DEPARTMENT OF
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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1974/116

GEOPHYSICAL RESULTS FROM THE CORAL SEA: CONTINENTAL MARGINS SURVEY REPORT.

by

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SUMMARY

The Bureau of Mineral Resources has collected nearly 20 000 nautical miles of multisensor geophysical data on the continental margin off Queensland, between 12°S and 24°S. The data were obtained at a systematic 20-nautical-mile line-spacing navigating by satellite Doppler/sonar Doppler.

Preliminary investigations into the data quality based on a rudimentary statistical analysis of the intersection misties has shown that no large systematic errors are present in the gravity, magnetic, or bathymetric data. Similarly, no gross navigational errors have been detected so far. Gravity recording is of low quality on 27 percent of the traversing owing to poor performance of the gravity meter in rough seas. The magnetic recording was generally reliable and showed noise levels around two to three gammas. Seismic data quality deteriorates in areas of deep water and during rough weather; however, the quality of graphic recordings is generally satisfactory.

A brief analysis of the Bouguer anomalies has shown that the Coral Sea Plateau and Marion Plateau are underlain by crust of continental thickness and that their marginal troughs are probably grabens with a fill of relatively low-density sediments. Structures east of the plateaus are probably oceanic in origin.

The contrast between oceanic and continental structures is not as evident from the magnetic results. Associated with the Queensland Trough and the western half of the Coral Sea Plateau are north to northwest magnetic trends, which parallel the structural grain of the Tasman Geosyncline in north Queensland, and these trends are interpreted as evidence of an offshore extension of the Tasman Geosyncline. Magnetic anomalies in the Mellish Rise/Dampier Ridge zone indicate that these structures are composed of oceanic basalts.

Seismic results indicate that the sites of greatest deposition are the Queensland and Townsville Troughs where sediments exceed 1000 m in thickness. Faulting in the Queensland Trough shows that it is a graben structure. It is suggested that a widespread unconformity on the Coral Sea Plateau marks an Eocene/Oligocene hiatus found by the Deep Sea Drilling Project.

Combining the above-mentioned results it has been possible to draw the following broad conclusions about the structure of the major physiographic units. The plateaus

appear to be submerged extensions of continental Australia that were covered by Palaeozoic sediments before they subsided, and by a veneer of Tertiary sediments after they subsided. The Cato Trough was probably formed at the same time as the Coral Sea Basin, and the Mellish Rise/Dampier Ridge junction zone appears to be formed of massive igneous bodies emplaced in an area of fractured oceanic crust.

INTRODUCTION

Nearly 20 000 nautical miles of multisensor geophysical data have been collected off the coast of Queensland by Compagnie Generale de Geophysique for the Bureau of Mineral Resources (BMR). The work was carried out as part of BMR's marine geophysical survey of the continental margin of Australia. Figure 1 shows the location of the survey area discussed, and Plate 1 shows the lines surveyed.

OPERATIONS AND EQUIPMENT

The traversing was carried out at 10 knots on a systematic grid of east-west lines spaced at 20 nautical miles (37 km). East-west traversing north of $13^{\circ}30'$S (lines 10/004 to 10/015) was carried out in late December 1970 after surveying in the Bismarck Sea and Gulf of Papua. The remaining lines were surveyed between 20 July 1971 and 5 December 1971. The ports of Cairns, Townsville, Gladstone, Brisbane, and Port Moresby were entered during the course of surveying, and at each a gravity tie was made to a station in the BMR isogal network (Dooley, 1965a). A magnetometer shore station was located at convenient ports along the coast to record the diurnal variation in the magnetic field. These data were used later in reducing the magnetic total force values recorded on board ship to magnetic anomaly values. Port Moresby was the shore station location in 1970, Mackay from 20 July 1971 to 2 November 1971, and Cairns for the remainder of the time.

The ship was navigated using a Marquardt-pulsed sonar Doppler system and a gyro compass. The continuous dead-reckoned ship's track provided by the sonar Doppler was adjusted to fixes taken from the US Navy's navigation satellites. Satellite fixes were available at about two hourly intervals and thus provided regular updating of the dead-reckoning data. A Chernikeeff electromagnetic log and a pressure log were also recorded but not used for on-board navigation.

A LaCoste & Romberg stabilized-platform gravity meter (No. S-24) was used to obtain gravity data. The output of this device is a gravity value corrected for accelerations experienced by the meter owing to motion of the ship. A Varian proton precession magnetometer measured the total magnetic intensity. The sensing head was towed about 200 m astern to avoid interference from magnetic effects produced by the ship. The instrument had a nominal accuracy of $\pm$ 1 gammas and was operated at a 10-second cycling rate.

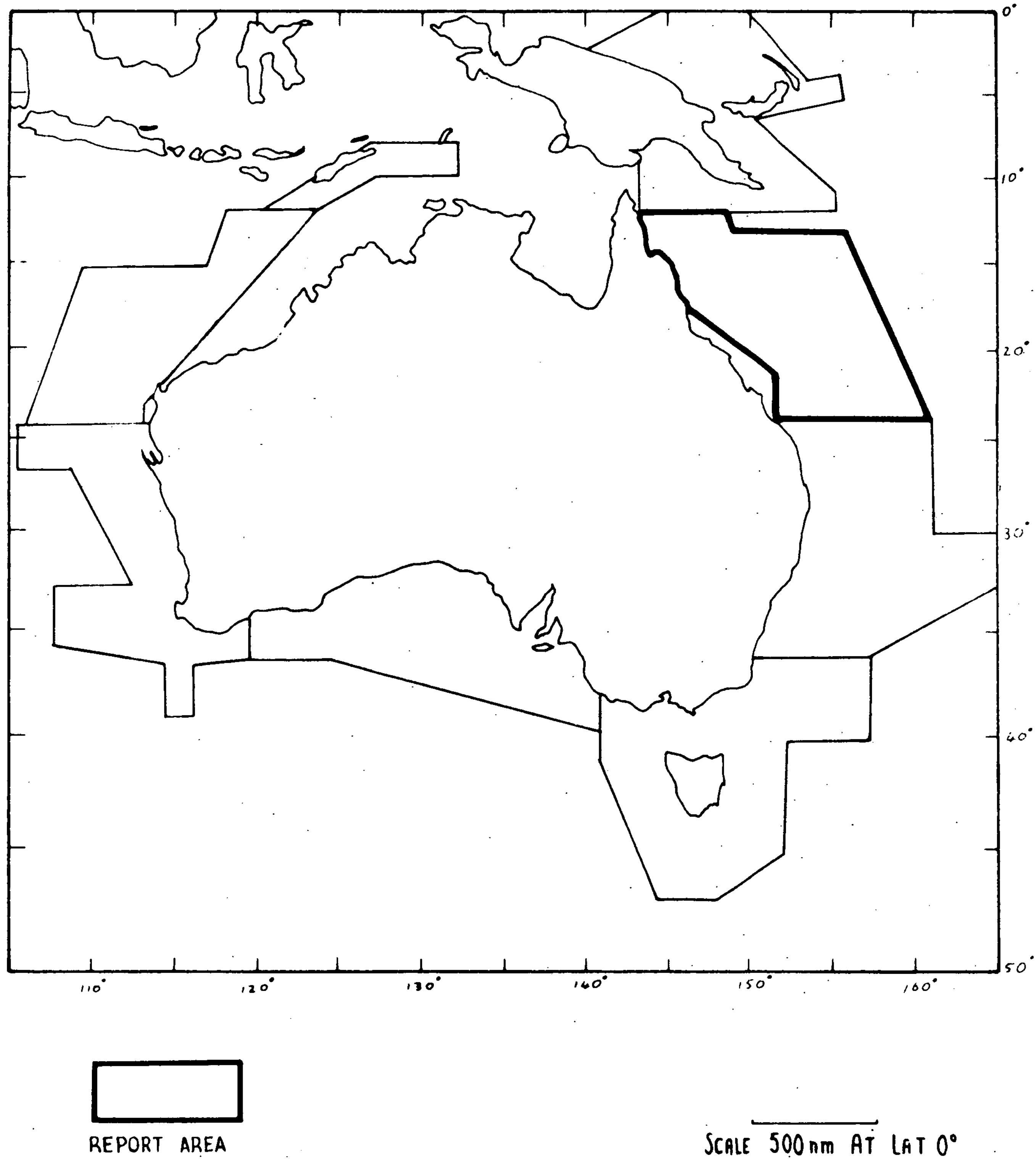
A data acquisition system (DAS) centred on a Hewlett Packard HP2116B computer sampled at 10-second intervals the data used for navigation and the outputs of the gravity meter and magnetometer. The DAS also provided dead-reckoned ship's positions updated by satellite fixes, checked recorded data, reformatted it, and wrote it onto magnetic tape. A teletype output, available from the DAS every 10 minutes, provided data suitable for on-line checking of data quality.

The seismic energy source was a Teledyne 120 kilojoule sparker discharging through four electrodes about 100 metres astern of the ship and about 5 metres below the sea surface. The dominant output frequency was around 60 Hz. The output from two seismic cables was recorded. A six-channel cable detected reflections in the frequency range 10 Hz to 200 Hz and provided recorded traces for a six-fold CDP stack. A single-channel cable was used to detect reflections in the frequency range 100 Hz to 300 Hz for high-resolution near-surface investigations. The seismic amplifiers used at first were a set of HTL7000B valve amplifiers. These had a heavy current drain and suffered from overheating; they were replaced in December 1970 with Sercel AS626X amplifiers which gave improved reliability without greatly improved performance characteristics. All seismic data were recorded on an Ampex FR1300 14-channel FM tape recorder.

Changes were made to the seismic graphic recording system as the survey progressed. In 1970 the set-up consisted of two E.G. & G 254 recorders (11-inch paper width), an Esterline-Angus E1101S (modified) recorder (12-inch paper width), and a Raytheon PSR1901 (19-inch paper width) recorder on loan from the University of New South Wales. The Raytheon recorder was returned after the 1970 work and the E.G. & G, and Esterline-Angus recorders were phased out during the cruises south of Mackay to be replaced with four EPC 4100 recorders. The new recorders had a 19-inch paper width, electrostatic writing, and easily controlled writing characteristics, paper speed, and sweep speed. The records from these recorders were superior in presentation to those from any of the recorders used before their installation.

The locations of refraction probes are shown in Plate 1. Forty-six successful refraction soundings were made using Acquatronics SM44 sonobuoys to pick up and transmit energy from the sparker. Failures resulted from sonobuoys being damaged on launching, or tangling with seismic cables or sparkers after launching. The quality of successful refractions is generally not good owing to poor signal

FIGURE 1



GEOPHYSICAL RESULTS FROM THE CORAL SEA

LOCATION MAP

(Based on A/B0-62A) Record No 1974/116

A/B8-72A

levels from the sonobuoys, and the low level of low-frequency seismic energy in the sparker signal; thus, reliable velocity determinations from the records cannot be made without heavy processing of the results, and this has not yet been done.

