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Mesoarchean to Mesoproterozoic evolution of the southern Gawler Craton, South Australia

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The Gawler Craton preserves a complex and prolonged tectonic history spanning the interval c. 3200–1500 Ma. Reworking of Paleoarchean, c. 3400–3250 Ma crust led to the formation of c. 3150 Ma granites now exposed within a narrow belt in the eastern Gawler Craton. Following this, there is no known record of significant tectonic activity until the onset of bimodal magmatism during the Neoarchean to earliest Paleoproterozoic, c. 2560–2470 Ma. This magmatism was terminated by high temperature metamorphism and deformation during the 2465–2410 Ma Sleafordian Orogeny. Magmatic events associated with widespread sedimentation over the interval c. 2000–1740 Ma largely sources this older crust. The c. 1730–1690 Ma Kimban Orogeny reworked these Paleoproterozoic basins and the Neoarchean basement in a pre-dominantly transpressional orogenic system. Juvenile mantle input followed by widespread crustal melting occurred over the interval c. 1620–1570 Ma. This period of intense magmatism initiated with emplacement of the relatively juvenile c. 1620–1608 Ma St Peter Suite. This was followed by the economically significant c. 1600–1570 Ma Gawler Range Volcanics/Hiltaba Suite magmatic event, which resulted from widespread mid-crustal melting. Synchronous deformation and high temperature metamorphism accompanied the Gawler Range Volcanics/Hiltaba Suite magmatic event indicating it occurred in an orogenic environment. Far field stress was distributed around a central core zone of largely undisturbed Gawler Range Volcanics with deformation localised in the northern and southern Gawler Craton. The Gawler Range Volcanics/Hiltaba Suite magmatic event resulted in formation of a province of major economic significance that includes the giant Olympic Dam Cu-Au-U ore body.

Introduction

The Gawler Craton preserves a complex and prolonged tectonic history spanning the interval c. 3200–1500 Ma and includes Mesoarchean gneisses which are the oldest rocks in Australia outside of the Western Australian shield (Fraser et al., 2010a). The evolution of the Gawler Craton is dominated by Neoarchean to Mesoproterozoic magmatic and mineralising events, and includes the formation of the giant Olympic Dam Cu-Au-U deposit. Olympic Dam occurs within an extensively altered and mineralised belt that is host to several other deposits and prospects of the iron-oxide copper gold (IOCG) style and related copper-gold mineral systems (Skirrow et al., 2007). This Cu-Au province along the eastern margin of the Gawler Craton receives considerable attention from mineral explorers and economic geologists, being a type-locality of the breccia-hosted IOCG deposit class (Groves et al., 2010).

Prior to the Jurassic-Cretaceous breakup of Australia and Antarctica, the Gawler Craton was part of a larger continental entity, the Mawson Continent (Figure 1; Fanning et al., 1996). Counterparts occur on the coast of Terre Adélie and George V Land (Peucat et al., 1999; Goodge and Fanning, 2010) and in the Nimrod Group of the Miller Range, which have been correlated with the Kimban Orogeny in the Gawler Craton (Goodge et al., 2001). More generally, similarity of the satellite-derived geophysical imagery of the Gawler Craton and the correlative region under the Antarctic ice sheet (Finn et al., 2006) together with geochronology from Antarctica indicate a Proterozoic crustal province of considerable extent (Figure 1; Fitzsimons, 2003; Payne et al., 2009). The relationship between the Mawson Continent and Laurentia is also of interest with numerous reconstructions of Rodinia placing the Mawson Continent proximal to western Laurentia (Goodge et al., 2001), providing a spatial relationship for the contemporaneous c. 1590 Ma IOCG breccias of the Gawler Craton and c. 1590 Ma IOCG breccias of the Wernecke Supergroup, northwestern Laurentia (Thorkelson et al., 2001).

