PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Some Aspects of the Panantarctic Cratonic Margin in Australia

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Some aspects of the Panantarctic cratonic margin in Australia

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The ancestral supershield of Panantarctica contains a tectonic grain which suggests a single continuous tectonic entity in Archean time. Within the Australian continent, this single cratonic province continued to late Carpentarian or early Adelaidean time with incipient mantle plume and junction-rift tectonics operating on the cratonic margin (Mt Isa) and probably within the craton (Batton Trough). In Early Adelaidean times, major cratonic separation and right lateral shear along the Musgrave mobile belt is proposed to displace the cratonic margin. This transcurrent displacement was probably localized by a Carpentarian aulacogen. These events established the pattern for subsequent separation and collision of the Gawler and Arunta subprovinces, which controlled intracratonic deposition in the Amadeus and Canning basins through Phanerozoic time.

Introduction

This presentation results from a long personal involvement with the geology of Carpentarian rocks in north Australia. It is not meant to be a review or a thorough treatment of the problems, but presents several new aspects and interpretations of Australian cratonic tectonics aimed at stimulating further work. The presentation is based on the framework of a continuous Precambrian crust.

In a recent article on Precambrian shield development, Goodwin (1974) used the term 'supershield' for each of the six cratonic nuclei which collectively define Pangaea. The marginal supershield of Gondwana, termed Panantarctica, encompasses the cratons of Australia, Antarctica, India and South Africa. One margin of Panantarctica is defined by the Damaran mobile belt which separates it from the Brazilian-Congolese supershield (figure 1).

The other Panantarctic supershield margin is a remarkably straight zone that delimits a Palaeozoic province in Australia, Antarctica and southern Africa and which extends into the Cordillera of the Americas.

Tectonic continuity of Panantarctica in Archean time is strongly suggested by a common orientation of structural elements. Greenstone belts throughout the supershield show a remarkable parallelism in orientation despite significantly different ages in the various subprovinces. Similarly, the suite of late basic dykes, including Jimberlana in the Yilgarn subprovince, are virtually parallel to the Great Dyke of Rhodesia. These features suggest a continuous Panantarctic supershield extending from Australia to southern Africa and subjected to similar deforming forces in Archean time.

The Australian shield

The Australian Archean shield consists of two cratonic nuclei, the Pilbara subprovince with 3100 Ma plutonism and the Yilgarn subprovince of 2650 Ma plutonism (figure 2). The remainder of the shield was cratonized by Lower Proterozoic times, a process which terminated in a widespread 1860–1730 Ma plutonic and volcanic event, comparable to the Hudsonian orogeny of Canada. The Proterozoic craton extends over two-thirds of continental Australia and is locally overlain by little deformed and metamorphosed platform sediments of Carpentarian (*ca.* 1800–1500 Ma) and Adelaidean (*ca.* 1400–600 Ma) age.

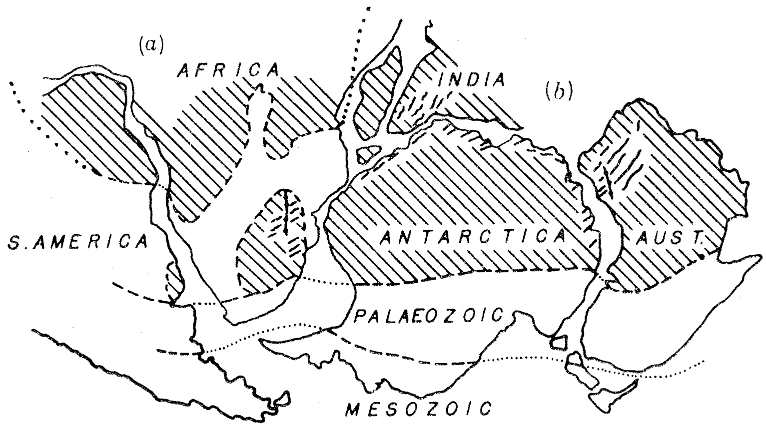

FIGURE 1. Reconstruction of part of Gondwana showing the Brazilian-Congolese (*a*) and Panantarctic (*b*) supershields. Parallelism of Archean greenstone belts and late Archean dykes support tectonic continuity of the Panantarctic supershield.

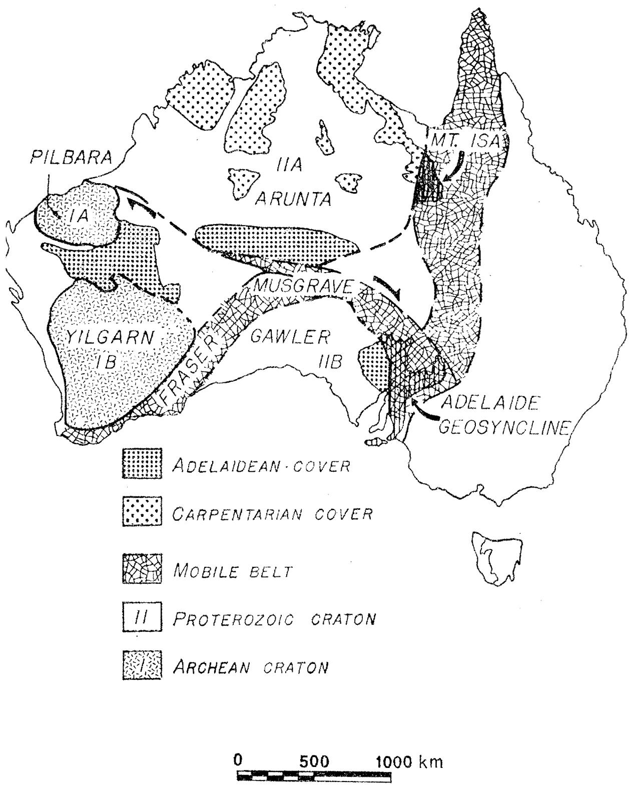

FIGURE 2. Major Precambrian provinces in Australia, showing the Mt Isa and Adelaide geosyncline areas situated on the eastern cratonic margin. Note the separation and apparent right lateral shear of the Arunta and Gawler subprovinces along the Musgrave mobile belt.

