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DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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GRAVITY SURVEY OF THE PERTH BASIN, WESTERN AUSTRALIA

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R. F THYER and I B. EVERINGHAM

Issued under the Authority of Senator the Hon. W. H SPOONER, M.M., Minister for National Development

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Minister—SENATOR THE HON. W. H. SPOONER, M.M.

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ILLUSTRATIONS

ABSTRACT

During 1949 and 1951, whilst investigating possible underground water supplies, staff of the Bureau of Mineral Resources surveyed two east-west gravity traverses near Watheroo Observatory (120 miles north of Perth) and Bullsbrook (20 miles north-north-east of Perth). Results of these investigations suggested the presence of a major fault a few miles to the east of both places and gave evidence of a large thickness of sediments underlying the coastal plains. It was decided, therefore, to extend the gravity investigations to a reconnaissance survey of the whole of the coastal region between Geraldton in the north and Cape Leeuwin in the south, extending inland from the coast for distances of 100 to 150 miles. This bulletin gives the results of the survey, which was made in 1951 and 1952 over an area of about 43,000 square miles and comprised gravity observations at 650 stations.

The survey revealed a negative gravity anomaly of large magnitude and areal extent. Bouguer anomaly values, with a minimum of more than −130 milligals, form a trough about 400 miles long and up to 55 miles wide. Steep gravity gradients on the flanks of the anomaly suggest the existence of faults which have resulted in relatively light sediments lying adjacent to denser basement rocks. Such steep gradients indicate that the major part of the anomaly is due to an accumulation of sediments which at their maximum development may be about 30,000 feet thick.

The Darling and Dunsborough Faults show up prominently on the gravity pattern, but other faults deduced from geological evidence are not apparent — probably because the vertical movement on these faults has been too slight to have affected the gravity pattern. On the other hand, the gravity results indicate the presence of other faults, previously undetected. Two minor synclines are indicated, diverging from the main synclinal axis, and the importance of anticlinal axes associated with these synclines is stressed.

The gravity pattern indicates that although the Perth Basin narrows to the north, between converging faults, it continues in that direction, to join the Carnarvon Basin.

Recommendations are made for more detailed gravity surveys to be made in certain localities and for seismic surveys of selected traverses across the basin.

INTRODUCTION.

The discovery of oil in the Rough Range Structure of the Carnarvon Basin, Western Australia, in December, 1953, stimulated interest in the search for oil in Australia, with the result that considerable attention is now being paid to other sedimentary basins on the continent. Little is known about the stratigraphy or total thickness of sediments in many of these, particularly in their deeper parts, and geophysical surveys, particularly regional gravity surveys, offer a rapid method for making a preliminary assessment of the total thickness of sediments in them.

The Perth Basin of Western Australia, lying on the western margin of the continent between Geraldton in the north and Cape Leeuwin in the south, is such a basin. The surface of the basin is mostly sand plains which extend along the coast north and south of Perth. Sediments of various ages are exposed at a few places in or adjacent to the basin. The oldest sediments are Upper Pre-Cambrian rocks and the youngest Recent sands. The limited evidence available from these exposures suggests that the sediments were deposited during a number of discrete periods of sedimentation. It is possible however that sediments of ages and types not represented in the outcrops are present deep in the basin.

The surface of the basin is mostly covered by sand of Recent age and the basin is bounded by faults. Apart from evidence provided at one or two places by water bores with a depth of about 2,000 feet, little is known regarding the thickness and age of the sediments in the basin. It will be shown that the gravity survey described herein indicates the accumulation of a very considerable thickness of sediments, perhaps exceeding 30,000 feet. In view of its closeness to the Indian Ocean it would be surprising if marine transgressions with accompanying sedimentation forming possible source beds for oil had not occurred during the history of the basin.

The results of the gravity survey are therefore of considerable importance in assessing the economic potentiality of the basin in that they indicate the presence of a much thicker sedimentary section than formerly thought likely.

The only gravity observations that had been made prior to the present ones were those made by the Dutch geophysicist, Vening Meinesz (1948). He made submarine observations of gravity supplemented by some land observations at widely-spaced points on a single east-west traverse through Perth. Owing to the wide separation of the stations his work did not reveal the true form of the Perth Basin anomaly.

The present survey was initiated in 1949 near the Bureau's magnetic observatory on the coastal plain at Watheroo, about 120 miles north of Perth. The observatory had inadequate water supply and a proposal to drill a deep bore was under consideration. A gravity traverse was made from the observatory to outcropping Pre-Cambrian rocks about 8 miles to the east in order to make a preliminary estimate of the thickness of the sediments at the proposed bore site. The gravity (Bouguer) anomaly was about −20 milligals on the Pre-Cambrian rocks but fell rapidly to −95 milligals at the observatory — an average gradient of 10 milligals per mile, although it was considerably steeper over part of the traverse. The traverse was later extended westward to the coast where the Bouguer anomaly rose to slightly positive values. An interpretation of this anomaly, based on the assumption that the gravity deficiency was due to light sediments, suggested the presence of a major fault about 5 miles east of the observatory and that the thickness of sediments on the down-thrown side of the fault might be of the order of 30,000 feet.

Shortly afterwards the Bureau was requested by the Government Geologist, Department of Mines, Western Australia, to make a similar investigation near Bullsbrook, about 20 miles north-north-east of Perth, where deep boring for artesian water was under consideration. An east-west traverse was made from the Pre-Cambrian rocks on the east through Bullsbrook for a distance of 3 miles to the west of the township. The results (Thyer, 1951) were similar to those obtained near Watheroo and gave additional evidence of a major fault and of a large thickness of sediments underlying the coastal plains. In view of the importance of these results it was decided to extend the gravity work to a reconnaissance survey of the whole of the coastal region between Geraldton in the north and Cape Leeuwin in the south, extending inland from the coast for distances of 100 to 150 miles.

In general, this survey consisted of a series of east-west traverses about 20 to 30 miles apart, with stations at 5-mile to 10-mile intervals. These traverses were tied together with north-south traverses along highways and railway lines. In the southern part the investigation was extended east to Albany. An area of approximately 43,000 square miles was surveyed, of which the Perth Basin occupies 15,000 square miles.

TECHNICAL MATTERS.

Field work was done as opportunity offered. The greater part of the gravity observations was made by I. B. Everingham (December, 1951, to September, 1952) and J. H. van Son (July, 1951), but W. H. Oldham and others assisted in the early stages. The final reduction and correction of the results were done by I. B. Everingham and J. van der Linden and type sections were calculated by R. Green. The work was carried out under the direction of the senior author.

