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REGIONAL GRAVITY SURVEY, NORTH-EASTERN NEW SOUTH WALES AND SOUTH-EASTERN QUEENSLAND 1960-1961

by

W.J. LANGRON and J.R.H. van Son

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ILLUSTRATIONS

SUMMARY

This report discusses the results of regional gravity surveys carried out in north-east New South Wales. The results are presented in the form of Bouguer and free-air anomaly contours. Two gravity profiles are examined in terms of their relation to geological cross-sections.

The Bouguer gravity pattern in general has a trend parallel to the coast but the survey area can be divided into five distinct zones. Positive Bouguer values along the coast indicate the rise in the Mohorovicic Discontinuity seawards, and it is suggested that this effect is reinforced in some regions by the presence of volcanic rocks and possibly by structural effects. The Clarence-Moreton and Lorne Basins are associated with gravity 'highs'.

Inland from this zone a central gravity 'low' region is associated with the New England Granite Bathylith. It extends southwards to include the Bathurst Granites. A central zone of gravity 'high' values, arcuate to the east, is located over a belt of folds and thrusts. Its gravity trend in the south is abruptly truncated by gravity features of the two zones mentioned previously. Bordering this zone on the west is a zone of low gravity which occurs over sediments of the Surat Basin. In the west of the survey area is an irregular high gravity zone, which it is suggested could be due to the Nebine Ridge or an extension of the Cobar Shelf.

Free-air gravity values are generally positive (and very high in some regions) and are usually associated with increasing elevations and with positive Bouguer anomalies. It is suggested that isostatic compensation may not be effective over this area if it is considered alone.

Finally some suggestions are made whereby the interpretation of the gravity data in the area could be improved and extended so as to include the examination of certain gravity features which at the present stage warrant only passing comment.

1. INTRODUCTION

Following the completion of the major portion of the regional gravity coverage of Victoria in 1960 it was decided to commence a similar type of coverage in New South Wales. A start was made in 1960 in the north-eastern corner of the State (Plate 1) because the network of roads and railways offered a density of cover desirable for regional work.

Main roads and railway levels were used for the reduction of most of the gravity data, but over some traverses, where no elevation data were available, a vehicle-borne elevation meter was used. The gravity work was done by J.R.H. van Son and S. Waterlander between 1960 and 1961; it was not extended beyond the area discussed in this report because in 1961 and 1962 the New South Wales Department of Mines commenced a programme of regional gravity traverses throughout the State. Although no results of this work have been received by the BMR it is understood that a consideralbe amount of work has been done in the area outside that discussed in this report.

The preliminary results from five 1:250,000 map areas in southern Queensland, which have been covered by reconnaissance gravity survey using helicopters (Lonsdale, 1965) have been considered for purposes of interpretation in the current presentation.

Reference has also been made to some detailed gravity surveys made in the area (see Appendix B), but the results from the more detailed surveys are not discussed in the present report, the main purpose of which is to analyse the gravity results in terms of the regional geology of the area. A brief account is now given of the background of the regional gravity work and of the collection of material discussed in this report.

In 1950 and 1951, measurements were made at various sites throughout Australia with the Cambridge Pendulum apparatus. The main purpose of this work (Dooley et al, 1961) was to establish a reference network of gravity base stations throughout Australia. There were two developments which helped to intensify the need for such a programme. The first of these was an increased world interest in geodesy, and the other was a result of the rapid increase in exploration using the gravity meter. It became apparent that as gravity surveys became more numerous and extensive, a revision of some of the gravity values at pendulum stations would be required. This was especially true for the pendulum stations along the east coast of Australia, many of which had been occupied by overseas observers using gravity meters and pendulum apparatus.

Adjustments to the pendulum values were made in 1957 and 1962, the latter adjustment (Dooley, 1965a) being very extensive and taking into account a large volume of gravity data which had been acquired between 1957 and 1962. A further point associated with this adjustment was that the calibration factors of gravity meters calibrated on the old Melbourne Calibration Range were required to be adjusted slightly. The 1962 adjustment included the results of work done in 1959 and 1960 by Flavelle and van Son (Flavelle, 1966), who read a chain of gravity stations (including all BMR pendulum stations) along the east coast of Australia between Melbourne and Cairns. This work was done to improve gravity values along and near the coast, primarily as a basis for a calibration line and ultimately to form part of the Australian segment of the Western Pacific Calibration Line. Flavelle's results have been included in Plate 4.

In 1964, Phase I of an Australia-wide survey was introduced specifically to improve the accuracy of the Australian Gravity Network and also to establish a greater number of control stations. This course was necessary because of a further stepping-up of activity in gravity surveys particularly in connection with oil search and complications arising in relating overlapping and adjoining surveys. An account of the first phase of this "Isogal" project is given by Barlow (in preparation).

All gravity data have been adjusted to the Isogal values of Barlow using a least-squares method of adjustment. The 'fixed' Isogal stations used for this purpose are listed in Appendix C.

In 1951, workers from Sydney University conducted gravity measurements along some of the main highways in Eastern Australia (Marshall and Narain, 1954). Some of this work coincides with traverses of the present area but the results are not included in this report because it is considered that their reliability is below that of the work presented here. The results of Marshall and Narain were useful, however, in planning the early stages of the BMR programme.

One other point should be mentioned here. One reason for the mismatching of surveys and poor adjustment applied to particular surveys in the past was very often an incorrect gravity meter calibration factor. This was largely corrected in the 1962 adjustment by Dooley (1965a); since then the calibration of gravity meters has been put on a firm basis by Barlow (1965) with the establishment of gravity meter calibration ranges at seven locations throughout Australia. Two of these ranges, Brisbane and Sydney, are adjacent to the area considered here, but were not available at the time of this survey. The instrument calibrations were based on the value of the Melbourne Calibration Range adopted at the time of the survey, and have been adjusted since on the basis of Barlow's value for the Melbourne Calibration Range.

Practically all of the work was done over fair to good roads and generally in reasonably good weather. Consequently a fairly good rate of progress for the survey was maintained. Also for these reasons, it was possible to maintain a strict schedule for checking instrument drift, and hence it is believed that the field readings are of good quality. The logistics for the survey are shown in Appendix A.

2. GEOLOGY

The geology of various parts of the area has been described by many writers. These accounts have generally been in connection with particular studies in the search for oil, coal, and metals, and descriptions of the geology of the area as a whole are not numerous. David (1950) discusses both the geology and physiography of the area. The geology of a considerable number of localities within the present area is discussed in the Australian Institute of Mining and Metallurgy publication, "The Geology of Australian Ore Deposits" (1953). One publication which must be mentioned because of the very extensive bibliography contained therein is McElroy's "The Geology of the Clarence-Moreton Basin" (1962). The problem of tectonic evolution in north-eastern New South Wales is discussed specifically by Voisey (1959). For the geology of the south-eastern part of Queensland and the adjacent region in New South Wales, and especially in relation to the development of the Tasman Geosyncline, reference is made to the Hill and Denmead (1960). Some 1:250,000 sheet areas have been mapped by the Geological Survey of New South Wales and the Geology Department of the University of New England, Armidale, but the published work is not extensive.

The geological map (Plate 2) is taken from the Tectonic Map of Australia. Reference has been made to the Geological Notes (BMR, 1962) which accompany this Map and to the Geological Map of New South Wales published by the Geological Survey of New South Wales. The discussion of the geology of the area considered in this report is based on these publications.

The area comprises the southern portion of an orogenic belt which continues northward into Queensland. It is bounded on three sides by Mesozoic sediments and is separated by them from the northern portion of the belt.

The region being investigated possesses a number of features characteristic of orogenic belts. It has a central complex of tightly folded and somewhat metamorphosed beds which is intruded by granites and porphyries and lies between two parallel belts of ultra-basic intrusives (the Great Serpentine Belt in the west and the Eastern Serpentine Belt). The complex is bounded on the west and south by thrust faults dipping inwards.

A large number of igneous rocks ranging from ultra-acid to ultra-basic are present and they vary from plutonic to volcanic types. Some are of Devonian age or older. During the Carboniferous and Permian periods there were great outpourings of rhyolitic and andesitic lavas, together with the ejection of much fragmental material. Then followed the flows of Tertiary basalt mentioned previously.

The sedimentary pile consists of a great variety of types and includes greywackes, cherts, jaspers, and phyllites of Lower and Middle Palaeozoic age, limestones, arkoses, and glacial and normal marine deposits intercalated with coal measures of Upper Palaeozoic age, and well-washed terrestrial Mesozoic sediments. The depression in which they were all laid down may be termed a typical eugeosyncline (Voisey, 1958).

