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RECORD No. 1966/210

NORTH EROMANGA AND DRUMMOND BASINS. RECONNAISSANCE GRAVITY SURVEYS,

QUEENSLAND 1959 - 1963

by

R.A. GIBB

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<u>Note.</u> This Record supersedes Geophysical Progress Reports 1963/7 and 1964/3

SUMMARY

The results of helicopter gravity surveys made in the north Eromanga and Drummond Basins by the Bureau of Mineral Resources, Geology and Geophysics between 1959 and 1963, together with the results of several detailed and semi-detailed surveys made by the BMR and private companies, are presented in the form of Bouguer anomalies.

The area is divided into five gravity provinces on the basis of Bouguer anomalies and geology. The regional gravity 'low' over the north Eromanga Basin is related partly to the gravity effect of the Mesozoic sediments and partly to a density discontinuity between the Lower Palaeozoic metamorphic rocks and Precambrian metamorphic basement. The bordering regional gravity 'highs' are related to the metamorphic rocks of the Cloncurry Fold Belt and the Anakie Structual High.

A brief study of the regional and free air anomalies suggests that the area as a whole is close to isostatic equilibrium.

Local residual anomalies are related to local geological structures. Previous geophysical surveys and drilling results are considered in relation to the Bouguer anomalies.

1. INTRODUCTION

This report discusses the results of several reconnaissance helicopter gravity surveys made by the Bureau of Mineral Resources, Geology and Geophysics (BMR) between 1959 and 1963, in the north Eromanga Basin and in the Drummond Basin, in central Queensland (Plate 1). The results of several semi-detailed and detailed gravity surveys made by the BMR and private companies have been incorporated with the results of the helicopter surveys. The localities of these surveys are shown in Plate 3.

Helicopter gravity surveys were made in the area during 1959 (Gibb, 1967), 1961 (Lonsdale, 1962; Gibb, 1967), and 1963 as part of the BMR oil search programme in Australia. The 1963 surveys were done in two parts. The first part, between April and June, was done in co-operation with the Division of National Mapping, and the second part, between August and October, was done under contract to the BMR by Velocity Surveys Ltd. Details of these two surveys are given in Appendix D.

In 1950-51 a pendulum station network was established by the BMR in Australia (Dooley, 1962). Between 1958 and 1963, in the area under review, a BMR regional network of gravity traverses was surveyed and tied to these pendulum stations. These gravity readings were made at bench-marks surveyed by the Survey Branch of the Department of the Interior. Thus gravity and elevation control had been established for the subsequent reconnaissance helicopter gravity and microbarometer surveys.

2. GEOLOGY

Surface geology

This brief account of the geology of the area is taken mainly from Reynolds et al (1963). In Plate 2 most of the Tertiary and Quaternary cover has been omitted to reveal the Cretaceous geology of the area.

Eromanga Basin. The Eromanga Basin contains Upper Permian to Cretaceous sediments and covers about 70,000 square miles of the central and south-western part of the Great Artesian Basin in Queensland, the Northern Territory, South Australia, and New South Wales. The basin margins are generally defined by the limits of fairly continuous outcrops of Mesozoic rocks, though some Permian rocks are included (Reynolds et al, 1963).

In the northern Eromanga Basin the basin margins have been mapped by field parties comprising personnel from the BMR and the Geological Survey of Queensland (Vine, 1962; Jauncey, 1962; Vine & Jauncey, 1962a & b; Vine, Bastian, & Casey, 1963; Vine, Casey, & Johnson, 1964).

In the north-west the Mesozoic rocks overlap the Precambrian rocks of the Cloncurry Fold Belt and in the east they overlap the Carbo-Devonian rocks of the Drummond Basin (Plate 2). It has been suggested that in the north the Carpentaria Basin is separated from the Eromanga Basin by the Euroka Ridge (Hill, 1951; Hill & Denmead, 1960) or Euroka Shelf (Mott, 1952). However, this basement feature has nowhere been completely defined and the latest evidence from geological mapping (Vine et al, 1963) and the helicopter gravity survey of 1963 suggests that this basement ridge or shelf is not a continuous feature separating the Carpentaria and Eromanga Basins. To the south and south-west of the survey area the Eromanga Basin widens out to cover an extensive area of eastern Australia.

The stratigraphy of the northern Eromanga Basin is summarised in Table 1.

TABLE 1

STRATIGRAPHIC SECTIONS, NORTHERN EROMANGA BASIN

Age ascribed to units				North-western part (Casey, 1959)	Northern and north-eastern part (Vine *et al*, 1963 & 1964)
CAINOZOIC or TERTIARY					Unconsolidated sand Basalt Glendower Fm.
CRETACEOUS	UPPER	Turonian Cenomanian			?-?-?-?-?-?-?-?-?-?-?-?-? Rolling Downs Gp.: Winton Fm.
CRETACEOUS	LOWER	Albian	U - M	Wilgunya Fm.: Toolebuc Mb.	Rolling Downs Gp.: Mackunda Bd.
CRETACEOUS	LOWER	Albian	L	Wilgunya Fm.: Toolebuc Mb.	Rolling Downs Gp.: Wilgunya Fm.: Allaru Mb. Toolebuc Mb. Ranmoor Mb. Jones Valley Mb. Doncaster Mb.
CRETACEOUS	LOWER	Aptian		Wilgunya Fm.: Toolebuc Mb.	Rolling Downs Gp.: Wilgunya Fm.
CRETACEOUS	LOWER	Neocomian		Longsight Sst.	Gilbert River Fm.
JURASSIC	Upper			Western Eromanga Basin -?-?-?-?-?-?-?-?-?-?-	Blantyre Sandstone
JURASSIC	Middle and Lower				Blantyre Sandstone
LOWER TRIASSIC					Warang Sandstone
UPPER PERMIAN					Betts Creek Beds
LOWER PERMIAN - UPPER CARBONIFEROUS					Boonderoo Beds
PRECAMBRIAN TO LOWER PALAEOZOIC					Metamorphic and igneous basement

Drummond Basin. The Drummond Basin extends from south of Charters Towers southwards to Springsure. On the west it is overlapped by Mesozoic rocks of the Great Artesian Basin and in the south by Permian rocks (Colinlea Formation), which extend across the Springsure Shelf area. The basin is bounded to the east by the rocks of the folded Anakie Metamorphics (Reynolds et al, 1963).

The lithologic succession is given in Table 2 (Reynolds et al, 1963).

TABLE 2

LITHOLOGIC SUCCESSION, DRUMMOND BASIN

Age	Maximum thickness (ft)	Lithological character
Tertiary	-	Basic and acidic volcanics of limited extent and continental sediments.
Carboniferous	15,000	Acid lava, tuff, agglomerate, and tuffaceous siltstone and sandstone.
	20,000	Siltstone, siliceous conglomerate, sandstone, tuff, and algal limestone.
Devonian	10,500	Siltstone, sandstone, limestone, conglomerate, algal limestone, tuff, tuffaceous sandstone, and intermediate to acidic lava. Includes some marine sediments.

The oldest rocks whose age is definitely known are Middle Devonian; the Ukalunda Beds near the northern part of the basin comprise at least 4000 ft of relatively undisturbed marine siltstone and possibly contain some Lower Devonian strata. Except in the Upper Devonian Mount Wyatt Beds no definite marine horizons are known above the Middle Devonian, and marginal and continental sediments predominate. In the absence of satisfactory fossil evidence, lateral relations are difficult to establish and the Devonian and Carboniferous are difficult to separate (Reynolds et al, 1963).

The overall structure of the basin is obscure. On the east, however, sediments of the basin dip westerly off the Anakie Metamorphics and associated granitic intrusions. Many anticlines of moderate complexity trend in a general north-south direction; some of these are large, e.g. the Pebbly Creek Anticline. Considerable faulting, including thrusting, is associated with the folding. The sediments are indurated in parts owing to igneous intrusions and folding (Reynolds et al, 1963).

S -surface geology

Much useful information about the pre-Mesozoic geology is available from water bores and exploration wells drilled by private companies in the search for oil (see Plate 2 and Appendix B).

For convenience, in this brief review of the drilling results, the area is discussed under the five gravity provinces, which are defined in the next chapter and which are shown in Plates 5 and 6.

A. Cloncurry Regional Gravity High. In this region, which occupies most of JULIA CREEK, McKINLAY, MACKUNDA, and BRIGHTON DOWNS, very many water bores have been drilled. The water bores have been listed and a study of their drilling logs has been made by Vine and Jauncey (1962a), Vine and Jauncy (1962b), Vine, 1962, and Jauncey, (1962). These authors have constructed useful maps contoured on the base of the Longsight Sandstone from a study of the drilling logs. As would be expected the contours indicate a thickening of the Mesozoic beds in an easterly direction. Below the Mesozoic rocks the basement rocks are described in driller's terms as granite, diorite, schist, slate, hard rock, bedrock, quartzite, etc. The variety of rock types encountered in the basement suggests that many of the local gravity anomalies in this area are related to variations in basement lithology and hence to variations in basement rock density. The metamorphic and igneous basement in this area indicates that the rocks of the Cloncurry Fold Belt extend much further east than their area of outcrop. This is also reflected in the large area covered by the Cloncurry Regional Gravity High (Gibb, 1967).

Ooroonoo No. 1 in BRIGHTON DOWNS was drilled as an exploration well and proved to be dry. In this bore the Longsight Sandstone lies on Precambrian granite, at a depth of 3840 ft. The total depth reached was 3852 ft (Queensland Dept. of Mines, 1961).

B. Anakie Regional Gravity High. Information on water bores in this area has been compiled by Vine, Casey, and Johnson (1964) for HUGHENDEN and CHARTERS TOWERS. Water bores in this area are generally shallow and do not reach basement. Water bores in BUCHANAN and GALILEE have not yet been reviewed. No exploration wells have been drilled in this area.

C. Muttaburra Gravity Ridge. This gravity province is mainly in MANUKA, WINTON, MUTTABURRA, LONGREACH, and JERICHO. Water bores are listed by Vine, Bastian, and Casey (1963) for MANUKA and by Vine, Casey, and Johnson (1964) for WINTON and MUTTABURRA. The data in the remaining areas are not yet available in list form.

Several deep water bores are shown in Plate 2. Of these Ashra Downs, Bundella, and Darr River Downs No. 4 reach basement at 2896 ft, 2819 ft, and 4000 ft respectively. Seven other deep bores, which do not reach basement, are shown in Plate 2. The average depth of these bores is 3420 ft, indicating that the sediments attain at least this thickness over much of the Muttaburra Gravity Ridge.

Several exploration wells have been drilled in this zone. Of these Longreach Oil Ltd Nos. 1, 2, 3, and 4, Brookwood No. 1 (Exoil N.L., 1963a), and Corfield No. 1 (Queensland Dept. of Mines, 1961) struck granitic basement and Beryl No. 1 (Associated Australian Oilfields N.L., 1964) struck metamorphic basement of ?Devonian age. The average depth to basement in these wells and in the three water bores that reached basement is 3600 ft.

The drilling information in this area supports the gravity interpretation of a basement swell in the area of the Muttaburra Gravity Ridge, which is an area of relatively high Bouguer anomalies.

Permian sediments have been found in some of these bores. In Beryl No. 1, 360 ft of Bandanna Formation lie above 420 ft of unnamed Lower Permian beds. In Brookwood No. 1, 1379 ft of Permian sediments were penetrated. No sediments older than Lower Permian have been found in the area of the Muttaburra Gravity Ridge.

D. Flinders Regional Gravity Low. This gravity province extends over RICHMOND, HUGHENDEN, MANUKA, TANGORIN, BUCHANAN, and GALILEE. Water bore data have been reviewed by Vine, Bastian, and Casey (1963) and Vine, Casey, and Johnson (1964).

Some drilling logs record granitic basement at Killarney (total depth 2066 ft) and in the Coalbrook area of RICHMOND, but basement is not reached in the majority of the bores. At Olive Downs (total depth 1890 ft), basement is 'hard rock'.

In TANGORIN, in the bore at Glenariffe, a Permian section was encountered at 3000 ft to a total depth of 4220 ft.

Lake Galilee No. 1 (Exoil N.L., 1964) is the only exploration well in this area. Preliminary results indicate that Mesozoic and Upper Permian beds occur to a depth of 3480 ft. These overlie Lower Permian to Upper Carboniferous strata to 9000 ft. Below 9000 ft to the total depth of 11,175 ft are beds of the Drummond Series.

E. Thomson Regional Gravity Low. Several exploration wells have been drilled within this gravity province, which is mainly in WINTON, MANEROO, and LONGREACH. In MANEROO, Penrith No. 1 penetrated 3787 ft of Mesozoic sediments before entering ?Upper Silurian - Middle Devonian recrystallised sediments; the total depth of this well is 4078 ft (Associated Australian Oilfields N.L., 1963b). Provisional information from Fermoy No. 1 and Maynside No. 1, also in MANEROO, indicates 5030 ft and 5105 ft of Mesozoic section overlying phyllite and slate of Upper Cambrian age (Australian Aquitaine Petroleum, 1965a & b). The total depths reached in these wells are 5262 ft and 5382 ft respectively.

In the western part of LONGREACH five deep exploration wells have been drilled. These are Maranda No. 1 (Oil Development N.L., 1963), Alice River No. 1 (Farmout Drillers N.L., 1963a), Saltern Creek No. 1 (Longreach Oil Ltd, 1964a), Hulton No. 1 (Longreach Oil Ltd, 1964b), and Marchmont No. 1 (Longreach Oil Ltd, 1964c). These wells have proved the westerly extension of Permian and Carbo-Devonian Drummond Basin sediments as far as the Hulton-Rand monoclinal zone and the Longreach basement 'high', respectively.

In Maranda No. 1 the Mesozoic section is 1764 ft thick. 3419 ft of Permian sediments overlie the Joe Joe Creek Formation, which is of Upper Carboniferous age. This formation unconformably overlies ?Lower Palaeozoic or Upper Proterozoic recrystallised mudstone, which is probably an equivalent of the Anakie Metamorphics. 2721 ft of Mesozoic beds overlie 2631 ft of Permian beds to a total depth of 5352 ft in Alice River No. 1.

The westerly extension of Permian and Drummond Basin sediments below the Mesozoic beds in JERICHO and LONGREACH has been further confirmed by recent seismic surveys and a drilling programme carried out by Longreach Oil Ltd. Hulton No. 1 was drilled at the south-eastern end of the Hulton-Rand monocline, three miles south of Saltern Creek No. 1. Interpretation of the drilling and seismic results indicates that the monoclinal feature overlies a probable fault, which has been active at different times. The monocline essentially marks the south-western margin of the Permian Galilee infra-basin, and the Drummond Basin sediments continue to the south-west terminating against the Longreach Spur (Longreach Oil Ltd, 1964b).

In Hulton No. 1, 1830 ft of Mesozoic beds overlie 288 ft of Permian beds, which in turn unconformably overlie Carbo-Devonian sediments of the Drummond Basin to a total depth of 2169 ft. On the downthrown side of the Hulton-Rand structure Saltern Creek No. 1 penetrated 2499 ft of Mesozoic beds and 2271 ft of Permian beds, which unconformably overlie Drummond Basin sediments to a total depth of 4966 ft.

Further to the north-west in LONGREACH, Marchmont No. 1 was drilled, also on the downthrown side of the monocline. In this well 3305 ft of Mesozoic beds overlie 3205 ft of Permian beds, which conformably overlie the Upper Carboniferous Joe Joe Creek Formation to a total depth of 6530 ft.

Water bores in south LONGREACH and south-east MANEROO do not usually penetrate the Mesozoic section; however, Permian sediments have been recognised between the interval 3380 to 4008 ft in Wellshot No. 6 (Plate 2).

Pre-Lower Jurassic geology. A preliminary review of the sedimentary basins of Australia was made by Trumpy and Tissot (1963), in which they have drawn up a sketch map of the pre-Lower Jurassic geology in the Great Artesian Basin. Part of this map is reproduced in Plate 10.

The north Eromanga Basin contains Mesozoic and some Permian sediments resting unconformably on older rocks. The possible western extent of Lower Permian - Upper Carboniferous beds is shown in east MANUKA and east WINTON (Plate 10). The possible western limit of the Lower Carboniferous-Devonian Drummond Basin sediments is also shown in Plate 10. However, recent drilling by Longreach Oil Ltd (1964a, b, & c) has shown that these sediments extend as far west as the Longreach Spur west of Hulton No. 1, and the information from Lake Galilee No. 1 also suggests that these sediments extend further to the west than indicated in Plate 10.

It is interesting to note that the westerly limit of the Upper and Middle Triassic sediments from HUGHENDEN to ?BRIGHTON DOWNS coincides with a line of north-easterly gravity trends and a distinct change in gravity pattern. In Plate 10 the area north-west of this line is shown as basement and the gravity pattern in general comprises small, irregular, gravity closures which are often associated with sharp gravity gradients. This type of pattern is often found associated with basement rocks in which lithological variations are frequent. To the south-east, particularly in the Flinders Regional Gravity Low, and to a lesser extent in the Thomson Regional Gravity Low, the gravity pattern is smoother and the areal extent of each gravity sub-unit tends to be larger. In these areas the presence of thicker sedimentary rocks may be the reason for the change in gravity pattern.

3. CLASSIFICATION OF THE BOUGUER ANOMALIES

Regions of distinctive Bouguer anomaly contour pattern have been classified into three types of gravity feature on the basis of their size, shape, gravity trends, relative Bouguer anomaly values, and relation to their geological setting where applicable.

In descending order of size these gravity features are defined as follows:

A gravity province is usually a large area in which the gravity pattern exhibits at least one characteristic property or has a clear correlation with a major geological entity.

A gravity unit is defined similarly to a gravity province but generally occupies a smaller area. A gravity province may comprise several gravity units.

A gravity sub-unit is a local Bouguer anomaly closure or series of related closures, or a gradient. Gravity provinces and gravity units may comprise several gravity sub-units.

In the survey area the Bouguer anomaly features have been classified into five gravity provinces (Plates 5 and 6). These are described below.

A. Cloncurry Regional Gravity High (gravity province)

Only the eastern part of this gravity province occurs in the survey area. The whole gravity province is however shown in Plate 5 and has previously been described by Gibb (1967). The term Cloncurry Regional Gravity High is used to describe the regional gravity 'high' that extends over the Cloncurry Fold Belt and its buried extensions.

Two of the gravity units that make up the Cloncurry Regional Gravity High occur in the area under discussion. These are the Mackunda Gravity Platform and the Julia Creek Gravity Shelf.

Mackunda Gravity Platform (gravity unit). The Mackunda Gravity Platform corresponds to part of the eastern geosynclinal zone of Carter, Brooks, and Walker (1961). The prevailing trends in this zone are north-north-west. The Bouguer anomalies are related to density contrasts within the Precambrian rocks of the Cloncurry Fold Belt.

Julia Creek Gravity Shelf (gravity unit). This gravity unit is correlated with the hypothetical stable shelf bordering the eastern Lower Proterozoic geosynclinal zone of Carter et al (1961). The predominant north and north-north-west trends that occur over much of the Cloncurry Regional Gravity High are not apparent in this gravity unit, which is characterised by more rounded, local gravity closures.

B. Anakie Regional Gravity High (gravity province)

The Anakie Regional Gravity High is a north-north-west trending regional gravity 'high' that comprises three gravity units, named the Charters Towers Gravity Complex, the Drummond Gravity Shelf, and the Clermont Gravity Ridge. The first two of these gravity units occur in the survey area.

Charters Towers Gravity Complex (gravity unit). The Charters Towers Gravity Complex has predominantly east-west gravity trends. The gravity sub-units in this zone are associated with Precambrian metamorphic rocks and exposed igneous rocks.

Drummond Gravity Shelf (gravity unit). The Drummond Gravity Shelf is an area of generally positive Bouguer anomaly values intermediate between the negative Bouguer anomaly values of the north Eromanga Basin and the positive Bouguer anomaly values of the Clermont Gravity Ridge. The Bouguer anomalies of the Drummond Gravity Shelf are related to the sediments of the Drummond Basin.

C. Muttaburra Gravity Ridge (gravity province). The Muttaburra Gravity Ridge is located in the centre of the area and has a regional north-west trend, although some local trends, particularly in the western part of the gravity ridge, are north-east. This ridge of relatively high Bouguer anomalies links the Cloncurry Regional Gravity High with the Anakie Regional Gravity High. It also separates two large regions of relatively low Bouguer anomaly values which lie to the north and south and which are named the Flinders Regional Gravity Low and the Thomson Regional Gravity Low respectively. The gravity ridge is not related to any exposed geological structure.

The Muttaburra Gravity Ridge comprises four gravity units as follows.

Manuka Gravity Embayment (gravity unit). The Manuka Gravity Embayment is a region of relatively low Bouguer anomalies with a regional north-north-east trend.

Winton Gravity Platform (gravity unit). The Winton Gravity Platform is characterised by relatively high Bouguer anomalies with predominantly north-east trends.

Longreach Gravity Spur (gravity unit). The Longreach Gravity Spur consists of a central gravity 'low' bounded to the east and west by gravity 'highs'. All three units have approximate north-south trends. This gravity unit is related to the geological feature the Longreach Spur.

Aramac Gravity Platform (gravity unit). The Aramac Gravity Platform is a zone of relatively high Bouguer anomalies with north-west trends. In the south-west of this gravity unit the Bouguer anomalies are more negative.

D. Flinders Regional Gravity Low (gravity province)

The Flinders Regional Gravity Low is an extensive region where the Bouguer anomalies are generally less than -20 mgal. It lies to the north of the Muttaburra Gravity Ridge and is open to the north, where the area is not yet surveyed. It is bounded to the west and east by the Cloncurry Regional Gravity High and the Anakie Regional Gravity High respectively (Plate 5). The regional trends in this zone are north-west but several component gravity sub-units have north-east trends. The Flinders Regional Gravity Low has been divided into three gravity units.

Nonda Gravity Depression (gravity unit). The Nonda Gravity Depression is a belt of negative Bouguer anomalies in which the main trend is north-north-west. Minor trends are north-east. There is no direct correlation between the gravity unit and the exposed geology of the area.

Richmond Gravity Complex (gravity unit). The Richmond Gravity Complex is a zone characterised by small local gravity 'highs' and 'lows'. These rapid variations in Bouguer anomaly may correlate with density contrasts in the shallow basement of this area.

Tangorin Gravity Depression (gravity unit). The Tangorin Gravity Depression is an extensive north-west trending gravity 'low' centred in TANGORIN. In general the gravity gradients in this gravity unit are less steep than elsewhere in the Flinders Regional Gravity Low. This gravity unit is probably directly related to the light sedimentary rocks of the area.

