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RECONNAISSANCE HELICOPTER GRAVITY SURVEY OF THE NORTHWEST OF WESTERN AUSTRALIA, 1969

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SUMMARY

A preliminary interpretation of the Bouguer anomaly field over the northwestern part of the Australian Precambrian Shield has been made. The gravity results were obtained in a reconnaissance helicopter gravity survey conducted between September and November 1969 by the Bureau of Mineral Resources, Geology and Geophysics (BMR). The 'cell method' of flying was used to establish 3297 new readings at 11-km spacing over all or parts of twenty-four 1:250 000 Sheet areas. Some results from three previous land surveys and a marine survey, carried out by BMR in 1960, 1962, and 1968, are included in the discussion.

The Bouguer anomaly field may be divided into six regional gravity provinces; three of these were partly defined from the results of the previous surveys. The gravity provinces mainly correspond to tectonic divisions within the Precambrian Shield.

A large oval-shaped gravity province of disturbed contour pattern and relatively low Bouguer anomaly level encompasses both the Archaean Pilbara Block and the Proterozoic Hamersley Basin, and is believed to correspond to an Archaean craton of which the Pilbara Block is only the exposed part. The name 'Pilbara Nucleus' is proposed for this craton. The gravity results suggest that large-scale folding within the Hammersley Basin is closely associated with structures in the underlying Pilbara Nucleus; specifically, anticlines and synclines in the Proterozoic sediments correspond respectively to granitic batholiths and 'greenstone' assemblages in the Archaean basement.

The Pilbara Nucleus is partly circumscribed by broad elongate gravity ridges. Gravity and geologic evidence together suggest that the gravity ridges are the expressions of Proterozoic mobile zones containing dense regionally metamorphosed rocks beneath the surface.

Proterozoic granites that crop out within or near the proposed mobile zones have no appreciable gravity expression and in this respect differ markedly from Archaean granites of the Pilbara Block, which are associated with intense gravity depressions. The observed difference in gravity expression indicates that the geometries or density contrasts of the Proterozoic granites differ from those of the Archaean granites.

An area of low Bouguer anomaly values in the southern part of the survey area indicates a regional mass deficient zone on the northern margin of the Yilgarn Block. This gravity depression may have similar tectonic significance to elongate gravity depressions along the southern and southeastern margins of the Yilgarn Block.

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The gravity pattern over the Carnarvon Basin differs from that over the adjoining shield area to the east. In this regard, the gravity results support the contention that gravity relief over the Carnarvon Basin relates mainly to basement topography rather than to intrabasement density variations.

Examination of the regional distribution of known mineral occurrences in relation to the Bouguer anomaly field suggests that mineral deposits are concentrated along the zones of steep Bouguer anomaly gradient surrounding residual gravity highs of the Pilbara Block.

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1. INTRODUCTION

The Bureau of Mineral Resources, Geology & Geophysics (BMR) extended the reconnaissance helicopter gravity coverage of Australia by conducting two surveys in Western Australia in 1969. Both were done under contract to BMR by Wongela Geophysical Pty Ltd, using the 'cell method', described by Hastie & Walker (1962), to establish an 11-km grid of gravity stations over the two areas. This report discusses the results in the northern area (Plate 1), in which 340 000 km^2 was surveyed covering twenty-four 1:250 000 Sheet areas. The results of previous gravity surveys by BMR, over the northwest continental shelf and over several 1:250 000 Sheet areas to the east of the main survey area, are also included in the discussion. Bouguer anomaly contours for the area discussed are shown in Plate 2.

The survey areas extend over the northern part of the Carnarvon Basin, the western tip of the Canning Basin, and a portion of the Australian Precambrian Shield. In the Carnarvon Basin, ties were made to a previous survey by West Australian Petroleum Pty Ltd, and new readings were taken only where gravity coverage was considered inadequate.

The topography is featured by a duricrusted plateau and gently seaward-sloping coastal plains. Height above sea level on the plateau generally ranges from 500 to 800 metres although several peaks exceed 1000 metres. Mount Bruce (1227 metres) is the highest point in the State. Erosion by rivers has reduced the plateau in some areas to a series of tablelands and mesas separated by wide valleys. In the Hamersley and Ophthalmia Ranges, folded sediments have been differentially eroded.

Rainfall within the survey area is generally low and irregular, and vegetation is sparse. It was easy to find landing spots for the helicopter, and a network of graded roads generally gave good access and facilitated the transport of crew and fuel.

Summaries of the geology and previous geophysical survey results, and a qualitative description and interpretation of major gravity features are presented. Operational statistics and a description of survey methods are given in appendices.

2. GEOLOGY

The survey areas extend over the northern half of the Carnarvon Basin, the western tip of the Canning Basin, and all or parts of the Pilbara Block, the Median Belt, the Gascoyne Block, and the Paterson Province of the Australian Precambrian Shield. These structural divisions are shown in Plate 3. With the exception of the Canning Basin, whose gravity expression is discussed in another report (Flavelle & Goodspeed, 1962), each structural element is discussed in some detail. The names of boreholes drilled in the sedimentary basins of the survey areas are listed in Appendix 4.

Carnarvon Basin

This is an epicontinental basin of mainly Phanerozoic sediments, extending on land from Onslow in the north to Geraldton in the south, and eastward from the coast for up to 200 kilometres. Recent sands and alluvium obscure the landward margin of the basin in the north, but centrally in the east the boundary is the junction of Palaeozoic sediments with Precambrian igneous and metamorphic rocks. The southeastern margin is not distinct and the boundary between the Perth and Carnarvon Basins is arbitrarily defined.

Geophysical and drilling evidence has shown that the Precambrian floor of the basin is irregular, consisting of a number of relatively deep troughs separated by narrow sinuous ridges, (Chamberlain et al. 1954; Parkinson, 1957; Forsyth, 1960; Spence 1961, 1962; Bow & Turpie, 1964). The main basement ridge is represented by an elongate belt of high Bouguer anomaly and divides the onshore part of the basin meridionally. On each side of the basement ridge are sedimentary troughs represented by gravity depressions.

Pilbara Block

The Pilbara Block constitutes one of the oldest known parts of the Australian Shield. Archaean granites and gneisses have generally yielded rubidium-strontium ages in the range 3100 to 2900 million years which is considerably older than the 2700 to 2600 m.y. range for most of the granites in the Yilgarn Block (Compston & Arriens, 1968).

The following description of the Pilbara Block is largely derived from reviews by Noldart & Wyatt (1961) Prider (1965), and Ryan (1965). The Archaean rocks of the Pilbara Block belong to the Pilbara System which comprises volcanic and sedimentary successions, metamorphics, and igneous intrusives. In the central and eastern parts of the Pilbara Block, the volcanic/ sedimentary pile is divided into the Warrawoona and Mosquito Creek Successions. The Warrawoona Succession is the older, and is made up of highly folded metamorphosed basaltic lavas and sills with a minor development of jaspilite. The predominantly clastic Mosquito Creek Succession unconformably overlies the Warrawoona Succession and consists of conglomerate, mudstone, shale, schist, sandstone, slate, and quartzite. In the western part of the Pilbara Block, two contemporaneous environments are represented by laterally equivalent volcanic and sedimentary successions which together comprise the Roebourne Group. The two successions are lithologically similar to the Warrawoona and Mosquito Creek Successions, but there is no evidence for an erosional break between them.

The oldest known intrusive rock of the Pilbara System is a dolerite which intrudes basic lavas about 15 km southwest of Roebourne. Two large complexes of intrusive and metamorphic basic and ultrabasic rocks are present immediately south of Roebourne and in YARRALOOLA*. The dominant igneous rock types in the Pilbara Block are granite and gneiss, which occupy large tracts of low-lying country where outcrop is poor. The commonest type is a leucocratic even-grained granite. Noldart & Wyatt have recognized two main types of granitic intrusives: those that appear to have concordantly intruded the rocks of the Warrawoona Succession, and those that have discordantly intruded the Mosquito Creek Succession.

The Pilbara System is unconformably overlain by a succession of flat-lying, unmetamorphosed, shallow-water sediments and interbedded volcanics of Lower Proterozoic age. The dominant rock types are conglomerate and pebbly sandstone with minor shale and siltstone interbedded with acid and basic igneous sills or flows. The youngest rocks are thin Tertiary and Quaternary sequences which occur in the valleys of the major rivers draining the Pilbara Block.

The dominant structural features of the Pilbara Block are the large granitic domes. The overlying successions form tight synclinoria between them, and there is a high degree of concordance between the stratification of the beds of the successions and banding and foliations in adjoining gneissic and metamorphic zones. Within the Warrawoona Succession, no overall regional fold trend is apparent and most of the internal structural trends and fold patterns follow marginally on the granitic plutons. Fold patterns are simpler in the Mosquito Creek Succession and the Roebourne Group and follow a regional trend varying from east-northeast to east. Noldart & Wyatt consider that the whole of the Pilbara System has been subject to regional superimposed folding with the dominant axes striking west-northwest. The regional folding postdates or was contemporaneous with folding of the Mosquito Creek Succession and is believed to have been due to a tangential compressive force imposed on the Pilbara Block from the southeast.

* Throughout this report, the names of 1:250 000 Sheet areas will be written in capital letters to distinguish them from place names.

Median Belt

Between the Pilbara and Yilgarn Blocks lies a broad southeast-trending Proterozoic basin containing unmetamorphosed sediments and interbedded lavas. The basin has been termed the Median Belt (Clarke, 1938; Prider, 1965; Hills, 1965) and the Nullagine Basin (Daniels, 1966). Daniels & Horwitz (1968) have divided the Median Belt into the Hamersley Basin to the north and the Bangemall Basin to the south (Plate 3). The Proterozoic geology of the area is the subject of a paper by Daniels (1966) on which the following account is based.