DATA QUALITY

Navigation

The accuracy of the navigation system varies from a probable figure of about 0.2 miles at a satellite fix to more than 1 mile between fixes. The bathymetric mistie histogram shown in Figure 2 may be used as a qualitative indicator or poor navigation. If the navigation system has no errors the histogram should show a normal distribution of errors with a mean of zero.

The distribution is close to normal with a mean of 5.2 metres and standard deviation of 40.2 metres. This gives a figure of 13.4 percent for the probability of obtaining the observed mean from a random distribution, i.e., no major errors can be detected in the navigation.

Gravity

Early in 1971, before the Coral Sea was surveyed, it became clear that the gravity meter was performing badly in moderate to rough seas. A criterion based on the amplitude/wave-length characteristic of the gravity trace was adopted for the acceptability of gravity results. It was assumed that, if a gravity trace persistently showed disturbances with periods of less than 10 minutes and peak to peak amplitudes greater than 6 milligals, then the corrections within the meter were not being applied successfully. Disturbances outside the above criterion were considered not to be representative of true gravity variations.

On this basis 2533 nautical miles (4694 km) of gravity data was rejected as being out of criterion. Only the 73 percent of data considered satisfactory was used in contouring the Bouguer anomaly map (Plate 3).

Other data were lost owing to instrument failure on 285 nautical miles (528 km) of traverse. Failures of this type were generally shortlived and have had little effect on the compilation of contour maps. Figure 3 shows the traverses from which gravity data was not used for contouring.

Further inaccuracies are introduced to a computed gravity anomaly value by errors in position, speed, and heading of the ship. Some indication of the reliability of the data, after introduction of navigational uncertainties, is available in the misties at intersection points shown in Figure 2.

The gravity misties show a distribution whose mean is 0.8 milligals and standard deviation is 6.1 milligals, and whose shape is unlike the expected random distribution of errors. The mean has 22.6 percent probability of occurring under this assumption. This probability indicates that the mistie distribution departs insignificantly from a random distribution, despite the unusual shape of the histogram.

Magnetics:

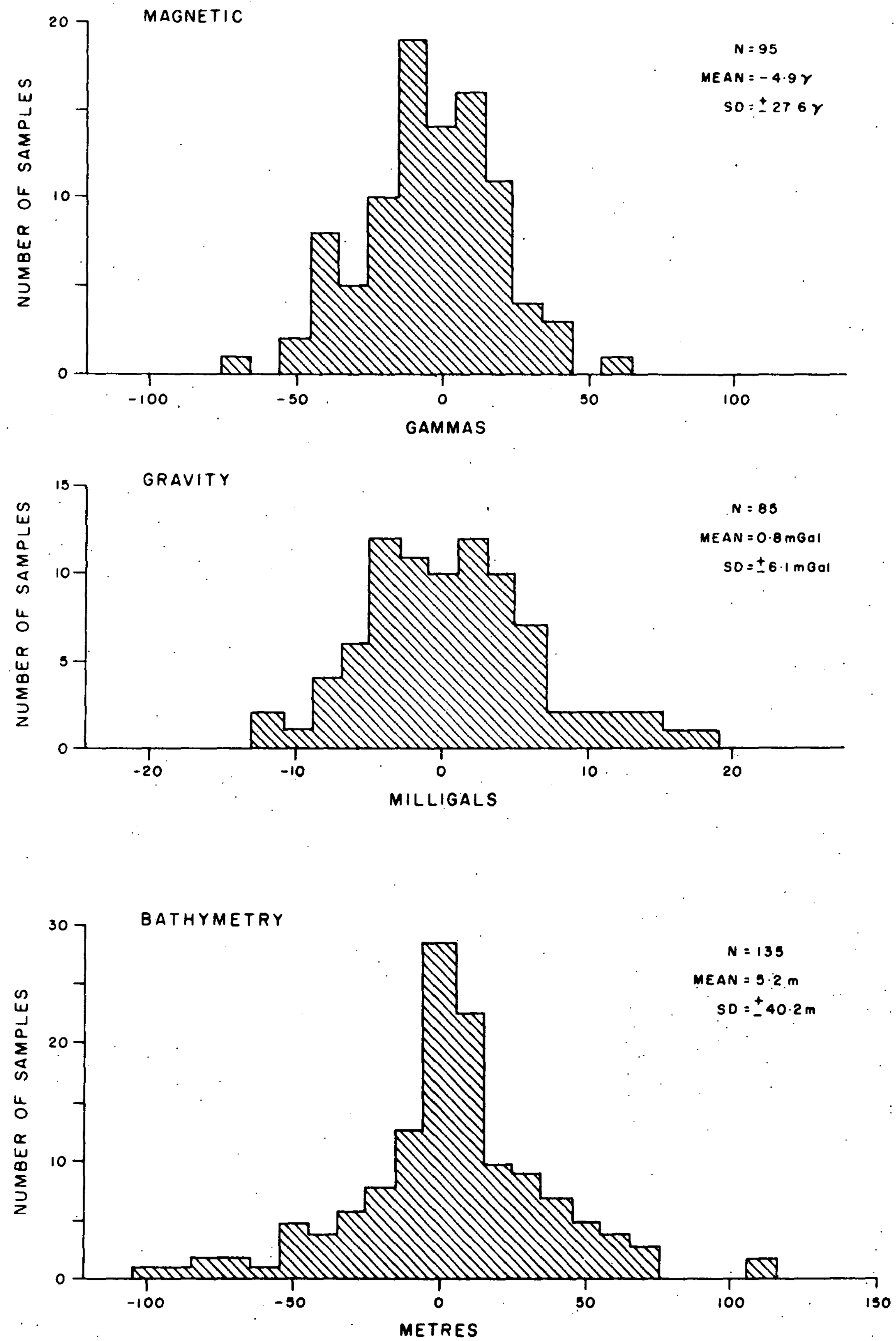
Problems which seriously affected magnetic recordings were generally shortlived. The main causes were clogging of electrical connectors with salt, which caused short circuits, and leakage in the tow cable. As a result of cable leakage, magnetic data were completely lost on lines 14/002 to 14/011 south of Cairns. A further 460 km of recording was lost on lines 14/040 and 14/055 east of 149°E owing to electronic malfunctions in the recording equipment, and an additional 560 km was lost on lines 13/079 and 13/080 owing to leakage into the tow cable after the sensor was struck by a floating tree trunk and became entangled with a sparker electrode and the single-channel cable.

The amount of magnetic data lost is not large compared with the total mileage surveyed. However, two of the three losses mentioned above occurred on tie lines, and this has made the assessment of data quality by misties less reliable in some areas. The amount of unusable or missing data is shown on a traverse plan in Figure 4.

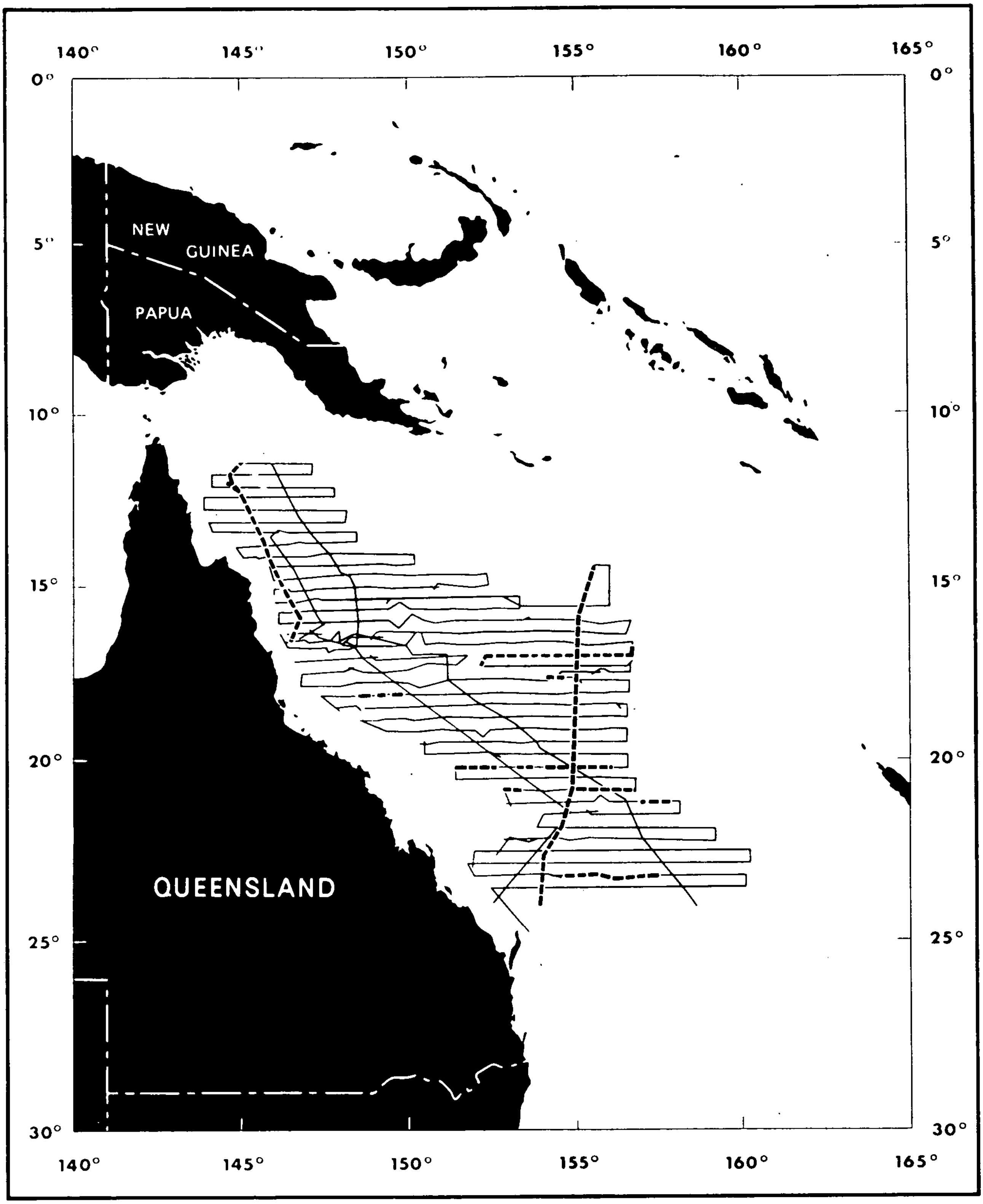
The continuously recorded analogue monitor chart allowed a constant check to be kept on the magnetometer noise level. The noise contributed minimum random variations of about 2 gammas peak-to-peak, but in rough seas this level increased to over 6 gammas peak-to-peak, and sometimes showed non-random oscillations with a period of around 5 minutes. The occurrence of oscillatory noise was intermittent and its source was not found during the Coral Sea cruises.

