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DONGARA - PERENJORI AREA GRAVITY SURVEYS,

PERTH BASIN, WESTERN AUSTRALIA

1950 - 1960

by

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SUMMARY

As a result of reconnaissance gravity surveys in 1950 and 1952 and an airborne magnetometer survey of the Perth Basin in 1957, a more detailed gravity survey of the Dongara-Perenjori area was made in 1960.

The results of the three gravity surveys have been combined in the form of a Bouguer anomaly contour map, the most prominent feature of which is a zone of steep gravity gradient that crosses the area in a north-north-west direction and is due to the Urella Fault.

East of the Urella Fault is a marginal zone of complex tectonic origin, bounded on the east by the Darling Fault and consisting of the Mullingarra Granitic Inlier, a steep asymmetrical syncline of beds of the Yandanooka Group, and a series of parallel step-faults between the Inlier and the syncline.

West of the Urella Fault are the deep sediments of the Perth Basin, in which raised basement ridges centrally and marginally situated must be regarded as important features in relation to possible oil trapping. It is recommended that these ridges receive more detailed investigation, especially by seismic methods.

1. INTRODUCTION

The first gravity survey made by the Bureau of Mineral Resources (B.M.R.) in the Perth Basin was in 1949 (Thyer & Everingham, 1956). Since then a systematic, semi-regional, gravity coverage has gradually been obtained over all of the Perth Basin, which is now recognized as an elongated, north-trending syncline, extending from latitude 26°S, south of Wooramel River, to as far south as latitude 34°30'S, near Cape Leeuwin (Konecki, Dickins, & Quinlan, 1958).

In the area under discussion in this Record, reconnaissance gravity surveys were made by the B.M.R. in 1950 and 1952, resulting in a regional gravity map of the area.

During 1957, magnetometer traverses were flown by the B.M.R. over the Perth Basin south of Greenough River, and also over a portion of the Byro 1:250,000 map area (Newman, 1959). The results of this work showed prominent magnetic variations occurring mainly over Precambrian outcrops along the eastern margin of the Perth Basin. In the Dongara-Perenjori area, well-defined magnetic anomalies (Plate 4) correlate with major faults and basement ridges of a more complex nature. However, in this particular area the gravity data obtained from B.M.R. work up until 1952 was insufficient to provide enough information for correlation with the anomalies, and a gravity survey was planned to obtain more detailed gravity information in relation to the magnetic anomalies. This survey was made between 29th February and 8th April, 1960, when 187 new gravity stations were read.

The location of the first Beagle Ridge stratigraphic bore, B.M.R.10, about forty miles west of Dongara, was selected on evidence obtained from the results of the B.M.R. regional gravity and airborne magnetometer surveys. The bore, drilled in 1959, penetrated beds considered as suitable source, reservoir, and cap rocks (McTavish, 1960a). Oil staining and a trace of visible oil, found in Permian sandstone, helped to stimulate interest in the area.

Certain sections of the Perth Basin have been subjected to detailed gravity investigations by the lease-holding company, the West Australian Petroleum Proprietary Limited (WAPET). South of Dongara and south-west of Coorow some of the gravity data obtained by WAPET from detailed traverses were in disagreement with the B.M.R. regional results. It was one of the objectives of the additional gravity work, done by the B.M.R. in 1960, to clarify any discrepancies, which might have occurred for reasons of insufficient station coverage or lack of repeat readings.

2. GEOLOGY AND PHYSIOGRAPHY

In the Perth Basin, comprehensive geological studies have been undertaken, mainly by WAPET and the B.M.R., with a view to increasing the information necessary for the assessment of oil possibilities. As a result of this work, the geology of the Perth Basin has become much better known than previously, when geophysical investigations were initiated. As gravity information increased, gravity anomaly data were important in interpreting the structural form of the Perth Basin. Prior to 1949, the geological conception of the basin, as a major structure, was exclusively based on formation outcrops and shallow water bores. This led to the suggested subdivision of the Perth Basin into the Perth Sunkland, as the deepest depressed section, which was visualized as being terminated by higher-standing faulted blocks to the north and south (Fairbridge, 1949).

The availability of gravity data was extremely valuable in reviewing the earlier geological conclusions. From Bouguer anomaly values the deepest portion of the Perth Basin could be clearly delineated in the area north of Dandaragan and south-west of Watheroo, where the most negative Bouguer anomalies were found. In the southern portion of the Perth Basin, an area of relatively low gravity intensity was also established south of Bunbury (Plate 1). The maximum thickness of sediments deposited in the deepest depressed sections of the Perth Basin was estimated from gravity data to be between 25,000 and 30,000 feet (Thyer & Everingham, 1956). This theoretical value of maximum sedimentary thickness is a conservative figure, as shown by more recent geological data obtained from the investigation of formation outcrops. From these, an aggregate thickness exceeding 55,000 feet has been suggested (Playford & Johnstone, 1959). The stratigraphic sequence of the Perth Basin sediments is tabulated in Table 1 (mainly after Playford & Johnstone, 1959).

TABLE 1

Stratigraphic sequence in the Perth Basin, WA.

Age	Lithology	Facies	Estimated maximum thickness (feet)
Quaternary	Coastal limestone, aeolian sand, gravel and silt.	Marine continental shelf	100(+)
Eocene	Shale and siltstone	Marine	2000
Upper Cretaceous	Green sand and chalk	Marine	200
Lower Cret. and Jurassic	Sandstone, minor siltstones, and limestone.	Continental paralic	8000
Triassic	Shale, siltstone, and sandstone.	Marine deltaic	6200(+)
Permian	Shale, siltstone, sandstone, and minor limestones.	Mixed marine and continental	6000
	Tillite, sandstone, and shale at the base	Glacial	
	UNCONFORMITY		
Pre-Permian	Red sandstone, siltstone, and conglomerate	Non-fossiliferous	10,000
Lower Palaeozoic (Proterozoic?)	Siltstone with minor sandstones, conglomerate, chert, lava flows, and volcanic tuffs. (Yandanooka Group)	Non-fossiliferous	30,000
		Estimated total thickness:	62,500 feet

In the western part of the Dongara-Perenjori 1:250,000 map area (Plate 3), the surface geology is Mesozoic and Cainozoic. Continental Jurassic deposits, which occur near the surface, are undisturbed. However, immediately south of the map area, extensively folded and faulted Jurassic sediments crop out north of Hill River, where these beds form the Cockleshell Gully Anticline.

Near the coast at Beagle Ridge, valuable information on the stratigraphic sequence has been obtained from the B.M.R.10 bore, the position of which is shown in Plate 3. The drilling revealed a sequence of Pleistocene, Mesozoic, and Permian beds. These sediments include approximately 100 feet of Pleistocene marine calcarenite (Coastal Limestone), approximately 1000 feet of coarse-grained Jurassic sandstone (Cockleshell Gully Sandstone), 2200 feet of marine to deltaic siltstone, sandstone, and dark-green shale of Triassic age, and approximately 1500 feet of Permian beds composed of carbonaceous siltstone and sandstone with a hydrocarbon show at a depth of 3720 feet (McTavish, 1960a). In June 1960, a second bore (B.M.R. 10A) adjacent to B.M.R. 10 was reported to have struck basement gneiss at 4794 feet (McTavish, 1960b).

East of Beagle Ridge, Mesozoic and Permian beds increase in thickness, as suggested by the gravity data shown in Plate 5. The thicknesses of formations as indicated in Plate 5 were estimated before the Eneabba No.1 bore was drilled.

The sequence of strata penetrated in the Eneabba bore (WAPET, 1962) includes Lower Cretaceous beds, which are present, under a thin veneer of alluvium, down to a depth of 2443 feet. Jurassic sandstone, siltstone, claystone, and shale occur in the interval from 2443 to 7553 feet and Triassic beds from 7553 feet down to the final depth of 13,712 feet. The results proved that the Triassic beds were thicker than earlier anticipated. In the area further east of the Eneabba bore site, Triassic beds might still increase in thickness, possibly reaching a maximum total thickness of well over 6200 feet. Consequently, the depth to metamorphic basement rocks near the eastern margin of the basin adjacent to the Urella Fault can be expected to be even larger than shown in Plate 5.

In the north-eastern part of the map area (Plate 3), Permian rocks crop out along the banks of the Irwin River, where these beds form the Mullingarra Anticline. In the Irwin Basin east of the Mullingarra Anticline, the fully developed Permian succession is at least 6000 feet thick (Playford & Johnstone, 1959). At the base of the Permian beds, there is a glacial formation including tillites, which is overlain by mixed marine and continental sediments composed of sandstone and shale and some coal measures and bands of marine limestone. A relatively thin veneer of Lower Permian sediments extends over the northernmost portion of the Perth Basin.

Pre-Permian rocks are represented by a monotonous sequence of sandstone and greywacke, up to 10,000 feet thick, which occur north of the Dongara-Perenjori map area adjacent to the Precambrian Greenough-Northampton Block north of Greenough River (Plate 2).

In the area east of the Urella Fault (Plate 5), Permian beds rest unconformably on a complex of rocks known as the Yandanooka Group. These include approximately 30,000 feet of non-fossiliferous siltstone with intercalations of sandstone. These beds originate from the erosion of andesitic volcanic rocks and form an extensively folded syncline in the area between Moora and Mingenew. The age of the Yandanooka Group is believed to be Lower Palaeozoic (Ordovician?) or possibly Proterozoic.