A total of 650 stations was observed by the usual technique of repeat readings to eliminate the effect of instrumental drift. Where practicable, stations were placed near railway and other bench marks to make use of the known elevations. At other places elevations were determined by microbarometers. At those stations observed near bench marks the elevations were known to ± 0.5 feet but the barometric elevations may be subject to errors of ± 20 feet.

Elevations range from sea level to about 1,200 feet above sea level on the Darling Ranges. On the coastal plains, i.e., over the sedimentary basin itself, the range of elevations is much smaller. In the region between Gingin and Bunbury the land slopes gently from the coast to the Darling Scarp. In the northern part of the basin the coastal plains rise to about 600 feet above sea level.

The readings were corrected for latitude and elevation in the usual way, an elevation correction factor of 0.06 milligals per foot being adopted.

The gravity values were adjusted to semi-absolute values by tying to pendulum stations at Albany, Perth, Watheroo and Geraldton.

Most of the stations on the coastal plains between Perth and Geraldton were read with a Norgaard meter (TMR.413) and the remainder with a Worden meter (No. 61). The values obtained with the Worden meter are more accurate than those obtained with the Norgaard. Due to the cumulative effect of errors in level, position and instrument reading, the Bouguer anomaly values are probably no more accurate than ± 2 milligals.

GEOLOGY.

Stratigraphy.

The following notes on the geology of the area are based on an unpublished review by Fairbridge (1949) prepared from existing reports. Field work carried out by others since that date may have added to the knowledge of the area, but, unless outcrops of rocks not previously recorded have been found, the description that follows is substantially correct. It is not intended to be a complete account of the geology but merely to present a geological background for describing the gravity results.

The area covered by the gravity survey lies between Cape Leeuwin in the south and Geraldton in the north, and extends inland for an average distance of approximately 100 miles. The Perth Basin lies to the west of the West Australian Plateau, which is about 1,500 feet above sea level and forms one of the world's ancient (Pre-Cambrian) shield areas. The western edge of the plateau is marked by a prominent scarp known as the Darling Scarp. The only rocks which crop out on the coastal plain are sediments ranging in age from Permian to Recent. In the extreme south-west, Pre-Cambrian rocks are exposed to the west of the sediments; the area between Cape Naturaliste and Cape Leeuwin is occupied by Pre-Cambrian rocks. Pre-Cambrian rocks crop out also near the coast north of Geraldton.

There are few outcrops in the coastal plain, which is covered mainly by sand, and little is known about the stratigraphy or lithology of the deeper rocks in the basin.

The oldest sediments known in the area are late Pre-Cambrian in age. They occur at two places along, and immediately to the east of, the Darling Scarp. In the north they extend from Moora to Mingenew and are generally called the Yandanooka Series, consisting principally of quartzite, shale, limestone and volcanic tuffs. In the south, the Cardup Series, comprising sandstone and shale, occurs along a narrow strip overlying the older Pre-Cambrian rocks south of Perth. The strike of these sediments is parallel to the Darling Scrap and they dip on an average 60° to the west. Their structure is consistent with an extensive downwarp to the west and they appear to be about 2,000 feet thick.

There are no known sediments with ages between Pre-Cambrian and Permian.

Permian sediments, including coal measures, glacial tillite, sandstone and shale with thin bands of marine limestone, crop out in the Irwin River area in the northern part of the basin. In this area their measured thickness is 3,350 feet. Two small and isolated basins containing Permian coal measures occur in the Darling Plateau at Collie and Wilga, east of Bunbury.

Mesozoic sediments, mainly Jurassic and Cretaceous, crop out in the northern portion of the basin and are believed to underlie most of the Coastal Plain. They form plateaus in the area north of Gingin. The rocks exposed in the extreme southern part of the coastal basin are thought to be Triassic (the Donnybrook Series). They include sandstones and shales and some coal measures but their age has not been established with certainty. The total thickness of the Mesozoic rocks is difficult to estimate but may be between 1,000 and 3,000 feet. They are mainly terrestrial in origin but contain marine facies to a minor extent in the Middle Jurassic and Upper Cretaceous.

Tertiary rocks are represented only by marine rocks of Eocene age, which range up to about 1,000 feet thick, and by basalt flows ranging from 30 to 100 feet thick. The basalt appears to occur only in a restricted area south of Bunbury.

The coastal limestones which constitute most of the outcropping rocks on the coastal side of the basin are Quaternary and are only a few hundred feet thick.

The total known thickness of the sedimentary rocks, including the Cardup Series, is therefore about 9,000 feet. It will be shown later, however, that the gravity results indicate a considerably greater total thickness.

Large negative gravity anomalies, such as that about to be described, are commonly associated with active vulcanism and earthquake zones, but in this basin there is little evidence of vulcanism apart from the limited occurrence of Tertiary basalt south of Bunbury, and the basin is seismically very quiet.

Structure.

The principal structural feature in the area is the Darling Fault, which forms the boundary between the Pre-Cambrian shield on the east and the Perth Basin on the west. This fault extends for over 500 miles as a rectilinear feature from Cape d'Entrecasteaux in the south to beyond the Murchison River in the north. The Darling Fault is for the most part marked by a pronounced topographic feature, the Darling Scarp, which is approximately 1,000 feet high near Perth. At the northern end of the basin, however, the scarp is insignificant.

There are some lower scarps on the coastal plains to the west of the Darling Plateau and these have been regarded also as normal faults. In the south there is a low scarp which diverges from the Darling Scarp near the Collie River in a south-westerly direction. This has been correlated with the so-called Whicher Fault. To the north of Perth another low scarp, which marks the Hill River Fault, diverges from the Darling Scarp in a north-westerly direction through

Gingin to the coast near Jurien Bay. Parallel to this, and further north, is the Irwin Fault, which intersects the coast about 5 miles north of Geraldton.

The ridge of Pre-Cambrian rocks cropping out between Cape Naturaliste and Cape Leeuwin is separated from the coastal basin by the Dunsborough Fault. The Darling, Whicher, Hill River, Irwin and Dunsborough Faults are shown on the geological plan (Plate 1), but although there is strong gravity evidence of the existence of the Darling and the Dunsborough Faults there is little, if any, gravity evidence of the others. It will be shown, however, that the gravity evidence indicates the presence of additional faults so far unnamed.