Central to developing paleogeographic reconstructions that involve the Gawler Craton (e.g. Myers et al., 1996; Cawood and Korsch, 2008), or to generating predictive models for metallogenesis, is a detailed understanding of the stratigraphic and tectonic events preserved within it. In this paper we briefly review the geology of the Gawler Craton, focusing on the southern portion of the province in order to provide a framework for its evolution. We consider the lithostratigraphic composition and examine the cycles of orogenic and magmatic reworking evident within the Gawler Craton.

Figure 1 Location of the Gawler Craton in the context of Gondwana reconstruction –160 Ma. After Fitzsimons (2003) and Myers et al. (1996).

Macroscale architecture of the Gawler Craton

The southern boundary of the Gawler Craton is the continental margin developed during rifting of Australia from Antarctica. The other boundaries are poorly constrained, being largely defined by the thickness of Neoproterozoic–Neogene cover sequences. The eastern boundary coincides with the Torrens Hinge Zone, the transitional zone between thick, folded Neoproterozoic sediments of the Adelaide Rift Complex and flat lying cover sequences of equivalent age that cover large region of the eastern Gawler Craton (Parker, 1990). It is probable that part of the Gawler Craton is the basement beneath the Adelaide Rift Complex. Likewise, the northern and western boundaries coincide with deep burial by Neoproterozoic–Paleozoic successions of the Officer Basin (Korsch et al., 2010). The nature of the boundary between the Gawler Craton and the adjacent c. 1600–1080 Ma Musgrave Province to the north (Figure 1) is poorly understood. Magnetotelluric experiments over the transition zone reveal a conspicuous lack of any major electrical discontinuity, which might be expected were there to be some type of ancient suture between the two provinces (Selway et al., 2011). Nevertheless, the Musgrave Province is composed of isotopically more juvenile material (Wade

et al., 2008) and cannot simply be the northern continuation of the Gawler Craton. Deep crustal seismic data reveal crustal-scale north-dipping structures in the northern Gawler Craton, which may form part of a transition zone between the two provinces (Korsch et al., 2010).

The southern Gawler Craton is exposed on Eyre and Yorke peninsulas (Figure 2). The dominant strike-direction of the deformed rocks is N-S and is largely due to the structural grain imposed during the c. 1730–1690 Ma Kimban Orogeny. The Kalinjala Shear Zone corresponds to a major discontinuity in geophysical data sets (Fraser et al., 2010b) and appears to separate zones of differing lithostratigraphic composition (Figure 3). This shear zone may be of fundamental significance in understanding the amalgamation of the proto-Gawler Craton (Hand et al., 2007).

Lithostratigraphic packages of the southern Gawler Craton

Mesoarchean–Neoproterozoic of northeastern Eyre Peninsula

Mesoarchean granitoids, emplaced between c. 3200–3150 Ma (Fraser et al., 2010a; Jagodzinski et al., 2011b), are exposed in the northeastern Eyre Peninsula (Figure 2). Inherited zircons, with ages up to c. 3400 Ma, occur within these granitoids suggesting still older crustal material is present at depth. This is also suggested by the geochemistry of the c.

3150 Ma Cooyerdoo Granite, which has characteristically elevated LREE (light REE) contents and low Na/K, and may be post-tectonic in origin, the product of melting a pre-existing tonalite–trondhjemite–granodiorite (TTG) crust (Fraser et al. 2010a).

A number of the c. 3150 Ma samples from this region contain c. 2500–2510 Ma metamorphic zircons and are associated with similarly aged leucogranites (Fraser et al., 2010a; Jagodzinski et al., 2011b). The gneissic fabric within the Mesoarchean granitoids may have developed during this Neoproterozoic event, and we note that c. 2510 Ma is an interval of metamorphic zircon growth for which there is no equivalence in the Neoproterozoic rocks that dominate the central and south-western portion of the craton (Figure 3). Possible Neoproterozoic sedimentary rocks also occur to the east of the Kalinjala Shear Zone, within the Middleback Ranges. Detrital zircons from these rocks yield maximum depositional ages c. 2560 Ma (Jagodzinski et al., 2011a; Szpunar et al., 2011).