Near Yandanooka an elongated ridge of granitic to gneissic rocks, called the Mullingarra Inlier, terminates the Yandanooka Group in the west. The axis of the inlier strikes north-northwesterly. From geophysical data, igneous rocks most likely extend north of the granite to form the core of the Mullingarra Anticline underneath the Permian beds.

Structurally, the Perth Basin is terminated to the east by the Darling Fault, a major lineament that extends north-south over a distance of more than 600 miles.

To some extent, faulting also terminates the western margin of the Perth Basin in the extreme northern and southern parts. Owing to the absence of data, the gravity anomaly picture is not conclusive over the complete length of the western margin of the Perth Basin. Portions of the basin might extend westwards into the adjacent continental shelf.

Geophysical evidence, provided by gravity and magnetic data, is suggestive of major basement ridges occurring at relatively shallow depth near the coast of the Indian Ocean. At Beagle Ridge, south of Dongara, a buried ridge was recently confirmed by the drilling of B.M.R. 10A bore into basement. Raised basement complexes of a similar type might exist beneath Rottnest and Garden Islands west and southwest of Perth.

A remarkable feature of the Perth Basin structure as a whole is its asymmetry, as shown by the distinct characteristics of the Bouguer anomaly pattern and from the dipping of the sediments, which is generally to the east. The asymmetric structure is indicated by the fact that the steepest gradients of the gravity contours occur along the western sides of several gravity 'highs' (except for the 'Ajana High') and are followed by a more gentle westerly rise in the gravity values, expressed by wider spacing between the gravity contour lines. Such an anomaly pattern is suggestive of tilted blocks, tilting down to the east and terminated in the west by faults.

In the Dongara-Perenjori map area (Plates 3 and 4), the physiographical or morphological expression of the Darling Fault is negligible, except for the area near Beere Hill, about sixteen miles east of Mingenew, where the position of the Darling scarp is indicated by a sharp drop in the surface topography from roughly 1000 feet east of the fault to approximately 800 feet west of it. West of Coorow, the Darling Fault runs north to Winchester and thence turns to the north-north-west, following a line that extends from a point between Carnamah and Prowaka to Beere Hill (Plate 4).

A second major fault, the Urella Fault, occurs parallel to, and about twelve miles west of, the Darling Fault; it runs south-south-east, following a line through a point one mile east of Mingenew (Plate 4). Gravity data indicate that the Urella Fault continues north-north-west over an appreciable distance, as shown in Plate 2.

The occurrence of parallel or slightly convergent faults west of the main Darling Fault is an important feature in the structural pattern of the northern section of the Perth Basin. At its northern end this basin narrows into the Coolcalalaya and Byro Basins (Konecki <u>et al.</u>, 1958) between the Precambrian Shield to the east and the Ajana-Wandagee Ridge to the west, which in the earlier geological literature is referred to as the Greenough-Northampton Block.

In the area covered by the Dongara-Perenjori map (Plate 3), elevations generally range from sea level to a maximum of nearly 1100 feet east of Coorow. The surface slopes gently from the coast to the 900 feet topographic contour, which runs roughly north-north-west from gravity station No. 164M (elevation 920 feet) near the south-eastern corner of the map to a point between gravity stations No. 117 (elevation 837 feet) and No. 118 (elevation 1004 feet) east of Beere Hill. East of this line, platform-like morphology prevails with altitudes exceeding 1000 feet on higher-standing ridges west of Three Springs, east of Beere Hill, and on a major ridge that occurs along the eastern margin of the map.

3. PURPOSE OF THE SURVEYS

Gravity surveys conducted by the B.M.R. in the northern portion of the Perth Basin between 1949 and 1952 were reconnaissance surveys to obtain gravity information on the general structure of the basin.

The main object of the work completed early in 1960 in the Dongara-Perenjori area, was to obtain more detailed gravity data in relation to magnetic anomalies (Plate 4). These anomalies can be briefly described as follows:

(a) An elongated magnetic 'high' of limited extent trending north-north-west about ten miles south-west of Three Springs.

(b) A group of more complex magnetic anomalies near Arrino and Pitfield.

(c) A major magnetic anomaly, north of Mingenew, extending north-north-west beyond the northern boundary of the Dongara-Perenjori map (Plate 4).

(d) A major trend in the magnetic contours parallel to the coast with maximum values immediately west of the coast line. This trend extends from Frenchman Bay to Jurien Bay and Cliff Head (Plate 2). A maximum in the magnetic values is reached immediately east of Beagle Islands (Plate 4).

(e) An irregularity in the magnetic expression over an extensive area that lies east of a line running north-west from a point at latitude 30° and longitude 115°55' across the map area (Plate 4).

(f) A bulging in the 980-gamma contour south-east of Ocean Hill is indicative of the northernmost end of a major trend in the magnetic anomalies, which extends into the Dongara-Perenjori map area from a point fifteen miles west of Dandaragan (Plate 2).

The specific aims of the 1960 gravity survey conducted in the Dongara-Perenjori area refer to the following problems:

(a) The position of the Darling Fault in the area between Winchester and Beere Hill.

(b) The structural relation between the Darling Fault and the Urella Fault.

(c) The structural relation between the basin west of the Urella Fault and the higher-standing block of older rocks east of the fault.

(d) The western boundary of the basin in relation to a basement structure confirmed by drilling at Beagle Ridge.

(e) The probable ridge in the basement centrally situated in the basin near Ocean Hill.

In reviewing the nature of the western boundary of the basin, referred to above under (d), the possibility of major faulting had to be investigated more fully. The existence of a major fault, running north from Cliff Head, has been suggested from earlier B.M.R. gravity data (Thyer & Everingham, 1956). The postulation of this fault was based on a relatively high gravity reading obtained at gravity station No.185 (Plate 3) during the course of the 1952 reconnaissance survey. This reading indicated a gravity gradient of unusual magnitude, suggesting a fault near Cliff Head. On the basis of the rapid gravity variation observed on a traverse west of Dongara, this fault was assumed to extend north over an appreciable distance. However, it was later realised that the B.M.R. observed gravity value at station No.185 disagreed with that obtained by WAPET from a more detailed investigation.

A similar situation arose in the area roughly sixteen miles south-west of Coorow where gravity results obtained by WAPET were in disagreement with the earlier B.M.R. observation at station No.165B in the Hill River 1:250,000 map area.

In order to clarify any such discrepancies that might have occurred for reasons of insufficient station density or lack of control readings, check-readings on the stations of the earlier B.M.R. surveys and additional gravity traverses were planned for inclusion in the 1960 detailed survey.

4. FIELDWORK

Arrangement of traverses

Gravity traverses and gravity station positions were identified in the field by using one-mile military maps together with ownership maps issued by the Department of Lands and Surveys of Western Australia. The 1:250,000 composite map of the Dongara-Perenjori area (Plate 3) was used as a topographic base in the final plotting of the gravity traverses.

The gravity data shown in Plate 3 incorporate all the work completed by the B.M.R. in the area since 1950, comprising gravity surveys as set out in Table 2.

TABLE 2

B.M.R. gravity surveys in the Dongara-Perenjori area, WA.

Year of survey	Type of survey	Gravity meter used	Observer	Number of stations shown in Plate 3
1950	Reconnaissance	Norgaard TNK 413	I.B. Everingham W.H. Oldham J. van Son	40
1952	Reconnaissance	Norgaard TNK 413 Worden No. 61	I.B. Everingham	23
1960	Semi-detailed	Worden No. 140	A.J. Flavelle	187
			Total :	250

During the initial stage of the gravity investigations, stations were placed at approximately five-mile intervals on traverses running west and north-west along the Geraldton Highway and two other major roads, one leading from Mingenew to Morawa and the other from Goomalling to Mullewa (Plate 2). In the area west of Arrino and west of Coorow, station roads were used for traverses.

With the aim of solving the problems mentioned in Section 3, traverses of the 1960 detailed gravity survey were selected at relatively close spacing. Existing roads were used as much as possible for the traverses, and gravity stations were placed at intervals averaging from 1½ to 2 miles.

In this way, a relatively dense station coverage was obtained in the area west and east of Coorow and Winchester, west, north, and north-west of Three Springs, and in the area between Yandanooka, Strawberry, and Beere Hill. In addition, the Irwin River valley north-west of Mingenew was more fully surveyed with about twenty new gravity stations, three of which (Nos. 135 to 137) are beyond the boundary of the Dongara-Perenjori map area and are in the adjoining Geraldton-Yalgoo map area.

A major loop of gravity traverses was planned to include several lines running south-west from Three Springs to the coast near Snag Island, thence north to Cliff Head and from Cliff Head east to Arrino. Unfortunately, a section of the track between Cliff Head and Arrino was impassable at the time, and gravity stations Nos. 161 and 165 on the traverse east of Cliff Head could not be linked by successive readings.

The surveyed area shown in Plate 3 covers approximately 5700 square miles. The total number of 250 gravity stations observed would provide in this area, if evenly distributed, an average station density of one observation to twenty square miles. This coverage must still be considered as insufficient by presently accepted overseas standards. A density of one station to ten square kilometres (four square miles) has been recommended as necessary in order to provide adequate station coverage (Trumpy et al, 1960).

Instruments

Worden and Norgaard gravity meters have been used by the B.M.R. in obtaining gravity readings in the Perth Basin area.

The Norgaard instrument is now considered somewhat outdated. It is not temperature-compensated and corrections must be applied from temperature observations, which have to be taken in addition to the gravity readings. The procedure in making gravity observations with the Norgaard instrument involves five readings of two different dials. At least twice the time is required at each station in completing the necessary readings in comparison with the time involved with a gravity meter of more advanced design.

