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GEOPHYSICAL RESULTS FROM THE SOUTHWEST CONTINENTAL MARGINS OF AUSTRALIA

by

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CONTENTS

CONTENTS (Cont.)

PLATES

SUMMARY

During 1970-1973 a marine geophysical survey of the continental margins of Australia and Papua New Guinea was conducted for the Bureau of Mineral Resources. Survey objectives were to investigate sediment distribution and upper crustal structure by recording bathymetric, seismic, gravity, and magnetic data. 10 000 line miles were surveyed around southwest Australia. The traverses extended to a water depth of 5000 m and included the Naturaliste and Wallaby Plateaus.

Sediment is generally less than 1 km thick on the Naturaliste and Wallaby Plateaus, though in the eastern half of the former it is over 2 km thick. The Naturaliste sequence includes two major unconformities, and the Carnarvon Terrace another. The steep parts of the continental slopes are rugged and dissected by erosion channels and canyons. The slope and Carnarvon Terrace are covered by at least 0.5 km of sediment.

Gravity results indicate that crustal thickness on the Naturaliste and Wallaby Plateaus is intermediate between those of continent and ocean.

Magnetic anomalies are intense over the Naturaliste Plateau, but need more work for accurate definition. To determine the age of the unconformities drill holes would be required, preferably in areas where seismic data are available. Information on the age of unconformities and type of basement, in conjunction with the present data, would help reveal the geological history of the southwest margins.

INTRODUCTION

The Continental Margin Survey by the Bureau of Mineral Resources (BMR) between December 1970 and January 1973 provided reconnaissance gravity, magnetic, and reflection seismic data, generally between shallow water and the 4000 m isobath, in order to outline regional geological structures. About 85 000 n miles of traverse were completed along lines separated by 20-35 n miles, whereby transverse geological structures **at least twice as long as the line spacing, could be resolved.**

The survey was contracted by Compagnie Generale de Geophysique (CGG). The vessel used was a converted North Sea trawler, the MV Lady Christine, which had initially operated, under the name MV Hamme, on the 1970 marine geophysical survey of the Gulf of Papua and Bismarck Sea. The two surveys were essentially continuous and the same basic equipment was used.

This report deals with the area between 24° to 36°S, and 106° to 120°E, which includes the Naturaliste Plateau and the southern part of the Wallaby Plateau (Fig. 1). 10 000 line miles were traversed in this area; the traverse grid was east-west over the west continental slope and north-south over the Naturaliste Plateau and off the south coast, as shown in Plate 1. The lines extended from shallow water to a water depth of about 5000 m. The collected data are described and interpreted here.

Equipment

Equipment on board Lady Christine is listed in Appendix I.

Primary navigation control was based upon the U.S. Navy TRANSIT satellite navigation system. Satellite transmissions were received on an ITT satellite radio receiver and processed in a PDP8 computer together with known parameters provided on board ship, which gave fixes at two hourly average intervals. Intermediate positions were computed using the ship's gyro compass coupled with the sonar Doppler, Chernikeeff electronic log, or ship's log, in order of reliability.

Gravity data were obtained using a LaCoste and Romberg marine gravity meter mounted on a gyro-stabilized platform. This meter incorporated analogue computation of corrections for beam motion and accelerations; the corrections were then applied automatically to the basic meter reading to give corrected gravity values, which were recorded directly.

A Varian proton precession magnetometer whose sensor was trailed about 200 m behind the ship was used to measure the total magnetic field.

All gravity, magnetic, and navigational data were sampled at 10-second intervals by a Hewlett Packard HP2116B computer, and then checked and reformatted by the computer, and recorded on magnetic tape. The computer also provided the ship's dead-reckoned position at 10-minute intervals, plus data for on-line assessment of systems performance and for geophysical computations.

The seismic system consisted of a 120 kJ sparker energy source, a six-channel cable for detecting deep reflections, a short single-channel cable for better resolution of near-surface geological structure, a multi-channel analogue amplifier bank, and a 14-channel FM tape recorder for permanent recording of the seismic signals. Four EPC electrostatic paper recorders were used for monitoring and display purposes. The sparker was also used as an energy source for the refracted seismic signals that were detected out to several miles distance by Aquatronics type SM42 sonobuoys.

A more detailed report on equipment is given by the contractor (CGG, 1974).

Operations

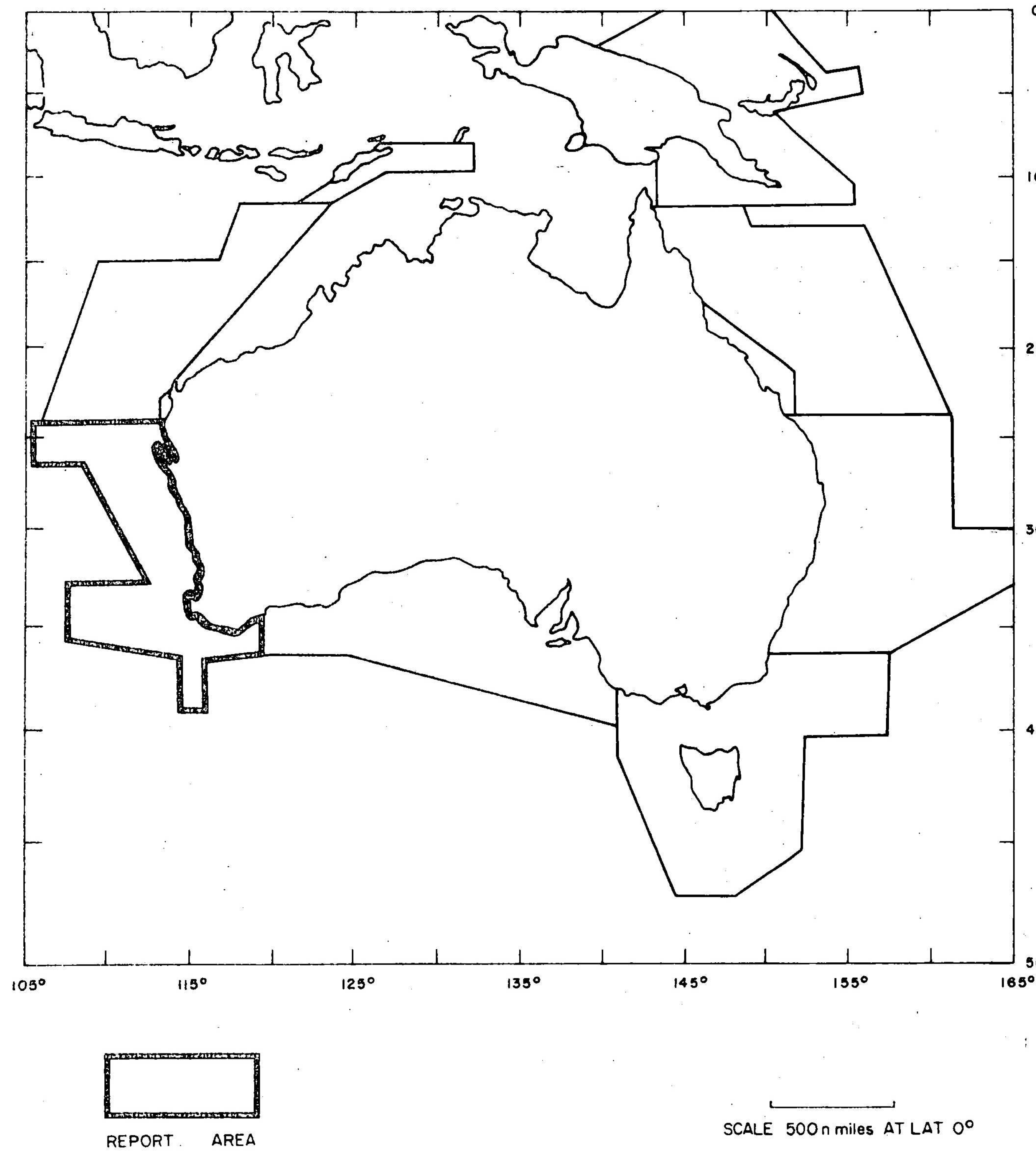
Traverses north of the Naturaliste Plateau were completed between 11 July and 2 August 1972 (Survey 17, days 8-20 and 26-33); the remainder were completed between 16 November 1972 and 6 January 1973 (Survey 18, days 56-75, and Survey 19). Eighteen percent of the survey time was spent in port or on standby because of bad weather or equipment failure. The two traverses that extended to 38°30'S (lines 19/007 to 19/009) were included to obtain data across the Diamantina Fracture Zone.

A new magnetometer cable and sensor were installed at Fremantle on day 25 of Survey 17. During Survey 18 the pressure log was not operating. Owing to multiverter failure, no VLF data were collected during survey 19. The other navigational and geophysical equipment worked without major break-downs throughout the surveys. The magnetic and VLF diurnal monitor was sited at Onslow during Survey 17 and at Albany during Surveys 18 and 19.

Data Quality

The data presented here are preliminary only. Bathymetric, gravity, and magnetic data were obtained by manual scaling of analogue records at hourly intervals, or directly from on-line printouts produced by the data acquisition computer. After conversion to digital form they were processed by computer. Contour maps of water depth, Bouguer anomaly, and magnetic anomaly were then prepared on a flat-bed plotter. The 'triangular' contouring technique is described on each of the contour maps, Plates 2, 3, and 4. The

FIG. 1



GEOPHYSICAL RESULTS FROM SOUTHWESTERN MARGIN

LOCALITY MAP

(Based on A/B0-62A)

A/B8-76A

Record No 1975/180

data grid used for contouring was approximately rectangular (17 x 50 km), with the short axis along the traverse line. In regions of short, intense magnetic anomalies, as found over the continental shelf east of the Naturaliste Plateau, the contours form densely packed triangular groups, which make the magnetic anomaly contour map less satisfactory than the corresponding maps of bathymetry and Bouguer anomaly.

The sonar-Doppler operated on bottom-lock over the continental shelf in water depths of 200 m or less, and it is expected that navigational accuracy in these waters should be about ± 0.2 n miles after post-survey processing of the satellite fixes. In water depths greater than about 200 m the sonar-Doppler operated from back-scatter of the sonar signal from the water. The currents in the water were unknown and therefore were not compensated for in computing the ship's position. As a result, the off-shelf accuracy is likely to fall to about ± 1 n mile.

The hourly gravity values were affected by errors in the Eötvös corrections, caused by uncertainties in measurement of the ship's velocity. The velocity used has been determined from the sonar-Doppler, from 10-minute averages before and after the hour.

For the production of the preliminary contour maps, the positions computed from the sonar-Doppler data were not tied to the satellite fixes; consequently navigational and Eötvös-correction errors are present in this preliminary reduction of data off the continental shelf. Two satellite fixes over the southern Naturaliste Plateau revealed errors of up to 5 n miles in the preliminary dead-reckoned positions. Strong currents affected most lines in the western part of the survey area: a one-knot error in eastwards component of velocity causes a 7.5 mGal error in the Eötvös correction. However, these errors will be considerably reduced before final maps are produced, as all navigational data will be tied to the satellite fixes.

In addition, the gravity data were degraded by intervals of spurious, short-period oscillations of the meter reading owing to rough seas, which cause the meter beam to operate beyond its linear range. The most reliable gravity data were obtained from lines close to the coast, where seas were calmer. Generally, the noise level ranged from 0 to 4 mGal peak-to-peak; but for a total of 83 hours (see Appendix II) the gravity data exceeded the adopted acceptability criterion of less than 6 mGal variation in 10 minutes.

Magnetic noise level was generally less than 5 nT peak-to-peak, but rose to 6-8 nT during the second cruise of Survey 17 owing to amplifier and sensor cable problems.

