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GRAVITY SURVEY

IN THE

FITZROY BASIN

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W.A.Wiebenga & J.v.d.Linden

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COMMONWEALTH OF AUSTRALIA
DEPARTMENT OF NATIONAL DEVELOPMENT
BUREAU OF MINERAL RESOURCES,
GEOLOGY AND GEOPHYSICS

RECORDS 1953, No. 64

GRAVITY SURVEY
IN THE
FITZROY BASIN,
KIMBERLEY DIVISION, WESTERN AUSTRALIA

WITH SPECIAL REFERENCE TO THE NERRIMA STRUCTURE

by

W.A. WIEBENGA and J. van der LINDEN

CONTENTS

ILLUSTRATIONS

PLATE NO.

TEXT FIGURE	Facing page
1. Bouguer gravity profile through B4 and Mt.James over Fenton Fault.	11
2. " " " " G155 and G30 over Fenton Fault.	11
3. " " " " " "	11
4. " " " " G174 and Mt. Density over Fenton Fault.	11
5. Throw of Fenton Fault and the depth of the higher density formation between Mt. James and Mt. Arthur.	11
6. Table illustrating the correlation between geology, seismic refraction data and densities for the Nerrima area.	11

A B S T R A C T

The Fitzroy Basin is situated south-east of Derby in the Kimberley Division of Western Australia. Results are given of a semi-detailed gravity survey which was made of the portion of the basin between longitudes 123°40' and 124°30' and latitudes 18°05' and 18°40'.

The survey disclosed a large basin structure at least 7,000-8,000 feet deep and a few minor anomalies which may prove important. It is not known whether the higher density formation at 7,000-8,000 feet depth in the basin represents Pre-Cambrian basement or sediments of Devonian or Ordovician age. The position of, and displacement on, the Fenton Fault system were indicated.

A detailed gravity survey of the Nerrima structure confirmed the existence of faults which had been mapped by the Bureau's geological and seismic parties, but was unable to determine the depths to which these faults penetrated.

Seismic refraction work and test drilling are recommended south of the Fenton Fault, between Barnes' Flow and Mt. James, to disclose the nature of the higher density formation. Recommendations are also made for an extension of the detailed gravity survey to areas in which anomalies were revealed by the semi-detailed survey.

1. INTRODUCTION

The Fitzroy Basin is situated to the south-east of Derby, in the Kimberley Division of Western Australia (Plate 1).

This Basin is one of several in Australia in which the search for oil has been carried out intermittently over a number of years. The Freney Kimberley Oil Co. N.L., holds three leases in the Basin and the West Australian Petroleum Pty. Ltd. holds the remainder of the area under an authority to prospect for oil.

In 1939, the Freney Kimberley Oil Co. started drilling the Nerrima No.1 bore, at a site selected by Dr. A. Wade, on the Nerrima Dome. As a result of the Japanese entry into the war in 1941, drilling was stopped at a depth of 4271 feet. Operations were resumed after the war, but ~~certain~~ drilling difficulties were encountered and the hole was finally abandoned.

During 1951 and 1952, negotiations took place for the resumption of drilling operations on the Nerrima structure, the cost to be divided equally between the Commonwealth Government, the Western Australian Government and the Freney Kimberley Oil Co.N.L. Because geophysical investigation in the Carnarvon (or North West) Basin, Western Australia, had shown that some structures mapped on the surface did not persist in depth, and were therefore unsuitable as drilling targets, it was considered essential that similar investigations be carried out on the Nerrima structure before further drilling was undertaken. It was also considered that if the geophysical survey proved that the structure persisted in depth, it would assist in determining the most favourable drilling site for the second bore. Accordingly, seismic and gravity surveys were commenced in 1952. ?

The Bureau began a geological survey of the Basin in 1948, continuing the work during succeeding field seasons. The Nerrima structure has been mapped and described in detail by Guppy, Cuthbert and Lindner (1950).

This report describes the results of the gravity survey, which was confined to that part of the Basin around the Nerrima Dome. The area covered by the survey is located between latitudes 18°05' and 18°40' and longitudes 123°40' and 124°30' (Plate 2). Field operations began on the 10th July, 1952, and ended on the 10th October, 1952.

The programme of gravity work proposed for the Fitzroy Basin consisted of:-

(a) Regional Survey. Regional gravity surveys are an important tool in the geological appraisal of large areas. The regional survey was started in the 1952 field season and continued during the 1953 season. Although the results of the regional survey are not included in this report, a section on Regional Gravity is included in order to give a general indication of the regional trend over the Fitzroy Basin.

(b) Semi-detailed Survey. During the 1952 season, a semi-detailed survey was made over 1,800 square miles, station intervals along survey lines being about one mile. The results of such a survey enable areas to be selected which warrant further investigation by detailed gravity and/or seismic methods.

(c) Detailed Survey. A detailed survey was made in 1952, mainly to determine whether or not a gravity high exists under the Nerrima structure, and to assist the seismic survey in the investigation of the fault and fracture pattern of the structure. The station interval along the survey lines ranged from a quarter to a half-mile.

The divisions between the three types of survey are not always clearly defined, as each type tends to merge into the others. However, the broad classification outlined above is useful in the discussion of results.

2. GEOLOGY

The Fitzroy Basin is bounded by two major fault systems, the Pinnacle and Fenton Faults (Plate 3). The geology of the basin has been described by Wade (1936), Teichert (1949), Guppy et al (1950), Schneeberger (1950, 1952) and Guppy (1953).

(a) Stratigraphy.

The Fitzroy Basin contains Ordovician, Devonian and Permian sediments, and in some places Mesozoic sediments. The basement is of Pre-Cambrian rocks (Plate 3).

Fossiliferous rocks of Ordovician age were discovered for the first time in Western Australia in 1949 (Guppy and Opik, 1950). They are confined to a small area of about 12 sq.miles near Price's Creek, and it is not known whether they attain regional significance within the basin, or whether they occur only as erosional remnants preserved in local depressions in the basement floor. in outcrop

The Devonian rocks crop out extensively along the north-eastern margin of the Basin and may extend under cover of Permian sediments over a large part of the basin.

Permian rocks extend over the greater part of the Basin and attain a maximum thickness of approximately 7,000 ft. They consist mainly of sandstones, siltstones and tillites, including the Grant Formation, Poole Sandstone, Noonkanbah and Liveringa Formations. The Nerrima No.1 bore, which commenced in the Noonkanbah Formation and was drilled to 4,271 feet, did not reach the base of the Permian, which is probably at a depth of not less than 5,700 ft. below surface.(at this locality)

A general columnar section of the sediments in the Fitzroy Basin is reproduced in Plate 4.

The Devonian sediments are mainly limestones (in the outcrop area) and are overlain by the Permian, with an angular unconformity. They are considered as one of the most important formations in the oil exploration programme, as they contain likely source, reservoir and cap rocks in the correct succession. The Ordovician rocks also contain likely source and reservoir rocks, and are known to contain traces of oil. It is believed that coral reefs were formed in the Devonian seas at the higher parts of the sea floor or along the shore lines. As the coral limestones may be reservoir rocks and perhaps source rocks, the detection of such higher levels is of great importance. Moreover, these Devonian highs may result in structures in the overlying beds through differential compaction. There seemed to be a reasonable possibility that the Nerrima Dome was such a structure.

(b) Structure.

The area covered by the semi-detailed gravity survey contains the following important geological structures:-

(i) The Fenton Fault.
(ii) The Nerrima Structure (Nerrima Dome).
(iii) The Myroodah Anticline (Deep Well Anticline).
(iv) A long, well-marked syncline between (ii) and (iii).
(v) The Myroodah Syncline.
(vi) A syncline north-east of Mt. James.

In investigating the structure of the Fitzroy Basin, it is important to consider how the Devonian limestones and the Permian sandstones will behave under stress. Sandstones near the surface will probably be fractured and faulted, while limestones at depth under higher pressures and temperatures will probably undergo plastic deformation. These conditions may cause the structure pattern near the surface to be different from that at depth (See Appendix 1). not likely at depths involved

3. GRAVITY METHOD

(a) Applicability of the Method.

The gravity method depends on density contrasts and may be used in the investigation of sub-surface structure if the density contrast between the different sub-surface rocks is great enough. The method has no great resolving power. In general, the interpretation of the results improves in proportion to the amount of information available from bore-holes and the knowledge of the geology of the area. Data obtained by other geophysical methods, particularly the seismic refraction method, may be used as controls.

The log of Nerrima No.1 bore shows a density break at 2,200 feet. Densities were determined in the laboratory from dry cores (Guppy and Lindner, 1953). The average densities are 2.3 from surface to 2,200 feet and 2.55 from 2,200 feet to 4,271 feet. To allow for the water content of the rocks underground the above densities are assumed to be 2.4 and 2.6 respectively. These figures give a density contrast of 0.2 at a depth of about 2,200 feet. This contrast is sufficient to enable the interpreter to detect from a detailed gravity survey the fault pattern of the Nerrima structure and to estimate the throws of faults as low as 200 feet with a fair degree of reliability. For the interpretation of the results of the semi-detailed and regional surveys it is assumed that the effect of this near surface density contrast is constant, unless the contrary is shown.

Schneeberger (1952, p.11) estimates that a minimum of an additional 1,500 feet of Grant Formation exists below the bottom of the Nerrima No.1 bore. If the Permian section is assumed to consist of about 2,000 feet of rocks with density 2.4 and 4,000 feet of 2.6, then the average density of the Permian section is about 2.53. The density of the Pre-Cambrian basement is probably between 2.7 and 2.8, and adopting a value of 2.75, the density contrast between the Permian and the Pre-Cambrian will be about 0.22. Guess Could be as low as 2.65

The density of limestones similar to the Devonian and Ordovician limestones in this region usually ranges from 2.6 to 2.8. If the Devonian or Ordovician limestone is present, the density contrast between the sedimentary section and the basement will depend largely on the density of this limestone.

If the average density of the limestone section is the same as that of the Pre-Cambrian basement, the two will be indistinguishable by gravity methods. For the purpose of interpretation of the gravity results, this has been assumed to be the case and the section below the Permian is referred to as the "higher density formation". It is shown in a later section that the use of a density contrast of about 0.22 between the Permian rocks and the higher density formation yields results in good agreement with those of the refraction seismic survey.

One of the main problems of the detailed gravity survey was to determine the structure in the deep sediments underlying the Nerrima Dome. It has been indicated in the previous paragraph that Devonian and Ordovician limestones, if present, may have the same average density as the Pre-Cambrian basement rocks, and may therefore be indistinguishable from them by gravity methods. On the other hand, the density contrast between the Permian and the underlying rocks, whether the latter are Devonian, Ordovician or Pre-Cambrian, might be expected to provide a means of mapping the structure at the base of the Permian, i.e. at a depth of approximately 6,000 feet below surface. The density contrast within the Permian at a depth of about 2,000 feet provides a means of mapping faults and determining their displacement at this depth in the Nerrima structure.

Another important problem for the gravity method was the mapping of the Fenton fault or fault system and the determination of the magnitude of the vertical displacement on it.

It was considered that the regional and semi-detailed surveys would indicate the thickness of the sediments in various parts of the basin and thus reveal the broader structural features.

The results of regional surveys generally include trends in the gravitational field which are due to changes in thickness of the granitic and basaltic layers deep in the earth's crust, or to other deep-seated density changes. These regional trends have to be measured and their effect eliminated from the results of detailed and semi-detailed gravity surveys before the effects of the sedimentary layers can be correctly evaluated.

(b) Elevation Correction Factors.

In the area of the Nerrima structure, elevation differences generally are small and therefore elevation correction factors are not very critical. The "3-point method" was used in the determination of an elevation correction factor. This is a statistical method, based on the relation between the variations in height and gravity at a number of selected groups of three collinear stations. The factor was calculated as about 0.73 G.U.* per foot of elevation for the detailed survey, which corresponds to a density of 1.6 to 1.7. This low density surface layer presumably corresponds to the low velocity, weathered layer found by the seismic survey. The thickness of the weathered layer ranges from 10 to 80 feet.

For the detailed survey an elevation correction factor of 0.70 G.U. per foot was used, as it was considered that the calculated factor of 0.73 was slightly high. Few 3-point groups were suitable for calculation of the factor and the result is not therefore very accurate.