In the Dongara-Perenjori area, ten stations of the 1952 field survey were re-occupied with Worden No. 140 during the course of the 1960 detailed work.

Worden-type instruments operate on temperature-compensated movements composed of quartz springs and give fewer irregularities in the readings and more moderate characteristics of the daily drift curve. Evacuation of the movement chamber inside the insulated case of the instrument to a few millimetres of mercury is required from time to time in order to reduce irregularities in the drift curve to a minimum.

Generally the gravity values earlier obtained with the Norgaard meter agree with the new work carried out with the Worden instrument, differences in readings averaging less than one tenth of a milligal. This shows the performance of the Norgaard instrument to be quite satisfactory if properly handled. However, at gravity station No. 185 on the coast near Cliff Head, and at station No. 165B roughly fifteen miles south-west of Coorow, immediately south of the area covered by the Dongara-Perenjori map, misreadings must have occurred with the Norgaard instrument during the course of the B.M.R. regional gravity survey. These misreadings have resulted in Bouguer anomaly values that differ from the results obtained with the Worden meter by more than 30 milligals. These occasional errors in reading the Norgaard instrument are explainable considering the over-complicated procedure involved.

Prior to the commencement of the 1960 survey, Worden No. 140 was calibrated on the B.M.R. calibrating range between Brenock Park and Kallista near Melbourne. A small calibration factor of 0.11135 milligal per scale division was determined.

During the 1960 detailed survey, modern-type Askania microbarometers Nos. 2362, 562699, and 531306 were used in establishing station altitudes. These instruments are of more advanced design than aneroid barometers. Microbarometers are sensitive to pressure changes of the order of one hundredth of a Torr unit (1 Torr = 1mm of mercury), which is equivalent to an elevation change of approximately three tenths of a foot.

In the field, fluctuations in atmospheric pressure provide a major obstacle in obtaining barometrically spot heights within the range of accuracy theoretically possible (O'Connor, 1957). These atmospheric pressure variations interfere with pressure changes caused by altitude variation. For this reason, efforts were made by the B.M.R. field parties to improve measuring techniques, so that barometric altitude determinations would be sufficiently accurate and economical.

Microbarometers are sensitive instruments that require careful handling in the field. One of the three instruments employed during the 1960 survey became faulty after about one week's use (No. 2362). The other two barometers worked satisfactorily throughout the survey.

5. REDUCTIONS

All the gravity meter readings obtained by the B.M.R. in the Perth Basin since 1949 have been recomputed using the revised values of the B.M.R. pendulum stations (Dooley et al., 1961). The adjusted Bouguer anomaly values have been plotted on 1:250,000 topographic base plans, from which gravity contour maps have been prepared. These gravity contours have been superimposed on the magnetic anomalies obtained from the B.M.R. airborne magnetic survey of the Perth Basin (B.M.R., 1964).

The positions of pendulum stations established by the B.M.R. in the area of the Perth Basin and its immediate vicinity are shown in Plate 1. Observed pendulum station values used in the reduction of gravity meter readings are listed in Plate 3. By accepting these values as correct, certain errors appear in the gravity intervals obtained from gravity meter readings between the pendulum stations. These errors are as follows:

Pendulum stations	Error in gravity meter ties (milligals)
Geraldton - Watheroo	1.3
Watheroo - Perth	0.9
Perth - Albany	0.2

It is immediately obvious that the errors are within the range of accuracy usually accepted for pendulum observations. However, the question is arguable whether or not gravity meter readings can be considered more reliable than pendulum results, where relatively short distances and smaller gravity intervals are concerned. For example, this could apply to the gravity interval between Geraldton and Watheroo, where perhaps the gravity meter results are more accurate than the pendulum data. As a matter of principle, the pendulum values shown in Plate 3 were used unaltered, and for that reason, gravity meter readings have been adjusted by distributing the errors as if involved in the gravity meter ties. Thus the closing errors that occur in each closed loop of the gravity survey were reduced to as near zero as possible.

For each station, the gravity meter readings were corrected for instrument drift. Temperature corrections were applied only to the Norgaard meter readings. The daily drift curve of Worden No. 140 during the course of the 1960 survey generally shows readings increasing at a rate from 0.3 to 0.7 scale division per hour. On a few days, the daily drift curve was characterised by a downward tendency during the morning at a rate of about 0.5 scale division per hour. The maximum total drift rate during one day was approximately 5 scale divisions during a nine-hour period.

On each day of the 1960 survey, the temperature rose gradually from approximately 20°C to about 34°C during the period of the daily field readings. No temperature effect is noticeable in the variations of the Worden drift curves. For that reason, the occasional reversals, which occur in the direction of the drift, are not easily explained.

Readings of Worden No. 140 were converted into milligals using a calibration factor of 0.11135 milligals per scale division and were used to obtain the observed gravity value at each station by tying to pendulum values referred to in Plate 3. Loops of traverses were usually closed with small errors. Maximum loop misclosures of several tenths of a milligal seldom occur. The resulting observed gravity values were corrected for the normal gravity value. Finally, free-air corrections and Bouguer corrections, using a density of 2.2 g/cm^3, were made.

The adopted density of 2.2 g/cm^3 for the rocks between the gravity station and sea level is considered as representative of near-surface layers, which in the area west of the Urella Fault consist of sandstone, siltstone, and limestone of Jurassic and Quaternary age.

A higher density of between 2.6 g/cm^3 and 2.7 g/cm^3 would be more applicable in areas of higher altitude where Palaeozoic and Precambrian formations crop out. Owing to the incorrect density used in the reduction of the Bouguer anomaly values east of the Urella Fault (Plate 3), these values must be considered as being too high. However, any error which might occur in the Bouguer anomaly values owing to an incorrect assumption of rock densities would not greatly affect the anomaly trends expressed by the contours.

Elevation errors involved in the procedure of barometric height establishment will contribute to the over-all error in the Bouguer anomaly values. During the course of the 1960 field work, station elevations were determined by reading a microbarometer at each station. Originally it was intended to use barometer readings obtained at a base station for eliminating atmospheric pressure variations. However, this procedure could not be performed during the whole period of the survey. Instead, drift curves were plotted for each day, using repeat readings, and from these, the drift of the instrument as well as the atmospheric pressure fluctuations could be allowed for. This method employs a somewhat simplified procedure in deriving the pressure-height relationship. To determine the peculiarities of the atmosphere more precisely would require much longer field procedures (O'Connor, 1957).

Barometric readings, after drift adjustment, were converted into feet by using conversion tables supplied by the manufacturer of the instruments. Relative altitudes were then referred to mean sea level by tying barometric heights to known railway station levels. The accuracy of the altitudes barometrically established by the B.M.R. can be assessed by comparison with spot heights determined by the army. At two localities, fourth-class survey altitudes are available for this purpose. Near the south-western corner of the area (Plate 3) the altitude at gravity station No.164 was found by the B.M.R. to be 163 feet, whereas the Trigonometrical Point at this site is shown as 178 feet on the one-mile army map of Logue and Beagle. The height of gravity station No.125 was determined by the B.M.R. as 926 feet at the site of an army altitude station, shown as 943 feet on the one-mile army map of Arrino. The resulting differences are 15 feet and 17 feet. In both instances the B.M.R. altitude figures are lower than those obtained by the army. This might be indicative of a systematic error occurring in either of the surveys. Assuming an elevation error of plus or minus ten feet, the corresponding deviation in the Bouguer anomaly values, computed using a density of 2.2 g/cm^3, is 0.6 milligal.

The combined results of the gravity surveys are shown in Plate 3 in the form of a Bouguer anomaly contour map. In the more densely covered section of the gravity map, e.g. in the area between Coorow and Mingenew and north-west of Mingenew, the contour pattern can be considered to be fairly accurate. A much denser grid of gravity stations would be required for accurate contouring in the area north, north-east, and east of Cliff Head, as well as north-east of Dongara, where gravity data are too widely dispersed to allow reliable interpolation between individual station values.

6. GRAVITY ANOMALY PICTURE

The pattern of the Bouguer anomaly contours (Plate 3) depicts significant anomalies in the area. The more important features are as follows:

(a) The most outstanding feature of the anomaly pattern is a zone of steep gravity gradient between the minus 60-milligal and the minus 20-milligal contours, which extends north-north-west from a point sixteen miles west of Coorow to as far as the Irwin River. The uniformity of this zone is slightly disturbed by an easterly bulge in the contours about eight miles west of Three Springs. A local deviation also occurs immediately south-east of Mingenew. A widening of the contour spacing is obvious north-west of Mingenew.

(b) Minor zones of relatively steep gravity gradient occur east of the main zone referred to under (a). A northerly trend of steeper gradient extends near gravity station No.25 from the adjoining Hill River-Moora map area into the Dongara-Perenjori map area, where it ends somewhere south of Winchester.
A northerly trend of steeper gradient between the plus 5-milligal and minus 20-milligal contours develops near Beere Hill. In Plate 1 this trend is shown to extend over a long distance with a mainly northerly trend into the 1:250,000 map areas of Geraldton-Yalgoo, Ajana-Murgo, and Yaringa.

(c) An elongated gravity 'high' of major proportions shows up from the Yarra Yarra Lakes area west of Carnamah and extends north-north-west to the Irwin River north-east of Mingenew. On this 'high' a closure occurs between Three Springs and Arrino. A maximum Bouguer anomaly value is reached immediately east of Pitfield. For convenience this anomaly is referred to in the following text as the 'Pitfield High'.