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The Frazer–Musgrave mobile belt divides the Proterozoic craton into two subprovinces termed Arunta and Gawler (Rutland 1973). Both portions of the belt record a 1330 Ma metamorphic event and the Frazer portion of the belt was then overlain by platform sediments of early Adelaidean age. The east–west trending Musgrave belt (figure 2) contains major fractures which were active and controlled the emplacement of mafic magma as late as 1050 Ma (Nesbitt, Goode, Moore & Hopwood 1970). These events controlled deposition of and subsequently deformed early Adelaidean sediments. It will be argued that this intracratonic movement apparently influenced the craton margin in the Adelaide geosyncline.

The eastern margin of Precambrian basement, as distinct from the cratonic margin (figure 2), is not well known and is largely buried beneath Phanerozoic sediments. Carpentarian rocks extend into northeast Queensland and east of the cratonic margin in Broken Hill. These areas appear to constitute a Carpentarian mobile belt bounding the Proterozoic craton on the east.

The cratonic margin is clearly defined in two areas; the Carpentarian Mt Isa District in northwest Queensland and the Adelaide geosyncline in south Australia (figure 2). Some aspects of each area, and their similarities and differences, will be presented below.

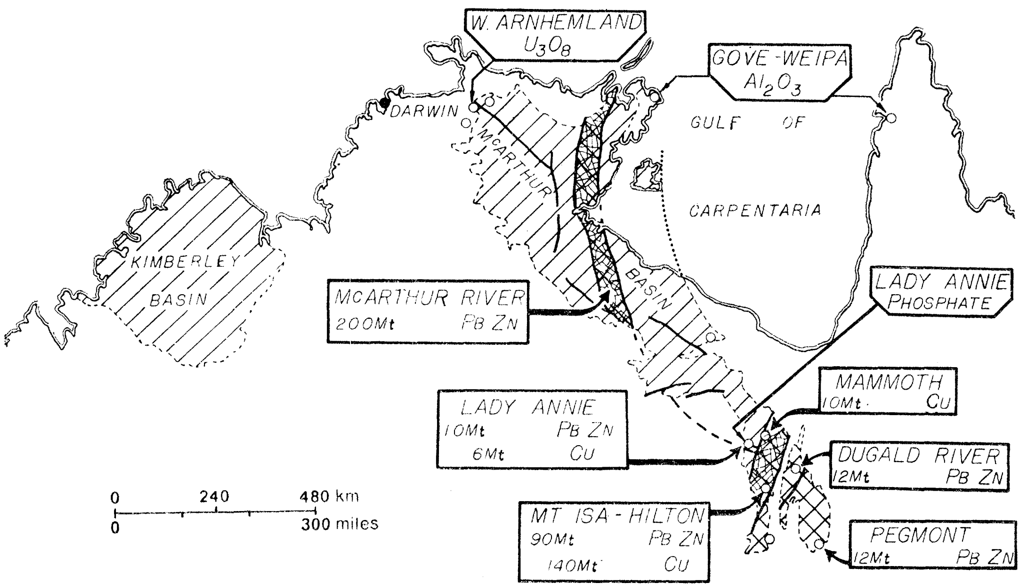

FIGURE 3. North Australia showing the Carpentarian McArthur and Kimberley Basins, and major mineral resources marginal to the Gulf of Carpentaria. McArthur River lies within the Batton trough and the group of base metal deposits within the Mt Isa geosyncline (cross-hatched patterns). (1 Mt = 10^{12} g.)

The McArthur Basin

The Mt Isa District is situated at the southeastern extension of the belt of Carpentarian rocks deposited in the McArthur Basin (figure 3). Weakly deformed and essentially unmetamorphosed platform sediments extend over 1300 km along the margin of the Gulf of Carpentaria. They rest on metamorphosed Archean to Lower Proterozoic rocks of the Pine Creek geosyncline and equivalents and are covered by Adelaidean to Recent sediments.

The Carpentarian stratigraphic section is remarkably constant over this vast area (Dunn, Smith & Roberts 1975) and can be subdivided into two major groups. The lower unit, the Tawallah group, is dominated by orthoquartzite and commonly rests unconformably on Lower

Proterozoic (*ca.* 1800 Ma) acid volcanics (Edith River, Whitewater Volcanics, Argylla Formation). Locally, the Tawallah group includes basic volcanic flows.

The overlying McArthur group is dominated by carbonates, including stromatolitic reefs, dolomitic oolitic sands and breccias with local shale, dolomitic silts, gypsum, and chert.

The basin is transected by a fault-bound intracratonic trough, the Batton Trough (figure 3), within which over 3600 m of fine-grained McArthur group carbonate sediments were deposited in contrast to less than 305 m on parts of the craton to the east.

Locally, the McArthur group is overlain by red bed sandstones and shales of the Adelaidean Roper group and equivalents.

