THE GEOLOGY OF AUSTRALIA

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Keywords: Australia; geology, Yilgarn, Pilbara, Musgrave, Arunta, Albany-Fraser, Capricorn, Lachlan Foldbelt, Sydney Basin, Bowen Basin, New England Foldbelt

Contents

Summary

There is a general younging in the age of Australian rocks with distance eastward. Archaean rocks include the granite-greenstone terranes of the Pilbara and Yilgarn Cratons, and metamorphic rocks of the Gawler Craton. Most of the continent can be divided into three Palaeoproterozoic cratons, fragments of older continents joined by the development of c. 1820 – 1200 Ma central Australian orogens, and contemporary intracontinental basins in northern Australia.

Proterozoic Australia remained largely intact during continent-wide downwarping that developed extensive Neoproterozoic basins. The eastern third of Australia is formed from Palaeozoic rocks that progressively accreted to the Neoproterozoic shield. Sedimentary basins along the western and southern margins formed during Mesozoic extension that ultimately led to Gondwana dispersal.

Flat-lying Mesozoic to early Tertiary sedimentary rocks cover much of inland eastern Australia, separated from the eastern seaboard by a low dividing range that is at least partially related to Cainozoic volcanism.

1. Introduction

The Australian continent is bordered on its western, southern and eastern margins by normal oceanic crust, which began to form at c. 155 – 165 Ma (Stagg et al., 1999; Müller et al., 2000). Seafloor spreading ceased at c. 55 Ma, except in the south where Australia continues to move north away from Antarctica. To the north, a Tertiary to Recent active margin is being created by the collision of the Australian and Eurasian plates in the Timor region, which is reactivating and overprinting older passive margin structures. The on-shore geology of Australia (Fig. 1) is dominated by five provinces: Archaean to Palaeoproterozoic cratons, Palaeo to Mesoproterozoic orogenic belts, Meso to Neoproterozoic sedimentary basins, Palaeozoic rocks of the Tasman Foldbelt, and Mesozoic rocks of the Great Artesian Basin (Fig. 1). There is a general younging in the age of exposed rocks with distance eastwards from Archaean rocks of the Yilgarn and Pilbara Cratons of Western Australia. Proterozoic basement complexes in Australia (Myers, 1993; Scott et al., 2000) show evidence for two main periods of orogeny (Page, 1988; Tyler et al., 1998). The first occurred in the Palaeoproterozoic between 1900 and 1750, during which the north, south and west Australian cratons can be inferred to have formed, probably as parts of larger continents (Fig. 2). The second occurred between 1300 and 1000 Ma during the assembly of the Rodinian supercontinent. Proterozoic Australia remained largely intact during the Neoproterozoic despite the break-up of Rodinia and the assembly of a new supercontinent. The west Australian craton, consisting mostly of unrelated rocks of the Pilbara and Yilgarn cratons, is inferred to have undergone extension centered on the Capricorn Orogen (Myers, 1993), a zone of Palaeoproterozoic orogenic activity that was reactivated during Meso- and Neoproterozoic basin formation and deformation. The southern and south-eastern margin of the craton is defined by high-grade Mesoproterozoic rocks of the Albany Fraser Complex, formed when the craton collided with rocks that now form parts of Antarctica. The Pinjarra Orogen (Fig. 2) contains Palaeo- to Neoproterzoic rocks that reflect repeated reactivation of the western margin of the Yilgarn Craton.