An overall estimate of the accuracy of the bathymetry, gravity, and magnetic data can be obtained from the misties at intersections. Should the errors be random, as one would expect, the mean mistie should be insignificantly different from zero, and it is unlikely that the maximum mistie would depart from the mean by more than three standard deviations. Table 1 is a summary of mistie statistics as given in Figure 2.

Table 1

Mistie Statistics

	Mean	Std. Dev.	Max. Mistie
Bathymetry (m)	1.9	60.6	155
Gravity (mGal)	-0.7	5.6	-16
Magnetic (nT)	4.0	22.6	100

The very large bathymetric mistie values generally occurred over very steep slopes where small navigational errors would predictably cause large misties. The same is true for the magnetic misties, which occurred in regions of intense anomalies and steep magnetic gradients. Most of the larger misties in both bathymetric and magnetic data occurred over the Naturaliste Plateau, over the shelf to the east of it, and over the steep southern continental slope.

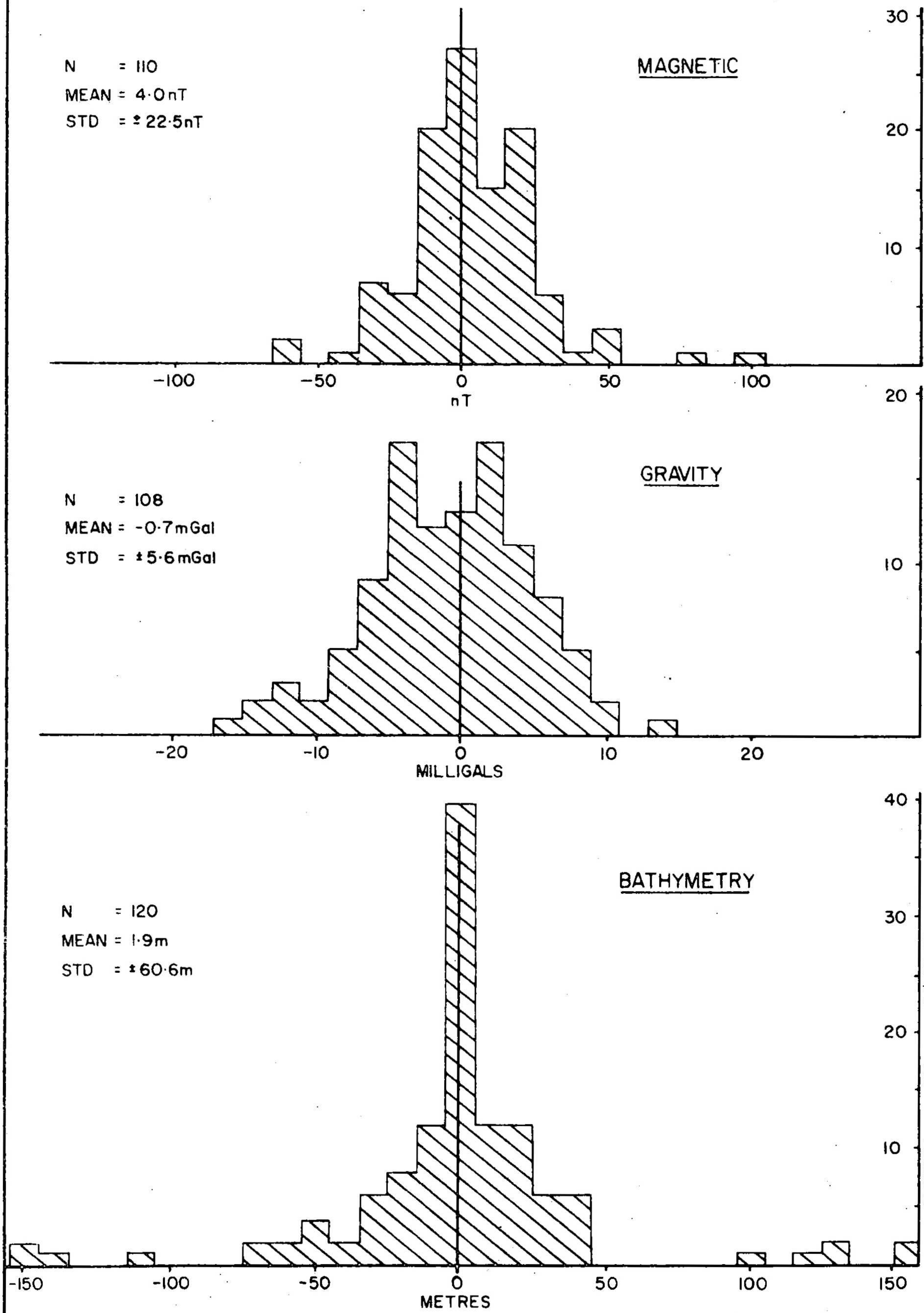
Single-channel monitor records were made from the seismic system as the data were collected. These have been inspected briefly to extract the regional information. On the continental shelf the monitor records are of poor quality with 'ringing' and multiple reflections obscuring much of the deep structure. Elsewhere, except over steep slopes and in water deeper than 4000 m, where resolution is poor, the records show a penetration of up to 2 seconds below sea floor.

Six-fold common-depth-point stacking of the multichannel seismic data recorded on magnetic tape should improve resolution and penetration.

The short cable records were good in water depths less than 1500 m. Later in the survey of this area the cable, which was in poor condition, broke down frequently.

The refraction records have not been examined in detail; the data quality ranges from poor to fair. The times at which refraction recording was attempted are listed in Appendix III.

FIG. 2



MAGNETIC, GRAVITY, & BATHYMETRIC MISTIES

GEOLOGY AND GEOPHYSICS

Onshore, adjacent to the report area, lie the Perth and Carnarvon sedimentary basins, and the Yilgarn metamorphic block (Fig. 3). They have been extensively mapped and surveyed; but little is known of the geology or geophysics of the continental slope or the deep-water plateaus.

Perth Basin

Geophysical exploration began with BMR gravity, aeromagnetic, and seismic surveys (Thyer & Everingham, 1956; Quilty, 1963). Subsequent drilling and geophysical investigations, mainly by West Australian Petroleum Pty Ltd (1969a, b, c; 1970) have added to the knowledge of the geology of the area.

Over 80 petroleum exploration wells and 11 BMR stratigraphic holes have been drilled in the Perth Basin since 1959. Most onshore wells were drilled in the Dandaragan Trough; those offshore were in the Vlaming Sub-basin. Over 70 land and marine seismic surveys have been carried out, as well as four government-subsidized gravity surveys in the north and several unsubsidized surveys covering the remainder of the onshore basin. BMR reconnaissance gravity surveys conducted in 1969, 1971, and 1972 covered parts of the basin. Two BMR onshore and offshore and two government-subsidized offshore aeromagnetic surveys have been flown since 1959. Jones & Pearson (1972) give a structural synthesis of the Perth Basin using all available data, and the following description is based mainly on their work. Stratigraphy follows McWhae et al. (1958).

The Perth Basin is an elongate trough which extends for about 700 km along the west coast of Australia southwards from 28°S. The eastern boundary is the north-trending Darling Fault whose southern end intersects the coast just west of Point D'Entrecasteaux. East of the Darling Fault are the metamorphic rocks of the Yilgarn Block. The basin is bounded to the north by the Hardabut Fault, the Northampton Block, and the Yandi-Madeline Hinge. The western and southern limits of the Perth Basin lie offshore and are not known.

The basin developed as a result of large vertical movements along the Darling Fault from Middle Triassic to Early Cretaceous times, and contains over 16 km of clastic sediments. The major trough is the Dandaragan Trough, which is bounded on the west by the north-trending Beagle Ridge. Offshore from Beagle Ridge is the Turtle Dove Ridge, a northwest-trending basement uplift. The two ridges merge to form the Edward's Island Block and form the southern boundary of the Abrolhos Basin (Jones & Pearson, 1972). South of the Edward's Island Block is the

Vlaming Sub-basin, whose western boundary lies off the continental shelf and has not been determined. The southernmost sub-basin is the Bunbury Trough, which is separated from the Dandaragan Trough by the Harvey Ridge and bounded to the west by the Dunsborough Fault. West of this fault Precambrian metamorphic rocks form the Naturaliste or Leeuwin Blocks, which gently dips westward to an unknown boundary.

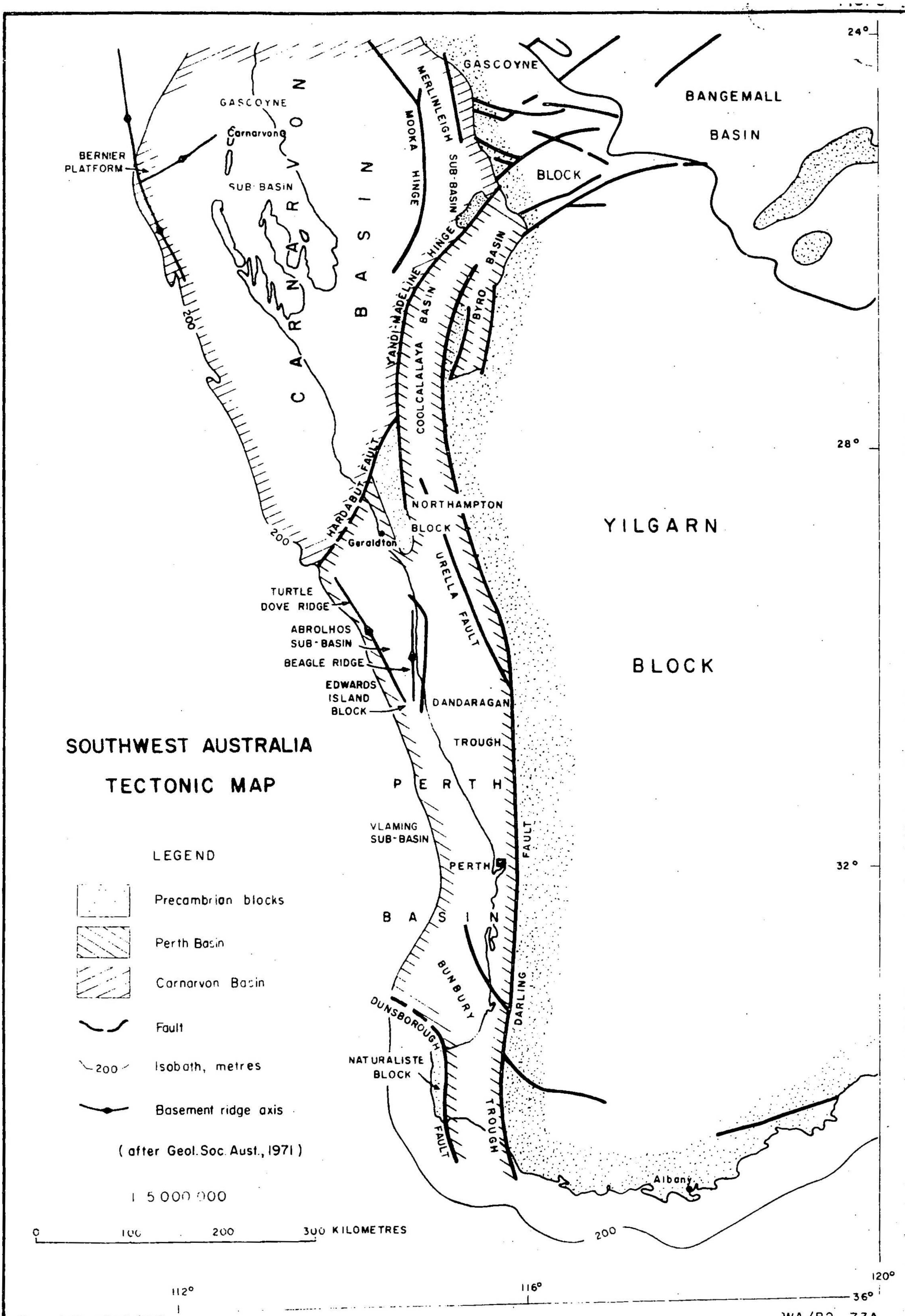
Sediments in the offshore Vlaming and Abrolhos Sub-basins are largely continental. The Abrolhos Sub-basin contains up to 10 km of sediments, half of which are older than Cretaceous: thick continental Lower Jurassic sequence of coal-bearing sandstone, siltstone, and shale is overlain by 300 m of Middle Jurassic marine shale. Severe Upper Jurassic tectonism resulted in deposition of coarse continental sandstone, followed by shelf carbonate deposition in the Tertiary. Gun Is.No. 1 in the Abrolhos Sub-basin was drilled to 4.1 km through Quaternary limestone, Tertiary carbonates, Upper Cretaceous marine clastics, and Jurassic fluviatile and paralic clastics (Hawkins, 1969).

