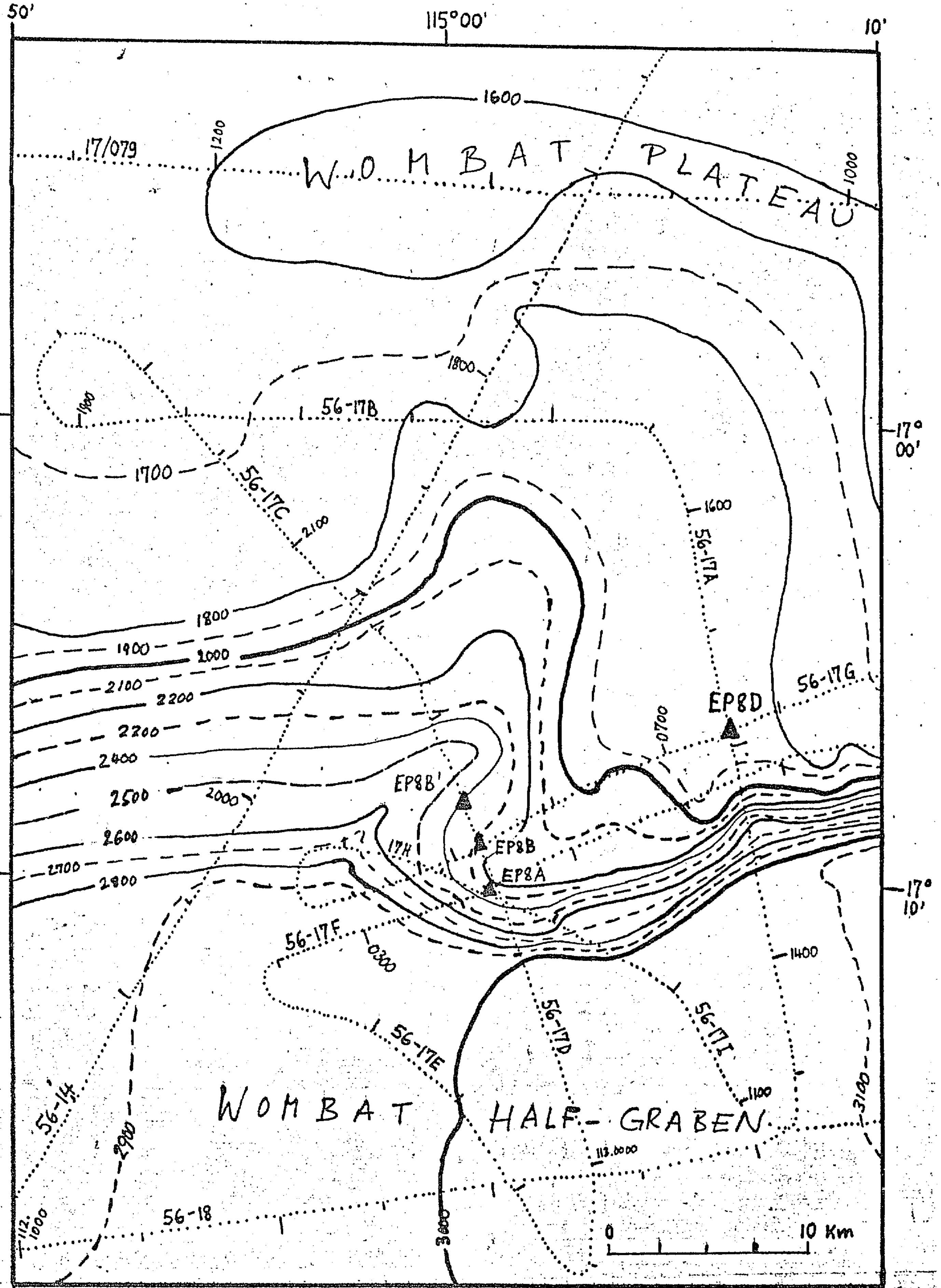
The site survey of Area C (Fig. 19) lies on the southeastern corner of the Wombat Plateau on regional tie line 56/013 (Fig. 10). Bathymetrically the area lies just northwest of a steep scarp running down to the northeast trending Montebello Canyon. The scarp is cut by one northerly-trending depression. The scarp has been dredged by R.V."Sonne" (von Stackelberg and others, 1980) and the "Rig Seismic", and consists of a variety of Triassic and Jurassic marine and non-marine rocks (see Geological Sampling). Structure contour maps of the C and E horizons (Figs. 20 and 21) indicate that there is a regional dip to the northeast, and that any hydrocarbons migrating through the location of site EP10A would be safely vented at the scarp. Cross-sections through the site (e.g. Fig. 23 and 24) emphasise that, although there is some small-scale north-south faulting near the



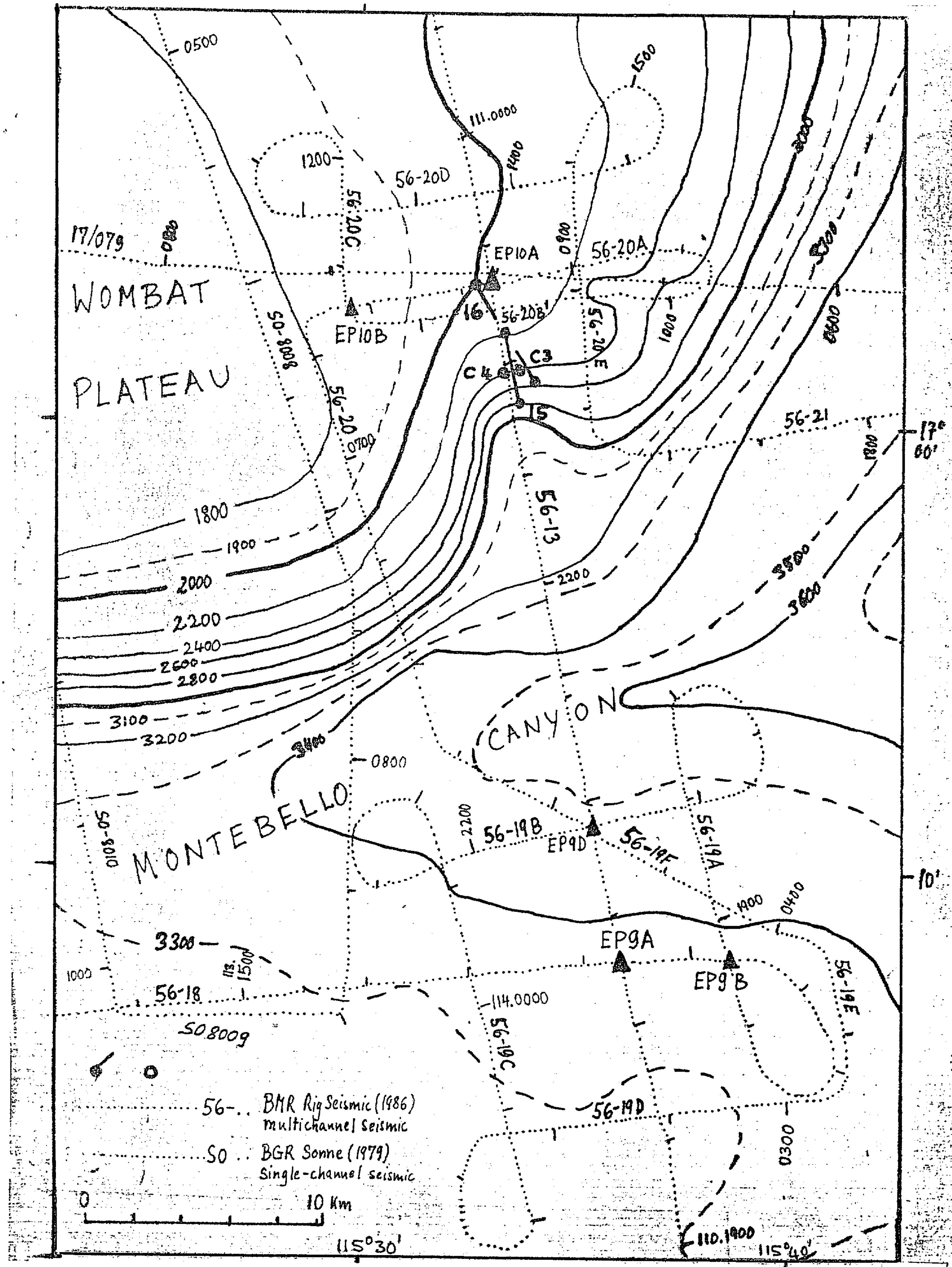
16. Site survey for the proposed ODP Site EP2A on the western Exmouth Plateau.

17. Interpretation of BMR seismic record 55/03E across Site EP2A on the western Exmouth Plateau.

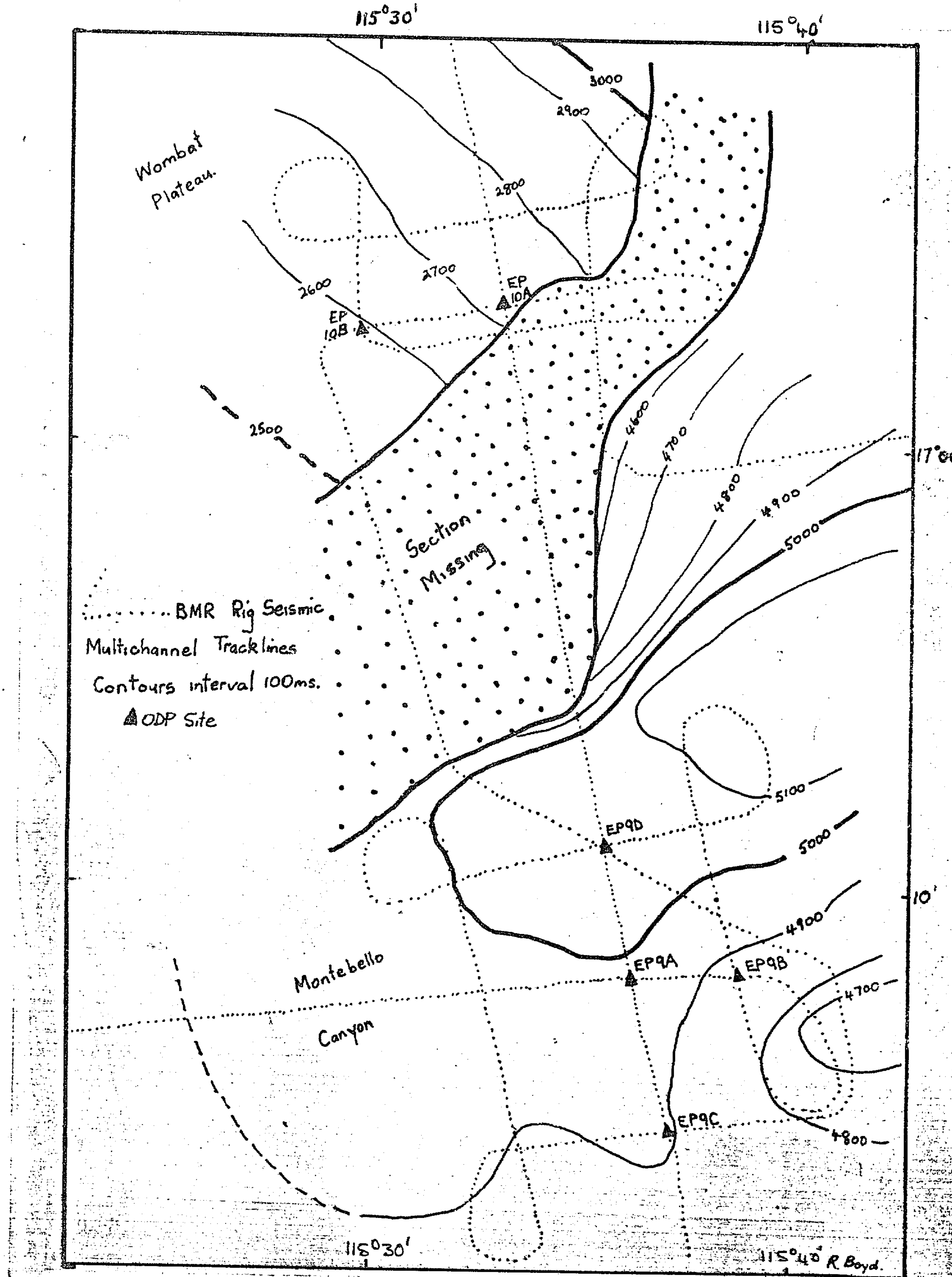




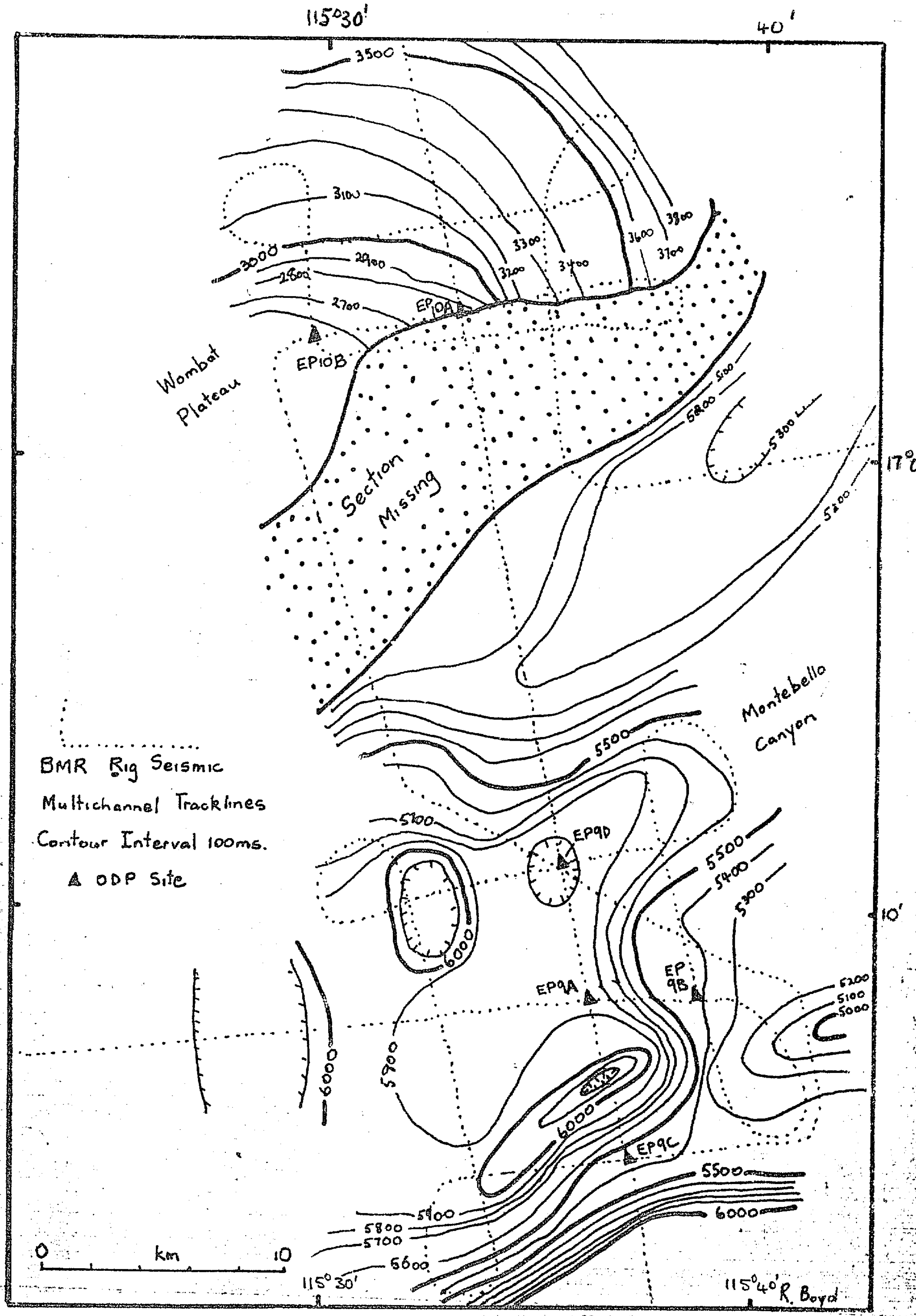
18. Site survey for the proposed ODP Site EP8, on the southwestern Wombat Plateau.