The histogram of magnetic misties shown in Figure 2 is almost symmetric although the negative branch shows anomalous peaks at -10 and -40 gammas. The mean of

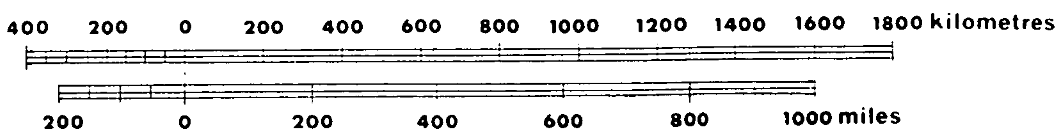
FIGURE 2



MAGNETIC, GRAVITY, AND BATHYMETRIC MISTIES



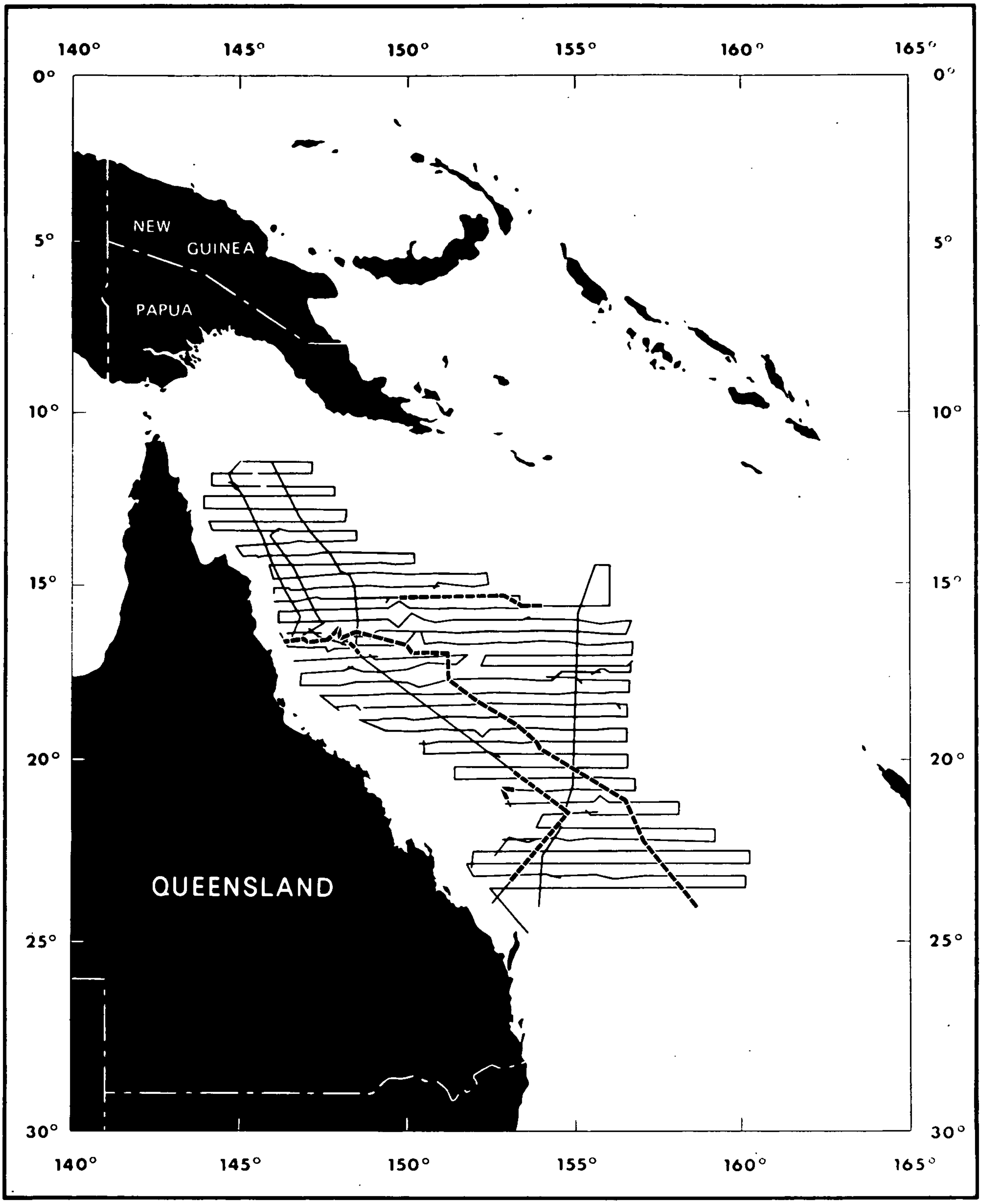
GRAVITY DATA



LEGEND

——— Data used for contour map compilation

- - - - Data not used for contour map compilation



MAGNETIC DATA

400 200 0 200 400 600 800 1000 1200 1400 1600 1800 kilometres

200 0 200 400 600 800 1000 miles

LEGEND

Data used for contour map compilation

Data not used for contour map compilation

-4.9 gammas has an 8.5 percent probability of occurring under the assumption of a random distribution. This is above the 5 percent significance level commonly used in statistics so it has not been shown that the magnetic mistie distribution departs significantly from randomness.

Seismic

The seismic recording system was modified and updated before and during surveying in the Coral Sea (Tilbury, in prep.). Resulting changes in the quality of graphic recording were partly responsible for the changes in the standard of results illustrated in Figure 5.

Quality is judged on the signal-to-ratio on the graphic recording, the depth of penetration of the seismic energy, and the resolution of reflectors within the section. This quality depends on the power and frequency content of the energy source and the good condition (and operation) of the seismic streamer and recording system.

In general the data quality deteriorated with increase in water depth and increasing sea state. Between 12°00'S and 13°30'S signal-to-noise ratio is lower than normal owing to high towing noise from the streamer and rough seas. On the eastern side of the area between 13°30'S and 15°30'S water depths range from 1500 to 4500 metres and here the signal-to-noise is low owing to reduced returning signal strength from the deeper water, and possibly to poor recording control. In the remainder of the survey, information content is acceptable for regional traversing although it is recognized that resolution and penetration are sacrificed by surveying at 10 knots. Where sub-bottom conditions were favourable, penetration was up to 2.5 seconds reflection time and 3 kilometres depth, as against the more general figure of 1.5 seconds and 2 kilometres.

The preliminary interpretation (Sections 3 and 4) was done on unprocessed records from the second channel of the six-channel cable.

REDUCTION TECHNIQUES

The contour maps (Plates 2, 3, and 4) were produced on the BMR flat-bed plotter from the output of a computer-contouring program. The program employs strict linear interpolation based on sets of three values whose maximum distance separation is given in the explanatory notes at the base of each map.

Gravity data have been reduced to a Bouguer anomaly using an infinite slab of density 2.2 g/cm^3 replacing the water layer. Both the velocity used for computing the Eotvos correction, and the water depth used for the included slab thickness are preliminary at this stage. The depth data have not been corrected for the variation in the velocity of sound propagation in sea water resulting from changes in temperature and salinity, as control over these variables is poor and the errors introduced are minimal. The error introduced by uncertainties in the ship's velocity and the water depth could be as high as 10 milligals at this stage of the processing.

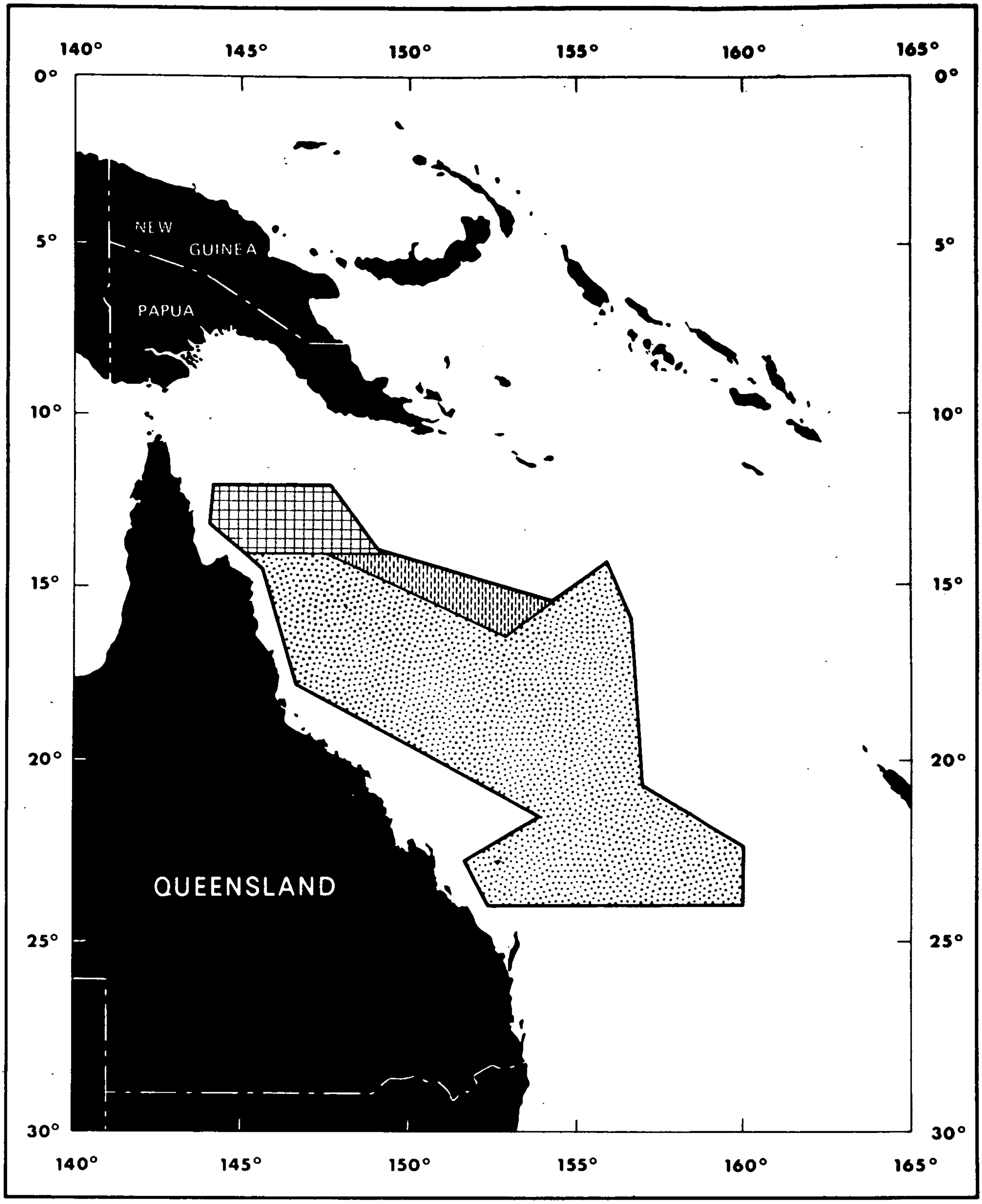
Magnetic data have been reduced to a magnetic anomaly by removal of the International Geomagnetic Reference Field, followed by removal of the magnetic diurnal variation measured simultaneously on shore.