The Vlaming Sub-basin has a similar history but without marine transgressions in the Middle Jurassic. It developed as a separate entity in the Neocomian. Sediments of this age consist of 6.5 km of fluvial sands and thin shales overlain with marked unconformity by up to 1.5 km of marine beds. The Tertiary and remainder of the Cretaceous saw deposition of thin shelf carbonates.

Few of the sedimentary sequences in the Perth Basin have been found to contain economic fuel or mineral deposits. In the Dandaragan Trough, the Lower Triassic sandstone and Lower to Middle Jurassic sandstone are reservoirs from which hydrocarbon gas is being extracted and piped to Perth. Beach sands south of Perth hold exploitable quantities of ilmenite, rutile, monazite, and zircon.

Carnarvon Basin

Since 1934, over 150 petroleum exploration wells and 5 BMR stratigraphic holes have been drilled, mostly in the northern part of the Basin. Only two wells (Pendock I.D. No. 1 and Edel No. 1) are in the southern offshore part of the basin. Over 48 seismic surveys have been conducted - predominantly offshore since 1968. BMR conducted four gravity surveys between 1968 and 1972, one of which was offshore, and a reconnaissance aeromagnetic survey in 1960. A similar number of government-subsidized gravity and aeromagnetic surveys have been completed.



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The stratigraphy of the Carnarvon Basin is given by Condon (1968), who first defined its limits in 1958. It is separated from the Perth Basin by the Yandi-Madeline Hinge and Northampton Block. The offshore boundary is a poorly defined basement ridge which may be the southwesterly extension of the Northampton Block. The Carnarvon Basin extends northwards to 19°S and inland for 220 km. It is bounded to the east by Precambrian igneous and metamorphic rocks of the Gascoyne and Yilgarn Blocks. Its western limits lie offshore and are not defined. It consists of Palaeozoic to Tertiary paralic and marine sediments which have accumulated on a down-warped basement of Proterozoic sedimentary, metamorphic, and igneous rock.

The southern Carnarvon Basin consists of the Gascoyne and Merlinleigh Sub-basins separated by the Mooka Hinge, which was active during Palaeozoic sedimentation. Offshore, the Gascoyne Sub-basin is separated into the northern and southern sub-basins by the northeast spur of the Bernier Platform (Geary, 1970). This basement high, lying west of Carnarvon, was first detected by aeromagnetic work and its existence later confirmed by an offshore seismic and magnetic survey (Ocean Ventures Pty Ltd & Endeavour Oil Co. N.L., 1972). The same survey revealed complex structural patterns with at least two fault trends, and at least 6.5 km of sediment in each sub-basin.

The stratigraphy of the southern Carnarvon Basin offshore is little known. Pendock I.D. No. 1, 80 km north of the area shown in Figure 3, was drilled to a depth of 2.5 km and penetrated Quaternary limestone, dolomite, and sandstone, Cretaceous marine clastics, Lower Carboniferous dolomite, Devonian marine carbonates and clastics including a reef complex, and Upper Silurian marine carbonates and clastics (Genoa Oil N.L., 1970).

At Edel No. 1, 220 km northwest of Geraldton, the drill passed through 3 km of sediment consisting of ?Cretaceous, Triassic, and ?Permian interbedded coarse sandstone, acid volcanics, and siltstone. The Permian age of the oldest unit was obtained by isotopic dating of the volcanic rocks; but the sandstone is very similar to the Upper and Middle Triassic sandstone of the northern Perth Basin, and is probably of this age (Ocean Ventures Pty Ltd, 1972).

Economic deposits found in the Carnarvon Basin include water, radiolarite, limestone, gypsum, glauconite, clays, and petroleum. The chance of locating more hydrocarbons within the basin is high since sediments are largely marine and a high structural relief developed during sedimentation. Consequently petroleum is the most vigorously sought mineral; it has been found principally in the northern parts of the basin.

The Southern Continental Margin

Geophysical investigations on the shelf south of Western Australia have included refraction studies during cruises by R.V. Vema and HMAS Diamantina (Hawkins et al., 1965) made in an attempt to locate the southern limit of the Perth Basin. The results were inconclusive.

Precambrian metamorphic rocks of the Yilgarn Block crop out along the southern shoreline east of the Darling Fault (Fig. 3). Some 200 to 300 km south of the continent lies the Diamantina Fracture Zone, or region of high relief elongated east-west. There is no evidence of present or past movement along the zone, and its tectonic history is as yet unknown. Its morphology and sediment cover are described by Hayes & Conolly (1972).

The Naturaliste Plateau

The Naturaliste Plateau has been described by Hayes & Conolly (1972):

'The Naturaliste Plateau is a rectangular-shaped block that forms a marginal plateau extending due west from southwest Australia. Its upper surface lies at depths of 2000-2500 m and is blanketed by at least 300-500 m of sediment that has been dated as old as upper Cretaceous (Burckle et al., 1967). The Plateau is bounded on its three ocean facing sides by steep (5° - 12°) continental slopes that merge at depths of 4500 m into a narrow, sediment-built continental rise. The troughs and ridges of the Diamantina trench parallel the southern margin of the Naturaliste Plateau. The western margin is oriented north-south in the direction of the major tectonic lineaments of the western edge of south-west Australia, such as the Darling Fault. The northern margin of the Plateau appears to be more irregular. The suggestion has been made that the Naturaliste Plateau is a block of Precambrian crystalline rocks that has been downfaulted and separated from the Australian continent since the Late Jurassic or Early Cretaceous (Conolly, 1970)'.

A bathymetric map of the area showing previous oceanographic investigations is given in Figure 4.

An Upper Cretaceous core was obtained from the northeast slope of the plateau by scientists from the Lamont-Doherty Geological Observatory on the USSRV Robert D. Conrad. The oldest sediments were dated as Turonian (Upper Cretaceous), which was the time of emergence and denudation of Western Australia. The core showed coarse-grained foraminiferal sand of Recent to Pleistocene age disconformably on a white Cretaceous chalk consisting largely of planktonic organisms. The pelagic nature of both the Cretaceous and Pleistocene sections of the core suggests that terrigenous sediments

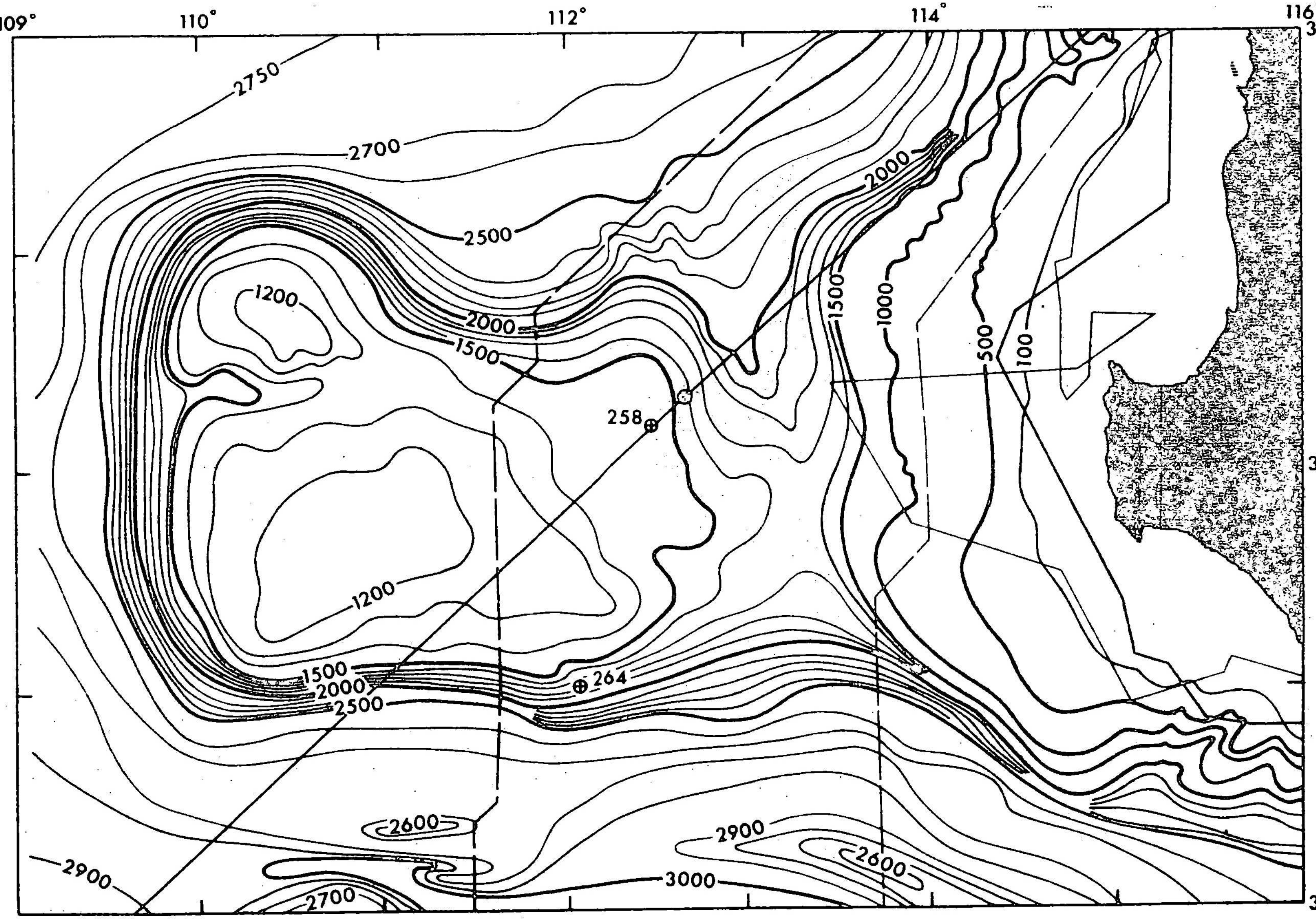
Record No 1975/180

PREVIOUS OCEANOGRAPHIC INVESTIGATIONS
NATURALISTE PLATEAU

Bathymetry after Hayes and Conolly, 1972

Contours in fathoms

50 0 50 100 150 200 km



LEGEND

Core ("Robert D. Conrad")	Cruise 9 of R.V. "Robert D. Conrad"
DSDP Site	Cruise 16 of R.V. "Vema"
Cruise 8 of R.V. "Robert D. Conrad"	Cruise 18 of R.V. "Vema"

WA/B8-28A

FIG. 4

contributed little to the in build-up of the central and western part of the Naturaliste Plateau.

