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RECONNAISSANCE HELICOPTER GRAVITY SURVEY IN THE FLINDERS RANGES, SOUTH AUSTRALIA, 1970

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SUMMARY

During September and October 1970, a reconnaissance helicopter gravity survey was made by the Bureau of Mineral Resources (BMR) in the Flinders Ranges area of South Australia. This report presents an interpretation of both the new and earlier Bouguer anomaly data in the area between longitudes 136°30' and 141° East, and latitudes 29° and 34° South.

The geology comprises predominantly tightly folded, weakly metamorphosed Adelaidean sediments occupying the Adelaide Geosyncline, which extends southward from the crystalline and metamorphic basement rocks of the Mount Painter Block, and lies between the Gawler Craton in the West and the Willyama Block in the East. Various exposed granites lie within, or adjacent to the areas of Adelaidean sediments: strong Bouguer anomaly lows lie over some of the granites. The survey also covered small areas of Phanerozoic sediments in parts of the Pirie-Torrens Basin in the west, and the Frome Embayment and Murray Basin in the east: the influence of these sediments on the Bouguer anomaly pattern is weak.

Prior to quantitative interpretation of selected anomalies, a study was made of the density of various rock units in the survey area. Three methods of density determination were used: these included direct measurements on 170 surface samples of Adelaidean sediments and 194 drill-core samples of granite, density profiling, and seismic P-wave velocity to rock density conversions. The new density data were combined with the very limited amount of density information previously available for the area. The results indicated considerable overlap of the ranges of average density of granites (2.65 - 2.70 g/cm^3), Adelaidean sediments (2.68 - 2.73 g/cm^3), and rocks of the metamorphic basement complexes (2.55 - 2.79 g/cm^3).

The Bouguer anomaly field over the Adelaide Geosyncline and surrounding areas is, broadly speaking, slightly negative. While in very general terms the geosyncline is outlined by gradients in the anomaly pattern, in terms of density contrasts, a simple basin model is inadequate. The most prominent anomalies are lows of amplitude 20 to 50 mgal below the background. These lie in two north-south belts to the east and west of the axis of the geosyncline. The lows are not attributed to accumulations of Phanerozoic of Adelaidean sediments. Rather they appear to be caused by low-density bodies at depths of several kilometres beneath Adelaidean sediments in the west, and by exposed or nearly exposed granites in the east. The granites with associated strong Bouguer anomaly lows include those of the Mount Painter Block, the Anabama Granite, and those on the northwest side of the Willyama Block. Computer modelling indicates that in these areas low-density bodies extend down to considerable depths, e.g. 23 km in the case of the Anabama Granite.

Prominent trends delineated by gradients and other features in the Bouguer anomaly pattern were selected for comparison with geological features, alignments of seismic epicentres, and alignments of mineral occurrences. Some trends correspond with surface faults, for example the Norwest Fault and Paralana Fault, but others have no obvious surface expression. It is possible that some deep-seated faults suggested from the gravity interpretation have a special association with the location of mineral occurrences and diapiric structures in the Flinders Ranges.

1. INTRODUCTION

During the period April to October, 1970 a reconnaissance helicopter gravity survey was conducted in South Australia by Wongela Geophysical Pty Ltd, under contract to the Bureau of Mineral Resources. The survey covered two separate areas, Area A in the west of the State and Area B over a major part of the Flinders Ranges in the east.

This report is concerned with the latter area, comprising about 90 000 km^2 shown outlined in Figure 1. Station density established in South Australia is about one per 50 km^2, which is higher than generally used in BMR reconnaissance helicopter gravity surveys. The stations are spaced on a uniform grid of about 7.2 km to conform with the spacing adopted by the South Australia Department of Mines (SADM) on their reconnaissance gravity surveys.

In the report, the geological setting is considered first (Figs. 2 to 7), followed by brief discussion of previous geophysical work in the area and its surroundings. A chapter on rock density considerations attempts to reach positive conclusions regarding ranges of density for all rock types concerned in the interpretation. The partition of the Bouguer anomaly field into provinces and units is described (Fig. 14) and an interpretation of the gravity field in each unit is proposed. In general, the interpretation is of a regional nature but a few larger, well formed anomalies have been represented by models (Figs. 16 to 22).

For simplicity, gravity contours are shown over a block of 15 map Sheets in the 1:250 000 series (Fig. 8). This block is referred to in a general way as 'the area'. The BMR 1970 survey region within it, outlined in Figure 1, is referred to as 'the survey area'. Ties were made to the surrounding previous work at permanently marked stations established by the South Australian Department of Mines and Delhi Australian Petroleum Ltd (Table 2).

Both heighting and gravity observations were established using the cell method of traversing described by Hastie & Walker (1962). The elevation of gravity stations was established by microbarometer readings adjusted to third-order bench mark control established previously by the South Australian Department of Lands and Mines. Gravity control was effected through ties to the BMR Isogal network of base stations (Barlow, 1970). A summary of the adjustment procedures is given in Appendix B with a table of standard deviations and maximum adjustments. Survey statistics and other details are included in Appendix A.

Broadly, the survey area straddles a topographic divide separating the Spencer Gulf/Lake Torrens depression on the west from the Lake Frome depression, both lying more or less at sea level. Elevations exceeding 500 m are reached everywhere along the divide from the southern reaches of ORROROO* north through the middle of ORROROO and PARACHILNA and then north-eastwards to the northeast corner of COPLEY. Within the survey area individual ranges and peaks consistently exceed this height throughout the length of the divide, e.g. Mount Hack (1080 m) in COPLEY, Point Bonney (1130 m) on the east side of Wilpena Pound in PARACHILNA, and Black Rock (839 m) in ORROROO. The ranges are referred to collectively as the Flinders Ranges and they tend to lie in entangled, contorted patterns, particularly in COPLEY.

South of Lake Frome a broad branch divide passes eastwards from the main divide through OLARY and on to Broken Hill in New South Wales. It reaches a general elevation of about 300 m, sloping gently north to Lake Frome and southwards to the Murray River Basin. Many individual ranges and peaks of this divide exceed 600 m in elevation. They are known collectively as the Olary Ranges.

Between the main divide and Spencer Gulf, a secondary divide develops rather sharply as a scarp east of Port Pirie, extending northward until it fades near the northwest corner of ORROROO. To its east lies the Willochra Basin, a minor sedimentary basin of Tertiary age standing generally at an elevation of 200 m and the intervening divide at 400 m. Two well-known peaks on the divide are Mount Remarkable (960 m) and Mount Brown (965 m), both lying between Melrose and Quorn.

2. GEOLOGY

The area surveyed covered three main tectonic units, the Adelaide Geosyncline and the Mount Painter and Willyama Blocks. The survey area is bounded on the west by the Gawler Craton and on the southeast by the Murray Basin (Figs. 2, 5).

Most of the survey was over the Flinders Ranges, which is a belt of fold mountains within the Adelaide Geosyncline. Geological mapping of the Flinders Ranges on a 1:250 000 scale has almost been completed by the S.A.D.M. As the gravity survey was of a regional nature, only those geological features which appear important to the interpretation are discussed here, although a wealth of detailed geological information is available. The following general discussion of the major structural units of the survey area was drawn mainly from Parkin (1969) and a number of SADM bulletins and reports.

*1:250 000 Sheet areas are spelt in capitals.

Tectonics

Gawler Craton. The Gawler Craton (sometimes referred to as the Gawler Platform or Gawler Block) is a stable block of metasediments, and intrusive and extrusive rocks, probably all of Lower Proterozoic age. Its extent, as shown in Figures 2 and 4, is based on geological mapping in the east, scattered drilling in the far west and mid-north of the State and also on aeromagnetic and gravity data from previous surveys. The craton is limited on the east by Adelaidean (Upper Proterozoic) sediments which thicken rapidly eastwards into the Adelaide Geosyncline. The tectonic history as seen by Thomson (in Parkin, 1969) and Thomson (1970) is shown in Figure 3. The oldest Lower Proterozoic stratigraphic components presently recognized are the Cleve Metamorphics which embody the Middleback Group (Iron Formations) and various gneisses, schists, and quartzites, which in total may exceed 10 000 m in thickness.

Several periods of regional metamorphism, folding, and deposition were recognized, and igneous activity was common. Two acid extrusive formations of considerable extent are the Moonabie Porphyry and the younger Gawler Range Volcanics (dated at 1535 m.y.) (Thomson, 1970). Thomson suggests that extrusion of the Gawler Range Volcanics stabilized the eastern part of the Gawler Craton before Adelaidean sedimentation began.

Willyama Block. This block of metasediments of Lower Proterozoic age is fault-bounded on the west. Shear zones trend northwest, and faults show overthrusting from the east. On the northern side the limits of the block are concealed beneath Phanerozoic cover (Figs. 2, 4, and 5). Magnetic rocks similar to those of the Willyama Block may continue to the north under the Frome Embayment. Granites are recognized on the northwest side of the block.

High-grade metamorphic sillimanite-garnet gneisses appear to be the oldest rocks in the Willyama Block. They extend east from rock units containing the Broken Hill lode. Associated with the gneisses are basic sills and plugs, and granitoid gneisses. The central part is dominantly intrusive adamellite, phyllites, and granitoid rocks. Although metamorphism has been strong, some sediments have survived. Schists similar to the Cleve Metamorphics of the Gawler Craton are recognized. The major period of metamorphism was the Willyama or Broken Hill Metamorphism (dated at 1600 to 1700 m.y.). The last important dated igneous event in the complex is the emplacement of the Mundi Mundi Granite (1520 m.y.), corresponding to the Gawler Range Volcanics.

Mount Painter Block. The geology of this area has been discussed by Coats & Blissett (1971). Two anticlinal cores of Lower Proterozoic crystalline and metasedimentary rocks which constitute the Mount Painter Block are exposed as inliers in the north of the Flinders Ranges. They are bounded on the east by the Paralana Fault. Adelaidean sediments lap onto the crystalline basement block on the west and south. The northern boundary is not clear. It has been suggested on the basis of a gravity high (Lonsdale & Ingall, 1965) that a concealed crystalline basement ridge extends from the Mount Painter area towards the Peake and Denison Ranges, northwest of the survey area.

The two main subdivisions of Mount Painter rocks are the Radium Creek Metamorphics (about 7500 m thick), which include quartzite, schist, phyllites, and porphyritic rhyolite, and the Older Granite Suite which consists mainly of intrusive granite (Fig. 16). The latter has been dated at 1500 to 1600 m.y. (Compston et al, 1966, p. 236).

Coats et al (1971) considered that the structure of the granites in the southern inlier is essentially laccolithic. Younger granite and pegmatites thought to be of Ordovician age intrude both the Radium Creek Metamorphics and the Older Granite Suite.

The Adelaide Geosyncline. The name Adelaide Geosyncline has been applied to the area in which a thick sequence of strongly folded Cambrian and Adelaidean sediments (560 to 1400 m.y.) are preserved. It has yet to be proved that the name 'Geosyncline' is appropriate. Evidence of deep faulting, possibly associated with mobile basement blocks, suggests that the Adelaidean sediments were deposited on a number of foundering basement blocks in a widening rift (Dalgarno & Johnson, 1965; Thomson, 1970).

The true extent of the Adelaide Geosyncline is unknown. Thomson (1970) has placed the western boundary on a complex fault structure called the Torrens Hinge Zone (Fig. 4). This boundary separates the more complete stratigraphic record of strongly folded Adelaidean sediments to the east from the incomplete record of flat-lying sediments to the west. Faults of the hinge zone are typified by the near-normal Ediacara Fault, which extends along the west side of the Flinders Ranges from the Norwest Fault to near Port Augusta (Johns, 1968; Binks, pers. comm).

Whether a thick sequence of folded Adelaidean sediments underlies the younger sediments of the Frome Embayment and Murray Basin is a matter for conjecture. Drilling has penetrated Palaeozoic sediments in both areas, for example, Cambrian at 80 m, near Curnamona Homestead (Daily, pers. comm.), and Permian at 1000 m in the Renmark Bore (Ludbrook, <u>in</u> Parkin, 1969) 80 km south of Canopus (Fig. 5). Strong linear magnetic anomalies in the north of the Murray Basin may indicate that a thick sequence of folded Adelaidean sediments is preserved under the younger cover rocks.

The extent of Adelaidean sediments under younger cover rocks north of the Mount Painter Block is unknown.

It is thought that the rocks underlying the Adelaidean sediments are similar to those observed on the Gawler Craton, Willyama Block, and the Mount Painter Block. Accordingly, Thomson (1970) has prepared a map showing basement form lines for the Adelaide Geosyncline using stratigraphic thicknesses and some aeromagnetic evidence (Fig. 4). While depth estimates to the basement on geological grounds may be valid, it has yet to be shown that depth estimates to magnetic basement correspond to the thickness of Adelaidean sediments. It is considered that the depth to what may be a transition zone from Adelaidean to Australian Shield rocks could vary quite markedly from the form lines proposed by Thomson.

Sedimentation

<u>Adelaidean age</u> (Upper Proterozoic). As exposure in the Flinders Ranges is exceptionally good, the succession of Adelaidean sediments has received international recognition as a record of a part of Precambrian time. Isotopic dating is sparse, but systematic mapping has shown a number of persistent regional marker beds which may be time-significant. Figure 6 (after Thomson, <u>in</u> Parkin, 1969) shows a recent summary of the presently recognized Adelaidean time and rock terms. Thickness and density variations of the sediments are important to the gravity interpretation and so a brief account of the stratigraphy is included here.

The oldest recognized sediments are the Lower Callanna Beds known to be 4500 m thick east of the Paralana Fault. Although consisting mainly of quartzite and altered dolomites, they are characteristically associated with the basic Wooltana Volcanics which range from 600 to 2500 m thick near Mount Painter (Coasts & Blissett, 1971, p.55). These are the only volcanics recognized within the great thickness of Adelaidean sediments and are only known in the Mount Painter area. Whether they underlie the central part of the Adelaidean Geosyncline is unknown. The Upper Callanna Beds, up to 2000 m thick, are essentially a deep-water sequence dominantly of carbonate-siltstone facies.

The Callanna Beds are overlain by the Burra Group which attains a maximum thickness of 6000 m in the west of the Adelaide Geosyncline. This groups marks a major sedimentary cycle commencing with a clastic unit, followed by carbonate siltstone, and terminated by a shallow-water clastic unit.

In the Umberatana Group, which reaches 9000 m in thickness, two ice ages are recorded. Sedimentation began with a tillitic sequence, the Yudnamutana Sub-group, up to 5500 m thick near Mount Painter, succeeded by a non-glacial shallow marine succession, the Farina Sub-group, and then terminated with a tillite in the Yerelina Sub-group.

The uppermost unit of the Adelaidean sequence is the Wilpena Group, which shows a cyclic character commencing with a carbonate-sandstone-siltstone sequence, followed by shallow-water siltstones, and terminated by a carbonate-sandstone sequence. The group reaches a thickness of 5000 m in COPLEY but shows a progressive decline in thickness to the south (e.g. 3500 m in ORROROO) and west.

Variations in thickness of sediments indicate that the axis of the geosyncline migrated eastwards as sedimentation proceded during Adelaidean time. The total stratigraphic thickness may exceed 20 000 m.

Palaeozoic Era. Cambrian rocks are well exposed in the central part of the northern Flinders Ranges. A great thickness of Lower Cambrian sediments, the Hawker Group, was laid down in the Adelaide Geosyncline. They are characterized by frequent changes in both thickness and facies, and include massive limestone, siltstone, shale, and greywacke. Lake Frome Group sediments were then laid down, forming a clastic sequence more than 3600 m thick.

Little is known of the Cambrian sediments underlying the Recent cover of the Frome Embayment. It has been suggested that they indicate a link with the Cooper Basin to the north.

Petroleum search activities and hydrology studies have contributed to the understanding of sedimentation in the basinal areas surrounding the Flinders Ranges. Most is known in the area of the Great Artesian Basin to the north of the survey area, where for example some 500 m of Palaeozoic sediments are buried beneath more than 2000 m of Mesozoic and younger sediments (Moomba No. 1 drillhole; Wopfner, in Parkin, 1969, p. 145). The thickness of Palaeozoic sediments in the north of the Murray Basin is unknown.

Mesozoic and Cainozoic Eras. Mesozoic sediments are present in the Great Artesian and the Murray Basins. In the Great Artesian Basin they thin southwards from about 2000 m at the Moomba gas field to less than 300 m east of Maree and near Lake Frome (Wopfner, in Parkin, 1969, p. 157). In the Murray Basin, 300 m of Cretaceous sediments were penetrated below 540 m in the Renmark Bore. Farther north the depth and thickness of the Mesozoic is unknown.

Substantial thicknesses of Tertiary and Quaternary sediments are known in the Murray, Pirie-Torrens, and Willochra Basins. In the Murray Basin, the Canopus bore (Ludbrook, in Parkin, 1969, p.178) was still in Palaeocene sediments at 290 m. In the Pirie-Torrens Basin a stratigraphic drill hole in Lake Torrens was still in Mesozoic sediments at 300 m (Johns, 1968), and a total thickness of 150 m was found east of Melrose in the Willochra Basin (O'Driscoll, 1956).

Intrusives

Diapirs. Breccia zones, considered by Dalgarno & Johnson (1965) to be diapiric structures, are common in the Flinders Ranges (Fig. 7). Although the structures have affinities with salt doming, evaporites are not recognized in the clastic breccia, which often appears to be composed of the lowest recognized Adelaidean sediments (Callanna Beds). Plugs, dykes, and blocks of dolerite and other basic igneous rocks are common in the diapiric breccia. Carbonatites occur in the Walloway Diapir 16 km north of Orroroo (Tucker & Collerson, 1972). The mechanism for initiating the diapirs is not clear, although they commonly lie in the core of anticlines.

Thomson (1970) supposed that they lie over the deepest part of the geosyncline and showed that they follow a strong northerly trend. The diapirs appear to be influenced by the north-northwest-trending and northeast-trending surface faults evident in the area. Dalgarno & Johnson (1965) suggested that the diapirs lie near basement faults.

Granites. On the eastern side of the Adelaide Geosyncline the Mount Painter Granites, the Anabama Granite, and the Murray Bridge and Palmer Granites (south of the survey area) form a north-south lineation. This line-up may indicate some deep-seated structural relationship between them.

Geological sketch maps of the Mount Painter and Anabama Granites are combined with the geophysics in Figures 16, and 20 respectively. The geology of the Mount Painter Granites has been discussed earlier.

The Anabama Granite, which is exposed on the southern limb of an anticlinal structure of strongly magnetic Adelaidean sediments, appears as an area of scattered outcrop about 11 km wide by 40 km long. Some contacts appear to slope outwards beneath Adelaidean rocks (Mirams, 1961). The granite has been dated at 473 m.y. (Compston et al, 1966). It is considered to be of Ordovician age and was probably emplaced late in the orogeny which folded the enclosing Adelaidean sediments.

Economic Geology

Mineralization. A feature of the Adelaide Geosyncline is the widespread occurrence of secondary copper, lead, and gold. Throughout the Flinders Ranges there are many small, abandoned, or intermittentently worked mines. Some of the copper mineralization appears to be associated with pyritic shales (e.g. the Tindelpina Shale) and some with diapiric structures (Coats, 1964). The origin of the copper is obscure, but on a map showing the distribution of copper and other mineralization there seems to be a number of prominent line-ups of the mineral occurrences, for example from Burra to Mount Gunson (Fig. 9). It has been suggested that these trends delineate a regional fracture system (Thomson, 1965).

There is localization of gold mineralization in OLARY and the east of ORROROO and BURRA. This area approximately corresponds to that in which the Adelaidean sediments are strongly magnetic (Tucker, 1972). To the north there is localization of gold mineralization across the northern part of COPLEY and in a small area at the boundary between COPLEY and PARACHILNA. Lead mineralization follows a similar distribution to gold in OLARY, ORROROO, BURRA, and COPLEY, but in PARACHILNA it appears more widespread than gold.

A number of sub-economic iron deposits within the Adelaide Geosyncline occur predominantly in the lower tillite of the Umberatana Group and the iron is variously named the Holowilena Ironstone or the Braemer Ironstone. A reserve was reported in northwest CHOWILLA of 300 million tonnes of quarryable ore comprising hematite, martite, and magnetite, with an average grade of 30 percent iron (Whitten, 1970). The iron appears to be of sedimentary origin.

The mineral potential of the Gawler Craton is largely untested, although significant Precambrian iron ore deposits are found in the Middleback Ranges (PORT AUGUSTA) and farther west at Warramboo.

Uranium has been found in both the Mount Painter Block and the Willyama Block. In the Mount Painter area, granites and metasediments are largely barren, but uranium is found in breccia pipes or in fractures near the unconformity with the Adelaide system (Coats et al, 1971). In the Willyama Block about 900 tonnes of uranium oxide was recovered from the Radium Hill Mine, now abandoned. Several smaller deposits are known, among them Crocker Well which is about 100 km northwest of Radium Hill.

Hydrocarbons. The natural gas fields of Gidgealpa, Moomba, Daralingie, and Toolachee are located on domes in Permian sands of the Cooper Basin, which is north of the survey area within the Great Artesian Basin. It is thought that flushing by waters of the Great Artesian Basin may have reduced the hydrocarbon potential of the CURDIMURKA, MAREE, and CALLABONNA areas (Wopfner pers. comm.). Exploration in the Frome Embayment is at an early stage. In the Murray Basin, exploration for hydrocarbons has not been fruitful although Permian sands are known.

The potential of the Pirie-Torrens Basin is largely untested. Drill holes in the northeast corner of PORT AUGUSTA (Wilkatanna area) passed deep into Cambrian sediments but no significant hydrocarbon shows were encountered (Johns, 1968).

3. PREVIOUS REGIONAL GEOPHYSICAL SURVEYS

Aeromagnetic Surveys

There are total field aeromagnetic contour maps for the 15 Sheets of the area (Table 1). Except for parts of PORT AUGUSTA and WHYALLA, which were flown at 450 m above ground level, the surveys were flown at 150 m above ground level on lines 1.6 km apart, in an east or west direction. In part of OLARY the lines were flown north-south.

TABLE 1

AEROMAGNETIC AND RADIOMETRIC SURVEYS FOR GOVERNMENT AGENCIES

MAP AREAS	MAGNETICS	RADIOMETRICS	REFERENCE
CURDIMURKA COPLEY	Yes	Yes	Young & Gerdes, 1966
MAREE CALLABONNA FROME	Yes		Milsom, 1965
ANDAMOOKA TORRENS	Yes	Yes	Young, 1964
PARACHILNA ORROROO	Yes	Yes	Tipper & Finney, 1966

TABLE 1 (Cont'd)

MAP AREAS	MAGNETICS	RADIOMETRICS	REFERENCE
CURNAMONA	Yes		Wells, 1962a
OLARY	Yes	Yes	SADM Map
CHOWILLA	Yes	Yes	Young, 1963
PT AUGUSTA	Yes	No	SADM Map, 1969
WHYALLA	Yes	Yes	SADM Map, 1965
BURRA	Yes	Yes	Wells, 1962b

Of most relevance to the interpretation of the gravity data are the depth estimates to magnetic basement, and the trend directions of magnetic anomalies (Fig. 10).