Gravity, magnetic, and water depth data were sampled at an interval of one hour for contouring. Obvious errors which showed as singularities in the maps have been removed. Detailed bathymetric contours around reefs and islands have been introduced by hand by reference to British Admiralty and GEBCO (General Bathymetric Charts for the Oceans) charts.

GEOLOGY AND GEOPHYSICS

The continental margin of Queensland is a seismically inactive region of submarine plateaus and troughs, and forms the junction zone between the mature continental Tasman Geosyncline and the relatively young Coral Sea Basin and adjacent oceanic regions.

The Tasman Geosyncline is a complex tectonic belt consisting of numerous structural highs and basins trending north to north-northwest. In Queensland the geosyncline began its development in the Ordovician and continued until the late Permian, when it ended with the Hunter/Bowen Orogeny (Hill & Denmead, 1960). Basins with considerable thicknesses of sediment formed after the orogeny although no major tectonism is known. Geocynclinal trends intersect the coastline of Queensland, and it is reasonable to assume that the geosyncline extends offshore, across the continental shelf into deep water. It is, therefore, likely that deep sedimentary basins may exist in the subsurface of the offshore plateaus and troughs.



SEISMIC DATA

400 200 0 200 400 600 800 1000 1200 1400 1600 1800 kilometres

200 0 200 400 600 800 1000 miles

LEGEND

Poor quality   Marginal quality   Satisfactory quality

Q/B8-2A

Results of the Deep Sea Drilling Project (DSDP) at site 287 in the east-central Coral Sea Basin (Andrews & Packham, et. al, 1973) indicate that the age of the basement, and, therefore, time of formation of the basin, is early Eocene. The basin contains sediments up to 1500 m thick, about 500 m of which are turbidites that were probably derived from New Guinea.

DSDP hole 209, drilled on the outer edge of the Coral Sea Plateau (Plate 1), showed that subsidence of the plateau began around mid-Eocene. It is cogent to suspect that the opening of the Coral Sea had a triggering effect on plateau subsidence. Details of the age relationship between plateau subsidence and trough formation, and the relative ages of Coral Sea and Marion Plateaus, are not known, as no detailed surveying was attempted before the BMR work.

In 1967, the Coral Sea Plateau and Coral Sea Basin were surveyed as a co-operative venture by the University of New South Wales and the Lamont-Doherty Geological Observatory. Their program consisted of five long lines of seismic reflection profiling with thirteen sonobuoy refraction shots, and deep crustal refraction shooting. The results were published in two papers (Ewing, Houtz & Ludwig, 1970; Ewing, Hawkins & Ludwig, 1970), and showed that the Coral Sea Plateau has a continental-type crust covered with a 1-km-thick layer of possible low-grade metamorphics. Overlying this is a thin sedimentary layer which thickens to about 2000 m at the inner and outer plateau edges. The Coral Sea Basin has an oceanic crustal thickness and contains up to 1500 m of sedimentary rocks.

Systematic aeromagnetic work has been confined to within the Great Barrier Reef (Hartman, 1962; Affleck & Landau, 1965), except for one excursion onto the Coral Sea Plateau (Shell, 1968), which resulted in the definition of the Halifax Basin, a depression at the junction of the Queensland and Townsville Troughs that contains up to 5 km of sediment. No systematic magnetic surveying of areas outside the Reef has previously been attempted. Just outside the BMR survey area, between Chesterfield Reef and New Caledonia, Adastra Hunting Geophysics flew a low altitude aeromagnetic survey for Compagnie Francaise de Petroles in 1965 (Compagnie Generale de Geophysique, 1966). Results from this survey showed that the area was underlain by 1 to 4 km of sediment, and that individual reefs lie atop prominent closed highs in the magnetic basement.

The greater part of the area discussed in this report has not previously been covered by oil company seismic surveys. Australian Gulf Oil has conducted surveys in the Capricorn Basins (McGrew, 1966, 1967), in the extreme southwest of the area, and followed these investigations by drilling (Carlsen & Wilson, 1967a, 1967b). Their results showed that at least 2400 m of Tertiary sandstone, claystone, and marl exist in the basin; however, lack of source beds suggest the area is low in petroleum potential. Little other relevant seismic work has been conducted.

Underwater gravity surveys were conducted by BMR from 1954 to 1960 (Dooley, 1965b) in the northern Great Barrier Reef, but no systematic coverage of the reefs exists. Several ships from oceanographic institutes investigating the Coral Sea region have carried gravity meters; their results have been combined into a free-air anomaly map by Falvey (1972). Reisz & Moss (1971) have compiled maps and a bibliography of the major marine geophysical surveys conducted around Australia. The reader is referred there for a fuller listing of previous geophysical investigations in the subject area.

RESULTS

BATHYMETRY

Major types of physiographic features present in the western Coral Sea in the area surveyed (Plate 2) are the plateaus (Coral Sea and Marion), marginal troughs (Queensland, Townsville, and Cato), and a complex rise in the east of the area. The wide continental shelf present between latitudes 19°S and 24°S was not surveyed at this time because the lavish and extensively developed Great Barrier Reef, which dominates its outer edge, would have required a modified survey technique.

The continental slope is diverse in form throughout the area, and does not form a simple recognizable unit. North of Cape Melville a single, steep slope is present; the water depth increases rapidly from 200 m at the edge of the shelf to 3000 m at the base of the slope. Between Cape Melville and 18°S both an inner and an outer continental slope are present; the inner slope is formed by the steep western flank of the Queensland Trough, and the outer slope is formed by the gentle gradient of the outer margin of the Coral Sea Plateau. South of the Coral Sea Plateau the outer slope is absent and the inner slope follows the outer margin of the Marion Plateau. The slope is considerably steeper south of the Marion Plateau than it is in the region of the Marion Plateau.

The larger of the two plateaus, the Coral Sea Plateau, lies between 14°S and 18°S at an average depth of 1500 m. Its surface is flat, and broken only by a number of areas of reef growth, some of which (e.g. Lihou and Tregrosse Reefs) are extensive. The plateau has a slight tilt to the northwest, toward Osprey Reef. It is completely separated from the continental shelf by the Queensland Trough, and is further isolated from the neighbouring Marion Plateau by the east-striking Townsville Trough. The marked linearity of the west and south margins of the Coral Sea Plateau may indicate that both have a tectonic origin. The eastern or outer margin of the plateau, which forms the outer continental slope in this area, is also strongly linear and has an average gradient of 1:30 compared with a normal continental slope gradient of 1:40. The linearity and steepness of this margin also point to a major tectonic influence in plateau formation. The presence of steep-sided reefs developed on the plateau surface suggests that the plateau has subsided slowly from around sea level to its present elevation, with reef growth keeping pace with subsidence.

The Marion Plateau forms a simple extension of the continental shelf between 19°S and about 21°30'S. The plateau surface falls away gently from the shelf to around 600 m, then dips steeply into the Cato and Townsville Troughs. Both outer margins of the Marion Plateau are strongly linear. The plateau surface is flat, and broken by one large reef (Marion Reef), which grows on the extreme outer edge of the plateau from a depth of around 600 m.

An extensive canyon system, not seen on the hourly value contour map, drains both plateaus into their adjoining troughs and basin.

Both the Queensland and Townsville Troughs are linear for more than 500 km. The strike of the Queensland Trough is parallel to the structural grain of the Tasman Geosyncline in north Queensland, but the east strike of the Townsville Trough bears no obvious relation to the continental geology. The western margin of the Queensland Trough is steep, and may reflect faulting; thus, the trough may be a graben or half-graben. South of Bougainville Reef, the Queensland Trough has a relatively simple profile with a steep western margin, a flat floor, and a gentle eastern flank. North of the reef, the eastern margin rises in two steps: a steep rise along 146°30', and a shallow gradient which leads onto the Coral Sea Plateau about 50 km farther east.

In contrast, the Townsville Trough is nearly symmetric, but its northern flank steepens in the region of Lihou and Tregrasse Reefs. The gentle U-shaped profile is maintained throughout the length of the trough. The Townsville Trough opens into the northern reaches of the Cato Trough, sometimes referred to as the Frederick Basin (Fairbridge, 1966).

The Cato Trough has a flat floor at a depth of 3000 m; it has a greater width to length ratio than the two previously mentioned troughs, and its two margins have a somewhat complex physiography. The eastern margin is formed by the rugged topography of an oceanic rise described below. The trend of this margin changes locally from the north to nearly east-west. The western margin in the south, where the trough narrows to form a valley leading into the Tasman Abyssal Plain, is steep and linear, and suggests major tectonism. Farther north, adjacent to the Marion Plateau, the western margin of the trough is formed by the gentle gradation of the continental slope into the trough floor. Wreck Reef grows from the floor of the Cato Trough on a structure similar to the Tasman Sea guyots. With its deep flat floor and rugged eastern margin, the trough is morphologically similar to, but much smaller than, the Tasman Sea, and may be the beginnings of a large ocean basin arrested in its early development.

On the eastern boundary of the area surveyed is a complex rise, which is mainly continuous between 16°S and 24°S. This rise is often rugged and shows several conflicting trends. It is clear from the contour map that the survey did not adequately define the limits of this structure. It appears to be the junction zone, or area of amalgamation of the Mellish Rise (Cullen, 1970) and the Dampier Ridge (Symonds, in prep.), but may be even more complex than that; some features in the south of the rise (e.g., between 21°S and 22°S) appear to be small plateaus.

A fundamental dextral offset displaces the rise along a north-east trend at 20°39'S. North of this offset the rise is more rugged and is linked with the Mellish Rise, whilst south of the offset the rise is undulating and appears to form an isolated structure at the northern tip of the Dampier Ridge (see also Symonds, 1973). Several steep, roughly conical structures rise to within or above sea level and on these are located Mellish Reef, Kenn Reef, and Cato Island. The roughly conical shape of the structures suggests that the reefs may be the emergent parts of large submarine volcanoes.

Other physiographic features which should be noted are the Osprey Embayment, the Nova-Argo Basin, the Nova-Argo Bank, and the Capricorn Channel. The Capricorn Channel is a shallow low-relief trough at the southern end of the Marion Plateau. It lies over the Capricorn Basin, in which two experimental oil wells have been drilled (Carlsen & Wilson, 1967a, 1967b), and, following the northwest trend of the Tasman Geosyncline, opens into the Tasman Sea.

The Nova-Argo Bank is formed by two guyots close together (the Nova and the Argo), and is the northernmost of the guyots in the Lord Howe chain (Symonds, 1973). The Nova-Argo Basin, of which only the northern part is shown in Plate 2, lies at about 2400 m and has a flat floor. It is the northern counterpart of the Lord Howe and Middleton Basins which lie between the Lord Hower Rise and the Dampier Ridge (Symonds, op. cit).