Seismic profile records from the Robert D. Conrad show a rather thin sedimentary layer with some thicker pockets, which are possibly sediment-filled grabens. The south side of the plateau is marked by a steep scarp with a well developed sediment 'ramp' at its base (Burckle et al., 1967). This is widest on the east and pinches out towards the west. Its southernmost limit is terminated by a rugged surface which trends in a general easterly direction and which is continuous with the Diamantina Fracture Zone. The existence and position of the ramp suggest that it has been built up by sediments carried by longshore currents which sweep around the southwest tip of Australia (Burckle et al., 1967).

In October 1972, on leg 26 of the Deep Sea Drilling Project (DSDP), US research vessel Glomar Challenger recovered a core (hole 258) from the Naturaliste Plateau (Luyendyk, Davies et al., 1973). The hole bottomed in sediments at 525 m below sea bed, so it was not possible to determine whether the plateau is of oceanic or continental origin. The core was composed of marine sediments, the oldest of which proved to be well sorted middle Albian detrital clays and glauconitic sand (105 m.y.). A very thick sequence of ferruginous detrital clays occupied the rest of the Albian section. A Tertiary-Cretaceous unconformity similar to that seen at Broken Ridge and Wharton Basin drill sites was found on the Naturaliste Plateau, only 100 m below sea floor. It represents a 70 m.y. break and may be related to the onset of a circumpolar current in the middle Eocene, when Australia and Antarctica began to separate.

On leg 28 of the Deep Sea Drilling Project a core was recovered at site 264 on the southern slope of the Naturaliste Plateau (Hayes, Frakes, et al. 1973). The basement encountered was undated volcaniclastic conglomerate which contained both acid and basic volcanic fragments. The results indicated that a subtropical deep-water environment prevailed at this site from at least Late Cretaceous to Recent times, but failed to reveal whether basement was of oceanic or continental origin.

The western margin north of the Naturaliste Plateau

Little geophysical work has been carried out on the continental slope north of the Naturaliste Plateau or on the Wallaby Plateau. Refraction profiles in 5 km of water at two locations, one near the foot of the slope at 30°S latitude, and the other west of the Wallaby Plateau, revealed normal crustal thicknesses of 5-6 km (Francis & Raitt, 1967). During 1971, Shell

International recorded gravity, magnetic, and reflection seismic data aboard MV Petrel, but the results have not been published.

DSDP holes 257 and 259 were drilled in the report area, and hole 263 just to the north (Fig. 5). Hole 257 (Luyendyk, Davies, et al., 1973) in the southeastern Wharton Basin reached a Lower Cretaceous sediment/basalt contact. Hole 259 (Veevers, Heirtzler, et al., 1973) at the foot of the slope in the Perth Abyssal Plain encountered a Lower Cretaceous/upper Palaeocene unconformity and reached Neocomian basaltic basement.

RESULTS

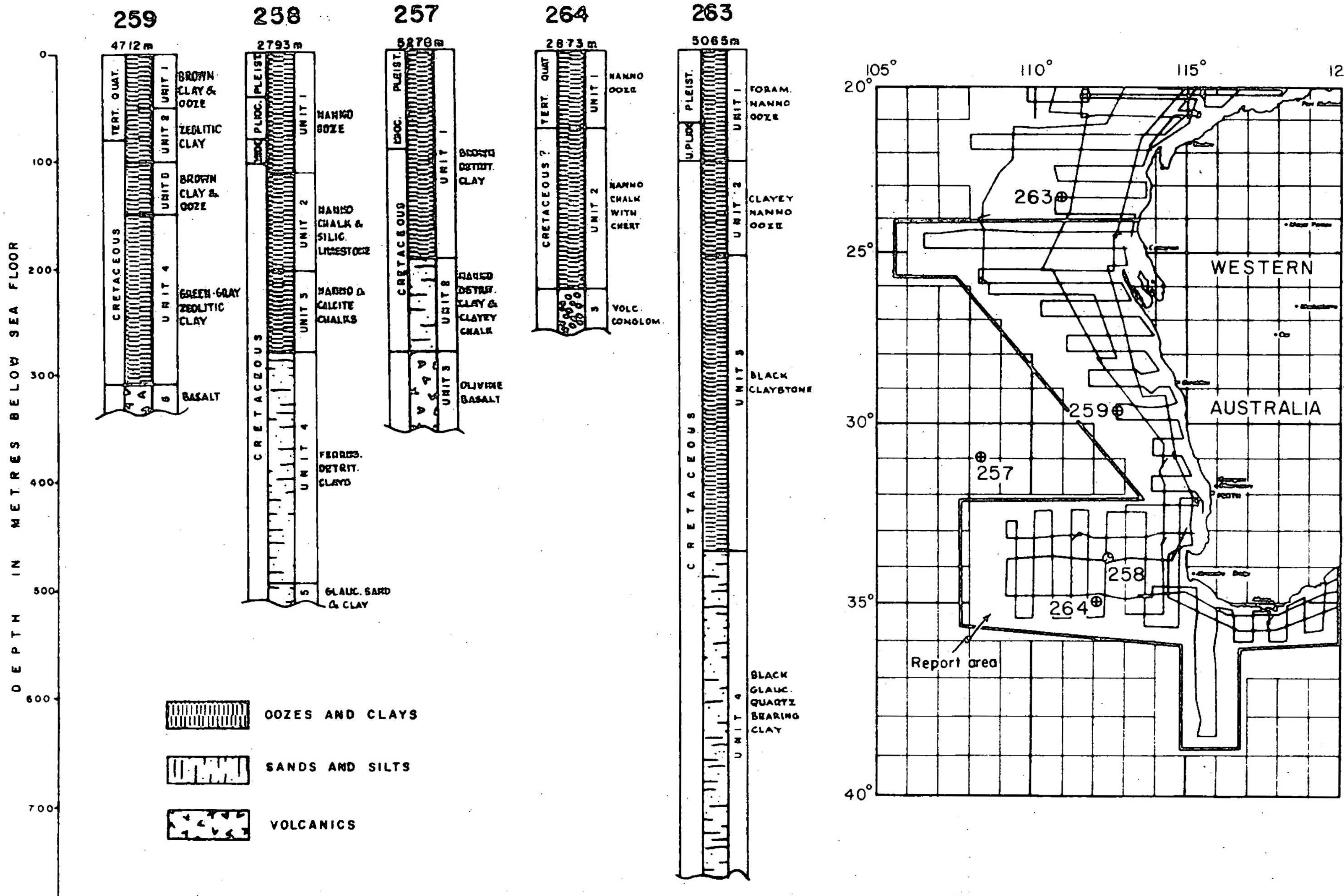
Bathymetry (Plate 2)

The most noticeable bathymetric features are the fairly steep continental slope, especially where it lies closest to the coast, and the Wallaby and Naturaliste Plateaus, which extend up to 600 km offshore. The seaward limit of the continental shelf is approximately the 200-m isobath, which lies between 20 and 100 km offshore. The shelf is widest north of Geraldton, between 27° and 29°, and narrowest south of Albany.

The continental slope is steepest along the southern margin, falling to the 5000-m abyssal plain in 60 km at an average gradient of 1:15 (4°). It is also steep just north of Perth, but farther north its gradient gradually decreases and the slope becomes broader. North of Geraldton the slope is interrupted by the Carnarvon Terrace (Branson, 1974), which extends north to about 21°S and attains a maximum width of 100 km near Carnarvon. It generally occupies the levels between 400 and 1200 m below sea level and has a gradient of 1:90 ($\frac{1}{2}$°) at 25°S. The gently dipping, smooth terrace surface is in strong contrast with the slope on its seaward boundary, which is rugged and cut by many down-slope erosion channels. The slope has a gradient of 1:35 (2°) at 25°S and falls from about 1400 to 4000 m below sea level.

The Naturaliste Plateau extends offshore for 500 km between the latitudes of Perth and Point D'Entrecasteaux. It is roughly rectangular and covers an area of 65 000 km^2 above the 3000-m isobath. The highest point, at 2000 m, lies about 350 km offshore. A saddle at about 3000-m joins the plateau to the continental slope. From this low point, about 200 km offshore, the plateau surface rises gradually westwards, and then falls abruptly to the abyssal plain level. The southern and western margins are steeper than the northern margin, which shows an extensive continental rise. The apparent linearity of the southern and western margins suggests fault control. An east-west section across the Naturaliste Plateau is given in Figure 6.

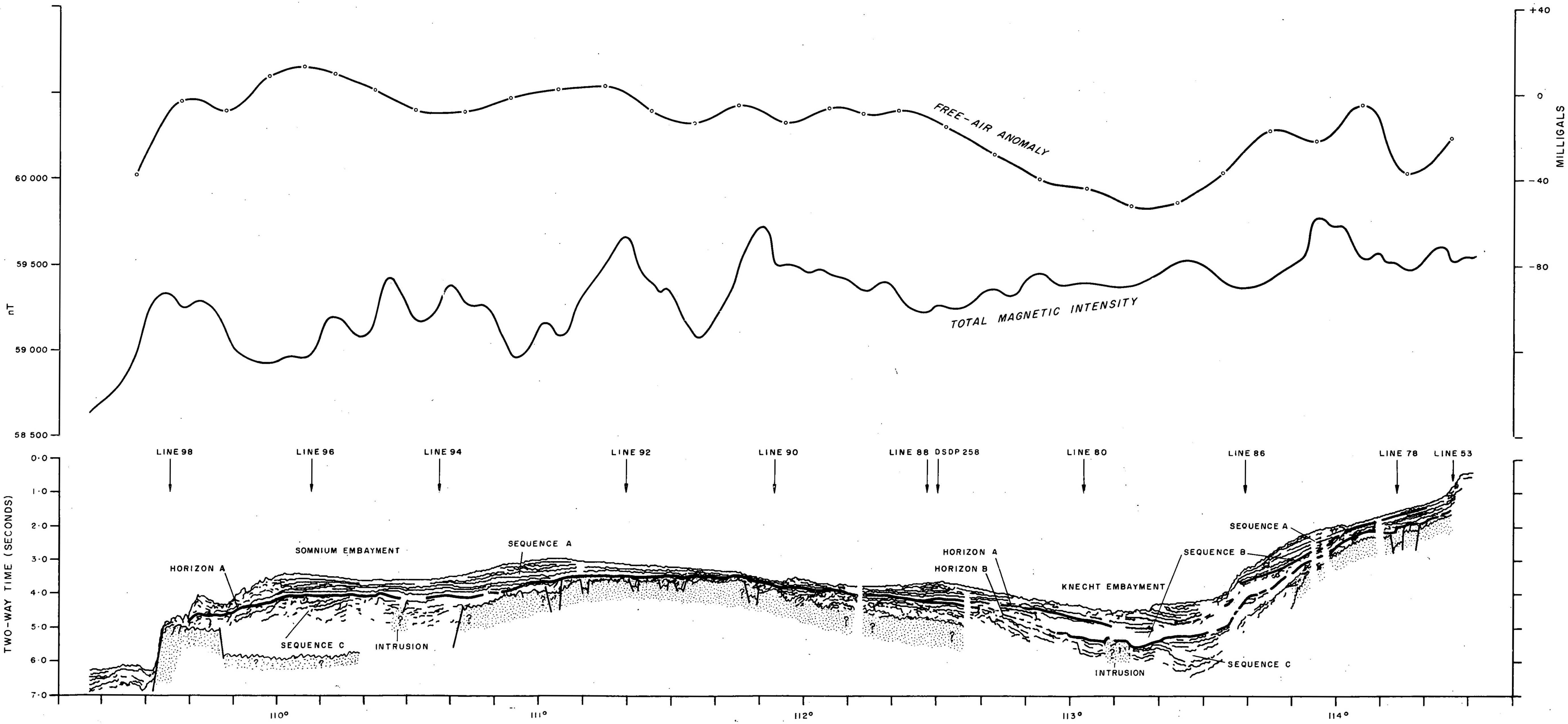
Record No. 1975/180



DEEP SEA DRILLING PROJECT STRATIGRAPHIC LOGS

FIG.5

WA/B8-49A



Sequence A : Pleistocene to Albian
Sequence B : Albian to Neocomian (?)
Sequence C : Neocomian(?) and older
Basement : Metamorphic and igneous complex

Fault
Unconformity
Basement
$\frac{V}{H} = 15$

LINE 19/002 ACROSS THE NATURALISTE PLATEAU

Cameron and Petkovic, (in prep)

In the extreme northwest of the report area lies the Wallaby Plateau, which is 2600 m below sea level about 450 km offshore. To the west there is a steep drop to the abyssal plain at a depth of over 5000 m. Between the plateau and the continental shelf a trough reaches a depth of 4000 m. The Wallaby Plateau covers 119 000 km^2, of which the central 23 000 km^2 is less than 3000 m deep. From this central area the slope is smooth and gentle to the trough in the east, but irregular and stepped to the steep margin of the abyssal plain in the west. Despite the smoothness, a distinct boundary separates the plateau from its eastern trough, and takes the form of a protruding ridge on line 17/048 and a gentle step on line 17/046. Figure 7 is a cross section of the Wallaby Plateau based on the seismic results along line 17/046.

