The upper crustal geology of the Georgina Basin region

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Pattern recognition in regional maps of Bouguer anomalies and total magnetic intensity contours suggests that the basement of the Georgina Basin can be divided into four regions, three of which contain subsurface extensions of the Tennant Creek Inlier, Arunta Inlier and Mount Isa Orogen-South Nicholson Basin (sensu Plumb, in press), and a fourth in the south, for which there is no known outcrop and whose composition differs from the others. The boundaries between these regions are in most cases not visible in outcrop.

The basement to the Georgina Basin thus consists predominantly of metamorphic rocks and granites inferred to be similar to the outcrop areas which surround it. This is overlain by Adelaidean and Phanerozoic sediments, which locally are up to 8000 m thick. With the exception of the Toko Syncline, Dulcie Syncline, Lander Trough and Burke River Structure, where up to 3500 m of Palaeozoic sediments are preserved, only a thin veneer up to 500 m thick of Phanerozoic sediments occurs in the basin. However, considerable thicknesses of possible Adelaidean sediments are interpreted to occur both beneath these structures and locally elsewhere, for example 3000 m in the Toko Syncline, 4000 m near Camooweal (this figure may include older Carpentarian rocks), and 6000 m in the Glenormiston-Sandover River area.

A geological history for the basement of the area is proposed, which provides a framework for subsequent deposition in the Georgina Basin. An important suggestion is that there was extensive thrusting to the northeast of the Arunta Inlier rocks at about 1000 m.y.—which produced scalloped thrusts, some of which may cut Mount Isa Orogen rocks. It is inferred that thick Adelaidean sediments were subsequently deposited in graben with active margins along these thrusts, and later, after a brief hiatus, a similar reactivation was accompanied by Palaeozoic sedimentation.

Introduction

This paper presents the results of a rapid interpretation of all available regional geophysical and geological information in the Georgina Basin region (Fig. 1). It may be viewed as an adjunct to the detailed study of the geology of the southern part of the basin (Shergold & Druce, in press) and recent seismic surveys in the Toko Syncline (Harrison, 1979). The research aimed to provide a better understanding of the basement structure and history of the Georgina Basin in order that its full economic potential could be assessed.

The methodology used was appropriate to provide, for the first time, a comprehensive model for the upper crustal geology of the area. In addition to the detailed seismic information from the southeastern part of the Basin, gravity and airborne magnetic information in the BMR data bank were analysed with all pertinent geological information. Individual geophysical surveys including seismic (Alliance, 1970; Davies, 1974; French Petroleum Co. 1964, 1965a, 1965b; Harrison, 1979; Harrison, Bauer & Hawkins; Harrison & Schmidt, 1978; Jones & Robertson, 1967; Milton & Seedsman, 1961; Phillips-Sunray, 1962; Robertson, 1963). magnetic (Adastra-Hunting, 1963a, 1963b, 1963c, 1966, 1967; BMR, 1976; Jewel, 1960; Quilty & Milson, 1964; Wells, Milson & Tipper, 1966), and gravity surveys (Barlow, 1965; Gibb, 1967, 1968) are given in the references. Because of the multidisciplinary nature of the task an iterative method was used. Firstly, the gross magnetic and gravity features were used to subdivide the basin and its fringes into areas with internally consistent geophysical patterns (Figs. 2 & 3); secondly. the geology of these areas was interpreted by extrapolation from the fringe beneath the sedimentary cover; thirdly, detailed cross-sections were selected to incorporate both drilling and seismic information and to cross the major features identified in step two; fourthly, detailed modelling of the gravity and magnetics along these cross-sections was undertaken (Fig. 1): and finally the geology deduced from the modelling was used to update the original regional upper crustal geology (Fig. 4).

Geology

The Georgina Basin (Smith, 1972; Shergold & Druce, in press) comprises Adelaidean and Lower Phanerozoic sediments which mask the junction of four major geological regions; the Arunta Inlier (Shaw & others, 1974; Shaw & others, 1977; Shaw & others, 1978), the Northwest Queensland Province, comprising Mount Isa Orogen and Lawn Hill Platform (Plumb & Derrick, 1975), the Tennant Creek Inlier (Ivanac, 1954; Crohn, 1975) and the South Nicholson Basin (Fig. 1). The basin sediments, which extend over an area of some 325 000 km^2 straddling the Queensland-Northern Territory border, consist of Adelaidean-Carpentarian siliciclastic rocks, Cambrian to earliest Ordovician carbonate rocks and Early-Middle Ordovician siliciclastic rock, unconformably overlain, firstly by Devonian and then by Cretaceous siliciclastic rocks.

The thick sequence of carbonate rocks in the Basin, apart from containing considerable phosphate resources, is a potential host environment for sedimentary lead and zinc mineralisation and, particularly in the Toko Syncline, for hydrocarbons.

Geophysical domains

In an Australia-wide examination of gravity trends, Wellman (1976a, b; Fig. 1) recognised within the Georgina Basin region four areas with distinctive gravity anomaly directions; aeromagnetic anomaly patterns substantiate these divisions with minor boundary alterations. Three of these areas are represented

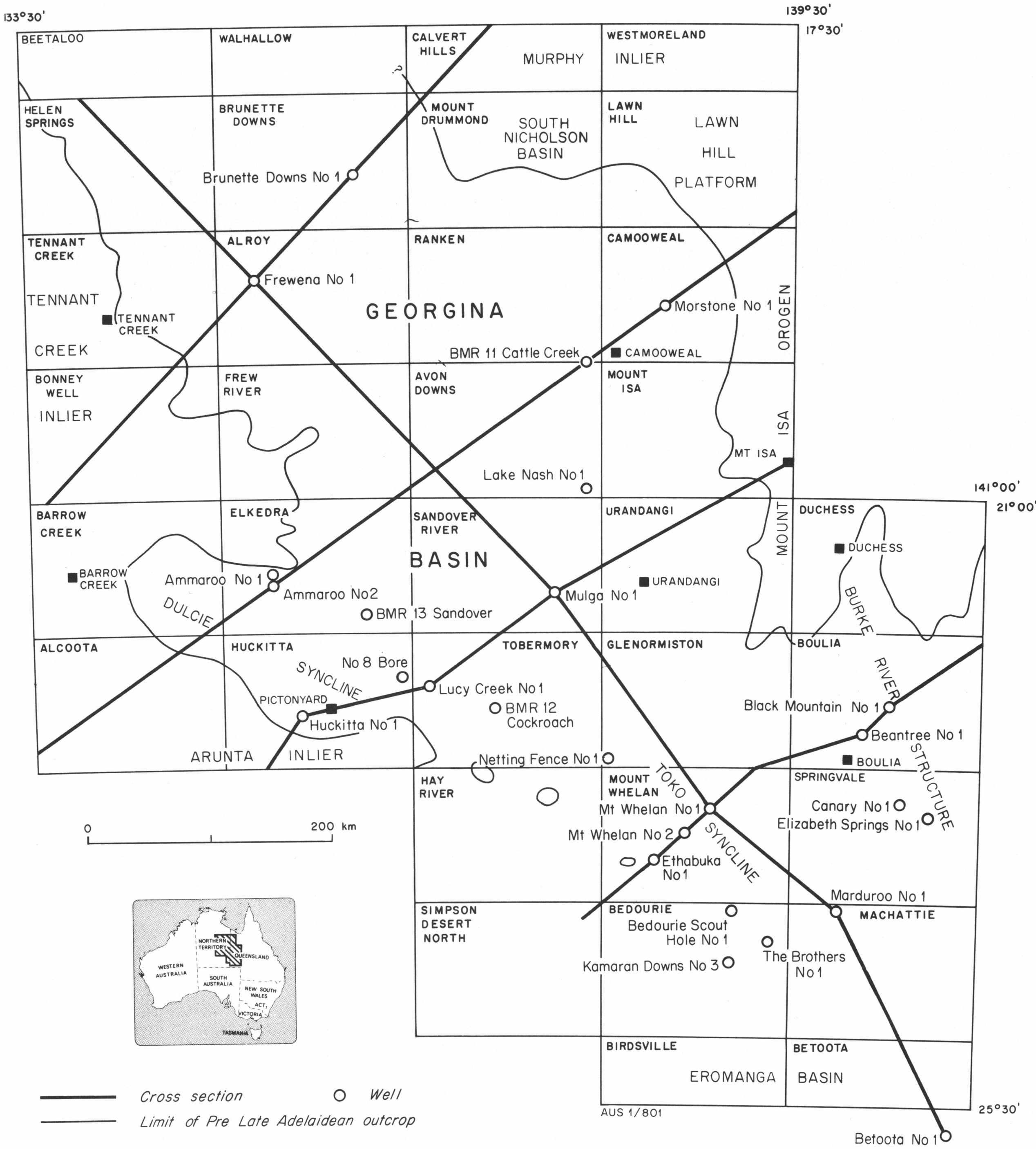

Figure 1. Locality map of Georgina Basin and surrounds.

in outcrop by the Tennant Creek Inlier to the northwest, the Arunta Inlier to the southwest, and the Mount Isa Orogen to the east. Sediments of the Eromanga Basin (Senior & others, 1978) entirely overlie the fourth area.

As a basis for pattern recognition the 1:5 000 000 Bouguer anomaly map (5 milligal contours) and the 1:2 500 000, 1:1 000 000 and 1:250 000 total magnetic intensity maps (50nT, 10nT, 10nT contours respectively) were used. Because of their importance to the following discussion of 'Geophysical Domain', a term coined for an area with magnetic and gravity patterns and trends distinct from those in adjacent areas, a Bouguer anomaly contour map and a Total Magnetic Intensity map are included here at a scale of 1:5000 000 in Figures 2 and 3.

Domain 1

The Domain 1 is characterised by several prominent and often near circular gravity lows in a region of generally negative Bouguer anomalies. The lows occur sporadically along arcuate lines which curve to the east and then northeast.