The Osprey Embayment has been described by Mutter (1972). It is a region of deep water between the Coral Sea Plateau to the south and the Eastern Fields Fan to the north, and is bounded on its western margin by a steep continental slope. Its eastern margin grades into the Coral Sea Basin. The Queensland Trough widens and opens into the Osprey Embayment. An isolated high along 12°50'S lies on an ill defined east-west trend across the centre of the embayment. North of this trend, at about 12°20'S, the Bligh Canyon skirts the southern edge of the Eastern Fields Fan. The contour map representation of this canyon has been considerably broadened by hourly value contouring. The Osprey Embayment appears to be a complex of small, flat-floored basin areas and isolated bathymetric highs. The average water depth of 3000 m is intermediate between the plateaus and the abyssal depth of the Coral Sea Basin, and is deeper than any of the troughs.

BOUGUER ANOMALIES

The most striking feature of the Bouguer anomaly map (Plate 3) is a steep gradient which is nearly continuous from the northwest corner to the southern edge of the map at around 154°30'. Across the gradient, Bouguer anomaly values rise from a level of about 50 milligals to 100 milligals in the southern part of the area, from 100 to 200 milligals in the central part of the map, and from about 100 to 150 milligals in the northern area. The correlation of this gradient with the continental slope is quite marked. The gradient overlies the outer edges of the Coral Sea and Marion Plateaus, which form the outer continental slope over much of the area. North of the plateaus the gradient corresponds with the continental slope leading into the Osprey Embayment, and south of Marion Plateau the gradient corresponds with the continental slope outside the Capricorn Channel region. In general, the deeper and steeper parts of the continental slope correlate with the larger and steeper parts of the regional Bouguer anomaly gradient. Reefs and other small features disturb the gradient locally. Thus, where the Townsville Trough strikes across the continental slope, the Bouguer anomaly gradient is distorted by a westerly plunging nose.

Using an infinite-slab assumption, a crust/mantle interface density contrast of $0.45 g/cm^3$, and a standard cruse 33 km thick, a first-order estimate of the thickness of crust can be made from the Bouguer anomaly and water depth values. These estimates give values of greater than 25 km inside the gradient and generally less than 20 km outside the gradient. The gradient clearly represents the zone of transition from continental to oceanic crust.

The Bouguer anomaly gradient (or crustal transition zone) has been taken as a convenient line to divide the map for ease of description. The inner (or continental) anomalies will be discussed first; the outer (or oceanic) anomalies later.

West of the regional gradient, Bouguer anomaly gradients are generally shallow and individual closures show little relation to physiographic features apart from those associated with the very steep-sided reefs. The Queensland Trough has no distinct Bouguer anomaly expression south of $14^{o}30'$S, the area being formed by a shallow gravity platform. North of $14^{o}30'$S the Queensland Trough is expressed as a gravity ridge which is part of the regional gradient. At $17^{o}10'$S a gravity ridge strikes across the trend of the Queensland Trough. Lack of a clear Bouguer anomaly expression of the trough is surprising as the trough is clearly a major structural feature.

The Coral Sea Plateau is expressed as a gravity platform with a gentle gradient increasing the Bouguer anomaly values from southwest to northeast. No individual anomalies of special interest occur in this region. The characteristic trend of the anomalies, although weak, is north to northwest, which reflects the trend of the Tasman Geosyncline in north Queensland. Individual anomalies cannot be related to physiographic features or to structures seen on seismic records, and must have their source in deep structures within the basement.

The Townsville Trough is expressed as a weak east-trending gravity nose, which has cross trends striking north. Lack of a clear Bouguer anomaly expression in this trough, as in the Queensland Trough, is somewhat unexpected.

Both the Queensland and Townsville Troughs are major physiographic depressions; the former closely parallels the structural grain of the continental geology, and the latter forms a major transcurrent structure. As remarked earlier, the linearity of these features suggests a major tectonic influence in their formation. It is unusual for such features not to be associated with a considerable mass anomaly, but lack of Bouguer anomaly expressions in the troughs may be related to the choice of density used in the Bouguer reduction.

A density of 2.2 g/cm^3 has been used throughout the area, and this is inappropriate in many places. In areas where the density contrast across the water-seabed interface is less than 1.17 g/cm^3 (2.2-1.03), the Bouguer anomaly pattern will reflect the seabed topography in an inverted sense; thus, a high will be expressed as a low, and a low will be expressed as a high. The opposite is true in areas where the contrast is greater than 1.17 g/cm^3, whereas if the seabed material has a density equal to 2.2 g/cm^3 the effect of seabed topography will be removed. With structures at different depths the effect of one density contrast can negate the effect of another in the total Bouguer anomaly field. This may be so in the Queensland and Townsville Troughs.

Sediments in the troughs probably consist largely of pelagic material with a density less than 2.2 g/cm^3, whereas the basement material probably has a density much greater than 2.2 g/cm^3. If the basement is displaced into a graben structure, as is suggested by seismic results in the Queensland Trough, the infill of low-density sediment could produce a cancelling effect in the Bouguer anomaly computed for a density of 2.2 g/cm^3. It is suggested that this has happened in both the Queensland and Townsville Troughs.

South of the Townsville Trough the Bouguer anomalies form a regional platform bounded on the eastern edge by the regional gradient. Within the platform are two depressions: one striking east-west along 20°10'S has a relief of 30 milligals and may reflect a local thickening of sediments in that part of the Marion Plateau; the other has a relief of 20 milligals and corresponds closely with the area of the Capricorn Channel. This anomaly clearly expresses the mass deficiency associated with a relatively thicker sedimentary sequence in the Capricorn Basin.

Employing a simple infinite-slab assumption, a sediment thickness of about 2.5 to 3.0 km may be deduced to be present in the Capricorn Basin. In the regional gradient just south of 23°S, local, closed gravity highs are located. These may be the expression of a structural high trending north-northwest underlying the Swain Reefs (Allen & Hogetoorn, 1970).

Outside the regional gravity gradient, the Bouguer anomaly gradients are more variable, often quite steep, and generally show a close relation to topography. The southern part of the Mellish Rise is clearly distinguishable by its Bouguer anomaly expression: Bouguer anomaly values ranging from 100 to 140 milligals form a contour pattern which closely resembles the bathymetric contours. Similarly, the shape of the Cato Trough is reproduced in the Bouguer anomaly contours as is the shape of the undulating southern part of the rise (south of the Mellish Rise).

The close correlation of gravity and topography may suggest that the structures east of the regional gradient are underlain by compensating roots and antiroots. In the Cato Trough it is reasonable to suppose that crustal thinning has taken place; an estimate of the crustal thickness in this area is 16 km, a thickness close to that of the crust in ocean basins. In the rise area, however, the correlation between gravity and topography probably indicates that the density of 2.2 g/cm^3 used in the Bouguer reduction is inappropriate in removing the effect of seabed topography. It is unlikely that the relatively small-scale topographic relief features of the rise would be locally compensated. Simple infinite-slab calculations suggest that a density of 2.8 or 2.9 g/cm^3 is more appropriate. This density is representative of igneous rocks, in particular, oceanic basalts.

The Osprey Embayment, north of the Coral Sea Plateau, has Bouguer anomalies up to 190 milligals. This is 40 milligals higher than the Cato Trough anomalies, and implies that the crustal thickness in the embayment is quasi-oceanic. A clear transitional gradient, however, leads from the embayment to the Coral Sea Basin and hence the crust in the embayment is likely to be distinct from oceanic crust. The area may represent a region of deeply subsided continental crust.

The Nova-Argo Basin has a Bouguer anomaly level around 100 milligals and no clear signature in the contours. The Bouguer anomaly level is low compared with the Cato Trough, Coral Sea Basin, and Osprey Embayment. This may arise from an unusually thick sedimentary sequence in the

Nova-Argo Basin. Nova-Argo Bank is associated with an 180-milligal positive anomaly, which indicates a considerable mass excess. This excess is probably related to the igneous composition of the twin guyots, which can be deduced to have a density of about 3.0 g/cm^3 from simple infinite-slab computations.

The numerous platform reefs on the plateaus, the isolated deep oceanic reefs, and the islands all display different levels of Bouguer anomaly (Plate 3). Any comparison of gravity expression is difficult to make, for limitations in the traversing resulted in the distance of closest approach being greatly different from one reef to another. Most of the differences in gravity expression can be explained in this way: the ship generally approached closer to the oceanic reefs than to the plateau reefs because the former rise more abruptly from the sea floor and give less-advance warning of their proximity. Near the plateau reefs a mild positive gravity anomaly was recorded; this may be caused by an underlying deep structural uplift. The recorded gravity anomalies near the oceanic reefs are strongly positive, which supports the suggestion that these reefs lie atop extinct volcanoes.

MAGNETIC ANOMALIES

The distinction which can be made between continental and oceanic structures on the basis of Bouguer anomaly pattern is not reinforced in the magnetic anomaly pattern (Plate 4). None of the physiographic features described above show a distinct magnetic signature although some weak correlation exists.

Magnetic anomalies in the area of the Queensland Trough and western Coral Sea Plateau are generally elongated in the same north-northwest direction as the Queensland Trough itself, and range in value from -100 gammas to 350 gammas. This suggests that the magnetic basement in the trough has the same general trend as the trough and as the Tasman Geosyncline.

On the Coral Sea Plateau few of the magnetic anomalies correlate with gravity anomalies; this indicates that the source of the two potential field variations are quite different in this area. Preliminary depth estimates indicate that the source of magnetic anomalies average about 1400 m below the plateau surface, whereas the source of most gravity anomalies appear to be more than 10 km deep. Several of the Coral Sea Plateau magnetic anomalies are lineated in a north to northwest direction, similar to the Bouguer anomalies. Longer wavelength anomalies on the eastern side of the Coral Sea Plateau suggest the magnetic basement lies at a greater depth on the outer edge of the plateau. Anomaly gradients generally increase when reef areas are approached, and this may point to a magnetic basement structure underlying the reefs.

The Townsville Trough shows no clear magnetic expression: the general trend of anomalies between 18°S and 19°S is close to north-south. The Marion Plateau can be identified as an area of relatively intense anomalies which range in value from -350 to +400 gammas and probably reflect shallow basement under the plateau. The source of the two gravity depressions within the Marion Plateau do not give rise to a distinguishable expression in the magnetic anomaly contours. The reason for this is not clear but may be as follows: the generally short-wavelength high-amplitude magnetic anomalies indicate that the magnetic basement is relatively shallow. Contouring hourly values in such a region gives a strongly aliased and generally unreliable indication of the true field variations. The gravity depressions, which are of low relief, suggest that any basement structure which they reflect are of similarly low relief. The magnetic expression of a low-relief depression in a generally shallow basement would probably be little more than a change in wavelength, which would not be distinguishable in the distorted representation of the field in an hourly value contour map.

