Targeting future mineral discoveries under cover using a mineral systems approach

Anthony Schofield
Geoscience Australia
GPO Box 378
Canberra ACT 2601
anthony.schofield@ga.gov.au

David L. Huston
Geoscience Australia
GPO Box 378
Canberra ACT 2601
david.huston@ga.gov.au

SUMMARY

Predictive mapping of mineral systems represents an important tool for assessing the potential for undiscovered mineral resources. Recently, assessments for a range of uranium mineralisation styles have been performed across three regional studies in Queensland, South Australia and the Northern Territory. These investigations have been undertaken using a mineral systems framework which considers key system components including sources, fluid-flow drivers and pathways, and depositional mechanisms.

This method places a strong emphasis on identifying important processes leading to ore formation, which are then translated into mappable geological proxies using a range of input datasets and derivatives. In areas of outcrop or shallow cover, these processes may be mapped using geochemical and observational geological data. However, deeper-buried terranes, such as those dominating most of the Australian continent, require the use of geophysical data to generate proxies for targeting the desired processes.

Importantly, and unlike many other available techniques, the method employed does not rely on the locations of known mineralisation to generate maps of mineral potential. This allows assessment of mineral potential in greenfield regions of Australia, including those beneath significant volumes of cover. Results from the regional studies completed to date successfully reproduce the locations of known mineralisation and highlight potential in areas not currently recognised as mineralised. Such mineral system analyses provide predictive models which may be the focus for follow-up investigation, including drilling.

Key words: Mineral systems, prospectivity, greenfields, under cover exploration

INTRODUCTION

Australia's mineral resources are a vital component of the national economy and have underpinned its prosperity for over 150 years. This long history of mining, together with declining exploration success in recent years has led to the perception of Australia as a 'mature' exploration destination by some. However, comparison between the distribution of known mineral deposits and areas of outcrop or shallow subcrop reveal that, with a small number of notable exceptions, previous mineral discoveries are restricted to areas of exposed geology. These exposed areas represent a fraction of the Australian landmass, with approximately 80% of the country obscured by relatively recent sedimentary cover. Geophysical data reveal that the geology of well-known mineralised terranes extends beneath cover, and therefore it is likely that potential exists for additional discoveries of ore deposits to be made beneath this veneer. In order to maintain a steady pipeline of exploitable mineral resources it is essential that new mineral discoveries are made. These future discoveries are likely to occur in covered and under-explored (greenfield) regions of the country. Therefore, Australia's extensive recent cover provides both challenges as well as significant opportunities.

Targeting mineral systems under cover

Potential for undiscovered mineralisation under cover may be assessed with predictive mapping of mineral systems. Wyborn *et al.* (1994) described a framework for targeting Australian Proterozoic mineralisation based on the recognition that a mineral deposit forms as a result of the coincidence of a number of favourable geological processes, which together constitute a mineral system. These processes typically occur at scales ranging from global- to deposit-scale and, as such, present significantly larger footprints than that of an orebody itself. The conceptual nature of these processes necessitates the translation of these critical processes into mappable geological proxies which may be derived using a range of input datasets.

Following the work of Wyborn *et al.* (1994), a number of subsequent adaptions of the mineral systems approach have been developed (e.g., Barnicoat, 2008; Skirrow, 2009; McCuaig *et al.*, 2010). Emphasised in each of these approaches is the mapping of critical mineralising processes through the identification of suitable geological proxies. In exposed areas and at relatively shallow depths, mappable proxies may be developed using geochemical and observational geological data. In more deeply-buried terranes, geophysical data are required to generate targeting criteria.

This paper provides a framework for addressing two major challenges arising from the discussion above: (1) how can we find new mineral deposits? and (2) how can we map key mineral system features beneath cover using geophysical data? This will be discussed in the context of three regional studies

examining the potential for uranium-rich iron oxide-copper-gold (IOCG) mineral systems in northern Queensland, east-central South Australia and the southern Northern Territory. Detailed information on these studies can be found in Skirrow and Huston (2010), Skirrow *et al*. (2011) and Huston *et al*. (2012).

METHOD

A number of published approaches exist for analysing the prospectivity of a given terrane. These may be broadly divided into two main categories: data-driven and knowledge-driven methods (Bonham-Carter, 1994; Knox-Robinson and Wyborn, 1997). Data-driven methods require the presence of numerous known deposits of the targeted mineralisation style and as such are best applied in brownfield terranes. In comparison, knowledge-driven approaches develop mappable criteria and weightings based on a conceptual model and thus may be readily applied in greenfield terranes lacking known mineralisation.

The method employed in this study uses a custom-developed knowledge-driven approach. The mineral systems framework used consists of four key system components, all of which are critical for mineralisation to occur: (1) sources of metals, fluids and ligands; (2) fluid-flow drivers; (3) fluid-flow pathways and architecture; and (4) depositional sites and mechanisms (Figure 1).