The stratigraphy of the area has been summarised by David (1950) and Voisey (1958), and the names of the rock units may be determined readily from these works and the articles listed in their bibliographies.

Voisey (1959) has divided the region into a number of structural elements (Plate 3) and these are now summarised :

The Border Thrusts. These form the western and south-western boundary of the orogenic belt and separate the region of intense folding and faulting from the relatively undisturbed areas to the west.

The Western Belt of Folds and Thrusts. This belt is parallel to the Border Thrusts and is bounded on the east for most of its length by the Great Serpentine Belt. It is characterised by a series of meridional folds and faults most of which appear to be thrusts, but the increase in the intensity of the deformation moving east from the Border Thrusts to the Great Serpentine Belt is its most outstanding feature.

The Great Serpentine Belt lies in the fractures that separate the Middle and Upper Palaeozoic rocks from those believed to be Silurian and older lying to the east.

The Basin Belt, which is adjacent to the Hunter Thrust in the Hunter Valley, is attributable (Carey and Osborne, 1939) to stresses resulting from the active advance of the Hunter-Bowen orogeny in relation to the relatively immobile area to the south.

The Dome Belt. The rocks of the Dome Belt, in contrast to those of the Basin Belt to the north, have been arched up into domes with relatively slightly deformed tracts between them.

The Eastern Belt of Folds and Thrusts is a zone of synclines, anticlines, faults and complicated minor structures in rocks of Middle Palaeozoic to Permian age. The granite shown in the centre of the Parrabel Anticline (Plate 3) was reported by the Geological Survey of New South Wales and its boundaries are largely conjectural.

The Central Complex is distinguished by the high degree of deformation and silicification of vertically disposed rocks ranging from Silurian to Permian in age. Associated with the siliceous beds are greywackes and phyllites lithologically similar to those included in the Brisbane Metamorphics.

The New England Granite Bathylith lies within the Central Complex and is made up of a wide variety of rocks including granites, granodiorites, and porphyries. Large roof pendants are common and many mineral deposits are associated with the granite (Voisey, 1953). A number of small intrusions east of the main bathylith could be earlier phases of the same body although lithologically they are quite distinct from any of the other rocks of the bathylith.

Associated with the granite inlier between Scone and Gloucester is a thinning of the Lower Carboniferous beds. This granite is probably related to granodiorite which crops out further south near Cessnock and the influence which this rise in the basement, implied by the presence of the granite, may have exerted on the major structure may be seen from Plate 3. In particular the Great Serpentine Belt swings to the north of it and could possibly mark the western and southern edges of the region of maximum total deposition of the main geosyncline.

<u>The Eastern Serpentine Belt</u> is an important thrust zone that separates Lower Palaeozoic rocks on the east from Upper Palaeozoic rocks on the west with considerable accompanying displacement. The northern continuation of the belt beneath the Mesozoic cover is suggested by the reappearance of serpentine in the Brisbane Valley, Queensland.

<u>The Transcurrent Faults</u> striking approximately east-west characterise the coastal belt and would appear to separate up-thrust blocks of strata which were pushed westward by varying amounts. All of the faults have apparently large throws, which can only be accounted for by the tearing movement.

<u>The Upthrust Blocks</u> contain the oldest rocks in north-eastern New South Wales. These are the lower members in a sedimentary pile which suffered intermittent deformation culminating in the uplift of the region at the end of the Palaeozoic.

The coastal blocks are structural 'highs' and have risen quite considerable distances. They are bounded by the transcurrent faults on both the north and south, and on the west probably by thrust faults. The northern block is largely covered by Triassic and Jurassic sediments belonging to the Clarence Basin. The older rocks are generally obscured, appearing only around the margins.

<u>The Mesozoic Basins</u> include the Sydney (Cumberland), Oxley, Great Artesian, Clarence, and Lorne Basins. The dominant rocks are well-washed sandstones, which are associated with shales; coal seams occur in the Clarence Basin.

It would appear from the presence of the encircling Mesozoic rocks that the New England region has been more or less consistently rising since the Permian, and that sediments derived from the mass have contributed largely to the deposits in the basins. Much of the sand must have been derived from the granites which were exposed from early Triassic times onwards. The positive tendency of New England follows from the presumed low density of the granite core which may have moved up isostatically. The tendency for the region to have moved upwards in the past is indicated by the terraced character of the highlands (Voisey, 1957).

3. REDUCTION OF GRAVITY DATA

All data were reduced in the field to the stage of observed gravity values. Drift curves were plotted each day to ensure that the particular gravity meter was performing satisfactorily. The reduction to free-air and Bouguer anomaly values was done at the end of the survey when the party returned to Melbourne. For the initial reductions, latitudes were scaled from 4-mile military maps, Robinson 4-mile maps of New South Wales, or Lands and Survey Maps of New South Wales, upon which stations had been plotted in the field. These maps were the most accurate available at the time of the survey. Since then the stations have been plotted on to more accurate base maps (graticules) and a revision of the theoretical gravity values has been incorporated in the present results. However, final base maps for most of the area have not yet been drawn and it is possible that some minor corrections may be necessary for the latitudes of some of the stations.

As previously mentioned, all gravity intervals have been adjusted on the basis of the revised calibration factors of the gravity meters used during the work. The maximum misclosure within the network was 0.43 milligal but most of the closures were much less than this figure (see Plate 4). The 'May 1965 Isogal' values of Barlow and BMR pendulum station values have been used (see Appendix C) as 'fixed' stations for the adjustment of the network, the only exception being the BMR pendulum station at Parkes, which was not occupied during the Isogal survey, and for which the 1962 revised value of Dooley (1965a) has been used.

The observed gravity intervals along traverses between 'fixed' stations were then adjusted proportionately over the intervals between fixed stations and intermediate junction stations, the outer loops being treated first in this way, and then extending the process into the inner loops. Thus a new set of misclosures was obtained. This network was then subjected to a least-squares adjustment process, setting an upper limit of 0.05-milligal misclosure in carrying out the adjustment. Final values for individual stations were then obtained by taking the differences between the adjusted observed gravity interval and the observed gravity interval along each traverse and dividing this in the proportion of the number of gravity stations along the traverse.

This network adjustment is not rigorous and adjusted observed gravity values when obtained from the computer will no doubt differ slightly from those used in this report.

Calculations from the observed gravity stage to free-air and Bouguer anomaly values have been done on a CDC 3200 computer. In the reduction to Bouguer anomalies, density factors of 1.9, 2.2, and 2.67 g/cc have been used. The values used in this report are those obtained with a density factor of 2.67 g/cc in the Bouguer correction; Bouguer values incorporating the other density values will be more appropriate for sedimentary studies within the area.

Terrain corrections have not been calculated for the stations within this area. In almost all instances stations were located such that a terrain correction could be ignored for regional gravity purposes. There are a few stations (e.g. in the New England district) that should have terrain corrections applied to them, but because of the lack of sufficient topographic information, the corrections have not been applied.

Isostatic anomalies have not been calculated for stations within the area.

Most of the elevation data used in the reductions were collected from the various authorities during the course of the survey. In general this was a simple task but in the case of some of the Main Roads and Irrigation and Water Supply data a considerable amount of time was spent in correlating changes of datum. All such problems have now been cleared up with the exception of the traverse between Guyra and Dorrigo, where additional check levels are required before the observed gravity values can be reduced to final Bouguer anomaly values.

4. DISCUSSION OF RESULTS

The results of the surveys are presented as Bouguer anomalies in Plate 5 and as free-air anomalies in Plate 6. Some departure has been made from the rules which the Gravity Group of the BMR has laid down with regard to contouring. Contours acceptable to these definitions are shown in the conventional way i.e. as full and dashed lines. To these have been added contours (shown dotted) which are based on insufficient traverse density. These dotted contours have been drawn on the principle of mechanical contouring without reference to geological trends, etc.

The main feature of Plate 5 is the general alignment of Bouguer anomaly contours approximately parallel to the coast, and the location of increasingly positive values near to the coast.

The general alignment of Bouguer anomaly contours parallel to the coastlines of continents is usual (more specifically, the trend is related to the continental shelf). The matter has been referred to by van Son and Langron (1967) for regional gravity work in eastern Victoria. Exceptions do occur; attention is drawn to one notable exception by Flavelle (in preparation) for gravity surveys in the Canning Basin of Western Australia. The general rise in Bouguer anomaly values near the coast and seawards is due to the rise in the Mohorovicic Discontinuity.