The basin structure underlying the Capricorn Channel cannot be identified in the magnetic anomalies although the anomalies do show the northwest trend of the basin. The confused anomaly pattern in this area may result from the magnetic expressions of the Bunker Ridge and Swain Reefs High, together with the Graham's Creek Volcanics which may underlie part of the Capricorn Basin (Allen & Hogetoorn, 1970; Carlsen & Wilson, 1967a, 1967b).

In the rise area east and north of the Cato Trough, the magnetic anomalies show a confused pattern that generally lacks a dominant trend. In the north of this region, an area of relatively intense anomalies with many closures roughly coincides with the southern Mellish Rise. The pattern of anomalies is complex as is the topography of the rise. The magnetic anomaly pattern, therefore, implies that the rise is composed of material of relatively high susceptibility - possibly volcanics or oceanic basalts.

The Osprey Embayment region shows very long wavelength anomalies which imply a great basement depth or possibly a low susceptability basement. This supports the suggestion made from gravity evidence that the embayment region may be underlain by deeply submerged continental crust.

In the Cato Trough the anomalies show long wavelengths that suggest a large depth to magnetic basement. The eastern margin of the southern part of the trough shows a steep-gradient anomaly striking north-south. This anomaly suggests that a large displacement in the magnetic basement forms this trough margin - possibly a major fault.

South of 21°S and east of Cato Trough the anomaly pattern forms a series of dipoles elongated with a northeast trend. These anomalies are probably the expression of massive igneous bodies that form the topographic rise in this region. The Nova-Argo Bank has intense magnetic anomalies, which suggest it has a volcanic composition.

SEISMIC RESULTS

These are illustrated by typical seismic profiles in Figure 6, and a sediment isopach map in Figure 7.

Two typical seismic profiles are AA' and BB' (Figure 6). Profile AA' extends from immediately east of the Great Barrier Reef, across the Queensland Trough and Coral Sea Plateau, to the slope leading down to the Coral Sea Basin. DSDP drill site 209 is located about 4 nautical miles south of the profile; it has been sited on the profile in a position where the water depth is the same as at the drill site, rather than in the position due south of the true location. The simultaneously recorded total magnetic intensity profile is included in profile AA'. Profile BB' shows a section of deep-water traversing in the southern area. The magnetometer was not operating on this line.

The structure of the northern area is well represented by Profile AA'. Most of the eastern margin of the Queensland Trough shows evidence of faulting. Faulting on the western side may be inferred from the steepness of this margin but cannot be interpreted with confidence from the seismic records. The intrusion? shown on the eastern flank of the trough can be located on most survey lines crossing the trough and is probably continuous. The trough is interpreted as a graben with a sediment fill exceeding 1 km. The surface of the Coral Sea Plateau is smooth, and broken only by reefs, such as Diane Bank, and erosional features, such as the valley east of Diane Bank. Such valleys are generally restricted to the outer margin of the plateau.

On the Coral Sea Plateau a strong reflection horizon lies at the base of a stratified sedimentary sequence. It does not, however, represent the top of an igneous basement as the material below shows a stratification in several places, and sonobuoy refraction records (Ewing, Houtz & Ludwig, 1970) indicate that the high-velocity basement layer is more than 1 km deeper than this horizon.

The results from DSDP drill site 209 indicate that the site has subsided since middle Eocene; subsidence was accompanied by a change from terrigenous to pelagic deposition as the major form of plateau sedimentation. Two depositional breaks also occur: one extends from late Eocene to late Oligocene, and the other from late middle Miocene to middle Pliocene. It is suggested that the strong reflection horizon corresponding to seismic 'basement' defines the presubsidence landscape. The unconformity surface (shown as a broken heavy line in Figure 6) is believed to have been formed during the late Eocene to late Oligocene hiatus. The Miocene/Pliocene hiatus cannot be identified on the seismic section and it is assumed that this is due to a lack of variation of both lithology and dip of sediments across the hiatus.

Reefs on the Coral Sea Plateau grow on the seismic 'basement' and faulting in the Queensland Trough disturbs both the 'basement' layer and the hiatus horizon. On the outer edge of the plateau faulting displaces the 'basement' layer but leaves the hiatus horizon relatively undisturbed. This indicates that trough formation postdates the formation of the outer margin.

The Townsville Trough forms the southern margin of the Coral Sea Figure 7 were computed as the depth of sediment overlying seismic 'basement', with confidence on the southern side. This trough may also be a graben similar to the Queensland Trough.

Profile BB' illustrates the faulted nature and rugged basement structure of the eastern margin of the Cato Trough, which has a sediment fill in excess of 1.5 km. The reflector shown as a heavy line may correlate with the Eocene/Oligocene horizon of the Coral Sea Plateau.

The contour levels shown on the preliminary sediment isopach map in Figure 7 were computed as the depth of sediment overlying seismic 'basement', assuming a sediment velocity of 2 km/sec. The map does not display the depth of sediment overlying igneous basement in all areas as acoustic and igneous basement do not always coincide. For

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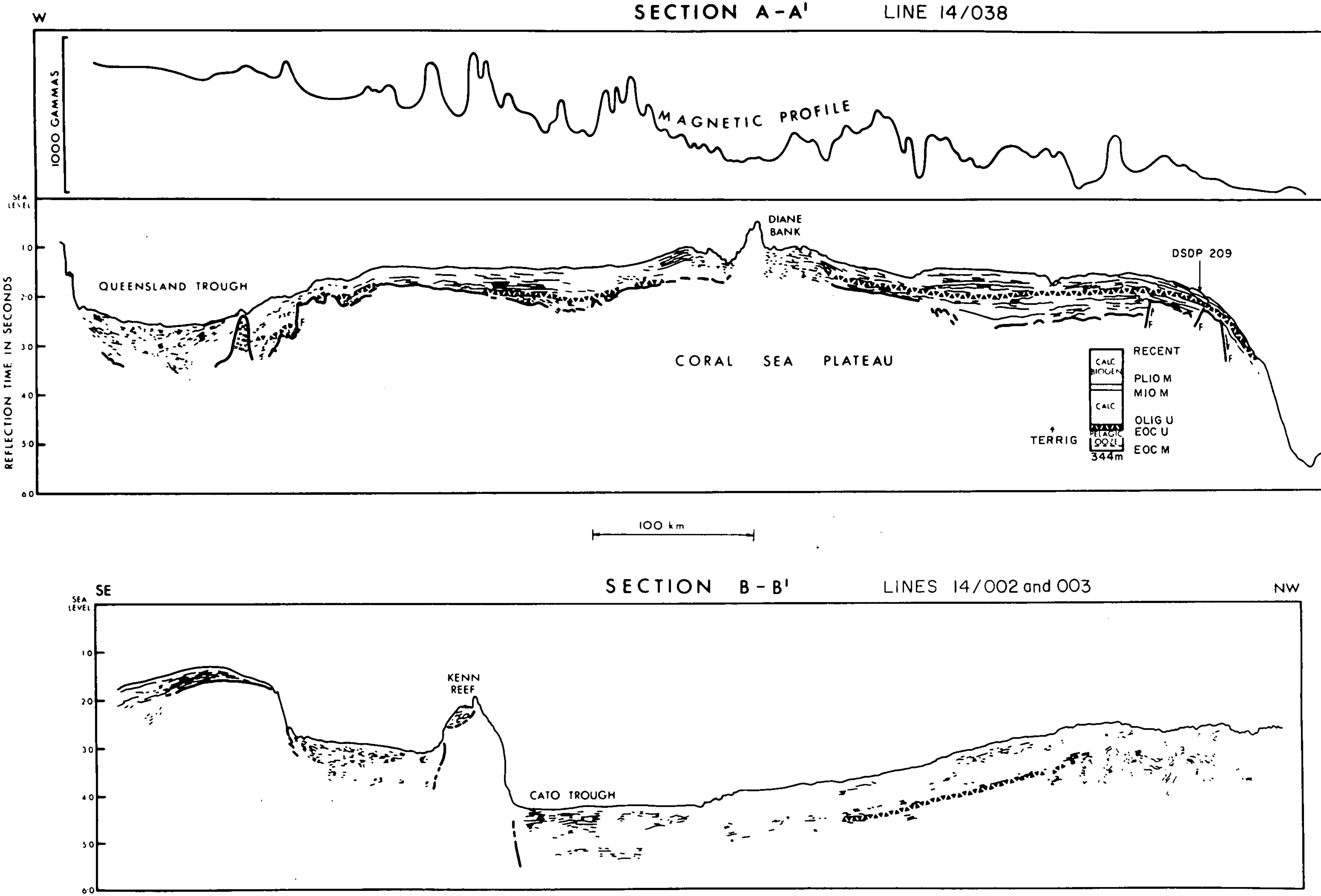


SEISMIC PROFILES AA' and BB'

FIGURE 6

Q/B8-27A

example, on the Coral Sea Plateau the strong reflector described above marks acoustic basement but not igneous basement. On the Mellish Rise and the structures east of the Cato Trough, acoustic and igneous basement certainly coincide. The basement underlying the Mellish Rise is rugged, and appears to be composed of a build-up of massive igneous bodies, possibly oceanic basalts. In the Cato Trough the limit of energy penetration by the sparker was reached before it had defined the base of the sediments; the depth to basement here may be well in excess of 1.5 km.

Most of the structural features may be distinguished in the sediment distribution. The three troughs are identified by narrow areas of deep sediments, while the plateaus have relatively even sedimentary cover. The Halifax Depression, which lies at the junction of the Queensland and Townsville Troughs, cannot be recognized. This would suggest that this aeromagnetically defined basin has a basement structure below the limit of penetration of the sparker.

CONCLUSION

The aim of this report was to give a preliminary assessment of the results of survey work in offshore Queensland as a guide for future study. In order to meet this aim, the results were first analysed to determine data quality. Then a tentative interpretation was sketched from a preliminary examination of the records.

Although a full analysis of data quality has not yet been undertaken, it has not been possible to demonstrate that the distributions of bathymetric, gravity, and magnetic misties depart significantly from the normal error distribution anticipated for random variables; that is, no major systematic errors have been detected. Seismic results show an average penetration of 1.5 seconds reflection time except in deep water, where a deterioration occurs.

A preliminary interpretation of the results suggest that the Coral Sea Plateau and Marion Plateau have a strong continental affinity. Basement velocities of 'continental type' (Ewing, Hawkins & Ludwig, 1970) underlie sediments on the Coral Sea Plateau. Estimates of the depth of the base of the crust from gravity data on both plateaus give figures of 26 to 29 km, only 4 to 7 kilometres less than the assumed standard continental crust. The two plateaus are essentially submerged extensions of the

Australian continent. A discussion of the mechanism responsible for the submergence is beyond the scope of this report but it is evident from DSDP drilling information that submergence is closely related to the formation of the Coral Sea in early Eocene time.