* The gravity unit (G.U.) = 0.1 milligal.

For the semi-detailed survey an elevation correction factor of 0.66 G.U. per foot (corresponding to a density of 2.2) was used. why

4. FIELD WORK

(a) Organisation.

The gravity party consisted of two geophysicists, one of whom was the party leader, two surveyors, four assistants, one cook and one mechanic. The two surveyors were made available by the Commonwealth Department of the Interior. The complete party operated as a single unit, both geophysical and topographical work being controlled by the party leader. This was an important factor in . . co-ordinating field operations in inaccessible and rough areas.

The motor vehicles used comprised one 3-ton W.D. 4 x 4 Ford, one 5-ton International truck and three Landrovers. Later in the survey one jeep was added to the party's vehicles.

(b) Topographical Survey.

The positions and elevations of most of the gravity stations in the semi-detailed survey were determined by compass traverses and levelling. The levelling instrument was also used as a tacheometer. The end stations of compass traverses were fixed by reference to trig. stations. The average output of the surveyors was about 3 miles per surveyor per day, i.e. 30 miles for the 2 surveyors per week.

The elevations of the gravity stations used in reducing the gravity values were all referred to the provisionally adopted datum of 255 feet for Station G118 at Myroodah homestead. A levelling traverse completed subsequently in the 1953 season showed that G118 is 177 feet above sea level. As a result of this error of 78 feet in the assumed datum elevation, all the Bouguer anomalies shown in the plans of this report are uniformly 51 G.U. too high.

Wherever possible, station positions were marked on aerial photographs, the scale of which is approx 1.27 inches = 1 mile.

On a few occasions, photographs and Askania barometers were used during the semi-detailed survey because sufficient surveyed stations were not available to permit the gravity meter to be fully occupied.

The stations in the detailed survey were mostly at seismic shot points, which were located by theodolite traverse. Some compass and level traverses were also used.

(c) Gravity Survey.

The gravity survey used in the semi-detailed and regional work was that commonly known as the "repeat method". The readings at some stations in each run were repeated to establish the drift of the readings. In the detailed work, well-established gravity stations were used as bases to determine the values of numerous stations within a relatively small area.

The accuracy of the reduced Bouguer anomalies depends on the accuracy of gravity, elevation and latitude determinations. The standard deviations of these factors in the semi-detailed survey are estimated at about 0.8, 0.4 and 0.3 G.U. respectively.

The total estimated accuracy is therefore the root mean square of these values, i.e. approximately ± 1.0 G.U. In detailed work the accuracy is slightly better.

The gravity meter used during the survey was a Worden instrument, with a calibration factor for the small dial of 0.758 G.U. per division.

The observed gravity values were tied by a regional traverse to the Pendulum Station at Derby.

5. REGIONAL GRAVITY

As the regional traverses commenced in 1952 require some additional field work for their completion, the results from the traverses are not included in this report. However, the data from two pendulum stations, one at Hall's Creek east of the area and the other at Derby, together with the Nerrima area results, give a general indication of the regional trend over the Fitzroy Basin.

The data of the pendulum stations are tabulated below:-

	Derby	Hall's Creek
Latitude	17°22.7'	18°14.0'
Longitude	123°39.2'	127°40.4'
Elevation	22 ft.	1410 ft.
Theoretical Gravity	978.5086 gal.	978.5533 gal.
Observed Gravity	978.5188 "	978.4607 "
Elevation Correction	0.0021 "	0.1326 "
Free Air Anomaly	+12.3 mgal.	+40.0 mgal.
Bouguer Anomaly	+11.6 "	- 8.7 "
Hayford Anomaly (Isostatic) -		
Depth of compensation 56.9 km.	+13.4 mgal.	+31.8 "
" " " 80.0 km.	+11.8 "	+28.8 "
" " " 96.0 km.	+10.6 "	+26.7 "
" " " 113.7 km.	+ 9.5 "	+24.5 "
Airy Anomaly (Isostatic) -		
Thickness of Crust 20.0 km.	+15.2 "	+33.1 "
" " " " 30.0 km.	+14.3 "	+30.5 "
" " " " 40.0 km.	+13.3 "	+27.8 "
" " " " 60.0 km.	+11.4 "	+22.7 "

The average Bouguer anomaly resulting from the semi-detailed survey of the Nerrima area is approximately -25 milligals.

Large regional trends are caused by deep-seated changes in the earth's crust, and to obtain a true representation of such trends, the Bouguer anomalies should be corrected for any near-surface structure showing appreciable deviation from the adopted density of the basement rocks. These corrections are usually called "geological corrections", and the corrected Bouguer anomalies may be called "normalised Bouguer anomalies". An attempt has been made to estimate the geological corrections for Nerrima and Derby. At Hall's Creek, the surface rocks are Pre-Cambrian and no geological correction is necessary.

From gravity and seismic evidence to be discussed in a later section of this report, it is estimated that the thickness of sediments in the basin at Nerrima is at least 7,000 feet. If these sediments are replaced by basement rocks with a density contrast of 0.22, the Bouguer anomaly will be increased by about 20 milligals, giving a geologically corrected (or normalised) value of -5 milligals.

At Derby a water bore reached a depth of 2,371 feet in Noonkanbah sandstone. If sediments to this depth are replaced by basement rocks, the Bouguer anomaly must be increased by 7 milligals to give +19 milligals. However, it is possible that the basin depth is considerably greater than 2,371 feet. In the area between the Fitzroy River and the Fenton Fault near Nerrima, the Liveringa-Noonkanbah junction is between +200 and -500 feet elevation relative to M.S.L., whereas at Derby this junction was shown to be at a depth of 1,860 feet. If it is assumed that the Permian section below the Liveringa-Noonkanbah junction is not greatly reduced in thickness towards the coast, a basin depth at Derby greater than 7,000 feet does not seem improbable. A geological correction based on a minimum basin depth of 7,000 feet and a density contrast of 0.22 would increase the Bouguer anomaly at Derby by 20 milligals to +32 milligals. The same increase applied to the isostatic anomalies at Derby would bring them into closer agreement with those at Hall's Creek.

The estimated normalised Bouguer anomalies are therefore:-

Hall's Creek	- Approx.	-8.7 mgal.
Nerrima area	- Approx.	-5.0 "
Derby	-	$>$+19.0 "

These results indicate a regional rise in the Bouguer anomaly between Hall's Creek and Derby which can be attributed to changes in the deep-seated structure of the earth's crust between the Nerrima area and Derby.

The regional gravity data are not yet complete enough to enable the gravity maps of the Nerrima area to be corrected for regional effects. The factors outlined above should be considered when interpreting the results of the regional survey.

6. RESULTS OF SEMI-DETAILED SURVEY

(a) General.

The semi-detailed gravity map (Plate 5) shows a deep minimum of which the northern boundary is formed by the Fitzroy River, the western boundary by Geegullie Creek and the southern boundary by the Fenton Fault. The minimum appears to continue south-east beyond the surveyed area.

Another minimum with a N.W. axis is indicated near Station B316 (Roebuck Branding Yards) on Geegullie Creek.

At surface, the Fenton Fault is easily traced geologically from Mt. James, in a north-westerly direction towards Mt. Arthur, Moulamen Hill and Charley's Knob. On the gravity map the same zone is characterised by very steep gravity gradients, which show that the south-western block is upthrown in relation to the north-eastern block. The gravity pattern shows no evidence of the existence of the Fenton Fault zone near Geegullie Creek.

In addition to the above major gravity anomalies, several small anomalies were recorded, and their relation to the surface features is discussed in detail later. There is no indication that the Nerrima Dome is underlain by a basement high, as might have been expected from surface evidence. The Myroodah Anticline may be indicated, but it is doubtful whether the gravity anomaly near Station B197 really has any relation to it.

(b) <u>The Larger Features of the Gravity Pattern</u>.

Plate 6 shows the geological structures at the surface superimposed on the Bouguer anomaly map. The large gravity minimum in the centre of the map coincides approximately with the synclinal structure between the Myroodah Anticline and the Nerrima Structure. There is also a gravity minimum which coincides approximately with the synclinal structure north of Mt. James. Two possible explanations are advanced for the coincidence of the gravity minima with the synclinal structures:-

(i) General synclinal folding may have accompanied sedimentation, through greatest compaction of the sediments occurring in the deepest part of the basin. The axes of such folds would coincide with the deepest parts of the basin, where gravity minima would also be expected.

(ii) The configuration of the basin may predetermine the location of large but gentle folds arising from the effect of lateral pressure or similar causes subsequent to sedimentation. The axes of such folds would not necessarily coincide exactly with the deepest parts of the basin, but a coincidence in position in a regional sense might occur.

To test the possibilities of a relationship between geological structures near the surface and Bouguer anomalies, a statistical investigation was made of the correlation between the elevation of a near-surface geological horizon and the Bouguer anomaly. For this purpose the Liveringa-Noonkanbah junction was chosen because its approximate position can be determined from information from the many water bores in the Basin. A compilation of data from these bores was made by the Bureau's geological party in the Fitzroy Basin. The data used for correlation were drawn from this compilation, and are listed in the table on the following page.

TABLE SHOWING THE APPROXIMATE ELEVATION OF THE LIVERINGA-NOONKANBAH DISCONTINUITY AND THE BOUGUER ANOMALY AT DIFFERENT BORES

Name of Bore	Station No.	Depth Liv/Noon. from surface (Feet)	Surface /Elevation rel. to M.S.L. (Feet)	Elevation Liv/Noon. Discont'y (Feet)	Bouguer Anomaly G.U.	Correction for surface layer on B.A., (G.U.) $\Delta\sigma = 0.2$	Corrected B.A., (G.U.) $\Delta\sigma = 0.2$	Correction for surface layer on B.A., (G.U.) $\Delta\sigma = 0.3$	Corrected B.A., (G.U.) $\Delta\sigma = 0.3$
Dry Corner	G181	-1040	326	-710	-206	+18	-188	+27	-179
Watson	G188	- 760	247	-510	-220	+13	-207	+20	-200
Webster	G201	- 720	284	-440	-208	+11	-197	+17	-191
Bamba	G141	- 600	292	-310	-121	+ 8	-113	+12	-109
Deep Well	B195	- 670	352	-320	-187	+ 8	-179	+12	-175
Waterford	B 68	- 600	383	-220	-144	+ 6	-138	+ 8	-136
McLarty	G 30	- 490	343	-150	-144	+ 4	-140	+ 6	-138
Windbag	G218	- 360	240	-120	- 86	+ 3	- 83	+ 5	- 81
Myroodah Woolshed	B182	- 350	255	-100	- 79	+ 3	- 76	+ 4	- 75
Tutu	G 72	- 400	298	-100	-228	+ 3	-225	+ 4	-224
Eldorado	B 64	- 240	300	+ 60	-133	- 2	-135	- 2	-135
Nerrima H.S.	G 17	- 200	283	+ 80	-139	- 2	-141	- 3	-142
Four Mile	G114	- 230	288	+ 60	- 84	- 2	- 86	- 2	- 86
McAlear	B 86	- 310	465	+160	- 48	- 4	- 52	- 6	- 54
Lake Daly	-	- 40	210±	+170±	-110	- 4	-114	- 6	-116
Victory	B119	- 60	292	+230	- 62	- 6	- 68	- 9	- 71
		N= 16		$\bar{X}$ = -139			$\bar{Y}$ = -134		$\bar{Y}$ = -132

The Bouguer anomalies are corrected for the assumption that the Liveringa Formation has a lower density than the underlying formations in the basin. The corrections are computed for density differences ($\Delta\sigma$) of 0.2 and 0.3.

In the following statistical results, Y indicates the corrected Bouguer anomaly and X the elevation of the Liveringa-Noonkanbah junction.