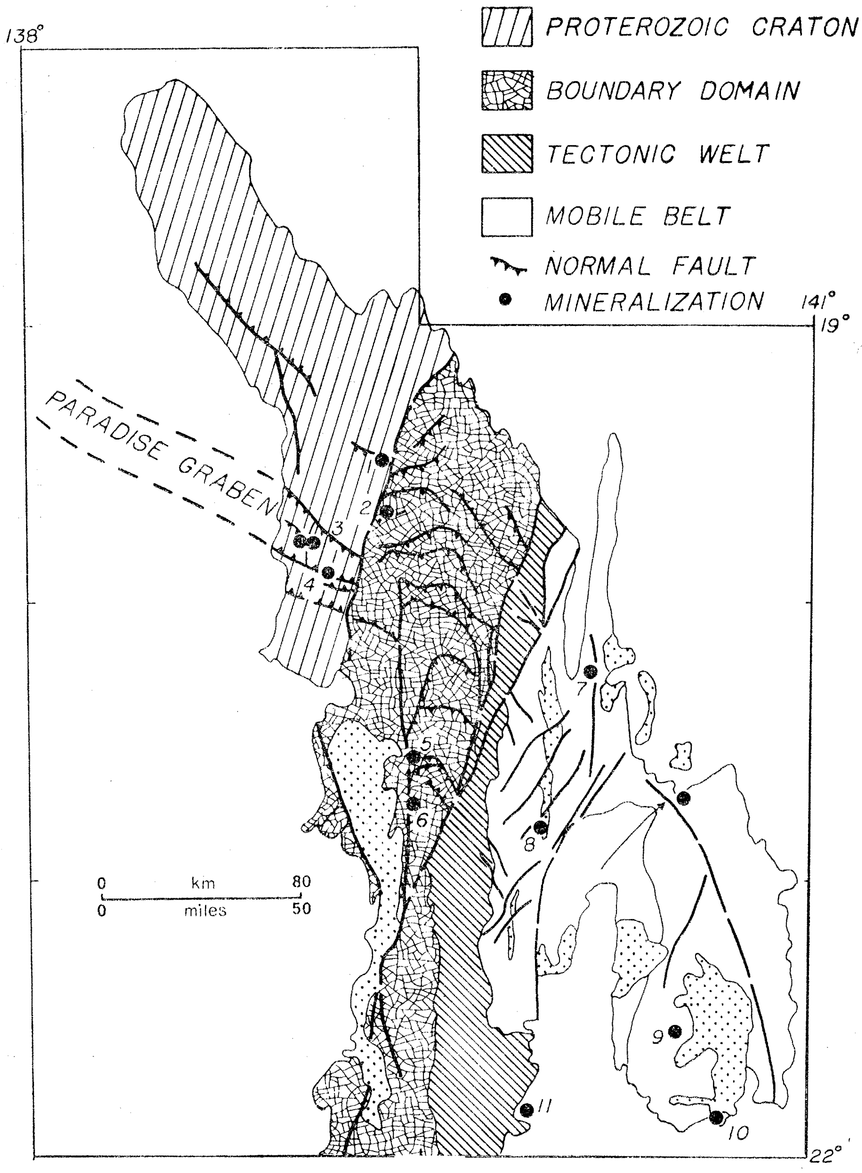

FIGURE 4. The Mt Isa District showing four major structural domains and the fragmented aulacogen of the Paradise rift. Areas of mineralization are: (1) Mt Oxide, (2) Mammoth, (3) Lady Annie, Lady Loretta, (4) Spinifex Queen, (5) Hilton, (6) Mt Isa, (7) Dugald River, (8) Mary Kathleen (uranium), (9) Mt Elliott, (10) Pegmont and (11) Duchess phosphate.

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The Mt Isa geosyncline

The Mt Isa District extends over 480 km along and 160 km across the cratonic margin. It can be subdivided into four tectonic domains, each with contrasting structural styles. The northwestern domain (figure 4) consists of relatively flat-lying, unmetamorphosed and moderately deformed Carpentarian platform sediments similar to the Tawallah and McArthur group facies elsewhere on the craton. As the boundary domain is approached (figure 4) and, particularly within a narrow (15–30 km wide) graben termed the Paradise Rift, the Carpentarian sequence thickness, basic volcanics (Eastern Creek Volcanics) became an important part of the Tawallah group and the McArthur group includes fine-grained facies similar to the Batton Trough.