The more remote oceanic feature south of Point D'Entrecasteaux, the Diamantina Fracture Zone (inset, Plate 2), is a rugged area with strong east-trending ridges having a relief of about 2000 m.

Bouguer Anomalies (Plate 3)

The Bouguer anomalies presented in Plate 3 were calculated as described in Appendix IV. The most noticeable features are the regional gravity gradient, the regional gravity low over the Wallaby Plateau, and the regional gravity platform over the Naturaliste Plateau.

The continental shelf and upper slope are covered mainly by the regional gradient except in areas where the onshore gravity provinces extend offshore. A small low of zero mGal south of Cape Leeuwin may indicate the southern extent of the Perth Basin. The gravity platform over the shelf and upper slope west of the Leeuwin Block is associated with shallow metamorphic rocks and may indicate the extent of the block. The north-trending trough down to -60 mGal offshore from Perth is a continuation of the Perth Regional Gravity low and is an expression of thick crust and sedimentary accumulation west of the Darling Fault. Two circular highs of +70 and +80 mGal over the upper slope south of Geraldton may further define the Turtle Dove Ridge. North-west of Geraldton a +20 mGal north-northeast trending gravity ridge is an offshore extension of an onshore gravity ridge over the Northampton Block. Northwest of this ridge is a regional gravity platform of +10 mGal lying over the shelf and Carnarvon Terrace. Mild, north-trending troughs and ridges over this platform are probably associated with sedimentary folds within the Carnarvon Basin.

The regional gradient lying over the continental slope throughout the area is associated by the author with crustal thinning to an oceanic crustal thickness. Bouguer anomaly values rise seaward from 0 to +220 mGal across it. Along the southern margins the gradient is steep but very disturbed. An isolated low of +10 mGal is prominent on the slope south of Albany. The gradient bifurcates around the Naturaliste Plateau but to the north of this it is again narrow and very steep (3 mGal/km). Farther north it becomes broader until it apparently bifurcates again around the Wallaby Plateau. A series of north-trending gravity ridges and troughs (+40 to +60 mGal) lies over the bathymetric saddle between the Wallaby Plateau and the Carnarvon Terrace, and may be an indication of ridges or block-faults within the basement.

The regional gravity platform over the Naturaliste Plateau shows a fairly undisturbed pattern with average values about +130 mGal. The central Bouguer anomaly low is an indication of the thickest part of the crust, whereas the three small anomalies near the southern margin of the platform are indications of variations in basement depth.

The regional gravity platform over the Wallaby Plateau has an average value of +150 mGal with a circular depression to +120 mGal over the central, shallowest part of the plateau. West of this central region, the platform is cut by two north-trending gravity troughs reaching +140 mGal, which mark graben structures and basement ridges.

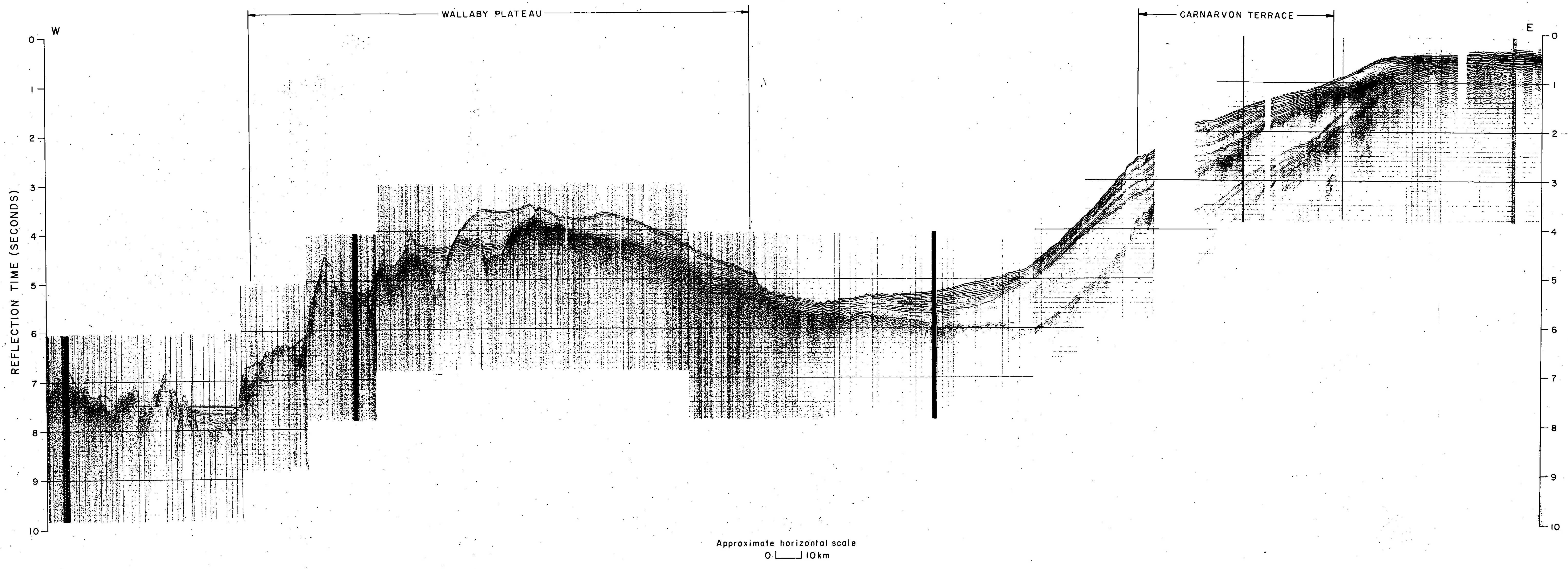
The Bouguer anomalies in the abyssal plain areas have an average value of +230 mGal. Over the Diamantina Fracture Zone the anomaly values vary from +180 to +260 mGal, and apparently form an east-trending contour pattern paralleling basement ridge structures.

Estimates of crustal thickness in the area have been made from the gravity results by assuming isostatic equilibrium and a standard continental crust of 31 km thickness. Based on these assumptions, the depth to the base of the crust below the Naturaliste and Wallaby Plateau is about 22 km.

Magnetic Anomalies (Plate 4)

The magnetic anomaly contours are shown in Plate 4. The magnetic values were calculated as described in Appendix IV. Because of the close data spacing along traverse lines relative to the line spacing, the magnetic contours are not a true representation of a field where short-wavelength anomalies are present. Such anomalies appear to be artificially concentrated on the traverse lines. The most disturbed magnetic contour patterns in the map area occur over the Naturaliste Plateau and the southern continental slope. The Wallaby Plateau area shows large magnetic anomalies but with a broader wavelength than over the first two areas.

FIG. 7



LINE 17/046
CARNARVON TERRACE, WALLABY PLATEAU
SEISMIC SECTION

Over the shelf and upper continental slope near Albany several intense magnetic anomalies have values up to +1800 nT. At the foot of the slope to the south lies a band of intense negative anomalies with values down to -800 nT. This pattern indicates a shallow magnetic basement under the shelf dropping steeply below the slope. However, quieter zones south of Bremer Bay and Point D'Entrecasteaux indicate deeper magnetic basement in those areas.

Intense magnetic anomalies (-600 to +500 nT) on all seaward sides of the Naturaliste Block indicate the shallow depth and extent of this metamorphic Precambrian block. A line of anomalies trending northwest from Cape Naturaliste marks the offshore extension of the Dunsborough Fault, the eastern edge of the Naturaliste Block.

Over the continental shelf north of the Naturaliste Plateau and over the Carnarvon Terrace the anomaly pattern is smoother, indicating thicker sediments and deeper magnetic basement. A circular +50 nT anomaly occurs on the shelf west of Geraldton over the boundary between the Perth and Carnarvon Basins, the Hardabut Fault. Anomalies which range in value from -500 to +100 nT occur along the outer slope from 27° to 29°S, and there is an intense, isolated +50 nT anomaly at 31°S. These anomalies may be an expression of shallow oceanic basement. The quietest region of the slope west of the Carnarvon Terrace is between 29° and 31°S.

East-west anomaly trends shown by the contours over the Naturaliste Plateau coincide with the east-west tie-lines and cannot be regarded as an accurate representation of real lineations. However, the magnetic contours show anomalies ranging from +200 to -550 nT. They are more intense in the western areas of the plateau, indicating a shallower magnetic basement there. Intense anomalies at the plateau edges suggest to the author the presence of oceanic basement highs.

Magnetic anomalies over the Wallaby Plateau range from -450 to +350 nT, with a wavelength of about 20 km, and show no particular trend. However, in the trough between the plateau and the continental slope, the magnetic anomaly contours show a series of north-trending closures with an intensity range +50 to -400 nT and a wavelength of 30 to 35 km. This anomaly pattern appears to be of the oceanic type with a suggestion of lineations. Thus, although the Wallaby Plateau may prove to be of continental origin, which is not contradicted by the magnetic data, it seems to be separated from the Australian continent by oceanic crust.

The magnetic contours over the Diamantina Fracture Zone reveal strong east-west lineations with an intensity range of -550 to +50 nT, and a wavelength of 50 km. They parallel the strong bathymetric trend of east-west oceanic ridges characteristic of the whole zone.

