DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1974/26

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

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CONTENTS

PLATES

SUMMARY

A preliminary interpretation of the Bouguer anomaly field in the southwestern part of Western Australia has been made. The gravity results were obtained in a reconnaissance helicopter gravity survey conducted from May to September 1969, by the Bureau of Mineral Resources, Geology & Geophysics (BMR). The 'cell method' of flying was used to establish 3961 new gravity stations at 11-km spacing over all or part of twenty-nine 1:250 000 Sheet areas.

The Bouguer anomaly field may be divided into eight regional gravity provinces; one of these was defined from the results of an earlier survey. With the exception of a major gravity depression associated with the Perth Basin, all the gravity provinces are believed to correspond to tectonic divisions within the Archaean Yilgarn Block and the Proterozoic Albany-Fraser Province of the Australian Precambrian Shield.

Over most of the Yilgarn Block, the Bouguer anomaly field is of low level, indicating that the block is largely composed of crystalline rocks of low density such as granite and gneiss. Broad low gravity features over the southern and western parts of the block are interpreted as the expressions of granitic masses engulfed in slightly denser gneiss and migmatite. Residual gravity highs of small area but high amplitude, mainly in the north of the survey area, are attributed to 'greenstone' belts of dense basic igneous rocks. The distribution pattern of the greenstone belts is different in the Kalgoorlie region, where the belts are closely spaced and interconnecting, from that in the Southern Cross region, where they are widely separated. Residual gravity lows in the Kalgoorlie area can generally be correlated with granitic outcrops. A region of high Bouguer anomalies in the southwest of the Yilgarn Block may correspond to an area in which a dense lower crustal layer is anomalously shallow.

The Yilgarn Block is flanked to the south and southeast by deep elongate gravity depressions. The depression to the south coincides with an outcrop of Proterozoic granite, but the depression to the southeast encompasses outcrops of Archaean granite and gneiss. The latter depression is parallel to a major Proterozoic metamorphic belt, and it may cover an area in which the Archaean shield was reactivated as a result of Proterozoic tectonic activity.

An intense narrow gravity ridge extending northeast from Fraser Range is evidently the expression of a partly exposed body of dense pyroxene granulite. The body is estimated to be up to 10 km thick and is probably in fault contact with granite and gneiss to the northwest and southeast. The Fraser Fault is represented by a gradient of about 10 mGal/km and is

considered to be reverse and southeast dipping. The gravity ridge appears to extend northeastward beyond the area surveyed.

Gravity relief over the western part of the Eucla Basin probably reflects lateral density variations in the Precambrian basement rather than variations in depth to basement. As the Bouguer anomaly field is low compared with that in areas of exposed granulite to the northwest, the basement may be composed predominantly of granite and gneiss.

1. INTRODUCTION

The Bureau of Mineral Resources, Geology & Geophysics (BMR) extended the reconnaissance gravity coverage of Australia by conducting two helicopter gravity surveys in Western Australia during 1969. Both were conducted under contract to BMR by Wongela Geophysical Pty Ltd, using the 'cell method', described by Hastie & Walker (1962), to establish a grid of gravity stations over the survey areas. The grid spacing was uniformly about 11 km, giving a mean station density of 1 per 120 km^2. This report discusses the results in the southern area (Plate 1), in which 407 000 km^2 was surveyed covering twenty-nine 1:250 000 Sheet areas. Bouguer anomaly contours are shown in Plate 2. Ties were made to permanently-marked stations of a previous private company survey in the Perth Basin.

The survey area extends over three major structural provinces of the southern portion of Western Australia. These are: the Australian Precambrian Shield, consisting principally of metasedimentary and meta-igneous rocks, granite, granulite, and gneiss; the Perth Basin of Phanerozoic sediments; and the Eucla Basin of Cretaceous and Tertiary sediments. No new readings were taken in the southern part of the Perth Basin, where existing coverage was considered adequate.

A network of graded roads gave good access throughout the survey area and facilitated transport of the crew and fuel. The large number of townships scattered throughout the survey area ensured good communications and supply. In some areas, the use of a helicopter had to be restricted in order to avoid disturbing livestock on farms, and ground transport was used instead.

The survey area extends over part of the Great Western Plateau, which is one of the major topographic features of the Australian continent. In the west, the plateau is separated from the Swan Lowlands by the Darling Scarp. Rainfall is moderate and uniform causing the plateau and scarp to be well dissected by rivers. Terrain is mainly undulating on the plateau except in the south, where prominent topographic features include the Stirling, Porongorup, and Mount Barren Ranges. Elevations vary, generally between 200 and 600 m, although the highest point in the much dissected Stirling Range is 1109 m above sea level.

Vegetation is mainly light on the plateau. Landing spots for the helicopter were located without difficulty in most areas. However, dense scrub near Norseman and heavy timber near Pemberton prevented helicopter access, and several loops were made by road.

Summaries of the geology of the area and previous geophysical 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 area covers parts of three major structural divisions: the Perth Basin, the Australian Precambrian Shield, and the Eucla Basin. The major divisions and subdivisions are shown in Plate 3.

Perth Basin

The onshore part of the Perth Basin extends from the south coast of Western Australia 950 km to the north, varying in width from 15 to 90 km and covering an area of 54 000 km^2. Only the southern part of the basin lies within the survey area.

The eastern margin is the prominent Darling Fault, which separates the Precambrian shield from a thick half-graben of sediments which in the deeper parts may exceed 7 km in thickness. The western margin in the south is the Dunsborough Fault, which separates the basin from the Naturaliste Block of Proterozoic granulite and gneiss. Significant movement of the Darling Fault began in the late Triassic and continued throughout the Jurassic and early Cretaceous. The magnitude of the steep gravity gradient which extends along the length of the Darling Fault indicates that vertical throw is very large. This is confirmed by seismic evidence which suggests that downthrow about the fault near Perth has been about 7.5 km (Mathur, 1973). This movement has given rise to a wedge of Palaeozoic and Mesozoic sediments, thickest in the east, with basement and sediments generally dipping east. The basin contains a number of subsidiary troughs and ridges which generally strike north. Two deep troughs, where the sedimentary thickness may exceed 7 km, are centred near the towns of Bunbury and Dandaragan.

In the south of the basin, geophysical evidence and drilling have shown that tholeiitic basalt of Cretaceous age fills the valleys of an ancient drainage system. The basalt may have been extruded in association with movement along the Darling Fault.

The names of boreholes drilled in the Perth Basin are listed in Appendix 4.

Australian Precambrian Shield

This account is largely drawn from papers by Prider (1965), Wilson (1969) and McCall (1972). Information on rock ages is extracted from works by Wilson et al. (1960), Compston & Arriens (1968) and Arriens & Lambert (1969), and the names of tectonic units are those suggested by Daniels & Horwitz (1968).

The western part of the Australian Precambrian Shield comprises the oldest known rocks in Australia. Granites and gneisses older than 3000 m.y. have been found in the northern and western parts of the shield, and most of the extensive Archaean terrains are composed of rocks older than 2600 m.y. Geological investigations have led to the division of the shield into a number of tectonic units, each of which is characterized by some uniformity of structure, age, or general rock type. The subdivisions of the shield wholly or partly within the survey area are the Yilgarn Block, the Albany-Fraser Province, and the Naturaliste Block. Each of these is described below.

Yilgarn Block. This block, composed mainly of Archaean rocks, is characterized by linear greenstone belts, trending north to northwest and enclosed within a large expanse of granitic gneiss. The greenstone belts consist of complex associations of basic and ultrabasic volcanics and penecontemporaneous sills, overlain conformably by clastic sediments and acid volcanics and intruded by massive granites. The block is intruded by east-trending norite dykes, mainly in the east, and by Upper Proterozoic basic dykes close to its western margin.

The geotectonic pattern and lithology of the greenstone belts vary considerably from east to west across the Yilgarn Block. The pronounced linearity of the greenstone belts in the eastern part of the block gives way to a less regular disposition in the west, and in contrast to the ultrabasic volcanic and subvolcanic assemblages in the Eastern Goldfields area near Kalgoorlie, the ultrabasics close to the western margin of the block tend to be serpentinized harzburgite and dunite of coarsely crystalline character. The greenstones near Mount Magnet are characterized by immense layered intrusions containing harzburgitic ultrabasic layers, in varying states of serpentinization.

The lithologic variation across the Yilgarn Block is reflected by the known distribution of nickel occurrences in Western Australia. All the important nickel deposits so far discovered are associated with the volcanics and shallow-level intrusives of the Eastern Goldfields, rather than with the more coarse-grained ultrabasics of the western half of the Yilgarn Block.

McCall suggests that the changes seen from east to west across the Yilgarn Block reflect progressively deeper levels laid bare by erosion, and that because of pressure controls on sulphide mineralization, important nickel deposits are confined to the relatively high crustal zone in the eastern part of the block.

Small remnants of former sedimentary platform covers are present in some areas of the Yilgarn Block. Elongate outliers of unmetamorphosed Proterozoic sediments lie near and parallel to the western, southern, and southeastern margins of the Yilgarn Block, and in COLLIE, WIDGIEMOOLTHA, and CUNDEELEE* there are small outliers of Permian sediments. Minor Tertiary and Recent deposits occur at other localities.

Albany-Fraser Province. Along the south coast of the western part of Western Australia, Precambrian rocks strike east-northeast in marked discordance with the north-northwesterly structural trend in the adjoining Yilgarn Block. Farther east, the trend swings to northeast and the province is separated from the Yilgarn Block by the northeast-striking Fraser Fault. Rocks within the Albany-Fraser Province are of Proterozoic age and are therefore substantially younger than the Archaean rocks of the Yilgarn Block.

The rocks along the south coast consist principally of granitic gneisses which are lithologically similar to the rocks of the southwest part of the Yilgarn Block. Near the eastern end of the province, quartzite and associated metasediments, together with coarse gneissic acidic and basic granulites crop out. These include rocks of the Mount Ragged Belt, 160 km east-northeast of Esperance, which are possibly the oldest in the Albany-Fraser Province (Prider, 1965). Granite bodies, enclosed within granitic gneisses, occur near Albany, Porongorup Range, Esperance, and Duke of Orleans Bay, and at many other localities. They are of two distinct types - an older coarser porphyritic adamellite, and a younger even-grained microgranite which intrudes as sills in the coarser type. Turek & Stephenson (1966) describe the granite near Albany as being of anatectic or rheomorphic origin.

Between the western part of RAVENSTHORPE and the central part of MOUNT BARKER lies a discontinuous belt of Middle Proterozoic sediments.

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

The belt evidently coincides with the junction between the Yilgarn Block and the Albany-Fraser Province, as Archaean granite and gneiss crop out to the north of the belt, and Proterozoic high-grade metamorphics and granites to the south. Mount Barren, near the eastern end of the belt, is composed of contorted chlorite-muscovite schists, all of which strike east-northeast and dip steeply south. At the western extremity of the belt, the Stirling Range rises abruptly from a flat plain. It is composed of flat-lying low-grade metasedimentary rocks such as slate, schist, quartzite, and phyllite; all have been intruded by dolerite dykes. The relation between the Stirling Range and Mount Barren metasediments is not clear. There is no physical link between the two systems, at least in outcrop. Kay (1962) (cited by Prider, 1965) suggests that the Stirling Range and Mount Barren beds, and the metasediments between them, were deposited simultaneously in an east-trending geosynclinal belt.

Turek & Stephenson (1966) use radiometric evidence in attempting to clarify the stratigraphic relation between the Stirling Range beds and the gneissic complex to the south, and to explain why the low-grade metasediments of the Stirling Range lie in such close proximity to highgrade metamorphic rocks that are younger. They conclude that metamorphism of the Stirling Range beds may have taken place during the thrusting from the south of the high-grade metamorphics that now lie adjacent to the Stirling Range. Such a movement could have been a marginal dislocation related to orogenic activity farther south.

Near the town of Ravensthorpe, greenstones and whitestones form a small geosynclinal remnant structure embedded in granitic gneiss. This structure, known as the Ravensthorpe System (Sofoulis, 1958), extends southeast from Mount Short to Kundip, where the axis is deflected east-northeast and follows the general direction of the coast.