The total magnetic intensity pattern varies considerably from the areas of magnetic basement outcrop in the west near Tennant Creek to the more deeply buried easterly part. In the central part, narrow curvilinear anomalies halo Bouguer anomaly lows, giving a clear and relatively intense curvilinear pattern lacking

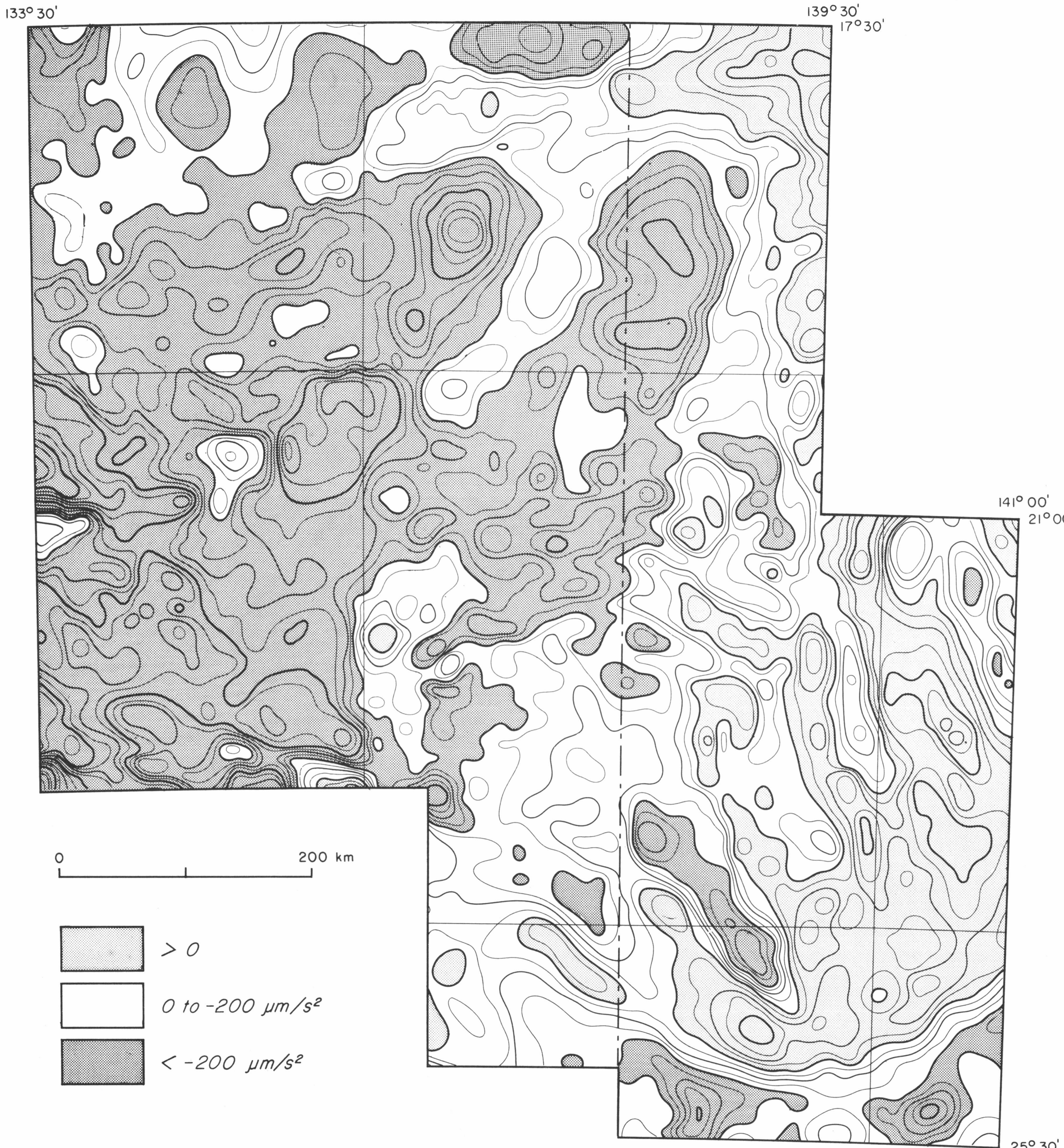

Figure 2. Bouguer anomaly contours at 50μm/s² intervals.

a uniform trend direction, except in the north where the anomalies are straight and trend to the northeast. To the west and northwest both westerly and northwesterly trending anomalies are dominant. Further east the anomaly amplitude and definition decreases, resulting in a relatively smooth pattern, in which northeasterly trending anomalies can still be discerned.

To the north the domain is bounded by an elongate Bouguer anomaly high extending from WESTMORELAND* west-southwest to BRUNETTE DOWNS. To the east it terminates against Domain 3, which embodies the Mount Isa Orogen. The westerly and southerly margins are less clearly defined: the western margin appears to be outside the area studied, and the present less than adequate aeromagnetic coverage prevents any attempt at resolution.

To the south Domain 1 is bounded by the strong west-northwesterly Bouguer Anomaly low reflecting the northern margin of the Arunta Inlier.

Domain 2

The gravity pattern in Domain 2 comprises linear doublets of lows and highs, which generally trend east-southeast, swinging more southerly farther to the east. This dominant pattern is superimposed on a regional gravity gradient which rises to the south-east, continuing into Domain 3.

*** Throughout this report 1:250 000 sheet areas are shown in capital letters.**

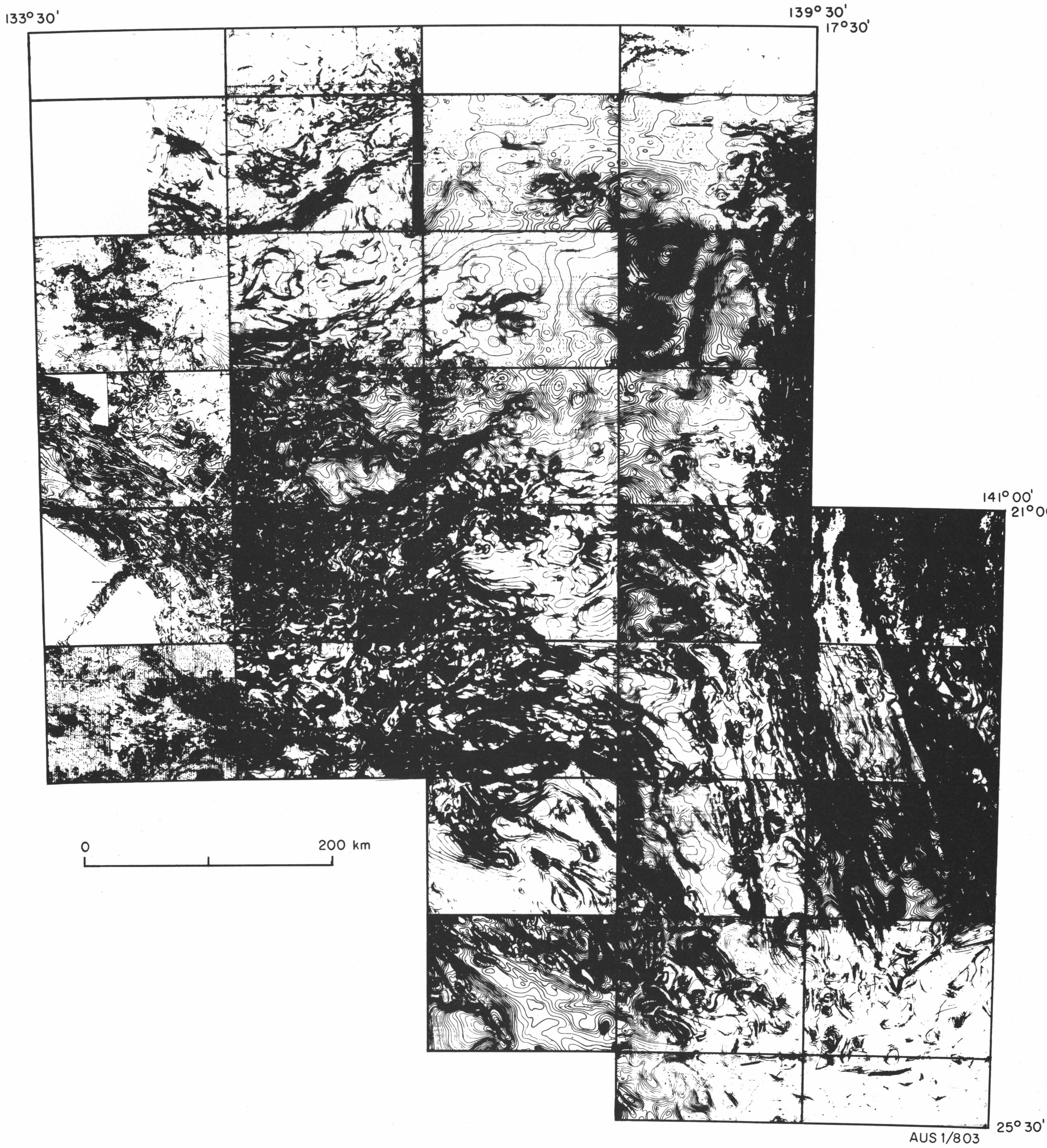

Figure 3. Total magnetic intensity map reduced from 10 nT contoured 1:250 000 sheets gives a regional view of the major patterns of anomalies.

Total magnetic intensity contours mainly reflect localised sources, commonly appearing as "bulls eyes" and blocky anomalies which are aligned to give an east-west trend. To the southeast the anomalies become elongate and trend southeastward. As in Domain 1 most anomalies are subdued as the source depth increases.

The southern part of TOBERMORY is crossed by a prominent arcuate magnetic gradient some 15 km wide becoming negative to the north, which is opposite to the usual expectations of anomaly sign for east-west-trending magnetic features in the southern hemisphere. There is no evidence in the contour pattern, or indeed in the original flight charts, of near-surface magnetic sources in the region of the gradient, so presumably the source is very deep. The gradient swings southeasterly on Mount Whelan, generally paralleling the gravity pattern described above.

Domain 3

The gravity pattern in Domain 3 consists of linear southerly to south-southeasterly trending highs and lows in a region of regionally high Bouguer anomalies.

The trend is mirrored by the total magnetic intensity contours. In the central area around Mount Isa and Duchess where the sources are shallow, the patterns are short and curvilinear, with an incipent north-south

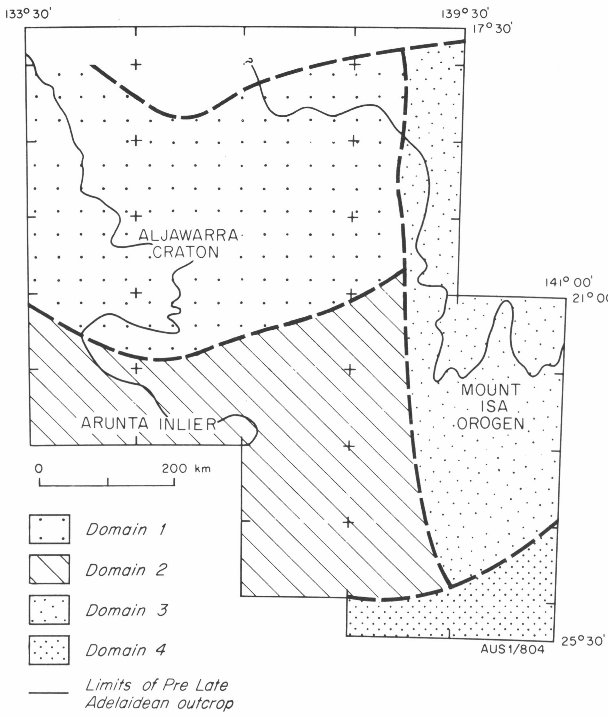

Figure 4. Geophysical Domains over the Georgina Basin region showing the extent of major areas with similar Total Magnetic Intensity and similar Bouguer anomaly patterns.

trend which is strengthened both to the north and south as the sources become deeper.