The north Australian craton (Fig. 2) comprises probable Archaean rocks buried by Palaeoproterozoic rocks of the Kimberley Craton, and Archaean to earliest Palaeoproterozoic rocks that form the basement to Meso- and Neoproterozoic sedimentary basins to the south and east (Tyler et al., 1998; Scott et al., 2000; Fig. 2). The south Australian craton consists of Archaean to Palaeoproterozoic rocks of the Gawler Craton (Parker, 1990). These are inferred to extend under Phanerozoic rocks into Western Australia, where they are separated from the Yilgarn Craton by the Albany-Fraser Orogen. A series of distinct Palaeo- to Mesoproterzoic orogenic belts form the central Australian terranes (Tyler et al., 1998; Fig. 2). They separate the west and north Australian cratons, and can be inferred to envelop the buried northern margin of the south Australian craton. These rocks are blanketed by extensive Neoproterozoic basins, which developed during intracratonic rifting that eventually led to the break-up of Rodinia. Rifting initiated on a northerly axis in central Australia and an easterly axis near Adelaide, South Australia (Walters & Veevers, 1997). Many basins now isolated by latest Neoproterozoic and Palaeozoic tectonic events (Fig. 2) have a common sedimentary history (Walter et al., 1995), more precisely defined by isotope stratigraphy and sequence analysis that define a Neoproterozoic Centralian Superbasin (Walter & Veevers, 1997).