(d) A second, though less prominent, gravity 'high' occurs east of Beere Hill. Plate 1 shows this 'high' as extending north-north-west into the adjoining 1:250,000 map area of Geraldton-Yalgoo, where this anomaly ends south of Mullewa.

(e) Immediately west of the trend of steep gradients referred to under (a), extremely low Bouguer anomaly values indicate a huge area of gravity deficiency with the most negative values occurring south-east of Ocean Hill near the southern margin of Plate 3. No closure in these negative values is shown in Plate 3, but in Plate 1, the complete extent of this gravity 'low' is expressed by the closure in the minus 100-milligal contour, which extends south over a distance of about 150 miles into the area near Perth. Plate 1 shows the most negative values of this anomaly to occur in the area west of Moora and Watheroo near Dandaragan.

(f) From the centre of the 'low' referred to under (e), gravity anomaly values rise to the west. South of Beagle Ridge a group of stations (Nos. 178 to 187) show positive Bouguer anomalies. Gravity data are not sufficient to show a closure in the contours. In the following text this anomaly is referred to as the 'Beagle Ridge High'.
A denser coverage by gravity stations would be required over the eastern flank of the 'Beagle Ridge High' in order to investigate more accurately the trend and the spacing between the minus 60-milligal and the minus 40-milligal contours.

(g) About eight miles north of Dongara, positive Bouguer anomaly values occur. Because of the absence of sufficiently dense station coverage the contouring near the north-western corner of the Dongara-Perenjori map is conjectural. From the data available there is no evidence suggesting an immediate connection between the 'Beagle Ridge High', referred to under (f), and the positive gravity anomaly north of Dongara. Plate 1 shows a relatively high gravity anomaly extending from Dongara with a north-north-easterly trend into the area near Ajana and further north. For convenience, this anomaly is referred to as the 'Ajana High'.

7. DISCUSSION OF RESULTS

The geophysical problem

Basically, Bouguer gravity anomalies are caused by contrasts in rock densities. These contrasts may occur between various geological structures or between the various types of layers that constitute the Earth's crust. Thus, gravity anomalies originate either from crustal deformations at depth, or from any particular geological structure nearer to the surface.

As a rule, sedimentary rocks generally have a lower density than igneous or metamorphic rocks. Sediments of younger geological age are frequently more porous than older beds, which, after deposition, have become denser by compaction and chemical infiltration causing, for instance, silicification.

The initial approach to problems relating to the geological interpretation of Bouguer anomalies is normally to attempt to correlate gravity contour trends, prominent gravity gradients, and closed anomaly features with geological data. In the area of the Perth Basin, the geophysical problem is more complex, owing to the unusual magnitude of the gravity variation and the regional extent of the main anomaly feature. For this reason, the extremely negative gravity anomaly associated with the Perth Basin has been visualised as partially due to the accumulation of relatively light sediments in the basin, the rest of the anomaly being caused by a depression or deformation of the crust. This deformation has been regarded as associated with lateral displacement of denser material from under the crust (Thyer & Everingham, 1956). In fact, the unusual magnitude of the Bouguer anomalies, in relation to the Darling Fault zone as a prominent lineament parallel to the west coast of the Australian Continent, suggests the existence of a dislocation in the crust of the Earth, caused by the contact between two major stable blocks or cratons. These are obviously represented by the continental block of Australia and the floor of the Indian Ocean. Over-riding of the continental block upon the ocean floor is one possibility to explain the extremely negative gravity anomaly values in the Perth Basin by an increase in the total thickness of the crust (Vening Meinesz, 1948).

The methods adopted in this Record for interpreting the gravity anomaly picture is mainly on a geological basis, making use of relevant data known from surface geology and drilling, in conjunction with more recent data geophysically obtained, including the results of the B.M.R. airborne magnetometer work.

Geological interpretation

A general interpretation of the gravity data. The general inspection of the gravity anomaly pattern (Plate 3) in relation to surface geology shows the prominent low Bouguer anomaly centrally located between Arrowsmith Hill and Three Springs to coincide with an area of sedimentary deposition, identifiable structurally as the northern portion of the main Perth Basin. Assuming that low Bouguer anomalies in the area most likely indicate a thickening of low density sediments, the axis of the gravity 'low' can be regarded as being approximately indicative of the deepest portion of the basin in the map area.

Distinctly high gravity values, referred to above as the 'Pitfield High', indicate that the low density sediments of the Perth Basin are terminated to the east by a complex of higher density rocks, which, from gravity evidence, occur at a relatively shallow depth over most of the eastern portion of the map area (Plate 3).

The contact between the sediments and higher density rocks is most distinctly marked by the trend of extremely steep gravity gradients. By correlation with surface geology, this zone of steep gradients is identifiable as a major fault in the area of the Irwin River north of Mingenew, where Jurassic rocks are faulted against Permian beds. This fault is geologically known as the Urella Fault. Gravity data indicate that the fault extends as a structure of essentially uniform magnitude from the Irwin River south-south-east to a point twelve miles west of Coorow, where the zone of steep gravity gradients ends. The development of this fault, as concluded from geophysical data, is described in more detail below.

The more gentle rise in the gravity intensity westwards from the axis of the gravity 'low' indicates that the sediments deposited in the part of the Perth Basin that appears in Plate 3 are thinning to the west. For this reason, easterly dipping can be expected to prevail in the beds that occur west of the Urella Fault.

Near the coast south of Cliff Head, higher density rocks can be assumed to occur nearer to the surface because the Bouguer gravity values become less negative. At the location of the Beagle Ridge bore B.M.R.10A, drilling has shown basement rocks to occur at a depth of 4794 feet. This leads to the suggestion of an elongated basement ridge extending south of Cliff Head. On the eastern side of the gravity anomaly, contours in the range from minus 60 to minus 40 milligals are more closely spaced. This might be indicative of a steepening of the dipping angles occurring on a monocline or fault, parallel to the eastern flank of the suggested basement ridge.

In contrast, in the more central part of the map a flattening in the gravity gradient is obvious immediately west of the axis of the gravity 'low', as seen between stations Nos.182 and 183 and west of gravity station No.91. This flattening is expressed in a bulging of the contours south-east and north of Ocean Hill. The station density is insufficient for accurate contouring, but this gravity anomaly feature is significant when considered in relation to the results of the airborne magnetometer survey (B.M.R., 1964). From west of Dandaragan, a magnetic 'high' extends north for a distance of sixty miles into the area east of Ocean Hill. This anomaly reaches a maximum near its southern end and gradually flattens to the north. The combined magnetic and gravity results suggest the existence of a raised basement ridge centrally located in the Perth Basin. The position of this ridge is shown diagrammatically in Plate 2. The northernmost extension of this basement ridge is shown superimposed on the magnetic anomaly pattern in Plate 4.

The rise in the Bouguer anomaly that occurs near the north-western corner of the gravity map (Plate 3), in the area between Irwin, Dongara, and Bookara, has been described above as representing the southern end of the 'Ajana High'. This anomaly as a whole is due to a complex of gneissic rocks of Precambrian age in conjunction with older Palaeozoic formations including greywacke and sandstone, which compose the geologically known Greenough-Northampton Block. The station coverage obtained by the B.M.R. in the north-western part of Plate 3 is insufficient for accurate contouring. Consequently, the gravity picture presented is not sufficiently accurate to be conclusive about the structural contact of the sediments contained in the northern portions of the main Perth Basin and the older rocks of the Greenough-Northampton Block. Naturally it would be of great interst to investigate more completely by detailed gravity work the structural relation that, under a cover of younger sediments, controls the contact between the sediments deposited in the deeper portion of the Perth Basin and the complex of Precambrian rocks under the northern part of the map area (Plate 3).

<u>Cross-section analysis</u>. To further illustrate the probable thickness of the sediments and the bedding of the strata accumulated in the Perth Basin, gravity data can be used to determine approximately the depth to the basement underlying the sequence of sedimentary rocks. The analysis is based on the assumption that the gravity deficiency found over the synclinal area is essentially caused by the density contrast produced by less dense sediments overlying a basement composed of higher-density rocks, most likely metamorphic in nature with intruded igneous rocks.

In the Perth Basin as a whole, as pointed out above, extremely low gravity values might be partially attributed to a deformation of the Earth's crust. However, this portion of the gravity anomaly is not easily determined. A probable downwarping in the crust must be visualised, which causes a gravity deficiency of regional dimensions that overshadows local gravity variations and somehow lowers the Bouguer gravity values of the whole area.

Cross-section AB (Plates 3 & 5) has been chosen to depict in more detail the possible arrangement of the beds by correlation of gravity data with surface geology as suggested from outcrops and the results of the drilling at Beagle Ridge. In the cross-section, no allowance has been made for the regional gravity anomaly caused by crustal deformation, which might interfere with the local gravity feature.

In analysing the gravity results, the depth to the basement under the sediments has been computed as a two-layer case, using the formula:

$$G_z = 12.77 \times \sigma \times L,$$

where G_z is the gravity variation expressed in milligals, σ the density contrast in g/cm^3 between the upper and the lower layer, and L is the thickness of the upper layer measured in kilo-feet (Dobrin, 1952). The formula is applicable only for a horizontal infinite sheet, but may be used with little error in the case of beds having a small dip, where the thickness is much less than the horizontal extent of the layer.

No density data are available from measurements, made on rock specimens in outcrop or from drilling. Instead, probable densities of the type-rocks that compose the geological formations must be estimated from the nature of those rocks. The Cainozoic and Mesozoic strata penetrated in the Beagle Ridge bore B.M.R.10 include Coastal Limestone, described as a "medium- to coarse-grained calcareous sandstone", and coarse-grained sandstone, siltstone, and shale of Jurassic age (McTavish, 1960a). A density figure of about 2.2 g/cm^3 can be expected to be representative of these beds.

