Geophysical vectors to IOCG mineralisation in the Gawler Craton

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SUMMARY

IOCG deposits within the Gawler Craton are an attractive exploration target that has been the focus of considerable exploration. Due to the extensive Neoproterozoic and Phanerozoic cover over prospective geology, geophysics is the predominant and most cost effective exploration tool.

The eastern Gawler Craton contains multiple deposits and prospects in areas defined by high amplitude gravity and magnetic anomalies. Seismic surveys define the craton boundary and large scale structures. Gravity, magnetics and structural breaks are terrane scale vectors.

Within tenements geological interpretation from geophysical data is critical due the many 'false alarm' anomalies. Vectors to targets from gravity highs, associated offset magnetic responses, chargeability highs and resistivity lows are important. Ambiguity in interpretation due to palaeotopography is a significant issue that seismic surveying is beginning to resolve.

Within an IOCG deposit the geophysical response of iron oxides dominates the sulphide response. Neither direct-detection of, or vectors to mineralisation within a deposit are provided from gravity, magnetics, chargeability, resistivity or acoustic properties.

Geophysics provides excellent vectors to IOCG deposits at the terrane and tenement scale but do not provide vectors within the iron oxide alteration envelope.

Key words: IOCG, geophysics, vector, Gawler Craton

INTRODUCTION

Discovery by WMC of the Olympic Dam deposit in 1975 led to the recognition of a new class of orebody defined by their high proportion of iron oxide, copper, gold +/- uranium mineralisation. The discovery of the Prominent Hill deposit by Minotaur Exploration in 2002 and the Carrapateena deposit by RMG Services in 2005 further highlights the prospectivity for large tonnage, high grade deposits on the eastern margin of the Gawler Craton where many other IOCG style mineral occurrences have been intersected.

This paper provides an update on the practical use and limitations of geophysics as a vector to mineralisation in the Gawler Craton. Thick and conductive, Neoproterozoic and Phanerozoic cover and a focus on the haematite-dominant end member of the sensu-stricto IOCG class (Groves et al., 2010) refine the geophysical techniques useful for exploration in the Gawler. Gravity, magnetic, electrical and seismic methods are discussed at the terrane, tenement and deposit scale in an attempt to elucidate a geophysical approach similar to that applied to geochemical data.

For the geology of the Gawler Craton, Drexel et al. (1993) provides a thorough description. At the deposit scale, the geology of Olympic Dam (Reynolds, 2000), Prominent Hill (Belperio et al., 2007), Oak Dam (Davidson et al, 2007) and some prospects (Bastrakov et al., 2007) have been published.

The geophysical responses of individual IOCG deposits and prospects have been documented at Olympic Dam (Esdale et al., 2003), Prominent Hill (Hart and Freeman, 2003), Carrapateena (Vella and Cawood, 2012) and Wirrda Well (Vella, 1997). Smith (2002) provides an overview of the geophysical responses from IOCG's that is purposely broad to encompass a wide range the IOCG related deposits, Austin and Foss (2012) modelled the gravity and magnetic response of a number of Australian IOCG deposits and Gow et al (1993) provides detail on interpreting the geology and IOCG alteration beneath the Stuart Shelf sediments from magnetic and gravity datasets.

TERRANE SCALE VECTORS

Within the Gawler Craton the known deposits and significant prospects all occur along the eastern margin (Figure 1). The geophysical expression of the Olympic Dam district and the Mt Woods Inlier are characterised by high amplitude magnetic and gravity anomalies are that are considered to be favourable for exploration (Smith 2002). However the thickness of the Stuart Shelf and younger Phanerozoic basins subdue the anomalous response. The area surrounding the Carrapateena deposit is an exception to this generalisation, occurring within an area of 'quiet' potential field at shallower basement depths than much of the Oak Dam, Emmie Bluff, Cockey Swamp area. It may be the case that, due to potential field anomalies being targeted undercover, the dataset of known prospects is biased to areas of such anomalism and areas with less background potential field anomalies are equally prospective. Regional high amplitude anomalies should increase a target areas appeal. Conversely a limited number of high amplitude potential field anomalies should not downgrade a prospective terrane.