The Proterozoic succession comprises three main divisions which are separated by angular unconformities. From oldest to youngest these are the Mount Bruce Supergroup, the Bresnahan Group, and the Bangemall Group.

Mount Bruce Supergroup. The lowermost part of the Mount Bruce Supergroup is termed the Fortescue Group and consists principally of quartzite, flood basalt, pyroclastics, and pillow lava, with interbedded dolomite, pisolite, and shale. The group has a total thickness of about 4300 m and overlies an Archaean basement of greenstone, jaspilite, and granite. The latter are exposed in a few small inliers in the cores of domal structures in the Proterozoic sequence. Overlying the Fortescue Group is the Hamersley Group, which consists predominantly of hydrogenic deposits such as chert, jaspilite, and dolomite. The group comprises eight formations of which the Brockman Iron Formation is the thickest, the most widely exposed, and the most important economically. The extensive iron ore deposits of the Hamersley Range occur mainly as hematite in synclinal folds of the Brockman Iron Formation (MacLeod, 1966). Disconformably overlying the Hamersley Group is the Wyloo Group which consists of coarse clastic sediments, shale, quartzite, dolomite, and minor volcanics. Unlike the sediments of the Hamersley Group, which accumulated under conditions of extreme stability, the Wyloo Group contains a wide variety of lithofacies suggesting that deposition took place in an unstable environment. This apparent instability during Wyloo Group times was probably the harbinger of a period of major folding which affected the whole of the Mount Bruce Supergroup.

Bresnahan Group. Deposition, folding, and erosion of the Mount Bruce Supergroup was followed by the deposition of a thick series of arenaceous beds named the Bresnahan Group. The nature of the clasts in the sediments indicates that the source material was granitic, and the high proportion of fresh feldspar probably indicates rapid mechanical weathering of the source rock and rapid accumulation in a quickly subsiding basin. Daniels contends that the source was an Archaean granite mass exposed immediately west of the Bresnahan outcrop and that the basin developed as a result of

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vertical movement along a fault forming the southwestern boundary of the Archaean inlier. Subsequent to deposition, the Bresnahan Group was slightly folded about easterly axes, and eroded.

Bangemall Group. The Bangemall Group was laid down unconformably on the Mount Bruce Supergroup and the Bresnahan Group. It is exposed over a wide area south of the Ashburton River. Daniels has identified formations of dolomite, shale, and orthoquartzite, all of which are intruded by quartz dolerite sills. Folding of the sequence has been about west to northwest axes and increases in intensity from north to south.

Daniels & Horwitz (1968) have divided the Median Belt into two basins - the Hamersley Basin comprising the Mount Bruce Supergroup and Bresnahan Group sediments to the north, and the Bangemall Basin comprising the Bangemall Group sediments to the south.

Gascoyne Block

The Gascoyne Block consists of low to medium-grade metamorphosed sediments, gneiss, and intrusive granite, and apparently forms the basement to the southern part of the Bangemall Basin. Metamorphism of the sediments dates from the Ophthalmian Orogeny during which the most intense folding of the Mount Bruce Supergroup took place (Tectonic Map of Australia, 1971). The metasediments are probably the metamorphosed equivalents of Mount Bruce Supergroup.

Paterson Province

This province was originally considered to form an easterly extension of the Pilbara Block (Prider, 1965) but was later recognized as a separate tectonic unit and renamed (Daniels & Horwitz, 1968). It consists of Lower Proterozoic metasediments and granite and appears to form the basement to parts of the Canning Basin in the north, and the Bangemall Basin in the south. The Paterson Province and Gascoyne Block have a similar spatial relation to the Hamersley Basin, and metamorphism and folding of both units dates from the Ophthalmian Orogeny (Tectonic Map of Australia, Geol.Soc.Aust., 1971). It follows that the Paterson Province may, like the Gascoyne Block, be composed of the metamorphosed equivalents of the Mount Bruce Supergroup.

3. PREVIOUS GEOPHYSICAL WORK

Numerous geophysical surveys have been carried out within the survey area by BMR and by mining and oil exploration companies. The surveys for which information is readily available are listed in Appendix 4 and their locations are shown in Plates 4 and 5. Marine seismic and magnetic surveys are not included. The major results of previous geophysical surveys that could have some relevance to the present investigation are discussed as follows:

Gravity surveys

Gravity surveys before 1968 were mainly confined to the Carnarvon and Canning Basins. In the Carnarvon Basin, two broad gravity depressions, separated by a gravity ridge, were revealed. Chamberlain et al. (1954) interpreted the gravity relief in terms of basement topography so that the depressions and ridge were regarded as the expressions of sedimentary troughs and a basement ridge respectively.

The Canning Basin gravity surveys revealed a broad northwest-trending gravity ridge along the southwest margin of the Canning Basin, and a depression covering most of RUNTON and MADLEY. Using the scant geochronological evidence available at the time, Flavelle & Goodspeed (1962) interpreted the gravity ridge as the expression of an ancient mobile zone marking the northeastern limit of the West Australian Shield. The depression was attributed to a thick section of relatively light Phanerozoic sediments.

Magnetic surveys

Airborne magnetic surveys have covered the entire Carnarvon Basin and parts of the Canning Basin. The BMR aeromagnetic surveys of the Carnarvon Basin clearly delineated the shield/basin boundary, sharp variations in magnetic intensity being recorded over Precambrian rocks and gradual variations over sediments. The magnetic results are in general agreement with gravity in regard to the overall structure of the Carnarvon Basin. The gravity ridge, interpreted as the expression of a basement ridge, coincides with an elongate band of high magnetic disturbance; and the gravity depressions on each side of the ridge, attributed to sub-basins of the Carnarvon Basin, correspond to areas of relatively undisturbed magnetic field. The magnetic results also indicate that basement is quite shallow along the coastline between Onslow and Dampier.

The magnetic contour pattern over the northern Canning Basin is smooth, suggesting that the Phanerozoic sediments form a thick layer there. The southwestern margin of the basin is represented by a broad band of relatively high magnetic disturbance which approximately coincides with the northwest-trending gravity ridge defined from the regional gravity results.

Seismic surveys

Numerous seismic surveys have been conducted in the Carnarvon and Canning Basins in the search for local structures favourable for the accumulation of petroleum. For the most part, the results of these surveys have only minor relevance in the discussion of gravity results.

Surveys in the Carnarvon Basin generally confirmed the gravity interpretation of Chamberlain et al. (1954). Sedimentary sections ranging from 3000 to 7000 metres were measured in the sub-basins of the Carnarvon Basin; locally thinner sections were measured over the inferred basement ridge. In the southern Canning Basin, a seismic survey by BMR indicated that the thickness of sediments may exceed 10 000 metres in southern MADLEY (Turpie, 1967). This large thickness of sediments is probably the cause of low Bouguer anomaly values in the area.

4. DISCUSSION OF GRAVITY RESULTS

Bouguer anomaly contours are shown in Plate 2. Survey statistics, personnel and equipment, and procedure are given in Appendices 1, 2, and 3, respectively. In keeping with current BMR practice, a rock density of 2.2 g/cm^3 was chosen for computing Bouguer corrections. As this density is intermediate between values adopted for gravity surveys over sedimentary basins and values adopted for surveys of hardrock areas, there are no great discontinuities of contour with previous surveys tied to.

No attempt has been made to apply terrain or isostatic corrections to the Bouguer anomalies. The former are not considered necessary since the greater part of the terrain is flat or undulating, and computation of isostatic corrections would involve doubtful assumptions about the manner in which isostatic compensation is achieved.

The contoured area has been divided into six regional gravity provinces. These cover large areas of fairly simple shape in which the gravity

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field is characterized by uniformity with respect to contour trend, Bouguer anomaly level, or degree of contour disturbance. Subdivisions of a province are termed 'units' and local Bouguer anomaly closures, lineaments or gradients within units are termed 'features'. The names of provinces totally or partly defined in the Bouguer anomaly map are listed in Table 1.

TABLE 1. GRAVITY PROVINCES

Province Name	Named after	BMR Gravity Survey in which province was first recognized	Reference
Fortescue Regional Gravity Complex	River	New	
Ashburton Regional Gravity Ridge	River	New	
Anketell Regional Gravity Ridge		1960	Flavelle & Goodspeed, 1962 Lonsdale & Flavelle, 1963
Gibson Regional Gravity Depression		1962	Lonsdale & Flavelle, 1963
Teano Regional Gravity Trough	Range	New	
Gascoyne Regional Gravity Complex	River	New	

Gravity Provinces

Each gravity province is discussed in relation to geology and previous geophysical results. The following maps were used in correlating gravity with geological features.

1. Geological Map of Western Australia (Geological Survey of Western Australia, 1966)
2. Tectonic Map of Australia and New Guinea (Geological Society of Australia, 1971)
3. 1:250 000 Geological Series Maps for DAMPIER, ROEBOURNE, PORT HEDLAND, YARRIE, ANKETELL, YARRALOOLA, PYRAMID, PATERSON RANGE, WYLOO, MOUNT BRUCE, ROY HILL, BALFOUR DOWNS, TABLETOP, WINNING POOL, EDMUND, TUREE CREEK, NEWMAN, and ROBERTSON.

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Fortescue Regional Gravity Complex (A). This is an oval-shaped province of generally disturbed contour pattern and relatively low Bouguer anomaly level. Gravity relief consists of intense disjointed residual highs and lows preferentially elongated about northeast or northwest axes. The average Bouguer anomaly level drops from close to zero in the northern part of the province to about -60 mGal in the south. The province is separated from the Anketell Regional Gravity Ridge to the east by a regional Bouguer anomaly gradient, and from the Ashburton Regional Gravity Ridge to the south and west by an arcuate line of steep local gradients extending from the north coast near Onslow to northwestern RUDALL. Offshore, the province is bounded by the seaward continuation of the Anketell Regional Gravity Ridge and a northeast-trending gravity ridge 100 to 150 km from the coastline.