The overall density of the Permian beds under the Mesozoic formations can be estimated from data obtained from density determinations of Permian rocks that occur in other states, as for instance in Queensland. In the Blair Athol coalfield, Permian sediments other than coal and including sandstone, shales, and conglomerates were found to have a density of approximately 2.4 g/cm^3 (Neumann, 1959). For this reason, the average figure of 2.3 g/cm^3 has been adopted as being representative of a combination of Mesozoic and Permian rocks in the area of the cross-section AB (Plate 5).

The existence of Palaeozoic beds older than Permian must also be considered as a possibility in assessing the thickness of the sedimentary succession deposited in the Perth Basin. Pre-Permian beds, if present, cannot be expected to provide a distinct density contrast of appreciable magnitude in relation to basement rocks. For that reason, the thickness of Palaeozoic rocks older than Permian is not easily estimated and the thickness of pre-Permian beds indicated diagrammatically in the cross-section AB is entirely conjectural.

For the purpose of the analysis, a complex of Precambrian metamorphic rocks has been assumed to form the basement under the sediments accumulated in the Perth Basin. The mean density of basement rocks composed of metamorphic rocks and granitic and other igneous intrusions can be assumed to be 2.7 g/cm^3, a well-founded figure based on data available from various sources of information.

Assuming from the above that a density contrast of 0.4 g/cm^3

is likely to exist between the sediments of mainly Mesozoic and Permian age relative to the basement of metamorphic rocks, a maximum thickness of approximately 23,000 feet can be concluded to occur in the deepest portion of the basin shown in the cross-section AB. This theoretical figure would be considerably larger (30,000 feet) if a density contrast of 0.3 g/cm^3 were used instead of 0.4 g/cm^3. This example could be illustrated by visualising a sedimentary column composed of three layers of equal thickness, with the density of the three layers progressively increasing from 2.2 to 2.4 to 2.6 g/cm^3, giving an average density of 2.4 g/cm^3 for the whole column. A density contrast of 0.3 g/cm^3 would occur if this column is underlain by a basement of density 2.7 g/cm^3.

While a maximum development of 30,000 feet of sediments is acceptable geologically, there arises the question of how large a part of the gravity variation must be attributed to the downwarping in the sub-basement layers. At present, this problem cannot be adequately investigated owing to the absence of relevant data, mainly those relating to the actual thickness of the crust under the Perth Basin. In this respect, the importance of seismic data must be stressed.

Prior to the drilling of the Eneabba bore, geological reasons pointed towards a general increase easterly in the thickness of the Jurassic beds, whereas the Triassic formation could be expected to extend with more constant thickness across the whole width of the Perth Basin. However, with the completion of the Eneabba bore, it is now evident that the Triassic beds also increase in thickness easterly (WAPET, 1962). Permian beds can likewise be assumed to be affected by diastrophic movements and, for that reason, might vary in thickness as indicated in the cross-section AB. These beds might be slightly warped on the assumed basement ridge, centrally located in the basin east of Ocean Hill, which can be postulated from the combined results of gravity and airborne magnetic data. Pre-Permian strata, if present, may also be warped over the assumed basement ridge and may thicken gradually to the east in the older beds.

Urella and Darling Faults - correlation with geophysical data. The tectonic arrangement of the strata west of the Urella Fault cannot be deduced from the gravity anomalies because the lateral gravity effect of the fault may obscure minor gravity variations, which might be indicative of detailed tectonics such as step faulting. The main fault plane appears to be relatively steeply inclined according to the steepness of the gravity gradients. The dipping angle of the fault plane obviously varies, being steepest in the southernmost portion of the fault west of Yarra Yarra Lakes. As suggested by the diverging gravity contours north-west of Mingenew, the Urella Fault is less steeply inclined near the northern margin of the Dongara-Perenjori map area (Plate 3).

Movements of a secondary nature, including two cross-faults and step-faulting east of the Urella Fault, can be deduced from gravity data, where the uniformity of the gravity contour pattern is disturbed by an easterly bulge between the minus 20-milligal and minus 60-milligal lines at a point about ten miles west of Three Springs. A similar bend in the contours occurs at a short distance south-east of Mingenew.

The gravity contour map (Plate 3) and the gravity anomaly curve shown in Plate 5 indicate significant gravity gradient variations on the west side of the 'Pitfield High'. These variations are indicative of step-faulting parallel to and east of the main Urella Fault. As discussed below, an interpretation of the magnetic anomalies in this particular area leads to a similar conclusion.

From the gravity contours, which indicate smaller anomaly features superimposed on the major anomaly, the tectonic movements generally attributed to and mainly connected with the Urella Fault can be regarded as having resulted in the development of a complex faulted zone rather than a simple fault.

To further analyse the geophysical expression of the tectonics in detail, major structure lines derived from gravity data are shown in Plate 4 superimposed on the pattern of magnetic anomalies. Examining more closely the relation between gravity and airborne magnetic data, it is abvious that combined gravity and magnetic anomaly features must be used in analysing the nature and establishing the position of major fault lines in the area. This fact mainly applies to the problematic position of the Darling Fault between Winchester and Beere Hill.

The zone of steep gravity gradients, which protrudes from the south into the map area south-west of Coorow (Plate 3), ends somewhere near Winchester. However, this zone of steep gravity gradients is persistent further south over a distance of about 300 miles, being obviously indicative of the main Darling Fault over the same distance. In this connection, the question has been raised whether the second trend of steep gradients, which develops into an outstanding feature about sixteen miles west of Coorow, should be considered as representative of a continuation of the Darling Fault, or whether it is a separate feature (Thyer & Everingham, 1956).

The gravity picture gives no expression of a major fault north of Winchester over a distance of about forty miles. In this particular section of the map the gravity pattern appears to be reversed, because of the 'Pitfield High' west of Three Springs and the relatively low Bouguer anomaly values east and south-east of Three Springs.

Referring to the magnetic contours (Plate 4), an area of prominent anomalies, irregularly arranged, extends east of a line north-north-west from a point at latitude 30° and longitude 115°55', east of Lake Eganu. Outcrops of metamorphosed Precambrian rocks, associated with igneous intrusions with appreciable magnetic properties, occur in the area of the irregular magnetic anomalies. The extent and the type of irregularities can be interpreted as indicative of the existence of Precambrian rocks, which in this area comprise the Western Australian Shield. More specifically the +1100 and +1000-gamma contours can be used for the purpose of delineating the approximate western boundary of the Precambrian Shield (Plate 4) and the approximate position of the Darling Fault, which is defined as the western termination of the shield area.

Specific geological conditions, in association with the absence of the fault expression in the gravity anomalies north of Winchester, indicate a significant change in the Darling Fault over a distance of appreciable length. This is due to the existence of a marginal zone, tectonic in origin, composed of folded and faulted rocks of higher densities, and inserted between the Precambrian complex of the shield and the thick sequence of lower density sediments that occur in the main Perth Basin. Cross-section AB (Plate 5) shows this marginal zone developed structurally as a steep syncline of beds of the Yandanooka Group, terminated to the west by a ridge of granitic rocks (the Mullingarra Inlier), which in turn is terminated to the west by the Urella Fault. In this zone of folded rocks north of cross-section AB, Permian rocks are found developed with increased thickness resting unconformably on the beds of the Yandanooka Group. North of Mingenew, Permian beds are folded into the Mullingarra Anticline, and further east they form a synclinal arrangement in the Irwin River Basin.

In the Geraldton-Yalgoo 1:250,000 map area, a narrow 'ridge' of relatively high Bouguer anomaly values continues north-north-west from the 'Pitfield High' into the area of the Greenough River. From this gravity expression, a northerly extension of the marginal tectonic zone referred to in the previous paragraph can be postulated in the form of a horst-like ridge, possibly linked with the Ajana-Wandagee Ridge in the area north of the Greenough River.

The inner structure of the marginal zone, which is 'sandwiched' by tectonic movements between the main Perth Basin and the Darling Fault, is essentially asymmetrical, as igneous rocks, which also provide the core for anticlinal warping in the Permian beds, predominate on the western edge of this zone; an asymmetrically developed syncline forms the eastern portion of the zone. In a more general manner, this marginal zone of peculiar tectonic development can be described as being formed by a separate block, terminated by parallel faults and tilting down to the east (Plate 5).

In the critical area of the marginal zone between the Darling Fault and the Urella Fault, there are three distinct major magnetic anomalies: south-west and west of Three Springs and north of Mingenew. The type of these anomalies is obviously different from those indicated by irregular and rather turbulent features in the magnetic pattern, which must be attributed to the Precambrian rocks.

Obviously the Urella Fault, in contrast to the Darling Fault, is not expressed magnetically throughout its complete length. The relatively sharp magnetic anomaly of approximately twelve miles length, which occurs about twelve miles south-west of Three Springs, coincides exactly with the suggested position and the strike of the Urella Fault, as derived from the gravity results. However, no magnetic anomaly indicative of faulting has been found on the southernmost portion of the gravitationally established Urella Fault (Plate 4).

It is to be noted that the group of magnetic anomalies centred near Pitfield does not coincide with the outcrops of crystalline rocks, which form the Mullingarra Inlier. In fact the strongest magnetic variations occur immediately south-east of the southern portion of the outcropping granite (Plate 4).