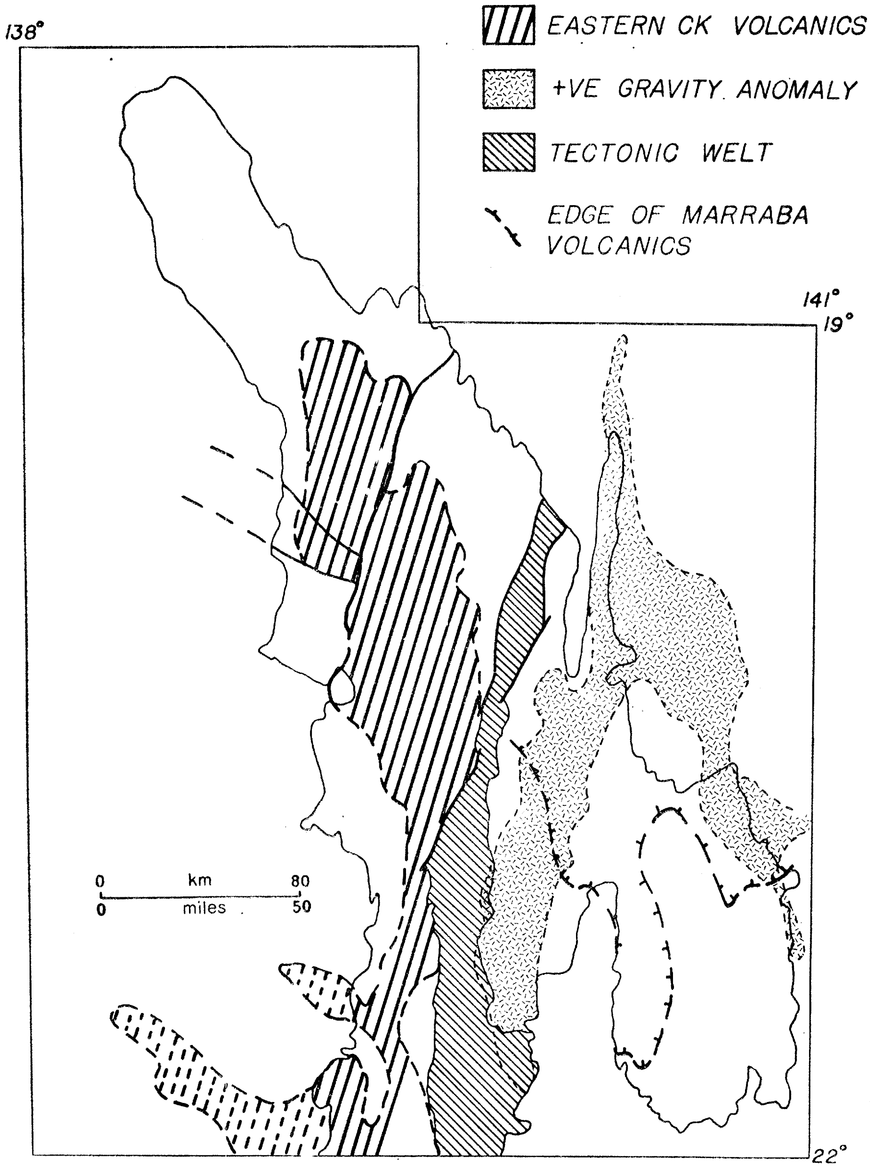

Figure 5. The Mt Isa District showing the distribution of Eastern Creek Volcanics, the positive gravity anomaly east of the Tectonic Welt and the southern boundary of the Marraba Volcanics. Compare with the unfaulted reconstruction of figure 6.

Interpretation of e.r.t.s. images, magnetic and gravity data suggest a possible continuity of the Paradise Rift and the Batton Trough beneath the younger strata. Locally, the westward extensions of the Paradise Rift control Cambrian sedimentation of the Georgina Basin and deep-seated fractures beneath Mesozoic rocks are visible on e.r.t.s. images.

The Boundary Domain (figure 4) is bounded by and includes several northeast trending tear and right lateral strike slip faults. The domain is characterized by an intense set of normal faults which trend subparallel to the Paradise Rift at a high angle to the cratonic boundary and generally dip to the south. These faults are believed to result from extreme extension along the axis of the domain and along the cratonic boundary. The extension rotates the fault blocks and faults to shallow dips and locally to a subhorizontal attitude (Dunnet 1975). The normal faults were active during Carpentarian sedimentation and controlled thickness and distribution of volcanics and sandstones (Smith 1969). Rapid facies changes and strong local unconformities are common within this domain due to the penecontemporaneous fault movements.

The sediments of the boundary domain are essentially unmetamorphosed and include platform and trough facies which can be directly correlated with the cratonic domain.

The Eastern Creek volcanics, intercalated with sands, form a major part of the section in the boundary domain and locally develop thicknesses over 6000 m. The distribution of volcanics is restricted, however (figure 5), and broadly correlated with the distribution of trough facies carbonates in the overlying McArthur group.

A large granite stock, the Sybella granite (figure 4) intruded along a major fault (the Mt Isa fault) within the boundary domain late in the deformation history (1550 Ma). This age is similar to the post tectonic granites of the Mobile Belt.

To the east and southeast of the boundary domain, a belt of Lower Proterozoic metamorphosed basement rocks, termed the Tectonic Welt, forms a suture between the mobile belt and cratonic boundary domain. The Tectonic Welt was a structural high throughout the lower part of Carpentarian deposition (Carter, Brooks & Walker 1961) and exhibits deformation characteristics of both bounding domains.

Gravity profiles (figure 7) suggest the Welt is the edge to thick sialic crust of the Proterozoic craton and a much thinner crust occurs beneath the mobile belt to the east.

The mobile belt includes recognizable equivalents of the two sedimentary groups seen throughout the McArthur Basin (Tawallah and McArthur groups) and the shelf and trough facies of the other domains can be locally defined. The McArthur group equivalents, however, include black shale and evaporitic facies indicative of more restricted sedimentation conditions. Features of intense ductile deformation, high grade metamorphism, and brine-induced metasomatism (scapolitization and iron flooding) and late tectonic plutonism all tend to mask primary sedimentation facies controls and make correlations very difficult. A deposition environment similar to the cratonic western area is indicated, but more restricted and thinner starved sections prevail.

Carter *et al.* (1961) refer to the eastern and western basin of the Mt Isa geosyncline and draw an analogy to a mio-eugeosyncline and separation by a volcanic median ridge of the Tectonic Welt. Detailed investigation by a large number of government and private company geologists in recent years fails to support such an interpretation. Greywackes, chert and andesite-rhyolite vulcanism are absent. Volcanics are tholeitic flood basalts without major rhyolitic end members. Local late trachytic intrusives are the principal acid components. Despite thick sedimentary sections along the cratonic margin, deltaic shallow marine and lagoonal conditions are dominant. The deeper water and thicker sections in the west are related to the Paradise Rift and associated boundary faults and isopachs and facies boundaries trend approximately east–west, not north–south.

The difficulty in recognition of initial basin margin orientations results in part from the extreme right lateral displacement along cratonic boundary faults and disruption of the deposition basins. Displacement of facies boundaries across the Mt Gordon fault system which separates the craton and boundary domain is indicated to be over 32 km and a similar movement is suggested by the offset of the Tectonic Welt.

A possible reconstruction of these fault displacements (figure 6) strongly accentuates the importance of the west-northwest trend to cratonic sedimentation and the continuity of early structures from craton to boundary domain.