In the eastern part of the Albany-Fraser Province a linear belt of high-grade metamorphic rocks extends northeastwards along the south-eastern margin of the Yilgarn Block. The belt passes through Fraser Range, about 100 km east of Norseman, which is described by Wilson (1969) as 'composed dominantly of basic pyroxene granulites derived from basalts, many of which appear to have been vesicular and pillowed'. Acidic and basic garnet-bearing granulites are present to the west of Fraser Range; acid granulite and narrow anorthosite layers are dominant in some areas to the east. An extensive flatlying olivine gabbro sheet cuts the granulite, and in places has been converted to spinel-bearing metagabbro and pyroxene granulite. The metamorphic belt is separated from the gneiss and granite of the southeastern Yilgarn Block by the Fraser Fault, across which there is a Bouguer anomaly gradient of up to 10 mGal/km. Wilson interprets some minor structures within the granulite as evidence that the Fraser Fault is a reverse fault with a strong sinistral transcurrent component.

No firm hypotheses have been put forward to explain the evolution of the metamorphic belt, but geochronological evidence places constraints on any proposed mechanism of evolution. Age determinations by Arriens & Lambert (1968) on 17 granulite samples from Fraser Range gave an isochron of unusually high precision, suggesting that metamorphism took place as a sharp episodic event or that there was a sudden termination to a protracted metamorphic process. Faced with these constraints, Arriens & Lambert conclude that the main geological alternatives are: deposition of geosynclinal sediments, probably mostly of contemporaneous volcanic origin, followed by orogenic, deep-seated, granulite-facies metamorphism and uplift, all within a few hundred million years; or deep-seated and possibly prolonged reworking, under granulite facies conditions, of older crustal rocks, ending with rapid uplift.

Naturaliste Block. This is a narrow strip of high-grade metamorphic rocks forming an outlying part of the shield along the western margin of the southern Perth Basin. It consists predominantly of gneiss and granulite aged about 650 m.y. (Compston & Arriens, 1968).

Eucla Basin

The Eucla Basin is broad and shallow, and contains several hundred metres of Tertiary and Cretaceous sediments overlying a basement which is variously composed of Precambrian, Cambrian, and Permian rocks. Its landward margin roughly coincides with the known limit of marine Tertiary deposition north of the Great Australian Bight and encloses an area of about 192 000 km^2. The sediments are mainly organic limestone with minor carbonaceous silt, quartz sand, and conglomerate.

3. PREVIOUS GEOPHYSICAL RESULTS

Numerous geophysical surveys have been carried out within the survey area by BMR, the Geological Survey of Western Australia, and mining and oil exploration companies. The surveys for which information is available are listed in Appendix 4 and their locations are shown in Plates 4, 5, and 6. The major results of previous geophysical surveys that could have some relevance to the present investigation are discussed as follows:

Gravity surveys

Gravity surveys have been conducted in the Perth Basin by BMR and West Australian Petroleum Pty Ltd (WAPET), and across the Precambrian shield and Eucla Basin by BMR. Everingham (1965a) has conducted a regional gravity survey of the southern part of the Precambrian shield.

An extensive gravity survey by BMR in 1951 and 1952 (Thyer & Everingham, 1956) indicated that the Perth Basin is associated with a regional gravity depression of large magnitude and areal extent. The gravity depression was interpreted as the expression of an accumulation of light sediments, up to 10 km thick in places. Steep Bouguer anomaly gradients along the flanks of the gravity depression were attributed to normal faults separating the basin from the Precambrian shield. The Darling and Dunsborough Faults, in particular, show up as prominent gradients in the gravity field.

Regional gravity traverses across the Precambrian Shield and Eucla Basin were surveyed in 1954 (Gunson & Van der Linden, 1956). The most prominent Bouguer anomaly feature of the profiles is a steep-sided high of 120 mGal amplitude across the Fraser Range. A similar but smaller Bouguer anomaly feature occurs 220 km east of Kalgoorlie. The centre of this feature is on a line projected northeast from the Fraser Range. In the Yilgarn Block, intense local gravity highs were measured over the greenstone belts, and lows over granites. Gravity features in the Eucla Basin were considered to be mainly the expressions of density variations within the basement.

Everingham (1965a) took gravity measurements along a network of roads in the southern part of the Precambrian shield in Western Australia. The main gravity features revealed were: an area of positive Bouguer anomaly in the southwest corner of the shield; elongate gravity depressions along the western, southern, and southeastern margins of the Yilgarn Block; a major gravity ridge associated with basic granulite in the Fraser Range area; and residual gravity highs and lows corresponding respectively to greenstone belts and granites in the Yilgarn Block. Everingham attributed the regionally high Bouguer anomaly field in the southwest of the shield to the unusual shallowness of a dense lower crustal layer. He interpreted the elongate gravity depressions south and southeast of the Yilgarn Block as the expressions of the granitic cores of former orogenic zones.

Magnetic surveys

Aeromagnetic surveys have been conducted by BMR over the Perth Basin and the Precambrian Shield.

A survey of the Perth Basin in 1957 (Quilty, 1963) confirmed that the Perth Basin consists of a deep elongate basement trough filled with sediments. The maximum thickness of the sediments was estimated to exceed 8 km. The magnetic contours reveal a number of intrabasinal features including subsidiary basement ridges, often near and parallel to the margins of the trough, and near-surface basalt in the southern part of the basin.

BMR aeromagnetic surveys have covered a number of adjoining 1:250 000 Sheet areas in the Yilgarn Block (Plates 5 and 7). Trends in the magnetic contour pattern are closely associated with structural trends in the greenstones and whitestones. The contours indicate that the greenstone belts are generally aligned north-northwest, parallel to the main axes of folding. East-trending magnetic lineaments are also present, and probably correspond to basic intrusives occupying fissures produced by subsidiary cross-folding.

Seismic surveys

With the exception of a deep crustal reflection and refraction survey of the Precambrian shield by BMR, all seismic surveys have been conducted in the Perth Basin. Most of the seismic surveys by private companies were aimed at locating structural traps for petroleum accumulation and are only of local interest in the analysis of the gravity results. The BMR surveys, however, did provide information on the more regional structures of the basin.

The main traverse line of the Gingin seismic survey (Vale, 1966) crossed the centre of the major gravity depression of the Perth Basin. A sedimentary thickness in excess of 5 km was measured and a deep-seated anticline, the Gingin Anticline, was revealed. The Bullsbrook seismic survey (Walker & Jones, 1966) located a major anticline beneath a synclinal sequence 2 km thick. The anticline is possibly the southern part of the Gingin Anticline. The Rockingham/Mundijong seismic survey (Moss, 1962) showed that a sedimentary section at least 4 km thick abuts older rocks on a plane that dips 60° to the west and cuts the surface some distance in front of the Darling Scarp. This suggests that the Darling Fault is a normal fault, and is in apparent contradiction with the results of the Cookernup seismic survey (Vale & Moss, 1962) which indicated that the sedimentary sequence at the eastern margin of the basin may continue east of the Darling Scarp at depth. If the Darling Fault is normal, the reflections obtained east of the Darling Scarp could be associated with local shear zones rather than with overthrusting along the Darling Fault plane. The Busselton seismic survey (Lodwick, 1962) showed the sedimentary thickness to be at least 2.5 km in the southern part of the Perth Basin. Several major faults were revealed.

Deep crustal studies

Seismic reflection, seismic refraction, and gravity data have been used for the purpose of determining the crustal structure of southwestern Australia.

From seismic refraction data collected at Mundaring Geophysical Observatory since 1959, Everingham (1965b) has shown that southwestern part of Western Australia has an unusual and complex crustal structure. Under the Perth Basin and the immediately adjoining shield area, the crust is anomalously thick (45 km) and consists of two non-sedimentary layers - an upper layer of velocity 6.18 km/s, and a lower layer of velocity 7.24 km/s. The velocity of the upper mantle in this region is about 8.48 km/s. The crustal structure and mantle velocity change from west to east across the shield. In the eastern part of the shield, the crustal thickness is normal for a continental region (35 km) and the lower crustal layer appears to be absent. In addition, the mantle velocity is slightly lower (8.21 km/s) than in the west.

Everingham suggests that the locus of the crustal, and possibly upper mantle, change is the Yandanooka/Cape Riche Lineament (Plate 8). This is a north-northwest trending line across which regional changes in gravity, geomorphology, and geology take place; it coincides in part with a zone of active seismicity.

Mathur (1973) has used the results of a deep crustal reflection survey by BMR, as well as seismic refraction and gravity data, in an attempt to determine the nature and structure of the crust and upper mantle in southwestern Australia. His conclusions differ in some respects from those of Everingham. Whereas Everingham implies that the crust consists of two main layers in the western part of the shield and one in the east, a crustal model computed by Mathur shows three layers in the western shield area and two in the east. The upper two layers have velocities of 6.12 and 6.67 km/s and probably correspond to the upper layer of Everingham which has a velocity of 6.18 km/s. The basal crustal layer of Mathur has a velocity of 7.42 km/s, thickens substantially from east to west, and probably corresponds to Everingham's 7.24 km/s lower crustal layer. Mathur's measurements of the total crustal thickness - 34 km in the east of the shield and 44 km in the west - are in approximate agreement with the measurements of Everingham. Mathur suggests that the crust thins from 44 km near Perth to 34 km offshore from Albany, and from 34 km at Coolgardie to about 32 km near the western end of the Great Australian Bight. There is some evidence for a vertical displacement (down to the west) of 1 or 2 km along the Fraser Fault.

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. 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 of sedimentary basins and values adopted for surveys of hardrock areas, there are no great discontinuities of contour with other surveys tied to.

The contoured area has been divided into eight regional gravity provinces. These cover large areas of fairly simple shape in which the gravity 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 provinces and units are termed 'features'.

Some province boundaries are clearly definable whereas others are arbitrarily drawn. Minor amendments to the gravity province division may be made when gravity coverage is obtained in areas adjoining the present survey area. The names of provinces wholly or partly defined in the Bouguer anomaly map, are listed in Table 1.

TABLE 1. GRAVITY PROVINCES

Province name	Named after	Previous definition
Perth Regional Gravity Low	City	Defined in BMR survey, 1951-52 Named by Vale (1965)
Porongorup Regional Gravity Low	Range	New
Avon Regional Gravity High	River	New
Narembeen Regional Gravity Shelf	Town	New
Coolgardie Regional Gravity Complex	Town	New
Dundas Regional Gravity Depression	Lake	New
Fraser Regional Gravity Ridge	Range	New
Gambanga Regional Gravity Low	Lake	New

Gravity provinces

With the exception of the Perth Regional Gravity Low, which is the subject of an earlier report (Thyer & Everingham, 1956), each province will be 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 BOORABBIN, KALGOORLIE, and WIDGIEMOOLTHA.

The vertical extents of some anomalous masses were calculated using the expression for the gravity effect of an infinite horizontal slab (e.g. Parasnis, 1962). Information on the typical densities of rock types was obtained from Joplin (1963) and is as follows:

Rock type	Density (g/cm^3)
Granite	2.67
Gneiss	2.76
Metasediments (whitestones)	2.78
Basic volcanics (greenstones)	2.97
Basic metamorphics	3.01

Porongorup Regional Gravity Low. This province is a narrow gravity depression extending eastwards from Northcliffe at least as far as Lookout Point, and probably beyond on to the continental shelf. To the north and south it is bounded by gradients of about 1.5 and 2 mGal/km respectively.

The province is approximately coextensive with a large outcrop of Proterozoic granite which forms the westen part of the Albany-Fraser Province. The gradient along the northern boundary coincides with the contact between granite and metasediments; the gradient along the southern boundary of the province probably follows the southern margin of the granite although this lies a short distance beyond the coastline. The steepness of these gradients and the large total Bouguer anomaly change across them (about 40 mGal) suggest that the granitic body is in the form of a steep-sided pluton extending to great depth. If the mean density contrast between the granite and the enclosing rocks is 0.1 g/cm^3, the depth to the lower surface of the granite would be about 10 km.

Gravity troughs, similar to the Porongorup Regional Gravity Low, flank the Yilgarn Block to the southeast and north. Everingham (1965a) has suggested that they are the gravity expressions of the granitic roots of former mountain chains which formed as a result of Proterozoic orogenic activity.

Avon Regional Gravity High. This triangular province is bounded on all three sides by Bouguer anomaly gradients. The intense gradient over the Darling Fault forms the western boundary; the lesser gradient on the north side of the Porongorup Regional Gravity Low forms the southern boundary, and the gentle gradient associated with the Yandanooka/Cape Riche Lineament forms the eastern boundary. Bouguer anomaly values are higher than in surrounding provinces and increase from about -20mGal in the east to positive values along the western province boundary.

