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A summary of the regional geology, geophysics, and petroleum potential of the Clarence-Moreton Basin.

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ABSTRACT

Mesozoic sediments of the Clarence-Moreton Basin were deposited over or near the southern end of a suture zone marking the line of collision between lithospheric plates. Subsequent movement on the suture plane may have generated a prominent meridional zone of folds and faults in the overlying Mesozoic sediments. Significant parts of the zone, and of the less disturbed basinal areas flanking it to the east and west, were subsequently covered by Miocene basalts.

Geophysical techniques have proved of only marginal value for petroleum exploration in the basin. Most well sites have been chosen as a result of surface mapping and photo-interpretation. Interpretation of the results of aeromagnetic surveys has indicated that magnetic basement lies well below 'economic basement' for petroleum. The station spacing in regional gravity surveys is too large to allow the detection of likely fault or fold structures suitable for hydrocarbon entrapment. The seismic reflection technique has been applied with limited success in the past, and future seismic surveys using modern technology in the more difficult (least explored) areas are unlikely to be much more successful because of the extremely difficult near-surface conditions. Refraction surveys have been used to assist interpretation of the regional structure.

Petroleum prospects in the Clarence-Moreton Basin are poor, but there is some potential for small gas discoveries. The most promising petroleum source rocks are Triassic coal measures, and these are more likely to have generated gas than oil. Gas reservoirs may occur in the Bundamba and Marburg Formations, possibly sealed by shales within these formations or by the overlying Walloon Coal Measures.

INTRODUCTION

The objectives of this report are to provide a framework for future assessments of the petroleum resources of the basin, to suggest future work which might provide a better basis for assessment, and to determine the prospectivity of the area.

The geology of the Clarence-Moreton Basin has been described by McElroy (1969) and Meyers (1970) and its petroleum prospects by Bembrick (1973) and Benstead (1976). A comprehensive bibliography covering the years up to 1970 has been prepared by Mayne (1972).

The basin sediments have a maximum thickness of approximately 3000 m and cover an area of some 27 000 km^2 straddling the border between NSW and Qld, extending between latitudes $26^{o}30'$S and 30^{o}S.

In Plate 1, the heavy line represents the generalised contact between Palaeozoic metamorphics and Mesozoic sediments as taken from available 1:250 000 scale geological maps north of the state border, and a 1:1 000 000 scale geological map south of the border. Benstead (1976) defines some Triassic rocks which fall within the area outlined as being part of the Ipswich basin, but the division is not indicated in the Plate. He also defines the Clarence-Moreton Basin as being bounded west of the Gatton Arch near 151^{o}W, by a subsurface feature known as the Kumbarilla Ridge (Plate 1). However the area between the Gatton Arch and the Kumbarilla Ridge is excluded from this study owing to the limited time and resources available.

TECTONICS AND BASIN ORIGIN

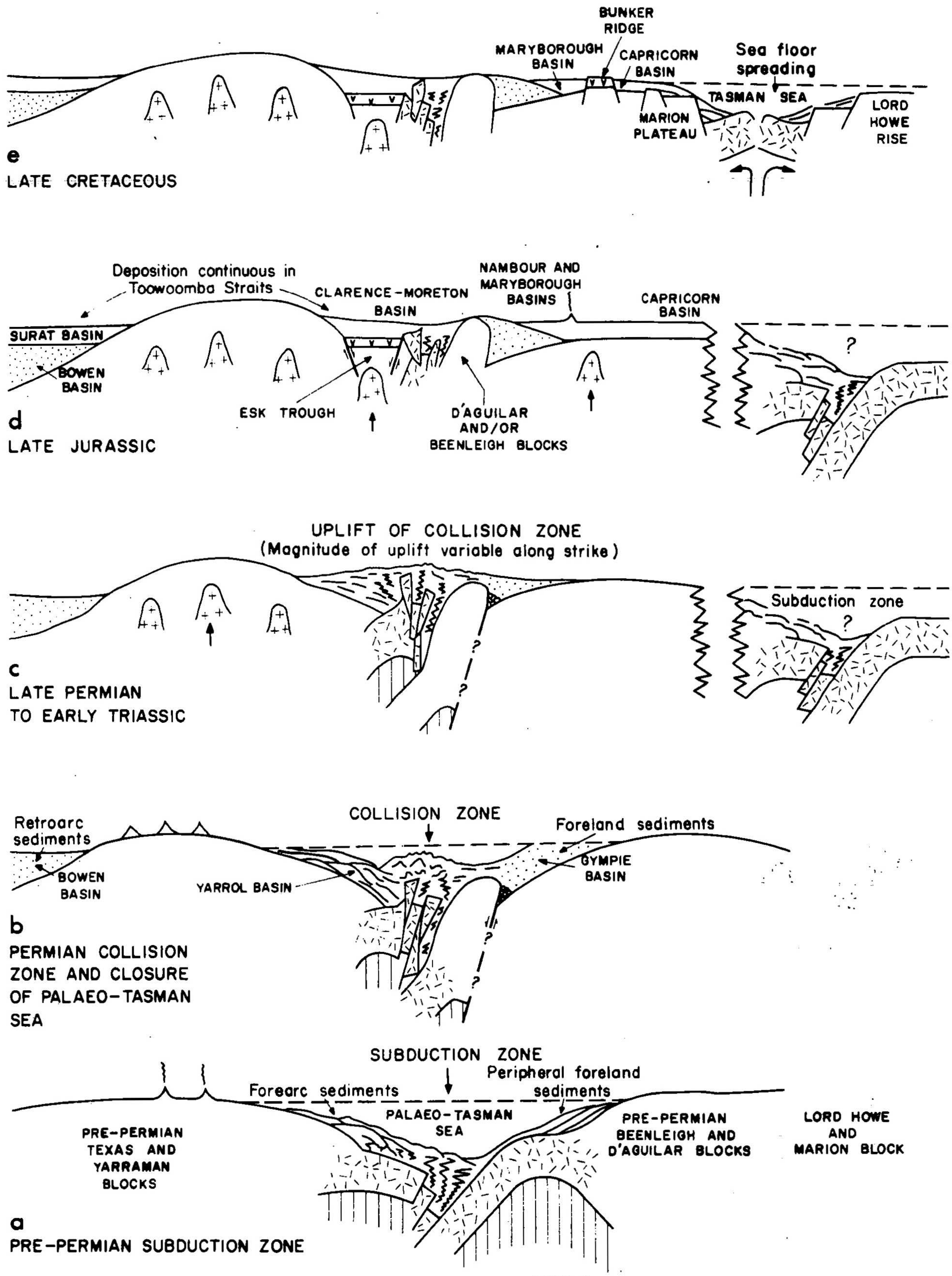
Palaeozoic - Mesozoic The Palaeozoic tectonics of the Tasman Orogenic Zone (Geosyncline) were reviewed by Packham and Leitch (1974), who pointed out the many difficulties involved in unravelling the plate tectonic history of the region. Such difficulties arise in regions which have been sites of strong plate convergence, because the processes involved are not well understood. The simple model of one rigid slab under-thrusting another without interruption cannot be universally applicable (Helwig and Hall, 1974). Other workers have developed schemes for the tectonic evolution of the area. The presence of the massive serpentinite body in the D'Aguilar block (Plate 1), and other minor bodies, has led Murphy and others (1976, Figures 6 and 7) to postulate that a large scale obduction process has operated. A similar but independently conceived scheme to be discussed below relies on a splintering mechanism (Figure 1) to explain serpentinite emplacement.

It is generally accepted that the Australian craton accreted eastwards during the Palaeozoic, and the mechanism assumed here is that of collision between major continental blocks, at least in Permian times. Other mechanisms, such as the conversion of oceanic crust to continental crust, or several collisions of arc systems with the craton, may be applicable to earlier accretionary episodes.

The line along which the collision of interest occurred (the suture zone) is taken to be that marked by the line of ultramafic rocks occurring from just northwest of Rockhampton, down the eastern edge of the Esk Trough to the vicinity of Brisbane (Murray, 1974), possibly continuing south beneath the rocks of the Clarence-Moreton Basin. The presence on the western flank of the basin, at 29°20'S of a large serpentinite body raises the possibility that the suture may be continuous beneath the basin. The distribution, petrology and tectonic significance of ultramafic rocks in this region have been discussed by Murray (1974) and Crook and Felton (1975).

