



Iron oxide-copper-gold potential of the southern Arunta Region

Iron oxide-copper-gold (IOCG) deposits are a diverse family of mineral deposits unified by a number of common geological features, including the presence of abundant iron oxides, extensive hydrothermal alteration and strong structural controls (Williams *et al.*, 2005). As well as copper and gold, a suite of other commodities such as uranium and rare earth elements may also be present. Deposits can have very high tonnages and an extensive geological footprint, creating favourable targets for mineral exploration.

Iron oxide-copper-gold deposits occur throughout the world and range in age from Archean to Mesozoic or younger. A number of world-class IOCG deposits occur in Australia, including Olympic Dam in South Australia and Ernest Henry in northern Queensland. Work in the Arunta Region of central Australia by Geoscience Australia, the Northern Territory Geological Survey and the minerals industry (e.g., Huston *et al.*, 2012; Whelan *et al.* 2012) suggests that this too has potential for hosting IOCG deposits.

The Arunta Region spans Western Australia, the Northern Territory and Queensland and is subdivided into three provinces based on distinct igneous and sedimentary protolith ages and tectonothermal histories: the Aileron Province, the Warumpi Province and the much younger Irindina Province (Scrimgeour, 2003). The 1860–1700 Ma Aileron Province and the 1690–1600 Ma Warumpi Province consist of metasedimentary and mafic to felsic igneous rocks and have both experienced a number of metamorphic and deformation episodes (Figure 1). The two provinces are separated by a series of major faults collectively known as the Central Australian Suture (Close *et al.*, 2005).

Iron oxide-copper-gold-style mineralisation in the Arunta Region shares a similar geological setting to other IOCG-hosting provinces, and occurs in a number of places along the length of the Central Australian Suture (Figure 1). An analysis has been undertaken of the potential for additional IOCG mineralisation in the southern Arunta Region in the vicinity of the Central Australian Suture using a mineral systems approach.

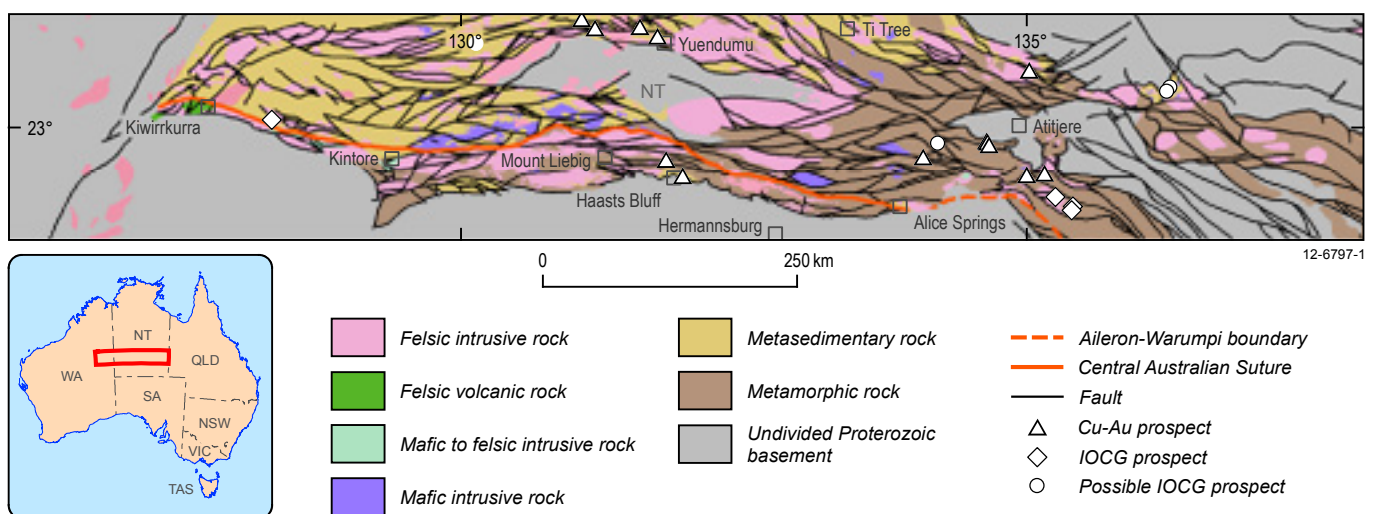
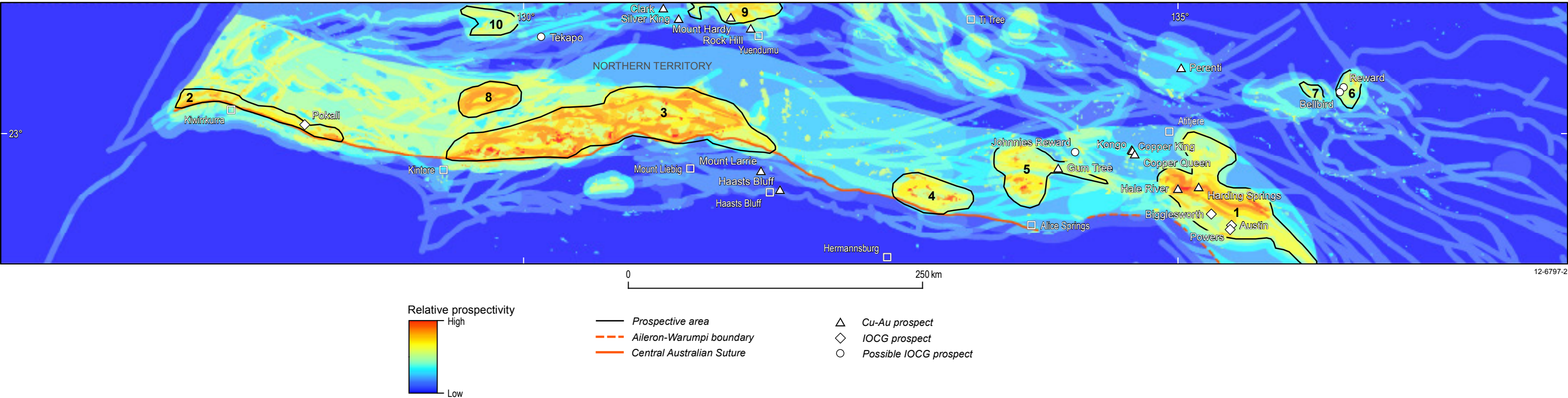


