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# THE GEOLOGICAL FRAMEWORK, DISTRIBUTION AND CONTROLS OF FE-OXIDE CU-AU MINERALISATION IN THE GAWLER CRATON, SOUTH AUSTRALIA.

## PART I - GEOLOGICAL AND TECTONIC FRAMEWORK

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**Abstract -** The Archaean to Mesoproterozoic Gawler Craton hosts a range of economic mineral commodities, including Au (central Craton), Ag-Pb-Zn (eastern Eyre Peninsula) and iron ore of the Middleback Ranges. A major iron-oxide copper-gold province containing the world class Olympic Dam Cu-U-Au-Ag-REE deposits extends ~ 500 km along the eastern margin of the Craton, from the Mount Woods Inlier in the north to the Moonta-Wallaroo district in the south. This paper presents new advances in our understanding of the structure, deformation history and tectonic evolution of the Gawler Craton, which may lead to a better understanding of the distribution of these mineral systems. The Craton is subdivided into tectonic domains, each encompassing an area of crust containing similar lithological and structural associations. New tectonic events have been defined within the three major orogenic cycles of the Gawler Craton (the Sleaford, Kimban and Kararan Orogenies). The recent discovery that much of the craton comprises relatively juvenile Proterozoic crust has improved our understanding of cratonic evolution. We propose growth through accretion in magmatic arc settings along the eastern margin of an arcuate Archaean core at ~ 1850 Ma (Donington Suite), and along the southwestern margin at ~ 1680 Ma (Tunkillia Suite) and 1620 Ma (St Peters Suite). We suggest an alternative model to a largely anorogenic setting for emplacement of the Hiltaba Suite, an intracontinental, extensional back-arc, located behind a northeast dipping subduction zone, south of the Nuyts Domain, which produced the arc-related magmatism of the St Peters Suite.

The Hiltaba Suite magmatic event was widespread across the Gawler Craton, and is broadly associated, both temporally and in places spatially, with a major mineralising event. At the Olympic Dam deposit, a close spatial and temporal association is recognised between its host rock, the Roxby Downs Granite, and iron-oxide copper-gold mineralisation. Other mineral prospects related to Hiltaba Suite magmatism include Tarcoola, Tunkillia, Myall, Sheoak, Barns, and possibly Weednana and Menninnie Dam. The presence of Hiltaba Suite granites is an important factor for exploration companies in tenement selection.

## Introduction

The Gawler Craton (Fig. 1) is an ancient crystalline shield comprising Archaean to Mesoproterozoic metasediments, volcanics and granites, which has been tectonically stable, with the exception of minor epeirogenic movements, since ~1450 Ma (Thomson, 1975; Parker, 1990, 1993). Due to very sparse basement outcrop, the geology of the Gawler Craton is poorly constrained, compared to other cratonic areas within Australia. The Craton records crust formation and tectono-thermal events in the late Archaean to early Palaeoproterozoic (Sleaford Orogeny), Palaeoproterozoic (Kimban Orogeny), and Palaeoproterozoic to Mesoproterozoic (Kararan Orogeny).

The boundaries of the Gawler Craton have been interpreted from a combination of both total magnetic intensity and gravity data. Limited regional geological outcrop information and irregularly distributed drill hole data have also been used to determine the outer most limit of rock types assigned to the Gawler Craton. The eastern limit of the craton is relatively well defined by the Torrens Hinge Zone, a zone of Neoproterozoic rifting initiated during the development of the Adelaide Geosyncline. Later deformation, during the Delamerian Orogeny, led to reworking of the eastern margin. Fig. 2 illustrates the extent of this domain.

The northern and western extent of the craton is less well defined. The boundaries are obscured by Neoproterozoic and Phanerozoic sediments which increase rapidly in thickness across faulted margins to the Officer Basin. The northwestern boundary is defined to coincide with a linear, magnetic and gravity anomaly which is interpreted to represent the extent of the Kararan Orogeny. The southern margin of the Gawler Craton is presently placed close to the edge of the Continental Shelf, in the southern ocean, along prominent gravity and magnetic features. These may indicate mafic intrusives associated with rifting during the Jurassic, which eventually led to separation of Australia and Antarctica during Tertiary times.

Continued acquisition of detailed aeromagnetic data, flown as part of the South Australian Exploration Initiative (SAEI) and Targeted Exploration Initiative (TEISA), have greatly enhanced the geological understanding of the Gawler Craton. Greater detail in structural trends and magnetic patterns, which together with regional mapping, further U-Pb geochronology, isotopic analysis and geochemistry have provided the basis for the subdivision of the Gawler Craton into domains (Fig. 2). These domains are considered to represent the major components which were assembled through polyphase tectonic events during the Proterozoic (~1850 to 1540 Ma).

The domain boundaries are based on; major crustal shear/fault zones (ie: Karari Fault Zone, Yerda Shear Zone); marked difference in metamorphic grade and zones of complex structural/metamorphic transitions where faults and late plutonic rocks have masked the boundary (e.g., Nuyts and Cleve Domain boundary). The geological characteristics of each Domain are summarised below.

The eastern Gawler Craton is a major iron-oxide copper-gold province within South Australia and hosts the world class Olympic Dam Cu-U-Au-Ag-REE deposit, located approximately 520 km north-northwest of Adelaide (Fig. 1). The mineralisation and alteration in this metallogenic belt, termed the Olympic copper-gold province, is described in part II (Skirrow *et al*., this volume). The Olympic Dam deposit contains ore reserves of >600 Mt averaging 1.8% Cu, 0.5 kg/t $U_3O_8$, 0.5 g/t Au and 3.6 g/t Ag (Reynolds, 2000). The total resource for the deposit is >2300 Mt containing 30 Mt of Cu, 930 000 t of $U_3O_8$, 1200 t of Au and 6700 t of Ag (Reynolds, 2000). Olympic Dam is hosted by the Olympic Dam Breccia Complex, which occurs within the Roxby Downs Granite, a member of the Hiltaba Suite. The Olympic Domain also hosts sub-economic mineralisation at Acropolis, Emmie Bluff, Wirrda Well, Oak Dam and within the overlying Pandurra Formation sediments at Mount Gunson (Fig. 1). Within the southern Olympic Domain, the Moonta-Wallaroo region, contains a number of significant historic mines as well as the Wheal Hughes and Poona copper mines (Fig. 1), which were discovered in 1985/86 and mined until 1994. Mineralisation is hosted by the Palaeoproterozoic Moonta Porphyry at Moonta and the Doora Schist at Wheal Hughes. A total of 355 000 t of copper and 2 t of gold have been extracted from the Wallaroo-Moonta region, largely in the late 19th century (Conor, 1995).

The recent discovery of the Prominent Hill prospect within the Mount Woods Inlier by Minotaur Resources Ltd (Minotaur Resources Ltd, 2001) has greatly increased the prospectivity of the Gawler Craton, with significant interest in areas containing oxidised Hiltaba Suite granite. Drill hole DDH URN1 intersected basement at 108 metres, below a cover of barren Mesozoic and Permian shale and sands. Copper mineralisation commences at 200 m with significant intersections of 107 m (200 to 307 m) at 1.94% Cu, 0.65 g/t Au (including 35 m at 3.86%, 272 to 307m) and 152 m (429 to 581 m) at 1.1% Cu, 0.61 g/t Au and 267 ppm U, in a hematite breccia host (Minotaur Resources Ltd, 2001, 2002). Significant intersections of copper have been reported from other prospects in the Mount Woods area, including Manxman, Joes Dam and Cairn Hill. Large resources of iron ore are also present within the Mount Woods Inlier (Polito and Davies, 1997). Drilling at Peculiar Knob outlined a resource of 14 Mt grading 63.2 % Fe to 100 m depth (Morris and Hough, 1997), with enrichment produced by hydrothermal replacement of the host BIF (Davies, 2000).

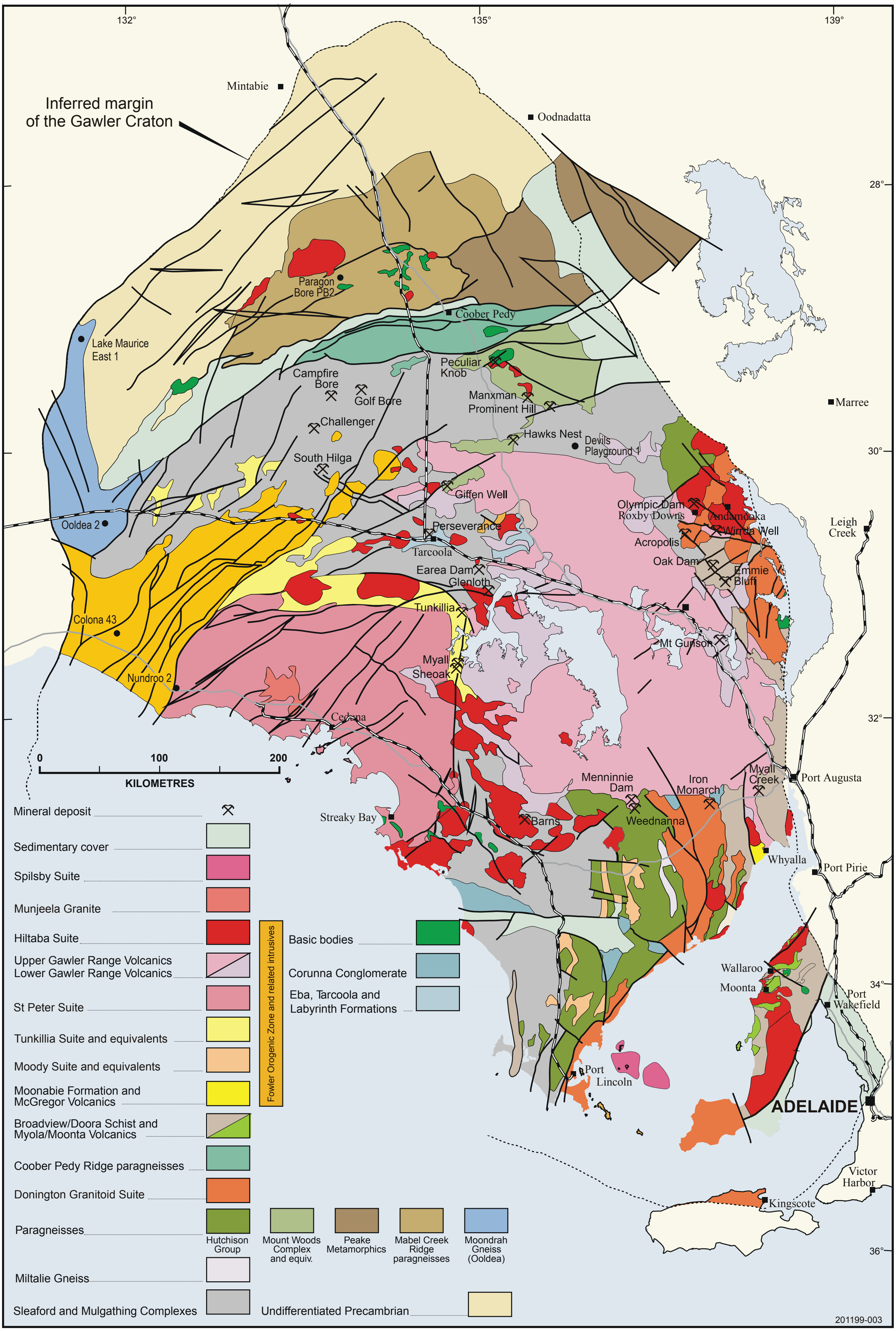
The extent of iron oxide related alteration on the eastern Gawler Craton including the Olympic, Mount Woods and northern Spencer Domains suggest that large volumes of hydrothermal fluids were involved and similar processes were occurring at the same time. The predominantly linear to arcuate nature of the eastern iron oxide alteration system and associated Hiltaba Suite plutons (Fig. 1) suggests control by a major tectonic feature. This may have been a major factor in extensive alteration and mineralisation on the eastern Gawler Craton. Distinct from the iron oxide associated mineralising system on the eastern Gawler Craton, Daly, *et al.* (1998) report gold and base metal mineralisation, with associated sericite-chlorite alteration, at Tarcoola, Tunkillia, Myall-Sheoak, Glenloth and Earea Dam related to central Gawler Craton, Hiltaba Suite magmatism. Hence, there appears to be two distinct arcuate belts of Hiltaba Suite magmatism and a difference between eastern and central, associated mineralisation styles.