On the basis of the faults described above, Fairbridge (1949) and others divided the Perth Basin into structural units. The central portion north and south of Perth, between the Hill River and Whicher Faults, is considered to be most depressed and is referred to as the Perth Sunkland. To the south of the Whicher Fault is the Donnybrook Block. That part lying to the north of the Hill River Fault has been referred to as the Dandaragan Block, and to the north of the Irwin Fault, the Northampton Block. These are shown on Plate 1. It will be shown, however, that this subdivision is not supported by the gravity results.

Although there are very few outcrops of sediments on which dips and strikes can be measured, it appears likely that the sediments are for the main part little disturbed by folding, although regional tilting may be present in some places. Marked folding occurs, however, in the northern part of the basin along its eastern side in the Irwin River area, where Permian sediments are exposed along the axis of an anticlinal structure (the Mullingarra axis). Similar folding may occur elsewhere in the basin but there is no surface evidence of it.

It is interesting to note that some geologists, for example Gibb Maitland (Fairbridge, 1949, p. 20), have favoured the idea that the ridge of Pre-Cambrian rocks which crop out between Cape Naturaliste and Cape Leeuwin (the Naturaliste Horst) extends north beneath Rottnest Island to the west of Perth, and that the Perth Sunkland is a broad graben or rift valley. The gravity results support this idea and, in fact, suggest that the Pre-Cambrian rocks may extend at no great depth from Cape Naturaliste to Geraldton and form the western border of a great rift or graben some 400 miles in length.

RESULTS OF THE SURVEY.

The results are shown as Bouguer anomalies relative to theoretical values on the International Ellipsoid. Isostatic corrections have been computed for only a few stations, but it is evident that such corrections will not modify the picture to any considerable extent. Their main effect would be to increase the values near the coast by 30 to 40 milligals and elsewhere by amounts which decrease with distance from the coast. The net effect would be to tilt the whole pattern to the east without affecting appreciably the contrast between the low values and the surrounding highs.

General Interpretation.

The Bouguer anomaly plan, Plate 2, shows a narrow and deep trough of negative Bouguer values extending from Geraldton to Cape Leeuwin and bounded on the east by the Darling Scarp and its prolongation to the north. To the east of this trough the Bouguer anomalies form a broad positive zone coinciding with the western margins of the Pre-Cambrian shield and fall to negative values still further east. This is illustrated by an east-west gravity section (Plate 3) from Kalgoorlie to Rottnest Island. Over the eastern portion, from Kalgoorlie to Cunderdin, Bouguer values range from −40 to −60 milligals; they rise to a maximum value of −10 milligals about 15 miles east of the Darling Scarp and drop to low values (−100 milligals) over the coastal basin. Negative Bouguer values over continental masses of granitic rocks, such as on the Western Australian Plateau, are common, and it may be assumed that the low gravity values on the far eastern side of the area are normal. The increase in gravity from Cunderdin towards the Darling Scarp may be due to a local thinning or up-turning of the granitic layer adjacent to the fault. Nothing is known of the crustal thickness in this region.

It is generally assumed that the average thickness of the continental (sialic) layer is about 10 km. Below this layer and down to the Mohorovicic discontinuity there are believed to be intermediate layers of basaltic (simatic) rocks. The Mohorovicic discontinuity marks the lower limit to which the crustal layers are deformed, the ultrabasic rocks below the discontinuity being sufficiently plastic to flow under sustained stresses. The depth to the Mohorovicic discontinuity, found from seismic evidence, ranges from 25 to 60 km. on continental masses. Densities of 2.67, 2.87 and 3.32 are assumed for the granitic, intermediate and ultrabasic layers respectively, and a thinning of the crust between Cunderdin and the Darling Scarp of the order of 6,000 feet could account for the observed gravity change of 50 milligals. The densities of the intermediate and ultrabasic layers are conjectural and may be somewhat lower than the values quoted above; in this case a somewhat greater thinning would be necessary.

The western edge of the gravity trough coincides with the coast between Geraldton and Jurien Bay, but evidently lies a little distance off the coast further south and as far as Busselton, near where it intersects the coast about 13 miles west of the town. There, the western edge coincides with the Dunsborough Fault, and the trough seems to terminate on the continental shelf of the south coast. The trough is about 400 miles long and averages about 55 miles in width.

A remarkable feature in the Bouguer anomaly plan is the very large gravity gradient along the Darling Scarp and on the western edge south-west of Busselton. These very large gradients strongly favour the assumption that the anomaly is mainly due to a near-surface mass deficiency, such as would result from the presence of relatively light sediments adjacent to denser masses of basement rocks. This interpretation is supported by calculations of gravity anomalies for geological sections incorporating the above structure.

Calculations have been made for a great number of theoretical sections and compared with observed gravity profiles for various sections across the basin. It is not proposed to illustrate or describe these individually but merely to point out the main conclusions that can be drawn from them. Considering first the geophysical evidence for the main Darling Fault, it is clear from the magnitude of the gravity gradients and the position of the contour pattern relative to the known contact between the sediments on the west and basement rocks on the east, that normal faulting with a steep westerly dip is most probable, at least in the near-surface layers. However, the evidence is not sufficiently clear to exclude entirely the possibility of overthrusting, although this seems unlikely.

In certain parts of the basin, for example in the latitude of Watheroo, there are no steep gradients on the western side which can be interpreted as due to faulting. In such places the structure would seem to be an east-tilted block of sediments hinged near the coast and deeply faulted at the Darling Fault. At other places, for instance south of Cape Naturaliste, the western margin of the basin also appears to be faulted, the down-throw being to the east, but not as great in magnitude as at the Darling Fault.

The maximum thickness of the sediments has been estimated from the calculated sections. For this estimation, it has been necessary to make certain assumptions regarding the thickness and density of the crustal layers and the manner in which they have been deformed during the formation of the sedimentary basin.

For the purpose of the calculations it was assumed that the sediments in the basin were deposited on a crust comprising a granitic layer of density 2.67 and 10 km. thick overlying an intermediate layer 30 km. thick of average density 2.87, in turn overlying ultrabasic rocks of density 3.32. As the basement of the basin was depressed, the granitic and intermediate layers, being more or less rigid, were depressed an equal amount, displacing ultrabasic rocks which, being sufficiently plastic, flowed laterally. This lateral flow resulted in the elevation of the crustal layers to the east of the major fault (Darling Fault) and the subsequent thinning of part of the granitic layer by removal during normal weathering processes. It will be recalled that such a thinning of the granitic layer to the east of the Darling Scrap was assumed to explain the increase in gravity between the Darling Scarp and Cunderdin. A similar elevation and thinning of the crustal layers to the west of the basin is possible but there is no supporting evidence from gravity data.