Evidence exists (Day and others, 1974) to show that Palaeozoic subduction was discontinuous in the region. The same authors state that the Late Carboniferous Kanimblan orogeny, which was strongly compressional in nature, coincided with a break in subduction. This is compatible with a bimodal behaviour of convergent plate boundaries, described by Helwig and Hall (1974). Little or no underthrusting of one plate by another may occur for significant geological time; the relative motion between plates being accommodated by brittle deformation in the upper crust, and presumably plastic deformation in the lower crust and mantle.

The series of cartoons shown in Figure 1 is based partly on the regional geology and tectonic history as presented by Day and others (1974), and is intended to convey the gross plate tectonic history of the region. The diagrams are highly generalised, and are not to be taken as formal cross-sections. They depict roughly west - to - east distributions of tectonic and structural elements, normal to the suture zone, and parallel to the direction of plate convergence (and divergence). Figure 1a shows the two continental blocks on opposite sides of a pre-Permian subduction zone. The eastern block is present to satisfy the requirement that a Late Cretaceous spreading episode must subsequently occur, in which the Lord Howe Rise



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is separated from the craton (Weissel and others, 1976). The closure of the "Paleo-Tasman Sea" by collision is shown in Figure 1b, and the collision process is assumed to be the mechanism by which relatively minor crustal blocks (oceanic and continental) may have become detached from the major plates. Permian sediments accumulated before and during the collision, to the west (Yarrol Basin), and to the east (Gympie Basin) of the suture. Subduction in the collision zone is assumed to have terminated at the time of collision and the zone of collision then became a zone of uplift under the influence of the buoyant, partly subducted, continental mass.

Subduction may possibly have begun again farther to the east (Fig. 1c). This Late Permian to Early Triassic time was a period of extensive granitic intrusion west of the suture zone.

In the Early Triassic, a tensional episode occurred during which the Esk Trough subsided. This is difficult to explain according to the model presently proposed. However, andesitic volcanism also occurred, and this is compatible with a convergence zone. By Middle Triassic times, compressional deformation was again occurring.

Figure 1d shows the situation in Late Jurassic time, with sedimentation occurring in the Surat, Clarence-Moreton, Nambour, Maryborough, and Capricorn Basins. Minor plutonic intrusions were emplaced at this time, near, and to the east of, the suture zone. Some andesitic volcanism occurred in the Maryborough Basin, suggesting that subduction was occurring along a trench to the east. While the Surat and Clarence-Moreton Basins are shown separated by a structurally high area, deposition was spatially continuous at this time. By Late Cretaceous the region had been uplifted and was undergoing erosion. An episode of sea floor spreading which formed the present day Tasman Sea occurred from the Late Cretaceous until early Paleocene (Fig. 1e). It is likely that at least the southern margin of the Marion Plateau was formed by the drift away to the east of the Lord Howe Rise at this time, (Mutter, 1973). A marine environment was hence provided for subsequent sedimentation in the Capricorn Basin.

Tertiary Significant tectonic events of the Tertiary in the region included the opening of the Coral Sea, beginning perhaps as early as the Latest Cretaceous (Karner, pers. comm.), and continuing throughout the Eocene. The outer edge of the Queensland Plateau subsided in mid-Eocene time, and an episode of vertical subsidence of the whole plateau continued until earliest Miocene (Mutter, 1973).

GEOLOGY

MAPS

A significant proportion of the basin is in the area of the Warwick 1: 250 000 map sheet. It is the portion west of longitude 153°E and between latitudes 28° and 29°S. Parts of the basin fall in the Gympie and Ipswich 1: 250 000 map sheet area. Exon and others (1974) have described the post-Palaeozoic rocks of the Warwick map area in detail, while Murphy and others (1976) have described the geology of the Gympie map area. Gray (1975) has discussed the stratigraphy of the Ipswich map area.

No other geological maps at the 1:250 000 scale covering the Clarence-Moreton Basin have been published, but geological maps at scales of 1:1 000 000 and 1: 500 000, and maps of geology and tectonics at a scale of 1: 5 000 000 have been published by the Geological Survey of New South Wales (GSNSW) covering the area south of the border between NSW and Qld.

STRATIGRAPHY

The following table summarises the stratigraphy.

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TABLE 1

Stratigraphy of the Clarence-Moreton Basin (after Benstead 1976)
Informal names "UNIT A" and "UNIT B" follow Wales. See Petroleum prospectivity, this work

Age		New South Wales stratigraphy		Thickness (Max., m)		Queensland stratigraphy		Thickness (Max., m)
Jurassic to Cretaceous	Clarence-Moreton Basin	Grafton Formation		270(?440)				
		Kangaroo Creek Sandstone		150(?290)		Kumbarilla		760
Jurassic		Walloon Coal Measures		600	Moreton Basin	Walloon Coal Measures		230
		Towallum Basalt		15				
		Marburg Formation		600		Marburg Formation		650
Upper Triassic to Jurassic		"Bundamba Group"	Tabulam Group "UNIT A" "UNIT B"	1400		Ripley Road Sandstone	Woogaroo Sub-Group, Bundamba Group	400
						Raceview Formation		140
						Aberdare Conglomerate		40
Triassic		Nymboida Coal Measures and correlatives		1000	Ipswich Basin	Ipswich Coal Measures		1220

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A detailed table by Exon and others (1974) gives the lithologies and distributions in the central western part of the basin. The work was based on both surface and subsurface data. Appendix 1 lists all petroleum exploration wells which provided the basic data on which the subsurface stratigraphy is based.

Mesozoic The oldest Mesozoic rocks are the Ipswich (in Qld) or Nymboida (in NSW) Coal Measures of Middle to Upper Triassic age. The formation consits mainly of volcanic rocks in the lower part, and mainly shale, siltstone, sandstone, conglomerate, and coal in the upper part. These rocks are usually regarded (e.g. Day and others, 1974) as comprising a separate underlying basin (the Ipswich Basin).

Unconformably overlying the Ipswich Coal Measures is the Bundamba Group of Upper Triassic to Lower Jurassic age. Lithologies are dominantly sandstone and conglomerate. Exon and others (1974) place the Marburg Sandstone as the youngest unit in the group, and describe it as resting with unconformable contact on Palaeozoic rocks in the western part of the Warwick Sheet.

Conformably overlying the Marburg Formation are the Walloon Coal Measures of Middle to Upper (?) Jurassic age. These rocks consist of thin coal seams interbedded with fine sandstone, siltstone and mudstone.

The remaining Mesozoic rocks are of Upper Jurassic age in the Warwick Sheet area (Exon and others, 1974) but may range in age from Jurassic to Cretaceous elsewhere (Table 1). The rocks are dominantly sandstone with some siltstone and mudstone. Unit names include Kangaroo Creek Sandstone (NSW) or Kumbarilla Beds (Qld) and Grafton Formation (NSW). The Woodenbong Beds of the Warwick Sheet area grade laterally into the Kangaroo Creek Sandstone.

Tertiary Volcanic rocks of Late Oligocene to early Miocene age occur as trachytes, basalts, rhyolites, and dolerites. Intrusions occur as sills, plugs, and dykes in Mesozoic rocks, and extrusions occur as flows and volcanogenic sediments, including breccias, agglomerates and conglomerates. Much of the igneous cover has been dissected and eroded, but thicknesses of about 1000 m remain, with perhaps 40% of the basin area still covered.

STRUCTURE

Principal structural features are shown in Plate 1. The feature names and locations have been taken from various sources, including geological maps, Exon and others (1974), Murray (1974), Day and others (1974), Bembrick (1973), and Gray (1975).

The main part of the basin is a syncline (the Clarence Syncline) with its axis lying meridionally along the longitude 153°E. An important structurally positive trend 15-20 km to the west of the axis and subparallel to it, forms a division between the Clarence Syncline and the Laidley Syncline to the northwest. The Laidley syncline is bounded in the northwest by a structural ridge depicted in a pre-Bundamba Group structural contour map by Gray (1975).