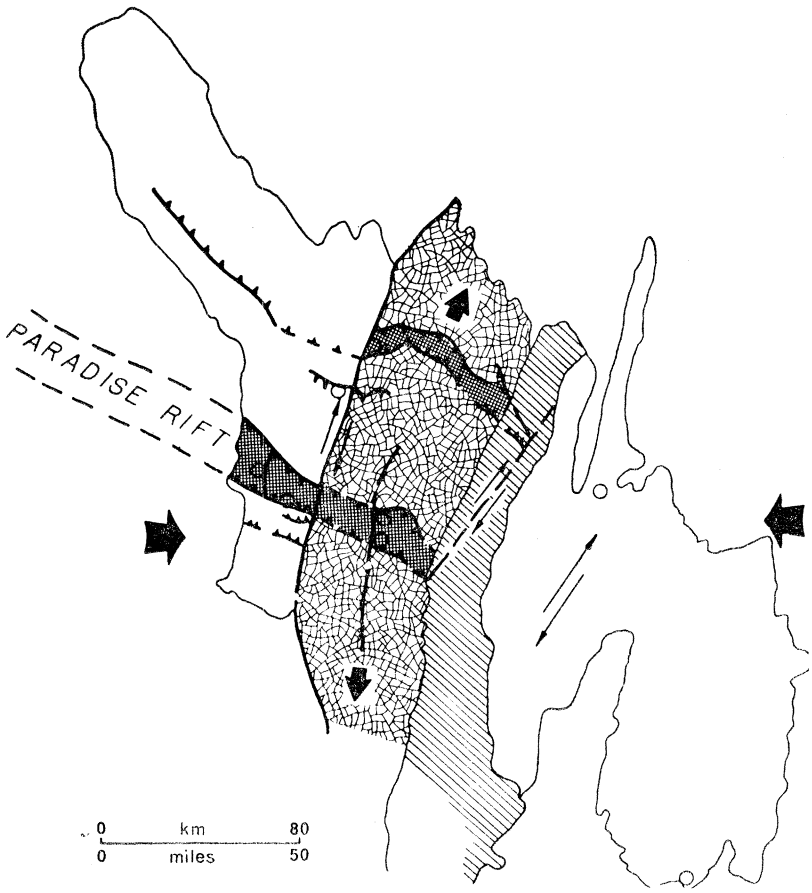

FIGURE 6. Reconstruction of the Mt Isa District with removal of major displacement on right lateral and spoon faults. Note the localization of basic volcanics and mineral deposits within the aulacogen and close to the triple junction site.

INTERPRETATION

In recent years there has been considerable discussion of mantle plumes, triple junctions and aulacogens and their recognition in older rocks (Burke & Dewey 1973; Hurley 1972; Goodwin 1974). The above description and reconstruction of the Mt Isa District is consistent with an ancient triple junction recording incipient cratonic separation and subsequent continental collision.

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The period of breakup was initiated early in Carpentarian time by rifting along the eastern margin of the Tectonic Welt and, to a lesser extent along the Paradise Rift, in a triple junction configuration. The triple junction region and two active rift arms were the site of basic volcanism, whereas, the failed arm or aulacogen of the Paradise Rift received considerable deltaic sand deposition associated with volcanism. The aulacogen was not a single trough, but a series of normal faults symmetrical to the Paradise Rift.

The absence of deep marine sediments and transition from volcanic-arenite to carbonate reef and evaporite sedimentation through time implies a relatively minor separation period prior to closing and impingement of the two plates. On collision, the normal faults associated with early aulacogen development became reactivated by the driving force of the collision, extension in the hot mobile zone, and strong right lateral shear couple along the cratonic margin. The boundary domain is thus analogous to a fluid boundary layer and represents an interaction between the rigid craton and mobile zone. Brittle extension in the boundary zone without marked lateral shortening resulted in drastic reduction in crustal thickness by a process of flat normal faulting and block rotation analogous to the Basin and Range Province of the western U.S.A. (Proffett 1971).

The gravity profile (figure 7) indicates a considerably thinner crust beneath the mobile zone. This feature is believed to reflect the Lower Proterozoic cratonic boundary which apparently acted as the locus for rifting. The thicker crust of the Tectonic Welt is, however, a direct result of the collision and resuturing of the cratonic boundary.

Glikson & Lambert (1973) consider the distinction between intercontinental (Cordilleran) and intracontinental mobile belts in the western Australian shield and differences between Precambrian mobile belts and Alpine systems. Many Precambrian mobile belts have features of an intracratonic rift process, sedimentation and subsequent collision (Hurley 1972; Windley 1973). Such a mechanism of relatively minor rift separation adequately explains the Mt Isa mobile belt, particularly the absence of oceanic crustal material and the continuity of platform type sediments into the mobile belt. The argument presented here suggests Mt Isa is a marginal cratonic mobile belt, not intracratonic in the sense of the Frazer–Musgrave system or the incipient rift of the Batton Trough. Despite the marginal location and associated variation in crustal thickness, the tectonic features are similar to those of an intracratonic mobile belt.

Relation to mineralization

The McArthur Basin includes at least eight stratiform base metal deposits of significant size including Mt Isa (140 million tonnes (Mt) of 3 % Cu and 56 Mt of 16 % combined Pb-Zn-Ag) and McArthur River (200 Mt of 14 % combined Pb-Zn-Ag). The association of such deposits with triple junctions and aulacogens has been recognized previously (Burke & Dewey 1973), and the close spatial correlation of deposits to the Mt Isa triple junction and Paradise aulacogen is shown in figure 6. In particular, known copper deposits are restricted to the immediate vicinity of the cratonic boundary domain and the volcanics above the mantle plume area, whereas, lead–zinc deposits show a broader geographic spread.

McArthur River occurs within a rift structure directly analogous to the Paradise Rift, but not near a cratonic boundary. Further work may indicate an incipient intracratonic triple junction at the southern margin of the Batton Trough in the vicinity of the McArthur River.

The absence of volcanics (and copper) at McArthur River implies a less advanced or deep-seated aulacogen than Mt Isa.

An observation of exploration importance is the gravity defined west-northwest trends parallel to and south of the Paradise Rift (figure 5). These join the rift arm of the Eastern Creek volcanics which extends into the Boulia area where lead–zinc mineralization has been reported.