The crystalline basement complexes show a complexity of strong magnetic anomalies commonly associated with metamorphic terrains. In the east of the Eyre Peninsula in WHYALLA, strong shallow-source magnetic anomalies trend northward (Middleback Ranges) while in PORT AUGUSTA and TORRENS they trend northwest. The northwest-trending anomalies are probably caused by dolerite dykes and appear to delineate a major fracture system (D. Boyd, University of Adelaide, pers. comm.). This fracture pattern is visible in aerial photographs over the Adelaidean sediments in north of PORT AUGUSTA. The age of the dykes is unknown.

Metasediments of the Mount Painter and Willyama Blocks have strong magnetic response. The most common trends over the Willyama Block are east and north, while over the smaller Mount Painter Block magnetic anomalies trend northeast following the mapped outline of Pre-Adelaidean metasediments. Broad magnetic anomalies between the Mount Painter and Willyama Blocks may indicate a continuity of Pre-Adelaidean material between these two units beneath a cover of Adelaidean and younger sediments. Broad magnetic anomalies in the east of PORT AUGUSTA and over much of TORRENS, ANDAMOOKA, and CURDIMURKA can be similarly interpreted. Along the middle of MARREE, COPLEY, PARACHILNA, ORROROO, and BURRA, anomalies which might be attributed to deep sources are usually weak and very broad. The half widths of the anomalies commonly exceed 30 km. Over much of BURRA, ORROROO, and OLARY, the Adelaidean sediments are strongly magnetic. Short wavelength anomalies tend to obscure broad anomalies which might be attributed to deep sources. Shallow-source anomaly trends closely follow the outcrop of mapped formations. The question is raised as to whether aeromagnetic depth estimates can give a thickness for the folded Adelaidean sediments in the Adelaide Geosyncline. Depth estimates made by various BMR authors (Young, 1964; Milsom, 1965; Young & Gerdes, 1966; Tipper & Finney, 1966) are shown in Figure 10.

Although contoured in the original reports, the estimates are not contoured here because it is considered that presentation of spot estimates is better for general reference in this report.

It is possible that Adelaidean sediments underlie younger sediments for much of the northern part of the Murray Basin (e.g. in CHOWILLA). Linear magnetic anomalies similar to those over Adelaidean sediments in OLARY, ORROROO, and BURRA are seen in the area. Estimates of depth to magnetic sources have not been reported for CHOWILLA, but a preliminary examination of aeromagnetic maps indicates that some sources are no deeper than 2 km.

Gravity Surveys

Bouguer anomaly contours from previous surveys surrounding the present survey area have been combined in Figure 8. The Bouguer density used in the reduction of data was 2.67 g/cm^3, except as shown in the figure.

The interpretation of the present survey includes discussion of the published results of these regional surveys. Table 2 shows the availability of data as 1:250 000 scale maps.

TABLE 2

GRAVITY SURVEYS

AREA	TYPE	REFERENCE	REPORT
MARREE	Helicopter	Delhi Aust. Pet. PSSA Report 1964/4811, 1964/4812	Strezelecki Creek and Lake Gregory gravity survey
CALLABONNA	"		
FROME	"		
CURNAMONA	"		
CURDIMURKA	"	SADM 1969	
ANDAMOOKA	"	" "	
PORT AUGUSTA	"	" "	
TORRENS	"	" 1968, 1969	
WHYALLA	Ground	" 1969	
BURRA	"	" 1967	
CHOWILLA	"	" 1956	

Mumme (1961) reported on a gravity survey across the Blinman Diapir (Fig. 7). He found that a Bouguer gravity low of 8 mgl over the structure could be caused by a breccia block with a density of 2.45 g/cm^3 between the surface and 2000 m within Adelaidean rocks having a density of about 2.62 g/cm^3.

4. DISCUSSION OF DENSITY DATA

It is of fundamental importance to have density data from an area in which an interpretation of gravity data is attempted. For the interpretation of individual gravity anomalies, the essential quantity required is a density contrast between the source body and country rock.

Densities of rocks in an area may be found by direct or indirect measurements.

Density Determination

Direct Measurement. A common method to determine the specific gravity of a solid sample is to weigh it in air and also while suspended in water. The density is assumed equal to its specific gravity for the purposes of this report. If samples are very porous, water soaks in during the second measurement. The upthrust is thereby reduced and thus the density measured is higher than true for the dry rock. A better method for porous rocks is to calculate their volume from the sample dimensions. The effect of interstitial filling is discussed later.

The density of a lithological unit can be deduced by taking a simple statistical mean of observations on a large number of representative specimens, say about 100.

The density of the rock depends on its composition and porosity. Thus a porous siltstone at the surface will have a lower density than at great depth where it is more compacted (Grant & West, 1965) or contains a dense interstitial filling. Weathering of rocks at the surface commonly reduces their density. Some minerals are weathered out and leave open interstices. However, in special cases weathering can increase the density. For example a porous sandstone can become silicified or have its pores filled with iron oxides. Thus the selection of rocks suitably representative of a lithological unit is difficult and the interpretation of the density measurements is even more difficult. The usual method is to collect specimens from the surface outcrops or from drill cores which seem solid and from field experience appear typical of rocks in the area. A dry density can then be measured and corrected for porosity and weathering effects to give an estimated bulk density - i.e. the density of unweathered rocks in place at depth. The true density of the unweathered rock in place (assuming weathering has caused no volume change) can be calculated from the following equation:

$$D = D_0 + D_2 \frac{V_2}{V} + D_3 \frac{V_3}{V}$$

where D is the true bulk density of the sample with total volume V.
D_0 is the dry, bulk density measured for the weathered rock.
D_2 is the density of water normally present with volume V_2 in the unweathered rock.
D_3 is the density of solid filling with volume V_3 now replaced by voids in the weathered sample.

Experimental studies (Woollard, 1959) show that for crystalline rocks collected at the surface, the elimination of an initial porosity of 3 percent (or less) by pressure can be exactly offset by thermal expansion at great depth. Within the scope of present knowledge it appears that a corrected density estimate made for surface specimens of well compacted rock with few voids may also be valid at depth (e.g. 5 km). For gravity interpretation, detailed studies of porosity and interstitial filling are only necessary if a very small density contrast exists between the lithological units of interest. Although porosity studies may have assisted in the analysis, only dry bulk density measurements were taken for this report.

Indirect Measurement. A simple approximate method to measure density of rocks at the surface is that of Nettleton (1942). Bouguer gravity profiles are drawn for various Bouguer densities and the profile which shows least correlation with the local topography gives the approximate density of the underlying rocks. This method assumes that the gravity is measured on the ground and that rocks are of uniform composition along the profiles. Nettleton advocated the use of the method for special cases where it could be assumed that the surface density is uniform. The method should also be valid on a regional scale if suitably large topographic relief is crossed. In the Adelaide geosyncline, this condition applies (Plate 1) and the underlying rocks are reasonably uniform in character. Therefore the method should give a good estimate of average surface density.

In special cases such as those discussed by Al-Chalabi (1971) where the shape of the source is known, a full solution of a gravity anomaly, including calculation of density contrast, can be achieved by optimization techniques. Density contrasts also can be established by studying the gravity field at lithologic boundaries.

Where seismic P wave velocity data are available, use can be made of the relation between velocity and density (Drake, in Grant & West, 1965, p.200; Woollard, 1959). Drake's graph shows seismic velocity plotted against densities obtained for a large number of core samples from a range of depths and from widely distributed points. The least squares fit to the scattered data points allows an estimate of density to be made for a given velocity.

Previous density determinations in South Australia. No unified discussion of densities of Adelaidean sediments and the metamorphic basement complexes has ever been reported, although measurements applicable to a number of localities have been made by various authors.

Rock types

The rocks important to the survey area are discussed in relation to rock density under three tectonic classifications: Adelaidean sediments, metamorphic basement rocks, and intrusives into Adelaidean sediments.

Adelaidean Sediments. For the purpose of the study the Adelaidean sediments are considered as four types:

1. Carbonates (dolomites, limestones and intermediate members);
2. Siltstones and calcareous siltstones;
3. Shales (argillaceous rocks); and
4. Quartzites (includes siliceous tillites).

The sediments of Cambrian age in the Adelaide Geosyncline can be similarly classified except that tillites are absent. It is likely that their average density is close to Adelaidean density, and for this report the two are taken in common.

Metamorphic Basement Rocks. Rocks of the metamorphic basement complexes (Willyama Block, Mount Painter Block, Gawler Craton) are considered in two groups:

1. Metasediments (including schists, quartzites, sandy metasediments, dolomites, gneisses, and iron formations); and
2. Extrusive and intrusive acid igneous and related rocks.

Intrusives into Adelaidean Sediments. For the purpose of this study only the Anabama Granite and diapiric breccia are considered.

Density of Adelaidean sediments

Direct Measurement. It is important to establish the weathering state of sediments before discussing their density. Magnetic data (Tucker, 1972) indicate that Adelaidean sediments are commonly magnetically weathered from the surface to about 100 m. Moreover, the outcrop of magnetic beds is often non-magnetic. Similarly, it is likely that the density of surface rocks differs from their unweathered equivalents.

TABLE 3

DENSITY OF ADELAIDEAN HAND SPECIMENS

Lithology	No. of Samples	Dry Density Mean (g/cm^3)	Standard Deviation	Range (g/cm^3)	Dry density Mode (g/cm^3)	Estimated 80% Confidence Limits (g/cm^3)	Average Densi- from Publicatio (g/cm^3)
Carbonates	21	2.76	.07	2.65-2.88	2.78	2.68-2.85	2.74 (marble) - 2.90 (Transvaal dolomite)
Siltstones & Calcareous Siltstones	47	2.63	.12	2.31-2.82	2.72	2.6-2.8	-
Shales	38	2.58	.15	2.18-2.81	2.68	2.6-2.8	2.8-2.85 (shales slates-Lower Wit watersrand Syste
Quartzites	15	2.63	.05	2.54-2.72	2.62	2.55-2.70	2.63-2.66

* Data from Smithson (1971), p.692, and Roux (1969), p.431

Ideally, the study of the density of fresh core samples from a number of deep drill holes in a number of localities is required to establish average density values for the various lithologic units. A comprehensive study would require the close attention of a stratigrapher to classify the rock types and a petrologist to determine what alteration has occurred. Furthermore, to produce representative densities for the stratigraphic units, detailed measurements of lithologic thicknesses are required.

One of the authors (D.H.T.) undertook a limited study of densities of 170 hand specimens collected from widely distributed points in the Adelaide Geosyncline. The hand specimens were selected because of their solid, non-porous appearance. Any which bubbled on immersion in water were discarded. Dry, bulk densities were determined by the upthrust method. Histograms of density for various lithologies in the Adelaidean section are shown in Fig. 11 and summary statistics in Table 3.

The density histograms (Fig. 11) all show a wide scatter of measured values indicative of variations of composition and the condition of weathering of the samples. Histograms A and D show that the range of densities measured for carbonates and quartzites is limited, while histograms B and C show a low density tail and the distributions are distinctly skewed. Thus for carbonates and quartzites the mean is very close to the mode while for siltstones and shales the mean and the mode are widely separated. It is considered that the low density tails of siltstones and shales may be attributed to higher porosity for those samples, and that the dry bulk density of solid specimens lies close to the mode rather than to the mean of distributions.

An estimate of the average density of the Adelaidean sedimentary section taken as a single unit composed of the four individual lithologies is shown in Table 4. Densities of each lithologic unit are weighted according to their proportionate thickness in the section.

TABLE 4

AVERAGE DENSITY OF THE ADELAIDEAN UNIT

Lithology	Estimated % of Section*	Dry Density Mode (g/cm^3)
Carbonates	7.5	2.78
Siltstones & Calcareous Siltstones	39.0	2.72
Shales	9.5	2.68
Quartzites	44.0	2.62
	Average Density	2.68 g/cm^3

*Approximate percentages for COPLEY calculated by R. Coats, Department of Mines, South Australia (pers. comm.)

The data give an average dry bulk density of 2.68 g/cm^3 when the modes of the density distributions are used. This probably represents a minimum value of true density as defined previously. If, for example, the porosity averages 1 percent but is replaced at depth by material with a density of 2.65 g/cm^3 then the true density would be 2.71 g/cm^3.

Indirect Measurement. Topographic profiles were drawn on 13 east-west lines crossing the highest topography of the Adelaidean sediments (Plate 1). Bouguer gravity profiles were calculated for each line using densities in the range 2.0 to 3.0 g/cm^3. The correlation was studied, and the Bouguer density appropriate to each profile determined (Table 5). An average of the density estimates yielded a value of 2.73 g/cm^3.

TABLE 5

DENSITY ESTIMATES FROM DENSITY PROFILES

Profile Latitude	Density
30°4'	2.7
30°15'	n.e.
30°31'	n.e.
30°46'	2.7
31°2'	3.0
31°14'	n.e.
31°29'	2.7
31°45'	2.6
32°0'	2.6
32°16'	2.8
32°31'	n.e.
32°47'	n.e.
32°58'	n.e.

Mean density = 2.73 g/cm^3

n.e. = no estimate made because of low topography or influence from granites

In Chapter 6 it is suggested that in the area of high topography between 30° and 31°30' the Adelaidean sediments may be underlain by a high-density block. Thus the Bouguer gravity profile chosen to have least correlation with the topography may give a maximum estimate of density.

Earthquake data for South Australia (Table 6) indicate that in the area occupied by the Adelaide Geosyncline the seismic P wave velocity is 6.25 (± 0.03) km/s. Furthermore, there appears to be virtually no vertical velocity gradient from near the surface to the bottom of the crust, at 38 km (Stewart, pers. comm.). Densities calculated with three velocity relations (Woollard, 1959: Drake, <u>in</u> Grant & West, 1965, p200) give three different answers (Table 6, viz. 2.70, 2.75, and 2.86 g/cm^3).

TABLE 6

DENSITY ESTIMATES FROM SEISMIC P WAVE DATA

Area	Crustal Thickness km	Velocity km/s	Density g/cm^3) A	B	C
Adelaide Geosyncline	38	[1]6.25 ± .03	2.75	2.86	2.70
Gawler Craton	38	[2]6.3	2.77	2.89	2.72

1. Seismic data from I.C.F. Stewart, Physics Department, University of Adelaide, 1972 (pers. comm.).
2. Seismic velocity from Doyle & Everingham (1964).

A. Velocity to density conversion using data from Drake (unpubl.) <u>in</u> Grant and West (1965), p.200. For rocks of many lithologies under surface conditions.
B. Velocity to density conversion using data from Woollard (1959), p. 1530. For crystalline rocks under surface conditions.
C. Velocity to density conversion using data from Woollard (1959) derived from references <u>in</u> Birch (1942). For rocks at a depth of 8 km or greater.

The seismic P wave velocity to density conversions give equivocal results and any of the values so obtained might be a valid estimate of the average density of Adelaidean sediments. The lack of a crustal velocity gradient in the Adelaide Geosyncline may indicate that this crustal material has a constant density as if composed entirely of Adelaidean sediments. However, experimental work indicates that different rock types under different pressure conditions can have the same velocity but a higher density (Woollard, 1959). Thus it does not necessarily follow that constant crustal velocity implies constant crustal velocity implies constant crustal density.

Density of metamorphic basement complexes

Direct Measurement. The various lithologies present in the metamorphic basement complexes of South Australia have never been systematically studied with a view to compiling density data.

The limited data available from previous determinations for the east side of the Gawler Craton are presented in Table 7. Results of the testing of rock densities on the Gawler Craton by the S.A.D.M. and The Broken Hill Co. Pty Ltd have been tabulated by Taylor (1964). Measurements have also been made by Gunn (1967) on the Middleback Quartzites (containing 30% iron) and on other metaquartzites in the Middleback Ranges. Direct measurements on 54 specimens from 10 core holes in the Broken Hill area (Broken Hill South Ltd, Russell, pers. comm.) are the only data available for the Willyama Block (**Table 8**). No density measurements are available for rocks of the Mount Painter Complex.

TABLE 7

DENSITY ESTIMATES FOR GAWLER CRATON

Rock Type	BHP, SADM & Gunn Results for the Middleback Ranges Density (g/cm^3)	Average Densities from Smithson (1971) and texts
Schist	2.4 - 2.6	2.65 - 2.85
Gneiss	2.4 - 3.0	Granite gneiss 2.57-2.82 Other gneiss 2.65-2.98
Amphibolite	2.7 - 3.0	2.85 - 3.20
Jaspilite	3.0 - 3.5	-
Quartzite	2.5 - 2.8	2.62 - 2.70
Granite	-	2.63 - 2.70

TABLE 8

DENSITY ESTIMATES FOR WILLYAMA BLOCK

Rock Type	Broken Hill South Results n	(g/cm^3)	SD	Range	Average Densities from Smithson (1971)
Garnet rich biotite & sericite schists & gneisses	14	2.88	.14	2.67-3.15	-
Biotite & sericite schists & gneisses	9	2.71	.03	2.66-2.77	2.66-2.88 (for biotite gneiss and schists)

One of the authors (D.H.T.) measured the dry density of four surface samples for the extrusive Gawler Range Volcanics. Flow-banded rhyolite gave the values 2.47 and 2.48 g/cm^3 and massive feldspar porphyry gave the values 2.58 and 2.60 g/cm^3. The mean of these densities is 2.53 g/cm^3. With so few measurements available it is valid to round this value to 2.55 g/cm^3.

The data, except for the Gawler Range Volcanics, have a close correspondence with the density data of Smithson (1971), although the measured density of schist of the Middleback Ranges falls outside this range. It is possible that the low value for schist is the result of using weathered samples.

There is no reason to doubt that the densities of most lithologies and of the general metamorphic terrains around the Adelaide Geosyncline agree substantially with those discussed by Smithson (op. cit.). He considered that average densities for metamorphic terrains fall in the range 2.70 to 2.79 g/cm^3. Intrusive and extrusive bodies of granitic composition probably have densities below 2.70 g/cm^3.

Indirect Measurement. The atomic blasts at the Maralinga test site in South Australia gave an opportunity to test the seismic velocity of the crust in the area of the Gawler Craton. The results of Doyle & Everingham (1964) indicated a crustal P wave velocity of 6.3 km/s (no error bounds stated). Densities calculated with three velocity-density relations give three different answers viz. 2.72, 2.77 and 2.89 g/cm^3 (Table 6).

The southwestern side of the Willyama Block provides a unique opportunity to test for a density contrast between metamorphic rocks of that basement complex and Adelaidean sediments. The Adelaidean sediments are overthrust by the metasediments of the Willyama Block (Fig. 5). However, in the Bouguer anomaly data (Fig. 8) there is no marked gradient across the northwest end of the contact; the maximum gravity difference is only 2 mgal. In the gravity data, the southeast end of the contact is not defined, possibly because of the strong influence of the gravity low associated with the Anabama Granite. Moreoever, the most significant gradient occurs along a northeast trend traverse to the contact. It is suggested that the average density of rocks in the northwest part of the Willyama Block is lower than in the southeast. From the data available it seems inappropriate to assign a value.

The absolute values of density derived from the seismic P wave velocities are equivocal. Rather than the density values derived, the actual velocity measured is of particular significance. It is almost identical with that derived for the crust in the area of the Adelaide Geosyncline. Thus the average density of rocks of the Gawler Craton and the Adelaide sediments may be the same.

Lack of a substantial Bouguer gravity gradient across the contact between Willyama Block metasediments and Adelaidean sediments indicates that their average densities also may be very nearly the same. If the thickness of Adelaidean sediments close to the Willyama Block is 2000 m, then a density contrast of .02 g/cm^3 (Adelaidean sediments less dense) would account for a 2 mgal change across the contact. The occurrence of both Bouguer gravity highs and lows over the western part of the Willyama Block indicates that no single value for density can be assigned.

Density of intrusives

Direct measurement of granite. Density measurements were made by one of the authors (D.H.T.) on 194 samples of core from three drill holes into the Anabama Granite (drill logs, in Hoskin, 1970 unpubl.), the deepest of which reached 140 m. Samples were taken at a regular interval over the length of each core; 3 m in two cores and 1.5 m in the third. Density logs are shown in Figure 12.

The densities obtained for depths less than 30 m were mainly low values attributable to weathering of the granite. The arithmetic mean density of samples below 30 m was 2.65 g/cm^3 (S.D. .09 g/cm^3, number of samples 167), and the geometric mean is 2.67 g/cm^3. It was noted that in DDH AN2 the density values apparently increase linearly with depth below 30 m down to the bottom of the core. If the linear increase of density with depth can be attributed to reduction of pore space, then it is likely that the true density of unweathered, solid granite at depth is no less than 2.65 g/cm^3 and probably close to 2.70 g/cm^3.

Direct Measurement of Diapiric Breccia. Little density information is available for diapiric breccia. Mumme (1961) measured densities of hand specimens from the Blinman Dome Diapir and calculated a mean of 2.45 g/cm^3. Measurements by the S.A.D.M. on drill core from the Lyndhurst Diapir gave densities in the range 2.1 to 2.4 g/cm^3 for drill hole LYD3, and 2.45 to 2.8 g/cm^3 for drill hole LYD5 (Figs. 7 and 13).

Conclusions

The Bouguer anomaly field over metamorphic basement complexes shows a number of negative anomalies attributable to granitic bodies. It is likely therefore that the lower density limit of rocks of the basement complexes is at least as low as that for granite. Because measurements on the Gawler Range Volcanics gave an average density of 2.55 g/cm^3, the lower limit has been set at 2.55 g/cm^3. An upper limit is difficult to establish because there are so few data available. There is a general conformity of densities of various metamorphic lithologies with those established by Smithson (1971). Therefore it is considered likely that his upper limit of 2.79 g/cm^3 for metamorphic terrains applies to the metamorphic complexes in the area.

Individual lithologies within the Adelaidean sediments have average densities which differ by up to 0.16 g/cm^3. Therefore it is to be expected that detailed gravity surveys will allow some of the mapped formations (often essentially of a single lithology of 1000 m thickness) to be traced below the surface.

Because Adelaidean sediments of different lithologies are essentially 'mixed' by the tight folding in the Adelaide Geosyncline, they correspond to a single geological unit for the interpretation of regional Bouguer anomaly data. However, stratigraphic mapping of the Adelaidean sediments shows that great changes in the thickness of individual lithological units are common throughout the Adelaide Geosyncline. Therefore the average density of the 'single geological unit' will certainly vary from place to place. Moreover the changes might fall outside the range established in this report (2.68 - 2.73 g/cm^3). For ease of discussion, the 'single geological unit' composed of Adelaidean sediments will later (Chapter 6) be referred to as the 'Adelaidean Sedimentary Unit'.