For convenience in discussing local gravity features the province has been arbitrarily divided into four units. In Unit I, gravity gradients are steeper, and the average Bouguer anomaly level higher, than in Units II, III, and IV. Local gravity relief in Unit II, is similar to that in Unit I, but the average Bouguer anomaly value is some 20 mGal lower. Unit III is characterized by low Bouguer anomalies and a comparative rarity of short-wavelength residual features. In Unit IV, Bouguer anomaly values average about 20 mGal higher than in Unit III.

Unit I covers a large portion of the Archaean Pilbara Block. Variations in gravity relief correspond closely to variations in outcrop: intense gravity highs and lows are associated respectively with greenstone belts (comprising the Warrawoona and Mosquito Creek Successions) and intrusive granites. Steep gradients in the gravity field reflect sharp density variations and steeply-dipping contacts between the greenstone and granitic masses. From the spatial relations between outcrops of the various bodies, and anomalies of gravity relief, the following local correlations can be made: Features 1, 2, 3, 5, and 10 (gravity highs) (Plate 2) relate to concentrations of basic igneous rock of the Warrawoona Succession. The vertical extent of the largest of these concentrations exceeds 4 km assuming that their average density is 0.3 g/cm^3 greater than that of adjacent granites. Features 4, 6, 7, 9, 11, and 12 (gravity lows) are the expressions of granitic masses. Feature 8 extends over Mesozoic and Quaternary sediments but is comparable with Features 1, 2, 3, 5, and 10 and probably relates to a basic igneous body in the Archaean basement. Feature 13 is similarly interpreted, as the expression of a sediment-covered Archaean granitic body.

Sediments of the Hamersley and Fortescue Groups cover most of Unit II, but major gravity relief is attributed to lateral variations in density of the Archaean basement. This is inferred from the similarity in gravity pattern between Unit II and Unit I. Features 6, 7, 8, 10, and 11 do not

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appear to correspond to any local surface geological structures. Gravity lows (Features 2, 3, and 4) are centred near granitic inliers and are attributed to granitic masses within the Archaean basement. Feature 1, an east-trending gravity high, is roughly coextensive with an area in which the lower members of the Fortescue Group are intruded by massive and layered dolerites. Feature 5, a gravity high, coincides with a closed synclinal structure within the Hamersley Group sediments, and Feature 9, an intense high near Roebourne, apparently relates to dense Archaean sediments and volcanics that crop out in the area.

Regionally low Bouguer anomalies in Unit III could be the expression of either:

1. A thick section of relatively light Proterozoic sediments; or
2. A basement composed predominantly of low-density rocks such as granite.

Of these, alternative (2) is more likely. Proterozoic sediments are absent in the north of the unit where low Bouguer anomalies are clearly attributable to Archaean granites of the Pilbara Block. Farther south, the presence of Archaean basement inliers in widely separated parts of the Hamersley Basin suggests that the Proterozoic section is too thin to depress Bouguer anomaly values by as much as 30 mGal. Bouguer anomalies are actually higher in the adjoining province to the south, where a thick Proterozoic sedimentary section is implied by the absence of basement inliers.

Local gravity features in Unit III have a close spatial association with anticlines and synclines in the Proterozoic succession. Features 1, 2, and 7, all gravity lows, are centred near outcrops of Archaean granite which evidently form the cores of anticlines in the Proterozoic sequence. Feature 3, also a gravity low, is coextensive with a large exposure of Archaean granite. The granite appears to be overlain by the Fortescue Group to the north, but in the south is overlain by, or faulted against, the Wyloo Group sediments. Gravity highs (Features 4,5, and 6) all coincide with closed synclines in the Mount Bruce Supergroup.

Similarity of gravity pattern between Units I and III, and the coincidence of gravity lows with Archaean granitic inliers, suggest that gravity relief in Unit III relates mainly to structural features within the Archaean basement. The close spatial association between gravity relief and Proterozoic sedimentary structures therefore reflects an important aspect of the basement/cover relation: granitic and base igneous masses in the Archaean basement correspond respectively to anticlines and synclines in the overlying Proterozoic sediments. It follows that Archaean granites formed topographic prominences before the deposition of the Mount Bruce Supergroup, or that the granitic batholiths rose after deposition, doming the overlying sedimentary cover. In either case, basic igneous masses between the granitic bodies would underlie synclines in the Mount Bruce Supergroup.

In Unit IV, the average Bouguer anomaly level is about 20 mGal higher than in Unit III. This may be the effect of a regional increase in the density of the basement. The eastern margin of the unit evidently corresponds to an age boundary separating Archaean basement to the west from Proterozoic rocks to the east. It is near and parallel to an elongated outcrop of Proterozoic granite, which is the westernmost of a number of Proterozoic granites cropping out in the Paterson Province. Except for Features 1 and 5 which are centred over Archaean granitic inliers, local gravity features (Features 2, 3, and 4) have no apparent relation to surface geology and are interpreted as the expressions of anomalous bodies in the Archaean basement.

<u>Ashburton Regional Gravity Ridge</u> (B). This province is a 60 to 100 km wide arcuate band of high Bouguer anomalies extending around the southern perimeter of the Fortescue Regional Gravity Complex. In contrast to the Fortescue Regional Gravity Complex, which is characterized by the presence of intense residual gravity features and an absence of any single predominant trend, the Ashburton Regional Gravity Ridge covers an area of relatively smooth gravity relief in which contour trends are generally parallel to the province margins. The province is most clearly definable between the north coast near Onslow, and Mundiwindi; east of Mundiwindi it is less distinct but may swing northwards to join the Anketell Regional Gravity Ridge. Offshore, the province is separated from an east-northeast trending gravity ridge, which crosses its northward projection, by a low centred near Barrow Island.

The surface geology changes markedly across the concave boundary of the province. Over the western and southern parts of the Fortescue Regional Gravity Complex the main outcropping units are sediments of the Fortescue and Hamersley Groups, with several Archaean basement inliers; Wyloo Group sediments are relatively minor and mostly confined to the cores of the major synclines. In contrast, the Ashburton Regional Gravity Ridge covers an area in which sediments of the Wyloo, Bresnahan, and Bangemall Groups crop out, largely to the exclusion of the Fortescue and Hamersley Groups. Proterozoic granites intruding the Wyloo Group are common, but Archaean granites are absent except for an inlier in WYLOO in which Archaean granites are exposed in the core of an anticline. Faults are numerous near the junction between the two gravity provinces, particularly in the west. Most of them occur within the Fortescue Regional Gravity Complex near and parallel to its southern and western margins. In YARRALOOLA, the province boundary coincides approximately with the eastward limit of an extensive Cainozoic/Mesozoic cover. No rapid geological changes are evident across the poorly-defined gravity province boundary east of Mundiwindi although in ROBERTSON the boundary is parallel to the axis of folding of the Middle Proterozoic sediments.

Three local gravity features in the Ashburton Regional Gravity Complex can be correlated with geological or magnetic features. Features 1 and 2, both gravity highs near the coastline in YARRALOOLA, coincide with the areas of high magnetic disturbance which are probably the expressions of basement rises under the Cainozoic/Mesozoic cover. Feature 3, an intense gravity low in WYLOO, coincides with an anticline in the Fortescue and Hamersley Group sediments, in the core of which Archaean granite is exposed.

Anketell Regional Gravity Ridge (C). This province is a broad northwesterly orientated gravity ridge defined on its northeastern and southwestern margins by fairly consistent gradients towards lower gravity levels. The northern part of the province, including its offshore extension, is similar to the Ashburton Regional Gravity Ridge in regard to its relative Bouguer anomaly level, shape, and spatial relation to the Fortescue Regional Gravity Complex, but is of considerably higher and more complex gravity relief. In TABLETOP, the province swings abruptly to east-southeast and becomes narrower. It continues as a sinuous, generally southeast-trending, gravity ridge across the Canning Basin, and joins up with an intense gravity ridge corresponding to the Musgrave Block of central Australia (Lonsdale & Flavelle, 1963). Although sediments of the Canning Basin extend across the northern and southern parts of the province, major gravity relief is attributed to a zone of dense metamorphic and granitic rocks in the basement. This is suggested by the approximate co-extensiveness of the exposed area of the Paterson Province with the Anketell Regional Gravity Ridge in PATERSON RANGE, RUDALL, TABLETOP, and RUNTON. The Paterson Province consists of low to medium-grade metamorphics intruded by Proterozoic granites. The granitic outcrops tend to be elongated in a north to northwesterly direction, roughly parallel to the elongation of the Anketell Regional Gravity Ridge; their alignment contrasts with the randomness of orientation of the Archaean granites in the Pilbara Block. The metamorphic rocks may date from the Ophthalmian Orogeny and are possibly the metamorphosed equivalents of the Wyloo Group sediments (Tectonic Map of Australia, 1971). A difference in the grade of metamorphism of the Wyloo Group between the Ashburton River area and the Paterson Province is possibly the cause of the difference in Bouguer anomaly level between the Ashburton and Anketell Regional Gravity Ridges.

From the Bouguer anomaly contours it is possible to define the full horizontal extent of the Paterson Province, including both its exposed and its buried parts. It remains conjectural, however, whether the Paterson Province extends southwards beyond the broad rectilinear zone of high Bouguer anomaly forming the northern part of the Anketell Regional Gravity Ridge. The abrupt change in orientation, width, and amplitude of the gravity province in TABLETOP suggests that the Paterson Province is terminated, and that the narrow southeastward continuation of the Anketell Regional Gravity Ridge (Lonsdale & Flavelle, 1963) is the expression of a different structural division.

Gibson Regional Gravity Depression (D). This province, bounded to the north and east by the Anketell Regional Gravity Ridge, and to the west by the Ashburton Regional Gravity Ridge, is discussed in detail by Lonsdale & Flavelle (1963). Regionally low Bouguer anomaly values are attributed to thick sedimentary section of the southern Canning Basin, and local gravity relief is interpreted in terms of variations in depth to basement.