Not only are the trends north-south but they are grouped into broad, long belts which essentially parallel the trend directions: alternate belts contain high-amplitude anomalies and quiet zones.

The westerly boundary is a major geophysical feature corresponding to the edge of the Mount Isa Orogen: to the north the domain may be bounded by the east-west-trending Bouguer anomaly high which also bounds Domain 1. The eastern boundary lies beyond the study area, probably beneath the northern part of the Eromanga Basin. To the south Domain 3 is bounded by a strong change in magnetic intensity which signifies Domain 4.

Domain 4

A broad Bouguer anomaly low to the south of a prominent northeast-trending gravity gradient characterises Domain 4. The total magnetic intensity is subdued, with anomalies of low amplitude trending to the northeast.

The northern boundary is recognised by a sharp termination of the high-amplitude south-trending anomalies of Domain 3. A commensurate change in the gravity from a region of high Bouguer anomaly in Domain 3 to low in Domain 4 is equally apparent. However, it is stepped some 40 km to the southeast. Other boundaries of Domain 3 are not recognised in the study area.

Pre-Adelaidean geology

The available evidence indicates that the Phanerozoic (and probably the Adelaidean) section does not contain extensive and distinctive magnetic units; it can be regarded essentially as a non-magnetic cover to older metamorphic rocks. Thus the magnetic pattern arises mainly from pre-Palaeozoic rocks.

Extrapolation of distinctive gravity and magnetic patterns from outcrop areas where associations with mapped rock units could be established, has given a basis for prediction of the pre-Phanerozoic basement composition in areas of cover.

Figure 5 shows an interpretation of the composition of the basement in terms of the major rocks groups known in outcrop, and others which could be reasonably predicted from the usual geophysical associations. For example magnetic quiet zones and Bouguer anomaly lows are commonly attributed to granites, and abrupt changes in the magnetic contours are commonly attributed to faults.

In the northwest in Domain 1 the Warramunga Group rocks are indicated to extend east and northeast from TENNANT CREEK across ALROY and BRUNETTE DOWNS. South of this, the Hatches Creek Group, characterised by curvilinear magnetic anomalies parallel to strike of sedimentary outcrop and often draped around granites, is indicated on at least nine map sheets.

Shaw & others (1977) have described the eastern part of the Arunta Block in three major groupings or divisions of rocks, each with characteristic geophysical responses. In Domain 2 our interpretation predominantly uses their Division 2, which is broadly divided into a granite-free zone and a granite-rich zone, typified by the Harts Range Group and Bonya sequence respectively. Division 2 rocks are interpreted to extend acoss seven map sheets in the study area, from ALCOOTA to BEDOURIE.

On HAY RIVER and BEDOURIE an extensive area of Adelaidean sediments, some of which appear to contain magnetic units, are predicted to extend away from the rather localised known outcrops in HAY RIVER.

Rock units in the Mount Isa Orogen are described by Derrick & others (1976), and Plumb & others (in press). Those with distinctive geophysical patterns which enter the study area in outcrop include the Mary Kathleen Group, Haslingden Group, Malbon Group, Tewinga Group, Soldiers Cap Group and various granites. In Domain 3 the basement composition has been predicted to the south and west of the areas of outcrop, in terms of these rock units. By far the most extensive is the Haslington Group, which embodies the Eastern Creek Volcanics. Rocks of this group probably extend westwards to just east of Silvermine Creek, where it is suggested that an abrupt change in basement composition occurs.

In Domain 4, the basement rock formations are not known in outcrop, but are thought to consist of metamorphics.

In the far north of the study area, the Peters Creek Volcanics and associated rock units (Plumb & Sweet, 1974) extend westwards from WESTMORELAND across five map sheets to HELEN SPRINGS.

Detailed description of sections

Detailed computer modelling of the subsurface geology was undertaken along selected cross-sections (Fig. 1). An iterative procedure was used to produce two-dimensional models from Bouguer anomaly profiles. The first iteration models used all relevant outcrop geology, well logs, depth-to-magnetic-basement estimates, seismic reflection information, and interpreted compositions from the magnetic and gravity patterns.

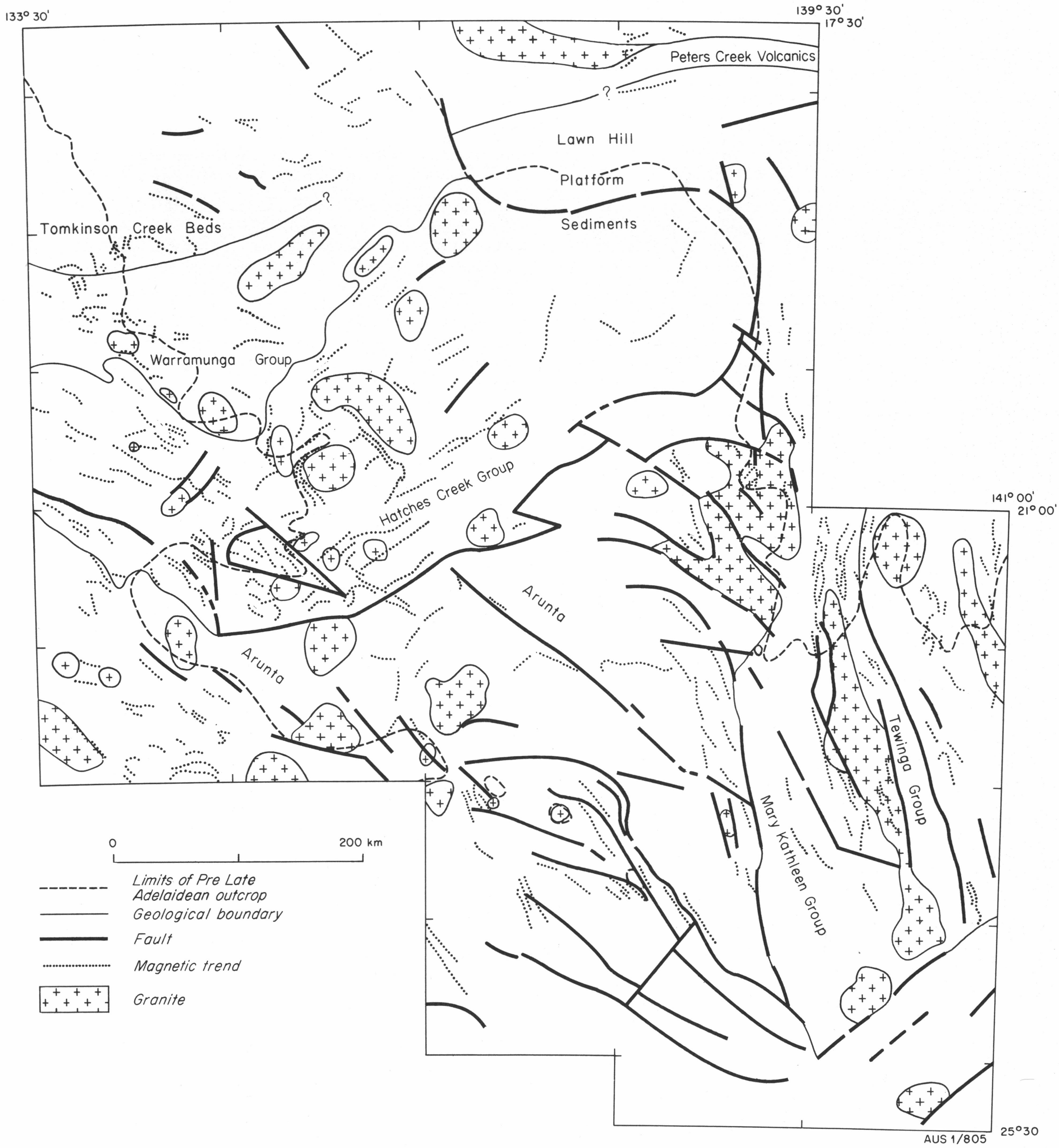

Figure 5. Magnetic basement composition interpreted by extrapolation from Precambrian outcrop areas fringing the Georgina Basin.

Depth to magnetic basement was estimated by use of iterative computer modelling on hand-digitised magnetic profiles for 123 selected anomalies which lay close to the geological cross-sections of interest. Two approaches were used, as appropriate; a dipping, tabular body model, and a fault-step model. In most cases two or three depth estimates were made on successive profiles across each anomaly to allow a judgement to be made on the tolerance of the methods. In addition, the earlier depth estimates of Wells & others (1966), and company reports, were used.

To facilitate gravity modelling a regional element was removed from the Bouguer anomaly data. If the crust is not in isostatic equilibrium then this regional element can be used to estimate the crustal thickness variations shown in Figure 6, and the sections of Figures 7 to 11 (Mathur, 1977). However, if the assumption that the region is in isostatic equilibrium is made, then a completely different model for crustal thickness would apply (Falvey, 1977).

Regardless of the cause of the regional gradients, the models computed for the upper crust are still valid.

There are few density measurements available for rocks in the study area, and of these, most apply to Palaeozoic sediments, particularly the carbonates (Gibb, 1967, 1968). Generally, the few measurements of core held at BMR do not show significant density differences between the Palaeozoic of the Georgina Basin and Precambrian strata penetrated beneath. Accordingly, it was usually necessary to adopt assumed densities for various

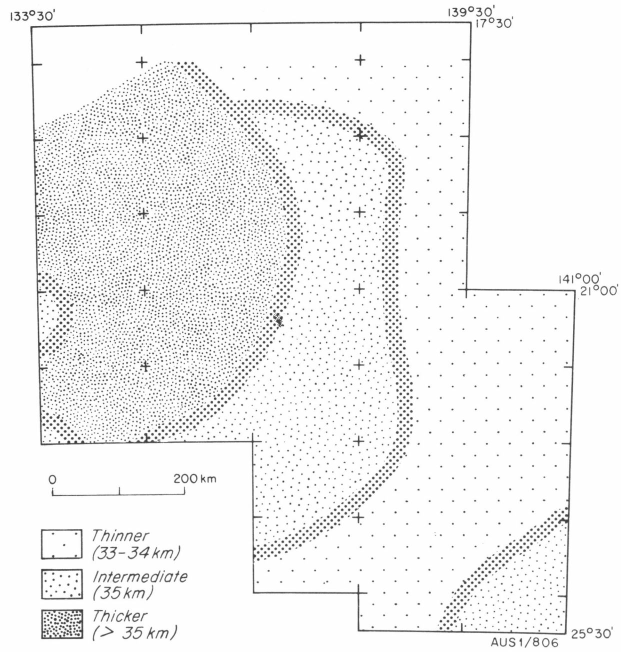

Figure 6. The 'Regional' removed from the Bouguer anomalies might be attributable to crustal thickness variations, or lateral density charges in the crust or both. For convenience in the modelling the former was assumed for a crust not in isostatic equilibrium, resulting in the crustal thickness model shown above; if isostacy was assumed then a totally different crustal thickness model would apply.

rock units, based mainly on considerations of the lithologies present in outcrop and the measured densities of similar units elsewhere (Table 1). The process of selection of densities was controlled by detailed gravity modelling across the Toko Syncline, where sediment thicknesses have been determined by seismic surveys.