Because the average density of the Adelaidean sediments lies within the range of densities for the metamorphic basement, the Bouguer anomaly field cannot be directly interpreted to give depth to basement.

From the data discussed in this chapter, the average true densities of the three important rock groups probably lie within the following limits:

Granitic intrusions	2.65 to 2.70 g/cm^3
Adelaidean sediments	2.68 to 2.73 g/cm^3
Metamorphic basement	2.55 to 2.79 g/cm^3

5. DESCRIPTION OF THE BOUGUER GRAVITY FIELD

In accordance with previous BMR practice (Darby & Vale, 1969) of dividing the Bouguer anomaly maps into large provinces which exhibit distinctive characteristics, and the provinces into units which generally each comprise a major Bouguer anomaly feature distinct from others in the province, the area has been divided into three provinces and 20 units (Fig. 14). The provinces are named:

Diamantina Regional Gravity Shelf
Hawker Regional Gravity Complex
Arcoona Regional Gravity Complex

The units are numbered consecutively, 1 to 20. Some contain a single large anomaly, others a group of similar anomalies. A number of steep gradients are discussed in Chapter 7 as Bouguer gravity trends.

Provinces

The Diamantina Regional Gravity Shelf was named by Lonsdale & Ingall (1965) and the southern limit put on this province includes an arcuate Bouguer anomaly high (Units 1 and 3) which terminates the area of lows to the north. The Hawker Regional Gravity Complex (after the town in the Flinders Ranges) covers most of the survey area and includes highs and lows with an essentially northerly trend. This province covers most of the Adelaide Geosyncline and therefore is also a reasonable division of the gravity field on geological as well as geophysical grounds. To the west of the Hawker Regional Gravity Complex lies the Arcoona Regional Gravity Complex (after a station property) which contains Bouguer highs and lows trending northwest to northeast.

Units

Unit 1 (high). Unit 1 is a flat-topped high anomaly of about 5 mgal, which passes northwest out of the area and reaches the Peake and Denison Ranges. This high, together with Unit 3, was named by Lonsdale & Ingall (1965) the Muloorinna Gravity Swell, and is recognized as a southern termination of the lows over the Great Artesian Basin. Unit 1 appears to be related to Unit 7.

Unit 2 (low). This sharply peaked Bouguer gravity low, which reaches -40 mgal, lies over an area of Recent sedimentation of the Great Artesian Basin. Lonsdale & Ingall (op. cit.) considered it to be of different character from other negative anomalies in the north.

Unit 3 (low). Discussed with Unit 1.

Unit 4 (low). This northwest trending Bouguer gravity low shows a net amplitude of 20 mgal. Its northwest extremity lies over Lake Eyre South; from there it coincides with the Willouran Ranges and is finally truncated on the southeast by a marked northeast trend in COPLEY. The low contains several sharply peaked 10 mgal highs, all with the same northwest trend.

Unit 5 (low). This sharply peaked Bouguer gravity low, which reaches -20 mgal, lies directly over part of the crystalline basement in the Mount Painter region.

Unit 6. This unit of low gravity relief has a general northwest trend, but contains several local highs with northeast elongation.

Unit 7 (high). This is a broad area with a net positive gravity response, commonly 15 mgal above surrounding units, which has a northeast trend on COPLEY and swings to southeast on PARACHILNA. Unit 7 corresponds in a general way with the higher topography of the North Flinders Ranges.

Unit 8 (low). This broad, flat-bottomed Bouguer gravity low reaches -25 mgal and covers most of FROME. It appears to have continuity to the south with unit 11. Most of this area is covered by Recent sediments.

Unit 9 (high). This irregular, arcuate Bouguer gravity high encloses several sharp culminations of about 10 mgal. It passes from central TORRENS southwards into PORT AUGUSTA. The unit lies within an area (Units 10 and 17) of negative Bouguer gravity anomalies. The distinction of this unit within Unit 17 is unusual in the definition of unit boundaries and has been done in this case because it seems uncharacteristic of Unit 17. It may extend 50 km farther south than indicated.

Unit 10 (low). This broad, elongated, north-trending Bouguer gravity low, which reaches -40 mgal, coincides in a general way with the western margin of the Flinders Ranges. This coincidence is mainly restricted to ORROROO and BURRA. In PARACHILNA the gravity anomaly is still clearly evident over areas covered by a broad plain of Recent sedimentation (Lake Torrens). Unit 10 encloses Unit 13.

Unit 11 (low). This sharply peaked, north-trending Bouguer gravity low, which reaches -40 mgal, lies over areas of Recent, Adelaidean, and Pre-Adelaidean rocks; some of the Pre-Adelaidean rocks are granites.

Unit 12 (low). This unit, which lies over metasediments of the Willyama Block and Recent sediments, encloses several Bouguer gravity lows, one of which is sharply peaked with a net amplitude of -20 mgal.

Unit 13 (low). This -5 mgal net Bouguer gravity low within a low (Unit 10) lies over the Willochra Basin. The definition of this unit entirely within Unit 10 has been done in this case in order to distinguish the effect of a young, shallow sedimentary basin.

Unit 14 (low). This sharply peaked Bouguer gravity low, which reaches -40 mgal, lies directly over a granite mapped by the SADM as the Anabama Granite. The anomaly has a strong, northeast elongation and is therefore not in keeping with most units in the Hawker Regional Gravity Complex, which trend mainly north.

Unit 15 (high). This northeast-trending Bouguer gravity high reaches 15 mgal in the survey area, cuts across a number of geological boundaries, and covers areas of outcrop of Recent, Adelaidean, and Pre-Adelaidean rocks. The northwest boundary is not as well defined as the southeast, where it is clearly terminated by a steep gravity gradient. The prolongation of Unit 15 may extend into the Broken Hill area in New South Wales.

Unit 16 (high). This broad, flat-topped Bouguer gravity high, which locally reaches 5 mgal, lies over the Southern Flinders Ranges. It may be related to Unit 7. A saddle near the north boundary of ORROROO may represent the division from Unit 7.

Unit 17 (low). This Bouguer gravity low, which reaches -25 mgal, does not have well defined boundaries in either the north or the south. It may be related to Unit 10, but unlike Unit 10 it has no definite trend direction. Rocks outcropping here are Recent, Cambrian and Adelaidean. It largely encloses Unit 9, with which it seems to have no common characteristics.

Unit 18 (high). The character of Unit 18 becomes more evident west of the area, where a broad Bouguer gravity high of 5 mgal occurs. Rocks in the area are Gawler Range Volcanics and Pre-Adelaidean metamorphics.

Unit 19 (complex). This unit continues west of the area across Eyre Peninsula and contains a number of sharply peaked Bouguer gravity highs and lows. Several lows reach -20 mgal and these establish trend directions from north to northwest. Rocks of the area are Recent and Pre-Adelaidean.

Unit 20 (high). This Bouguer gravity high reaches 25 mgal, trends west but encloses a number of sharply peaked anomalies with a general north to northeast trend. Rocks of the area are Pre-Adelaidean.

6. INTERPRETATION OF UNITS

As the surface geology for the area covered by the helicopter gravity survey is known, a moderately detailed interpretation is warranted. Quantitative interpretation has been limited to the survey area but a qualitative interpretation is given for all units shown in Figure 14.

Neither terrain corrections nor isostatic corrections have been applied to the data, therefore the interpretations are of a preliminary nature. Nevertheless, the interpretations are considered to be substantially valid, because the terrain, although locally rugged, is broadly very gentle and not very high and surface density contrasts are small.

The quantitative interpretations were carried out using a C.D.C. 6400 computer, with programs written by one of the authors (D.H.T.), and one written by Trethewie (1971), which follows the method of Talwani (1965) for analysis using three-dimensional models. Where these anlyses were made, gravity values from all stations in a strip up to 15 km wide were projected onto a baseline and a linear profile was drawn through the points; thus local gravity effects were minimized. For three anomalies where this summing technique was particularly successful, models are given in this report. In other cases estimates of the thickness of sediments required to account for the anomalies were made using the simple slab formula (Parasnis, 1966, p.242).

General Observations

The gravity data from the present survey allow investigations of the large-scale structure of the Adelaide Geosyncline. However, the density data discussed in Chapter 4 indicate that the range of average densities for the metamorphic basement complexes is probably greater than for the Adelaidean sediments constituting the Adelaidean Sedimentary Unit. Thus, any model proposed for the Adelaide Geosyncline on the basis of gravity data must necessarily be complex.

About two-thirds of the area of exposed Adelaidean sediments has negative Bouguer gravity response (Fig. 15), characteristic of a thick, low-density unit overlying a denser gravity basement. It is important to test this model. The areas involved are Units 4, 10, 17, part of Unit 14 and the area between Units 14 and 10. The strongest negative response is along the centre of Unit 10 and it is possible that the Adelaidean Sedimentary Unit achieves great thickness here. A general level in this unit is -35 mgal despite the intense low in the northeast corner of BURRA. If a regional level of zero mgal is taken, together with a density contrast of -0.05 g/cm^3, the corresponding thickness of the Adelaidean Geosyncline is 16 500 m. Corresponding magnetic basement depth estimates by Tipper & Finney (1966) are approximately 8000 m. Similarly, in Unit 4 the thickness derived from gravity data could be 9500 m and in the area between Units 14 and 10, 5000 m. Over much of Unit 17 the thickness could be 9500 m. However, aeromagnetic depth estimates in Unit 17 (Fig. 9) suggest that magnetic basement is usually less than 1000 m deep.

If the depth estimates to magnetic sources indicate the true thickness of the Adelaidean Sedimentary Unit, then the gravity model is inconsistent with this. In this case, the basement underlying the Adelaidean Geosyncline may possibly contain low-density blocks (e.g. granite) which cause the gravity lows. Support for this is given by the fact that some rocks on the Gawler Craton are of low density (e.g. Gawler Range Porphyry); furthermore, some rocks in the northwest of the Willyama Block are of granitic composition and produce negative Bouguer anomalies.

The Bouguer gravity highs in Units 7 and 16 could be caused by a regionally higher density of the Adelaidean Sedimentary Unit or the underlying basement. Thomson's (1971) model (Fig. 4) indicates depth to basement of more than 10 000 m. Interpreted depth to magnetic basement is about 6000 m.

A great thickness of high-density Adelaidean sediments may occur in the area of Unit 15 beneath a thin cover of younger sediments (e.g. 2000 m). This is the opposite view to that indicated by Thomson (1971) (Fig. 4), who shows shallowing of the basement against the inferred Anabama Fault.

It seems likely that the total thickness of the Adelaidean Sedimentary Unit and overlying sediments is not great in the area of the Frome Embayment, although Thomson's model indicates the opposite. The magnetic pattern in this area shows similar north-trending directions to those on the north side of the Willyama Block. Depth estimates to magnetic basement by Milsom (1965) seldom exceed 3000 m. In addition, it is likely that the Bouguer gravity low of Unit 11 is caused largely by granitic rocks at shallow depth. The oldest materials found in the limited number of drill holes in the area are sediments of Cambrian age.

The thickness of the Adelaidean Sedimentary Unit under younger cover north of Mount Painter area is unknown. Thomson (1971) suggested rapid thinning onto the 'Muloorinna Ridge'. It is considered that neither the gravity nor magnetic data rule out the possibility of substantial basement depth both in the area of the 'Muloorinna Ridge' and northwards.

Units

Unit 1. Lonsdale & Ingall (1965) considered that this unit, together with Unit 3, may be caused by a high-density basement ridge buried under Palaeozoic or Adelaidean rocks. When interpreted, there was no defintion of the gravity field to the south. With the present information, it now appears that these units are expressions of minor variations in either density or depth of basement. Depth estimates to magnetic sources (Young & Gerdes, 1966) may indicate the top of the Adelaidean Sedimentary Unit but its thickness is undefined. The gravity field shows no clear evidence of shallow basement. Therefore neither gravity nor magnetic data rule out the possibility that a substantial thickness of Adelaidean sediments exists in the area of Unit 1.

Unit 2. Lonsdale & Ingall (1965) suggested that this low is caused by either low density 'basement' rocks near the surface or a local increase in thickness of Lower to Upper Palaeozoic sediments. The present authors favour the former suggestion and consider that the low is caused by a large, low-density intrusive beneath a relatively thin cover of Great Artesian Basin sediments.

There is a striking similarity between Units 2, 5, 11, and 14 which all lie in a north-south belt. Unit 14 encompasses an exposed granite intrusion, and Units 5 and 11 may also be caused by similar bodies. Regarding Unit 2, the aeromagnetic contour map of CALLABONA shows a half-circle of deep-source magnetic anomalies closely circling the northern and eastern sides of the gravity anomaly; these magnetic anomalies could well indicate the margin of a buried granite body. Granites are recognised by the SADM 35 km south of the gravity minimum of Unit 2 (Mount Painter Special 1:125 000 map Sheet) but their gravity response is weak. Possibly Unit 2 lies over the original source of some of the Mount Painter Granites.

Unit 3. This gravity high is probably caused by a buried topographic ridge of Pre-Adelaidean rocks near the surface. Estimates of depth to magnetic basement by Milsom (1965) are approximately 1000 m and it is believed that this corresponds to the depth to the top of the ridge. However, the remarks concerning Unit 1 apply also to Unit 3.

Unit 4. Part of this complex low lies over the Willouran Ranges; therefore, it seems that rocks of the types found in the ranges also extend to the northwest under younger cover. The southeast margin is too diffuse to justify a specific structural interpretation. Modelling suggests that the steep gradients on the southwest and northeast margins are probably caused by near-vertical faults. The southwest margin correlates with the geologically recognised Norwest Fault, which separates the Willouran Ranges (estimated density 2.68 g/cm^3) from younger Adelaidean and more recent sediments (estimated density range 2.2-2.65 g/cm^3) to the southwest. The negative anomaly is clearly not related to the density difference between these two rocks groups because it is if anything in the wrong sense. Possibly the general low is caused by a low-density block within the crystalline basement underlying the Adelaidean sediments. Possibly the Willouran Ranges represent a deep trough of Adelaidean rocks bordered at some intermediate depth, at least to the southwest, by more dense rocks of the metamorphic basement complex.

Unit 5. This low lies directly over part of the geologically recognised crystalline basement of the Mount Painter Block, which includes an anticlinal core of Pre-Adelaidean metasediments and granites (Fig. 16). The anomaly is mainly localized over this ellipse-shaped core, which shows successive intrusion by Older Granite Suite granites, probably laccolithic, and Palaeozoic granites and pegmatites.

No density data are available for the Pre-Adelaidean rocks of the Mount Painter area. If the density data for metasediments are used as a guide, then a weak Bouguer gravity high over the anticlinal structure may be expected, whereas in fact there is an intense low. On the other hand, if some of the granites have a density similar to the Gawler Range Porphyry (about 2.55 g/cm^3), then the intense low can be accounted for by a basin-shaped granite body (Fig. 17). Such a model appears contrary to the geological evidence which indicates Older Granite Suite granites on the flanks of an anticlinal core of metasediments. However, it is plausible if one assumes a mushroom-shaped laccolith with a central, plug-like feeder.

Unit 6. Most of the exposure in the Unit 6 area is of Recent rocks except in the south where Cambrian and Adelaidean sediments crop out. The gravity anomalies tend to positive values. Consideration of Units 4 and 17 is important to an interpretation of Unit 6 because in both units Adelaidean or Cambrian rocks are exposed but the Bouguer gravity is notably negative. For this reason it seems unlikely that the positive anomalies in Unit 6, some of which have corresponding magnetic highs, are caused by Adelaidean or Cambrian rocks.

Estimates of depth to magnetic basement decrease from 300 m in the north of Unit 6 to 300 m in the south. The character of the magnetic pattern indicates that these are depths to Pre-Adelaidean basement. The rise in magnetic basement corresponds to Bouguer gravity highs near the southern limit of the unit. The Bouguer gravity field appears unaffected by the sediments of Lake Torrens which are known to exceed 300 m in thickness (Johns, 1968), corresponding to 3 mgal theoretical negative gravity anomaly. It seems probable that the gravity highs represent Pre-Adelaidean basement topography.

Unit 7. Two explanations are offered for this unit which may be represented as a broad, residual gravity high of 15 mgal. It could be caused either by a regional density increase of the thick Adelaidean and Cambrian section or by a high density basement block beneath them.

Assuming Adelaidean and Pre-Adelaidean density of 2.68 g/cm^3, we can postulate a slab of Wooltana Volcanics of density 2.76 g/cm^3 and thickness 4500 m, near the base of the Adelaidean Sedimentary Unit to account for the residual anomaly. This formation occurs in the Mount Painter region in the northeast of Unit 7 where the maximum observed thickness is 2400 m (Coats & Blissett, 1971). A density measurement of 2.76 g/cm^3 has been made on a single specimen. Magnetic depth estimates of about 6000 m may indicate the top of this slab. On the other hand, Preiss (1971) measured sections of calcareous rocks in the Flinders Ranges and found a thickening of up to 900 m in the Wundowie Limestone, the Balcanoona Formation, and the Etina Formation and its equivalents, which correlates in a general way with Unit 7. Density measurements (Table 3) indicate that Adelaidean carbonates are about 0.1 g/cm^3 denser than the average for the Adelaidean Unit (Table 4), but the 900 m increase of section is not made up solely of dense carbonates. Often it is more than 50 percent siltstone or calcareous siltstone. These calcareous beds could contribute +3 mgal to the Bouguer gravity field, and the measured thickness of Wooltana volcanics, 8 mgal. Considerations such as these can fully account for the gravity high.

The second explanation requires a high-density block within Pre-Adelaidean basement. The 6000 m depth to magnetic basement (Fig. 10) might indicate the top of such a block. The density contrast for this model need not be as great as for the Wooltana Volcanics model.

Unit 8. Lonsdale & Ingall (1965) suggested that this unit is caused by up to 3300 m of Lower Palaeozoic sediments with a density contrast of -0.2 g/cm^3 relative to the underlying basement. The new data in southern CURNAMONA have now introduced a complication. There appears to be a close relationship between Units 8 and 11, and Unit 11 is a much stronger gravity low which may be related to granite outcropping in the southwest of CURNAMONA. Magnetic anomalies in the area of the culmination of the gravity low in Unit 8 form a circular pattern 70 km across. These anomalies might define the limits of a block of low-density crystalline basement, possibly of granitic composition. It is probable that some contribution to the gravity field is made by this body. If depth estimates from aeromagnetic data indicate the top of the body then it lies 6000 m below the surface in the west of Unit 8, and 2000 m deep near the centre.

Unit 9. This northwest-trending Bouguer gravity high lies between Spencer Gulf and Lake Torrens. It is proposed that in this area there is a belt of high-density Pre-Adelaidean rocks at shallow depth underlying thin Adelaidean and younger sediments.

Unit 10. This unit lies over the Torrens Hinge Zone (Thompson, 1971) which marks a transition from thick Adelaidean sedimentation and strong deformation within the Adelaide Geosyncline, to thin Adelaidean sedimentation and weak deformation on the Gawler Craton to the west. The western margin of Unit 10 is consistent with the character of a deep fault or contact between adjoining blocks.

The north-trending low is considered to be caused by a deep, low-density block in the Pre-Adelaidean rocks. Four points are important in arriving at this interpretation. First, the low lies over Recent sediments in PARACHILNA but over Adelaidean on the west side of Flinders Ranges in BURRA and ORROROO. Thus it can be caused only partly by Recent sediments. Secondly, in BURRA the west margin of the anomaly coincides with the west side of the Flinders Ranges, while in PARACHILNA the east margin marks the west side of the ranges (Fig. 4). Thirdly, aeromagnetic data indicate that the northern margin coincides with lateral east-west displacement of magnetic sources at a depth of about 4500 m, and in BURRA a northeast-trending magnetic anomaly is cut off close to the west side of the low. This suggests deep-seated block-faults. Fourthly, gradients into the low from both the west and the east are gentle. These points favour a deep source.

A deep block of Gawler Range Volcanics might cause the gravity low. If a regional level of -10 mgal is taken across Unit 10 the residual anomaly is approximately -25 mgal. A 4000 m thick block of material similar to the Gawler Range Volcanics (density 2.55 g/cm^3) can account for the residual anomaly if the enclosing basement has a density of 2.70 g/cm^3. Aeromagnetic depth estimates near the centre of Unit 10 in ORROROO (Fig. 9) are about 8000 m and this may be the depth to the top of the low-density block.

The strong gravity low in the northeast of BURRA reaches -60 mgal. In this area the Adelaidean sediments are folded into a domed anticlinal structure. The magnetic pattern shows a broad but weak low over the area. It is suggested that a low-density plug-like body, possibly of granitic composition, underlies the Adelaidean sediments.

Unit 11. This strong low is believed to be due to a block of low-density rock, probably granite. Granitic rocks within the Willyama Block outcrop at the south end of the low; it is suggested that similar material extends for at least 50 km to the north beneath Recent (and older) cover.

Figure 18 shows a combination of geology, aeromagnetics, and the Bouguer gravity contours, and indicates the outline of the block. The boundary on the east side follows a line of magnetic anomalies which may be caused by a contact metamorphic effect. Magnetic indication of the northwest boundary is somewhat more subtle.

The three-dimensional model (Fig. 19) was deduced, holding excess mass and density contrast constant, while varying dimensions to match theoretical gravity to the averaged, observed values. It indicates that the block may extend to a depth of 26 000 m. While this could be reduced by choosing a higher density contrast, or a more complex model, it seems inescapable that the low-density block would need to extend down to at least 15 km to account for the flanks of the anomaly.

Unit 12. Several negative anomalies lie within this unit; some lie over the Willyama Block and are associated with areas of granites, gneiss, and pegmatites. The strongest anomaly (residual amplitude - 20 mgal) is centred 30 km to the north of the Willyama Block. It is similar in character to Unit 11 although smaller in both amplitude and areal extent. The source could be a deep-seated plug-like, low-density body. As such, it may form an extension of the Willyama Block under sedimentary cover. The variable thickness of the surface and near surface sediments may influence this and the other gravity lows in the area.

Unit 13. The -35 mgal contour enclosed by the boundary of this unit correlates well with the limits of the Tertiary/Quaternary Willochra Basin. The averge density of Willochra Basin sediments is inferred to be avout 2.2 g/cm^3 compared to 2.68 g/cm^3 for Adelaidean sediments. The measured depth of the basin, from bores, is 165 m (O'Driscoll, 1956). A model based on this depth, a basin width of 25 km, and a density contrast of -0.48 g/cm^3 gives an anomaly of -3 mgal which corresponds well with the residual Bouguer anomaly enclosed within the -35 mgal contour. From this it is clear that the major part of the larger anomaly enclosed by Unit 10 is unrelated to the Recent sedimentation, even over the Willochra Basin.

Unit 14. The strong negative anomaly which is the dominant feature of Unit 14 is associated with the Anabama Granite. This body is interpreted to have considerable depth extent. The geology and geophysics of the area is summarized in Figure 20.

