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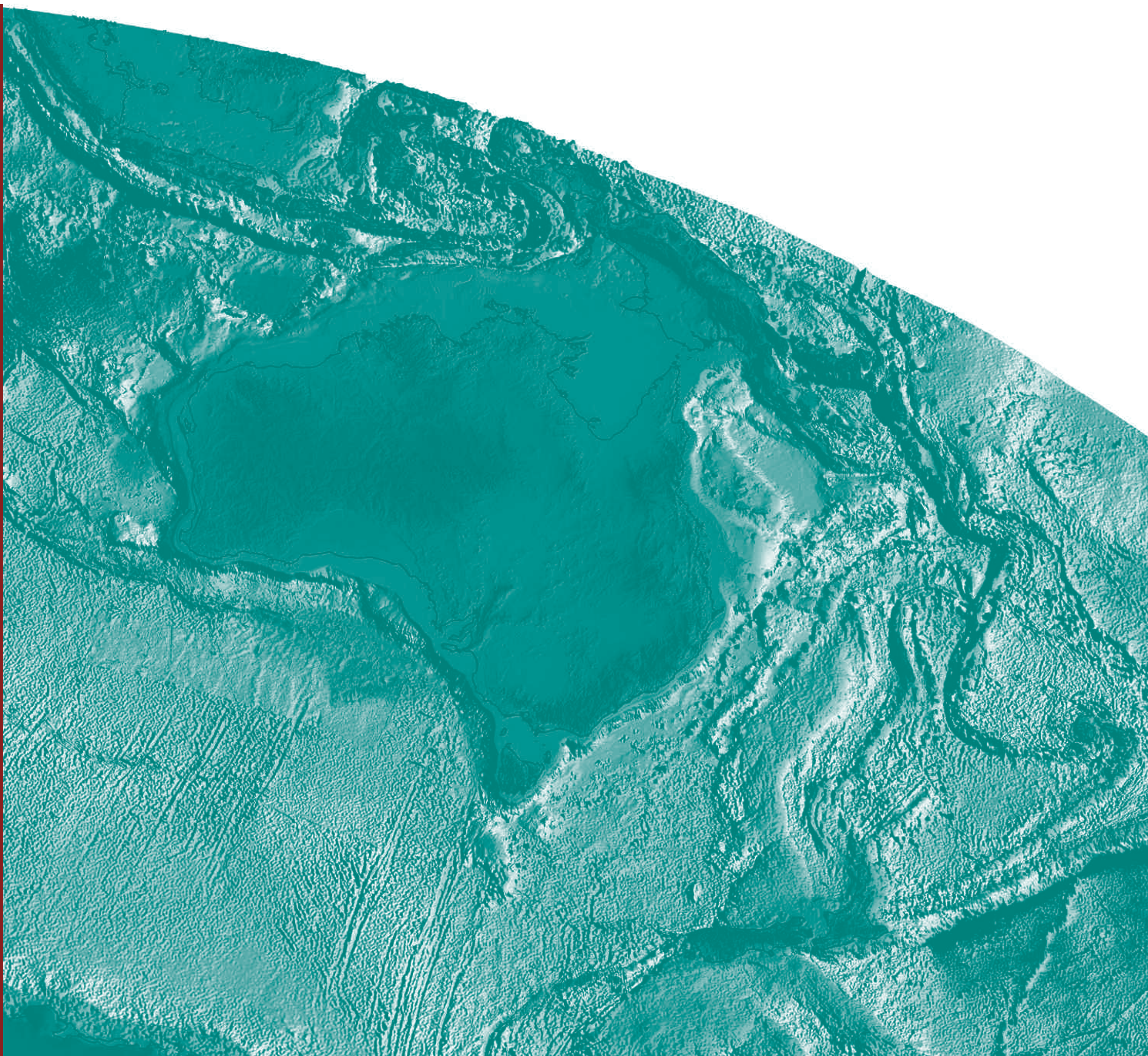
Gawler Craton Mineral Promotion Project Plan

2000-2004

Roger G. Skirrow

Record

2005/16



SPATIAL INFORMATION FOR THE NATION

Gawler Craton
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by

Roger G. Skirrow

Australian Government
Geoscience Australia

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Abstract

The Gawler Craton Mineral Promotion Project commenced in July 2000 and will conclude in December 2005. The project is one of several under the auspices of the National Geoscience Agreement, between Geoscience Australia and Primary Industries and Resources South Australia (PIRSA). This Plan for the Gawler Craton Project was written in 2000 for a planned four year project.

The project consists of four integrated modules:

A. Framework for discovery of Proterozoic Cu and Au in the eastern and central Gawler Craton
B. Regional controls on gold systems in the Archaean Mulgathing Complex
C. Ni-Cu potential of the Archaean Harris Greenstone Belt
D. Recognition of gold and base metal ore-forming systems through the regolith

This multidisciplinary project involves production of new geological, geophysical, geochemical and metallogenic datasets in targeted regions of the Gawler Craton. The planned outcomes are greater exploration investment in the Gawler Craton and enhanced mineral exploration strategies in area selection and targeting. Results are available on the project website:
http://www.ga.gov.au/minerals/research/regional/gawler/gawler.jsp

Exploring an obscured craton

GAWLER CRATON OVERVIEW

The Gawler Craton has been defined as that region of South Australia where Archaean to Mesoproterozoic crystalline basement has undergone no substantial deformation (except minor brittle faulting) since 1450 Ma (Figure 1; Thomson, 1975; Parker, 1993; Daly et al, 1998). The eastern and southeastern boundaries conventionally are defined by the Torrens Hinge Zone (THZ), although Gawler Craton basement that was deformed during the Delamerian Orogeny is known to the east of the THZ (eg Barossa Complex, Peake and Denison Inliers). The southern boundary corresponds to the inboard edge of the continental shelf. The Gawler Craton and the East Antarctic Craton are rifted segments of the Mawson Continent (Fanning et al, 1995). Western, northwestern and northern boundaries of the Gawler Craton are defined by the faulted margins of thick Neoproterozoic and younger basins.