The strike of the Bouguer anomaly contours is coincident with that of the rocks of the Tasman Geosynclinal Zone, and this trend appears to persist to the south over the Sydney Basin. More gravity information would be required in this portion of the area before commenting in detail on the relation between the gravity results and the structure as shown in Plates 2 and 3. However, it is clear that there is a dominant northerly trend in the gravity contours and that from this regional coverage there is little if any expression of the Sydney Basin or of the structural features associated with the northern margin of the Sydney Basin.

A relation similar to the above exists over the Clarence-Moreton Basin. Here the zero gravity contour follows the margin of the Mesozoic sediments of the basin approximately, and the relatively higher gravity values continue northward into the Moreton Basin. This phenomenon of a 'density reversal' wherein an increasing thickness of sediments give rise to increasingly positive Bouguer anomalies is in contrast to the relation between gravity values and thickness of Mesozoic sediments in the western part of the Great Artesian Basin (e.g. Lonsdale, 1965). It is possible that here the phenomenon is related not only to the 'normal' rise in Bouguer gravity seawards but in addition to crustal warping associated with offshore sedimentation. It may be significant that the highest Bouguer anomaly values are located in the region where the coastline changes direction, thus suggesting that there could have been considerable movement of basaltic material here. Such movement is possibly related to the formation of the nearby island arcs and deeps in the Pacific Ocean.

In addition there could be a much simpler explanation to account for the increase of the gravity values along this portion of the coast. Palaeozoic rocks of higher than normal density, similar to those occurring along the eastern margin of the Tasman Geosyncline under cover of sediments of the continental shelf, could lie fairly close to the coast in the region of north-eastern New South Wales (BMR, 1962). Rocks having higher densities, such as Middle and Lower Palaeozoic volcanics, limestones, and dolomites, crop out along the western flank of the Geosyncline and may be expected to occur in its eastern portion also. Volcanics, where they occur in eastern Queensland, give rise to high positive gravity values.

Further north where these rock types occur near the coast there are also positive Bouguer values, but not significantly higher than what would be expected when approaching the coast. Dooley (1965b) has shown, however, that near-shore Bouguer anomaly values decrease from about plus 80 milligals near Cooktown to about plus 30 milligals near Townsville. Thereafter, Bouguer anomalies are generally about plus 20 to 30 milligals in the vicinity of the coast with occasional higher values; one significant exception occurs over the Maryborough Basin where Lonsdale (1965) has reported values of up to plus 60 milligals. The only consistent correlation inferred from the Tectonic Map is that higher gravity values occur where the 100-fathom water depth line (or in Queensland, the Great Barrier Reef) is close to the coast.

It would seem therefore that the high Bouguer anomaly values in the north-east of the areas under discussion are due primarily to the rise in the basaltic layer, which is interrelated with the change in the trend of the coast line. In addition, a factor contributing to the high Bouguer anomalies in this region is the likely presence of volcanics along the eastern margin of the Tasman Geosyncline.

Further south, high positive Bouguer anomalies are associated with the Lorne and Sydney Basins. One factor may be the presence of volcanics, though the major factor is probably faulting, especially the major cross-faulting of the Tasman Geosynclinal Zone. The large number of basic intrusives mapped in the Sydney Basin indicates the wide distribution of higher density material in this region, though their presence (e.g. near the Oxley Basin) is not always associated with positive Bouguer anomalies.

Referring again to Plate 5, it can be seen that the area may be divided into five distinct zones:

1. The near-coastal gravity 'high'.
2. The central gravity 'low', in general associated with the outcrop of New England Granite.
3. The central gravity 'high', arcuate and along the western margin of zone 2.
4. The western gravity 'low', occupying western Dalby, most of SURAT, ST. GEORGE, MOREE, western NARRABRI, GILGANDRA, and probably DUBBO.
5. The western gravity 'high' in DIRRANBANDI, ANGLEDOOL, and WALGETT.

Several comments have been made already in connection with zone 1. The westerly bulge of the Bouguer anomaly contours in south-east Queensland is probably due in part to the widespread occurrence of volcanics in this region. The zero contour line near the coast at Port Macquarie is in a zone of multiple (and arcuate) faulting, with which is associated granite intrusions north of the Lorne Basin. With the exception of this bulge seawards, the contour pattern follows the trend of the eastern margin of the Eastern Serpentine Belt (Plate 3), which is shown in Plate 2 as a high-angle reverse fault. Moreover, the gravity trend continues to follow the southern extension of the structural features until the Manning River Fault System is reached. Here the gravity contours are distorted abruptly to form a westerly trending 'low' and presumably they continue eastwards to the coast. The gravity pattern is ambiguous here because of paucity of data but such a gravity 'low' will result whatever way the data are contoured. This indicates the southern termination of the Lorne Basin and in contrast to the zone of upthrust blocks to the north of the Basin, this zone could indicate downthrust blocks. The gravity trends clearly follow the direction of faulting within this entire eastern coastal region.

Within the central gravity 'low' (zone 2), the lowest gravity values are located over granite of the New England Bathylith. This belt of low values continues southwards with a slight rise across the Oxley Basin and develops strongly negative values over the southern continuation of the granite province (e.g. the Bathurst granites). Marshall and Narain (1954, p.48) suggest that the region of the New England Bathylith is in approximate isostatic equilibrium with a root of about 5.5 kilometres extending below the Mohorovicic Discontinuity. The gravity 'low' obtained in the Bathurst area can be explained on the same basis.

The low gravity values continue north-westerly and decrease in magnitude towards ROMA over deepening sediments of the Surat Basin. Gravity results in more detail over this portion of the area are discussed by Lonsdale (1965).

The gravity gradient trending north through the eastern half of GRAFTON has been commented upon above and marks the margin of the Eastern Serpentine Belt. It is possible that the minus-20-milligal contour has an inflexion connected with the gravity 'low' in the northern part of NEWCASTLE.

The central gravity 'high' (zone 3) is an arcuate feature associated with the Western Belt of Folds and Thrusts and the related Great Serpentine Belt. The higher gravity values appear to be associated with the folds and thrusts rather than with the occurrence of serpentine. Hence the gravity values here may be due to higher density metamorphic rocks associated with the folding in this belt, although it is also noted from the geological map (Plate 2) that volcanic rocks are fairly widely distributed within the zone. The northward extent of the zone is associated with volcanics and dominantly deformed Lower Palaeozoic rocks extending into Queensland.

The southern continuation of the zone in TAMWORTH is interrupted by the 'bridging' of granite between the northern and southern portions of the Tasman Geosynclinal Zone. Although large-scale faults and thrusts continue through this zone to the coast the associated gravity trend is cut off completely by the dominant gravity trends of zones 1 and 2. In addition, in the portion of the zone being considered here, there occurs mainly north-trending faulting of the Eastern Belt of Folds and Thrusts. However, it is impossible to examine correlation in detail between the various structural subdivisions of Plate 3 and the present density of gravity cover within this zone.

The western gravity 'low' (zone 4) occurs over sediments of the Surat Basin, the lowest gravity closures indicating increased thicknesses of Mesozoic sediments. There are one or two small relative gravity 'highs' within this zone; one along the northern boundary of DUBBO is associated with an outcrop of volcanics.

Detailed gravity work within an area along and north and south of the border between MOREE and INVERELL is discussed by Neumann (in preparation), who shows that the low gravity region in the western portion of GOONDIWINDI is in fact a very narrow strip over one hundred miles in length. Neumann also discusses those portions of the central gravity 'high' (including his Moree Gravity High) lying within the area of the detailed survey.

The western gravity 'high' (zone 5) is a rather irregular zone, which could be due to the Nebine Ridge or a northward extension of the Cobar Shelf, though both these structural features are located to the west of the present survey. There is some similarity between the gravity pattern in this zone and that of zone 1, however, and both include portions of the Tasman Geosynclinal Zone. Unfortunately no gravity information is available in the area immediately west of DIRRANBANDI-WALGETT.

It will be seen from the free-air anomaly map (Plate 6) that in general free-air anomalies are positive and in some localities exceed plus 70 milligals. This generality of positive free-air anomalies indicates that the area surveyed, considered alone, is not isostatically compensated. However, compensation may occur over a wider area.