The Anabama Granite is non-magnetic, but it is enclosed by strongly magnetic Adelaidean rocks. The magnetic Braemar Ironstone forms a frame 11 km wide around the scattered granite outcrops, and dips away to the southeast but a few small outcrops of granite lie to the north and east, outside the Braemar Ironstone. The aeromagnetics indicate that Adelaidean sediments also underlie Recent cover between the Braemar Ironstone and the Anabama Granite. It appears that the present granite exposure represents very nearly the original top of the granite body.

Measurements made by one of the authors (D.H.T.) on unweathered granite gave a density of 2.65 g/cm^3, which is close to the minimum average Adelaidean density, 2.68 g/cm^3.

Three-dimensional modelling was carried out using the derived density contrast of -0.03 g/cm^3 and trapezoidal bodies of modified triangular section. It was found necessary to expand the base of the model unreasonably to obtain a fit, and this model was discarded. A simple model using a density contrast of -0.1 g/cm^3 was tested, holding excess mass constant and varying dimensions. The result finally accepted is shown in Figure 21. The depth to the bottom of this model is 23 000 m; the northwest side dips away at 42° and the southeast side dips away initially to 46° and then becomes vertical. It will be noticed that it tapers to 6 km wide and that the top is 350 m below the ground surface. This apparent 350 m depth of burial could mean that there is little density contrast between the country rock and the granite near the surface, in agreement with the density measurements.

Because density measurements indicate little difference between the granite and the minimum average for Adelaidean rocks, and because the block model (1) indicates such a great depth to the base of the granite, it was considered of interest also to use the basin analysis method of Bott (1960), (Fig. 22, models 2 and 3). Here the regional Bouguer gravity was taken as flat at +5 mgal, and the anomaly to arise from a basin-like trough of Adelaidean sediments enclosing a granite block of the same density, together set in a more dense crystalline basement. In Figure 22 the width of the granite is shown as 11 km, which is the maximum revealed by geological mapping. The computed gravity for both models fits the experimental data at all points.

Although model 1 is strongly favoured, models of the form 2 and 3 should not be discarded until more density data are available and a model optimization analysis is carried out.

Unit 15. Most of Unit 15 lies over Recent sediments. A preliminary study of the aeromagnetic maps indicates that the trend of magnetic anomalies closely follows that of shallow-source anomalies over the Adelaidean sediments to the northwest of Unit 15. It is therefore likely that the top of the Adelaidean unit lies at a depth not exceeding 2000 m. Moreover, the strong magnetic response indicates a high iron content for the sediments. It is possible that a belt of high density Adelaidean sediments causes the Bouguer gravity high.

Where the northeast end of Unit 15 lies over Pre-Adelaidean metasediments of the Willyama Block the gravity is the highest for the area (+15 mgal). On the assumption that the metasediments have a corresponding high density they may extend to the southwest under the Murray Basin and perhaps, also, under the Adelaide Geosyncline. The southern side of Unit 15 is marked by a steep gravity gradient which indicates a major fault under the Murray Basin.

The nature of the gravity field over the contact between the Willyama Block metasediments and the Adelaidean sediments is of interest. The southwest margin of the Willyama Block is shown by geological mapping to trend generally northwest (Fig. 15). If the density of the Willyama Block metasediments is higher than for the Adelaidean sediments as suggested in the previous paragraph, a northwest gravity gradients should parallel the contact. However, the Bouguer gravity contours trend generally northeast, transcurrent to the geological boundary. Thus if Adelaidean sediments lie under cover in Unit 15, their density must equal that of Willyama Block metasediments.

Unit 16. Rocks outcropping in this area are mainly of Adelaidean age and it is considered that the general intermediate value of the Bouguer anomaly and relatively undisturbed contour pattern suggest a homogenous mass which may comprise a great thickness of Adelaidean sediments.

Unit 17. Rocks in this area are flat-lying or gently folded Adelaidean and Cambrian sediments. It is conceivable that here on the Gawler Craton their density is sufficently lower than in the Flinders Ranges to accout for the negative anomaly. If we consider the regional Bouguer gravity value to be -10 mgal then we must account for a residual anomaly of -15 mgal. This requires about 4000 m of sediments having a density contrast of -0.1 g/cm^3 with underlying basement. Magnetic depth estimates are much less (Fig. 10).

Unit 17 appears closely related to Unit 10, which may be caused by a low-density basement block below the Adelaide Geosyncline. This interpretation seems likely also for Unit 17.

Unit 18. This unit encloses the Gawler Ranges, extending to the west beyond the area shown (Figs. 14 and 15). It is a broad region of positive Bouguer gravity associated with rocks of Pre-Adelaidean age. Many of these are acid volcanics. However, the Gawler Range Porphyry which lies on the southeast margin of Unit 18 appears to produce local negative anomalies of the order of -5 mgal. This tends to validate the low density, about 2.55 g/cm^3 found for specimens of the porphyry (Chapter 4).

Unit 19. This unit covers part of the area for which Taylor (1964) and Gunn (1967) measured densities of rocks near the Middleback Range (Fig. 15). Their measurements indicated 2.7 g/cm^3 as a typical value for the density of Pre-Adelaidean rocks in this part of the Gawler Craton. The complexity of the Bouguer gravity field may indicate a corrsponding variety of basement rock types in the area. However, the variable thickness of surface and near surface sediments could contribute also the complexity.

Unit 20. This unit lies over Pre-Adelaidean metasediments (Cleve Metamorphics) of the Gawler Craton. On geological grounds the Cleve Metamorphics are thought to be similar to some of the metasediments in the northern part of the Willyama Block (Thomson, in Parkin, 1969, p. 33) but the gravity response of the two crystalline basement areas is different. Unit 20 is distinctly positive, has a fairly clear-cut gradient separating it from its adjacent unit and exhibits a banded character whereas the Willyama Block tends to have a net negative Bouguer anomaly field, indistinct gravity boundaries and little detailed gravity character. Therefore no direct comparison is possible (Figs. 14 and 15).

7. BOUGUER GRAVITY TRENDS

Figure 23 shows 18 linear trends in the Bouguer gravity data which seem important; these are given the letters A to R for description. Some of them lie over steep gradients in the gravity field, probably arising from shallow or major deep-seated faults, or lateral compositional changes; others follow the axes of narrow Bouguer gravity highs or lows, and others mark lateral displacements or the apparent termination of linear Bouguer gravity anomalies. The geological significance of only a few of the trends is understood. It is, moreover, beyond the scope of this report to do more than suggest the meaning of them.

The map of seismic epicentres for the depth range 5 to 40 kilometres (White, 1969) for South Australia is of use for predicting the location of faults. The part of the map concerned in this report is presented here (Fig. 24). There are several noteworthy groupings and trends in the location of epicentres which could delineate deep structures. With this in mind, the Bouguer gravity trends were superimposed on the epicentres (Fig. 25). The character and interpretation of each trend is summarized in Table 9. Where a gravity trend appears associated with seismic activity a comment is made in the notes which follows.

TABLE 9

BOUGUER GRAVITY TRENDS

TREND	DIRECTION	NOTES ON THE CHARACTERISTICS OF TRENDS
A	NW	Gradient in northwest, coincides with Norwest Fault (Fig. 4). Upthrow to northeast. Seismically active. Displaces north-trending anomalies in the centre of survey area. May continue beyond the indicated limit to join the west side of the Willyama Block.
B	NE	Gradient. Coincides with a topographic break between Flinders and Willouran Ranges. Deep fault, or composition change in the Adelaidean **Sedimentary Unit**
C	NW	Gradient, partly on north side of Willouran Ranges. Deep fault, or composition change in the Adelaidean **Sedimentary Unit**
D	NW	Gentle gradient. Deep fault, or composition change in the Adelaidean **Sedimentary Unit**

TREND	DIRECTION	NOTES ON THE CHARACTERISTICS OF TRENDS
E	NE	Gradient. Coincides with Paralana Fault (Fig. 4). Upthrow to northwest.
F	N	Line-up of positive residual anomalies between top of Spencer Gulf and the west side of Lake Torrens. Fault or topographic high in Pre-Adelaidean basement
G	E	Gradient. Coincides with displacement of north-trending magnetic anomalies originating at a depth of 3000 m in PARACHILNA. Deep fault.
H	NW	Line of positive residual anomalies. Coincides with fault between Adelaidean and Tertiary rocks (Ediacara Fault). At least 200 m downthrow on west side (Binks, pers comm.)
I	N	Gradient. In north coincides with fault on west side of Flinders Ranges. Cuts across Adelaidean formations to south. Seismically active in north and south. Fault
J	NE	Marks the alignment of a number of flexures in the contours and the cut-off of the Bouguer gravity high in the south end of Unit 7. Fault
K	N	Gradient. West side of Flinders Ranges. Fault. Upthrow to west
L	N	Axis of Bouguer gravity low (Unit 11). Axis of granite (?) batholith. Approximate coincidence with photo-inferred Pepegoona Fault (Fig. 4).
M	NE	Weak alignment of negative anomalies
N	NE	Axis of Bouguer gravity low. Axis of Anabama Granite
O	NE	Gradient. Composition change within metasediments of the Willyama Block
P	NE	Gradient. Probably related to Trend O. Composition change in the Adelaidean Unit or in the Pre-Adelaidean
Q	NE	Gradient. Deep fault; downthrow to southeast
R	N-NW	Gradient. West side of Flinders Ranges. Fault

8. ECONOMIC GEOLOGY AND GEOPHYSICS

Hydrocarbons

The part of the survey area covered by Adelaidean rocks is regarded as non-prospective because the sediments are ancient, extremely well compacted, and often strongly folded and faulted. Except for the shallow Willochra Basin and Walloway Basin, the Post-Adelaidean sedimentary basins (Fig. 5) are prospective. The Bouguer gravity highs in the Pirie-Torrens Basin in Unit 6 and the lows in Unit 12 may represent interesting, buried topographic highs.

Uranium and granites

Gravity anomalies in Units 2, 5, 11, and 12 may be caused by deep-seated granite bodies; their location and extent should be considered in the search for ancient placer uranium deposits in Palaeozoic and younger sediments.

Mineralization trends

Thomson's (1965) map of the distribution of Cu, Pb, and Au mineralization in S.A. shows a number of marked northwest, north, and east trends. Part of the map has been superimposed on the geology base (Fig. 9) and should be compared with the Bouguer anomalies and gravity trends (Fig. 23). It is not implied that the Bouguer gravity trends are mineralization trends. However, it is thought that there may be a relationship between mineralization and several of them e.g. trends A, H, I, J, M, and N.

The Bouguer gravity trends have been superimposed on a map which shows the location of diapirs in the North Flinders Ranges (Fig. 26) (Coats, in Parkin, 1969). A number of diapirs lie close the gravity trends (e.g. A, B, C, I, and J). As some trends appear related to deep faults or compositional changes, the gravity interpretation supports the idea that diapirs are localized along faults in the Pre-Adelaidean basement (Dalgarno & Johnson, 1965).

The concentration of diapirs in COPLEY and the north of PARACHILNA may be related in some way to the Bouguer gravity high in Unit 7 and the complexity of Bouguer anomaly trend directions in the area.

A study of the combination of Bouguer anomaly trends, mineralization trends, and diapir location trends might give an indication as to which diapirs are mineralized.

9. CONCLUSIONS

Geology

In places there is a direct correlation between surface geological features and features in the Bouguer gravity field, and in others there is not. Areas of Palaeozoic and younger sediments, and granites predominantly show negative anomalies while Adelaidean rocks in the Adelaide Geosyncline correlate in places with positive, and at other times with negative, anomalies. The Gawler Craton, Mount Painter Block, and Willyama Block, which are recognized geologically as crystalline basement, have a similar range of Bouguer gravity anomalies to the Adelaide Geosyncline. Owing to the uncertainty of the density contrast between Adelaidean and Pre-Adelaidean rocks, it seems impossible to produce a simple model for the geological basement of the geosyncline from gravity data.

A Bouguer gravity low follows the west side of the geosyncline along the area referred to as the Torrens Hinge Zone. Igneous rocks of low density, possibly granites or Gawler Range Porphyry, might underlie the Adelaidean sediments here. The Anabama Granite and other postulated low-density igneous bodies on the east side of the survey area appear to extend to great depths.

The gravity data may be useful for predicting trends related to the location of mineral occurrences in the Flinders Ranges.

There appears to be some relationship between the location of diapirs and Bouguer gravity trend lines.

Status of the density data

The data presented are inadequate to provide a full interpretation of the Bouguer gravity field. There is a great quantity of drill core available from various parts of South Australia. The density of this should be measured systematically and studied in detail before a more comprehensive analysis of the gravity field in the area discussed in this report is attempted. The present interpretation has indicated the following:

1. The gross density of the Adelaidean rocks appears to change from place to place and may vary through a wider range than the suggested 2.68 to 2.73 g/cm^3.
2. The Pre-Adelaidean formations of the west part of the Willyama Block may have the same density as the Adelaidean rocks.
3. The density of major components of the Pre-Adelaidean Gawler Craton varies over a range too wide to justify a simple average for the area.
4. The range of densities of Adelaidean rocks lies within the range of densities of metamorphic basement.

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APPENDIX A

SURVEY STATISTICS AND DETAILS (AREA B)

Area surveyed:	75 000 km^2
Field work commenced:	27 September 1970
Field work completed:	27 October 1970
New Readings:	1887
Flights (cell centre/tie point/cell centre):	195
Helicopter serviceability:	100% (54 helicopter days)
" utilization :	98% (53 helicopter days)
Flights (as above) per helicopter day flying:	3.7
New readings per helicopter day flying:	35.6

Note: Figures concerning helicopter serviceability are taken from the Certification of Results forms submitted by the contractor.

Isogal stations observed:

Hawker	6491.9117	979,394.27 mgal	
Leigh Creek	5099.9937	,319.82 mgal	(Pendulum station)
Mannahill	6491.9116	,445.75 mgal	
Wooltana	6491.9103	,350.37 mgal	

Gravity meters used:

Worden 274, factor 0.09177 mgal/div.
Worden 708, factor 0.08330 mgal/div.

Calibration:

Meter	Date	Result	Date	Result	Adopted
W274	2/2/70	0.09163	19/1/71	0.09181	0.09177
W708			19/1/71	0.08329	0.08330

The cell method of observing was used.
No tidal corrections were made.

Elevations were obtained by the two-barometer technique, one at the base station and one in the field. Mechanism Ltd microbarometers were used.

Station positions were photo-identified.

The density used for the Bouguer correction for the purpose of this report was 2.67 g/cm^3. For use in preparing 1:250 000 and other scale maps, including the Preliminary Bouguer Anomaly Map of Australia at 40 miles to 1 inch, the density used was 2.2 gm/cm^3. This conforms to BMR practice since 1964 and permits compilation without contour discontinuities. See the report text for density considerations.

No terrain corrections were applied.

Station numbering

This followed the standard BMR convention using a four-figure survey number prefixing a four-figure station number, the two separated by a period.

Survey numbers were used as follows:

General stations:	7006
Bench mark stations:	7007

The bench mark stations were given the bench mark number as a gravity station to ensure ready identification. General gravity station numbers, were distributed as follows, the range of ordinary station numbers first, tie points and cell centres second, by 1:250 000 map Sheets:

COPLEY, 0001-0267
9001-9009
PARACHILNA, 0400-0693
9040-9051
CURNAMONA, 0800-0975
9080-9086
ORROROO, 1200-1469
9120-9129
OLARY, 1600-1882
9160-9169
CHOWILLA, 2000-2100
9200-9204
PORT AUGUSTA, 2400-2422
9240-9242
FROME, 2500-2580
9250-9251
CALLABONNA, 2600-2622
9205

The survey area was divided for computation purposes in two segments along a line of bench marks which follows the road from Port Pirie north to Port Augusta, northeast through Quorn and Hawker, eastwards into CURNAMONA, south to OLARY, and then again northeast along the Barrier Highway.

Personnel:	Party leader, J.R. Harrison Meter readers, H. Reith, D. Durant Cell centre readers, P. Hall, H. Blumentals
Transport:	Three long-wheel-base Landrovers with flat-bed cargo area. Two G3B-1 helicopters from Rotor Works.

APPENDIX B

STANDARD DEVIATIONS OF NETWORK ADJUSTMENTS

(after Whitworth, 1970)

The networks of gravity and barometric observations are reduced to final values in segments of a size suited to the computer and the physical distribution of control points on the ground. Ideally, each segment is surrounded by a ring of fixed values such that no errors in one segment are propagated into another. In this way, each segment may be adjusted in isolation without affecting surrounding areas.

In the actual height network each segment is bounded by bench-marks except at the survey boundaries. The latter are generally coincident with map sheet boundaries which do not usually have level control. Each loop reaching the edge of the segment must include as a station, preferably as a tie point, one of these bench marks. Given this condition, the adjustment of field barometric observations to yield final height values is done in three stages aimed at providing a basis for assessing the quality of the network and the accuracy of the final values. The standard deviation of adjustments is used as the criterion of quality.

In the first stage, the segment network is adjusted to a single bench mark of the set observed in the segment. The method of least squares is used and the object of the adjustment is to create a network with the minimum misclosure, preferably zero, without excessively high adjustment of any particular leg. The standard deviation of adjustments which arises from this operation is referred to as the Internal Standard Deviation. The implication in this name is that the result has been obtained through simple adjustment of the network using the method of least squares without other external constraints. It shows the self-consistency of the network of observations and this tends to reveal mis-readings at tie points.

The second stage is an identical adjustment of the network but with the height specified at all points which fall at bench marks. Since this imposes notable constraint on the adjustment, the standard deviation of adjustments will normally be greater. This is known as the External Standard Deviation and this name implies that some values are fixed before making the adjustment.

To obtain a figure of merit for the final data accuracy, another network adjustment is made in which only about half the fixed values, distributed uniformly over the network, is used. The standard deviation of differences between the true values omitted and the values computed in this way for these points is known as the Forecast Standard Deviation of the network. This name implies that a value of standard deviation of computed station heights from true station heights has been obtained which is taken to represent the accuracy of final height values.

It is worth noting that the Internal and External Standard Deviation refer to the adjustment of the difference between adjacent tie points in the network, i.e. the adjustment of 'legs', to obtain what amounts to the best fit of the data. The Forecast Standard Deviation, on the other hand, refers to the departure of the computed value at a point from its true value, i.e. it represents the error at a point.

In computing gravity values a different procedure is adopted because control is generally limited to only one or two points (Isogal stations) in any given segment and thus there would be only slight differences in the Internal and External Standard Deviation and no significance in the value of Forecast Standard Deviation. The initial adjustment is made using all fixed control; this is about the equivalent of the initial adjustment of the height network. For uniformity, the same segment boundaries are used for gravity networks as for height networks. However, as there are generally no fixed values of gravity along these boundaries, values must be obtained from the adjustment of the network. Gravity stations lying on common boundaries between two segments will thus each yield two values of gravity. These rarely differ by more than a few hundredths of a milligal and so it is considered reasonable to mean them and adopt this as the fixed value for each such point. Using these in addition to the Isogal fixed control, further adjustment is made yielding the final value of observed gravity for all stations in the segment. This adjustment is the equivalent of the second stage of height adjustment.

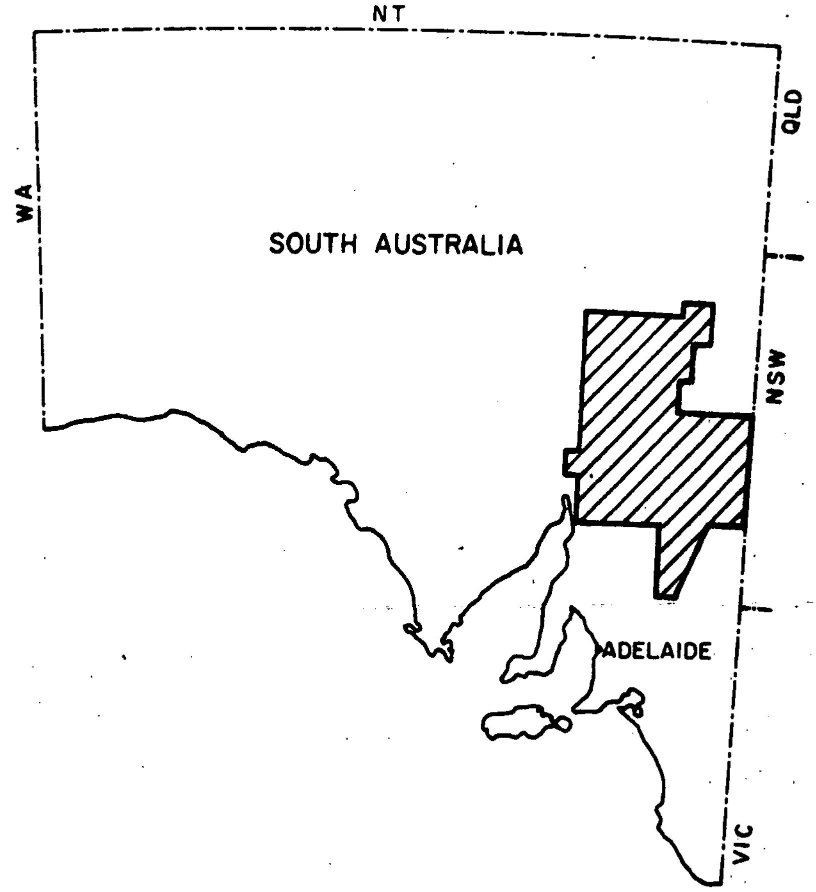
The values of the various standard deviations (S.D.) and maximum adjustment (M.A.) or maximum departure (M.D.) are tabulated below.

SEGMENT	HEIGHTING						GRAVITY	
	INTERNAL		EXTERNAL		FORECAST			
	S.D.	M.A.	S.D.	M.A.	S.D.	M.D.	S.D.	M.A.
G (m)	2.17	9.1	2.77	12.1	1.80	5.4		
(mgal)	.14	.60	.18	.80	.12	.35	.04	.11
H (m)	1.62	5.4	2.40	7.4	1.94	7.7		
(mgal)	.11	.36	.16	.49	.13	.51	.03	.10

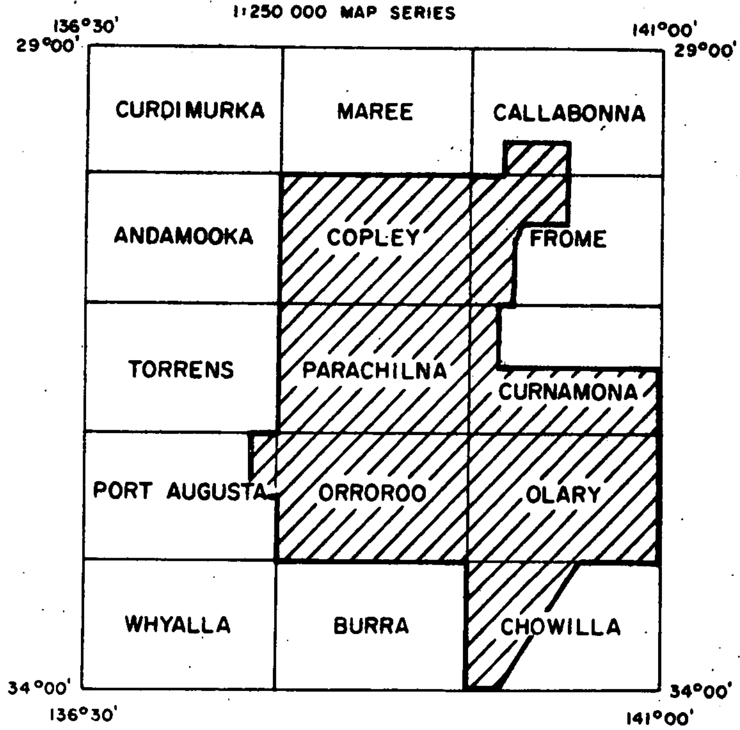
The values for heights are given in both meters and equivalent milligals. The latter are computed as representing Bouguer corrections; they have been obtained using a factor of 0.2164 mgal/m which is based on a rock density of 2.2 gm/cm^3 to conform to the similar table in the report on Area A of the 1970 South Australian Gravity Survey.