For $\Delta\sigma = 0.2$, the correlation coefficient is 0.67 ± 0.14, and the regression equations are:-

$$Y = 0.134X - 115 \pm 39 \text{ G.U.}$$
$$\text{and } X = 3.36Y + 312 \pm 192 \text{ feet.}$$

For $\Delta\sigma = 0.3$, the correlation coefficient is 0.64 ± 0.15, and the regression equations are:-

$$Y = 0.122X - 115 \pm 38 \text{ G.U.}$$
$$\text{and } X = 3.37Y + 306 \pm 200 \text{ feet.}$$

By applying a significance test to the correlation coefficients calculated above (Weatherburn, p.192), it is found that the possibilities of X and Y being uncorrelated are less than 1%. The statistical analysis indicates therefore a significant relation between the elevation of the Liveringa-Noonkanbah junction and the Bouguer anomaly, or, in other words, a probable relation between the depth of the junction and the depth of the basin.

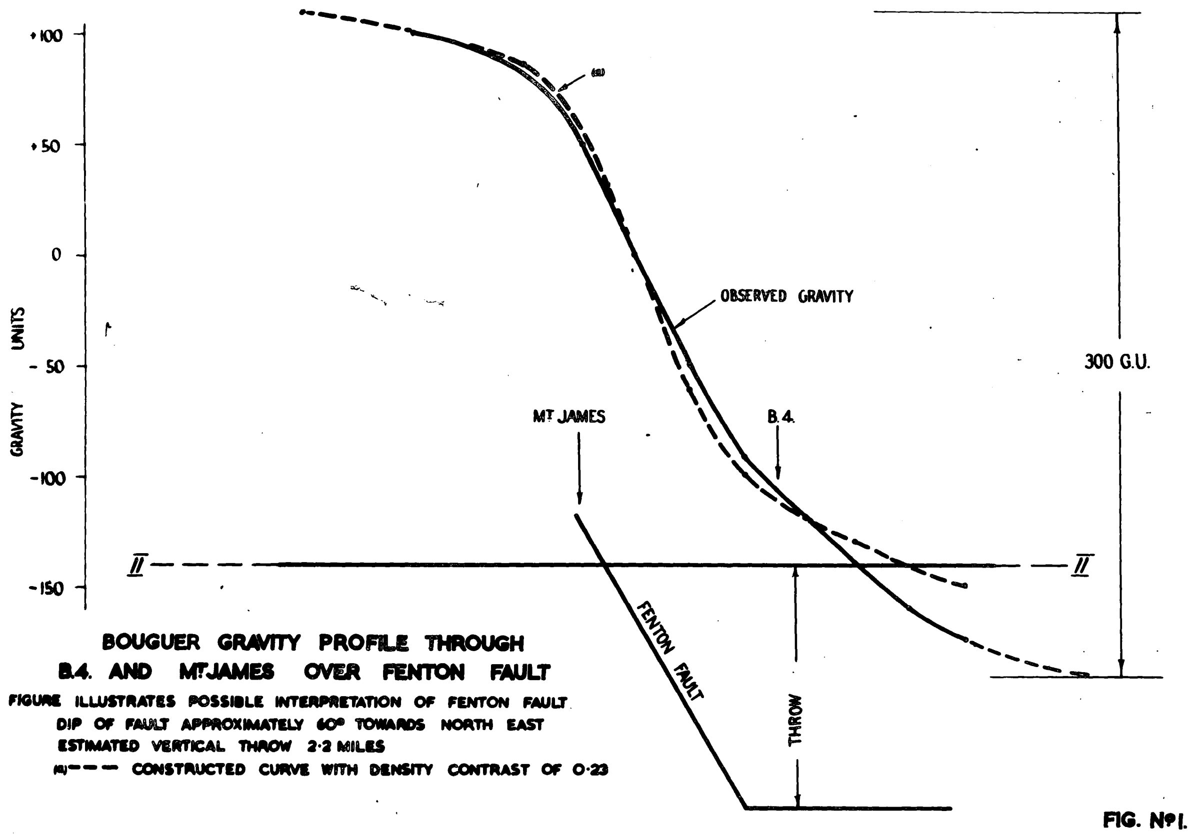
It is considered that this relation is due mainly to differential compaction of the sediments in the basin. The decrease in the Bouguer anomaly in going from a basin depth of 1,000 feet to a basin depth of 7,000 feet may be shown, by the foregoing equations, to correspond to an increase of 860 ± 270 feet in the depth of the Liveringa-Noonkanbah junction. This could be explained by a compaction of $\frac{590}{6000}$ (=10%) to $\frac{1130}{6000}$ (=19%). This compaction is probably nearer 10% than 19%. That compactions of this order are within the range of possibility may be shown by using the formula $(1-3p)d_1=d_2$, in which

p = linear compaction ratio
d_1 = rock density after compaction
d_2 = " " before "

Assuming $d_1 = 2.7$ and $d_2 = 1.8$ (values which could be reasonably expected), $p = 11\%$.

It is of interest to consider what dips are likely to be produced in the sediments by differential compaction of this order of magnitude. From the topography of the basement as inferred from the Bouguer anomalies, and assuming compaction of 10%, it is estimated that the dips resulting from differential compaction will not exceed $1\frac{1}{2}^\circ$ in the area of the gravity survey. However, Wade (1936) shows dips up to 8° in the synclinal area around Tutu bore. Steeper dips such as these must be associated with folding or faulting.

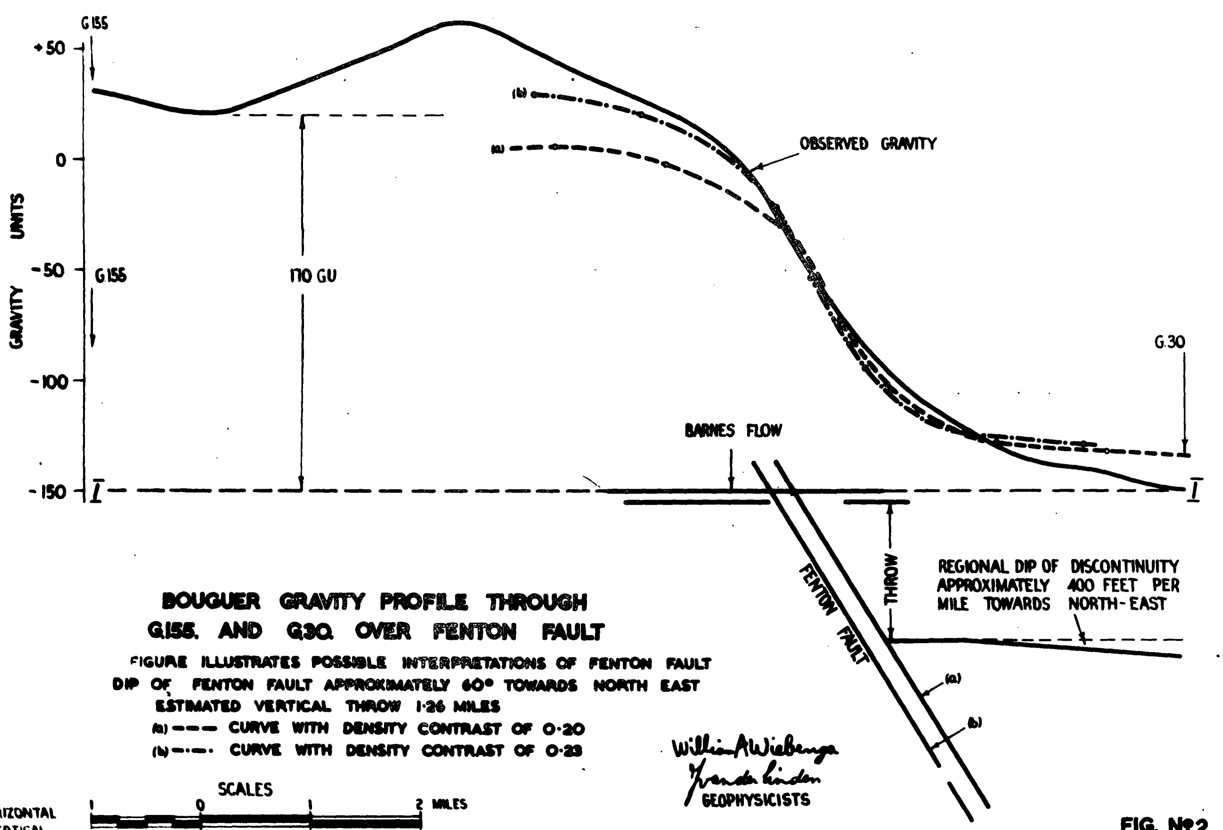
Although according to the above analysis, differential compaction probably plays a part in the structural relationships of the basin, it does not account for the dips of sediments exceeding two degrees. It seems likely therefore that the sediments have undergone gentle folding which is superimposed on the effects of differential compaction.



BOUGUER GRAVITY PROFILE THROUGH B.4. AND MT JAMES OVER FENTON FAULT

FIGURE ILLUSTRATES POSSIBLE INTERPRETATION OF FENTON FAULT.
DIP OF FAULT APPROXIMATELY 60° TOWARDS NORTH EAST
ESTIMATED VERTICAL THROW 2·2 MILES
(a) — — — CONSTRUCTED CURVE WITH DENSITY CONTRAST OF 0·23

FIG. Nº1.



BOUGUER GRAVITY PROFILE THROUGH G155. AND G30. OVER FENTON FAULT

FIGURE ILLUSTRATES POSSIBLE INTERPRETATIONS OF FENTON FAULT
DIP OF FENTON FAULT APPROXIMATELY 60° TOWARDS NORTH EAST
ESTIMATED VERTICAL THROW 1·26 MILES
(a) — — — CURVE WITH DENSITY CONTRAST OF 0·20
(b) —·—· CURVE WITH DENSITY CONTRAST OF 0·23

William A. Wiebenga
J. van der Linden
GEOPHYSICISTS

SCALES

HORIZONTAL 1 0 1 2 MILES
VERTICAL 1 0 1 2 MILES

FIG. Nº2.
G115-23

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

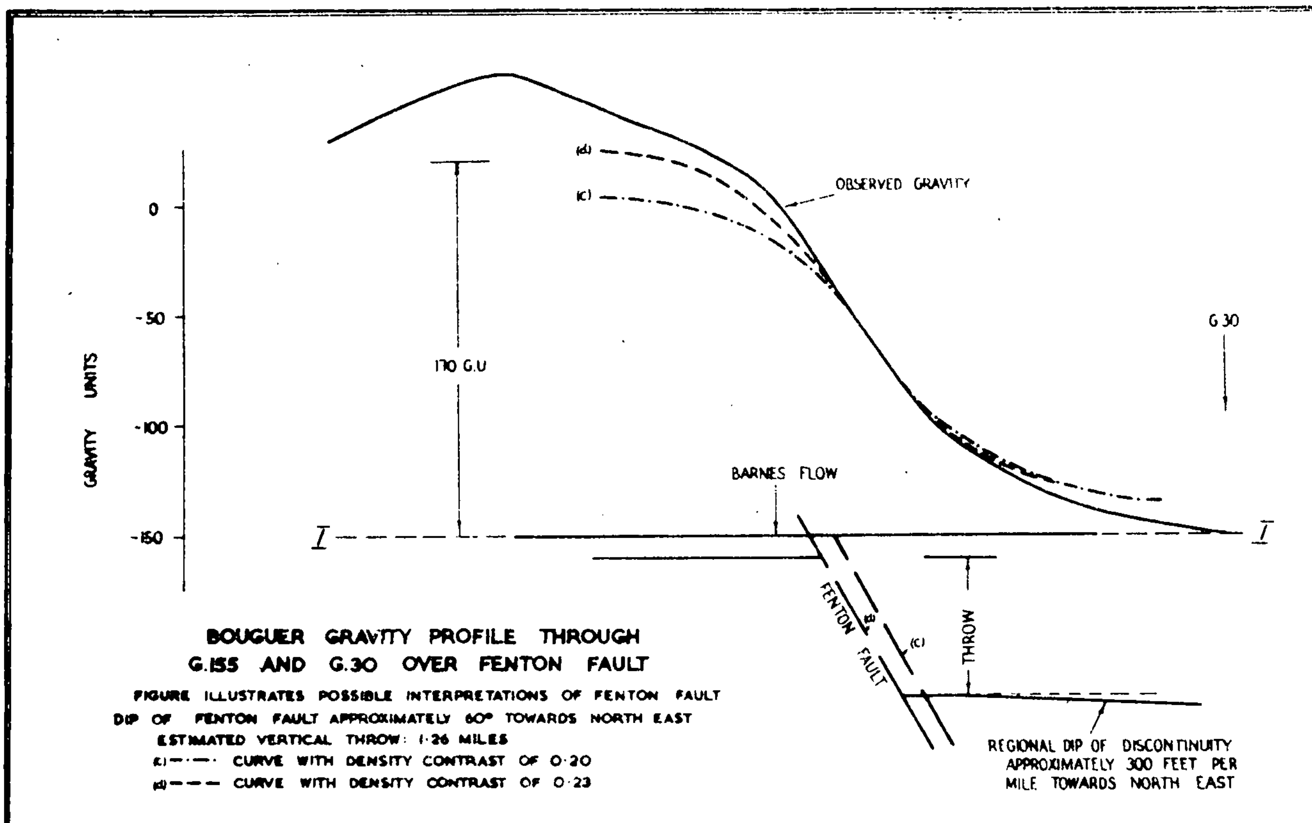


FIG. Nº 3.