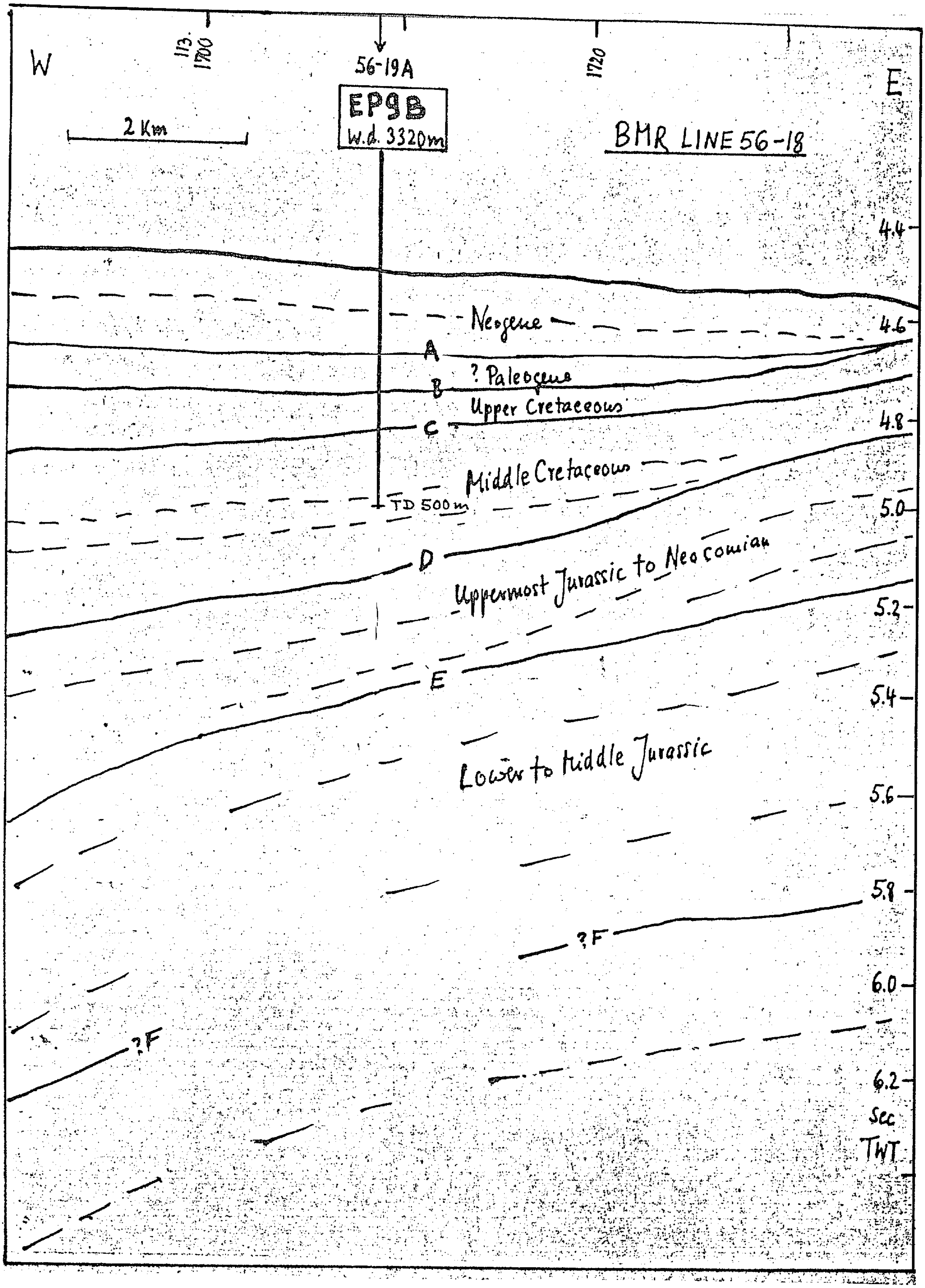
19. Site survey for proposed ODP Sites EP9 and EP10 (Wombat Half-Graben/S.E. Wombat Plateau).



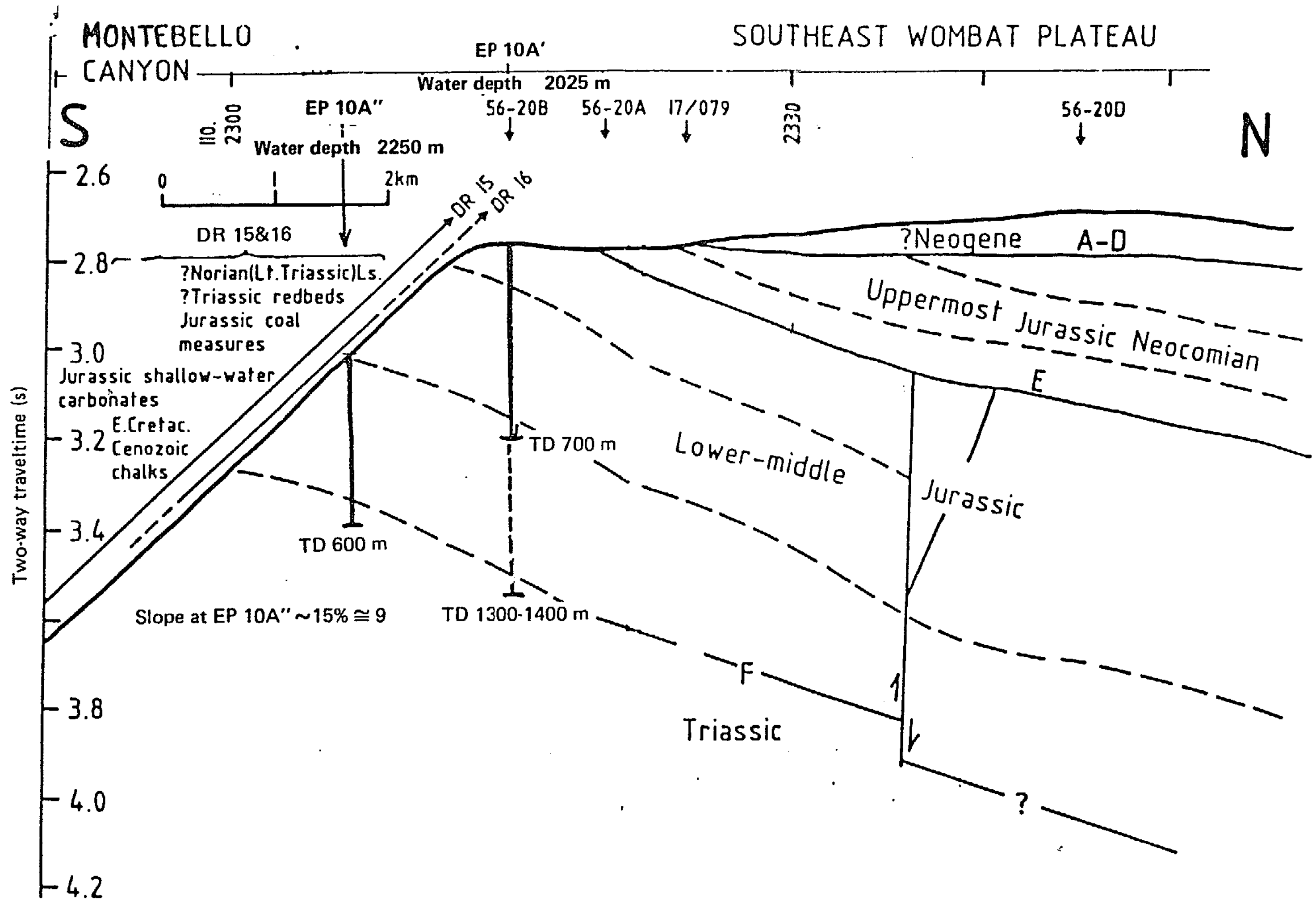
20. Time structure on the Late Cretaceous "C" horizon near proposed ODP Sites EP9 and EP10 in and on the Wombat Half-Graben, S.E. Wombat Plateau.



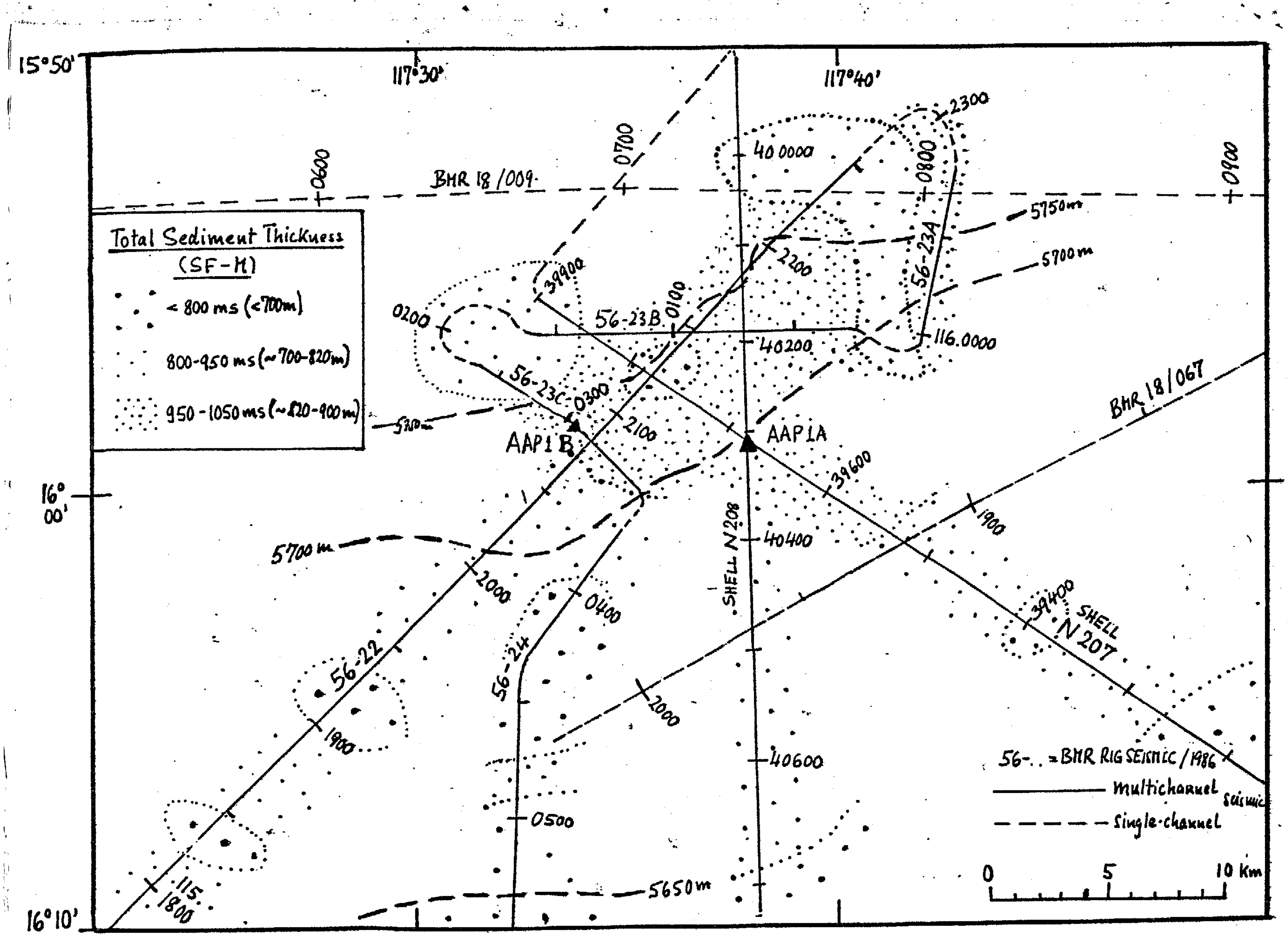
21. Time structure on the Late Jurassic "E" horizon near proposed ODP Sites EP9 and EP10 in the Wombat Half-Graben and on S.E. Wombat Plateau.



22. Interpretation of BMR seismic monitor record 56/18 across Site EP9B in the Wombat Half-Graben.



23. Interpretation of BMR seismic monitor record 56/13 across Site EP10A on the southeast Wombat Plateau.



27. Site survey for proposed ODP Site AAP1 on Argo Abyssal Plain together with track chart, bathymetry and sediment thickness.

site, at the levels of the E and F horizons it is not present.

The hole would drill through 980 m of sediment of Jurassic age, terminating just below the F horizon in the latest Triassic. The dredge data indicate that much of the sequence would be shallow marine, so the site would provide an excellent record of Tethyan faunas, and sea level rises and falls in the Jurassic. It would greatly add to the Late Jurassic palaeo-oceanographic history to be recovered from site AAP1B on the Argo Abyssal Plain to the northeast.

5.2.6 Proposed site EP11B (Area E)

The site survey of area B around the Cygnet Spur (Fig. 25) was carried out not only to prepare a possible ODP site, but also in order to continue dredging in the Swan and Cygnet Canyons which proved so successful during the 1979 "Sonne" cruise (von Stackelberg and others, 1980). The "Sonne" dredge hauls (Fig. 25) showed that there was an extensive Early to Middle Jurassic suite of shelf carbonates and coal measures lying between the E and F horizons on the Emu Spur. The "Rig Seismic" survey resulted in an improved bathymetric map of the area (Fig. 27) and the seismic data enabled a depth structure contour map of the E horizon to b constructed which showed that EP11B was in a situation where any migrating hydrocarbons would be vented updip to the north, through the slope of the Cygnet Spur. "Rig Seismic" dredged more Jurassic and younger rocks from the two canyons (Fig. 25 and Geological Results).

Site EP11B (Fig. 26) has similar Jurassic objectives to EP10A, and is clearly in a safe position. It, like EP8A, is an alternate site to EP10A.

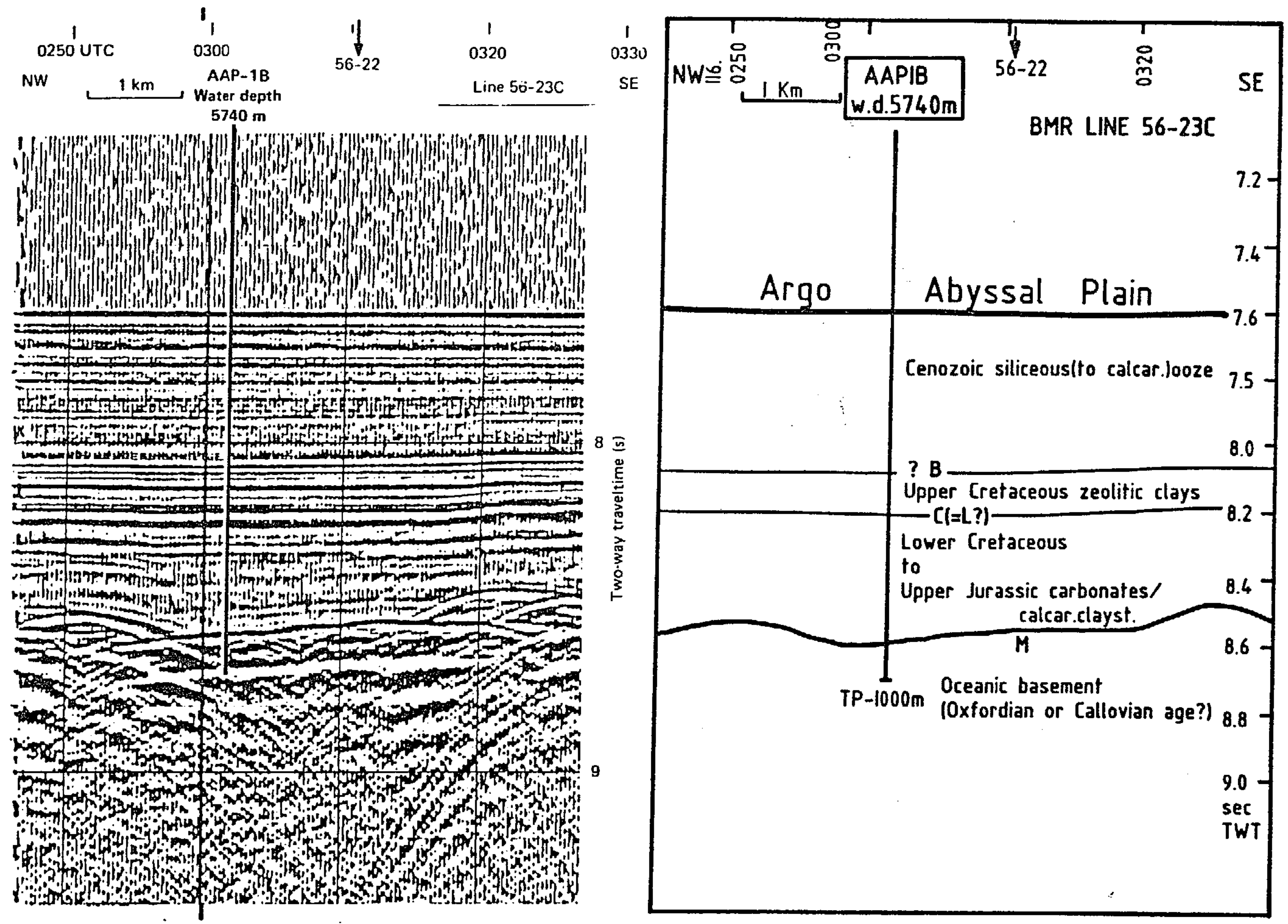
5.2.7 Proposed Site AAP1B

The site survey of area C, on the southeastern Argo Abyssal Plain, was designed to find an optimal location for this highly-rated site. Bathymetrically the area is almost flat (Fig. 27). The main aim of the survey was to define a location with the oldest possible sediments overlying Callovian oceanic crust beneath the magnetic quiet zone. There is no chance of encountering significant hydrocarbon accumulations at this site, so structural definition was not important.

Site AAP1B was selected in a depression in oceanic basement where an additional 50m of lowermost strata could be identified on the seismic profiles (Fig . 28).