As a consequence of the extensive surficial and sedimentary basin cover, the level of understanding of the craton's geology and prospectivity are limited in comparison with most other Australian Archaean and Proterozoic cratons. Application of high-resolution regional aeromagnetic surveying during the mid-1990s (South Australian Exploration Initiative - SAEI), for the first time allowed an integrated interpretation and synthesis of the geology of the craton (Fairclough and Daly, 1995a; Fairclough and Daly, 1995b; Schwarz, 1996). A revised interpretation of the tectonic evolution of the Gawler Craton incorporating SHRIMP U-Pb geochronology, was presented by Daly et al (1998). Three principal orogenies have been proposed: The Sleafordian Orogeny (peak metamorphism at ~2420-2440 Ma), the Kimban Orogeny (KD1-KD2-KD3: 1845-1700 Ma), and the Kararan Orogeny (~1650 Ma and 1565-1540 Ma). It has been suggested that the Kararan Orogeny in the western and northern Gawler Craton represents the continental collision of the 'eastern proto-Yilgarn' and the Mawson Continent (Daly et al, 1998). The geodynamic significance of the Sleafordian and Kimban Orogenies is unclear. Subdivision of the Gawler Craton into tectonic domains has evolved as further information has become available (Figure 1; eg Parker, 1993; Flint and Parker, 1982; Drexel et al, 1993; Teasdale, 1997). In general the definition and nature of the domain boundaries are not well understood - addressing this problem is a key objective of the Gawler Craton Project. The resultant framework will be important for assessing prospectivity because the ore-forming systems are products of crustal-scale processes that may vary between tectonic domains.

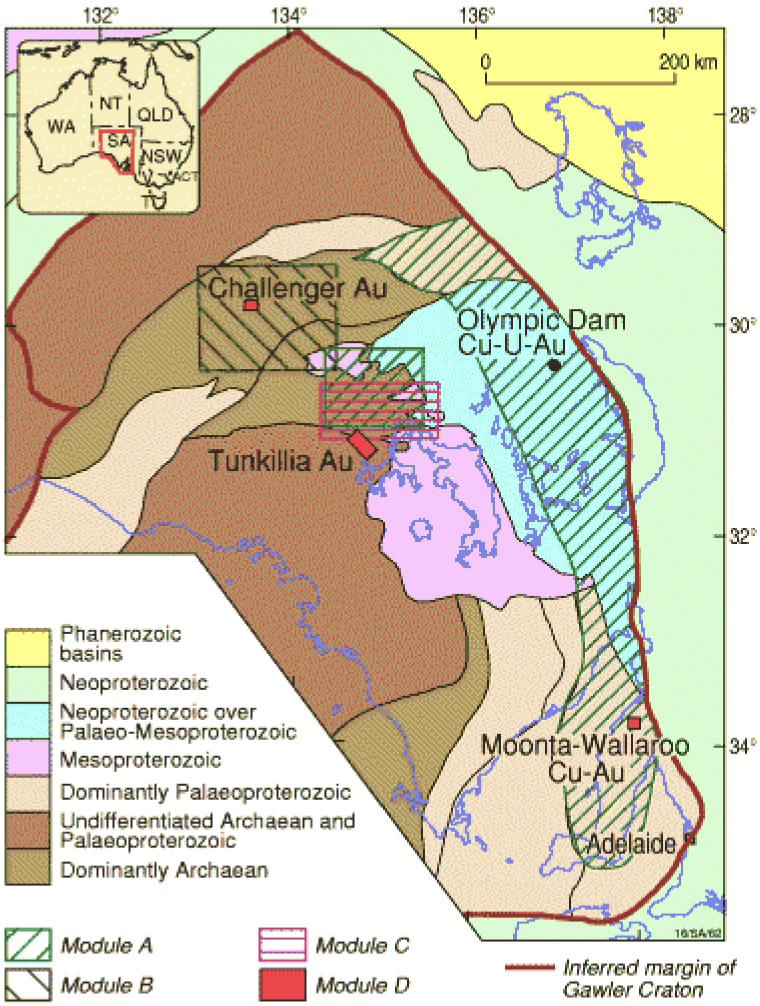

Figure 1: *Tectonic domains of the Gawler Craton, showing project modules.*

THE CHALLENGE TO EXPLORATION

Release of the SAEI data resulted in a boom in exploration licence uptake and expenditure during the mid-1990s. Discoveries of anomalous gold followed in the central Gawler Craton (eg Tunkillia, Myall-Sheoak, Barns), and northwest Gawler Craton (eg Challenger, Gulf Bore, ET), using the improved aeromagnetic coverage (among other datasets) for area selection, and calcrete geochemical sampling as one of the principal targeting tools. However, the Challenger gold prospect is the only economically significant mineralisation identified from this phase of exploration (currently undergoing a feasibility study). Testing of some of the major magnetic-gravity anomalies with characteristics believed to be similar to those of Olympic Dam or Ernest Henry has also met with limited success. Momentum in exploration of the Gawler Craton slowed in the late 1990s, reflecting both the difficulties in exploring this region and the global downturn in exploration activity. New insights into ore-forming systems of the Gawler Craton are required if there is to be a reversal of this trend.