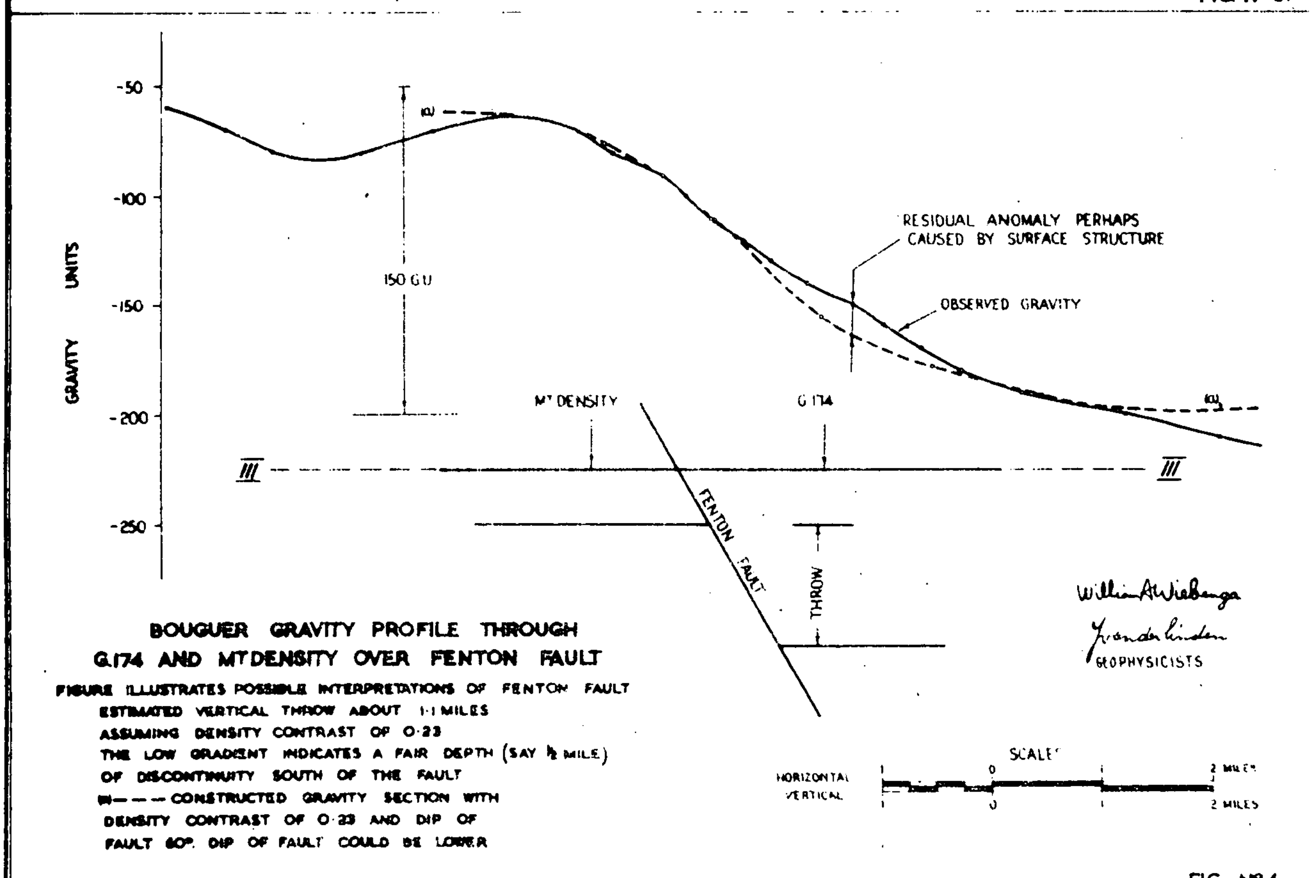
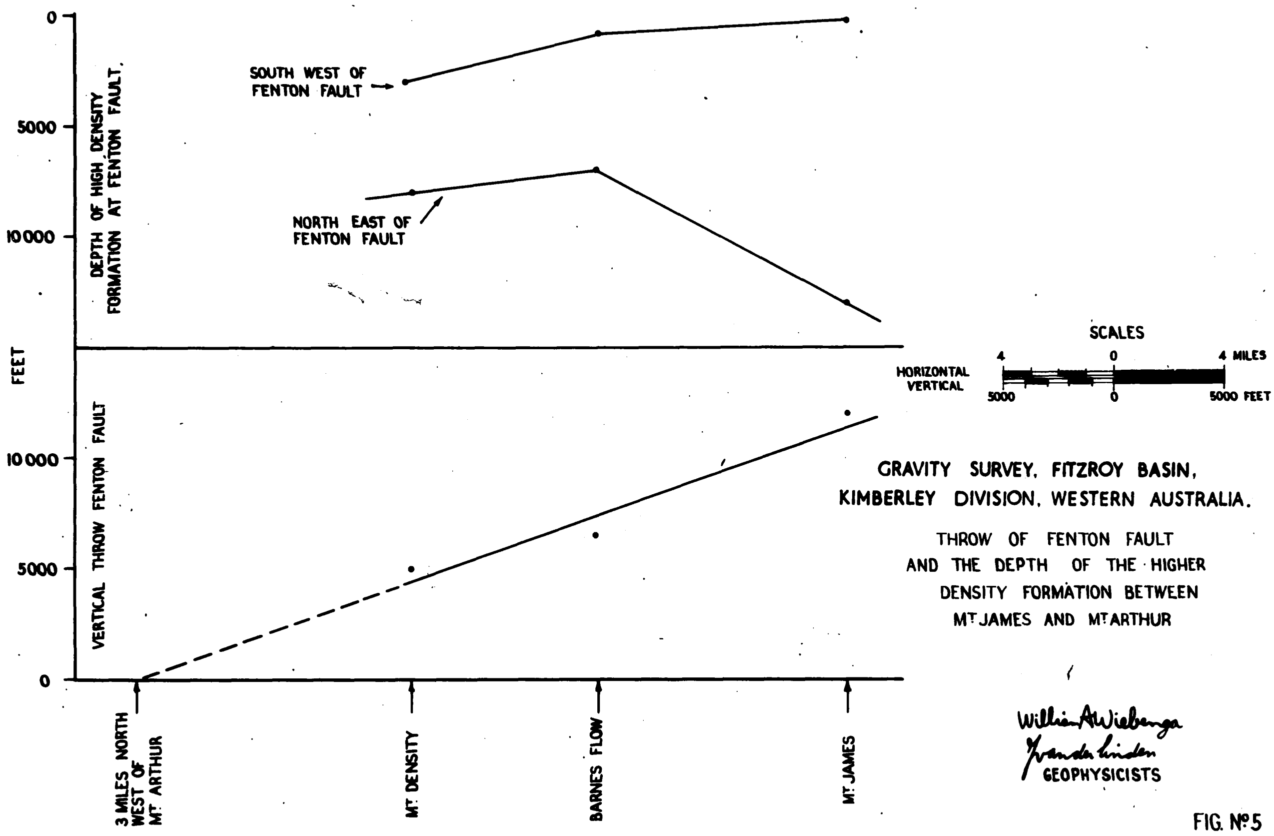


FIG. Nº 4
G115-24



GRAVITY SURVEY, FITZROY BASIN, KIMBERLEY DIVISION, WESTERN AUSTRALIA.

THROW OF FENTON FAULT AND THE DEPTH OF THE HIGHER DENSITY FORMATION BETWEEN MT. JAMES AND MT. ARTHUR

William A. Wiebenga
J. van der Linden
GEOPHYSICISTS

FIG. Nº 5

	FORMATION	APPROXIMATE THICKNESS IN FEET	DENSITY	SEISMIC REFRACTOR	DEPTH OF DISCONTINUITY AT SP102–SP104	VELOCITY LONG. WAVE IN FT/SEC.
	WEATHERING LAYER	50 – 100	1·7+	V_0		5250
					80	
	NOONKANBAH			V_1		8450
					275	
	NOONKANBAH		2·4 ±	V_2		9700
					1100	
	POOLE			V_3		11550
	UNCONFORMITY				2800	
PERMIAN	GRANT			V_4		12650
		3500 ±	2·6 ±			
	DISCONTINUITY BETWEEN V_4 AND V_5 NOT FOUND EAST OF SP95; POSSIBLY TILLITES				4200	
	GRANT			V_5		14500
	UNCONFORMITY				7500	
	DEVONIAN OR PRE-CAMBRIAN BASEMENT	UPPER DEVONIAN 4000 ±	2·7 – 2·8	V_6		16000

TABLE ILLUSTRATING THE CORRELATION BETWEEN GEOLOGY, SEISMIC REFRACTION DATA AND DENSITIES FOR THE NERRIMA AREA

FIG. Nº 6
G115-27

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

(c) The Fenton Fault.

The gravity data gives clear evidence that the Fenton Fault is downthrown on the north-eastern side relative to the south-west. This is contrary to the geological interpretation held formerly (Schneeberger, 1952), but it is understood that more recent geological evidence supports the gravity findings.

By using the gravity data at the Fenton Fault zone, it is possible to estimate the depth in the basin to the higher density formation underlying the Permian. The position of the zone of maximum gravity gradient relative to the fault trace on the surface indicates that the fault plane dips to the north-east. This agrees with the geological evidence disclosed by the Bureau's geological party, which found that the dip was probably between 55° and 60° to the north-east (oral information, Lindner, 1952).

It has been shown (p.3) that the average density of the Permian is about 2.53. A density of about 2.75 is assumed for the formation underlying the Permian (whatever the formation may be). If the density contrast and the dip of the fault plane are reasonably well known it is possible by a process of curve fitting to estimate the depths on either side of the fault to the higher density formation and hence the throw. Figures 1, 2, 3 and 4 show such curve fittings with an assumed dip of the fault plane of 60° and density contrasts of 0.20 and 0.23.

The computed vertical throws are about 12,000 feet near Mt. James, 7,000 feet near Barnes' Flow and about 6,000 feet at Mt. Density. These estimated throws are probably slightly high because no allowance has been made for the fact that the density of the Permian sediments increases with depth and consequently the average density of the Permian north-east of the fault will be slightly less than to the south-west where the upper, and therefore less dense, portion of the Permian has been eroded.

The estimated depths of the high density formation are given in the following table:-

Location	Depth of high density formation	
	North-east of Fenton Fault	South-west of Fenton Fault
Mt. James	12,000 ft.	Near or at surface
Barnes' Flow	7,000 "	500-1,000 ft.
Between Barnes' Flow and Mt. Arthur	8,000 "	3,000 "

The accuracy of the estimates is not better than ± 10%.

The results of the table are also shown on the diagram of Figure No.5. Extrapolation of the diagram to the north-west seems to indicate a fading out of the fault at a point about 3 miles north-west of Mt. Arthur. This appears to be in agreement with the findings of the Bureau's geological party that the Fenton Fault is a hinged fault with the hinge somewhere near Mt. Arthur. (Oral information, Lindner, 1953).

Both gravity and geological evidence suggest a schematic sub-division of the Fenton Fault zone into the following three sections:-

(i) A section from Mt. Fenton, via Mt. James, Barnes' Flow and Mt. Density to Mt. Paul. The strike of this section is north-west and the throw of the fault decreases to the north-west until it fades out completely north of Mt. Arthur.