The axis of the gravity 'high' and the axis of the coinciding magnetic 'high' north of Mingenew agree generally with the geological axis of the Mullingarra Anticline of Permian beds.

The irregular magnetic anomalies in the marginal zone between the Darling and the Urella Faults, in comparison with the magnetic anomalies east of the Darling Fault, indicate a similar diversity in the geology. Irregularity in the magnetic contours and lack of orientation in the arrangement of the individual anomalies was described previously as typical of the magnetic pattern attributed to metamorphosed rocks of the Precambrian Shield. The geological process principally involved in the granitisation of huge masses of crystalline rocks such as those contained in the Precambrian shields has resulted in the Precambrian rocks being 'riddled' with basic and acid intrusions (Skeats, 193[illegible]). This process of regional metamorphism has been explained as mainly related to periods of violent and deep-seated movements associated with fusion.

Australian regional gravity investigations have shown huge masses of granite in the form of batholiths, expressed by consistently negative gravity Bouguer anomalies of considerable magnitude, indicative of deep-seated root development of these granites (Marshall & Narain, 1954). On the other hand, intrusive granites of relatively small size are also known in Australia. These granites occur as dykes, sills, or laccoliths associated with faults, and thus frequently follow orientated trend directions. In eastern Australia, for instance, intrusions of granite are linked with fold movements in successive geological periods. These smaller granitic masses have been attributed to the injection of magma in essentially liquid condition into lines of structural weakness, caused by tensional stress (Skeats, 1931). In contact with sediments, intrusive granites frequently develop an aureole of highly magnetised metamorphosed rocks, which are genetically connected with the intrusion of magma.

Plate 4 shows the position of the Mullingarra Inlier immediately east of the gravimetrically determined position of the Urella Fault. Outcrops of this granite are mainly restricted to a distinct section of the gravity anomaly pattern, limited by bulging contours. This irregularity in the gravity contours can be interpreted as indicative of secondary cross-faults.

The close relation between the occurrence of the Mullingarra Inlier and the Urella Fault suggests that the Mullingarra Inlier is essentially intrusive into the zone of structural weakness created by the Urella Fault plane. Magnetic anomalies south of Arrino and Pitfield could be interpreted as indicative of highly magnetised rocks formed by contact-metamorphism in the vicinity of the granitic intrusion. On the other hand, the peculiar type of these magnetic anomalies could be also regarded as being connected with a dyke of intrusive rocks or a minor fault, parallel to and east of the main Urella Fault (Plate 4). The existence of a second fault parallel to the Urella Fault can be suggested also from gravity results.

As an explanation of the magnetic anomaly twelve miles south-west of Three Springs, highly magnetised intrusive material may have invaded a limited section of particular weakness, brought into existence by the Urella Fault. This possibility is supported by the presence of granitic outcrops of limited extent in the northernmost area of the anomaly.

The magnetic anomaly north of Mingenew is of broader appearance and agrees generally with the gravity 'high' in that area and also with the geological structure of the Mullingarra Anticline. A core of granite, forming an extension of the Mullingarra Inlier, might exist under the Mullingarra Anticline with a layer of metamorphosed, and thus magnetised, rocks immediately above the granite. A similar cover of metamorphosed magnetic rocks might have existed upon the Mullingarra Inlier before being removed by erosion and denudation.

8. CONCLUSIONS AND RECOMMENDATIONS

The results obtained by gravity work in the Dongara-Perenjori area show the usefulness of Bouguer gravity anomalies in the outlining and assessing of major structural features.

The vertical movements of unusual magnitude relative to the main Darling Fault are regarded as primary events, and principally caused by a major fracture in the crystalline shield (McWhae et al, 1958). Movements along linear trends in the area west of the Darling

Fault are secondary events, which, however, reach major proportions in the development of a marginal tectonic zone between the Darling Fault and the Urella Fault. Correlation of geophysical and geological data leads to the conclusion that the action of liquid magma resulting in igneous intrusions provides an important factor in the development of this marginal zone. Initial magmatism might have caused tectonic movement, and magmatic intrusions might have accompanied the movements that resulted in the forming of this zone. Diastrophic movements in association with, or after the end of, the magmatic events have resulted in the folding of sedimentary beds as young as Permian. Movements of a much later date are responsible for the structural development in the Jurassic sediments west of the Urella Fault.

The secondary tectonic features in the Perth Basin include elongated ridges, partially associated with magnetic intrusions and basically caused by fracturing and faulting. Asymmetrical tectonic features in the form of blocks tilting down to the east and terminated by westerly-dipping faults appear to be important features in the general structure pattern of the Perth Basin. Raised basement ridges centrally and marginally situated in the area of sedimentary deposition must be regarded as important in relation to possible oil trapping. These ridges require more detailed investigation, mainly by seismic surveys.

It is recommended that more empirical density data be obtained by the determination of rock densities on specimens collected in the field from outcrops and from bore cores. More reliable density data are important to support theoretical computations and the final evaluation of gravity anomalies in relation to geology.

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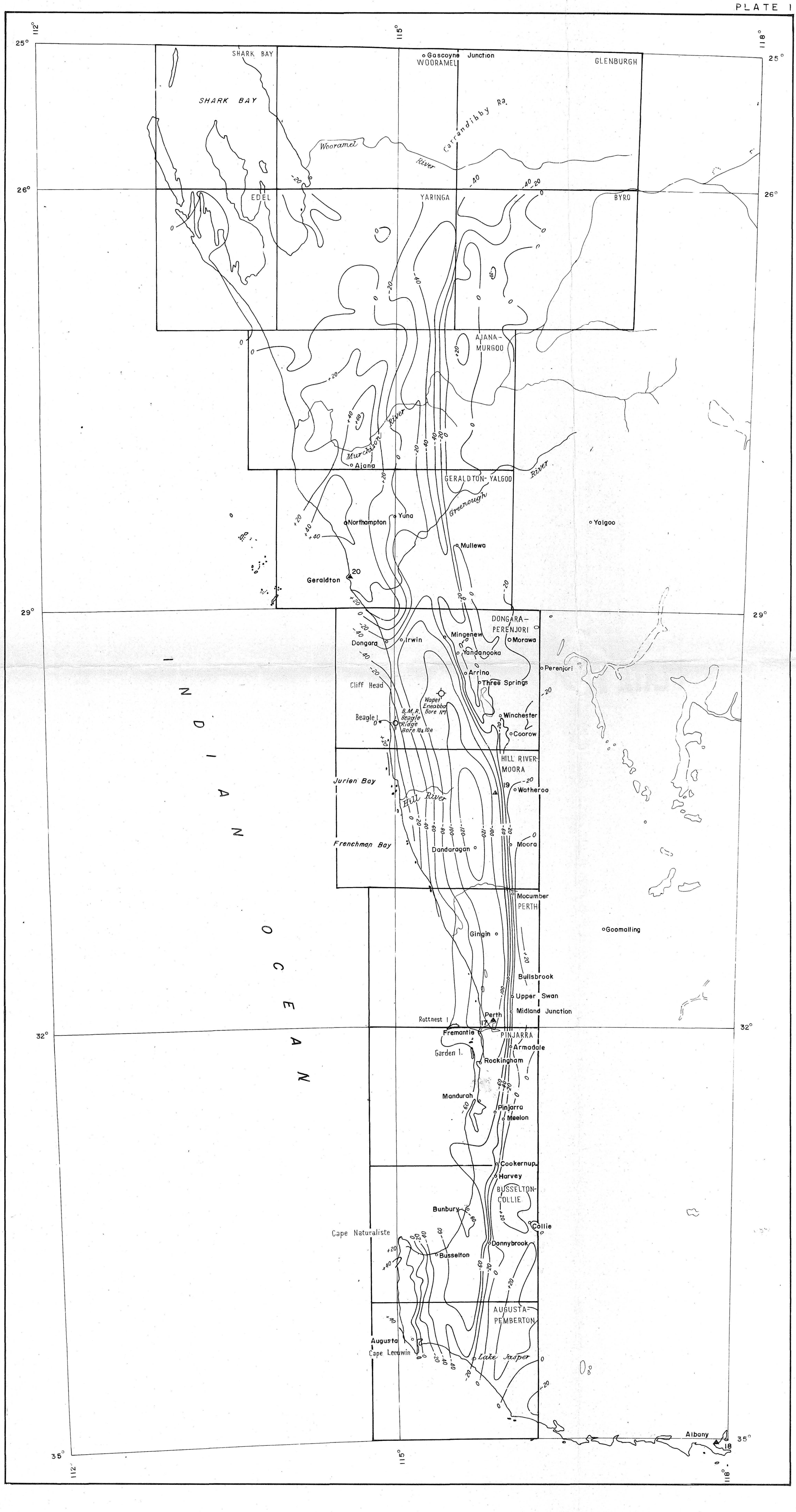
PLATE I



LEGEND

—20— Isogals (values in milligals)

▲18 B.M.R. gravity pendulum station

PERTH " 4 mile gravity map area

COMPILED AUGUST 1960

To accompany Record No 1965-140

RECONNAISSANCE GRAVITY SURVEY (1949-1960)
PERTH BASIN, W.A.