E. Thomson Regional Gravity Low (gravity province)

Only the northern portion of the Thomson Regional Gravity Low occurs in the survey area (Plate 5). It is bounded to the north by the Muttaburra Gravity Ridge and to the south by the Eulo Gravity Platform. To the north-west and south-east it is bounded by the Cloncurry Regional Gravity High and the Nebine Gravity Ridge. The predominant gravity trends in this gravity province are north-east. The regional gravity 'low' can be partly explained by variations in sedimentary thickness in this area.

The Thomson Regional Gravity Low has not been subdivided into gravity units in this report as the subdivision depends on the results of the 1964 reconnaissance gravity survey (Lonsdale, 1965).

The gravity units have been subdivided into gravity sub-units, which have been numbered for each gravity province, as shown in Table 3. These numbers, together with the names of the gravity provinces and units, are also shown in Plate 6.

TABLE 3

GRAVITY ANOMALY FEATURES

A. Cloncurry Regional Gravity High (gravity province)

(a) Mackunda Gravity Platform (gravity unit)

Number	Short description	Gravity sub-unit
1	NNW-trending gravity 'low' in MACKUNDA	Williams Gravity Low
2	NE-trending local gravity 'low' in BRIGHTON DOWNS	Brighton Downs Gravity Low
3	NNW-trending elongated gravity 'high' in MACKUNDA and McKINLAY	Middleton Gravity High
4	NE-trending gravity gradient from BRIGHTON DOWNS to WINTON	Diamantina Gravity Gradient

(b) Julia Creek Gravity Shelf (gravity unit)

Number	Short description	Gravity sub-unit
5	Gravity 'low' in JULIA CREEK	
6	Gravity 'low' in JULIA CREEK	
7	Gravity 'low' in McKINLAY	
8	Gravity 'high' in McKINLAY	
9	Gravity 'high' in JULIA CREEK	St Elmo Gravity High
10	Extensive gravity gradient trending NNW from MANUKA to MILLUNGERA	
11	Gravity 'low' in JULIA CREEK	
12	Gravity 'high' in JULIA CREEK	

B. Anakie Regional Gravity High (gravity province)

(a) Charters Towers Gravity Complex (gravity unit)

Number	Short description	Gravity sub-unit
1	Strong gravity gradient in HUGHENDEN bounding the Flinders Regional Gravity Low	White Mountains Gravity Gradient

Number	Short description	Gravity sub-unit
2	Prominent gravity ridge extending east-west from Pentland into HUGHENDEN	Cape River Gravity Ridge
3	Gravity 'low' in north CHARTERS TOWERS and HUGHENDEN with east-west trend	Lolworth Gravity Low
4	Local gravity 'high' in north CHARTERS TOWERS	
5	Gravity 'low' in north-east CHARTERS TOWERS	Ravenswood Gravity Low

(b) Drummond Gravity Shelf (gravity unit)

Number	Short description	Gravity sub-unit
6	Belt of north-trending gravity 'highs' in BUCHANAN and CHARTERS TOWERS	
7	Gravity 'low' in BUCHANAN	
8	Gravity spur in BUCHANAN	
9	Prominent NNW-trending gravity ridge in GALILEE and BUCHANAN	Beresford Gravity Ridge
10	Strong gravity gradient bounding the Beresford Gravity Ridge	

C. Muttaburra Gravity Ridge (gravity province)

(a) Manuka Gravity Embayment (gravity unit)

Number	Short description	Gravity sub-unit
1	Gravity 'low' in south-west MANUKA	
2	Gravity 'low' in north-east MACKUNDA	
3	Gravity 'low' elongated in north-east direction in north-west WINTON	
4	Strong gradient bounding sub-unit 3	Cork Gravity Gradient

(b) Winton Gravity Platform (gravity unit)

Number	Short description	Gravity sub-unit
5	Strong gravity gradient with north-east trend in MANUKA	
6	Local gravity 'high' on extension of sub-unit 9 in MANUKA	Cannum Gravity High
7	Local gravity 'low' in MANUKA	
8	Local gravity 'low' in MANUKA	
9	Elongated gravity ridge with north-east trend in WINTON	

(c) Longreach Gravity Spur (gravity unit)

Number	Short description	Gravity sub-unit
10	North-trending gravity ridge in MUTTABURRA and LONGREACH	Darr Gravity Ridge
11	Belt of gravity 'lows' from Longreach in to MUTTABURRA	Longreach Gravity Low
12	Southerly offshoot of sub-unit 14	Ilfracombe Gravity Spur
13	Local gravity 'high' in LONGREACH	

(d) Aramac Gravity Platform (gravity unit)

Number	Short description	Gravity sub-unit
14	Extensive gravity 'high' in MUTTABURRA	
15	Extensive gravity 'high' in GALILEE and JERICHO	
16	Large gravity 'low' in JERICHO open to the south	Jericho Gravity Low

D. Flinders Regional Gravity Low (gravity province)

(a) Nonda Gravity Depression (gravity unit)

Number	Short description	Gravity sub-unit
1	Gravity 'low' in JULIA CREEK	
2	Belt of gravity 'lows' from JULIA CREEK to MANUKA	

(b) Richmond Gravity Complex (gravity unit)

Number	Short description	Gravity sub-unit
3	Extensive gravity 'high' in RICHMOND	Stawell Gravity High
4	Gravity 'low' in north RICHMOND	Coalbrook Gravity Low
5	Local gravity 'high' in RICHMOND	
6	Local gravity 'high' in north-east RICHMOND	
7	Local gravity 'high' in RICHMOND	
8	Gravity 'low' in north-west HUGHENDEN	Dumbano Gravity Low
9	Gravity 'low' in HUGHENDEN and RICHMOND	
10	Gravity spur in HUGHENDEN	

(c) Tangorin Gravity Depression (gravity unit)

Number	Short description	Gravity sub-unit
11	Zone of gravity 'lows' in RICHMOND	
12	Extensive gravity 'low' in TANGORIN	
13	Gravity 'low' in GALILEE; extension of sub-unit 12	

E. Thomson Regional Gravity Low (gravity province)

Number	Short description	Gravity sub-unit
1	NE-trending belt of gravity 'lows' south-east of the Diamantina Gravity Gradient extending from BRIGHTON DOWNS to WINTON	Vergemont Gravity Depression
2	Region of local gravity high closures in MANEROO	Penrith Gravity High
3	Gravity 'high' in south MANEROO	Maneroo Gravity High
4	Series of gravity 'lows' in MANEROO open to south	Part of Jundah Gravity Depression
5	Area of 'low' gravity anomalies in east LONGREACH	Saltern Gravity Low
6	Local gravity 'high' in east LONGREACH	Barcaldine Gravity High

4. REGIONAL GRAVITY ANOMALIES AND AEROMAGNETIC ANOMALIES

Two of the major aims of BMR helicopter reconnaissance gravity surveys are to map the probable boundaries of sedimentary basins and to delineate their regional geological structure.

A map showing smoothed Bouguer anomalies (Plate 7) has been derived from the Bouguer anomalies (Plate 6) by a smoothing process described by Holloway (1958). Bouguer anomaly values at the corners of a square grid of side 32 miles were smoothed three times by the Fjrtoft method. This method reduces the anomaly range of small-scale anomalies without much affecting large-scale anomalies of wavelength some 160 miles or greater in this case. The effectiveness of the smoothing is obvious in Plate 7. In both Plates 7 and 6 the regional anomaly features are of course essentially the same. On the basis of the smoothed anomalies a clear subdivision of the anomalies is possible. Eastern and western gravity 'highs' are linked by a central east-west gravity ridge which separates two gravity 'lows' to the north and south.

These five gravity provinces have been named in the previous section and they can be related to broad structural units. The western 'high' is associated with the Cloncurry Fold Belt and the eastern 'high' is associated with the Charters Towers Complex and the Anakie Structural High. The central area of negative Bouguer anomalies which comprises the remaining three gravity provinces is related to the north Eromanga Basin of Mesozoic sediments.

Several effects may contribute to the regional Bouguer anomalies over the north Eromanga Basin. These effects are as follows:

1. The largest part of the negative anomaly may be attributed to the gravity effect of the low density Mesozoic and older sediments and metasediments in relation to denser basement rocks of Precambrian age.

2. The anomalies may be explained in part by intra-basement density contrasts.

3. The regional gradients may be associated with variations in crustal thickness and density.

4. Part of the regional gravity 'low' may be related to downwarping of the crust at one or more discontinuities in sympathy with the basin configuration.

The residual Bouguer anomalies or small-scale gravity sub-units that remain after removal of the smoothed regional anomalies may be interpreted in terms of local geological structure. In this area the basin sediments comprise a sequence of Mesozoic and upper and middle Lower Palaeozoic rocks. Measurements of rock density have shown that these sediments are less dense than the basement rocks. From bores and outcrops it is known that basement in this area comprises a Precambrian and Lower Palaeozoic metamorphic complex into which igneous rocks have been intruded locally.

As a working hypothesis it will be assumed that two major density discontinuities contribute to the gravity effect of the fill sediments. These occur between the Mesozoic and basement rocks and between the Upper-Middle Palaeozoic and basement rocks. This is of course a simplification of the true conditions as many lithological changes and variations of density with compaction and depth within the sedimentary sequence will have contributing gravity effects. However, the adopted density relations should give reasonable estimates of regional sedimentary thickness. More precise estimates in areas of interest must come from follow-up seismic surveys.

If the regional gravity 'low' or part of it is explained by the effect of the widespread basin sediments, then the residual anomalies mapped in the north Eromanga Basin may be explained by local variations in basement topography and local pockets of pre-Mesozoic sediments and intra-basement density contrasts. This last effect may be a significant cause of many of the residual anomalies in the basin area, as in exposed basement areas to the west, variations in lithology of the Precambrian basement give rise to large residual anomalies (Gibb, 1967). Similar lithological variations in the basement are known from a study of boreholes in the north Eromanga Basin.

As a first step in the interpretation it is necessary to find the gravity effect of the Mesozoic sediments. Firstly the density contrast between the Mesozoic rocks and basement must be estimated and then the gravity effect of the sediments may be computed.

An empirical method of finding the density contrast between the Mesozoic sediments and basement is that used by Falcon and Tarrant (1951). Using data from water bores and deep wells in the area in which the Mesozoic beds lie directly on metamorphic basement, the Bouguer anomalies are plotted against depth to basement from sea level datum. As the more negative values occur with larger Mesozoic thicknesses, the points will tend to lie on a straight line with a negative gradient. The graph is shown in Plate 8 in which 60 points have been plotted each representing a gravity value and a Mesozoic thickness. The best straight line through these points was computed using the method of least squares. The results were shown to be significant and indicate that on average every 1000 ft of Mesozoic rocks are associated with a gravity deficiency of 7.51 ± 0.96 mgal.

On simple theory this gives a density contrast between the Mesozoic rocks and metamorphic basement of $0.59 \pm .08$ g/cm^3, which is in reasonable agreement with the scant information from rock density measurements.

The true average density of the Mesozoic sediments of the Great Artesian Basin measured from samples and cores is between 2.2 and 2.4 g/cm^3 and that of the Precambrian metamorphics of the Cloncurry Fold Belt is between 2.75 and 2.85 g/cm^3. This evidence was considered along with the empirical result from the borehole study in adopting a density contrast of 0.50 g/cm^3 between the Mesozoic sediments and the Precambrian basement. This result may be used to correct for the Mesozoic thickness where it is known. The Mesozoic thickness is known over much of the area from bores and wells and can be estimated from seismic results.

Fortunately many seismic surveys have been done in his area mainly by private oil companies. From the results of such surveys and boreholes a regional section across the Mesozoic basin along latitude 23°30'S has been drawn. This section together with the Bouguer anomaly and smoothed Bouguer anomaly is shown in Plate 9. The Bouguer anomaly profiles have been extended beyond the area of interest both to the west and east. Also shown is the computed gravity effect of the Mesozoic sediments. The Mesozoic effect was obtained using a computer programme which has been developed in the BMR to calculate the gravity effect of polygonal cross-sections of two-dimensional bodies. The assumption that the body is two-dimensional will introduce errors of the order of 5 percent. The thickest Mesozoic section of about 5000 ft, which is in BRIGHTON DOWNS and MANEROO, results in a gravity deficiency of 31.8 mgal. This value decreases to zero both to the west and east as the Mesozoic beds thin out to their outcrop boundaries (Plate 9). The computed gravity effect of the Mesozoic sediments has been added as a correction to the smoothed Bouguer anomaly (Plate 9). The resultant gravity profile has a minimum value of -37 mgal centred in the eastern part of MANEROO. This value is relative to a datum drawn between the western and eastern culminations of the profile, which are in west BRIGHTON DOWNS and on the border of DUARINGA and ROCKHAMPTON. The western maximum is in an area where the Mesozoic beds lie directly on Precambrian basement rocks and the eastern maximum is in an area where Lower and Middle Palaeozoic rocks of the Gogango Structural High and the Yarrol Basin crop out. One possible interpretation of the smoothed regional 'low' is that it is related to a smoothed boundary between the Precambrian basement metamorphic rocks and the younger rocks. The term smoothed boundary is introduced to describe a phantom horizon derived from the assumption that the Precambrian rocks are homogeneous and have a constant density throughout. This assumption is valid because local anomalies arising from intra-basement density contrasts and local basement relief have been removed in the smoothing process and are shown in Plate 9 as residual anomalies. In the west the Precambrian rocks are known to be near the surface from the results of water bores drilled through the Mesozoic cover beds. In the east the regional 'high' extends northwards and embraces the area of outcrop of the Precambrian rocks of the Marlborough Block. This evidence, together with the geological setting at the eastern end of the gravity profile, supports the assumption that Precambrian rocks may be present at shallow depths in the eastern area.

Depths to this Precambrian surface have been calculated from the smoothed Bouguer anomaly corrected for the Mesozoic effect. Geological information from exploration wells and outcrops indicate that between longitude 142°30' and about 147°30' the sediments of the north Eromanga Basin and the Drummond Basin lie on metamorphic basement. East of 147°30' metamorphic rocks of the Anakie Structural High crop out; these rocks are known to be pre-Devonian in age. In the present interpretation these rocks are given a Lower Palaeozoic age and it is postulated that they form unprospective basement below the north Eromanga Basin, the Drummond Basin, and the Bowen Basin. A density of 2.65 g/cm^3 has been adopted for these Lower Palaeozoic metamorphics (Anakie Metamorphics). This density results in a density contrast of 0.15 g/cm^3 between the Lower Palaeozoic metamorphics and the Precambrian metamorphics. The difference in density may be explained by the different grades of metamorphism in the two rock series. Low-grade metamorphic rocks such as slate and phyllite have been found in exploration wells in this part of the north Eromanga Basin. Higher-grade metamorphics are known in the Cloncurry Fold Belt and the Marlborough Block.

To compute the depths to the Precambrian surface along the profile an anomaly curve was constructed by assuming that all the material above the Precambrian has a density of 2.65 g/cm^3. This required a correction to the smoothed Bouguer anomaly curve already corrected for the Mesozoic sediments of density 2.3 g/cm^3, in which the Mesozoic sediments are replaced by material of density 2.65 g/cm^3. This profile has a gravity minimum of 40 mgal in east MANEROO and the computed depth to the Precambrian surface is 21,000 ft at this point. The Precambrian surface rises to a depth of about 11,000 ft below the Anakie Structural High and then deepens to 16,000 ft below the Bowen Basin (Plate 9). These depths compare with the postulated geological section across EMERALD (Veevers, Mollan, Olgers, & Kirkegaard, 1964) as shown in Plate 9.

It has been shown that the smoothed regional Bouguer anomalies can be related to the gravity effects of the Mesozoic sediments and the Lower Palaeozoic metamorphics that overlie a homogeneous Precambrian basement. The Precambrian basement is of course not homogeneous and this is reflected in the residual Bouguer anomalies (Plate 9). Some of these residual Bouguer anomalies are related to intra-basement density changes and some are related to pre-Mesozoic sediments, whereas others are related to structures in the Lower Palaeozoic metamorphics. It is very probable that some of the residual Bouguer anomalies may be related to local relief at the base of the sediments and to local Precambrian basement relief.

The residual anomaly profile has been subdivided into several segments in which the anomalies are attributed to different sources (Plate 9). These segments are numbered for reference.

(1) In this segment the residual Bouguer anomalies are related to density variations in the Precambrian basement and to local basement relief. Anomalies west of segment 1 have been previously discussed by the author (Gibbs, 1967). The Brighton Downs Gravity Low (A2) is probably caused by a granitic body of Precambrian age and will be more fully discussed in the section on residual Bouguer anomalies. The Vergemont Gravity Depsression (E1) and the Maneroo Gravity High (E3) can be explained by local deviations within the Lower Palaeozoic or Precambrian metamorphics.

(2) E4 is part of the Jundah Gravity Depsression, which is known, from recent gravity survey results (Lonsdale, 1965) to extend as far south as WINDORAH. This gravity 'low' may be explained by the presence of Permian sediments below the Mesozoic beds. However, the Jundah Gravity Depression has a trend and gravity deficiency somewhat similar to the Adavale Gravity Low over the Adavale Basin (Darby, 1966b). It is not unlikely that Palaeozoic sediments similar to those in the Adavale Basin are the main cause of this 'low'.

(3) The Longreach Gravity Low (C11) and the Ilfracombe Gravity Spur (C12) are related to a granite and a local rise in the level of the Lower Palaeozoic metamorphic basement (Anakie Metamoprhics) respectively. The presence of granite and metamorphics in this area is known from drilling. It is possible that the granite at Longreach extends south-west and may also correlate with E4 (see above) and this possible interpretation is shown diagrammatically in Plate 9.

(4) In this segment the Saltern Gravity Low (E5) can be correlated with the Permo-Carboniferous rocks of the Galilee infra-basin (Longreach Oil Ltd, 1964b). Sediments of this age have been found in several exploration wells in this area. These sediments are known to reach a thickness of just over 4000 ft in Maranda No. 1. Because of the paucity of information on the average density of these rocks the base of these sediments is shown only diagrammatically in Plate 9.

(5) Lower Carboniferous sediments of the Drummond Basin crop out in this segment. They include the Ducabrook Formation, the Raymond Sandstone, and the Mount Hall Conglomerate. These Lower Carboniferous rocks are about 11,000 ft thick in the area of the Jericho Gravity Low (C16). They overlie the Carbo-Devonian Teleman Formation and the Silver Hills Volcanics as shown in the geological section across EMERALD (Veevers et al, 1964). The possible westerly extent of these Lower Carboniferous rocks is shown in Plate 10 (Trumpy and Tissot, 1963). This is in agreement with the gravity evidence. The possible base of the Drummond Basin sediments is shown diagrammatically in Plate 9.

(6) The residual Bouguer anomalies of the Anakie Regional Gravity High are related to the Anakie Structural High. This area has been discussed by Darby (1966a).

(7) The residual gravity 'lows' in this area are explained by the Permian sediments of the Bowen Basin (Darby, 1966a).

(8) This zone is also discussed by Darby (1966a). The residual Bouguer anomalies correspond to basement structures.

The residual Bouguer anomalies are discussed more fully in Chapter 6.

It has been shown that the Bouguer anomalies in the area under discussion can be related to the geology of the area. Thus the Bouguer anomalies can be interpreted in geological terms without considering possible anomaly sources deep in the crust. In the next chapter the possibility that some part of the anomalies may arise from variations in crustal configuration will be considered.

Aeromagnetic anomalies

Several aeromagnetic surveys have been made in the area by the BMR and private operators. The locations of these surveys and traverse lines are shown in Plate 4. The total magnetic intensity maps of these surveys have been reduced to a scale of 40 miles to 1 inch (Plate 11) for comparison with the Bouguer anomaly map (Plate 6). An interpretation map of depth to magnetic basement (Plate 12), also at the same scale, has been compiled from the company results. No new interpretation has been made.

The aeromagnetic anomaly pattern (Plate 11) provides an interesting comparison with the Bouguer anomaly pattern. Areas in which basement is interpreted as fairly shallow from the gravity results, and where the local gravity anomalies are explained by intra-basement density contrasts, correspond to zones of small intense aeromagnetic anomalies often characterised by steep gradients. In sharp contrast to this the broad, smooth aeromagnetic anomalies with more gentle gradients correspond to areas thought to contain the thickest sediments.

It is of course very often found that as the magnetic basement deepens the anomalies become broader and smoother and the above general correlation may be expected.

It may be concluded that the aeromagnetic anomalies support the interpretation of the regional gravity features.

In particular the following correlations are found:

(a) A marked change in aeromagnetic anomaly pattern occurs parallel to the Diamantina Gravity Gradient (A4) but displaced about four miles to the west in BRIGHTON DOWNS. The change is marked by a steep magnetic gradient and it extends to the north-west along the line of the Cork Gravity Gradient (C4) in WINTON and MANUKA. To the north-west of this line the small, intense anomalies, which also appear on the single BMR aeromagnetic traverses in this area are related to differences in the magnetic susceptibility of the Precambrian basement rocks of the Cloncurry Fold Belt.

(b) The pattern of intense local aeromagnetic anomalies can be followed from MANUKA and TANGORIN through the eastern part of MUTTABURRA and the western part of GALILEE to JERICHO. In essence this trend or pattern follows the Muttaburra Gravity Ridge and supports the interpretation of fairly shallow basement in this zone.

(c) The broad anomalies that have little magnetic relief in eastern BRIGHTON DOWNS, much of WINTON, and in MANEROO may be correlated with deeper magnetic basement. This agrees with the gravity interpretation in this area of the Thomson Regional Gravity Low where the sediments reach a thickness of at least 5000 ft.

(d) The smooth aeromagnetic profile across TANGORIN and the broad anomaly pattern in much of BUCHANAN and central GALILEE correspond to negative gravity features of the Flinders Regional Gravity Low and are again in agreement with the gravity interpretation of deeper basement in this area.

Thus at least qualitatively it may be said that on a regional scale the aeromagnetic and gravity methods of surveying are mapping different properties of the same basement in this area.

5. RELATION OF THE GRAVITY ANOMALIES TO ELEVATION

Woollard (1962) has shown from gravity data from all over the world that there are three types of correlation between gravity values and near-surface geological features. These are as follows:

(1) An excellent correlation between gravity values and near-surface geological features.

(2) No correlation between gravity values and near-surface geological features.

(3) An inverse relationship between gravity values and near-surface geological features.

This lack of coherence in the relation of gravity values to geology can be partially explained by regional variations in the thickness of the Earth's crust and totally explained by regional variations in the mass distribution associated with the crust and mantle. This factor will also account for the lack of coherence in the relation between regional surface elevation values and free air anomaly values (Woollard, 1962).

Furthermore, Woollard (1962) has shown that to compare gravity relations with geology and elevation in different areas one must have some method for recognising where there are differences in crustal and mantle composition and structure. He concludes that the easiest way of doing this is through the relation of the Bouguer anomaly values to surface elevation values.