The remarkable similarity between ore deposits of Sullivan and Mt Isa warrant re-emphasis. The North American western cratonic margin in mid-Proterozoic times included five or six aulacogens (Stewart 1972, fig. 4; Burke & Dewey 1973, fig. 11). Kanasewich, Clowes & McCloughan (1968) defined one of these as a buried Precambrian rift beneath Alberta. The Sullivan ore body is localized near the junction of this rift and the cratonic margin in a tectonic situation similar to Mt Isa and broadly analogous to the Red Sea situation.

It may be very significant that younger mineralization centres at Butte, Coeur d'Alane, Park City and Bingham appear to be situated above Proterozoic cratonic boundary aulacogens comparable to Mt Isa and Sullivan.

One feature inconsistent with the aulacogen-triple junction concept is the occurrence of lead–zinc mineralization within the mobile belt or active rift arms of Mt Isa (Dugald River and Pegmont), and possibly located on extensions of the Paradise Rift zone *across* the Tectonic Welt. This continuity implies a structure more complex than the simple triple junction configuration.

A similar feature is recognized in the Uinta–Gold Hill trend of Utah where a series of aeromagnetic highs, a line of young intrusives, and mineralized areas, coincide with the late Precambrian Uinta aulacogenic trough, but extend to the west into Nevada and well beyond the cratonic margin of the Wasatch line (Erickson 1975).

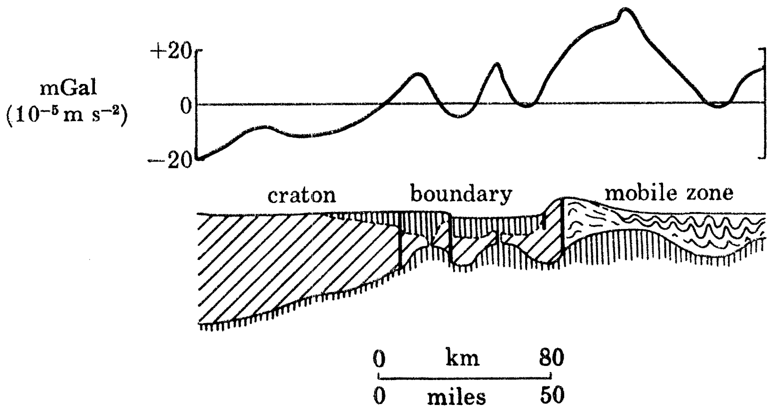

FIGURE 7. Gravity profile across the Mt Isa cratonic boundary with interpretation of crustal significance.

THE ADELAIDE GEOSYNCLINE

The Adelaide geosyncline extends over 960 km along the Proterozoic cratonic margin in south Australia and a broad tapering arm extends into the craton between the Gawler and Arunta subprovinces into the Musgrave mobile zone (figure 2). The geosyncline includes a thick sequence of weakly metamorphosed Adelaidean and Cambrian sediments deposited in a continuously subsiding trough without major volcanism. The western edge of the trough is delimited by a zone termed the Torrens Hinge.

The Gawler Platform, cratonic margin west of the Torrens Hinge (figure 8), consists of Lower Proterozoic and probably Archean basement mobilized and cratonized in early Carpentarian time (*ca.* 1750 Ma). Middle to late Carpentarian platform sediments and acid volcanics of the Gawler Range (1535–1470 Ma) are covered by a thin sequence of Adelaidean platform sediments.

The Willyama Complex to the northeast of the Adelaide Geosyncline (figures 8 and 9) exhibits similar tectonic relations. The Broken Hill metamorphism (1700–1650 Ma) is followed