Neoproterozoic–early Paleoproterozoic complexes, western Eyre Peninsula and central-northern Gawler Craton

Most of the Archean units in the Gawler Craton occur in two belts of latest Neoproterozoic–earliest Paleoproterozoic rocks, the

Figure 2 Interpreted solid geology of the southern Gawler Craton, shown over a 1st vertical derivative magnetic intensity image (PIRSA data).

Mulgathing Complex and Sleaford Complex (Figure 2). Although they are probably contiguous, any structural continuity between the two is concealed by the Gawler Range Volcanics and younger cover (Figure 2). The age of basement to the Mulgathing and Sleaford complexes is uncertain. It is possible that correlatives of the Cooyerdoo Granite underlie some parts, as rare inherited zircons and whole rock Nd isotopes indicate the presence of Paleo- to Mesoproterozoic crust,

c. 3400–2800 Ma (Daly and Fanning, 1990, 1993; Fanning et al., 2007; Jagodzinski et al., 2009; Fraser and Neumann, 2010). The oldest rock within these complexes is the protolith of the Coolanie Gneiss, which was emplaced at 2823 ± 37 Ma (Fraser and Neumann, 2010) although the dominant rock forming interval in both the Mulgathing and Sleaford complexes was between c. 2555–2480 Ma.

The oldest Neoproterozoic unit in the Mulgathing Complex is the

c. 2555 Ma bimodal Devils Playground Volcanics, which have a calc-alkaline composition, moderately juvenile $\epsilon\text{Nd}_{2555\text{Ma}}$ values (-2.3–3.1; Figure 4), Nb-, Ta-, Ti-depletions, and elevated LREE signatures (Reid et al., 2009). They have been interpreted to have formed in a continental magmatic arc setting (Swain et al., 2005). Correlates of the Devils Playground Volcanics have not been identified in the Sleaford Complex.

The c. 2520 Ma Hall Bay Volcanics are dominantly felsic, with some basaltic and komatiitic members (Teale et al., 2000). Coeval komatiitic volcanics also occur in the c. 2520 Ma Harris Greenstone Belt in the central Gawler Craton. These are typical Al-depleted Archean komatiites derived from a depleted mantle source (Hoatson et al., 2005). Clastic and chemical sedimentation, including carbonates and banded iron formations, took place between c. 2520 Ma until c. 2485 Ma, in both the Mulgathing and Sleaford complexes (Swain et al., 2005; Fanning et al., 2007; Jagodzinski et al., 2009). Syn-sedimentary intrusives (e.g., the 2519 ± 8 Ma Coultas Granodiorite of the Sleaford Complex; Fanning et al., 2007), are also known.

The abundance of bimodal magmatism and continuity of sedimentation across the Archean–Paleoproterozoic boundary suggests that the overall tectonic setting during the Neoproterozoic–earliest Paleoproterozoic of the Gawler Craton is most likely to have been extensional. The resulting high heat flow may have primed the crust for the subsequent high temperature metamorphism and deformation associated with the c. 2465–2410 Ma Sleafordian Orogeny, an event which terminated deposition within the volcano-sedimentary basin.

The relationship between the Mulgathing and Sleaford complexes to any possible Neoproterozoic sedimentary rock in the Middleback Ranges is not clear. Metasedimentary rocks in the Middleback Ranges record only the effects of the Kimban Orogeny (Jagodzinski et al., 2011a), whereas the Neoproterozoic c. 2510 Ma event is only recorded in the orthogneisses to the west of the Middleback Ranges (Jagodzinski et al., 2011b). It is possible that the metasedimentary units in the Middleback Ranges were in fact deposited sometime after the 2510 Ma metamorphic event, or that there is a structural discontinuity between the gneisses and the metasedimentary rocks.