For each key mineral system component, conceptual 'theoretical' criteria are developed, which represent important geological processes. These are themselves translated into mappable geological proxies. Each criterion is weighted based on the product of three factors: (1) the importance of the 'theoretical' criterion to the mineral system; (2) how well the mappable proxy reflects the desired process; and (3) confidence in the source data. The first factor quantifies the significance of the criterion, while the latter two aim to quantify its uncertainty. The weighted criteria are then combined in a 2D GIS-based environment into intermediate maps representing each of the system components, which in turn are summed to derive the final map of mineral potential (Figure 1).

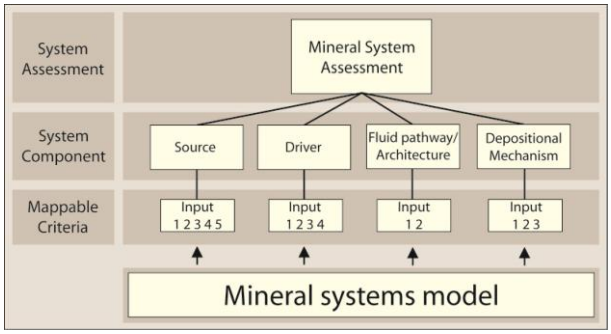

Figure 1. Generalised workflow used for developing mineral potential maps

The method used here has a number of advantages, such as transparency, reproducibility and ease of implementation. Most importantly, because the method applied does not require the presence of known mineralisation, the mineral potential of greenfield regions may be assessed semi-quantitatively. Furthermore, known deposits have been explicitly excluded from the assessment in order to prevent bias, although they are used for subsequent verification of results. Extending the analysis to areas of significant cover requires the use of datasets capable of reflecting the interpreted critical processes at-depth.

ANALYSIS OF IOCG POTENTIAL

Iron oxide-copper-gold systems represent favourable exploration targets since they are commonly large to giant, multi-commodity, can have a large footprint and generally have distinctive geophysical signatures. Of the three regional assessments of IOCG potential undertaken, two (north Queensland and east-central South Australia) are in known IOCG provinces, while the third (southern Northern Territory) represents a potential or emerging IOCG province.

Criteria and proxies

An abbreviated list of the key 'theoretical' criteria used is shown in Table 1. While mappable proxies for these criteria may be readily developed in cropping out areas from surface-derived datasets, none are able to be directly mapped beneath cover. However, a number of these criteria are mappable under cover using geophysical proxies. Many of these (such as the locations of mafic igneous rocks and faults) are readily mappable using solid geology interpretations, especially those which simply seek to map lithology beneath cover. Others however, especially those seeking to map mineralogical or geochemical variation, require the use of geophysical datasets in such a way as to derive mineral systems meaning.

An example of this is the use of magnetic and gravity inversion to constrain volumes of IOCG-related alteration, especially for identifying areas of potential hematite and magnetite alteration. The technique of Chopping and van der Wielen (2011) has been successfully applied in each of the study areas. Similarly, major IOCG provinces show a spatial relationship to major crustal sutures, such as those imaged in seismic data beneath Olympic Dam and the Cloncurry IOCG province. These sutures are able to be mapped and characterised using a range of geophysical datasets, such as magnetics, gravity, magnetotellurics and seismic. Finally, geophysical data have been used as a proxy for geochemical data. This has been particularly usefully applied to constraining intrusive geochemistry. As well as identifying mafic (dense, commonly magnetic) versus felsic (less dense) character, granite oxidation state is also able to be inferred based on their magnetic character, with more oxidised granites belonging to the magnetite-series (magnetic) of Ishihara (1977) and more reduced granites belonging to the ilmenite-series (non-magnetic). The redox character may also be used as a proxy for granite type, with S-type granites dominantly belonging to the ilmenite-series (non-magnetic), while I-type (and some A-type) rocks are typically more oxidised (magnetic), although this is not universally the case. As suggested by Table 1, these characteristics have important metallogenic implications.

Although geophysical techniques offer a useful tool for mapping mineral system features under cover, it must also be recognised that the mappable proxies are often far from perfect. As such, the uncertainties assigned to these features must increase and be reflected in the overall criterion weighting. Nevertheless, using geophysical data in such a

manner will be essential for targeting future undercover mineral discoveries.

System component	'Theoretical' criteria
Sources	Basinal sources of Fe, Cl, S
	Magmatic brine sources
	Igneous U ± REE sources
	Sources of Cu ± Au (mafic rocks)
Fluid-flow drivers	High-temperature crustal melts (high-temperature I- and A-type intrusives)
	Mafic-ultramafic (intrusive) magmatism
Fluid-flow pathways	Fluid flow along permeable structures
	Crustal-scale weak zones
Depositional mechanisms	Iron-rich rocks
	IOCG alteration

Table 1. Abbreviated list of conceptual ('theoretical') criteria used in the assessment for IOCG systems

Results

Using the approach described above, the potential for uranium-rich IOCG systems was assessed in the three regional study areas. Within the two regions known to host significant IOCG mineralisation (east-central South Australia and northern Queensland), the results of the analysis satisfactorily reproduce the locations of known mineralisation, as well as predicting additional prospective areas, including many beneath cover. The southern Northern Territory hosts a number of small prospects which are interpreted to have affinities with IOCG mineralisation, but unlike the two other regions contains no major deposits. The results of the southern Northern Territory assessment suggest that potential for IOCG systems is high along an east-west-trending belt parallel to a major crustal suture, including areas which have demonstrated potential for IOCG-style mineralisation (Figure 2).