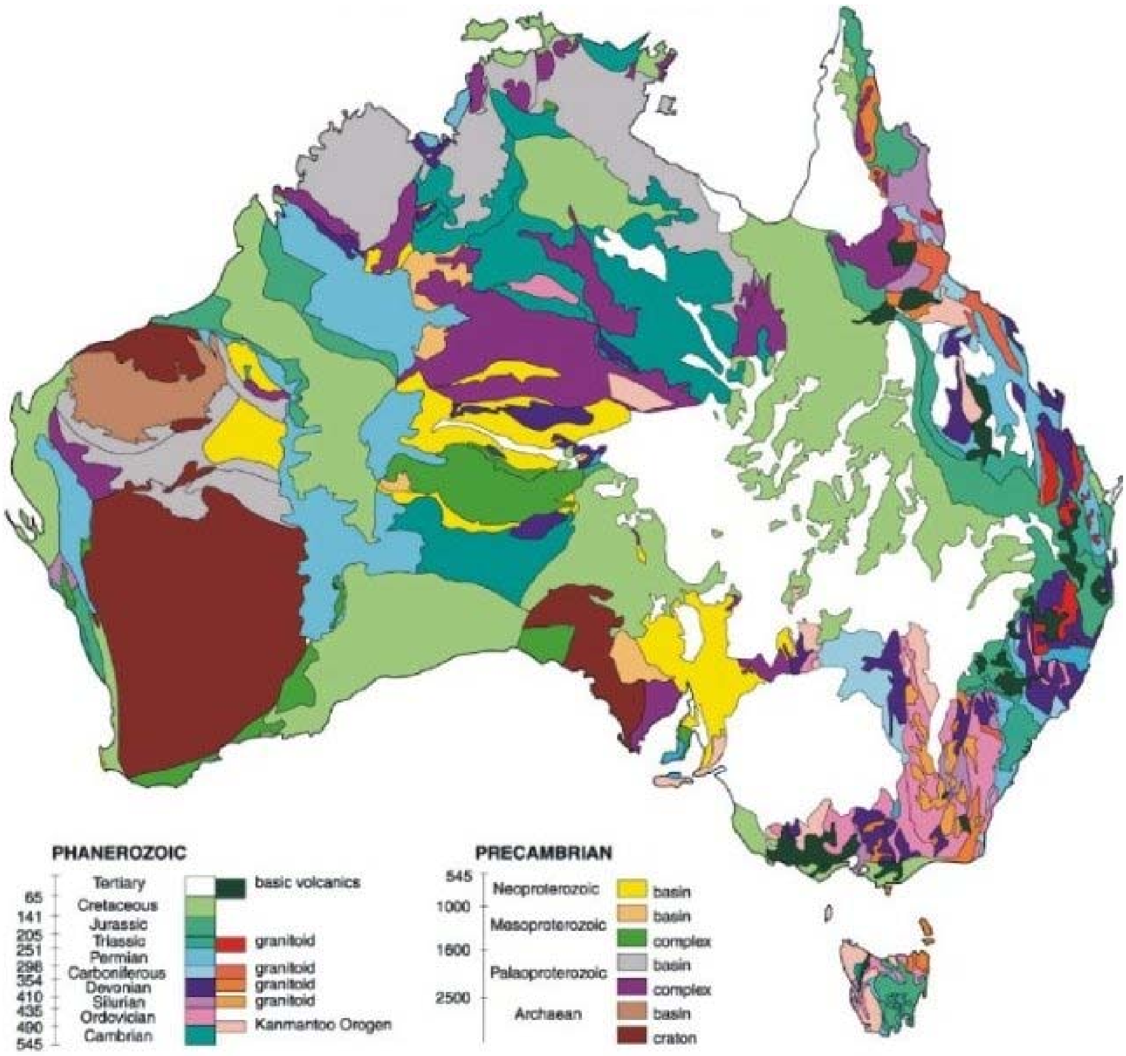

Figure 1: The on-shore geology of Australia (after Addario et al., 1980)

The eastern third of Australia, formed from Palaeozoic rocks of the Tasman Foldbelt (Fig. 3), was accreted in stages onto a shield formed mostly of Archaean and Proterozoic metamorphic rocks, and continues the general pattern of tectonic activity younging with distance from west to east. Lower Palaeozoic rocks of the Kanmantoo, Lachlan and Thomson Foldbelts (Fig. 3) include extensive Late Ordovician turbidites, which developed with remarkable compositional uniformity over an apparent width of more than 500 km. Upper Palaeozoic rocks of the New England Foldbelt (Fig. 2) reflect the accretion of a Devonian and Carboniferous volcanic arc, flanking fore-arc basin, and subduction complex material along a zone more or less parallel to the present coastline. The Lachlan and New England Foldbelts are now separated by Permo-Triassic sediments of the Sydney and Bowen Basins, which unconformably overlie the Lachlan Foldbelt and developed as a foreland basin in front of the deforming New England Foldbelt. Triassic to Cretaceous, continental sediments of the Clarence-Moreton Basin (Fig. 2) were deposited as a consequence of the rifting of the New England Foldbelt. Sedimentary basins along the western and southern margin of Australia, including the Bremer, Great Australian Bight and Otway Basins (Fig. 6) mostly formed during

Mesozoic extension that ultimately led to the break-up of Gondwana (Willcox & Stagg, 1990). Flat-lying Jurassic and Cretaceous sediments of the Great Australian Basin (Fig. 3) cover much of western New South Wales and Queensland, and eastern South Australia. The Murray Basin contains Tertiary and Quaternary, mostly non-marine rocks and is up to 600 m thick. A belt of Cretaceous to Cainozoic basaltic volcanic rocks (Fig. 3) approximately 150 km wide follows an arc almost parallel to the east coast of Australia. Some of the Cainozoic volcanism formed large volcanoes or volcanic complexes, and track the northwards movement of the Indo-Australian plate over a mantle plume.

2. Archaean (>2500 Ma)

The Pilbara and Yilgarn Cratons are formed from granite-greenstone associations of different ages. The Pilbara Craton (Fig. 2) consists of two major tectonic units: a 60K km^2 granite-greenstone association formed between 3500 and 2800 Ma, and a 100K km^2 volcano-sedimentary succession belonging to the Late Archaean – Early Proterozoic Hamersley Basin. The granite-greenstone terrane is characterized by ovoid to elongate orthogneiss complexes and granitoid batholiths separated by greenstone belts (Hickman, 1983). Greenstone belts are dominated by bimodal volcanic successions and volcaniclastic sedimentary rocks. Rifting of cratonized granite-greenstone terrane in the southern part of the Pilbara Craton began at c. 2770 Ma (Arndt et al., 1991) and formed the lower part of the Hammersley Basin succession (Fortescue Group; Tyler & Thorne, 1990). The rift sequence is overlain by a c. 2700 – 2450 Ma passive margin sequence (uppermost Fortescue Group and overlying Hammersley Group) consisting of mudstone, siltstone, banded iron formation (BIF), carbonate, chert and mafic and felsic volcanics that were deposited on a shelf or platform that was open to the ocean (Blake & Barley, 1992). The Yilgarn Craton (Fig. 2) is the largest Archaean craton in Australia (exposed area 657K km^2), consisting of 3000-2600 Ma granite-greenstone associations with minor older gneiss alternating with granite along a distinctive, north-west-trending structural grain. It contains the oldest rocks in Australia in the Narryer Gneiss Complex, with rocks as old as c. 3700 Ma and detrital zircons up to 4200 Ma old. The greenstone belts may have formed as basins during the rifting of adjacent continental crust. A variation on this model ascribes craton-wide volcanism, plutonism and regional deformation to the effects of a giant mantle plume. An alternative model envisages the greenstone belts forming at some ancient continental margin, as a series of back-arc or marginal basins. Various tectonic domains may have developed together before collision, or been swept together from distant locales and accreted during collision (Myers, 1993). The Yilgarn Craton is the most prospective of Australian Archaean domains, especially for gold, nickel and tantalum. It contains world-class deposits of each of these commodities, as well as bauxite, heavy mineral sands and lateritic nickel deposits formed during Tertiary weathering.