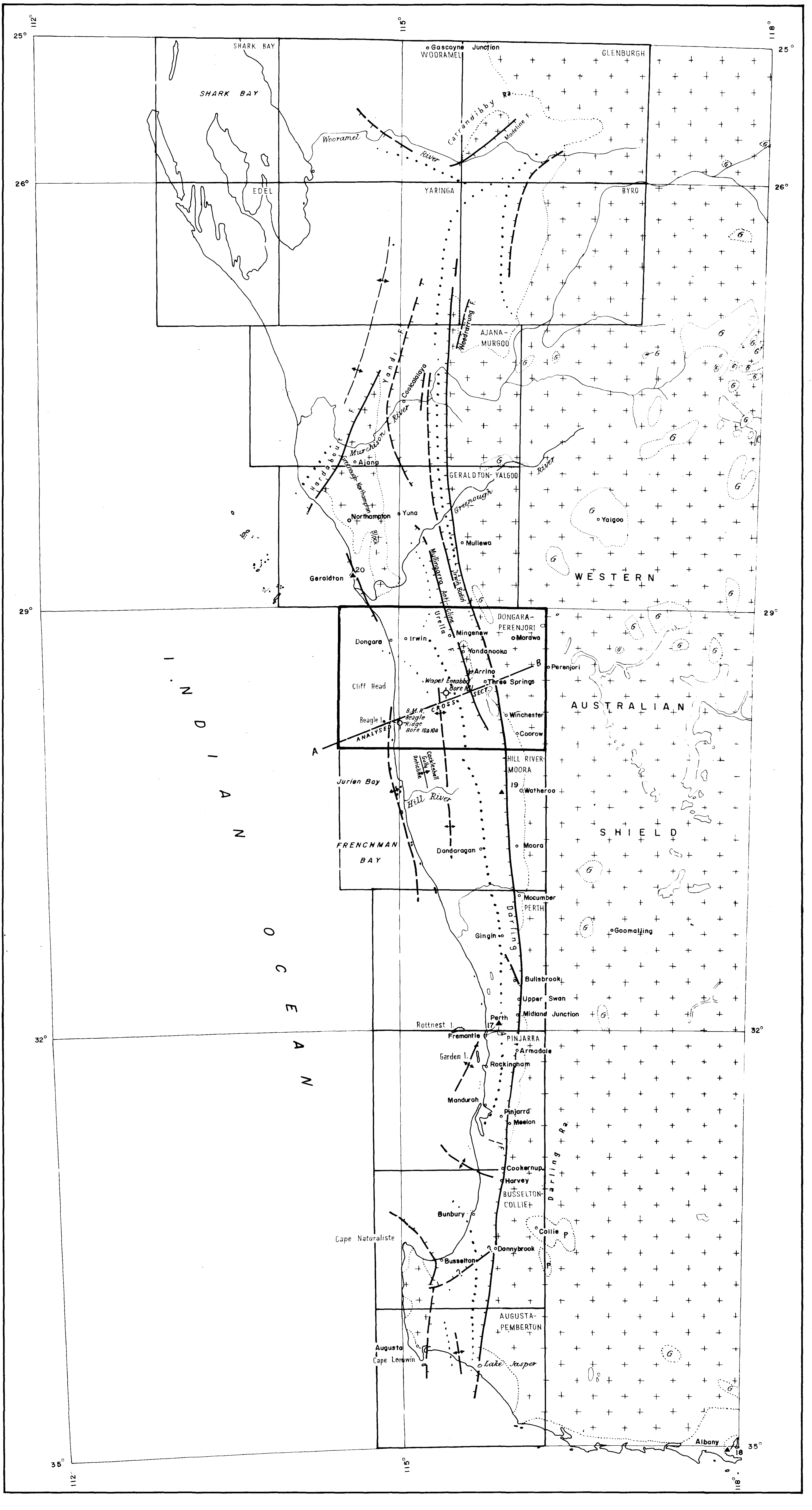
BOUGUER ANOMALIES

SCALE IN MILES
40 0 40 80 120

Reference - W.A. Mines Dep't 1950 geological sketch map

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS G 193-47

PLATE 2



LEGEND

up / down	Major fault, certain
	" " uncertain
	Anticlinal axis, geophysically indicated
	" " geologically "
	Synclinal " indicated by low gravity anomaly
+ +	Precambrian (Granite, gneiss, metamorphics)
G	Greenstone P - Permian
▲ 18	B.M.R. gravity pendulum station
PERTH	" 4 mile gravity map area

COMPILED AUGUST 1960

RECONNAISSANCE GRAVITY SURVEY (1949-1960)
PERTH BASIN, W.A.

MAJOR TECTONICS

SCALE IN MILES

40 0 40 80 120

Reference - W.A. Mines Dep't 1950 geological sketch map

To accompany Record No 1965-140

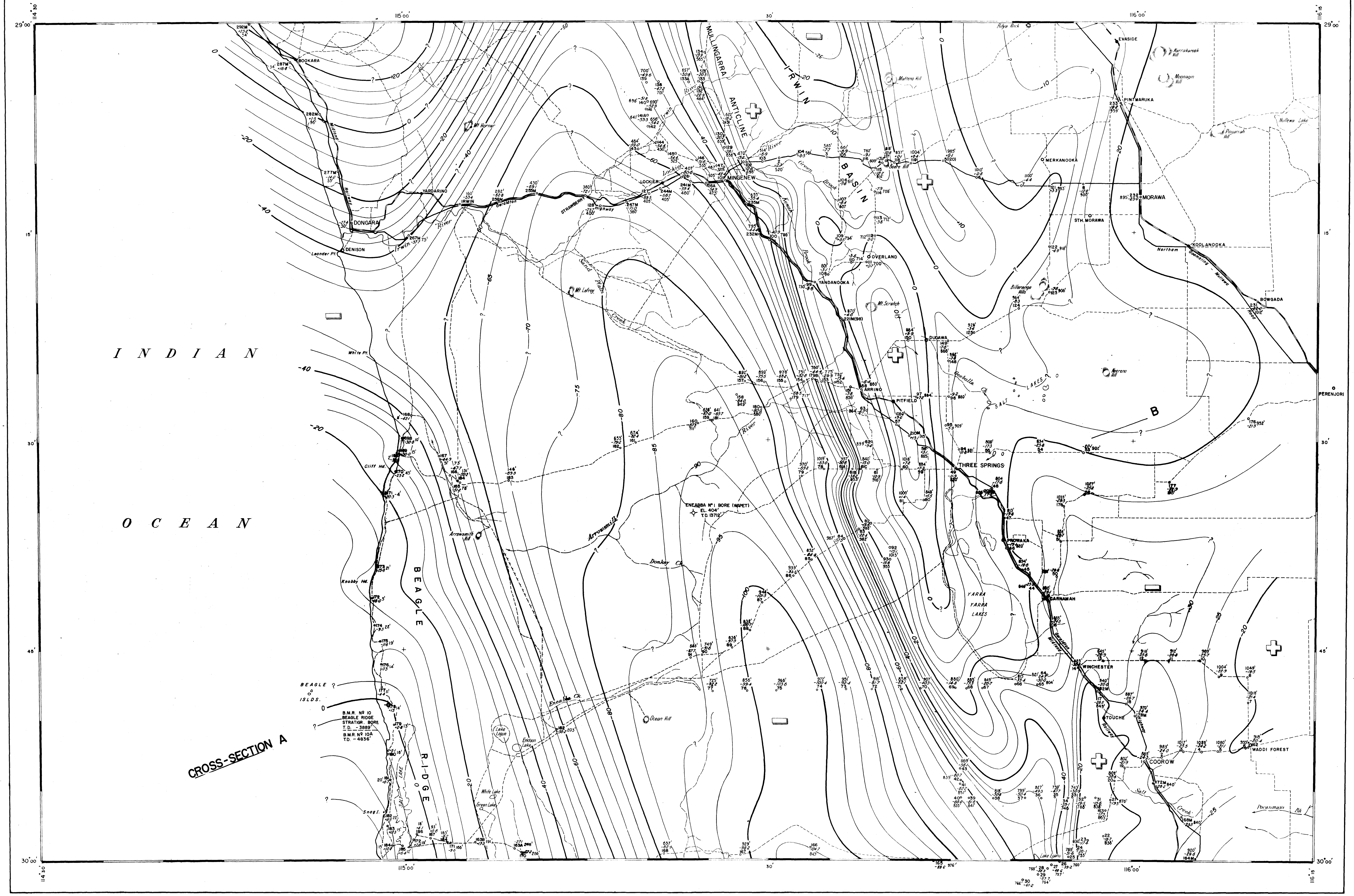
GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS G 193-46-1

AUSTRALIA 1 253,440

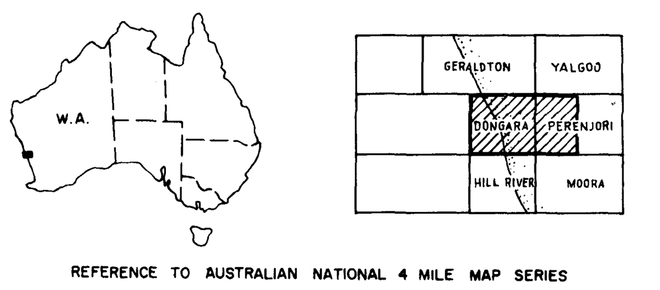
DONGARA–PERENJORI
WESTERN AUSTRALIA

PLATE 3

H 50 – 5 & 6 ZONE 1



LOCATION



REFERENCE TO AUSTRALIAN NATIONAL 4 MILE MAP SERIES

MAP DATA

PROJECTION: TRANSVERSE MERCATOR, AUSTRALIAN SERIES

CONTROL: ROYAL AUSTRALIAN SURVEY CORPS 4 MILE MAPS OF THE AREA.

DETAIL: GRAVITY STATIONS PLOTTED FROM 1949 – 1960 SURVEY DATA.