CONCLUSIONS

Using a mineral systems-based approach allows for the mineral potential of greenfields regions to be assessed. Critical to this process is the development of mappable geological proxies for key mineralising processes. Under regions of significant cover, these mappable proxies are able to be developed by processing geophysical data to derive mineral systems significance. The successful replication of the locations of known mineralisation and the prediction of additional IOCG potential away from known areas suggests that this approach represents a powerful tool for targeting future mineral discoveries under cover.

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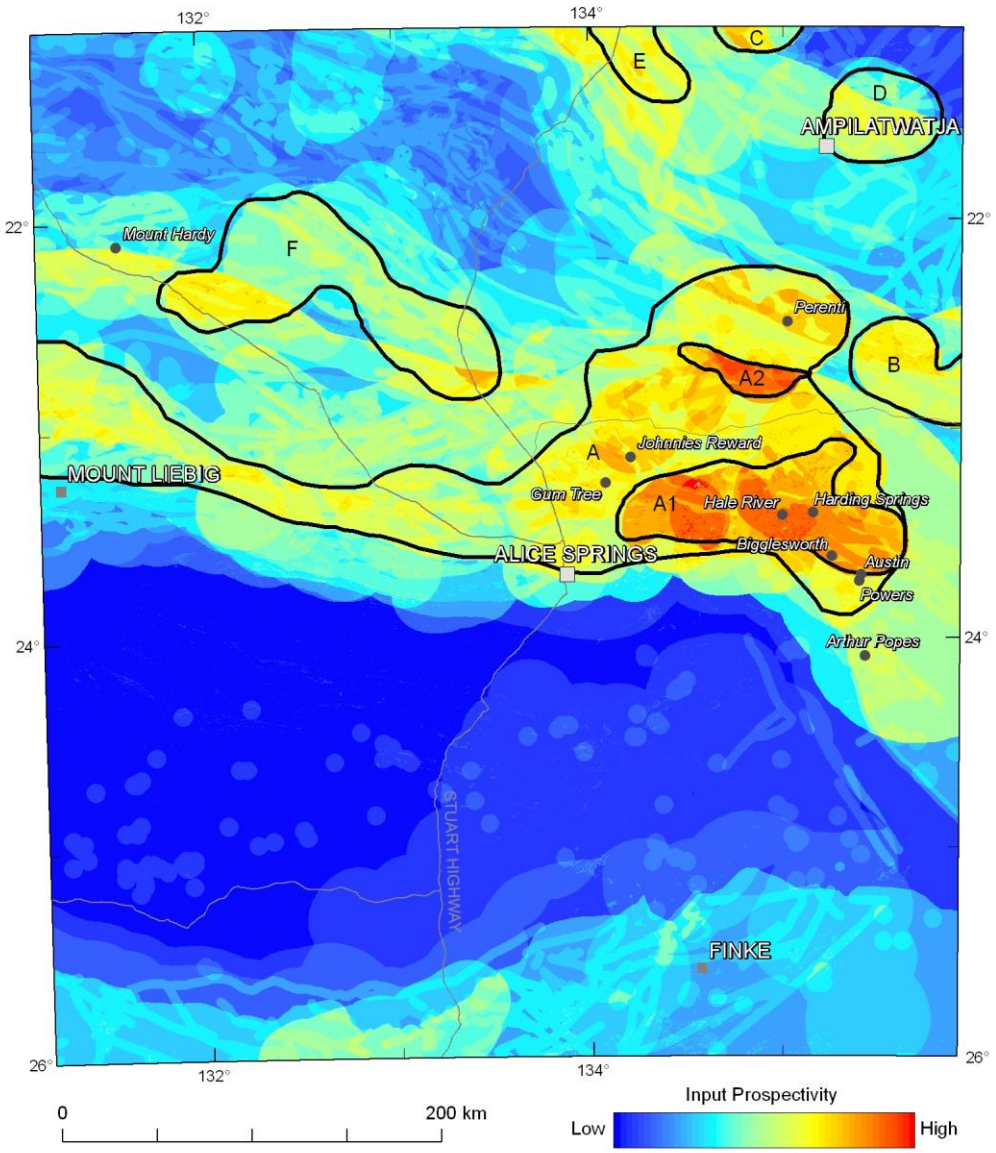

Figure 2. Map showing interpreted prospectivity for uranium-rich iron oxide-copper-gold systems in the southern Northern Territory. Locations of known copper-gold prospects (some with IOCG affinities) and interpreted prospective regions are shown. Figure from Huston *et al.* (2012)