Ethabuka-Black Mountain (Fig. 7)

The Ethabuka-Black Mountain section traverses the Toko Syncline and trends northeast, extending for some 360 km from the southwestern corner of the MOUNT WHELAN 1:250 000 sheet area to the northeastern corner of the Boulia 1:250 000 sheet area. The section ties Ethabuka No. 1, GSQ Nos. 1 & 2, Beantree No. 1 and Black Mountain No. 1 wells and is contiguous in its southwestern part with several BMR and AOD seismic traverses (Harrison & Schmidt 1978; Harrison, 1979).

The crustal thickness has been calculated at 33 km and appears to be relatively uniform, probably thickening slightly to the southwest.

The section traverses Domains 2 and 3 and is normal to the regional structures. The cross-section was constructed using seismic, gravity and magnetic data.

The area underlain by Domain 2 is characterised by negative Bouguer anomalies and seismic sections which show thick sedimentary sequences, that are best explained by drawing the boundary between the metamorphic basment (Domain 2) and overlying sediments at 6-8 km. However the metamorphic rocks outcrop immediately to the southwest of the Toomba Fault (southwest margin of the Toko Syncline), at which point they are overthrust to the northeast. This outcrop area is marked by a Bouguer anomaly high and its eastern edge by a magnetic high.

	Adopted g/cm^3	*Contrast* g/cm^3
Mesozoic sediments	2.40	—0.40
Palaeozoic (carbonates,	2.75	—0.05
(silicic sediments	2.60	—0.20
Adelaidean sediments	2.65 to 2.70	—0.15 to —0.10
Undifferentiated metamorphics	2.80	—0.00
Basic intrusives/extrusives	2.90 to 2.95	+0.10 to +0.15
Granites/acid volcanics	2.70	—0.10
Lower crust		+0.30

Table 1. Density of rock units.

The boundary between Domains 2 and 3 is drawn 25 km northeast of GSQ Mount Whelan No. 1; although marked only by a subtle change in the magnetic pattern indicative of a fault, its location is some 2 km to the northeast of very weathered basement outcrop which is considered to be more Arunta-like than Mount Isa-like (S. Simpson, pers. comm). This boundary does however correspond to a change from essentially granite-free basement in Domain 2 to a sequence in which large granitic bodies are intruded into the metamorphic rocks of Domain 3.

The basement of Domain 3 is generally shallow, the top being at about 2 km, but for some 100 km southwest of Beantree No. 1 well the basement is at about 0.5 km. Granitic bodies extending to 8-10 km are conspicuous, and can account for some of the prominent Bouguer anomaly lows. In the area of Black Mountain No. 1 the Bouguer anomaly high and the marked magnetic high immediately to the northeast of the well are probably associated with a high density basic body within the metamorphic rocks.

Adelaidean sediments occur both in the southwest and northeast, and reach up to 6 km in thickness in the southwesthern corner of MOUNT WHELAN and beneath Phanerozoic sediments in the Toko Syncline. Within the Toko Syncline the gravity low, depths to magnetic basement, and weak seismic reflections support this interpretation. Southwest of the Toomba Fault a gravity low suggests that the Adelaidean sequences reappears and thickens to 6 km in the southwest; it has a stronger magnetic response than normal

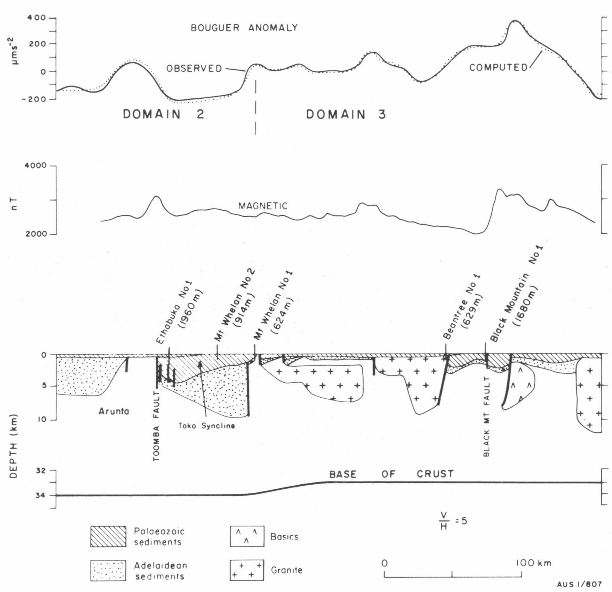

Figure 7. Modelled cross-section, Ethabuka to Black Mountain.

for inferred Adelaidean sediments, one that is more characteristic of the responses from outcrop of Adelaidean tillite in the Barrow Creek area. There is a possibility that some of the inferred Adelaidean at the southwestern end of the section could comprise Phanerozoic sediments. To the northeast of the Toko Syncline the Adelaidean thins to less than 100 m, and may be entirely absent. It appears as a thickening wedge 25 km west of Boulia, reaching a thickness of 2 km near the eastern margin of BOULIA.

The Phanerozoic sediments are up to 4 km thick in the Toko Syncline on this section; to the northeast they comprise only a veneer, although in Black Mountain No. 1 they are up to 1.3 km thick. Good control from seismic sections (Harrison, 1979), and the gravity low, are evidence from the asymmetric synform of the Toko Syncline sediments. To the northeast the interpretation is based on well data and the gravity profile.

Apart from the changes in thickness of the major rock bodies, faults are major features in this cross-section. The most conspicuous is the Toomba Fault which thrusts basement rocks of Domain 2 over Phanerozoic sediments of the Toko Syncline. To the west of GSQ Mount Whelan No. 1 there is rapid thinning of Adelaidean sediments across a fault which is considered to be the boundary between Domains 2 and 3. Immediately to the east of Black Mountain No. 1 a major fault upthrown to the east brings a high density body closer to the surface: there is a suggestion from seismic data, and possibly from the magnetic profile, that this fault is a reverse fault at depth, although at the surface it is normal. Another possibility is that a thrust fault occurs in the basement immediately to the east of the Black Mountain Fault.

Huckitta-Mount Isa (Fig. 8)

The Huckitta-Mount Isa section parallels the Ethabuka-Black Mountain section, some 200 km to the northwest. The section extends for 500 km from the southern margin of the HUCKITTA 1:250 000 sheet area northeastward to Mount Isa, and tied the Huckitta No. 1, Lucy Creek No. 1, and Mulga No. 1 wells.

The crust has been calculated to thicken from about 34 km at Mount Isa to 35 km in Huckitta.

The section traverses Domains 2 and 3 and is normal to the regional structures. Domain 2 extends from HUCKITTA to 7 km southwest of Mount Isa.

Depth-to-magnetic-basement calculations suggest that over much of the area the top of Domain 2 is at a depth of 1-2 km. However, in five locations a combination of magnetic quiet zones and gravity lows suggest either the presence of thick sedimentary sequences, or massive granitic bodies. Three of these areas—the Dulcie Syncline, the Lucy Creek area, and an area just northeast of Urandangi—have been interpreted as granites. The "Dulcie Syncline" and "Lucy Creek" granites have been intersected in the bottom of wells; the "Dulcie Syncline" granite is characterised by a magnetic quiet zone and gravity low, whereas possible magnetic edge effects mark the "Lucy Creek" granite. A combination of gravity low, shallow depth to magnetic basement, and possible magnetic edge effects providethe geophysical information upon which the "Urandangi" granite, 90 km northeast of Mulga No. 1, is interpreted.

In the part of the section which crosses the southeastern part of SANDOVER RIVER there is a broad gravity low which is accompanied by an equally broad magnetic quiet zone. Near Mulga No. 1 a short seismic traverse (Davies, 1974) indicated probable reflectors at a depth of 5 km; nearby the estimated depth to magnetic basement is 4 km. These features are interpreted as resulting from a thick sedimentary sequence rather than a granite.

The boundary between Domains 2 and 3 has been drawn 70 km southwest of Mount Isa at an observed change in geophysical trends from essentially northwest to north. Domain 3 to the east of the section is characterised by shallow high-amplitude magnetic responses and a gravity high: the top of the basement rocks which comprise the zone in our section is calculated to be 0-300 m. A granitic body is probably present near the function of the domains, because there is a gravity low in an area of shallow magnetic basement.

Adelaidean rocks outcrop in HUCKITTA and were insected in Huckitta No. 1; but none were found in Lucy Creek No. 1 well, which bottomed in granite.

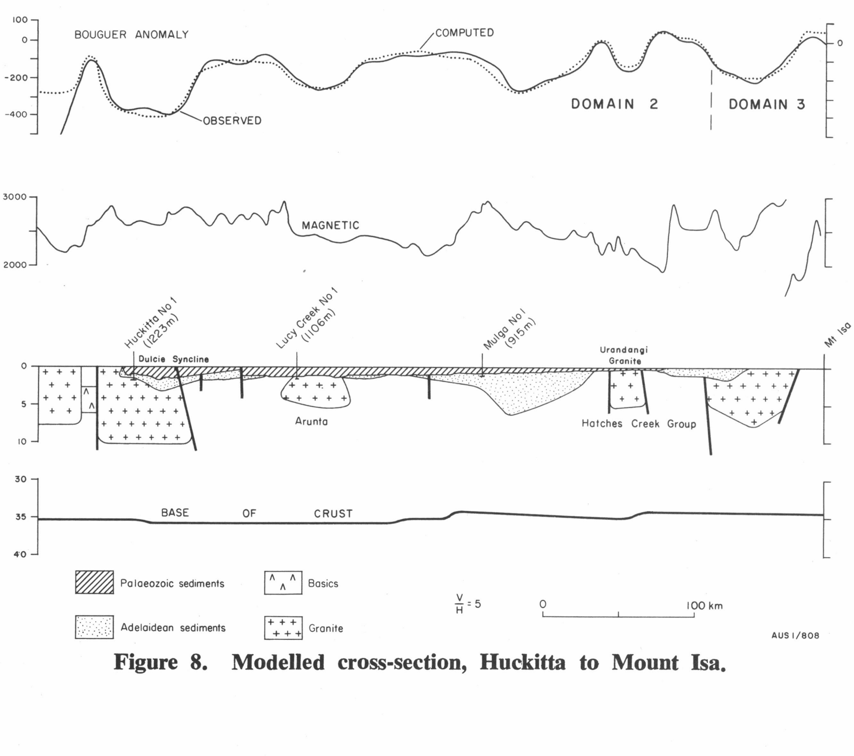

Figure 8. Modelled cross-section, Huckitta to Mount Isa.