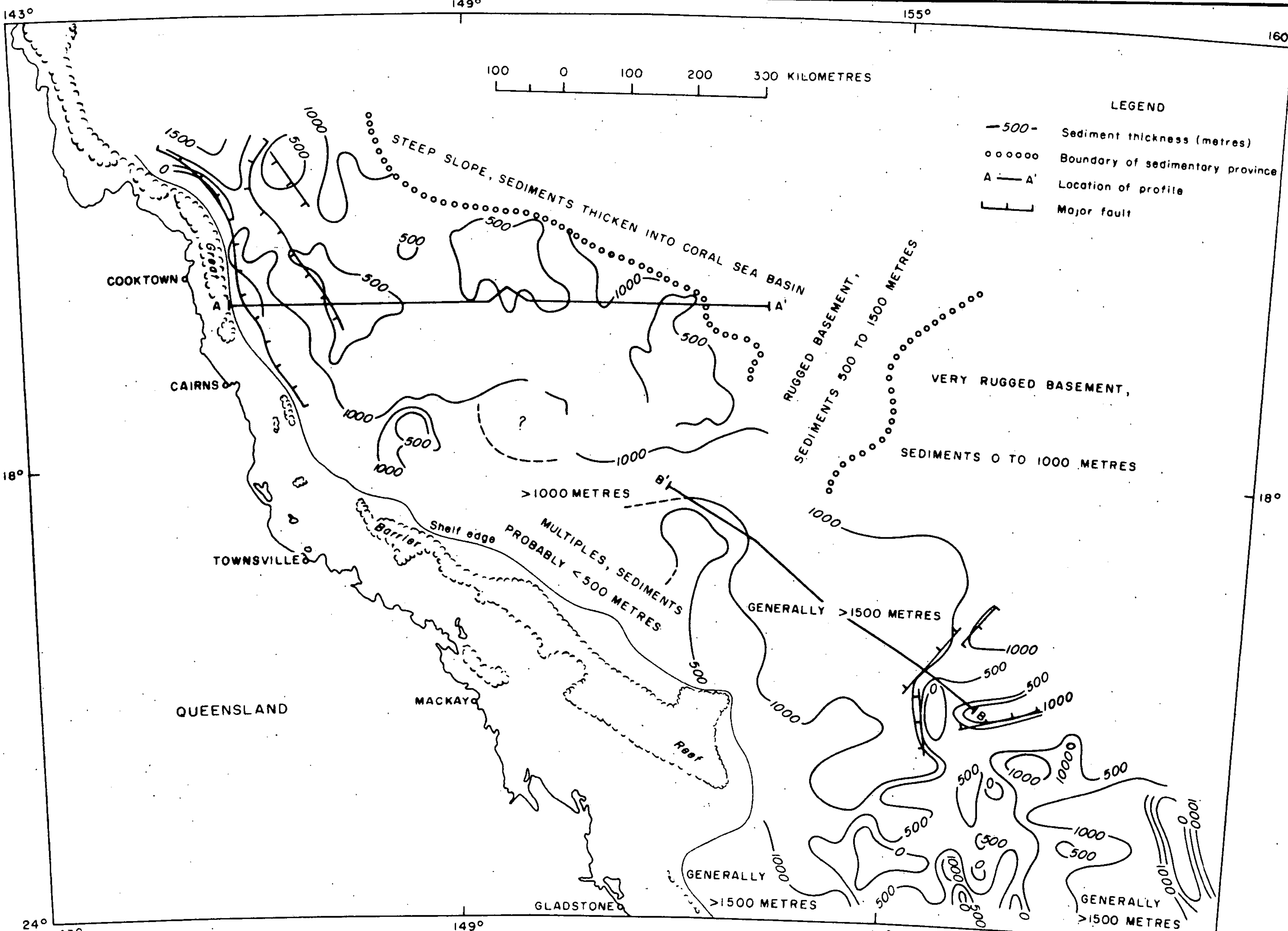
Both the gravity and magnetic fields show weak lineations across the Coral Sea Plateau in a north to northwest direction. These trends do not generally coincide with physiographic features or structures which could be observed on seismic records. The north to northwest trend of the anomalies is the same as that of the Tasman Geosyncline in north Queensland, and it seems reasonable to assume that the anomalies arise from deep basement structures of the geosyncline, i.e., the geosyncline extends offshore onto the plateau regions. The Queensland Trough probably forms a relatively shallow graben within the framework of the geosyncline. The Townsville Trough is a transcurrent structure which may be a graben or half-graben.

Other structural features appear to be oceanic in nature. The limit of continental crust is suggested to follow the eastern margin of the Coral Sea Plateau to around 153°E, where it changes strike to south-southeast and follows the margin of the Marion Plateau.

Crustal thickness (including sediments) in the Cato Trough is about 17 km. This figure is intermediate between continental and oceanic crustal thicknesses, and from the analysis given here the origin of this feature cannot be definitely stated. However, it is suggested that it is a small ocean basin formed at around the same times as the Coral Sea. The Mellish Rise and the northern Dampier Ridge have rugged basement structures, and strong magnetic anomalies suggest that oceanic basalts underlie them. The sediment cover is thin, and it is suggested that the structures formed in an oceanic rift or fracture zone.

An analysis of the structure and tectonic history of the region is given by Mutter (1973).

Future work should aim at detailing the offshore structural trends. In particular the inferred Halifax Basin should be tested by deep penetration seismic techniques. Structural highs in reef areas should be investigated to determine their nature. Further seismic work on the Coral Sea Plateau should aim to establish ages for the observed unconformities from ties to drill information.



PRELIMINARY SEDIMENT THICKNESS AND STRUCTURES

FIGURE 7

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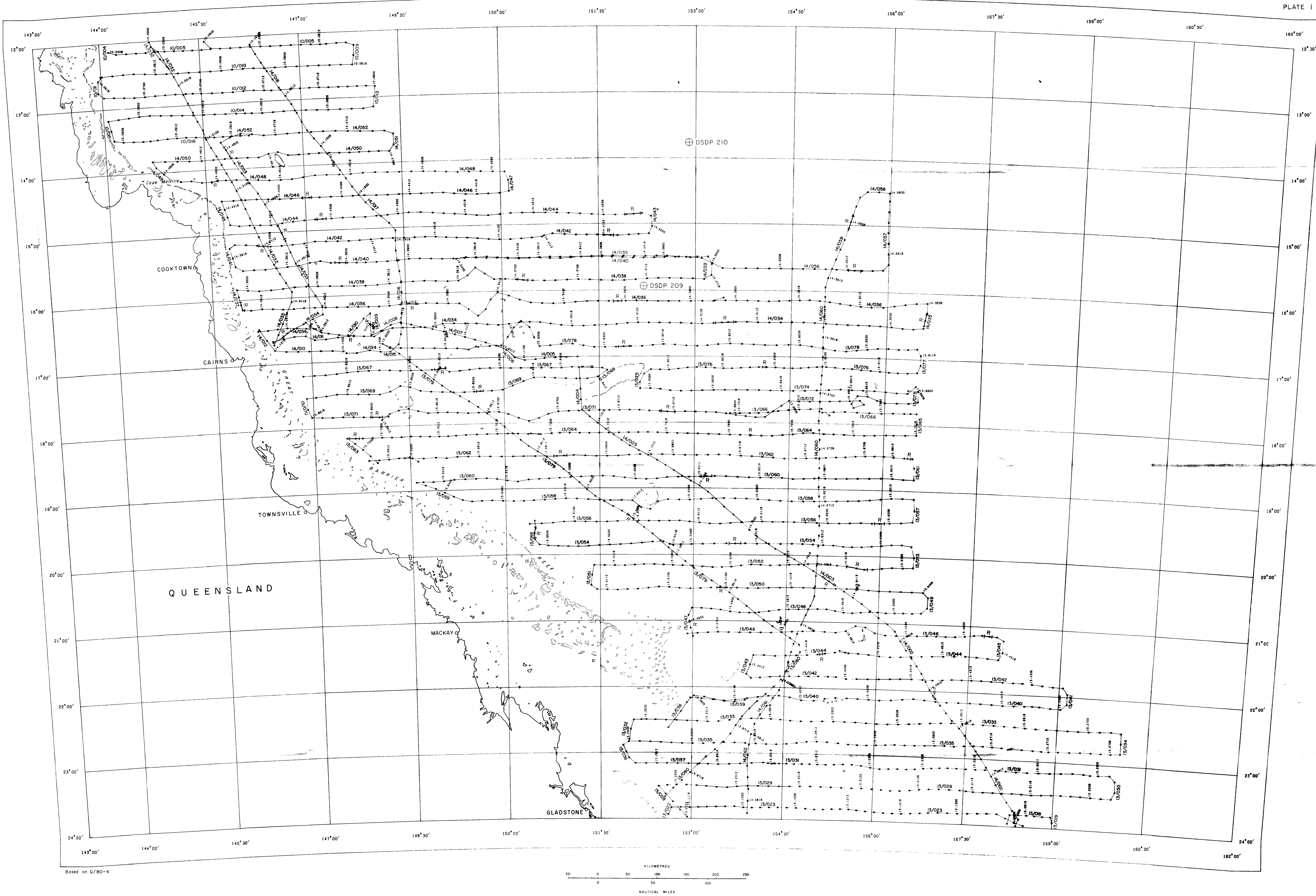
CORAL SEA

PLOTTED 73/08/14

AUSTRALIA 1: 2500000

PLATE I



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

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.

B.M.R. 1970-73 MARINE SURVEYS

TRACK CHART

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.