Part one of this paper will describe the regional geology and tectonic setting of the Gawler Craton as a framework for the eastern Gawler Craton iron oxide copper-gold province. Part two will discuss the different alteration assemblages associated with regional alteration, and the controls on mineralisation across the eastern Gawler Craton.

## Domains of the Gawler Craton

Thomson (1970) and Parker (1990) divided the Gawler Craton into tectonic sub-domains based on structural, metamorphic and stratigraphic characteristics. Teasdale (1997) defined three new sub-domains, the Fowler, Coober Pedy and Lincoln Sub-domains. Based on recent geochronology and geochemical work on the Gawler Craton (Teasdale, 1997; Steward and Foden, 2001; Ferris, 2001), a new domain map of the Gawler Craton has been produced (Fig. 2). This process has been undertaken as a first step into a holistic tectonic interpretation of the Gawler Craton. It is intended to reveal those areas that require further research in order to produce robust tectonic interpretations (and the genetic connotations contained therein) of each domain. It also allows the spatial relationship of mineralising systems to be investigated. Within this map, the term domain is preferred because it is non-genetic and the next subdivision of a province. Each domain of the Gawler

**Figure 1** (facing page): Interpreted sub-surface geology of the Gawler Craton, South Australia, modified from Daly *et al.* (1998). Geology of the Stuart Shelf basement courtesy of Geoscience Australia (see also Part II, Skirrow *et al.*, this volume).



132°
135°
139°
28°
30°
32°
34°
36°
Inferred margin of the Gawler Craton
Mintabie
Oodnadatta
Marree
Leigh Creek
Paragon Bore PB2
Coober Pedy
Lake Maurice East 1
Campfire Bore
Golf Bore
Peculiar Knob
Manxman
Prominent Hill
Challenger
Hawks Nest
Devils Playground 1
South Hilga
Giffen Well
Olympic Dam
Roxby Downs
Andamooka
Wirrda Well
Acropolis
Oak Dam
Emmie Bluff
Ooldea 2
Perseverance
Tarcoola
Earea Dam
Glenloth
Tunkillia
Colona 43
Mt Gunson
Myall
Sheoak
Nundroo 2
Ceduna
0
100
200
KILOMETRES
Menninnie Dam
Iron Monarch
Myall Creek
Port Augusta
Streaky Bay
Barns
Weednanna
Whyalla
Port Pirie
Wallaroo
Moonta
Port Wakefield
Port Lincoln
ADELAIDE
Victor Harbor
Kingscote
Mineral deposit
Sedimentary cover
Spilsby Suite
Munjeela Granite
Hiltaba Suite
Upper Gawler Range Volcanics
Lower Gawler Range Volcanics
St Peter Suite
Tunkillia Suite and equivalents
Moody Suite and equivalents
Moonabie Formation and McGregor Volcanics
Broadview/Doora Schist and Myola/Moonta Volcanics
Coober Pedy Ridge paragneisses
Donington Granitoid Suite
Paragneisses
Hutchison Group
Mount Woods Complex and equiv.
Peake Metamorphics
Mabel Creek Ridge paragneisses
Moondrah Gneiss (Ooldea)
Miltalie Gneiss
Sleaford and Mulgathing Complexes
Fowler Orogenic Zone and related intrusives
Basic bodies
Corunna Conglomerate
Eba, Tarcoola and Labyrinth Formations
Undifferentiated Precambrian
201199-003

*Reverse of colour plate, intentionally blank*

Craton encompasses an area of crust, which has similar lithological and structural associations, which differ broadly, from the surrounding domains. Boundaries are commonly placed along major crustal shear zones or zones of contrasting litho-stratigraphy. Fig. 3 shows a tectono-stratigraphic diagram for the Gawler Craton based on the Domains presented below.

## *Peake and Denison Domain*

The Peake and Denison Domain (Peake and Denison Inlier) is located on the northern margin of the Gawler Craton (Fig. 2) and comprises quartzite (Baltucoodna Quartzite), amygdaloidal basalts and acid volcanics (Tidnamurkuna Volcanics), and quartz-chlorite-muscovite schists collectively termed the Peake Metamorphics. A rhyolite, within the Tidnamurkuna Volcanics, has a SHRIMP U-Pb zircon age of 1780±12 Ma (Fanning, 1997). The syn-tectonic Wirriecurrie Granite has tectonised contacts with the surrounding Peake Metamorphics and gives a 1793±8 Ma age (Fanning, 1997). Younger unnamed granites give a SHRIMP U-Pb zircon age of 1536±6 Ma and intrude the Peake Metamorphics on the eastern side of the inlier (Fanning, 1997). The boundaries of the Peake and Denison Domain are defined by faulted and unconformable contacts with overlying Adelaidean sediments. Delamerian folding of Adelaidean sediments has mildly overprinted the basement units (Rogers and Freeman, 1996).

## *Nawa Domain*

The Nawa Domain contains magnetite-rich metasediments of the Moondrah Gneiss (Daly *et al*., 1998), thought to represent aluminous, magnesium-rich meta-pelites. Interpretation of regional aeromagnetics suggest the presence of polygonal, relatively non-magnetic, sheet-like intrusives of Hiltaba Suite (Fairclough and Daly, 1995). The domain comprises an intensely faulted, rigid crustal block, which appears relatively unaffected by the ductile, arcuate, roughly northeast-southwest to east-west shear zones which separate domains to the south. It is bounded by the Cambrian to Neoproterozoic Murnaroo Platform to the northwest, the Karari Fault Zone to the south, and the Torrens Hinge Zone to the northeast. Rb-Sr isotope data indicates that samples from drill hole Ooldea 2 (Fig. 2) have a minimum metamorphic age of ~1700 Ma (Parker, 1993). Pb-Pb analysis using the Kober zircon evaporation technique yielded two ages, 1690±9 Ma and 2426±6 Ma (Teasdale, 1997). U-Pb SHRIMP analysis yielded a concordant age of 1653±8 Ma with inherited components at ~1700 Ma (Fanning, 1997; Daly *et al*., 1998). Teasdale (1997) interpreted the data to indicate two events, one zircon forming event at 1690 Ma, followed by a high temperature event at 1653 Ma. Fanning, (1997) considered initial zircon growth occurred at 1653 Ma, with 1690 Ma inheritance. The difference of opinion remains problematic, however the onset of the Kararan Orogeny buried these sediments. A quartz-plagioclase-garnet-biotite-sillimanite paragneiss, from drill hole Paragon Bore PB2 within the Mabel Creek Ridge, has a U-Pb SHRIMP age of ~1540 Ma, which is interpreted as recording the timing of later high-grade metamorphism (Fanning, 1997). The Mabel Creek Ridge is separated from the Coober Pedy Ridge, and Mount Woods Domain by the Karari Fault Zone. On the north western margin of the Nawa Domain, a U-Pb emplacement age of 1740 Ma was recorded for a foliated granite from the Yoolperlunna Inlier (Fanning, pers comm).

## *Coober Pedy Domain*

The Coober Pedy Domain (formerly known as the Coober Pedy Ridge) comprises sinuous, high magnetic intensity, iron-rich meta-sedimentary granulites. The northern and southern boundaries are defined by the Karari Fault Zone (Fig. 2). The northern boundary is delineated on aeromagnetics and the southern boundary by gravity. U-Pb zircon geochronology of meta-granodiorite or tonalite and cordierite-garnet-biotite-sillimanite paragneiss containing zircons with relic cores which were dated at 1750 Ma, with metamorphic rims recording an age of 1565±8 Ma (Daly *et al*., 1998; Fanning, 1997). It is inferred that the paragneisses forming the Coober Pedy Ridge were derived from the Mount Woods Domain and deformed under granulite facies conditions at 1568 Ma, an event apparently not recorded in the Mount Woods Domain (Daly *et al*., 1998).

## *Mt Woods Domain*

The Mt Woods Domain contains fine-grained, finely layered, banded iron formation and calc-silicates (Daly *et al*., 1998). Aeromagnetic images show ductile metamorphic layering inferring reworking of the underlying Archaean. Within the Mount Woods Domain, metasediments underwent granulite facies metamorphism at 1736±14 Ma (Fanning, 1997), hence these sediments are older than ~1740 Ma. Also within this domain is the Engenina Adamellite which has a SHRIMP U-Pb zircon age of 1691±25 Ma (Fanning, 1997). The Engenina Adamellite has a similar age to the Moody Suite granites of the southern Gawler Craton (Parker, 1993), although the high error may allow for a syn-Kararan intrusive age. The Mt Woods Domain contains undeformed Hiltaba Suite, such as the Balta Granite which has a SHRIMP U-Pb age of 1584±18 Ma (Fanning, 1997). The northern boundary of the Mount Woods Domain is the Karari Fault Zone. The southern boundary in fault controlled and the eastern boundary is defined by a dramatically increasing thickness of overlying sediments.

### *Economic Geology*

The Mount Woods Domain hosts the recently discovered Prominent Hill (copper-uranium-gold) prospect as well as the Joes Dam, Cairn Hill and Manxman prospects (Fig. 2). It appears that the Hiltaba Suite has a strong temporal and spatial association with iron-oxide copper-gold mineralisation within these prospects, as is the case with the Olympic Domain. The Mount Woods Domain also contains significant strike lengths of Palaeoproterozoic BIF within a sequence of metasediments. Depth of cover varies from a few tens of metres deepening to >100 m to the south.

## *Christie Domain*

The original Christie Sub-domain of Parker, 1990, has been subdivided to exclude the Fowler Domain (Fowler Orogenic Zone), the Coober Pedy Domain and the Mount Woods Domain. The Christie Domain comprises Archaean to earliest Palaeoproterozoic rocks, which comprise the original protolith, on which younger units were deposited/incorporated (Daly and Fanning, 1993; Teasdale, 1997). Major rock units include low magnetic intensity Mulgathing Complex paragneiss (e.g., host of the Challenger gold deposit), interlayered with, linear highly magnetic zones of banded iron formation and ultramafic rocks, including peridotite, and intruded by highly magnetic ~1690 to 1670 Ma intrusives. The western boundary is the Karari Fault Zone and the eastern boundary is the Coorabie and Tallacootra Shear Zones (Fig. 2).

*Economic Geology*

The Challenger gold deposit was discovered by Dominion Mining Ltd and Resolute Ltd (Gawler Joint Venture) in 1995. Drilling has outlined a combined indicated and inferred resource of 1.71 Mt at 8.5 g/t Au containing 14.5 tonnes (0.465 Moz) of gold (Dominion Mining, 2002). Development of the project to mine status is currently underway with the first gold production expected during the second half of 2002. The mineralised system occurs within a meta-sedimentary plagioclase, perthitic K-feldspar, quartz, cordierite, garnet and biotite variant of the Archaean Christie Gneiss (Mulgathing Complex). Syntectonic, ~2440 Ma, high grade gold mineralisation occurs within and adjacent to a complex array of quartz veins (Dominion, 2002). These veins occur within structurally controlled shoots with a north-northeasterly strike and northerly plunge (Dominion, 2002). The internal vein geometry is oblique to the plunge azimuth of the shoots, probably reflecting Proterozoic overprinting. Numerous other prospects have been identified with a similar mineralisation style including the Birthday, Golf Bore, Campfire Bore, South Hilga and Birdie prospects (Daly *et al.*, 1998). Potential also exists for Archaean, granite-greenstone style gold mineralisation in the Harris Greenstone Domain in the western Gawler Craton.

## *Harris Greenstone Domain*

The Harris Greenstone Domain (formerly part of the Wilgena Domain), comprises supercrustal Archaean ultramafic (komatiite) and mafic volcanics and Archaean aluminous metasediments (Christie Gneiss), felsic extrusives and/or intrusives (Kenella Gneiss) and syn-tectonic acid intrusives (Glenloth Granite) (Daly and Fanning, 1993). Mafic/ultramafic packages in the Christie Domain are generally intrusive whereas in the Harris Greenstone Domain they are dominantly extrusive. This may be due to significantly different crustal levels exposed within the different domains. Alternatively, the intrusive and extrusive ultramafics may be different geological units. The Yerda Shear Zone represents the southern boundary and the northern boundary is a lithological zone boundary with the Wilgena Domain.