5.3 REFRACTION SONOBUOY PROFILES

Five REFTEK sonobuoys were deployed on the northern margin of the Exmouth Plateau and can be located using Figure 9 and the data below. The hydrophone of each was set to extend fully immediately on deployment, but in all cases the frequency content of the early part of the monitor record indicates that there was some delay (varying from about 11 to 20 minutes) before this occurred. Each sonobuoy was



28. Interpretation of BMR seismic monitor record 56/23C across Site AAP1B on Argo Abyssal Plain.

recorded for more than three hours over distances of thirty or more kilometres. Details of deployment are as follows:

Sonobuoy	Area of Deployment	Coincident Reflection Line	Approx Time Recorded	Total Time Recorded	Approx. Distance km
1	Platypus Spur	55/09	079:0240-0530	2h 50m	27
2	N. Exmouth Plateau	56/013	110:105019.4 - 1400	3h 10m	29.6
3	Wombat Plateau	56/014	111:133156.4 -1650	3h 20m	31
4	Montebello Canyon	56/018	113:125412.2 -1610	3h 20m	31
5	Argo Abyssal Plain	56/024	116:035355.2 -0840	4h 45m	44.5

For sonobuoy 1 on the Platypus Spur no direct wave (D wave) was recorded, so the water velocity was taken to be 1.5 km/sec with an intercept of zero on the time axis (see below). A refractor from the seafloor was also not recorded, so sediment velocity of 1.8 km/sec was assumed for the first layer and the intercept adjusted iteratively until the depth of the water column corresponded with the recorded in the bathymetry (1.71 km). The ship's speed was assumed to average 5 knots.

Two refractors were identified at larger offsets. The first has apparent velocity of 5.13 km/sec, but the true velocity will be greater as recording is down-dip. The second refractor has an apparent velocity of 7.23 km/sec which is consistent with arrivals ref acted in the crust. These refraction branches deviate little from a straight line, despite the complexity of the upper sequences of the Plateau.

Only sonobuoy 2 was deployed in water depths shallow enough to observe the direct arrival. It gave a water velocity of 1.48 km/sec. This velocity was assumed to apply to the water column for each of the other sonobuoys. As for sonobuoy 1 (Leg 1) no sea floor refraction was observed. Sediment veloc ties of 1.8 and 2.1 km/sec were assumed and the intercept time which gave the water depth recorded by the precision depth recorder were developed iteratively. The velocity/intercept pair used to model the sea floor sediments was chosen to be consistent with deeper observed refraction branches and their intercepts.

Sonobuoy 2 was deployed on the Exmouth Plateau proper (water depth 1273.5 m) where Tertiary, Cretaceous and Jurassic sediments are interpreted from the reflection records. These sediments are broken into horst and graben blocks by almost vertical faults. This structuring has a marked effect on the arrivals refracted in the shallower parts of the section, and their apparent velocities. Refraction branches traced back to reflectors at the zero time axis give two way reflection times considerably lower than those calculated from the apparent velocities and thicknesses of refracting layers.

The first observed refractor has an apparent velocity of 2.32 km/sec and can be traced back to a reflector which corresponds to the base of the Cretaceous. Similarly, the second observed refractor has an apparent velocity of 2.75 km/sec and represents the top Triassic. Deeper refractors trace back to the zero axis in the region where the primary reflectors are obscured by multiples. However, apparent velocities of 3.73 and 4.74 km/sec calculated are relatively low and suggest refraction within the deeper sedimentary section. No basement refractor was observed.

Sonobuoy 3 was recorded NE-SW on the upper western margin of the Wallaby Plateau (water depth of 2342.6m). The sea floor is arched along the profile but the underlying sediments are fairly flat lying and only the deeper part of the section is structured by faults. Accordingly the refraction branch with the largest offset shows shingling, turn overs and deviations from a straight line. The shallowest observed refractor has apparent velocity of 2.31 km/sec and probably corresponds to the base of the Cretaceous. The second observed refractor gives a calculated reflection time which corresponds to a horizon where there is a marked change in seismic character. The apparent velocity of 5.37 km/sec suggests that it is igneous material. This corresponds to the Triassic-Jurassic volcanics shown in Figures 11 and 12, and dredged from this margin (see Geological Results). The highest apparent velocity of 7.48 km/sec at 4.6 km depth, is too shallow for crustal material and can be attributed to structural effects. Deeper in the section, refractors travel down dip, giving an apparent velocity lower than true velocity.

Sonobuoy 4 was recorded W-E along the southern side of the Montebello Canyon (water depth 3173.8m), over a thick sedimentary sequence which thins to the east. Along profile Tertiary and upper Cretaceous sediments are flat lying but the lower Cretaceous, Jurassic and older(?) sediments are structured by faults. The refraction branches observed on this record are straight showing little effect of structure. The first and second refractors picked have apparent velocities of 2.89 and 3.34 km/sec, respectively give calculated reflection times (TWT) which correspond to refraction within the lower Cretaceous. The base of the Cretaceous has an apparent velocity of 4.29 km/sec which is high compared with elsewhere. Greater compaction due to thicker sedimentation may account for this. However, the effect of shooting down dip is to give an apparent velocity which is lower than the true velocity. The fastest calculated velocity of 6.04 km/sec at a depth of 8.7 km may be high due to structural effects but possibly represents refraction within the basement.

Sonobuoy 5 was recorded N-S over the margin of the Argo Abyssal Plain (water depth 5685 m). Flat lying sediments which thin to the south overlie rising faulted basement. Faulting becomes more intense as the western margin of the Exmouth Plateau is approached. No refractions were recorded from within the sediments. The first two observed refractors with apparent velocities of 3.11 and 5.91 km/sec respectively, originate from narrow layers at about 6.5 km depth. These velocities are lower than true velocity as shooting is down dip. Strong structural effects can be seen on the observed refraction branches. The refraction branch at the largest offset is underlain by a broard band of record devoid of any secondary arrivals. An apparent velocity of 7.78 km/sec at 11.5 km depth was calculated for this refraction branch, which may indicate the base of oceanic crust.

The following table gives simple flat layer models for each of the sonobuoys. It was developed from measured intercept times on he zero axis and apparent velocities calculated from the slope of the refracted travel time branches. As each sonobuoy record is one way (unreversed), no information on structure or dip of refractors could be included in these preliminary models. They will be refined by ray tracing through models incorporating structural and stratigraphic information derived from the coincident reflection lines. Sonobuoy Layer Apparent Intercept Thickness Depth Reflection Velocity Time Time (TWT) km/sec sec km km sec

5.3.1 Summary of Sonobuoy Results from the Northern Exmouth Plateau

Sonobuoy	Layer	Apparent Velocity km/sec	Intercept Time sec	Thickness km	Depth km	Reflection Time (TWT) sec
	1	(1.50)	0.00	1.71		
					1.71	2.280
	2	(1.80)	1.26	0.54		
					2.54	2.880
	3	2.44	2.20	0.24		
					2.49	3.077
	4	2.96	2.55	2.15		
					4.64	4.529
	5	5.13	4.10	5.31		
					9.95	6.600
	6	7.23	5.78			
2	1	1.478	0.00		0.00	
	2	1.80	0.98		1.27	1.99
	3	2.32	1.80		1.95	2.75
	4	2.75	2.78		3.59	4.16
	5	3.73	3.59		4.09	4.52
	6	4.74	4.20		5.12	5.07
3	1	1.478	0.00		0.00	
	2	2.10	2.25		2.34	3.15
	3	2.31	2.46		2.41	3.22
	4	5.37	3.46		2.86	3.61
	5	7.48	4.62		7.02	5.16
4	1	1.478	0.00		0.00	
	2	1.80	2.45		3.17	4.3
	3	2.89	4.65		4.28	5.5
	4	3.34	4.95		4.47	5.7
	5	4.29	5.59		5.39	6.2
	6	6.04	6.98		8.65	7.7
5	1	1.478	0.00		0.00	
	2	1.80	4.39		5.68	7.6
	3	3.11	7.4		6.38	8.4
	4	5.91	8.265		6.53	8.5
	5	7.78	9.47		11.43	10.13

Note : Velocities in brackets are assumed

5.4 HEAT FLOW

One heat-flow station was occupied successfully during the cruise to augment the heat-flow programme which formed Phase 1 of the Exmouth Project. The site was chosen to coincide with the location of the Jupiter No. 1 well site (Fig. 2). A four metre lance with the full 'A' series of 8 thermistors was used. A monitor problem was channel 8 not digitizing was not prohibitative as it is the thermistor location furthest from the lance head. A total of 10 weights (130 km) was loaded onto the housing and a drop of 50 m at 50 m/minute achieved a penetration of 4 thermistors (about 2 m). Tilt data indicates that the lance remained upright until it was pulled out on retrieval. Consequently, the temperature gradient in the watger column immediately above the site was also recorded on three thermistors. On pullout the usual problem of bending the lance was encountered.

A 4 point gradient of 19 C/km was calculated. Barber (1982) reported a present day geothermal gradient of 34 C/km from well log temperature data. The three thermistors in the water column indicate a super-adiabatic gradient and so the large discrepancy in the gradients could be explained by convective overturn of the near-bottom water column. Choi, Stagg and others (1987) report thermal conductivities of 0.8 W/mC as representative for the central Exmouth Plateau, giving a heat-flow value of 15.2 mW/m2. This is a very low heat-flow value, well below the world average of 40 mW/m2.

5.5 MAGNETICS

Magnetics were recorded during conventional multichannel seismic reflection profiling and in transit using 2 Gradiometrics G801/803 proton procession magnetometers. Where gradiometer data were not collected due to equipment servicing or complexity of manoeuvres, single channel magnetometer data were recorded. Diurnal effects during the study were monitored by an onshore magnetic station maintained by NATMAP personnel. Details of magnetic data collected are given in Appendix A and are plotted along with seismic profiles on Figs. 10-15.

Total field magnetic anomalies recorded over the plateau are of long wavelength and low amplitude reflecting a substantial thickness of non-magnetic sediments. Towards the plateau eddge and on the slope and rise the shallower basement and the presence of igneous rock types at the rift unconformity produce higher amplitude shorter wavelength anomalies.

5.6 GRAVITY

Gravity data were recorded during conventional multichannel seismic reflection, and in transit using a Bodenseewerk Geosystem KSS-31 Marine Gravity Meter. Locations of traverse are given in Appendix A and gravity data, corrected for Eotvos effects but not latitude, are displayed along with seismic data on Figs. 10-15. The raw gravity data largely reflect changes in water depth. However, increased gravity values correspond to interpreted shallowing of the deep crust interpreted from the Expanded Spread Profile gathered during phase 2 of the Exmouth Plateau work. Processing of the gravity data and modelling in conjunction with the results of the ESP, WACDP and multichannel seismic reflection results have allowed a more refined definition of the structure and crustal composition of the plateau (Williamson, Falvey et al., 1988).

CHAPTER 6
GEOLOGICAL RESULTS

6.1 GEOLOGICAL SAMPLING PROGRAMME

The study of the northern margin (Fig. 9) of the Exmouth Plateau fell into two phases: a multichannel seismic reflection survey 8 days long and a geological sampling program 7 days long.

The multichannel seismic program itself was split into two components. The first was a regional seismic survey of 950 km, which consisted of ten lines. In essence these provided three regional ties from the central Exmouth Plateau across the Wombat Half-graben and the outer highs to the Argo Abyssal Plain, an east-west tie from the western Wombat Plateau to the Echidna Spur, and a tie from the Echidna Spur to the Argo Abyssal Plain. In addition five detailed surveys were carried out in areas of particular interest, as site surveys for geological sampling and potential ocean drilling program proposals. An additional single channel seismic survey was carried out during the geological sampling program across the Bullant Canyon northwest of Emu Spur (Fig. 9). Altogether the additional seismic data gathered during the site surveys amounted to 500 km.

The geological sampling program is summarized in Section 6.2 (Dredge Stations) and Tables 1 and 2. Dredging was undertaken in four areas: Swan Canyon/Cygnet Canyon, Bullant Canyon, northern Wombat Plateau, and southeastern Wombat Plateau. Sixteen dredge stations were occupied and rocks were obtained from all of them, in water depths ranging from 5600 m to 2000 m. The equipment used consisted of a large chain bag dredge with two small pipe dredges shackled behind. Problems with spooling gear caused delays amounting to more than a day.

Overall the dredging program was a great success, adding considerably to the knowledge acquired during "Sonne" Cruise 8 (von Stackelberg and others 1980). Rocks recovered included Triassic volcanics and shelf carbonates, Jurassic shelf carbonates and coal measure lithologies, Cretaceous shallow marine sandstones and mudstones, and Tertiary marls, chalks and oozes. The relationship of the rocks to the seismic profiles needs detailed study, but preliminary results tend to confirm the seismic interpretations of von Stackelberg and others (1980), and Exon and others (1982).

The coring program was restricted to five stations in two areas: the Emu Spur and the southeastern Wombat Plateau. A five metre gravity corer was used at stations ranging in water depth from 3500 m to 2000 m. Two stations were unsuccessful - GC01 because the bottom was not reached, and GC02 because the pipe separated from the core head on impact. The other three cores (Table 1) recovered pinkish to greenish gray Holocene foram-nanno ooze. At the base of GC03 was a white consolidated chalk of late Miocene age.

The dredge material was studied in some detail aboard ship, using a binocular microscope and smear slides, and then all lithotypes from all stations were compared to come up with a comprehensive and coherent listing. It was soon apparent that many of the lithofacies types were the same as those dredged by R.V. "Sonne", and that an expansion of the lithofacies classification used by von Stackelberg and others (1980) and von Rad and Exon (1983) would be appropriate. This lithofacies classification is related to "Rig Seismic" dredge rock types, making use of post-cruise petrographic studies (von Rad et al., in prep.) in Table 3, and lithofacies numbers have been added to the short dredge descriptions in 6.2 (Dredge Stations).

The palaeontological results of the "Sonne" cruise (von Stackelberg and others, 1980, Quilty 1980, 1981), and the palaeontological work carried out by Quilty on and after this cruise (see Biostratigraphy), in conjunction with general sedimentological and seismic stratigraphic information, enabled us to assign most rock types recovered to a lithofacies and assign a probable age.

The major lithofacies and their probable ages are:

A. Coal measure association - mainly Early to Middle Jurassic; some Late Jurassic.
B. Ferruginous association - ?Jurassic.
C. Shallow water carbonate association - Late Triassic to Middle Jurassic.
D. Marginal marine mudstone association - mid Cretaceous.
E. Pelagic chalk and marl association - Late Cretaceous to Cainozoic.
F. Volcanic and volcaniclastic rocks - Late Triassic to early Liassic.
G. Manganese nodules and crusts - Neogene.
H. Volcanic and volcaniclastic association - Late Triassic to Early Jurassic.
I. Highly tectonized association - ?Palaeozoic.

An outline of the geological results for pre-Pleistocene material from each sampling area follows. Pleistocene and younger material is covered under Biostratigraphy.

6.1.1 Swan Canyon

Dredge hauls in the Swan Canyon all came from the western slope up to Emu Spur (Fig.27) well below seismic horizon E. Dredges 1,2, and 3 all came from deep water near the northern end of the canyon (5600-4000 m). The predominant rock types were from the Jurassic coal measure association, consisting of gray claystone, mudstone, silty mudstone and fine to medium grained quartz sandstone. The finer grain sizes are either massive, or are laminated to cross-laminated, and frequently pyritic. The sandstones are lighter gray or buff and vary from laminated to massive. The rocks are well-lithified and contain some black coal and siderite nodules. Environments were probably largely paralic. Subordinate rock types in dredges 1 and 2 belong to the shallow marine detrital association. One is a black sticky semiconsolidated clay with bivalve and bone fragments. Another is a (non-calcareous) quartz sandstone. Its grainsize is fine and coarse, and it contains small gastropods and bivalves. The age of these rocks is probably Early Cretaceous, and they were deposited in marginal marine environments. A crinoidal quartz sandstone of the Jurassic shelf carbonate association from dredge 2 contains a limited fauna (see Biostratigraphy). Overall these three dredges suggest that the lower slope lies between horizons E and F, with some younger material also resting on it.

Dredges 7 and 8 came from shallower water further south in the canyon (4700-3150 m). The Jurassic coal measure association was completely missing, and rocks of the shallow marine detrital association predominate. These include gray shale, silty claystone, silty sandstone and fine quartz sandstone. Most are only moderately lithified. The finer grainsizes are organic rich, some contain abundant nannofossils, and most are burrowed.

Bedding varies from massive to thin-bedded to laminated. Deposition was probably in marginal marine, restricted shelf and pro-delta environments. Early Cretaceous ages are indicated, and the seismic sequence sampled was between horizons C and E. Associated rocks from the ferruginous association - Fe claystone and sandy ironstone - probably represent a period of subaerial weathering. A gray porcellanite is an altered pelletal limestone of shallow water origin.

Dredge 1, Lithology L, consists of a black plastic clay, which may be an equivalent of the Muderong Shale. It yielded <u>inter alia</u>, four spherical bodies (three black, one clear) each approximately 0.2 mm in diameter. These may be micrometeorites.