Though the province extends over Archaean granite, gneiss, granulite, and basic igneous rocks of the southwestern part of the Yilgarn Block, variations in surface geology are not generally associated with local changes in gravity relief. Bouguer anomaly highs close to the Darling Fault in PEMBERTON and PERTH roughly coincide with outcrops of metamorphic and basic igneous rocks, and a broad shallow low in northwest DUMBLEYUNG is centred over granitic outcrops, but elsewhere in the province there is no consistent relation between gravity and geological features. Most of the contacts between granite and gneiss, for instance, have no gravity gradients associated with them, and a large irregularly shaped granulite terrain (Plate 9) mapped by Wilson (1969) lies mainly east of the region of high Bouguer anomaly, although its elongation is parallel to the Yandanooka/Cape Lineament.

8 12

It is evident therefore that regionally high Bouguer anomalies in the Avon Regional Gravity High cannot be satisfactorily interpreted in terms of surface geology. Furthermore, the rise in Bouguer anomaly value across the Yandanooka/Cape Riche Lineament cannot be explained as an isostatic effect due to the proximity of the continental margin, as the lineament is not parallel to the coastline, and seismic evidence (Everingham, 1965b; Mathur, 1973) indicates that thickening rather than thinning of the crust occurs as the Perth Basin is approached from the east. If follows that the Yandanooka/Cape Riche Lineament may be, as Everingham contends, the locus of a change in crustal structure. This is implied not only by the otherwise unaccountable change in gravity level, but by the regional nature and rectilinearity of the other features associated with the lineament (Plate ~~9~~ 8).

The Bouguer anomaly change across the lineament varies along its length owing to the presence of relatively local gravity features on each side. If local components of the gravity field were removed, the change in gravity would be about 25 mGal. In terms of Everingham's model, this change could be explained by a thickening of about 2.5 km in a 3.0 g/cm^3 lower crustal layer at the expense of a 2.75 g/cm^3 upper crustal layer, depth to the mantle remaining constant. Similarly, for Mathur's model, thickening by about 4 km in a 3.10 g/cm^3 lower crustal layer at the expense of a 2.94 g/cm^3 intermediate layer, or thickening by 4 km of the intermediate layer at the expense of a 2.78 g/cm^3 upper layer from east to west across the lineament, could account for the observed change in gravity level.

<u>Narembeen Regional Gravity Shelf</u>. This province encompasses an area of smooth gravity relief in which Bouguer anomalies generally range from -20 to -50 mGal. The province is bounded to the west by the gentle gradient associated with the Yandanooka/Cape Riche Lineament, and to the south and east by provinces of different contour trend or more disturbed contour pattern. Its northern boundary lies beyond the survey area.

The province covers a large area of the southwestern Yilgarn Block. The smoothness of gravity relief and low level of Bouguer anomaly imply that most of this part of the shield is of uniformly low density; the long-wavelength Bouguer anomaly variations which are observed within the province probably correspond to transitions between granitic and gneisses terrains. For instance, broad shallow gravity lows of about 20 mGal relief on KELLERBERRIN, CORRIGIN, NEWDEGATE, and RAVENSTHORPE are centred over granitic outcrops and may represent large granitic bodies that have intruded slightly denser gneiss and migmatite.

It would be expected that greenstone bodies, being composed largely of dense basic igneous rock, would be associated with residual gravity highs. However, a greenstone body in southern BENCUBBIN has no observable gravity expression, and only the northern part of a large area of metamorphosed greenstone in western KELLERBERRIN is of high Bouguer anomaly. On the other hand, a high of 10-15 mGal relief in western BENCUBBIN occurs in a large expanse of granite, far removed from any greenstone outcrop. Notwithstanding this apparent lack of correlation between gravity highs and geological features over most of the province, the Ravensthorpe System (Sofoulis, 1958) is represented by a narrow gravity high of 15-25 mGal relief which extends southeastwards from Mount Short to near Kundip, where it abuts the southern part of the Fraser Regional Gravity Ridge.

The southern boundary of the province is characterized by an abrupt change in contour trend from north or northwest to east-southeast, and may coincide with the junction between the Yilgarn Block and the Albany-Fraser Province.

Coolgardie Regional Gravity Complex. This province is characterized by the presence of short-wavelength high-amplitude Bouguer anomaly features. To the east, a fairly steep gradient separates the province from a region of lower Bouguer anomalies. The southern and western boundaries are arbitrary but drawn so as to include residual highs in HYDEN, SOUTHERN CROSS, and JACKSON. The northern limits of the province will remain unknown until gravity coverage is extended northwards.

The province is divided into three units. These are the Koolyanobbing Gravity Complex (named after Koolyanobbing Range), the Mount Holland Gravity High (named after the mountain), and the Lefroy Gravity Complex (named after Lake Lefroy).

In the Koolyanobbing Gravity Complex an intense high that trends west-northwest in the northern part of JACKSON (Feature 1) covers an area in which basic igneous rocks crop out. The high also coincides with a magnetic feature of great intensity. Steep gradients bordering the gravity high suggest it is the expression of a steep-sided body of dense rock. Assuming the density contrast between this rock and the surrounding gneiss is 0.21 g/cm^3, the calculated depth to the base of the body is about 5 km. Smaller highs within the unit (Features 2, 3, and 4) also coincide with outcrops of igneous rocks and with magnetic highs.

In the Mount Holland Gravity High, four highs of sharp relief but small area are superimposed on two broad highs of low relief which trend east and north-northwest. One of the four, an elongated high in HYDEN (Feature 1) covers an area in which Archaean sediments crop out. These sediments may be underlain by dense basic rocks as the density contrast between the sediments and surrounding granitic gneisses is probably too small to cause a gravity high of the observed magnitude and relief. Small but fairly intense highs in SOUTHERN CROSS and HYDEN (Features 2, 3, and 4) can be correlated with outcrops of basic igneous rock. The broad east-trending Bouguer anomaly high within the unit is possibly the expression of dense rocks forming the core of an anticline of a cross-fold system, subsidiary to the main north-northwest trend of folding. The presence of basic dykes (coincident with magnetic lineaments) within the area covered by the high is consistent with this interpretation. Slight increases in Bouguer anomaly values in a zone extending eastwards along the northern parts of HYDEN and LAKE JOHNSTON can similarly be interpreted as the expression of dense rocks at the core of an anticline.

The Lefroy Gravity Complex is characterized by a highly disturbed contour pattern consisting of elongate residual highs and lows with a north to northwest trend. The unit covers the southern part of the Eastern Goldfields region of the Yilgarn Block, and the sharp changes in gravity level from place to place probably correspond to transitions between the greenstones belts (comprising mainly basic volcanics and subvolcanics) and intrusive granites. The gravity contour pattern in this unit differs markedly from those of the Koolyanobbing Gravity Complex and the Mount Holland Gravity High. Whereas residual highs in the latter two units are of small area and widely spaced, residual highs in the Lefroy Gravity Complex are close together and joined to each other by gravity saddles. Features 1 and 2 for instance, are only local culminations of a broad elongate belt of high Bouguer anomaly extending northwards from Norseman to the northern part of KURNALPI. To the west and east, this belt is connected via gravity saddles to a high centred near Ora Banda (Feature 3); and to a circular high in the area of Mount Monger (Feature 4). Features 4, 5, and 6 are all joined together by gravity saddles, but are nonetheless distinguishable gravity features; Feature 5 is a belt of high Bouguer anomaly, about 120 km long, which trends north-northwest and extends as a gravity spur into the Dundas Regional Gravity Depression; Feature 6 is elongated to the north-northeast but swings abruptly westward at its northern end.

The contrast in gravity pattern between the Lefroy Gravity Complex on the one hand, and the Mount Holland Gravity High and the Koolyanobbing Gravity Complex on the other, can be attributed to a difference in the geometry of the greenstone belts in the two areas. Whereas the greenstone belts in the Eastern Goldfields appear to form an interconnecting system, the belts in the area to the west occur as discrete bodies separated by granitic or gneissic terrain. This implies that either erosional activity was greater in the western part of the Yilgarn Block than in the east, as suggested by McCall (1972), or the Eastern Goldfields and western Yilgarn Block are discrete tectonic units of contrasting geotectonic patterns. A more conclusive interpretation may be possible when gravity coverage of the Yilgarn Block is completed.

Residual gravity lows in the Lefroy Gravity Complex are interpreted as the expressions of granitic batholiths intruding the greenstone belts. Features 7, 8, 9, and 10 can all be correlated directly with granitic outcrops. Features 11 and 12 extend over greenstone/whitestone outcrops but probably correspond to granitic bodies at shallow depth.

Dundas Regional Gravity Depression. This is an elongate northeast-trending gravity trough which has three separate minima below -90 mGal. A steep Bouguer anomaly gradient forms the eastern boundary, and in the west, a less steep gradient separates the province from the Coolgardie Regional Gravity Complex. At its southern end the province terminates against an area of higher Bouguer anomaly, and to the north it apparently extends beyond the survey area.

The province extends along the southeastern margin of the Yilgarn Block. The areas of lowest Bouguer anomaly roughly coincide with Archaean granitic outcrops, and a gravity spur extending southeast through the eastern part of WIDGIEMOOLTHA is probably the expression of a greenstone belt. In the central northern part of NORSEMAN, however, outcropping metamorphics have no expression in the contours.

Northeasterly regional contour trends within the province are in contrast with a predominant north-northwest trend of contour elsewhere on the Yilgarn Block, suggesting that the influence of a Proterozoic orogeny at the southeastern margin of the Yilgarn Block extended for a considerable distance into the block itself. A small outlier of Middle Proterozoic sediments in WIDGIEMOOLTHA is elongated northeast, parallel to the trend of contour. Daniels (1970) has suggested that these sediments and others near the margin of the Yilgarn Block, which form elongated outliers parallel to Bouguer anomaly trends, accumulated in long narrow troughs. The troughs may have developed as a result of movements in narrow zones associated with the Proterozoic orogenic belt.

Fraser Regional Gravity Ridge. This province is a narrow zone of high Bouguer anomalies extending northeastwards from the coast near Esperance through Fraser Range to, and probably beyond, the northeast corner of the survey area. It is most pronounced at Fraser Range and to the northeast where it consists of an intense gravity ridge of positive Bouguer anomaly, bounded by gradients of up to 10 mGal/km. Peak Bouguer anomaly values of about +40 mGal at Fraser Range and +25 mGal in CUNDEELEE are more than 100 mGal greater than minimum values in the adjoining Dundas Regional Gravity Depression. South of Fraser Range, the amplitude of the province attenuates abruptly; the province continues to the southwest as a gravity ridge of comparatively small relief. At its southern end the western province boundary is displaced some 80 km to the northwest to encompass a broad high close to the coastline in RAVENSTHORPE.

The Fraser Regional Gravity Ridge extends along the northwest margin of the eastern part of the Albany-Fraser Province. The steep gradient that forms the northwest boundary of the province coincides with the Fraser Fault, which separates the Archaean Yilgarn Block, of granite and gneiss, from Proterozoic granulite and gneiss of the Albany-Fraser Province. Positive Bouguer anomalies in the northern half of the Fraser Regional Gravity Ridge are attributable to a body of dense pyroxene granulite which forms prominent outcrops in the Fraser Range area. The granulite body may extend to a depth of about 10 km assuming that its mean density is 0.34 g/cm^3 greater than that of granite to the northwest. The steep gradient along the eastern side of the Fraser Regional Gravity Ridge is possibly the expression of a major fault as it coincides, near Fraser Range, with a seemingly abrupt transition from granulite in the west, to garnet gneiss in the east (Arriens & Lambert, 1969).

The province can be divided into four units of differing shape or gravity level. From north to south these are the Kitchener Gravity Plateau (named after Kitchener railway siding), the Simon Hill Gravity Ridge (named after the hill), the Mount Andrew Gravity Platform (named after the mountain), and the Muncalinup Gravity High (named after town).

The Kitchener Gravity Plateau is an intense gravity high, plateau-shaped in relief, and is probably the expression of a dense tabular body of basic granulite. It is separated from the Simon Hill Gravity Ridge by a gravity saddle, which may be caused by a reduction in the thickness or density of the granulites or the close proximity of low-density rocks to both the northwest and southeast of the metamorphic belt. The Simon Hill Gravity Ridge is an intense narrow gravity ridge with a peak Bouguer anomaly value of +40 mGal at Fraser Range. It also includes a fan-shaped area of high Bouguer anomaly to the southeast of Fraser Range. Locally high Bouguer anomalies at Fraser Range may be associated with the flat-lying olivine gabbro sheet, described by Wilson (1969). A slight gravity saddle between the local high at Fraser Range and the high to the southeast is probably related to gneisses interposed between metamorphic rocks of more basic composition. The steep gradient forming the northwest margin of the unit is centred to the east of the boundary between acid and basic granulites in WIDGIEMOOLTHA. It follows that the contact separating dense basic granulite from lighter crystalline rocks to the northwest (Fraser Fault ?) dips southeast.