A plot of complete (terrain corrected) Bouguer anomalies as a function of elevation will incorporate the effect of all anomalous mass distributions influencing the gravity values (Woollard, 1962, pt VII, p. 3, Figure 1). Woollard has compared data from all over the world, divided up both geographically and geologically, and concludes in both cases that there appears to be no fixed pattern in the relation between Bouguer anomaly values and surface elevation values. However, three basic patterns recur, which are as follows:

(a) Essentially no change in Bouguer anomaly values with elevation. This suggests no thickening of the crust to compensate for the surface mass distribution, which implies either a strong crust or a deep-seated mass distribution within the mantle that is the effective agent for compensation.

(b) A change in Bouguer anomaly values similar to the mean variation of elevation noted for data taken on a world-wide basis (Woollard, op. cit.). This appears to be related to the thickness of the crust, and the pattern is very similar to that obtained for average isostatic correction values plotted as a function of surface elevation.

(c) A large change in Bouguer anomaly value with little change in elevation. This is related to near-surface mass distributions.

Woollard's plot of Bouguer anomaly as a function of surface elevation is an empirical representation of what the mean isostatic correction values should be for any elevation. If this curve is adopted as a reference standard, then it is possible to refer the relations observed in any part of the world to it for establishing differences in crustal and mantle mass distributions and for studying the effects associated with different geological provinces. In essence this may be regarded as a substitute for studying isostatic anomaly relations.

To apply this procedure to the present area a map of regional Bouguer anomalies (derived using an average rock density of 2.67 g/cm^3) was prepared. Terrain corrections have not been made owing to the lack of topographic information in the area. Over most of the western and central areas this effect will be very small. However, corrections of up to 3 or 4 milligals may occur at some stations read in the Great Dividing Range. These should be few in number as station sites in helicopter surveys are always selected to keep the terrain effect at a minimum.

All the Bouguer anomaly values in each 15-minute square were averaged. The mean values in four adjacent squares were then averaged to give a mean value at the centre of each block of four 15-minute squares. A fifty-percent overlap was used to compute adjacent points. A similar process was used to obtain regional surface elevation values.

These mean Bouguer anomaly values were then contoured at 5-milligal intervals on a map at a scale of 1:500,000. This map was reduced to a scale of 1 inch to 40 miles and is presented in Plate 13.

From the regional surface elevation values derived in the above manner, corresponding Bouguer anomaly values were read off Woollard's curve (Woollard, op. cit.) and these values were applied as corrections to the regional Bouguer anomalies of Plate 13. As stated previously this is an empirical isostatic correction. The resultant anomalies were contoured and are shown in Plate 14, and may be referred to as pseudo-isostatic anomalies.

In Plates 15, 16, and 17 the regional Bouguer anomaly values have been plotted as a function of elevation in three areas, viz. the Cloncurry Regional Gravity High, the north Eromanga Basin, and the Anakie Regional Gravity High. The plots of the data for the Cloncurry Regional Gravity High (Plate 15) and the north Eromanga Basin (Plate 16) show a fairly large range of Bouguer anomaly values with little change in elevation indicating that a near-surface mass distribution is the source of the anomalies. In the Anakie Regional Gravity High (Plate 17) the Bouguer anomaly values become significantly more negative with increasing elevation. This general trend of negative correlation between Bouguer anomaly and topography in the mountainous area is in accordance with the principle of isostasy, although other evidence suggests, as will be shown later, that in this eastern area compensation does not appear to be complete.

From a comparison of the relative magnitudes of the anomalies in Plates 13 and 14 in the five gravity provinces it may be concluded that the major part of the anomalies can be explained in terms of near-surface mass distributions, i.e. in terms of geological features, except for the anomalies over the Great Dividing Range, which have strongly positive pseudo-isostatic anomalies. This belt of positive pseudo-isostatic anomalies, which shows large deviations from the 'world average' values, indicates a departure from a normal crust in this area. It may be concluded that the positive anomalies occur because the mass load of the Great Dividing Range is too small to force the Earth's crust to sink into equilibrium i.e. it is an example of small mountains with no roots.

Free air anomalies

The average value of free air anomalies is fairly close to zero over the western and central parts of the area i.e. the Cloncurry Regional Gravity High and the north Eromanga Basin (Plate 18). This is to be expected as a result of isostasy in any area such as this of fairly constant elevation. However, in the north-eastern and eastern parts of the area, i.e. in the Great Dividing Range, the free air anomalies are positive, ranging from +21 to +31 milligals (Plate 18). This indicates that isostatic compensation is not quite complete in this area when considered alone.

However, conditions near to complete compensation may prevail over a wider area, as discussed by Dooley (1963) in his report on the area to the north of the present area. This hypothesis is supported by the fact that the average free air anomaly (+11 milligals) for the whole area under discussion is fairly close to zero (Plate 19).

6. DISCUSSION OF THE LOCAL BOUGUER ANOMALIES

Regions of distinctive Bouguer anomaly pattern have been classified in chapter 3 into gravity provinces, gravity units, and gravity sub-units. These gravity features will be discussed in turn.

A. Cloncurry Regional Gravity High

This gravity province has previously been described by Gibb (1967). Two gravity units of the Cloncurry Regional Gravity High occur in the area under discussion. These are part of the Mackunda Gravity Platform (gravity sub-units A1 to A4) and the Julia Creek Gravity Shelf (gravity sub-units A5 to A12).

Mackunda Gravity Platform. The four gravity sub-units (A1 to A4) occur in MACKUNDA and BRIGHTON DOWNS. The local Bouguer anomalies bear no relation to the superficial Cretaceous geology;

owever, they seem to be related to density variations in the underlying Precambrian rocks, which form an extension of the Cloncurry Fold Belt. It has been shown in chapter 4 that part of the regional anomaly can be explained by the gravity effect of the Mesozoic sediments.

The gravity survey of MACKUNDA in 1963 revealed the important fact that the Williams Gravity Low (A1) extends from the outcrop area of the Williams Granite in DUCHESS to link up with the Brighton Downs Gravity Low (A2). It now seems very probable that both gravity sub-units A1 and A2 result from the presence of massive acidic rocks at shallow depth. The Williams Gravity Low is a pronounced linear feature some twenty miles wide with a north-northwest trend in common with other major gravity trends in the zone. The Brighton Downs Gravity Low (A2) is slightly elongated in a north-east direction. At first it was thought that the Williams Granite and the granitic basement penetrated in Ooroonoo No. 1 were parts of the same body, but it is known that they vary in composition and age. The ages of samples of the Williams Granite have been given as 1399 and 1458 million years by radioactive dating methods (Richards, Cooper,& Webb, 1963), whereas the age of the basement granite found in Ooroonoo No. 1 has been given as 860 million years (Webb, Cooper, and Richards, 1963). Both granites are Precambrian. The Williams Granite is a gneissic granodiorite somewhat different in composition from the medium-grained granite encountered in Ooroonoo No. 1.

The Middleton Gravity High (A3) and the Diamantina Gravity Gradient (A4) have previously been discussed (Gibb, 1967); the Diamantina Gravity Gradient will be further discussed together with the Thomson Regional Gravity Low.

The Julia Creek Gravity Shelf. In a previous report (Gibb, 1967) the Julia Creek Gravity Shelf (Plate 6) was correlated with a hypothetical eastern stable shelf bordering the Lower Proterozoic geosyncline of Carter, Brooks, and Walker (1961). The gravity anomalies in JULIA CREEK and McKINLAY suggest a shallow extension of the Precambrian of the Cloncurry Fold Belt below the Mesozoic sediments that crop out in these areas. This interpretation is supported by the drilling logs of many water bores in the area which penetrate 'hard rock', 'slate', and 'granite' (drillers' terms) at shallow depths (Vine & Jauncey, 1962a & b). Small outcrops of Precambrian granite and metamorphics occur in the south-west of JULIA CREEK.

Vine and Jauncey (1962a) noted a broad relation between the Bouguer anomaly contours and the contours at the base of the Longsight Sandstone and concluded that in the JULIA CREEK area " ... depth to basement is largely the determining factor in the location of gravity anomalies and trends". Although it has been shown in chapter 4 that the regional anomalies can be partly explained by this effect, the available evidence from bores drilled to basement within the Julia Creek Gravity Shelf suggests that many of the local gravity anomalies are caused rather by variations in the density of the Precambrian rocks themselves.

A prominent gravity 'low' (A5) of about 12 mgal amplitude, is located in the south-west corner of JULIA CREEK. Within the bounds of this 'low', Precambrian granite is exposed and five water bores bottom in 'granite'. This strongly suggests that this 'low' is related to a granite of density less than the surrounding basement metamorphic rocks. In seven water bores penetrating basement around this feature drillers have recorded 'rock', 'bedrock', 'hardrock', and 'slate'.

By analogy with A5, another gravity 'low' (A6) is probably related to a similar cause. Four water bores have reached basement within this anomaly with recordings of granitic basement. Another gravity 'low' (A7) which is a south-westerly continuation of A6 is attributed to an extension of the granitic basement associated with A6. Three water bores have struck 'granite' within the area of A7.

Many other water bores have struck 'granite' in this zone but cannot be directly correlated with specific gravity 'lows'. This may be explained by the station density of the survey (approximately 1 station per 50 square miles), which maps only the larger anomalies associated with the larger granites intruding the basement. Such bores probably strike much smaller granitic bodies than those associated with A5, A6, and A7. Detailed gravity surveys in the area should be able to confirm or reject this explanation.

An area of positive gravity anomaly (A8) is related to the denser country rock (Precambrian metamorphics) into which the large granitic bodies, causing A5, A6, and A7, have been intruded.

In the eastern half of McKINLAY the distribution of the stratigraphic units shows a gentle regional dip to the south-east. This gentle dip correlates with a gentle gravity gradient to the south-east towards the Manuka Gravity Embayment. In this area depth to basement would appear to be a controlling factor of the Bouguer anomaly field.

A structurally controlled limestone ridge (Toolebuc Member) extends from near Lara Downs to east of Julia Creek. The structure is a very gentle fold named the St Elmo Structure and was caused by draping over a basement ridge (Vine & Jauncey, 1962a). It is probably related to the Manfred Fault of Whitehouse (1955), but recent geological mapping shows no evidence of faulting. Whitehouse shows the Manfred Fault to extend northwards on the eastern side of the Precambrian inliers of Mount Brown and Mount Fort Bowen in MILLUNGERA. Vine and Jauncey (1962a) suggest that these inliers could be part of the basement ridge of the St Elmo Structure where it reaches the surface. Another basement ridge trending roughly east-west forms the southern limit of the St Elmo Structure. This ridge also caused draping and thinning of the Longsight Sandstone.

The gravity anomaly associated with the St Elmo Structure is partly obscured in the north by a strong regional gradient (A10) trending north-north-west across the east of McKINLAY and JULIA CREEK. East of this gradient the Bouguer anomalies are strongly negative indicating the presence of excess light material in the geological section. This conclusion is in agreement with Vine and Jauncey (1962a), Whitehouse (1955), and Ogilvie (1955), who have all suggested deepening basement and thickening sedimentary section in that direction on the basis of geological evidence. East of the St Elmo Structure no water bores penetrate the base of the Longsight Sandstone and it appears certain that the Mesozoic section thickens astwards. The possibility of older sediments in the area of negative gravity anomalies, named the Nonda Gravity Depression, bordering the east and south-east of the Julia Creek Gravity Shelf cannot be excluded. This zone of low gravity anomalies will be discussed in a later section. Thus the gravity gradient (A10) is related to a marked deepening of the basement just to the east of the St Elmo Structure and indicates that the Euroka Ridge of Hill (1951) is not a continuous basement ridge separating the Carpentaria and Eromanga Basins.

The southern culmination of the St Elmo Structure is well defined by the St Elmo Gravity High (A9). The larger part of this gravity 'high' is probably caused by the basement ridge of the St Elmo Structure. A similar explanation is probable for another local 'high' (A12) separated from the St Elmo Gravity High by a narrow zone of negative anomalies (A11). This 'low' could be related to a granitic body of low density. Several water bores penetrate 'granite' in this zone.

Some faults inferred from contours drawn on the top and bottom of the Longsight Sandstone (Vine & Jauncey, 1962a & b) cannot be correlated with the Bouguer anomalies.

<u>Aeromagnetic anomalies</u>. The results of some aeromagnetic profiles and surveys that have been flown within the area of the Cloncurry Regional Gravity High are illustrated in Plate 11. The highly disturbed magnetic pattern in this area can be correlated with the Precambrian rocks of the Cloncurry Fold Belt (Jewell, 1960).

The sharp change from a highly disturbed to a fairly smooth magnetic pattern is well illustrated in Plate 11. This change in pattern parallels the Diamantina Gravity Gradient but is displaced from it about 20 miles to the north-west. The change in pattern marks the position of the rapid thickening of the Mesozoic section and hence deepening basement. Therefore qualitatively at least there is a good correlation between the aeromagnetic results and the gravity results in the area of the Cloncurry Regional Gravity High.

B. Anakie Regional Gravity High

The Anakie Regional Gravity High is a large, elongated gravity 'high' with a north-north-west trend that extends from CHARTERS TOWERS to EDDYSTONE. It is bounded to the west by the north Eromanga Basin and to the east by the Bowen Basin (Darby, 1966a). This gravity province has been divided into three gravity units, two of which occur in the area under discussion. These are the Charters Towers Gravity Complex and the Drummond Gravity Shelf.

<u>Charters Towers Gravity Complex</u>. Gravity sub-units B1 to B5 occur in this zone. The outstanding feature of this zone is the east-west alignment of the major gravity sub-units B2, B3, and B5.

The Cape River Gravity Ridge (B2) is the gravity expression of outcropping Cape River Metamorphics of Precambrian age, which are relatively dense metamorphic rocks. In north-west HUGHENDEN this gravity ridge has a north-west trend and is bounded to the south-west by the White Mountains Gravity Gradient (B1), which corresponds in part to the White Mountains Structure mapped by Vine et al (1964). The White Mountains Structure is a zone of monoclinal folding adjacent to the basement outcrops and is considered by Vine et al to be the surface expression of faulting of basement. The gravity results suggest a contact along this gravity gradient (B1) between the dense metamorphic basement and much lighter material to the south-west. The most plausible explanation is that a thick section of light sediments older than the Betts Creek Beds (Upper Permian) is present at depth and faulted against the Precambrian Cape River Metamorphics. Seismic results in the Torrens Creek survey (Exoil N.L., 1963b), in an area of similar Bouguer anomaly values, indicate up to 12,000 ft of section, which supports the present interpretation.

The Cape River Gravity Ridge (B2) extends in an east-west direction across CHARTERS TOWERS. The northern boundary of this gravity ridge closely follows the northern boundary of the Cape River Metamorphics. The southern boundary of these rocks is obscured by Cainozoic and older deposits but is clearly shown by the Bouguer anomalies.

The Lolworth Gravity Low (B3) corresponds to outcrops of the Lolworth Igneous Complex in north-east HUGHENDEN and extends almost half-way across CHARTERS TOWERS. The main rock types in the Lolworth Igneous Complex are granite, adamellite, granodiorite, and diorite. These rocks have, in general, lower densities than metamorphic rocks. This difference in density explains the gravity 'low' and the sharp gravity gradient between B3 and B2. This steep gradient supports the belief that the southern contact between the Lolworth Igneous Complex and the Cape River Metamorphics may be faulted (A. G. L. Paine, pers. comm.).

In north-east CHARTERS TOWERS the Ravenswood Gravity Low (B5) corresponds to extensive outcrops of the Ravenswood Granodiorite. In north CHARTERS TOWERS between B3 and B5 a small gravity 'high' (B4) is associated with exposures of Cape River Metamorphics. Some local 'differentiated bodies' of gabbro in the Ravenswood Granodiorite in this area may contribute to the high gravity values in this zone.

Drummond Gravity Shelf. The Drummond Gravity Shelf is an area of positive Bouguer anomalies that coincides with the exposed portion of the Drummond Basin in south CHARTERS TOWERS, BUCHANAN, and GALILEE. Gravity sub-units B6 to B10 occur in this zone.

The probable source of the local Bouguer anomalies in this zone is the density contrast between the Drummond Basin sediments and the Anakie Metamorphics, which form basement in this area. A series of gravity 'highs' (B6) in east CHARTERS TOWERS and BUCHANAN reflect shallow metamorphic basement, which is exposed in places in this area. The Beresford Gravity Ridge (B9) is attributed to a similar cause, although in this case, the density contrast between the basement ridge and the sediments to the west is much greater, as shown by the steep gravity gradient (B10) between B9 and the south-eastern extension of the Tangorin Gravity Depression (D13). The thick section of Upper Palaeozoic rocks penetrated in Lake Galilee No. 1 on the north-east flank of D13 would account for the higher density contrast.

A gravity 'low' (B7) in central BUCHANAN corresponds to a synclinal area of Drummond Basin sediments. The gravity spur (B8) in BUCHANAN is a continuation to the east of the basement spur in TANGORIN over which the Torrens Creek seismic survey was done by Exoil N.L. (1963b). According to the interpretation of the aeromagnetic anomalies in this area (Exoil, 1962a), which are discussed below in relation to the Tangorin Gravity Depression, the deepest sedimentary section occurs on the southwest flank of this gravity spur (B8), and the sedimentary trough (Plate 12) cuts across the north of the Beresford Gravity Ridge (B9).

The aeromagnetic interpretation is in conflict with the gravity interpretation in the Drummond Basin if normal correlation exists between sedimentary thickness and Bouguer anomaly. If the Drummond Basin sediments were denser than the Anakie Metamorphics then the gravity data would be more compatible with the aeromagnetic interpretation. There is no evidence, however, that this is so.

C. Muttaburra Gravity Ridge

The Muttaburra Gravity Ridge links the Cloncurry Regional Gravity High and the Anakie Regional Gravity High. It also separates the Flinders Regional Gravity Low from the Thomson Regional Gravity Low (Plates 6 and 7).

This gravity province has been subdivided into four gravity units, which will be discussed in turn. These are the Manuka Gravity Embayment, the Winton Gravity Platform, the Longreach Gravity Spur, and the Aramac Gravity Platform (Plate 6).

Manuka Gravity Embayment. The Manuka Gravity Empayment is a zone of relatively low Bouguer anomaly values in the extreme west of the Muttaburra Gravity Ridge. There are three local minima (C1 to C3) in this gravity unit, two of which (C1 and C2) are probably related to intra-basement density contrasts although the regional gravity minimum is probably related to local thickening of the Mesozoic sediments.

In the area of the local gravity 'low' (C1) a deep water bore, Clio (total depth 3375 ft), bottomed in hard pink rock according to the driller's description. This may be granite. The form of the anomalies C1 and C2 is similar to that of several gravity 'lows' (A5, A6, and A7) in the Julia Creek Gravity Shelf, which have been related to basement granites. Thus in the absence of other evidence, gravity 'lows' C1 and C2 are tentatively interpreted as the gravity expression of local basement granites.

A linear gravity 'low' (C3) extends from MACKUNDA across north-west WINTON to MANUKA. This gravity 'low' was mapped by Magellan Petroleum Corporation (1961), during the north Winton gravity survey in 1959. A strong gravity gradient (C4) bounds C3 to the south-east. Aeromagnetic surveys made over this area by Central Queensland Petroleum Pty Ltd, Catawba Corporation, and Transpacific Corporation in 1956 also reveal a steep magnetic intensity gradient in this area with a similar north-east trend but displaced a few miles to the north-west of the gravity gradient. A reinterpretation of the

..omagnetic data was carried out by Magellan Petroleum Corporation (1961), and the magnetic gradient was interpreted as a fault with downthrow to the south-east. In 1960, the BMR shot a seismic reflection traverse across gravity gradient C4 in an effort to resolve the conflict between the interpretation of the aeromagnetic results and the gravity results (the gravity results indicated a fault zone with downthrow to the north-west). The seismic results indicate a fault or monocline with downthrow to the north-west and also a smaller fault or monocline about two miles to the south-east with downthrow to the south-east (Robertson, 1964). The variations in thickness of the Mesozoic sediments caused by these features are insuffieient to cause the variations in Bouguer anomaly values, but the seismic results did indicate the possibility of a thick section of pre-Mesozoic or Lower Mesozoic sediments in the zone to the north-west of gravity gradient C4.

J. H. Quilty (pers. comm.) has suggested that it is possible that the magnetic anomaly is not related to the structure from which the gravity anomaly originates, but probably relates to a fault or contact in the basement further to the north-west.

The aeromagnetic results are shown in Plate 11. The sharp magnetic gradient in question is shown to continue uninterrupted as far south as BRIGHTON DOWNS, where it is related to the contact (as shown in Plate 9) between the Precambrian metamorphic basement and the Lower Palaeozoic metamorphic basement. It is possible that the gravity 'low' (C3) is caused by a wedge of sediments preserved in a downfaulted block overlying Precambrian basement in the north-west and faulted against Lower Palaeozoic basement in the south-east. If this is so the magnetic gradient could then be associated with the contact between the Precambrian basement and the ?Lower Palaeozoic basement to the south-west, and the gravity gradient could be related to a different fault forming the south-western edge of the postulated wedge of preserved sediments.

Winton Gravity Platform. This gravity unit has been divided into five gravity sub-units (C5 to C9). The prevailing gravity trends are north-east. It is bounded to the north-west by steep gravity gradients C4 and C5. The Cork Gravity Gradient (C4) coincides with the Cork Fault (Vine, 1962) and with a fault zone in north-west WINTON first mapped by Magellan Petroleum Corporation (1961). The gravity results suggest that these faults occur along a continuous zone of faulting 100 miles in length. The fault zone is a line of weakness in the basement along which movement has taken place as late as Tertiary times.

Contours on the base of the Wilgunya Formation, drawn from interpretations of bore logs, indicate a marked linear displacement trending north-north-east across MANUKA. This can best be interpreted as a major fault, at least at depth, which possibly grades to a monocline in the Wilgunya Formation near the surface. Displacement is down to the west (Vine et al, 1963). This fault is coincident with a steep gravity gradient (C5) which separates the Nonda Gravity Depression to the west from the Cannum Gravity High (C6) and which supports the geological interpretation of basement faulting.

The Cannum Gravity High (C6) and a north-east trending linear gravity 'high' (C9) are local culminations of the basement swell, the gravity effect of which is expressed by the Muttaburra Gravity Ridge. A water bore (Sesbania) drilled in the area of the Cannum Gravity High ceased drilling while still in sediments at a total depth of 4016 ft. This suggests that the presence of a local dense body in the basement rather than a local 'high' in the basement topography is the main source of the local gravity 'high'. In the area of the gravity sub-unit C9 two deep water bores, Winton Town and Jarvisfield, struck 'hard sandstone' and 'hard rock' at total depths of 4017 ft and 3692 ft, respectively.