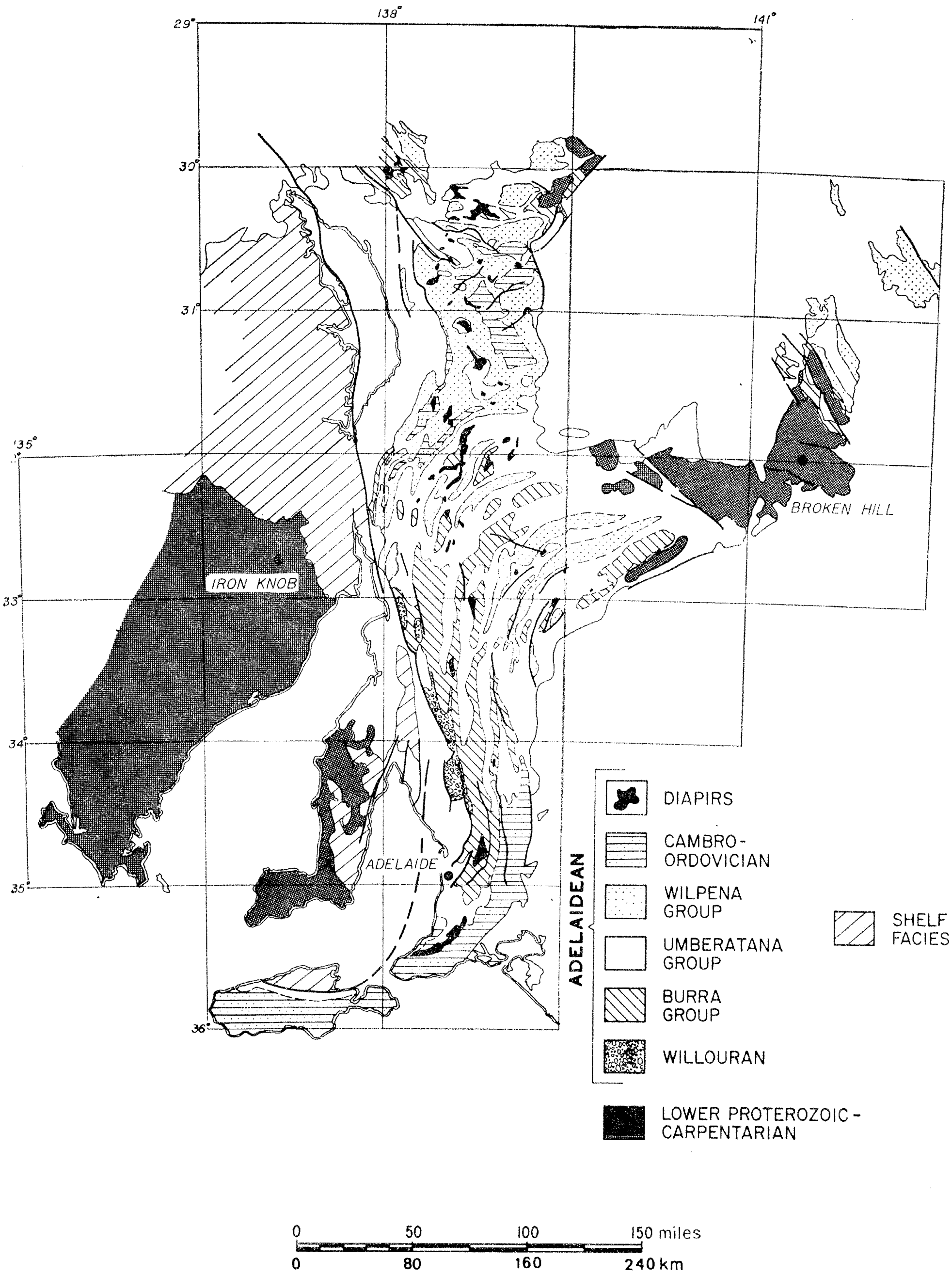

Figure 8. Geological map of the Adelaide geosyncline showing major lithological units and the Torrens Hinge separating shelf facies from the geosyncline.

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by a local granite emplacement (1550 Ma), equivalent to the Gawler Range volcanic event and to late tectonic granites in the Mt Isa District. Mid to late Carpentarian sediments are absent, but a thin cover of Adelaidean sediments is preserved.

Thus, both boundaries of the geosyncline were mobile in early Carpentarian and relatively stable through to the start of Adelaidean deposition heralded by Willouran sediments and volcanics (1350 Ma). At this time the Torrens Hinge zone started to control sedimentation and continued as an active hinge for nearly 800 Ma into Cambrian times. Locally, over 15000 m of Adelaidean shallow water clastic sediments and carbonates were deposits. Turbidites are absent despite the thick sections involved. Two periods of glaciation are represented by the Sturtian (750 Ma) and Maranoan (650 Ma) tillites.

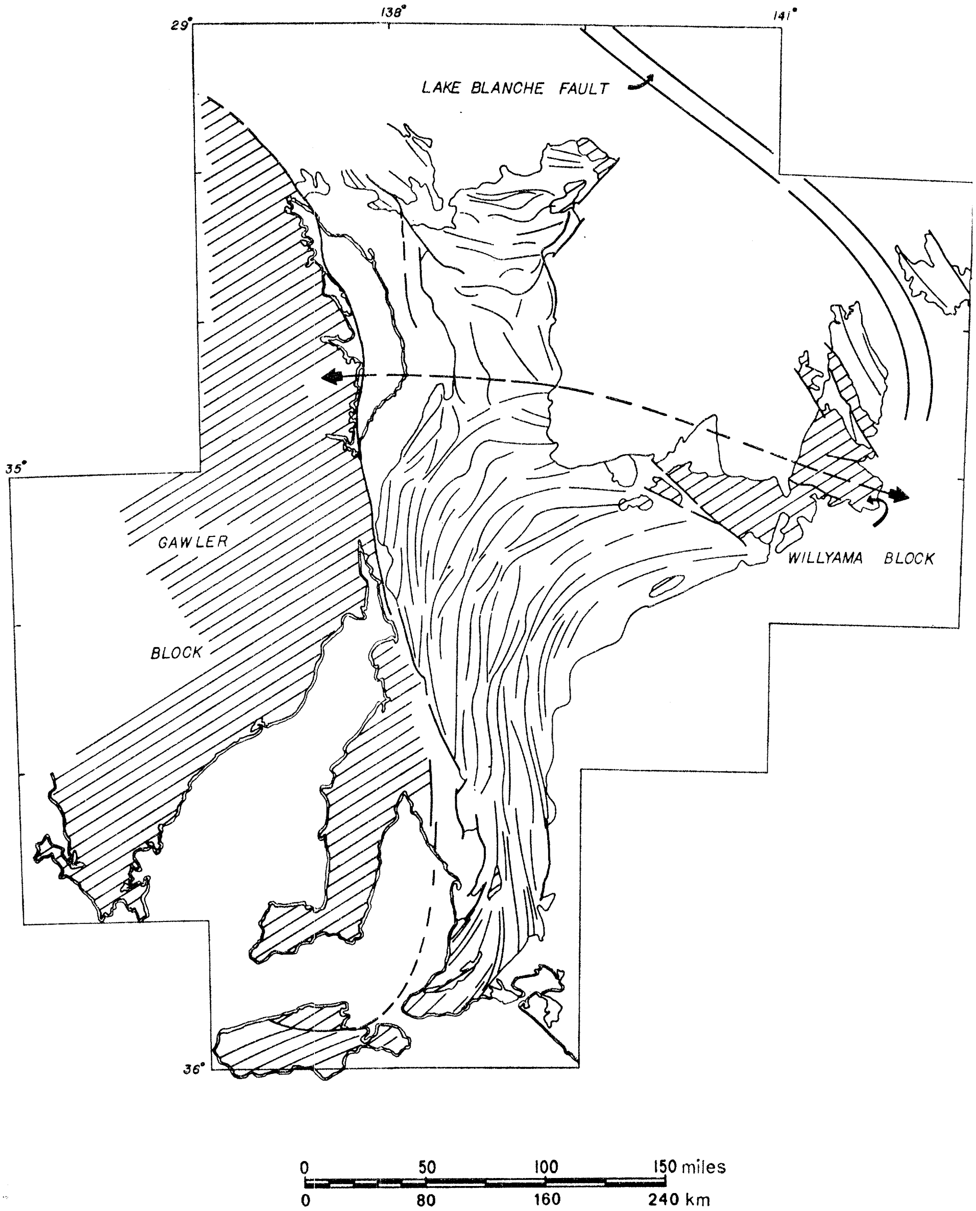

Figure 9. Structural map showing fold axes within the Adelaide geosyncline and the distribution of basement areas. The arrowed line marks a deformational null reflecting the offset cratonic margin beneath Adelaidean.