6.1.2 Cygnet Canyon

Dredges 4,5 and 6 came from the eastern wall of Cygnet Canyon in water depths of 3970-3000 m, and dredge 9 from its western wall (Fig. 27) in water depths of 3650-2600 m. The eastern dredges contain a great variety of rocks: ?Jurassic coal measures, Jurassic coal measures, Jurassic shelf carbonates, ?Early Cretaceous shallow marine detrital sediments, and ferruginous claystone, sandstone, boxstone and crusts. Dredge 6, Lithology I, a possible equivalent of the Windalia Radiolarite, contained a single ammonite, 4-5 cm in diameter, which will undergo detailed study. Lithologies B and K, also possible Windalia Radiolarite equivalents, contain an Aptian fauna of foraminifera, radiolaria and bivalves (see Biostratigraphy).

The coal measures, shallow marine detrital sediments and ferruginous sediments are much like those in Swan Canyon, but the shelf carbonates from dredge 4 are a new element (although some were dredged previously on the "Sonne" cruise). They consist of four lithotypes. The first is a yellowish-brown quartz-rich calcareous silty sandstone to calcarenite with molluscan fragments. The second is a pink, well-cemented micro-coquina with oncolites, gastropods and mollusks. The third is a yellowish gray, crinoid rich calcarenite with bivalves, gastropods and bryozoans. The fourth is a yellowish gray to pink, coarse grained, quartz rich calcarenite to calcirudite containing molluscan fragments. These rocks (see Biostratigraphy) also contain echinoid debris, brachiopods, bryozoans and ostracods, and Early-Middle Jurassic foraminiferids. They appear to have been laid down on the shelf or on banks, with some terrigenous influx.

Dredge 9 (3650-2600 m) contains Jurassic shallow marine coquina and calcarenite, chert, and ?Early Cretaceous marine mudstone and siltstone. The carbonates contain bivalves, foraminifera, echinoid spines, ostracods and radiolaria (see Biostratigraphy), as well as rounded carbonate pellets. Yellow calcareous sandstone (Lithology M) from Dredge 9 yielded, in addition to its Jurassic fauna, 20-30 almost perfect, clear, bipyramidal quartz crystals. They appear not be overgrowths of pre-existing quartz grains but to have grown in place.

6.1.2.1 Pelletoid Sediment

The Holocene clay in Dredge 5, Lithology C, is in pellet form, the pellets being 1.5 x 0.5 mm and ovoid. They are made clear in sediment because they are marked at their margin by a rim of Fe oxide staining. They would be worthy of little comment were it not for the fact that the same structure is a characteristic of samples which represent the Windalia Radiolarite in Dredge 7, Lithology C, where on cut slabs the pellets are seen to be the same, but surrounded by pyrite rather than Fe oxide.

It is not known what produces the pellets as faecal material, but worms or echinoderms would be likely candidates. Whatever produced them seem to have undergone little change in bowel habits since the Early Cretaceous.

6.1.3 Echidna Spur

Dredges 10 and 11 came from Bullant Canyon east of Echidna Spur in water depths of 3700-2840 m (Fig. 9). The deeper dredge (10) recovered ?Jurassic coal measures, ?Early Cretaceous marine detrital sediments, and pelagic limestone, chalk and marl. The coal measure and marine detrital sequences are much like those in Swan and Cygnet Canyons. The marine detrital sequence contains abundant foraminifera of Aptian age, along with radiolaria, calcispheres, coccoliths, bivalves, gastropods and brachiopods (see Biostratigraphy).

The pelagic carbonates are varied nanno chalk, foram nanno limestone, and foram nanno marl. Ages determined are Late Santonian - Early Campanian and late Paleocene (see Biostratigraphy).

The shallower dredge (11) contained ?Early Cretaceous marine detrital sediments and pelagic chalks, but no Jurassic coal measures. An additional element was a highly tectonized brown slate with two directions of schistosity, plus a cleavage direction and boudinage structures. This may be a fault related rock but, if not, it is clearly of pre-Mesozoic age. Chalks recovered are of late Oligocene and Pliocene age (see Biostratigraphy).

Dredge 10 presumably intersected outcrop of Jurassic coal measures (pre E horizon), and younger debris, whereas dredge 11 was higher on the slope, intersecting the tectonized (? basement) material, and material from between the E and C horizons, and above the Oligocene unconformity.

6.1.4 Northern Wombat Plateau

Dredges 12,13 and 14 came from the steep northern slope of the Wombat Plateau in water depths of 4600-2690 m (Fig. 29). Dredge 12 was a deep dredge aimed at the volcanic sequence of the Plateau, some of which had been dated earlier as Late Triassic and earliest Jurassic. It recovered a large haul of volcanics: brown very fine grained, aphanitic probable flows, which may prove to be trachyte or andesite, fine grained tuff, and volcaniclastic breccia and sandstone.

Dredge 13 was aimed at the top of the volcanic sequence, and the overlying sedimentary rocks. It recovered a very diverse suite of volcanic rocks, and also ?Early Cretaceous marine claystone, and ferruginous clayey limestone and boxstone. The volcanics include aphanitic basalt, basic or intermediate fine grained amygdaloidal flows, microporphyitic intermediate flows, various tuffs, and volcaniclastic sandstone and conglomerate. Traces of Jurassic fossil-bearing quartz sandstone containing bivalves and foraminifera were also recovered (see Biostratigraphy).

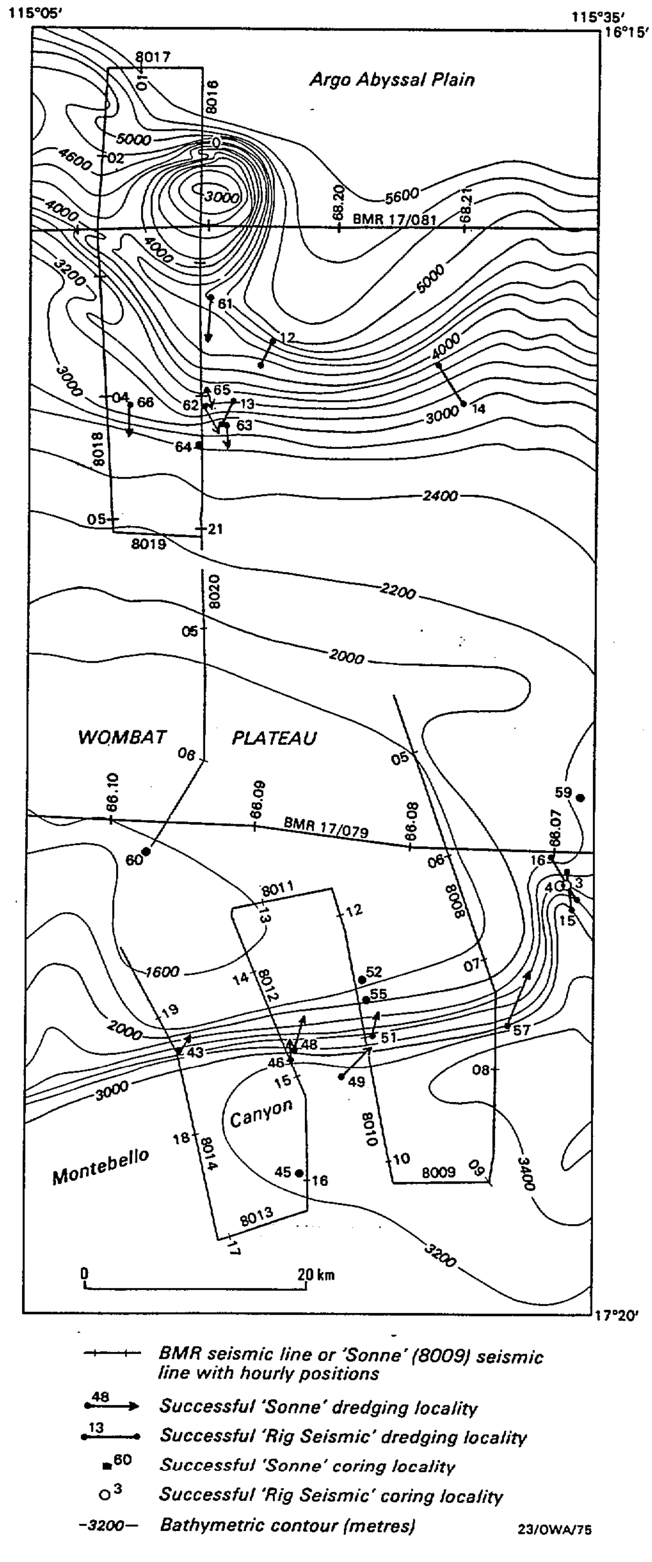
Dredge 14 was aimed at the sediments above the volcanics of the northern Wombat Plateau. Rocks recovered are Late Triassic shallow water carbonates; and pelagic limestones and chalks; Mn nodules and crusts are also present. The shallow-water carbonates are largely cream-coloured very fine grained recrystallized sparitic limestone, and there are lesser amounts of sparitic mollusk grainstone. The fauna includes bivalves, corals, gastropods, echinoderms, forams, ostracods and sponge spicules. The fauna is of Late Triassic age on foraminiferal evidence (see Biostratigraphy), and the rocks were laid down in a shelf environment of low energy. Pelagic rocks include a foraminiferal limestone and a foram nanno marl of late Miocene age. The manganese crusts have a botryoidal surface and are up to 4 cm thick, the thickness suggesting a long period with no sedimentation on the slope where they formed. The manganese nodules have a diameter of 2-5cm. The dredge results confirm the interpretation of the pre-E sequence and C-E sequence on this margin.

6.1.5 Southeastern Wombat Plateau

Dredges 15 and 16 were taken on the southeastern slope of the Wombat Plateau in water depths of 2700-2030 m (Figs. 19 and 29). The dredges recovered Late Triassic to Jurassic shallow water carbonates; ?Triassic red beds; ?Jurassic quartz sandstone; ferruginous claystone; ironstone crusts, boxstones and breccia; and pelagic chalk and silty clay.

Dredge 15, the deeper one, contained purplish gray laminated, quartz-free, carbonate-free, silty claystone which may be Triassic. Other detrital rocks are a ?Jurassic silty, fine grained, calcite-cemented quartz sandstone and a highly porous medium grained sandstone. Shelf carbonates include gray, highly recrystallized microsparitic limestone, and a less recrystallized former grainstone. Pelagic rocks include a Quaternary semiconsolidated marl, and a foram nanno chalk of late Miocene age.

Dredge 16, the shallower one, contained several types of shelf



29. Bathymetry, tracks, dredge and core sites on Wombat Plateau.

carbonate, one of which, a very coarse echinoderm-crinoid-mollusk limestone, contains Late Triassic foraminiferids (Biostratigraphy). Other types are very poorly sorted crinoid bryozoan breccia and a finer biocalcarenite which is a packstone. The fauna includes a minute ammonite, bryozoans, gastropods, bivalves, corals, brachiopods, crinoids and foraminifera. The ammonite, 0.2 mm in diameter, was recovered from Lithology B. It is well preserved, but probably too small to be specifically identifiable. Minor rock types are calcareous, medium grained quartz sandstone, clayey ironstone boxstone, and Quaternary silty clay.

The dredges clearly show that the slope is composed dominantly of Triassic and Jurassic rocks. The interpretation of the F horizon cropping out on the slope is thus strengthened.

GC03 contained a late Miocene chalk at the base.

TABLE 1: CORING RESULTS, CRUISE 56

Core	Area	Lat.(S)	Long.(E)	Water depth (m)	Recovery	Comments
GC01	Emu Spur	16 48.3	117 29.0	3500	0	Probably no contact
GC01A	Emu Spur	16 46.8	117 29.0	3780	321cm	Quat. nanno ooze
GC02	Emu Spur	16 48.2	117 29.0	3560	0	Pipe fell off head.
GC03	SE Wombat	16 58.5	115 33.5	2400	223cm	Quat. nanno ooze; late Miocene nanno chalk in core cutter.
GC04	SE Wombat	16 58.5	115 33.3	2160	243cm	Quat. nanno ooze.

6.2 DREDGE STATIONS, CRUISE 56

Station	Between Lat(S) Long(E) begin/end	Seismic profile	Depth (m)	Recovery	Description of main rock types
DR 01 Swan Canyon (west side)	16 44.8' 117 33.8' 16 45.7' 117 32.2'	56-25B 56-24	5600- 5450	45 Kg	? Jurassic coal measures: gray fissile shale, silty mudstone, and brownish gray silty fine sandstone (A2,3,4). ? Early Cretaceous marine: dark gray clay (D3).
DR 02 Swan Canyon (west side)	16 46.2' 117 33.8' 16 46.1' 117 32.7'	56-25C 56-24	5500- 4000	75 Kg	? Jurassic coal measures: gray silty to sandy shale, silty mudstone and light gray quartz sandstone (A2,3,4). ? Early Cretaceous marine: brownish marly clay (D2).
DR 03 Swan Canyon (west side)	16 47.0' 117 33.6' 16 47.0' 117 31.4'	56-25C 56-24	5400- 4000	75 Kg	? Jurassic coal measures: dark gray silty claystone with some siltstone laminae and buff laminated quartz sandstone (A2,3,4).
DR 04 Cygnet Canyon (east side)	16 50.4' 117 23.4' 16 51.0' 117 26.5'	S08-04 56-25F	3970- 3360 (pulls 3970-3830m)	80 Kg	Ferruginous association: Fe claystone, sandstone, and boxstone (B1,2,3). ?Jurassic coal measures: medium gray claystone (A2). ?Early Cretaceous marine: buff semi-consolidated claystone (D5). Callovian shallow water carbonates: yellowish gray quartz-rich and crinoidal cal-arenite (C2,3,4,8).
DR 05 Cygnet Canyon (east side)	16 50.5' 117 24.1' 16 50.5' 117 25.7'	S08-04 56-25F	3800- 3300	5 Kg	?Jurassic coal measures: medium gray semicon-solidated silty clay-stone (A2). Ferruginous association: Fe box-stones and goethite crusts (B3).
DR 06	16 50.7'	S08-004	3700-	50 Kg	?Early Cretaceous marine:

Cygnet Canyon (east side)	117 25.5' 16 51.0' 117 27.5'		3300		gray, brown and buff claystone, sandy mudstone and quartz sandstone(D2, 4,6). Ferruginous association: Fe boxstones(B3).
DR 07 Swan Canyon (west side)	16 51. ' 117 34.3' 16 51.9' 117 32.3'	56-25A	4700- 3870 (pulls 4470- 4280m)	10 Kg	?Early Cretaceous marine: gray shale, silty sandstone & quartz sandstone (D3,4,6). Pelagic chalk association: gray porcellanite (C9).
DR 08 Swan Canyon (west side)	16 52.5' 117 32.7' 16 53.7' 117 29,5'	56-25A	4070- 3170 (pulls 4030- 4000m)	15 Kg	?Early Cretaceous marine: gray silty claystone, shale & quartz sandstone (D3,4,6). Ferruginous association: Fe claystone & sandy ironstone (B1,2,5).
DR 09 Cygnet Canyon (east) side)	16 49.5' 117 22.5' 16 50.3' 117 18,3'	S08-004	3650- 2600	55 Kg	?Early Cretaceous marine: gray silty sandstone & sandy mudstone(D2,4,6,7) ?Jurassic shallow water carbonates: coquina & calcarenite, cherty limestone, chert(C1,3,4). Pelagic chalk association: late Miocene chalk (E1).
DR 10 Echidna Spur (east side)	16 51.4' 116 46.2' 16 51.2' 116 46.2'	56-28A	3790 -3710 (pull 3760m)	10 Kg	?Early Cretaceous marine: gray claystone (D5,6). ?Jurassic coal measures: reddish brown sandy mudstone (A6). Pelagic chalk association :gray nanno limestone, chalk & marl (Santonian, late Paleocene) (E3,5,6).
DR 11 Echidna Spur (east side)	16 51.0' 116 46.2' 16 50.5' 116 45.2'	56-28A	3230- 2840 (pulls 3225- 3215m)	8 Kg	Tectonized association: reddish brown tectonized silty slate (I). ?Early Cretaceous marine: silty shale & clay, clayey siltstone to sandstone (D6). Pelagic chalk association: late Oligocene & late Miocene chalk (E1).
DR 12 N Wombat Plateau (slope)	16 30.8' 115 17.6' 16 31.9' 115 17.0'	56-14	4600- 3500	50 Kg	?Triassic volcanic association: brown fine grained volcanics (?trachyte-andesite), fine grained tuff, breccia (H4,8). Thick

					Mn crusts (G2).
DR 13 N.Wombat Plateau (slope)	16 34.0' 115 15.6' 16 35.1' 115 15.0'	56-14	3380- 2800	100 Kg	?Triassic volcanic association: dark gray basalt, brown microporphyritic intermediate volcanics, amygdaloidal basic or intermediate volcanics (?trachyte-andesite), buff tuff, coarse volcaniclastic sandstone (H1,4,7,8). Ferruginous association: clayey ironstone / boxstone (B2,3). ?Early Cretaceous marine: gray mudstone (D2,6). Jurassic shallow water carbonates: fossiliferous quartz sandstone.
DR 14 N.Wombat Plateau (slope)	16 31.3' 115 26.5' 16 34.0' 115 27.8'	56-13	3440 2690	80 Kg	Late Triassic shallow water carbonates: cream sparitic limestone with shelly macrofauna (C2, 4,6). Pelagic chalk association: foram nanno limestone and chalk (E5,6). Mn crusts & nodules (G1, 2).
DR 15 SE Wombat Plateau (slope)	16 59.5' 115 33.7' 16 57.6' 115 33.2'	56-13	2720- 2030	5 Kg	?Triassic redbeds: silty mudstone (D6). ?Jurassic coal measures: gray silty quartz sandstone (D4). ?Jurassic shallow water carbonates: recrystallized limestone (C6). Pelagic chalk association: stiff beige silty clay (E6).
DR 16 SE Wombat Plateau (slope)	16 59.0' 115 34.0' 16 56.8' 115 32.7'	56-13	2570- 2040 (pulls 2480-2200m)	10 Kg	?Early Cretaceous marine: gray medium quartz sandstone (D4). Late Triassic shallow water carbonates: shelly & crinoid limestone breccia, & biocalcarenite (C2,4). ferruginous association: claystone, ironstone crusts, boxstones, breccia (B1,3). Pelagic chalk association: ?Cainozoic stiff calcareous clay (E6).