(ii) A section from Mt. Paul, via Mt. Arthur, to a point 3 miles west of Mt. Arthur. The strike is west.

(iii) A section from a point 3 miles west of Mt. Arthur to the north-west via Moulamen Hill and Charley's Knob. The fault gradually fades out between Charley's Knob and Geegullie Creek.

The Fenton Fault has been described in some detail because (i) its nature has an important bearing on the general structure of the Fitzroy Basin, and (ii) by analysis of the gravity anomaly produced by the fault, it is possible to make fairly reliable estimates of the depth to the higher density formation.

(d) <u>The Higher Density Formation</u>.

The problem remains of finding with which formation or formations of the stratigraphic column the higher density formation can be correlated.

There is fairly strong evidence that the higher density formation is the same as the high speed refractor detected by the seismic refraction survey (Vale, Smith and Garrett, 1953). This refractor, denoted by V6, appears to have a velocity between 16,000 and 17,000 feet per second. Its depth is of the same order as that estimated for the higher density formation on the basis of a density contrast of 0.22. North of Barnes' Flow the depth of the higher density formation is about 7,000 feet and the Bouguer anomaly -150 G.U. Near S.P.95 on the refraction seismic traverse D, the gravity anomaly is about -195 G.U., which corresponds to a depth of about 8,600 feet. The depth of the V6 refractor near S.P.95 was estimated from the seismic results to be about 7,500 feet. The accuracy of the depth estimates from both seismic and gravity surveys is not better than 10%. If it is assumed that the V6 refractor is the same as the higher density formation, the seismic data give an indication of the probable density contrast between this formation and the Permian, that agrees very closely with the adopted figure of 0.22. At the western end of traverse D near S.P.95 the high speed refractor is about 1,250 ± 250 feet lower than at the eastern end near S.P.57. The gravity difference between these points is about 35 G.U. The density contrast computed from these figures is $\frac{35}{0.13\ (1250 \pm 250)}$ that is, 0.22 ± 0.05. Hence there is satisfactory agreement between the seismic and gravity data if the high density formation is identified with the V6 refractor.

At present it is impossible to judge whether the formation at 7,000-8,000 feet, which is characterised by high density and high velocity, represents Pre-Cambrian basement or a formation between the Pre-Cambrian and the Permian, e.g. Devonian or Ordovician. The stratigraphic column of the area (Plate 4), shows that the Devonian and Ordovician sections are mainly limestones. Such limestones may have densities of the same order of magnitude as the Pre-Cambrian basement. Also, the speed of the longitudinal waves in limestone, as would be shown by a seismic refraction survey, will probably be of the same order as that in the Pre-Cambrian basement. Because of serious technical difficulties it was not practicable for the seismic party to determine whether or not important discontinuities are present below the 7,000-8,000 ft. level.

Further gravity work in progress may reveal information concerning the contrast in density, if any, between the Devonian and/or Ordovician and Pre-Cambrian basement. Further seismic work may give information on the seismic velocities associated with these rocks of different ages. On the basis of present knowledge, however, it seems unlikely that either the gravity or the seismic method will differentiate between the Pre-Cambrian basement and Devonian or Ordovician rocks if present.

(e) The Smaller Anomalies.

If at some later phase in the exploration, the presence of Devonian or Ordovician rocks below Permian could be proved, then the small anomalies in the basin, as disclosed by the semi-detailed survey, may be significant for the following reasons:-

(i) The Devonian and Ordovician systems are considered by the geologists who studied the stratigraphy of the Fitzroy Basin as the most promising for oil exploration. They can include both source and reservoir rocks. Coral reefs are present in the Devonian.

(ii) The small anomalies may indicate higher levels of the basement. Higher levels of the Pre-Devonian basement would be favourable for coral reef formations, as coral reefs are generally formed in shallow parts of the sea or along shore lines.

(iii) Structures in the Devonian may have been formed by gentle folding or differential compaction and may be indicated by small gravity anomalies.

In the following list, the anomalies are mentioned in the order of their believed importance:-

(1) The anomaly near Station B197, that is, about 1 mile north of the Myroodah (Deep Well) Anticline as observed on the surface (See Plate 5). The magnitude of the anomaly is 5-10 G.U.; its axis strikes approximately west and the width is estimated at 1 to 2 miles. Additional detailed work is necessary to investigate the relationship between the anomaly and the Myroodah Anticline.

(2) The anomaly located near the centre of the gravity minimum in a line from G79 via Webster Bore and Mill Bore to Howard Bore (Plate 5). The length of the anomaly is at least 10 miles, the width about 2 miles and the magnitude 5-10 G.U. It requires further detailed work.

(3) An anomaly indicated between Sandfly and Windbag bores on the fringe of the large gravity minimum (Plate 5). The delineation of this anomaly requires more detailed work. The relatively small negative Bouguer values indicate a shallow basin depth which makes this anomaly particularly attractive for testing by a scout drill.

(f) The Nerrima Structure.

One of the objects of the gravity survey was to determine whether the Nerrima Dome mapped at the surface persists in depth and, in particular, whether the dome is situated over a basement high. The density contrast between the Permian and underlying high density formation provides a means of mapping the configuration of the base of the Permian at a depth of 6,000 feet or more. If the Permian section to this depth were conformable with the structure at the surface, a gravity high would be expected coinciding with the Nerrima Dome. The map (Plate 5) showing results of the semi-detailed survey shows however that the axis of a large gravity minimum extends across the Nerrima structure. It can be inferred therefore that the base of the Permian is probably synclinal and not domal. This interpretation is supported in part by the results of the seismic refraction survey. For example, the seismic results on traverse D, which runs approximately E-W along the axis of the structure, show a rise in the refractors from west to east which corresponds to an observed decrease in gravity in this direction. Calculations based on a density contrast of 0.22 between the Permian and underlying rocks indicate that the thickness of the Permian sediments ranges from 7,000 to 8,000 feet within the area occupied by the Nerrima Dome. It can therefore be inferred that the domal structure is probably not present at this depth, and consequently that the Nerrima structure does not present a suitable target for further drilling. However, if petroliferous sediments, such as Devonian or Ordovician, are proved to exist within the area, some of the faults indicated by the detailed survey and discussed in the next section may warrant further investigation, as they may have acted as fault traps.

In the south-eastern corner of the surveyed area, and within the lease of the Freney Kimberley Oil Company, the semi-detailed gravity survey indicates a saddle between the two major minima. It is situated immediately to the south-east of the Nerrima Structure and may indicate a basement high or dome. The gravity pattern is not well defined because of insufficient data and more detailed work is required before it can be determined whether or not a structure favourable for the accumulation of oil coincides with this saddle. If additional detailed gravity work indicates the presence of such a structure, further seismic work would be needed to confirm the gravity results.

7. RESULTS OF DETAILED SURVEY

(a) The Fault Pattern.

A detailed gravity survey was carried out in the area previously surveyed by the seismic party. The results show that the gravity method can supplement the work of the seismic party in detecting the fault pattern. The minor unconformity at 2,200 feet between the Poole and Grant Formations, as shown by the log of Nerrima No.1 Bore, gives a density break of 0.20 - 0.25. The interpretation of the detailed gravity map is based on the assumption that sudden changes in the gravity gradient indicate faults, a gravity change of 10 - 12 G.U. corresponding to a fault with a throw of about 400 feet. The detailed gravity map and its interpretation are shown in Plate 7.

It should be borne in mind that on the gravity map many effects are superimposed. Nevertheless, the interpretation on Plate 7 shows fair agreement with the fault pattern mapped by the geological and seismic surveys. In this area the throw of most faults does not exceed 1,000 feet.

(b) Correlation with Seismic and Geological Data.

An interesting anomaly is indicated north of Nerrima No.1 Bore, extending from S.P.3 via S.P.5 and S.P.10 towards G.10. The gravity map shows a fault with the eastern side upthrown relative to the western side. The seismic party found evidence on traverse D of a fault near S.P.5 at a depth of 7,000 feet, also with the eastern side upthrown. No seismic data were recorded for shallower levels. Previous geological mapping (Guppy et al, 1950, Plates 3 and 4, Sections A-B and E-F) shows a fault (indicated as ABC on Plate 8) which coincides with, and is therefore presumably the same fault as, that indicated by the gravity results. However, the threw indicated by the geological mapping is reversed from that indicated by the gravity results. The geological interpretation is based on the relative position of the marker beds on an anticlinal structure. However, it is believed that both geophysical and geological data can be reconciled by assuming that faulting took place under compressional stress, as shown diagramatically in Plate 8. The lateral movement would have reversed the relative positions of the marker beds produced by the vertical threw.

In the eastern part of the area, another interesting feature is indicated near S.P.54. The gravity pattern suggests a hinged fault, the hinge being not far north of S.P.54.

(c) Faults as Oil Traps.

Faulting is an important factor in the localising of oil deposits, as it can lead to the formation of traps, especially if the faults are formed by compressional stresses. Clay formed by the pulverising of the rocks at the fault may seal off reservoir rocks. However, when faults and fractures are formed by tensional stresses, as at the summits of anticlines, then instead of sealing off reservoir rocks, they may form natural outlets for fluids.

As explained previously, economic oil deposits are possible in Devonian or Ordovician rocks, and these may be present at a depth below 7,000 feet. In the Nerrima area, it is important to determine whether the faults penetrate into the zones below this depth.

From the gravity results alone, it is not possible to determine the depths to which the faults penetrate. However, the seismic survey along traverse D indicates that some of the faults shown on the gravity map may have reached a depth greater than 7,000 feet. These have northerly or north-easterly strikes and cross traverse D at S.P.100, S.P.79, S.P.62 and S.P.54. If, in a later phase of the exploration, the existence of oil-bearing strata can be proved beneath this area, these faults may act as traps, and the following could be considered as target areas:-

(i) The area between Stations B160b, B161A, S.P.167, B18 and S.P.170.

(ii) West of the fault between S.P.52 and S.P.149.

(iii) West of the fault between S.P.5 and S.P.13.

8. THE CONTROLS

In the interpretation of the gravity data many results of geological and seismic refraction work have been used as controls. It seems appropriate to list these controls (see also the table on Figure 6) :-

(i) Stratigraphical Section of the Desert Basin (Plate 4).

(ii) Log of Nerrima No.1 Bore (depth 4,271 feet). The log indicates the unconformity between the Poole and Grant Formations at about 2,200 feet, corresponding to a density discontinuity and the top of seismic refractor V4. A locally higher density layer between 3,600 and 3,700 feet is seismically important (V5 refractor).

(iii) Tabulated data of water bores in the Fitzroy Basin, compiled by the Bureau's Geological Party.

(iv) The exact position of the Fenton Fault at the surface and the north-easterly dips of the fault plane (55-60 degrees).

(v) Seismic refraction work showed the depths to different refractors and the velocity of the longitudinal waves. By comparison with the geological results the refractors could be identified with geological formations and the V6 refractor could be correlated with the higher-density formation of the gravity interpretation.

9. CONCLUSIONS AND RECOMMENDATIONS

Conclusions.

1. The gravity results are believed to indicate mainly variations in thickness of the Permian sediments. Near the Nerrima structure these sediments appear to range in thickness from 7,000-8,000 feet. There is no evidence that the domal structure mapped at the surface persists to this depth. On the contrary, there is reasonable evidence that a trough underlies the Nerrima structure and forms the south-eastern extremity of an extensive basin. Immediately to the south-east of the Nerrima structure, but at depth, there is a saddle which appears to separate two basin structures and which may possibly correspond to a structure favourable for the accumulation of oil. However, further geophysical work would be necessary to determine this.

2. The area between the Fenton Fault and the Fitzroy River, covered by a semi-detailed gravity survey, shows a basin structure extending from the vicinity of Luluigui Homestead to a point about 6 miles south of Nerrima Homestead. There is some evidence of a second basin situated further to the south-east and separated by a saddle from the first basin.

3. Underlying the Permian sediments is a higher density formation, corresponding with the refractor V6 of the seismic refraction survey. This higher density formation could be either Pre-Cambrian basement or Devonian (or Ordovician) sediments.

4. The throw of the Fenton Fault south-east of Mt. Arthur shows an increase to the south-east. At Mt. James a downthrow to the north-east is estimated at 11,000-12,000 feet.