The lack of discoveries since Olympic Dam in 1975 of world-class economic metallic mineral deposits in the Gawler Craton is the result of impediments which may include:

1. Areal extent and depth of cover rocks and sediments over Precambrian basement

2. Problems in application of exploration geochemistry in areas of deep cover
3. Limited understanding of the regional geological and tectonic framework
4. Restricted predictive capability of exploration and genetic models, due to limited understanding of Fe-oxide Cu-Au systems, Archaean Au systems and other ore-forming systems in the Gawler Craton
5. Access to ground for exploration (cultural, geographic, environmental factors)
6. Limited infrastructure

A New Geological Framework for Exploration

THE GEOSCIENCE AUSTRALIA-PIRSA GAWLER CRATON PROJECT

Primary Industries and Resource South Australia (PIRSA) have been addressing aspects of impediments 1, 2 and 3 through regional mapping programs and acquisition of regional geophysical data over the past several decades. A number of government initiatives are in place that will have impact on the last two impediments (eg SA Government Resources Task Force program).

Through the new Gawler Craton Project, Geoscience Australia and PIRSA are contributing to reducing the geological impediments 1-4. The project consists of four integrated modules (see Figure 1):

Module:

A. Framework for discovery of Proterozoic Cu-Au in the eastern and central Gawler Craton
B. Regional controls on gold systems in the Archaean Mulgathing Complex
C. Ni-Cu potential of the Archaean Harris Greenstone Belt
D. Recognition of gold and base metal ore-forming systems through the regolith

Impediments 2 and 3 exist largely due to the extensive cover, although there are vast areas of the craton where the depth of cover is <100 m. The Gawler Craton Project has embarked on a program of regolith studies in collaboration with Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) that will assist exploration companies in the recognition of ore-forming systems through in-situ and transported regolith. The program, described in Module D, includes acquisition of airborne electromagnetic (AEM) data, drilling and groundwater geochemistry.

An improved regional geological and tectonic framework is being developed in the Gawler Craton Project through a series of integrated geophysical, geological and geochronological studies, initially within Module areas. As this understanding advances, the framework will be developed at craton-scale. For example, within Module B, regional gravity and Ar-Ar geochronological data are being acquired concurrently with a new solid geology interpretation, to develop a model of crustal architecture and evolution in the northwestern Gawler Craton. Similarly, in the Olympic Cu-Au province (Module A), seismic reflection data (program planned for 2002) and interpretations based on gravity, magnetic and geological data, will provide insights into the crustal architecture along the eastern margin of the Gawler Craton.

A major impediment to exploration, that of limited predictive capability of ore system models, is a key aspect of all modules in the Gawler Craton Project. A new generation of discoveries of major metallic deposits in the Gawler Craton will most likely be dependant on a major advance in our understanding of the regional-scale factors and processes that are critical in formation of the deposits. Application of new geophysical and geochemical technologies will be most effective when combined with this advanced understanding of the ore-forming systems.

ORE-FORMING (MINERAL) SYSTEMS: AN INTEGRATED, PREDICTIVE APPROACH

Feedback from AMIRA-sponsored meetings of explorationists over the past 1-3 years indicates that industry places high priority on (i) development of integrated, predictive models of ore-forming systems, and (ii) understanding ore signatures through and within the regolith. Geoscience Australia and PIRSA are well placed to deliver such information via the approach outlined below through utilising the specialised resources of each organisation.

The term ore-forming system is used here in preference to 'mineral system' (Wyborn et al, 1994) as the former emphasises our focus on economic mineralisation, and most importantly on systems producing world class or giant ore deposits. An ore-forming system comprises all those geological-geochemical-geophysical attributes and processes at regional/craton-scale to deposit-scale that resulted in economic mineralisation and its post-depositional modification. One system may produce many deposits of different types or a single deposit. The aim of characterising and reconstructing the ore-forming systems is to build a set of validated criteria for the exploration industry to apply in area selection, so that the geological risk is reduced in locating undiscovered resources. By defining not only the 'essential ingredients' of the system but also the actual distribution of these geological elements in space and time (eg in 2-D, 3-D or 4-D models), ultimately we may be able to extrapolate or interpolate from the relatively well-known to the less-known, eg in areas of covered basement. A proviso is that information on the presence of the most important components of the system must be available for the less-known areas in order to make useful predictions ('mappable criteria'; see below). Although potential deposit types may differ from the known deposits, each will be the product of fundamentally the same ore-forming systems. It is this capability of the whole-of-system approach that makes it a more powerful predictive method in poorly-exposed terranes such as the Gawler Craton than empirically exploring for analogues of a given mineral deposit type.

Based on the source-transport-trap-preservation paradigm, key components in building models of hydrothermal ore-forming systems with predictive capability are:

A. The thermal structure of the system during ore formation, and its evolution
B. The crustal architecture/structure during the period of ore system operation,
C. Metal pathways (including sources) and their lithological character,
D. Compositions and character of fluids, their flowpaths, and timing of flow,
E. Attributes of the depositional regime leading to economic mineralisation (PT gradients, permeability, reactivity, rheology and their variations in space & time),
F. Post-mineralisation modifiers (eg deformation, erosion, burial, weathering).

A methodology for building an ore-forming system model has proved instructive and is employed in the Gawler Craton Project (Figure 2). Research is progressively focussed on specific components of the ore-forming system, to arrive at an integrated spatially-located model that may be expressed in 2-D, 3-D or possibly 4-D.

Application of this integrated, multidisciplinary and regional- to deposit-scale approach to Proterozoic Cu-Au and other ore-forming systems in the Gawler Craton is a key difference between the Geoscience Australia-PIRSA collaborative project and previous research.

Projection of key features of the known ore-forming system into less-well understood areas, or into different terranes, requires that some geological-geophysical-geochemical expressions of these key features are measurable and mappable. The work program in the Gawler Craton Project focusses on identification of the fundamental ingredients of the regional systems that produced large economic deposits, and on practical methods of extrapolation and interpolation into areas away from known mineralisation.