The gravity anomaly over the Perth Basin is thus due in part to an accumulation of relatively light sediments in the basin, and in part to the depression of the crustal layers with attendant lateral displacement of the dense ultrabasic rocks which underlie the crust. The amount contributed respectively by these two causes to the total anomaly depends on the thickness and density of the various layers and the extent of their displacement from "normal." It cannot be assessed except by assuming definite values, such as quoted above, and definite shapes. When this is done, calculations show that somewhat less than half the observed gravity deficiency is due to the sediments, the rest being due to the depression of the crust itself.

In calculating sections across the basin a variety of thicknesses, shapes and densities of the crustal layers was assumed in an endeavour to get a "best fit" to the observed gravity anomalies. This is a time-honoured procedure in gravity interpretation, even though it is perfectly clear from considerations of potential theory that there are an infinite number of mass distributions which could account for the observed anomalies. Nevertheless, the procedure has the virtue of showing whether or not a section postulated as "geologically reasonable" and used to explain the observed gravity anomalies, would give rise to anomalies of the right magnitude and shape.

On the basis of the uncertain evidence provided by the calculations it is estimated that the maximum thickness of sediments in the basin is of the order of 25,000 to 35,000 feet, the depth being greatest where the Bouguer anomaly is most negative, i.e., near Watheroo, where a value of −130 milligals was observed. Except at its northern and southern extremities, the shallowest part of the basin appears to be to the west of Harvey, between Perth and Bunbury, where the maximum thickness of sediments is probably less than half the value given above. It is seen therefore that even at its shallowest part, near Harvey, the basin appears to have considerably more than 9,000 feet of sediments, the maximum thickness formerly thought likely from geological evidence.

The main conclusions to be drawn from the calculated sections are therefore:—

(*a*) The basin is for the most part bounded by normal faults of great magnitude.

(*b*) The basin contains a great thickness of sediments, which at their maximum development may be 25,000 to 35,000 feet thick.

The most likely cause of the gravity anomaly is a deep graben or rift, filled with light sediments. The graben contains two deep troughs, one centred opposite Moora and Watheroo corresponding to a Bouguer anomaly of −130 milligals, and the other centred about Bunbury and enclosed by the −80 milligal contour line. The gravity evidence does not support the division of the Perth Basin into Perth Sunkland and Donnybrook and Dandaragan Blocks, but suggests rather that the subdivision should be into the two main troughs mentioned above, which might be called the *Dandaragan* and *Bunbury* Troughs.

Structure as Revealed by Gravity Results.

The outstanding structural feature in the gravity anomaly pattern is the Darling Fault. There is little doubt that this is a normal fault with an unusually large throw. Apart from the steep gradient which coincides with the Darling Fault, there are similar but less steep gradients coinciding with the Dunsborough Fault. A steep gradient with decreasing gravity towards the east and about 8 to 10 miles east of Dunsborough Fault in the latitude of Busselton almost certainly indicates the presence of another fault. The gravity contour pattern suggests that towards the south this converges with and joins the Dunsborough Fault.

There is no gravity anomaly corresponding to the Whicher Fault but near where the Whicher Scarp joins the main Darling Scarp there is a pronounced break in continuity of the Darling Fault, as indicated by the corresponding gravity pattern. The general southerly strike of the Darling Fault persists, but at the southern end it appears to be displaced about 3 miles to the west with respect to the northern part.

The gravity contours give little, if any, evidence of the Hill River Fault. Apart from a slight change in trend of the gravity contours for 20 or so miles to the north of Gingin and a slight steepening of the gradient 29 miles west of Moora, there is no disturbance in the gravity pattern which could be related to this fault. On the basis of the present gravity evidence, therefore, it must be assumed that the throw on this fault is too small to affect appreciably the thickness of sediments on either side of it.

The Irwin Fault cuts across the trend of the gravity contours south-east of Geraldton. The gravity contours are smooth and undistorted where it crosses them and it seems likely, therefore, that the Irwin Fault, like the Hill River Fault, is a minor structural feature — at least as far as vertical movement is concerned.

In the northern part of the area, north of Three Springs, the general pattern of the gravity anomalies becomes more complex in conformity with the more complex geological environment. The zone of steep gradients, which for 300 miles south of Coorow has a persistent northerly trend (and which corresponds to the main Darling Fault), swings abruptly to the north-north-west, passing about 6 miles west of Arrino and through Mingenew. It thus passes to the west of the Mullingarra Anticline and coincides with the western edge of the Pre-Cambrian rocks which are exposed to the south of this anticline. The zone of steep gradients evidently corresponds to a fault of major displacement but whether this should be considered as the continuation of the main Darling Fault or whether it is a cross-feature is open to question. In strike, this fault is roughly parallel to the Hill River and Irwin Faults, but nevertheless it appears to be continuous with the main Darling Fault. Over a length of approximately 100 miles it forms the eastern margin of the Perth Basin but it appears to die out at its northern end. The gravity contours suggest that the Perth Basin continues to the northern edge of the gravity map (Plate 2), gradually shallowing as the northern edge of the map is approached.

The Mullingarra Anticline shows up prominently as a low ridge in the gravity pattern which continues for a distance of approximately 50 miles north of Mingenew, passing about 12 miles to the west of Mullewa. The Mullingarra Anticline is bordered on the west by the main (north-north-west striking) fault described above. To the east of the Mullingarra Anticline the gravity results indicate the presence of another trough only a few miles wide and flanked on the east by another major fault. This fault coincides with the continuation of the Darling Fault as shown by Fairbridge (1949) and has been traced by gravity work for at least 100 miles south of Mullewa. This eastern basin continues to the northern edge of the gravity contour plan (Plate 2) where, together with the northerly continuation of the main Perth Basin, it forms a broad but relatively shallow trough some 20 miles wide.

Although the gravity map presented in this report terminates on the 28th degree parallel of latitude, it is of interest to note that further gravity work done by the Bureau to the north of this shows that the Perth Basin is joined to the Carnarvon (North-West) Basin by this narrow trough.