Archaean rocks of the Gawler Craton (Fig. 2) consist mainly of high-grade metamorphic gneiss (Parker, 1990). Extensive felsic orthogneiss, including c. 2650 Ma hypersthene gneiss, and mafic granofels, are interpreted as synorogenic intrusions that cut granulite facies paragneiss sequences that include banded iron formation, calc-silicates and migmatite (Daly et al., 1998). Much of the craton experienced intense orogeny at c. 2450 Ma. It is typical of high-grade Archaean gneiss terranes with substantial orthogneiss; greenstone belts have not been recognized, but pillow basalts, komatiites and peridotite-hosted nickel prospects occur. Gold mineralization at Challenger in the northern part of the craton is hosted by complexly deformed Archaean migmatite.

3. Proterozoic

3.1. Palaeoproterozoic (2500 to 1600 Ma)

The Capicorn Orogen (Fig.2) involved the collision of the geologically-distinct Pilbara and Yilgarn Cratons at c. 1840 Ma. On the northern margin of the Yilgarn Craton, restricted sedimentation, controlled by sag and rift, formed the Yerrida and Byrah Basins (Fig. 2). At the southern margin of the Pilbara Craton, the folding of Hammersley Basin rocks was followed by the deposition of conglomerate, sand and basalt that now forms the lower Wyloo Group in the Ashburton Basin. Stitching plutons of the 1840-1800 Ma Minnie Creek Batholith indicate that the two cratons were together at that time. Contemporary high-grade metamorphism and deformation resulted in migmatitic pelitic and psammitic gneiss, quartzite, calc-silicate and orthogneiss in the Gascoyne Complex (Fig. 2). Sandstone, siltstone, shale, cherty granular iron formation and chert breccia and associated stromatolitic carbonate were deposited on a marine shelf in the Eraheedy Basin, off the northeast Yilgarn Craton, before c. 1630 Ma. In the Rudall Complex, pre-2000 Ma volcanic and sedimentary rocks were deformed and metamorphosed at amphibolite facies (Clarke, 1991) before being intruded by 1790 to 1760 Ma orthogneiss.

In the Lamboo Complex of the eastern Kimberley region (Fig. 2), c. 1910 Ma mafic and felsic volcanics were intruded by high-level granitoids (Tyler et al., 1998). Archaean zircons occur in unconformably overlying conglomerates and sandstones, which are themselves overlain by c. 1880 Ma mafic volcanics, clastic and carbonate metasediments of the lower Halls Creek Group. In both the Hooper and Lamboo Complexes, c. 1870 Ma turbidites were deposited in a basin marginal to the Kimberley craton. C. 1860 Ma metamorphism was contemporaneous with the emplacement of numerous felsic and intermediate sills derived from the north-westerly subduction of oceanic crust beneath the Kimberley craton. Submarine alkaline volcanism in the eastern Lamboo Complex may mark 1870 to 1855 Ma rifting. Conglomerate, sandstone, siltstone, mudstone and minor felsic igneous rocks of the Speewah Group were deposited on the Kimberley Craton at c. 1835 Ma. The c. 1830 Ma collision of the Kimberley craton with northern Australia resulted in deformation and high-grade metamorphism in the Lamboo Complex, and formed the north Australian craton (Tyler et al., 1998). Voluminous c. 1800 Ma mafic magmatism (Hart Dolerite) may have been related to a mantle plume and the rifting of whatever lay to the north or north-west of the Kimberley craton.