SELECTION OF ORE-FORMING SYSTEMS FOR INVESTIGATION

A wide variety of metallic mineral deposit types are known from the Gawler Craton, including Archaean Au (eg Challenger), Palaeoproterozoic and Mesoproterozoic iron ore (eg Middleback Ranges, Hawksnest), Mesoproterozoic Cu-Au±U±REE (eg Olympic Dam, Moonta-Wallaroo districts), vein and disseminated gold (eg Tarcoola district, Tunkillia), Proterozoic stratabound Pb-Zn-Ag±Cu (eg Meninnie Dam, and prospects in Hutchison Group), and Neoproterozoic stratabound Cu (eg Mt Gunson). The craton is also considered prospective for Archaean komatiite-associated and Proterozoic intrusion-hosted Ni-Cu sulfide mineralisation (Daly et al, 1998), and has been explored for diamonds, Archaean volcanic-associated massive sulfide deposits (Teale et al, 2000), Broken Hill style Pb-Zn deposits, and a number of other mineralisation styles.

Strong industry interest in the Gawler Craton was registered at an Geoscience Australia Minerals Division Open Day in 1998, spurning an embryonic project proposal and initial discussions with PIRSA (Skirrow and Daly, 1999). Geoscience Australia work in the industry-sponsored AMIRA 'Metallogenic Potential of Australian Proterozoic Granites' project had highlighted the need for further research on the Gawler Craton in order to better assess its prospectivity (Budd et al, 1998). Subsequent evaluation by the Minerals Division of opportunities across Australia resulted in selection of the Gawler Craton as one of several high-priority regions for the Division's future program (Jaques et al, 2000). Analysis of known and potential ore-forming or mineral systems in light of industry trends led to the conclusion that the Gawler Craton has (1) very significant prospectivity for Proterozoic Cu and Au deposits, (2) significant potential for Archaean Au and Ni, and (3) unknown but possibly significant potential for Proterozoic Ni-Cu(-PGE). The analysis noted that the geoscientific information base was inadequate for informed decision-making by the resources industry.

Geoscience Australia and PIRSA have judged (see Table 1) that their resources and efforts will have the greatest impact on achievement of planned outcomes for the respective organisations by focussing on three ore-forming systems:

1. Proterozoic Cu-Au
2. Archaean komatiite-associated Ni-Cu
3. Archaean Au.

Table 1. Qualitative risk assessment and prioritisation of modules within the Gawler Craton Project, based on potential impact of carrying out work on the modules.

MODULE	MODULE A	MODULE B	MODULE C	MODULE D
Ore-forming system & area	Prot Cu-Au in Olympic prov & central Gawler	Archaean Au in Mulgathing Complex	Archaean Ni-Cu in Harris greenstones	Au & base metals in the regolith
Commodities	Cu, Au, U, Ag, REE, Fe	Au	Ni, Cu, PGE, Au	Au, base metals
Impact on tenure uptake	moderate/high	moderate/high	moderate/high	moderate
Impact on explor. expenditure	high	moderate/high	moderate/high	moderate
Impact on chance of discovery	moderate	moderate	unknown	moderate
Scientific impact	high	moderate	high	moderate
Resources/cost	high (seismic)	low	high (drilling)	high (AEM, drilling)
Logistic ease	good	moderate	good	good
Risk of negative result	low	moderate	significant	significant
Priority	1	2	3	2

Most resources from Geoscience Australia for at least Years 1 and 2 are assigned to scientific problems related to Proterozoic Cu-Au systems along the eastern margin of the Gawler Craton. Geoscience Australia has also invested in studies of the Archaean Mulgathing Complex in the northwestern Gawler Craton, within which the Challenger Au prospect is located. PIRSA are focussed on Archaean Ni-Cu systems of the central Gawler Craton. Both organisations are collaborating on each of the study regions to varying extents.

Definition of the scientific problems

MODULE A - FRAMEWORK FOR DISCOVERY OF PROTEROZOIC CU-AU IN THE EASTERN AND CENTRAL GAWLER CRATON

Overview

Deposits in the Fe-oxide Cu-Au family, of which Olympic Dam is a key member (Hitzman, 2000), tend to occur in clusters within metallogenic provinces (eg Cloncurry district, Queensland; Carajas district, Brazil; Tennant Creek district, Northern Territory; Iron Belt, Chile). Most districts contain numerous small-medium Cu-Au deposits and one or two large-superlarge deposits (eg Ernest Henry, Salobo, Candelaria). If this size distribution is representative of Cu-Au deposits in the Gawler Craton, we must question the probability of another superlarge Cu-Au deposit occurring 'near' Olympic Dam. But what is the 'footprint' size of the Olympic Dam ore-forming system, and do other hydrothermal systems of equivalent scale occur elsewhere in the Gawler Craton? Reviews of the literature, Open File corporate data, and preliminary work in the current project, suggest that related styles of Proterozoic Cu-Au mineralising systems were active within an arcuate province extending over 600 km along the eastern margin of the Gawler Craton. This metallogenic domain, which we term the Olympic Cu-Au province, extends from the Moonta-Wallaroo Cu-Au district (Conor, 1995) to the Mt Woods Inlier, and includes the pre-Neoproterozoic basement to the Stuart Shelf in the Olympic Dam region (also known informally as the Olympic Subdomain). In our view, the scale of this metallogenic province is sufficiently large to accommodate other large or superlarge Cu-Au deposits. The limits of the Cu-Au metallogenic province are poorly known, and extensions into the Peake and Denison Inliers and westwards into the central Gawler Craton are plausible. The metallogenic province may or may not transgress tectonic domain boundaries.