Seismic Features

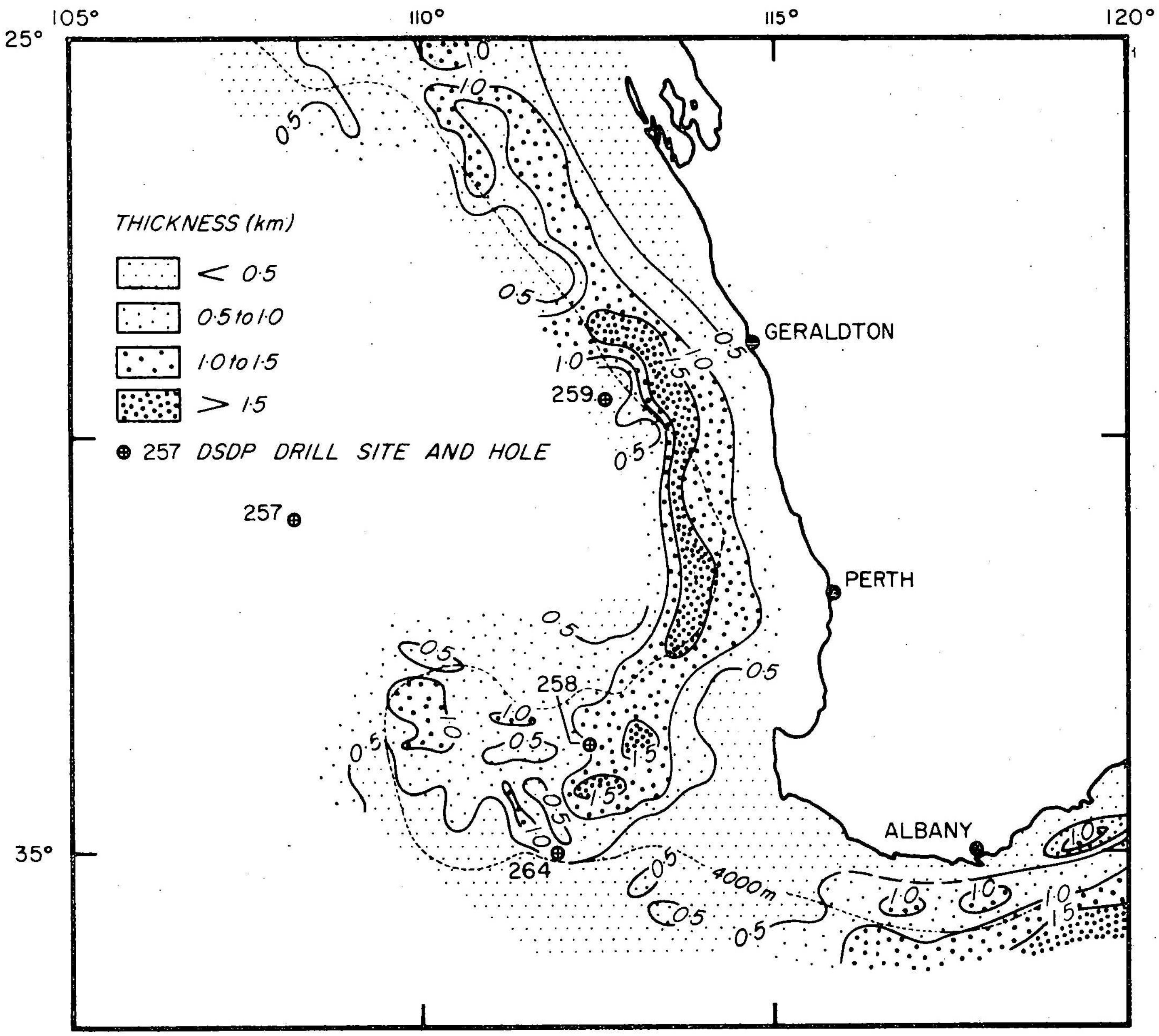
Two east-west seismic sections are represented in Figures 6 and 7. Figure 6 is the central tie line 19/002 across the Naturaliste Plateau. Figure 7 is from the traverse line 17/046 across the Wallaby Plateau. The seismic sections over the Naturaliste Plateau have been described by Cameron and Petkovic (in prep.). A minimum sediment thickness map is presented in Figure 8, and shows either the depth to basement where a basement reflection has been identified, or limit of penetration as seen on the seismic records. Sediment thickness was calculated assuming acoustic wave velocity in sediment of 2 km/s.

Along the southern continental margin basement can be observed on the seismic sections only in areas where sea floor topography is not too rough. It lies about 1 km below mean sea floor, but crops out in canyon walls.

On the Carnarvon Terrace there is a prominent unconformity about 600-1000 m below sea floor, between gently dipping sediments and the underlying moderately folded or tilted sediments with a predominantly eastward dip. The whole sedimentary section contains strong reflectors. The upper sequence thickens westwards, but interference from diffracted seismic energy off the rugged outer slope has obscured many of the sedimentary reflections on the BMR records. South of the Carnarvon Terrace, between 30° and 31°S, acoustic basement was identified below the strong unconformity. The basement reflector appears to show intermittent layering. This is the only strong basement reflection on Carnarvon Terrace or the slope north of 32°S.

At least 2 km of sediment was found from the seismic results in parts of the eastern half of the Naturaliste Plateau, but observable sediment thickness generally varied from 0.5 to 1 km. Below this level seismic penetration was poorer and it was difficult to identify the basement reflection. There are two widespread unconformities in the section, which divide three tectonically undisturbed sedimentary sequences (Figure 6). The strongly layered upper sequence is thickest in the extreme northwest of the plateau where it exceeds 1 km in thickness. The sequence below it in the topographically low area to the east is acoustically transparent and attains a maximum thickness of 700 m. The oldest sequence fills basement relief in the west of the plateau, and its maximum thickness in the east is not known.

FIG. 8



SOUTHWEST MARGIN, SEDIMENTARY THICKNESS AND DSDP SITES

Like the youngest sequence, it is well stratified.

On the Wallaby Plateau there is a relatively thin sediment cover over a basement which appears to consist of igneous or metamorphic rocks. A basement block about 75 km in diameter is centred near the intersection of lines 17/046 and 18/073. It underlies the topographically highest area of the Plateau and is covered by about 300 m of flat-lying, undisturbed sediments. (At the base of the eastern slope of the plateau several small basement highs form a boundary between the Wallaby Plateau and the trough to the east. The sediments in this trough are over 1 km thick, are not continuous with the plateau sediments, and contain two, well defined unconformities.) Outcropping basement along the western margin of the plateau separates the Wallaby Plateau sediments from the Perth Abyssal Plain to the west.

Two long traverses were made south and north across the Diamantina Fracture Zone but seismic resolution was not adequate to detect basement structures. Between the continental rise and the oceanic ridges which start at about 36°40'S on both lines, there is about 200-600 m of flat-lying sediment. No sediments are evident in the seismic records over the ocean ridges.

INTERPRETATION AND CONCLUSIONS

Naturaliste Plateau

The Naturaliste Plateau has a sedimentary cover 0.5 to 1.0 km thick. The areas of thickest sedimentation are in the northwest corner and in the topographically low area to the east where at least 2 km of sediment is present. There are two major unconformities within the plateau sediments; one extends over the whole Plateau; below it, the other is restricted to the eastern part. The basement unconformity is not clearly visible on all seismic sections. These unconformities distinguish at least three major periods of sedimentation.

The DSDP 258 drill-hole was located near the pinch-out between the two intra-sediment unconformities (Fig. 5, 6), and bottomed just short of the older. Core samples indicate that the upper sedimentary sequence consists largely of Cretaceous marine clay and chalk with only about 100 m of Miocene and younger beds (Luyendyk, Davies, et al., 1973). Albian, glauconitic sand, and clay were recovered near the base of Sequence B. It is proposed that the unconformity at the bottom of Sequence B is probably of Early Cretaceous age because of its close proximity to the overlying Albian beds at DSDP 258. It could be contemporaneous with the with the Neocomian tectonism most strongly expressed in the offshore Vlaming Sub-basin of the Perth Basin (Jones & Pearson, 1972).

DSDP 264 on the southern slope of the plateau penetrated Cretaceous marine beds to reach a basement of undated volcaniclastic conglomerate.

The sediments of the plateau have not been significantly folded or faulted. There is evidence of tectonic activity only along the southern and parts of the western margins, where scarp-like bathymetric features indicate faulting in the basement. This faulting may be associated with Gondwanaland break-up.

The basement rocks of the plateau do not appear from the seismic records to be typically igneous although there may be several intrusions into the deeper sedimentary rocks. Seismic basement topography shows considerable correlation with the magnetic field and it seems probable that basement is a metamorphic and igneous complex. The western and eastern halves of the plateau differ significantly on the basis of bathymetric, seismic, and magnetic results. The western area, which is higher than the east, is characterized by shallow basement and intense magnetic anomalies. The eastern area has a thick sedimentary cover and less intense magnetic anomalies. The boundary between eastern and western areas trends northwest approximately along the 2600-m bathymetric contour.

Gravity modelling indicates a crustal thickness of about 22 km beneath the centre of the plateau, a thickness intermediate between continental and oceanic crust (Cameron & Petkovic, in prep.).

Wallaby Plateau

The Wallaby Plateau is trough-bounded with both continental and oceanic characteristics. Its western, seaward-dipping slope is a complex series of oceanic type ridges covered by a relatively thin, flat-lying sedimentary sequence. However the central high area appears to be a block of continental origin covered by 300 m of similar flat-lying sediments. Like the Naturaliste Plateau, the Wallaby Plateau's western and southern margins are the steepest, and seismic basement is rugged in these areas. Magnetic data indicate the presence of large igneous bodies in the southern and eastern parts.

Seismic data shows less than 600 m of sediment over most of the plateau. The fact that sediments are not continuous between the plateau and the continental slope to the east may indicate different sediment sources or severe erosion between the two areas.

Gravity modelling indicates a crustal thickness under the plateau of about 23 km.

The plateau may be either a continental fragment detached from the mainland by rifting, or a sediment-covered oceanic ridge; no drilling has been carried out to determine basement type. However the magnetic anomalies over the plateau are distinctly different from the anomalies in the surrounding area which are oceanic in type. This suggests a continental origin for the Wallaby Plateau.

The slope north of the Naturaliste Plateau

The most prominent features in this area are the magnetic anomalies along the lower parts of the slope, the gravity anomaly at 30°S, and the prominent unconformity about 800 m beneath the Carnarvon Terrace.

The magnetic anomalies along the lower parts of the slope are probably due to igneous basement highs, although the seismic sections do not give a clear indication of such bodies because of poorer resolution in deeper water.

The 80 mGal Bouguer anomaly at 30°S is located over the Turtle Dove Ridge. A basement reflection event is visible on the seismic section from line 17/017 and it rises to within 400 m of the sea floor. The unconformity visible on the sections to the north is also present here. The beds between the unconformity and basement are more strongly folded than to the north and were probably disturbed during the last period of basement uplift. These beds pinch out against basement on traverse line 17/017. Overlying sediments dip gently westwards. If the unconformity correlates with the Neocomian unconformity over the Naturaliste Plateau (Cameron & Petkovic, in prep.) it may be deduced that the Turtle Dove Ridge has not been uplifted since that time.

The southern margin

The southern margin is characterized by a narrow shelf and a steep slope (approx. 10°) cut by numerous canyons. Intense magnetic anomalies and seismic evidence indicate shallow basement. Sediments on the continental rise thicken eastwards from zero thickness south of the Naturaliste Plateau to nearly 2 km south of Bremer Bay. Between the continental rise and the oceanic ridges 150 km farther south is an area of shallow basement covered by flat-lying sediments. The abrupt change from shallowly buried basement to oceanic ridge structure may suggest at least two phases of sea-floor spreading between Australia and Antarctica in this region during the early stages of separation.

Recommendations for Future Work

Despite the considerable advances in our knowledge of the southwest margins because of JOIDES drilling and BMR geophysical surveying, we are still largely ignorant of the area's tectonic and sedimentary history. On the Naturaliste Plateau the age of horizon B (Fig. 6), the age and type of sediments below it, and the basement rocks have not been adequately investigated. Similar questions remain about the Wallaby Plateau and about the large areas of deep-water sediment on the Carnarvon Terrace, continental slope, and continental rise in the south.

Many of these problems can be resolved by suitable drilling. Two more holes on the Naturaliste Plateau which could be sited on line 19/002, at 111°40'E and 112°40'E (see Fig. 7) with a maximum required penetration of 500 m, would provide information on basement and the major sedimentary sequences. More detailed seismic and magnetic surveys over the western half of the Naturaliste Plateau are recommended to map the basement structure, and to determine the sedimentary thickness in the basement grabens and downwarps. In the eastern part of the Plateau the seismic character of the sedimentary sequences has been described, but penetration greater than 2 seconds of two-way time would be desirable to determine the maximum thickness of sediments there.