Two local gravity 'lows', C7 and C8, also occur in the Winton Gravity Platform in south-east MANUKA. Corfield No. 1 struck granitic basement of pre-Permian age at a depth of 4488 ft. This well was drilled on the western flank of C7. In view of this evidence these gravity 'lows' (C7 and C8) can be explained in terms of a density contrast between local granitic intrusions and the metamorphic basement.

Longreach Gravity Spur. This gravity unit is mainly in west LONGREACH and west MUTTABURRA. Within this gravity unit, gravity sub-units C10 to C13 have mainly northerly trends.

The Darr Gravity Ridge (C10) has a distinctive northerly trend (Plate 6). It extends from north-west LONGREACH to north-west MUTTABURRA. In the south it coincides with a well defined basement 'high' 13 miles west of Longreach as shown by the results of the Longreach - Silsoe seismic traverse (Cree Oil of Canada, 1962). Seismic work done by Associated Australian Oilfields N.L. (1963a) in this area has revealed some local structures on this ridge and Beryl No. 1 was drilled on one of these, the Beryl Anticline (Associated Australian Oilfields N.L., 1964). It penetrated 3280 ft of Mesozoic sediments, 780 ft of Permian sediments, and 94 ft of recrystallised siltstone of ?Devonian age. Thus depth to basement in this well is 4060 ft, which is close to that found in a water bore further south (Darr River Downs), which struck 'quartzite' at 4000 ft. This bore is also within the bounds of the Darr Gravity Ridge. The regional dip of the sediments as revealed by the seismic survey is to the south-west, which supports the gravity interpretation of a basement ridge in this area.

Immediately to the east of the Darr River Gravity Ridge is the almost north-trending Longreach Gravity Low (C11). This 'low' is centred round Longreach and extends north to MUTTABURRA, and includes an offshoot to the east in south-west MUTTABURRA (Plate 6). Around Longreach, several bores (Longreach Oil Ltd Nos. 1 to 4) struck granitic basement at depths ranging from 3056 ft to 3404 ft. Further north, Brookwood No. 1 (Exoil N.L., 1963a) struck granite at a depth of 4796 ft on the flank of C11 having penetrated 3406 ft of Mesozoic section and 1379 ft of fresh-water Permian section. This test was drilled on a structure, the 'Brookwood Anticline', which was outlined during a seismic survey of the area (Artesian Basin Oil Company Pty Ltd, 1962). In view of the evidence from these bores it is almost certain that the gravity 'low' (C11) is the gravity expression of the Longreach granite. The age of this granite is dated as ?Silurian

420 million years) by radioactive dating methods (Webb, Cooper, & Richards, 1963). However, the suggestion by Whitehouse (1955) of a Precambrian age for this granite cannot be ruled out as the sample in question was poor.

East of C11, the Ilfracombe Gravity Spur (C12) and a southerly extension of this 'high' (C13) are related to the Longreach basement 'high', which is probably composed of Anakie Metamorphics and which forms the western margin of the Drummond Basin in this area. Seismic surveys by Longreach Oil Ltd (1962 & 1963a) in the Balmoral and Rodney Downs areas have confirmed the existence of this basement 'high'. In the Balmoral area the seismic results confirm the presence of shallow bedrock over most of the west of the area and indicate a Mesozoic section about 3000 ft thick, which dips regionally to the south and west. In the Rodney Downs survey, gently undulating Mesozoic structures that overlie shallow bedrock have been broadly defined. Of these gravity sub-units, C11 and C12 are also shown in cross-section in Plate 9.

<u>Aramac Gravity Platform</u>. The Aramac Gravity Platform forms a major part of the Muttaburra Gravity Ridge in MUTTABURRA, GALILEE, and JERICHO. It is subdivided into the three gravity sub-units C14 to C16. C14 and C15 are extensive gravity 'highs' which reflect a probable swell of the Anakie Metamorphics or their equivalent. No bores have so far been drilled in this zone of gravity 'highs'.

The Aramac Line of the Muttaburra survey (Artesian Basin Oil Company Pty Ltd, 1962) was shot along the southern flank of C14. The depth of the sedimentary rocks increases from 3500 ft in the north-west of the line to the south-west where some deeper isolated reflections were recorded at 4000 ft. The Inverness Line of the same survey was shot along the north western flank of C14 where the deepest continuous reflections were recorded at 3500 ft. Some deep random reflections were recorded along this line. These seismic results support the gravity evidence for a basement swell in this area.

In east JERICHO a large gravity 'low' (C16) is probably the gravity expression of Permian beds and Carbo-Devonian sediments of the Drummond Basin as discussed in chapter 4 and shown in Plate 9.

The results of the Alpha seismic refraction survey in JERICHO (Oil Development N.L., 1962) indicate that depth to the basement refractor increases from about 5764 ft at Maranda No. 1 to 11,496 ft to the south of Jericho. The basement refractor is thought to be either a high velocity bed in the Devonian or the unconformity between the Devonian and metamorphic basement. These results support the gravity interpretation of a basement 'high' associated with the gravity 'high' (C15). The Jericho seismic refraction and reflection survey was later done in the area south of Jericho (Alliance Oil Development Australia N.L., 1963). The results revealed two anticlinal structures south and south-west of Jericho with sedimentary sections of 7000 ft and 12,000 ft respectively, and confirmed the south-trending sedimentary trough in this area, which probably contains sediments ranging in age from Permian to Devonian below the Mesozoic and younger cover beds.

Aeromagnetic anomalies. The aeromagnetic anomalies (Plate 11) show a marked change in pattern over the area of the Muttaburra Gravity Ridge. In the area of the Thomson Regional Gravity Low and the Tangorin Gravity Depression the aeromagnetic anomaly pattern is made up of broad smooth anomalies in sharp contrast to the irregular smaller anomalies with steep gradients found in the area of the Muttaburra Gravity Ridge. This change in pattern suggests that magnetic basement is much nearer the surface over the Muttaburra Gravity Ridge and thus supports the gravity interpretation of a basement swell in this region.

D. Flinders Regional Gravity Low

The Flinders Regional Gravity Low is an extensive region of negative Bouguer anomalies lying to the north of the Muttaburra Gravity Ridge. It is bounded to the west by the Julia Creek Gravity Shelf and to the east by the Drummond Gravity Shelf. In the north-east it is bounded by the Charters Towers Gravity Complex although in places it is open to the north and it may extend to the north of the survey area.

This gravity province has been divided into three gravity units. These are the Nonda Gravity Depression, the Richmond Gravity Complex, and the Tangorin Gravity Depression (Plate 6).

Nonda Gravity Depression. In this area water bores do not penetrate the base of the Longsight Sandstone although Mesozoic sediments are present at depths ranging from 319 to 1120 ft below sea level in the south-east corner of JULIA CREEK (Vine & Jauncey, 1962a). There is evidence, therefore, that the Mesozoic sediments thicken to the east from the Julia Creek Gravity Shelf. It is possible that the gravity gradient (A10) that separates the Nonda Gravity Depression (D1 and D2) from the Julia Creek Gravity Shelf reflects this thickening of the Mesozoic section. However, the mass deficiency in the Nonda Gravity Depression may be caused by the combined effect of a thicker Mesozoic section and the presence of older light sediments or a change in basement density.

Aeromagnetic anomalies are generally smoother in eastern JULIA CREEK (Plate 11) and support the gravity evidence for a thickening section in this area.

The Precambrian of the Cloncurry and Georgetown areas are thought to be continuous under the Great Artesian Basin sediments along the Euroka Ridge, a basement ridge whose surface is nowhere as much as 1000 ft below sea level and which falls away rapidly northwards under the Carpentaria Basin and southwards under the Eromanga Basin (Mott, 1952). The gravity results suggest that fairly strong basement relief is present locally on this ridge or shelf and is expressed by the gravity sub-units D3, D4, and D6.

Richmond Gravity Complex. In this gravity unit the local anomalies are mainly small, irregularly shaped 'highs' and 'lows' bounded generally by fairly steep gradients. This disturbed gravity pattern suggests that variations in basement lithology are the main source of the Bouguer anomalies.

Interpretation of drilling logs of water bores in this area shows that the base of the Wilgunya Formation dips gently to the south. Southward thickening of the Doncaster Member and the Gilbert River Formation is also suggested from the interpretation of the bore logs (Vine et al, 1962). In the north, Precambrian crystalline basement is directly overlain by the Blantyre Sandstone.

Outcrops of Precambrian metamorphics, which include metasediments, metamorphosed granites, and metamorphosed basic igneous rocks, occur as inliers in valley bottoms in north-east RICHMOND and north HUGHENDEN. The main trends are north-east in contrast to the north-west trending belt of metamorphics that forms the Great Dividing Range in the east around Pentland (Vine et al, 1962). Many of the gravity trends are also northeasterly in this zone, supporting an interpretation in terms of basement structure.

A gravity 'high' (D6) in north-east RICHMOND occurs where Precambrian metamorphics crop out. It is bounded to the west by the Coalbrook Gravity Low (D4) and to the east by the Dumbano Gravity Low (D8). In the area of D8 the Dumbano Granite (White, 1959) crops out and in several bores around Coalbrook Homestead drillers have recorded granitic basement. In view of this evidence it seems probable that an interpretation of these anomalies in the Richmond Gravity Complex in terms of density contrasts between less dense granites and denser metamorphic rocks is valid. Thus by analogy, the Stawell Gravity High (D3), D5, and D7 can be equated to near-surface metamorphic basement, and D9 may be related to a southerly extension of the Dumbano Granite below the Tertiary basalt, which has been mapped in this area.

A Gravity spur (D10) trends south-west as an offshoot of the Cape River Gravity Ridge (B2). It is probably related to shallow metamorphic basement.

Tangorin Gravity Depression. This gravity unit extends from central RICHMOND to central GALILEE and occupies almost all of TANGORIN. It has a north-west trend and is bounded to the south by the Muttaburra Gravity Ridge and to the west by the Anakie Regional Gravity High. Mesozoic sediments crop out over the whole gravity depression and afford few indications of the possible structure at depth. The gravity unit has been divided into three gravity sub-units (D11, D12, and D13), which are local minima.

In 1959 the Artesian Basin Oil Company Pty Ltd (1962) did a reconnaissance seismic survey in the Muttaburra area. An isolated reflection line (Tangorin Line) was shot across the small south-eastern closure of D12. The results indicate a thickness of up to 5000 ft of sediments in places. In general the Mesozoic thickness in this area is about 3500 ft as shown by the gently undulating 'P' horizon, which was mapped on all seismic lines of this survey.

The Artesian Basin Oil Company Pty Ltd believe that the Muttaburra area straddles the junction of the Longreach basement ridge and a buried Permian trough to the east. They suggest that this junction may be faulted and predict that Carbo-Devonian rocks of the Drummond Basin probably underlie the Permian sequence.

Further to the south-east, on the north-east flank of D13, Lake Galilee No. 1 was subsequently drilled by Exoil N.L. (1964). Preliminary results indicate that Mesozoic and Upper Permian beds occur to a depth of 3480 ft. These beds overlie Lower Permian to Upper Carboniferous strata to a depth of 9000 ft. Below 9000 ft to the total depth of 11,175 ft, rocks of the Drummond Basin are present.

The gravity results show that D13 and D12 are part of a continuous gravity depression; thus, in view of the section penetrated in Lake Galilee No. 1 it seems likely that the predictions of the Artesian Basin Oil Company Pty Ltd in TANGORIN may be valid. The gravity results, seismic results, and drilling results all point to the existence of an extensive sedimentary trough in the area of the Tangorin Gravity Depression with the thickest pre-Mesozoic section in TANGORIN.

In north-west HUGHENDEN, Lower Permian or Carboniferous Boonderoo Beds have been mapped by Vine et al (1964). The base of these beds is not exposed but they were probably deposited on an irregular crystalline basement of Cape River Metamorphics of Pre-cambrian age. A sequence of comparable age to the Boonderoo Beds was found in Brookwood No. 1 in MUTTABURRA between the interval 4120-4740 ft (Exoil N.L., 1963a).

The Boonderoo Beds are overlain by Upper Permian Betts Creek Beds which overlap them and overlie or are faulted against the Cape River Metamorphics on the present north-east margin of the Eromanga Basin in HUGHENDEN and CHARTERS TOWERS (Vine et al, 1964). These beds have also been recognised in Brookwood No. 1 between the interval 3417-4120 ft (Exoil N.L., 1963a) and their presence has been inferred from the occurrence of coal recorded near the bottoms of several deep water bores from Hughenden to west of Aramac.

This evidence strongly supports the interpretation of the gravity results in the Tangorin Gravity Depression, which suggests that light pre-Mesozoic sediments are present in this area.

An aeromagnetic survey of the Aramac - Mount Coolon area was carried out by Exoil N.L. (1962a). Part of this survey covers BUCHANAN, GALILEE, and the eastern parts of TANGORIN and MUTTABURRA. The magnetic results and interpretation are shown in Plates 11 and 12.

The magnetic anomalies in the area under discussion can be divided qualitatively into three regions of different magnetic character:

1. A large zone of broad, smooth magnetic anomaly occupying most of BUCHANAN and central GALILEE.

2. A south-western zone of smaller irregular magnetic anomalies in west GALILEE and MUTTABURRA.

3. An eastern zone of fairly smooth magnetic anomalies in north-west BUCHANAN and east GALILEE.

The interpretation of the magnetic results by Exoil N.L. (1962a) may be summarised as follows. In the BUCHANAN and GALILEE areas, depths to magnetic basement have been computed and range from 9000 to 16,000 ft. The authors do not consider these estimates to be good or even fair. However, they are the best results of the survey. In the area of the Great Artesian Basin to the south-west, the depths to magnetic basement range from 6000 to 12,000 ft. Magnetic relief is generally related to intra-basement susceptibility changes in this area, and magnetic basement appears to correlate with geological basement, which is considered to be crystalline basement of Lower Palaeozoic or Precambrian age.

The most striking feature of the interpretation is a large north-westerly trending trough about 17,000 ft deep centred in north GALILEE and flanked to the north-east and south-west by higher-standing, probably upfaulted areas. The trough becomes shallower to the south-east towards the Anakie Structural High, and to the north-west it terminates abruptly in north BUCHANAN, where basement is at a depth of 9000 ft.

If correlation between sedimentary thickness and the Bouguer anomalies is normal in this area, as it appears to be, then the interpretation of the aeromagnetic results does not agree with the gravity interpretation. The gravity results indicate that the sedimentary trough (D13 and D12, Plate 6) has its north-west trending axis displaced some 40 miles to the south-west of that interpreted from the magnetic data. In other words, the gravity trough can be broadly correlated with the dominant smooth magnetic anomaly that occupies most of BUCHANAN and central GALILEE. The irregular magnetic pattern in south-west GALILEE and TANGORIN can be correlated with the Muttaburra Gravity Ridge, which is interpreted as a basement swell from the gravity and drilling results. The eastern zone of magnetic anomalies in north-east BUCHANAN and east GALILEE corresponds to an area of relatively positive Bouguer anomalies, which become more positive to the east and suggest a basement rise in this direction.

The Torrens Creek seismic survey was done by Exoil N.L. (1963b) in east TANGORIN. The interpretation of the seismic results indicates a parallel series of anticlinal folds trending north-west. An optimistic estimate of the sedimentary thickness in this area is 12,000 ft. Some regional north-east dip is suggested.

Gravity stations were established by the BMR at the shot-points of this survey. The results confirm the regional gravity contours, which delineate a broad gravity spur in this area. Local irregularities in the gravity contours suggest that if the regional gravity gradient, which increases to the east, were removed, the remaining residual anomalies would correlate with the north-west trending structures delineated by the seismic survey. The gravity results suggest that the sediments may be draped over a basement spur, which might explain the local north-east dip in this area, as immediately to the north-east of the gravity spur there is a large gravity embayment or extension of the Tangorin Gravity Depression.

The gravity 'low' (D11) in south RICHMOND and the small gravity closures to the south-east of it have also been included in the Tangorin Gravity Depression. D11 may be related to thickening sediments or to light basement material. However, it should be noted that these anomalies lie to the north-west of the line of north-east gravity trends which corresponds closely to the western limit of pre-Jurassic sedimentation shown in Plate 10 (Trumpy & Tissot, 1963) and mentioned in chapter 2.

E. Thomson Regional Gravity Low

The Thomson Regional Gravity Low is bounded to the north by the Muttaburra Gravity Ridge and to the south by the Eulo Gravity Platform (Plate 5). The Cloncurry Regional Gravity High forms the south-western boundary of this gravity province and the Nebine Gravity Ridge forms its south-eastern boundary. Only a small northern portion of the Thomson Regional Gravity Low is in the area under discussion. No division into gravity units has been formally adopted at this stage, but the region has been subdidived into six gravity sub-units (E1 to E6). A cross-section drawn across this zone has been discussed in chapter 4 (Plate 9).

The Vergemont Gravity Depression (E1) was formerly throught to be the gravity expression of locally preserved light sediments of Lower Mesozoic or pre-Mesozoic age (Gibb, 1967). However, the recent drilling of Fermoy No. 1 and Mayneside No. 1 (Australian Aquitaine Petroleum Pty Ltd, 1965a & b) in this elongated local gravity closure (E1) in BRIGHTON DOWNS and MANEROO has shown that about 5000 ft of Mesozoic sediments lie directly on low-grade metamorphic basement of Upper Cambrian age. These well-sites were selected on the basis of seismic, gravity, and magnetic surveys by Australian Aquitaine Petroleum Pty Ltd (1963a & b). The seismic results did not confirm the presence of any pre-Mesozoic sediments in this area. In chapter 4 it has been shown that after correction for the effect of the known Mesozoic rocks, a regional gravity 'low' remains across the basin. This 'low' has been explained by a density discontinuity between the low-grade metamorphic basement considered to be of Lower Palaeozoic age and the Precambrian basement that emerges to the west in the Cloncurry Fold Belt.

It now seems certain that the residual minima mapped in the Vergemont Gravity Depression are caused by intra-basement density variations or by local basement relief rather than by the presence of local pockets of light sediments. In the most easterly gravity minimum of the Vergemont Gravity Depression (E1), in south-east WINTON, a water bore, Paralos Park (Plate 2), struck quartz crystalline basement at a depth of 4071 ft according to the driller's description. This result further supports the present interpretation.

The Penrith Gravity High (E2) and the Maneroo Gravity High (E3) are regions of relatively high Bouguer anomaly values which separate the Vergemont Gravity Depression (E1) from the Jundah Gravity Depression (E4). Penrith No. 1 (Associated Australian Oilfields N.L., 1963b) was drilled on the Penrith Anticline (Associated Australian Oilfields N.L., 1962), a local culmination in the Penrith Gravity High (E2). In this well, Jurassic Walloon Coal Measures lie unconformably on recrystallised sediments of ?Upper Silurian to Middle Devonian age t a depth of 3787 ft. These gravity 'highs' (E2 and E3) are probably related to local relief on the surface of the Lower Palaeozoic metamorphic basement or the Precambrian basement.

The Jundah Gravity Depression (E4), part of which is in east MANEROO, extends southwards to WINDORAH as shown by recent gravity mapping by the BMR. This gravity depression as stated in chapter 4 may be caused by a Palaeozoic basin similar to the Adavale Basin to the south-west, from which it is separated by a north-east trending belt of gravity 'highs'. Alternatively it may be the gravity expression of granitic basement i.e. a south-westerly extension of the Longreach granite. It is interesting to note that granite was struck in W.O.L. Warbreccan No. 1 in JUNDAH at a depth of 5399 ft. However, steeply dipping shales were encountered in Westland Oil Ltd No. 1 (345 ft thick) and No. 3 (at a depth of 5263 ft to total depth of 6054 ft). These shales have been tentatively dated as Drummond sediments of Carboniferous age (Queensland Dept of Mines, 1960) and their presence supports the possibility of a pre-Mesozoic basin in the area of the Jundah Gravity Depression (E4).

The Ruthven seismic survey covers part of the Thomson Regional Gravity Low along the southern margin of MANEROO (Marathon Petroleum Australia Ltd, 1963). Four fault zones were mapped in southern MANEROO with throws down to the west ranging from 1000 to 1500 ft. One of these faults correlates with the eastern flank of the Jundah Gravity Depression (E4) and it will be interesting to note whether this correlation continues southwards when current gravity surveys are completed.

The Saltern Gravity Low (E5) corresponds to part of the Galilee infra-basin, first named the Galilee Basin of Mesozoic and Permian sediments by Whitehouse (1945 & 1955). Longreach Oil Ltd have done much geophysical work in this area and have drilled several exploration wells. Three seismic surveys have been done recently in the Balmoral, Rodney Downs, and Brixton areas (Longreach Oil Ltd, 1962, 1963a & b). These surveys revealed an area of thin section in the Balmoral area and a steeply dipping monoclinal zone known to extend from 'Hulton' to 'The Rand' in LONGREACH. North-east of this feature the sediments thicken over the indicated basin. The 'Hulton-Rand' monoclinal zone has virtually no gravity expression on the reconnaissance gravity map (Plate 6). This is an unexpected result in a zone where about 3500 ft of Permian sediments are apparently truncated. However, it is possible though unlikely that the rock densities of the Drummond beds and the Permian sequence are almost the same in this area resulting in a virtually homogeneous rock density across the structure.

The drilling results are discussed in chapter 2 of this report. The gravity results may prove useful in selecting areas for more seismic work and drilling in this interesting area. A diagrammatic cross-section of the infra-basin is shown in Plate 9.

A detailed gravity survey was done in the Barcaldine area in 1963-64 (Farmout Drillers N.L., 1964). The Barcaldine Gravity High (E6) is related to the Barcaldine basement 'high' on which two structural 'highs' were delineated at Lagoon Creek and Alice River by a seismic survey (Farmout Drillers N.L., 1963b).

An east-west zone of faulting with a very steep dip was mapped near the Alice River No. 1 well location. In this well 2631 ft of Permian sediments were encountered below 2721 ft of Mesozoic sediments.

7. CONCLUSIONS

The following conclusions have been reached from the present study of the gravity results in the north Eromanga and Drummond Basins.

Regional anomalies

(1) The regional anomalies can be explained in terms of a near-surface mass distribution i.e. they originate from near-surface geological structures rather than crustal structures.

(2) The regional gravity 'low' across the north Eromanga Basin has been related partly to the gravity effect of the known thickness of light Mesozoic sediments in the basin and partly to a density discontinuity between the low-grade metamorphic basement of Lower Palaeozoic age and the Precambrian metamorphic basement.

(3) The regional gravity 'highs' to the west and east of the basin over the Cloncurry Fold Belt and the Anakie Structural High are related to rises in the Precambrian surface.

(4) The aeromagnetic anomalies agree qualitatively with the gravity interpretation.

