OLARY–BROKEN HILL DOMAIN BOUNDARY — MINGARY 1:100 000 MAP AREA

A.F. Crooks
Geological Survey Branch

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A.F. Crooks

Current mapping on the Mingary 1:100 000 map area has been investigating the nature of the boundary between the Olary Domain and Broken Hill Domain, both of which are subdivisions of the Curnamona Province. Earlier work had settled on a prominent north-northeast-trending TMI feature, which coincides roughly with an equally prominent change in regional gravity, as the boundary. The geological mapping, however, shows no major changes across this zone. A different domain boundary based on the regional influence of a 1690 Ma thermal event is supportable by the mapping. Alternatively, metamorphic-grade zonation established at 1590 Ma could also be used to define a domain boundary. Since these two events are 100 Ma years apart, they define two separate domain boundary conditions. Neither of these possible domain boundaries correlates with the TMI feature.

INTRODUCTION

The Broken Hill Exploration Initiative (BHEI) began in 1994 as a joint project of data acquisition and interpretation by Primary Industry and Resources South Australia (PIRSA), New South Wales Department of Mineral Resources (NSWDMR) and the Australian Geological Survey Organisation (AGSO). The aim was to better understand the geology of the Curnamona Province (Fig. 1) and so improve the mineral exploration effort in the area.

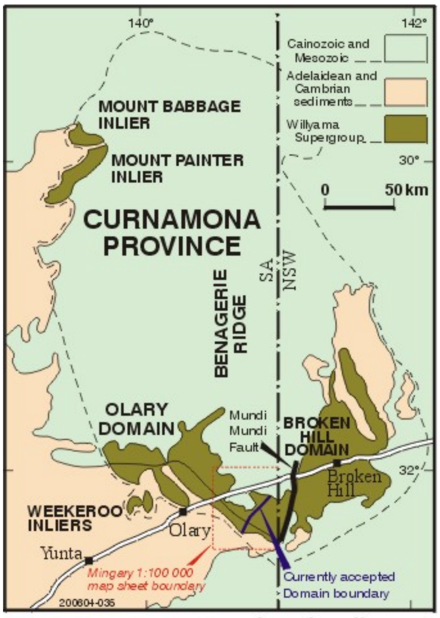

Fig 1 Curnamona Province locality map.

One of the projects PIRSA committed to was the mapping of the Mingary 1:100 000 map area on the SA–NSW border. The Curnamona Province can be subdivided into several domains and the boundary between the two southern domains of the province, the Olary and Broken Hill Domains, was interpreted to cross this area (Fig. 2).

The boundary between these domains had been based on loosely defined lithological and magnetic characteristics (e.g. Robertson et al., 1998). Uncertainty over the specific nature of this boundary is reflected in the recent use of the term 'domain' rather than the earlier term 'block' (Robertson et al., 1998).

THE MAPPING PROJECT

The Mingary project commenced in May 1995 and concentrated on the mapping of lithologies using a slightly modified version of the lithological labelling scheme developed by NSWDMR (Stevens and Stroud, 1983). The mapping project used new 1:25 000 scale airphotos with the intention of publishing at 1:50 000 scale. To date all mapping has been compiled at 1:25 000 scale. Five of the eight 1:25 000 map sheets covering the Mingary 1:100 000 map area are available as draft digital compilations. These are Cockburn North and South, Mutooroo North and South, and Radium Hill South. B. Stevens (NSWDMR), G. Gibson (AGSO) and A. Donaghy (Monash University) are acknowledged for their input to the mapping project.