Paleoproterozoic magmatism

Recurrence of magmatism in the Gawler Craton took place at c. 2000 Ma (Fanning et al., 2007) when a series of intrusives were emplaced in the southern Gawler Craton producing the felsic protoliths to the Miltalie Gneiss. Since the Miltalie Gneiss occurs structurally below metasedimentary units of the Hutchison Group (Parker et al., 1993), the protoliths to the Miltalie Gneiss have been interpreted to represent stitching granites formed during extension that signalled the onset of basin formation (Daly et al., 1998). However, very little is known of the geochemical and petrogenetic affinities of the Miltalie Gneiss.

At c. 1850 Ma, the Donington Suite was emplaced along the eastern margin of the Gawler Craton, extending some 600 km from the southern-most coastal outcrops to the vicinity of Olympic Dam (Figures 2 and 3) in the north. The Donington Suite ranges in composition from granite to charnockite and includes a mafic unit, the Jussieu Metadolerite. The Donington Suite is enriched in elevated incompatible elements and LREE and has $\epsilon\text{Nd}_{1850\text{Ma}}$ values between -4 and -2 (Figure 4). It is interpreted to have evolved from a contemporary mantle source substantially contaminated by Archean

lower crust (see Reid et al., 2008a and references therein). The Donington Suite was associated with a brief compressional orogenic phase recorded only in Donington Suite units on Yorke Peninsula, east of the Kalinjala Shear Zone and known as the Cornian Orogeny (Reid et al., 2008a).

Paleoproterozoic volcano-sedimentary basins

Several volcano-sedimentary packages in the southern Gawler Craton formed during the interval c. 1865–1740 Ma (Figure 3). While the lithostratigraphic units referred to above occur either east or west of the Kalinjala Shear Zone, basin development during the c. 1865–1740 Ma period occurred at different times on both sides of the shear zone. The basal group of this basin system is the Hutchison Group (Parker et al., 1993). Recent zircon studies suggest that the Hutchison Group is an amalgamation of units of differing provenance and maximum depositional ages (Szpunar et al., 2011). They recognised two depositional packages: the c. 1860 Ma Darke Peak Group and the c. 1790 Ma Cleve Group. Detrital zircons in the Darke Peak Group have age-components at c. 2520–2440 Ma and c. 2000 Ma (see also Warrow Quartzite samples in Fanning et al., 2007), reflecting a predominantly local source, an inference supported by the presence in southern Eyre Peninsula of an unconformity between the Warrow Quartzite (basal package to the erstwhile Hutchison Group), and the underlying c. 2440 Ma Kiana Granite (Fanning et al., 2007). The Warrow Quartzite is overlain by metamorphosed dolomitic and pelitic units and iron formations, all indicative of deposition on a stable shelf (Parker, 1980b). Interlayered amphibolites within the Cleve Group have continental tholeiitic affinities, consistent with emplacement on a passive margin (Parker, 1993). Detrital zircons from the Cleve Group are dominated by c. 1850 Ma and c. 1790 Ma populations, suggesting the sediments may have been derived, at least in part, from the c. 1850 Ma Donington Suite (Szpunar et al., 2011). This implies that the Cleve Group was deposited proximal to the Donington Suite (Figure 3).