The gravity contours near Dongara show a steep gradient, which is interpreted as a fault with a down-throw to the east. A relatively steep gradient about 25 miles to the east of Geraldton also suggests a fault with a down-throw to the east, and in the interpretation shown on Plates 2 and 4 this has been correlated with the fault through Dongara. This fault marks the western margin of the Perth Basin in this region.

On Plate 4 are shown the faults as described by Fairbridge (1949) and, by a different symbol, those indicated from the gravity results. There is close agreement between the Darling Fault, as indicated by the gravity results, and as mapped geologically over its entire length.

Except in the extreme northern and southern parts there is no strong evidence of faulting on the western margin of the basin. However, the gravity results indicate that for a considerable distance the western margin lies on the continental shelf, where, even if faulting is present, there are no gravity observations to confirm it. From the evidence available, however, it is assumed that the western margin of the basin is, like the eastern margin, marked by faults.

The structural picture as a whole is, therefore, that of a graben or rift. In horizontal dimensions the rift is similar to many of those in East Africa and it is of interest to compare the gravity results obtained over the Perth Basin with those obtained by Bullard (1936) over some of the rifts in East Africa. Bullard made a limited number of gravity observations with pendulum equipment over some of these and showed that large gravity minima, of magnitude similar to that obtained over the Perth Basin, occurred over them. His observations were not sufficiently numerous to determine whether or not large gravity gradients similar to those obtained on the Darling Fault and elsewhere are present. In drawing his gravity profiles he obtained relatively broad minima which he showed could be explained satisfactorily by anomalous mass distributions at the base of the granitic layer. The possibility of a thick accumulation of sediments is ruled out on geological grounds. As shown above in the general discussion of the results of calculated sections, a substantial part, perhaps more than half, of the gravity anomalies measured over the Perth Basin might be attributed to similar mass distributions at and below the base of the granitic layer, but it is again emphasised that the very steep gravity gradients measured leave no doubt that a significant part of the Perth Basin anomaly is due to a thick accumulation of sediments.

Axes of Sedimentation.

As a first approximation it can be assumed that the axes of the gravity minima also represent the axes of maximum sediment thickness, or sedimentation. On Plates 2 and 4 these axes have been shown by lines with appropriate symbols. The principal axis is a single linear feature, but at four places additional axes are shown. At the northern end of the area the main basin appears to terminate at the latitude of Geraldton but another trough, parallel to the axis of the Perth Basin and lying to the east of it, appears to commence east of Mingenew and extends to the northern edge of the map (Plates 2 and 4). As mentioned before, this trough extends still further north and joins the Carnarvon Basin. Between this and the main Perth Basin lies the Mullingarra Anticline.

To the west of Watheroo and Coorow there is a minor disturbance in the gravity pattern which suggests the presence of a minor synclinal axis diverging in a north-easterly direction from the deepest part of the Perth Basin towards the Darling Fault opposite Coorow. If this interpretation is correct, it suggests that an anticlinal axis exists between this and the main Perth Basin axis. Such an anticlinal axis would be of interest in oil prospecting because of the possibility of favourable structures being present.

South-west of Pinjarra the gravity pattern indicates the possibility of another minor synclinal axis diverging in a southerly direction towards the Darling Fault from the main axis near Mandurah. It is of interest to note that the southward continuation of this axis would intersect the Darling Fault near where the latter shows a distinct break in continuity such as might be expected from a cross feature. The minor synclinal axis and the break in continuity in the Darling Fault may be related, but there is insufficient gravity data to confirm this.

It will be noted also that the gravity results suggest the presence of a saddle between two deeper parts of the Perth Basin, namely that centred about 12 miles to the south of Bunbury (the Bunbury trough) and that centred opposite Moora and Watheroo (the Dandaragan trough). From the gravity results it might be predicted that this region is one in which structures favourable to the accumulation of oil, if present in the basin, might be found and therefore it should be of considerable interest to oil prospectors. It is an area which, on gravity evidence, would be favourably placed to receive drainage from the deep parts of the basin to the north and south of it. Further, the suggestion of a split in the axis of sedimentation implies the possibility of an anticlinal axis between the two synclines.

In the southernmost region the main Perth Basin axis appears to terminate before reaching the coast, but parallel to it and further to the west another trough is developed which on gravity evidence extends to, and presumably beyond, the south coast, east of Augusta. Gravity contours are shown as closing further south but there is no real evidence of this. It might be expected on geological grounds, however, that the trough does not extend beyond the limits of the continental shelf, which lies about 8 miles further south.

In an area about 35 miles north-west of Gingin there is a minor disturbance in the gravity contour pattern and this could be due to faulting or folding of the sediments.

Although not related to the structure of the Perth Basin it is interesting to note that the Collie Basin (Chamberlain, 1947) shows as an isolated gravity trough on the Pre-Cambrian plateau to the east of Bunbury.

Age of Faulting.

Faulting evidently plays an important part in the structure of the Perth Basin, although the main subdivisions of the basin (as suggested by the gravity data) into the Dandaragan and Bunbury troughs is not necessarily controlled by it.

It is beyond the scope of this report to discuss fully the geological evidence for the age of the faults — the gravity results themselves give no indication of the age. The Darling Fault appears from the gravity evidence to be a normal fault, at least near the surface, dipping steeply (70° - 80°) to the west with a maximum throw of perhaps 30,000 feet or more. It must not be inferred from this interpretation that the movement on this fault is visualised as occurring as a single event or even within a restricted time. There is ample geological evidence to suggest that the movement along this fault line commenced in Palaeozoic times and was rejuvenated at intervals throughout its history. There is some evidence to suggest that the movement was not unidirectional and that periods of elevation and depression succeeded one another — the nett movement of course being a major depression of the Pre-Cambrian basement to the west of the fault. The gravity evidence suggests that this was accompanied by an elevation of the crustal layers or basement rocks to the east of the fault, with subsequent thinning by erosion of the granitic layer.

Nothing is known of the dips of the beds in the basin. When these are known it is possible that unconformities and disconformities may shed some light on this interesting and important problem.

CONCLUSIONS.

The gravity survey of the Perth Basin has revealed a gravity anomaly of great magnitude and areal extent. The anomaly is a negative one, indicating a substantial mass deficiency. Bouguer anomaly values with a minimum of more than —130 milligals form an extensive trough about 400 miles long and up to 55 miles wide.

Very steep gravity gradients on the flanks of the trough suggest the existence of normal faults which have resulted in relatively light sediments lying adjacent to denser basement rocks. The gradients are so steep that a near-surface mass deficiency, such as would be produced by a thick layer of sediments, must be one of the principal causes.