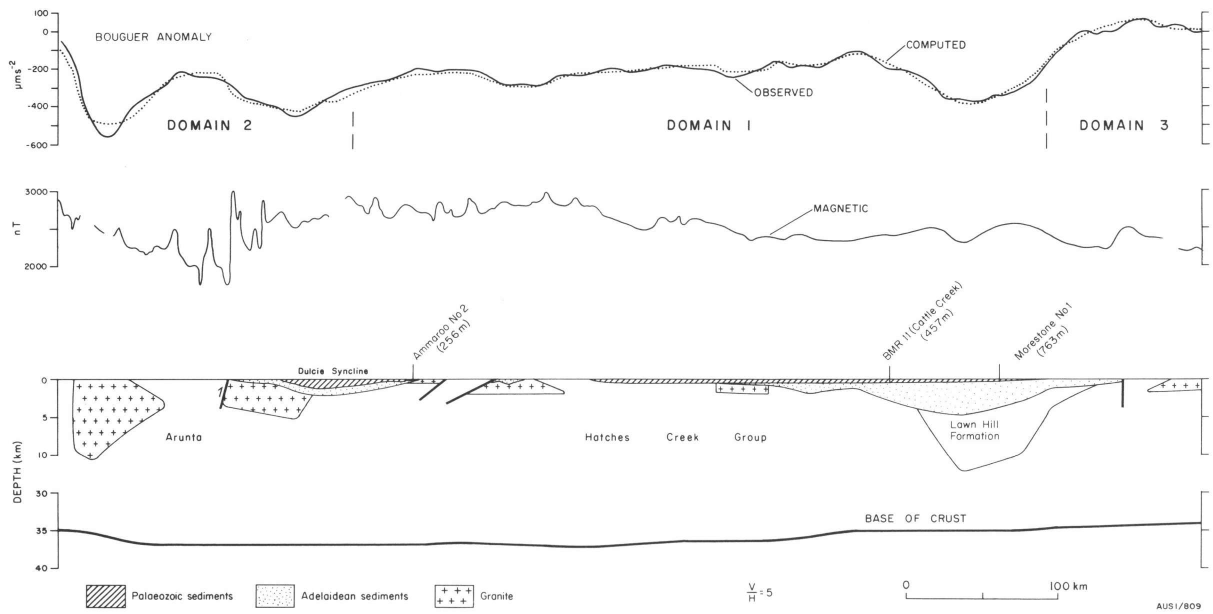

Figure 9. Modelled cross-section, Alcoota to Morstone.

The Adelaidean sequence is thus interpreted to thin from some 800 m at Huckitta to nothing at Lucy Creek. Farther northeast in SANDOVER RIVER the geophysical evidence indicates that the Adelaidean present in Mulga No. 1 well could extend to a depth of 6 km in a 50-km-wide basinal downwarp: some of the sequence could be equivalent to the Carpentarian Pilpah Sandstone (Plumb, pers. comm.). A similar sequence, up to 1.5 km thick. may be present in the Oban area some 80 km southwest of Mount Isa.

The Palaeozoic sequence forms a 200-400 m veneer over the whole section, except in the southwest where up to 1.8 km are preserved in the Dulcie Syncline.

Over the whole section several major faults have been interpreted, of which two are seen in outcrop. One of these, 25 km northeast of Huckitta No. 1, could have been a growth fault downthrown to the northeast during the Adelaidean; later it may have become an incipient high-angle reverse fault. In outcrop this fault trends northwest from near Picton Yard in HUCKITTA. The second fault seen at the surface and shown on the section 35 km southwest of Lucy Creek No. 1, parallels this trend, and extends from near No. 8 bore (HUCKITTA) to some 10 km west of BMR 13 on ELKEDRA: it is a normal fault.

To the northeast there are several buried faults. One 40 km southwest of Mulga No. 1 is marked by a change in magnetic character. The fault appears to have been active in the Adelaidean, and may possibly be a major growth fault. A fault is inferred to separate Domains 2 and 3.

Alcoota-Morstone (Fig. 9)

The Alcoota-Morstone section is some 100-150 km northeast of and roughly parallel to the Huckitta-Mount Isa section; it extends for some 760 km.

The majority of the section cuts Domain 1, but in the southwest and northeast Domains 2 and 3 respectively, are traversed. The crust is inferred to thicken from 34 km in the northeast to 31 km beneath the southwest end. Abrupt thinning to 35 km at the southwest end accounts for part of the large gravity gradient.

Rocks which comprise Domain 1 extend for some 400 km from beneath the Dulcie Syncline in the southwest to east of Morstone No. 1 in the northeast. The top of the basement is at a depth of 0-7 km, the deepest points being beneath the Dulcie Syncline (2.5 km) in the southwest and in the Undilla area in the northeast. However, over most of the section the calculated depth to magnetic basement (rocks of Domain 1) is less than 500 m. This is reflected in the pattern of narrow magnetic anomalies; the gravity profile is generally featureless, except in the Undilla area, where there is a prominent gravity low. The rocks of Domain 1 are inferred to be metamorphic rocks of the Hatches Creek Group with some granitic bodies in the southwestern part of the section.

The boundary between Domain 1 and 2 on this section is drawn beneath the Dulcie Syncline some 25 km southwest of Ammaroo No. 2, and is marked mainly by a change in magnetic anomaly style and trend directions.

The basement of Domain 2 is generally shallow, the top being at less than 200 m, but towards the northeastern side it is at a depth in excess of 500 m, reaching some 2500 km in the Dulcie Syncline. Granitic bodies extending to 10 km can account for some of the Bouguer anomaly lows.

Rocks which comprise Domain 3 extend some 100 km from the northeastern end of the section to a boundary with Domain 2, which is placed 20 km east of Morstone No. 1. The position of this boundary is indefinite, but is marked by the onset of relatively narrow, low-amplitude north-south-trending magnetic anomalies attributed to Mount Isa Orogen-South Nicholson Basin rocks at depth. The basement in Domain 3 shallows markedly from several kilometres near Morstone No. 1 to 200 or less in the northeast.

Adelaidean rocks occur in outcrop off the southwestern end of the section, in the Ngalia Basin, and again in the Dulcie Syncline—where they are interpreted to reach a thickness of some 1100 m. They thin to the east, and were not intersected in Ammaroo No. 2. They occur again, perhaps together with older Carpentarian sediments, in the Undilla area, and were intersected in drillholes Cattle Creek No. 1 and Morstone No. 1 beneath a few hundred metres of younger sediments. In this area a broad Bouguer anomaly low is attributed to a thickening of these sediments of up to 5000 m and to the presence of 8000 m of Carpentarian Lawn Hill Formation. A seismic survey near Morstone No. 1 (Robertson, 1963) indicated reflections to 3000 m, supporting the existence of a thick sedimentary sequence. The Adelaidean and associated sediments may thin rapidly to 1000 m, and then only reappear as a thin veneer to the northeast of a fault, which is inferred from the magnetic pattern to mark the western limit of near-surface rocks of the Mount Isa Orogen.

The Phanerozoic sediments are up to 1500 m thick in the Dulcie Syncline; to the northeast and southwest they comprise a local veneer. Further to the northeast in AVON DAWNS and CAMOOWEAL, intersections in Cattle Creek 1 and Morstone 1 show that they thicken to some 500 m above the interpreted Adelaidean section.

Some 120 km from the southwestern end of this section a major fault is inferred, from the gravity and magnetic patterns, to indicate thrusting of metamorphic rocks over granites, a feature noted by Kennewell & others (1977). Again 40-80 km to the northeast of Ammaroo No. 2, inferred faults may indicate overthrusting from the southwest, which may bring up rocks more typical of the Arunta Block in Domain 2 into Domain 1.

Bonney Well-Brunette Downs (Fig. 10)

The Bonney Well-Brunette Downs section is 370 km long and ties Frewena No. 1 and Brunette Downs No. 1 wells. It crosses the Lander Trough, for which seismic control is available (Kennewell & others, 1977). Crustal thickness along the section varies from 34.5 km to 37 km beneath the centre of the cross-section and thickens locally to 40 km beneath the Lander Trough.

The section traverses Domain 1 and terminates in the northeast at the junction of the domain with basement rocks of the Murphy Tectonic Ridge, which are the southern edge of the McArthur Basin (Plumb & Derrick, 1975; Plumb & others, in press).

Domain 1 is composed of extensive granitic material enclosing four synforms of metasedimentary rocks—the two southwesternmost being Hatches Creek Group, and the remaining two synforms contain Warramunga Group. The depth to the upper surface varies from 0-1.5 km.

The Warramunga Group synform extends for some 140 km to a point 20 km northeast of Frewena No. 1 well, and from outcrop geology the sequence is inferred to be up to 5.5 km thick. The southwesternmost Warramunga Group synform has been extrapolated from outcrop in the southwest and is characterised by low amplitude, magnetic anomalies which give a depth to basement of less than 300 m. The southern synform of Warramunga Group produces a slight relative Bouguer anomaly high in the broad regional gravity low.

Adelaidean rocks were tentatively identified in Brunette Downs No. 1 well, but have given a tentative Rb-Sr shale isochron of about 1510 m.y. (Plumb & Derrick, 1975); these rocks have been questionably extended as a thickening wedge which terminates some 10 km southwest of Frewena No. 1 well.

Palaeozoic rocks form a 300 m veneer over rocks of Domain 1 in the northerly two-thirds of the section, and no structural features are interpreted.

Only one major fault has been recognised in this section—at the extreme southwestern end; the fault is marked by a gravity gradient, and a change in the magnetic pattern from relatively flat in the northeast to high-amplitude narrow anomalies in the southwest. These patterns are suggestive of an overthrust from the southwest, a feature also recognised by Kennewell & others (1977): the intense gravity low immediately to the northeast could be explained by a synform of low-density Palaeozoic sediments up to 3 km thick overlying a relatively thick crust.

The presumed thrust fault trends east-southeast across BARROW CREEK and may, based on a subtle linear feature in the total magnetic intensity contours, extend onto ELKEDRA (see Alcoota-Morstone section. Alternatively it may swing more southeasterly out of BARROW CREEK and extend across HUCKITTA, running parallel to other major faults in this area—including the Tarlton Fault.