Volcano-sedimentary packages deposited at c. 1790 Ma include the bimodal Myola Volcanics and associated Broadview Schist in northern Eyre Peninsula. These packages were succeeded by compositionally similar volcanics and interlayered sediments of the Wallaroo Group (Cowley et al., 2003). Volcanic sequences in the Wallaroo Group include the 1772 ± 14 Ma Wardang Volcanics, 1753 ± 8 Ma Moonta Porphyry and the 1740 ± 6 Ma Mona Volcanics (Fanning et al., 2007). Detrital zircons from Wallaroo Group equivalent units, including those present to the north in the vicinity of Olympic Dam, typically contain c. 1850 Ma and c. 1790 Ma detrital zircons (Jagodzinski, 2005; Reid et al., 2011) suggesting a local source for the sediment and that the Donington Suite, or equivalents, was exposed during the deposition of the c. 1790–1740 Ma packages. Other temporally equivalent sedimentary packages include the c. 1770 Ma Price Metasediments (Oliver and Fanning, 1997) on southwestern Eyre Peninsula and the metasedimentary rocks in the northern and western Gawler Craton (Payne et al., 2006; Howard et al., 2011). Detrital zircon age data suggest the sequences in the eastern Gawler Craton have different source regions to those in the western and northern parts of the craton (Payne et al., 2006; Fanning et al., 2007; Howard et al., 2011). Sm-Nd isotopic data suggests the c. 1790 Ma and c. 1740 Ma bimodal volcanics were largely derived from pre-existing continental crust, with $\epsilon\text{Nd}_{1740\text{Ma}}$ values for the McGregor Volcanics between -3 and 0 (Turner et al., 1993; Szpunar and Fraser,

Figure 3 Time-space plot for the southern Gawler Craton. The division into eastern Eyre Peninsula-Yorke Peninsula vs central-western Eyre Peninsula reflects the approximate location of the crustal-scale discontinuity represented by the *Kalinjala Shear Zone*.

2010). Sedimentation in the southern Gawler Craton was terminated by the c. 1730–1690 Ma Kimban Orogeny.

Paleo- to early Mesoproterozoic magmatism

Following the Kimban Orogeny, the lithostratigraphy of the Gawler Craton changed from dominantly volcano-sedimentary basins to the emplacement of voluminous magmatic suites (Figure 3). The

c. 1690–1670 Ma Tunkillia Suite was emplaced during the waning stages of the Kimban Orogeny and represents a late to post-orogenic magmatic event (Payne et al., 2010), as the age of deformation in the western Gawler Craton overlaps with the age of the Tunkillia Suite (Howard et al., 2011). Limited sedimentation and volcanism (Tarcoola Formation) occurred in the central Gawler Craton at c. 1660 Ma in a local rift setting (Daly et al., 1998).

The c. 1630 Ma rhyodacitic–rhyolitic Nuyts Volcanics occur in the southwestern Gawler Craton (Rankin et al., 1990) and are succeeded by a more-extensive, bimodal, c. 1620–1608 Ma intrusives (St Peter Suite; Flint et al., 1990; Fanning et al., 2007). Felsic and mafic rocks from the St Peter Suite are characteristically juvenile, with pronounced Nb and Ti anomalies, marked Y depletion, moderate to high Sr along with $\epsilon\text{Nd}_{1620\text{Ma}}$ values between -2 and $+2$ (Swain et al., 2008), reflecting the formation of new continental crust from a mantle source. They argue that the St Peter Suite represents a continental magmatic arc and that the Gawler Craton was, therefore, the hinterland of a plate margin at this time. However, as Hayward and Skirrow (2010) have suggested, the St Peter Suite could simply reflect I-type magmatism derived in part from metasomatised subcontinental lithospheric mantle, in which case there is no need to invoke contemporaneous subduction to explain the petrogenesis of this suite.

St Peter Suite magmatism was followed by the c. 1592 Ma Gawler Range Volcanics and co-magmatic c. 1600–1570 Ma Hiltaba Suite. The Gawler Range Volcanics forms part of a felsic large igneous province, with correlative units in the Curnamona Province (Benagerie Volcanic Suite), estimated to occupy some 100,000 km³ (Wade et al., 2012). There may also be correlatives in Antarctica (Peucat et al., 2002). The Gawler Range Volcanics are dominantly felsic, although minor basalts are also present (Allen et al., 2008), indicating widespread crustal melting was associated with mantle melting. Gabbroic intrusives are also present within the Hiltaba Suite such as the Curamulka Gabbro from central Yorke Peninsula (Zang et al., 2007). Hiltaba Suite granites (Flint et al., 1993) occur throughout the central and southern Gawler Craton, and are implicated as sources of heat ($\pm$ metals?) for the IOCG mineral system of the eastern Gawler Craton (Skirrow et al., 2007; Groves et al., 2010).