It is believed that the negative gravity anomaly is caused by such a sedimentary layer, which reaches a maximum thickness of some 30,000 feet. This figure has been estimated from the results of calculated sections in which assumptions have been made regarding the density, thickness and displacement of the crustal layers underlying the sediments in the basin.

The general structural picture revealed by the gravity survey suggests a graben or rift of dimensions similar to some of the major rifts of East Africa. Within the graben are two depressions or troughs deeper than the average. These are shown by the closing of the gravity contour lines about them and have been called the Bunbury and Dandaragan troughs. These can be regarded as forming the main subdivision of the basin. No gravity evidence was found to support the subdivision based on surface geological mapping into the Perth Sunkland and Donnybrook and Dandaragan Blocks.

Faulting is an important structural feature of the basin. The Darling Fault, which forms its eastern edge, is shown prominently in the gravity pattern by the steep gradients associated with it. In the south the Dunsborough Fault is similarly shown, but other faults deduced from surface geological evidence, namely the Whicher, Irwin and Hill River Faults, do not appear to have affected the gravity pattern, except that in the case of the Hill River Fault, the trend of the gravity contour lines is roughly parallel to it and may have been influenced by it. It can only be assumed, therefore, that if these faults exist, the vertical movement on them has been too slight to have produced any substantial differences in depth to basement rocks on either side of them.

On the other hand, the gravity pattern suggests the presence of faults so far undetected and unnamed. There is strong evidence of a major fault diverging from the Darling Fault to the north-north-west near Coorow and of other faults along the western margin of the basin, notably near Dongara and Busselton.

Minor irregularities in the gravity contours at two places in the basin, namely west of Watheroo and Coorow and to the south-west of Pinjarra, suggest the presence of minor synclines diverging from the main synclinal axis of the basin. It may be inferred that an anticlinal axis may be found between the synclines; such an axis might favour the occurrence of structural traps for oil and gas, if present in the basin.

The "saddle" in the gravity contours, centred about 20 miles south-west of Pinjarra between the Bunbury and Dandaragan troughs, might well be a place favouring the occurrence of suitable structural traps. Any closed structure in this region would presumably be favourably placed to receive drainage from the basins to the north and south of it.

The gravity pattern in the northern part of the area is more complex than in the south, in conformity with the more complex geological structure. The Perth Basin becomes narrower and shelves to the north between converging faults on its eastern and western flanks. It does not terminate within the area described in this report, but continues northward to join the Carnarvon (North-West) Basin (Chamberlain, Dooley and Vale, 1954).

The anticlinal structure (Mullingarra axis) in the Irwin River area to the north-west of Mingenew shows up as a ridge in the gravity contours, no doubt due to the elevation of the denser basement rock beneath it. East of this axis a narrow trough, only a few miles wide and flanked on the east by a major fault, stretches northward and joins the main Carnarvon Basin. The gravity "ridge" corresponding to the Mullingarra axis continues northward.

The effect of the Mullingarra axis on the gravity pattern suggests that similar anticlines, if present in the basin, would be indicated by localised increases in gravity, and for this reason the implied anticlinal axis between diverging synclinal axes west of Watheroo and to the south-west of Pinjarra may be significant.

The strong probability of a much thicker sedimentary section than formerly thought likely greatly enhances the prospects of finding oil or gas in the basin. At present there is little, if any, direct evidence of suitable source beds, but as the gravity results strongly suggest at least 20,000 feet more sediments than are known in outcrop, source beds might well be included in the "unknown" beds.

Further, the gravity pattern contains several minor disturbances which could be related to folded structures not visible at the surface. The inference from the gravity results that such structures might occur in the basin is in contrast to the views expressed in the geological section of this report that the sediments are "little disturbed by folding, although regional tilting may be present in some places" (see page 4). The inference therefore that favourable structures may be present in the basin offers added incentive to explore it thoroughly for oil.

The gravity pattern may also be useful in the search for coal. Coal seams of Permian age crop out on the Irwin River about 21 miles north-east of Mingenew and have been found in bores at various places, for example at Eradu, on the flanks of the Mullingarra axis. The gravity pattern, particularly if more detailed surveys are made followed by seismic traverses at selected places, might assist in working out the detailed structure of the coal measures and indicate favourable drilling targets. The coal revealed to date has been low grade and at Eradu occurs in thick but lenticular seams. The coal measures may be much more extensive than at present known and there is a reasonable possibility that better quality coal may be found elsewhere in them.

RECOMMENDATIONS.

The gravity survey described is at best a broad reconnaissance which serves a useful purpose in outlining the structural pattern of the Perth Basin. Much more gravity work would be needed to fill in and clarify the picture. The results described suggest some immediate targets for such work. These would be:—

(*a*) West of Watheroo and Coorow where the gravity pattern suggests diverging synclines.

(*b*) The saddle south-west of Pinjarra between the Bunbury and Dandaragan troughs.

(*c*) A zone along the strike of the Hill River Fault.

(*d*) The northern extension of the Mullingarra axis.

(*e*) The Darling Fault, north and south from the Collie River.

(*f*) An area 35 miles north-west of Gingin where the gravity pattern is disturbed.

More interesting and important than further gravity work would be seismic surveys of selected sections crossing the basin. In the first place an east-west section through Gingin is recommended. This would cross the Hill River Fault near the town of Gingin and would provide useful information on the thickness and dip of the sediments.

Other sections should be run south of Pinjarra across the gravity "saddle" and through Watheroo at the widest part of the basin.

The Bureau has already embarked on a seismic programme in the basin and the results will be described in a subsequent report.