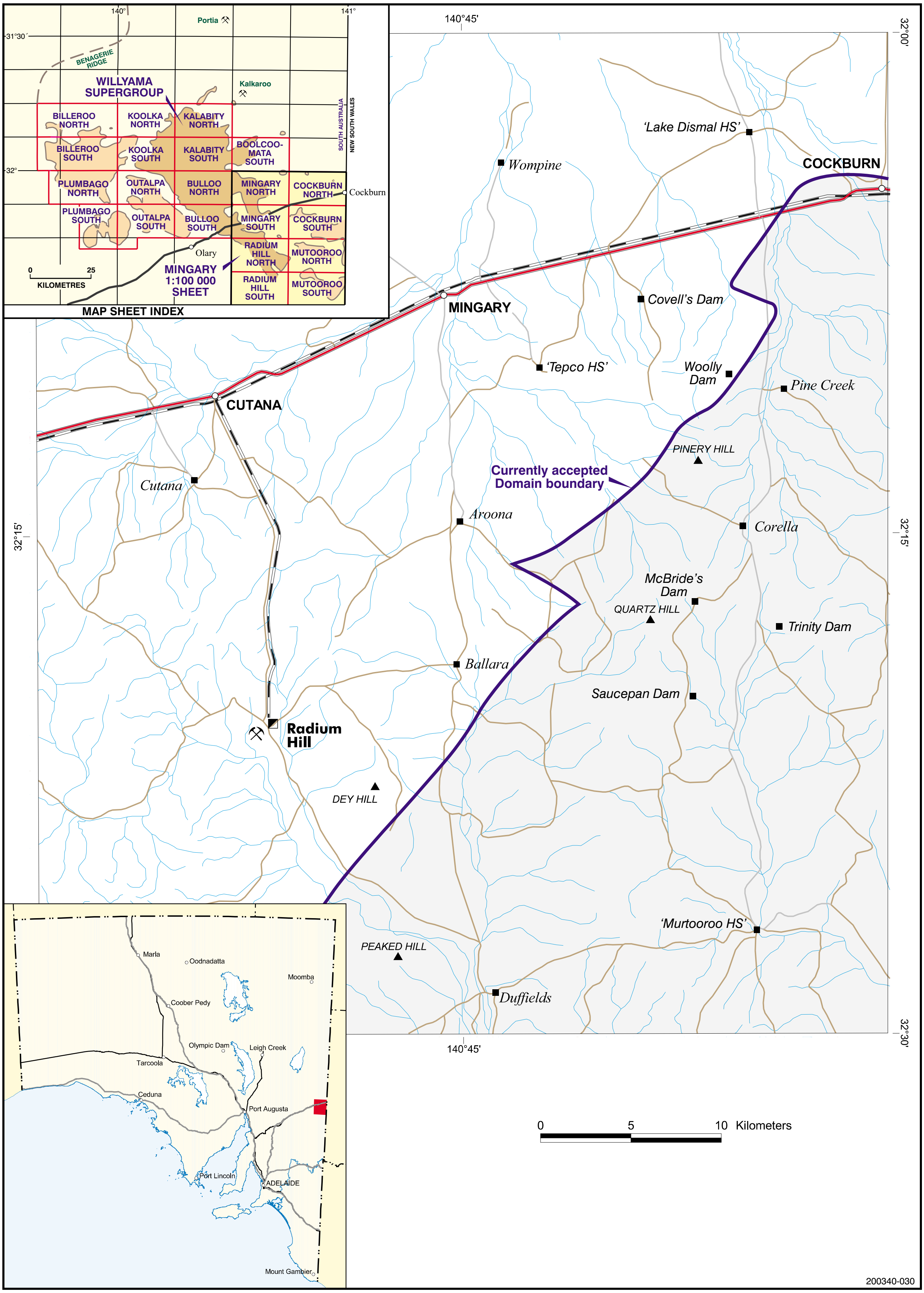

Fig. 2 *Location map of Olary Region SA.*

Table 1 New lithostratigraphic units for the Willyama Supergroup, Olary Domain, and comparison with previous units, and units of the Broken Hill Domain (after Conor, 2000a,b)

Ga (U–Pb)	NEW UNITS	SUITES OF CLARKE et al. (1986)	BROKEN HILL GROUPS
	Strathearn Group	Pelite	
1.65	Mount Howden Subgroup		Paragon
1.69	Saltbush Subgroup		Broken Hill and Sundown
	Curnamona Group		
1.71	Ethiudna Subgroup	Bimba and calcsilicate	Broken Hill
1.71	Wiperaminga Subgroup	Quartzofeldspathic and composite gneiss	Thackaringa and below

U–Pb determinations from Page et al. (2000)

Table 2 New lithostratigraphic units for the older igneous suites of the Olary Domain and reference to possible correlatives in the Broken Hill Domain (after Conor, 2000a,b)