Sm-Nd isotopic data indicate that the Hiltaba Suite contains a significant component of pre-existing crust (Stewart and Foden, 2003). The composition individual plutons varies with their country rocks. For example, Hiltaba Suite granites that intruded the St Peter Suite are significantly more juvenile ($\epsilon\text{Nd}_{1590\text{Ma}} = 0.1$ – 1.2) than those that intruded the Mesoarchean gneisses of north-eastern Eyre Peninsula (e.g., Charleston Granite, $\epsilon\text{Nd}_{1590\text{Ma}} = -13.7$ to -7.3). This isotopic variation is mirrored in the associated early Mesoproterozoic mineral

Figure 4 *Compilation of ϵ_{Nd} values for igneous rock suites of the Gawler Craton. Data derived from published references and unpublished PIRSA and University of Adelaide data and that the data compilation is available upon request from the authors.*

systems of the Gawler Craton. The Olympic IOCG province occurs in the eastern part of the craton (Skirrow et al., 2007), whereas Au-dominated systems occur in the central part (Ferris and Schwarz, 2003). The spatial distribution of IOCG versus Au-dominated mineral systems is controlled, to some extent by the composition of associated Hiltaba Suite granites. The more evolved, U- and Th-rich, and oxidized granites occur in the Olympic IOCG province (Budd et al., 2001). Modern-day heat flow in the IOCG province is also significantly higher ($90 \pm 10 \text{ mWm}^{-2}$) than that of the Au-dominated province ($54 \pm 5 \text{ mWm}^{-2}$). This suggests lithospheric compositional differences between the eastern and western/central Gawler Craton. These differences may reflect an older phase of craton assembly (Hand et al., 2007). The presence of the Kalinjala Shear Zone along the western boundary of the IOCG province suggests that strain was partitioned along a fundamental lithospheric boundary during the Kimban Orogeny.

The volumetrically minor c. 1500 Ma Spilsby Suite occurs in the southern Gawler Craton on a number of islands in the Spencer Gulf and at Corny Point on Yorke Peninsula (Fanning et al., 2007; Jagodzinski et al., 2007); however, their petrology has not been studied in any detail.

Orogenic framework

Several orogenies have affected the Gawler Craton. The oldest recorded metamorphic zircon growth, at c. 2510 Ma occurs within the Mesoarchean gneisses of northern Eyre Peninsula and is associated with the emplacement of leucogranites and the formation of a gneissic fabric within the Mesoarchean granitoids (Fraser et al., 2010a). It is not clear whether this deformation was part of a distinct, widespread tectonothermal event.

The c. 2465–2410 Ma Sleafordian Orogeny resulted in high-temperature metamorphism, isoclinal folding, and transpressional deformation of the supracrustal sequences within the Mulgathing and Sleaford complexes (McFarlane, 2006). The Sleafordian Orogeny is best expressed in the Mulgathing Complex, as the effects of the Kimban Orogeny have largely overprinted Sleafordian-aged fabrics elsewhere (Dutch et al., 2010).

The c. 1855–1840 Ma Cornian Orogeny is defined within the Donington Suite cropping out on Yorke Peninsula. It is characterised by migmatites and orthogneisses, and syn-kinematic granites reworked by late-stage, broadly south-directed extensional fabrics (Reid et al.,

2008a). No record of the Cornian Orogeny is found west of the Kalinjala Shear Zone.