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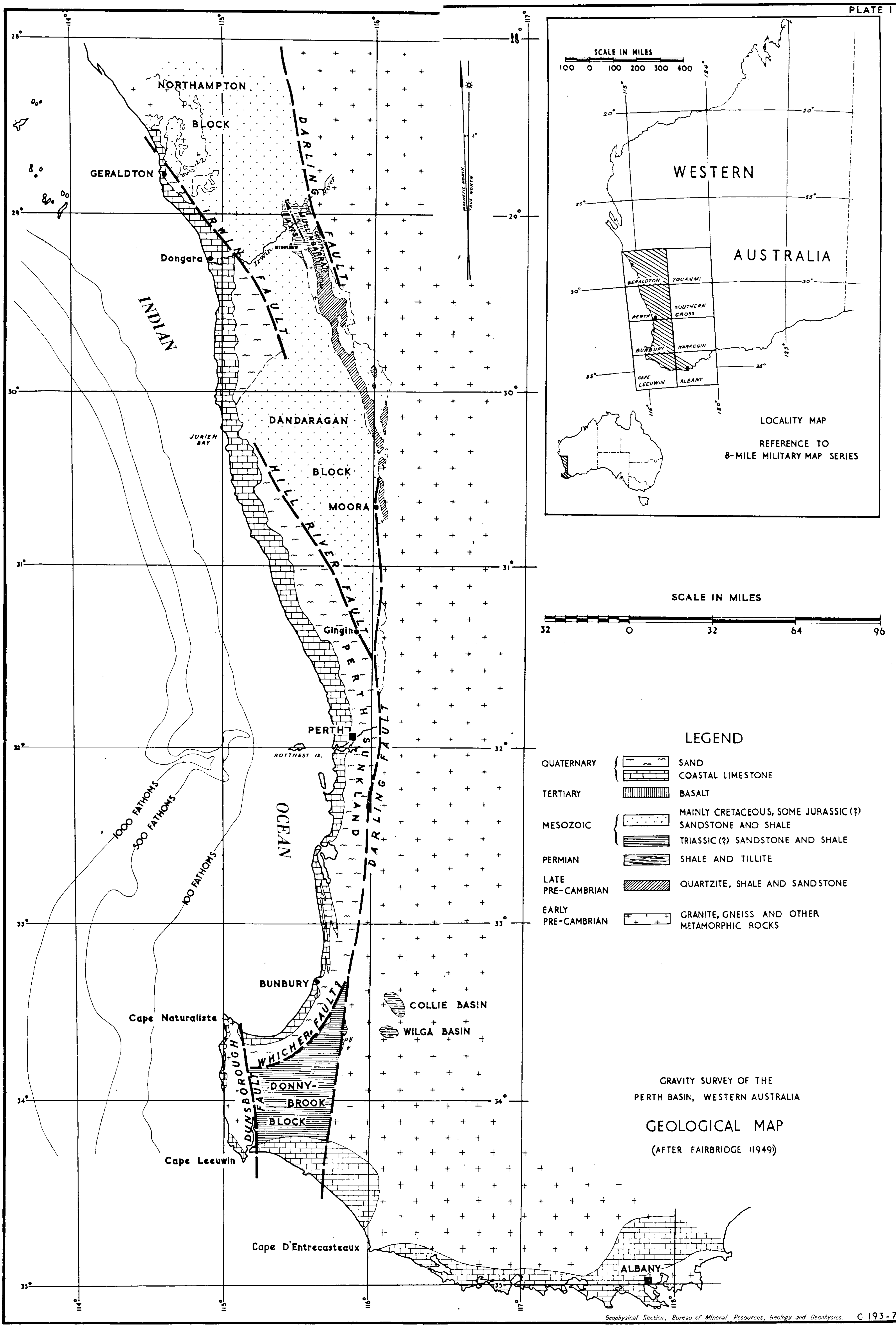
PLATE I



NORTHAMPTON
BLOCK
GERALDTON
Dongara
IRWIN FAULT
DARLING FAULT
INDIAN
OCEAN
JURIEN BAY
DANDARAGAN
BLOCK
MOORA
HILL RIVER FAULT
Gingin
PERTH SUNKLAND
PERTH
ROTTNEST IS.
1000 FATHOMS
500 FATHOMS
100 FATHOMS
BUNBURY
Cape Naturaliste
WHICHER FAULT ?
DUNSBOROUGH FAULT
DONNY-BROOK BLOCK
COLLIE BASIN
WILGA BASIN
Cape Leeuwin
Cape D'Entrecasteaux
ALBANY
MAGNETIC NORTH
TRUE NORTH
SCALE IN MILES
100 0 100 200 300 400
WESTERN
AUSTRALIA
GERALDTON
YOUANMI
PERTH
SOUTHERN CROSS
BUNBURY
NARROGIN
CAPE LEEUWIN
ALBANY
LOCALITY MAP
REFERENCE TO
8-MILE MILITARY MAP SERIES
SCALE IN MILES
32 0 32 64 96
LEGEND
QUATERNARY
SAND
COASTAL LIMESTONE
TERTIARY
BASALT
MESOZOIC
MAINLY CRETACEOUS, SOME JURASSIC (?) SANDSTONE AND SHALE
TRIASSIC (?) SANDSTONE AND SHALE
PERMIAN
SHALE AND TILLITE
LATE PRE-CAMBRIAN
QUARTZITE, SHALE AND SANDSTONE
EARLY PRE-CAMBRIAN
GRANITE, GNEISS AND OTHER METAMORPHIC ROCKS
GRAVITY SURVEY OF THE
PERTH BASIN, WESTERN AUSTRALIA
GEOLOGICAL MAP
(AFTER FAIRBRIDGE (1949))
Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics.
C 193-7

PLATE 2

Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics.