Except for a northeast-trending high in ESPERANCE, Bouguer anomalies in the Mount Andrew Gravity Platform are in the range, -20 to -40 mGal. The gradients across the northwest and southeast boundaries of the unit are much less intense than to the north, suggesting that horizontal density changes are either deeply buried or are near-surface but small and gradual. The local high in ESPERANCE lies on the southerly projection of the axis of the gravity highs associated with the Fraser Range metamorphic belt and is probably the expression of a shallow body of dense basic metamorphic rocks. Tertiary and Quaternary sediments obscure most of the Precambrian basement in the area and prevent positive correlation of the feature with geology.

The Muncalinup Gravity High is defined on its northwestern boundary by a gradient of up to 2 mGal/km. Gentler gradients form the northern and southeastern boundaries of the unit. Its seaward extension will remain undefined until gravity coverage of the continental shelf is obtained. High Bouguer anomaly values are probably associated with basic metamorphic rocks which crop out over much of the unit. A granitic outcrop passing north through the centre of the high has no apparent effect on Bouguer anomaly values and must be of small vertical extent or density contrast.

Gambanga Regional Gravity Low. This province is a northeast-trending regional gravity low in which Bouguer anomaly values range from -20 to -60 mGal. It is bounded to the west by the Fraser Regional Gravity Ridge, and to the south and southeast by a gentle Bouguer anomaly rise towards the coastline. It appears to extend northeastwards beyond the area surveyed.

The province extends over parts of the Eucla Basin of Tertiary and Cretaceous sediments, and the Albany-Fraser Province of Proterozoic gneiss, granite, and sediments. Low Bouguer anomaly values are attributed to Precambrian rocks of low density rather than to thick sediments of the Eucla Basin. This is supported by the following observations:

1. Bouguer anomalies are low in the south of the province where Precambrian rocks are exposed. A Proterozoic granitic inlier near Balladonia lies on the margin of an extensive gravity low that covers most of the north of the province.
2. An overall northeasterly contour trend over Precambrian rocks in the south of the province persists over the sediment-covered area in the north.
3. There is no Bouguer anomaly gradient associated with the boundary of the Eucla Basin.
4. Boreholes drilled in the Eucla Basin east of the survey area have all encountered a Precambrian basement of granite or gneiss at depths less than 600 metres (Peers & Trendall, 1967).

The foregoing observations suggest that the Eucla Basin, within the survey area, is underlain at shallow depth by a Proterozoic basement of granite and gneiss, which is structually continuous with the part of the Albany-Fraser Province exposed in MALCOLM and eastern ESPERANCE.

A transition from continental to oceanic type crust may account for the gentle Bouguer anomaly rise towards the coastline.

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

The locations of reported mineral deposits were plotted on the Bouguer anomaly contour map (Plate 9) to determine whether the gravity contour pattern is related to the distribution of mineral deposits.

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 deposits are not of economic importance.

There is a strong tendency for mineral deposits to be concentrated around the residual gravity highs associated with the greenstone belts of the Yilgarn Block.

5. CONCLUSIONS

The following conclusions are drawn from the analysis of gravity results:

1. Gravity contour trends closely reflect regional structural trends over most of the Yilgarn Block and Albany-Fraser Province. Along the margin of the Yilgarn Block, however, contour trends characteristic of the Albany-Fraser Province persist for some distance into Archaean terrain, suggesting that Proterozoic tectonic activity caused structural overprinting of pre-existing Archaean patterns. This is particularly striking at the southeast margin, where a 70 km wide gravity depression over Archaean rocks extends parallel to the Proterozoic Fraser Range metamorphic belt. A small outlier of Middle Proterozoic sediments within the area covered by this depression is elongated parallel to the regional contour trend, suggesting that the deposition and preservation of the sediments were controlled by Proterozoic tectonic activity.

2. A Bouguer anomaly gradient, which forms the eastern boundary of a region of high Bouguer anomaly covering the southwestern part of the Yilgarn Block, coincides with a zone of supposed

crustal change. Gravity evidence suggests that the crustal change may be in the form of a thickening, from east to west, of a lower or intermediate crustal layer at the expense of a less dense upper layer.

3. The greenstone belts of the Yilgarn Block are associated with residual gravity highs of small area and large amplitude. The distribution pattern of the greenstone belts differs in the eastern and western parts of the Yilgarn Block. In the Kalgoorlie area the belts appear to form an interconnecting system, whereas in the Southern Cross area they are separated from each other by large areas of granite or gneiss.

4. Low gravity features over the Precambrian shield can generally be correlated with outcropping granitic bodies. The most distinctive features are deep, elongate gravity depressions bordering the Yilgarn Block to the south and southeast; these may be the expressions of the granitic cores of former orogenic zones. In the Yilgarn Block proper, the amplitude and intensity of gravity lows associated with granites decrease from east to west, suggesting that the granitic masses decrease correspondingly in density contrast or vertical extent.

5. An intense, narrow gravity ridge extending northeast from Fraser Range is evidently the expression of a partly exposed body of dense pyroxene granulite. The body is estimated to be up to 10 km thick and is probably in fault contact with granite and gneiss to the northwest and southeast. The Fraser Fault is represented by a gradient of about 10 mGal/km and is considered to be a reverse fault and to dip southeast. The gravity ridge appears to extend northeastwards beyond the area surveyed.

6. Gravity relief over the western part of the Eucla Basin probably reflects lateral density variations in the Precambrian basement. As the Bouguer anomaly field is low compared with that in areas of exposed granulite to the northwest, the basement may be composed predominantly of granite and gneiss.

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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.

APPENDIX 1: SURVEY STATISTICS

Survey Commenced	:	9 May 1969
Survey Completed	:	19 September 1969
Total Survey Days	:	133
Total Helicopter days available	:	237 (the first 29 days were conducted as a single helicopter operation after which two helicopters were used)
Days Unserviceable	:	52
Pilot Days off	:	15
Maintenance	:	2
Weather	:	2
Loops	:	586
New Readings	:	3961
Flying Time	:	811 hours
Ferry Time	:	119 hours

Statistics by Sheet area

Sheet	New readings	Flying hours	Ferry hours	New rdgs per flying hour	New rdgs per flying and ferry hour	Loops
Balladonia	160	40.35	6.60	4.0	3.4	24
Bencubbin	157	28.55	4.30	5.5	4.8	24
Boorabin	153	23.15	2.20	6.6	6.0	24
Bremer Bay	64	13.05	2.25	5.5	4.2	9
Collie	120	22.20	2.35	5.4	4.9	18
Corrigin	162	31.10	5.50	5.2	4.4	24
Cundeelee	157	39.05	7.35	4.0	3.4	24
Dumbleyung	158	33.30	5.10	4.7	4.1	22
Esperance	151	41.55	11.00	3.6	2.9	24
Hill River	48	9.15	1.45	5.2	4.5	7
Hyden	157	33.25	1.40	4.7	4.5	24
Jackson	157	29.15	3.30	5.4	4.8	24
Kalgoorlie	157	31.50	3.15	5.0	4.5	24
Kellerberrin	164	33.45	3.05	4.9	4.5	24
Kurnalpi	154	33.80	4.25	4.6	4.0	24
Lake Johnston	153	35.40	3.0	4.3	4.0	24
Malcolm	104	29.30	7.30	3.5	2.8	16
Mondrain Island	19	4.50	1.0	4.2	3.5	2
Moora	144	5.55	1.35	5.8	4.6	14
Mount Barker	157	35.25	2.50	4.5	4.2	23
Newdegate	157	34.30	4.05	4.6	4.1	24
Norseman	157	38.00	6.35	4.1	3.5	24
Pemberton	104	21.45	4.10	4.8	4.1	17
Perth	126	-	-	-	-	12
Pinjarra	101	14.25	1.35	6.2	5.6	15
Ravensthorpe	148	32.30	3.30	4.6	4.2	23

Sheet	New readings	Flying hours	Ferry hours	New rdgs per flying hour	New rdgs per flying and ferry hour	Loops
Southern Cross	160	33.38	2.55	4.8	4.5	24
Widgiemooltha	161	41.15	6.30	3.9	3.4	24
Zanthus	151	43.35	12.45	3.5	2.7	24

APPENDIX 2: SURVEY PERSONNEL AND EQUIPMENT

Staff

(Wongela Geophysical Pty Ltd)

Party leader - L.N. Ingall

Chief meter reader - H. Keith

Meter reader - D. Durant

Draughtsman - L. Spain

Base readers from Messrs Galvin, Grandt, Weber, Hall, Gutke, Wandell, Blumenthal, Burrows, Barker, Ingall, O'Rorke, Spain

Helicopter staff of 2 pilots and 2 engineers

BMR Supervisor - A. Fraser

Equipment

2 Worden gravity meters

1 LaCoste & Romberg gravity meter

6 Mechanism microbarometers

Helicopters

1 Hughs 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 private 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 bench marks 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 10. While flying 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 accurate gravity stations termed 'Isogal stations' (Barlow, 1970) which have been established by multi-meter traversing.

Horizontal control was maintained by accurately pinpricking aerial photographs and by taking a 35-mm photograph of the station from 500 feet, as a check on the original pinprick. The location of the gravity station was plotted 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 only 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 for the fixed nodes computed as 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 table. The internal and external standard deviations are the standard deviations of the least squares adjustments to legs in the network. The forecast 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.).

Network Adjustments

Segment	Elevation (m)							Gravity (mGal)			
	Internal network		External network		Forecast network			Internal network		External network	
	S.D.	Max. adj.	S.D.	Max. adj.	S.D.	Max. adj.	Max. adj. / S.D.	S.D.	Max. adj.	S.D.	Max. adj
A	1.45	3.80	1.80	5.32	2.62	4.57	1.75	0.04	0.13	0.04	0.12
B	2.03	6.12	2.39	8.21	1.98	4.57	2.31	0.04	0.14	0.04	0.14
C	1.83	5.69	2.61	7.14	2.90	6.40	2.2	0.03	0.07	0.03	0.08
D	1.26	3.84	1.67	4.74	0.94	1.83	1.9	0.05	0.13	0.05	0.13
E	1.11	3.11	1.74	5.38	3.35	6.10	1.9	0.03	0.10	0.03	0.11
F	1.80	5.64	2.12	10.80	1.58	4.27	2.7	0.03	0.08	0.03	0.09
G	1.81	5.11	2.46	7.14	1.95	3.05	1.6	0.03	0.07	0.03	0.07
H	1.56	6.26	2.09	7.93	2.32	3.96	1.7	0.03	0.11	0.03	0.11
I	0.97	3.11	1.54	4.08	2.10	4.57	2.2	0.06	0.19	0.06	0.19

APPENDIX 4: LISTS OF PREVIOUS GEOPHYSICAL AND DRILLING SURVEYS

The following lists give the names of, and references to geophysical and drilling surveys conducted prior to 1970. The locations of these surveys are shown on Plates 4, 5, and 6.