Table : Lithofacies (microfacies = MF) types of pre-Quaternary dredge samples of Rig Seismic S6 cruise (and of Sonne-8 cruise)

Age : ( ) estimate, * forams (Quilty), ** microfacies (Schott), + rads (Thurow), ++ polynom/dinoflag (Brenner/Burger)

	MF Type	Colour and generalized lithology	Tentative facies interpretation (paleoenvironment)	Age	Occurrence in R.S.56 dredge samples
Coal measure assoc.	A1	Black vitreous coal (subbituminous)	Paralic (coal swamp)	M.-Lt.Jur++	Only in SO-8 samples
	A2	Grey (brown) carbonaceous (plant-rich) silty clayst)		)	01A & A1,04C4,06E,08E,08-I,09E?,15A
	A3	Grey (brown) carbonac. mica-rich qtz siltst to v.f. sandstone)	Paralic (fluviatile, flood plain, delta...)	)(?Triassic/) ?Jurass.)	01C2,01G,01H,03B,06E,?08D,08E,09A, 15C
	A4	Grey (brown) fine to med. (coarse) qtz sandstone)		)	07A,15B
	A4a	-ditto, but phosphatized -)		)	16A
	A5	reddish-brown sandy smectite/kaolin shale	Paralic, flood plain?	)(?Triass/	?091,10L,10-0,
	A5a	-ditto, but phosphatized -		) Jurass.)	4E1,10D
	A6	Siderite concretions & sideritized clayey qtz siltst etc	Paralic, coal swamps, ?also neritic marls	)	01H,01-I,07C, 11C
Ferrugin assoc.	B1	reddish-brown clayey ironstone	terrestrial/paralic) later subaerially	)	10M
	B2	reddish-brown ferrugin.qtz sdst (sandy ironstone) and ironstone	fluviatile/littoral) exposed to arid conditions	)(? Jurass.))	02G,04C2,8E
	B3	brown ferruginous concretions & boxstones & ironstone breccia	terrestrial	)	04C4,06-Ia&b, 16D
Shallow-water carbonate assoc. (Lt. Triassic - ?M. Jurassic)	C1	Algal biosparite/grainstone (calcirudite)	Shallow platform, no terrigen. influx,)	(Lt.Triass.)	16B1,16B2
	C2	Cream-col. coral biolithite/framestone	algal or other high-energy reef (perirefal)) platform : coral reef, ± sessile foraminif.) Subtidal no terrigen. influx)	(Lt.Triass.)	14B1 c.f.Oberhaet-Riffkalk
	C3	yell.-grey qtz-rich, fine-grained biopelspar./grain packstone	well-sorted, near-shore environm.))	Lt.Triass**	04-I
	C4	lt.-grey, fine-grained, qtz-rich biopelspar./ grainstone	high-energy intertidal flat))	))	09-K
	C4a	sideritized, qtz-& plant-bearing ?pelsparite/grainst.	nearshore, ?deltaic influence) intertidal) (to shallow-	))	02H
	C5	bivalve-dasycladacean coquina/bioclastic packst.	Coquina-"tempestites", local) subtidal) deeps in platform)	))(Lt.Triass**)	09M2
	C6	oomicrosparite/grain-to packst. w. terrig.qtz	?tidal channels : redeposition) of ooids in adjacent quiet water)	))	09M1
	C7	pink oosparite/grainstone	high-energy tidal bars)	)	04G1
	C8	light-yell.-grey biomicrite/wackestone	adjacent-marine subtidal platform below wave base	))	09H
	C8a	red.-brn, ferruginized (+dolomitized) qtz-rich micrite/wackest.	Subtidal w. terrigen. influx	)	11A, ?14C

Shallow-water carbonate assoc. (Lt. Triassic -?M Jurassic)	C9	yell.-grey encrinite/bioclastic,qtz-rich crin. packst.	foreslope of platform slope or outer shelf) calcaren. turbidites)	)	))	04K,04H1
	C10	yell.brn biomicrite/wacke-mudstone w.bioclastic horizons and terr.qtz	turbidity currents into deeper-marine platform margin w.pelagic background sed.	)resediment)carbonate	))	13M 13M
	C11	chaotic microbreccia w.echinoderm fragments, lithoclasts & terr. qtz	poorly sorted local grain flows(?)	)	)(Liassic to)?Dogger)	10E
	C12	echinoderm biomicrite/bioclastic packstone	transition of autochth. C13/14 to C9-11 (local resedimentation of bank sediment)	))	)**)	14B2
	C13	reddish biomicrite/wackstone	deep bank deposit of fragmented carbonate platform	)± autoch-) thonous	))	13L c.f. Adneth Liassic Red Ls.
	C14	biomicrite/spiculitic wackestone	hemipelagic basin sediment	)	)	14E.14A c.f. Allgäu Fleckenkalk
	C14a	Lt.-grey dolomitized micrite/wackstone	basin sediment?	)	)	09L
Marg-marine to bathyal clayst assoc.	D1	Kaolinitic dark-grey(-brown), qtz & mica-rich, plant mat.-bearing claystone	?prodelta mudst (?Muderong-equivalent) transition - D1 & A5!		?M. Cret. (Apt.++)	07B,09B,09E?,10L?
	D2	green/brown smectite-rich silty claystone, also kaolinite	flood plain or prodelta?		?Jur./?Cret.	11B,?10-0
	D3	buff/white, qtz-,foram-, nanno-bearing palygorskite claystone	marginal marine (?prodelta)		M.Cret.	06C, 14D
Pelagic marls & chalks (± silicified)	E1	Lt.green-grey hemipelagic, qtz-bear. foram. nanno marl	hemipelagic-bathyal		M-Lt.Cret	10F,?14C
	E1a	pelagic foramin. biomicrite/packstone	winnowed foram.sand-bathyal		?Lt.Cret-Tert	16C
	E2	lt.-grey qtz-bearing radiolarian-foramin.marl, porcellaneous (opal-CT + clinoptilolite)	hemipelagic-bathyal-high-productivity (? upwelling). ?Windalia Radiol.-equiv.		Albian+ (M.Cret.)	06A,06D,06G1 & 2, 10B
	E3	porcellanite = silicified, terrig. qtz-bearing rad.(-for.) marlstone (opal-CT>diag.qtz)	hemipelagic-bathyal, as above		?M.Cret.	06K,10C2
	E4	qtz-chert = silicified foram. chalk (cryptocryst.qtz >opal-CT)	as above, diagenetically more mature		(?M.Cret.)	10H
Volcanic & volcaniclastic rocks	H1	highly altered (?tholeiitic) basalt	?		?	13B, ?13C
	H2a	Lt.-yell-brn aphanitic, felsic volc.rock) (potassic rhyolite))	?felsic early rift volcanism dated in SO-8 rhyolites as 213-192 Ma old		)Late Triass)to early	12A1, ?13C
	H2b	brown(alkali) rhyolite with porphyric texture) (large qtz & sanidine phenocr.))			)Liassic)(K-Ar)	12A2
	H3	brown altered tuff and tuffaceous sandstone)			)	13G,?13H.13-1
	H4	epiclastic, volcaniclastic breccia/altered lapilli tuff (± phosphatized)))	subaerial (or shallow-submarine?) deposition of volcaniclastics		))	12B, 12D, 13F
	H5	bentonitic smectite claystone, buff-grey)			)	13E1 & 2, ?13H, 13K1

6.3 BIOSTRATIGRAPHY

Palaeontological studies on board R.V. "Rig Seismic" included analysis of foraminiferid faunas, limited studies of macrofaunas, comparison of lithology and processed residues with those known to the author from the onshore Carnarvon Basin and ad hoc aspects where appropriate.

Studies of foraminifera have identified Late Triassic, Early or Middle Jurassic and a great diversity of Cretaceous and Cenozoic faunas. Age information derived from the planktonic faunas of the Cretaceous and Cainozoic can be taken as firm but those from the Triassic and Jurassic must be tentative at both taxonomic identification and age assignment levels. The Jurassic and Triassic faunas received priority in post-cruise studies.

Shipboard processing was restricted to sampling lithologies which could be disaggregated using hydrogen peroxide, simple soaking or washing, or simple boiling. A few nannofossil slides were made to test presence/absence.

6.3.1 Triassic

The most rewarding result of the foraminiferid studies was the identification of several Late Triassic marine samples which yielded abundant, diverse faunas with strong Tethyan affinities. Triassic foraminiferids have not been documented properly from Australia although Triassic marine sediments are known from Western Australia and Queensland. Although foraminiferids were sought in the Perth Basin (Early Triassic Kockatea Shale), Canning Basin (Early Triassic Blina Shale) and Carnarvon Basin onshore (Early Triassic Locker Shale) the author has had little success in even recognizing Triassic foraminiferids. Oil company drilling in offshore northwestern Australia has penetrated good marine Triassic sequences but their foraminiferid faunas have not been documented in the literature. Foraminiferids were recorded from the Sydney Basin Triassic by Chapman (1909) but this has now been discounted.

The Late Triassic fauna is recorded here from Dredges 14 (north Wombat Plateau) and 16 (southeast Wombat Plateau).

6.3.1.1 Dredge 14

Four samples representing lithologies B,C,E and F are taken as of Late Triassic (Norian ?) age although only three (B,C,E) contain an identifiable Triassic fauna. The sample from Lithology B contains the best Late Triassic fauna from the voyage including the following forms:

- _Diplotremina_ cf _subangulata_ Kristan-Tollman
- _D._ (?) cf _multifimbriata_ Fuchs

- Involutina communis (Kristan)
- Involvina cf obliqua Kristan-Tollman
- polymorphinids etc.,

Of these I. communis, I. obliqua and D. subangulata are indices for the Norian.

In addition to the foraminiferids the sample contains a branching colonial hexacoral fragments of bivalves and echinoids, and abundant ostracods. The coral will be identifiable by an expert in this field.

The rocks consist of a moderately indurated massive chalky limestone which although appearing ideal, did not yield coccoliths in smear slides. It lacks any obvious bedding or other sedimentary structures. The environment of deposition seems to have been fully marine, low energy and of sub-tropical to tropical water temperature. Depth of deposition was within the photic zone, say less than than 100 metres.

The sample from Lithology E consists of a yellow ferruginous saccharoidal friable calcarenite of uniform medium sand size grains. It contains internal moulds of foraminiferids including Diplotremina cf subangulata and thus also is Norian. In addition it yielded ostracods, sponge spicules, bivalve and gastropod fragments.

The samples from Lithologies C and F do not contain an identifiable Triassic fauna but the lithological similarity (chalky limestone and white fine saccharoidal calcarenite respectively) and the presence of ostracods the same as those in B and E suggest a similar age and environment of deposition.

6.3.1.2 Dredge 16

This sample is of an orange-brown coarse, poorly sorted ferruginous biocalcarenite with an abundant diverse fauna of small macrofauna including an ammonite (c. 0.2 mm in diameter), bryozoans, flat and high spired gastropods, nuculid bivalves, discoid solitary corals, terebratulid brachiopods and the crinoid Pentacrinites.

The foraminiferid fauna is rich but not particularly diverse. The dominant element is Involutina communis (Kristan), a Norian index (although also occuring rarely in the Carnian). Other elements required considerable post-cruise study before they could be adequately identified and their significance documented. They all appear to be consistent with a Carnian age (sensu Zaninetti) which includes the Rhaetian. The fauna lacks the Tethyan elements of dredge 14.

6.3.2 Jurassic

Jurassic faunas were recovered from the Swan Canyon - Emu Spur - Cygnet Canyon region (dredges 2,3,4 and 9) and from the northern Wombat Plateau (dredge 12). Some of the records are based on weak evidence and must be regarded as very tentative. Quilty has recorded the first Early Jurassic foraminiferids from Australia from R.V. "Sonne" cruise 8A at Wombat Plateau. They were Sinemurian-

Pliensbachian in age. The newly recorded faunas contain no species in common with those already known and may be a little younger.

The only documented Jurassic foraminiferid faunas from Australia are those from the Newmarracarra Limestone (Middle Jurassic, Middle Bajocian) of the Perth Basin and those recorded by Quilty (op. cit.) from the Early Jurassic. One of the new faunas from dredge 4 contains elements in common with the Newmarracarra Limestone fauna but an age equivalence has not yet been shown.

6.3.2.1 Dredge 4

The best faunas come from two ferruginous biocalcarenite samples of Lithology I. The rocks are crinoidal quartz sandstone with Pentacrinites, echinoid spines and plates, bivalves including Inoceramus, terebratulid brachiopods and bryozoans. Much of this macrofauna is broken, attesting to a high energy environment. Ostracods are also present.

Foraminiferids include

- Trocholina cf nodulosa Seibold and Seibold
- T. sp. 2
- Citharina sp.
- Frondicularia sp.
- Lenticulina sp.
- Astacolus sp.
- Tristix sp.
- ? Conorboides sp.

The age of the fauna is not yet narrowed down but the rocks appear to be Early - Middle Jurassic. This fauna will also be given priority in post voyage study.

The rocks accumulated in a shallow marine, high energy environment. No water temperature data are available.

Lithology A in dredge 4 contains bone fragments and overgrown echinoderm debris, the latter suggesting a possible origin similar to those listed above.

6.3.2.2 Dredge 2

Lithology H contains a much less diverse fauna, including only Trocholina, Lenticulina, and Frondicularia in common with dredge 4. The rock is a similar reddish, well sorted, crinoidal quartz sandstone with angular grains. Inoceramus is again an important bivalve component. Lithology H(4) appears to be Callovian in age.

6.3.2.3 Dredge 3

Dredge 3 contains black shale with (?) sideritic concretions up to at least 15 cm diameter. It is very similar lithologically to the Dingo Claystone but is barren of any fossil material. Its suggested age is based only on lithological comparison.

6.3.2.4 Dredge 9

Dredge 9, Lithology M has yielded three samples taken as Jurassic. Two consist of yellow calcareous, micaceous sandstone, one including the bivalves Oxytoma and Inoceramus. This sample also has the foraminiferids Frondicularia and a polymorphinid, both with a Jurassic aspect. The other yellow sandstone is barren of fossils and its age is based on lithological comparisons.

This same sample, alone among all studied, contains many excellently preserved, clear bipyramidal quartz crystals which appear to have grown in place without the need for a seed grain in the core.

Some of the yellow sandstones in dredge 9 have depressions in them, apparently caused by biological activity, up to some 2 cm in diameter and 1 cm deep. They have been filled with white crinoidal limestone consisting of very poorly preserved crinoid ossicles, echinoid spines and a few foraminiferids, including Frondicularia and Spirillina akin to those found in the yellow sandstone itself. Ostracods are also present. The Jurassic age is based on faunal similarity but it is a weak basis.

Dredge 13 (north Wombat Plateau) produced a yellow sandstone bonded by a white argillaceous "cement". The quartz is not clear and not monocrystalline but consists of large grains of turbid quartzite in contrast to most other quartz grains seen. The sample contains the bivalve Inoceramus in addition to crinoid ossicles, bone fragments and the foraminiferid Trocholina sp., the same species as recorded in Jurassic sediments identified above. The environment of deposition is marine, shallow water, high energy.

6.3.3 Cretaceous

All samples assigned to the Cretaceous come from the Swan Canyon - Emu Spur - Cygnet Canyon region in dredges 1,2,4,6,7,8,9,and 10. Several from the Aptian and younger contain excellent faunas of planktonic microfossils including radiolara and (?) calcisphaerulids. A second group of sporadically fossiliferous samples is either barren of fossils or contains a fauna and lithology reminiscent of the Muderong Shale fauna and lithology.

In the Carnarvon Basin the Cretaceous sequence above the "intra - Neocomian" unconformity consists of Late Neocomian - Aptian Muderong Shale of an marginal marine aspect, overlain by the Windalia Radiolarite, characteristically very rich in radiolaria. The age is debated but Late Aptian is a commonly believed age and is consistent with results discussed below.