Teano Regional Gravity Trough (E). This province is separated from the Ashburton Regional Gravity Ridge to the north by an east-southeast trending gradient. Bouguer anomaly values decrease from north to south across this gradient and attain minimum values of less than -100 mGal along the southern edge of MOUNT EGERTON. The province extends west and south beyond the limits of the present survey.

The province can not be correlated with any known geological structure. Sediments of the Bangemall Basin extend over most of the province, but the presence of an Archaean granitic inlier in COLLIER indicates that the sediments are too thin to cause a gravity depression of the observed magnitude. Low Bouguer anomaly values may therefore be associated with a regional mass deficiency of large vertical extent, within the crystalline Precambrian basement.

The province appears to flank the northern margin of the Yilgarn Block, and may have similar tectonic significance to gravity depressions along the southeastern and southern margins of the block (Fraser, 1973).

Gascoyne Regional Gravity Complex (F). This province covers an area extending westwards from the Ashburton Regional Gravity Ridge to, and probably beyond, the coastline; its southern part lies outside the survey area. The province has no single dominant characteristic, but embraces a region of relatively high Bouguer anomaly level in which local gravity features generally have a medium wavelength (30 to 60 km) and an overall northerly trend.

The province extends over the northern parts of the Carnarvon Basin and the Gascoyne Block. Gravity coverage of most of the Carnarvon Basin was obtained by BMR in 1950, 1951, and 1953; the survey results are discussed by Chamberlain, Dooley & Vale (1954), who interpreted variations in gravity relief in terms of basement topography, so that gravity highs and lows were regarded as the expressions of basement ridges and troughs respectively. The results of the present gravity survey appear to be consistent with this interpretation inasmuch as the residual gravity features of the Carnarvon Basin are dissimilar in shape, orientation, wavelength, or amplitude to those of the adjoining shield area to the east. This implies that basement density variations are not likely to be the main cause of Bouguer anomaly variations in the Carnarvon Basin unless the margin of the basin is the locus of a major change in Precambrian geology.

The relatively high regional Bouguer anomaly level in the northern and western parts of the province is probably as isostatic effect. Thyer (1951) has calculated isostatic corrections which, if applied to the Bouguer anomaly field, would reduce the gravity anomaly level by about 45 mGal at Cape Range, and 30 mGal at Carnarvon and Onslow.

The eastern part of the Gascoyne Regional Gravity Complex extends over parts of the Gascoyne Block and the overlying Bangemall Basin. Gravity contour trends are generally north-northwest, parallel to the main direction of folding and to the preferred orientation of Proterozoic granitic outcrops.

The Proterozoic granites show little tendency to be associated with gravity lows, and in this respect differ from the Archaean granites of the Pilbara Block, which are the sources of intense gravity depressions. This suggests one or more of the following:

1. The Proterozoic granites are of lower density contrast with their enclosing rocks than are the Archaean granites.
2. The Proterozoic granites are smaller vertically than the Archaean granites.
3. The Proterozoic granite forms a continuous layer beneath the surface, whereas the Archaean granites form discrete batholiths.

Discussion

The Fortescue Regional Gravity Complex and the Ashburton Regional Gravity Ridge are separated by an arcuate line of steep local gradients (henceforth to be termed the 'Pilbara Gradient') extending from the north coast near Onslow to the western part of RUDALL. The total Bouguer anomaly change across the Pilbara Gradient varies, but is generally at least 40 mGal. The change is normally a decrease radially inwards except in TUREE CREEK and ROBERTSON where the gradient is locally reversed. Accompanying this change in Bouguer anomaly level is a distinct change in contour pattern. In the Ashburton Regional Gravity Ridge, Bouguer anomaly features are usually of long wavelength and gentle relief, and are elongated parallel to the margins of the province, whereas in the Fortescue Regional Gravity Complex, the features are areally small, often of sharp relief, and are preferentially elongated about northeast and northwest axes.

On a regional scale, the Pilbara Gradient coincides with what appears from the surface geology to be a major hinge or fault about which downthrow to the south and west has occurred. Numerous faults, near and often roughly parallel to the Pilbara Gradient, lie in a zone which forms the boundary between an area where sediments of the Fortescue and Hamersley Groups are the predominant outcrops (corresponding to the Fortescue Regional Gravity Complex), and an area where younger sediments of the Wyloo, Bresnahan, and Bangemall Groups are predominantly exposed (corresponding broadly to the Ashburton Regional Gravity Ridge).

Despite this correlation between regional gravity and geologic features, there remains an inconsistency. The Bouguer anomaly level is higher over the presumed downthrown block (where Proterozoic sediments should be thicker) than over the upthrown block, so that an interpretation of the Pilbara Gradient in terms of simple faulting, with the densities of rock layers increasing with depth, is untenable. Several alternative interpretations can be made:

1. The overall vertical movement of the area corresponding to the Fortescue Regional Gravity Complex has been downwards, resulting in the preservation from erosion of a thick and comparatively light Proterozoic section. The presence of younger Proterozoic sediments in the area to the south and west (presumed to be the upthrown block) is explained by relatively minor reverse movement about faults since the deposition of the Wyloo Group sediments.

2. The Proterozoic section has a higher bulk density than the underlying basement and is thicker in the area corresponding to the Ashburton Regional Gravity Ridge.

3. The Fortescue Regional Gravity Complex and the Ashburton Regional Gravity Ridge represent two distinct basement tectonic units composed of rocks of different average densities.

The available evidence suggests that alternative (1) can be discounted. Sediments appear to form only a thin layer in the Fortescue Regional Gravity Complex, and gravity minima generally coincide with granitic inliers. Low Bouguer anomaly values north and east of the Pilbara Gradient are therefore attributable to a low-density granitic basement rather than to thick sediments as implied by alternative (1).

Alternative (2) is not so easily discounted, as the Proterozoic sediments contain chert, jaspilite, dolomite, and interbedded volcanics and together may form a sedimentary pile denser than granite. However, it is difficult to reconcile alternative (2) with the abrupt change in contour pattern across the Pilbara Gradient. A thick pile of dense sediments south and west of the gradient could cause the observed increase in Bouguer anomaly level, but small-scale gravity relief corresponding to local basement inhomogeneities should be similar or either side of the gradient. This is not the case - the characteristic trends of the Fortescue Regional Gravity Complex are sharply truncated by transgressive trends in the Ashburton Regional Gravity Ridge.

Alternative (3) appears to be the most likely possibility in view of the following observations and inferences. The Fortescue Regional Gravity Complex broadly encompasses both the Archaean Pilbara Block and the Proterozoic Hamersley Basin. Residual gravity features of characteristic orientations and magnitudes, which in the Pilbara Block are closely related to surface geological structures, are present in the Hamersley Basin where the Archaean rocks are largely obscured by Proterozoic cover. This, together with the absence of any abrupt change in gravity field across the northern boundary of the Hamersley Basin, suggests that the basement of the Hamersley Basin is structurally continuous with the Pilbara Block. In other words, the Fortescue Regional Gravity Complex corresponds to an Archaean craton of which the Pilbara Block is only the exposed part. Since this craton apparently forms an 'island' of older rock surrounded by younger terrains, the name 'Pilbara Nucleus' seems appropriate.

The Ashburton Regional Gravity Ridge probably corresponds to a Proterozoic mobile zone. This is inferred from the following evidence:

1. Sediments of the Wyloo Group, which crop out over much of the province, contain a wide variety of lithofacies, suggesting that the sediments were deposited in an unstable environment (Daniels, 1966).

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2. In the presumed cratonic area north and west of the Ashburton Regional Gravity Ridge, individual beds of the Fortescue and Hamersley Groups show a marked degree of lateral continuity, indicating that depositional conditions were exceptionally stable. The transition between stable and unstable depositional environments takes place across the Pilbara Gradient, which is considered to mark the boundary between the Pilbara Nucleus and the inferred mobile belt.

3. Folding of the Mount Bruce Supergroup due to the Ophthalmian Orogeny increases in intensity southwards towards the postulated mobile belt (Daniels, 1966).

4. The Ashburton Regional Gravity Ridge is similar in shape and relative Bouguer anomaly level to the gravity expressions of known mobile belts such as the Halls Creek and King Leopold Mobile Belts (Whitworth, 1970).

5. The postulated mobile belt is peripheral to an older craton and is therefore similar in tectonic setting to the Halls Creek and King Leopold Mobile Belts which girdle the Kimberley Block, and to the Fraser Range metamorphic belt, which borders the south-east margin of the Yilgarn Block.

The density boundary between the Pilbara Nucleus and the inferred mobile belt (henceforth to be termed the 'Ophthalmian Mobile Belt'), although evident from the change in gravity level across the Pilbara Gradient, is not manifested in the surface geology. The shale, sandstone, conglomerate, arkose, greywacke, quartzite, dolomite, and andesitic volcanics of the Wyloo Group are not likely to be denser collectively than the abundant iron formations, dolomite, chert, quartzite, and basic volcanics of the Fortescue and Hamersley Groups. It is probable, therefore, that intense folding of the Wyloo Group at supracrustal levels during the Ophthalmian Orogeny was accompanied by regional metamorphism of sediments and igneous intrusion at depth, with the result that the Wyloo sedimentary section is now denser than the predominantly granitic Pilbara Nucleus to the north and east. That deep-seated regional metamorphism was confined mainly to the area of the Ashburton Regional Gravity Ridge is entirely consistent with the proposed division between the Pilbara Nucleus (stable since the Archaean) and the Ophthalmian Mobile Belt along its southern periphery (active during the Proterozoic).