G193-8

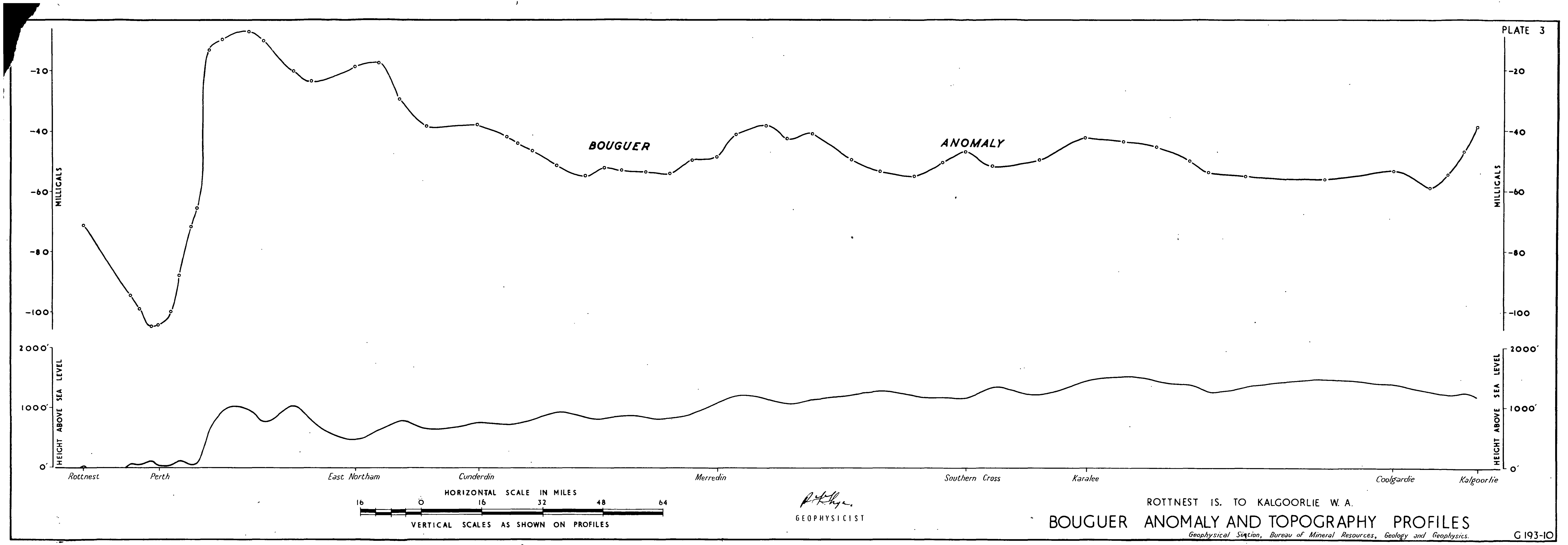


PLATE 3
BOUGUER
ANOMALY
MILLIGALS
-20
-40
-60
-80
-100
2000′
1000′
0′
HEIGHT ABOVE SEA LEVEL
Rottnest
Perth
East Northam
Cunderdin
Merredin
Southern Cross
Karalee
Coolgardie
Kalgoorlie
HORIZONTAL SCALE IN MILES
16 0 16 32 48 64
VERTICAL SCALES AS SHOWN ON PROFILES
GEOPHYSICIST
ROTTNEST IS. TO KALGOORLIE W. A.
BOUGUER ANOMALY AND TOPOGRAPHY PROFILES
Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics.
G 193-10

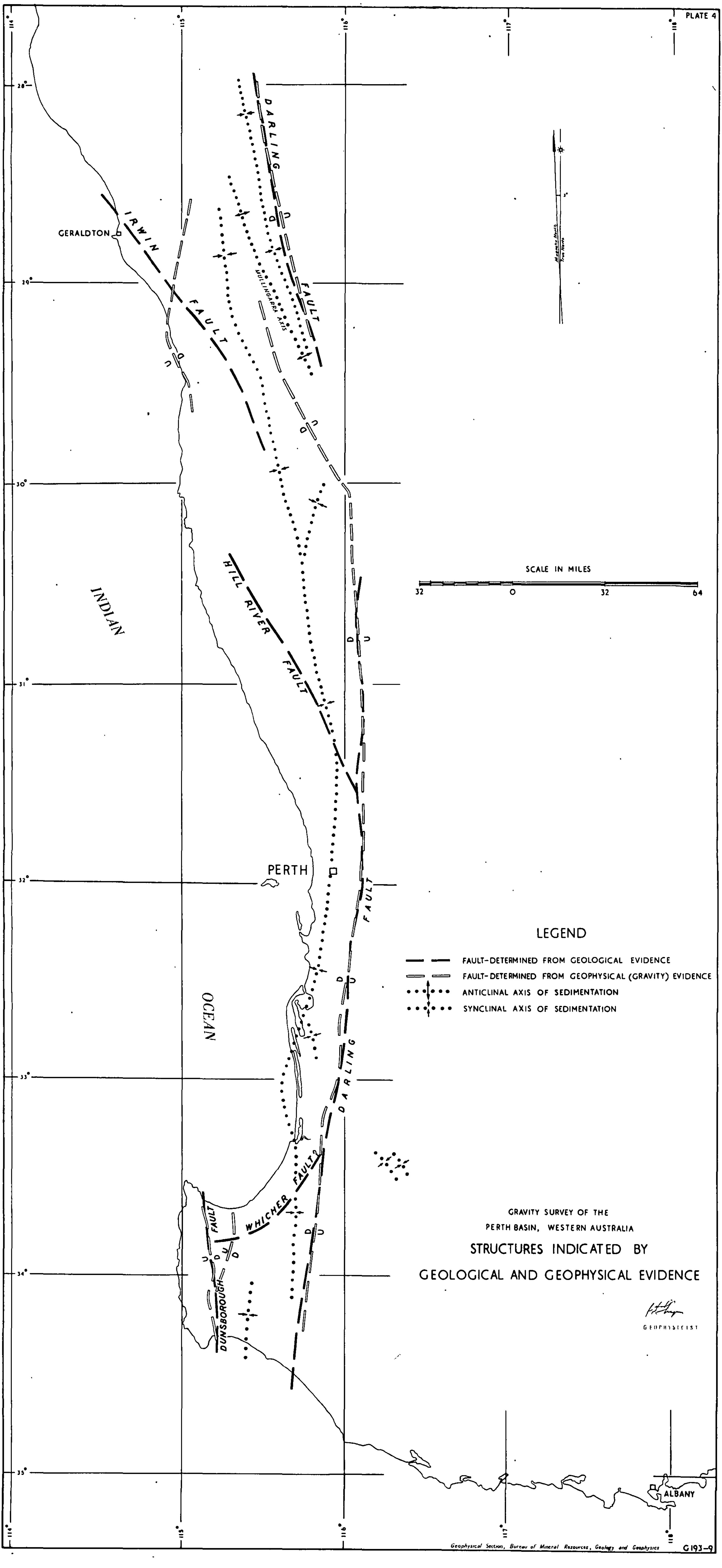


PLATE 4
GERALDTON
IRWIN FAULT
DARLING FAULT
BULLINGARRA AXIS
HILL RIVER FAULT
INDIAN OCEAN
PERTH
DARLING FAULT
WHICHER FAULT?
DUNSBOROUGH FAULT
ALBANY
SCALE IN MILES
32 0 32 64
LEGEND
FAULT-DETERMINED FROM GEOLOGICAL EVIDENCE
FAULT-DETERMINED FROM GEOPHYSICAL (GRAVITY) EVIDENCE
ANTICLINAL AXIS OF SEDIMENTATION
SYNCLINAL AXIS OF SEDIMENTATION
GRAVITY SURVEY OF THE
PERTH BASIN, WESTERN AUSTRALIA
STRUCTURES INDICATED BY
GEOLOGICAL AND GEOPHYSICAL EVIDENCE
GEOPHYSICIST
Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics
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