## *Fowler Domain*

The Fowler Domain comprises a northeast trending sinuous high magnetic intensity belt of Palaeoproterozoic igneous and metamorphic rocks. Boundaries are the Karari Fault Zone to the west and the Coorabie Shear Zone to the east (Fig. 2). The Fowler Domain was previously termed the Fowler Suture Zone (Daly *et al.*, 1995), but is more recently described as the Fowler Orogenic Belt (Daly *et al.*, 1998). Teasdale subdivided the Fowler Domain into four blocks; the Nundroo, Central, Colona and Barton Blocks which show different metamorphic grade. SHRIMP U-Pb zircon geochronology of mildly deformed, coarse-grained, cumulus gabbro, in drill hole Colona 43, gives an emplacement age of 1730±10 Ma (Fanning, 1997). Small zircons grown during high-grade metamorphism of a gabbro or basalt in drill hole Nundroo 2 define a U-Pb age of 1543±9 Ma (Fanning, 1997). Possible host paragneisses include sillimanite bearing aluminous metasediments and banded iron formation of unknown age (Afmeco, 1982). Deformed Hiltaba Suite granite also occurs within the Fowler Domain. The eastern margin of the Fowler Orogenic Zone is markedly discordant to the gross litho-tectonic trends in the Nuyts Domain to the east and represents a major crustal discontinuity. Aeromagnetic data suggests a significant strike-slip component to this boundary, but outcrop data shows a dominant vertical displacement. This suggests significant transpressive strike-slip displacement.

## *Nuyts Domain*

The Nuyts Domain comprises possible Palaeoproterozoic, ductile deformed metasediments and meta-igneous rocks into which variably magnetic, Palaeoproterozoic to Mesoproterozoic granitoids were emplaced. The Nuyts Domain was previously interpreted to represent Archaean basement, but recent geochronology and isotopic analyses show juvenile crust produced during Palaeoproterozoic orogenic activity. The domain is broadly delineated by a distinctive gravity low, reflecting the predominantly felsic igneous composition. It is bound to the north by the Yerda Shear Zone, and the west by the Coorabie Shear Zone. The overlying Gawler Range Volcanics obscure the eastern boundary but it appears to be strongly controlled by the Yarlbrinda Shear Zone (Fig. 2). The south east boundary remains problematic. A noticeable feature of the Nuyts Domain is the concentration of large Hiltaba Suite plutons around its structurally controlled northern and eastern margins (Fig. 2). Both deformed and undeformed plutons occur within shear zones bounding the Nuyts Domain, suggesting at least a partly syn-orogenic emplacement. Spatially, the plutons form an arcuate belt distinct from a similar belt to the north-east, within the Olympic and Mt Woods Domains. Based on empirical evidence, the Hiltaba Suite within, and adjacent to, this belt appears to be associated with a quartz-sericite-chlorite-gold dominant style of mineralisation as opposed to iron oxide copper-gold in the Olympic and Mount Woods Domains.

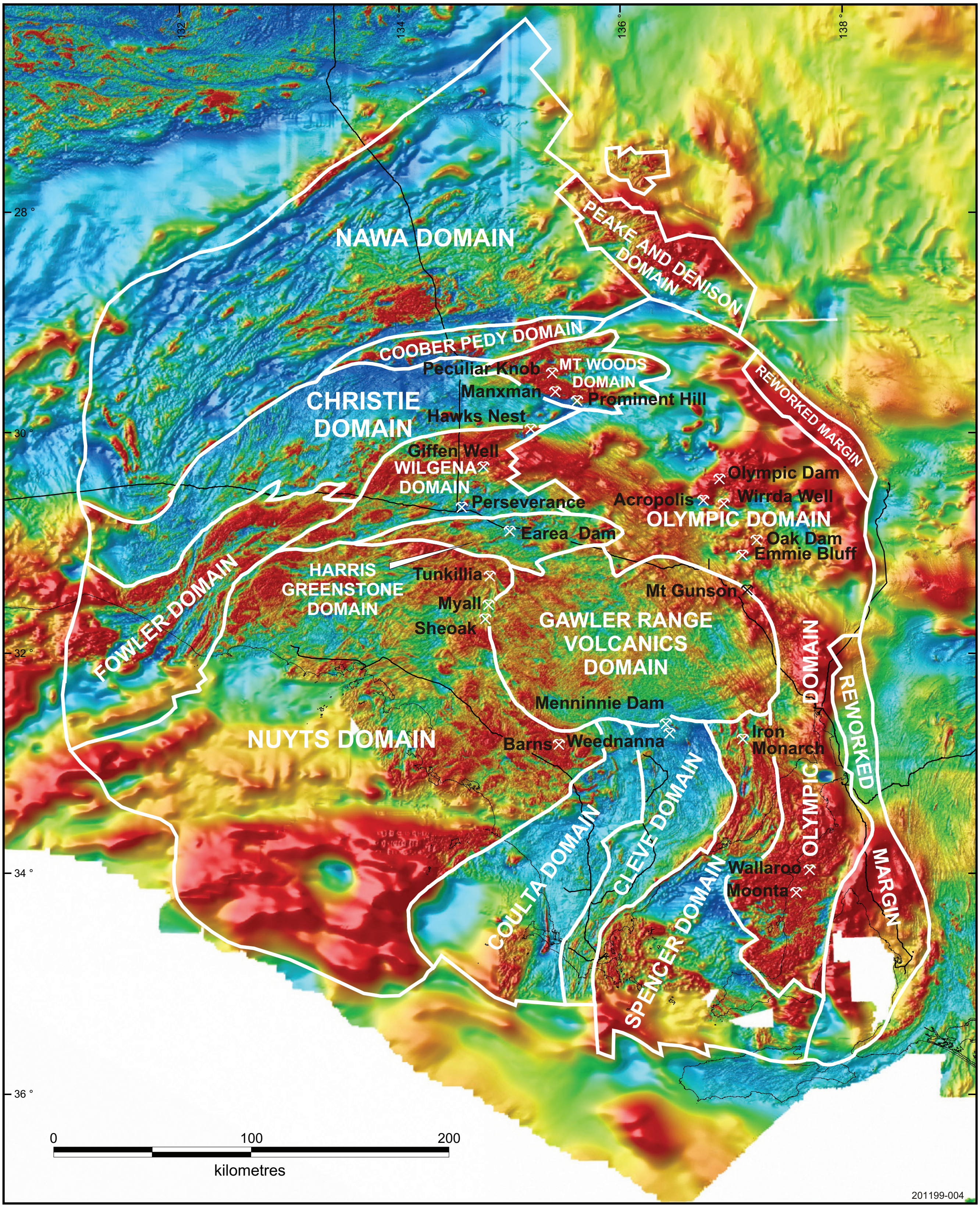



**Figure 2:** Domains of the Gawler Craton on Total Magnetic Intensity

*Reverse of colour plate, intentionally blank*

## Wilgena Domain

The Wilgena Domain was originally defined by Parker (1990), as a large northeast trending zone. Teasdale (1997) subdivided the Wilgena and part of the Christie Sub-domains into the Christie, Fowler and Coober Pedy Sub-domains, based on different metamorphic histories. The Wilgena Domain comprises high magnetic intensity metasediments, including banded iron formation, intruded by large elliptical Hiltaba Suite plutons. Boundaries are the Coorabie Shear Zone to the north and west, Yerda Shear Zone and the Harris Greenstone Domain to the south and the Olympic Domain to the east (Fig. 2).

*Economic Geology*

Alluvial gold mineralisation was discovered at Tarcoola in 1893 and gold-bearing quartz reefs were located in 1900. Between 1900 and 1955, gold bullion totalling 2400 kg was recovered from 64 000 t of ore at an average grade of 37.5 g/t. Gold is found in quartz veins within carbonaceous siltstone and interbedded quartzite of the Palaeoproterozoic Tarcoola Formation. Gold also occurs in altered quartz-feldspar granite, inferred to be Hiltaba Suite from a nearby 1575±7 Ma U-Pb zircon age, from unaltered granite. Alluvial gold was also discovered at Glenloth and gold-bearing reefs discovered in 1901. Between 1901 and 1955, ~315 kg of gold was produced from 14 620 t of ore, at an average grade of 21.6 g/t. Mineralised veins are hosted by sheared and fractured Archaean to Palaeoproterozoic Glenloth Granite. North of the Glenloth Goldfield, gold was discovered at Earea Dam in 1899 and during 1899-1903 and 1933-1941 produced 59 kg of gold from ~1870 t of ore at an average grade of 35.5 g/t.

Recent exploration for iron ore, at the Hawks Nest prospect, has identified a series of disconnected ridges of BIF, where magnetite occurs as the dominant iron oxide beneath relatively shallow cover of younger sediments and weathered BIF (Davies, 2000). Close-spaced drilling on one of the strike ridges has identified an inferred resource of 220 Mt to 135 m depth, grading 36% Fe (AuIron Energy, 2000). The potential for further resources is significant. A similar deposit occurs at Giffen Well, 60 km to the southwest, with resources estimated at 240 Mt to 150 m depth, grading 36% Fe.

## Gawler Range Volcanics Domain

The Gawler Ranges Volcanics Domain is a large area of dominantly felsic volcanics, which are flat lying and relatively undeformed (Fig. 2). Lower parts of the sequence contain interlayered basalts. U-Pb zircon dating for the Wanganny and Yardea Dacites give ages of 1591±3 and 1592±3 Ma (Fanning *et al.,* 1988) respectively. The boundaries are coincident with the distinct elliptical magnetic signature of the domain. Recent work (Morrow and McPhie, 2000) indicates that the greater part of the Gawler Range Volcanics, originally interpreted as predominantly ignimbrites (Blissett, 1980), may be lavas. This concept has significant implications for exploration.

## Olympic Domain

The Olympic Domain (incorporating the Moonta Domain of Parker, 1993) is an arcuate zone of Palaeoproterozoic sediments and felsic igneous rocks and Mesoproterozoic granite, volcanics, quartz-rich sediments and conglomerates.

The oldest rocks known from the Olympic Domain comprise a schistose unit which occurs as enclaves within deformed granites of Suite #1 (Creaser, 1989). These rocks are strongly deformed, containing at least one foliation, and are thought to represent Hutchinson Group metasediments based on relationships with the Suite #1 granites of Creaser (1989). The Hutchinson Group is an extensive sequence of shallow clastic and chemical marine sediments, with minor acid and mafic volcanics (Parker, 1993). Parker and Lemon (1982) subdivided the Hutchinson Group into three main sequences:

- a basal quartzite sequence (Warrow Quartzite)
- a mixed chemical and clastic sequence (Middleback Subgroup)
- an upper pelitic unit (Yadnarie Schist)

Within the Olympic Domain, numerous drill holes intersect coarse grained, deformed granite. U-Pb SHRIMP analysis of zircons from hole PD-2, give a crystallisation age of 1845 Ma; hence this is considered to be part of the Donington Granitoid Suite (Creaser, 1995). The unit is of batholithic extent, which supports a Donington Suite classification (Creaser, 1995). In addition to the coarse-grained, deformed granite, Creaser (1989) recognised two other distinct lithological groups:

- Felsic, medium grained, equigranular granite and pegmatite, and
- Intermediate to mafic lithologies including tonalite, gabbroic anorthosite, granodiorite and quartz monzonite.

The Donington Granitoid Suite is defined from the southern Gawler Craton, where it outcrops on the eastern coast of the Eyre Peninsula through to the west coast of the Yorke Peninsula. In this region the suite forms a batholithic series of intrusions ranging from quartz gabbro-norite to ultra-fractionated granite (Parker *et al.*, 1988). The batholith contains small volumes of mafic to intermediate magmas, voluminous felsic, megacrystic granite and gneiss, and smaller volumes of late, ultra-fractionated, fine, even-grained granite. Distinct lithological units within the Donington Granitoid Suite exhibit abundant co-magmatic relationships, suggesting evolution from a common magma source (Schwarz, 2003). Original anhydrous orthopyroxene ± clinopyroxene bearing compositions have been variably retrogressed to biotite and hornblende. Numerous U-Pb zircon dates on different lithological units have all returned crystallisation ages within error of 1850 Ma (Fanning, 1997).