Reflection seismic surveys, usually government funded, provide an excellent terrane scale tool for defining the architecture of the Gawler Craton, the major faults and potential fluid pathways within the lithosphere. If the exploration model invokes anorogenic melting due to subcontinental lithospheric mantle (Groves et al., 2010), areas

of thickened crust and bland responses from intruded melts will assist in locating prospective tenements. The northeast-

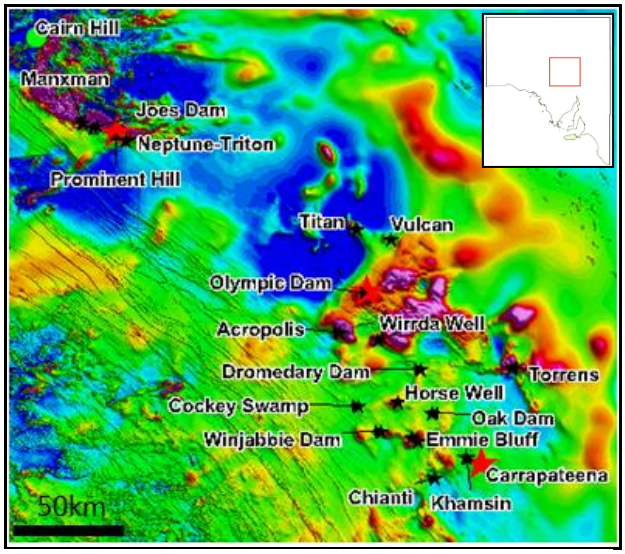

Figure 1. Location of the IOCG deposits (red), prospects (black) and mesothermal vein/skarn deposits (green) on regional RTP magnetic image.

southwest Gawler Craton line centred on Olympic Dam and the north-south GOMA line both help define the eastern and northern extent of the Gawler Craton respectively.

Magnetotellurics (MT) can be used at the terrane scale. Its application has imaged a possible fluid pathway beneath the Olympic Dam deposit defined by a large zone of anomalous conductivity (Heinson et al., 2006). Where economic skin depths are applied to tenement selection, electrical surveys including MT and particularly electromagnetics (EM) can map the depth of conductive post-Proterozoic basins.

TENEMENT SCALE VECTORS

The first step at the tenement scale is to interpret the basement geology by combining detailed gravity and high resolution magnetic datasets with the available drilling. This provides a lithological and structural interpretation to refine targeting.

The only economic IOCG deposits discovered to date in the Gawler Craton have an association with hematite; as a result gravity is the premier discovery tool. Olympic Dam was discovered while testing a gravity and magnetic anomaly considered as a basement high in regional data (Esdale et al., 2003). Prominent Hill was discovered by the drilling a gravity high with an offset magnetic anomaly, to test the model of a higher level hematite system with a transition to magnetite at depth (H Freeman, pers. comm.).

The relationship of mineralisation with hematite and peripheral/deep magnetite is well established. Olympic Dam, Oak Dam, Wirrda Well, Carrapateena, Khamsin, Prominent Hill, Neptune-Triton and Torrens all contain a gravity response offset spatially or in wavelength from a magnetic anomaly (Figure 2). Such a relationship should increase a targets ranking significantly but a 'gravity only' anomaly could be the result of complete oxidation of magnetite and be considered favourable as well.

Detection of magnetite IOCG deposits has also been a focus. Large tonnage, low grade, magnetite, pyrite, chalcopyrite deposits have been discovered at Acropolis, Joes Dam and Manxman. The relationship between these deposits and hematite deposits is widely debated. Where no significant oxidation to hematite facies has occurred, economic intersections have not been drilled. Many 'false-alarm' drill holes testing magnetic anomalies, with or without perfectly coincident gravity anomalies, are not a vector to economic IOCG mineralisation. However such anomalies are vectors to mesothermal vein/skarn mineralisation at Cairn Hill and Hillside.

A characteristic of sensu-stricto IOCG deposits is a lack of sulphur in the mineralisation system (Groves et al., 2010). This is true in the Gawler Craton with sulphide mineralisation occurring as disseminated blebs and minor veins. As a result, the most successful electrical technique has been Induced Polarisation (IP). Conceptually, if iron oxides form a small component of the IOCG system, IP surveys will work as a stand-alone target generation and local geology mapping tool. Where significant volumes of iron oxides (5-50%) are observed, IP is an excellent screening tool of gravity +/- magnetic anomalies to prioritise drilling.