On the basis of limited exposures and abundant isotopic inheritance, Archaean crust is inferred to underlie extensive, late Palaeoproterozoic (1800 – 1575 Ma) basins in north central Australia that are mostly weakly deformed and metamorphosed (Scott et al., 2000). Geophysical and isotopic characteristics suggest that basement rocks are heterogeneous, but were amalgamated to form the north Australian craton by 1800 Ma. Late Palaeproterozoic and Mesoproterozoic basins host five world class, stratiform sediment-hosted Zn-Pb-Ag orebodies (Mt Isa, Hilton, George Fischer, Century and HYC). Scott et al. (2000) have divided the period covered by rocks of the Victoria River, Pine Creek, McArthur, Murphy and Mt Isa regions into the Leichhardt (c. 1800 – 1750 Ma), the Calvert (1735 – 1690 Ma) and the Isa (1665 – 1575 Ma) superbasins. Continental basalts and felsic volcanics and intrusives from an important part of the rift stages of the basins; they are overlain by diverse terrestrial, peritidal and deep marine sediments that are characterized by extensive fine-grained carbonaceous siltstones and shales. Local and regional sedimentary facies variations are thought to have been controlled by major long-lived fault systems that provided pathways for mineralizing fluids. Basin development and at least five discrete major, mafic magmatic events at c. 1780, 1725, 1710, 1590 and 1300 Ma (Scott et al., 2000) are inferred to be related to major orogenic events and the accretion of the central Australian terranes (see below). On the eastern edge of the Kimberley region, rocks considered equivalent to the Victoria River Basin are cut by the diamondiferous Argyle lamproite pipe (Boxer & Jaques, 1990), which is dated at c. 1200 Ma.