The principal orogenic event of southern Gawler Craton is the c. 1730–1690 Ma Kimban Orogeny (Parker et al., 1993). On Eyre Peninsula, the Kimban Orogeny is characterised by transpressional deformation in a belt up to 100 km wide, including the Kalinjala Shear Zone, a subvertical high-strain zone, 4–6 km wide, along eastern Eyre Peninsula (Parker, 1980a; Vassallo and Wilson, 2002; Dutch et al., 2008, 2010). The Kalinjala Shear Zone and its flanking structures mark the eastern-most limit of Kimban-aged deformation in the Gawler Craton, with rock to the east (such as the Wallaroo Group) showing little or no effects of Kimban deformation. In contrast to the high grade metamorphism evident in southern Eyre Peninsula, the metamorphic grade in northern Eyre Peninsula shows more variability, with amphibolite facies shear zones (Reid et al., 2008b) interspersed with granulites (Fraser and Neumann, 2010). Deformation in northern Eyre Peninsula is characterised by fold-thrust systems that verge to the east, away from the orogenic core (Parker et al., 1993). Thus, in the southern Gawler Craton, the structural architecture of the Kimban Orogeny forms an obliquely exposed crustal-scale positive flower structure (Hand et al., 2007).

The Kimban Orogeny is also recorded in strongly deformed Paleoproterozoic metasedimentary sequences in the northern and western Gawler Craton (Payne et al., 2008; Howard et al., 2011; Jagodzinski and Reid, 2010) indicating that, aside from regions to the east of the Kalinjala Shear Zone, the Kimban Orogeny was virtually craton-wide (Fanning et al., 2007). Syn-Kimban sedimentation is recorded in the central Gawler Craton, where the c. 1715 Ma Labyrinth Formation contains clastic material derived from local sources (Daly et al., 1998).

The next major phase of reworking occurred during the interval c. 1600–1550 Ma and is broadly termed the Kararan Orogeny, although Hand et al. (2007) recognise a slightly more complex orogenic history over this period than is summarised here. The apparent lack of deformation in the Gawler Range Volcanics and Hiltaba Suite in central Gawler Craton has led many workers to infer an anorogenic setting for these high-temperature felsic igneous rocks (Flint et al., 1993; Allen and McPhie, 2002). However, it is clear that deformation and high-temperature metamorphism did occur across the Gawler Craton during the time and that it continued for several tens of millions of years (Hand et al., 2007). Examples of Kararan-aged tectonism include greenschist facies fabrics within the Wallaroo Group and Hiltaba Suite granites on Yorke Peninsula (Conor, 1995), syn-Hiltaba deformation accompanied by cooling of mid-crustal rocks to below c. 500°C on Eyre Peninsula, (Foster and Ehlers, 1998), and overprinting of Kimban-aged fabrics adjacent the Kalinjala Shear Zone (Hand et al., 2007). Further, high- to ultra high-temperature metamorphism in the Coober Pedy Ridge and adjacent Mt Woods Domain, of the northern Gawler Craton, also occurred c. 1585 Ma (Cutts et al., 2011; Forbes et al., 2011). This suggests that this orogenic phase was widespread, yet partitioned into zones of deformation that increase in intensity to the north and east, away from the central Gawler Craton, which may have acted as a strain-buffer during this event (Figure 5; Hand et al., 2007, 2008). The formation of the Gawler Range Volcanics internal to zones of active deformation has led to the suggestion that the Gawler Range Volcanics may be part of a foreland basin fill (Hand et al., 2008).

Post-Kararan reworking in the Gawler Craton is restricted to the growth of muscovite in major structures in the western Gawler Craton

Figure 5 Inferred early Mesoproterozoic NW-SE contractional tectonic system in southern Australian Proterozoic terranes with a foreland region occupied by the Gawler Range Volcanics and Benagerie Volcanic Suite flanked by regions of deformation. Also shown are outlines of the Olympic IOCG and central Gawler Au provinces. Data sources are given in Hand et al. (2008).

at c. 1450–1400 Ma (Fraser and Lyons, 2006). Regional cooling of the craton to below closure of biotite in the K-Ar system, c. 300°C, occurred by 1400 Ma (Webb et al., 1982).