In the north the major north trending system of faults and anticlines which separates the two synclines is represented by the West Ipswich Fault. This fault forms the eastern boundary of the Esk Trough. Southward, the West Ipswich Fault trends en echelon with the South Moreton Anticline, which in turn trends en echelon with the East Richmond Fault. The names Grevillia Anticline and Toonumba Anticline have been assigned to local parts of the system in N.S.W. The fault and anticline structural system terminates some 25 km northeast of the serpentinite body on the western flank of the basin. The location of this system shows some correlation with the location of the postulated suture zone discussed in the previous section. It is probable that the structures were generated by pre-Miocene movement on the Palaeozoic suture plane. Jorgenson and Barton (1966) first associated crustal weakness with structure in this area.

Domes, anticlines and faults occur in both the Laidley and Clarence Synclines.

The Mount Alford Dome and the Mount Barney Dome have been generated by Tertiary intrusions, but the Maryvale and Swan Creek Anticlines are due to basement movement. The West and East Richmond Faults form the boundaries of the Richmond Horst, a feature recognisable for 24 km along a north trend, but probably extending much further beneath basaltic cover.

The Hogarth Dome, the Clifden Dome, and the Kyogle Anticline are examples of structures in the main basin area. While igneous sills have been intersected during oil drilling, notably in the Hogarth Dome, it is not known to what extent structural growth in the Clarence Syncline was influenced by intrusion.

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GEOPHYSICAL SURVEYS

In this section, the nature and distribution of known geophysical surveys in the Clarence-Moreton Basin are discussed. Operational details are not covered, but are generally available from the Petroleum Search Subsidy Act (PSSA) reports listed in Appendix 2. Results are presented in composite form on a 1: 000 000 scale map and discussed in the text.

MAGNETIC SURVEYS

The locations of the flight lines of two airborne surveys are shown on Plate 2.

The coastal area between 29° and 30°S was the subject of a survey in 1962. Only a limited number of reliable estimates of depth to magnetic basement were made, and these suggested shallow basement in the northwest of the survey area, perhaps deepening to the south. The lack of magnetic response over outcrops of Palaeozoic meta-sediments suggested that a deeper underlying crystalline basement gave rise to the mapped anomalies.

In 1965 the Casino airborne magnetometer survey was flown over the central portion of the basin between the NSW-Qld border and 29°S (Plate 2).

Magnetic intensities were measured along the tracks of the BMR Continental Margin survey to the east of the basin, and these are discussed by Symonds (1973, and work in preparation).

Estimates of depth to magnetic basement in meters are given on Plate 3 and identified by the letter 'M'.

GRAVITY SURVEYS

Regional gravity coverage over the Clarence-Moreton Basin has been achieved by both ground and helicopter surveys. The ground surveys have been described by Langron and van Son (1967), and the helicopter surveys by Lonsdale (1965) and Darby (1969). Plate 4 shows the onshore Bouguer anomalies and offshore free-air anomalies for the area, taken from the BMR gravity data bank used to compile the 1:5 000 000 gravity map of Australia (Anfillof and others, 1976). Names of gravity provinces have been collated by Fraser (1976). Detailed gravity surveys have not yet been undertaken in the basin.

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To the southwest of the basin lies the extensive New England Regional Gravity low, of amplitude -70 mgal, which is associated with the granites of the New England Batholith. An elongate north trending gravity ridge of amplitude +80 mgal follows the 200 m shelf-edge isobath to the east of the basin. It has been shown to arise from a combination of mantle and ocean gravity effects (Symonds and Willcox, 1976), and is known as the Gladstone-Eden Regional Gravity Ridge.

Between these two large amplitude gravity provinces lies the Coastal Regional Gravity Complex of which the gravity effect of the Clarence-Moreton Basin forms a part. The steep gradients on the flanks of the bounding provinces are separated by this terrace-like feature, whose gradients are gentle, and whose gravity values are largely confined to the range -15 mgal to +15 mgal.

A positive anomaly occurs to the west of Casino, of wavelength 50 km, and amplitude 15 mgal which may have two separate culminations (Bembrick, 1973, Fig. 4). It partly coincides with the largest, most intense magnetic anomaly detected during the Casino aeromagnetic survey. Surface mapping and petroleum drilling (Clarence Oil, 1968) show that the culmination of a structural dome occurs near the centre of the anomaly, and that the sedimentary section is (at least locally) intruded by a dolerite sill 130 m thick. The dolerite alone does not provide sufficient excess mass to explain the amplitude of the observed gravity anomaly. A much more massive, deep-seated source must be present, giving rise to both magnetic and gravity anomalies. Two possible explanations are:

(i) The dolerite sill was fed from a deep basic intrusive mass now preserved in the upper crust, below about 3000 m of sediments and metamorphics, or

(ii) a mass of ultramafic rock is present marking a buried suture zone, an extensive of the line of rocks described by Murray (1974).

It is possible also that the emplacement of the intrusive mass caused the growth of the dome, and hence the structure might persist to depths as great as 3000 m.

Gravity values over the remainder of the basin are generally negative except on the northeastern flanks where magnetic evidence shows that basement is shallow.

The broad station spacing used during the helicopter surveying is not conducive to the identification of local anomalies likely to arise from structures within the sedimentary section, or from surface volcanic rocks. There is little incentive to undertake detailed gravity surveying because of the large density contrasts associated with surface basalts and alluvium.

SEISMIC SURVEYS

The locations of seismic traverses are shown on Plate 2. Coverage is sparse. Traverses are grouped in two main onshore areas, one near the northern end of the basin at latitude 27°30'S, and the other in the central part of the basin. Some offshore surveying has been undertaken on the continental shelf at latitude 29°15'S. Seismic data were also recorded along the traverses of the BMR Continental Margin survey. Outside the Clarence-Moreton Basin proper, several exploration companies have conducted operations in the Brisbane and Moreton Bay areas.

No reliably identified basement reflection has been widely mapped. The basin has proved to be an extremely difficult environment in which to apply the seismic reflection technique. Rapid lateral variations occur in the seismic properties of the near-surface material, which includes hard basalt adjacent to pockets of loose alluvial fill. Seismic energy penetration and return may also be limited by large velocity contrasts associated with surface volcanic rocks, and with igneous sills known to occur within the sedimentary sequence.

A lower Triassic horizon (identified by a seismic tie to Lockrose No. 1) is shown in simplified form on Plate 3 for the northern part of the basin. A poorly controlled basal Mesozoic "phantom" horizon is shown for the Casino area.

Very shallow basement was reported (Wales, pers. comm.) for the offshore area between 29°S and 29°30'S, as a result of the seismic survey there (Plate 2).

DISCUSSION OF GEOPHYSICAL RESULTS

The magnetic layer mapped by the airborne surveys is unlikely to correspond to the Palaeozoic metamorphic rocks which constitute economic basement for petroleum, as these have little or no magnetic expression, even where they outcrop. Hence the usefulness of the magnetic method as an indicator of thickness of prospective section is limited to areas where the non-magnetic and non-prospective rocks are of known thickness. Uniformity of thickness appears not to prevail over significant areas of the basin. In the coastal area where Palaeozoic rocks outcrop, magnetic basement lies in the range 300 to 2000 m below sea level. In the vicinity of Kyogle No. 1, it lies 600 m below Palaeozoic rocks intersected in the well. It is concluded that the interpreted depths to magnetic basement are of little significance from the point of view of petroleum exploration.

Seismic refraction probes in the Ipswich-Toowomba area detected two high velocity refracting horizons of then unknown lithology. The upper horizon of velocity 4500-5200 m/sec proved to be a Lower Triassic Basalt just above economic basement when Baylam No. 1 was later drilled. The lower horizon of velocity 5800 m/sec is below total depth of the well, and hence probably correlates with crystalline rocks which have magnetic expression in the central part of the basin.

Intrusive dolerite sills occur elsewhere in the basin, and the possibility exists that igneous high velocity refracting layers may be widely distributed laterally and vertically. This would tend to reduce the effectiveness of the refraction method as a detector of deep structure.

The siting of wells in the basin has largely been decided on the basis of photo-interpretation and surface mapping, and such techniques have served to locate surface structures in exposed Mesozoic rocks. Some reflection seismic survey results have confirmed structure at depth. All structures of prospective size in areas of good surface geological exposure have presumably been located. However large areas of the basin are covered by Tertiary volcanic rocks, and none of the geophysical techniques so far tried is capable of locating structures beneath this cover.