FIGURE 1

LOCALITY MAP



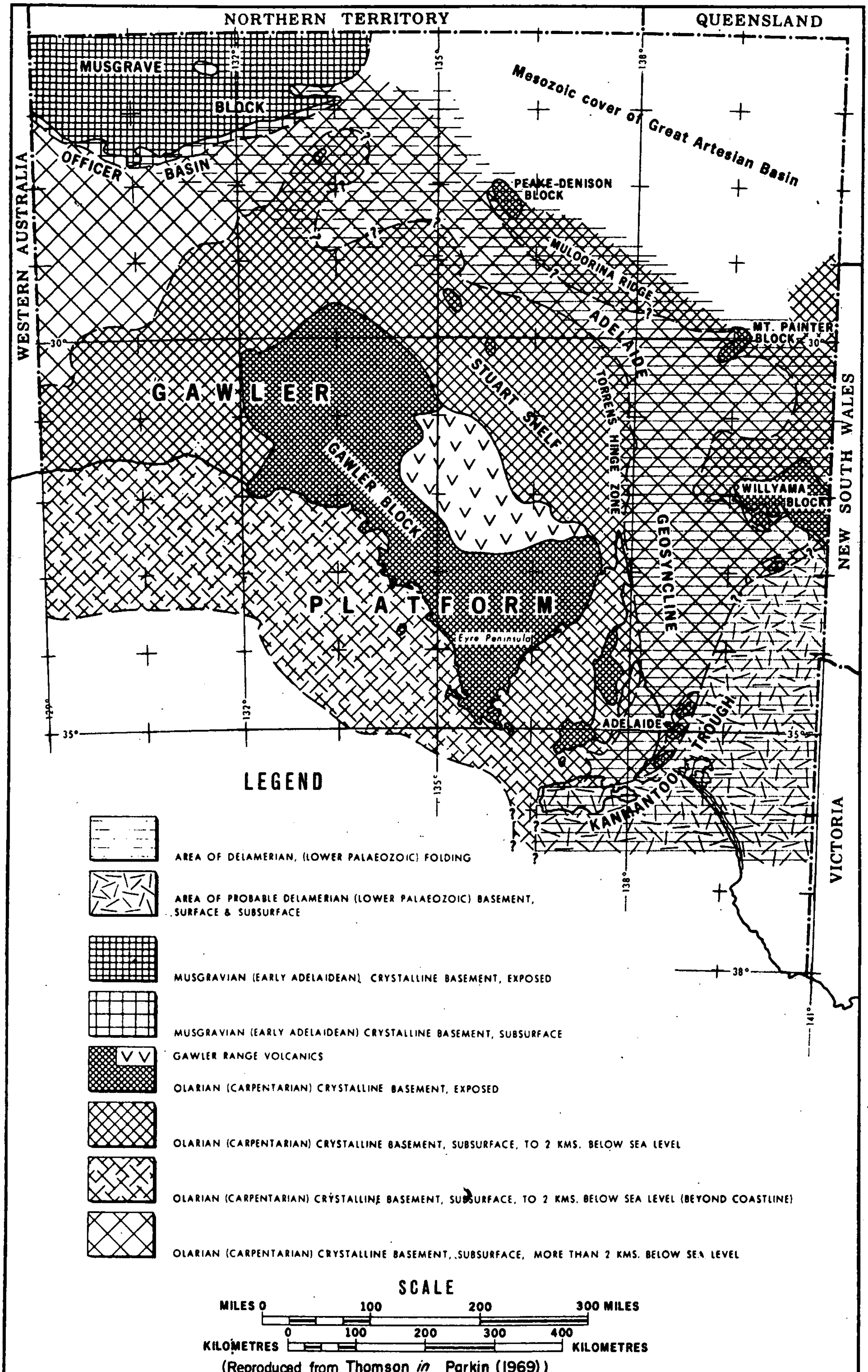
REFERENCE TO AUSTRALIA STANDARD
1:250 000 MAP SERIES



1970 HELICOPTER GRAVITY SURVEY, SA - AREA 'B'

To accompany Record No 1973/12

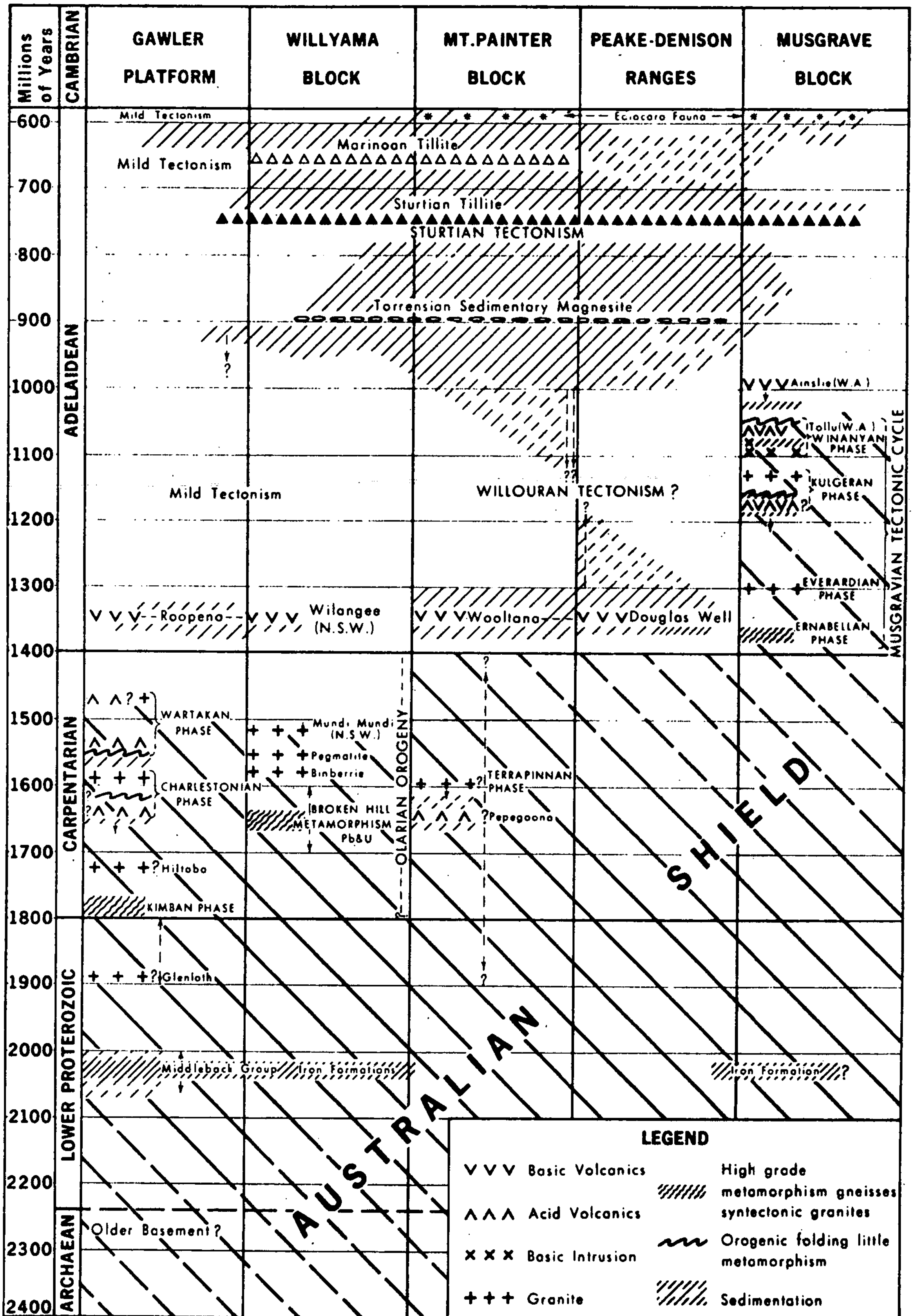
SA/B2-14A



Major structural units of South Australia.

To accompany Record No 1973/12

SA/B2-8-1A

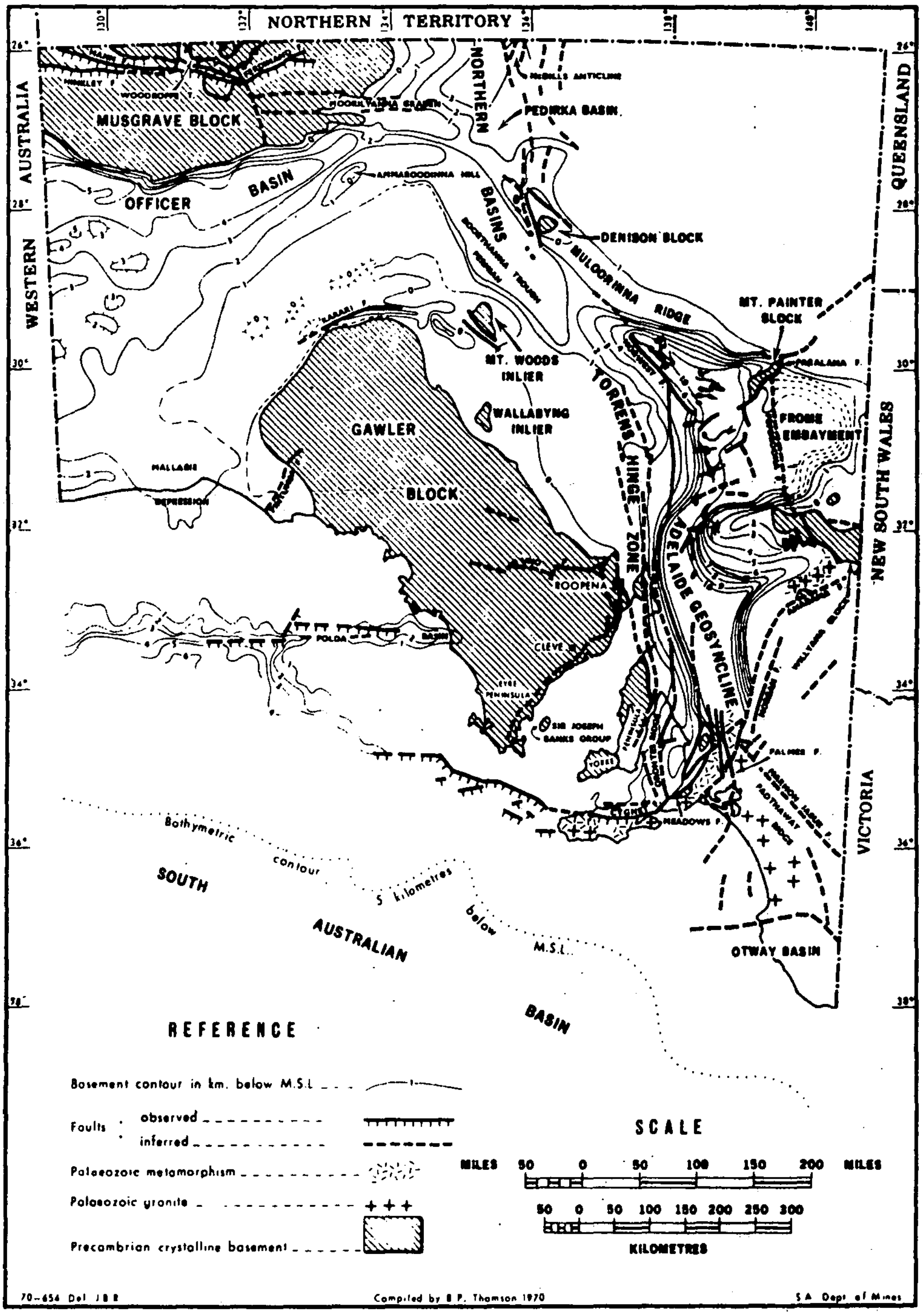


(Reproduced from Thomson *in* Parkin (1969))

Major stratigraphic and tectonic events of the Precambrian.

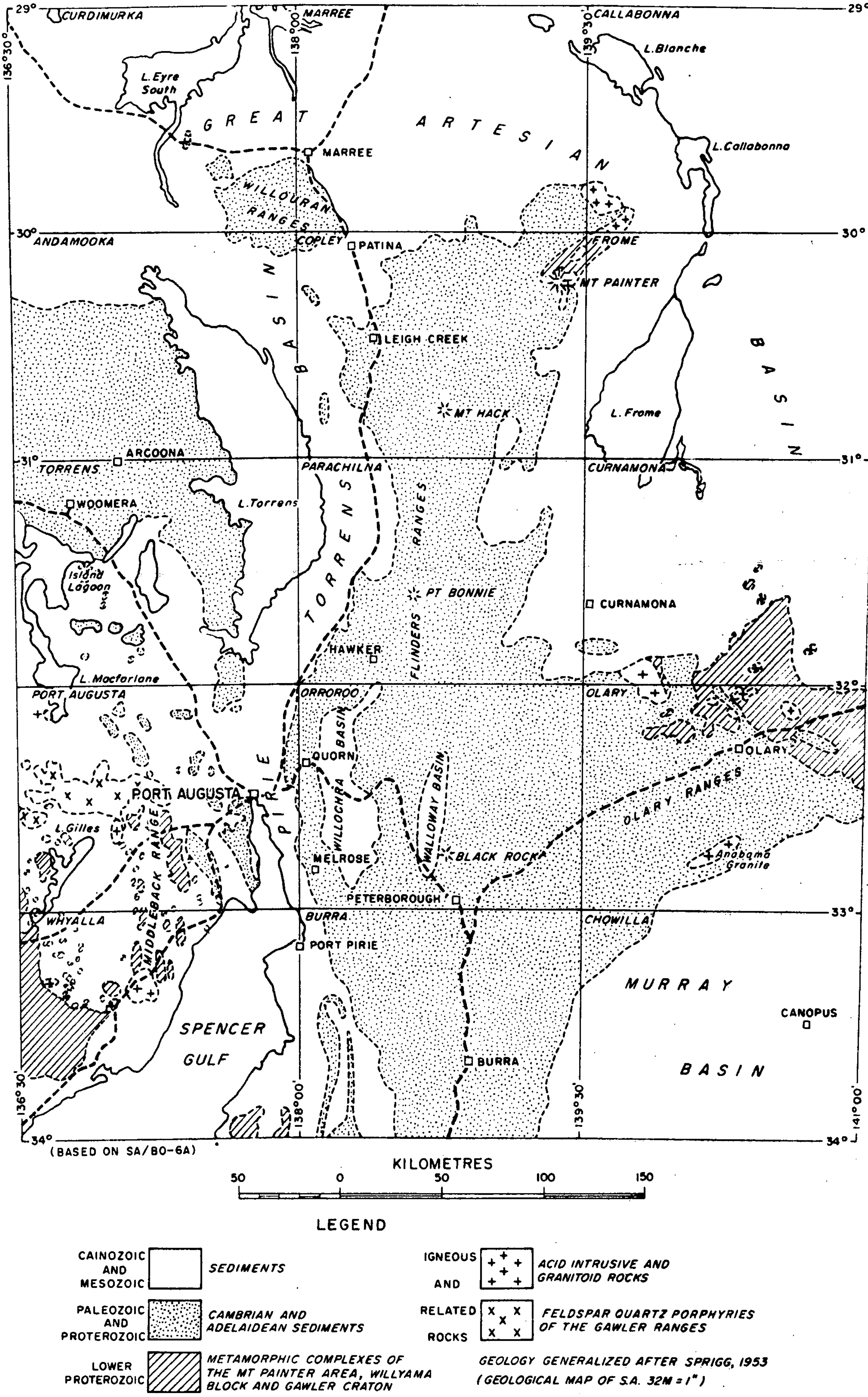
To accompany Record No 1973/12

SA/B2-9-1A



Precambrian basement contours, form lines and other structural features in South Australia.