Figure 1: Regional basement geology of the southern Arunta Region. The geology shown is a new solid geology interpretation produced for this assessment, and is compiled from existing solid geology coverages, 1:250 000 geological maps, and new interpretation of magnetic and gravity data.



Methodology

The formation of a mineral deposit occurs as a result of a coincidence of favourable geological processes, operating on a range of scales, which together constitute a mineral system (Wyborn *et al.*, 1994). This mineral systems approach to understanding ore deposits has been used to assess the potential for IOCG systems in the southern Arunta Region. The mineral systems framework employed here recognises four key system components:

- Sources of metals, fluids and ligands
- Fluid-flow drivers
- Fluid-flow pathways and architecture
- Depositional sites and mechanisms.

For each component, ‘theoretical’ criteria representing favourable geological processes are identified and translated into mappable geological proxies with assigned weightings. The weighting given to each criterion is the product of three factors, which are expert estimations of the importance of the targeted process to the mineral system, how well the mappable geological proxy reflects the desired process, and the confidence in the data sources used. Each criterion is weighted between zero and one.

Each system component represents the combination of a number of these processes. The four component maps are then combined to generate the final map of IOCG system potential (Figure 2). The locations of known deposits are not used at any stage of the assessment and hence the coincidence of known deposits and prospects with areas independently identified as having high IOCG potential provides a measure of confidence in the mineral systems approach used. A detailed discussion of this approach

can be found in in Huston and van der Wielen (2011) and Schofield (2012).

The mineral systems approach allows for the identification of a much larger footprint than a deposit itself, and can be applied in greenfield and/or undercover areas. Since it seeks to map the key components of a mineral system, the final map highlights areas where an IOCG system may have operated, rather than identifying specific locations where an orebody may be found.

Results

Figure 2 summarises the results of the analysis of the IOCG potential in the southern Aileron Province and adjacent area. A total of ten prospective areas have been identified, several of which contain known IOCG or Cu-Au prospects. Figure 3 illustrates that many of prospective areas are undercover. Details of the analysis are provided on the overleaf.