Ga (U–Pb)	NEW SUITES NAMES (OLARY)	BROKEN HILL (approximate correlatives)
1.69	**Lady Louise Suite**	Parnell Formation and amphibolites, Rasp Ridge Gneiss
	Basso Suite	
1.71	Abminga Subsuite	
1.71	Ameroo Gneiss Subsuite	Alma Gneiss

U–Pb determinations of Lady Louise Suite from C.M. Fanning (ANU, pers. comm., 1998) and Basso Suite from Page et al. (2000)

GEOLOGY

The Curnamona Province is a roughly circular feature comprising outcropping to deeply buried Proterozoic basement rocks extending from the northeastern Flinders Ranges in South Australia into northwestern New South Wales. The best outcrops of these multiply deformed Palaeoproterozoic and Mesoproterozoic rocks occur along the southern margin of the province where they have been subdivided into the Broken Hill Domain in the east and Olary Domain in the west (Figs 1, 2). Geochronological work and mapping has long recognised that the rocks in each domain are part of the same broad stratigraphic sequence, though detailed correlation has always been difficult. The most recent correlations are presented in Tables 1 and 2. The difficulty in correlation from known Olary Domain stratigraphy to known Broken Hill Domain stratigraphy reflects the reality that differences between the two areas do exist, indicating that there may be significant differences between the geological histories of the two regions.

PREVIOUS DOMAIN BOUNDARY DEFINITIONS

Among the suggested geological features which could define differences between the two domains are:

- The absence of a thick sequence equivalent to the Broken Hill Group of the Broken Hill Block in the Olary Domain.
- The absence of a pronounced ‘Bimba gossan’ level equivalent in the Broken Hill Domain.
- The rarity of the amphibolite sills, dykes and bodies in the Olary Domain relative to the Broken Hill Domain.
- A generally lower metamorphic grade in the Olary Domain.
- The relative paucity of ~1590 Ma Bimbowrie Suite granites (of Conor, 2000a) in the southern part of the Broken Hill Domain when compared to the Olary Domain.

These interpreted differences have led to attempts to draw a domain boundary.

- Clarke et al. (1987) reported that Thompson (sic) used the SA–NSW border as an arbitrary domain boundary (Thomson, 1976). Clarke et al. (1986) appear to have used this arbitrary boundary, but Clarke et al. (1987) preferred the Mundi Mundi Fault.
- Stevens (1986) recorded that Scheibner used the Mundi Mundi Fault as the domain boundary in an unpublished manuscript but he himself recognised no significant differences in the geology on either side of the fault. He

therefore suggested a boundary further to the west in South Australia based on a southwesterly magnetic trend, interpreted to be a fault (Fig. 3a).

- Geophysicists working on the Broken Hill and Olary areas agreed to a boundary centred on the same southwest–northeast-trending magnetic low zone west of Cockburn as identified by Stevens (1986), Isles (1983) and Mills (1986).

- Ashley and others used this consensus position to assert that the Olary Block is separated from the Broken Hill Block 'by a north-northeast fault and marked change in aeromagnetic character'(Ashley et al., 1994, 1995).

- An alternative domain boundary criterion is a zone of steep gravity gradient that appears to subdivide higher density rocks of the Broken Hill Domain in the east from generally lower density rocks of the Olary Domain in the west. D. Tucker (consultant, pers. comm., 1995) suggested that this density contrast could be the result of a change in metamorphic grade, with the Broken Hill Domain being characterised by high density, high metamorphic grade minerals (e.g. garnets) compared to the Olary Domain. The abundance of amphibolites also increases the overall bulk density of the Broken Hill Domain. Conveniently, this gravity gradient coincided approximately with the previously accepted domain boundary as defined by the Total Magnetic Intensity (TMI, Fig. 3b).

  By 1997, Ashley et al., using a reference to Robertson and Preiss (1996), had incorporated these new data into their annual excursion guidebook where the domain boundary was defined 'on the basis of lithological and geophysical character with an intense gravity gradient and linear magnetic feature striking approximately northeast to north-northeast marking the boundary' (Ashley et al., 1997).

- Similarly, Robertson et al. (1998) used the linear magnetic feature to define the boundary.