There is a general similarity between the free-air anomaly pattern and the topographic map of the area and also between the free-air and Bouguer anomaly contour maps. There are some features that are worth noting. For example, the relatively high free-air anomaly values west of ST GEORGE, MOREE, and NARRABRI occur in a region of low elevation but correspond very closely to increased Bouguer anomaly values. The belt of very high free-air anomalies extending from near Tamworth and trending approximately north through Armidale contains free-air anomalies in excess of plus 90 milligals and is located along the highest portion of the Dividing Range. The high free-air anomalies along the coast correspond to the zone of positive Bouguer anomalies discussed previously and are due to the rise in the Earth's basaltic layer.

Generally, in the area under investigation there is a distinct similarity in the trends of the free-air and Bouguer anomaly patterns even to particular features such as the 'low' in the north-west corner of NEWCASTLE. However, no attempt has been made to interpolate contours in the complicated free-air anomaly pattern in the south-east portion of the area. It is felt that interpolation of gravity data in plates 5 and 6 has been pushed to the justifiable limits.

Finally, two profiles, with corresponding geological cross-sections, are presented in Plate 7. The gravity profiles have been constructed as far as possible from values along traverses on the individual map areas; otherwise the interpolated contours in Plate 5 have been used. The geological cross-sections are taken from Voisey (1959).

The gravity profiles are similar in shape, although the one along section CD is the more symmetrical. The negative gravity anomaly is located over granite of the New England Bathylith, though section CD crosses rocks of the Central Complex, which contains outcrops of pre-Permian granite. It would appear that these rock units have approximately the same density.

One could draw in a regional curve along the two gravity profiles but the difficulty would still remain of deciding the magnitude of the effect due to the granites and of deciding upon a figure for the density contrast between the granite and country rock. For example, if one assumes that a gravity anomaly of minus 40 milligals is due to the granite mass and the density of the country rock in this case is 2.67 g/cc, i.e. approximately equal to that of the granites in the area (Marshall and Narain, 1954, p 68) then the 'slab' formula (Dobrin, 1960 p 175) gives a value of 1.5 kilometres for the depth of granite root extending below the Mohorovicic Discontinuity. This compares with 4.7 kilometres given by Marshall and Narain, who used Heiskanen's expression (Heiskanen, 1953), and values of 2950 feet and minus 55 milligals for the average elevation of the gravity stations over the bathylith and the mean value of the Bouguer anomalies over this region.

The local anomaly on the western flank of section CD and its weaker (deeper source) expression on section AB is due to higher density rocks of the Western Belt of Folds and Thrusts. This correlation has been discussed previously.

Similarly, the rise in Bouguer anomaly values towards the eastern ends of these sections has been discussed already.

5. CONCLUSIONS AND RECOMMENDATIONS

In analysing the results of gravity surveys in relation to the structural geology, interpolation of gravity contours has been carried to the extreme and in some instances justification for this treatment may be subject to doubt. However, those contours not complying with the station density requirements laid down by the Gravity Group of the BMR are clearly indicated as such on the accompanying contour plans.

The first requirement to test adequately the various possible relations which have been suggested between the gravity results and the geology is that the station density be increased in many parts of the area under investigation. A density of about 1 station per 100 to 150 square miles is desirable and is achieved already over a large part of the area. This would serve as an interim target until the area is included in the BMR helicopter gravity reconnaissance programme, which would provide a uniform coverage of 1 gravity station per 50 square miles. It is not envisaged that the gravity investigation be carried into any greater detail than this bearing in mind the purpose of the present work. The suggested gravity station density could be obtained on most map areas (excluding those in the western portion of the area) by reading traverses along existing roads and railways. As the main problems requiring further investigation lie in the central and eastern portion of the area, the additional work would probably be limited to existing roads and railways.

Another essential requirement is that all field data be reduced by computer using programmes that have just been finalised by the Gravity Group of the BMR (Lodwick, in preparation). Such reductions will include a rigorous least-squares adjustment using a standard procedure adopted by the BMR for all gravity work calculated by computer. As part of this recalculation it will be necessary to have accurately plotted station positions; it is understood that the Division of National Mapping will be able to supply accurate base maps for some map areas in the near future.

Additional levelling, by means of microbarometers or elevation meter, may be necessary along some traverses (e.g. from Guyra to Dorrigo). Terrain corrections should be applied, especially to stations situated in highly dissected country.

The problem of density reversal should be the subject of special study. From gravity work done so far this problem seems to be confined to the region of south-east Queensland and north-east New South Wales and is no doubt bound up with a closer examination of isostatic conditions in the eastern portion of the present area of survey. The effect of the New England Bathylith and other granites in the Tasman Geosynclinal Zone should be examined in more detail, especially with respect to the roots beneath these granite masses. In conjunction with this zone of low gravity, its extension southwards should also be examined, particularly with regard to the extent of the Oxley and Sydney Basins. To enable such examinations as these to be carried out the more detailed and uniform gravity coverage recommended previously is essential.

It is not recommended that additional gravity work be done in the western portion of the area as it is felt that to examine the problems here sufficiently would require a lot of additional gravity work. Some light will be thrown on this region by examining results of private company gravity work that is now being done and possibly by gravity work done by the New South Wales Department of Mines. In addition, the whole of this western region will be included in a programme of uniform gravity coverage using helicopter transport.

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APPENDIX A

Organisation of the Surveys

1960, Party No.1. (6004 Survey)

Staff: J. van Son (geophysicist)

Vehicle: One International station wagon, C84829

Duration of survey: 1st September to 6th December 1960.

Number of new stations: 198

Instruments: Master Worden No.548 with calibration factor 0.08984 mgal/scale division was used throughout the survey. The instrument was calibrated on the Brisbane Calibration Range on 13th September 1960. During the survey, instrument drift was determined by using a looping method i.e. reading stations in the order 1, 2, 3, 4, 5, 1, 3, 5, 6, ... etc.

The vehicle-mounted Western Elevation Meter No.204 was used to determine elevations along some traverses.

Tie stations: BMR Pendulum Station No.45 at Walgett and existing gravity stations of the 6003 survey (Flavelle, 1966) revised to "May 1965 Isogal" values.

Elevations: Main Roads Department bench-marks, railway bench-marks, and Western Elevation Meter determinations.

Plotting: Stations were plotted in the field on to 4-mile Military and similar maps. Later, station positions were transferred to 1:250,000 graticules for purposes of obtaining co-ordinates.

Bouguer Anomalies: The Bouguer anomalies were calculated using a density of 2.67 g/cm^3 in the Bouguer correction. (Bouguer anomalies with density values of 1.9 and 2.2 g/cm^3 are also available).

Gravity data files: (National Gravity Repository, BMR)

No. 6004.1	:	Station descriptions and new numbers for stations.
6004.2	:	Gravity field sheets and drift plots.
6004.3	:	Elevation meter field and calculation sheets.
6004.4	:	Gravity calculation sheets.

1960, Party No.2. (6005 survey)

Staff: S. Waterlander (geophysicist).

Vehicle: Holden Utility.

Duration of survey: 31st August to 17th December 1960.

Number of new stations: 420.

Instruments: World-Wide No.35 with calibration factor 0.11511 mgal/scale division was used throughout the survey. The instrument was calibrated on the Melbourne Calibration Range on 15th July 1960. During the survey, instrument drift was determined by using a looping method, i.e. reading stations in the order 1, 2, 3, 4, 5, 1, 3, 5, 6, ... etc.

Tie stations: Existing gravity stations of the 6003 survey (Flavelle, 1966) revised to "May, 1965 Isogal" values.

Elevations: Main Roads Department bench-marks, railway bench-marks, and elevation data from the Water Conservation and Irrigation Commission.

Plotting: Stations were plotted in the field on to 4-mile Military and similar maps. Later, station positions were transferred to 1:250,000 graticules for purposes of obtaining co-ordinates.

Bouguer anomalies: The Bouguer anomalies were calculated using a density of 2.67 g/cm^3 in the Bouguer correction (Bouguer anomalies with density values of 1.9 and 2.3 g/cm^3 are also available).

Gravity data files: (National Gravity Repository, BMR)

No.6005.1	:	Station descriptions, new numbers for stations, and some level data.
6005.21	:	Gravity field and drift sheets and calculation sheets for traverses 1,2,3, & 5.
6005.22	:	Gravity field and calculation sheets for traverse 4 and for seismic shot-points along Phillips Petroleum Company traverses.
6005.2	:	Level information.

<u>1961 survey</u> (6105)

<u>Staff</u>: J. van Son (geophysicist).

<u>Vehicle</u>: One International station wagon, C84829.

<u>Duration of survey</u>: 15th May to 28th September 1961.