5. South of Mt. James and Barnes Flow the higher density formation mentioned under 3 will probably be found within 1,000 feet of the surface.

6. Near the Myroodah Anticline an anomaly which might correspond to a favourable structure is indicated but has not yet been mapped in sufficient detail.

7. A correlation between the elevation of the Noonkanbah-Liveringa junction and the Bouguer anomaly or depth of the basin could be explained by differential compaction of the sediments in the basin.

8. The detailed gravity work confirms the existence of faults on the Nerrima structure mapped by the Bureau's Geological Party and by the Seismic Party. If it can be shown that oil-bearing strata are present, some of these faults may act as oil traps.

Recommendations.

1. A regional gravity survey should be extended over the whole Fitzroy Basin. Special attention should be given to the Pinnacle Fault and the continuation of the Fenton Fault south-east of Mt. James. Traverses across these large fault systems (and well beyond) will facilitate estimates of density contrasts and render it possible to make estimates of the depth of the Fitzroy Basin.

2. The main question concerning the area covered by the semi-detailed gravity survey is whether the higher density rock formation is Pre-Cambrian basement or Devonian. The higher density formation comes near the surface (possibly within 1,000 feet) south of Barnes' Flow and Mt. James. This should be checked by a seismic refraction survey, followed by test drilling. Test drilling south of Barnes' Flow and Mt. James would disclose the nature of the higher density formation at these places. If this should prove to be Devonian or Ordovician the chances of similar rocks occurring throughout the basin are considerably increased.

3. It is suggested that the area between Watson Bore, Tutu Bore and Four Mile Bore be covered by a detailed gravity survey to delineate the anomalies found by the semi-detailed gravity survey. The possibility exists that the Myroodah Anticline will show up as a well defined anomaly.

4. It is suggested that the area between Luluigui Homestead, Eldorado Bore and Sandfly be covered by a detailed gravity survey. The gravity pattern suggests an east-west anomaly near Windbag Bore. The small Bouguer values indicate a relatively shallow, high density formation which could be interpreted either as Pre-Cambrian or Devonian. This anomaly would be a good target for the scout drill.

5. It is suggested that the area north-east of Barnes' Flow (around McLarty's Bore) be covered by a detailed gravity survey to disclose the structure of the saddle in the gravity pattern.

6. For the benefit of future exploration work it is suggested that no detailed seismic exploration work be carried out in an area until it has been covered by a semi-detailed and possibly a detailed gravity survey. In many places such gravity surveys have provided targets and data for seismic work. The use of gravity surveys may result in a large saving in exploration costs. For example, at Nerrima the gravity survey might have given the seismic party the following information:-

(i) The critical mapping horizon is most likely 7,000 - 8,000 feet deep.

(ii) The Nerrima structure probably does not exist at 7,000 - 8,000 feet, at least not in the same form that it was mapped at the surface.

(iii) With more detailed work the gravity survey might have indicated alternative targets.

In general, seismic traverses for detailed work can be planned more efficiently when both geological and gravity information is taken into account.

10. REFERENCES

Gunn, R., 1937 - A Quantitative Study of Mountain Building on an Unsymmetrical Earth, Jnl.Frank.Inst., 224,1339-1344.

Guppy, D.J., 1953 - A Preliminary Report on the Geology of the Fitzroy Basin, Kimberley Division, Western Australia, Bur.Min.Res.Geol.& Geophys., Records 1953, No.146.

Guppy, D.J., Cuthbert, J.O. and Lindner, A.W., 1950 - The Geology of the Nerrima Dome, Bur.Min.Res. Geol.& Geophys., Rep.No.4.

Guppy, D.J. and Lindner, A.W., 1953 - Personal Communication.

Guppy, D.J. and Opik, A.A., 1950 - Discovery of Ordovician Rocks, Kimberley Division, Western Australia, Aust. Jnl.Science, 12,205-6.

Schneeberger, W.F., 1950 - Notes on the Oil Prospects of the North-West and Desert Basins, Bur.Min.Res.Geol. & Geophys., Records 1950, No.35.

Schneeberger, W.F., 1952 - A Review of the Petroleum Prospects of the N.W. and Fitzroy Basins of Western Australia and Suggestions for a Future Exploration Programme, Bur.Min.Res.Geol. & Geophys., Records 1952, No.59.

Teichert, C., 1949 - Observations on Stratigraphy and Palaeontology of Devonian, Western Portion of the Kimberley Division, Western Australia, Bur. Min.Res. Geol.& Geophys., Rep.No.2.

Vale, K.R., Smith, E.R., and Garrett, M.J., 1953 - Seismic Survey of the Nerrima Dome, Kimberley Division, Western Australia, Bur.Min.Res.Geol.& Geophys., Records 1953, No.72.

Wade, A., 1936 - The Geology of the West Kimberley District, Western Australia (Unpublished company report and maps).

Weatherburn, C.E., 1947 - A FIRST COURSE IN MATHEMATICAL STATISTICS, Cambridge Univ.Press.

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APPENDIX 1.

SKINFOLDING IN THE FITZROY BASIN.

Skinfolding is a type of folding by which, under tangential stress, the surface layers are sheared from the underlying formations and are compressed into a series of more or less symmetrical folds. (In German: Epidermis Faltung). The idea of skinfolding as a mechanism originated in Switzerland where Albert Heim and Buxtorf in their classical studies of the Jura mountains found that surface formations were sheared from older formations on a contact formed by a formation of rocksalt. The rocksalt served as a lubricant between the surface and older formations. Under tangential stress the surface formations were folded into anticlines and synclines.

The Fitzroy Basin between the Fenton Fault and the Pinnacle Fault, north of Mt. James, shows a series of anticlines and synclines. (Guppy et al., 1950, Figure 2). On purely geological grounds Dr. Schneeberger considered skinfolding in the Fitzroy Basin as a possibility because the Fitzroy Basin is a large basin whose sediments, wedged between two major fault systems, contrast in strength and elastic properties with the basement rocks. (Personal communication, Lindner, 1953).

Gunn (1937) developed a formula in which the wave length of surface folds is expressed as a function of tangential pressure, the thickness of the sedimentary section subject to skinfolding and the density of the underlying formation. In the application of the formula, it is considered that the effective rigidity of the surface rocks is decreased by the development of numerous fractures and the limiting condition is assumed in which the rigidity is zero, or what amounts to the same, Young's modulus E equals zero. This condition is probably valid for the fractured and faulted basin rocks in the Fitzroy Basin.

The formula is (Gunn, 1937, p.33):-

$$\lambda = 2\pi\ (ST/dg)^{\frac{1}{2}},$$

in which:-

λ = wavelength surface fold in cm.

S = stress in dynes/cm^2.

T = thickness of folded rocks in cm.

d = density of underlying formation.

g = gravitational constant in cm/sec^2.

The stress S is considered to be of the order of 10^9 dynes/cm^2, which has been determined as the most probable breaking stress of most crustal rocks.

λ, measured from the geological map north of the Fenton Fault at Barnes' Flow is approximately 13 miles or 21 kilometres.

For d = 2.5, $ST = 3 \times 10^{14}$.

For S = 10^9 dynes/cm^2.,

$T = 3 \times 10^5$ cm = approximately 10,000 feet.

Thus, theoretical reasoning shows skinfolding in the

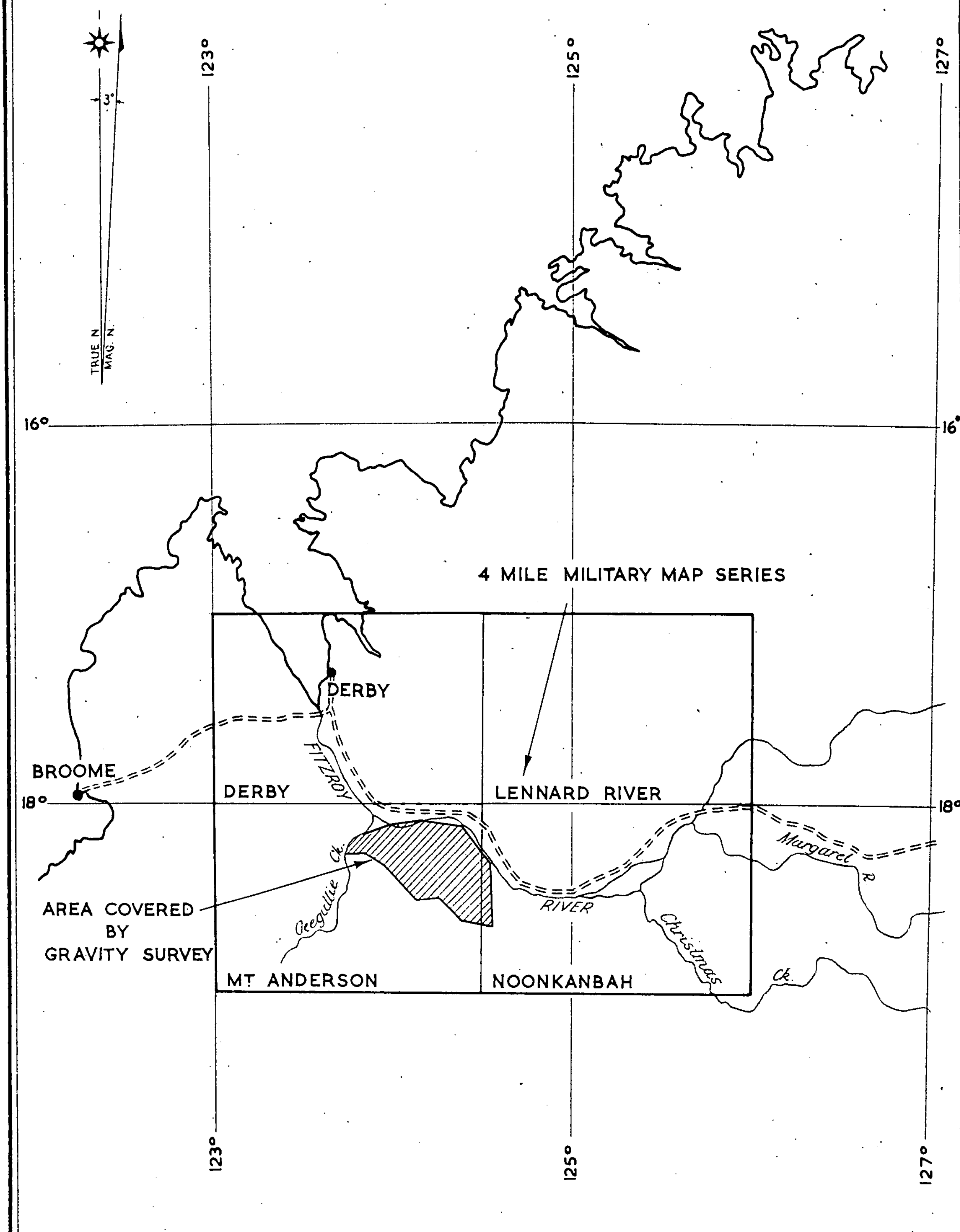
Nerrima area to be limited to a sedimentary section of about 10,000 feet. Taking into account erosion since the folding took place, it may be said that it corresponds in order of magnitude with the thickness of the sedimentary section (7,000-8,000 feet) above the higher density formation as found by geophysical methods.

Skinfolding implies that surface structure in the basin has little relation with the deeper sub-surface structure. This lack of correlation between surface structure and the deeper formations is exactly what has been found up-to-date from the results of the gravity and seismic surveys in the Nerrima area. The above evidence shows that skinfolding may be an important mechanism in the Fitzroy basin.

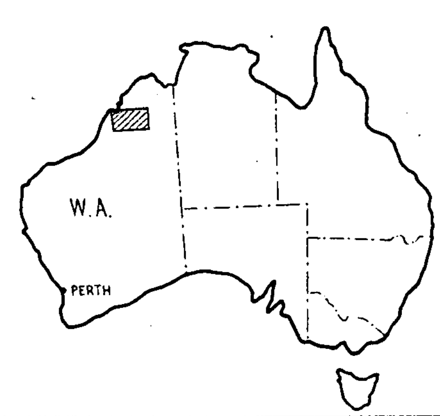
These results should be considered significant because they show that:-

(a) Structures mapped by geological methods at the surface will not be a reliable guide in the detection of deep sub-surface structures by other methods.