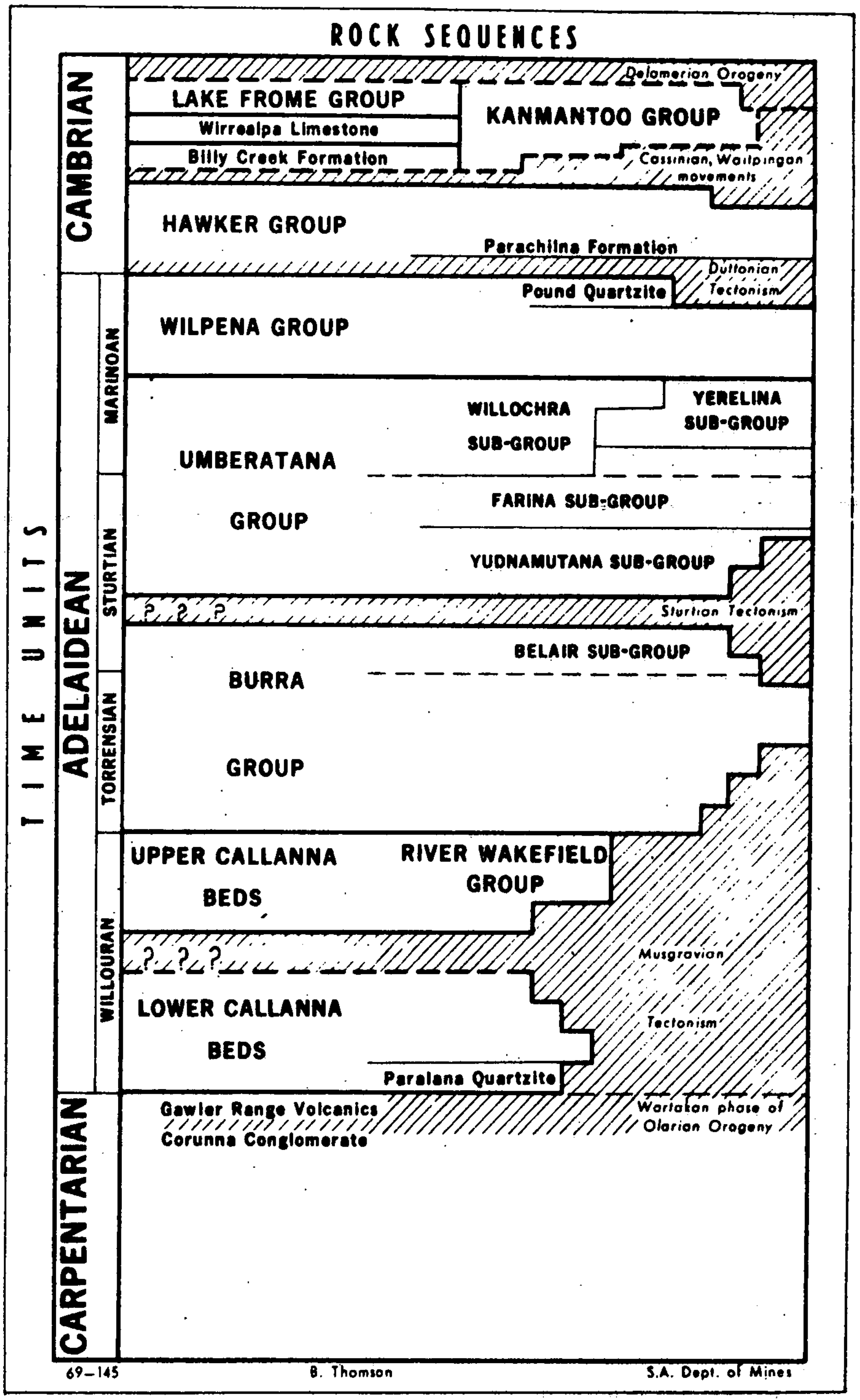
FIGURE 5



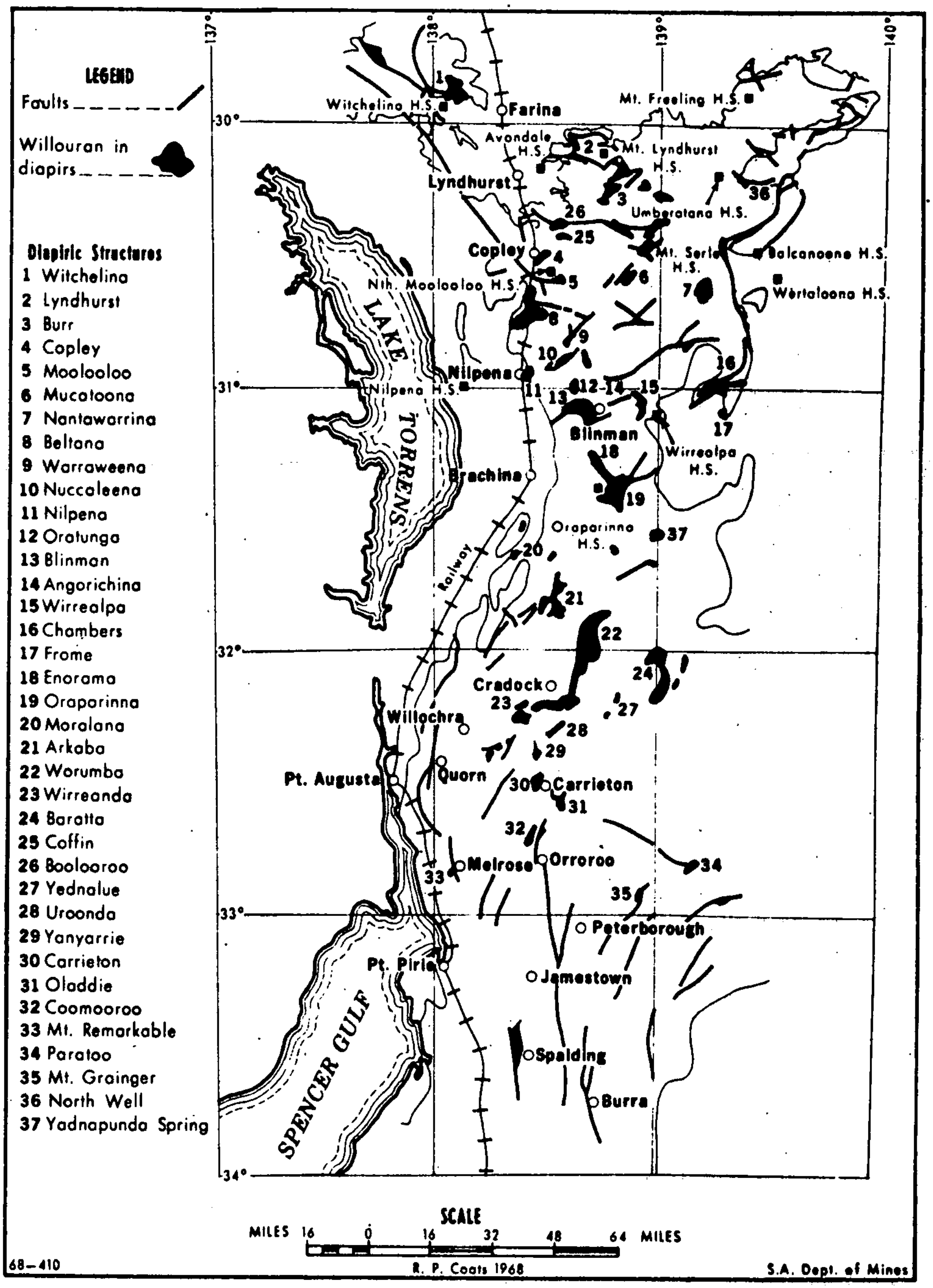
GENERALIZED GEOLOGY

To accompany Record No 1973/12

SA/B2-28A

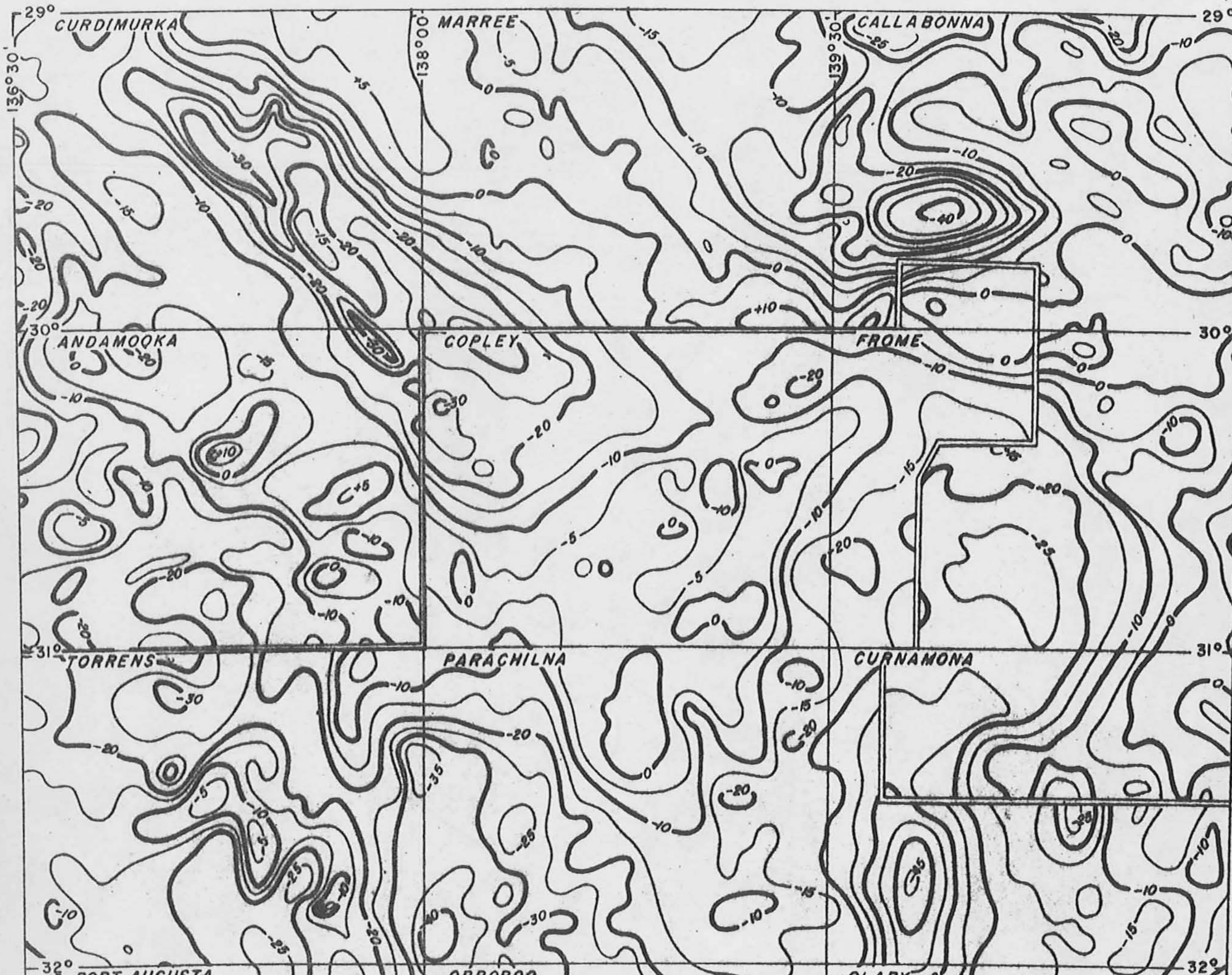


Time and rock terms used in the Adelaide Geosyncline and adjoining areas.



Diapirs in the Adelaide Geosyncline.

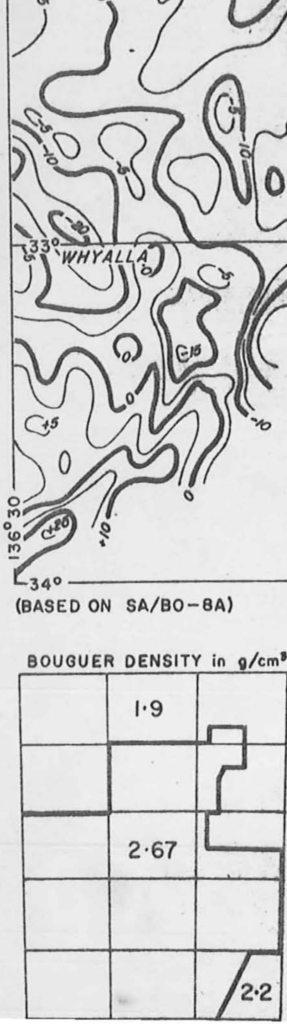
FIGURE 8



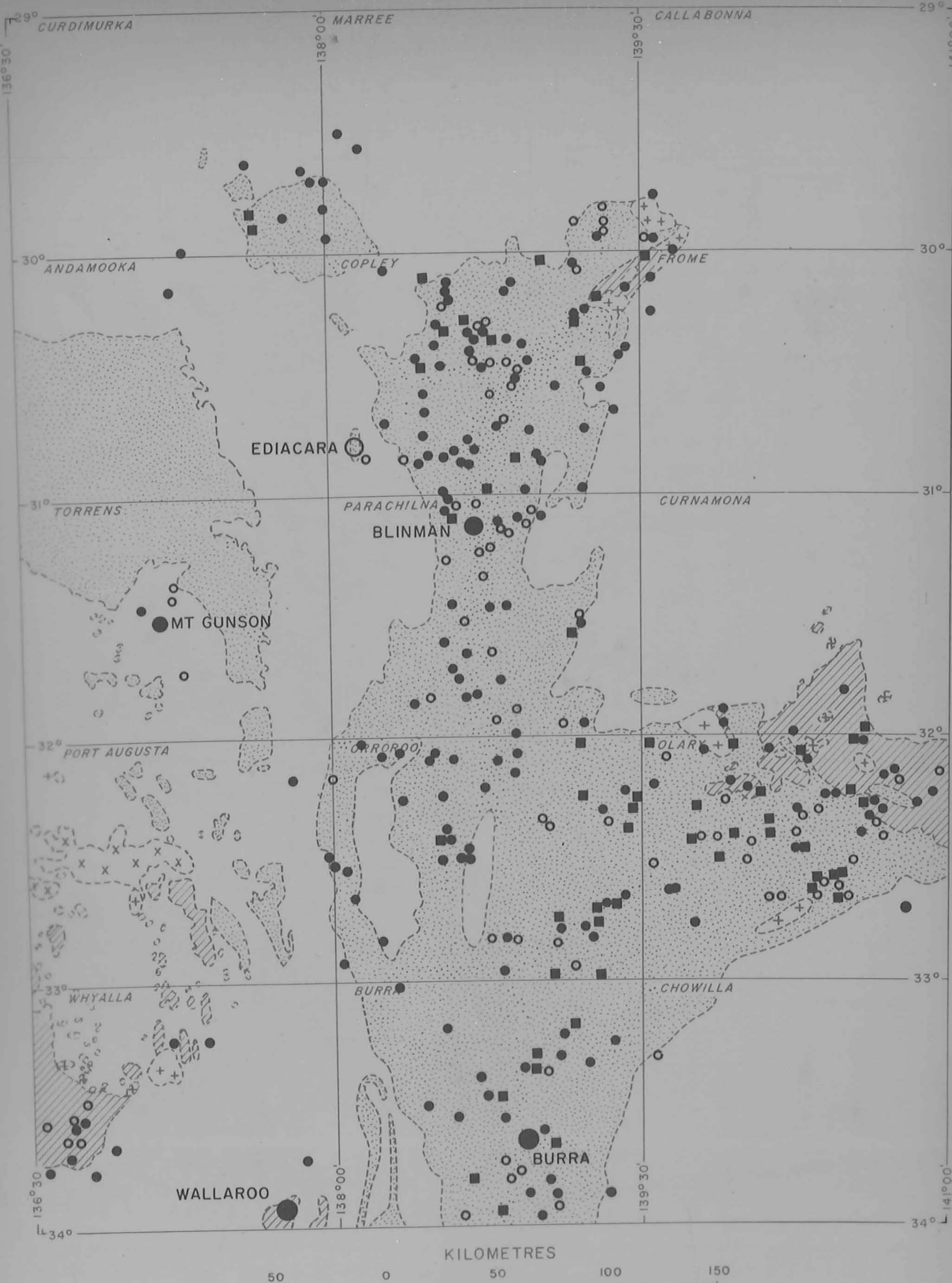
(BASED ON SA/BO-8A)

KILOMETRES

50 0 50 100 150



BOUGUER ANOMALIES

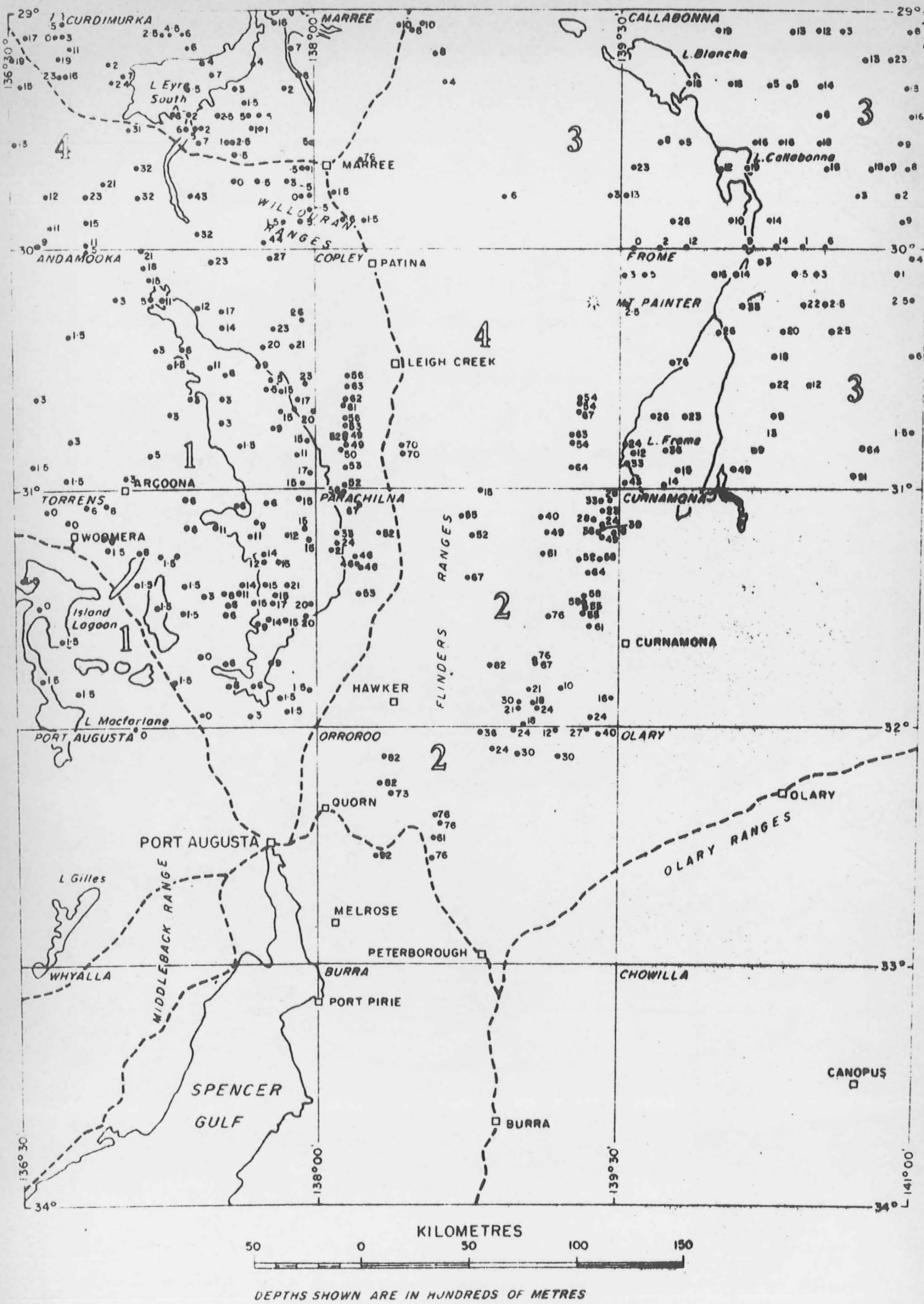


DISTRIBUTION OF Cu, Pb, Au MINERALIZATION

See figure 5 for explanation of Geology.

DEPOSITS	Copper	Lead	Gold
Large	● ●	○	
Small	•	∘	■

FIGURE 10

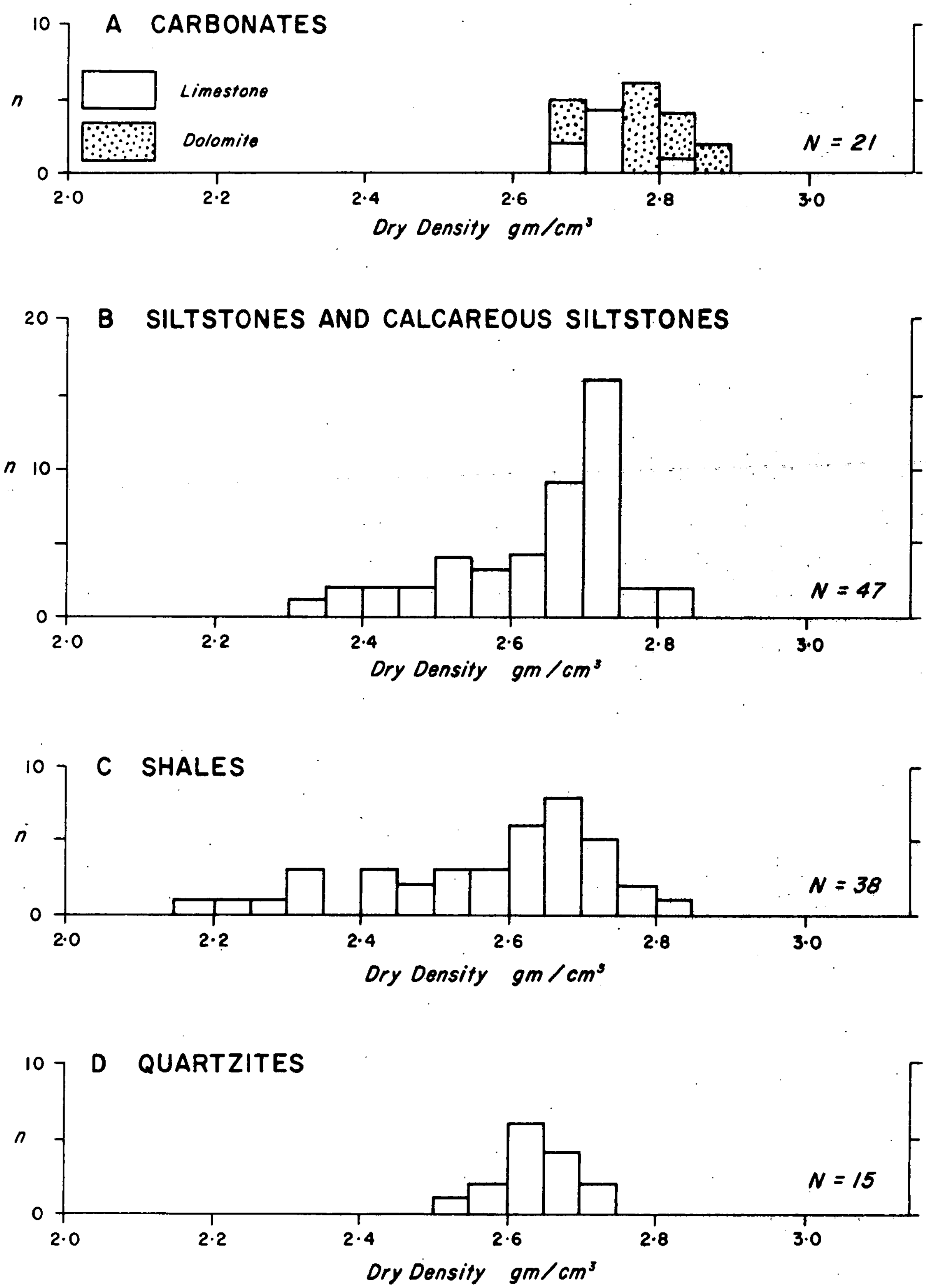


DEPTHS SHOWN ARE IN HUNDREDS OF METRES

ESTIMATES FROM BMR RECORDS:
1 1964/31
2 1966/126
3 1965/1
4 1966/224

INTERPRETED DEPTH TO MAGNETIC SOURCES

FIGURE 11

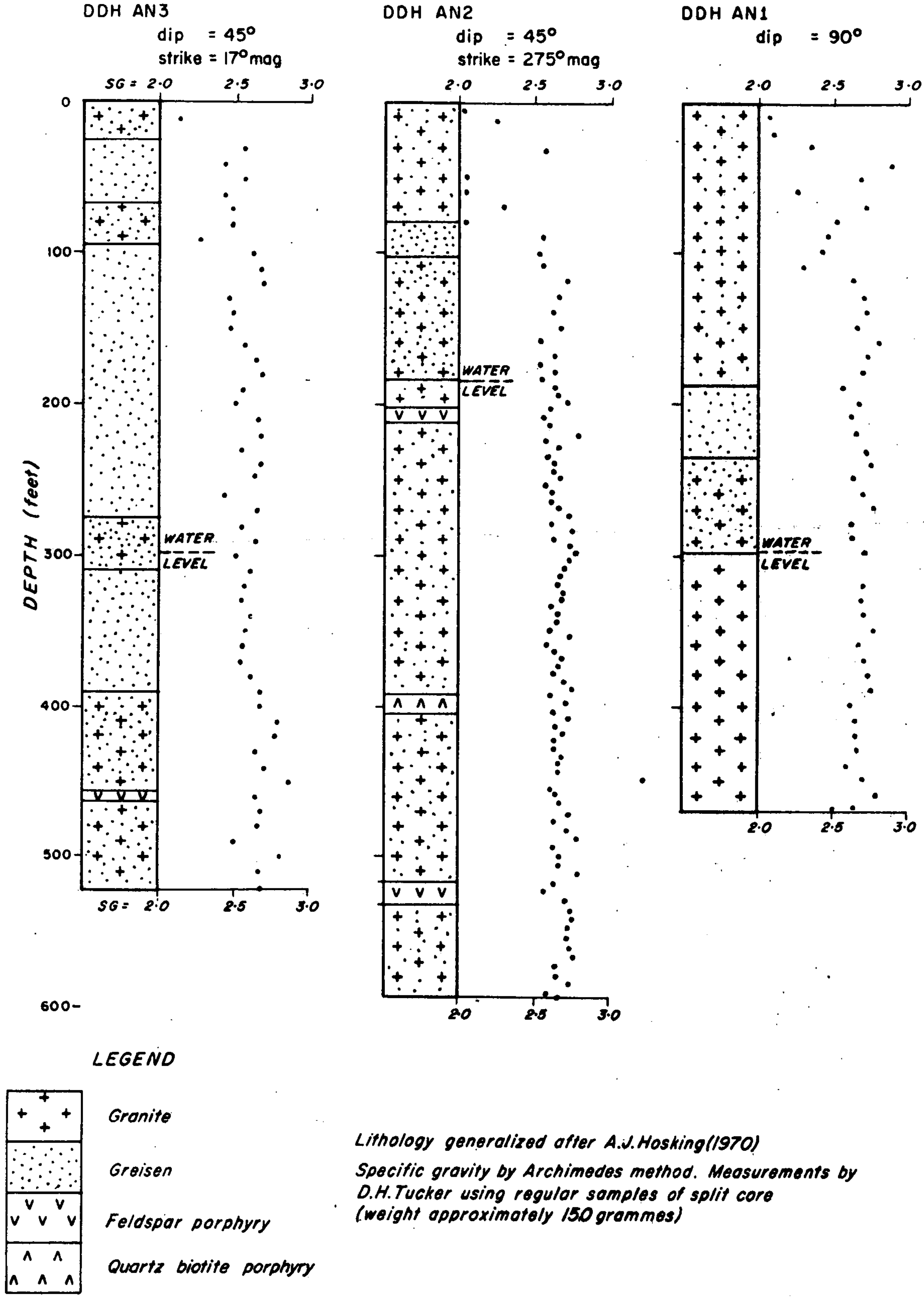


DENSITY OF ADELAIDEAN SEDIMENTS

To accompany Record No 1973/12

SA/B2-40A

FIGURE 12



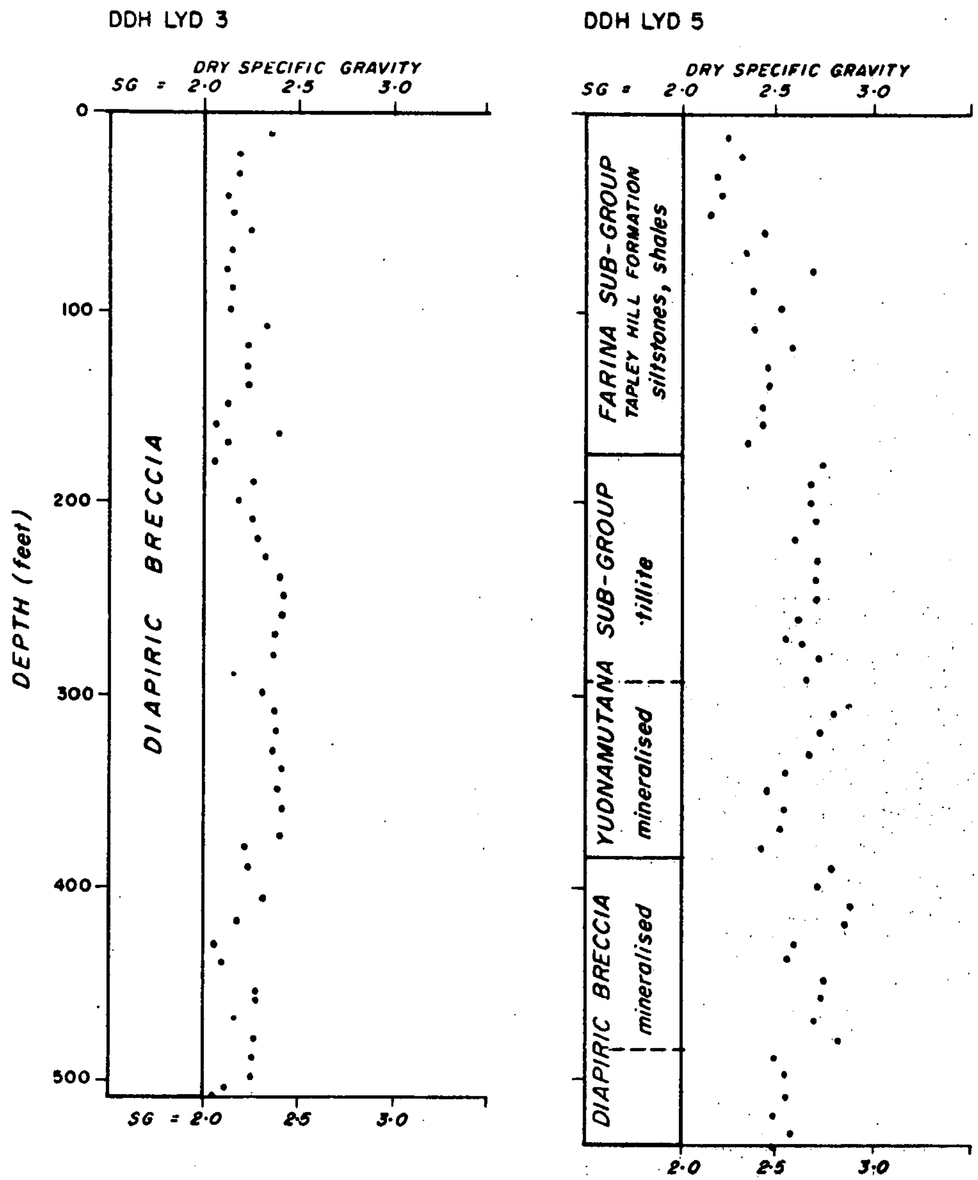
Lithology generalized after A.J. Hosking (1970)