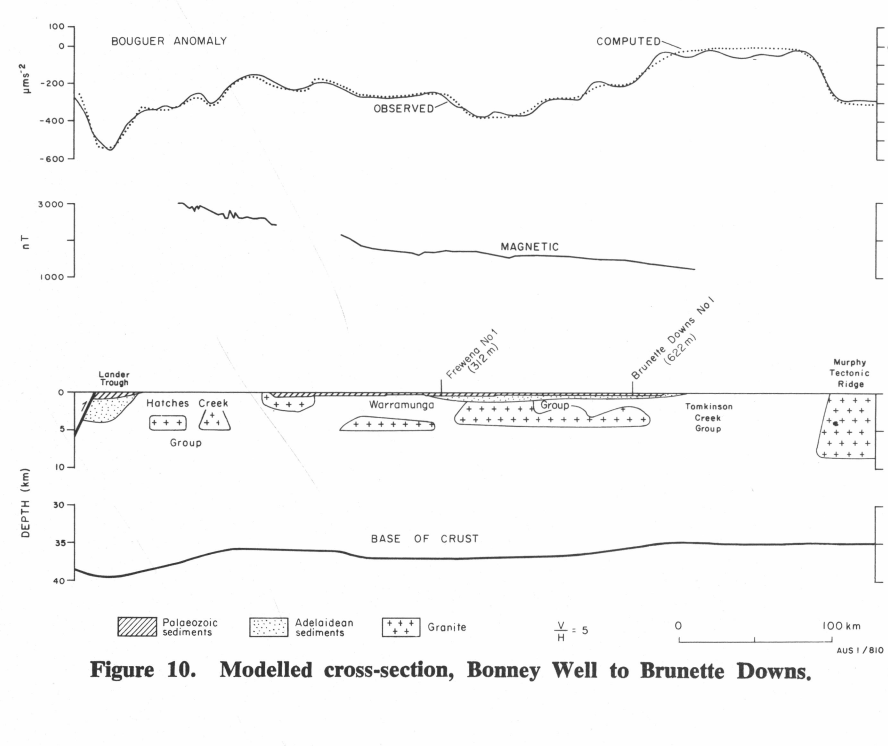

Figure 10. Modelled cross-section, Bonney Well to Brunette Downs.

Frewena-Betoota (Fig. 11)

The Frewena-Betoota section is over 1100 km long and extends from HELEN SPRINGS in the northwest corner of the study area along the major axis of the sediment outcrop to BETOOTA in the southeast. It ties Frewena No. 1. Mulga No. 1. GSQ Mount Whelan No. 1, Marduroo No. 1 and Betoota No. 1 wells.

Over part of its length the section parallels the major geophysical features, and consequently the modelling lacks precision, particularly between Mulga No. 1 and Marduroo No. 1 wells. The crust model varies in thickness over the length of the section, from approximately 36 km to 37 km from HELEN SPRINGS to GLENORMISTON and to 33 km in MOUNT WHELAN and MACHATTIE; south-east to the Cork Fault the crust thickens to 35 km again.

The section traverses all four geophysical domains from Domain 1 in the northwest to Domain 4 in the southeast, and is normal to the four previously described sections.

Domain 1, the upper surface of which is at a depth of about 500 m, extends for some 500 km, and is composed of granitic crust with four synforms of higher density metasediments. In the northwest the synform contains Tomkinson Creek Group sediments—no determination of the thickness of this synform could be modelled, but it overlies in the southeast an extensive synform of rocks with geophysical characteristics comparable to those of the outcropping Warramunga Group sediments, and a possible structural relationship is indicated on the section. To the southeast the remaining synforms comprise rocks with the geophysical character of Hatches Creek Group sediments. No estimates of depth to the base of these synforms could be made, and the modelling relies on thickness estimates from outcrop.

The junction of Domain 1 and 2 has been tentatively drawn at a point 45 km southeast of the northern margin of SANDOVER RIVER. The boundary is based on a changed style of magnetic intensity pattern and a change in anomaly trend direction.

The upper limit of the rocks in Domain 2 varies from 1-7 km in depth, the deepest area being near Mulga No. 1 well. Modelling suggests that the rocks are relatively high density metasediments interpreted as Arunta Complex which extend for some 300 km onto MOUNT WHELAN.

In Domain 3, the boundary of which is interpreted 10 km southeast of GSQ Mount Whelan No. 1, the basement lies at a depth of 1-4 km, being deepest near Marduroo No. 1. The boundary on the section is marked by a change in magnetic response from high amplitude to a quiet zone. The rocks of the domain are inferred to be mainly Eastern Creek Volcanics, with a granitic body at the southeasternmost part.

The boundary with Domain 4 is drawn at the Cork Fault, but the offset relationship between the abrupt change in magnetic pattern and the steep gravity gradient suggests that a change in crustal thickness lies 40 km southeast of the change in lithology at the Cork Fault. The interpretive geology of Domain 4 is based on seismic information farther to the northeast (Harrison & others, in prep.) which indicates a thick sequence, up to 12 km, of deformed rocks of undoubted pre-Permian age. The inference is that they may be lower Palaeozoic metasediments.

Two kilometres of Adelaidean rocks are inferred beneath Frewena No. 1. In the area of Mulga No. 1 up to 7 km of the sequence may be Adelaidean. This is based on poor reflections from a local seismic survey combined with an area of slightly lower than normal Bouguer anomalies. This Adelaidean sequence thins toward GSQ Mount Whelan No. 1, where it is about 100 m thick. Southeastward it thickens to some 4 km at Marduroo No. 1, but is then thin or absent southeast of the major fault in the vicinity of Marduroo No. 1. No Adelaidean rocks are interpreted southeast of the Cork Fault, although the metasediments beneath the Permian could have been deposited at this time.

The Palaeozoic rocks form a thin veneer of some 300-500 m over most of the section, with some thickening between Mulga No. 1 and GSQ Mount Whelan No. 1. Southeast of this point the Palaeozoic rocks are thinner, only about 100-200 m overlying the Adelaidean, and they eventually feather out before the Cork Fault is reached.

Only two major faults, which separate Domains 2 and 3 and 3 and 4, are crossed—the former is described in the Ethabuka-Black Mountain section, whilst the latter, the Cork Fault, is described in both the Domain descriptions and above.

Geological history

The recognition of domains rests mainly on the differing trend directions of both Bouguer and magnetic anomalies—a technique used by Wellman (1976) for gravity data over the Australian continent. The separation of domains based on trend direction does not necessarily divide the crust temporally, but it rather separates regions which may have a different tectonic history. The domains which we recognise fit the major crustal blocks delineated by Plumb (in press) fairly well.

The addition of possible ages to the rocks within each domain should, however, provide some guide to the geological history, always remembering that domain recognition is qualitative and ages are usually of metamorphic events rather than age of formation. Thus, any reconstruction is at best tentative, and the geological history which follows must be regarded as speculative—a hypothetical model to be tested as further data become available.

In developing this geological history we have used a conventional time-sequence method, commencing with the earliest recognisable interval even though the available facts decrease with increasing age—confidence in the model thus increases as the present is approached.

Pre-1900 m.y. (Figs. 12 & 13)

Within this interval we have provisionally placed Division 1 of the Arunta Inlier (Stewart & others, 1976) and gneissic basement in the Tennant Creek Inlier (Plumb, pers. comm). A metamorphic event affects the gneisses of the Tennant Creek Inlier prior to sedimentation of the Warramunga Group and there is an unconformity between Division I and II of the Arunta Inlier, the latter division being metamorphosed at about 1800 m.y. (Plumb, in press).

1900-1800 m.y. (Figs. 12 & 13)

Within this interval we place the Warramunga Group of the Tennant Creek Inlier; Division II of the Arunta Inlier (Stewart & others, 1976) and the Yaringa Metamorphics, and part of the Tewinga Group (Plumb & others, in press) of the Mount Isa Orogen. The Warramunga Group, which comprises interbedded greywacke and shales, with intercalated tuffs and acid volcanic rocks (Crohn, 1975) is considered to have been

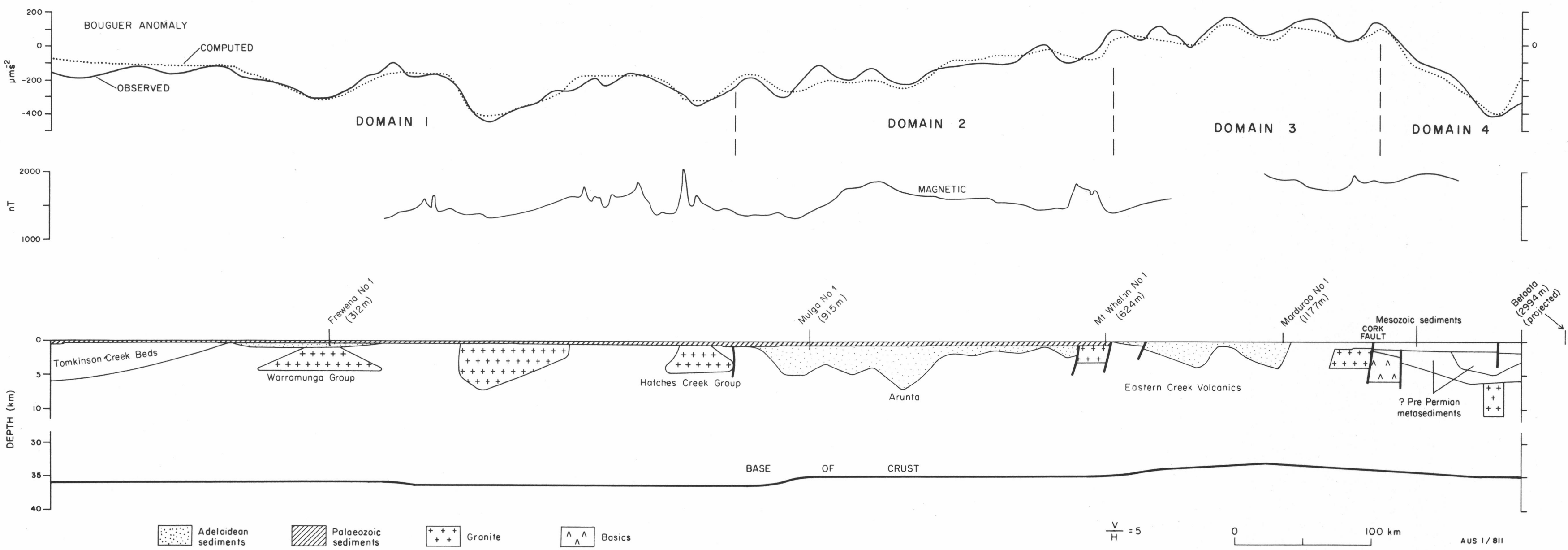

Figure 11. Modelled cross-section, Frewena to Betoota.