(b) Geophysical methods should be used in the search for deep sub-surface structures.



GEOPHYSICISTS



GRAVITY SURVEY, FITZROY BASIN,
KIMBERLEY DIVISION, WESTERN AUSTRALIA.

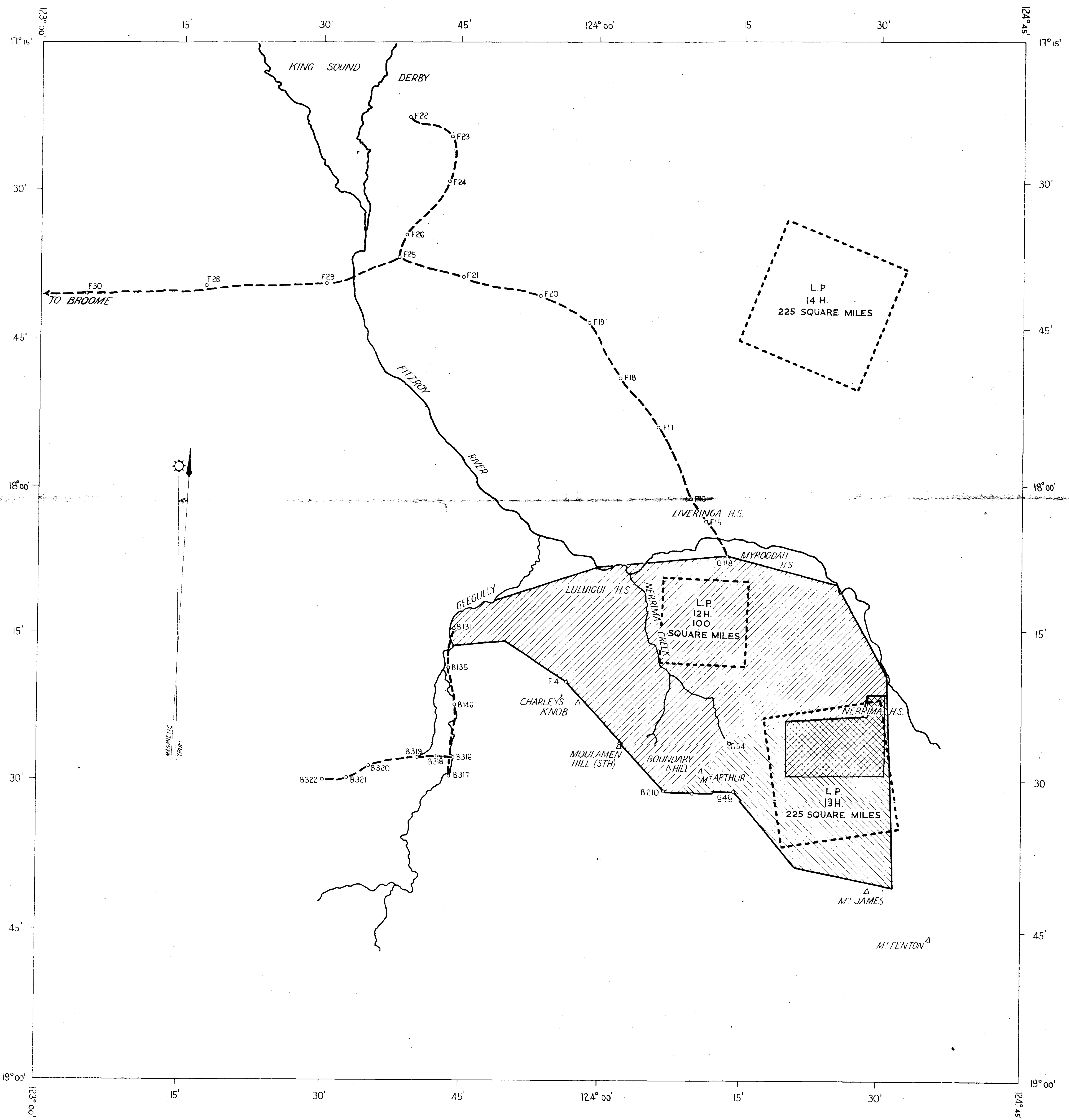
LOCALITY MAP

SCALE

50 0 50 100 MILES

G115-30

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



AREAS COVERED BY

SEMI-DETAILED AND DETAILED SURVEYS

GRAVITY SURVEY

FITZROY BASIN, KIMBERLEY DIVISION

WESTERN AUSTRALIA

SCALE

8 0 8 16 24 32 MILES

LEGEND

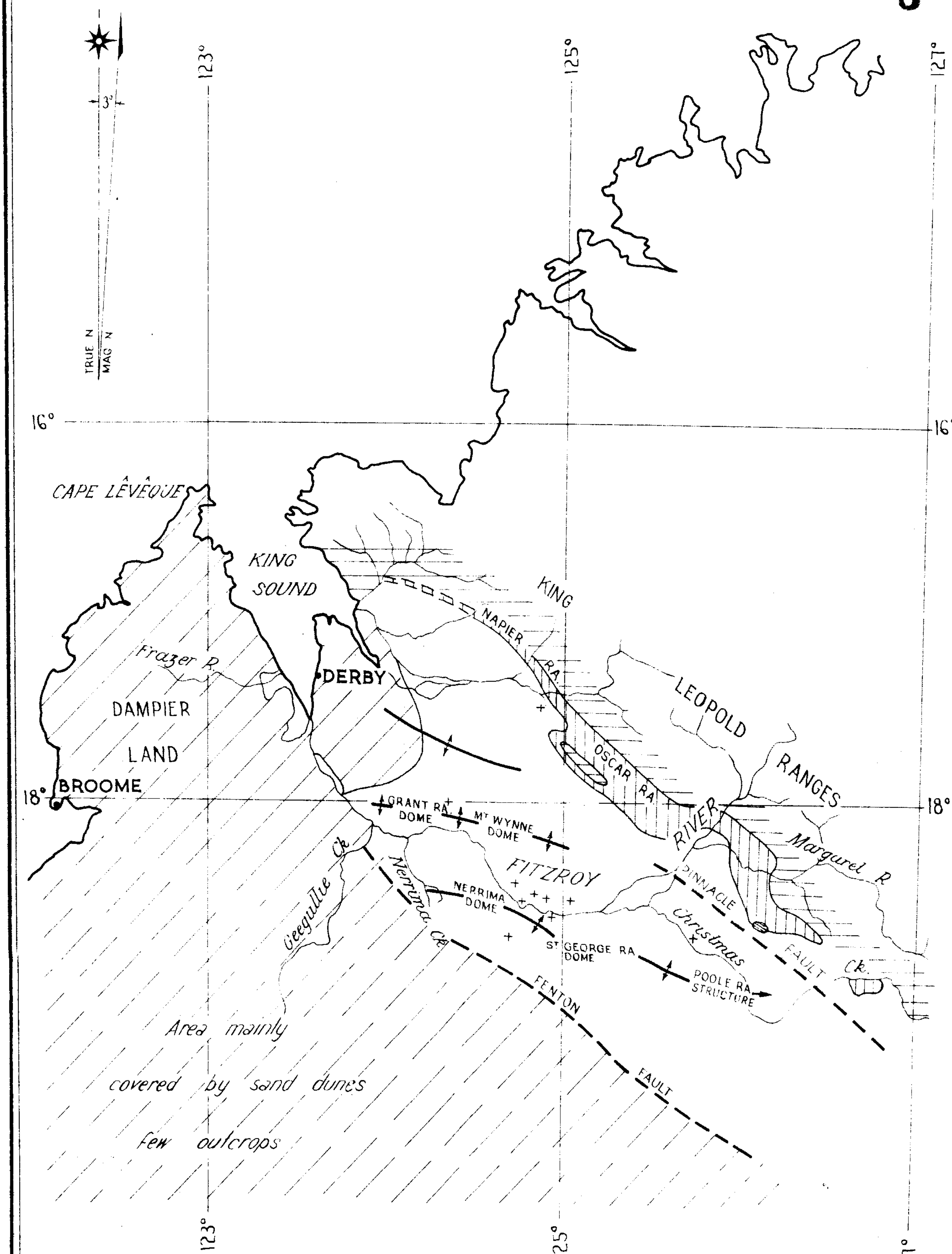
- REGIONAL TRAVERSE
- AREA COVERED BY SEMI-DETAILED GRAVITY SURVEY
- AREA COVERED BY DETAILED GRAVITY SURVEY, ALSO INVESTIGATED WITH SEISMIC METHOD
- LEASES HELD BY FRENEY KIMBERLEY OIL COMPANY (1932)

SURROUNDING AREA HELD BY WEST AUSTRALIAN PETROLEUM PROPRIETARY LIMITED

William A Wiebenga
J van der Linden
GEOPHYSICISTS

Geophysical Section, Bureau of Mineral Resources, Geology & Geophysics G115-21

PLATE 3



LEGEND

- MESOZOIC
- PERMIAN
- DEVONIAN
- ORDOVICIAN
- PRE-CAMBRIAN
- \+ TERTIARY LEUCITITES
- REGIONAL FAULTS
- MAJOR ANTICLINES

GRAVITY SURVEY, POOLE RANGE AREA,
KIMBERLEY DIVISION, WESTERN AUSTRALIA.

GEOLOGICAL SKETCH MAP

INFORMATION PROVIDED BY GEOLOGICAL SECTION
BUREAU OF MINERAL RESOURCES

SCALE

0 10 20 30 40 50 60 70 80 90 100 MILES

G115-33

Geophysical Section, Bureau of Mineral Resources, Geology & Geophysics

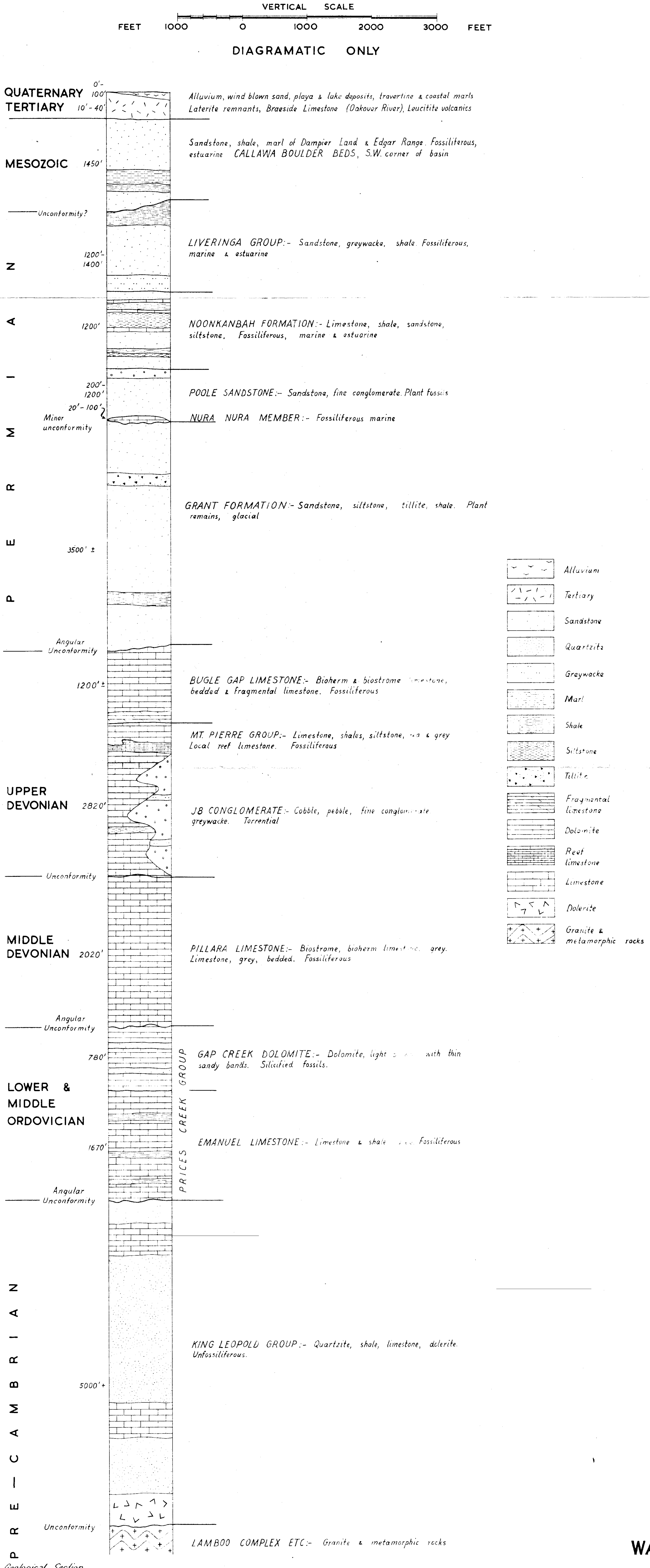
COLUMNAR SECTION

PLATE 4

FITZROY BASIN

KIMBERLEY DIVISION, W.A.