Detailed gravity surveys of the kind usually undertaken to locate basement-controlled structures would probably reflect the distribution of shallow volcanic rocks for many areas in the basin. Although it may be theoretically possible to discriminate between near-surface and near-basement sources of gravity anomalies by sophisticated processing of gravity data, some preliminary research would be necessary before this could be regarded as a feasible exploration approach. It may be possible to measure the thickness of volcanic cover rocks by seismic methods, and numerically remove their gravity effects to produce a residual anomaly map reflecting

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deeper mass distribution. That part of the fault and fold zone which is buried beneath basalt cover is the most favourable locality for testing such an approach.

PETROLEUM SOURCE ROCKS AND PROSPECTS

Source rock studies have been conducted on core material recovered from selected subsidised wells in the Clarence-Moreton Basin (Saxby, 1977). Table 2 shows the results of the analyses. The paragraphs and accompanying figure which follow constitute an interpretation of these results and are largely based on the work of Gorter (1978).

VITRINITE REFLECTANCE

The rationale for the use of vitrinite reflectance in maturation studies is based on research in coal petrography. Much of the significant literature has been referenced by Burne and Kantsler (1977). They also give a relationship between maximum palaeo-temperature and vitrinite reflectance. Their relationship has been used in Figure 2, to permit comparison between modern temperatures and palaeotemperatures.

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TABLE 2. Clarence-Moreton Basin source rock analysis.
(After Saxby, 1977)

Well	Core	Depth (m)	Total Extract (ppm) (±60)	Aliphatic Fraction (ppm) (±10)	Aromatic Fraction (ppm) (±20)	Polar Fraction (ppm) (±100)	Organic Carbon (%)	Vitrinite Reflectance (%) (±.05)
Kyogle 1	7	699.5	481	85	34	378	0.55	0.71
" "	11	1043.0-1043.1	2,279	458	170	1,515	3.00	1.24
" "	22	1925.0-1925.2	111	13	7	91	0.10	1.60
" "	25	2145.2-2145.3	182	5	4	158	0.50	1.70
" "	26	2208.6-2208.8	600	2	10	602	2.00	2.00
" "	27	2293.6-2293.9	377	14	10	358	0.65	2.13
Lockrose 1	2	411.2- 411.5	843	67	41	643	0.30	0.66
" "	6	806.8- 806.9	230	5	2	142	0.25	0.83
" "	7	903.4- 903.6	191	1	9	175	0.15	0.80
" "	8	988.7- 988.9	3,357	91	197	2,975	6.60	0.96
" "	9	1074.7-1074.9	12,494	933	995	10,530	21.7	0.84
" "	10	1183.5-1183.8	977	14	8	846	0.95	0.85
" "	11	1219.9-1220.0	3,476	66	122	2,974	7.50	0.97
" "	15	1527.0-1527.1	74	12	10	65	0.45	2.34

TABLE 2 (continued)

Well	Core	Depth (m)	Total Extract (ppm)	Aliphatic Fraction (ppm)	Aromatic Fraction (ppm)	Polar Fraction (ppm)	Organic Carbon (%)	Vitrinite Reflectance (%)
			($\pm$60)	($\pm$10)	($\pm$20)	($\pm$100)		($\pm$.05)
Hogarth 1	1	627.7- 627.8	234	63	67	101	0.25	1.08
Clifden 3	1	300.5- 300.6	133	3	27	107	0.75	1.22
" "	3	496.2- 496.3	279	13	21	252	0.50	1.17
" "	7	780.6- 780.7	504	20	27	363	0.80	1.19
" "	10	1067.4-1067.5	142	5	8	100	0.15	1.33
" "	11	1160.1-1160.2	524	6	18	500	0.85	1.41
" "	14	1428.3-1428.4	190	5	8	176	0.35	1.72
" "	19	1865.7-1865.8	165	27	67	45	9.40	2.75
" "	22	2149.4-2149.5	80	13	21	55	1.15	2.34
" "	24	2286.6-2286.7	108	16	52	38	9.50	2.49

(Figures in parentheses at the top of some columns indicate the probable uncertainty in the results)

Bottom hole temperatures from five wells are plotted on the left side of Figure 2. The approximate geothermal gradient is indicated to be 18°C/km. Plaeotemperatures as indicated by vitrinite reflectance are significantly higher. Subjective straight lines drawn through the data points in Figure 2 show that, at Kyogle No. 1, the palaeogradient lies in the range 22-50° C/km, while at Clifden No. 3, a more precisely defined gradient of 36° C/km is inferred. The broad range at Kyogle may be interpreted as two independent palaeogradients separated by an unconformity. To honour all data points plotted for the Lockrose No. 1 well, an improbably high palaeogradient of approximately 130° C/km would be required. The preferred interpretation is that the sample from Core No. 15 contained migrated oil. The generally higher palaeotemperatures which prevailed at Clifden No. 3 can be interpreted as indicating either a greater depth of burial there, or that a local increase in heat flow occurred. Since about 1 000 m of sediment is known to have been eroded from the northeast part of the Warwick Sheet area (Exon and others, 1974) it can be postulated that a maximum thickness of the order of 2 000 m has been removed from the Clifden area. The high palaeotemperatures may be related, at least in part, to the presence of igneous intrusions.

The only promising source rocks occur in the Triassic Ipswich Coal Measures and their equivalents, and the woody nature of the contained organic material suggests that the rocks would be likely to generate gas. Some oil has apparently been generated from sub-mature to mature Triassic rocks in Core No. 9 from Lockrose No. 1. The underlying overmature (?)Permian (Core No. 15) has probably received traces of migrated oil from the Triassic. The Ipswich Coal Measures at Kyogle are post-mature, and likely to have generated dry gas. A little oil in an Upper Triassic-Jurassic sandstone (Core No. 11) was probably generated from coaly material in situ, and the oil in the immature Walloon Coal Measures (Core No. 7) migrated from below. At Clifden No. 3 the equivalent to the Ipswich Coal Measures (Nymboida) is also post-mature. One result showed an anomalously high vitrinite reflectance and is attributed to the close proximity of an igneous sill.