Figure 2: Map showing the modelled potential for IOCG mineral systems in the southern Arunta Region. Based on the assessment, ten zones of elevated or high IOCG potential have been identified and are ranked in approximate order of potential. Zone 1 contains a number of recently identified IOCG prospects, and appears to be associated with the Atneeqa Granitic Complex. Similarly, Zone 2 is associated with IOCG-style mineralisation in the Mount Webb area of Western Australia and is associated with the Mount Webb Granite. Zone 3, in the central Aileron Province, is largely controlled by the distribution of the Andrew Young Igneous Complex and is not associated with known copper-gold mineralisation. Zone 4 lies close to the Aileron–Warumpi Province boundary and is centred around the Mount Hay Granulite. It includes a number of interpreted hematite-bearing zones. Zone 5 includes the Gum Tree copper-gold prospect and includes a number of interpreted magnetite and hematite zones. Zone 6 marks a region of moderate potential that includes prospects in the Jervois district that have been interpreted as IOCG-style mineralisation. An area of similar potential, labelled Zone 7, occurs just west of this area. Zone 8 includes the Taupo gold prospect (not shown) and occurs near interpreted mafic igneous rocks. However, no iron oxide alteration was interpreted in this area from magnetic and gravity data. In the north of the study area, Zone 9 contains the Mount Hardy Cu-Au prospect. It has overall moderate potential. Zone 10 exhibits some potential associated with interpreted faults.

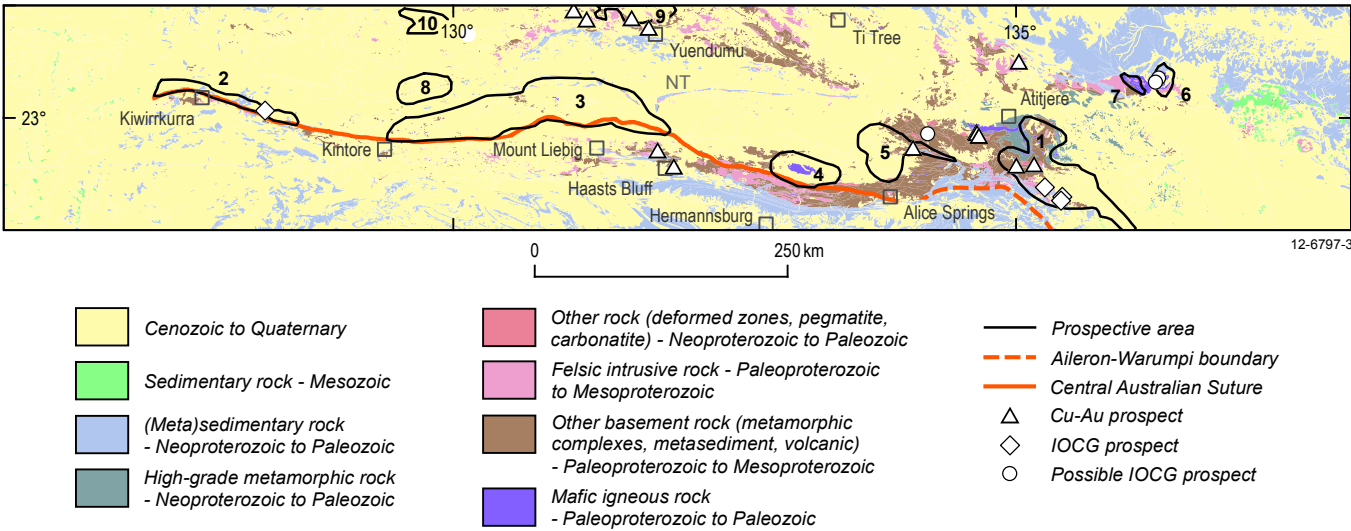


Figure 3: Map of the zones of modelled prospectivity from Figure 2 plotted over the regional surface geology (Liu *et al.*, 2012). Many of the areas highlighted occur in regions with significant amounts of recent sedimentary cover. These areas present potential greenfield opportunities.