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During early Adelaidean time, the trough extended to the northwest towards the Musgrave mobile zone (figure 2) where local rifts are filled with thick clastic sediment wedges. The Musgrave belt was mobile well into Adelaidean time (1100 Ma) with granulite metamorphism, thrusting and east–west trending major deep-seated fractures (Hinkley–Mann System) which localized layered mafic bodies of the Giles complex (Sprigg & Wilson 1958). These features indicate a major intracratonic fracture operative in early Adelaidean time.

Eastward extension of the Musgrave fracture zone is largely concealed, but probably formed the northern margin of the Adelaide geosyncline, now represented by the Lake Blanche Fault (figure 9) and parallel structures such as the McDonald shear in the Willyama block.

In late Adelaidean and Cambrian time, maximum geosynclinal deposition moved southwards into the Kanmantoo trough and sediments developed miogeosynclinal characteristics. Up to 13500 m of sediments in the trough are separated from a thin shelf sequence to the west by the Torrens hinge. The Hinge has a character similar to the cratonic boundary Wasatch line in the western U.S.A. (Stewart 1972), a line of active, but continuous slow subsidence over a long period of time. In late Adelaidean, the Torrens Hinge was apparently the boundary between cratonic Australia and the developing Tasman geosyncline to the east.

Geosyncline and cratonic boundary relation

The cratonic character of Adelaidean platform sediments on the Gawler Platform and Willyama block suggest that the Adelaide geosyncline occurs as an intracratonic trough or within a marked re-entrant in the craton, and that the Proterozoic continental margin lies somewhere to the east (Rutland 1973). Such a setting seems inconsistent with the cratonic boundary nature of the Torrens Hinge. Unfortunately, Precambrian basement data is meagre in the critical area north of Broken Hill. Is the triangular area of figure 2 between Mt Isa and Broken Hill cratonic or part of the Proterozoic mobile crust? A cratonic basement necessitates a very sharp step in the eastern cratonic boundary between the Gawler and Arunta subprovinces.

A solution to the problem is suggested by internal structure of the geosyncline (figures 7 and 8). Fold axes show a remarkable S-shaped arcuation, indicative of intense compressional strain in the Kanmantoo trough in the area coincident with maximum regional metamorphism. In contrast, there is a compressive null point in the northern part of the trough where fold axes trend east–west through an irregular zone and finally northwest along the Musgrave re-entrant. The northern area is coincident with maximum diapiric activity as would be expected in a tensional or low compressive strain situation.

The pattern of inhomogeneous strain is believed to result largely from deformation across an offset or stepped cratonic margin during the Delamerian orogeny (Late Cambrian). A thick and more rigid crust extended right across the northern area, whereas, the craton was coincident with the hinge line in the south. There is ample evidence, however, that diapirs were active since early Adelaidean times (Coats 1962), and penecontemporaneous faulting on northwest to east–west faults effected Willouran and Burra group sediments in the northern areas of figure 8.

The strain pattern could, in part, relate to a right lateral shear system acting along the Musgrave–Broken Hill zone in early Adelaidean times. It is suggested that a major intracratonic separation between the Arunta and Gawler cratons occurred along this zone with right lateral displacement of the craton of over 320 km. Offset of the present coastline and continental margin of Western Australia by approximately 320 km along the northern margin of the Paterson Range and Pilbara block on a zone continuous with the Musgrave belt supports such displacement. It is also consistent with the high pressure granulites, pseudotachylites and mafic intrusives recognized in the Musgrave Range. Substantiation of such displacement may be possible by matching of pre-Adelaidean features across the Musgrave belt.

Reconstruction of the proposed displacement brings the eastern margin of the Panantarctic craton to an approximate straight line between northern and southern Australia. The general areas of the Willyama complex (and the major base metal mineralization of Broken Hill) then occupies a gentle re-entrant in the cratonic margin which may have been a Carpentarian triple junction comparable to Mt Isa. The failed arm of such a rift system would form a natural locus for subsequent Adelaidean transcurrent displacement and sedimentation.

This summary and interpretation of Adelaide geosynclinal development indicates a depositional trough very different to Mt Isa and dominated by a continuously active hinge. The trough is analogous to the miogeosynclinal tectonic setting of the Cordilleran geosyncline, but where hinge rotation was almost in equilibrium with sedimentation rates. There is, thus, a closer analogy with the Proterozoic Beltian geosyncline of the western U.S.A. (Stewart 1972). The Beltian and Cordilleran miogeosynclines appear to be virtually superimposed deposition troughs, whereas, the Tasman geosyncline lies east of the Proterozoic trough in what may be an eastward cratonization of the Australian continent.

If the proposed displacement along the Musgrave belt is valid, then prior to displacement, the Australian Proterozoic cratonic margin was a continuous gently curved element, along which at least two mantle plume sites are indicated in Carpentarian and along which a hinge developed in the Adelaidean. These features are consistent with an extensive, continuous continental crust in Proterozoic times, marginal to which Cordilleran-type orogenies have not been recognized.

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