The Kalinjala Mylonite Zone separates the Donington Granitoid Suite in the south from similar lithologies in the Cowell-Cleve region, northern Eyre Peninsula. In this region the Minbrie Gneiss is interpreted as an equivalent to the Donington Granitoid Suite (Parker, 1993). Lithological units comprise granite gneiss, granodiorite gneiss and augen gneiss, are multiply deformed and contain enclaves of Hutchison Group metasediments. Rb-Sr analysis on the granite gneiss suggests a crystallisation age >1800 Ma (Webb *et. al*., 1986).

Within the Olympic Dam region, a sequence of intercalated, deformed felsic volcanics and schists overlie the Donington Granitoid Suite (Creaser, 1989). This unit has not been dated, but is thought to be correlated with either the Myola (~1791 Ma) or Moonta Volcanics (~1760 Ma) or possibly the Tidnamurkuna Volcanics (~1780 Ma).

Unconformably overlying the older granites within the Olympic Domain is a widespread sequence of finely laminated meta-siltstone, feldspathic sandstones, calc-silicates and amphibolites. This sequence is unconformably overlain by Gawler Range Volcanics, hence Creaser (1989) correlated this unit with the Wanderah Meta-siltstone found within the Moonta Domain. Conor (1995) defined the Wallaroo Group to include all meta-sedimentary and meta-igneous units older than the Mesoproterozoic Tickera-Arthurton Granites and the Oorlana Metasomatite within the Moonta Domain. The Wallaroo Group includes the Wardang Volcanics, Willamulka Volcanics, Wanderah Metasediments and Doora Metasediments (Fig. 3). The age of the sequence has been determined from the interbedded Moonta Volcanics, dated by U-Pb zircon analyses at 1760±7 Ma (C.M. Fanning, PRISE, *pers. comm.*, 2002).

The last major magmatic event observed in the area is the Hiltaba Suite/Gawler Range Volcanic magmatic event (1595 to 1575 Ma). The Gawler Range Volcanics cover an area of approximately 25 000 km$^2$ and are the dominant Proterozoic outcropping unit on the Gawler Craton. They consist of a series of dominantly felsic lavas and ignimbrites, with minor mafic lavas. The Hiltaba Suite intrudes the Gawler Range Volcanics and is a suite of mostly oxidised, K-feldspar dominant granite. The discovery of the Olympic Dam Cu-U-Au ore body, hosted within the Roxby Downs Granite, a member of the Hiltaba Suite, has greatly increased the prospectivity of the Gawler Craton.

Unconformably overlying these older units is the Pandurra Formation, a thick sequence of undeformed arenaceous red bed sediments that extend over a greater part of the Olympic Domain (Cowley, 1991). Fanning *et al*. (1983) reports that the Pandurra Formation has a minimum depositional age of 1424±51 Ma based on Rb-Sr geochronology. Unconformably overlying the Pandurra Formation in the Cultana area (Moonta Domain) are subaerial basalts of the Beda Volcanics and intercalated coarse fluvial clastics of the Backy Point Formation.

*Economic Geology*

The eastern Gawler Craton contains one of the largest iron oxide-copper-gold provinces in the world extending for some 700 km from the Peake and Denison Range, in the north, through the Mount Woods Inlier, Olympic Dam, Mount Gunson, to the Moonta-Wallaroo and Iron Monarch areas, in the south.

The Olympic Dam deposit contains ore reserves of >600 Mt averaging 1.8% Cu, 0.5 kg/t $U_3O_8$, 0.5 g/t Au and 3.6 g/t Ag (Reynolds, 2000). The total resource for the deposit is >2300 Mt containing 30 Mt of Cu, 930 000 t of $U_3O_8$, 1200 t of Au and 6700 t of Ag (Reynolds, 2000). The Hiltaba Suite/Gawler Ranges Volcanic magmatic event was widespread across the Gawler Craton (Fig. 3) and was a major mineralising event. The timing of mineralisation at Olympic Dam overlaps the emplacement age of the Roxby Downs Granite, suggesting the granite was a source of heat and possibly fluids for the deposit.

Overlying the Olympic Domain, copper mineralisation also occurs in Adelaidean sediments. Copper mineralisation was discovered at Mount Gunson in 1875 with approximately 149 000 t of copper metal and 65 t of silver from 8.4 Mt of ore (grading 1.7% Cu) produced since 1898. Mineralisation is located within the (~1400 Ma) Pandurra Formation and Adelaidean cover sediments.

A joint venture between Australian Selection (Pty) Ltd and Sims Metals Pty Ltd discovered the Myall Creek prospect located south of Port Augusta in March 1975, during exploration for Copperbelt type orebodies on the Stuart Shelf. Drill holes intersected copper sulphides, with lesser zinc and lead, and accessory silver and cobalt, over an area extending 15 km north-south by 3 km east-west, at a depth of approximately 160 metres. Mineralisation occurs at the base of the Tapley Hill Formation within a thin white sandstone and an overlying silt-dolo-laminite facies. Minor copper sulphide mineralisation is also found in underlying Beda Volcanics. The deposit shows metal and mineral zoning both vertically and laterally. Apart from pyrite, the sulphide minerals are of epigenetic origin. The deposit exhibits many features in common with the Kupferschiefer of Europe.

Copper was discovered in the Moonta-Wallaroo are in 1860 and approximately 350 000 t of copper at 3.7% Cu was recovered between 1860 and 1923 mainly from underground workings. The Wheal Hughes and Poona deposits produced 17 500 t of copper (grade 3.7%) between 1988 and 1993. The Wallaroo and Moonta copper deposits also produced approximately 3.6 t of gold with an average grade of 0.4 g/t between 1860 and 1923. Recent mining at Wheal Hughes and Poona produced 423 kg of gold (0.9 g/t) from 476 000 t of ore. The host rocks include feldspar porphyry (Moonta Porphyry) and schists (Doora Schist) with mineralisation associated with the Hiltaba Suite magmatic event (~1590 Ma).

Spatially, the Hiltaba Suite forms an arcuate belt from the Mt Woods Domain in the north through to the Olympic Domain (Moonta Wallaroo region) in the south. Within this belt, apparent concentrations of plutons occur in the Moonta-Wallaroo region, Olympic Dam region and the eastern portion of the Mt Woods-Nawa Ridge region (Fig. 2). Mineralisation associated with the Hiltaba Suite within this belt is dominated by iron oxide copper-gold.

## *Coulta Domain*

The Coulta Domain is dominated by Archaean metasediments and volcanics of the Sleaford Complex, and high level, granitoid intrusives of the Dutton Suite. These rocks comprise the original protolith on which younger units of the southern Gawler Craton were deposited. The Coulta Granodiorite of the Dutton Suite gives a U-Pb zircon age of 2517±14 (Fanning, 1997). The northern boundary is inferred to be an east-west trending shear zone stitched by Hiltaba Suite plutons (Fig. 2). The western boundary represents a faulted margin with the Nuyts Domain, which marks a transition into significantly younger intrusives.

## *Cleve Domain*

The Cleve Domain is dominated by basinal sediments of the Palaeoproterozoic Hutchison Group unconformably overlying Palaeoproterozoic Miltalie Gneiss and Archaean paragneiss and orthogneiss with a metamorphic age of ~2440 Ma. Syn-tectonic intermediate to felsic Moody Suite (~1700 Ma) intrude the Hutchison Group metasediments. The Cleve Domain is separated from the Coulta Domain by a major northeast trending shear zone, which brings high level granites of the Dutton Suite, within the Coulta Domain, into juxtaposition with granulite facies para- and orthogneiss of the Sleaford Complex. The Kalinjala Mylonite Zone separates the Cleve Domain from the Spencer Domain (Fig. 2).

*Economic Geology*

Within the Cleve Domain, Pb-Zn mineralisation is known from the Palaeoproterozoic Hutchinson Group metasediments. Many small deposits are located on eastern Eyre Peninsula with the largest being the Miltalie Mine (lead-silver). Ore grades up to 61.5% Pb and 118.5 g/t Ag are reported, the mine operating intermittently between 1860 and 1914. Other small mines include Atkinson's Find, Cleve, Elson, Lady Franklin, Mangalo, Mount Miller, Poonana and Yalpoundie.

Drilling of aeromagnetic targets adjacent to the southern margin of the Gawler Ranges in 1981 resulted in discovery of significant lead-zinc-silver mineralisation at the Menninnie Dam and Telephone Dam prospects. Mineralisation is hosted by Hutchison Group serpentine marble, laminated graphitic, ankeritic, dolomitic marble and carbonate-facies BIF, and comprises massive pyrite-sphalerite-galena with minor chalcopyrite and pyrrhotite. The mineralising event is related to intrusion of Mesoproterozoic rhyolitic dykes (Roache and Fanning, 1994). An inferred resource of 1.7 Mt at 5% Pb, 8% Zn and 100 g/t Ag is reported for Menninnie Dam.

## *Spencer Domain*

The Spencer Domain comprises irregularly shaped intrusives of the Donington Granitoid Suite ranging in composition from gabbro-norite to highly evolved leucogranite. Results of U-Pb zircon dating, from the southern part of the domain, give a consistent intrusive age of 1850 Ma (Fanning, 1997). Interfolded inliers of Palaeoproterozoic Hutchison Group metasediments occur within the Donington Granitoid Suite in the northern part of the domain. The Spencer Domain is separated from the Cleve Domain by the Kalinjala Mylonite Zone. The Olympic Domain is distinguished from the Spencer Domain by the development of characteristic iron oxide alteration within the former (Fig. 2).

*Economic Geology*

Deposits of iron-rich chemical sedimentary rocks occur within the Spencer Domain and are easily recognised by their prominent linear aeromagnetic signature. The Middleback Ranges comprise a series of prominent, discontinuous ridges of Palaeoproterozoic BIF extending north-south for 60 km. Oxidised BIF, with haematite as the dominant iron oxide, occurs from surface to an average depth of 90 m, and is underlain by unoxidised BIF with magnetite as the dominant iron oxide. Currently it is considered to be uneconomic to beneficiate the near surface haematite-rich ore. The first major iron ore mining in Australia began at Iron Knob in the Middleback Range in 1915. From 1915 to the present, over 200 Mt of high-grade ore has been mined from haematite deposits within the Middleback Range (Iron Monarch, ~130 Mt until closed in 1998; Iron Baron - Iron Prince area, ~56 Mt until closed in 1995; Iron Duke - Iron Duchess - Iron Knight area, ~15 Mt). For some 50 years from 1915 to 1965 these deposits were the main supply of ore for Australia's iron and steel industry, and the favourable logistics of the region led to the establishment of an integrated steelworks at Whyalla in 1964. The remaining measured reserves of high-grade ore in the Middleback Range are reported at 26 Mt (Davies, 2000).

# Deformation History of the Gawler Craton

Three major tectonic events have fundamentally affected the formation of the Gawler Craton

1. ?2700 to 2300 Ma - Late Archaean sedimentation and volcanism followed by early Palaeoproterozoic plutonism and metamorphism (*Sleaford Orogeny*);
2. 2000 to 1700 Ma - initial basin/platform sedimentation followed by widespread plutonism, metamorphism and deformation (*Kimban Orogeny*) with local volcanism and continental sedimentation; and
3. 1690 to 1450 Ma - development of spatially separated granulite and amphibolite facies rocks during the *Kararan Orogeny* (1690 to 1540 Ma) in the northern and western portion of the craton. This was accompanied by syn-tectonic intrusion of acid, ultramafic and mafic plutons with associated development of major ductile shear zones encroaching on the central Gawler Craton. Emplacement of extensive Hiltaba Suite plutonism and felsic volcanism (Gawler Range Volcanics), accompanying the formation of the iron oxide copper-gold systems on the eastern Gawler Craton. Intra continental clastic sedimentation occurred late in this event.

The following section is a summary of the current understanding of the deformation history of the Gawler

Craton, based of recent work of the Geological Survey and numerous workers referenced within. New tectonic events have been defined within the three major tectonic cycles outlined above. On the southern Gawler Craton the historical Kimban Orogeny (1850 to 1700 Ma) has been separated into two discrete events, the Neill Event (1850 Ma) and the new Kimban Orogeny (1730 to 1700 Ma).