<u>Number of new stations</u>: 363.

<u>Instruments</u>: Worden No.169 with calibration factor 0.10563 mgal/scale division was used throughout the survey. The instrument was calibrated on the Melbourne Calibration Range on 12th May 1961. During the survey, instrument drift was determined by using a looping method, i.e. reading stations in the order 1, 2, 3, 4, 5, 1, 3, 5, 6, ... etc.

The vehicle-mounted Western Elevation Meter No.204 was used to determine elevations along some traverses.

<u>Tie stations</u>: Existing gravity stations of the 6003 (Flavelle, 1966), 6004,and 6005 surveys revised to "May 1965 Isogal" values.

<u>Elevations</u>: Main Roads Department bench-marks, railway bench-marks and Worden Elevation Meter determinations.

<u>Plotting</u>: In the field, stations were plotted on to 4-mile Military maps, maps from the Water Conservation and Irrigation Commission, and Robinson 4-mile maps of New South Wales (sheets No's. 10 and 11). Later, station positions were transferred to 1:250,000 graticules for purposes of obtaining co-ordinates.

<u>Bouguer Anomalies</u>: The Bouguer anomalies were calculated using a density of 2.67 g/cm^3 in the Bouguer correction (Bouguer anomalies with density values of 1.9 and 2.2 g/cm^3 are also available).

<u>Gravity data files</u>: (National Gravity Repository, BMR)

No.6105.1	:	Station descriptions.
6105.2	:	Gravity field and drift sheets.
6105.3	:	Elevation meter field and calculation sheets.
6105.4	:	Observed gravity calculations (including network adjustment).
6105.5	:	Bouguer anomaly calculations.

APPENDIX B

Other gravity surveys in the area

1. BMR survey in the Moree area (Neumann, in preparation).

2. BMR gravity readings along L. H. Smart Oil Exploration Co. Ltd. seismic traverses in SINGLETON (unpublished data).

3. Dandaloo gravity survey* by A.J. Wood (BMR ref. 64/4803).

4. Carinda gravity survey* by The Papuan Apinaipi Petroleum Co. Ltd. (BMR ref. 63/1916).

5. Wee Waa gravity survey* by Alliance Oil Development Australia N.L. (BMR ref. 63/1912).

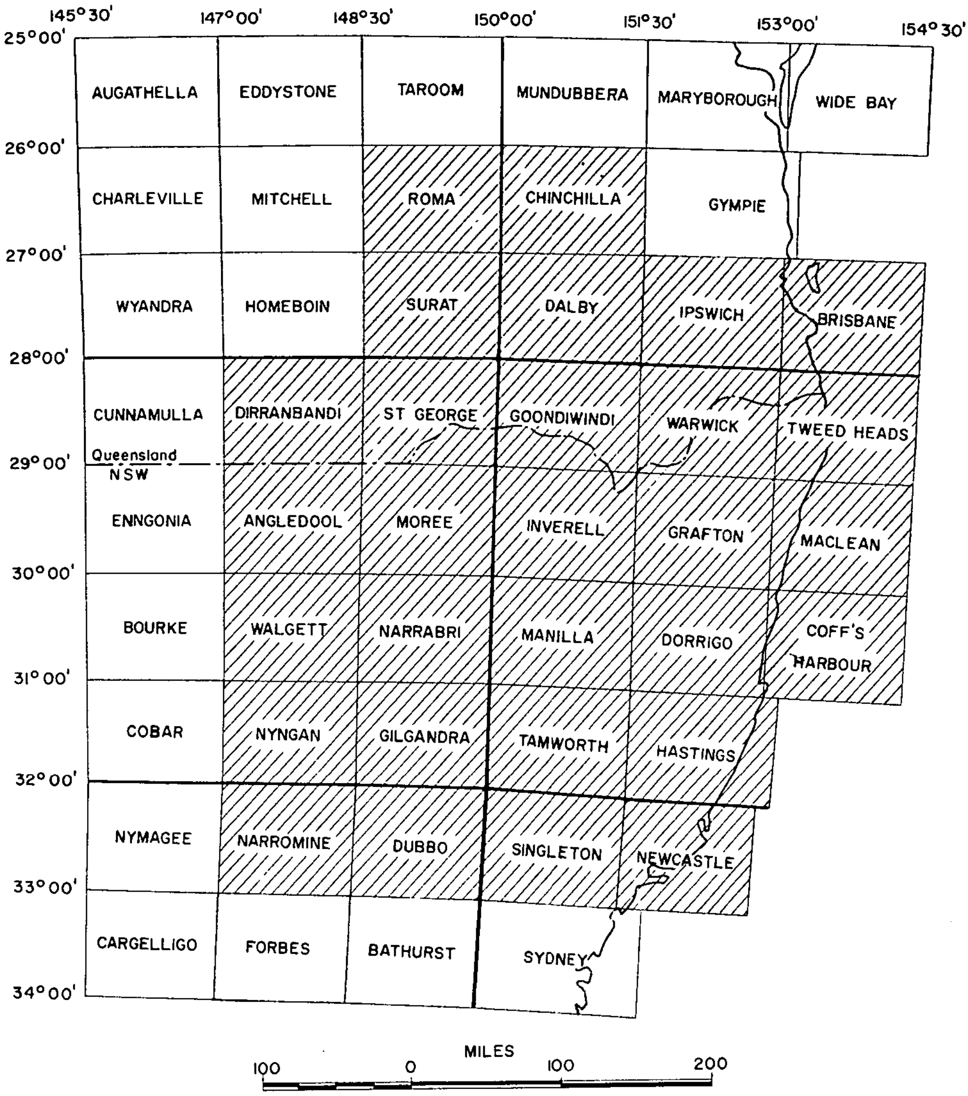
6. Details of gravity work carried out in the Sydney Basin have been made available by Australian Oil & Gas Corporation Ltd.

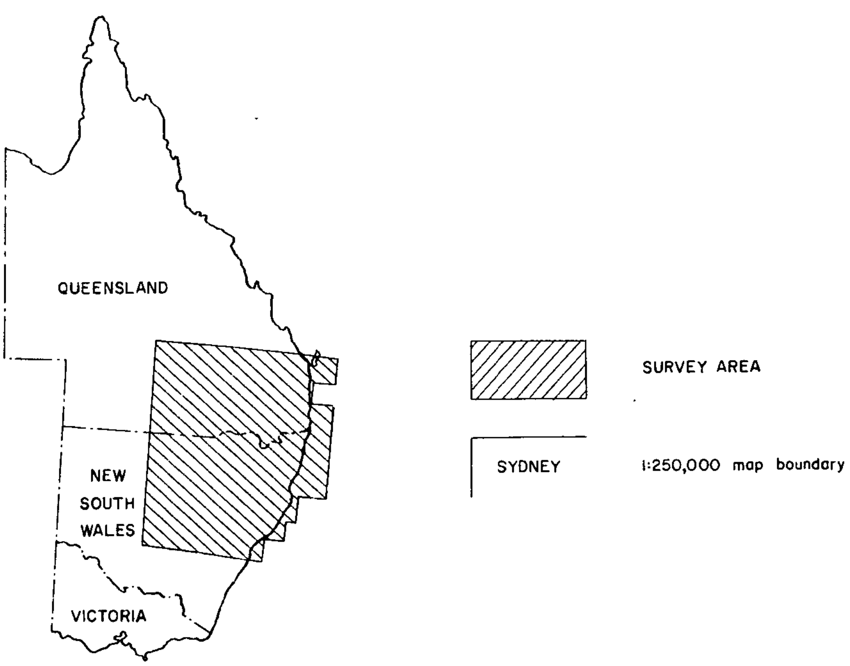
* Commonwealth-subsidised operation.

APPENDIX C

Isogal and BMR pendulum stations used in the adjustment of data

Station No.	Gravity value (mgal)	Remarks
5099.9959	978,979.35	Roma. P.S. No. 59
6499.0147	979,170.01	Brisbane, (Eagle Farm Airstrip)
6491.1010	127.95	St. George, M-15.
6491.2009	159.07	Goondiwindi BM-26
6491.2007	100.98	Warwick, QBM-75.
6491.1110	320.31	Grafton, 1-46
6491.0246	120.08	Armidale, A-1
6491.9109	325.05	Tamworth, airstrip.
6491.9008	112.85	Inverell, airstrip.
6491.2108	313.48	Narrabri, 5-37.
5099.9945	319.75	Walgett, P.S. No.45.
6491.2113	440.08	Dubbo, EA-336.
6491.1112	423.57	Scone, EA-408
6491.1111	436.10	Kempsey, 1-90
5099.9905	685.74	Sydney. P.S. No. 5.
5099.9944	509.0	Parkes, P.S. No. 44.