(5) The Muttaburra Gravity Ridge is related to a basement swell which separates areas of thicker sediments to the north and south.

(6) Isostatic compensation does not appear to be complete in the area of the Great Dividing Range. However, conditions near to complete compensation may prevail over a wider area.

Local Bouguer anomalies

Local Bouguer anomalies have been related to local geological structure.

Several areas of thick sedimentary section have been mapped. Some of these have been proved by drilling and others are postulated on strong evidence from the seismic, aeromagnetic, and gravity results. Such areas include the following:

(a) The Nonda Gravity Depression probably contains a thick Mesozoic section with a possibility of older sediments.

(b) The Tangorin Gravity Depression probably contains a thick Mesozoic section underlain by Permian beds and a north-westerly extension of the Drummond Series.

(c) In the Drummond Gravity Shelf relative gravity 'lows' indicate zones of thicker sedimentary section.

(d) In the Muttaburra Gravity Ridge, the Jericho Gravity Low is associated with Permian beds and thick Drummond Series sediments, and in the Manuka Gravity Embayment the gravity low C3 has been interpreted as a local trough of Mesozoic and probable older beds.

(e) In the Thomson Gravity Low the Mesozoic beds reach their greatest known thickness in the area in the Vergemont Gravity Depression and the Jundah Gravity Depression. Drilling has shown that in the former area the Mesozoic beds lie directly on Upper Cambrian metamorphic basement but in the latter area it is postulated that the sedimentary section may be similar to that of the Adavale Basin.

The gravity results agree qualitatively in the Saltern Gravity Low with the seismic and drilling results which have shown the presence of the Galilee infra-basin.

Several local Bouguer anomalies have been related to intra-basement structures and igneous intrusions in the area.

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APPENDIX A

List of Gravity Surveys in the Area

Gravity surveys done in the area and parts of other gravity surveys which lie within the area are listed below.

Date	Authority	Type of surveys	Reference
1940-42	Shell	Regional (road traverses)	Shell (Qld) Development Pty Ltd 1952
1951-52	University of Sydney	Regional (road traverses)	Marshall & Narain, 1954
1955	Westland Oil Ltd	Semi-detailed	Westland Oil Ltd, 1955
1955	Longreach Oil Ltd	Semi-detailed	
1958	BMR	Regional (road traverses)	
1959	BMR	Regional (road traverses)	
1959	Minad	Regional (road traverses)	
1959	Magellan	Semi-detailed	Magellan Petroleum Corporation ~~1967~~ 1961
1959	BMR	Helicopter reconnaissance	Gibb, 1967
1961	BMR	Helicopter reconnaissance	Lonsdale, 1962 Gibb, 1967
1963	BMR	Helicopter reconnaissance	Appendix D
1963	BMR	Helicopter reconnaissance	Appendix D
1963	BMR	Regional (road traverses)	--
1963	BMR	Seismic line readings	Darby, 1965
1963	Australian Aquitaine	Seismic line readings	Australian Aquitaine Petroleum Pty Ltd, 1963a
1963	Amoseas	Semi-detailed	American Overseas Petroleum Ltd, 1963
1963	Farmout	Semi-detailed	Farmout Drillers N.L., 1964

APPENDIX B

Borehole Information

The following water bores and exploration wells have been referred to in this report. They are listed according to the 1:250,000 maps on which they are shown in Plate 2.

JULIA CREEK

Refer to Appendix C in Vine and Jauncey (1962a).

RICHMOND

Refer to Appendix B in Vine, Bastian, and Casey (1963).

Bore	Position		Elevation (ft)	Total depth (ft)
Killarney	20°59'	143°32'	876	2066
Olive Downs	20°53'	142°46'	?	1890
Coalbrook	Unknown		?	344
Coalbrook	Unknown		?	280

HUGHENDEN

Refer to Appendix E in Vine, Casey, and Johnson (1964).

CHARTERS TOWERS

Refer to Appendix E in Vine, Casey, and Johnson (1964).

McKINLAY

Refer to Appendix A in Vine and Jauncey (1962b).

MANUKA

Refer to Appendix B in Vine, Bastian, and Casey (1963).

Bore	Position		Elevation (ft)	Total depth (ft)
Cairnhope No.2	21°47'	143°57'	1000	2732
Myuna	21°2'	143°15'	830	2880
Sesbania	21°28'	143°17'	797	4016
Cooinda	21°53'	142°52'	655	3289
Clio	21°35'	142°39'	730	3375
Corfield No. 1	21°42.7'	143°22.5'	842	4507

TANGORIN

Refer to Appendix E in Vine, Casey, and Johnson (1964).

Bore	Position		Elevation (ft)	Total depth (ft)
Bundella	21°53'	144°7'	825	2819
Glenariffe	21°40'	144°45'	1005	4220

BUCHANAN

No information used.

MACKUNDA

Refer to Appendix C in Vine (1962)

Bore	Position		Elevation (ft)	Total depth (ft.)
Glenmore	22° 7'	141° 23'	857	3085
Llanrheidal	22° 14.3'	141° 34.7'	?	3008

WINTON

Refer to Appendix E in Vine, Casey, and Johnson (1964)

Bore	Position		Elevation (ft)	Total depth (ft)
Evesham No. 1	22° 59.6'	143° 34'	750	4150
Beryl No. 1	22° 22.1'	143° 58.4'	882	4154
Darr River Downs No. 4	22° 52'	143° 52'	835	4006
Jarvisfield	22° 31'	142° 35'	745	3692
Paralos Park	22° 39'	143° 39'	857	4071
Winton Town	22° 24'	143° 2'	610	4017

MUTTABURRA

Refer to Appendix E in Vine, Casey, and Johnson (1964)

Bore	Position		Elevation (ft)	Total depth (ft)
Brookwood No.1	22° 28.9'	144° 20'	735	4806
Stainburn No.3	22° 47'	145° 01'	770	1804
Astra Downs	22° 0.7'	144° 0.8'	768	2896

GALILEE

Bore	Position		Elevation	Total depth (ft)
Lake Galilee No.1	22° 11.6'	145° 58.6'	?	11,175

BRIGHTON DOWNS

Refer to Appendix 1 in Jauncey (1962)

Bore	Position		Elevation (ft)	Total depth (ft)
Dorobnbo No. 1	23° 10.8'	141° 3.32'	400	3852

MANEROO

Bore	Position		Elevation (ft)	Total depth (ft)
Penrith No. 1	23° 10.3'	143° 38.5'	700	4078
Fermoy No. 1	23° 8.5'	143° 3.4'	795	5262
Mayneside No.1	23° 35.4'	142° 31.2'	661	5382
Westland No. 1	23° 58.5'	143° 47'	678	2890

LONGREACH

Bore	Position				Elevation(ft)	Total Depth(ft)
L.O.L. No. 1	23°	25.7'	144°	23.5'	706	3068
L.O.L. No. 2	23°	26.8'	144°	15.8'	628	3224
L.O.L. No. 3	23°	26.8'	144°	15'	629	3490
L.O.L. No. 4	23°	27'	144°	15.8'	630	3277
L.O.L. No. 5	23°	18'	144°	39'	714	1367
L.O.L. No. 6	23°	18'	144°	38'	748	1268
Wellshot No. 6	23°	57.3'	144°	16.3'	888	4008
Portland No. 2	23°	56'	144°	45'	800	3607
Westland (Thomson Watershed)	23°	58'	144°	6'	747	3319
Saltern Creek No.1	23°	20.9'	144°	56.4'	753	4966
Hulton No. 1	23°	23.4'	144°	55.3'	759	2169
Marchmont No. 1	23°	10.3'	144°	44.3'	740	6530
Maranda No. 1	23°	12.2'	145°	26.7'	850	6491
Alice River No. 1	23°	37.1'	145°	19.3'	868	5352

JERICHO

No information used.

APPENDIX C

Density Information

The lack of rock density measurements of a truly representative range of rock samples from the area discussed in this report is a serious omission from the present analysis of the gravity data. However, some data are available.

The rock densities of several cores from exploration wells in the area under discussion and in adjacent areas of the Great Artesian Basin have been measured in many cases by the BMR Petroleum Technology Laboratory for the oil companies concerned.

The results of some such measurements are shown in Plate 20. The saturated density has been computed from the dry bulk density and the effective porosity of the sample. The saturated density is probably more representative of the true density of a sample in situ than,for example, the dry bulk density.

Within the area of the survey, density measurements have been made using cores from Alice River No. 1, Fermoy No. 1, and Lake Galilee No. 1. In Alice River No. 1 the average density of the Triassic is 2.38 g/cm3 (4 samples) and that of the Permian is 2.49 g/cm^3 (4).

In Fermoy No. 1 there is definite evidence of a density change at the Mesozoic - metamorphic contact. 171 measurements of samples taken from the Transition Beds and the Cretaceous-Jurassic continental facies between the depths of 3375 and 5040 ft have an average density of 2.42 g/cm^3. The average density of the metamorphic basement is 2.63 g/cm^3(2 samples).

In Lake Galilee No. 1 the average density of the Lower Mesozoic - Upper Permian section is 2.49 g/cm^3 (13 samples) and that of the Lower Permian - Upper Carboniferous section is 2.55 g/cm^3 (13 samples). No information is at present available for the Drummond Basin sediments encountered in this well.

South of the survey area in Boree No.1 the average density of the Mesozoic-Permian section is 2.38 g/cm^3 (8 samples) and of the Middle Devonian is 2.61 g/cm^3 (9 samples) and the Lower Devonian 2.55 g/cm^3 (3 samples).

Density data from Wyaaba No.1 to the north of the area are: Tambo Formation 1.93 g/cm^3, Roma Formation 2.12 g/cm^3, and Blythesdale Group 2.27 g/cm^3.

Surface sampling indicates that the Lower Cretaceous marine facies and the Upper Cretaceous beds are less dense than the Lower Cretaceous-Jurassic continental facies and the Triassic sediments. Thus the value of 2.3 g/cm^3 adopted as the average density of the Mesozoic is probably very close to the true average density.

The average densities of the Lower Palaeozoic metamorphics and of the Precambrian basement remain the same as those previously adopted by Gibb (1967), viz. 2.65 g/cm^3 and 2.8 g/cm^3.

APPENDIX D

Details of the 1963 helicopter gravity surveys

PART 1

Statistics

Departed Melbourne	31st March
Commenced training of observers from the Division of National Mapping	6th April
Commenced survey	12th April
Completed survey	7th June
Returned Melbourne	9th June
Days traversing	$42\frac{1}{2}$
Days training	5
Days in transit only	$3\frac{1}{2}$
Days lost	18
Days total	69
Days lost: helicopter unserviceable	7
area flooded	5
pilot rest days and party rest days	6
total	18
Hours flying: normal traverses	192 hrs 54 min
follow up and ties	14 hrs 49 min
training flights	14 hrs 29 min
transit only	10 hrs 53 min
total	233hrs 05 min
Total number of gravity observations	818

1:250,000 map areas completed:

LONGREACH
MUTTABURRA
MANEROO
MACKUNDA
WINTON
MANUKA ($\frac{1}{8}$, SW corner)

Survey technique

Flight planning. The flight planning of the area was completed in Melbourne and the proposed traverses and station positions were marked on aerial photographs which were used for navigation and final plotting purposes. Station positions were selected on an approximate 7 x 7 mile grid to satisfy the requirements of both the Division of National Mapping and the Bureau of Mineral Resources.

A slight modification of the cell method of flying (Hastie & Walker, 1962) was used. Base camps were positioned at the centre of four adjacent cells which were flown from the same camp. One cell was flown per day (i.e. four loops) and operations commenced and finished at the cell centre. Thus each loop was independently closed and tied to at least two adjacent loops.

Mapping. Station positions were plotted in the field on a photo-mosaic (4 miles to 1 inch approx.) from the aerial photographs. These positions were transferred to a black positive map of the 4-mile area supplied by the Division of National Mapping and the latitudes were scaled from this map. The results were then plotted and contoured on the black positive maps.

Elevations. Ties were made to levelled stations on traverses previously established by the Department of the Interior. These stations provided adequate control elevations for the barometric levelling, which gave good results.

Observed gravity values. The survey was tied to the BMR Longreach Pendulum Station No. 54. Gravity ties were made to several BMR ground traverses read along traverses levelled by the Department of the Interior. Gravity ties were also made to previous BMR helicopter gravity stations and to several gravity stations established by the Magellan Petroleum Corporation in the area. These results were satisfactory.

Party Organisation

Division of National Mapping Staff

Party leader, surveyor	E.F.N. Seton
Surveyor	F.J. Leahy
Observer	J. de Stefani
Observer	N. Fenton
Field Assistants	A. Lukas, D. Locke

Mr. Seton was recalled to Melbourne on 18/5/63 and Mr. Leahy took over as party leader. T. Douglas, field assistant, joined the party on 16/5/63.

BMR Representative

Geophysicist	R.A. Gibb

Helicopter Utilities Pty Ltd Staff

Helicopter crew of one pilot and one engineer were drawn from the following personnel :

Pilots	G. Treatt
	J. Gillie
	L. Yeats
Engineers	G. Dalitz
	P. Latz

Equipment and vehicles

Master Worden MW 548 (1/4/63 to 17/5/63)

Worden W 273 (18/5/63 to 7/6/63)

Mechanisms Barometers 509/63

" " 510/62

Two thermister temperature indicators

Two Lambrecht Hair Hygrometers

2 Traegar TM2 transceivers

1 Traegar 59M10 transceiver

1 Traegar 51MA transceiver

1 Bedford 3-ton 4 x 4

3 International 1-ton 4 x 4

Bell 47G2 VH-UTC (Helicopter Utilities Pty Ltd)

Light camping equipment was provided by the Division of National Mapping. Average duration of a camp was 8 days.

PART 2

Statistics

Commenced survey (at Julia Creek)	12th August
Completed survey (at Alpha)	17th October
New readings	1509
Grid stations	1205
Control stations used	200
Total control stations in area	458
Total number of new stations	1663
Loops covered	199
Follow-up loops	10
Area covered	52,500 square miles
Helicopter hours	372
Total helicopter days	123

Days lost:	Helicopter unserviceable	45
	not required	4
	bad weather	1
	earthquake disturbance	1
Days available		72
Loops per day		2.9
Percentage helicopter unserviceability		36.6%
New readings per hour		3.2
Average station density		1 station/32 square miles
Standard deviation of tie stations		0.5 mgal

1:250,000 map areas completed:

- JULIA CREEK (part)
- McKINLAY (part)
- MANUKA (part)
- RICHMOND
- HUGHENDEN
- TANGORIN
- CHARTERS TOWERS
- BUCHANAN
- GALILEE
- JERICHO

Survey technique

The field operations were carried out by a private geophysical contractor, Velocity Surveys Ltd of Canada. The method of operation used by the contractor was identical with procedures adopted by the BMR on previous helicopter gravity surveys. All traversing was done by the cell method described by Hastie and Walker (1962). The general operational procedures used on helicopter parties are described by Vale (1962).

Party organisation

Velocity Surveys Ltd Staff

Party Leader	D. Robertson
Chief Meter Reader	K. Schulte
Meter Reader	J. Koekebakker
Draftsman	A. Potter, J. Anketell
Computors	J. Almekinders, P. Smith.

Helicopter staff of 2 pilots and 2 engineers

For the first six weeks of the survey 1 helicopter engineer was used. Casual staff comprised 1 cook and 1 field hand.

BMR Representative

Geophysicist A.J. Flavelle

Equipment and vehicles

2 x Canadian (Sharpe) gravity meters

4 x Wallace and Tiernan microbarometers

1 x Paulin microbarograph

1 x Taylor hydrograph - thermograph

10 x Taylor sling psychrometers

2 x Bell 47D - 1, UTK and UTL (Helicopter Utilities Pty Ltd)

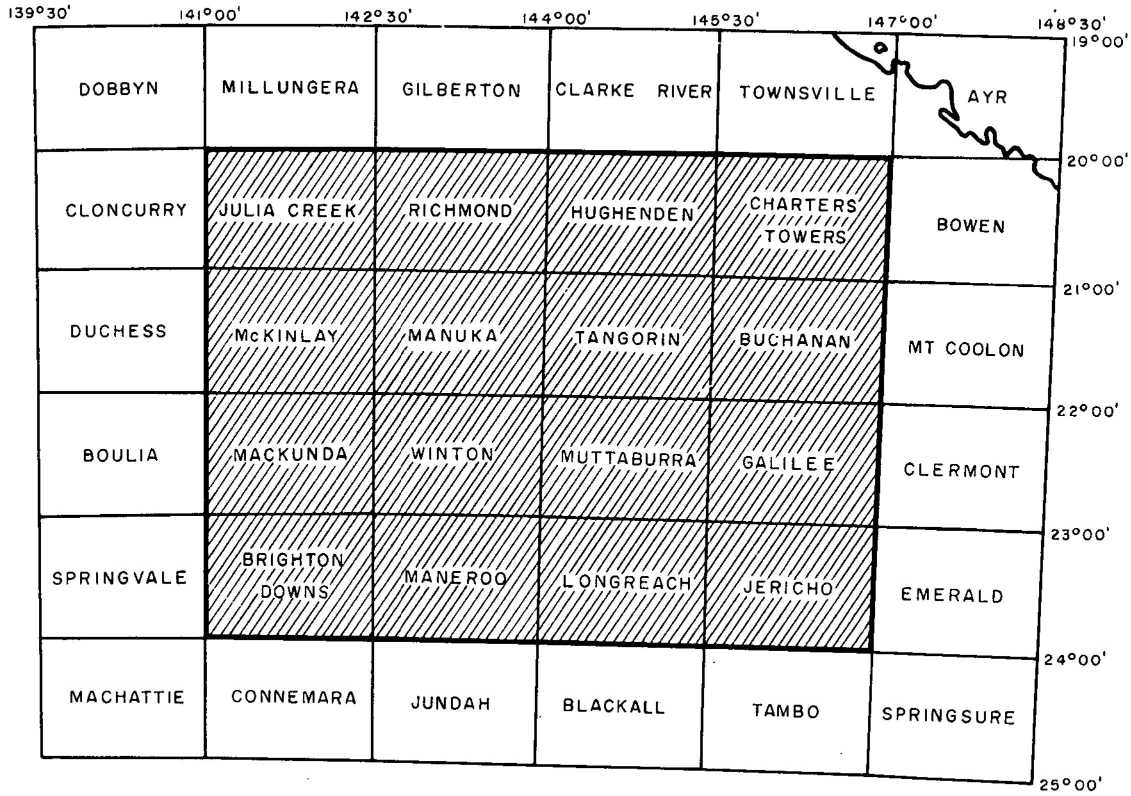
1 x Ford 3-ton 4 x 4

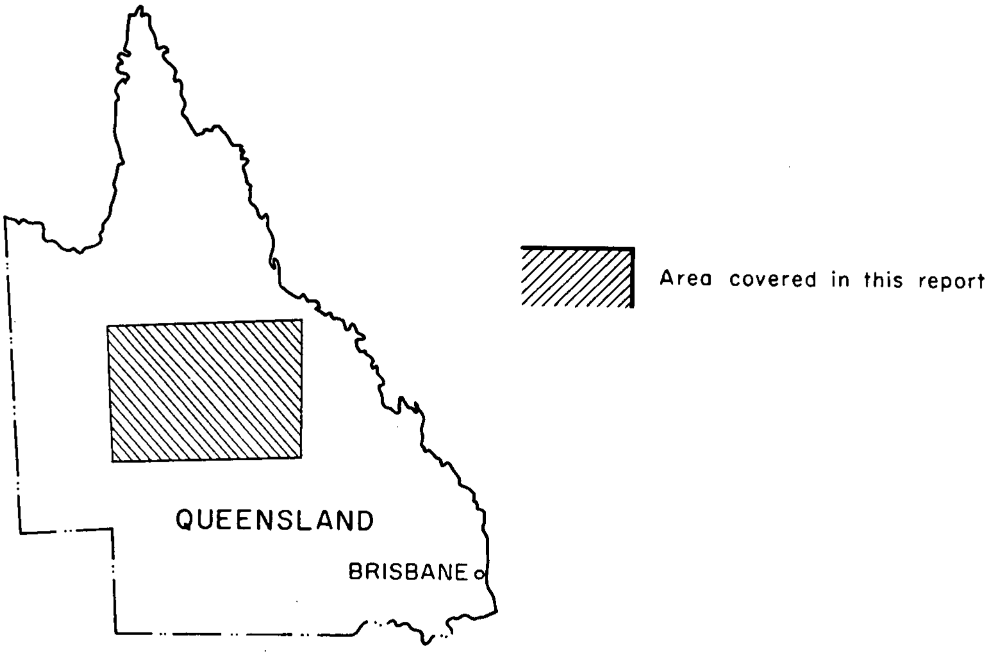
1 x International utility 2 x 2

2 x Landrovers 4 x 4

Tents were used for sleeping and general office work. Two 15-ft caravans were supplied, one for cooking and messing, and one for use as a drawing office.