LEGEND

⊕ Deep Sea Drilling Project drill site

R Location of refraction probes

CORAL SEA

AREA 2

Record No 1974/116

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CORAL SEA

PLOTTED 73/08/07

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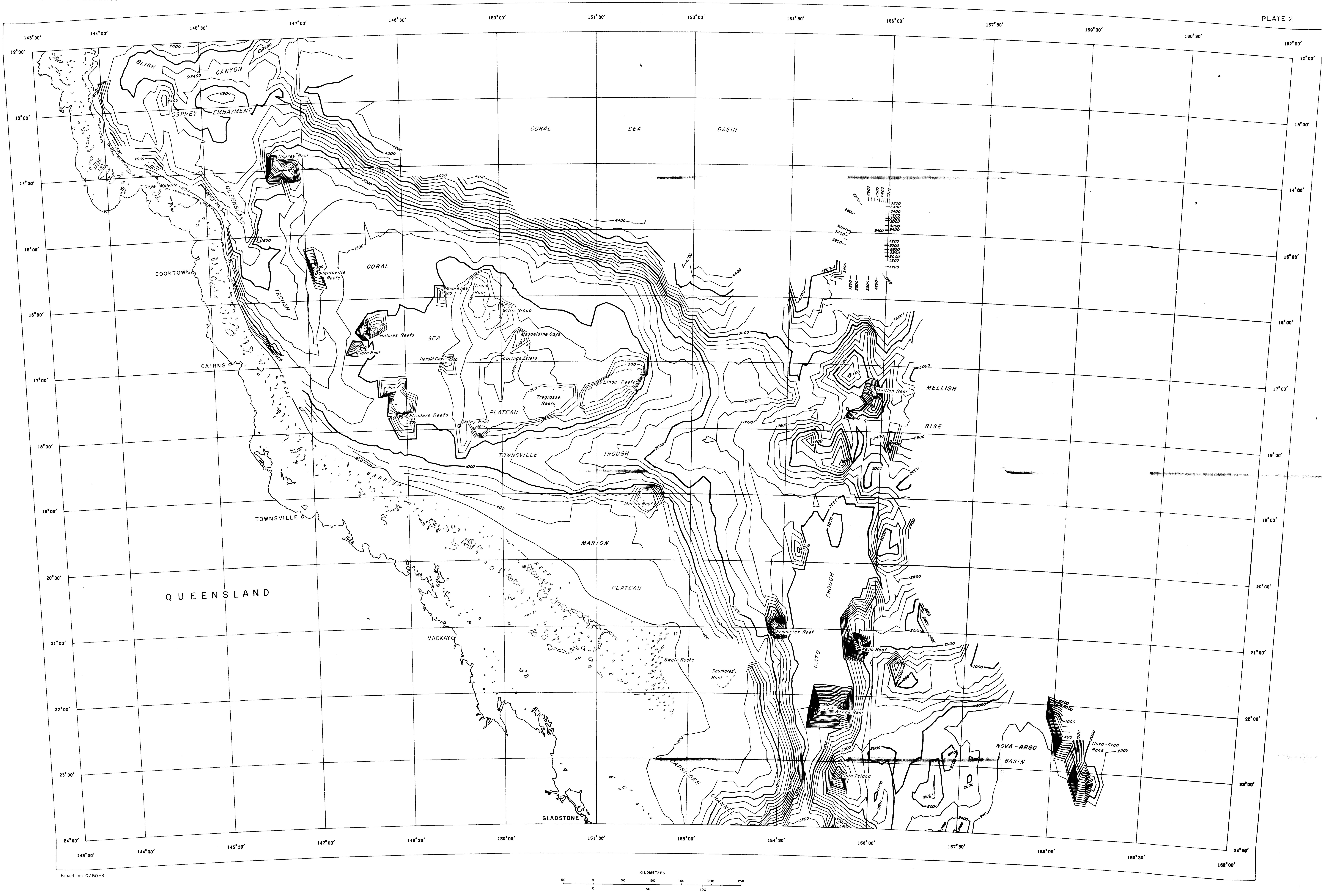
PLATE 2



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B.M.R. 1970-73 MARINE SURVEYS

WATER DEPTH (METRES)

Contour interval 200 metres
Water velocity assumed constant at 1500 m/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 30 nautical miles that plate is not contoured.

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CORAL SEA

AREA 2

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CORAL SEA

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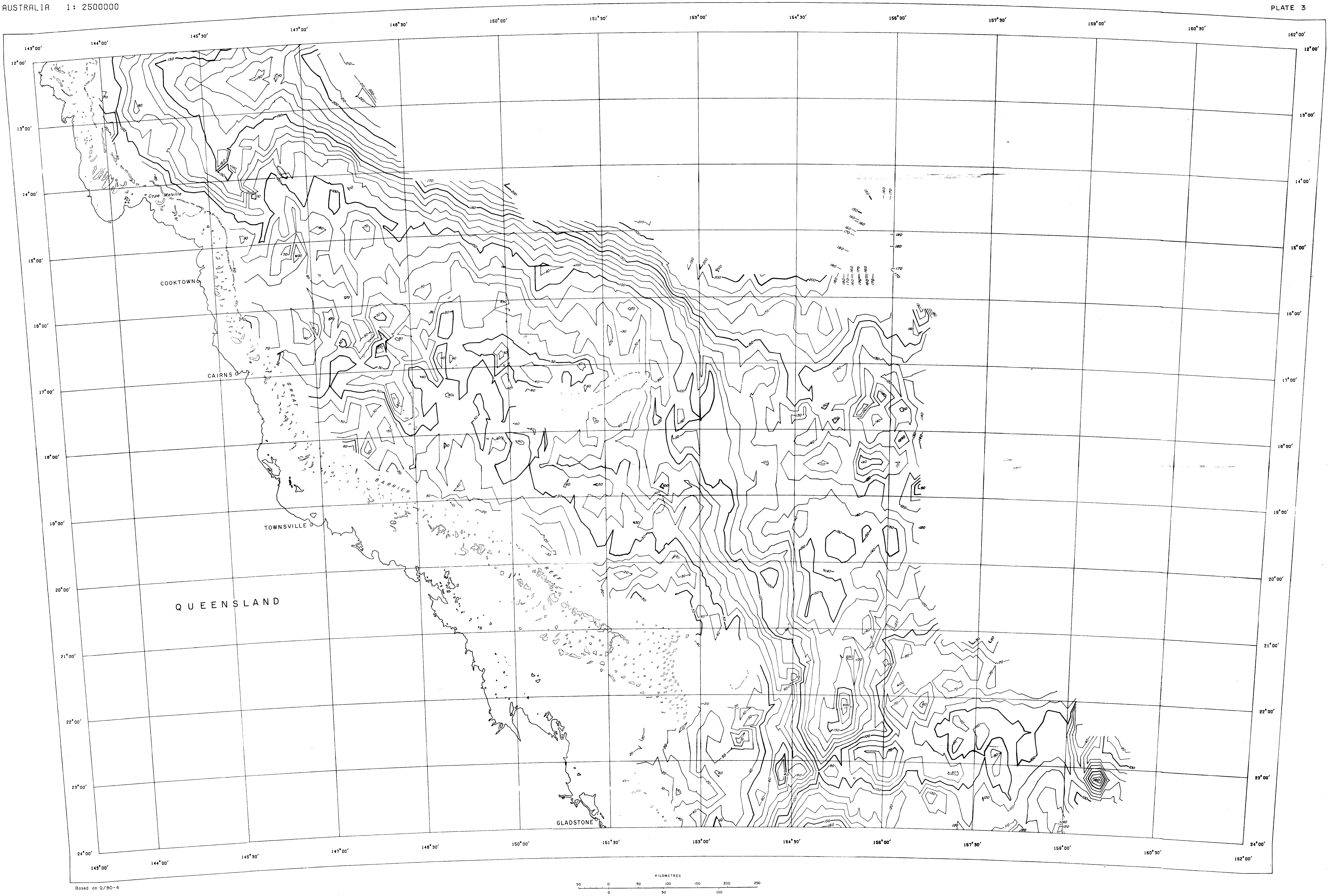
PLATE 3



Based on Q/80-4

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

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B.M.R. 1970-73 MARINE SURVEYS

BOUGUER ANOMALIES

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 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 30 nautical miles that plate is not contoured.

DENSITY = 2.20 g/cm³

CORAL SEA

AREA 2

Record No. 1974/116

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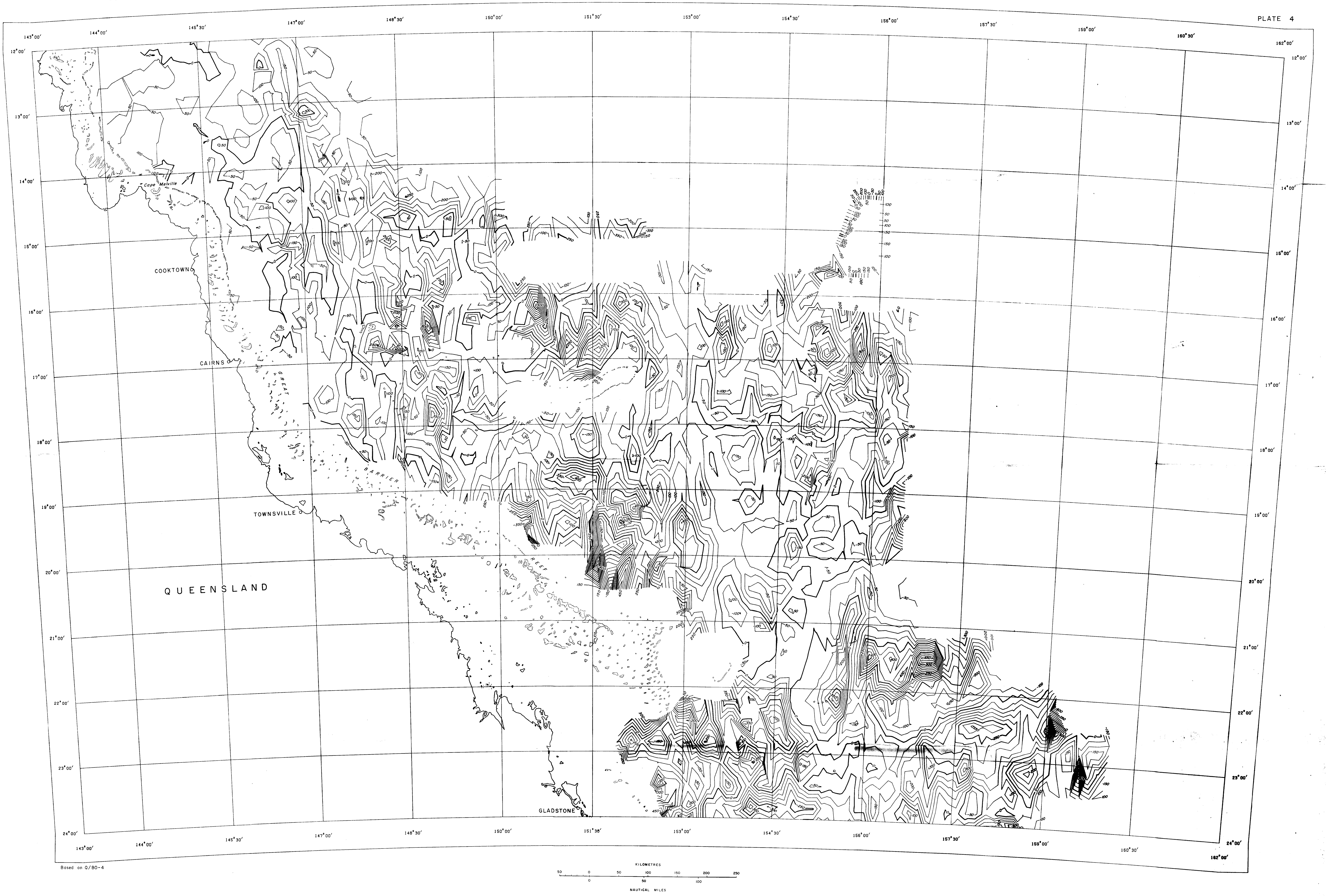
CORAL SEA

PLOTTED 73/08/13

AUSTRALIA 1: 2500000



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

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B.M.R. 1970-73 MARINE SURVEYS

MAGNETIC ANOMALIES

Magnetic values reduced to the International Geomagnetic Reference Field

Contour interval: 50 gammas

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 30 nautical miles that plate is not contoured.

CORAL SEA

AREA 2

Record No. 1974/116

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