Mineral system analysis components

Sources of metals, fluids and ligands

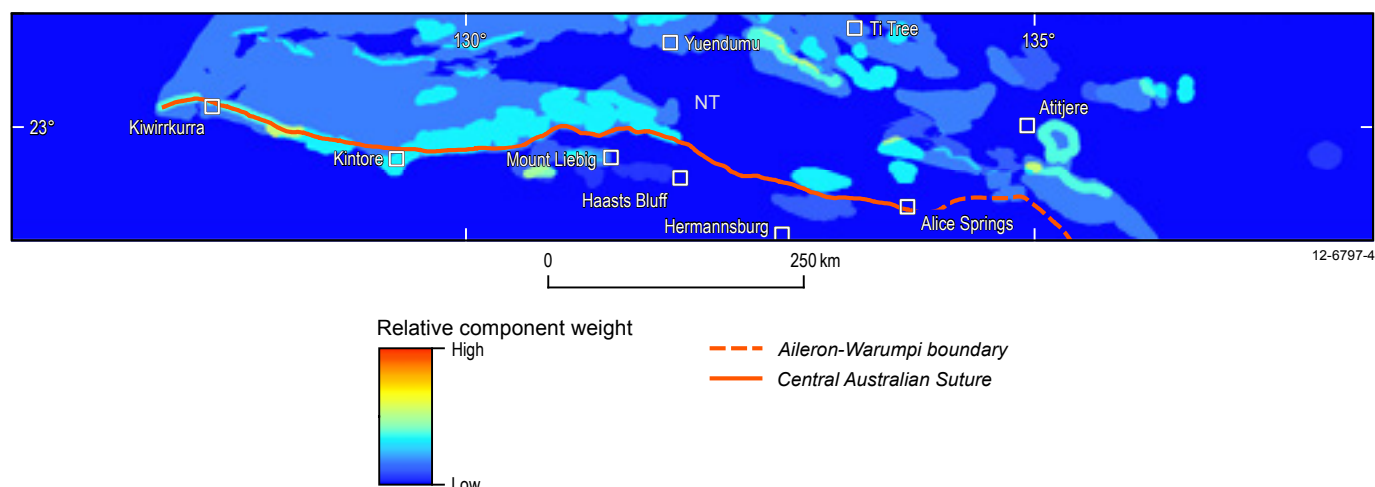


Figure 4: Map of the variation in potential for the sources system component. The colour stretch used for each system component is identical.

The sources system component reflects potential sources of metals, fluids and ligands (Figure 4; Table 1). The primary commodities in IOCG systems are copper and gold. The sources of these have been mapped using the distribution of mafic igneous rocks. Multiple fluid sources have been hypothesised for IOCG systems. Highly oxidised, surface-derived fluid sources, which may be sources of brines, chlorine and sulphur, are mapped using the distribution of basin sediments deposited in shallow marine to subaerial settings. These may also be the source of some of the iron in IOCG systems. Higher temperature, more deeply-sourced fluids may have a magmatic-hydrothermal origin, and are mapped by the distribution of oxidised and fractionated felsic to intermediate magmas.

Table 1: Criteria used to develop the sources system component.

'Theoretical' criteria	Mappable criteria	Dataset(s)	Weight	Description	Comments
Basinal sources of brines, Fe, Cl and S	Fe-rich basins; no buffer	Preliminary solid geology interpretation	0.240	(Meta)sedimentary units deposited in a shallow-water environment and/or scapolite-bearing units were extracted from the solid geology dataset	Overall oxidised packages with subaerial to shallow marine depositional settings may act as a source of Cl and some of the Fe or S. Scapolite-bearing rocks may suggest Cl-rich fluids.
	Scapolite-bearing rocks; no buffer		0.192		
Magmatic brine sources	Oxidised (I- to A-type) and fractionated felsic-intermediate magmas; 5 km buffer	Preliminary solid geology interpretation; geochemical data; magnetic data	0.294	Felsic to intermediate I- and A-type magmas were identified from the solid geology dataset. The degree of oxidation was determined according to Champion and Heinemann (1994). The degree of fractionation was determined according to El Bouseily and El Sokkary (1975).	Many IOCG deposits show evidence of deep, potentially magmatic-derived fluids.
	Oxidised (I- to A-type) and moderately fractionated felsic-intermediate magmas; 5 km buffer		0.210		
	Unknown or no data		0.105		
Sources of Cu and/or Au	Mafic-ultramafic igneous rocks (abundant); 5 km buffer	Preliminary solid geology interpretation	0.512	Mafic-ultramafic units were extracted from the solid geology dataset. Classified as to whether the mafic component is abundant or minor.	Mafic-ultramafic rocks may be a source of Cu and/or Au.
	Mafic-ultramafic igneous rocks (minor); 5 km buffer		0.256		