REGIONAL GRAVITY SURVEY

NORTH-EASTERN NSW AND SOUTH-EASTERN QLD

1960-61

LOCALITY MAP

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics

N/B2-5

TO ACCOMPANY RECORD No. 1967/12

PLATE 2

GEOLOGY

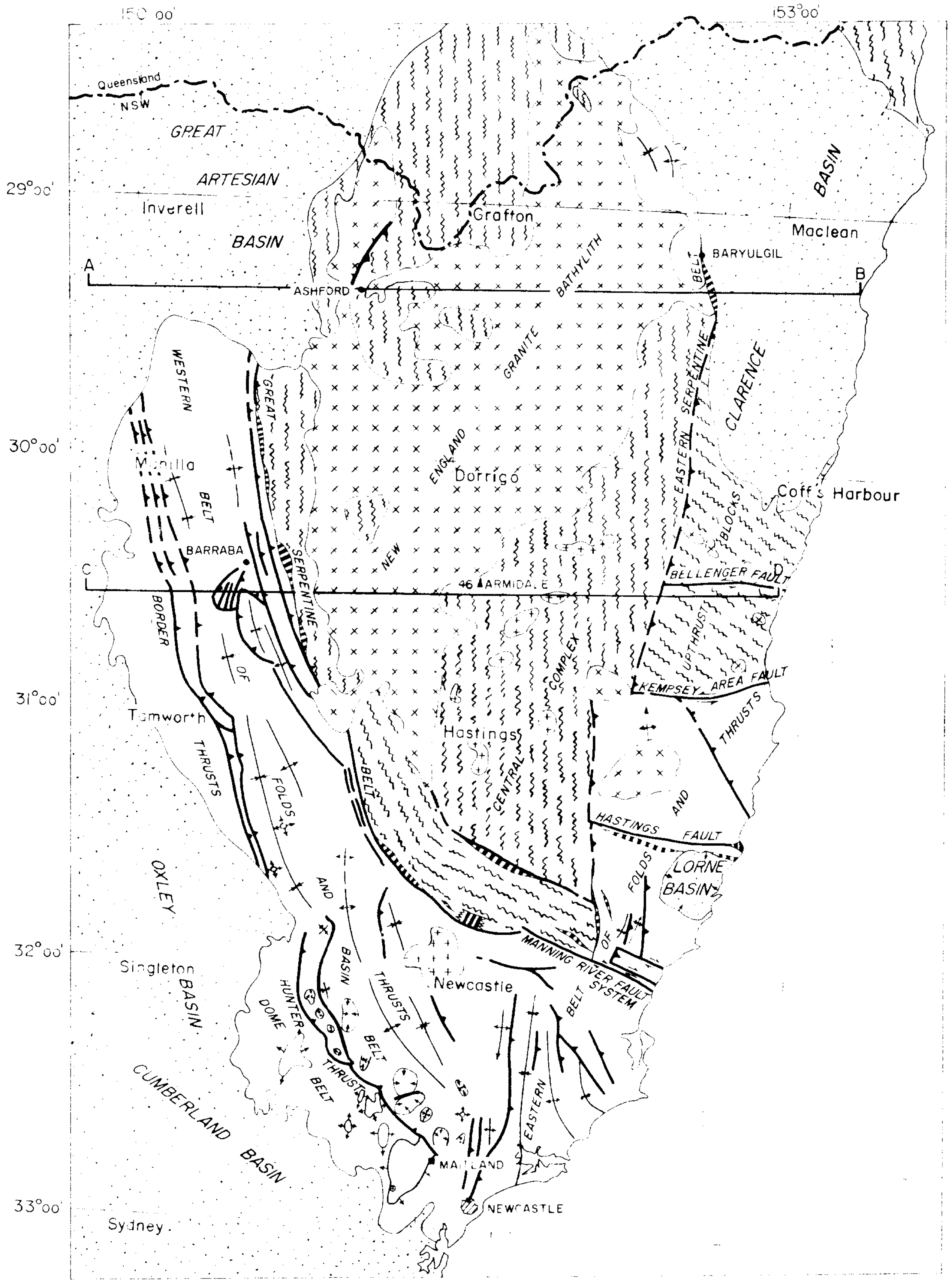
(AFTER TECTONIC MAP OF AUSTRALIA)

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics

N/B2-1

TO ACCOMPANY RECORD No. 1967/12

REGIONAL GRAVITY SURVEY N.E. NSW AND S.E. QLD 1960-61



LEGEND

FOLDS

- Anticline
- Syncline
- Dome
- Basin

FAULTS

- Reverse
- Fault with dominantly horizontal movement
- Character unknown
- Conjectural

SEDIMENTARY

- Mesozoic
- Upper Palaeozoic (Devonian to Permian)
- Dominantly deformed Lower Palaeozoic with infolded and infaulted Upper Palaeozoic

IGNEOUS ROCKS

Basalts not shown

- Permian granites
- Serpentines
- Pre-Permian granites

STRUCTURAL GEOLOGY

(AFTER VOISEY, 1959)