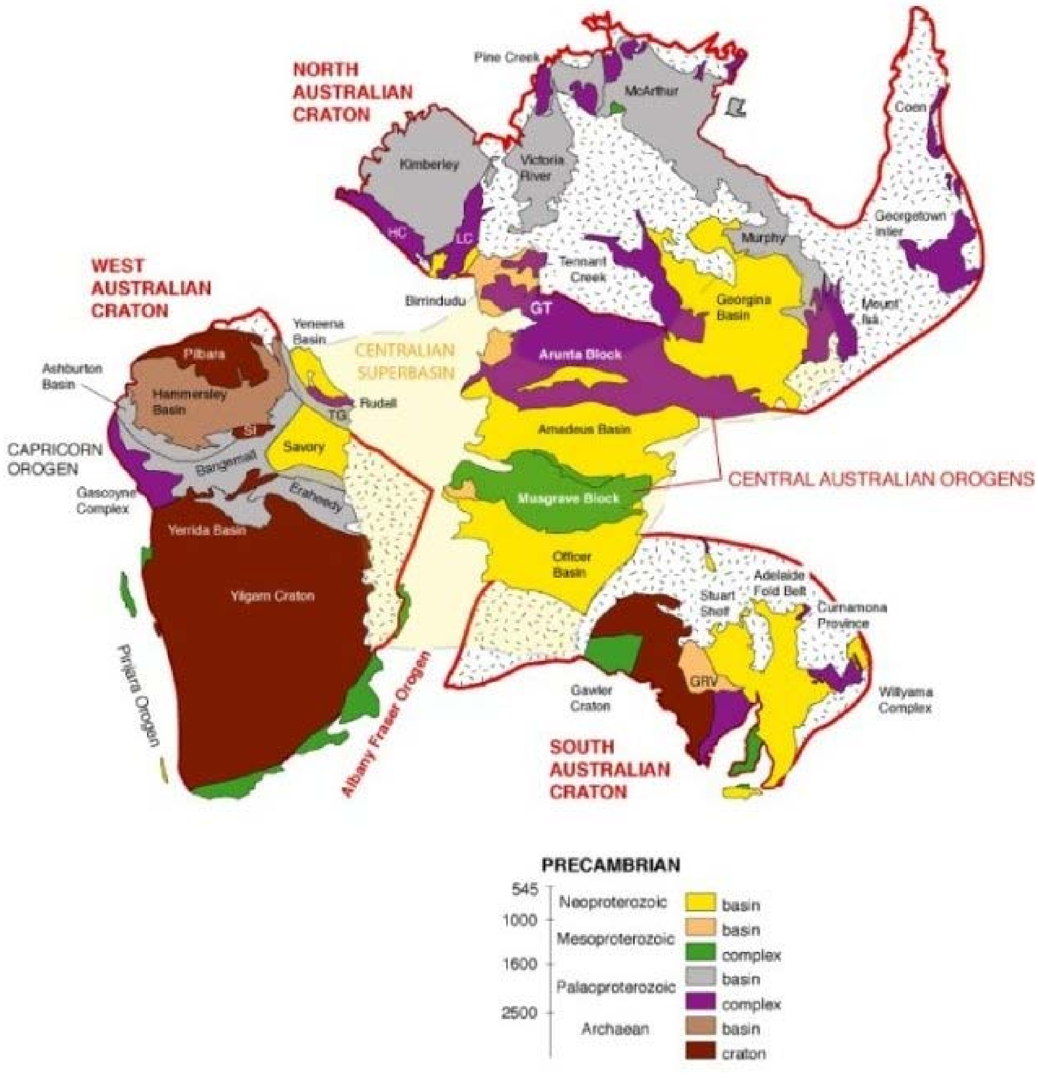

Figure 2: Precambrian geological elements of Australia, indicating the three main c. 1820 Ma cratons separated by c. 1820-1200 Ma central Australian orogens

(Whereas the main components of the north Australian, west Australian and Gawler Cratons had formed by c. 1820 Ma, the eastern portion of the south Australian craton formed slightly later at c. 1600 Ma. Abbreviations: GRV- Gawler Range Volcanics; GT- Granites Tanami; HC- Hooper Complex; LC - Lamboo Complex; SI- Selwyn Inlier; TG- Tabletop Group. The approximate extent of the Neoproterozoic Centralian Superbasin is indicated by pale yellow shading.)

Turbidites of the Lander Rock beds in the northern Arunta Block (Fig 2) have been correlated with the c. 1870 Ma Warramunga Group in the Tennant Creek Inlier (Fig. 2; Blake & Page, 1988), and may also be equivalent to greywackes and metavolcanics of the Granites-Tanami Inlier to the northwest (Fig. 2).

They were locally metamorphosed at very low-*P* high-*T* conditions, contemporary with the emplacement of c. 1820 Ma granitoids; some are inferred to have experienced granulite facies before the intrusion of c. 1880 Ma granite. Regionally extensive c. 1820 Ma granitoids (Collins & Williams, 1995) are probably equivalent to 1830-1815 Ma felsic volcanism in the Granites-Tanami Inlier. The Arunta Block experienced uplift and erosion before the deposition of quartzose platform sedimentary rocks of the 1820 to 1780 Ma Reynolds Range Group (Stewart, 1981), which has been correlated with the c. 1770 Ma Nicker beds and Patamungala beds in the western Arunta Block, and the Hatches Creek Group in the Tennant Creek Inlier (Blake et al., 1986). Another major phase of tectonism, granite intrusion and localized granulite facies metamorphism at c. 1770 Ma affected both the northern and central Arunta Block. In the Granites-Tanami Inlier, the Granites Granite was emplaced at c. 1800 Ma (Scott et al., 2000). The southern province of the Arunta Block is composed of c. 1680 Ma banded quartzofeldspathic and granitic gneiss (Collins et al., 1995) that is unconformably overlain by silicic and aluminous rocks (Shaw et al., 1984). Both were deformed and metamorphosed at c. 1610 - 1600 Ma.