Fluid-flow drivers

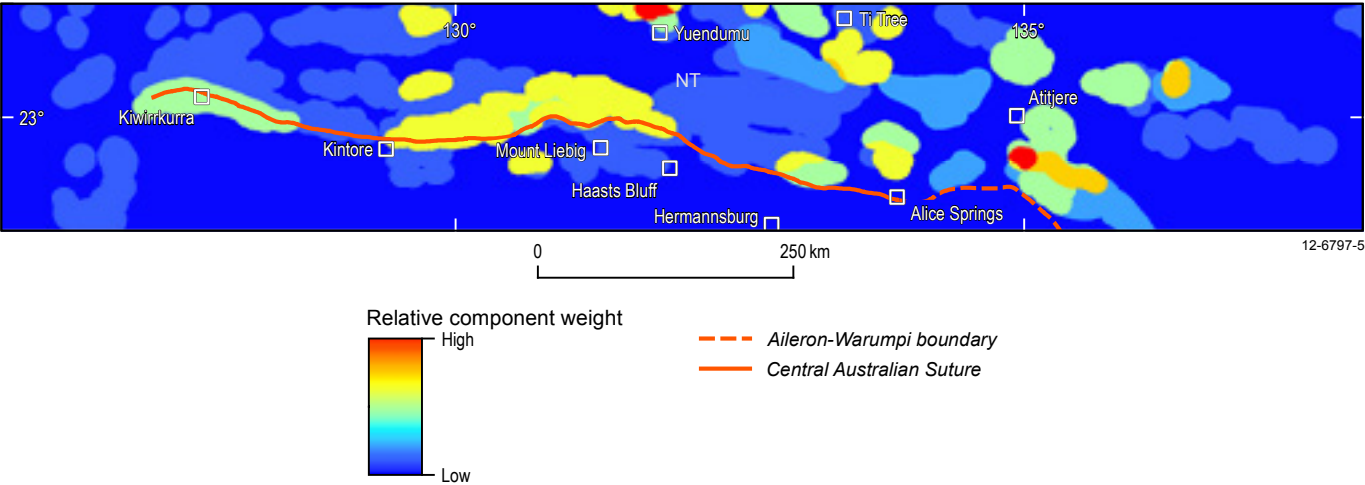


Figure 5: Map of the variation in potential for the fluid-flow drivers system component.

The fluid-flow drivers system component seeks to identify and map the geological processes involved in mobilising ore-bearing and other fluids (Figure 5; Table 2). The extensive hydrothermal alteration in IOCG systems indicates massive amounts of fluid flow. High paleogeothermal gradients, represented by thermal anomalies, may drive this. The possible locations of thermal anomalies contemporary with IOCG deposit formation have been mapped using the distribution of mantle melting, represented by mafic to ultramafic igneous intrusions. Felsic intrusive magmas emplaced in the crust may also contribute to an elevated thermal regime, and therefore high-temperature I- or A-type intrusive igneous rocks have been included as a mappable criterion.

Table 2: Criteria used to develop the fluid-flow drivers system component.

'Theoretical' criteria	Mappable criteria	Dataset(s)	Weight	Description	Comments
Large volume, high-temperature crustal melts	A- and high-temperature I-type felsic intrusive and volcanic rocks; 10 km buffer	Preliminary solid geology interpretation	0.512	Felsic to intermediate I- and A-type magmas were identified from the solid geology dataset. Zircon saturation temperatures (Watson and Harrison, 1983) were used	Potentially reflects an elevated thermal regime
	Transitional I-type felsic intrusive and volcanic rocks; 10 km buffer		0.256		
	Unknown or no data		0.128		
Mafic-ultramafic (intrusive) magmatism	Mafic-ultramafic intrusive igneous rocks (abundant); 10 km buffer	Preliminary solid geology interpretation	0.512	Intrusive mafic-ultramafic units were extracted from the solid geology dataset. Classified as to whether the mafic component is abundant or minor	
	Mafic-ultramafic intrusive igneous rocks (minor); 10 km buffer		0.256		