In the north of the report area, core samples from the Wallaby Plateau, the trough to its east, and the Carnarvon Terrace would be essential to any further investigations.

Multisensor surveys on the Carnarvon Terrace and nearby continental shelf coupled with some drill-holes are needed to delineate the offshore limits of the Carnarvon Basin.

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APPENDIX I

Equipment List for M/V Lady Christine

Seismic

Amplifiers:	SIE PT 700
Recorders:	Four EPC 4100
6-Channel hydrophone streamer:	CGG manufacture
Single-channel streamer:	Geotech
Tape Recorder:	14-channel Ampex FM
Sparker:	Teledyne 120 kJ single electrode

Gravity and magnetics

Gravity Meter:	LaCoste & Romberg stabilized platform air sea gravity meter (S-24)
Magnetometer:	Varian proton precession

Data acquisition system

Computer:	Hewlett Packard 2116B, 8K
Interface:	SERCEL
A/D Converter:	HP 2301B
Tape Recorder:	HP 2020B, 32-channel, 556bpi
Teletype:	ASR 35

Navigation

Satellite receiver:	ITT
Computer:	Digital PDP 8/1
Gyrocompass:	Anschutz
Sonar Doppler:	Marquardt
Electronic log:	Chernikeeff
Pressure log:	Hartmann and Braun
VLF receivers:	Tracor

Other equipment

Fathometers:	One Elac, one Atlas Edig, one EDO Western Digitrack
Anemometers:	Alcyon
Analogue recorders:	Westronix and Linax
D/A Converters:	SERCEL and HP 580A

The details of the equipment are given in a separate report (C.G.G. 1974)

APPENDIX II

Unreliable Gravity Measurements

The following is a list of times during which gravity values fluctuated by more than 6 mGal in less than 10 minutes, and were therefore considered unreliable.

	Day.Time	to	Day.Time
Survey 17			
	03.0520		03.0700
	03.0920		03.1120
	03.2030		03.2250
	04.0750		04.0940
	08.1620		08.1740
	08.2000		09.0140
	09.1930		09.2040
	09.2210		10.0210
	10.1930		11.0420
	11.1050		11.1630
	12.0000		12.0450
	12.0610		12.0940
	30.2000		31.1900
	32.1100		32.1500
	32.2000		33.0000
Survey 18			
	53.1530		53.1720
	56.0310		56.0430
	59.0630		59.0730
	59.0900		59.1110
	59.1900		59.2210

Gravity was unreliable for a total of 83 hours.

APPENDIX III

Refraction probes

The sonobuoy was dropped overboard at the first time given and signals were transmitted to the ship till the second time. Ship speed during refraction work was about 6 knots.

	Day Time	to	Day Time	Water depth (m)	Velocities (km/s)
Survey 17	13.1145		13 1245	33	2.3
	17.0633		17.0740	100	2.8, 5.1
	17.1707		17.1818	800	2.4, 5.9
	19.0512		19.1646	3800	-
	32.0814		32.1020	2850	-
Survey 18					
	66.0926		66.1020	110	5.3
	67.1101		67.1200	2300	3.0
	75.1430		75.1530		2.0,2.4,3.4
Survey 19					
	02.2324		03.0050	2700	-
	03.1200		03.1340	2550	4.1
	04.1640		04.1745	2500	2.5, 4.6
	05.1125		05.1240	50	2.9, 5.2

No estimates for depth to refractor have been made.

APPENDIX IV

Computation of Bouguer gravity anomalies and magnetic anomalies

The Bouguer anomalies were computed by applying latitude corrections and Eötvös corrections (Glicken, 1962) to the observed gravity data, and then applying a Bouguer correction, $2\pi G d \Delta\rho$, at each station, where

G = universal gravitational constant

$\Delta\rho$ = difference in density between water and sediments, assumed to be $1.2 g/cm^3$

d = water depth

The magnetic anomalies were computed using the formula:
Magnetic anomaly = observed total magnetic field - IGRF - diurnal
where

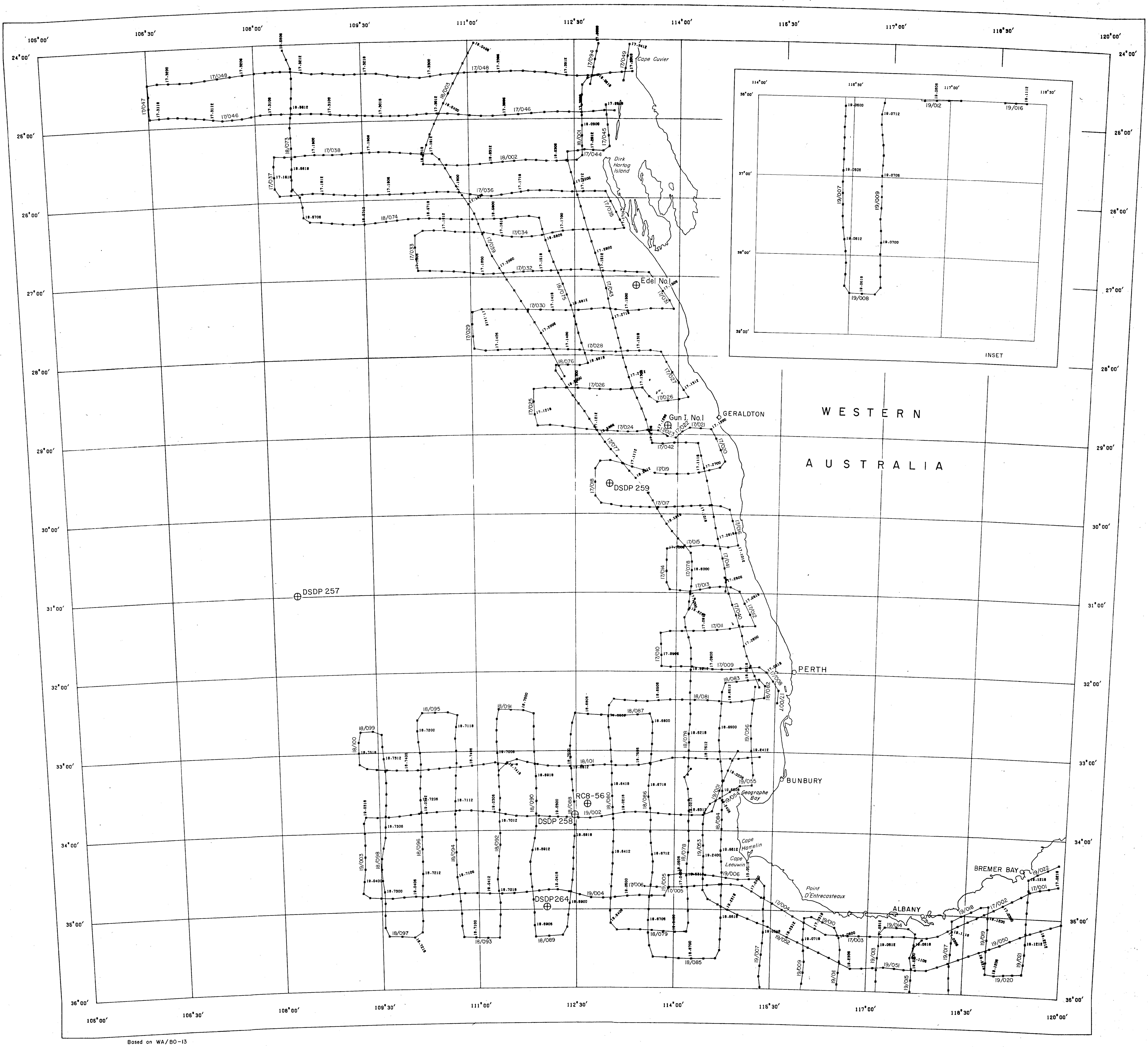
IGRF is the International Geomagnetic Reference Field, and diurnal is the departure of the field from its mean value, measured at a shore monitor station.

SOUTHWESTERN MARGINS

PLOTTED 73/07/26

PLATE I

AUSTRALIA 1: 2500000



Based on WA/80-13

AUSTRALIAN NATIONAL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH

B M R 1970-73 MARINE SURVEYS

SOUTHWESTERN MARGINS

TRACK CHART AND CORE SITES

AREA 6

KILOMETRES

50 0 50 100 150 200 250

0 50 100

NAUTICAL MILES

NOTE: The information contained in this map has been obtained by the Department of Minerals and Energy, as part of the policy of the Australian Government, to assist in the exploration and development of mineral resources. It may not be published in any form or used in a company prospectus or statement without the permission in writing of the Director, Bureau of Mineral Resources, Geology and Geophysics.

The ship's position is plotted from hourly values based on preliminary data and tied to the satellite navigation fixes. The track line is a linear interpolation between these hourly positions. No adjustments have been applied for misties at traverse intersections.

Record No. 1975/180

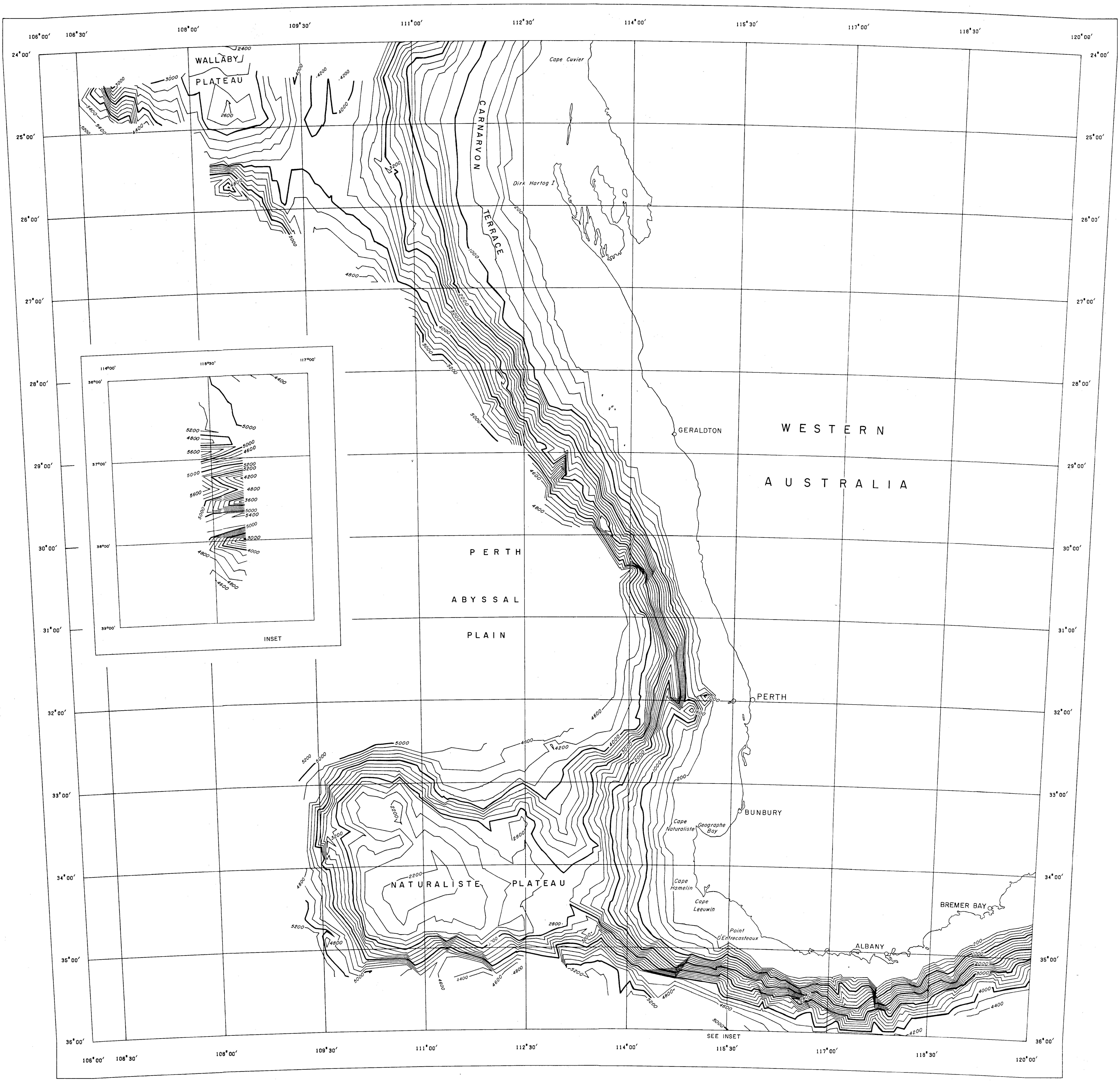
WA/88-33-2

SOUTH WESTERN MARGINS

PLOTTED 73/07/27

PLATE 2

AUSTRALIA 1: 2500000



Based on WA/80-13

AUSTRALIAN NATIONAL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH

B M R 1970-73 MARINE SURVEYS

SOUTH WESTERN MARGINS

WATER DEPTH (METRES)

AREA 6

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KILOMETRES 50 0 50 100 150 200 250

0 50 100 NAUTICAL MILES

Contour interval : 200 metres

Water velocity assumed constant at 1500m/s

Data used are preliminary, and are based on hourly values extracted on board the survey vessel. No adjustments have been applied for misties at traverse intersections.