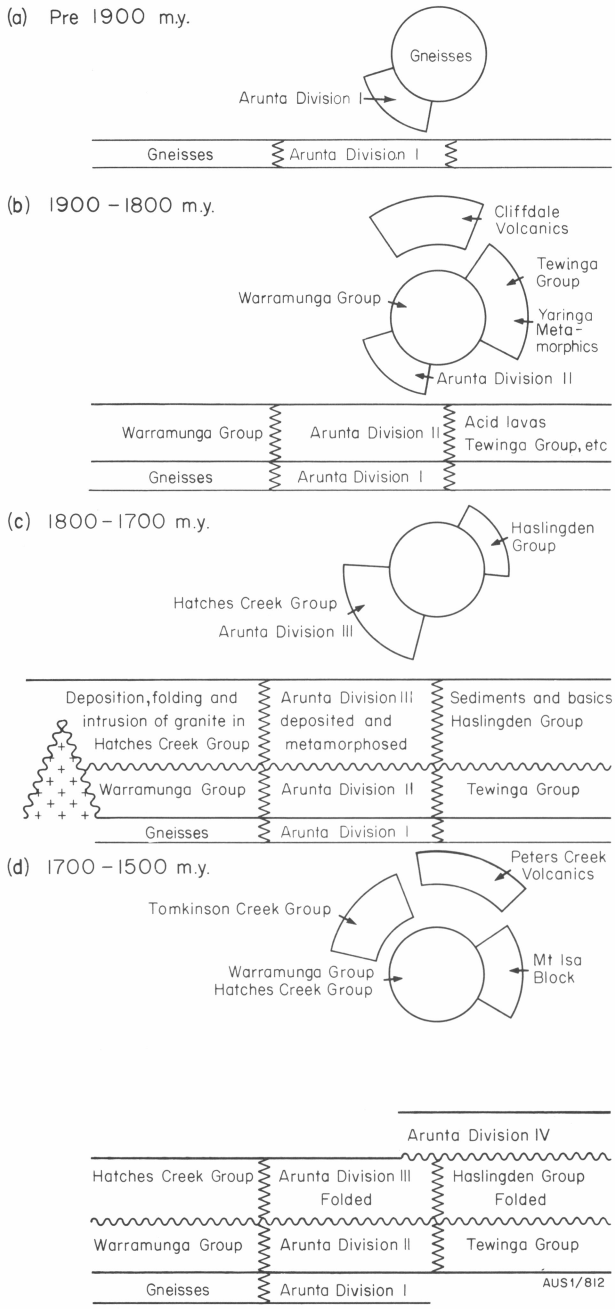

Figure 12. Spatial and temporal distribution of Precambrian metasediments.

deposited before 1800 m.y.—based on Rb-Sr muscovite ages of 1810 m.y. from various mines in the Tennant Creek area (Black, 1977). Division II of the Arunta Block underwent widespread high-grade regional metamorphism at about 1800 m.y. (Plumb, pers. comm.; Warren, pers. comm.) and thus the mafic gneisses, metapelites and calcsilicates (Stewart & others, 1976) must have been deposited prior to that date, suggesting that the Warramunga Group sediments are contemporaneous with Arunta Division II sediments. Generally the Warramunga sediments were deposited in an area where gravity modelling suggests the crust is thicker and spatially more uniform than in the southern and eastern part of the study area (Figure 6). The northern area may be interpreted as being an ancient cratonic mass circumscribed by tectonically deformed strata, which is here named the Aljawarra Craton after an Aboriginal tribe which inhabited this general region.

We thus speculate that the Warramunga sediments formed near the margin of a cratonic shelf, with deposition of Arunta II rocks occurring peripherally.

This period of deposition was terminated by a tectonic event at about 1800 m.y.

1800-1700 m.y.

Subsequent to the deposition of Division II of the Arunta Inlier there was widespread deposition of sediments both in the south of the study area, of Arunta Division III; to the east in the Mount Isa Orogen; and possibly in the central part of Hatches Creek Group.

Radiometric datings in the Arunta Inlier are dates of metamorphic events, but there is reasonable control on the time of deposition because Division III rocks postdate the 1800 m.y. metamorphic event, but are themselves affected by a widespread metamorphic event at 1700 m.y. (Plumb, pers. comm.). For the most part, the Hatches Creek Group may also be correlated with Division III of the Arunta Inlier (Warren, pers. comm.).

The dating sediments in the Mount Isa Orogen is based on a consideration of granite ages, using for example the Rb/Sr dating on the Ewen Granite of 1780 m.y.; and the zircon ages on the Kalkadoon Granite of 1862 m.y., on the metasediments of the Argylla Formation, 1777 m.y., and the Leichardt metamorphics of 1865 m.y. (Page, 1978).

The dating of the Hatches Creek Group is based on the Elkedra Granite, which cuts both the Warramunga and Hatches Creek Groups, and is dated at 1695 m.y. (Compston & Arriens, 1968).

The distribution of the rocks deposited in the interval 1800-1700 m.y. suggests extensive contemporaneous deposition around the margin of the Aljawarra Craton; a craton surrounded by sedimentary basins. The Hatches Creek Goup could have been deposited on the craton, or the present location of this group could be the result of thrusting of Arunta Division III sediments from the south.

The distribution of rocks of this age indicated that the 1700 m.y. metamorphic event was also a major circumcratonic tectonic event. The sediments of the Mount Isa Orogen and of Arunta Division III were extensively folded and, in the case of the southern, buried part of the Mount Isa Orogen, faulted. The high-angle reverse faulting appears to have been from the east, for the major faults are aligned north-south (Fig. 5). It is also possible that there was coeval compression from the south, resulting either in the thrusting of Arunta Division III rocks onto the southern margin of the craton or, depending on the preferred depositional model, the large-scale folding *in situ* of Hatches Creek Group together with the underlying Warramunga Group. However, the Hatches Creek Group has undergone a thermal event, whereas the Warramunga Group is virtually unmetamorphosed, which supports the suggestion that the Hatches Creek Group may have been deposited and metamorphosed at the southern margin of the craton before being moved to its present position.

1700-(?)1200 m.y.

Within this broad time interval we place the Peters Creek Volcanics and associated rocks, the Tomkinson Creek Group, and the Mount Isa and South Nicholson Group and associated rocks of the Mount Isa area.

The Peters Creek Volcanics are thought to be ?1600 m.y. old, based on the belief that they contain correlatives of the Packsaddle Microgranite in the north

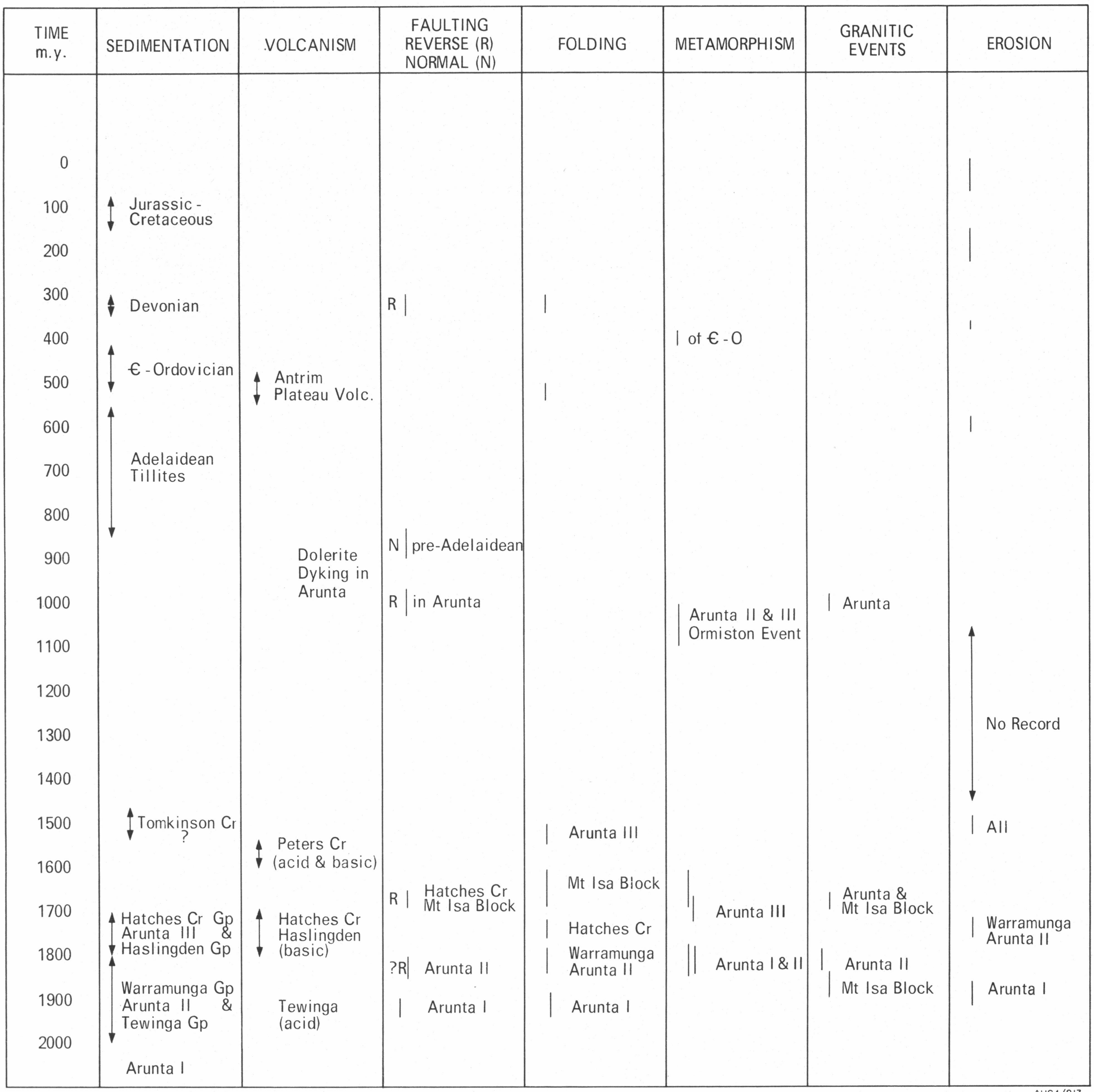

Figure 13. Temporal distribution of structural events.

of the Murphy Tectonic Ridge, which has been dated by the Rb-Sr method (Plumb & Sweet, 1974). More recently Plumb & others (in press) have correlated the microgranite with the Carters Bore Rhyolite, which has a zircon age of 1680 m.y.

The sedimentary rocks distributed in the northwest (Tomkinson Creek) and east (Mount Isa Group and associated rocks) of the study area suggest that sedimentation continued on the margin of the northern half of the Aljawarra Craton. To the north, in an easterly trending strip, the Peters Creek Volcanics were extruded—they comprise interbedded intermediate and acid lavas, tuffs, and arenaceous sediments (Carter, 1959). The formation of these lavas may be coeval with the metamorphism, emplacement of granite and extrusion of volcanics in the Mount Isa area (Plumb & others, in press) at about 1680-1620 m.y.

Apart from the Chewings event in the Arunta area, and metamorphism in the Mount Isa region at about 1450 m.y., the region was generally tectonically quiet for some 400 m.y.—a quiescence which was shattered by a major tectonic event of about 1000 m.y.

(?)1200-700 m.y.

Widespread migmatisation occurred between 1000-1200 m.y. within the Arunta Inlier (Majoribanks & Black, 1974) and the northern part of the Musgrave Block, with the emplacement of granites and the Kulgeran phase of metamorphism. Arunta Inlier rocks in the south of HAY RIVER show no evidence of having been affected by this metmorphism and are presumed to have been discrete blocks within the crystalline basement (Warren, 1978).