Name of Survey or Report	Year(s) of Survey	Operator	Reference
GRAVITY SURVEYS			
Perth Basin Gravity Survey	1951-2	BMR	BMR Bull. 33
Regional Gravity Traverses across the Eucla Basin	1954-55	BMR	BMR Rec. 1956/145
Eganu Gravity Survey	1962	WAPET	BMR Subsidy File 62/1933
Augusta-Moora Gravity Survey	1962	WAPET	BMR Subsidy File 62/1935
MAGNETIC SURVEYS			
Airborne magnetic & radiometric surveys in Kalgoorlie-Southern Cross region	1956-57	BMR	BMR Rec. 1958/45
Reconnaissance airborne magnetic survey of the Eucla Basin	1954	BMR	BMR Rec. 1958/87
Airborne magnetic & radiometric survey of the Kurnalpi-Widgiemooltha areas	1958	BMR	BMR Rec. 1959/137
Boorabbin and Norseman airborne magnetic and radiometric survey	1959	BMR	BMR Rec. 1961/55
Ravensthorpe airborne magnetic and radiometric survey	1960	BMR	BMR Rec. 1962/2
Lake Johnston area airborne magnetic & radiometric survey	1960	BMR	BMR Rec. 1962/100

Name of Survey or Report	Year(s) of Survey	Operator	Reference
Norseman geophysical surveys	1946, 1953	BMR	BMR Rec. 1963/62
Perth Basin aeromagnetic survey	1957	BMR	BMR Rec. 1963/74
Kalgoorlie detailed aeromagnetic survey, 1964	1964	BMR	BMR Rec. 1965/26
Norseman detailed aero-magnetic survey	1964	BMR	BMR Rec. 1965/203
Kalgoorlie detailed aero-magnetic survey, 1965	1965	BMR	BMR Rec. 1966/104
Merredin-Perth airborne magnetic & radiometric traverses	1966	BMR	BMR Rec. 1968/4
SEISMIC SURVEYS			
Gingin seismic reflection survey	1955	BMR	BMR Rec. 1956/26 BMR Rec. 1966/149
Rockingham-Mundijong seismic survey	1956	BMR	BMR Rec. 1962/107
Brusselton seismic reflection survey	1956	BMR	BMR Rec. 1962/108
Cookernup seismic survey	1955-56	BMR	BMR Rec. 1962/109
Bullsbrook seismic survey	1964	BMR	BMR Rec. 1966/203
Deep crustal reflection survey, southwestern Australia	1973	BMR	BMR Rec. 1973/63
Hill River-Dongara seismic survey	1960	WAPET	BMR Subsidy File 62/1534
Perth Basin seismic survey	1962	WAPET	" " " 62/1590 " " " 62/1602 " " " 62/1627
Wicherina seismic survey	1962	WAPET	" " " 62/1651

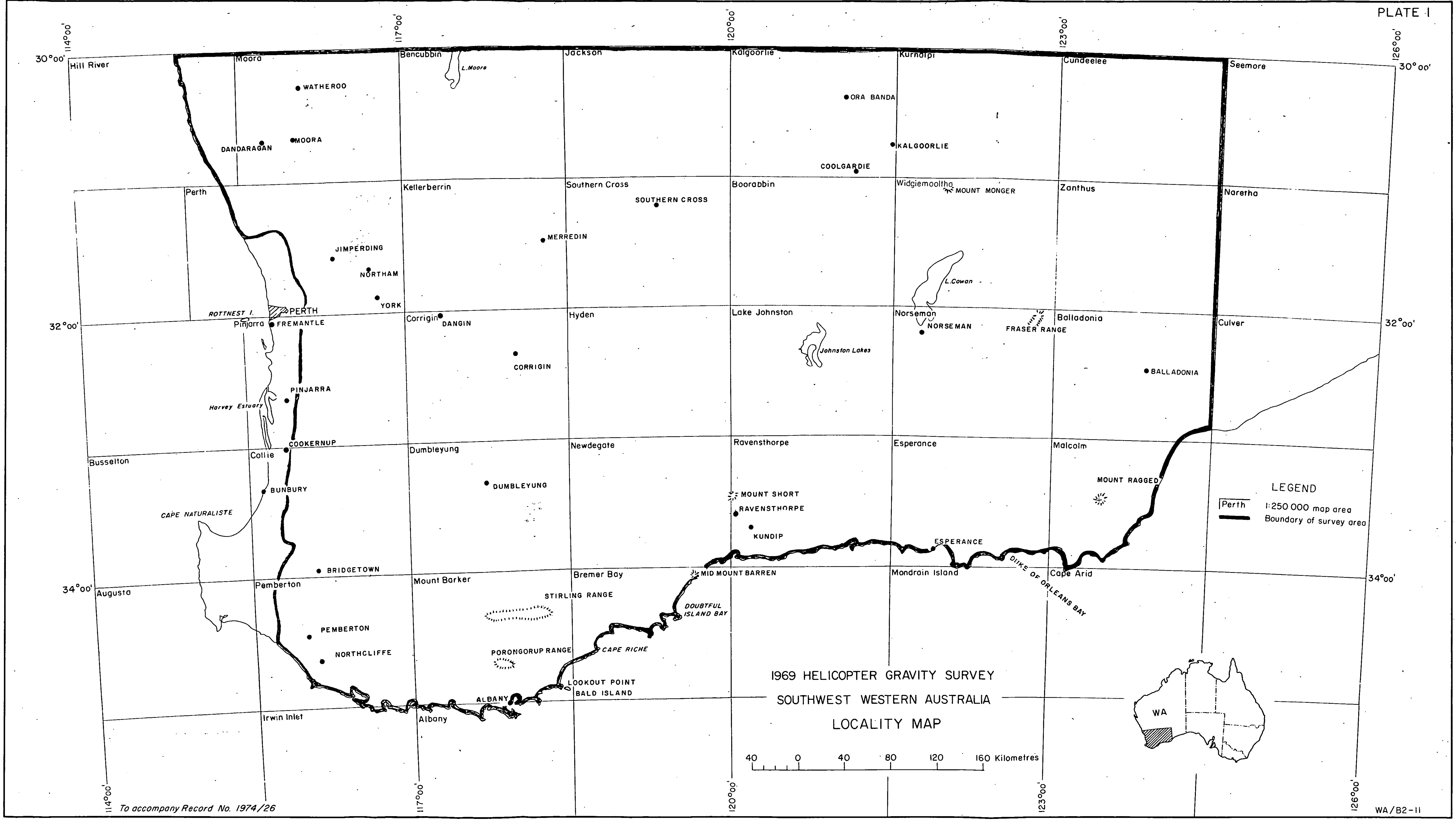
Name of Survey or Report	Year(s) or Survey	Operator	Reference
Gingin seismic survey	1963	WAPET	BMR Subsidy File 63/1541
Lake Preston seismic survey	1964	WAPET	BMR Subsidy File 64/4501
Darradup seismic survey	1964	WAPET	BMR Subsidy File 64/4502
Pinjarra seismic survey	1965	WAPET	BMR Subsidy File 65/4578
Bullsbrook seismic survey	1965	WAPET	BMR Subsidy File 65/11048
Yanchep seismic survey	1965	WAPET	BMR Subsidy File 65/11050
Dandaragan seismic survey	1966	WAPET	BMR Subsidy File 66/11065
Karnup seismic survey	1966	WAPET	BMR Subsidy File 66/11069
Charla seismic survey	1966	WAPET	BMR Subsidy File 66/11071
Wedge seismic survey	1966	WAPET	BMR Subsidy File 66/11082
Smokebush seismic survey	1966	WAPET	BMR Subsidy File 66/11114
Coogee seismic survey	1966	WAPET	BMR Subsidy File 66/11125
Sabina seismic survey	1966	Union Oil	BMR Subsidy File 66/11154
Margaret River seismic survey	1966	Union Oil	BMR Subsidy File 66/11191
Walyering seismic survey	1967	WAPET	BMR Subsidy File 67/11143
Lancelin seismic survey	1967	WAPET	BMR Subsidy File 67/11182
Sugarloaf seismic survey	1968	WAPET	BMR Subsidy File 68/3039

Name of Survey or Report	Year(s) of Survey	Operator	Reference
Wonnerup-Flinders seismic survey	1968	Union Oil	BMR Subsidy File 68/3060
Harvey seismic survey	1969	WAPET	BMR Subsidy File 69/3022
Namban seismic survey	1969	WAPET	BMR Subsidy File 69/3025
Harvey D-1 seismic survey	1969	WAPET	BMR Subsidy File 69/3074

Jurien No. 1	1962	1026	WAPET	BMR Subsidy File 62/1110
Woolmulla No. 1	1962	2811	WAPET	BMR Subsidy File 62/1127
Eganu No. 1	1962	606	WAPET	BMR Subsidy File 62/1221
Hill River No. 1	1962	579	WAPET	BMR Subsidy File 62/1402
Hill River No. 2	1962	116	WAPET	BMR Subsidy File 62/1402
Hill River No. 2A	1962	494	WAPET	BMR Subsidy File 62/1402
Hill River No. 3	1962	264	WAPET	BMR Subsidy File 62/1402
Hill River No. 4	1962	308	WAPET	BMR Subsidy File 62/1402
Gingin No. 1	1964	4544	WAPET	BMR Subsidy File 64/4121
Cadda No. 1	1965	2795	French Petrol	BMR Subsidy File 65/4164
Pinjarra No. 1	1965	4572	WAPET	BMR Subsidy File 65/4176
Sue No. 1	1966	3059	WAPET	BMR Subsidy File 65/4186
Preston No. 1	1966	762	WAPET	BMR Subsidy File 66/4219

Name of Survey or Report	Year(s) of Survey	Operator	Reference
Cockburn No. 1 1967	3054	WAPET	BMR Subsidy File 67/4251
Whicher Range No. 1 1968	4653	Union Oil	BMR Subsidy File 68/2005