- More recently, the Mundi Mundi Fault has again been suggested as a domain boundary based on an interpreted difference in reflection characteristics on both sides of the fault as seen in the AGSO deep seismic (Gibson et al., 1997).

Each of the above lithological criteria used to define the differences between the domains has been tested across the geophysical feature currently accepted as the domain boundary during the current Mingary mapping.

BROKEN HILL GROUP OF THE BROKEN HILL DOMAIN

The Broken Hill Group of the Broken Hill Domain, host to the Broken Hill Pb–Zn–Ag lode, is a sequence of sediments with minor calcsilicates, volcanics and/or volcanoclastics (Stevens et al., 1988). In the Broken Hill Domain, the basal part of the Broken Hill Group is a calcsilicate unit, the Ettlewood Calcsilicate, which forms a convenient marker horizon. In the Olary Domain, a calcsilicate horizon in the Ethiudna Subgroup of the Curnamona Group, referred to in part as the Bimba formation, also forms a marker horizon at the same stratigraphic level (see Conor, 2000a,b).

Mapping of the Mingary 1:100 000 sheet has found calcsilicate rocks to be uncommon but widespread over much of the area. The calcsilicates are well bedded to delicately laminated, and are often tightly folded. The mineralogy, consisting of quartz, plagioclase, clinopyroxene, scapolite, actinolite, garnet and variable amounts of albite, is consistent with mid-amphibolite to granulite-facies metamorphism.

On geochronological evidence (Page et al., 2000), calcsilicates of the 'Bimba formation' of the Olary Domain are time equivalents of the Ettlewood Calcsilicate of the Broken Hill Domain. Since it is not possible to distinguish between these two units, they appear to be of little assistance in defining a domain boundary. However, if this correlation is valid, the thick sequence of metasediments and volcanoclastics of the Broken Hill Group that sit above the Ettlewood Calcsilicate in the Broken Hill Domain appears to be absent or much reduced in thickness (with the exception of the Weekeroo Inlier) in the Olary Domain.

In the South Australian portion of the Broken Hill Domain, possible equivalents of the Broken Hill Group psammitic, psammo-pelitic and pelitic metasediments are known near 'Mutooroo'