However, high-angle reverse faults of pre-Adelaidean age are present in the basement (Tobermory magnetic gradient); these appear to recur in curvilinear features far to the northeast (Fig. 5), and apparently cut across the dominant north-south trends of the east of the Mount Isa area. Thus the tectonic event which pro-

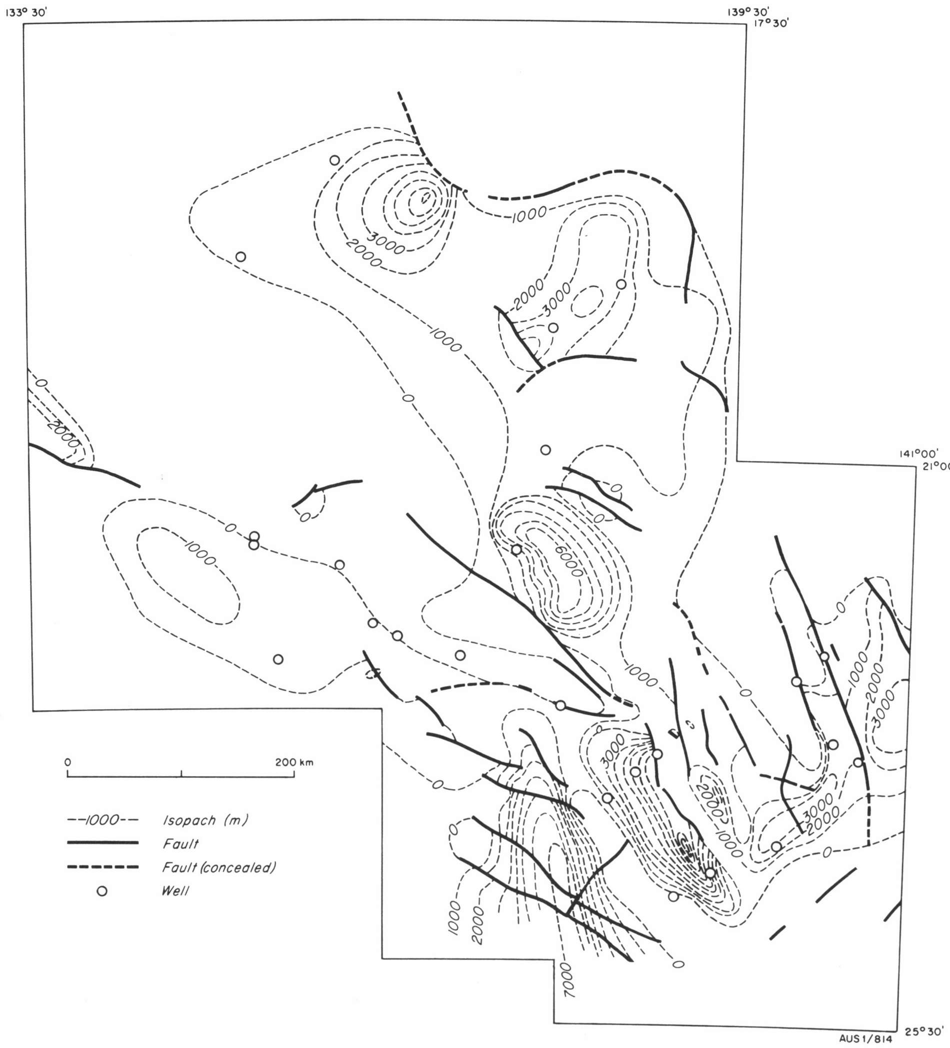

Figure 14. Isopachs of probable Adelaidean rocks, based on gravity and magnetic modelling. Note that deeps are usually adjacent to major faults.

duced these scalloped thrust sheets would appear to postdate the latest Mount Isa movements (1450 m.y.), but pre-date the deposition of Adelaidean sediments (700 m.y.). We thus infer that there was thrusting to the northeast of the Arunta Inlier rocks at about 1200-1000 m.y., on the eastern margin of the Aljawarra Craton, whereas to the south, on the old margin of the craton, a widespread and major thermal event took place.

The Adelaidean rocks in the southern part of the Georgina Basin show extremely rapid thinning, for example in the southeast of TOBERMORY the Adelaidean is some 5 km thick, whereas only 15 km to the east in Netting Fence No. 1 Well it is absent, a relationship which is repeated on HUCKITTA (Walter, in press). The inference is that the Adelaidean was deposited in graben with active margins; thus major block-faulting must have taken place subsequent to the thrusting and prior to or contemporaneously with the deposition of the Adelaidean. Veevers (1976), and other previous authors, have suggested that the Amadeus Basin is an aulacogen, or failed arm, of a newly generated Tethys which had developed in the latest Vendian or earliest Cambrian (600-550 m.y.). Evidence from the Georgina Basin suggests that several graben normal to the presumed continental margin to the southeast developed prior to the deposition of the Adelaidean; if these are interpreted as aulacogens, then plate divergence on the eastern margin of Australia may have begun prior to the Adelaidean (cf. Veevers).

700-550 m.y.

Widespread deposition of Adelaidean sediments, including glacigenic sequences, took place in the Georgina Basin area in a northwest-trending graben during this period (Fig. 14). The margins of the graben appear to have been growth faults, being active during deposition. Adelaidean sediments are confined to the eastern and southern half of the area. In the eastern half we infer their presence because the Bouguer anomaly lows, in magnetic quiet zones, suggest the presence of sediments rather than granites. Thus the extent of the Adelaidean in the subsurface has been considerably extended, with a large wedge present in the Glenormiston-Sandover River area and the Undilla area (CAMOOWEAL), although there remains the possibility that the latter wedge may be of Carpentarian age.

On the southern margin of the Georgina Basin an unconformity is present between the Adelaidean, and the Early (but not earliest) Cambrian. The movement during this period was relatively gentle; a combination of Adelaidean deposition and contemporaneous and subsequent erosion produced a relatively smooth surface over the whole Georgina Basin area at the onset of the Cambrian transgression.

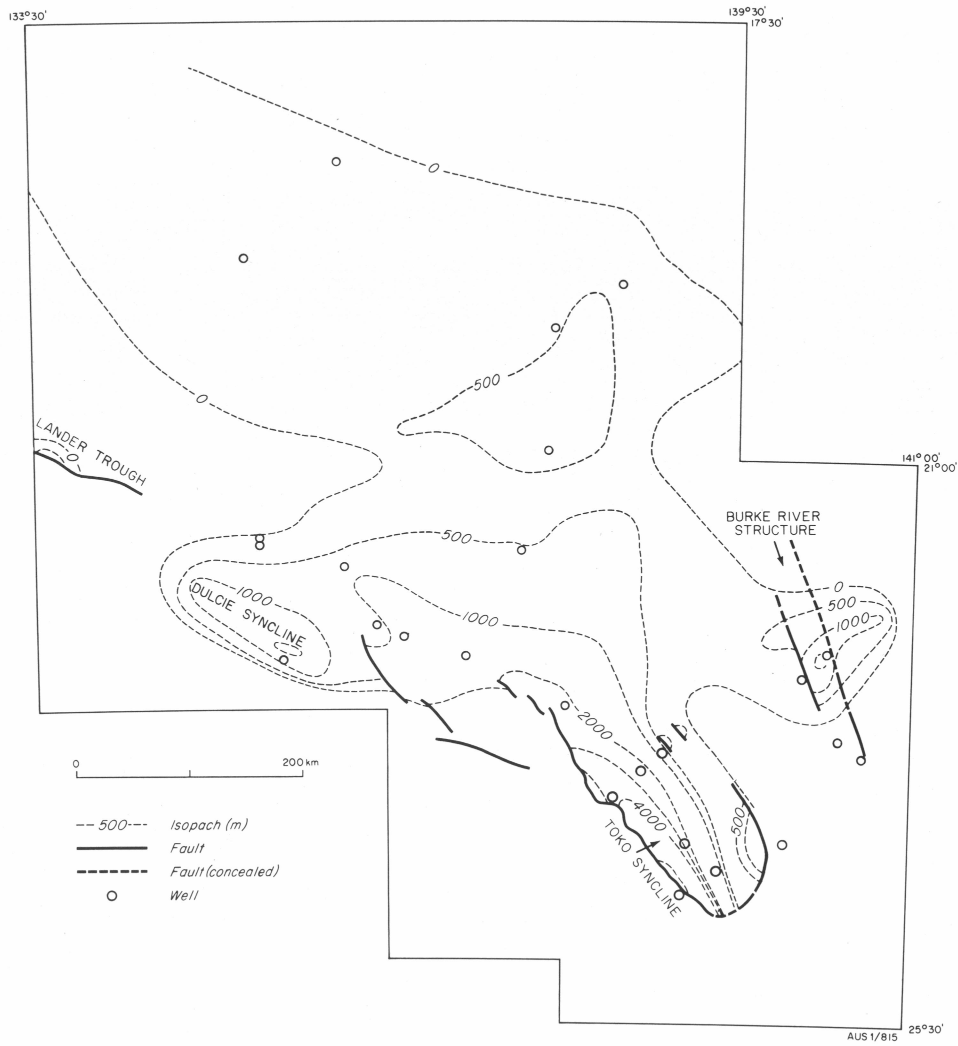

Figure 15. Isopachs of Probable Palaeozoic rocks.

500-350 m.y.

Widespread deposition, predominantly of carbonates, took place in the Georgina Basin in various pulses of sedimentation during this period (Smith, 1972; Shergold & Druce, in press). Usually the sediments are relatively thin, and probably total less than 500 m. The greatest accumulations are found in the Toko Syncline where 3500 m is developed, in the Dulcie Syncline, the Lander Trough, and in the general vicinity of the Burke River Structural belt. Our interpretation has not restricted the presence of thicknesses elsewhere in the study area. Broadly the Georgina Basin consists of a relatively thin veneer of Palaeozoic sediments, with a few localised centres of considerably greater thickness.

Faults bounding the Toko Syncline, Lander Trough and possibly the Dulcie Syncline were reactivated as growth faults in Middle Cambrian time, possibly as a distant pulse of the Delamerian Orogeny in South Australia (Thomson, 1970). At the same time the southern part of the Mount Isa Orogen subsided gently, with some reactivation of north-south basement faults and tilting of the plane of sedimentation southwards.

High-angle reverse faults typified by the southern margin of the Lander Trough (Kennewell & others, 1977) and the Burke River Structure (Casey & others, 1960), and overthrusting as seen on the western margin of the Toko Syncline (Harrison, 1979) indicate later compressional movements possibly coincident with continental breakup. In the Burke River Structure those movements have juxtaposed a relatively thin Mesozoic cover with Cambrian rocks across the Black Mountain Fault (Casey, 1968).

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