Magmatic reworking through time

The early period of magmatism within the Gawler Craton is distinctly punctuated, with Mesoarchean and Neoarchean–early Paleoproterozoic events that were followed by a period of some 250 million years, between c. 1850–1570 Ma, of frequent and abundant magmatism (Figure 4). The Nd isotopic signatures of the Mesoarchean Cooyerdoo Granite are somewhat evolved, suggesting they derived from pre-existing felsic crust (Fraser et al., 2010a). The Neoarchean magmatism, c. 2555–2500 Ma, displays a significantly more juvenile character, particularly related to widespread mafic magmatism, involving a significant mantle component in addition to the likely remelting of pre-existing crustal material (Figure 4).

Magmatism occurring between c. 2000–1670 Ma has ϵNd values

that define a trend expected if their source was reworked Neoarchean crust (Figure 4) e.g., younger units, such as the c. 1850 Ma Donington Suite have ϵNd values varying from -7.4 to 1.45 whereas units aged between c. 1790–1730 Ma have ϵNd values from -11.3 to -0.58. This trend suggests an increase in the proportion of crustal melting driven by thermal and material input from the mantle that occurred in the c. 60 million years leading up to the onset of the Kimban Orogeny. The post-Kimban Tunkillia Suite has ϵNd values from -10.4 to 2.6, implying both mantle and crustal input, as would be expected for post-orogenic magmatism occurring in an extensional setting.

Emplacement of the St Peter Suite signaled a change in the pattern of ϵNd values, with a marked shift towards more juvenile compositions (Figure 4). The associated mantle input immediately pre-dates the voluminous magmatism of the c. 1600 – 1570 Ma Gawler Range Volcanics and Hiltaba Suite. They show a large range in ϵNd values (-13.5–2.5) and trends towards a significant crustal component, consistent with studies that show the Gawler Range Volcanics/Hiltaba Suite are dominantly derived from crustal melting (e.g., Creaser, 1995). The major juvenile input evident in the St Peter Suite likely indicates the influence of mantle-scale processes, possibly a plume (Flint et al., 1993) or magmatic arc (Swain et al., 2008). Whatever the origin, if the increased contribution from the mantle, it was likely important in generating the widespread lower crustal melting during

the 1600–1570 Ma Gawler Range Volcanics/Hiltaba Suite magmatic event. Indeed it may be that the temporal gap between the onset of the c. 1620–1608 Ma, St Peter Suite magmatism and the c. 1595 Ma, evolved Gawler Range Volcanics/Hiltaba Suite magmatism reflects a period during which the thermal regime of the lower to middle crust across the Gawler Craton was re-heated to levels required for widespread anatexis, resulting Gawler Range Volcanics/Hiltaba Suite magmatic event, a felsic large igneous province of global significance.

Conclusion

The interplay between crustal melting, episodic mantle inputs, and orogenesis is a feature of the Mesoarchean–Mesoproterozoic evolution of the Gawler Craton. Of the three major orogenic events, the 2465–2410 Ma Sleafordian Orogeny, the 1730 – 1690 Ma Kimban Orogeny, and the c. 1590–1560 Ma Kararan Orogeny, both the Sleafordian and the Kararan were preceded by significant mantle-

derived heating of the crust. Mafic magmatism in the Neoarchean is manifest as ultramafic volcanics (including komatiites) as well as mafic and mafic-related felsic igneous rocks. The juvenile mafic and felsic intrusives of the c. 1620–1608 Ma St Peter Suite may have initiated the c. 1595–1575 Ma Gawler Range Volcanics/Hiltaba Suite magmatic event and associated high-temperature metamorphism and distributed deformation. Crustal melting and thermal and material inputs from mantle resulted in rheological changes that facilitated the localisation of deformation. In each case, high-temperature metamorphism accompanied deformation indicative of the steep geothermal gradients that both preceded and resulted from the crustal reworking. In contrast, the Paleoproterozoic c. 2000–1740 Ma magmatic events that predate the Kimban Orogeny largely sourced older crust, consequently, the Kimban Orogeny does not appear to have been instigated by significant mantle melting. The drivers for this craton-wide event may have operated at a length scale beyond the present boundaries of the Gawler Craton.

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