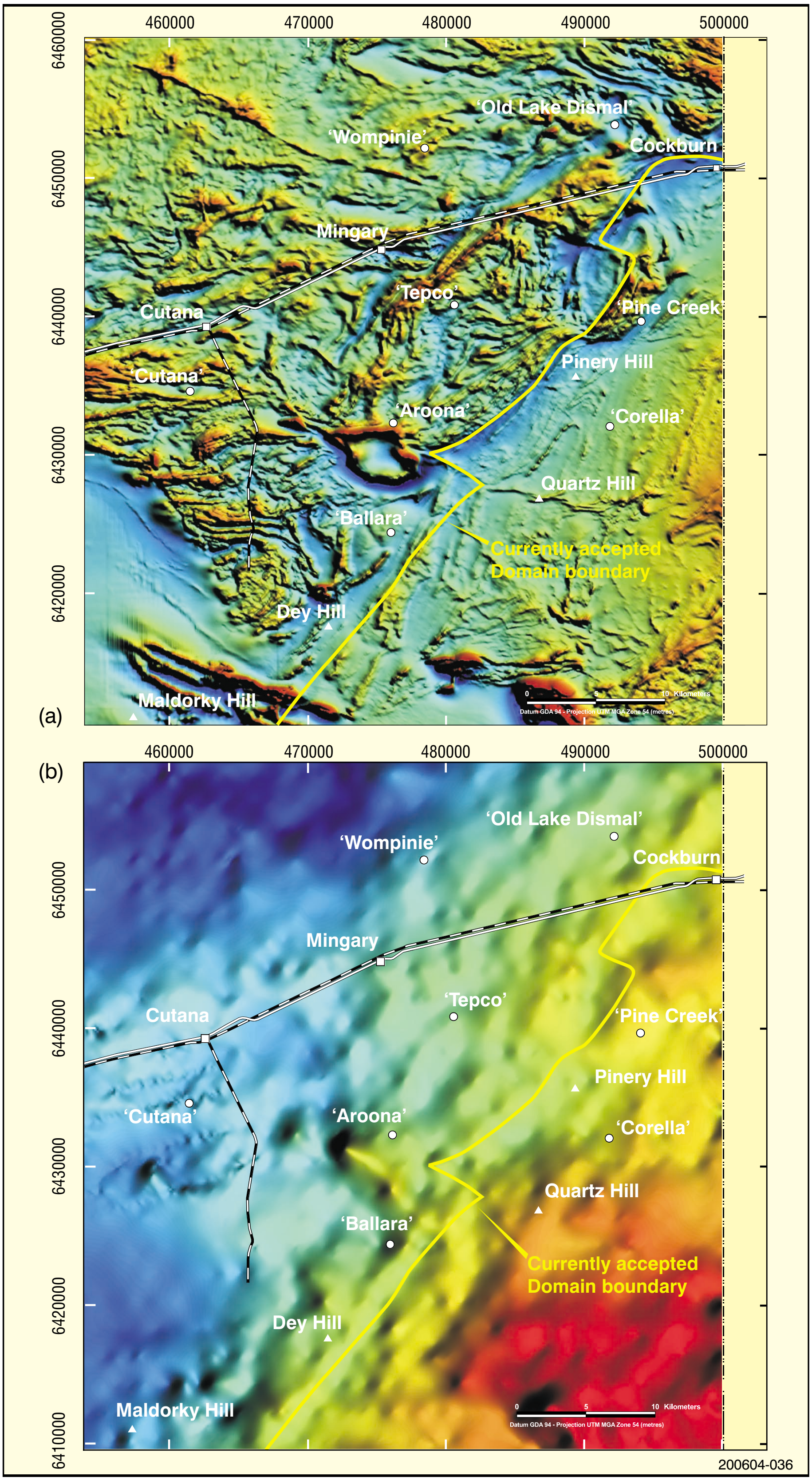

Fig 3 *Mingary 1:100 000* ***(a)*** *TMI and* ***(b)*** *gravity with currently accepted domain boundary.*

homestead. Similar garnet – 2 mica metasediments considered part of the Broken Hill Group occur in a pit near 'Lake Dismal' homestead and also south of Radium Hill. These latter two occurrences of Broken Hill Group metasediments occur west of the currently accepted domain boundary in the interpreted Olary Domain.

A significant suite of Broken Hill Group lithologies that have been used as a vector to Broken Hill type mineralisation is the Hores Gneiss and Parnell Formation ('Potosi' lithology). The Hores Gneiss is thought to be a volcanoclastic rock, while the Potosi is considered to be a variant of the same rock (Stevens, 1998; Wyborn et al., 1998). Neither of these lithologies have been positively identified on the South Australian side of the border, although one outcrop east of McBrides Dam on the eastern side of the Mingary map area has been compared to the Potosi Gneiss (B. Stevens, NSWDMR, pers. comm., 1998). Another outcrop further to the west of McBrides Dam has been described in thin section as a possible tuff (Purvis, 1996) and may also be a Hores Gneiss equivalent.

The lithological association of gahnite (zinc spinel) and blue ('lode') quartz is considered an indicator of Broken Hill Group rocks. Quartz–gahnite rocks occur on the Mingary 1:100 000 sheet but are restricted to the eastern side. Gahnite has been reported from calcsilicate outcrop near Covell's Dam (T. Moody, Rio Tinto Exploration, pers. comm., 1998). Quartz–gahnite rock has also been mapped near Open Dam, south of Radium Hill. Both these occurrences are on the Olary Domain side of the currently accepted, magnetically defined domain boundary. These occurrences aside, gahnite is known from only a few localities in the Olary Domain (N. Cook, Pasminco. pers. comm., 1998), including near 'Outalpa' (Zdziarski, 1997).

AMPHIBOLITES AS A BASIS FOR A DOMAIN BOUNDARY

Mapping on Mingary has verified that amphibolites are common on the eastern half of the map area. They form mainly intrusive, layer-parallel bodies, and are considered to be correlatives of similar amphibolite bodies in the Broken Hill region which have an intrusive age of 1683±5 Ma (Nutman and Ehlers, 1998). They appear to be contemporaneous with felsic volcanism represented by the Hores Gneiss at 1686±3 Ma (Page et al., 2000). While the amphibolites occur in lower parts of the sequence, in the Broken Hill and Thackaringa Groups of the Broken Hill Domain they do not occur in the Sundown and Paragon Groups in the upper parts of the sequence. No amphibolites have been recorded stratigraphically above the Hores Gneiss.