The Anketell Regional Gravity Ridge is similar to the Ashburton Regional Gravity Ridge in shape, comparative Bouguer anomaly level, and spatial relation to the Pilbara Nucleus. Furthermore, the oldest rock types which it encompasses are the metamorphics of the Paterson Province, which are possibly the metamorphosed equivalents of the Wyloo Group. For these reasons, the tentative conclusions of Flavelle & Goodspeed (1962), that the gravity province relates to an ancient mobile zone, seem to be justified.

Relation between gravity contour patterns and the regional distribution of mineral occurrences

The locations of reported mineral occurrences were plotted on the Bouguer anomaly contour map (Plate 6), to determine whether the gravity contour pattern as related to the distribution of mineral deposits. Most of the mineral locations were obtained from the map entitled 'Regional Divisions and Reported Mineral Occurrences, Western Australia' (Mineral Division of the West Australian Government Chemical Laboratories, 1961); many of the deposis indicated are not of economic importance. Mineral deposits shown on the metallogenic map of Australia and Papua New Guinea (BMR, 1972) are also included in Plate 9.

Apart from a tendency for deposits to be concentrated along the zones of steep Bouguer anomaly gradient surrounding residual gravity highs over the Pilbara Block, there is little apparent correlation between the gravity and mineral distribution patterns.

5. CONCLUSIONS

The following general conclusions are made on the basis of the gravity results:

1. Residual gravity highs and lows over the Pilbara Block are respectively coextensive with outcrops of greenstones and granite. Gravity evidence indicates that an Archaean basement of granite and greenstones underlies Mesozoic and Cainozoic sediments north of the exposed Pilbara Block.
2. The Pilbara Block is probably only the exposed part of a more extensive Archaean craton which forms the basement to most of the Hamersley Basin. An arcuate line of steep local Bouguer anomaly gradients delineates the southern perimeter of this inferred craton, for which the name 'Pilbara Nucleus' is proposed.
3. Folding of the Proterozoic sediments of the Hamersley Basin is apparently related to structures within the Archaean basement. Gravity geologic evidence combined suggest that synclines and anticlines in the Fortescue and Hamersley Group sediments correspond respectively to greenstones and granites of the underlying Pilbara Nucleus.

4. A broad arcuate band of high Bouguer anomaly extending around the southern perimeter of the Pilbara Nucleus is interpreted as the expression of a Proterozoic mobile belt, composed of rocks which at depth became denser as a result of regional metamorphism and igneous intrusion.

5. A broad elongate gravity ridge east of the Pilbara Nucleus encompasses metamorphic and granitic outcrops of the Paterson Province. It is interpreted as the expression of an extensive Proterozoic mobile belt.

6. An area of low Bouguer anomaly in the south of the survey area is probably part of an elongated gravity depression on the northern border of the Yilgarn Block. Such a depression could have similar tectonic significance to elongated gravity troughs at the southern and southeastern margins of the Yilgarn Block.

7. Proterozoic granites of the Gascoyne Block and Paterson Province have no appreciable gravity expression, whereas Archaean granites of the Pilbara Block are associated with intense residual gravity lows of large amplitude. This suggests that the Proterozoic granite is of smaller density contrast or vertical extent than the Archaean granite, or that the Proterozoic granite forms a horizontal layer of fairly uniform thickness beneath the surface.

8. An earlier interpretation that gravity relief over the Carnarvon Basin relates mainly to basement topography (Chamberlain et al., 1954) is unchanged by the results of the present survey.

9. Examination of the regional distribution of mineral occurrences in relation to the Bouguer anomaly contour pattern shows some concentration of mineral deposits along the zones of steep Bouguer anomaly gradient surrounding residual gravity highs of the Pilbara Block.

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NOTE Additional abbreviated references for previous geophysical and borehole surveys, not specifically referred to in the text, are given in Appendix 4.

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APPENDIX 1: SURVEY STATISTICS

Basic grid

Survey commenced:	2 September 1969
Survey completed:	24 November 1969
Total survey days:	84
Total helicopter days available:	157 (first 11 days were conducted as a single helicopter operation after which 2 helicopters were used)
Days unserviceable:	45
Pilot days off:	7
Days lost due to maintenance:	3
Days lost due to weather:	2
Loops:	467
New readings:	3297
Flying hours:	552.45
Ferry hours:	91.20

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SURVEY STATISTICS:

Sheet name	New readings	Flying hours	Ferry hours	New rdgs per flying hours	New rdgs per flying & ferry hour	Loops
Balfour Downs	169	31.50	3.50	5.4	4.8	24
Barrow Island	17	2.45	1.25	6.9	4.6	2
Buller	167	30.40	5.35	5.5	4.7	24
Collier	168	32.20	2.35	5.2	4.9	24
Dampier	51	9.55	0.55	5.3	5.0	6
Edmund	167	22.30	6.50	7.5	5.8	24
Marble Bar	168	32.25	3.40	5.2	4.7	24
Mount Bruce	169	24.45	5.55	6.9	5.6	24
Mount Egerton	167	38.15	3.50	4.4	4.0	24
Newman	167	30.25	4.35	5.5	4.8	24
Ningaloo	10	2.05	0.00	4.9	4.9	1
Nullagine	169	30.05	3.40	5.6	5.1	24
Onslow	61	11.15	1.40	5.5	4.9	7
Port Hedland	162	28.35	2.55	5.7	5.2	22
Pyramid	167	30.25	4.55	5.5	4.8	24
Robertson	167	18.00	6.20	9.3	6.9	24
Roebourne	91	17.00	1.50	5.4	4.9	13
Roy Hill	169	19.50	6.10	8.7	6.6	24
Turee Creek	166	24.10	5.50	6.9	5.6	24

SURVEY STATISTICS (Contd):

Sheet name	New readings	Flying hours	Ferry hours	New rdgs per flying hours	New rdgs per flying & ferry hour	Loops
Winning Pool	112	21.00	2.40	5.3	4.8	16
Wyloo	166	23.20	6.35	7.2	5.6	24
Yanrey	114	15.05	5.40	7.6	5.6	16
Yarraloola	163	28.00	3.30	5.8	5.2	24
Yarrie	170	31.25	4.20	5.4	4.8	24
Averages:				6.0	5.1	

APPENDIX 2: SURVEY PERSONNEL AND EQUIPMENT

Staff

(Wongela Geophysical Pty Ltd)

Party leader:	L.N. Ingall
Chief meter reader:	H. Reith
Meter reader:	D. Durant
Draughtsman:	L. Spain

Base readers from Messrs Blumenthal, Hall, Weber, Spain.

Helicopter staff of 2 pilots and 2 engineers.

BMR Supervisors:	F. Darby and A. Fraser

Equipment

2 Worden gravity meters.

1 LaCoste & Romberg gravity meter

6 'Mechanism' Microbarometers

Helicopters

1 Hughes 300, VH-IHN

1 Bell 47G3B-1, VH-AHO

1 Jetranger, VH-AHV

Vehicles

3 Landrovers

1 Ford Falcon panel van

APPENDIX 3: SURVEY PROCEDURE

Field operations

The field operations were carried out by a geophysical contractor, Wongela Geophysical Pty Ltd of Sydney, using methods similar to those adopted on previous BMR helicopter gravity surveys. All traversing was done by the cell method (Hastie & Walker, 1962).

Before the helicopter gravity operation, the Survey Branch of the former Department of the Interior (now Department of Services and Property) established a network of optically levelled and photo-identified elevation traverses. The benchmarks on these traverses were elevation control stations for the survey, and an area enclosed by the traverses is called a segment. The segmentation of the survey is shown in Plate 7. In the flying of the survey no loop was allowed to cross a segment boundary. This method of flying meant that each segment could be computed independently for elevation control.

Gravity control on the survey was maintained by tying to previously established 'isogal stations' (Barlow, 1970).

Horizontal control was maintained by accurately pinpricking aerial photographs and plotting the locations of the gravity stations on photo-centre base maps.

Computing procedure

The computing was conducted at Monash University using a CDC 3200 computer. For the barometric results each segment was computed three times:

1. Using only one fixed elevation node. This is computed to determine the internal accuracy of the segment, and systematic errors are not taken into account.
2. Using all of the fixed elevation nodes. This is computed to determine the external accuracy of the segment and to obtain the final station elevations for the computation of Bouguer anomalies. In this computation systematic errors are corrected, so that the external standard deviation of the adjustments is always higher than the internal standard deviation.
3. Using half of the fixed elevation nodes. This is computed to determine the forecast standard deviation. Enough fixed points are included to eliminate systematic errors, and the difference between the true elevation and measured elevation at the fixed nodes computed as

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free nodes is a good estimate of the accuracy of the heights in any segment.

For the gravity network, only steps (1) and (2) were carried out.

The internal, external and forecast standard deviations for the gravity and elevation networks are shown in the following tables. The internal and external standard deviations are the standard deviations of the least-squares adjustments to legs in the network. The forcast standard deviation is the standard deviation of differences between true and measured elevations for those fixed nodes which were computed as free nodes, as in (3).