Above the Windalia Radiolarite is the Gearle Siltstone , commonly divided into Albian Lower (essentially a non-calcareous grey shale with or without glauconite and small barite bodies, occasionally formed into major concretions in outcrop) and Upper (a more open marine Cenomanian - Early Turonian more calcareous phase often with planktonic foraminiferids towards the top).

Thus radiolaria are essentially absent below the Late Aptian but can occur in sediments well above that level.

6.3.3.1 Muderong Shale or equivalent (Aptian)

The following samples are taken as Muderong Shale or equivalent. The basis is included in parenthesis.

Dredge 1 - Lithology J - 3 samples (soft grey shale either barren or with few very poor indices such as traces of unidentifiable shell material or foraminiferids, microscopic plant fragments)

Dredge 1 - Lithology L - one sample - soft dark grey shale (Saccammina sp., bivalve internal mould, evidence of framboidal pyrite, bone fragment, therefore marine and consistent with Early Cretaceous marine)

Dredge 2 - Lithology B,C - soft dark grey or brown shale with small plant fragments and trace glauconite)

Dredge 4 - Lithology B and unnamed lithology on lip of dredge - soft grey shale (microscopic plant remains, traces pyrite, pyrite-cored rod shaped structures)

Dredge 7 - Lithology B - soft grey shale (microscopic plant fragments, traces of bivalves, either small Inoceramus or Aucellina on bedding surfaces, finely burrowed and therefore marine and likely to be Early Cretaceous)

Dredge 8 - Lithology B - soft grey shale (traces marine microfossils and microscopic plant fragments)

Dredge 9 - unnamed lithology - mixed with Tertiary faunas (poor lithological comparison - a weak identification)

Dredge 10 - Lithology D - soft grey shale (excellent Muderong shale foraminiferid fauna, diverse and abundant including Glomospira, Rhizammina spp., Trochammina spp.).

Core 1A - fragments of grey shale in otherwise Quaternary core - soft pale shale (with microscopic plant remains and traces of bone with traces of interbedded ferruginous fine quartz sandstone).

Identification as Muderong Shale may appear weak in many instances but the processed residues are typical of processed Muderong Shale. A Late Aptian or younger age is unlikely as such sediments are calcareous and/or radiolarian rich. Older sediments are more lithified.

6.3.3.2 Windalia Radiolarite or equivalent (Aptian)

The samples included here are united by the presence of considerable numbers of radiolaria, with or without foraminiferids. All are very fine grained white or pale greenish massive sediments. Samples are from dredges 4,6 and 10.

6.3.3.3. Dredge 4

Lithology B from dredge 4 contains abundant radiolaria and is lithologically similar to the Windalia Radiolarite.

6.3.3.4 Dredge 6

Five samples from dredge 6 are included here.

The sample of lithology A is a soft massive, pale green, finely laminated claystone lacking foraminiferids. The assignation is based on lithology only but is strengthened by other lithologies in the same dredge haul.

Lithology B appears to be a softer variant of the Windalia Radiolarite but is much richer in carbonate than the Windalia normally is. This is however a feature of seve al Windalia correlated samples in dredges 6 and 10. The excellent total fauna included abundant <u>Hedbergella</u> as well as radiolaria (freed well by processing) and what seems to be calcisphaerulids (probably <u>Pithonella</u> sp.).

Lithology I yielded an ammonite (see later notes) covered with a ferruginous weathering crust. This crust consists in places of a boxwork incorporating radiolarian rich clay which probably is an equivalent of the Windalia. Radiolaria are the only microfossils recovered.

Lithology K yielded two similar samples with apparently very differen ages, one Late Aptian, one Cenomanian. The latter will be discussed later.

The Late Aptian fauna comes from a shelly conglomeratic bed associated with a well bedded, highly calcareous, well sorted medium calcarenite. The conglomerate is pinkish grey in colour with broken bivalves, sandstone clasts and fragments of Windalia Radiolarite and would appear to be a shallow water, high energy deposit. It contains a very rich planktonic foraminiferid fauna of Late Aptian age. Key forms are : -

<u>Globigerinelloides algeriana</u> Cushman and Ten Dam
- genus internec <u>Hedbergella - Ticinella</u>
- <u>Hedbergella</u> sp.

Rather than a shallow water deposit it may represent shallow and deep elements mixed by slumping.

6.3.3.5 Dredge 10

Lithology B consists of a soft apparently radiolarian claystone. Strew mounts show that it consists of three main elements, radiolaria, calcisphaerulids and coccoliths. The calcisphaerulid element is of smaller specimens than the radiolaria but constitutes an important part of the fauna. The foraminiferid element contains no Aptian indices but the common nodosariid element is typically mid Cretaceous. Other elements are the bivalve <u>Inoceramus</u> and traces of bone.

Lithology C appears to be typical Windalia Radiolarite lithology and planktonic foraiminiferids appear to be present in broken fragments. Further processing of both dredge 10 samples is required.

Lithology H is of solid limestone which contains typical Windalia Radiolarite as clasts in a high energy deposit with fragmented strongly ribbed ivalves, gastropods and terebratulid brachiopods.

6.3.4 Late Cretaceous Carbonates

Dredge 6 included shelly fine sandstone genetically akin to the Late Aptian conglomerate from the same dredge (see above). The age appears to be quite different. Both contain faunas of similar structure and environment of deposition. The sample is also included in Lithology K but is Middle to Late Cenomanian rather than Aptian in age. Key species are :

- Globigerinelloides bentonensis (Morrow)
- Hedbergella amabilis Loeblich and Tappan
- H. brittonensis Loeblich and Tappan
- H. planispira (Tappan)

The composition of the fauna would suggest an outer continental shelf, low energy environment.

Dredge 10 yielded two interesting faunas. One - Lithology Q - is a very small (ca. 1 cm) sample which yielded both Late Cretaceous and Late Paleocene faunas. The Late Paleocene is referred to later. The Late Cretaceous fauna can only be described as magnificent in diversity, abundance and preservation. The fauna and ag are basically the same as those documented from the Toolonga Calcilutite by Belford (1960), but is much more diverse, reflecting the deeper water aspect of the fauna. Key species include :

- Gublerina decoratissima (de Klasz)
- Schackoina cenomana (Schacko)
- S. multispinata (Cushman and Wickenden)
- Heterohelix globulosa (Ehrenberg)
- H. pulchra (Brotzen)
- H. striata (Ehrenberg)
- Globotruncana cf. arca (Cushman)
- G. linneiana linneiana (d'Orbigny)

This is of Late Santonian - Early Campanian age.

The same dredge was hung up on the seafloor and the dredge on recovery contained a thin veneer of yellowish tough clay on the yoke. This was assigned to lithology E. It contains a very well preserved residue dominated by thick shelled white, excellently preserved Inoceramus in a form typical of its occurrence in the Korojon Calcarenite, a facies variant of the Toolonga Calcilutite In addition it contains abundant coarse, sand sized, concentrically laminated Fe oxide grains similar to those known from the same onshore Late Cretaceous sediments.

An equivalence with the Korojon Calcarenite is indicated as is a period of subaerial weathering at about this time.

6.3.5 Tertiary

Tertiary faunas are dominantly of planktonic forms of warm water aspect. They are quite well known and can be dated quite quickly in zonal schemes such as those proposed by Blow (1969). That system is employed here.

Tertiary and younger rocks and faunas are somewhat incidental to the main aims of the voyage which were Mesozoic and they are neither as abundant nor discussed in as much detail.

6.3.6 Paleocene

Paleocene foraminiferids were recovered in one very small sample only - Dredge 10 - Lithology Q - and then only as incidental to the excellent Late Cretaceous fauna in that chalk. Few specimens were recovered but they include the key species :

- Globorotalia pseudomenardii Bolli
- G. chapmani Parr
- G. simulatilis (Schwager)
- Globigerina nitida (Martin)

These are consistent with a Late Paleocene age, P4 (G. pseudomenardii zone) in the scheme of Blow (1969). This age is well known in marine Tertiary sequences around the Australian (particularly Western) coast. This is an equivalent of the Cardabia Group of the onshore Carnarvon basin or Kings Park Shale of the Perth area.

6.3.7 Eocene

No Eocene faunas were recovered.

6.3.8 Oligocene

An excellent Late Oligocene (N3 fauna was recovered from Dredge 11 - Lithology F. The fauna is diverse, abundant, very well preserved and shows no signs of dissolution. It is a clean white chalk. The only accompaniment to foraminiferids in the residue consists of a few ostracods. Key species include :

- Globigerina binaiensis Koch
- G. venezuelana Hedberg
- G. sellii (Borsetti)
- G. tripartita Koch
- Globorotalia kugleri Bolli

This fauna shows that the chalk is the age equivalent of the lower part of the Mandu Calcarenite of the Carnarvon Basin. No equivalent is yet known from the Perth Basin.

6.3.9 Miocene

Dredge 9 - Lithology C - contains {{Globorotalia peripheroacuta}} Blow and Banner attesting to the presence of a Middle Miocene (N 10/11 of Blow) element in an otherwise Late Miocene fauna.

All other Miocene faunas are of the same age (Late Miocene N17 - N18; take for simplicity, N18 to be Miocene rather than half Miocene, half Pliocene).

Samples from :

- Dredge 9, Lithology C and two others unnamed
- Dredge 14, Lithology D
- Dredge 15, Lithology G
-Gravity Core 3, core catcher sample

are all taken as Late Miocene because of the presence of some or all of the following:
- Globoquadrina dehiscens dehiscens (Chapman, Parr and Collins)
- G. altispira altispira (Cushman and Jarvis)
- Globigerinoides conglobatus (Brady)
- Sphaeroidinellopsis seminulina kochi Caudri
- Pulleniatina primalis Banner and Blow
- Globigerina venezuelana (Hedberg)
- Globorotalia tumida tumida (Brady)
- Beella praedigitata (Parker)

Most are white chalk but two deserve further brief comment.

One sample from Dredge 9, unnamed lithology, yielded a residue consisting of a mixture of sand and foraminiferids rather than a purely biogenic residue The sample from Dredge 14 contains virtually no keeled globorotalids suggesting that it is from a cooler water interval than other samples examined. This may reflect a very late Late Miocene age. approximating that of the Messinian "salinity crisis".

6.3.10 Pliocene

A white chalk sample (Lithology G) from dredge 11 consists of an early Pliocene foraminiferid fauna characterized by :
- Globigerina nepenthes Todd
- Candeina nitida d'Orbigny
- Sphaeroidinellopis paenedehiscens Blow
- Globoquadrina altispira (Cushman and Jarvis)

It is a rich fauna lacking any evidence of dissolution.

6.3.11 Quaternary

The Quaternary was divided by Blow (1969) into two zones, N22 and N23, the latter representing the last 12 000 years only (Holocene) and N22, the rest (Pleistocene). Not all authors are happy that the zones can be so well differentiated. However faunas recovered here can be placed generally in one zone or the other. The differentiation is made here but its significance is under some cloud.

6.3.11.1 Pleistocene

The following are taken as Pleistocene (N22) in the absence of N23 indices.

- Dredge 2, Lithology A, white ooze
- Dredge 9, unnamed lithology, yellow clay
- Dredge 15, Lithology D, yellow clay
- Dredge 16, Lithology E, yellow clay

They are characterized by the presence of **Globorotalia truncatulinoides** (d'Orbigny), the internationally accepted index for the Quaternary.

Three of the above samples have planktonic foraminiferids associated with yellow clay samples rather than the expected ooze or chalk. The association appears to be real rather than an artifact of dredging. Evidence of dissolution is lacking except in the Dredge 2 sample where two faunas seem mixed - one having signs of dissolution with preservation in the form of glauconitic moulds and the other showing no signs of dissolution at all.

6.3.11.2 Holocene

All dredges yielded pipe dredge modern ooze samples. Not all have yet been fully examined.

Other samples can be divided into ooze or chalk lacking terrigenous debris, and those of yellow clay. The ooze or chalk samples are from:

- Dredge 1, Lithology M, several samples
- Dredge 2, unnamed lithology, several samples
- Dredge 3, Lithology A
- Dredge 4, unnamed lithology
- Dredge 5, Lithology C
- Gravity Core 1A, core catcher
- Gravity Core 4, above Late Miocene sample.

The yellow clay samples with modern fauna are from

- Dredge 3, Lithology C
- Dredge 4, Lithology B
- Dredge 5, Lithology S
- Dredge 10, unnamed lithology
- Dredge 13, Lithology O.

All samples are characterized by the presence of either or both - **Sphaeroidinella dehiscens excavata** Banner and Blow - **Globorotalia ungulata** Bermudez.

6.3.13 Ammonites

A very small Triassic ammonite, 0.2 mm in diameter, was recovered from Dredge 16, Lithology B. It is well preserved but probably too small to be of any use.

Dredge 6, Lithology I, Windalia Radiolarite, produced a single ammonite some 4-5 cm in diameter. It will be studied further.

6.3.13 Cruise 54 Samples

The opportunity was taken to examine two sets of samples taken on Cruise 54 but not studied since. One set consists of Dredges 1 and 2 from the Perth Basin part of that cruise. The samples are noteworthy in providing evidence for a considerable extension of the known distribution of Late Paleocene (P4) of the Perth Basin. This will be studied further.

The other set consists of samples from Gravity Core 16, Outer Exmouth Plateau. The core catcher contains what appears to be Gearle Siltstone with quite a significant foraminiferid fauna and small discoid structures quite characteristic of that formation. Age would be in the Albian to Cenomanian.

CHAPTER 7
SYSTEMS RESULTS

7.1 DATA ACQUISITION SYSTEM

7.1.1 General

The objectives of this Exmouth Plateau cruise were the collection of multichannel seismic data for framework petroleum potential studies and to define ODP well site locations for future occupation, and sampling of sites defined by seismic profiling carried out earlier on the cruise. Because of these requirements the cruise offered a considerable challenge in providing high accuracy navigation in deep water. A major effort has been mounted by the Division of National Mapping (NATMAP) to provide a HIFIX radio navigation system in a difficult and remote environment.

The Data Aquisition System computer is still managing to acquire and process the data without any particular difficulties even though the demand from external users is increasing. Details of non-seismic data channels are given in Appendix D. A considerable amount of post processing was carried out during the cruise to produce raw data profiles on the ZETA plotter. A full equipment list is given in Appendix B.

7.1.2 Navigation

Positioning of the ship was derived from a hierarchy of three largely independent systems. The hierarchy of navigation was a) Global Positioning System (GPS) , b) HIFIX radio navigation and c) dead reckoning.

The vessel is fitted with a Magnavox T-SET GPS receiver which can navigate to an accuracy of approximately 20 metres rms under optimum conditions. Due to the necessity to have at least two satellites visible in order to operate, the coverage of the GPS is limited to about 10 - 12 hours each day. It was found however that the coverage was somewhat less than the maximum possible due to problems either within the T-SET receiver or with the satellites themselves. At times the receiver gave worse results when four satellites were visible than when three were visible. A major problem also occ rs when two satellites were received after a 'dead' period. The T-SET receiver determines a frequency bias between its external atomic standard and the satellite frequency and this bias is used to calculate the position when only two satellites are visible. For some reason, as yet undetermined, the receiver is holding an incorrect bias figure during the satellite 'dead' periods and this causes large artificial jumps in position when navigation starts again with two satellites. These are problems that will require further investigation.

The HIFIX system is typically used for position fixing over distances of 100-200 kms where shore transmitters can be located to provide acceptable accuracy in hyperbolic range mode. The Exmouth Plateau exercise required operation in the range 300-500 kms while the shape of the coastline meant a restrictive shore station geometry. As a result, only two transmitters were likely to be received at any one time. The HIFIX was therefore operated in a pseudo-range mode by using two atomic standards, one to stabilise the on-board receiver and the other the on-shore master transmitter. In theory the only error is the drift between the two standards. Shore stations were set up at Karratha, Onslow, Exmouth and later at Ningaloo and Gnaraloo, and their co-ordinates are given in Appendix C. Only three transmissions can be received at any one time. The prime transmitter was at Onslow for the northern chain and Ningaloo for the southern chain, with Exmouth as a common slave station. HIFIX reception on the ship has proven successful most of the time despite the long range. Onslow and Exmouth have been picked up 24 hours per day with a tendency to lose lane lock between dusk and midnight local time when over the western side of the Plateau. Less success has been obtained with Karratha and similarly with Ningaloo when night time reception was almost nonexistent. The main problem appea s to be due to loss of lock between the shore stations rather than with the on-board receiver. Despite these problems, adequate real-time navigation (25-50 metres) has been achieved over much of the plateau for most of the cruise. When a comparison was made between the dead reckoning system and the HIFIX at each transit satellite fix, and when T-SET was operational, the HIFIX gave consistently better results. This was true even when the HIFIX was operated at long distances (400 km), with poor geometry (15 degrees station separation), and with reasonably noisy data.

Due to fortunate circumstances the GPS operated for a large part of the night an so we were able to get accurate fixes from it at night and from the HIFIX during the day. Also, by a small alteration within the DAS software we were able to not only detect lane jumps in the HIFIX but were able to tie the HIFIX positions down to either the T-SET or to the transit satellite fixes.