In the Olary Domain, amphibolites termed the Lady Louise Suite (Conor, 2000a,b), also occur in the lower parts of the sequence in the Curnamona Group but not in the upper part of the sequence in the Strathearn Group. An amphibolites of the Lady Louise Suite at the Woman-in-White Mine has been dated at 1685±4 Ma (Conor and Fanning, 2001), strongly supporting a correlation with amphibolites in the Broken Hill Domain.

On Mingary, amphibolites occur on both sides of the currently accepted domain boundary at Radium Hill and at Covell's Dam. On the western half of the Mingary map area, only rare amphibolites have been mapped. They include the pre-tectonic amphibolite 'plugs' of the Radium Hill Mine (Whittle, 1954) which are believed to be the same age as amphibolites in the east. Sprigg (1954) also described concordant amphibolites he considered part of the sedimentary sequence that may also be part of the same suite of amphibolite sills.

Since they occur in both the Thackaringa and Curnamona Groups on both sides of the accepted domain boundary, they are not diagnostic of either the Broken Hill or Olary Domains. However, the volume of amphibolitic material varies dramatically across the Mingary map area and so could form the basis of a domain boundary.

Some caution is required though. As seen above, the most commonly accepted domain boundary follows a particularly prominent northeast–southwest-trending magnetic low which crosses Mingary diagonally. Mapping across this feature has revealed that there are no amphibolite bodies immediately on the Olary Domain side (although they do occur further west as described above). The dominant lithology on this western side, is a muscovite±kyanite±staurolite(minor) schist. In terms of the Broken Hill and Olary Domain stratigraphy, this lithology could correlate with the Sundown–Paragon Groups and Strathearn Group, the deposition of which postdate the intrusion of the amphibolites. It is not surprising then that no amphibolite bodies are present, and this, rather than evocation of a domain boundary, may be the reason for their absence.

'BIMBA FORMATION' AND GOSSANS OF THE OLARY DOMAIN

In the Olary Domain, a suite of calcsilicate rocks termed the 'Bimba formation' is equivalent to the Ettlewood Calcsilicate of the Broken Hill Domain (Page et al., 2000; Laffan, 1997) as described above. Of particular interest is a gossanous ironstone horizon, derived from oxidised disseminated, laminated and vein sulphides, which forms a distinctive feature of the 'Bimba formation', but which has no direct correlative in the Broken Hill Domain. This gossanous ironstone outcrop can be found associated with calcsilicates in several locations in the northwestern part of the Mingary map area, on the Olary Domain side of the magnetic feature currently used as a domain boundary.

TECTONIC AND METAMORPHIC HISTORY ACROSS THE SUGGESTED DOMAIN BOUNDARY

The Curnamona Province is dominated by Mesoproterozoic deformations termed the Olarian Orogeny. Examination of the metamorphic and tectonic history of both the eastern and western sides of the Mingary 1:100 000 map area during this orogeny demonstrates many similarities.

A very strong, high grade S_1 fabric parallel to bedding (S_0), along with a co-parallel early melt forming event, is evident on all parts of the map area and hence on both sides of the interpreted domain boundary. On both sides of this boundary, these early pegmatite veinlets and leucosome segregations, along with the S_1 foliations, have been folded by the F_2 folding event, into tight, upright to isoclinal folds with a northeast-trending axial plane schistosity (S_2). Plunges are generally fairly flat, oscillating between shallow northeast to shallow southwest. In both the eastern and western parts of the Mingary map area, D_2 appears to have been the peak metamorphic event, dated at ~1580 Ma (C.M. Fanning, ANU, pers comm., 1998) from the extensive partial melting which occurred. Migmatites with remnant S_1 biotite layers are common. In the east, near Trinity Dam, these D_2 partial melts contain a late-stage fibrolite–sillimanite growth.