Segment	Elevation Network Adjustments (metres)						
	Internal network		External network		Forcast network		
	S.D.	Max. adj.	S.D.	Max. adj.	S.D.	Max. adj.	Max. adj. S.D.
S	1.22	3.15	1.83	5.57	1.59	4.79	3.01
T	1.62	4.17	2.58	8.00	3.58	6.46	1.80
U	1.17	2.94	2.09	8.03	2.20	6.09	2.77
W	1.61	4.19	2.80	9.23	2.31	4.70	2.03
Y	1.07	4.31	1.61	3.84	1.50	2.40	1.60

Segment	Gravity Network Adjustments (mGal)			
	Internal network		External network	
	S.D.	Max. adj.	S.D.	Max. adj.
S	0.04	0.08	0.04	0.08
T	0.03	0.07	0.03	0.14
U	0.03	0.08	0.03	0.08
W	0.03	0.12	0.04	0.12
Y	0.03	0.09	0.03	0.09

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APPENDIX 4: LISTS OF PREVIOUS GEOPHYSICAL SURVEYS AND BOREHOLES

Name of survey or report	Year(s) of survey	Operator	Reference
GRAVITY SURVEYS			
Geophysical exploration in the Carnarvon (N.W.) Basin, Western Australia	1950-53	BMR	BMR Record No. 1954/44
Carnarvon Basin gravity survey	1956	WAPET	Unpublished
Fitzroy and Canning Basins Reconnaissance gravity surveys	1952-60	BMR,WAPET	BMR Record No. 1962/105
Amadeus and South Canning Basin reconnaissance gravity survey	1962	BMR	BMR Record No. 1963/152
Reconnaissance helicopter gravity survey, W.A., 1968	1968	BMR	In prep.
Marine geophysical survey of the Northwest Continental Shelf, 1968	1968	BMR	BMR Record No. 1969/99
MAGNETIC SURVEYS			
Canning Basin aeromagnetic reconnaissance survey, W.A.	1954	BMR	BMR Record No. 1960/11
Preliminary report on airborne surveys (scintillometer and magnetometer) of Geraldton-Onslow region, W.A.	1956	BMR	BMR Record No. 1957/9
Carnarvon Basin airborne magnetic and radiometric survey, W.A.	1957	BMR	BMR Record No. 1960/132
Carnarvon Basin airborne magnetic and radiometric survey, W.A.	1959	BMR	BMR Record No. 1961/56
Carnarvon Basin airborne magnetic and radiometric survey, W.A.	1961	BMR	BMR Record No. 1962/191
South Canning Basin aeromagnetic survey	1962,1963	WAPET	BMR Subsidy File No. 62/1728

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Name of Survey or Report	Year(s) of survey	Operator	Reference
Airborne magnetometer survey of Gibson Desert area	1965	Union Oil/ Alliance Petroleum	BMR Subsidy File No. 65/4610
Airborne magnetometer survey, offshore Wallal, Western Australia	1969	WAPET	BMR Subsidy File No. 69/3037
SEISMIC SURVEYS			
Giralia Anticline seismic survey	1951	BMR	BMR Records Nos.1954/44,1954/67
Wandagee Hill/Middalya seismic reflection survey	1955	BMR	BMR Record No. 1962/117
Giles-Carnegie seismic survey	1961-62	BMR	BMR Record No. 1967/123
Wandagee Ridge seismic survey	1961	WAPET	BMR Subsidy File No. 62/1576
Salt Marsh seismic survey	1961	WAPET	BMR Subsidy File No. 62/1585
Quail Anticline seismic survey	1962	WAPET	BMR Subsidy File No. 62/1622
Whaleback seismic survey	1962	WAPET	BMR Subsidy File No. 62/1635
Kubura-Learmonth seismic survey	1962	WAPET	BMR Subsidy File No. 62/1637
Ningaloo seismic survey	1963	WAPET	BMR Subsidy File No. 63/1504
Paterson seismic survey	1963	WAPET	BMR Subsidy File No. 63/1509
Barrow Island seismic survey	1963	WAPET	BMR Subsidy File No. 63/1536
Onslow seismic survey	1966	WAPET	BMR Subsidy File No. 66/11073
Cane River seismic survey	1967	WAPET	BMR Subsidy File No. 67/11159
Locker seismic survey	1967	WAPET	BMR Subsidy File No. 67/11162

Name of Survey or Report	Year(s) of survey	Operator	Reference
Mia Mia seismic survey	1967	Marathon Petroleum	BMR Subsidy File No. 67/11179
Munro R-1 seismic survey	1969	WAPET	BMR Subsidy File No. 69/3081
Anketell seismic survey	1970	WAPET	BMR Subsidy File No. 70/896
Lake Auld seismic survey	1970	WAPET	BMR Subsidy File No. 70/933
Lyndon-Quobba seismic survey	1972	WAPET	BMR Subsidy File No. 72/891

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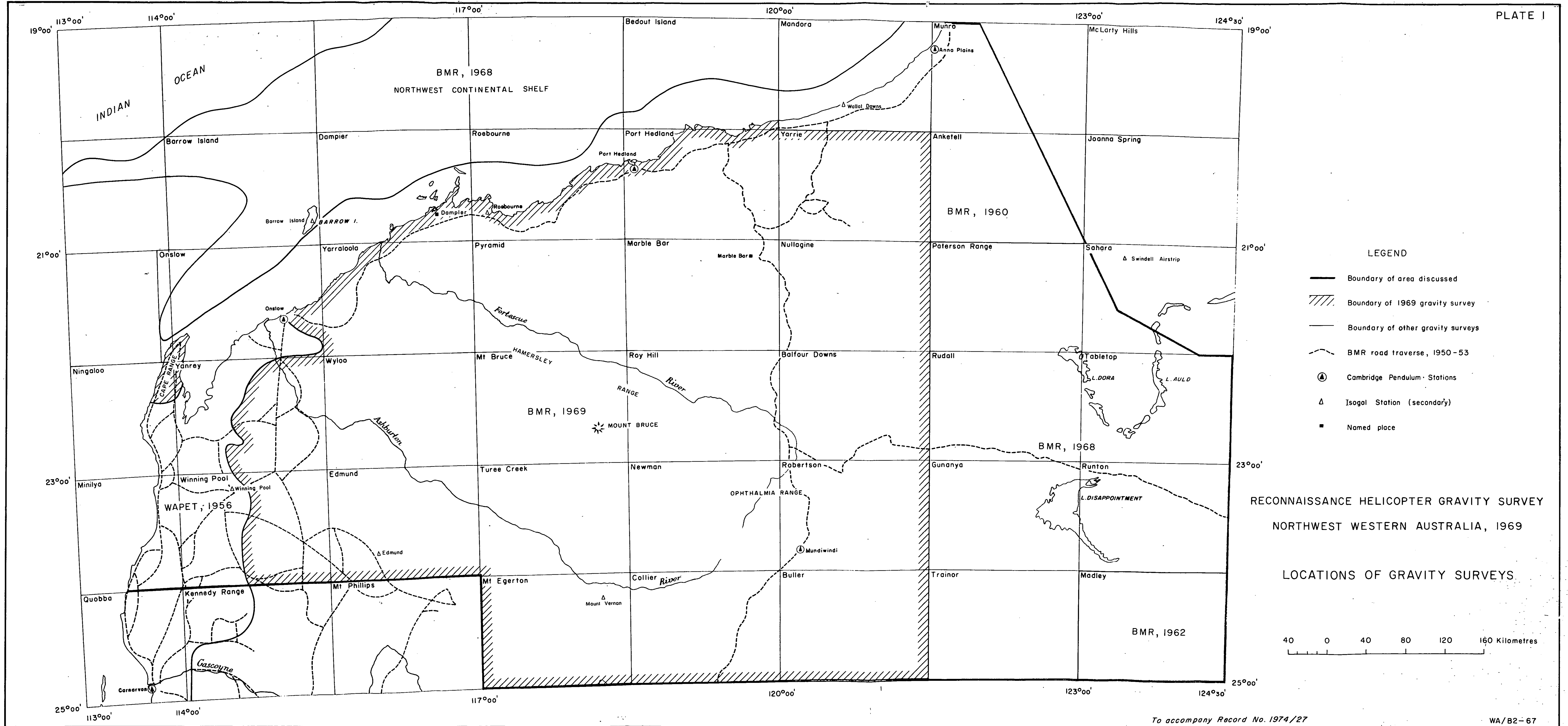
BOREHOLES

Name of Borehole	Year	Total Depth (metres)	Operator	Reference
BMR 4A Wallal	1958	679	BMR	BMR Report No. 60
Samphire Marsh No. 1	1958	2031	WAPET	BMR Subsidy File No. 62/1002
Wandagee No. 1	1962	1073	WAPET	BMR Subsidy File No. 62/1215
Quail No. 1	1963	3580	WAPET	BMR Subsidy File No. 63/1010
Marrilla No. 1	1963	457	WAPET	BMR Subsidy File No. 63/1200
Minderoo No. 1	1963	610	WAPET	BMR Subsidy File No. 63/1200
Paterson No. 1	1963	2286	WAPET	BMR Subsidy File No. 63/1211
Whaleback No. 1	1963	1528	WAPET	BMR Subsidy File No. 63/1319
Learmonth No. 2	1963	1871	WAPET	BMR Subsidy File No. 63/1327
Barrow No. 1	1964	2982	WAPET	BMR Subsidy File No. 64/4030
Onslow No. 1	1966	2998	WAPET	BMR Subsidy File No. 66/4218
Hope Island No. 1	1968	1426	WAPET	BMR Subsidy File No. 68/2003
Remarkable Hill No. 1	1968	3206	Marathon Petroleum	BMR Subsidy File No. 68/2050
Cane River No. 1	1971	694	Hematite Petroleum	BMR Subsidy File No. 71/751
East Marrilla No. 1	1972	638	WAPET	BMR Subsidy File No. 72/960