Specific gravity by Archimedes method. Measurements by D.H. Tucker using regular samples of split core (weight approximately 150 grammes)

ANABAMA GRANITE

ANABAMA HILL SA

DRY SPECIFIC GRAVITY LOGS



Core sampled at 10ft intervals. Specimens of approximately 40g.
Specific gravity by Archimedes method.

After South Australian Department of Mines general drilling programme 1966

LYNDHURST DIAPIR

DRY SPECIFIC GRAVITY LOGS

GRAVITY PROVINCES, UNIT BOUNDARIES AND BOUGUER ANOMALIES

To accompany Record No 1973/12

SA/B2-38A

SEDIMENTS

CAMBRIAN AND ADELAIDEAN SEDIMENTS

METAMORPHIC COMPLEXES OF THE MT PAINTER AREA, WILLYAMA BLOCK AND GAWLER CRATON

ACID INTRUSIVE AND GRANITOID ROCKS

FELDSPAR QUARTZ PORPHYRIES OF THE GAWLER RANGES

BOUGUER ANOMALY CONTOURS

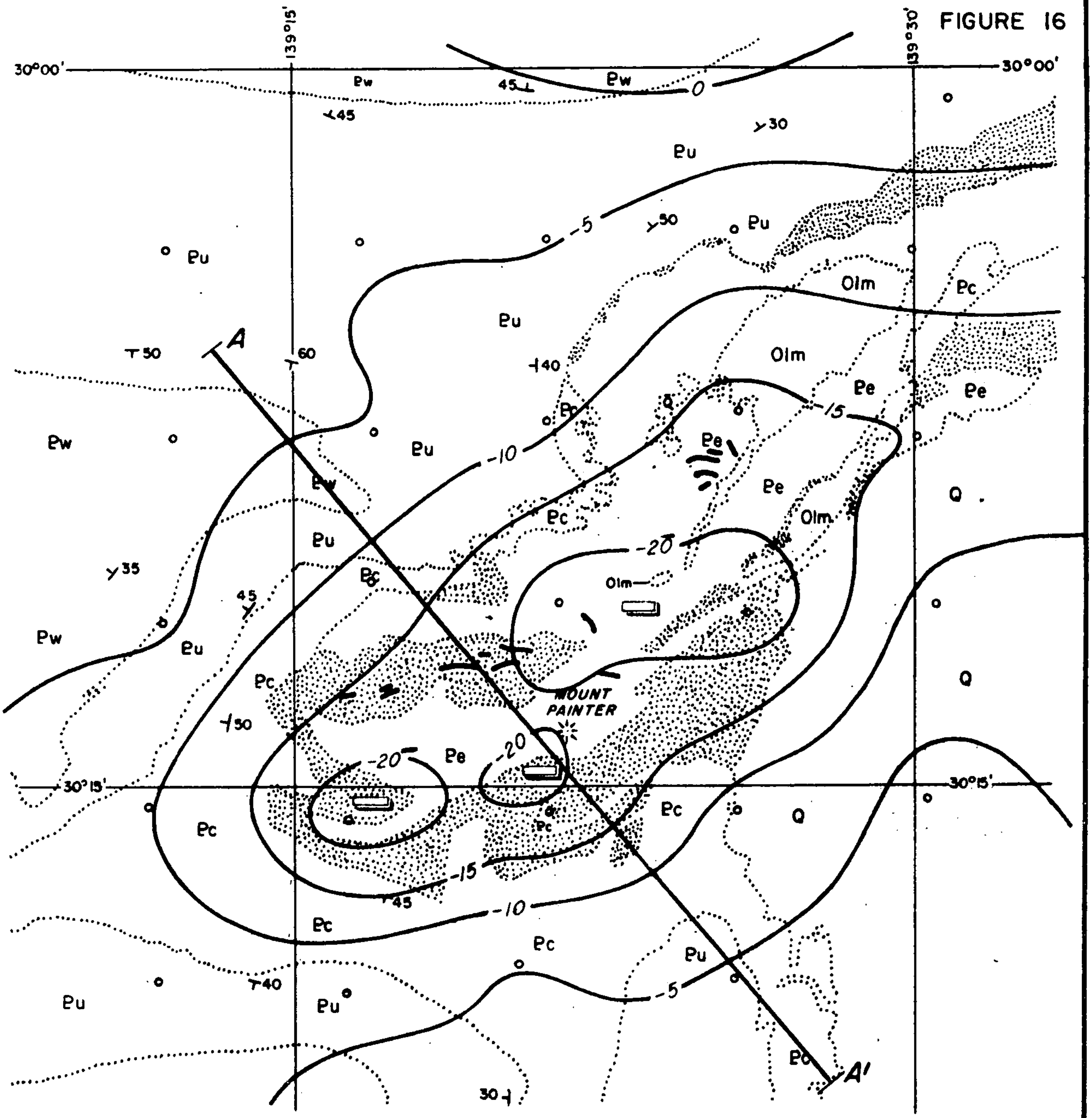
GEOLOGY GENERALIZED AFTER SPRIGG, 1953 (GEOLOGICAL MAP OF S.A. 32M = 1")

GEOLOGY AND BOUGUER ANOMALIES

To accompany Record No 1973/12

SA/B2-33A

FIGURE 16



KILOMETRES

5 0 5 10 15

Geological boundary

Bouguer anomaly contour (mgal)

Gravity 'low'

Gravity station

Strike & dip of bedding

Olm — Mudnawatana granite and pegmatite

Pw — Wilpena group

Pu — Umberatana group

Pc — Burra group and Callanna beds

Older Granite Suite

Pe — Radium Creek metamorphics

Geology generalised after SA Department of Mines Mt Painter provisional. 2m = 1" map and Copley preliminary 1:250,000 sheet

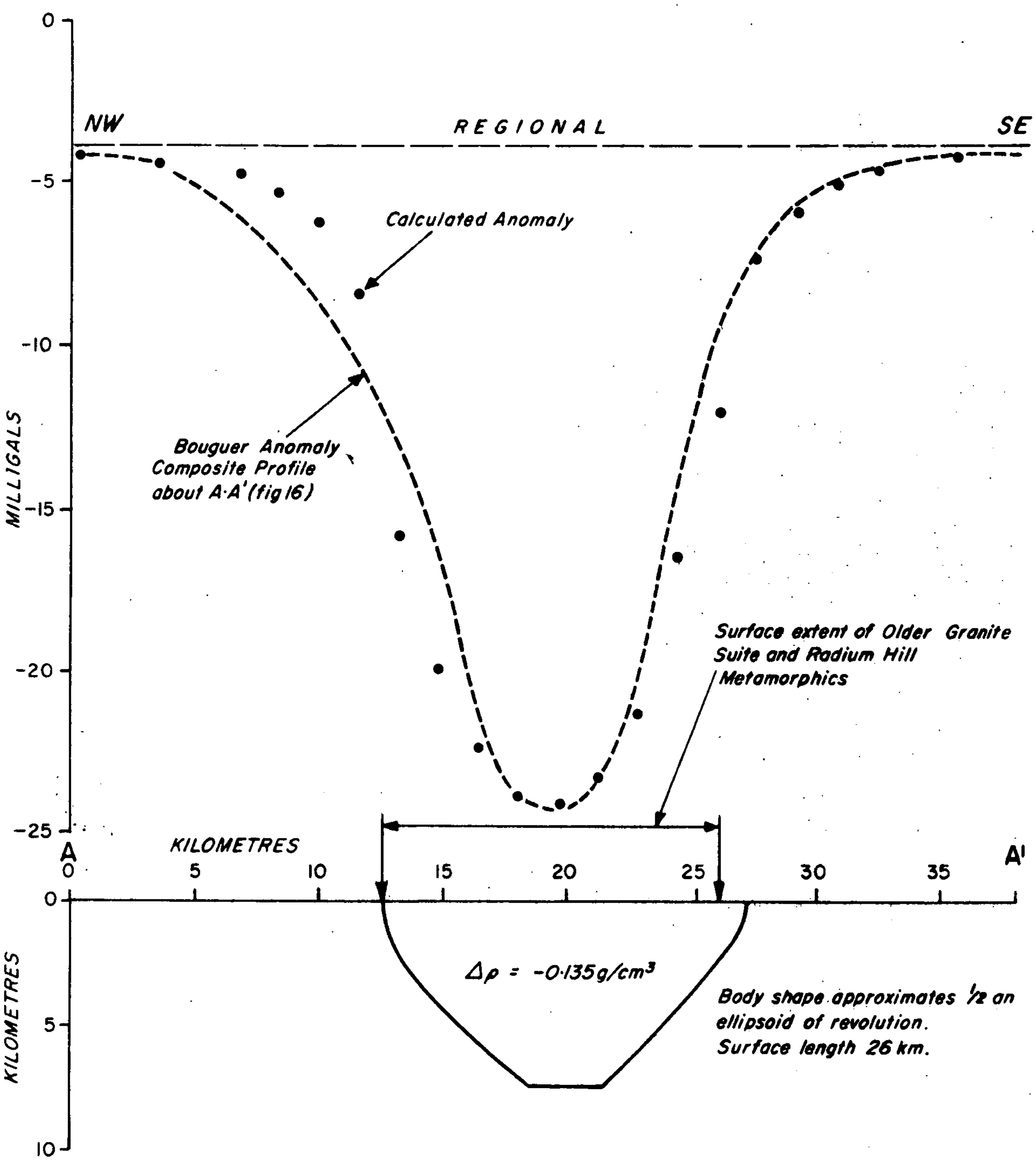
For the calculation of Bouguer anomalies 2·67 g/cm³ has been adopted as an average rock density

GEOLOGICAL AND GEOPHYSICAL SKETCH MAP OF AREA COVERING ANOMALY 5

To accompany Record No 1973/12

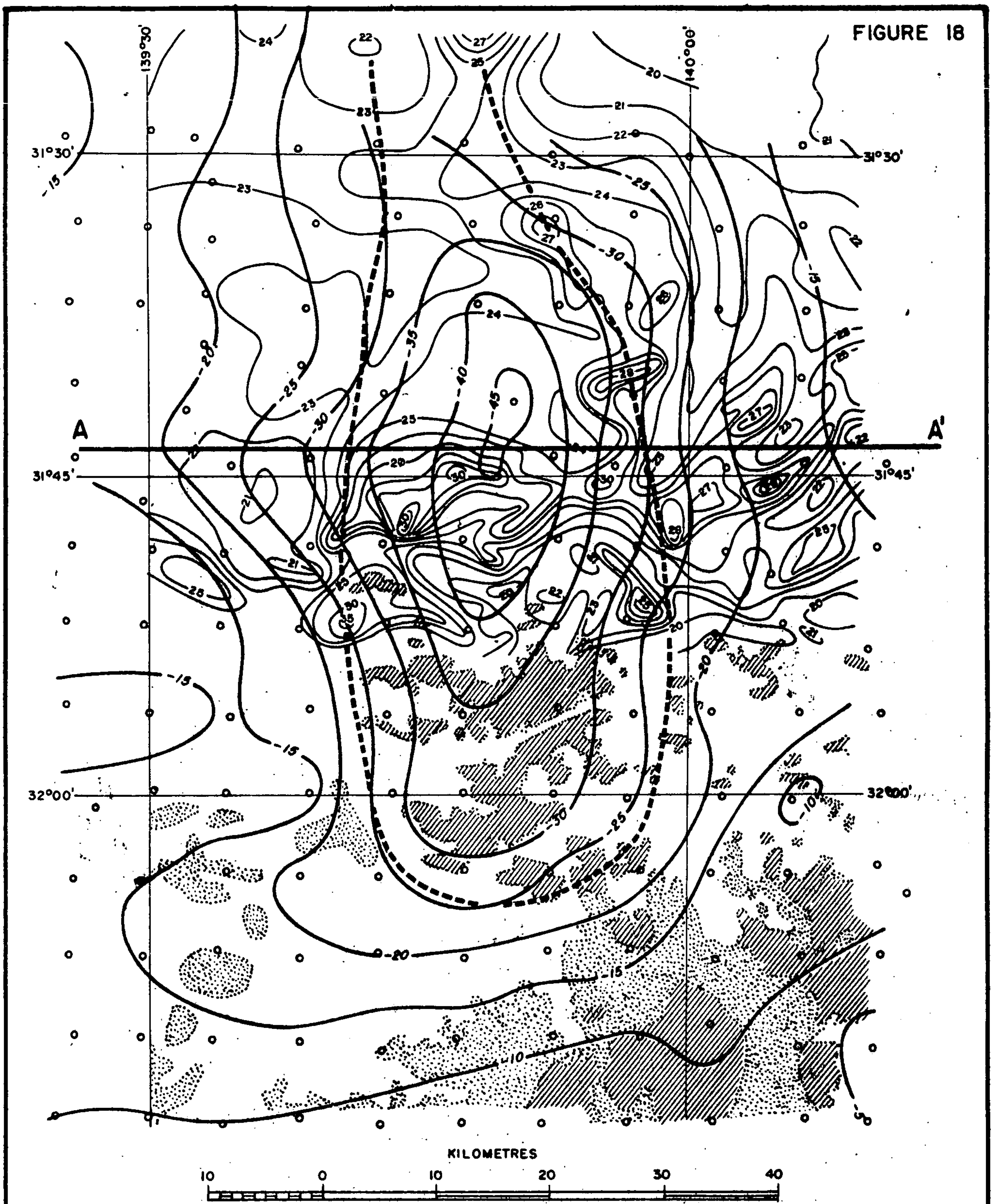
SA/B2-24A

FIGURE 17



GEOPHYSICAL MODEL - FOR ANOMALY 5

FIGURE 18



RECENT SEDIMENTS

ADELAIDEAN SEDIMENTS

WILLYAMA COMPLEX

BOUGUER GRAVITY CONTOURS

AERO MAGNETIC CONTOURS (x100 GAMMAS)

GRAVITY STATIONS

BOUNDARY OF LOW DENSITY BLOCK AS INDICATED BY GEOLOGY AND GEOPHYSICS

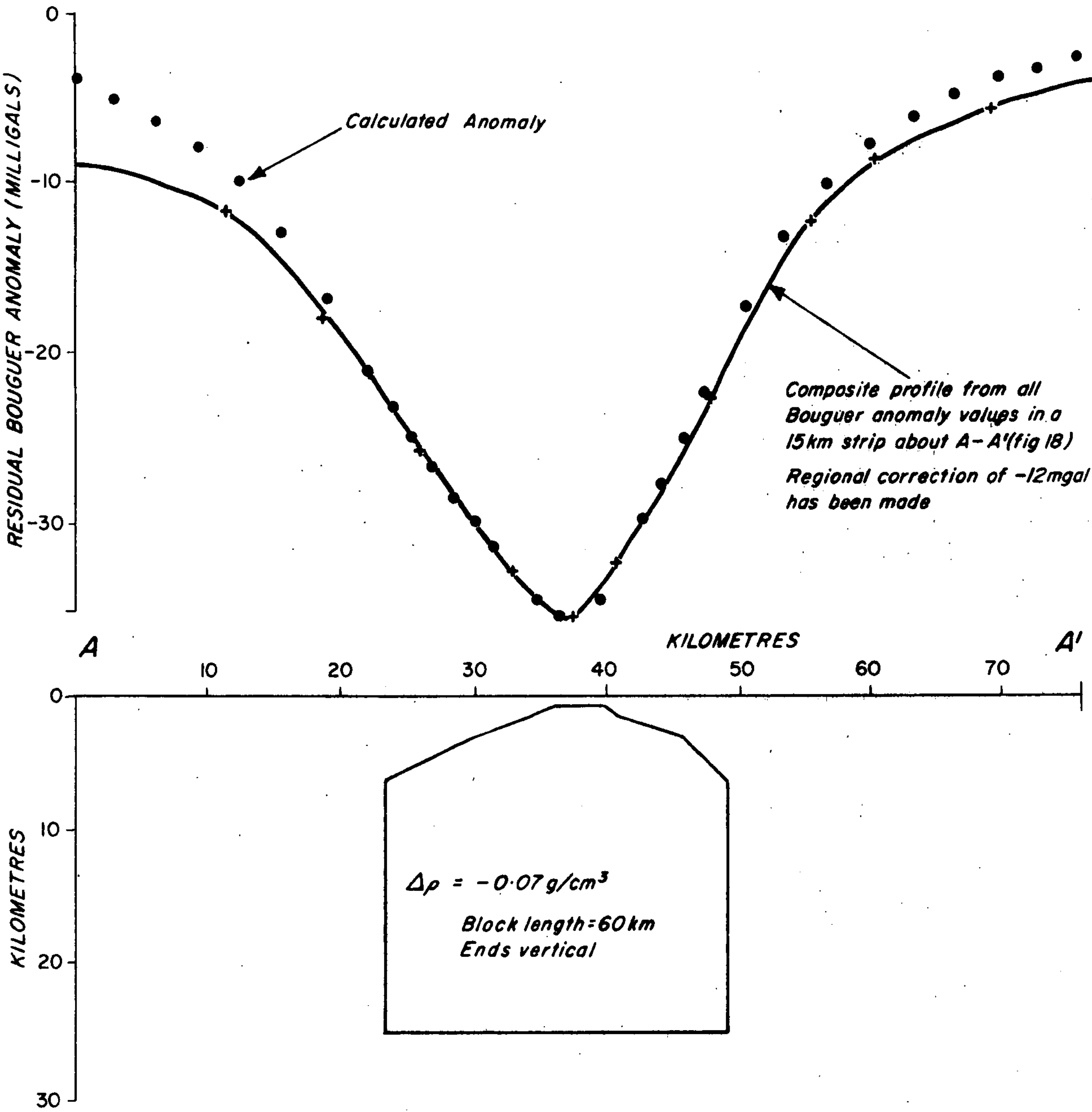
GEOLOGY GENERALIZED FROM SA DEPT OF MINES PRELIMINARY 1:250,000 SHEETS; CURNAMONA AND OLARY.