Fluid-flow pathways and architecture

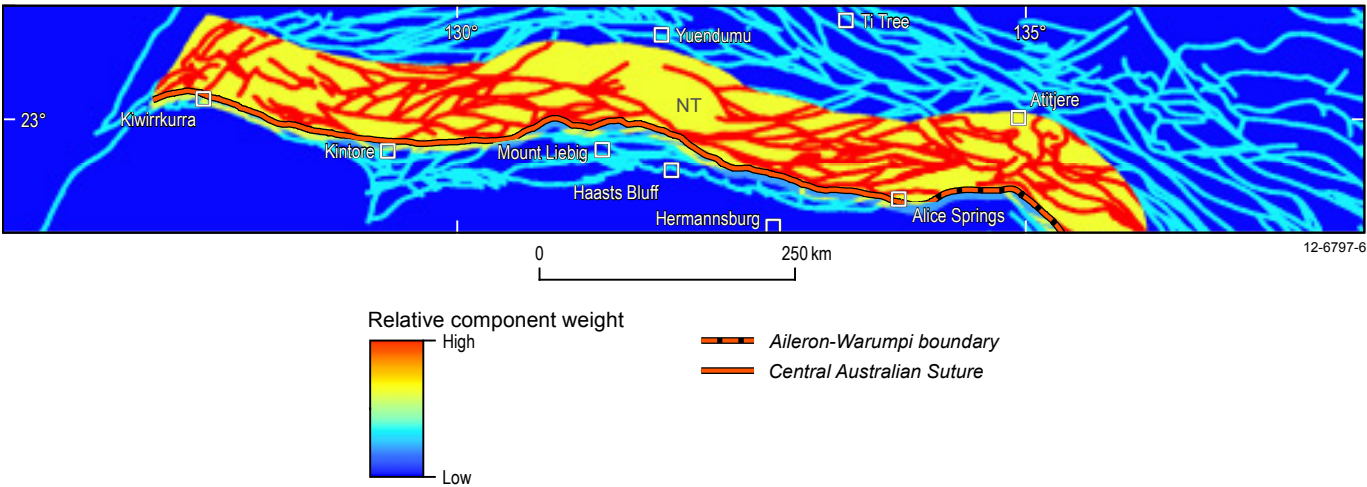


Figure 6: Map of the variation in potential for the fluid-flow pathways and architecture system component. The asymmetric buffer of high potential around the Central Australian Suture reflects the relatively greater favourability of the hanging wall of major structures associated with IOCG systems, and reflects the hanging wall position of north-dipping subduction between approximately 1810–1750 Ma.

The fluid-flow pathways and architecture system component primarily describes zones where ore-bearing fluids may be channelled. However, this component also includes possible pathways for other fluids involved in the mineral system, as well as the overall architectural setting of the system (Figure 6; Table 3). An apparent first-order architectural control on the distribution of IOCG deposits is proximity to major crustal-scale structures, which may focus the transport of magmas and fluids and/or signify locations of mantle fertilised during earlier subduction processes. This architecture may be established long before IOCG mineralisation occurs. Known examples of IOCG deposits generally occur in the hanging wall of these structures.

The evolution of the southern margin of the Aileron Province is summarised by Fraser *et al.* (2007) and is separated into two main phases: (1) interpreted north-dipping subduction between approximately 1810–1750 Ma, followed by (2) interpreted south-dipping subduction prior to accretion of the Warumpi Province at around 1640 Ma and the formation of the Central Australia Suture (Close *et al.*, 2005; Scrimgeour *et al.*, 2005). The Central Australian Suture, approximated by the southern margin of the Aileron Province, has been used to represent this architecture. Brittle, lower-order structures may localise fluid flow and mineralisation, and are mapped using interpreted faults.

Table 3: Criteria used to develop the fluid-flow pathways and architecture system component.

'Theoretical' criteria	Mappable criteria	Dataset(s)	Weight	Description	Comments
Fluid flow along permeable structures	Faults; 2.5 km buffer	Preliminary solid geology interpretation	0.336	Faults from the solid geology dataset were buffered	
Crustal-scale weak zones allowing mantle to crust magmatism and fluid flow	Crustal domain boundaries; 75 km buffer (hanging wall)	Preliminary solid geology interpretation	0.640	Mapped using the interpreted Warumpi-Aileron Province boundary	Examples of IOCG deposits are located in the hanging wall of major structures. Therefore, the hanging wall has been assigned a larger buffer
	Crustal domain boundaries; 10 km buffer (footwall)		0.240		