PLATE I



RECONNAISSANCE HELICOPTER GRAVITY SURVEY

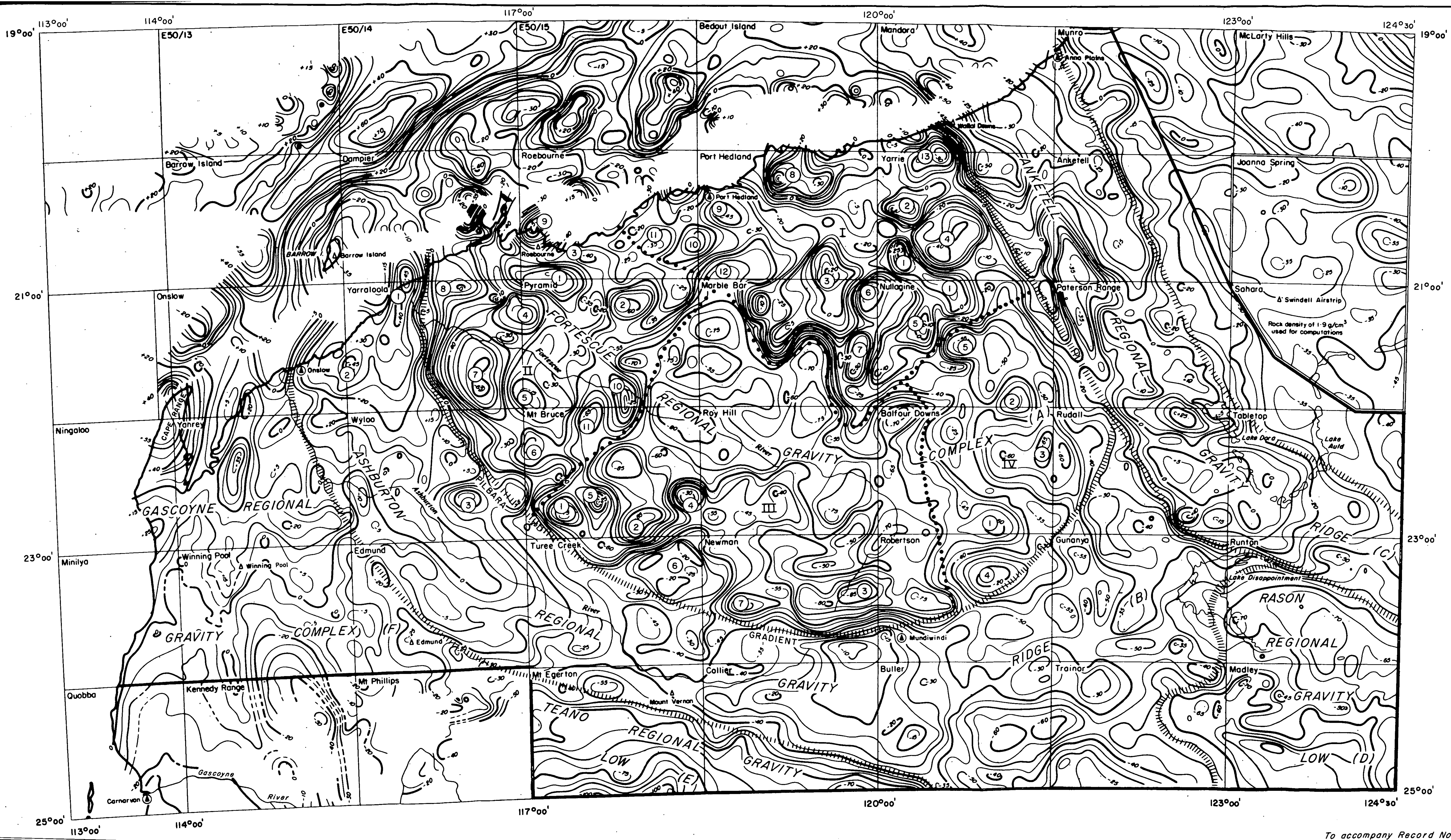
NORTHWEST WESTERN AUSTRALIA, 1969

LOCATIONS OF GRAVITY SURVEYS

To accompany Record No. 1974/27

WA/B2-67

PLATE 2



LEGEND

- Boundary of area discussed
- Province boundary
- Unit boundary
- (6) Feature
- Cambridge station
- Isogal station (secondary)