Similarities between Cu-Au systems in the Olympic Cu-Au province and the Curnamona Province to the east of the intervening Neoproterozoic Adelaide Geosyncline (Conor, 1996; Skirrow et al, 2000; Skirrow et al, in review) raises questions about the scale of the ore-forming systems in the period ~1630 Ma to ~1590 Ma. A key objective of the Gawler Craton Project (Module A) is to define the extent of the Olympic Cu-Au province, and to understand what makes this an especially fertile metallogenic province.

Our approach in Module A is to synthesise investigations on hydrothermal systems and their regional settings in three contrasting parts of the Olympic Cu-Au province: Moonta-Wallaroo Cu-Au district, the Olympic Dam region, and the Mt Woods Inlier (through a planned collaborative Ph.D. study through CODES). Alteration systems and Cu-Au mineralisation in the Moonta-Wallaroo district and Mt Woods Inlier appear to have formed at deeper crustal levels than Olympic Dam and nearby systems, and show some similarities to Cu-Au systems of the Cloncurry region (Mt Isa Inlier). Understanding these variations within the Olympic Cu-Au province will lead to identification of the 'critical ingredients' in formation of high-grade Cu-Au mineralisation. A longer term aim is to use this information to understand the differences and links between Olympic Dam style and other global styles of Fe-oxide Cu-Au ore-forming systems.

The Enigma of Olympic Dam

Four different models of formation have been published for the Olympic Dam Cu-U-Au deposit in the past decade, and several other models have been suggested. The key differences relate to which of two fluids carried the ore metals, whether the metal sources were mafic or felsic igneous, and the relative timing of fluid interaction. The implications of the different models for exploration are profound. An earlier model of formation within sedimentary breccias (Roberts and Hudson, 1983) is now generally considered inapplicable.

1. Reeve et al (1990) proposed a model of near-surface formation of both Fe-oxides and Cu-U-Au-Ag-REE mineralisation, within the Olympic Dam Breccia Complex (ODBC). The ODBC, which according to these authors developed by combined hydrothermal, phreatomagmatic and faulting processes related to regional-scale rifting, is hosted by the 1588 ± 4 Ma Roxby Downs Granite (Creaser, 1989). U-Pb dating of felsic igneous rocks in the ODBC has bracketed Cu-U-Au mineralisation to ~1590 Ma (Johnson and Cross, 1995). Diatreme and maar volcanic activity, driven by intrusion of mafic, ultramafic and felsic dykes into the ODBC, were considered important processes in development of the ODBC and ore-forming system. Reeve et al proposed that primary Cu-U-Au ore deposition resulted from interaction of ascending hot, reduced, metal-rich brines and descending cooler, relatively oxidising, meteoric waters, producing a broad zonation from lower chalcopyrite ± pyrite to upper bornite ± chalcocite.
2. Based on the geological model in (1) and on thermodynamic modelling, Haynes et al (1995) also advocated fluid mixing as an ore depositional mechanism, but favoured Cu-U-Au transport in the cooler, descending, oxygenated meteoric waters. The authors acknowledged the alternative possibility (suggested by Reeve et al, 1990) that ore metals were introduced in the hotter fluid. Basalts of the Gawler Range Volcanics were preferred as a significant source of the copper, leached by saline waters derived from a playa lake. A temperature of 150°C was assumed for a Cu-U-Au-rich cooler fluid, and 250°C for an Fe-rich hotter fluid.
3. Oreskes and Einaudi (1990; 1992) postulated that the ODBC and associated Cu-Au-Au-Ag-REE mineralisation formed ~190 m.y. later than the host Roxby Downs Granite, at and immediately below the paleosurface following uplift and erosion of the granite. Brecciation was viewed as hydrothermal in origin, with major amounts of Cu-Fe sulfides introduced during the waning stages of brecciation. Like Reeve et al (1990) and Haynes et al (1995), two fluids were suggested by Oreskes and Einaudi (1990; 1992), but with hotter (~400°C) deep-sourced fluids of possible felsic magmatic origin preceding rather than mixing with cooler oxidising surficial waters (seawater, groundwater, or closed-basin water). According to Oreskes and Einaudi (1990; 1992; Oreskes and Einaudi, 1992), the hotter fluid may have carried Fe, Cu and other metals but the oxidising fluids responsible for the formation of hematitic breccias were considered the key to the higher grade Cu mineralisation. Oreskes and Einaudi (1990; 1992) further proposed that Proterozoic surface weathering led to local development of supergene chalcocite ores.
4. Johnson and McCulloch (1995) suggested that the Cu-REE-enriched fluid may have been an ascending volatile phase exsolved from mafic/ultramafic magma chamber(s), and which post-dated the magnetite-forming fluid. They presented Sm-Nd isotopic evidence supporting involvement of two fluids in ore genesis, one of which was in isotopic equilibrium with Hiltaba suite granites (εNd = ~ -5) and probably precipitated early magnetite. The other fluid had a more primitive εNd signature, and resulted in hematitic breccias and Cu ores with εNd = ~ -2.5. Using a two-end-member model these authors calculated a minimum proportion of 13% of the Nd, and by implication, Cu, were contributed from mafic/ultramafic rocks or magmas with εNd = 4 either directly in a volatile phase or via leaching. The remaining Nd was modelled as sourced from granite or its volcanic equivalent. In the leaching scenario, a volume of at least 1 x 20 x 22 km of mafic/ultramafic + felsic rock would have been required to supply the metals in Olympic Dam. Johnson and McCulloch (1995) found no isotopic evidence for a supergene origin of bornite-chalcocite ores.

1. Reynolds (2000) recently alluded to magmatic sources for both ore fluids and metals at Olympic Dam. However, no detailed arguments and only limited supporting data have been published (eg Eldridge and Danti, 1994).