Depositional sites and mechanisms

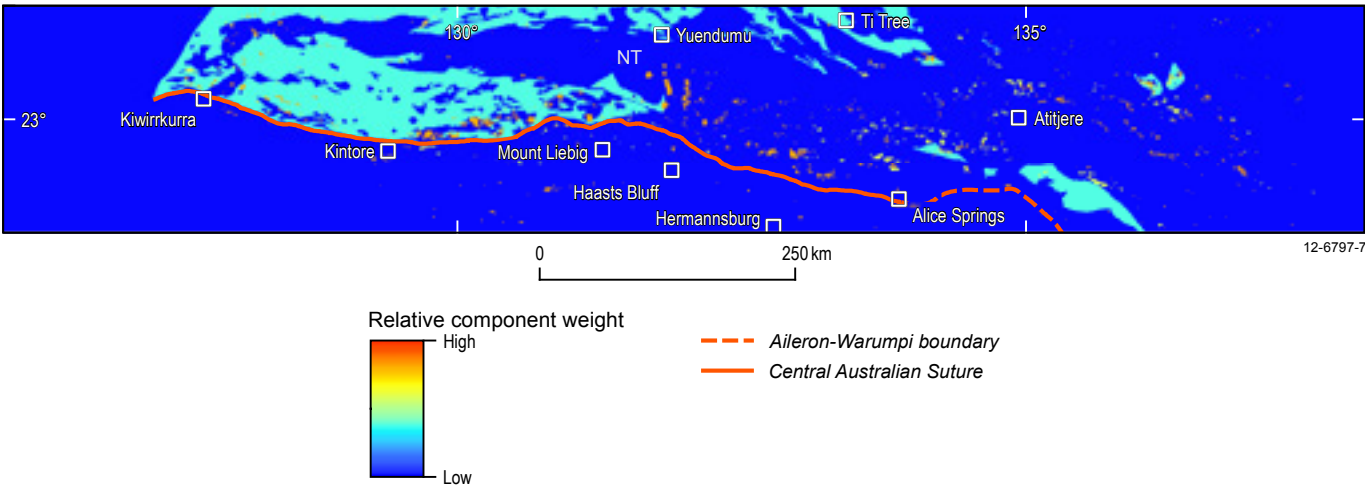


Figure 7: Map of the variation in potential for the depositional sites and mechanisms system component. The broad light blue zones represent lithologies which include iron-rich components. The smaller regions shown in hotter colours are locations of interpreted magnetite and/or hematite alteration.

The depositional sites and mechanisms system component concerns mechanisms whereby minerals are deposited from an ore-bearing fluid, and the identification of potential sites where this may have occurred (Figure 7). Such indicators include evidence of hydrothermal alteration and physical or chemical gradients (Table 4). Chemical modelling (Bastrakov *et al.*, 2007) suggests that zones where hematite has replaced magnetite are the most favourable for copper, gold and uranium, with the highest potential expected to be found where hematite-rich alteration is juxtaposed with magnetite-rich alteration. Iron oxide alteration has been mapped using geophysical inversion of magnetic and gravity data, following the method described by Chopping and van der Wielen (2011). From this analysis, zones of hematite, magnetite, and the interface between the two have been used as mappable criteria. Pre-IOCG iron-rich rocks also represent potential depositional sites where oxidised, ore-bearing fluids may react with reduced iron to deposit metals, and were mapped by iron-rich lithologies.

Table 4: Criteria used to develop the depositional sites and mechanisms system component.

'Theoretical' criteria	Mappable criteria	Dataset(s)	Weight	Description	Comments
Chemical gradients	Ironstones and iron formation (abundant)	Preliminary solid geology interpretation	0.280	Units containing Fe-rich lithologies were extracted from the solid geology dataset. Classified as to whether the Fe-rich component is abundant or minor	Identifies potential sites of reaction of Cu-bearing brines with ironstones
	Ironstones and iron formation (minor)		0.200		
	Inversion model of magnetite alteration	Inversion model of magnetic and gravity data	0.300	Identified from geophysical inversion of magnetic and gravity data using the method of Chopping and van der Wielen (2011)	Zones of hematite are more favourable than magnetite (Bastrakov <i>et al.</i> , 2007)
	Inversion model of hematite alteration		0.400		
	Contact between hematite and magnetite alteration; 500 m buffer		0.450	Gradient between hematite and magnetite zones was identified and buffered	Transition from magnetite to hematite represents the most favourable location for Cu±Au deposition (Bastrakov <i>et al.</i> , 2007)