AEROMAGNETIC CONTOURS FROM SA DEPT OF MINES 1:250,000 CONTOUR MAP OF CURNAMONA

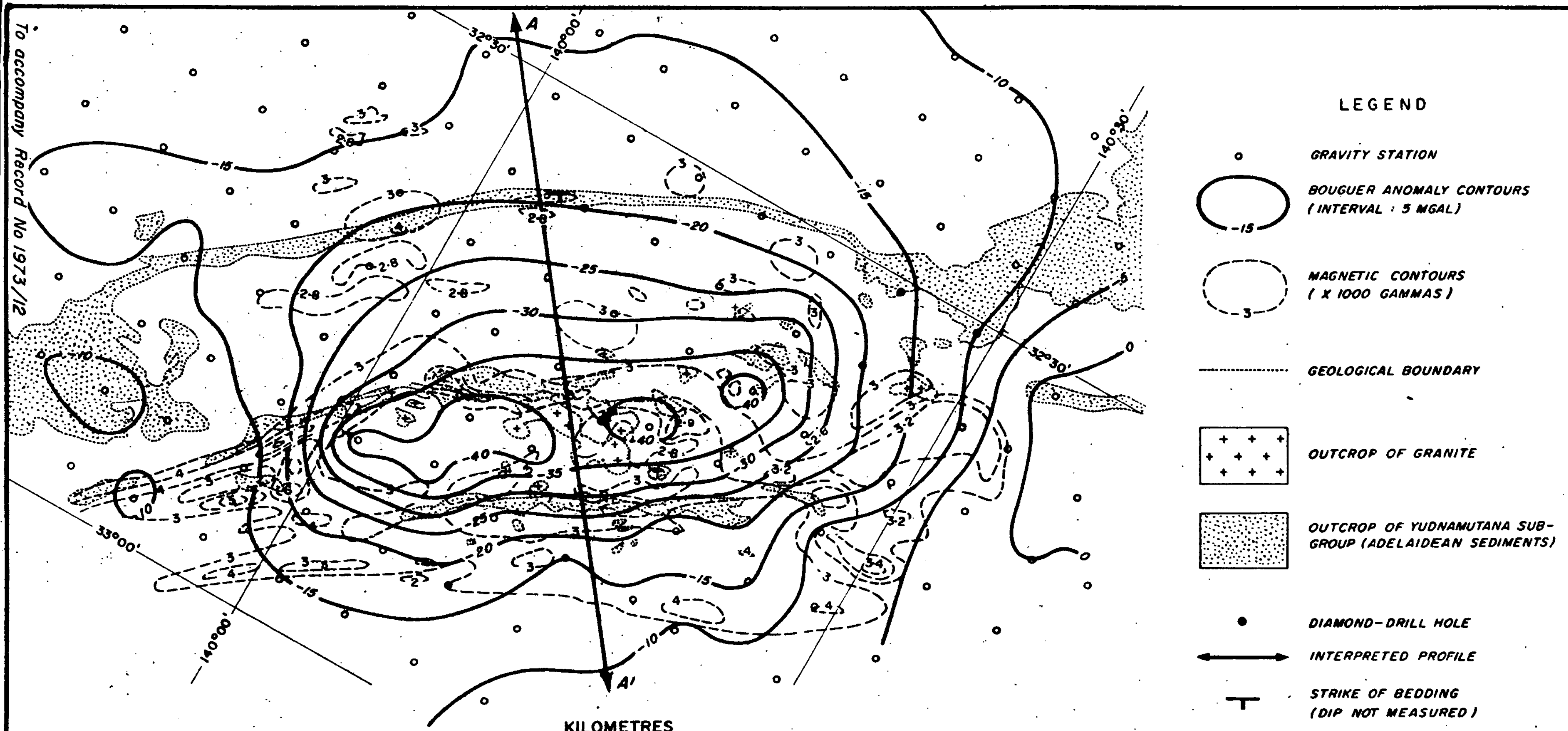
GEOLOGICAL AND GEOPHYSICAL SKETCH MAP OF AREA COVERING ANOMALY 11

To accompany Record No 1973/12

SA/B2-20A



GEOPHYSICAL MODEL - FOR ANOMALY 11



FOR THE CALCULATION OF BOUGUER ANOMALIES 2·67 G/CM^3 HAS BEEN ADOPTED AS AN AVERAGE ROCK DENSITY

GEOLOGY AFTER S.A. DEPT OF MINES 'OLARY' 1:250,000 SHEET (UNPUBLISHED)

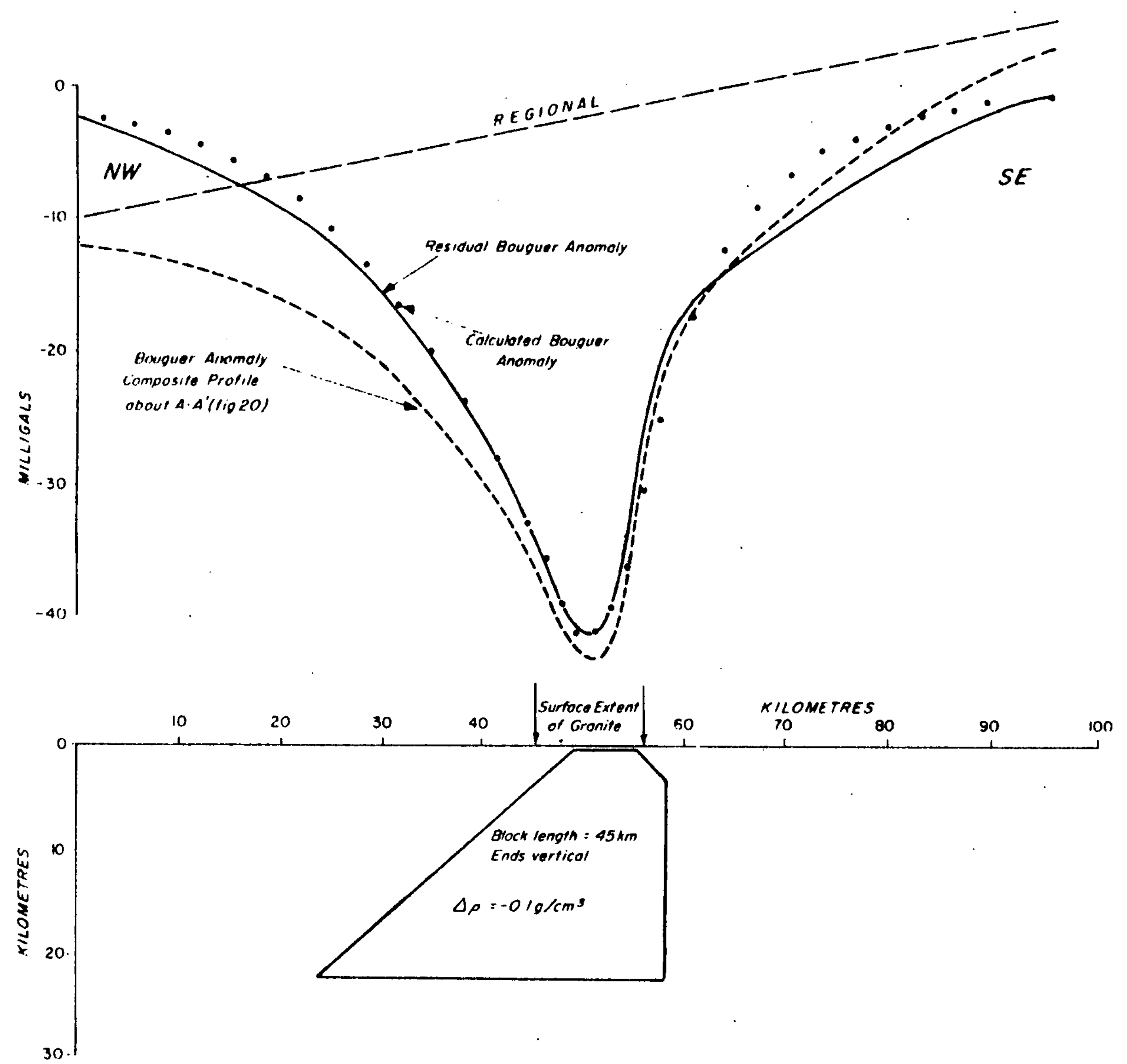
AEROMAGNETICS AFTER S.A. DEPT OF MINES 'OLARY' 1:250,000 SHEET

To accompany Record No 1973/12

GEOLOGY AND GEOPHYSICS FOR ANABAMA GRANITE, ANOMALY 14

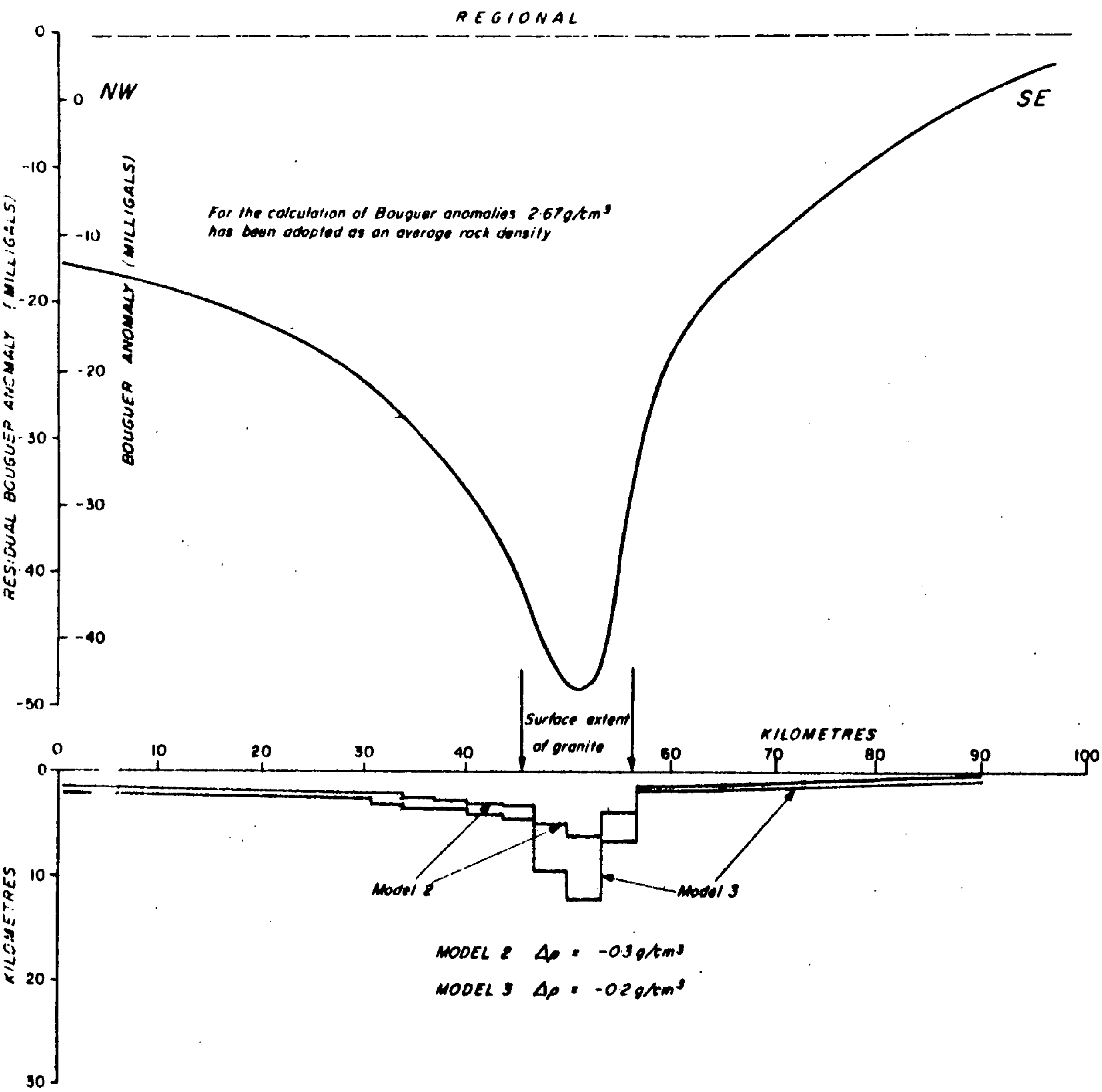
FIGURE 20

SA/B2-17A



GEOPHYSICAL MODEL 1 FOR ANOMALY 14

FIGURE 22



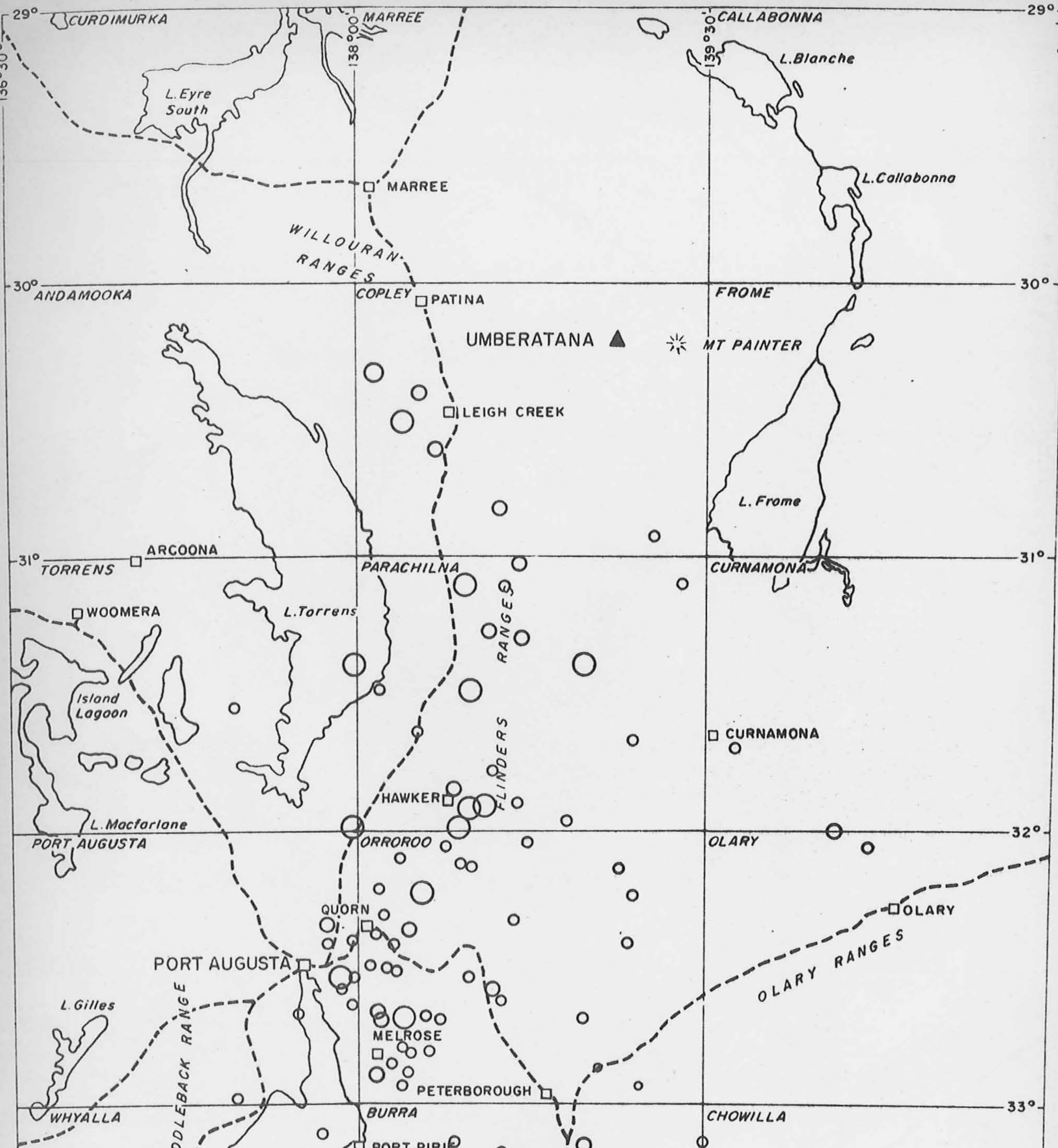
GEOPHYSICAL MODELS 2 & 3 FOR ANOMALY 14

GRAVITY TRENDS

AND BOUGUER ANOMALIES

To accompany Record No 1973/12

SA/B2—34A



SEISMIC EPICENTRES (after White, 1969)

LEGEND

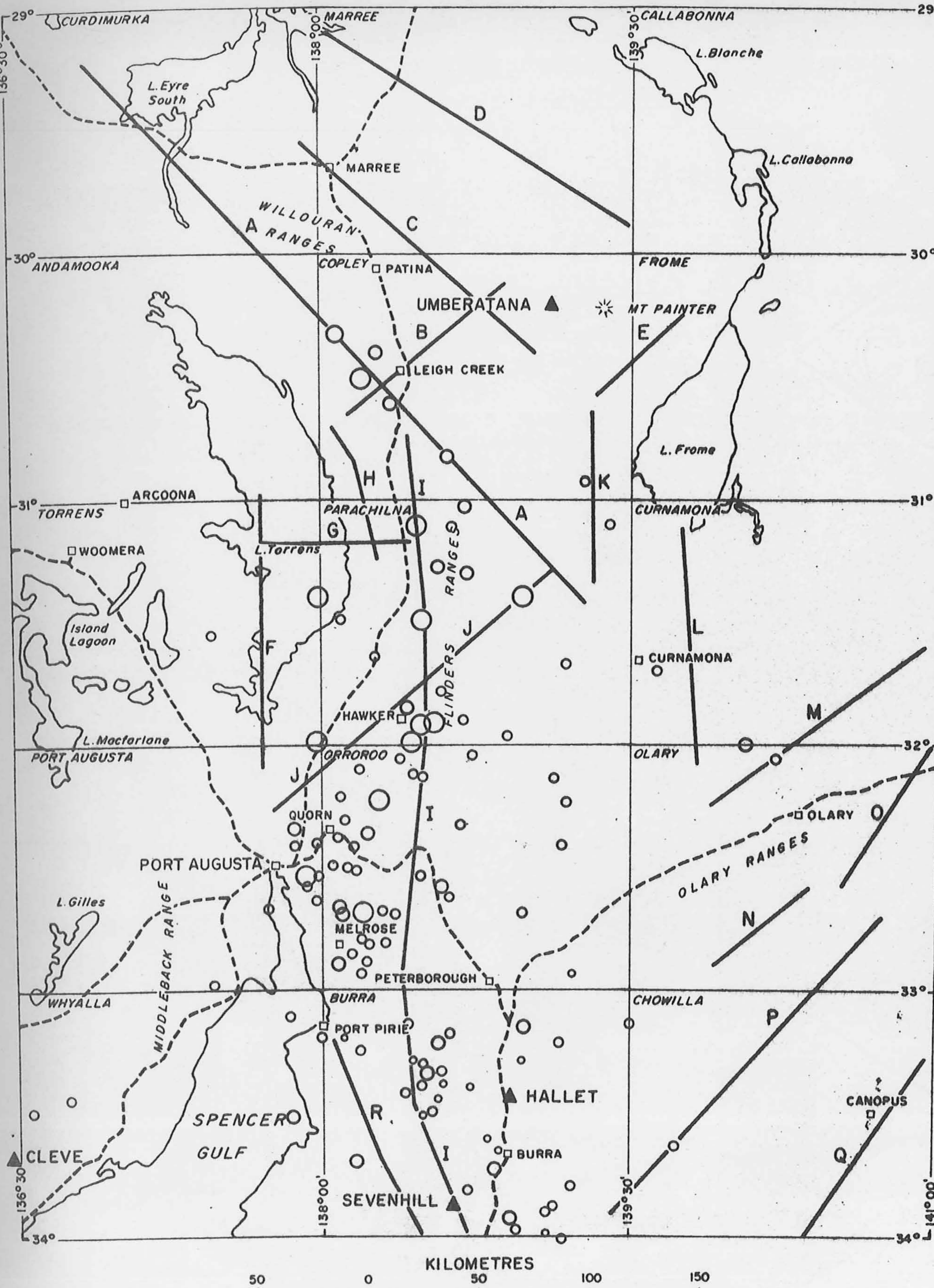
MAGNITUDE (local scale)

- o = <2
- o = 2–3
- O = 3–4
- O = >4
- ▲ Recording station

Footnote:

Locations of epicentres taken from White, 1969; all foci lie within the crust, most within the upper 20 km

FIGURE 25



SEISMIC EPICENTRES AND GRAVITY TRENDS

MAGNITUDE (local scale)

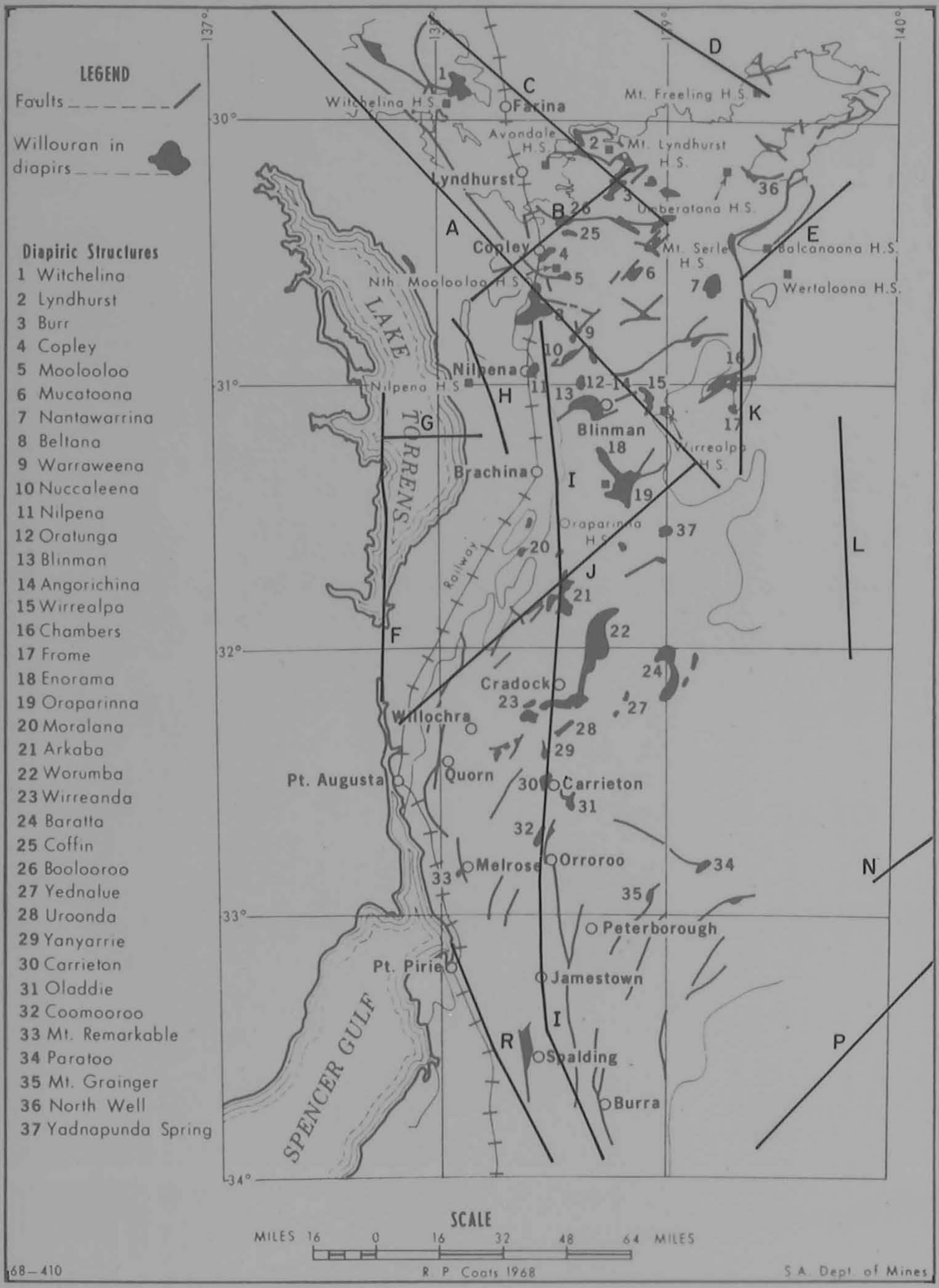
o = < 2

o = 2–3

O = 3–4

O = >4

▲ Recording station



DIAPIRS AND GRAVITY TRENDLINES IN THE ADELAIDE GEOSYNCLINE


DENSITY PROFILES
MILLIGALS
METRES (AMSL)
KILOMETRES
A
30°04'S
B
30°15'
C
30°31'
D
30°46'
E
31°02'
F
31°14'
G
31°29'
H
31°45'
I
32°00'
J
32°16'
K
32°31'
L
32°47'
M
32°58'
PLATE 1