In the eastern Gawler Craton (Fig. 3), several graben like basins (Hutchison Group) developed at c. 1900 Ma and filled with fluvial to shallow marine clastics, carbonates, iron formations and mafic volcanics (Parker, 1990). High-grade haematite orebodies occur in the Middleback Ranges of the eastern Gawler Craton, where north-trending synclinal keels of banded-iron-formation were exploited up to the 1990s. These rocks are cut by c. 1860 Ma granitoids, and experienced high-*T* metamorphism and deformation in the period between 1845-1795 Ma (Kimban Stage I; Daly et al., 1998). In the north-eastern Eyre Peninsula, scattered outcrops of c. 1790 Ma felsic volcanics are interbanded with felsic and hornblende-rich gneiss east of the Middleback Ranges. These rocks are younger than the Hutchison Group, but similar in age to high-grade paragneiss forming the Peake and Denison Inliers in the eastern Gawler Craton (Fig. 3) which include weakly deformed quartzite and interbanded c. 1780 Ma basalt and rhyolite. A second phase of the Kimban Orogeny affected the Eyre Peninsula in the period 1795-1745 Ma, with the grade of metamorphism during this period increasing to the south (Parker, 1990). Extensive felsic magmatism of the c. 1700 Ma Moody Suite accompanied a third phase of the Kimban Orogeny. Fluvial to marine sedimentary rocks of the Tarcoola Formation were then deposited on a basement of deformed Archaean and Palaeoproterozoic rocks in alluvial fans adjacent to active faults, which were probably conduits for contemporaneous c. 1660 Ma volcanism (Daly et al., 1998).

The Curnamona Province (Fig. 2) is an area of Proterozoic crust straddling the NSW-SA border, surrounded by Palaeozoic rocks. The late Palaeoproterzoic (c.1730-1650 Ma) Willyama Supergroup (Willis et al., 1983; Fig. 2) consists of extensive metaturbidite and minor chemical metasediments and felsic metavolcanics that were deformed, metamorphosed and intruded by abundant granitoids at c. 1600 Ma (Clarke et al., 1986). Rocks of the Willyama Complex were infolded with Neoproterozoic metasedimentary rocks of the Adelaide Folbelt during the Delamerian Orogeny. In the Mt Lofty Ranges just east of Adelaide (SA), sheared and retrogressed Proterozoic metamorphic rocks occur as thrust sheets and anticlinal cores within deformed Neoproterozoic cover.

Australian Palaeoproterozoic rocks are characterized by large, stratiform, sediment-hosted base metal sulphide deposits. They also host polymetallic, high-level hydrothermal deposits that are structurally-controlled and up to 300 Ma younger than their host rocks. Many of the high-grade orogenic belts are weakly mineralized, except where they host younger hydrothermal deposits (Rutland et al., 1990). Sedimentary sequences deposited in the period 1700 to 1600 Ma host some of the world's largest ore deposits, including the giant sediment-hosted Pb-Zn deposits at Broken Hill, Mount Isa, McArthur River and Century, and high-grade uranium deposits in the East Alligator River and Pine Creek areas. The Hammersley Basin contains several very large haematitic Fe-orebodies, formed by the supergene enrichment and metamorphism of banded iron formation (BIF) within the Hammersley Group. Magmatic Ni-Cu sulphides, chromite and platinum group elements occur at a number of localities in layered ultramafic-mafic bodies of the Halls Creek Orogen.

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Biographical Sketch

Geoff Clarke received his PhD from Melbourne University with a project in Antarctica, but has wide experience with the field geology of Australia, in particular the central Australian high grade gneiss terrains. Geoff is currently teaching metamorphic petrology, mineral textures, and field geology at the School of Geosciences at the University of Sydney. His actual research interests comprise mineral equilibria in eclogites and blueschists from New Caledonia; structural and metamorphic analysis of Precambrian terranes in east Antarctica and Cretaceous granulites in Fiordland, New Zealand.