SCALE

40 0 40 80 120 MILES

14 Parkes

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. N/B2-6

TO ACCOMPANY RECORD No. 1967/12

REGIONAL GRAVITY SURVEYS, N.E. NSW AND S.E. QLD 1960-61

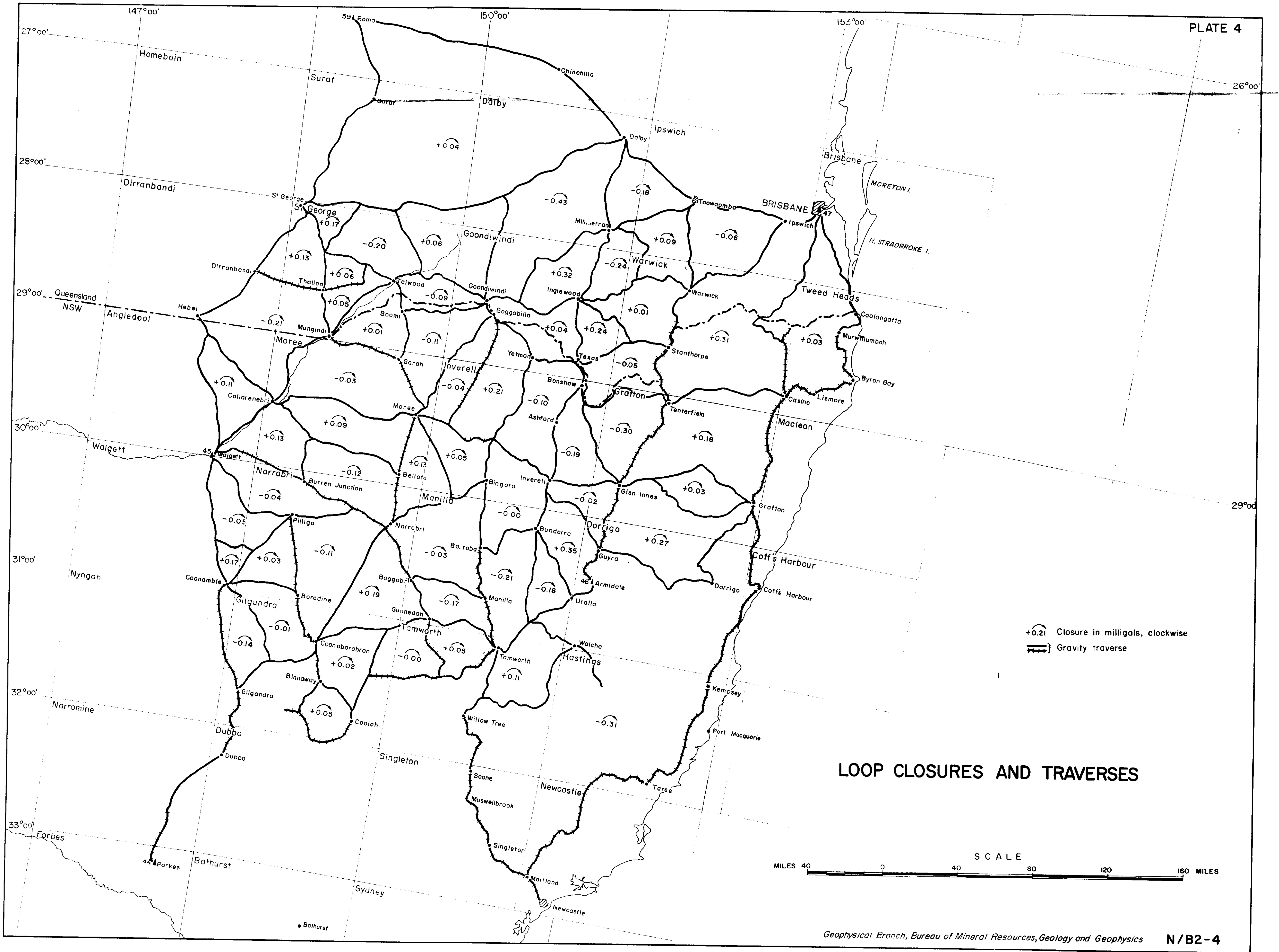


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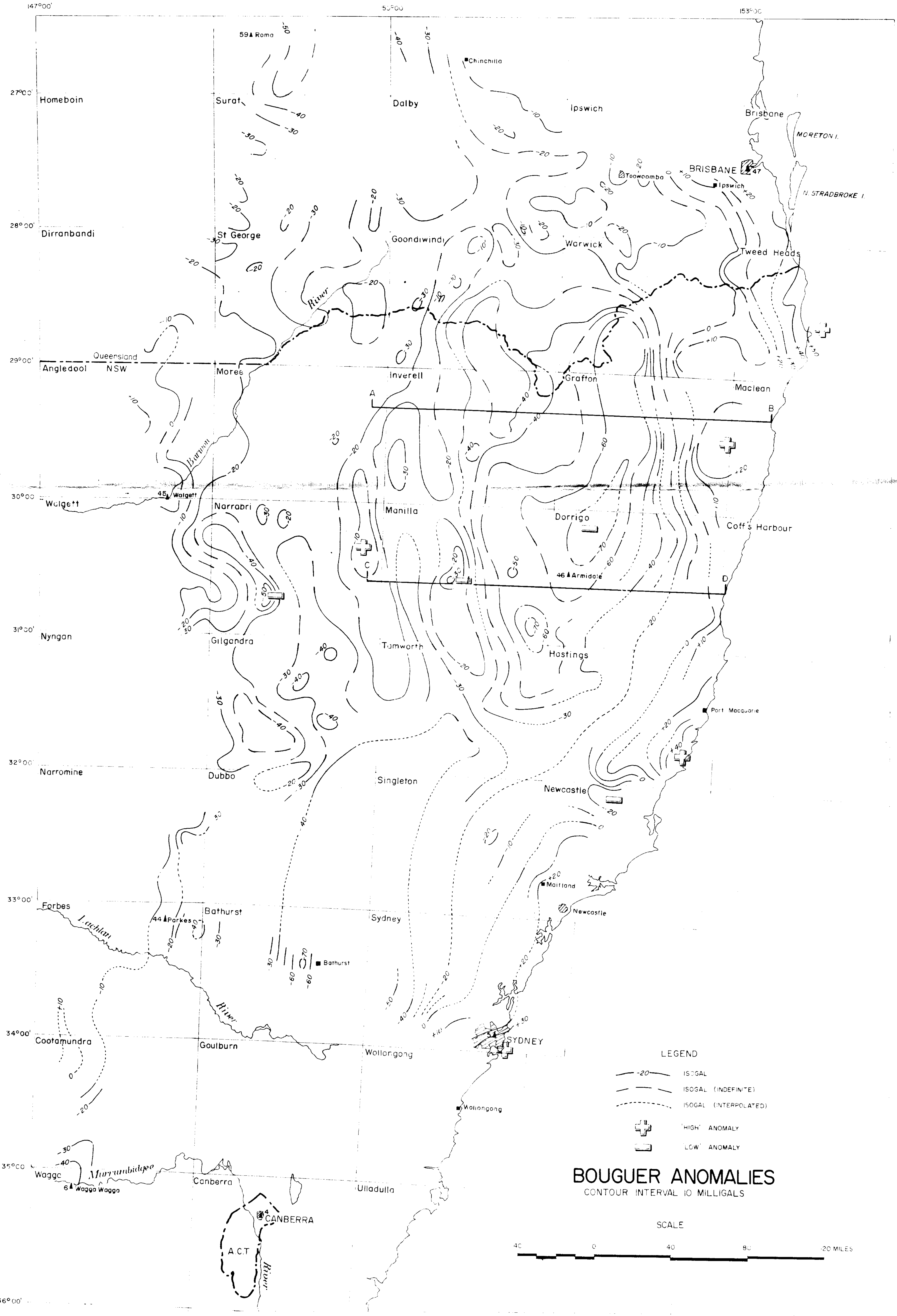
PLATE 5