Current exploration models applied by some companies in their search for Olympic Dam style deposits incorporate several 'ingredients' on which there appears to be a general consensus:

1. the temporal association of Cu-U-Au mineralisation with magmatism of the Hiltaba Suite and Gawler Range Volcanics, at ~1590 Ma,
2. the importance of breccias in localising mineralisation,
3. a high crustal level of Fe-oxide and Cu-U-Au ore formation,
4. a strong (brittle) structural control on the location of breccias and ore,
5. the importance of hematite accompanying higher grade Cu-U-Au mineralisation,
6. the roles of two fluids of contrasting physico-chemical properties, one of which was meteoric in origin.

There are, however, some major unresolved problems that have important ramifications for exploration models and area selection for Olympic Dam style deposits. The questions listed below, and approachs to answering these questions (in italics), form the framework of the program in Module A. Many of the questions are also relevant to Proterozoic Fe-oxide Cu-Au systems elsewhere in Australia and globally (Skirrow, 1999; Hitzman, 2000).

Q1 What role did felsic magmas play - heat, metal or fluid sources? Are felsic intrusions necessary in an Olympic Dam style ore-forming system?
A1 *Ph.D. study on relationships between Hiltaba granites and mineralisation in the central Gawler, with comparison to Olympic Cu-Au province; U-Pb, Re-Os? and Ar-Ar geochronology of mineralisation and igneous rocks; stable isotopic and fluid inclusion studies; Sm-Nd and Re-Os tracing studies; geochemical criteria discriminating magmatic systems in fertile versus barren provinces, and Cu-Au versus Au provinces.*

Q2 How critical is the presence of mafic rock as a source of Cu-Au? If critical, are basalts or mafic/ultramafic intrusions most important?
A2 *New Sm-Nd and Re-Os tracing data for reservoirs in the region; alteration studies of mafic and other rocks.*

Q3 Is the observed structural control in the Olympic Cu-Au province the product of regional extensional tectonics (eg rifting), or other tectonic processes? What was the crustal architecture during the late Palaeoproterozoic - early Mesoproterozoic?
A3 *Modelling of gravity & magnetics in 2.5D and 3D; worming of potential field data; seismic data (proposed); characterisation of regional gravity, magnetic and seismic signatures of fertile terranes; application of igneous geochemistry in discriminating tectonic settings.*

Q4 Was groundwater/surface water essential, and if so what hydrological regime was favourable? Were phreatomagmatic activity or evaporites critical?
A4 *Stable isotopic studies for regional alteration systems; paleoenvironmental reconstuction including volcanic architecture; lithological mapping-logging.*

Q5 Which fluid(s) carried the ore metals, and was fluid mixing essential to produce economic mineralisation?
A5 *Alteration studies; fluid inclusion studies of hydrothermal systems of the Olympic Cu-Au province, including laser or PIXE analysis; thermodynamic modelling of barren and mineralised systems.*

Q6 Which were the fluid pathways, what was their physico-chemical character, and what regional alteration and geochemical patterns/tracers may be vectors to high-grade ore?
A6 *Crustal architecture modelling; alteration mapping; lithogeochemistry; mineral trace element characterisation (eg magnetite, pyrite); stable isotope patterns; fluid inclusion studies.*

Q7 Were other Fe-oxide and Cu-Au hydrothermal systems of the Olympic Cu-Au province contemporaneous and co-genetic with Olympic Dam?
A7 *Geochronology, stable and radiogenic isotope studies, thermodynamic modelling.*

Q8 What is the significance for exploration, of the observed variation in styles of Fe-oxide Cu-Au mineralisation within the Olympic Cu-Au province? Are styles other than Olympic Dam potentially economic?
A8 *Synthesis of critical ingredients in Cu-Au ore-forming systems; 3-D model of regional ore-forming system with predictive capacity; thermodynamic modelling of varying ore-forming scenarios.*

MODULE B - REGIONAL CONTROLS ON GOLD SYSTEMS IN THE ARCHAEAN MULGATHING COMPLEX

The Mulgathing Complex

Recognition of Archaean terranes in the northwestern and southern Gawler Craton came only in the 1970s with the application of Rb-Sr geochronology (eg Cooper et al, 1976; Daly et al, 1998). The geology and prospectivity of the largely concealed Mulgathing Complex within the Christie and Wilgena Subdomains of the northwestern Gawler Craton has remained particularly poorly understood. Outcrop of the Mulgathing Complex in the Christie Subdomain is dominated by pelitic high grade gneiss, and minor BIF and mafic extrusive rocks, however drill hole data indicates a greater proportion of mafic rocks. The depositional age and setting of the supercrustal sequence in the Christie Domain remains poorly constrained (max. ~2950-3150 Ma, zircon inheritance and Sm-Nd data from granulites in other parts of the Gawler Craton). There appears to be general agreement that the Christie Subdomain was subjected to granulite facies metamorphism (>750-800°C) during the Sleafordian Orogeny at ~2450-2420 Ma (U-Pb and Rb-Sr data (Daly and Fanning, 1993; Daly et al, 1998; Teasdale, 1997). However, two significantly different interpretations of the PTt history have been presented: Daly and Fanning (1993) suggested peak pressures of 7-9 kb were followed by retrogression at 4-6 kb, 600-700°C during the Kimban Orogeny, whereas Teasdale (1997) proposed peak pressures of 4.5-5.5 kb followed by isobaric cooling (ie no late Paleoproteozoic metamorphism). Metamorphism and poly-deformation were accompanied by minor felsic and mafic/ultramafic plutonism.

As noted by Teasdale (1997), the Mulgathing Complex in the Wilgena Subdomain differs from the Christie Subdomain in its much lower metamorphic grade (greenschist to lower amphibolite facies) and contains greater proportions of mafic-ultramafic volcanics, eg Lake Harris Komatiite and Hopeful Hill Basalt (<2670 Ma? Daly and Fanning, 1990) and calc-alkaline volcanics (2553±9 Ma, Fanning, 1997).