Near the 'Tepco' gate on the Barrier Highway, well-laminated calcsilicate rocks with a well-developed 'Bimba formation'-style gossan cropping out on the margin of the Olary Domain invite a correlation with central Olary Domain rocks. Petrology on adjacent rocks of probable Curnamona Group (the quartzofeldspathic suite of Clarke et al., 1986), indicate a mesoperthite–sillimanite mineral assemblage, indicative of granulite-grade metamorphic conditions (Purvis, 1996). This indicates that rocks, which would normally be considered Olary Domain rocks on the basis of the well-developed 'Bimba-style' gossan, can reach granulite-grade metamorphism.

Clarke et al. (1986, 1987) mapped a more or less seamless metamorphic gradient from high-grade sillimanite–K-feldspar–garnet in the Broken Hill Domain adjacent to the Mundi Mundi Fault to lower grade, andalusite-dominated rocks to the northwest of the Olary Domain. They considered the area to be one single tectonic unit. This recent mapping on Mingary has verified that there is no major change in metamorphic grade either side of the suggested domain boundary.

As the D_2 deformation event evolved post-peak metamorphism, isobaric cooling resulted in a move in the stability field for aluminosilicate polymorphs and the growth of retrograde kyanite. Near Radium Hill, the mineral kyanite is so common it has been mined as a refractory. Kyanite is present on both sides of the interpreted domain boundary. Crystal growth appears to be confined to beds rotated into parallelism with the axial planes of the F_2 folds. Crystals are usually randomly aligned on those planes, but in places the blades are orientated parallel to F_3 fold axes.

Clearly, both the Olary and Broken Hill Domains have undergone similar tectonic and metamorphic histories since early in the Mesoproterozoic.

THE REGIONAL GRANITES

There are differences between the domains though, probably influenced by the regional metamorphic gradient. As indicated previously, earlier workers had noted a dearth of the 'regional' S-type granites in the Broken Hill Domain compared to the Olary Domain. These granites are now termed the Bimbowrie Suite on Olary (Conor, 2000a). This difference is reflected on the Mingary 1:100 000 map area. In the Olary

Domain these Mesoproterozoic granites, dated at ~1580 Ma (Ludwig and Cooper, 1984; Cook et al., 1994), intruded during the Olarian Orogeny and are variously deformed by it. In the northwest of Mingary, relatively undeformed granites intrude Willyama Supergroup metasediments. Near 'Lake Dismal' Homestead, to the north of Cockburn, a small intrusive granite plug has been dated at 1573.8±4.5 Ma (C.M. Fanning, ANU, pers. comm., 1998) on simple magmatic zircons, and is within the expected range for a post-D_2 intrusive.

Further south and east on Mingary, in interpreted Broken Hill Domain rocks, these granites are rare to absent although zircons associated with post-deformation melting near Saucepan Dam gave a similar age at 1572.1±6.1 Ma (C.M. Fanning, ANU, pers. comm., 1998). In general, partial melts, composite gneiss lithologies and migmatisation dominate the Broken Hill Domain rocks on Mingary. Thus, the Broken Hill Domain on Mingary appears to be a region dominated by 'failed granites', where the local melts have only partially separated from restite.

Although at peak and post-peak metamorphism the temperatures and pressures reached granulite grades, some other factor, perhaps dehydration reactions at the amphibolite–granulite-grade boundary, suppressed the formation and pooling of significant amounts of melt. D'Lemos et al. (1992) described a similar zonation from the Cadomian Belt of northern France. There, a distinction was drawn between the deeper, source regions for the granite melt, the migma zone of unsuccessful granite production in middle crustal levels and the final emplacement zone for homogeneous, relatively undeformed granites in the higher levels of crust. In the migma zone, in particular, these workers postulated that intense transpressional shearing transported the granite melt directly through the migmatite zone to higher crustal levels. Progressive deformation and attenuation could result in complete closure of the magma conduits, such that evidence for their prior existence could be removed. Possible D_2 shearing and attenuation of parts of the stratigraphy are common features of the Mingary map area.

Recent dating of the Mundi Mundi type granites such as the Purnamoota Road 'Lf gneiss' at 1597±3 Ma, Cusin Creek pluton at 1596±3 Ma and Mundi Mundi granite itself at 1591±5 Ma (Page et al., 2000), indicate that more 'regional' S-type granites may exist in the Broken Hill Domain than previously recognised. These appear to be concentrated in the northern, and perhaps lower grade upper level part of the domain.