References

- Bastrakov, E. N., Skirrow, R. G. and Davidson, G. J. 2007. Fluid evolution and origins of iron oxide Cu-Au prospects in the Olympic Dam District, Gawler Craton, South Australia. *Economic Geology*, 102: 1415-1440.
- Champion, D. C. and Heinemann, M. A. 1994. Igneous rocks of northern Queensland: 1:500 000 map and explanatory notes. *Record 1994/11*. Geoscience Australia: Canberra.
- Chopping, R. and van der Wielen, S. E. 2011. Mapping the footprint of ore deposits in 3D using geophysical data. *AusGeo News*, 101: 3-7.
- Close, D. F., Scrimgeour, I. R., Edgoose, C. J., Wingate, M. T. D. and Selway, K. 2005. Late Palaeoproterozoic oblique accretion of a 1690-1660 Ma magmatic arc onto the North Australian Craton. *Geological Society of Australia Abstracts*, 81: 36.
- El Bouseily, A. M. and El Sokkary, A. A. 1975. The relation between Rb, Ba and Sr in granitic rocks. *Chemical Geology*, 16: 207-219.
- Fraser, G. L., Huston, D. L., Gibson, G. M., Neumann, N. L., Maidment, D., Kositsin, N., Skirrow, R. G., Jaireth, S., Lyons, P., Carson, C., Cutten, H. and Lambeck, A. 2007. Geodynamic and metallogenic evolution of Proterozoic Australia from 1870-1550 Ma: a discussion. *Record 2007/16*. Geoscience Australia: Canberra.
- Huston, D. L. and van der Wielen, S. E. (editors) 2011. An assessment of the uranium and geothermal prospectivity of east-central South Australia. *Record 2011/34*. Geoscience Australia: Canberra.
- Huston, D.L., Whelan, J.A., Schofield, A., Chopping, R.G. and Gallagher, R. 2012. 'Uranium-rich iron oxide-copper-gold systems' in Schofield, A. (ed.) *An assessment of the uranium and geothermal energy prospectivity of the southern Northern Territory*. *Record 2012/51*. Geoscience Australia: Canberra, pp.45-87.
- Liu, S., Raymond, O. L., Gallagher, R., Zhang, W. and Highet, L. M. 2012. *Surface geology of Australia, 1:1 000 000 scale, 2012 edition*. Geoscience Australia: Canberra.
- Schofield, A. 2012 (editor). An assessment of the uranium and geothermal prospectivity of the southern Northern Territory. *Record 2012/51*. Geoscience Australia: Canberra.
- Scrimgeour, I. 2003. 'Developing a revised framework for the Arunta Region' in Annual Geoscience Exploration Seminar (AGES) 2003, record of abstracts. *Record 2011-003*. Northern Territory Geological Survey.
- Scrimgeour, I. R., Kinny, P. D., Close, D. F. and Edgoose, C. J. 2005. High-T granulites and polymetamorphism in the southern Arunta Region, Central Australia: Evidence for a 1.64 Ga accretional event. *Precambrian Research*, 142: 1-27.
- Watson, E. B. and Harrison, T. M. 1983. Zircon saturation revisited: temperature and composition effects in a variety of crustal magma types. *Earth and Planetary Science Letters*, 64: 295-304.
- Whelan, J., Webb, G., Close, D., Kositsin, N., Bodorkos, S. and Maas, R. 2012. 'New copper-gold discoveries in the eastern Arunta Region: implications for Cu-Au mineralisation in the Arunta' in Annual Geoscience Exploration Seminar (AGES) 2012, record of abstracts. *Record 2012-002*. Northern Territory Geological Survey, pp.38-42.
- Williams, P. J., Barton, M. D., Johnson, D. A., Fontboté, L., de Haller, A., Mark, G., Oliver, N. H. S. and Marschik, R. 2005. Iron oxide copper-gold deposits: Geology, space-time distribution, and possible modes of origin. *Economic Geology*, 100: 371-405.
- Wyborn, L. A. I., Henrich, C. A. and Jaques, A. L. 1994. Australian Proterozoic Mineral Systems: essential ingredients and mappable criteria. *AusIMM Publication Series*. 5/94: 109-115.

For Further Information:

Anthony Schofield, David Huston and Carina Kemp

Email: anthony.schofield@ga.gov.au; david.huston@ga.gov.au; carina.kemp@ga.gov.au

Ph: +61 2 6249 9833; +61 2 6249 9577; +61 6249 9228

Digital GIS data of all criteria used in this assessment, together with the results and information about data sources used, are downloadable from www.ga.gov.au



GA 13-6784 | GeoCat 76423
© Commonwealth of Australia (Geoscience Australia) 2013

Geoscience Australia
GPO Box 378
Canberra ACT 2601
www.ga.gov.au