7.1.3 Dead Reckoning System

Two independent systems incorporating gyro compass, dual-axis sonar doppler log and satnav receiver provide basic dead reckoning for periods where the other systems prove inadequate. The primary dead reckoning system of Arma-Brown gyro, Magnavox MX610D sonar doppler and MX1107RS satnav receiver provides the best available positioning of this type. A lower grade system of Robertson gyro, Raytheon DSN450 sonar doppler and MX1142 satnav receiver is the backup.

The transit satellite fix information from both the MX1107 and the MX1142 are saved, in blocks of 20 floating point words, when it becomes available. The data from each navigator is in a similar form, each being identified by the first word. The raw satellite fix data from the MX1107 transit satellite receiver is saved every 2 minutes during each satellite pass as a block of 600 single words. These data are saved in the Magnavox 702 emulation mode. The first 4 words of each block (4 F.P. words) identify the block, 702, and the start time of the block. Details of the data transmitted by the transit satellite fixes are given in Appendix E.

Both sonar-doppler systems have problems in rough weather or when heading into the sea due to air being trapped under the hull and blanking the transmission of all sonar systems. A small paddle wheel log is still under test as a way of validating the information coming from the sonar dopplers. It should allow identification and rejection of suspect data at such times. was also used to maintain vessel separation during WACDP work.

7.1.4 Bathymetry

Bathymetric data was obtained using 3.5 kHz and 12 Khz Rayheon echo sounders. For most of the cruise these both gave very good results, due more to the good sea conditions than to any technical reasons. Both systems still tend to loose resolution when any moderately rough weather occurs, especially when the vessel is head-to-sea.

7.1.5 Magnetics

The vessel is fitted with two magnetometers which can be operated in a gradiometer configuration via a cable fitted with two sensors. Consistently smooth data was obtained for most of the cruise. However, due to an unforunate incident the gradiometer cable was damaged during a deployment about half way through the cruise and this necessitated using the single sensor system while repairs were carried out. The deployment of the magnetometer cable is still a major operation and a continuing source of trouble due to the lack of a convenient location for the winch holding the magnetometer cable.

7.1.6 Gravity

Gravity data were collected with the Bodenseewerke KSS-31 marine gravity meter and, as usual, it gave almost no problems.

7.2 SEISMIC ACQUISITION SYSTEMS

7.2.1 Conventional CDP Data Acquisition

To enable the modification of a general system to cope with the variations required for ESP and WACDP profiles, changes were needed to the basic philosophy of the system timing. Previously, shot interval, acquisition delay and acquisition rate timings were intermingled providing an opportunity for illegal interrupts to corrupt the system and bring it to a halt.

The clock interrupt program in which the 0.1 sec clock interrupt is serviced, now handles the shot firing and the acquisition delay. The current shot rate is converted into a negative counter which is incremented until it reaches zero. Control on the interface card responsible for the pulse to the firing box is set and the guns fire. The shot interval is then reset and the process repeated.

After the shot is fired a secondary counter which handles the acquisition delay is set and incremented on each interrupt. When this counter has reached zero, the Time Base Generator interface card, which is used to control the acquisition rate, is set to give a 1/2, 1, 2 or 4 millisec pulse depending on the recording interval required.

This pulse is used to start acquisition of the seismic data. A further counter is kept in synchronization with the TBG and reset on each firing of the air-guns, allowing a check on the shot interval to better than 1 millisec accuracy. The control of the shot firing is therefore separate from the aquisition process and can be modified without affecting that process.

On previous cruises, trouble has been encountered with the writing of data to magnetic tape, especially immediately after tape changes. The tape drive units have been checked by the manufacturer and found to be within specifications. To ensure that faults do not occur with the tape writing process, the dynamic status of the tape drives is checked before any attempt is made to write or move the tape. This allows for such error conditions as tape drive off-line and no write-ring to be detected and an appropiate error message to be posted. No data will attempt to be written to the tape until this condition has been rectified.

A colour display of the seismic streamer's depth has been fully incorporated and has been used successfully to aid in the control of the streamer's depth. but no control is set to fire the guns, thus producing a non-shot acquisition cycle.

7.2.2 Single Channel Data Aquisition

Single channel seismic data were collected on three profiles, totalling 50 km, and effectively assisted in locating a dredge site. A cable for the purpose was configured with one active section (four 25m groups), one water break/depth transducer, three stretch sections at the front and one at the rear and using a Norwegian buoy as a tail buoy. Fifty metres of armoured leader were deployed for gross balance of the cable and one adjustable bird attatched for fine depth control. One 8 litre airgun was used. The Seismic Aquisition System was configured as a four channel seismic system with channel 3 being used for monitor display of a single channel record; the system defaulted to an overall 8 channel system. Data were of good quality and were recorded on magnetic tape.

CHAPTER 8
CONCLUSIONS

Data collection for the sedimentary basin framework study of the Exmouth Plateau was successfully completed during BMR Cruises 55 & 56. Good quality regional multichannel data totalling 950 km were collected over the northern plateau margin along with dredge samples from 16 locations and cores from three locations, and 1150 km of multichannel seismic data were collected on the western margin. These data will be used along with existing data in a re-evaluation of the structure and stratigraphy of the plateau and its margins and of their hydrocarbon potential.

Detailed multichannel seismic surveys for the sampling program, and as a basis for Ocean Drilling Program (ODP) site proposals, amounted to a further 550 km of good quality data. A number of ODP site proposals were prepared. Geological samples obtained range in age from Triassic to Recent, and their environments of deposition vary from abyssal marine to terrestial. Marine Late Triassic carbonates, not encountered on an earlier sampling cruise by R.V. "Sonne", were dredged on the northern margin, along with numerous other sedimentary and igneous rock types. Preliminary biostratigraphic ages were obtained during the cruise and they assisted in refining the geological history of the northern margin, and dating seismic horizons. The results showed how effective detailed sampling of the continental margin can be.

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APPENDIX A : GEOPHYSICAL DATA SET, BMR CRUISE 56

LINE	TIME START GMT	TIME FINISH GMT		WAY-POINT LATITUDE DEG S	WAY-POINT LONGITUDE DEG E	TAPES	LINE LENGTH	DATA COLLECTED
3	101:0927	101:2239	SOL	20 19.00	112 51.00	56/001-023	126	W2 G M N B
4	101:2240	102:0909		20 48.50	111 45.00	56/024-042	100	W2 G M N B
			EOL	21 26.00	111:0600			
5	102:1548	102:1659		ABORTED		56/043-044		
5	103:1957	104:0445	SOL	21 30.00	111 35.00	56/045-058	84	CR4 GM N B
			EOL	21 15.50	111 18.25			
6	104:1018	104:2008	SOL	21 26.00	111 06.00	56/059-075	86	W3 G M N B
			EOL	22 13.00	111 30.00			
7	104:2009	105:2205	SOL	22 13.00	111 30.00	56/076-120	242	W4 G M N B
			EOL	23 16.00	113 33.00			
8	105:2331	106:0510	SOL	23 14.50	113 28.50	56/121-129	53	C5 G M N B
			MP	23 39.00	113 16.00			
9	106:1249	106:2345	SOL	23 21.00	112 41.00	56/130-146	102	C4X G M N B
			MP	22 59.00	112 56.50			
10	107:0211	107:1303	SOL	22 34.00	113 06.00	56/147-164	101	C3X G M N B
			MP	22 53.25	112 46.00			
11	107:2004	108:0705	SOL	22 17.00	112 37.00	56/165-182	103	C2X G M N B
			MP	22 57.00	111 58.00			
12	108:1042	108:1730	SOL	22 09.00	112 20.00	56/183-193	64	C1 G M N B
			MP	22 29.75	112 02.00			
13	110:0815	111:0806	SOL	17 58.00	115 46.00	56/194-248	223	S G M N B
			EOL	16 18.00	115 25.00			
14	111:0806	112:0331	SOL	16 18.00	115 25.00	56/249-293	181	S G N M B
			EOL	17 39.00	114 37.00			
15	112:0331	112:0736	SOL	17 39.00	114 37.00	56/294-303	38	S G M N B
			EOL	17 20.00	114 37.00			
16	112:0736	112:1312	SOL	17 20.00	114 37.00	56/304-316	52	S G M N B
			EOL	17 15.00	115 10.00			
17	112:1312	113:1120				56/317-367	207	SOA G M N B
17A			SOL	17 15.00	115 08.00			
			EOL	17 00.00	115 05.00			
17B			SOL	17 00.00	115 05.00			
			EOL	17 00.00	114 54.00			
17C			SOL	17 00.00	114 54.00			
			EOL	17 06.00	114 59.50			
17D			SOL	17 06.00	114 59.50			
			EOL	17 16.00	115 03.00			
17E			SOL	17 16.00	115 03.00			
			EOL	17 11.00	114 58.00			
17F			SOL	17 11.00	114 58.00			
			EOL	17 06.00	115 11.00			
17G			SOL	17 05.20	115 10.00			
			EOL	17 09.00	114 09.00			
17H			SOL	17 09.00	114 09.00			
			EOL	17 11.00	115 04.00			
17I			SOL	17 11.00	115 04.00			
			EOL	17 15.00	115 07.00			
17J			SOL	17 15.00	115 07.00			
			EOL	17 15.00	115 08.00			

18	113:1120	113:1745	SOL	17 15.00	115 08.00	56/368-382	60	S G M N B
			EOL	17 11.90	115 38.80			
19	113:1745	114:0550				56/383-410	113	SOB G M N B
19A			SOL	17 11.90	115 38.80			
			EOL	17 08.40	115 37.80			
19B			SOL	17 08.40	115 37.80			
			EOL	17 09.80	115 32.40			
19C			SOL	17 09.80	115 32.40			
			EOL	17 16.00	115 33.80			
19D			SOL	17 16.00	115 33.80			
			EOL	17 15.20	115 39.70			
19E			SOL	17 15.20	115 39.70			
			EOL	17 11.50	115 41.00			
19F			SOL	17 11.50	115 41.00			
			EOL	17 06.50	115 32.00			
20	114:0550	114:1637				56/411-435	101	SOC G M N B
20A			SOL	17 06.50	115 32.00			
			EOL	16 57.20	115 29.00			
20B			SOL	16 57.20	115 29.00			
			EOL	16 55.70	115 36.00			
20C			SOL	16 55.70	115 36.00			
			WP	16 56.80	115 36.00			
			EOL	16 37.80	115 30.70			
20D			SOL	16 37.80	115 30.70			
			EOL	16 55.30	115 30.00			
20E			SOL	16 55.30	115 30.00			
			EOL	16 54.20	115 35.00			
20F			SOL	16 54.20	115 35.00			
			EOL	16 57.80	115 35.30			
21	114:1637	115:0338	SOL	16 57.80	115 35.30	56/436-461	103	S G M N B
			EOL	17 01.50	116 32.00			
22	115:0338	115:2246	SOL	17 01.50	116 32.00	56/462-505	179	S G M N B
			EOL	15 53.00	117 40.00			
23	115:2248	116:0331				56/506-516	41	SOD G M N B
23A			SOL	15 53.00	117 40.00			
			EOL	15 56 40	117 41.00			
23B			SOL	15 56.40	117 41.00			
			EOL	15 56.50	117 30.50			
23C			SOL	15 57.20	117 30.50			
			EOL	15 58.00	117 34.50			
23D			SOL	15 58.00	117 34.50			
			EOL	15 59.80	117 36.20			
24	116:0331	116:1402	SOL	15 59.80	117 36.20	56/517-541	98	S G M N B
			EOL	16 54.00	117 28.50			
25	116:1402	117:1005				56/542-601	237	SOE G M N B
	117:1149	117:1722						
25A			SOL	16 54.00	117 28.50			
			EOL	16 45.00	117 49.50			
25B			SOL	16 45.00	117 49.50			
			EOL	16 45.00	117 17.00			
25C			SOL	16 45.0	117 17.00			
			WP	16 47.50	117 17.00			
			EOL	16 47.50	117 39.00			
25D			SOL	16 47.50	117 39.00			
			EOL	16 52.50	117 39.00	25E		SOL 16 52.
			EOL	16 52.50	117 34.50			
25F			SOL	16 50.00	117 34.50			
			EOL	16 49.60	117 43.50			

25G			SOL	16 49.60	117 43.50			
			WP	16 52.50	117 43.50			
			EOL	16 52.50	117 37.50			
25H			SOL	16 52.50	117 37.50			
			EOL	16 48.00	117 25.70			
25I			SOL	16 48.00	117 25.70			
			EOL	16 52.30	117 30.00			
26	117:1722	118:0150	SOL	16 52.30	117 30.00	56/602-621	70	S G M N B
			EOL	17 20.00	117 03.00			
27	118:0150	118:0751	SOL	17 20.00	117 03.00	56/622-635	56	S G M N B
			EOL	17 47.00	116 55.00			

S	48 channel seismic reflection
SOn ODP	deep ocean drilling program seismic reflection site survey
Rn	sonobuoy
En ESP	expanded spread profile using airguns
EXn ESP	expanded spread profile using airguns to the midpoint and explosives for the remainder of the line.
CRn CR	Cape Range ESP
CRXn CR	Cape Range as for EXn
Cn	Canarvon Terrace ESP
CXn	Carnarvon Terrace ESP as for EXn
Wn WACDP	wide aperture constant depth profile
*n	n is the line number
SOL	start of line
MP	midpoint of line
WP	way point on line, line number unchanged
EOL	end of line
G	gravity data
M	magnetic data
N	navigation data
B	bathymetry

APPENDIX B : EQUIPMENT LIST

B.1 GEOPHYSICAL

B.1.1 Primary Seismic Systems

2400 m Teledyne hydrophone streamer cable; minimum group length of 12.5 m; maximum 96 channels.

Syntron RCL-2 idividually addressable cable levelers.

3 BOLT 1500C airguns, each of 500 cu in (8.2 l) capacity, with wave-shape kits; one or two guns, fired simultaneously, would normally be used.

Teledyne gun signature phones and gundepth sensors, and Input/Ouput SS-8 shot-instant transducers (1 each per gun).

3 Price A-300 compressors, 300 scfm each; output pressure 2000 psi.

1 Price AGM W2 compressor, 200 scfm; output pressure 2000 psi.

B.1.2 Secondary Seismic Systems

2 Teledyne 28420 single-channel hydrophone streamers.

1 BOLT 1500C airgun of 100 cu in (1.6 l) capacity, with wave-shape kit.

Reftek 6 sonobuoy receiver.

Teledyne 28990 acoustic beacon cable location system.

B.1.3 Bathymetric Systems

Raytheon deep-sea echo sounder; 2 kW maximum output at 3.5 kHz.

Raytheon deep-sea echo sounder; 2 kW maximum output at 12 kHz.

B.1.4 Magnetic System

2 Geometrics G801/803 proton precession magnetometers; may be used as standard single-sensor cable or in horizontal gradiometer configuration.

B.1.5 Gravity meter System

1 Bodenseewerk Geosystem KSS-31 Marine Gravity Meter.

B.2 NAVIGATION

B.2.1 Prime Systems

(1). Magnavox G.P.S. T-Set

(2). Decca Hi-Fix

(3). Magnavox MX1107RS dual channel satellite receiver.
Magnavox MX610D sonar doppler speed log.
Arma-Browm SGB1000 gyro-compass.

B.2.2 Secondary System

Magnavox MX1142 single channel satellite receiver.

Raytheon DSN450 sonar doppler speed log.

Robertson gyro-compass.

B.3 COMPUTER EQUIPMENT

B.3.1 Non-Seismic Acquisition System (DAS)

Hewlett-Packard 2113 F-Series 16-bit minicomputer with 512 kw of memory.

2 x Hewlett-Packard 7905 15 Mb, moving-head disc and multi-access disc controller.

2 x Hewlett-Packard 7970E 1600 bpi, 9-track magnetic tape drives.

Facit cassette recorder. Hewlett-Packard 12979 I/O extender.

Hewlett-Packard 2748A paper tape reader. BMR-designed and built

16-channel digital multiplexer (up to 3). BMR-designed and built

16-bit gyro/speed log interface.

Phoenix 6915 15-bit analogue-to-digital multiplexer.

GED, NCE, or CHRONOLOG digital clocks (x2).

KSR-43 teletypes, TELEVIDEO TVI-910 VDU's, and EPSON RX-80 line printers (various combinations).

KAGA RGB colour monitors (up to 7) driven through RCA microcomputers.

W & W 6-pen strip-chart recorders (x3).

CALCOMP 1044 8-pen high-speed 36-inch drum plotter.

B.3.2 Seismic Acquisition System (MUSIC)

Hewlett-Packard 2113 E-Series 16-bit minicomputer with 1 Mega word of memory (acquisition system).

Hewlett-Packard 2117 F-Series 16-bit minicomputer with 256 kw of memory (development system).

Hewlett-Packard 7905 15 Mb moving-head disc drive and multi-access disc/cpu controller.

3 x Hewlett-Packard 7970E 1600 bpi, 9-track magnetic tape drives.

Phoenix 6915 15-bit analogue-to-digital multiplexer.

BMR-designed 48-channel SMF-1 computer-controlled preamp/filters.

KSR-43 teletype and TELEVIDEO TVI 910 VDU.

EPSON MX-100 dot-matrix line printers (x4).

EPSON MX-100 shot logger.

Tektronix 611 X-Y storage CRO.