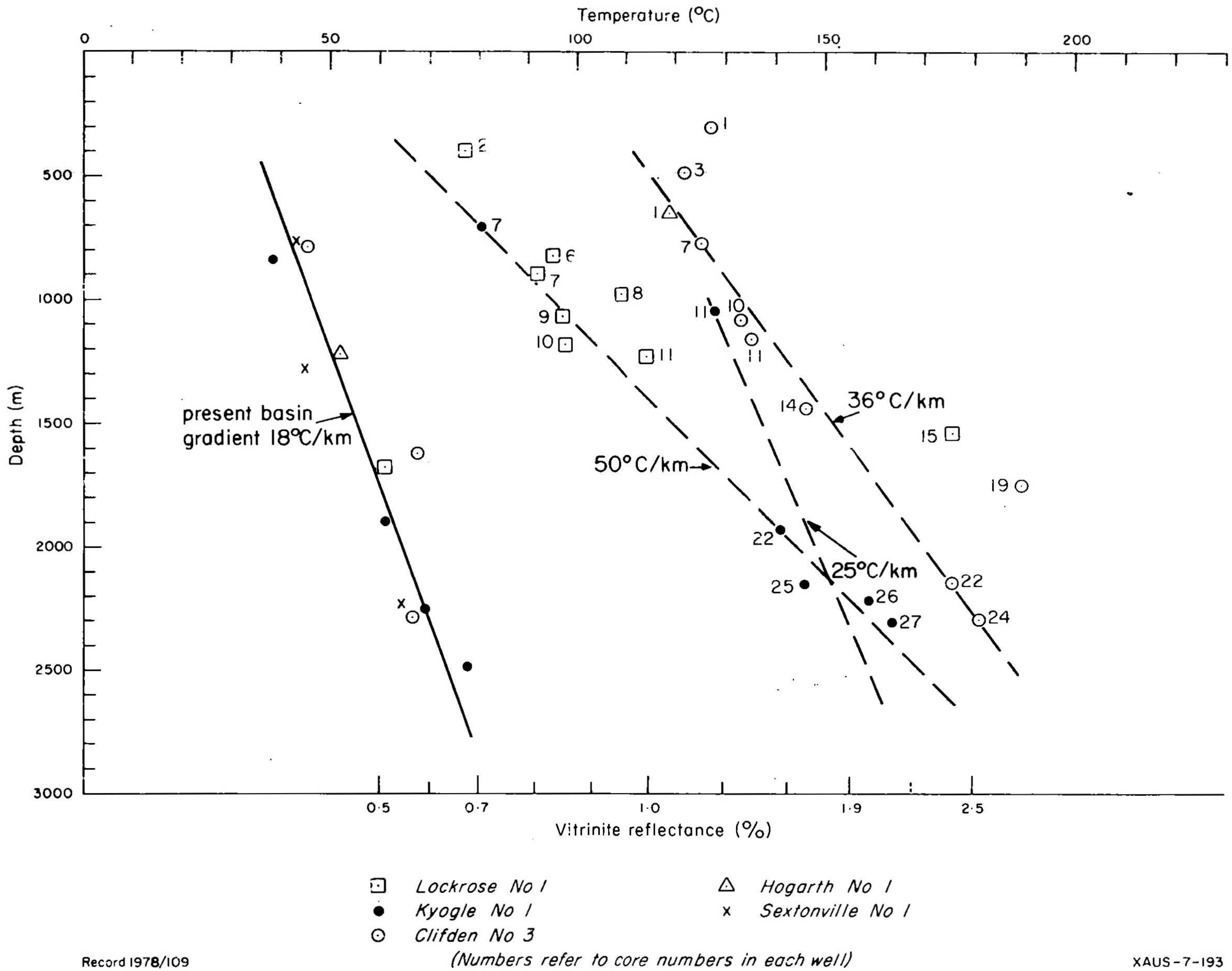

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Fig 2 Bottom-hole temperatures versus depth (fitted with firm line) and vitrinite reflectance versus depth (fitted with dashed lines) for wells in the Clarence-Moreton Basin

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PETROLEUM PROSPECTIVITY

Gorter (1978) has concluded from a consideration of the preceding data that the Clarence-Moreton Basin is prospective for gas only. Gas reservoirs should be sought in the Bundamba and Marburg formations, sealed by shales in these formations or by the overlying Walloon Coal Measures. Because of the poor permeability and porosity so far encountered in exploration drilling, suitable reservoirs can be expected to be rare.

The following appraisal of petroleum prospectivity is largely based on unpublished notes prepared by D. Wales in 1977.

The interval between the top of the Ipswich Coal Measures, and the base of the Walloon Coal Measures (covering rocks in the age range Upper Triassic to Lower Jurassic) is usually divided into a lower (Bundamba Group) and an upper (Marburg Formation) sequence (for example, Table 1). In this summary, following D. Wales, division into a lower, sandy unit (UNIT A) and an upper shaly unit (UNIT B) is preferred, based on the drilling results of Hogarth No. 1, Tullymorgan No. 1, and Clifden No. 3. Unit B was not intersected by Sextonville No. 1 or Lackrose No. 1. The contact between Units A and B does not correspond to the various Marburg-Bundamba contacts described in subsidised well reports listed in Appendix 1.

(a) Source The oldest rocks in the basin, the Ipswich Coal Measures, have source potential except where locally metamorphosed by intrusives as at Clifden No. 3. Above the Ipswich Coal Measures, coaly and carbonaceous shales in Unit B make up less than 20% of the unit, and although they are generally mature, their relatively low total volume and small areal extent are unfavourable source factors. Unit B and Walloon shales are perhaps marginally mature and therefore have some source potential, but are generally rather low in organic content.

(b) Seal There are no thick widespread seals in the Clarence-Moreton Basin beneath the Walloon Coal Measures and Unit B shales. Walloon cover in the Laidley Syncline is thin or absent, and there is consequently a lack of effective seal in this part of the basin. The most significant hydrocarbon shows detected in the Clarence Syncline were at or near the base of Unit B, and this tends to lend support to the argument that Walloon and Unit B shales form an effective seal.

(c) Reservoir Sands in Units A and B constitute the only potential reservoir rocks of interest. Porous sands in the younger Kangaroo Creek and Grafton Formations are exposed and the older Ipswich Coal Measures sands are tight. Unit A sandstones are generally tight although there are instances of weakly-developed porosity at both Hogarth (where only a limited thickness of Unit A was investigated) and Clifden. At Hogarth No. 2, a gas flow of 15,000 m^3/day was tested from a probable channel sand about 150 m above the base of unit B, whilst at Clifden No. 2, 3 000 m^3/day of gas was obtained from an uncored sand at the top of Unit A. The equivalent sand in Clifden No. 3 was untested but has a porosity of 11% and permeability up to 25 md. Smaller shows, the gas-cut and oil-cut muds at the top of Unit A in Tullymorgan No. 1 and Kyogle No. 1 respectively, are significant in that they point to the lack of porosity and permeability in the section. The sandstones of both Units A and B are commonly very hard and although sometimes well-sorted and with sub-rounded grains, their interstices are tightly plugged with a dense feldspathic cement. A possible exception to this circumstance may occur at Kyogle No. 1, where relatively high porosities and permeabilities have been determined for a number of Unit A sidewall cores. However, this sampling technique can often cause impact fracturing which may result in artifically-high porosities and permeabilities. At Kyogle No. 1, despite the fact that the most basal core is poorly friable, conventional cores cut over the interval sidewall-sampled show no significant porosity under a hand lens.

(d) Traps Assumming that somewhere in the basin Unit A has adequate porosity, then the anticlines which are known to occur in the basin can be considered viable exploration targets. Of the significantly sized, mapped anticlines in the prospectively thick part of the basin, only the Halfway Creek structure remains untested by modern drilling. Unknown structures may exist beneath the thick and widespread cover of Tertiary volcanics. The difficulty of effectively penetrating this cover by geophysical techniques has already been explained.

(e) Timing According to McElroy (1962), folding movements and faulting occurred during and after deposition in the Cretaceous and possibly early Tertiary. The younger volcanic strata are undisturbed. Since much of the source material in Units A and B are just now entering the range of optimum maturation, traps were probably present when early gas generation and migration were occurring.

(f) Migration The general lack of porosity in sandstones of the Walloon Coal Measures results from the early plugging of pore spaces by the products of in situ feldspar breakdown. A similar explanation probably applies to the tight Unit A sandstones. It can be concluded that vertical migration from below Unit A did not play an important part in the accumulation of petroleum shows at the contact between Units A and B. The presence of these shows suggests that nearby Walloon Coal Measures or Unit B rocks formed the source. The relative immaturity and low organic content of the Walloon suggest that the existence of large accumulations at the level of the Unit A, Unit B contact is improbable.

Gray (1975), in an examination of the petroleum prospects of the Bundamba Group in the northernmost part of the basin, concluded that good reservoir potential exists at several stratigraphic levels. Porosity is controlled by a clay matrix, and tends to improve westward. Although no maturation data were presented, the group was described as having generally poor source potential. The petroleum exploration play favoured by Gray depends on a wedge-out of the upper sandstones (his Helidon Sandstone) of the Bundamba Group against basement 'highs' west of the Gatton Arch.

UNDISCOVERED PETROLEUM RESOURCES

Discussion of the undiscovered petroleum resources of the basin can conveniently follow a geographical division into three areas; the Laidley Syncline, the Clarence Syncline, and the structural trend which separates them.

Structures in the Laidley Syncline (Plate 1) include the Mount Barney Dome and the Mount Alford Dome, two volcanogenic structures of Tertiary age. The timing and preservation factors in these cases were probably not favourable for accumulation of hydrocarbons. Two other structures were generated by basement movement, one of which, the Swan Creek Anticline, has been drilled. The well was dry, plugged and abandoned, but no other information is available. The other structure is the Maryvale Anticline, but it is not known whether this structure is closed at prospective depths. Other structures which may exist beneath basaltic cover have similar potential to those tested by the wells The Overflow No. 1 and Sextonville No. 1. The results of these wells were not encouraging.

Because of the results of the two unsuccessful stratigraphic tests, the probability of finding hydrocarbons in stratigraphic traps in the Laidley Syncline is regarded as negligible.

Two wells have been drilled along the structural trend, the Overflow No. 1, and Sextonville No. 1, the latter being located on the Toonumbar Anticline. Another structure on the trend, the Grevillea Anticline, is untested, and it is not known whether structural closure is present. Evidence from the wells suggests that adequate reservoir conditions are unlikely to be present.