PLATE I

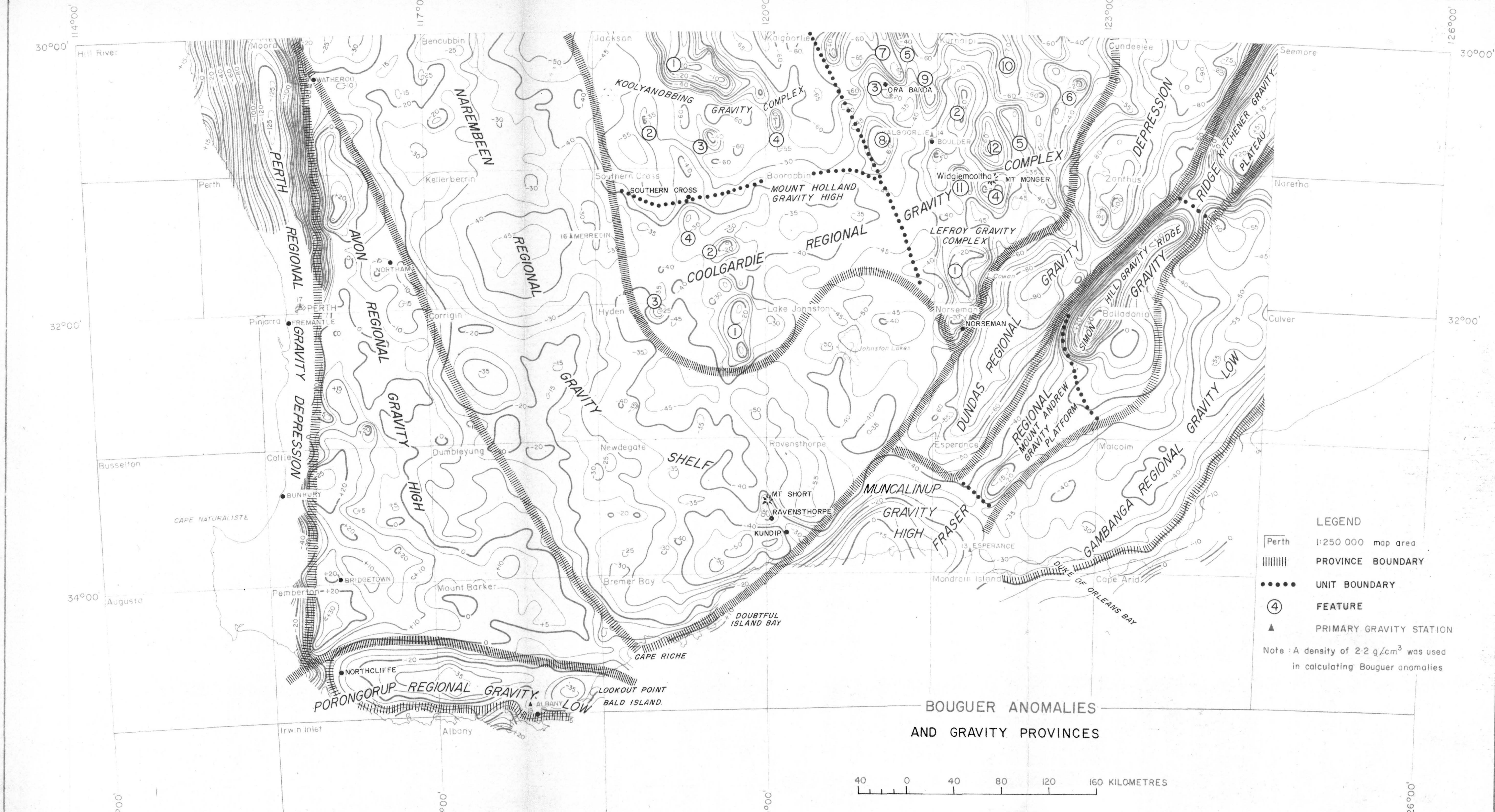


1969 HELICOPTER GRAVITY SURVEY
SOUTHWEST WESTERN AUSTRALIA
LOCALITY MAP

To accompany Record No. 1974/26

WA/B2-11

PLATE 2



To accompany Record No. 1974/26

WA/B2-30-1

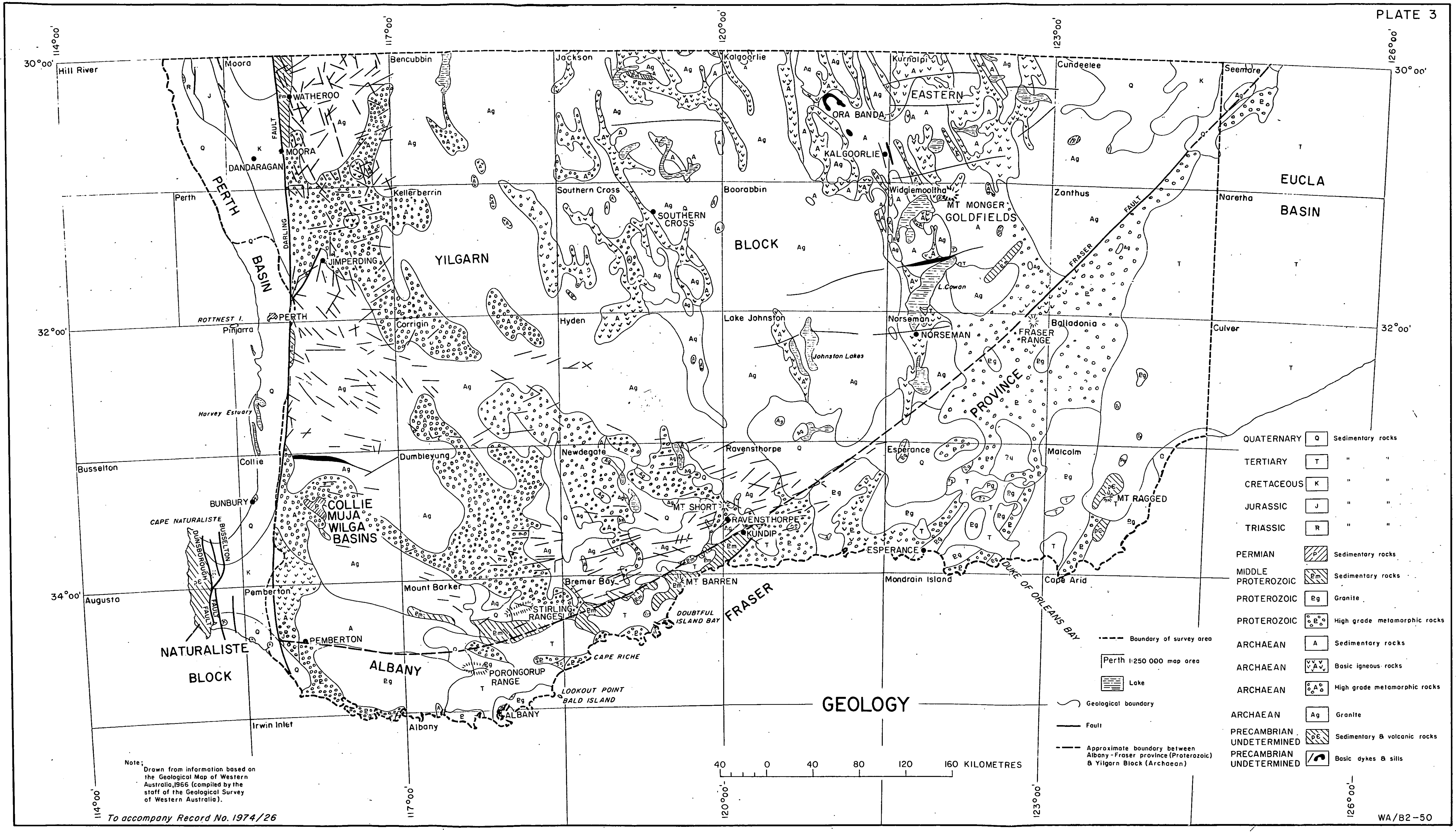


PLATE 3
GEOLOGY
Hill River
Moora
Bencubbin
Jackson
Kalgoorlie
Kurnalpi
Cundeelee
Seemore
Perth
Kellerberrin
Southern Cross
Boorabbin
Widgiemooltha
Zanthus
Naretha
Pinjarra
Corrigin
Hyden
Lake Johnston
Norseman
Balladonia
Culver
Collie
Dumbleyung
Newdegate
Ravensthorpe
Esperance
Malcolm
Busselton
Augusta
Pemberton
Mount Barker
Bremer Bay
Mondrain Island
Cape Arid
Irwin Inlet
Albany
WATHEROO
MOORA
DANDARAGAN
JIMPERDING
PERTH
ROTTNEST I.
Harvey Estuary
BUNBURY
CAPE NATURALISTE
DUNSBOROUGH
BUSSELTON
FAULT
DARLING
PERTH BASIN
YILGARN BLOCK
EASTERN GOLDFIELDS
ORA BANDA
KALGOORLIE
SOUTHERN CROSS
MT MONGER
L.Cowan
Johnston Lakes
NORSEMAN
FRASER RANGE
FRASER FAULT
ALBANY FRASER PROVINCE
EUCLA BASIN
COLLIE MUJA WILGA BASINS
MT SHORT
RAVENSTHORPE
KUNDIP
ESPERANCE
MT RAGGED
MT BARREN
STIRLING RANGES
DOUBTFUL ISLAND BAY
CAPE RICHE
DUKE OF ORLEANS BAY
PORONGORUP RANGE
LOOKOUT POINT
BALD ISLAND
ALBANY
PEMBERTON
NATURALISTE BLOCK
114°00'
117°00'
120°00'
123°00'
126°00'
30°00'
32°00'
34°00'
40 0 40 80 120 160 KILOMETRES
QUATERNARY Q Sedimentary rocks
TERTIARY T " "
CRETACEOUS K " "
JURASSIC J " "
TRIASSIC R " "
PERMIAN P Sedimentary rocks
MIDDLE PROTEROZOIC Pm Sedimentary rocks
PROTEROZOIC Pg Granite
PROTEROZOIC High grade metamorphic rocks
ARCHAEAN A Sedimentary rocks
ARCHAEAN Basic igneous rocks
ARCHAEAN High grade metamorphic rocks
ARCHAEAN Ag Granite
PRECAMBRIAN UNDETERMINED pC Sedimentary & volcanic rocks
PRECAMBRIAN UNDETERMINED Basic dykes & sills
Boundary of survey area
Perth 1:250 000 map area
Lake
Geological boundary
Fault
Approximate boundary between Albany-Fraser province (Proterozoic) & Yilgarn Block (Archaean)
Note; Drawn from information based on the Geological Map of Western Australia, 1966 (compiled by the staff of the Geological Survey of Western Australia).
To accompany Record No. 1974/26
WA/B2-50

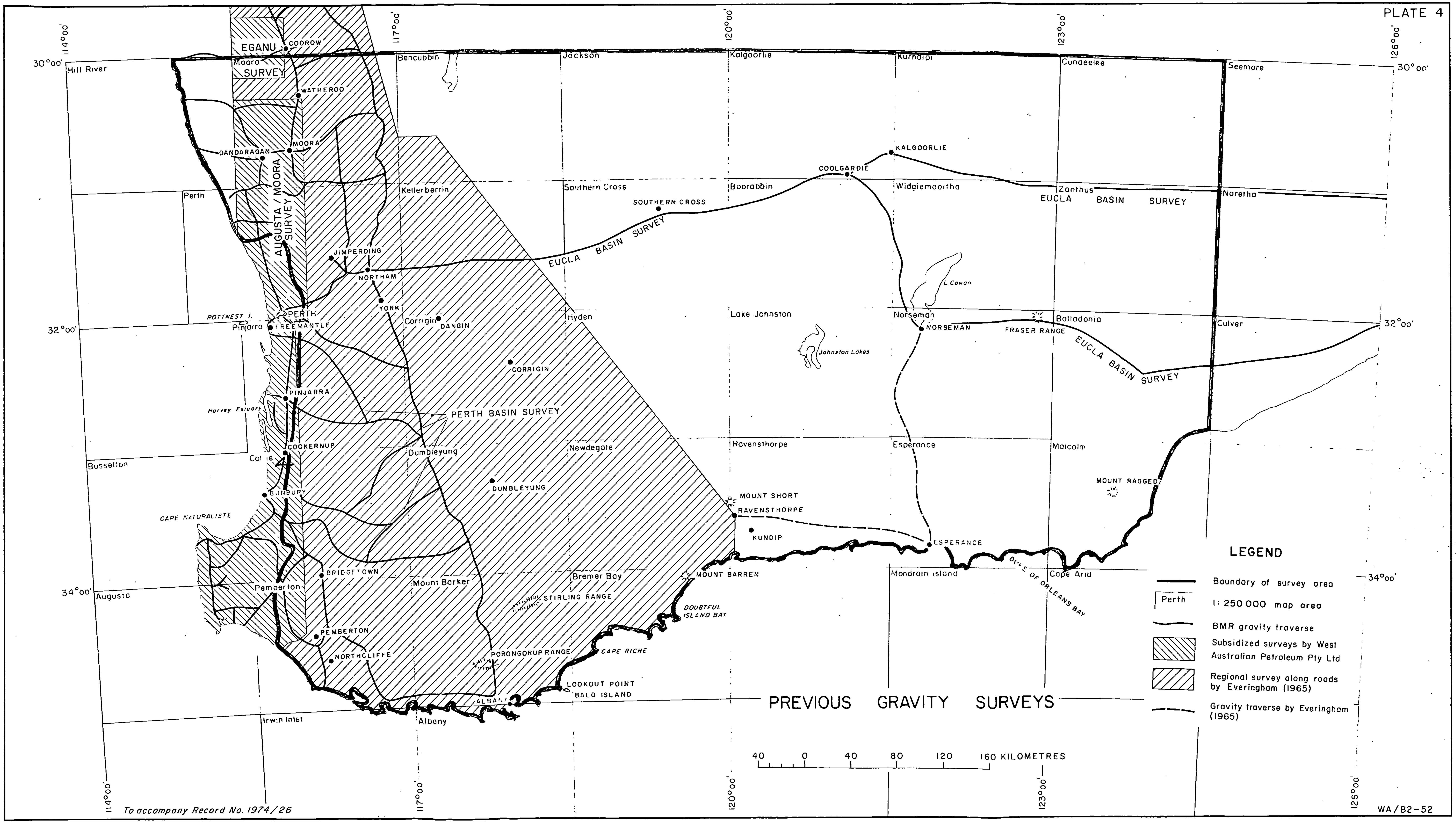


PLATE 4
PREVIOUS GRAVITY SURVEYS
LEGEND
Boundary of survey area
Perth 1: 250 000 map area
BMR gravity traverse
Subsidized surveys by West Australian Petroleum Pty Ltd
Regional survey along roads by Everingham (1965)
Gravity traverse by Everingham (1965)
40 0 40 80 120 160 KILOMETRES
114°00'
117°00'
120°00'
123°00'
126°00'
30°00'
32°00'
34°00'
EGANU
Moora SURVEY
AUGUSTA / MOORA SURVEY
EUCLA BASIN SURVEY
PERTH BASIN SURVEY
Hill River
Bencubbin
Jackson
Kalgoorlie
Kurnalpi
Cundeelee
Seemore
Perth
Kellerberrin
Southern Cross
Boorabbin
Widgiemooltha
Zanthus
Naretha
Pinjarra
Corrigin
Hyden
Lake Johnston
Norseman
Balladonia
Culver
Busselton
Collie
Dumbleyung
Newdegate
Ravensthorpe
Esperance
Malcolm
Augusta
Pemberton
Mount Barker
Bremer Bay
Mondrain Island
Cape Arid
Irwin Inlet
Albany
COOROW
WATHEROO
MOORA
DANDARAGAN
KALGOORLIE
COOLGARDIE
SOUTHERN CROSS
JIMPERDING
NORTHAM
YORK
ROTTNEST I.
PERTH
FREEMANTLE
DANGIN
CORRIGIN
NORSEMAN
FRASER RANGE
L. Cowan
Johnston Lakes
PINJARRA
Harvey Estuary
COOKERNUP
DUMBLEYUNG
BUNBURY
CAPE NATURALISTE
MOUNT SHORT
RAVENSTHORPE
KUNDIP
ESPERANCE
MOUNT RAGGED
DUKE OF ORLEANS BAY
BRIDGETOWN
MOUNT BARREN
STIRLING RANGE
DOUBTFUL ISLAND BAY
PEMBERTON
NORTHCLIFFE
PORONGORUP RANGE
CAPE RICHE
LOOKOUT POINT
BALD ISLAND
ALBANY
To accompany Record No. 1974/26
WA/B2-52