## *Sleafordian Orogeny ~2700 to 2300 Ma*

Effects of the Sleafordian Orogeny are recorded in Archaean crust within the Coulta Domain, Harris Greenstone Domain, Wilgena Domain, and Christie Domain. Very little is known of Sleafordian kinematics as many original structures have been reworked by later tectonic events. The onset of high grade metamorphism is thought to have occurred around 2600 Ma (Fanning *et al*., 1988) with the most pervasive, peak granulite facies metamorphism occurring between 2440 and 2420 Ma. Waning stages of the orogeny are recorded by Rb-Sr whole rock geochronology at ~2300 Ma (Webb *et al.*, 1986). Following the cessation of the Sleafordian Orogeny at ~2300 Ma there was a period of relative tectonic quiescence until 2000 Ma, the onset of the Miltalie Event.

## *Miltalie Event, Southern Gawler Craton, ~2000 Ma*

The Miltalie Event separates the Sleafordian Orogeny from the Neill Event described below (Fanning, 1997). The Miltalie Gneiss at Plug Range (WHYALLA map sheet, Parker, 1983, Parker and Fanning, 1997), granite west of Tumby Bay and hypersthene gneiss within the Carnot Gneisses at Redbanks, all record zircon crystallisation at about 2000 Ma (Fanning, 1997). Fanning *et al*., (1995), Fanning (1997) and Daly *et al*., (1998) have proposed that during this event, the lower crustal, high grade Carnot Gneisses were brought into juxtaposition with higher crustal level, lower grade intrusions of the Dutton Suite. Aeromagnetic data of the southern Gawler Craton reveal a roughly northeast-southwest boundary between magnetically busy Carnot Gneisses to the east and relatively quiet Dutton Suite to the west (Fig. 2). This is interpreted as a major fault or terrane boundary formed during this event. Further evidence that this is a major crustal feature comes from a crustal scale electromagnetic conductor coincident with this boundary (White & Milligan, 1984).

## *Redefining the Kimban Orogeny*

The Kimban Orogeny, as defined by Thomson (1969), Glenn *et al*. (1977), and Parker and Lemon (1982) occurs over a relatively long time period of ~150 Ma. Parker (1993), defines three major events having occurred between ~1845 and ~1710 Ma. Based on relationships to various igneous units, $KD_1$ was inferred between ~1845 and 1795 Ma, $KD_2$ between ~1795 and 1745 Ma and $KD_3$ between ~1745 and 1710 Ma. Subsequent geochronology (principally reported in Fanning, 1997) has led to a refinement of the tectono-thermal history. The first major event is now constrained to the waning stages of intrusion of the Donington Granitoid Suite at 1850 Ma. The second and third major events occurred between ~1730 and ~1700 Ma, constrained by Sm-Nd data on granulite facies assemblages within the Kalinjala Mylonite Zone (Hand *et al*., 1995), intrusion of the syntectonic Middle Camp Granite at ~1730 Ma and syn- to post-tectonic Moody Suite at ~1700 Ma. Hoek and Schaefer (1998) suggest that the first tectono-thermal event of the Kimban Orogeny be separated from the latter, due to the ~150 Ma separation between the two. Significant crustal extension at ~1770 Ma (Oliver and Fanning, 1997), involving deposition of the Price Metasediments, supports a division. Wilson (1999) has termed the first event, at 1850 Ma, the Lincoln Orogeny and redefined the Kimban Orogeny as the second event correlating with $KD_2$ and $KD_3$ of Parker and Lemon (1982). Considering the term "Lincoln" is well established with the term "Lincoln Complex" (Parker, 1993), the authors feel that it would cause much confusion to adopt the nomenclature of Wilson (1999). We suggest that the term Neill Event be applied to the earlier, and Kimban Orogeny be restricted to the later, episodes of deformation.

## *Neill Event, Southern Gawler Craton, ~1850 Ma*

The Neill Event is well constrained by intrusion of the Donington Granitoid Suite. Mortimer *et al*. (1988) identified foliated enclaves of megacrystic granite gneiss within relatively undeformed Colbert Granite. Both rocks have subsequently been dated at ~ 1850 Ma. Parker's early layer parallel foliation in the Hutchison Group metasediments is thought to have formed during this event, as did metamorphic zircons in Corny Point Paragneiss, (Zang and Fanning, 2001)

## *Kimban Orogeny, Southern Gawler Craton, ~1730 to 1700 Ma*

The redefined Kimban Orogeny contains $KD_2$ and $KD_3$ of Parker and Lemon (1982). The orogeny is currently constrained by intrusion of the Middle Camp Granite at ~1730 Ma (Fanning, 1997), granulite facies metamorphism within the Kalinjala Mylonite Zone, at ~1730 Ma (Hand *et al.*, 1995), and intrusion of the late to post tectonic Moody Suite at ~1700 Ma (Fanning, 1997).

## *Transitional Kimban - Kararan Deformation*

Metasediments from the Mount Woods Domain underwent high-grade metamorphism at ~1740 Ma, possibly coeval with the Kimban Orogeny outlined above. However, tectonic activity continued within the Mount Woods Domain beyond activity recorded in the southern Gawler Craton (Betts, 1992; Finlay, 1993). Within the Fowler Domain, the host sediments were intruded by voluminous sheets, sills and plutons of strongly magnetised, mafic-intermediate, I-type, cumulus layered intrusives at ~1730 Ma (Teasdale, 1997). Hence, deformation pre-1650 Ma, was occurring on the western and northern Gawler Craton and the relationship between these events and the Kimban Orogeny, on the southern Gawler Craton, is uncertain.

### *The Kararan Orogeny*

The Kararan Orogeny was defined by Daly *et al*. (1995, 1998) to describe high-grade metamorphism and associated deformation between ~1650 and 1540 Ma on the northern and western Gawler Craton. Daly *et al*. (1998) report that deformation associated with the Kararan Orogeny is related to continental collision between the eastern proto-Yilgarn Craton, to the northwest, and the central Gawler Craton-East Antarctic Craton (Mawson Continent) in the south. The name Kararan Orogeny is derived from the Karari Fault Zone, a major crustal feature on the northwestern Gawler Craton. The temporal relationships associated with the Kararan Orogeny are poorly constrained, due to lack of exposures along the northern margin of the Craton.

Daly *et al*. (1998) reported the effective minimum age for the onset of the Kararan Orogeny was ~1650 Ma, defined by metamorphic zircons from the Ooldea Region. Magnetite-rich aluminous metasediments from DDH Ooldea 2 have a mineral assemblage comprising hypersthene-sillimanite and sapphirine-quartz which indicate high grade metamorphic conditions (>950°C and >9.5kb; Teasdale, 1997). Teasdale (1997), using the Kober Pb-Pb technique, reports that the main zircon forming event occurred at ~1690 Ma and these zircons were recrystallised at ~1653 Ma during the ultra-high temperature event. Fanning (1997) records zircon growth at ~1653 with inheritance at ~1700 Ma. This problem has not yet been resolved; however, burial of these sediments is regarded as occurring during the onset of the Kararan Orogeny, so that the metamorphic ages must be regarded as a minimum age for this event. Additional SHRIMP dating, by Fanning, for Teasdale (1997) record abundant syntectonic intrusives from 1690 to 1670 Ma, in the Fowler Domain. This suggests that the Kararan Orogeny should be extended to 1690 Ma.

If this change in concept is accepted, then those deformed granites assigned by Daly *et al.* (1998) to the Kimban Orogeny, now become Kararan Orogeny syntectonic granites. For example, the Symons Granite (1690±10 Ma) immediately west of Mulgathing Homestead and the Engenina Adamellite (1691±10 Ma) in the Mt Woods Domain. Syntectonic granites described by Teasdale (1997), at Wynbring Rocks (1669±10 Ma), Barton South (~1675 Ma) and at Lake Ifould (1672±17 Ma) would also become syn-Kararan Orogeny granites. Included in this group is Little Pinbong from the Coulta Domain (1670±17 Ma; Fanning, 1997).

Teasdale (1997) used the term Ifould Complex for variably deformed I-type granitoids and mafics at Lake Ifould in the western Gawler Craton. Daly *et al.* (1998) used Ifould Complex for all syntectonic Kararan Orogeny intrusives so that further subdivision would be individually named suites within this very large region. To avoid confusion, Teasdale's (1997) usage has precedence and should be used strictly for those granites in the Lake Ifould area. The stratigraphic term proposed here is the Ifould Suite.

Ferris (2001) has now defined a suite of comagmatic felsic and mafic granitoids, within the Yarlbrinda Shear Zone with a U-Pb zircon age of ~1680 Ma, as the Tunkillia Suite. These rocks show an arc-affinity on a Pearce *et al*. (1984) diagram (Fig. 4).

Between ~1630 and 1610 Ma, the St Peter Suite was intruded into the Nuyts Domain, producing a suite of tonalitic to granodioritic rocks, similar in chemistry to Archaean tonalite-trondhjemite-granodiorites. Fig. 4 shows the St Peter Suite plot predominantly within the volcanic arc granite field on a Pearce *et al*. (1984) tectonic diagram. This event is not witnessed within the eastern Gawler Craton.

The Hiltaba Suite/Gawler Range Volcanics magmatic event (~1595 to 1575 Ma) represents a major tectonic/tectono-thermal event which affected much of the Gawler Craton (Fig. 3). Geochemistry and Sm-Nd isotope analysis of the Hiltaba Suite shows that it is highly variable across the Gawler Craton. The suite is dominantly felsic, although intermediate lithologies are known from the northern Gawler Craton (Andamooka and Olympic Dam areas). $\varepsilon_{Nd}$ values for Hiltaba Suite granites within the Nuyts Domain record positive values including 0.11 (Nunnyah Rockhole) and 1.19 (Wallala Rock) (Stewart and Foden, 2001), which suggest a depleted mantle source (Rollinson, 1993). Hiltaba Suite samples to the east of the Nuyts Domain record a range of negative $\varepsilon_{Nd}$ values indicating a continental crustal source (Stewart and Foden, 2001). Johnson and Cross (1991) record a mixed $\varepsilon_{Nd}$ signature, indicating a partial mantle source mixed with older Archaean crust.

The episodic Kararan Orogeny in the western and north western Gawler Craton, (1690 to 1670, 1650 and 1565 to 1540 Ma) has produced ductile gneisses of amphibolite facies to granulite facies metamorphism. In the central and eastern parts of the craton, major ductile shear zones were imposed on older rocks. It is highly likely the Kararan Orogeny has produced major structures into which the St Peters Suite, Gawler Range Volcanics and Hiltaba Suite were emplaced. If, within these areas, deformation is consistent across each domain, magnetic alteration and associated mineralisation sourced from Hiltaba Suite granite or the Gawler Range Volcanics will appear as ductile layering (Daly, *et al.,* 1998).

Major compressional deformation on the western Gawler Craton occurred again between ~1565 and 1540 Ma related to oblique transpression along major shear zones. Metasediments within the Coober Pedy Domain and Nawa Domain underwent ductile deformation at ~ 1565 and ~1550 Ma respectively (Daly *et al.,* 1998). High-grade metamorphism within the Fowler Domain is recorded by zircons from MESA DDH Nundroo 2, which have a U-Pb age of 1543±9 Ma (Fanning, 1997).