BWD 804 single-channel CRO.

BWD 845 dual-channel storage CRO.

CHRONOLOG digital clock.

BMR-designed and built NTM-1 marine timing unit.

B.3.3 Hi-Fix Acquisition System (Hi-Fix)

Hewlett-Packard 2108 M-Series 16-bit minicomputer

BMR-designed and built 16-channel digital multiplexer

TELEVIDEO TVI-910 VDU

B.3.4 Sub-bottom Profiler Acquisition System}}

Hewlett-Packard 2108 M-Series 16-bit minicomputer.

Facit Cassette recorder.

Phoenix 6915 15-bit analogue to digital multiplexer.

TELEVIDEO TVI-910 VDU

EPC Graphic Recorders (up to 4)

B.4 GEOLOGICAL EQUIPMENT

Chain bag dredges

Small pipe dredges (to trail behind chain bag dredges)

Gravity corer

Laboratory equipment including palaeontological and petrological microscopes

APPENDIX C: CO-ORDINATES OF HI-FIX TRANSPONDERS

STATION	LATITUDE		LONGITUDE	
Withnell Bay	20	34.939	116	48.440
Onslow	21	38.119	115	6.654
Vlaming Head	21	48.363	114	6.314
Ningaloo	22	40.090	131	41.183

APPENDIX D : NON-SEISMIC DATA CHANNELS

The following is a list of the channel allocations for the non-seismic data for the Exmouth Plateau cruises.

Main Data

The main data is saved on magnetic tape every 60 seconds in **blocks of 80 X 6 floating point words.**

1 - Clock (Survey and Day Number)
2 - Acquisition time (GMT) from computer clock
3 - Master clock time at acquisition
4 - Latitude, best estimate (Radians)
5 - Longitude, best estimate (Radians)
6 - Speed, best estimate (knots)
7 - Heading, best estimate (degrees)
8 - Magnetometer no. 1
9 - Magnetometer no. 2
10 - Depth no. 1
11 - Depth no. 2
12 - F/A Magnavox sonar-doppler (counts)
13 - P/S Magnavox sonar-doppler (counts)
14 - F/A Raytheon sonar-doppler (counts)
15 - P/S Raytheon sonar-doppler (counts)
16 - Paddle log
17 - Seismic shot point time .HHMMSSD **
18 - Instrument room gyro (degrees)
19 - Bridge gyro (degrees)
20 - Seismic shot number **
21 - not used
22 - not used
23 - not used
24 - not used
25 - Hifix Fine A (centilanes)
26 - Hifix Fine B (centilanes)
27 - Hifix Fine C (centilanes)
28 - Hifix Coarse A (centilanes)
29 - Hifix Coarse B (centilanes)
30 - Hifix Coarse C (centilanes)
31 - T-SET not used
32 - T-SET time (GMT seconds)
33 - T-SET Dilution Of Precision (DOP)
34 - T-SET latitude (radians)
35 - T-SET longitude (radians)
36 - T-SET height above geoid (metres)
37 - T-SET speed (knots X 10)
38 - T-SET course (degrees X 10)
39 - T-SET frequency bias
40 - T-SET GMT (.HHMMSS)
41 - Latitude, Magnavox Sonar-Doppler
42 - Longitude, Magnavox S-D/Brown gyro
43 - Latitude, Raytheon S-D/Ship's gyro
44 - Longitude, Raytheon Sonar-Doppler
45 - Latitude, radio-nav (or MX1107 speed/gyro)
46 - Longitude, Radio-nav (or MX1107 speed/gyro)
47 - not used

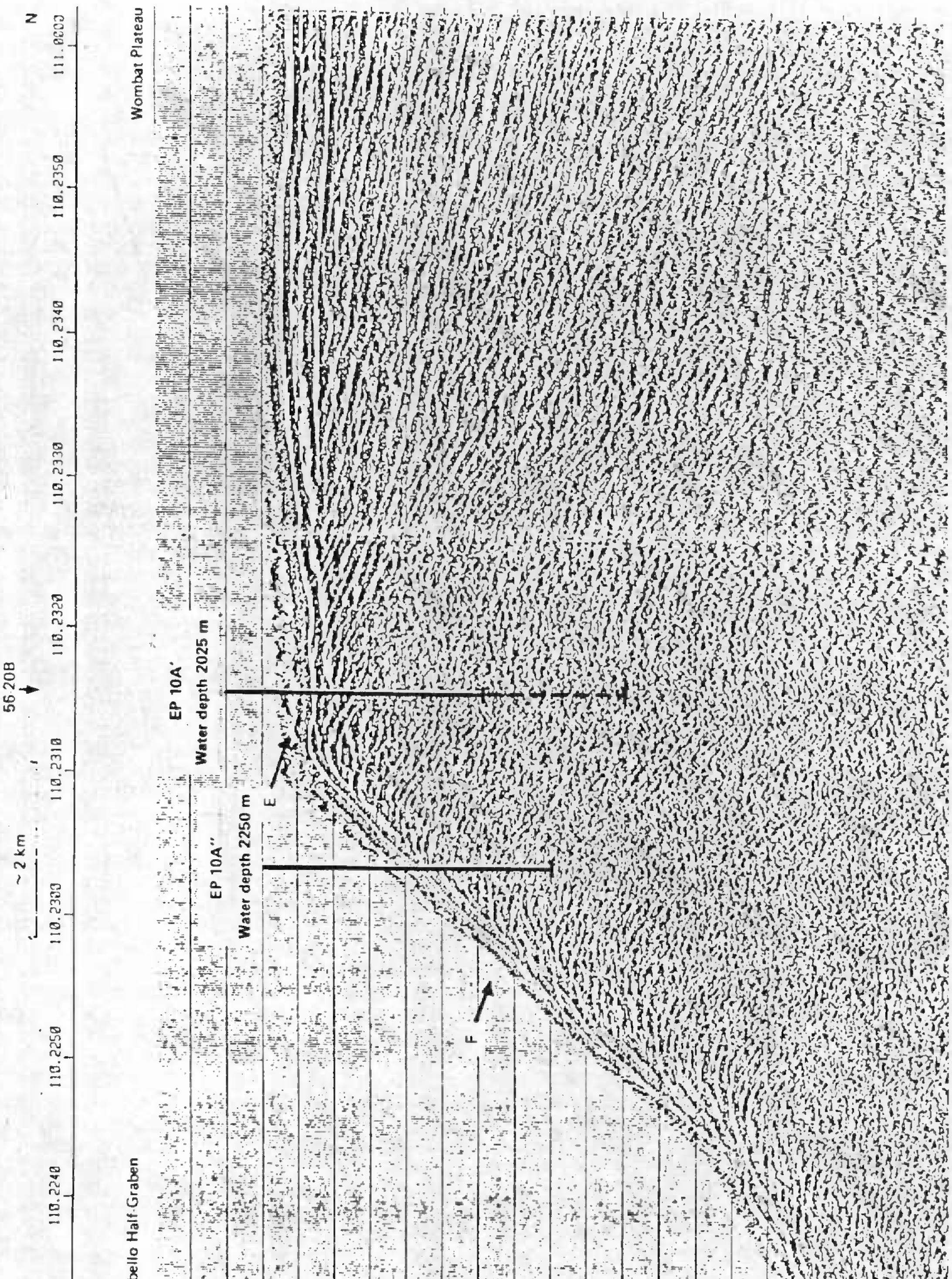
48 - not used
49 - not used
50 - GMT from Magnavox MX1107 sat nav
51 - Dead Reckoned Time from MX1107
52 - Latitude (radians) MX1107
53 - Longitude (radians) MX1107
54 - Speed (knots) MX1107
55 - Heading (degrees) M 1107
56 - Set (degrees) M 1107
57 - Drift (knots) MX1107
58 - Set/Drift flag, 0=manual, 1=auto
59 - GMT from Magnavox MX1142 sat nav
60 - Dead Reckoned Time from MX1142
61 - Latitude (radians) MX1142
62 - Longitude (radians) MX1142 63 - Speed (knots) MX1142
64 - Heading (degrees) MX1142
65 - Set (degrees) MX1142
66 - Drift (knots) MX1142
67 - Set/Drift flag, 0=manual, 1=auto
68 - Vector speed, Magnavox sonar-doppler
69 - Vector speed, Raytheon sonar-doppler
70 - Vector speed, paddle log **
71 - Vector heading, Magnavox Sonar-Doppler
72 - Vector heading, Raytheon Sonar-Doppler
73 - Vector heading, paddle log **
74 - Gravity (mGal * 100)
75 - ACX (m/s/s * 10000)
76 - ACY (m/s/s * 10000)
77 - Sea state 78 - Magnetics difference (gradiometer)
79 - AGRF magnetic anomaly no. 1
80 - AGRF magnetic anomaly no. 2

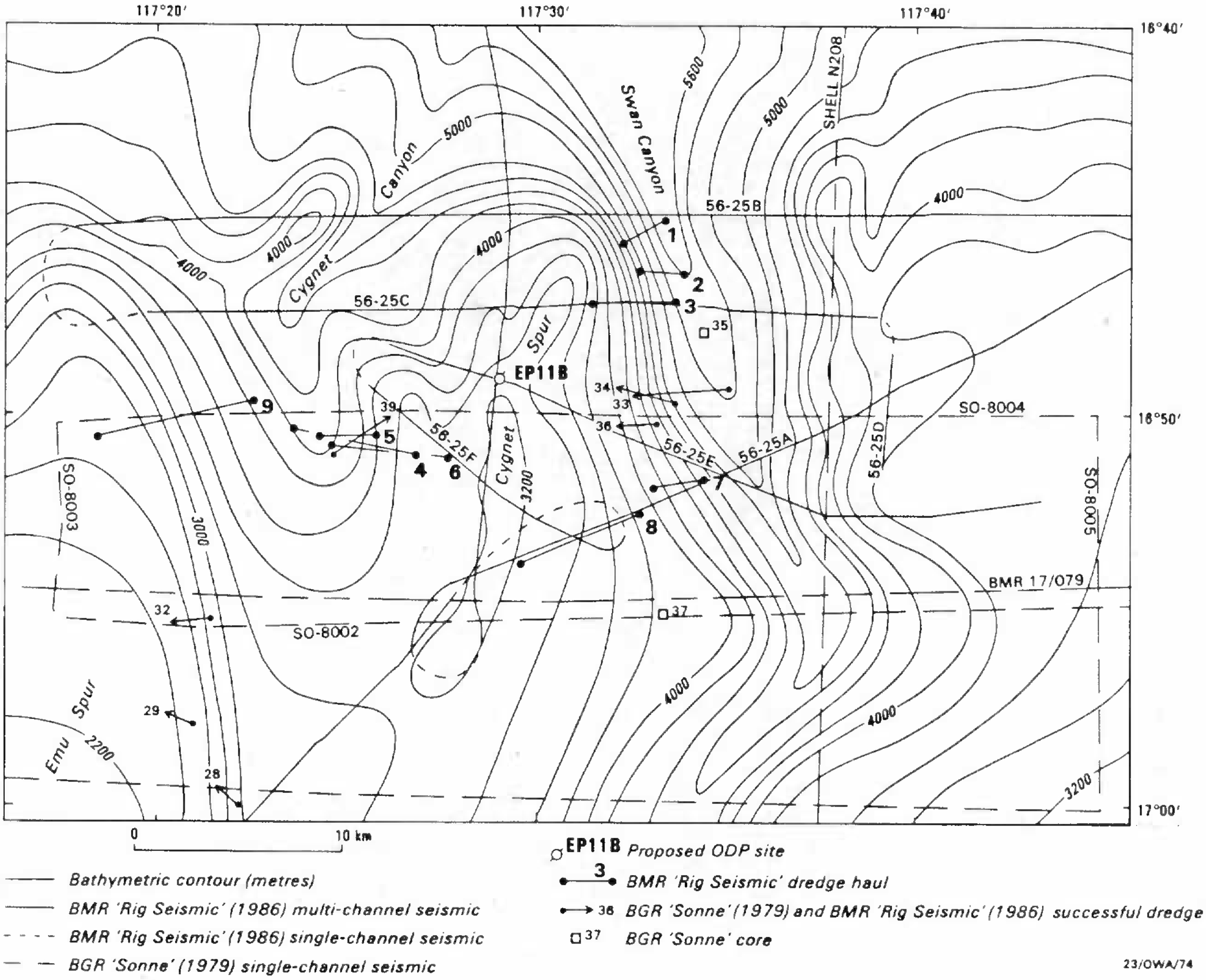
N.B. Those channels marked ** were only used after the 10th April 1986.

APPENDIX E : DATA TRANSMITTED BY TRANSIT SATELLITES

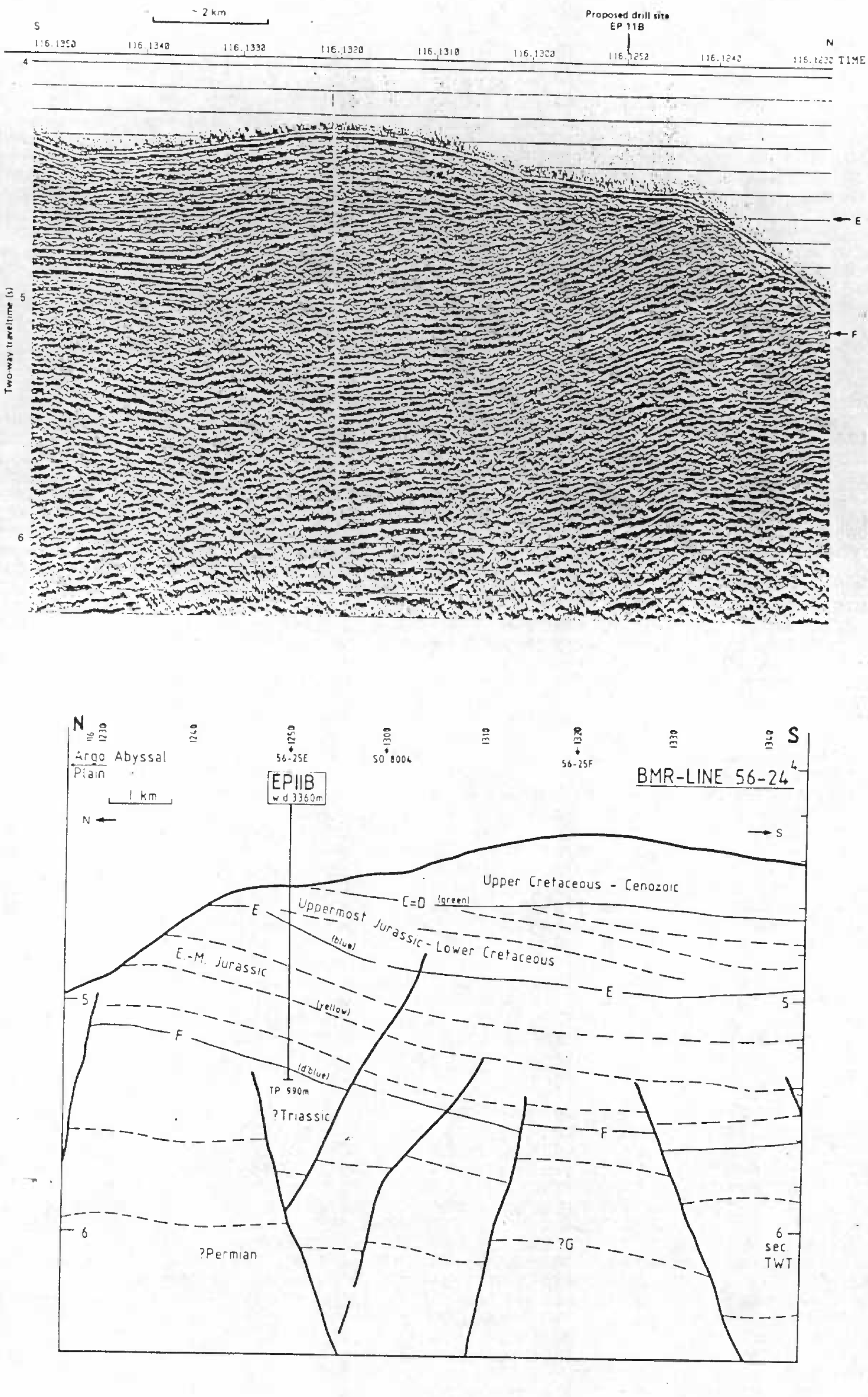
1 - 1107 or 1142
2 - Day number (1107) or dat2 (1142)
3 - GMT
4 - Latitude (radians)
5 - Longitude(radians)
6 - Used Flag (0 = not used; 1 = used)
7 - Elevation (degrees)
8 - Iterations
9 - Doppler counts
10 - Distance from DR (naut miles) 11 - Direction from DR (degrees) 12 - Satellite number 13 - Antenna height (metres) 14 - 20 - Doppler spread flags (1107 only)

24. BMR seismic monitor record 56/13 across Site EP10A on southeast Wombat Plateau.





25. Bathymetry, location of proposed Site EP11 and main cross-ties of Swan Canyon-Emu Spur area of the northeast Exmouth Plateau. Shows RIG SEISMIC & SONNE dredge sites.



26. Site EP 11B on BMR seismic profile 56/24.