The Clarence Syncline is the most prospective of the three areas. Little information is available from the wells drilled in the Clifden Dome, but wells in the Hogarth Dome, Kyogle Anticline, and the Tullymorgan structure produced gas to the surface, the most significant flow being in Hogarth No. 2 which flowed 10^4 m^3 per day. A minor gas show was also encountered at Grafton.

Given the fair porosities which were indicated by the results of drilling anticlines in the Clarence Syncline, stratigraphic traps may also have some potential in this area if such traps can be located.

The gas in place at Hogarth has been estimated to be 100×10^6 m^3 (Benstead, 1976) of which about 60% is theoretically recoverable. Currently available information suggests that at best only a few relatively small traps containing gas are likely to exist in the Clarence-Moreton Basin. These would probably be confined to the Clarence Syncline. It is considered that the likely maximum quantity (cumulative probability of exceeding = 10 percent) of recoverable gas in the basin is of the order of five times the quantity of recoverable gas at Hogarth. The undiscovered gas resources of the basin are therefore believed to lie in the range of zero to 300×10^6 m^3, and the most likely value is considered to be about 150×10^6 m^3.

It is unlikely that liquid petroleum resources will be discovered in significant amounts anywhere in the basin.

CONCLUSIONS

A consideration of the tectonic origin of the rocks surrounding and underlying the basin has led to the conclusion that sediments were deposited in a crustal plate suture zone. Sufficient post-depositional relative movement between the two major crustal blocks on opposite sides of the suture occurred to generate a major trend of faults and folds in Mesozoic strata of the basin. Some parts of the trend were subsequently buried beneath Tertiary volcanics. Little can be concluded as to the relative importance of basement movements and intrusions in the generation of structures in the Clarence Syncline.

The principal conclusion to be drawn from a review of the petroleum source rocks and potential is that the best source rocks lie at a deeper stratigraphic level than most drilling has so far explored. The best potential reservoir rocks are Jurassic sands beneath the Walloon Coal Measures. Shales in the Walloon Coal Measures and underlying formations may form an effective seal.

A review of the geophysical techniques used during the exploration of the basin, and the results derived from them, has shown that orthodox techniques are not likely to locate many potential structural traps. The application of sophisticated data acquisition and processing methods to multisensory geophysical approaches holds the best hope.

The Clarence Syncline is considered to be the most prospective part of the basin. The basin has some potential for small gas discoveries but negligible potential for oil.

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APPENDIX 1

Petroleum Bores - Clarence-Moreton Basin

(based largely on Bembrick, 1973)

Bore name	State	Latitude (S.) Longitude (E.) °	'	"	Total depth (m)	Year completed	BMR file no. if subsidised
Grafton 1	NSW	29 152	40 55	48 43	1127	1902	-
Halfway Creek	NSW	29 153	57 00	32 25	784	1931	-
Grafton 2	NSW	29 152	40 55	37 40	1397	1955	-
Clifden 1	NSW	29 152	33 55	54 21	393	1959	-
The Overflow 1	QLD	27 152	56 51		912	1960	62/1037
Clifden 2	NSW	29 152	33 55	57 21	592	1962	62/1088
Clifden 3	NSW	29 152	34 54	08 57	2288	1963	62/1310
Kyogle 1	NSW	28 152	37 58	37 36	2490	1963	63/1001
Clifden 4	NSW	29 152	34 55	00 24	762	1963	-
Sextonville 1	NSW	28 152	40 48	50 26	2230	1964	63/1325
Tullymorgan 1	NSW	29 153	21 04	16 56	2311	1965	65/4147
Clifden 5	NSW	As for No. 2			608	1965	-
Baylam 1	QLD	27 152	29 21	17 59	1203	1965	65/4178
Lockrose 1	QLD	27 152	29 28	06 48	1675	1965	65/4169
Swan Creek 1	QLD	28 152	13 11	40 40	507	1965	-

APPENDIX 1 (continued)

Bore name	State	Latitude (S.) Longitude (E.)			Total depth (m)	Year completed	BMR file no. if subsidised
		o	'	"			
Hogarth 1	NSW	28 152	54 51	10 20	1218	1968	68/2030
Clifden 6	NSW	29 152	34 55	00 30	603	1969	-
Hogarth 2	NSW	28 152	54 51	06 36	1113	1970	-
Hogarth 3	NSW	28 152	54 51		957	1970	-
Hogarth 4	NSW	28 152	54 51	04 26	1173.5	1974	-

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APPENDIX 2
GEOPHYSICAL SURVEYS

Seismic surveys

Survey name and type	Year	Operator	Contractor	Energy source	Reference
Casino Area reflection	1962	Mid-Eastern Oil	Austral Geo Prospectors	Explosives	PSSA 62/1643
Blue Knob reflection	1963	Alliance Petroleum Australia	General Geophysical	Explosives	PSSA 63/1542
Caboolture-Gatton	1964-65	Phillips Petroleum and Sunray DX Oil	Austral Geo Prospectors	Explosives	PSSA 64/4570
Nimbin reflection	1966	Mid-Eastern Oil Prospectors	Austral Geo	Explosives	PSSA 66/11079
Lockyer Valley reflection	1966	Phillips Australia Oil and Sunray DX Oil	Petty Geophysical	Explosives	PSSA 66/11103
Brisbane refraction	1966	Associated Australian Oilfields	United Geophysical	Explosives	PSSA 66/11130
Moreton marine reflection	1967	Amalgamated Petroleum	Namco	Airguns	PSSA 67/11202
South Grafton reflection	1968	South Pacific Drilling	Namco	Explosives	PSSA 68/3009
NSW Offshore P.E.4 marine reflection & refraction	1971	Clarence Oil and Minerals	Teledyne	Sparker	P(SL)A 71/17

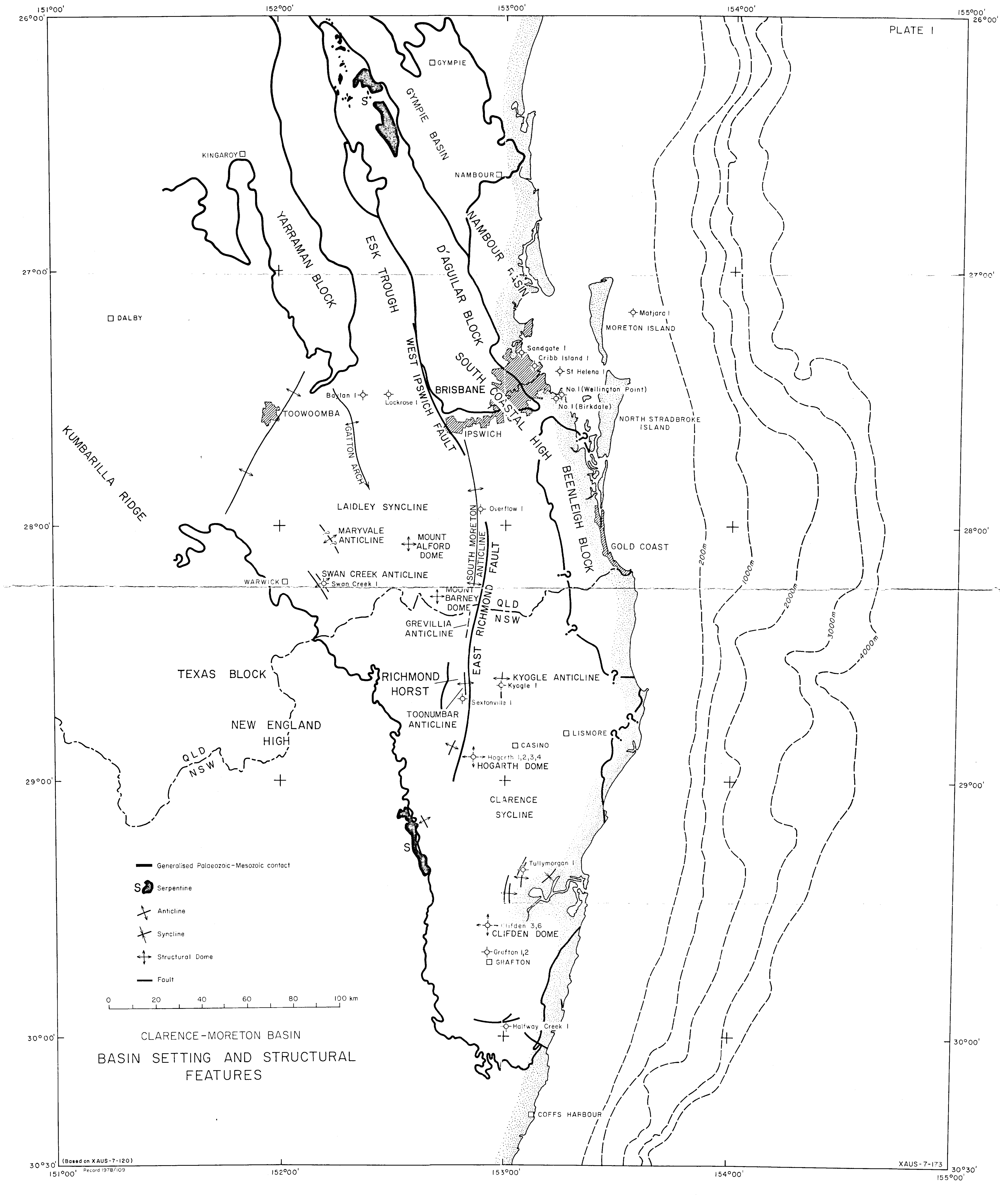
APPENDIX 2 (continued)