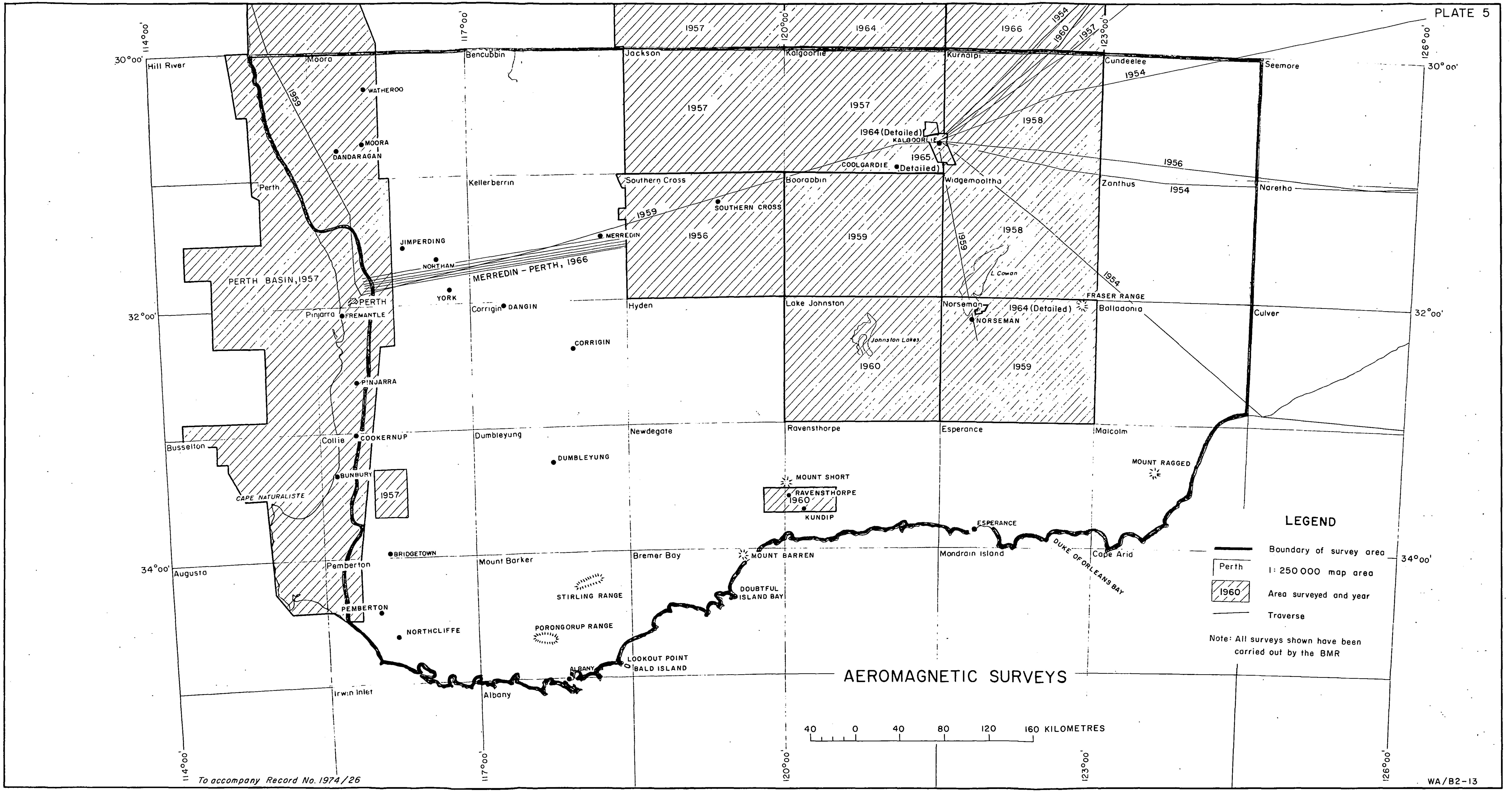
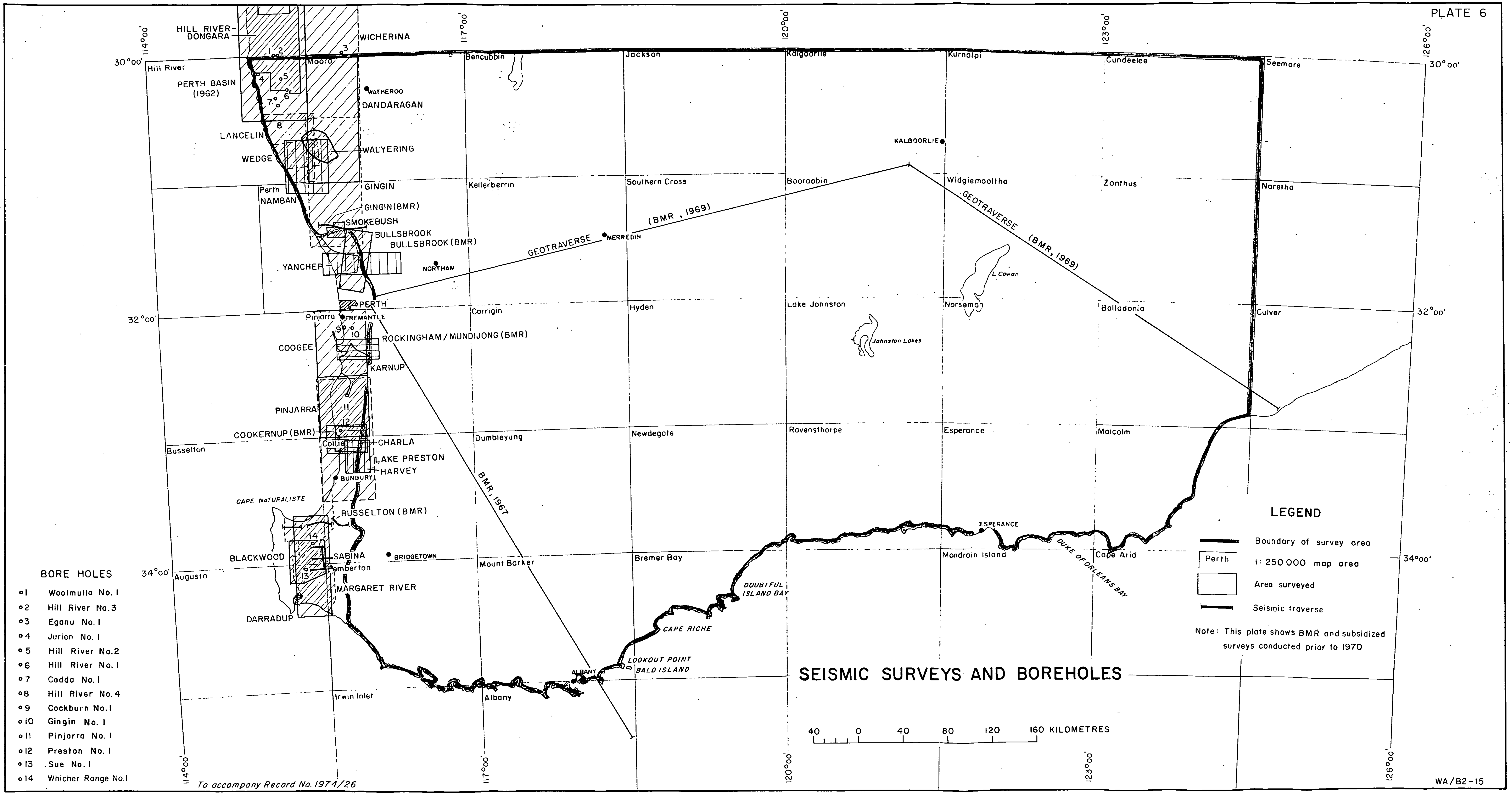
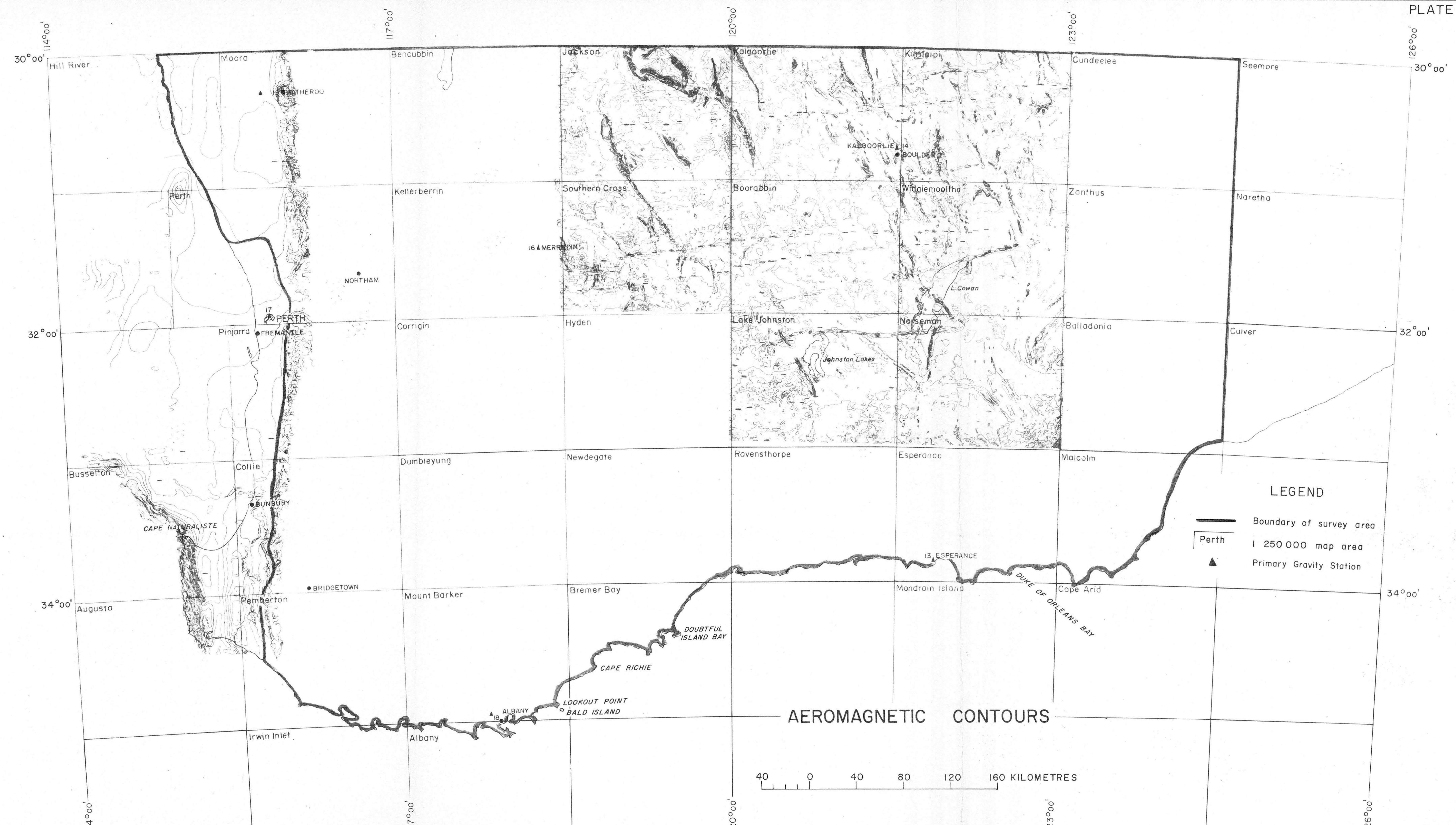


PLATE 5
AERОMAGNETIC SURVEYS
PERTH BASIN, 1957
MERREDIN – PERTH, 1966
1964 (Detailed)
1965 (Detailed)
Hill River
Moora
Bencubbin
Jackson
Kalgoorlie
Kurnalpi
Cundeelee
Seemore
Perth
Kellerberrin
Southern Cross
Boorabbin
Widgemooltha
Zanthus
Naretha
Pinjarra
Corrigin
Hyden
Lake Johnston
Norseman
Balladonia
Culver
Busselton
Collie
Dumbleyung
Newdegate
Ravensthorpe
Esperance
Malcolm
Augusta
Pemberton
Mount Barker
Bremer Bay
Mondrain Island
Cape Arid
Irwin Inlet
Albany
WATHEROO
MOORA
DANDARAGAN
JIMPERDING
NORTHAM
YORK
PERTH
FREMANTLE
DANGIN
CORRIGIN
MERREDIN
SOUTHERN CROSS
KALGOORLIE
COOLGARDIE
NORSEMAN
FRASER RANGE
PINJARRA
COOKERNUP
BUNBURY
CAPE NATURALISTE
DUMBLEYUNG
MOUNT SHORT
RAVENSTHORPE
KUNDIP
ESPERANCE
MOUNT RAGGED
DUKE OF ORLEANS BAY
BRIDGETOWN
MOUNT BARREN
DOUBTFUL ISLAND BAY
STIRLING RANGE
PORONGORUP RANGE
PEMBERTON
NORTHCLIFFE
ALBANY
LOOKOUT POINT
BALD ISLAND
L. Cowan
Johnston Lakes
LEGEND
Boundary of survey area
1:250 000 map area
Area surveyed and year
Traverse
Note: All surveys shown have been carried out by the BMR
40 0 40 80 120 160 KILOMETRES
To accompany Record No. 1974/26
WA/B2-13