## Regional Tectonics

Previous tectonic interpretations of the Gawler Craton show a predominant Archaean basement with two major periods of Proterozoic deformation (Kimban Orogeny and Kararan Orogeny). One of the most recent advances in the understanding of the Gawler Craton has been the recognition that large parts of the south western Gawler

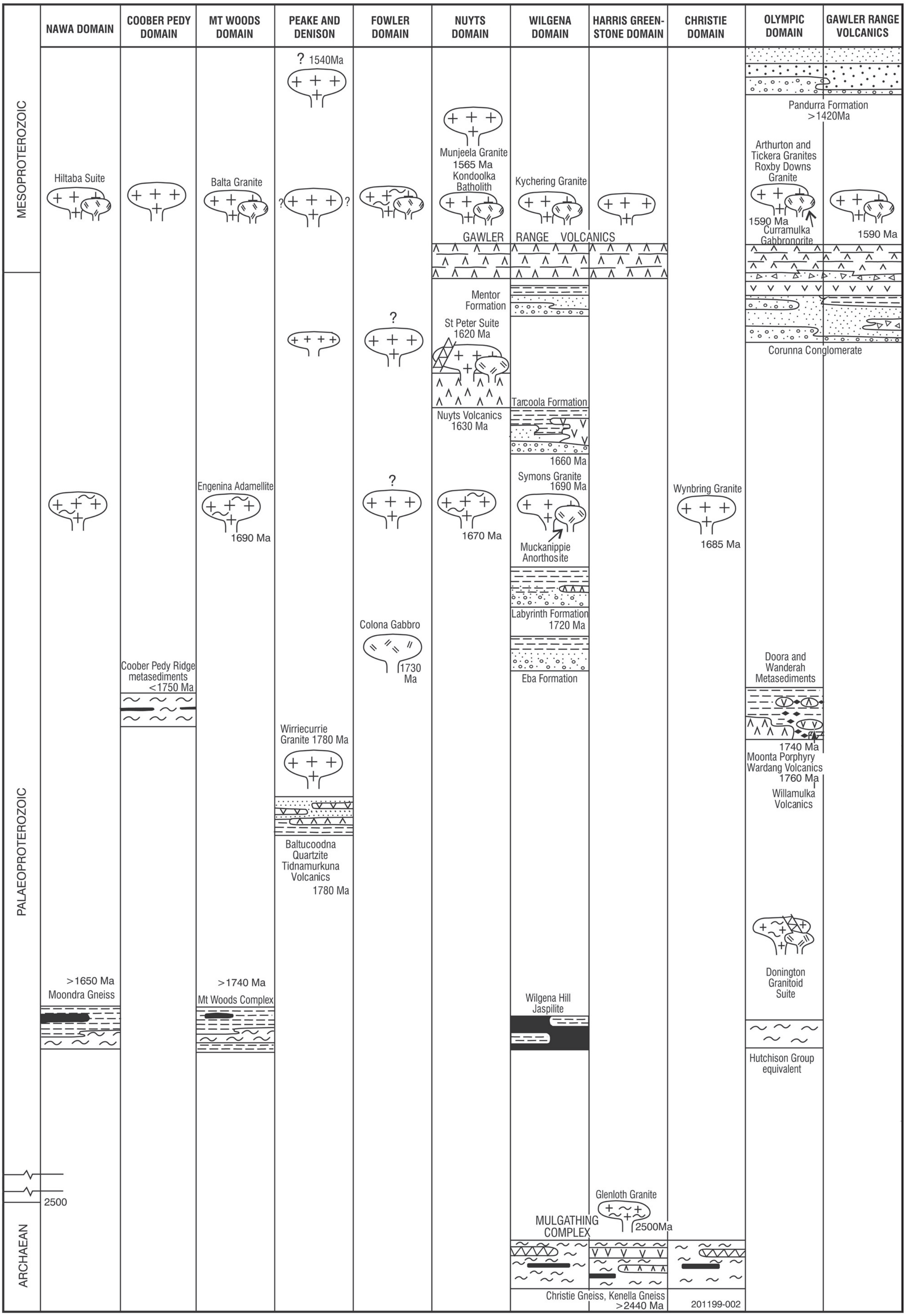



**Figure 3:** Strato-tectonic elements of the Gawler Craton (adapted from Daly *et al.*, 1998)

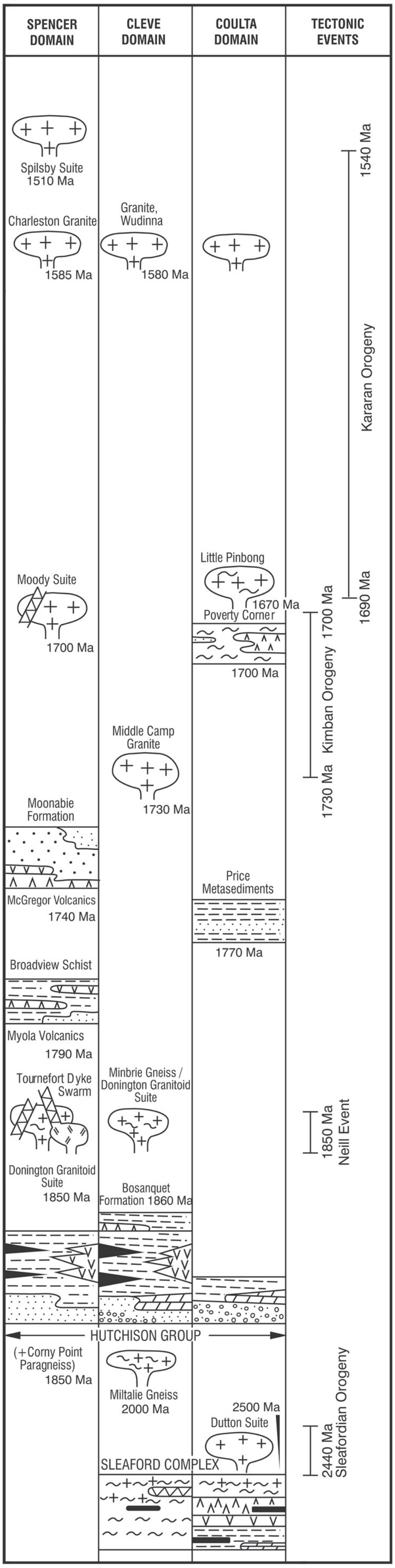
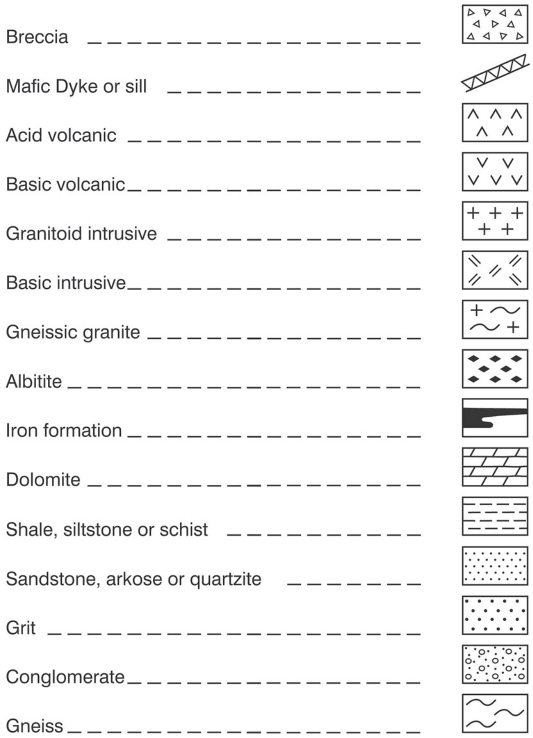



Figure 3: *continued*.




Craton comprise relatively juvenile crust (Ferris, 2001) added to the craton during the early stages (1630 to 1610 Ma) of the Kararan Orogeny. Fig. 1 shows an arcuate zone of known Archaean basement into which major pulses of Palaeo- to Mesoproterozoic igneous suites have been emplaced. Traditional models for crustal growth within the Gawler Craton have suggested growth dominantly through vertical accretion processes (e.g., Donington Granitoid Suite - Schaefer, 1998; Hiltaba Suite - Stewart *et al.*, 1999). In the light of recent information it appears that the tectonic evolution of the Gawler Craton may also be explained through accretion in a series of magmatic arc settings. This model is still at the speculative stage but the authors feel that it is useful to present these ideas to promote discussion and should only be considered as an alternative at this stage. The ideas are currently being investigated further and will be expanded upon in the near future (Ferris *et al.*, 2003; Schwarz *et al.*, 2002).

Recent updates to the interpreted sub-surface geology (Fig. 1) have led to the recognition of an arcuate Archaean core to the Gawler Craton. Various intrusive suites (e.g., Donington Granitoid Suite, Hiltaba Suite) and sedimentary basins (e.g., Hutchison Group Metasediments) form arcuate belts along the margins of the Archaean core suggesting lateral accretion.

The Archaean core contains an arcuate belt of Hutchison Group metasediments on it's eastern margin. This sequence comprises a basal quartzite overlain by a series of clastic and chemical sediments, with interlayered basaltic material. The sequence is interpreted to have been deposited onto a composite Archaean-Proterozoic continent (Sleaford Complex and Miltalie Gneiss), within a passive margin, continental shelf environment, deepening to the east (Daly *et al.*, 1998). We speculate the Hutchison Group was deformed during the Neill Event at 1850 Ma during the initiation of east dipping subduction and collision between the Gawler and an unknown craton fragment to the east (perhaps basement to the Curnamona Craton; Schwarz *et al.,* 2002).

The Donington Granitoid Suite forms a regionally extensive linear to arcuate belt on the eastern margin of the Gawler Craton, extending from southern Eyre Peninsula, Yorke Peninsula, north to the Olympic Dam region. Previous interpretations for emplacement of the Donington Granitoid Suite have proposed generation within a rift environment via mafic under-plating of the crust (Schaefer, 1998). Several characteristics have been used to support this interpretation; the system has overall chemical and isotopic homogeneity, the suite was emplaced during a relatively restricted time frame, in the order of ~10 Ma and the range of initial $\varepsilon_{Nd}$ values are relatively restricted between -2.1 to -4.2 (Schaefer, 1998). However, geochemical and isotopic data from the Donington Granitoid Suite and associated mafic rocks is somewhat equivocal, and do not preclude having formed in an active continental margin or alternatively from partial melting of arc-type under-plates or intrusions. The coincidence of deformation during the Neill Event and emplacement of the Donington Granitoid Suite suggests a convergent tectonic setting at the time of emplacement. Potentially, the Donington Granitoid Suite either, directly marks the existence of a magmatic arc that developed along the margin of the Archaean-Palaeoproterozoic continent, or may have been produced in a back arc environment and then accreted onto the eastern margin of the Gawler Craton during the Kimban Orogeny. Following accretion of the Donington Granitoid Suite, a transition to transpressional convergence resulted in the development of the Kalinjala Mylonite Zone during the Kimban Orogeny between ~1730 and 1700 Ma.

The previously interpreted Ifould Complex, now Ifould Suite (see Kararan Orogeny) was thought to have formed during continental collision within the Fowler Orogenic Zone, producing major crustal thickening, which resulted in the formation of a crustal suite of granites between 1690 and 1670 Ma (Teasdale, 1997). However within the Yarlbrinda Shear Zone, these granites are termed

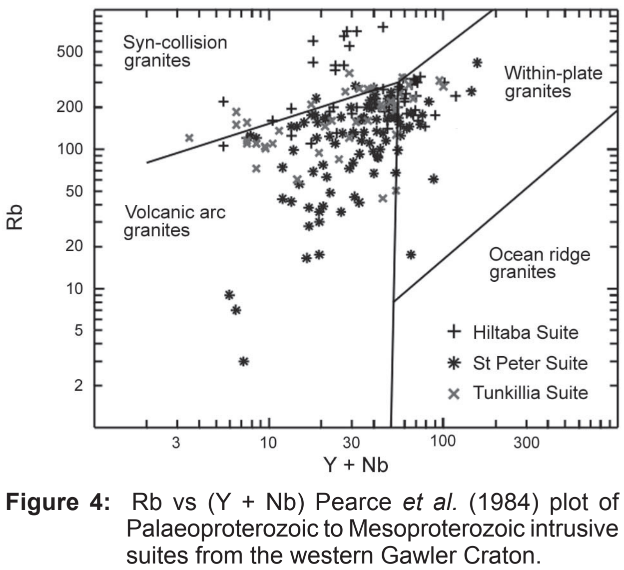



**Figure 4:** Rb vs (Y + Nb) Pearce *et al.* (1984) plot of Palaeoproterozoic to Mesoproterozoic intrusive suites from the western Gawler Craton.

the Tunkillia Suite and have a geochemical signature consistent with a volcanic arc environment (Fig. 4). The Tunkillia Suite and equivalents are predominantly felsic with minor mafic dykes, but the full extent of this magmatic event is still unknown. At approximately 1630 Ma, the St Peter Suite, a suite of tonalitic to granodioritic rocks, similar in chemistry to Archaean tonalite-trondhjemite-granodiorites, was emplaced within the Nuyts Domain. As with the Tunkillia Suite, the St Peters Suite has a geochemical signature consistent with emplacement in a volcanic arc setting. Alternatively continental extension between ~1640 and 1630 Ma could have resulted in mantle under-plating, producing arc-like chemical signatures in the Tunkillia and St Peters Suites.