PLATE 1





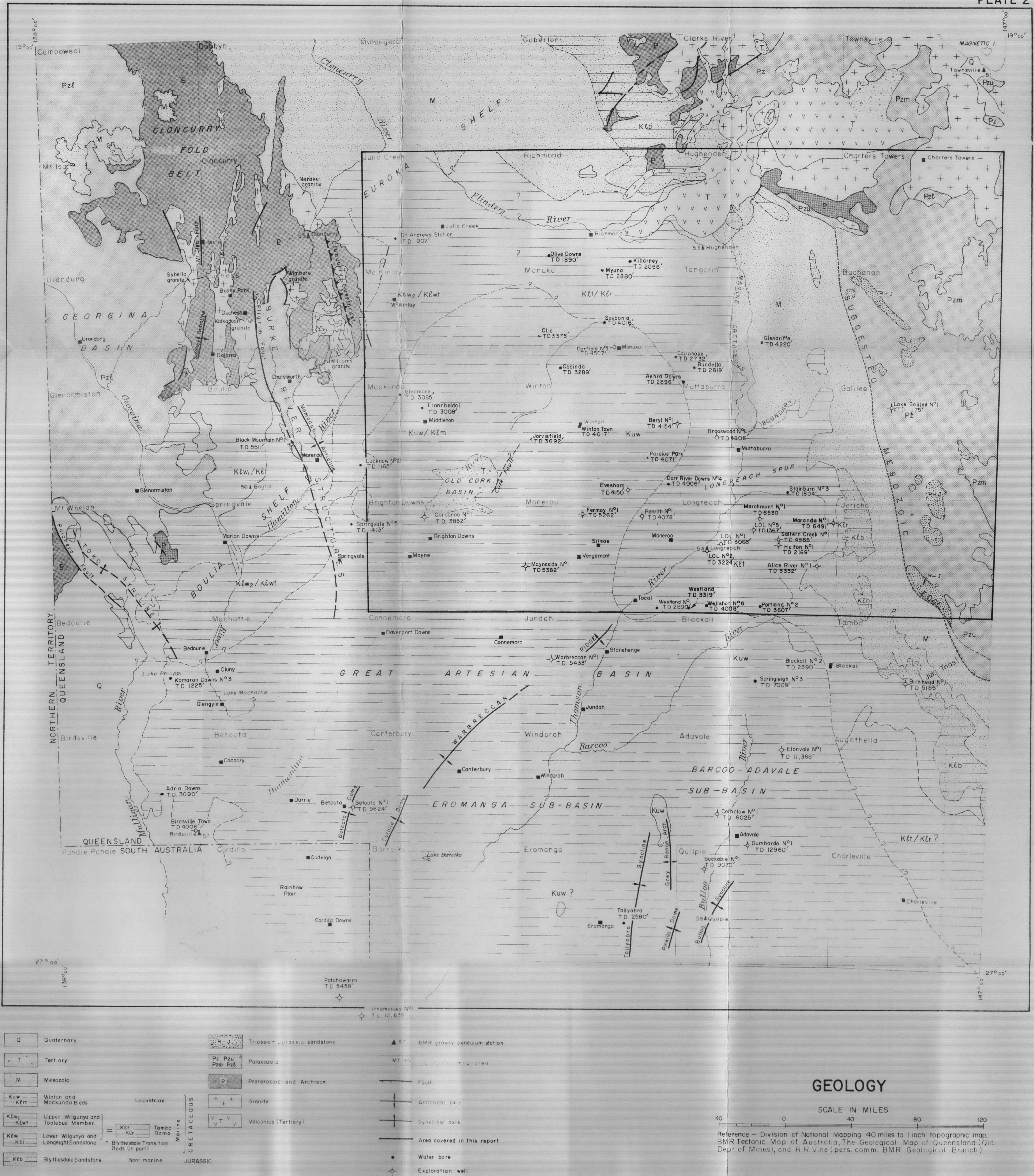
RECONNAISSANCE GRAVITY SURVEYS 1959-63
NORTH EROMANGA AND DRUMMOND BASINS

LOCALITY MAP

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS. F54/B2-35

To accompany record No 1966/210

PLATE 2



GEOLOGY

SCALE IN MILES

40 0 40 80 120

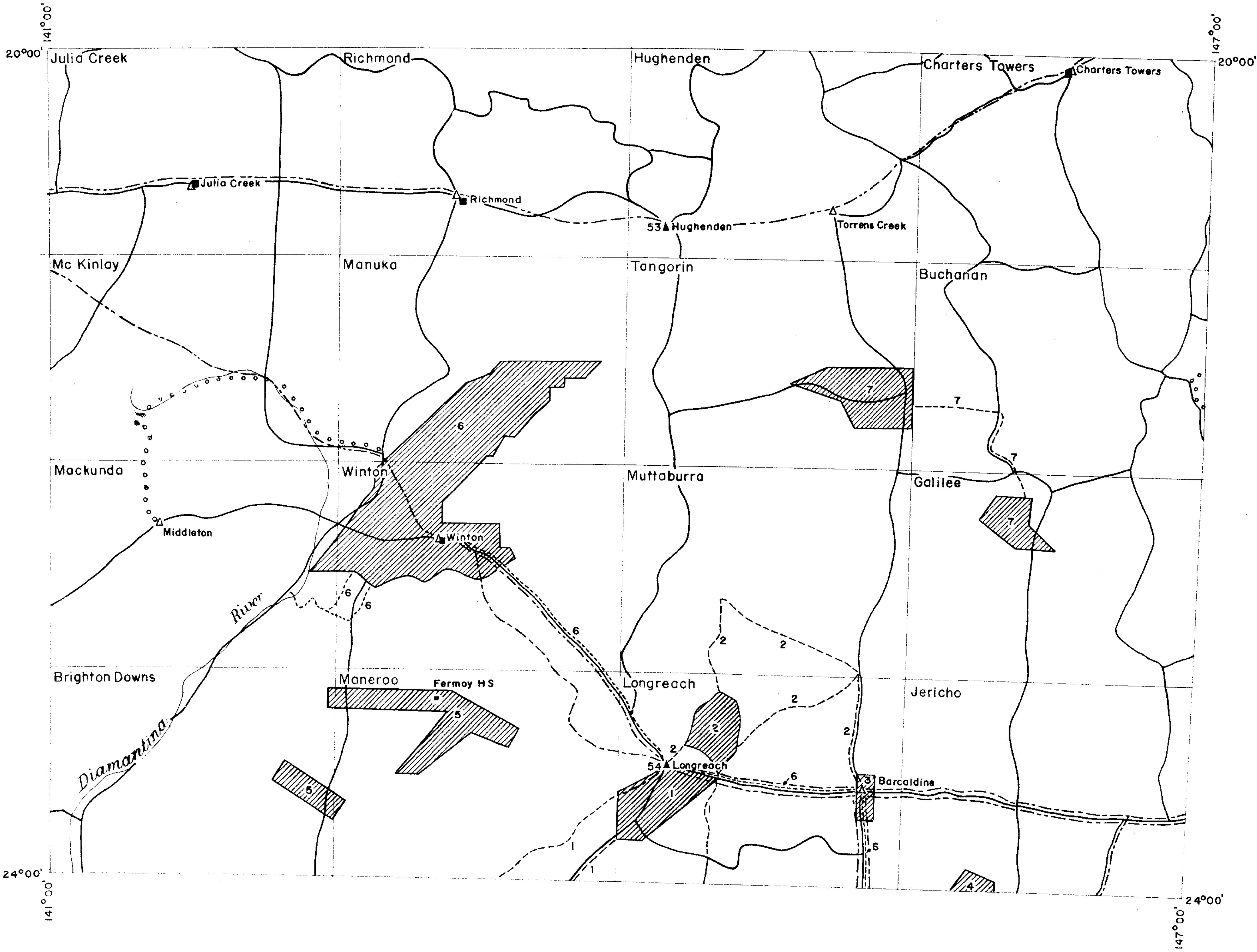
Reference – Division of National Mapping 40 miles to 1 inch topographic map, BMR Tectonic Map of Australia, The Geological Map of Queensland (Qld. Dept of Mines), and R.R Vine (pers. comm BMR Geological Branch)

Compiled August 1962

To accompany record No1966/210

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS F54/B2-44

PLATE 3



KEY TO GRAVITY SURVEYS

SCALE IN MILES

40 0 40 80

DETAILED AND SEMI-DETAILED GRAVITY SURVEYS

1 Westland Oil Ltd
" 2 Longreach Oil Ltd
" 3 Farmout Drillers N.L. (1964)
" 4 American Overseas Petroleum Pty Ltd (1963)
" 5 Australian Aquitaine Petroleum Pty Ltd (1963 a)
" 6 Magellan Petroleum Corporation (1961)
" 7 BMR readings at Exoil N.L. shotpoints (Darby, 1965)

GRAVITY TRAVERSES

7 BMR (Darby, 1965)
6 Magellan Petroleum Corporation (1961)
1 Westland Oil Ltd
2 Longreach Oil Ltd

REGIONAL GRAVITY SURVEYS

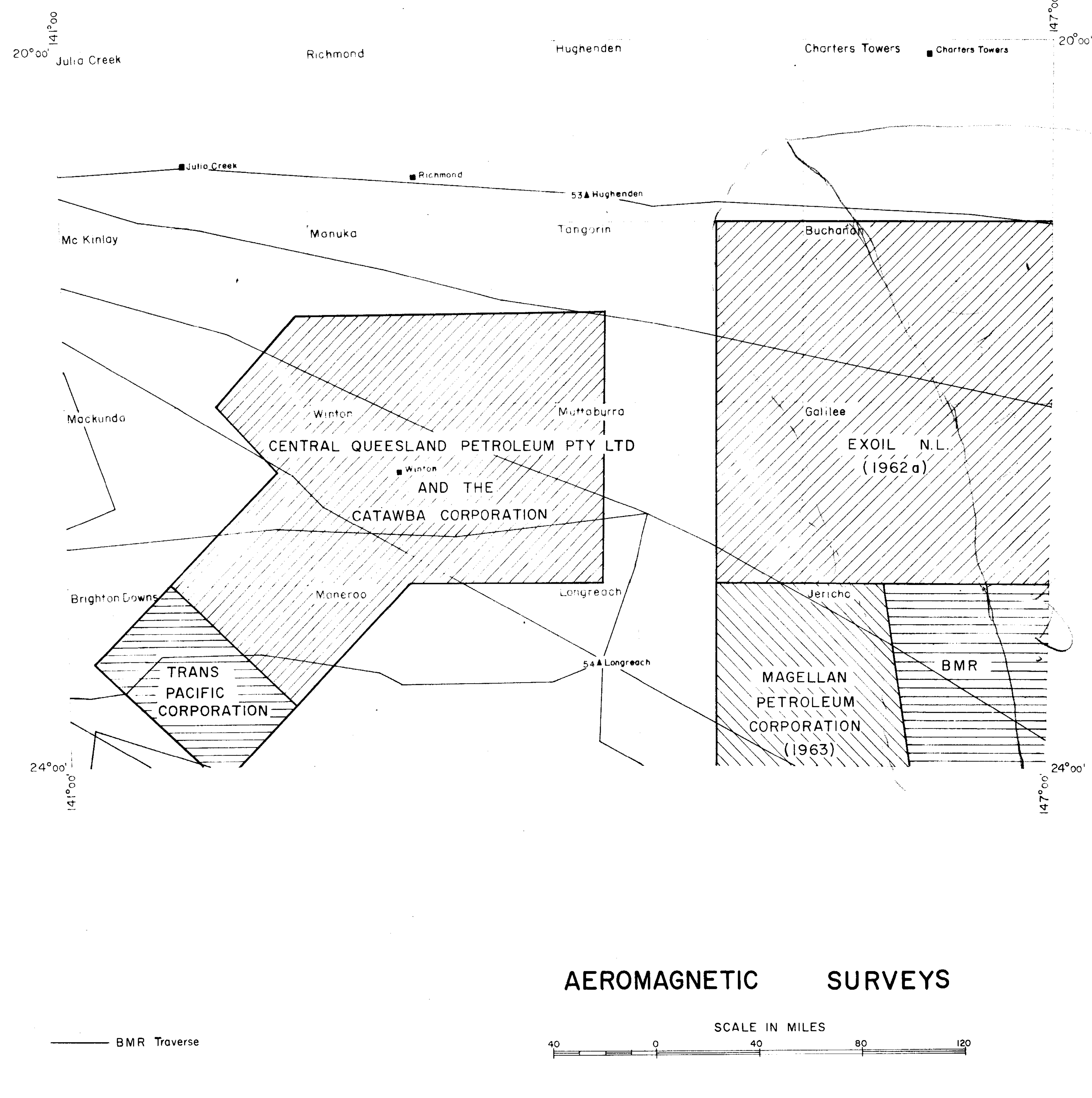
BMR
BMR Pendulum station
BMR Secondary station
Shell (Qld) Development Pty Ltd (1952)
Marshall and Narain (1954)
Mines Administration Pty Ltd

To accompany record No 1966/210

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics

F54/B2-39

PLATE 4



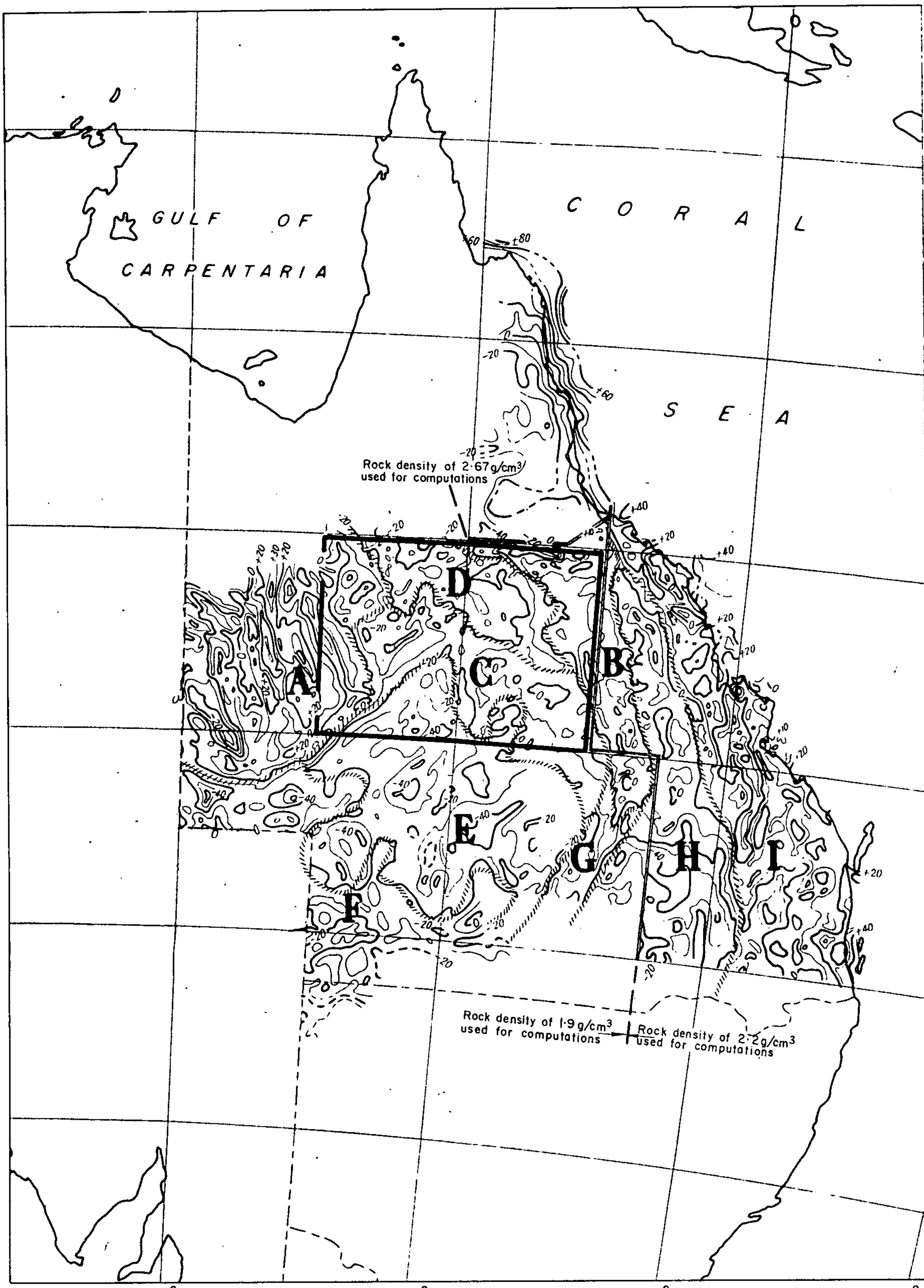
AEROMAGNETIC SURVEYS

REC. GRAV. 1959-63 N. EROMANGA & DRUMMOND BASINS

To accompany record No 1966/210

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

F54/BI-27



A Cloncurry Regional Gravity High
B Anakie Regional Gravity High
C Muttaburra Gravity Ridge
D Flinders Regional Gravity Low
E Thomson Regional Gravity Low
F Eulo Gravity Platform
G Nebine Gravity Ridge
H Bowen-Surat Regional Gravity Low
I Coastal Gravity Complex
Gravity Province Boundary

Area covered in this report

QUEENSLAND

BOUGUER ANOMALIES AND GRAVITY PROVINCES

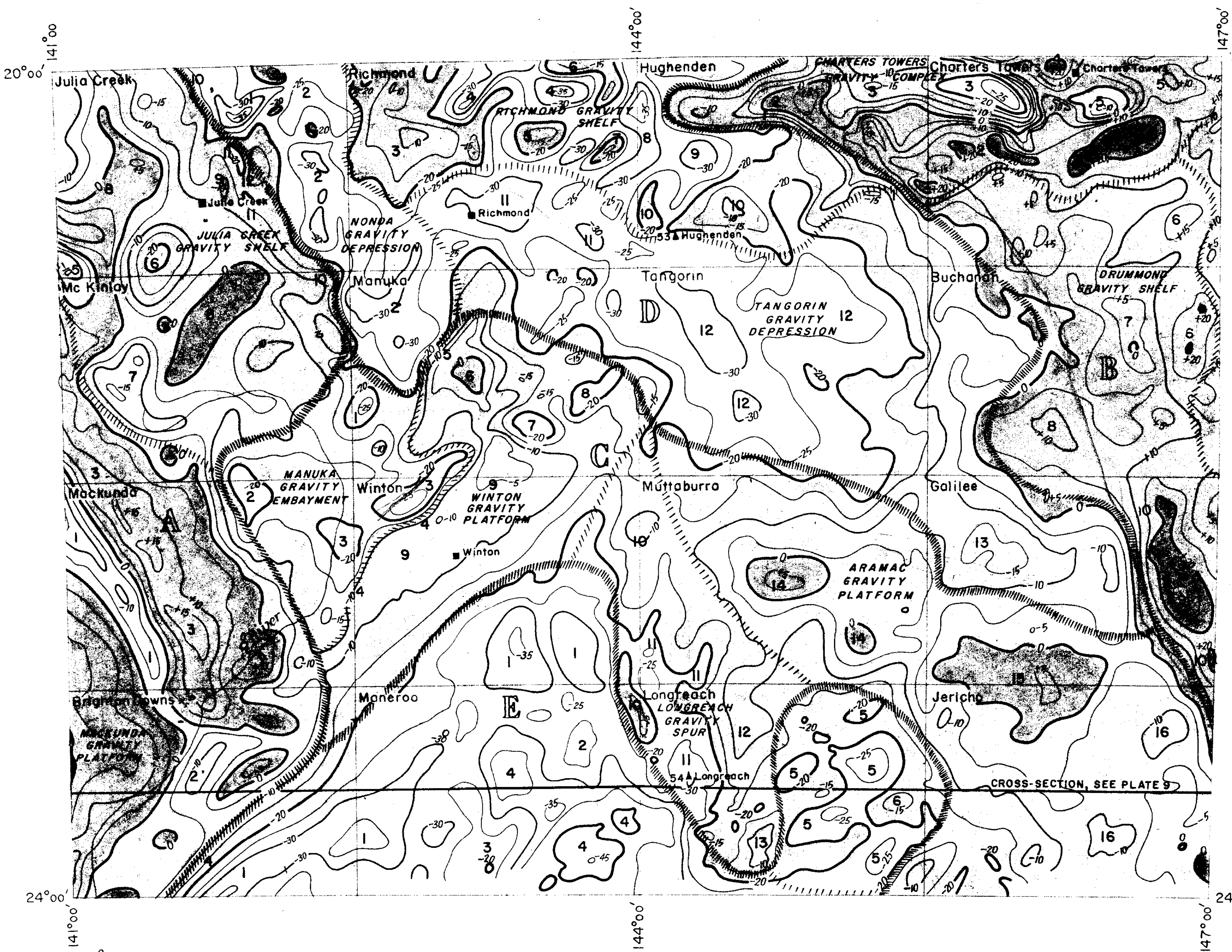
100 0 100 200 300 400 500 MILES

CONTOUR INTERVAL 10 MILLIGALS

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS Q/B2-1-1

(BASED ON A/BO-1) To accompany record No 1966/210

PLATE 6



Isogals, values in milligals

▲53 BMR gravity pendulum station

Maneroo 1:250,000 map area

Gravity 'high'

Gravity 'low'

A Gravity province

Gravity province boundary

Gravity unit boundary

15 Gravity sub-unit

BOUGUER ANOMALIES AND GRAVITY PROVINCES

WITH SHADING EMPHASIS

SCALE IN MILES

40 0 40 80 120

Reference – Division of National Mapping 40 miles to 1 inch topographic map

Contour interval 5 milligals

Bouguer anomalies are based on the observed gravity values at BMR pendulum stations :

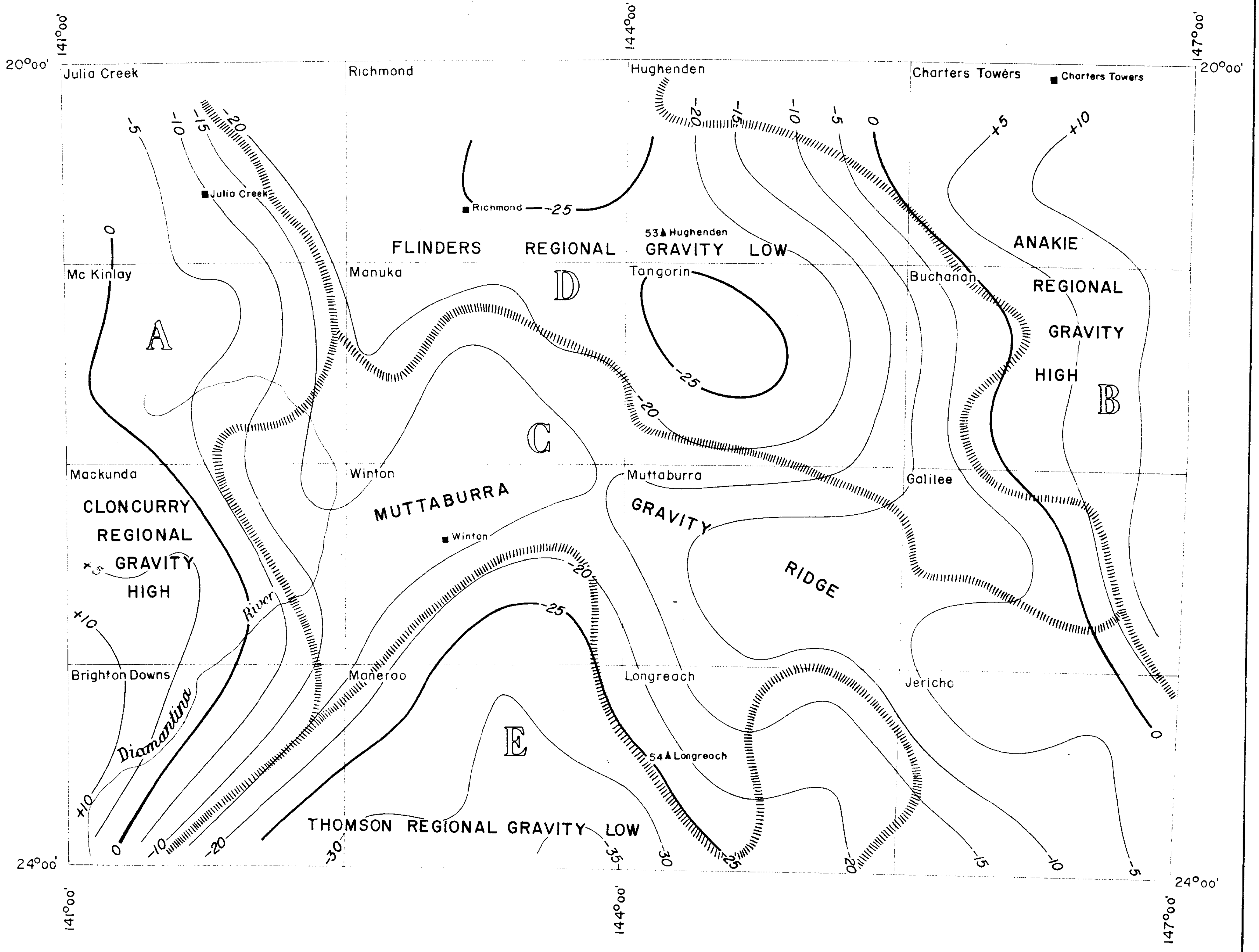
N° 50 Clermont............978,776·1 milligals
N° 51 Townsville..........978,624·0 "
N° 53 Hughenden..........978,604·2 "
N° 54 Longreach..........978,790·2 "
N° 55 Cloncurry..........978,651·4 "
N° 56 Boulia..........978,793·2 "
N° 57 Birdsville..........979,003·0 "