The Mulgathing Complex in the southwestern Christie Subdomain was intruded extensively by intermediate-felsic I-type magmas of the Ifould Complex at ~1700-1670 Ma in an hypothesised collisional plate margin setting (Daly et al, 1995). Both complexes were reworked by Mesoproterozoic shear zones at conditions up to 7kb. The Mulgathing Complex was evidently differentially exhumed along the Coorabie Shear Zone (>20-30 km of vertical displacement) possibly at 1100-1200 Ma (Teasdale, 1997).

In summary, there is currently a very limited understanding of the timing, structural geometries, PTt evolution and origins of tectonic events in the Mulgathing Complex. In general, the relationships between tectonic (sub)domains within the northwestern Gawler Craton are not well understood, including the significance of 'Grenvillian' aged events. The role of structure and crustal architecture in the development of the gold ore-forming systems is also virtually unknown. These elements of the 'plumbing system' and 'trap' must be better documented and understood in order to significantly change perceptions of gold prospectivity in the northwestern Gawler Craton.

To tackle these geological framework problems the Gawler Craton Project has implemented a program (Module B) of semi-regional gravity data acquisition, interpretation of aeromagnetics, Ar-Ar dating, and structural studies in the Mulgathing Complex. Future activities may include U-Pb dating, geophysical modelling of crustal structure, and metamorphic petrology of the Mulgathing Complex.

Gold ore-forming systems in the Mulgathing Complex

Following encouraging geochemical results by SADME/MESA/PIRSA, numerous discoveries of gold prospects were made in the Mulgathing Complex during the 1990s, using calcrete geochemical sampling. The only significant gold deposit known to date in the Mulgathing Complex is the Challenger deposit, with an indicated and inferred gold resource of 503,000 oz (Dominion Mining Ltd, Annual Report 2000). It is currently the subject of a mining feasibility study. Gold is hosted by the Christie Gneiss, a granulite facies aluminous metapelite within the Mulgathing Complex of the Christie Subdomain. Unpublished U-Pb dating of monazite intergrown with gold at Challenger has yielded an age of ca 2440 Ma (S. Daly & M. Fanning, pers. comm. 2001), close to that of a high-grade regional metamorphic event. Syn-metamorphic introduction of gold is implied, although deposition under these high-temperature conditions is improbable (Loucks and Mavrogenes, 1999; Tomkins and Mavrogenes, 2000) suggested that gold introduction was pre-metamorphic. Gold occurs in association with anomalous Bi, As, Co and Ni, commonly hosted by migmatitic leucosomes and melanosomes (Tomkins and Mavrogenes, 2000). The mineralisation style, composition, and setting appear to be unlike Archaean orogenic lode-gold deposits, which occur predominantly in greenschist and amphibolite metamorphic facies hostrocks within greenstone-granite terranes (eg Hagemann and Cassidy, 2000). The extent of similarity with those few lode-gold deposits in high metamorphic grade areas has yet to be determined.

The prospectivity of the Mulgathing Complex has been difficult to assess, due to the extensive cover. Perceptions of its prospectivity for epigenetic lode-gold are based in part on the relative amounts of 'greenstone' (the most common 'traps' for Au), metamorphic grade of the complex, and on the known gold inventory, all of which could be viewed negatively in comparison with, for example, the Yilgarn Craton. However, there is presently an inadequate understanding of the extent of 'greenstones', the distribution of metamorphic grade, and the regional structural and lithological controls on the location of gold mineralisation. Assessment of prospectivity based on models of Archaean lode-gold deposits may be misleading if the Challenger mineralisation represents a different type of ore-forming system. A PhD study (A. Tompkins, ANU) is currently addressing the nature and evolution of the Challenger gold deposit. Through the program outlined above (Module B), the Gawler Craton Project aims to develop a more rigorous basis for assessing the prospectivity of the Mulgathing Complex.

MODULE C - NI-CU POTENTIAL OF THE ARCHAEAN HARRIS GREENSTONE BELT

Archaean komatiites in the Lake Harris area of the central Gawler Craton were first recognised in the 1990s (Daly and van der Stelt, 1992), and form part of the Mulgathing Complex in the Wilgena Subdomain. The poorly exposed Lake Harris Komatiite has a probable strike length of 25 km with composite thickness of 2000 m, but the full extent and thickness of ultramafic-mafic volcanic units in the Harris greenstone belt is unknown. Two diamond drill holes by PIRSA intersected metamorphosed komatiite with relict spinifex texture, now composed predominantly of serpentine with lesser chlorite, tremolite, magnetite and chromite (Daly and Fanning, 1993). Although no significant Ni, Cu, or PGE mineralisation is known as yet (eg limited intersections of up to 2500 ppm Ni), the potential of the ultramafic rocks for Kambalda-style or other Archaean Ni-Cu sulfide mineralisation is unknown due to a paucity of basic geological and geochemical data on the Harris greenstone belt.

PIRSA have recently commenced a major program of semi-regional gravity data acquisition, bedrock drilling, airborne EM, remote sensing, and regolith studies over the Harris greenstone belt and surrounding areas. The gravity surveys are part of the PIRSA-Geoscience Australia gravity acquisition program in the Gawler Craton Project. Through Module C, Geoscience Australia will contribute specialist petrological, geophysical and geochemical expertise to assist in assessing the fertility of the mafic-ultramafic magmas for Ni-Cu ore-forming systems, and to develop geochemical criteria useful in exploration of the greenstone belt.