Both the Tunkillia Suite and St Peters Suite may have been emplaced in a magmatic arc setting on the south western margin of the arcuate Archaean core during north east dipping subduction. This represents a switch from subduction related convergence on the eastern margin of the Craton to the south western margin coincident with the end of the Kimban Orogeny in the east and onset of the Kararan Orogeny in the west.

Traditionally the formation of Hiltaba Suite/Gawler Range Volcanic magmatic event (~1595 to 1575) Ma has been attributed to development of a mantle plume within an anorogenic, intracontinental environment (Creaser, 1989, Flint, 1993, Stewart and Foden, 2001). An anorogenic interpretation applied because the Hiltaba Suite was thought to be undeformed and contain relatively homogeneous geochemistry across the Craton. However, evidence from the western Gawler Craton shows the Hiltaba Suite ranges from syn-tectonic, within the Yerda Shear Zone to post-tectonic massive, coarse-grained granite. Therefore at least some of the Hiltaba Suite was contemporaneous with activation of crustal scale shear zones. Sm-Nd isotope analysis shows the Hiltaba Suite changes its isotopic characteristics from the western Gawler Craton, where it records juvenile basement rocks, to the eastern Gawler Craton, where it records Archaean to Palaeoproterozoic crust within the Moonta-Wallaroo and Stuart Shelf regions of the eastern Gawler Craton (Stewart and Foden, 2001).

The eastern Gawler Craton has similarities with the Phanerozoic Coastal belt in Chile. Hitzman (2000) describes iron-oxide copper-gold deposits within the Mesozoic of northern Chile and southern Peru, which were formed within a volcanic arc extensional environment.

A possible tectonic setting at the time of the Hiltaba Suite magmatic event may be related to the previously proposed northeast dipping subduction zone located south west of the Nuyts Domain, which produced a major suite of arc-related magmatism at ~1620 Ma (St Peter Suite). Potentially, a period of subduction related transpression followed resulting in the Hiltaba Suite being emplaced within a back-arc, intra-continental environment. The Hiltaba Suite granites, which form a convex plutonic belt located close the margin of the Nuyts Domain (and St Peters Suite), record positive $\varepsilon_{Nd}$ values. This indicates a juvenile source for the western belt of Hiltaba Suite plutons (Fig. 1), possibly related to basaltic under-plating of the subducting slab, at the base of the crust, during subduction. The eastern belt of Hiltaba Suite plutons, in the Olympic Domain, have $\varepsilon_{Nd}$ values suggesting derivation from pre-existing older crust. Back-arc environments are characterised by crustal thinning, which results in increased geothermal gradients. The eastern belt may therefore have formed in an extensional back arc environment. Large linear strike-slip structures (Reynolds, 2000) were active at this time along the eastern part of the Gawler Craton providing fluid pathways for deep seated hydrothermal fluids, as well as allowing surface waters to penetrate below the surface providing a suitable environment for fluid mixing. This is consistent with models for the formation of the Olympic Dam deposit which are discussed in Part II (Skirrow *et al*., This Volume).

## Relationship of the Hiltaba Suite to Copper-Gold Mineralisation and Regional Alteration

The Hiltaba Suite is a variable suite of granitoids, which range in composition from granite (*s.s*) to granodiorite. Texturally the Hiltaba Suite ranges from high-level, sub-volcanic, porphyritic granite, to microgranite, to medium to coarse-grained equigranular granite. The Hiltaba Suite shows considerable geochemical variation both within individual plutons and between plutons. This variability is also reflected in the Sm-Nd isotopes which show a range of values from $\varepsilon_{Nd}$ of -12.67 to 2.78 (Stewart and Foden, 2001). Table 1 outlines the characteristics of selected Hiltaba Suite granites on the Gawler Craton.

The Hiltaba Suite is typically K-feldspar dominant and is pink to red in colour due to disseminated hematite in feldspar. The suite is dominantly felsic and $SiO_2$ ranges from 54 to 81 wt %. Drill holes in the Olympic Dam and Andamooka areas intersect mafic lithologies, including hornblende bearing monzodiorite, quartz monzonite and quartz syenite (Creaser, 1989). The Hiltaba Suite is dominantly oxidised (Fig. 5). Major elements show calc alkaline trends with decreasing $Al_2O_3$, $Fe_2O_3$, $TiO_2$, MgO, CaO and $P_2O_5$ with increasing $SiO_2$. $K_2O$ and $Na_2O$ show a general increase with increasing $SiO_2$. The Hiltaba Suite is enriched in Rb, Y, Zr, Th and U and depleted in Ba and Sr. Stewart and Foden (2001) report increasing Rb/Ba ratios with increasing $SiO_2$, indicating fractionation of K-feldspar. Chondrite normalised REE plots for the Hiltaba Suite show similar REE patterns; steep LREE patterns, significant negative Eu anomalies and relatively flat HREE patterns (Ferris, 2001; Stewart and Foden, 2001). The Hiltaba Suite plots predominantly within the A-type field on Ga/Al plots (Whalen *et al*., 1987).

The age of the Hiltaba Suite ranges from ~1600 to 1575 Ma, based on U-Pb zircon analysis. Rb-Sr analysis show ages which are approximately 100 m.y. too young, probably reflecting resetting of the isotopic system during later thermal perturbation (Table 1). Fig. 1 shows the interpreted sub-surface extent of the Hiltaba Suite on the Gawler Craton, which appears to form clusters of discrete igneous centres and ongoing collaborative research between PIRSA and Geoscience Australia (formerly AGSO) is aimed at determining the geochemical characteristics and mineral potential of these discrete centres. Emplacement of the Roxby Downs Granite and the formation of the Olympic Dam Breccia Complex overlap at ~1590 Ma. U-Pb zircon geochronology constrains the date of the Roxby Downs Granite and surrounding granites between 1592±8 and 1588±4 Ma (Cooper *et al*., 1988; Creaser, 1989; Creaser and Cooper 1993). The breccia complex was formed at ~1590 Ma, hence its formation and emplacement of the Hiltaba Suite appear intimately linked. The source of metals at Olympic Dam remains a point of contention. Johnson and Cross (1991) report Sm-Nd isotope data which show a primitive Nd component, suggesting that the mantle was the source of ore fluids. Alternatively, Knutson *et al*. (1992) report that Mesoproterozoic basalts are a possible source of copper for the Olympic Domain deposits.

Budd *et al.* (1998) divided the Hiltaba Suite into two distinct suites, the "Olympic Dam and Kokatha suites" and reported a broad spatial correlation of these types of granites with different mineralising systems. The Olympic Dam Suite are strongly fractionated and oxidised, and are related to copper-gold systems on the eastern Gawler Craton. The Kokatha suite are less fractionated and are generally related to gold, silver and base metal systems (Budd *et al*., 1998). Fig. 5 shows that the Hiltaba Suite within the Moonta-Wallaroo and Olympic Dam areas, together with granites from the Williams and Naraku Batholiths (of the Mount Isa Inlier, which are linked to copper-gold mineralisation at Ernest Henry and Osborne), are oxidised to strongly oxidised. Only a small number of Hiltaba Suite samples plot within the reduced fields. Wyborn (1992, 1998) reports the Hiltaba Suite is geochemically similar to the Williams and Naraku Batholiths. Wyborn (2001) termed these granites the "Hiltaba Association" and suggests a spatial relationship between these granites and copper-gold mineralisation.

The role of magmatic fluids in the genesis of iron-oxide copper-gold deposits remains ambiguous, with many researchers favouring an orthomagmatic origin, while

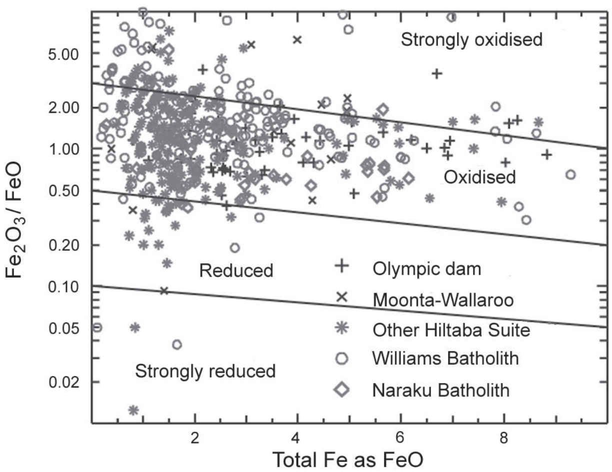



**Figure 5:** Redox plot of Champion and Heinemann (1994) showing Hiltaba Suite and granites from the Williams and Naraku Batholiths from the Mount Isa Inlier.