For the calculation of Bouguer anomalies 1·9 g/cm³ has been adopted as an average rock density

Elevation datum – Queensland State Datum

REC. GRAV. 1959-63 N. EROMANGA & DRUMMOND BASINS

To accompany record No 1966/210 GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS F54/B2-43



SMOOTHED BOUGUER ANOMALIES

SCALE IN MILES

40 0 40 80

Smoothed Bouguer anomalies derived from Bouguer anomalies calculated using an average rock density of 1·9 g/cm³

Contour interval 5 m gal

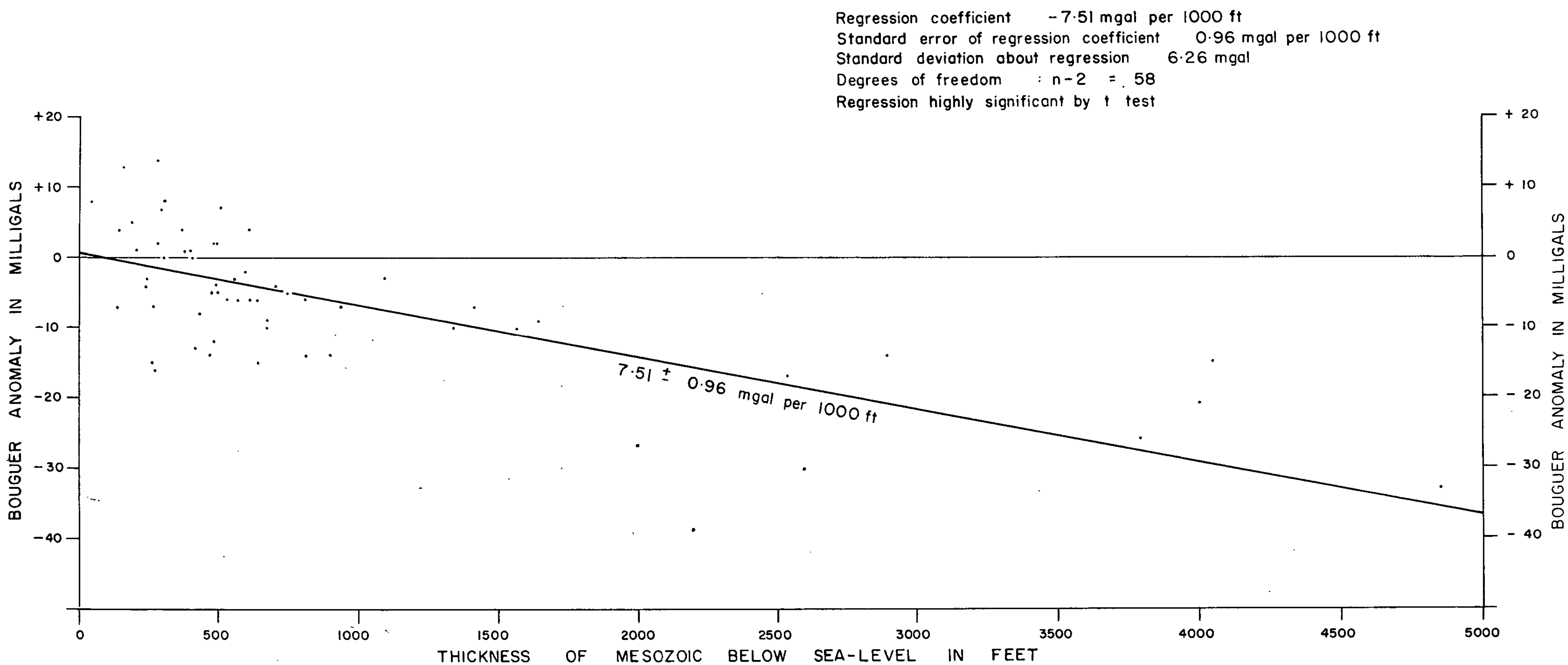
Gravity province boundary

A Gravity province

To accompany record No 1966/210

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

F54/B2-34



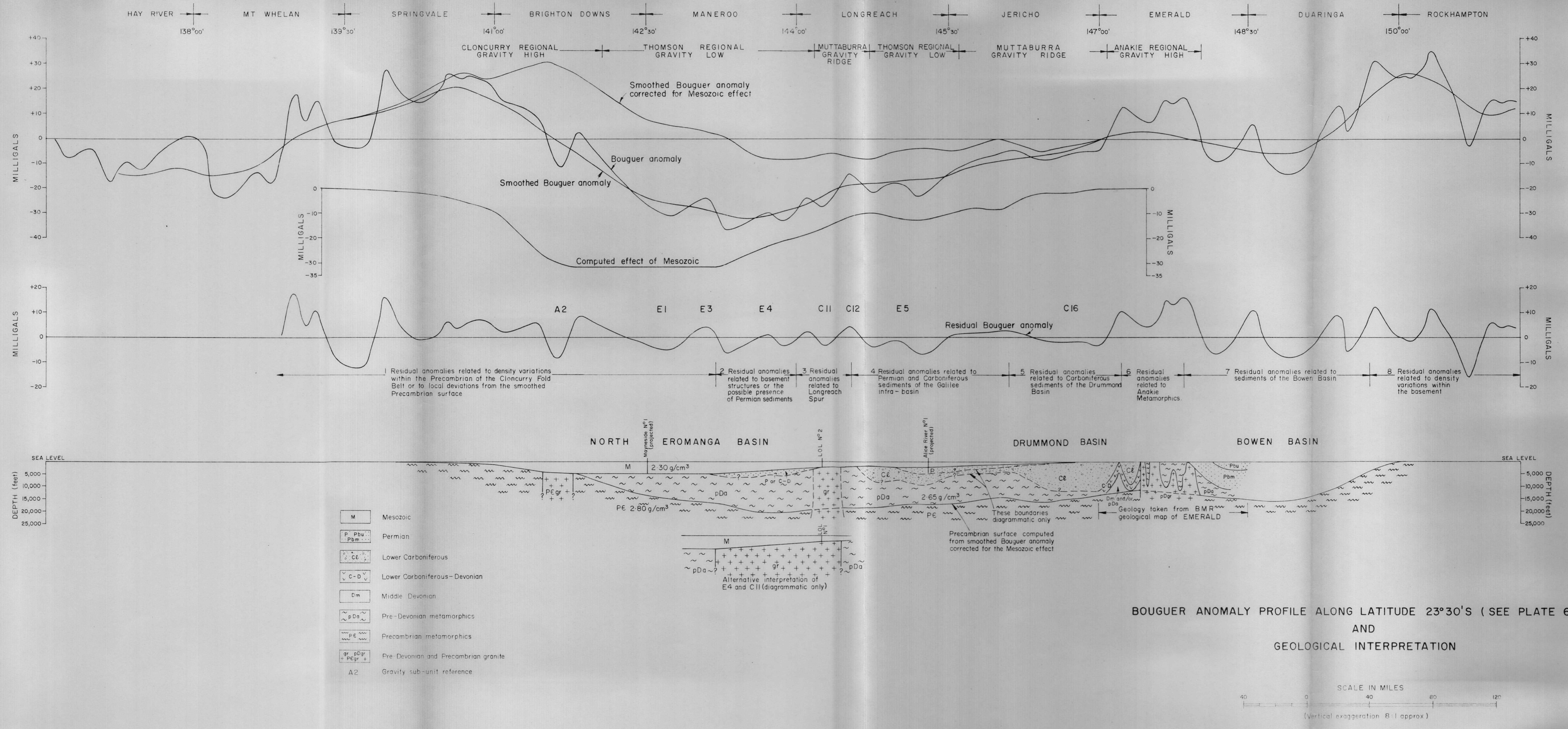
GRAPH SHOWING THE RELATIONSHIP BETWEEN BOUGUER GRAVITY ANOMALIES AND THICKNESS OF THE MESOZOIC IN THE NORTH EROMANGA BASIN

PLATE 8

To accompany record No 1966/210

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics

F54/B2-38



BOUGUER ANOMALY PROFILE ALONG LATITUDE 23°30'S (SEE PLATE 6) AND GEOLOGICAL INTERPRETATION

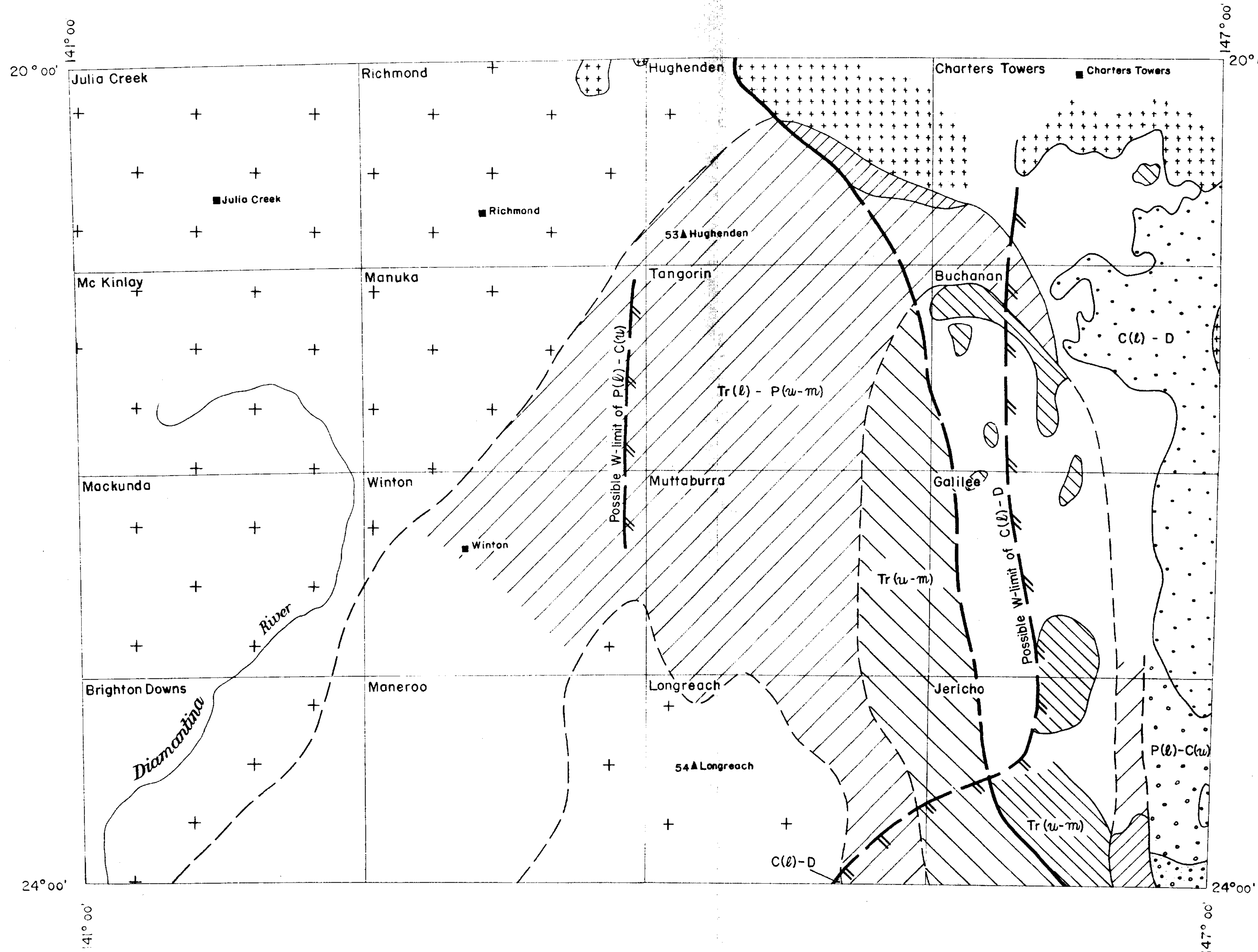
REC. GRAV. 1959-63 N. EROMANGA & DRUMMOND BASINS

To accompany record No. 1966/210

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

F54/B2-45

PLATE 10



SURFACE · SUBSURFACE

- Upper and middle Triassic Tr (u-m)
- Lower Triassic, Upper and middle Permian } Tr (ℓ) - P (u-m)
- Lower Permian, Upper Carboniferous } P (ℓ) - C (u)
- Lower Carboniferous, Devonian } C (ℓ) - D
- Basement any age
- Geological boundary (outcrop)
- Geological boundary (subsurface)
- Limit of Great Artesian Basin (Unconformity between J (ℓ) or younger beds and Tr or older beds)

GEOLOGICAL SKETCH MAP OF PRE-LOWER JURASSIC BEDS

AFTER TRUMPY AND TISSOT, 1963

SCALE IN MILES

40 0 40 80

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS F54/B2-40

To accompany record No 1966/210

PLATE 11

TOTAL MAGNETIC INTENSITY

LEGEND

CONTOURS IN GAMMAS

AEROMAGNETIC PROFILE (ALONG SINGLE FLIGHT LINE)

SCALE IN MILES

40 0 40 80

APPROX PROFILE SCALE

1000 GAMMAS

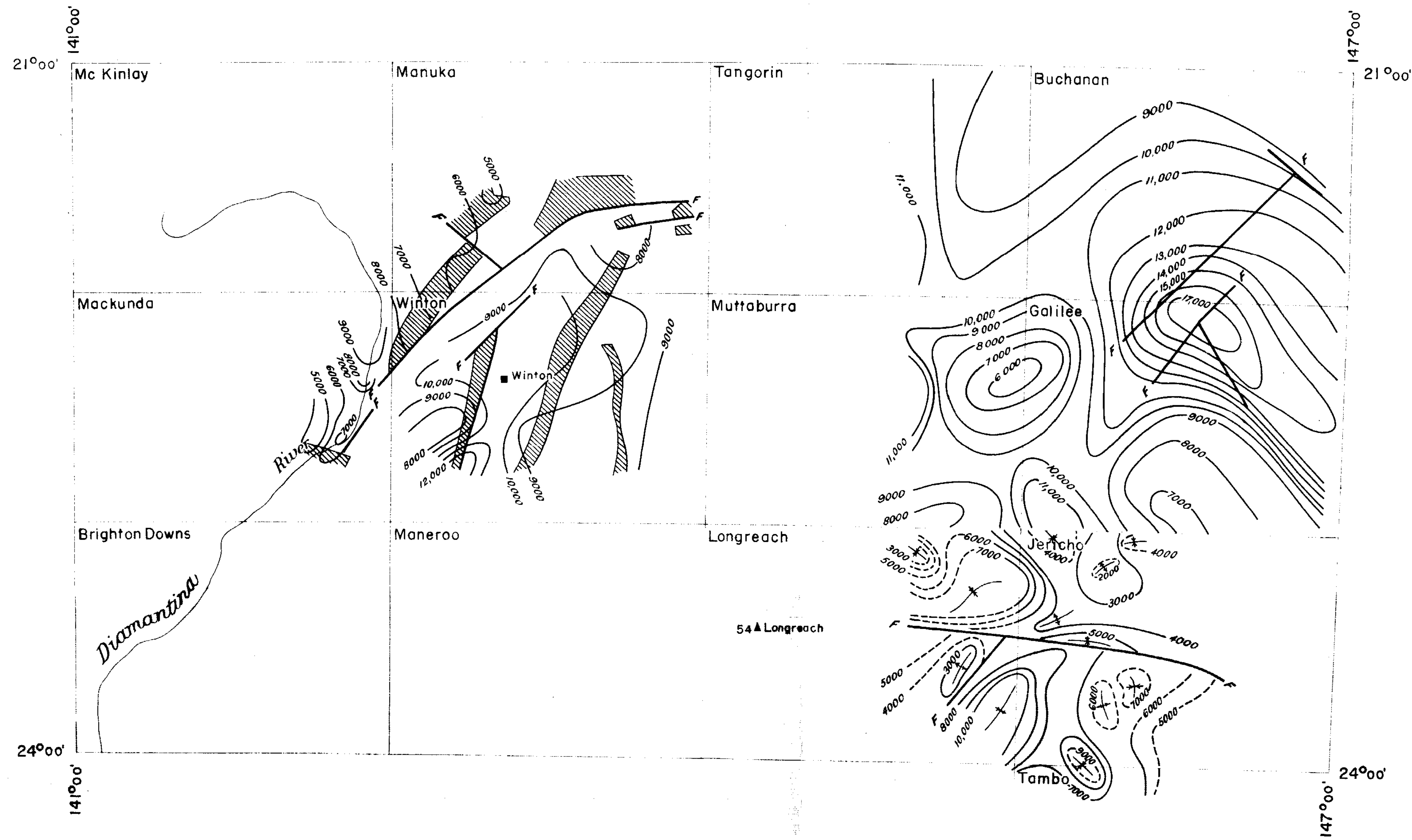
0

To accompany record No 1966/210

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

F54/B1-28

REC. GRAV. 1959-63 N. EROMANGA & DRUMMOND BASINS



LEGEND

Anticlinal axis

Synclinal axis

—5000— Depth to basement

"Basic mass"

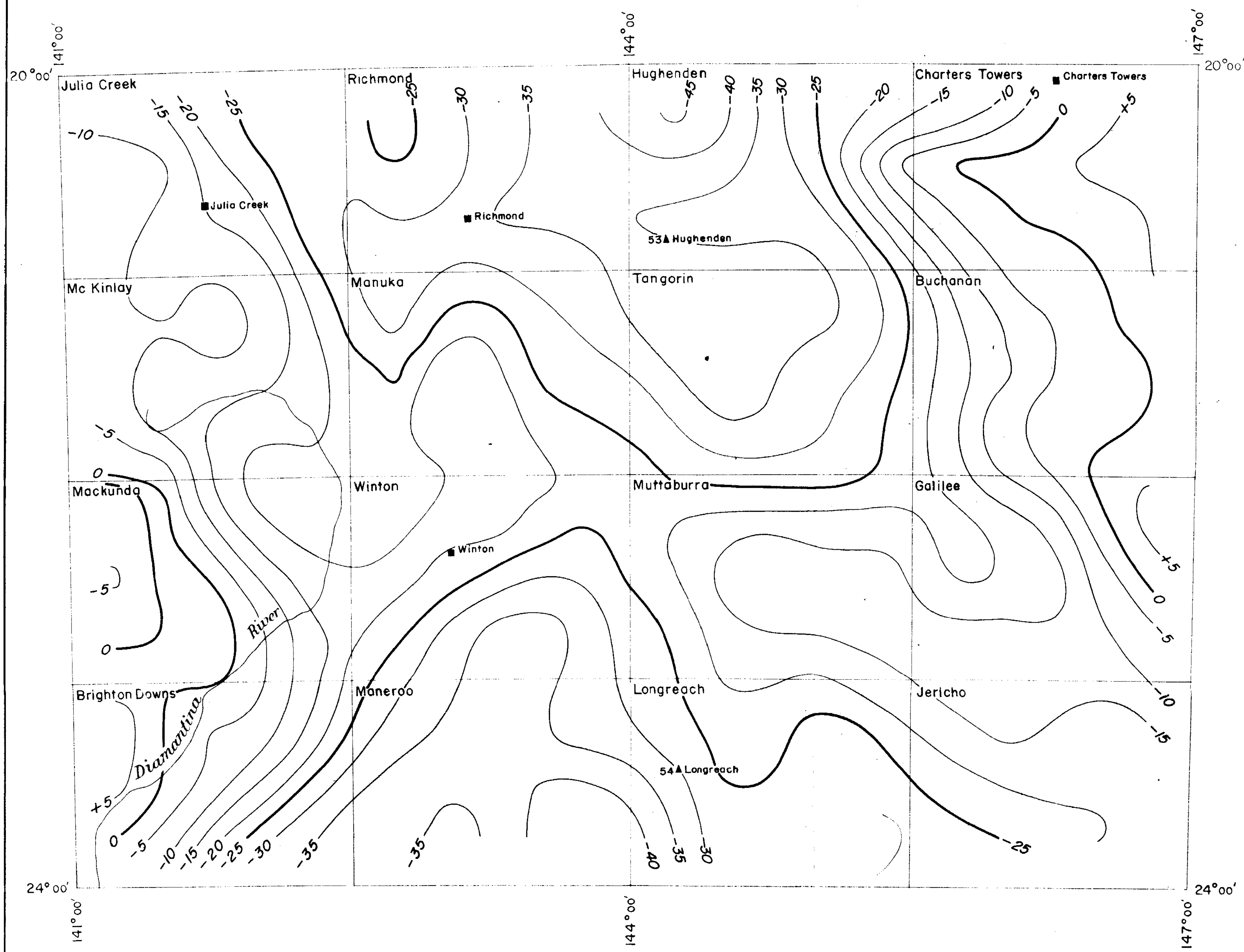
——F Fault

Compiled from interpretations by Magellan Petroleum Corp. and Exoil N.L.