BOUGUER ANOMALIES

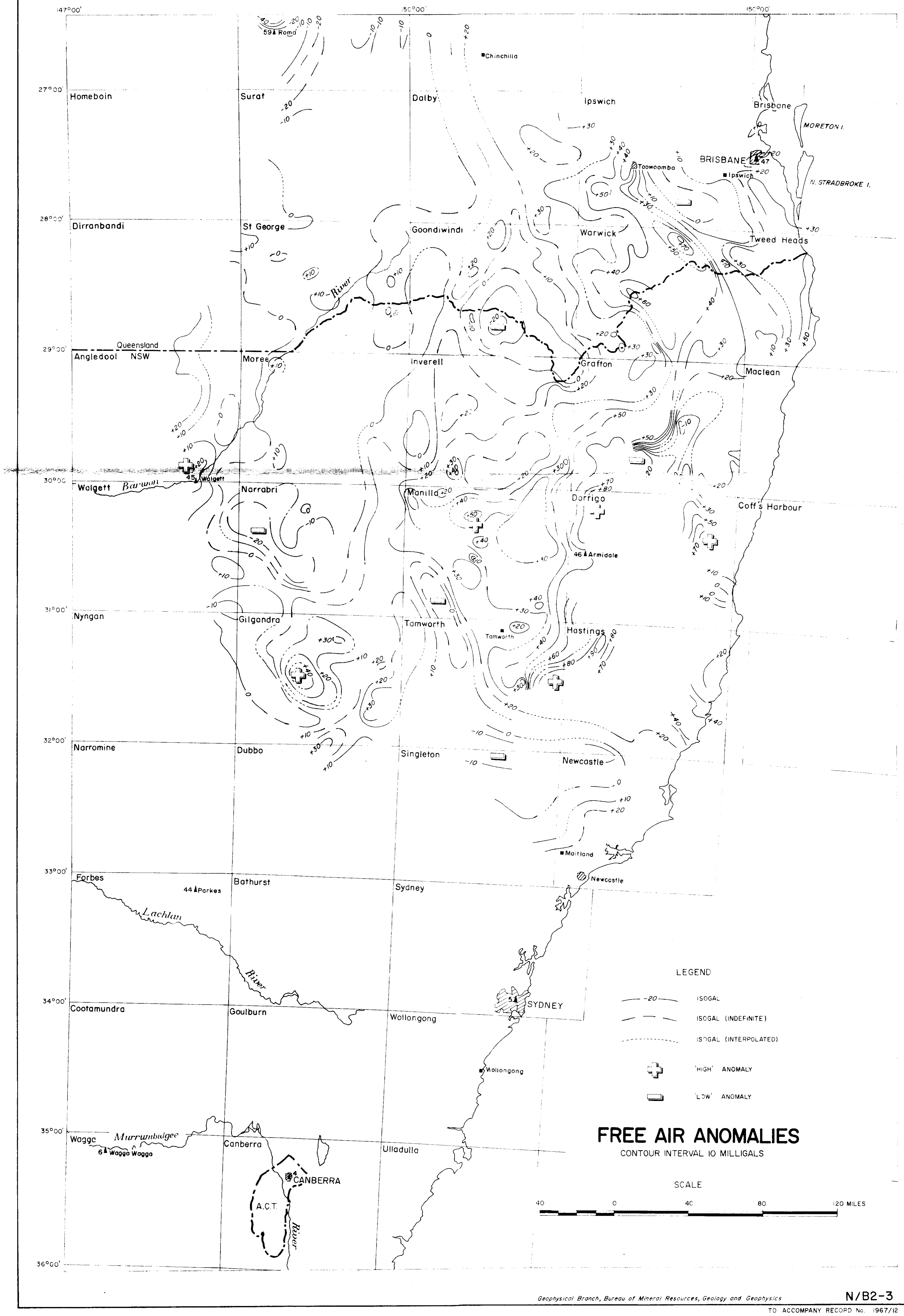
CONTOUR INTERVAL 10 MILLIGALS

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics

N/B2-2

TO ACCOMPANY RECORD No 1967/12

PLATE 6



FREE AIR ANOMALIES

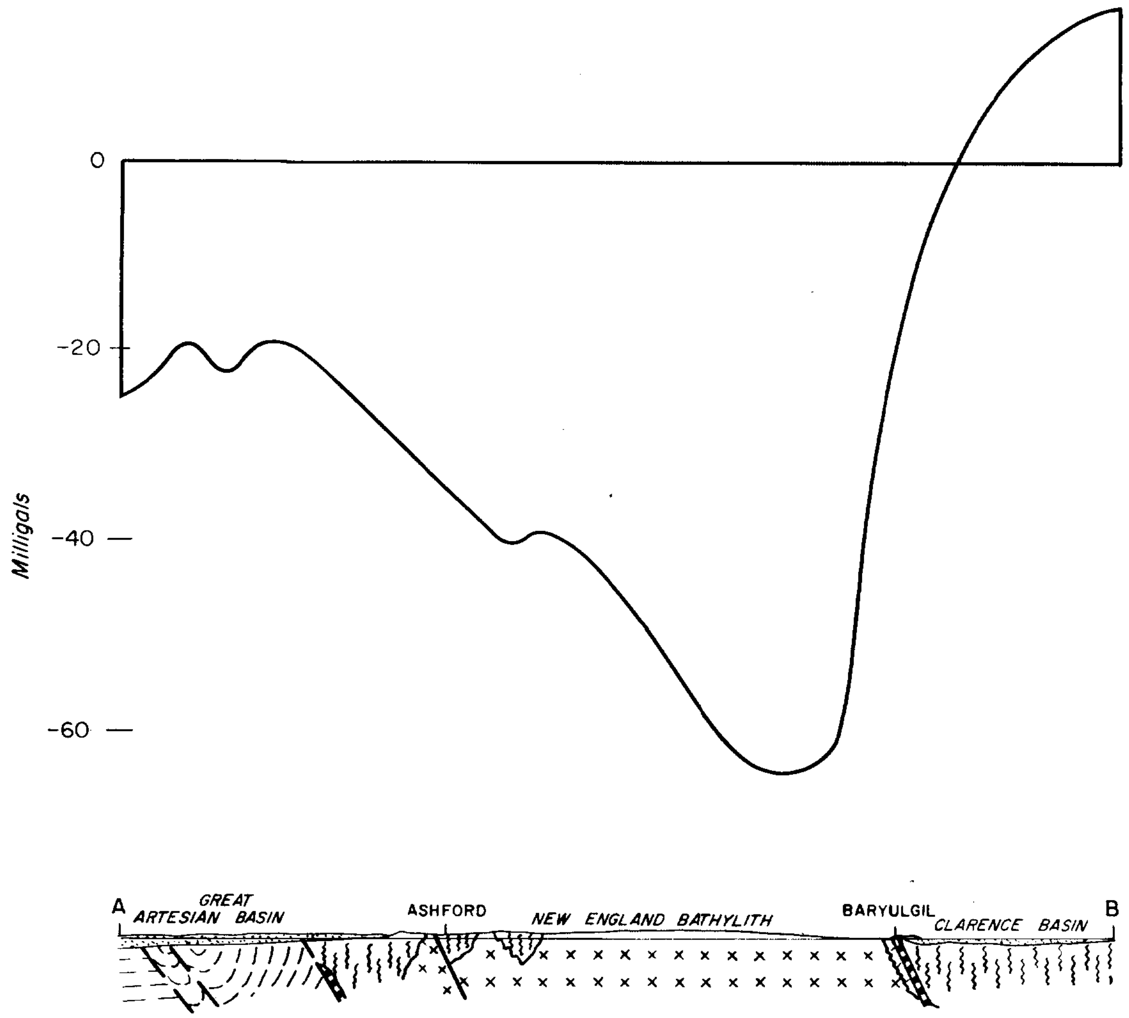
CONTOUR INTERVAL 10 MILLIGALS

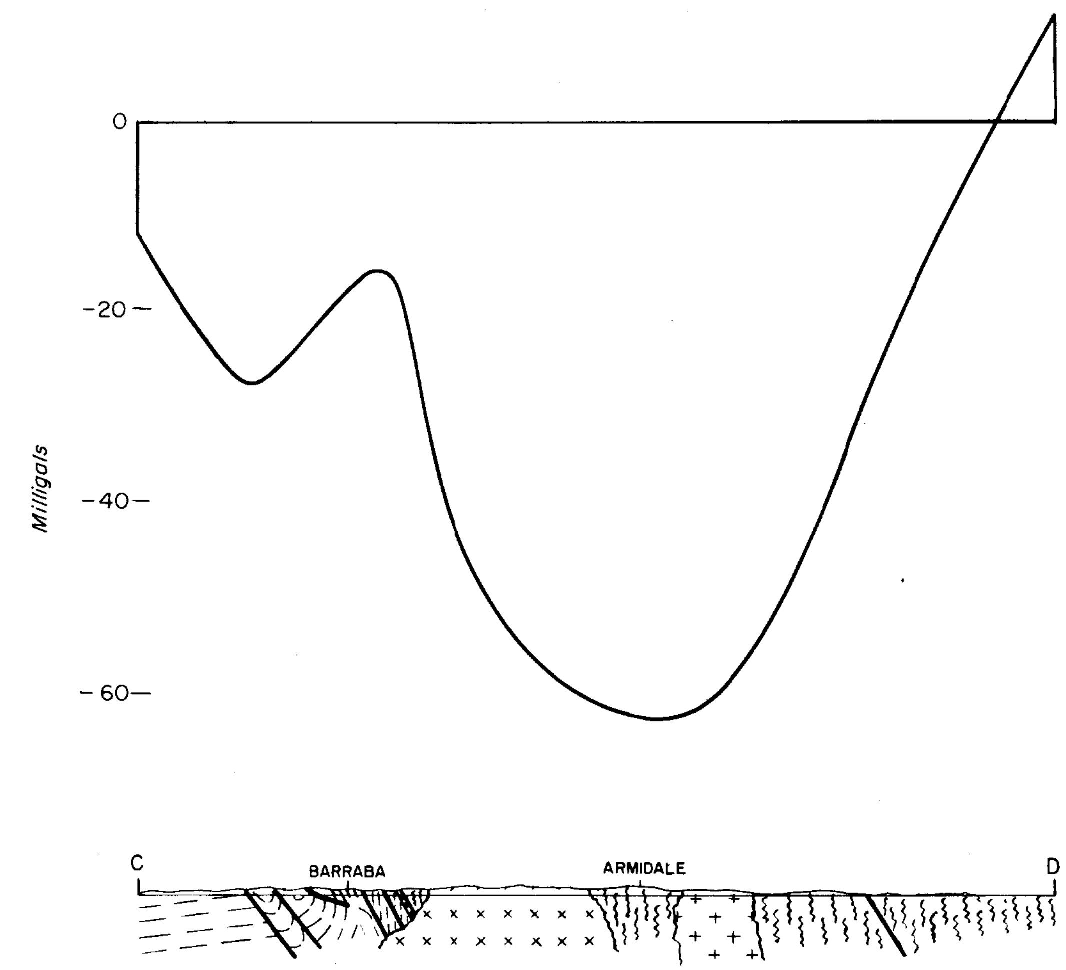
Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics

N/B2-3

TO ACCOMPANY RECORD No. 1967/12

PLATE 7





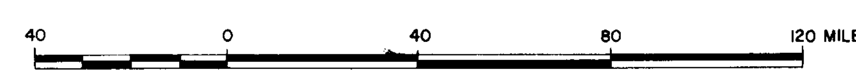
LEGEND

Mesozoic	}	SEDIMENTARY ROCKS
Upper Palaeozoic (Devonian to Permian).		
dominantly deformed Lower Palaeozoic with infolded and infaulted Upper Palaeozoic.		
Permian granites	}	IGNEOUS ROCKS
Serpentines		
Pre-Permian granites		
Disposition of beds		

BOUGUER ANOMALY AND GEOLOGY PROFILES

(Geological cross-sections after Voisey, 1959)

SCALE



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

N/B2-7

TO ACCOMPANY RECORD No 1967/12

REGIONAL GRAVITY SURVEY N.E. NSW AND S.E. QLD