**Table 1:** Summary characteristics of the Hiltaba Suite granite from the Gawler Craton (Flint, 1993).

| Unit | Lithology | Petrography | Relationships and extent | Geochronology |
|---|---|---|---|---|
| **Charleston Granite** | Homogeneous, coarse-grained, megacrystic granite. | Large K-feldspar phenocrysts (30-40%), greenish plagioclase (10-15%), quartz and biotite. Zoned feldspar phenocrysts. | Intrudes McGregor Volcanics and Corunna Conglomerate as indicated By local hornfelsing, epidotisation and quartz-epidote veins within 10 m of the granite contact (Miles, 1954; Smale, 1966; Giles *et al*., 1980). Forms discrete pluton 20x15 km. | **~1576 Ma** (U-Pb zircon: Fanning *et al*.,1988); **1585±5 Ma** (u-Pb zircon: Creaser and Fanning, in press); **1556±30 Ma** (Rb-Sr:Crompston *et al*., 1966); **1445±39 Ma** (Rb-Sr; Webb *et al*.,1986); **1568, 1567, 1532 Ma** (K-Ar Biotite: Webb *et al*., 1986). |
| **Granite, 'Hiltaba'** | Homogenous, coarse-grained, red granite. | Dominantly graphic quartz and perthitic orthoclase, lesser plagioclase and chloritised biotite. Fluorite is a common accessory. Feldspars are intensely reddened. | Intrudes Yardea Dacite (Blissett and Thomson, 1978). Forms several Plutons in a zone 70x20 km. | **$1514^{+32}_{-24}$ Ma** (U-Pb zircon: Cooper *et al*. 1985); **1581±16 Ma** (Reinterpretation: Creaser and Cooper, 1993); **1478±38 Ma** (Rb-Sr: Webb *et al*., 1986); **1508,1361 Ma** (K-Ar biotite: Webb *et al*., 1982). |
| **Granite, 'Kokatha'** | Leucocratic pink, medium to coarse-grained granite to adamellite, including some porphyritic varieties. | Dominantly graphic quartz and K-feldspar; also plagioclase, interstitial hornblende and biotite. Accessory minerals include apatite and fluorite | Intrudes Chitanilga Volcanic Complex, forming several plutons in A zone 30x10 km. Also includes granitic exposures in an area 70x30 km west of Lake Everard. | **1478±38 Ma** (Rb-Sr isochron pooled with granite at 'Hiltaba': Webb *et al*., 1986). |
| **Wirrda Subsuite, OlympicDam** (Creaser, 1989) | Bimodal suite of medium-grained and porphyritic rock types including quartz monzo-diorite, quartz monzonite, syenite and aplite (eg. drill-holes PD 3, RD 80, 87, 161, WRD 3, BLD 2). | Mafic varieties consist mainly of plagioclase with lesser quartz and K-feldspar; mafic minerals include augite, hornblende and biotite. Apatite and zircon are common accessories. Granites are leucocratic, though containing hornblende, biotite and magnetite. Fluorite is common. | Dykes of porphyritic granite intrude acid volcanics at acropolis prospect. | **$1613^{+20}_{-19}$, 1606±7**, **$1590^{+5}_{-4}$ Ma,** (U-Pb zircon: Mortimer, Cooper *et al*., 1988); **1598±2**, **$1590^{+5}_{-4}$**, **1593±4**, **1593±2 Ma** (U-Pb zircon: Creaser & Cooper, 1993). |
| **Roxby Downs Granite** | Coarse-grained (**<**20 mm) equigranular to porphyritic Syenogranite. | Modal composition of 50% alkali feldspar, 20-25% quartz, 20-25% plagioclase, 5-8% amphibole and biotite (halogen-rich <2wt% F, 2wt% Cl). Accessory magnetite, fluorite, sphene, uranothorite. | Hosts the mineralised breccias of the Olympic Dam Cu-U-Au deposit. | **1588±4 Ma**(U-Pb zircon: Creaser and Cooper, 1993). |
| **White Dam Subsuite, Andamooka** (Creaser, 1989) | Variety of rock types including quartz monzodiorite, quartz monzonite and aplite (eg. drillholes OFD 1-3). | | Restricted to the subsurface. | **1590±10 Ma** (U-Pb zircon: Creaser and Cooper, 1993). |
| **Granitoids Kingoonya** | Bimodal suite of fine to coarse-grained and porphyritic Granite (high $SiO_2$) and syenite to granodiorite (low $SiO_2$). | Granites consist of perthitic orthoclase and microcline phenocrysts in a matrix of graphic quartz and K-feldspar,plagioclase, and minor biotite and muscovite. Syenite contains orthoclase and hornblende. | Microgranite intrudes Tarcoola Formation, forming abundant quartz-muscovite ± fluorite ± topaz greisen. Restricted to the Lake Labyrinth area (Cowley and Martin, 1990). | |
| **Balta Granite** | Even-grained and porphyritic granite and adamellite, brick-red granite, hybrid granite and (?) diorite. | Brick-red granite characterised by high (~60%) microcline content. Hybrid granite contains hornblende and scapolite, feldspar megacrysts and quartz-feldspar xenoliths. Diorite mineralogy includes olivine, hypersthene, clinopyroxene and calcic plagioclase. | Intrudes Palaeoproterozoic Granulites and gneisses, forming several small, discrete plutons; Mt Woods Inlier. | **~1550-1450 Ma** (Rb-Sr: Ambrose and Flint, 1981b). |
| **Granite, Tarcoola** | Coarse-grained (~5 mm) red granite and adamellite in Tarcoola DDH 1-3. | Microcline is fresh, plagioclase is heavily sericitised, quartz exhibits strong undulose extinction and sutured grain boundaries. High chlorite content (10-15%). Accessories include apatite, fluorite and sulphides. | Pluton 20x5 km intrudes Tarcoola Formation just west of Tarcoola. Relationships to numerous other Hiltaba Suite granites in the region are not known (Daly, 1985). | **1474±45 Ma** (Rb-Sr: Webb *et al*., 1986). |
| **Granite, Kychering Rockhole** | Medium-grained pinkish granite, adamellite and granodiorite. | Granodiorite is plagioclase-rich (<50%) with high muscovite (<5%) and absence of biotite. Adamellite & granite contain perthitic microcline, quartz, plagioclase and minor biotite. | Discrete plutons at least 10x5 km intrude Tarcoola Formation near Kychering Rockhole (Daly, 1985). | **1475±45 Ma** (Rb-Sr: Webb *et al*., 1986). |
| **Calca Granite** | Distinctive, red, coarse-grained granite. | Very high content of perthitic orthoclase and microcline (50-75%) and low plagioclase (<5%). Characterised by abundant, very fine-grained haematite. | Relationship to Blue Range Beds not exposed. Occurs on Flinders and Waldegrave Islands in the Investigator Group, and in the Calca-Colley Hill area (50x20 km). | **1456±26 Ma** (Rb-Sr: Webb *et al*., 1986). |
| **Granites, Minnipa, Wudinna, Buckleboo** | Pinkish, coarse-grained granite-adamellite, minor porphyritic varieties and minor aplite dykes. | Perthitic K-feldspar crystals range up to 20 mm, with interstitial plagioclase, quartz and biotite. Pyrite is a common accessory. | Occurs as inselbergs and discrete plutons on central Eyre Peninsula and intrude GRV. | **1519±67 Ma**, Wudinna 1 (Rb-Sr: Webb *et al*., 1986); **1477±34 Ma**, Minnipa and Buckleboo (Rb-Sr: Webb *et al*., 1986). |
| **Granite, 'Cultana'** | Red, coarse grained granite. | Dominantly feldspar (~60-70%) and quartz (~30%), but with tourmaline common (<5%). | Considered intrusive into porphyritic rhyolite along western side of Cultana Inlier. | Disturbed U-Pb systematics. |
| **Tickera Granite** | Coarse-grained granite-adamellite. | Equal proportions of microcline, Plagioclase and quartz, with minor Biotite and opaques. | Intrudes Doora Schist. Exposed along coast north of Point Riley. | **1215±554 Ma**, IR=0.7357 (Rb-Sr: Webb *et al*., 1986). |
| **Adamellite, Moonta** | Coarse-grained granite, adamellite and granodiorite. | Varying proportions of quartz, K-feldspar and plagioclase. High chloritised biotite content (7-10%) opaques (2-3%), and accessory apatite and fluorite. | Occurs at least in drillholes WMC DDH 33, 57, 103, 147, 221; full lateral extent unknown. Equivalents include Arthurton Granite. | **1583±7 Ma** (U-Pb zircon from WMC DDH 33: Creaser and Cooper, 1993); **1282±179 Ma** (Rb-Sr: Webb *et al*., 1986); **1251, 1505 Ma** (K-Ar biotite: **Webb *et al*., 1986).** |

others report the dominant factor is basinal brines, particularly saline evaporitic basins, or a combination of the two. The orthomagmatic origin for hydrothermal fluids and derivation of some or all of the metals from granites is favoured by Hitzman *et al*. (1992), Pollard *et al*. (1997, 1998), Williams (1998), Menard (1995) and Lindblom *et al*. (1996), or from mafic magmas with alkaline affinity (Johnson and Cross, 1991). Hildebrande (1986) reports that iron oxide copper-gold districts in Scandinavia, and the Great Bear Magmatic Zone in northwest Canada, are closely related to mafic to intermediate intrusions. Menard (1995) reports that iron-oxide copper-gold deposits within the Chilean Iron Belt are closely associated with intermediate intrusives emplaced within an extensional (island arc) setting. Hitzman *et al*. (1992) described iron-oxide copper-gold deposits as expressions of deeper seated, volatile rich igneous hydrothermal systems, with numerous stable isotope studies suggesting a dominantly magmatic source for the hydrothermal fluidsand sulphur.

Barton and Johnson (2000) report the variability of iron-oxide copper-gold deposits cannot be produced by a single model. Table 1 in Barton and Johnson (2000) describes the geological characteristics of a range of deposits from interpreted fluid sources including magmatic, coeval brines, older brines/evaporites and hybrid systems. All groups are believed to source fluids and metals from igneous rocks.

Iron-oxide copper-gold deposits tend to occur within districts (ie: eastern Gawler Craton, Cloncurry, Chilean Iron Belt), and these districts also contain suites of 'late' oxidised granites (eg: Hiltaba Suite on the Gawler Craton and the Williams and Naraku Batholiths at Cloncurry). Davidson and Large (1994) report that major copper-gold mineralisation within Australian copper-gold provinces are correlated with emplacement of regional granites (Fig. 6). The Olympic Dam copper-uranium-gold-silver deposit is hosted within the Roxby Downs Granite, a member of the Hiltaba Suite, but other deposits within the Olympic Domain are hosted in older granitoids and volcanic units. Reynolds (2000) reports that the formation of the Olympic Dam deposit is related to the Hiltaba Suite magmatic event, with the granites and ultramafic and mafic magma, supplying both the hydrothermal fluids and metals. Sulphur isotopes and fluid inclusion data supports a magmatic source (Reynolds, 2000). However, similar granites are located within areas of no iron-oxide copper-gold mineralisation/alteration. These oxidised suites of granite do not appear to represent the dominant, controlling factor on the location of iron-oxide copper-gold provinces. On the Gawler Craton, the Hiltaba Suite is widespread (Figs. 2 and 3), but iron-oxide copper-gold deposits are dominantly located along the eastern part of the Craton. This may reflect deeper crustal fractures, focussing mafic and ultramafic mantle fluids. The more mafic Hiltaba Suite at Olympic Dam indicates a greater mantle component.

Pollard (2000) reports that meta-igneous rocks, which are the source of many granitoids linked to iron-oxide copper-gold deposits, require high temperatures to initiate partial melting. The higher temperatures increase the solubilities of refractory minerals including iron-titanium phases and zircon, hence leading to enrichment of titanium,

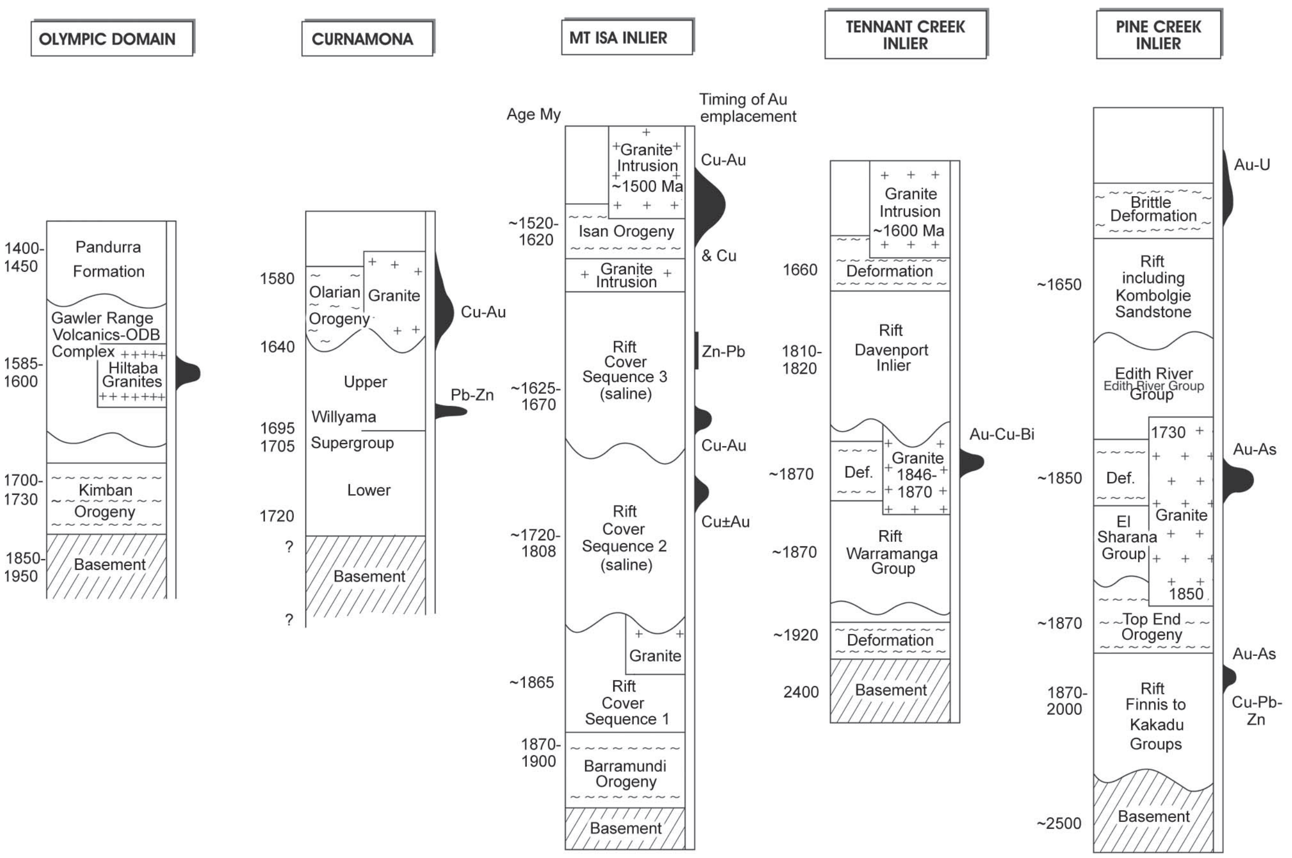



**Figure 6:** Correlation of Cu-Au mineralisation with regional granite suites, within major Cu-Au provinces in Australia (after Davidson and Large, 1994; Skirrow *et al.*, 2000; Teale and Fanning, 2000).

zirconium, uranium and REE (Pollard, 2000). The different mineralising systems reported on the eastern Gawler Craton may reflect a difference in source rocks, or even more importantly, variations in depth of formation and degree of fractionation.

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