MODULE D - RECOGNITION OF GOLD AND BASE METAL ORE-FORMING SYSTEMS THROUGH THE REGOLITH

Drilling of surface geochemical anomalies in the central and northwestern Gawler Craton has shown that many gold anomalies are situated over or near to bedrock-hosted gold mineralisation, but several anomalies have no known local bedrock source. CRC LEME, PIRSA and collaborators have significantly advanced our understanding of the regolith in the Gawler Craton in the recent past, yet many problems remain in identifying which regolith geochemical anomalies are the most significant, how they relate in 3-D to bedrock-hosted mineralisation, and where high-grade gold mineralisation is located within the known mineralised systems.

The Gawler Craton Project is addressing these problems through a collaborative program of regolith studies (Module D), aimed at improved recognition of Cu-Au, Ni-Cu and Au ore-forming systems within and through the regolith. The program involving Geoscience Australia, CRC LEME, PIRSA, CSIRO and industry is centred on the acquisition and interpretation of AEM data and integration of these data with other geophysical data, geological investigations and geochemical studies of gold and base metal dispersion within the regolith and in groundwaters. AEM data have been acquired (released December 2000) in three geologically and geochemically contrasting areas of the Gawler Craton, to test the application of AEM in mapping of both regolith and basement geology. The Moonta-Wallaroo area was selected as representative of a regolith-covered base-metal - gold mineralised district (Cu-Au, minor Pb-Zn). Base metal dispersion will be characterised in the regolith and groundwaters, and this understanding will underpin the more problematic interpretation of gold dispersion. Recent drilling undertaken within the Gawler Craton Project has provided a major new geological, geochemical and geophysical dataset for this study (Worrall, 2001). Subsequent studies of regolith over the Tunkillia prospect (Proterozoic? Au) and Challenger prospect (Archaean Au) will focus on understanding gold dispersion through the regolith from basement-hosted primary mineralisation.

Project operation

COLLABORATORS AND LINKAGES

- Geoscience Australia
- Primary Industries and Resources South Australia (PIRSA), Office of Minerals and Energy Resources SA (MER)
- Minerals exploration & mining companies
- CRC LEME & CSIRO (D. Grey, M. Lintern)
- University of Tasmania - CODES (Garry Davidson & Ph.D. student; Jocelyn McPhie)
- Australian National University (PhD student)
- PRISE
- Rural communities

COMMUNICATION

- Presentations to industry and general audiences on the Project (eg Resources Week 2000, PIRSA Open Day 2000, Gawler Craton Seismic Workshop, July 2001).
- Articles in AusGeo News, MESA Journal (eg May 2001)
- Conference presentations, eg session at 16th AGC (July 2002) on Gawler Craton research and exploration, Archaean Symposium (Sept 2001), & excursions
- Regular meetings with PIRSA under the auspices of the National Geoscience Agreement
- Community consultation and briefings as required
- Regular team meetings
- Papers in peer-reviewed journals

TIMING AND PRODUCTS

Table 2. Summary of generalised proposed outputs of the Project for Years 1-4.

GENERALISED PROPOSED OUTPUTS	
Year 1 2000-01	Project proposal; compilations of basement geology, U-Pb geochronology, geochemistry, gravity, aeromagnetics, metallogenic data; selected new AEM, geochronology, and pilot petrological and drill hole datasets
Year 2 2001-02	Workshop on seismic reflection program; gravity datasets; preliminary 2.5D crustal models; tectonic domains map; mapping results; U-Pb and Ar-Ar geochronology; whole-rock geochemistry; stable and radiogenic isotope geochemistry; petrology; fluid chemistry; alteration distribution; new drill hole datasets; models of metal dispersion in the regolith; conference session on Gawler Craton and excursions
Year 3 2002-03	Seismic dataset; preliminary seismic interpretation & workshop; follow-up data acquisition (mapping, geochronology, geochemistry, petrology, drilling, metallogeny); synthesis & interpretation from Years 1 & 2 results
Year 4 2003-04	Final seismic interpretation; completion of basement geology datasets and 2.5-4D model of crustal evolution, incorporating seismic; definition of critical components in mineral systems and prospectivity; conference on final results; project finalisation and evaluation

INFORMATION MANAGEMENT

- Digital data will be stored in Geoscience Australia and PIRSA corporate databases, and will be made available to clients (subject to confidentiality conditions) in a variety of formats including the world wide web. All such data are subject to Quality Assurance / Quality Control checking prior to release.
- Systems will be put in place for efficient information transfer between Geoscience Australia and PIRSA.
- The Gawler Project Data Manager will ensure that data within the project are managed efficiently (eg version control, metadata) and in accordance with Geoscience Australia standards.
- A 'Systems Level Agreement' has been made between the Gawler Project and the Geoscience Australia Information Management Branch. This agreement covers the work undertaken by IMB staff for the Gawler Project.

PERSONNEL SUMMARY

Table 3. Personnel for the Gawler Craton Project (2000-01, from Geoscience Australia unless specified otherwise).

MODULE	MODULE A	MODULE B	MODULE C	MODULE D
	Olympic Cu-Au province & central Gawler	Archaean Mulgathing Complex	Harris greenstone belt	Regolith studies
Geologists	Lithostratigraphy/ volcanology; Mineral syst. Tect/geophys Igneous geochem Regional mapping	Regional mapping, tect. Tect/geophys	Mafic igneous petrology (2001-02), Geologist	Regolith geologists, Geochemist
Geophysicists	Gravity, mag. processing	Gravity, mag. processing	Gravity, mag. processing	AEM processing & interpret
GIS / database specialists	GIS, data integration	GIS, data integration	GIS, data integration	GIS, data integration AEM database development (2001-02)
Seismic team	Part-time (2001-02)			
Geochronologist/paleomag	Part-time Paleomag. (2001-02) Compilation (2001-02)	Part-time Compilation (2001-02)	Compilation (2001-02)	

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