Contour lines are drawn by computer using a triangular contouring program. A triangular plate is defined by three adjacent stations whose circumscribing circle contains no other stations. Linear interpolation is then used on the triangular plate. Should any side of an acceptable triangle exceed 40 nautical miles, that plate is not contoured.

Record No. 1975/180

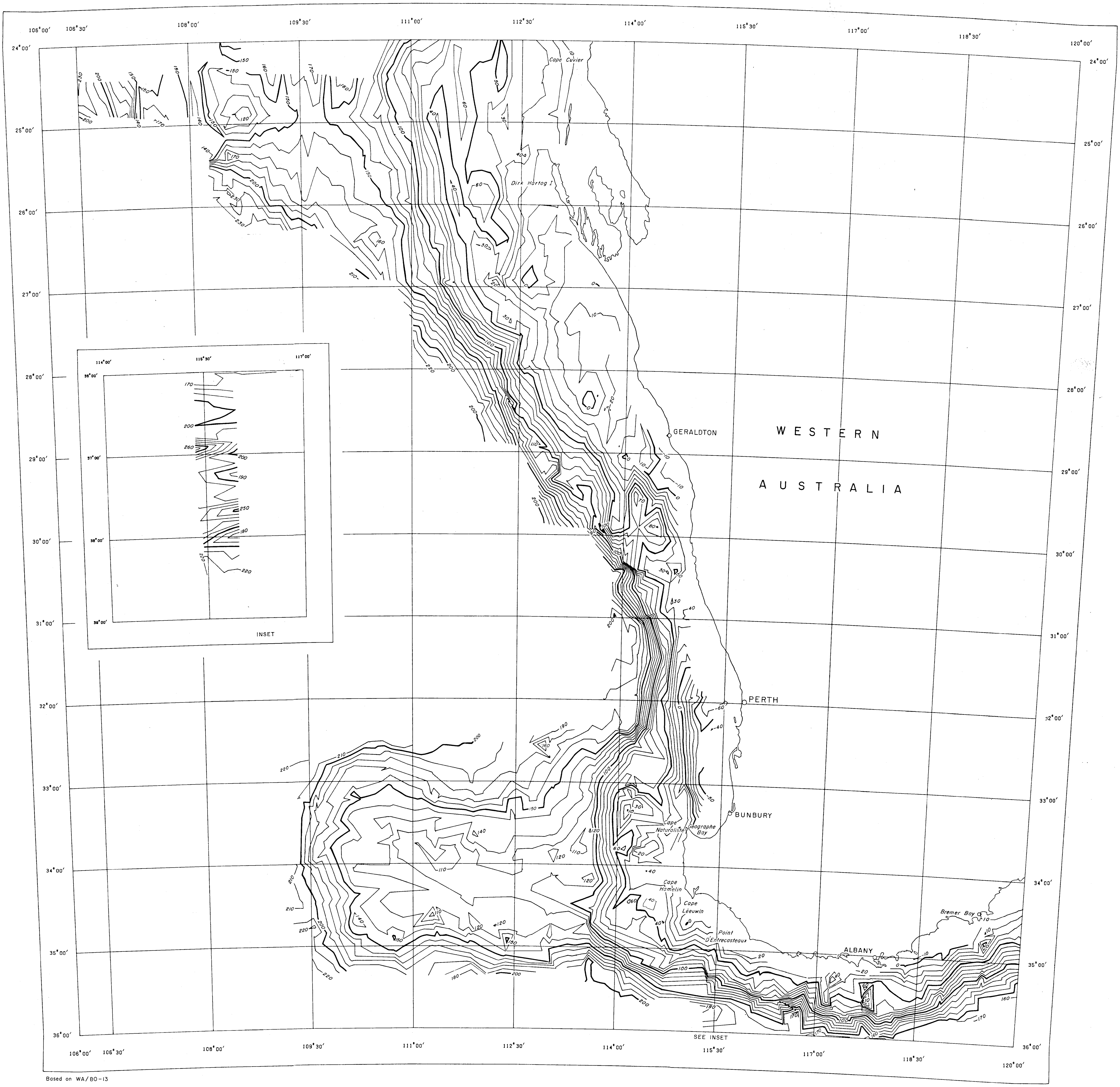
WA/B8-29-1

SOUTH WESTERN MARGINS

PLOTTED 73/07/27

PLATE 3

AUSTRALIA 1: 2500000



AUSTRALIAN NATIONAL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH

B.M.R. 1970-73 MARINE SURVEYS

DENSITY = 2.20 G/CC

SOUTH WESTERN MARGINS

BOUGUER ANOMALIES

AREA 6

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KILOMETRES

50 0 50 100 150 200 250

0 50 100

NAUTICAL MILES

Contour interval : 10 milligals

Data used are preliminary, and are based on hourly values extracted on board the survey vessel. No adjustments have been applied for mistries at traverse intersections.

Contour lines are drawn by computer using a triangular contouring program. A triangular plate is defined by three adjacent stations whose circumscribing circle contains no other stations. Linear interpolation is then used on the triangular plate. Should any side of an acceptable triangle

Record No. 1975/180

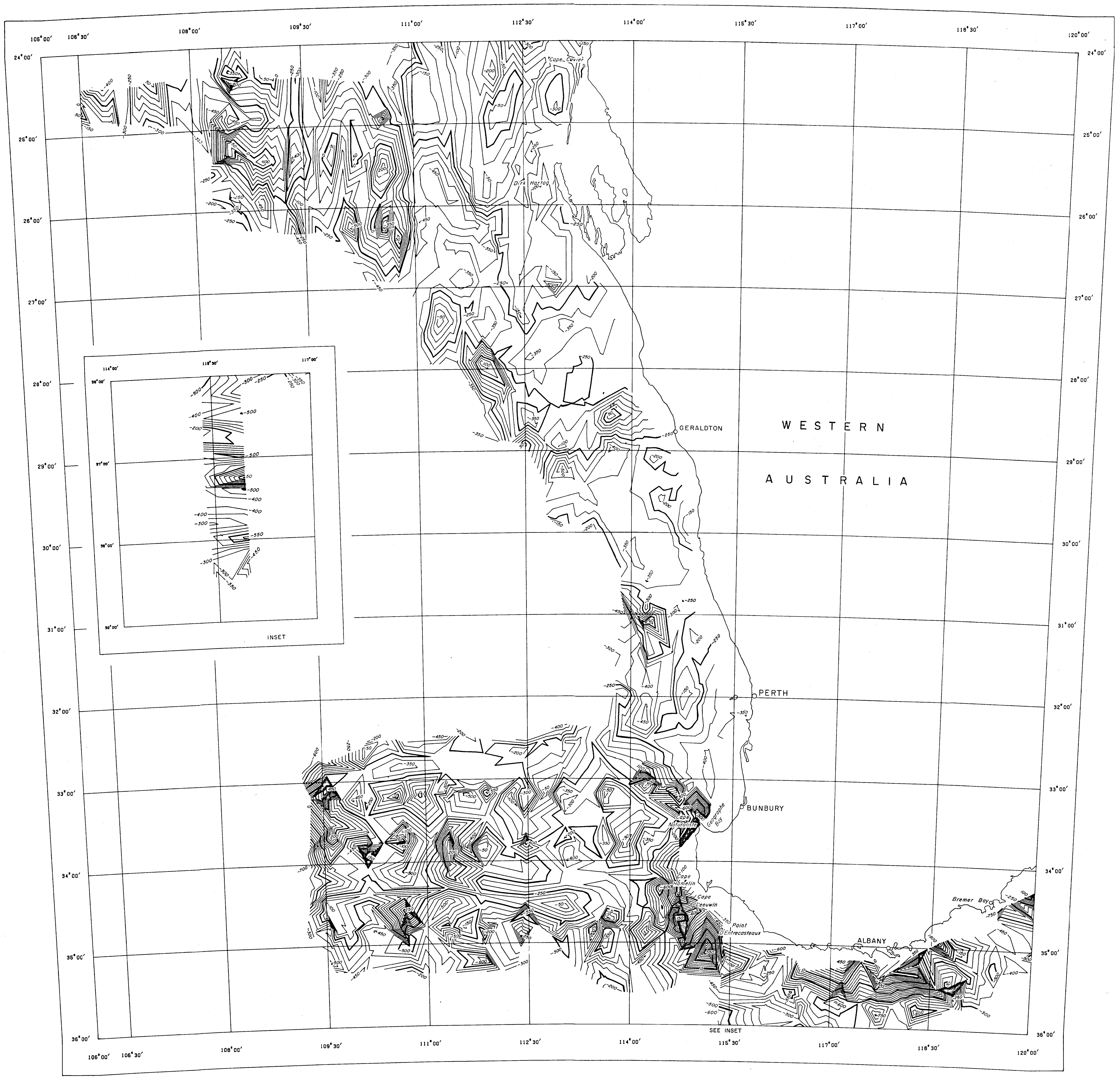
WA/B2-60-1

SOUTH WESTERN MARGINS

PLOTTED 73/07/27

AUSTRALIA 1: 2500000

PLATE 4



Based on WA/BO-13

AUSTRALIAN NATIONAL SPHEROID
SIMPLE CONICAL PROJECTION
WITH TWO STANDARD PARALLELS
AT 18° 0' AND 36° 0' SOUTH

B.M.R. 1970-73 MARINE SURVEYS

SOUTH WESTERN MARGINS

MAGNETIC ANOMALIES

AREA 6

WA/BI-2-1

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KILOMETRES

50 0 50 100 150 200 250

0 50 100

NAUTICAL MILES

Magnetic values reduced to the International Geomagnetic Reference Field
Contour interval : 50 nT

Record No. 1975/180

Data used are preliminary, and are based on hourly values extracted on board the survey vessel. No adjustments have been applied for misties at traverse intersections.

Contour lines are drawn by computer using a triangular contouring program. A triangular plate is defined by three adjacent stations whose circumscribing circle contains no other stations. Linear interpolation is then used on the triangular plate. Should any side of an acceptable triangle exceed 40 nautical miles, that plate is not contoured.