Aeromagnetic surveys

Survey name	Year	Operator	Contractor	Reference
Sydney-Nowra	1963	L.H. Smart Oil Exploration	Aero Service	PSSA 62/1726
Casino	1965	Mid-Eastern	Aero Service	PSSA 65/4618

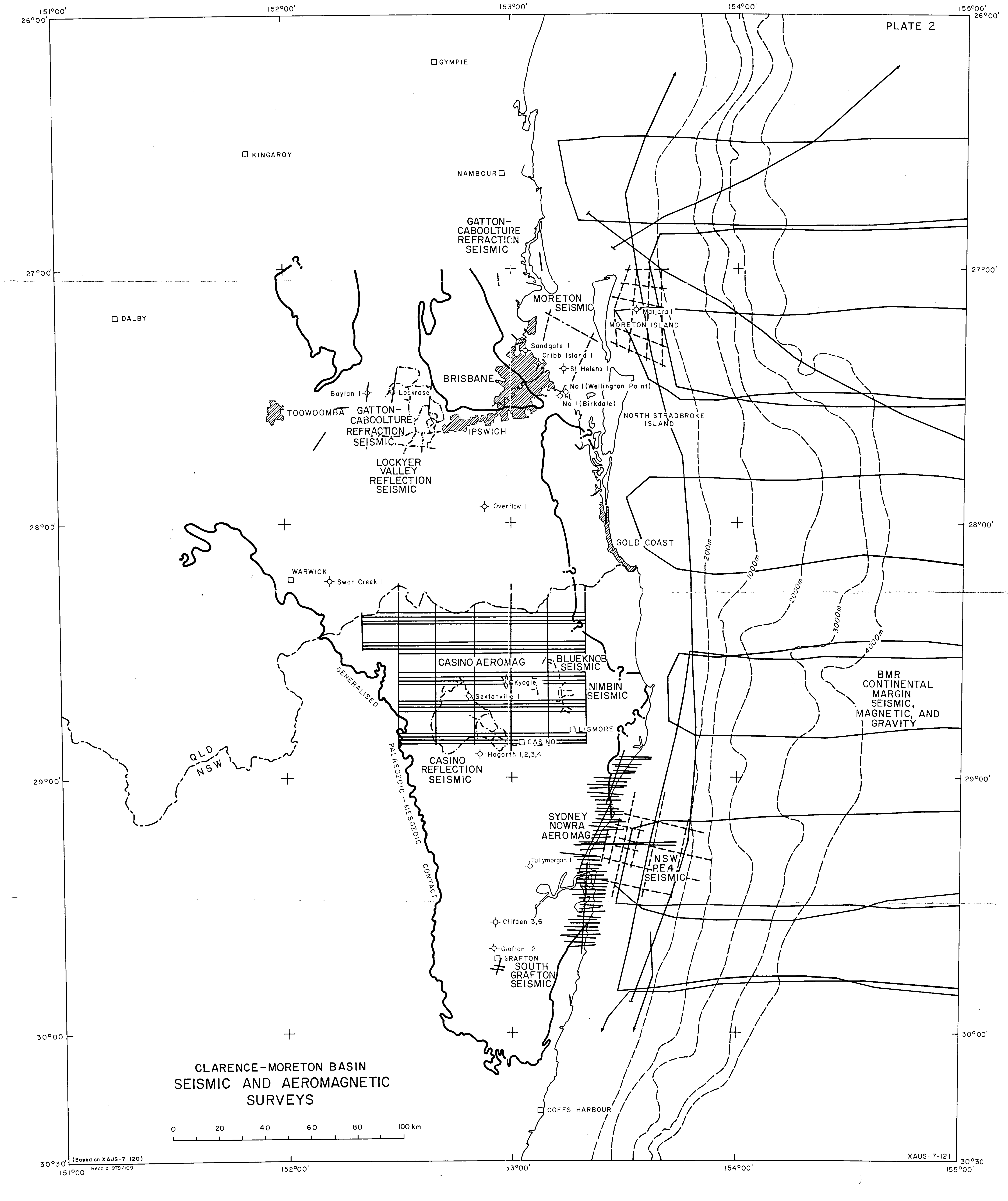
Gravity surveys

Survey name	Year	Operator	Contractor	Reference
NE N.S.W. and SE Qld.	1960-61	B.M.R.	-	BMR record 1967/12
Southern Qld helicopter reconnaissance	1964	B.M.R.	Wongela Geophysical	BMR record 1965/251
Southern Qld & northern NSW helicopter reconnaissance	1968	B.M.R.	Wongela Geophysical	BMR record 1969/109
BMR Continental Margin	1970-73	B.M.R.	Compagnie Generale de Geophysique	BMR record 1973/167 and Symonds, in prep.