Note: A density of 2·2 g/cm³ was used in calculating Bouguer anomalies

BOUGUER ANOMALIES AND GRAVITY PROVINCES

40 0 40 80 120 160 Kilometres

To accompany Record No. 1974/27

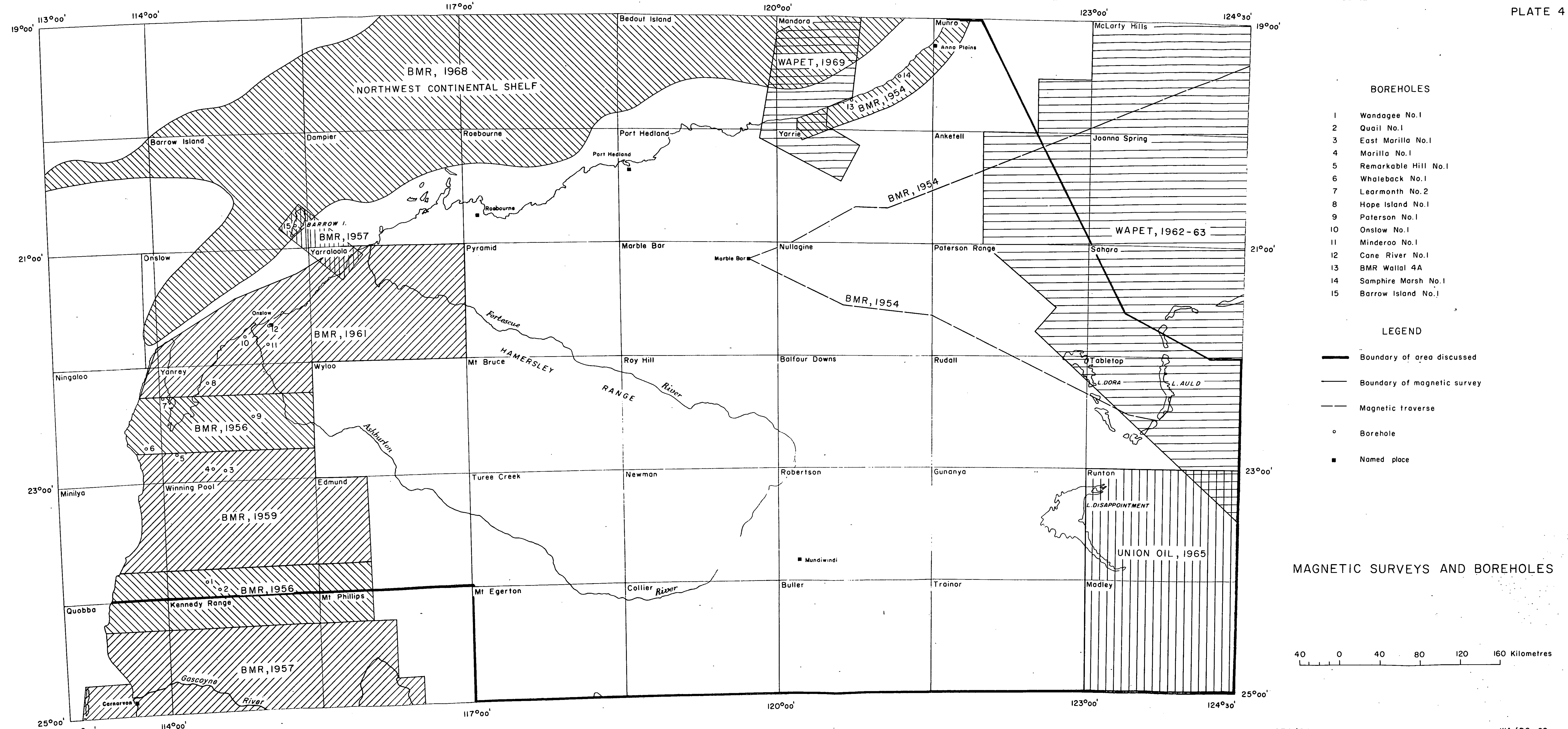
WA/B2-68-1

PLATE 3

To accompany Record No. 1974/27

WA/B2-51

PLATE 4

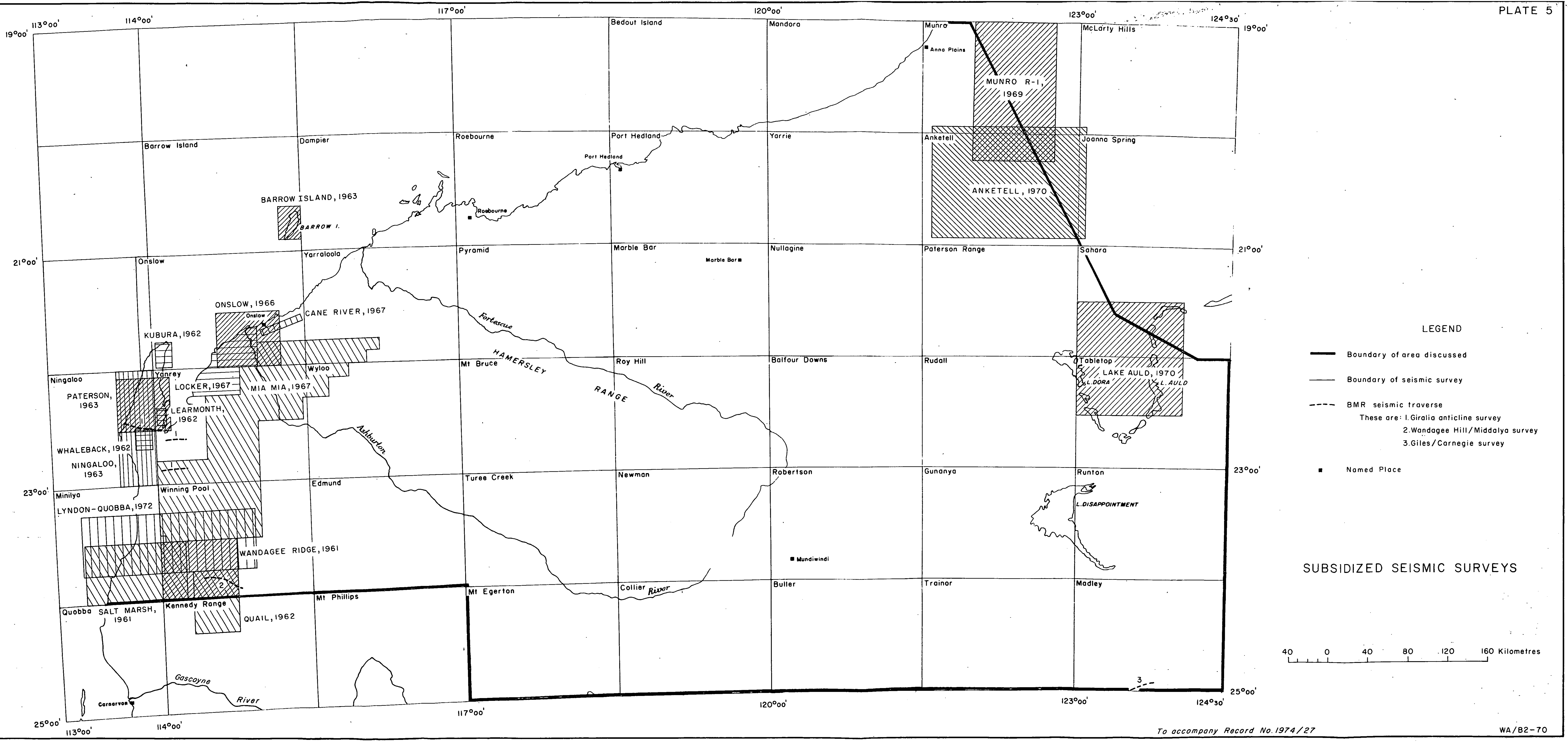


MAGNETIC SURVEYS AND BOREHOLES

To accompany Record No. 1974/27

WA/B2-69

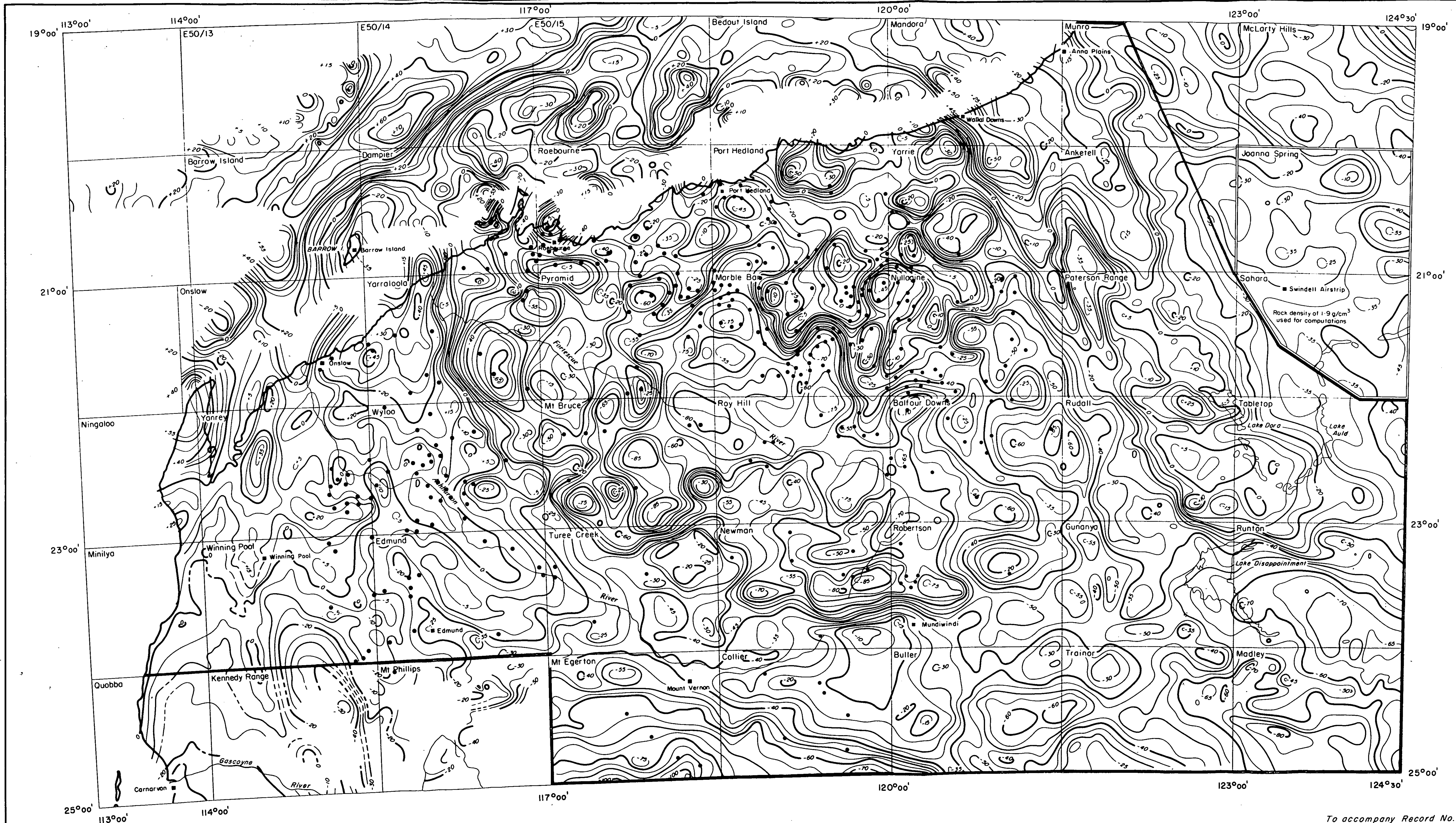
PLATE 5



SUBSIDIZED SEISMIC SURVEYS

To accompany Record No. 1974/27

WA/B2-70



LEGEND

Boundary of area discussed

Mineral occurrence

Note: Information was obtained from the map entitled "Regional Divisions and Reported Mineral Occurrences, Western Australia" (Mineral Division of the WA Chemical Laboraties, 1961), and the Metallogenic Map of Australia and Papua New Guinea (BMR, 1972)

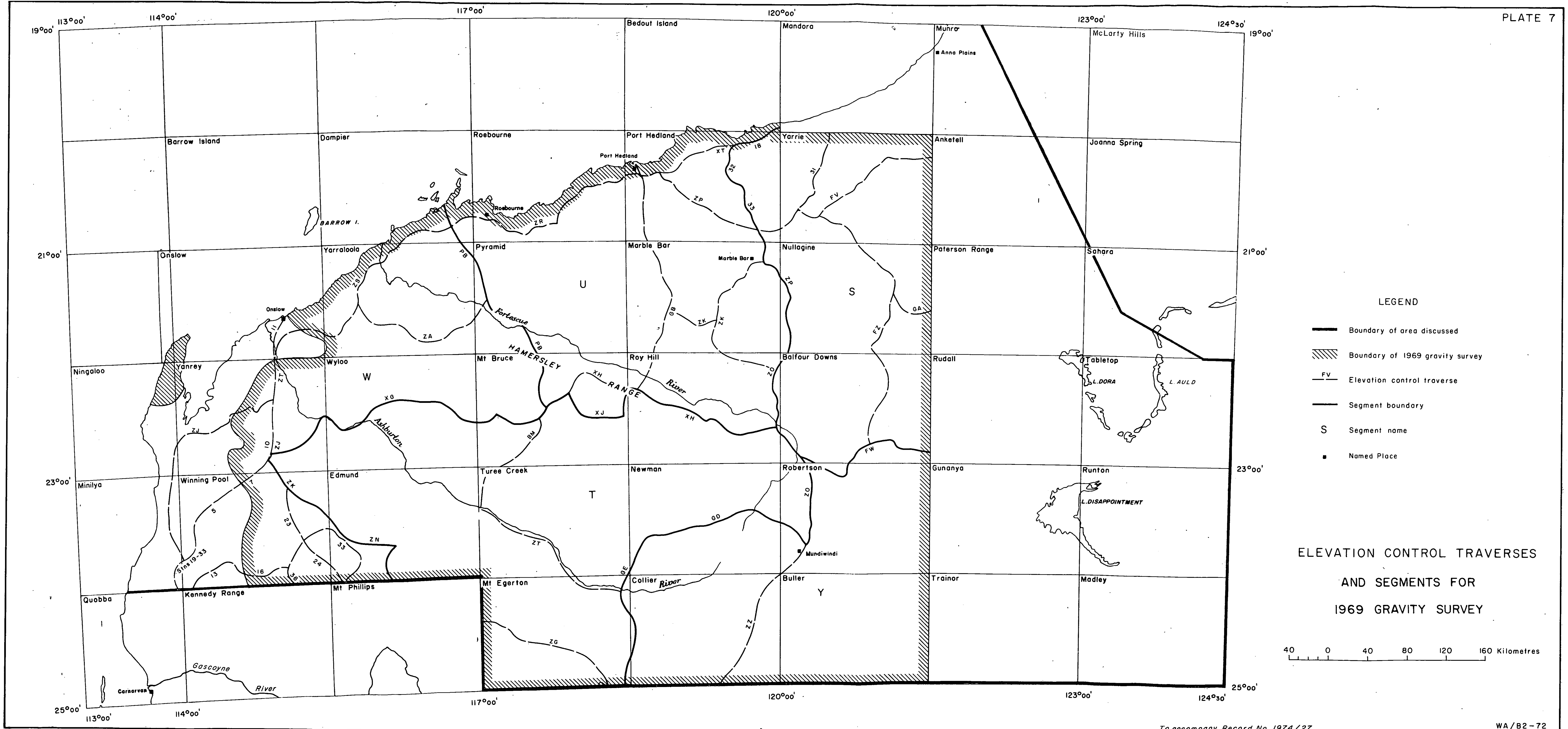
Note: A density of 2·2 g/cm³ was used in calculating Bouguer anomalies

Named place

BOUGUER ANOMALIES AND REPORTED MINERAL OCCURRENCES

40 0 40 80 120 160 Kilometres

PLATE 7



To accompany Record No. 1974/27

WA/B2-72