AEROMAGNETIC INTERPRETATION
MAGNETIC BASEMENT CONTOURS

SCALE IN MILES

40 0 40 80



REGIONAL BOUGUER ANOMALIES

Regional Bouguer anomalies derived from Bouguer anomalies calculated using an average rock density of 2·67 g/cm³

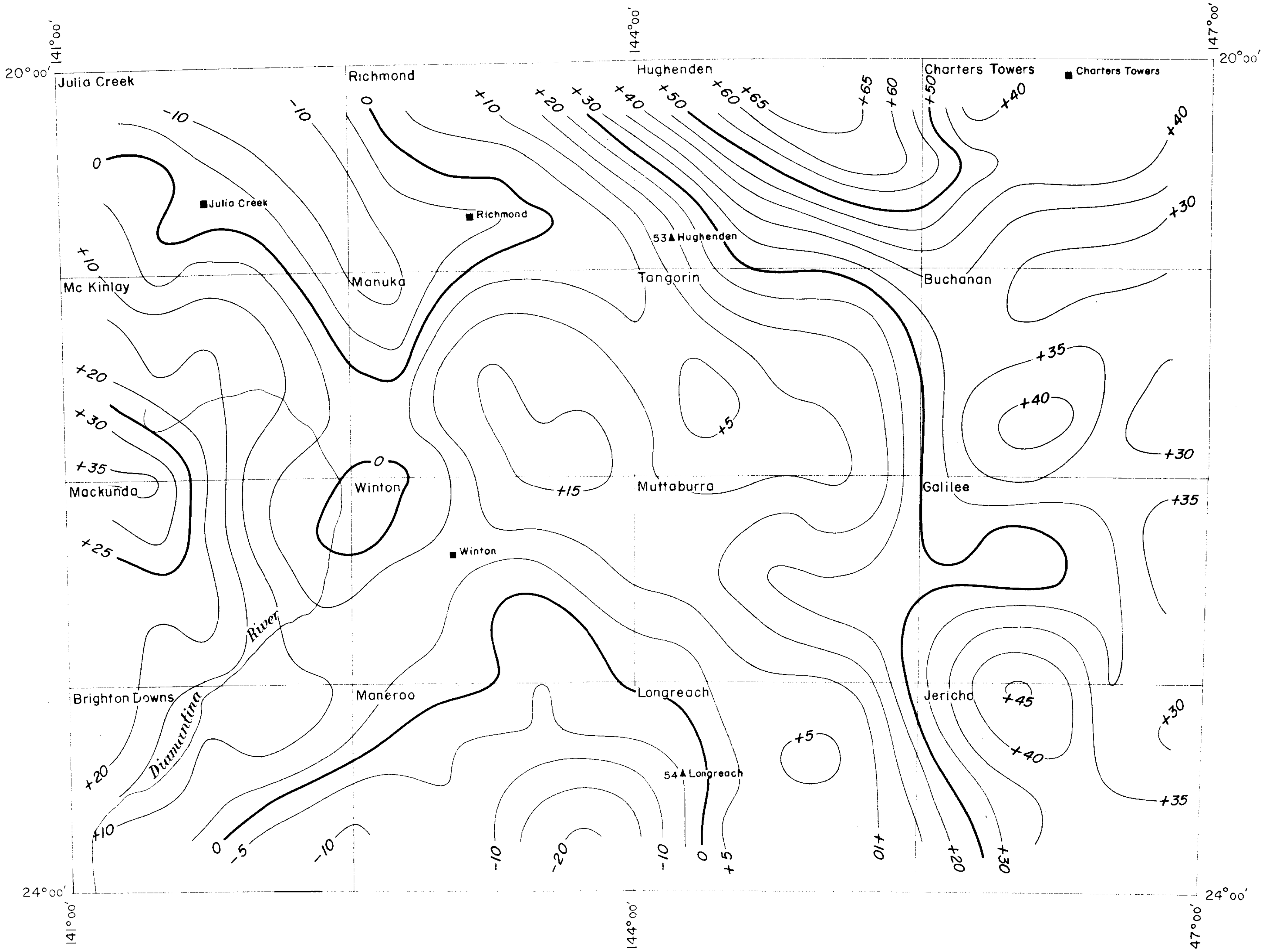
Contour interval 5 milligals

SCALE IN MILES

40 0 40 80

To accompany record No 1966/210 GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS **F54/B2-36**

REC. GRAV. 1959-63 N. EROMANGA & DRUMMOND BASINS



MAP SHOWING DEVIATION OF BOUGUER ANOMALY FROM A WORLD AVERAGE BOUGUER ANOMALY

This map shows the deviation of the regional Bouguer anomaly of Plate 13 from a world average Bouguer anomaly taken from a graph showing the "Relation of Bouguer anomaly to surface elevation mean world values." (Woollard, 1962)

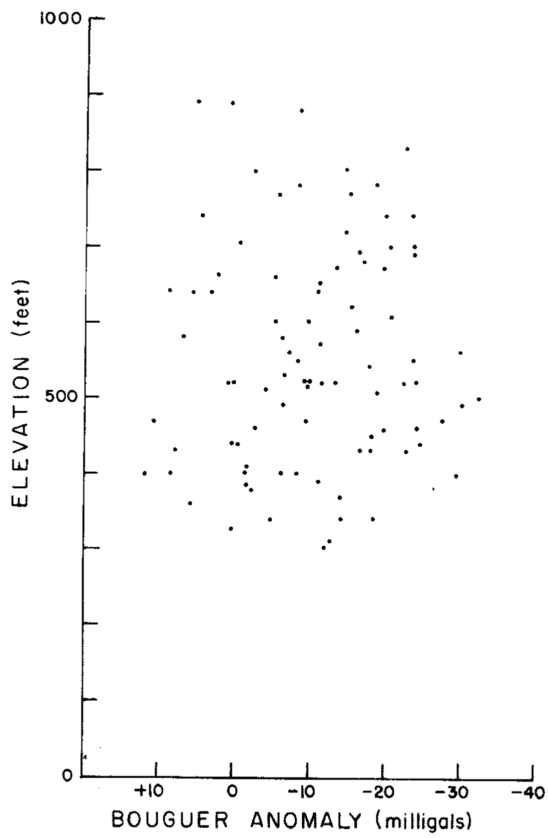
Contour interval 5 milligals

SCALE IN MILES

40 0 40 80

REC. GRAV. 1959-63 N. EROMANGA & DRUMMOND BASINS

PLATE 15



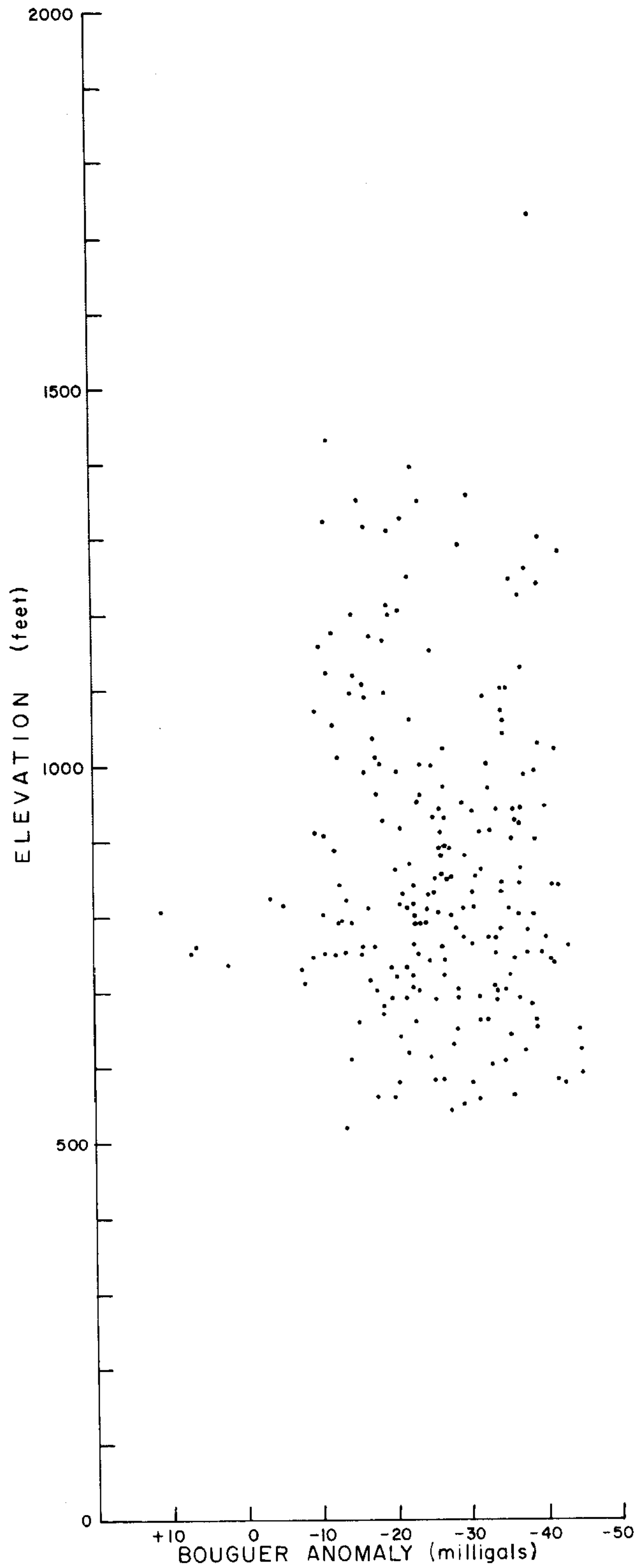
CLONCURRY REGIONAL GRAVITY HIGH

RELATION OF BOUGUER ANOMALIES TO ELEVATIONS

To accompany record No 1966/210

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

F54/B2-46

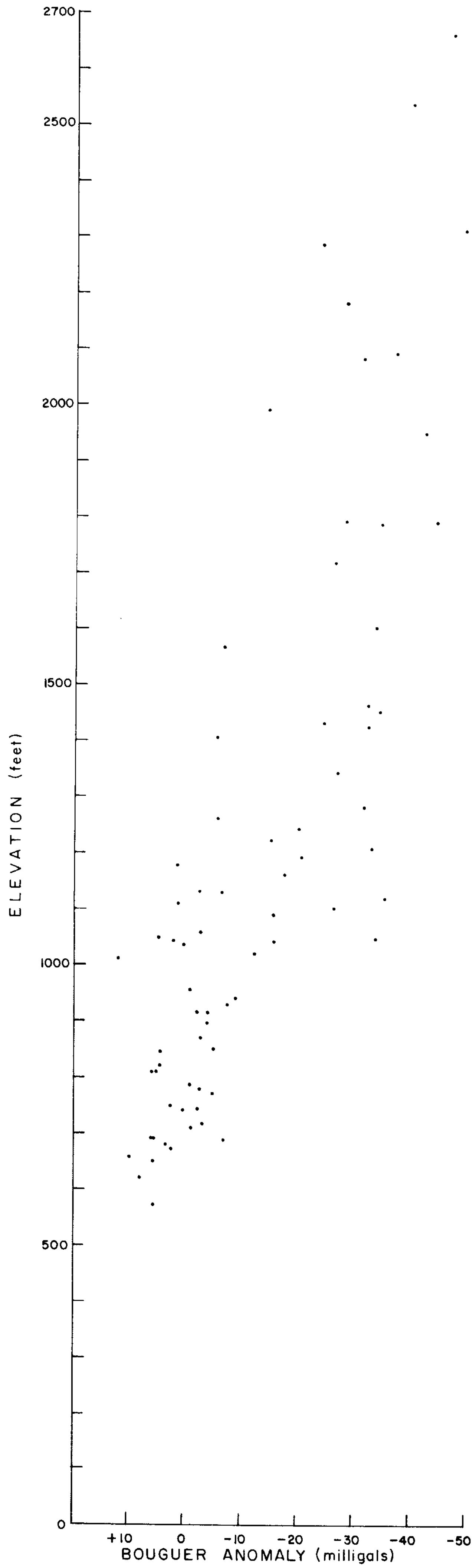


NORTH EROMANGA BASIN

RELATION OF BOUGUER ANOMALIES TO ELEVATIONS

To accompany record No 1966/210

PLATE 17



ANAKIE REGIONAL GRAVITY HIGH

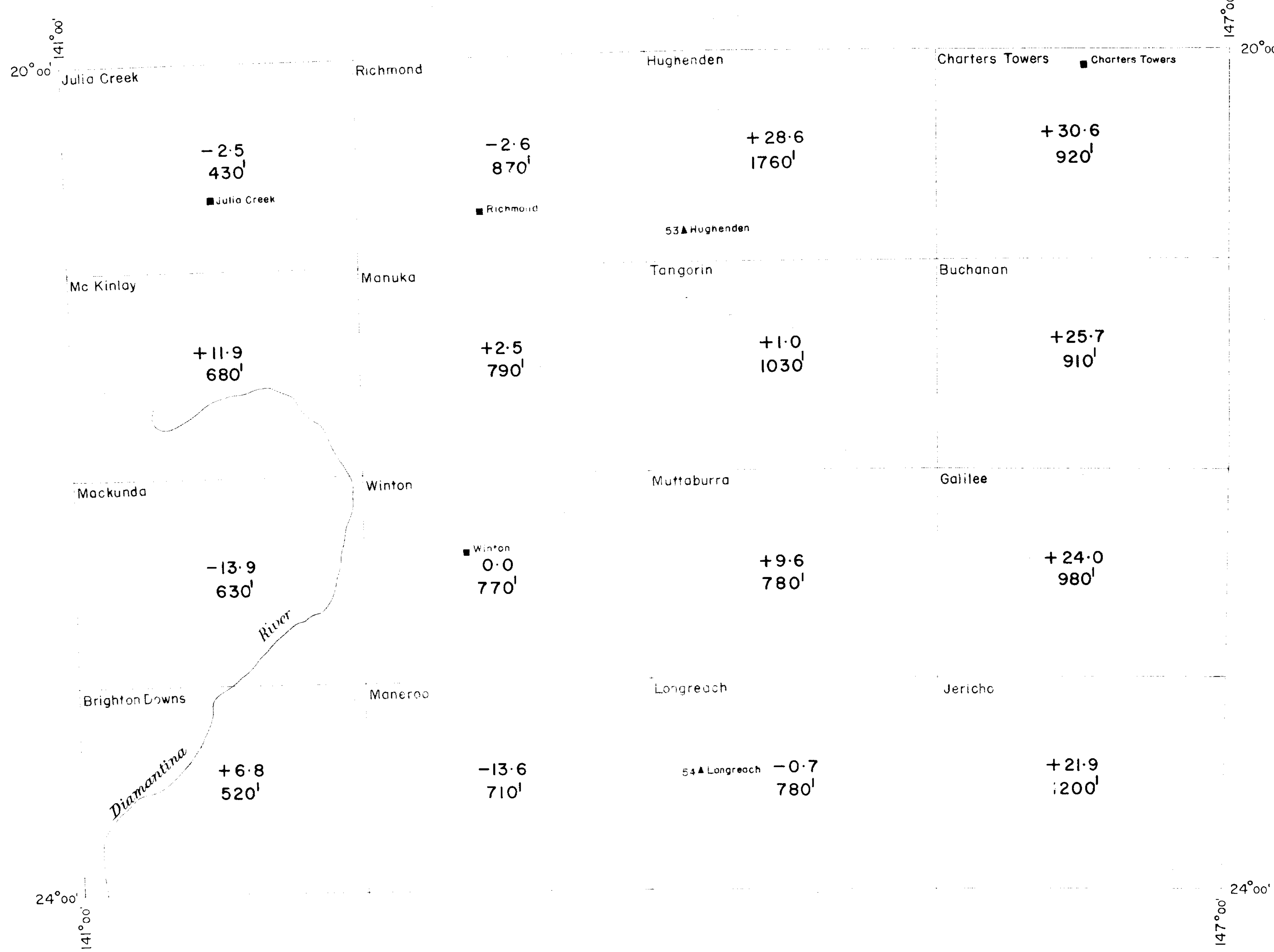
RELATION OF BOUGUER ANOMALIES TO ELEVATIONS

To accompany record No 1966/210

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

F 54/B2-48

PLATE 18

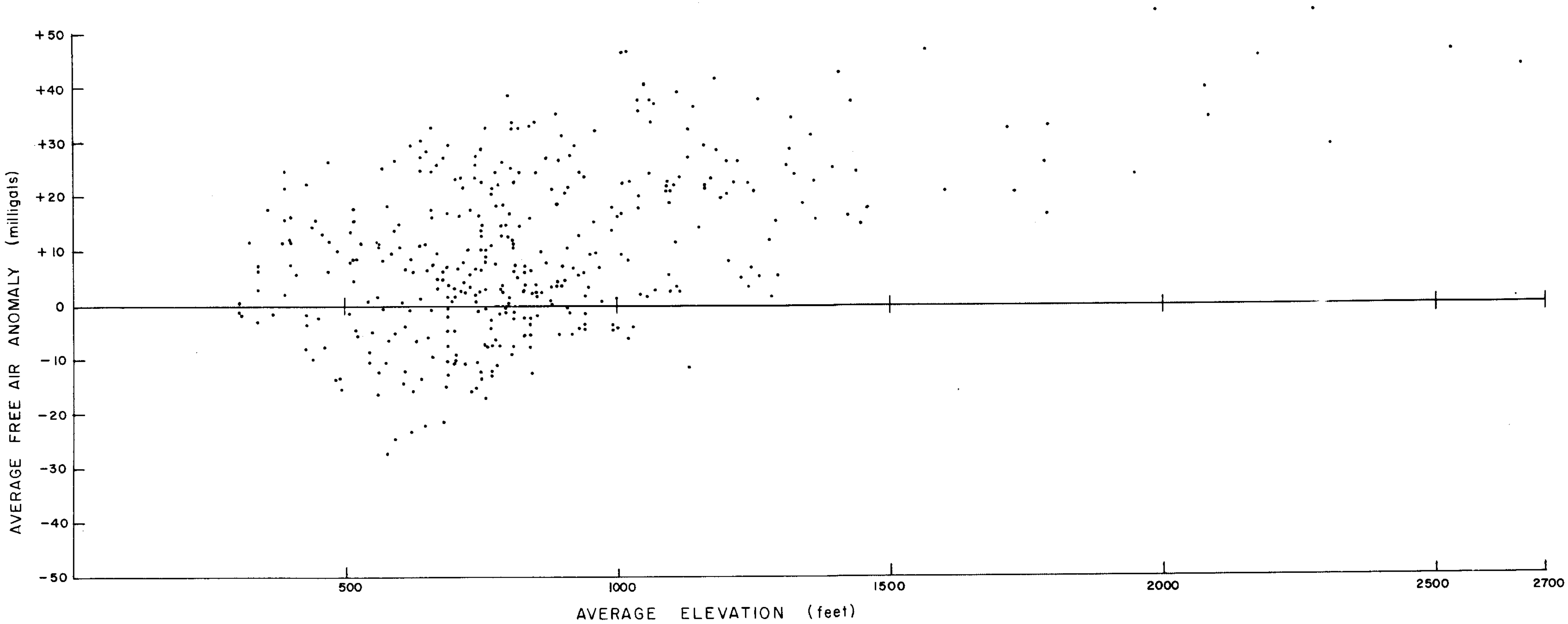


AVERAGE FREE AIR ANOMALIES AND AVERAGE ELEVATIONS PER 1:250,000 MAP AREA

REC. GRAV. 1959-63 N. EROMANGA & DRUMMOND BASINS

To accompany record No 1966/210

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS F54/B2-41

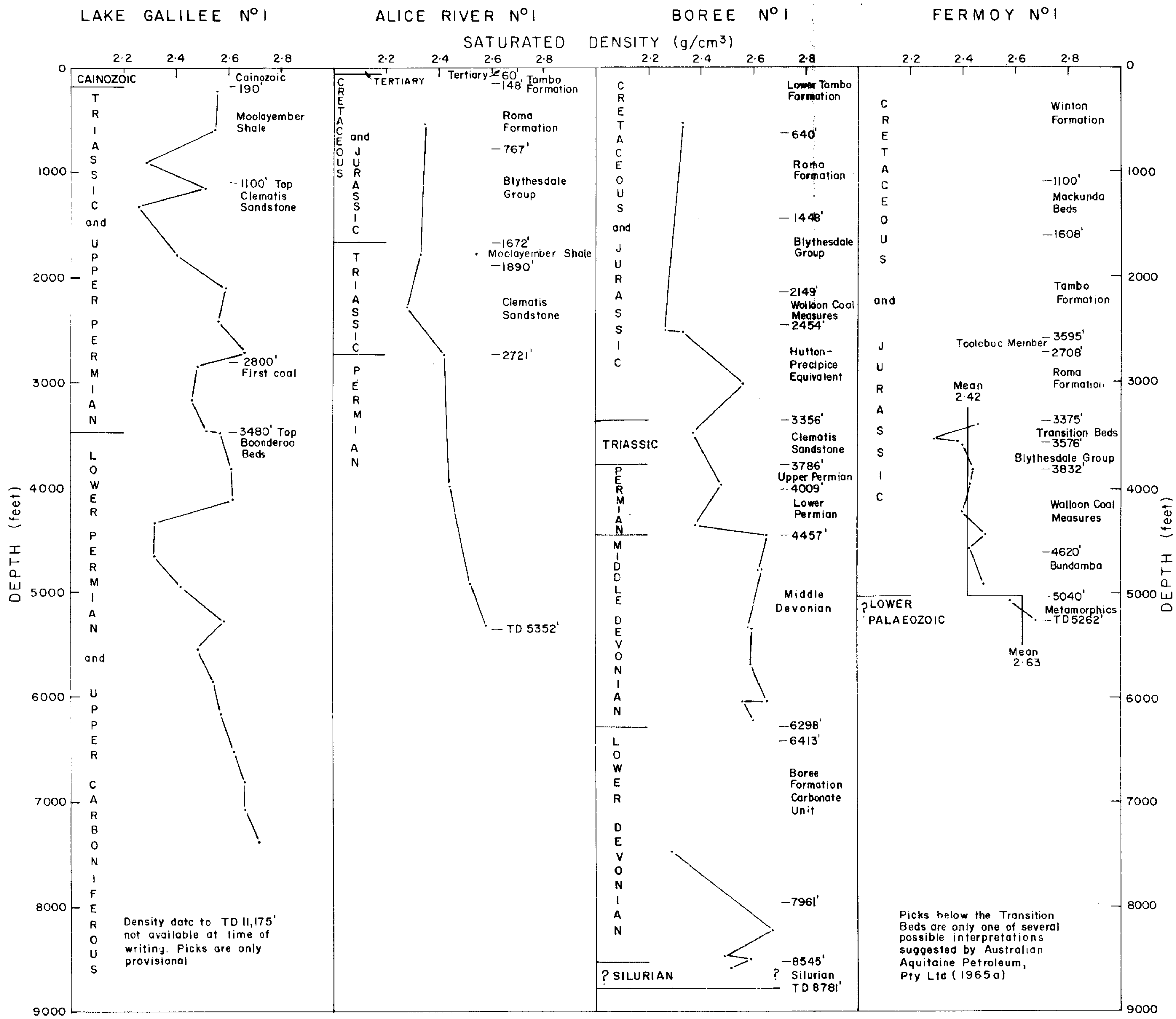


AVERAGE FREE AIR ANOMALIES AS A FUNCTION OF AVERAGE ELEVATION
(15-minute squares)

PLATE 19

To accompany record No 1966/210

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS F54/B2-42



SATURATED DENSITIES OF BOREHOLE CORES