CLARENCE-MORETON BASIN

BASIN SETTING AND STRUCTURAL FEATURES



CLARENCE-MORETON BASIN
SEISMIC AND AEROMAGNETIC SURVEYS

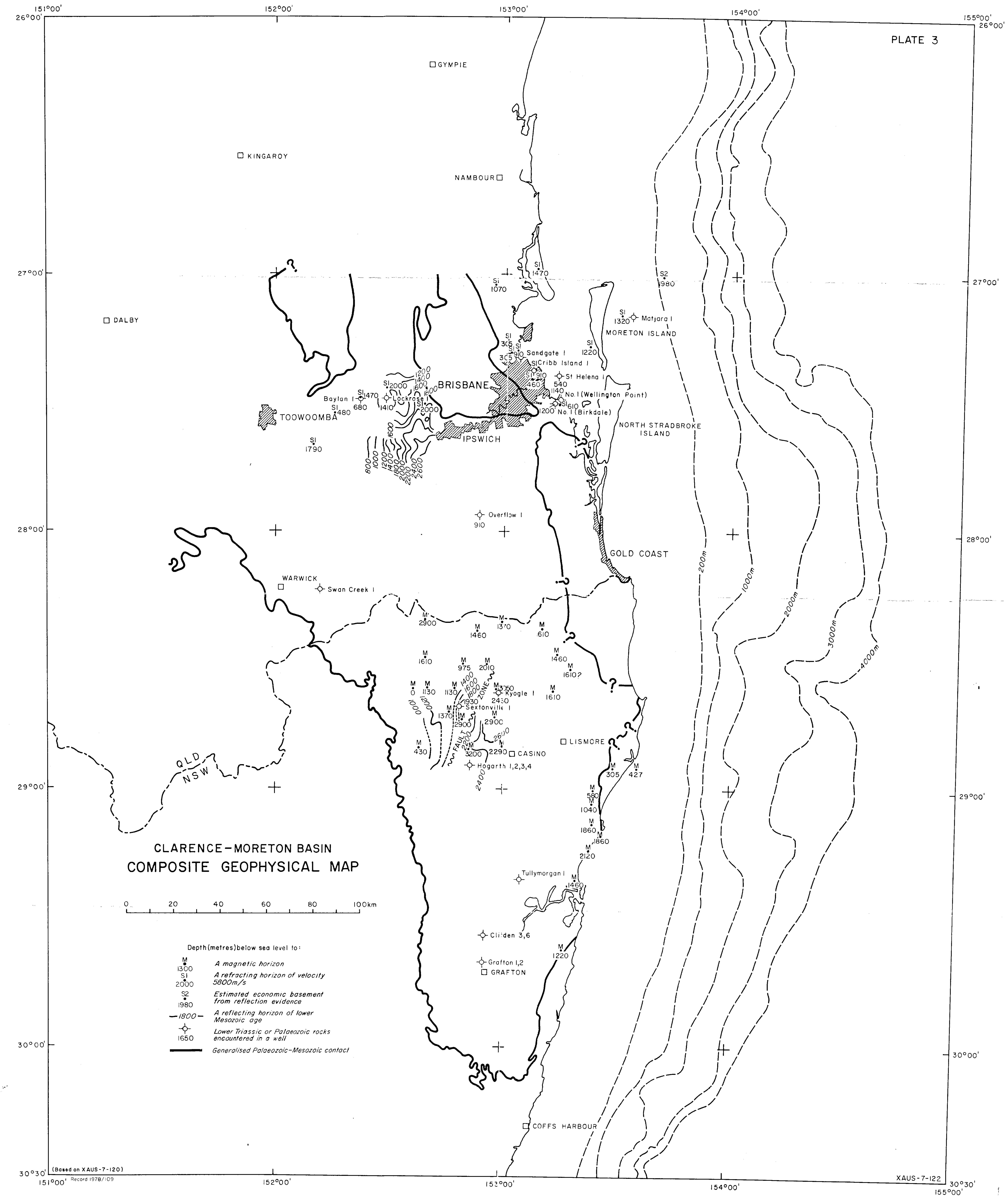
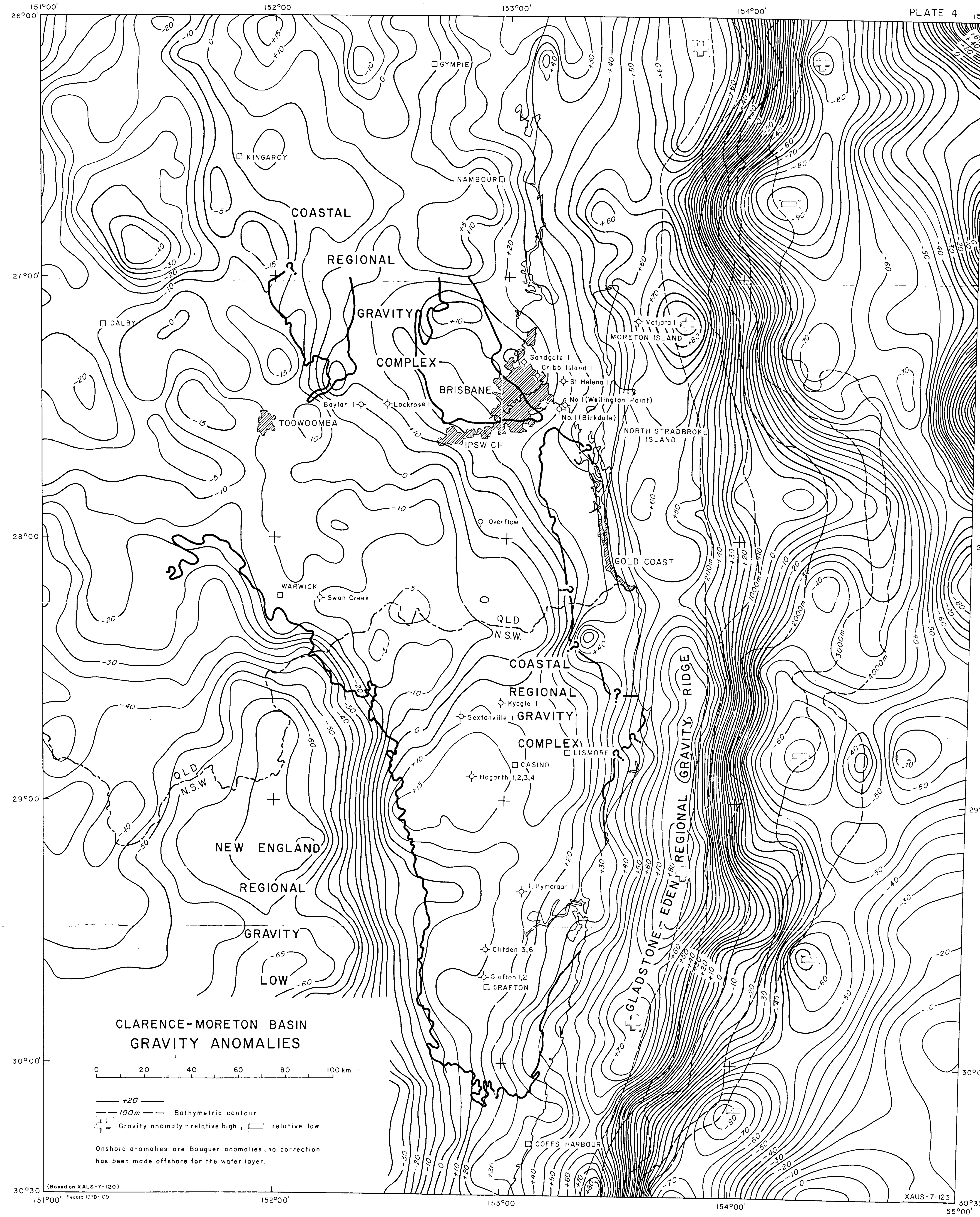


PLATE 3
CLARENCE-MORETON BASIN
COMPOSITE GEOPHYSICAL MAP
0 20 40 60 80 100km
Depth (metres) below sea level to:
M 1300 A magnetic horizon
S1 2000 A refracting horizon of velocity 5800m/s
S2 1980 Estimated economic basement from reflection evidence
—1800— A reflecting horizon of lower Mesozoic age
1650 Lower Triassic or Palaeozoic rocks encountered in a well
Generalised Palaeozoic-Mesozoic contact
GYMPIE
KINGAROY
NAMBOUR
DALBY
MORETON ISLAND
Moatara 1
Sandgate 1
Cribb Island 1
St Helena 1
No. 1 (Wellington Point)
No. 1 (Birkdale)
BRISBANE
Baylan 1
Lockrose 1
TOOWOOMBA
IPSWICH
NORTH STRADBROKE ISLAND
Overflow 1
GOLD COAST
WARWICK
Swan Creek 1
Kyogle 1
Sextonville 1
FAULT ZONE
LISMORE
CASINO
Hogarth 1,2,3,4
QLD
NSW
Tullymorgan 1
Clifden 3,6
Grafton 1,2
GRAFTON
COFFS HARBOUR
200m
1000m
2000m
3000m
4000m
151°00'
152°00'
153°00'
154°00'
155°00'
26°00'
27°00'
28°00'
29°00'
30°00'
30°30'
(Based on XAUS-7-120)
Record 1978/109
XAUS-7-122

PLATE 4


151°00'
152°00'
153°00'
154°00'
155°00'
26°00'
27°00'
28°00'
29°00'
30°00'
30°30'
GYMPIE
KINGAROY
NAMBOUR
DALBY
COASTAL
REGIONAL
GRAVITY
COMPLEX
BRISBANE
TOOWOOMBA
IPSWICH
Sandgate 1
Cribb Island 1
St Helena 1
No 1 (Wellington Point)
No 1 (Birkdale)
Baylan 1
Lockrose 1
Matjara 1
MORETON ISLAND
NORTH STRADBROKE ISLAND
Overflow 1
GOLD COAST
WARWICK
Swan Creek 1
QLD
N.S.W.
Kyogle 1
Sextonville 1
LISMORE
CASINO
Hogarth 1,2,3,4
NEW ENGLAND
REGIONAL
GRAVITY
LOW
Tullymorgan 1
Clifden 3,6
Grafton 1,2
GRAFTON
COFFS HARBOUR
GLADSTONE - EDEN REGIONAL GRAVITY RIDGE
200m
1000m
2000m
3000m
4000m
CLARENCE-MORETON BASIN
GRAVITY ANOMALIES
0 20 40 60 80 100 km
+20
100m Bathymetric contour
Gravity anomaly - relative high, relative low
Onshore anomalies are Bouguer anomalies, no correction has been made offshore for the water layer.
(Based on XAUS-7-120)
Record 1978/109
XAUS-7-123