MAXIMUM THICKNESS OF POST PRE-CAMBRIAN, 18,000 FEET



Information provided by Geological Section,
Bureau of Mineral Resources, Geology, and Geophysics. March 1951.

WA3-14
W.T.C.

PLATE 5.

GRAVITY SURVEY, FITZROY BASIN.
KIMBERLEY DIVISION, WESTERN AUSTRALIA.

SEMI-DETAILED BOUGUER GRAVITY MAP

1344 Mt ANDERSON 4 MILE SERIES
CONTOUR INTERVAL 10 G.U.=1 MILLIGAL
APPLIED ELEVATION CORRECTION 0.66 G.U./FOOT

SCALE

MILES 2 0 2 4 6 8 10 MILES

AREA INDICATED ON LOCALITY MAP PLATE 1

LEASES HELD BY FRENEY KIMBERLEY OIL COMPANY (1932)
SURROUNDING AREA HELD BY WEST AUSTRALIAN PETROLEUM PROPRIETARY LIMITED

GEOPHYSICISTS

Geophysical Section Bureau of Mineral Resources, Geology & Geology.

G 115-32

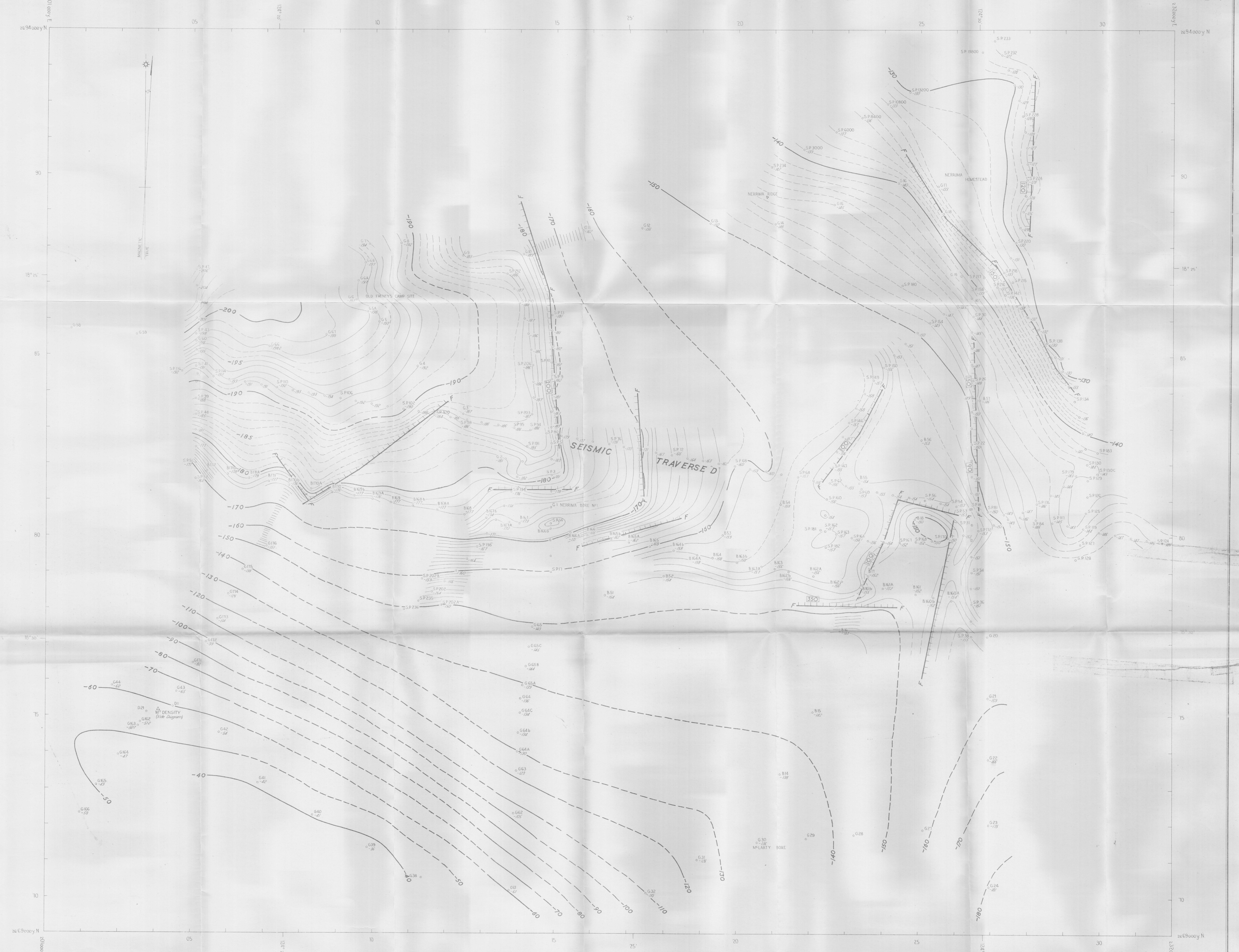
GRAVITY SURVEY, FITZROY BASIN,
KIMBERLEY DIVISION, WESTERN AUSTRALIA.

SURFACE FEATURES SUPERIMPOSED ON BOUGUER GRAVITY MAP

1344 MT ANDERSON 4 MILE SERIES
CONTOUR INTERVAL 50 G.U. = 5 MILLIGALS
AREA INDICATED ON LOCALITY MAP PLATE 1

SCALE
2 0 2 4 6 8 MILES

LEGEND
- BOUGUER GRAVITY CONTOUR LINE
- TRENDLINES FROM AERIAL PHOTOGRAPHS INDICATING BASIN STRUCTURES
- FAULTS FROM AERIAL PHOTOGRAPHS
- FENTON FAULT FROM DR. A. WADE'S GEOLOGICAL MAP OF PART OF THE WEST KIMBERLEY DIVISION W.A. 1937



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KIMBERLEY DIVISION, WESTERN AUSTRALIA.

DETAILED BOUGUER GRAVITY MAP OF NERRIMA DOME

CONTOUR INTERVAL 1 G.U. AND 10 G.U.
APPLIED ELEVATION CORRECTION 0·70 G.U./FOOT

SCALE

MILES 1 ½ 0 ½ 1 2 MILES

LEGEND

F —DOWN/UP— F FAULTS INDICATED BY GRAVITY SURVEY

150 APPROXIMATE THROW IN FEET

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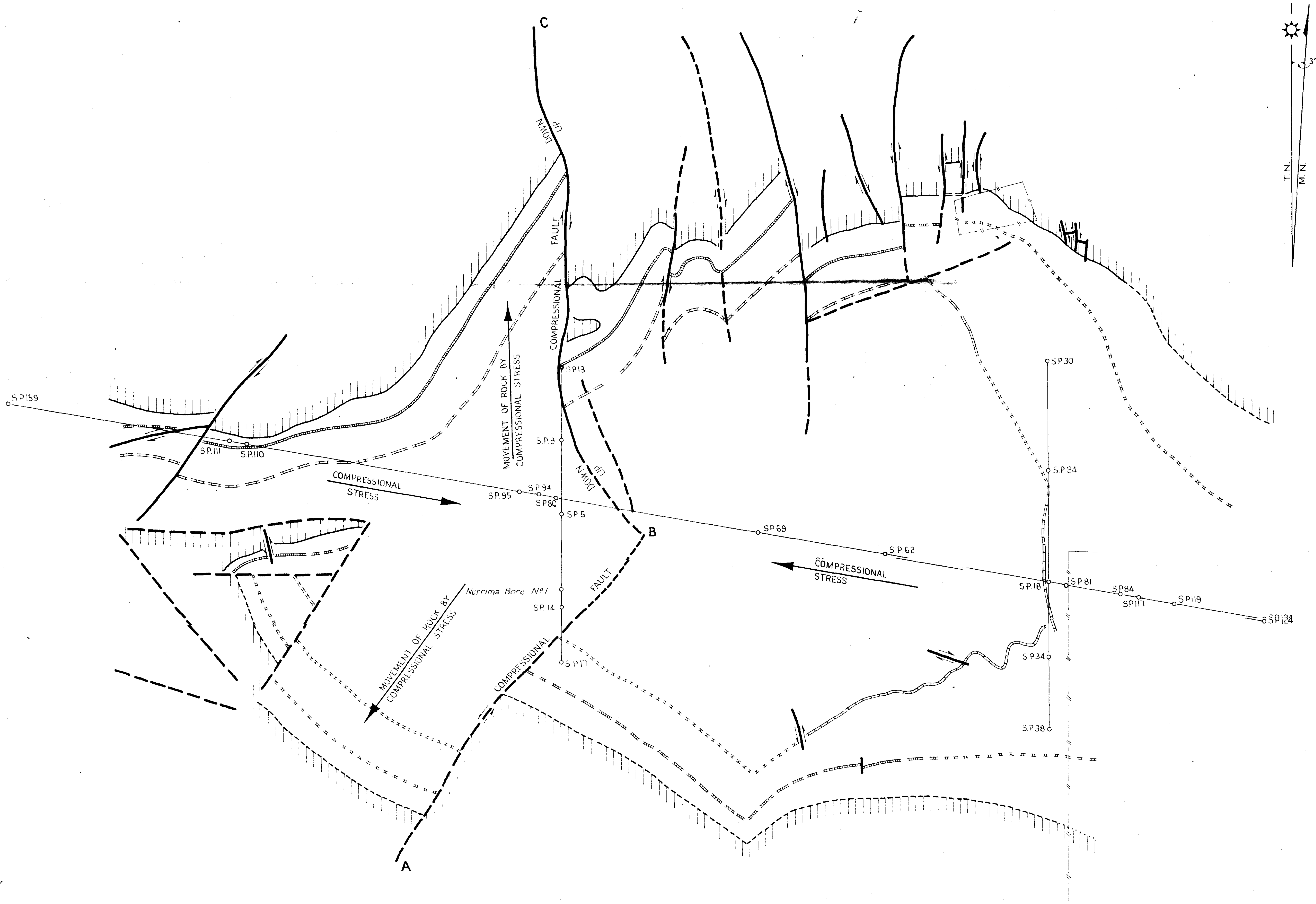

SCALES

1 0 1 2 3 MILES

5000 0 5000 10000 15000 FEET

LEGEND

DEFINITE / PROBABLE	}	BOUNDARY BETWEEN LIVERINGA SANDSTONE AND NOONKANBAH SHALE
DEFINITE / PROBABLE	}	FAULTS
DEFINITE / PROBABLE	}	STROPHALOSIA KIMBERLEYENSIS MARKER BED
DEFINITE / PROBABLE	}	POLYZOAL LIMESTONE MARKER BED
		FENCE
o		SHOT POINT

William A. Wiebenga
J. van der Linden
GEOPHYSICISTS

GRAVITY SURVEY. FITZROY BASIN
KIMBERLEY DIVISION. WESTERN AUSTRALIA

PLAN OF NERRIMA AREA INDICATING THE FAULT PATTERN, THE COMPRESSIONAL FAULT A B C, AND THE MOVEMENT OF ROCK BY COMPRESSIONAL STRESS.

(GEOLOGY BY GUPPY, CUTHBERT & LINDNER, EXCEPT THAT, MOVEMENT ON FAULT A B C IS AMENDED TO CONFORM WITH GEOPHYSICAL DATA.)

Geophysical Section, Bureau of Mineral Resources Geology & Geophysics