DISCUSSION AND CONCLUSIONS

In the past, broad lithological differences have been recognised in rocks across the southern Curnamona Province, leading to a subdivision into distinct domains. A boundary to separate these has been arrived at on the basis of geophysical patterns associated with both TMI and gravity. Detailed mapping on the ground, however, determined that the broad lithological differences used to define each of the subdomains can be found on either side of this geophysically derived boundary. The broad tectonic history is also repeated on both sides. As a domain boundary it therefore is not supported on geological grounds.

In addition, it is noted that the geological criteria for province subdivision suggest not one but two possible domain boundaries. The first and perhaps most significant relates to the thinning and wedging out of Broken Hill Group lithologies towards the west, but certainly west of the currently accepted domain boundary. Of particular importance is the distribution of the Hores Gneiss and Potosi Gneiss, the quartz–gahnite rocks and restriction in the distribution of the coeval amphibolite bodies. Each of these key lithologies is apparently related to a ~1690 Ma thermal event. This event in turn appears to be related to a fundamental change in basin morphology involving possible extension and crustal weakening. Sedimentary deposition recorded after this indicates a basin-wide change from shallow water clastics and volcanoclastics to deeper water pelites at this time. The extent of the influence of the 1690 Ma thermal event is one possible criterion for domain subdivision.

However, the presence of pillow lavas in the 'Weekeroo' region (Jones et al., 1962), considered to be part of the Lady Louise Suite in the Olary Domain and consequently equivalent to parts of the Broken Hill Group (Laing, 1996), indicates that other 1690 Ma magmatic centres may exist elsewhere in the Olary Domain. Since this thermal event may be a significant driver for Pb–Zn–Ag mineralisation at Broken Hill, the identification of these magmatic centres may have important metallogenic implications.

Alternatively, a domain boundary can be drawn based on the degree of exhumation of the two domains exposing different crustal levels. Such a domain boundary would have to be drawn across the very northern and northwestern margins of the Mingary map area. While most rocks from the Mingary sheet have seen the same upper amphibolite to low granulite-grade peak metamorphic conditions that has taken them into the sillimanite => kyanite stability fields, the rocks in the northwest are probably the lowest grade. This is in line with the regional metamorphic gradient mapped by Clarke et al. (1986, 1987) for the Olary Domain. This gradient implies shallowing to the west. The outcrop zonation of the migmatites and S-type granites on Mingary is also consistent with the same pattern of crustal level shallowing to the north and northwest based on the D'Lemos model (D'Lemos et al., 1992). If crustal level is a significant determinant of granite formation, then this may have important implications for the emplacement of associated Cu–Au (–Mo) mineralisation (Skirrow and Ashley, 2000).

Note that the fundamental criteria on which both of these suggested domain boundaries are based relate to different events 100 million years apart. The first is related to early basin development at 1690 Ma. The second is related to peak metamorphism at 1590 Ma, although the current location of the domain boundary based on this is more a product of the much later process of exhumation.

The above findings de-emphasise the importance of a previously accepted domain boundary. Exactly what this feature means in terms of a domain boundary is now not clear. On Mingary, it appears to be one of several north to northeast-trending faults, this one having demagnetised Thackaringa Group rocks in the east in juxtaposition with Sundown and Paragon Group rocks in the west. Its continued use, therefore, can only be justified on geographic rather than geological grounds.

This report forms the basis for a presentation delivered at the BHEI 2000 Conference during 29–31 May at Broken Hill. A shortened version appears in the Abstracts volume of this conference (Crooks, 2000) and in an article in MESA Journal 20 (Crooks, 2001).

Plate 1 Laminated gahnite-bearing calcsilicate SE of Covell's Dam *(Photo No. 047545)*

Plate 2 Multiply deformed early leucosome, Radium Hill *(Photo No. 047546)*

Plate 3 Horizontal plunge on rodded Alma Gneiss equivalent, Woolly Dam *(Photo No. 047547)*

Plate 4 Kyanite aligned with L_3 fold plunge, Radium Hill *(Photo No. 047548)*

Plate 5 “Regional” S-type granite NE of “Lake Dismal” Homestead *(Photo No. 047549)*

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