PLATE 6

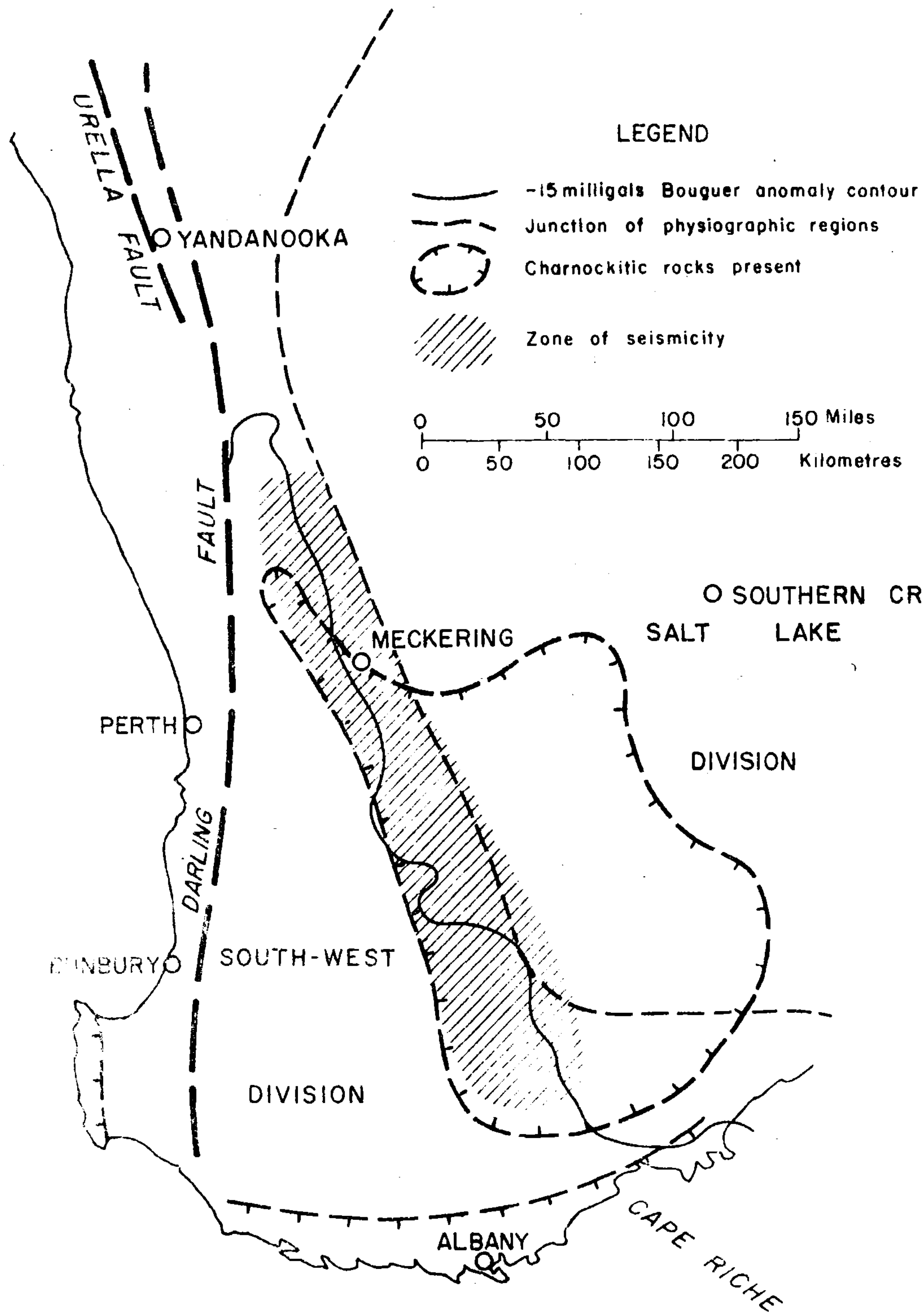


SEISMIC SURVEYS AND BOREHOLES



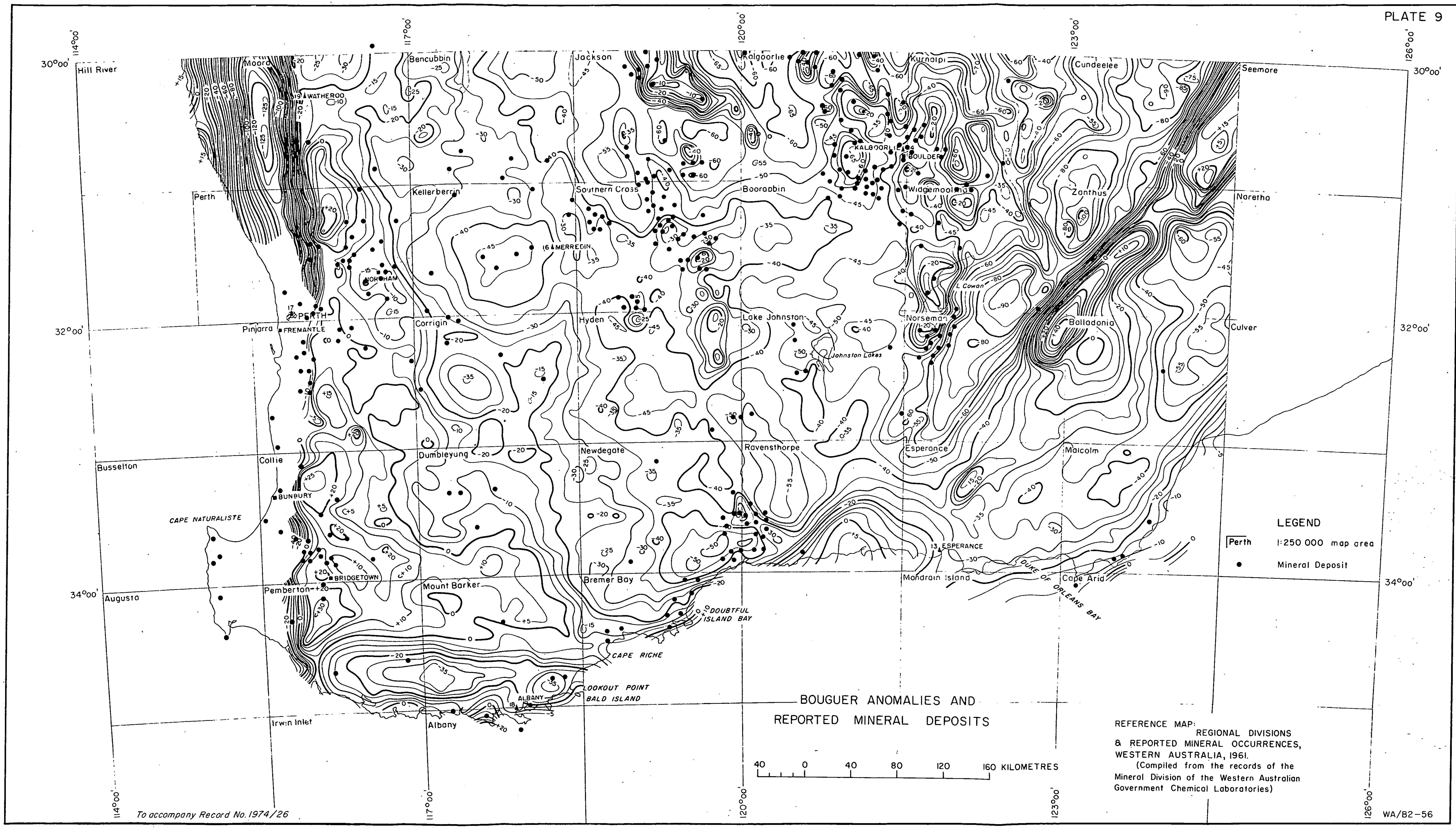
To accompany Record No. 1974/26

WA/B2-53



FEATURES OF THE CAPE RICHE–YANDANOOKA LINEAMENT
(AFTER EVERINGHAM, 1965)

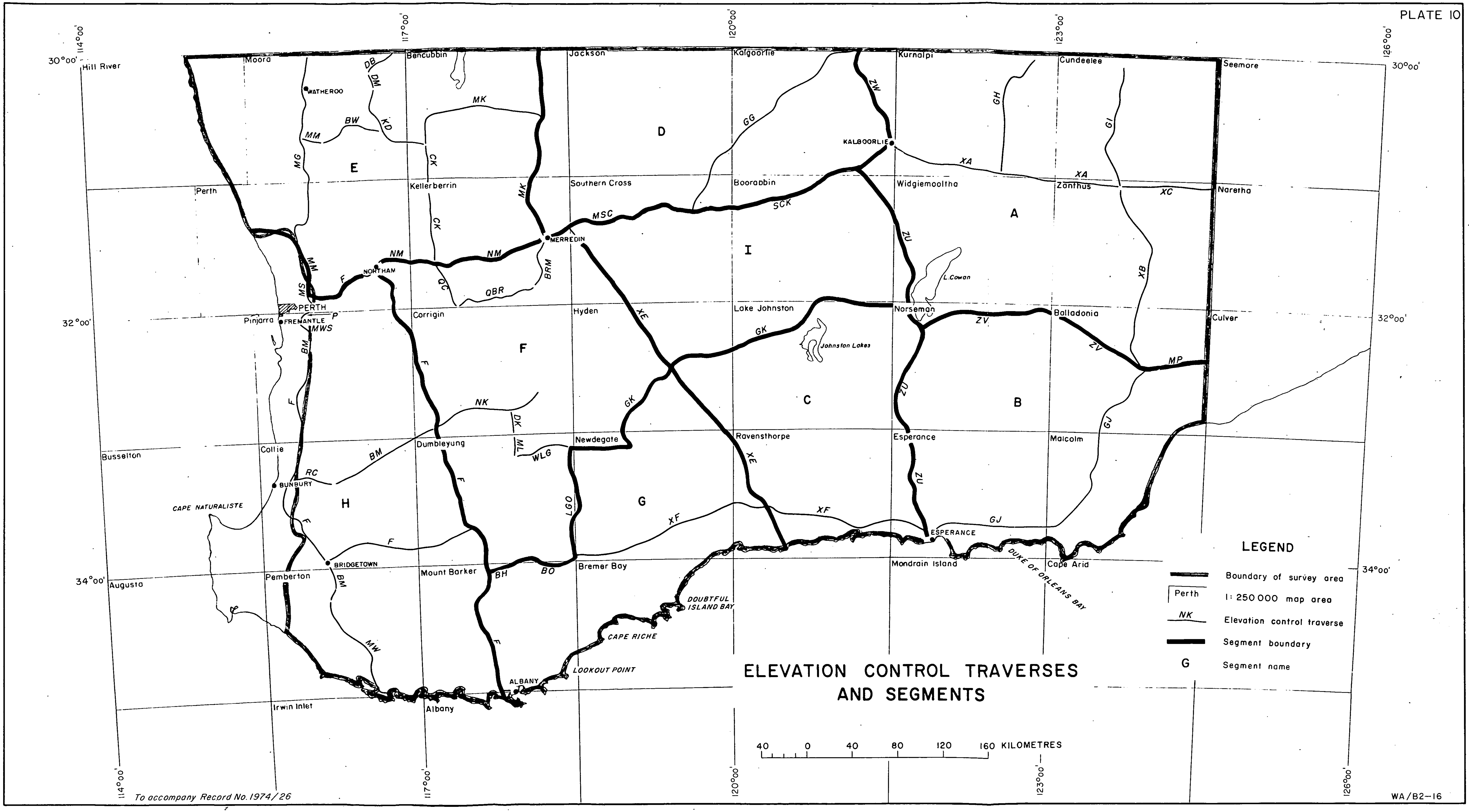
PLATE 9



To accompany Record No. 1974/26

WA/B2-56

PLATE 10



ELEVATION CONTROL TRAVERSES AND SEGMENTS