RELIABILITY: PLANIMETRIC – RELIABLE
GEOPHYSICAL – GRAVITY RECONNAISSANCE

RECONNAISSANCE GRAVITY SURVEY (1950-1960)
PERTH BASIN, W.A.
BOUGUER ANOMALIES

SCALE IN MILES

4 0 4 8 12 16 20

CONTOUR INTERVAL 5 MILLIGALS

To accompany Record No 1965-140

LEGEND

TOPOGRAPHY
- RIVER OR CREEK
- H'WAY OR MAIN ROAD
- ROAD OR TRACK
- RAILWAY
- FENCE
- TELEGRAPH LINE
- NAMED PLACE
- AERODROME OR LANDING GROUND

GRAVITY
- GRAVITY STATION
- RELATIVE BOUGUER ANOMALY (MILLIGALS)
- ELEVATION ABOVE M S L
- ISOGALS
- HIGH ANOMALY
- LOW ANOMALY

EXPLANATION

RELATIVE BOUGUER ANOMALIES ARE BASED ON THE OBSERVED GRAVITY VALUES OF THE FOLLOWING B.M.R. PENDULUM STATIONS:

Nº 17 PERTH	979,394·3	MILLIGALS
Nº 18 ALBANY	979,705·5	"
Nº 19 WATHEROO	979,216·0	"
Nº 20 GERALDTON	979,270·6	"

FOR THE CALCULATION OF BOUGUER ANOMALIES 2·2 GR/CM³ HAS BEEN ADOPTED AS AN AVERAGE ROCK DENSITY

NOTE: TOPOGRAPHY AND CULTURAL FEATURES SHOWN ONLY TO LOCATE GEOPHYSICAL DATA.

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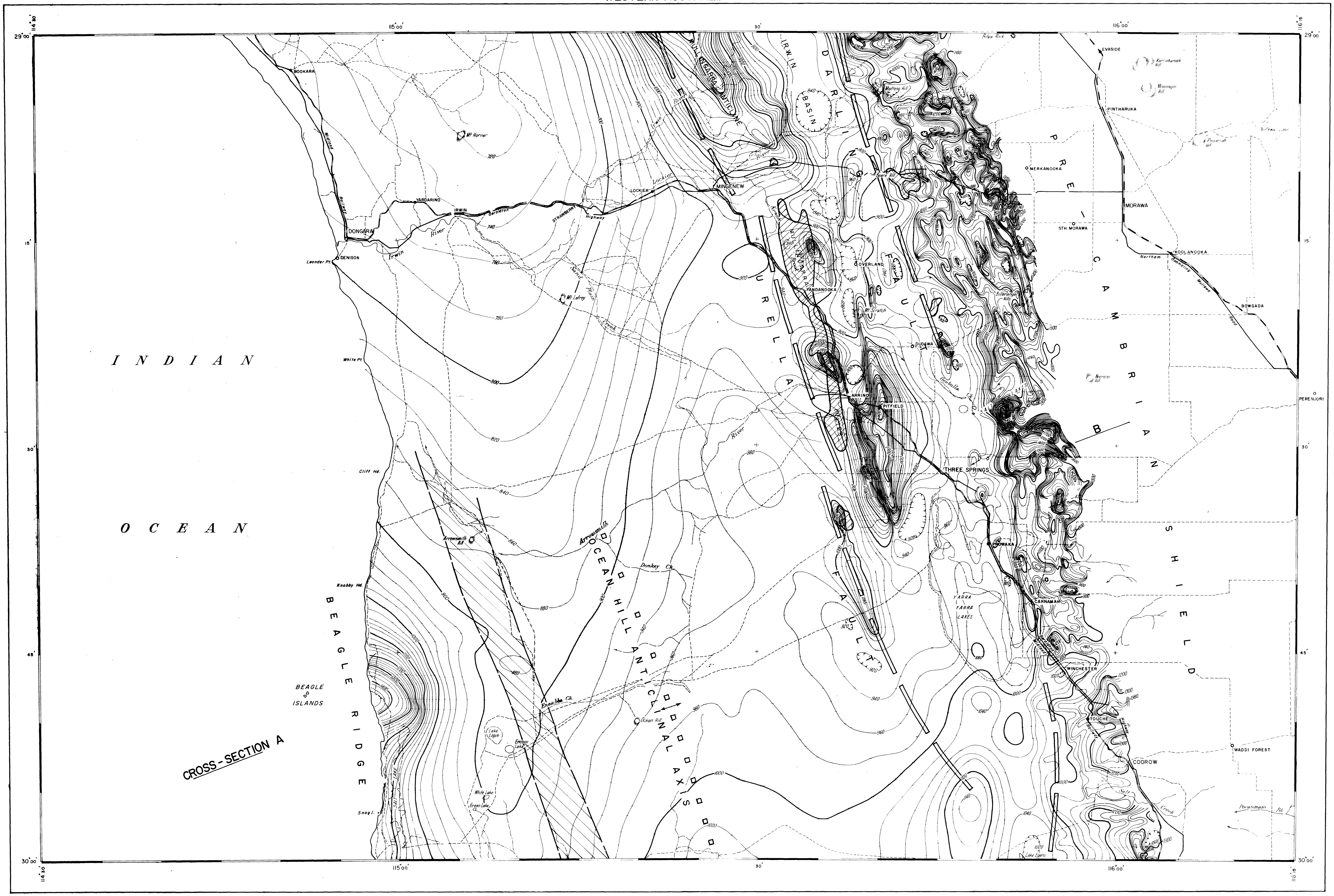
DONGARA–PERENJORI
WESTERN AUSTRALIA

PLATE 4



LOCATION

REFERENCE TO AUSTRALIAN NATIONAL 4 MILE MAP SERIES

RECONNAISSANCE GRAVITY SURVEY (1950-1960)
PERTH BASIN, W.A.
MAGNETIC CONTOURS AND MAJOR STRUCTURAL FEATURES
DERIVED FROM GRAVITY DATA

SCALE IN MILES
4 0 4 8 12 16 20

CONTOUR INTERVAL 20 GAMMAS

LEGEND

Fault (Position from gravity data)
Zone of steeper gravity gradients
Granite outcrop (Mullingarra inlier)

To accompany Record No1965-140

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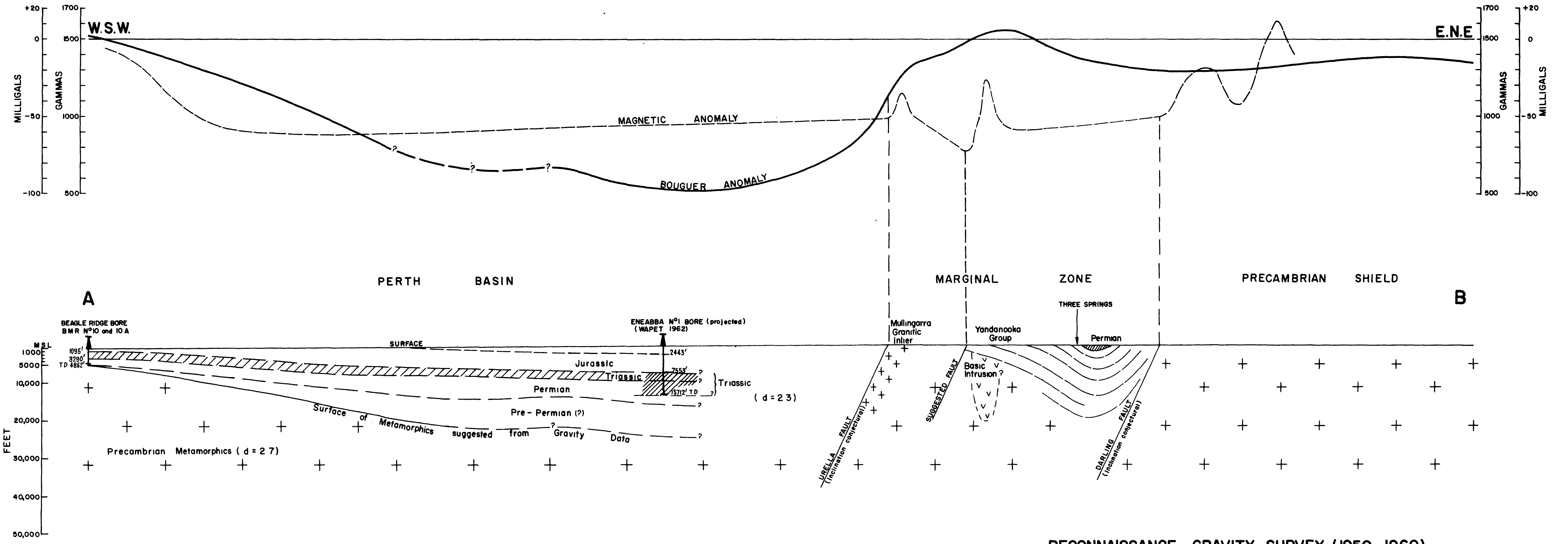

RECONNAISSANCE GRAVITY SURVEY (1950-1960)

PERTH BASIN, W.A.

BEAGLE RIDGE - THREE SPRINGS AREA

ANALYSED CROSS-SECTION A-B

CORRELATION OF GEOLOGY AND GEOPHYSICS

The stratigraphy was suggested before the completion of ENEABBA bore

Triassic beds proved to be much thicker than expected and the metamorphic basement may be much deeper than shown

HORIZONTAL SCALE IN MILES

4 0 4 8 12

VERTICAL SCALES AS SHOWN

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