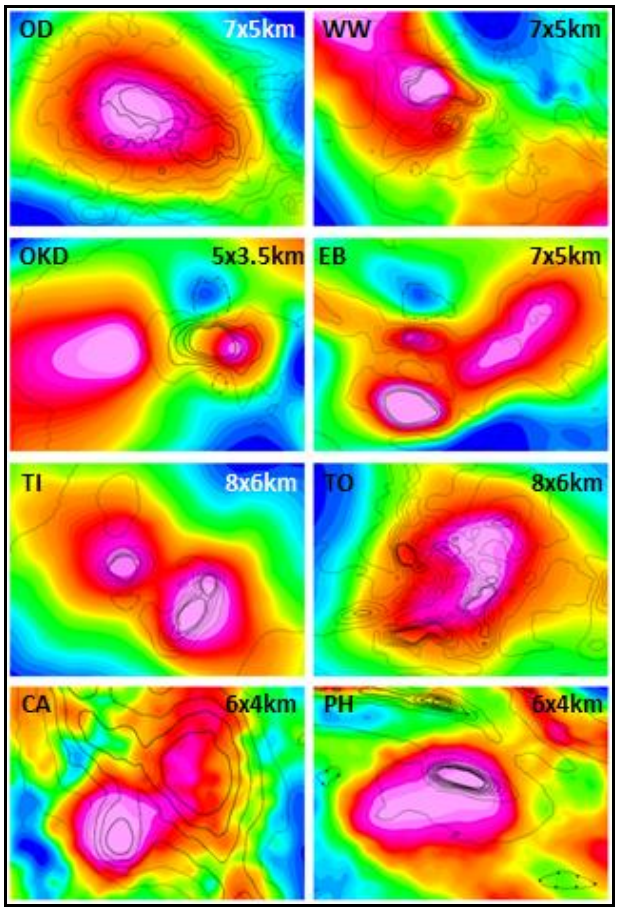

Figure 2. Residual gravity grids (local colour histograms) with 1VD RTP magnetic contours at OD: Olympic Dam, WW: Wirrda Well, OKD: Oak Dam, EB: Emmie Bluff, TI: Titan, TO: Torrens, CA: Carrapateena and PH: Prominent Hill. All data sourced from DMITRE except CA and PH from OZ Minerals datasets.

The combination of gravity and IP surveys is an effective tool to discriminate IOCG deposits from gravity only 'false

alarms'. Olympic Dam and Prominent Hill both have coincident chargeability and gravity anomalies (Esdale et al., 2003, Hart and Freeman, 2003). A significant limitation of IP surveying is the highly conductive cover, variations in the conductivity of the cover result in no recognisable anomaly over Carrapateena but a strong response, at similar depths, only 9km away at Khamsin with the same survey specifications (Figure 3). Where the IP is considered an effective test, a chargeability anomaly coincident with a gravity anomaly is a strong indication of a hematite iron oxide deposit. The lack of a potential field anomaly will similarly downgrade a 'chargeability-only' response.

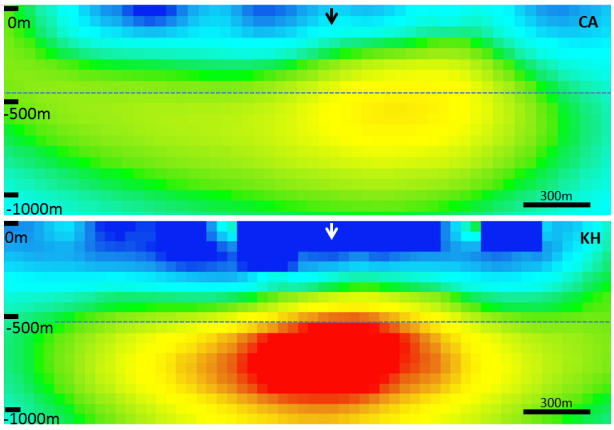

Figure 3. North-South chargeability sections through CA: Carrapateena (top) and KH: Khamsin (bottom). Deposits locations are beneath arrows, dashed line is top of basement.

Resistivity data collected with IP, EM (ground and airborne), controlled source audio magnetotellurics (CSAMT_ and MT surveys is also a vector, though it generates a significant number of false positives. Initial ground EM surveys at Olympic Dam, Carrapateena and Prominent Hill failed to detect the IOCG deposits but Esdale et al. (2003) allude to later success at Olympic Dam. MT data collected with the Mt Isa mines data acquisition system (MIMDAS) system by MIM resolved a low resistivity anomaly broadly coincident with the gravity anomaly at Carrapateena that was targeted with the discovery hole. MT collected with the MIMDAS system was collected at Prominent Hill and also shows a low resistivity zone coincident with the IOCG system.

Regional 2D and 3D IP resistivity surveys completed in the Mt Woods Inlier and on the Stuart Shelf has produced numerous low resistivity anomalies similar to IOCG responses that drilling has shown to be 'false alarms'.

The uptake of seismic methods in mineral exploration is proving to be an excellent tool for high resolution mapping of the basement-cover interface. No technique has reliably distinguished density contrasts in the basement rocks from variations in the basement topography. Using gravity and magnetic data in isolation has resulted in many drill holes into hills of barren basement.

In 2012 a reflection seismic survey was completed by OZ Minerals on the southern margin of the Mt Woods Inlier (Harris et al., submitted). The survey produced a high resolution profile of the basement topography which demonstrates the technique is an excellent dataset to correct gravity and magnetic grids for the palaeotopography, leaving a clearer map of density variation within the prospective basement rocks. In addition to the reflection surveys, refraction models produce velocity estimates for the basement lithology's that, when combined with drilling, help map geology. A 5.6x5km survey area completed at Carrapateena by OZ Minerals in 2013 produced a grid of the palaeotopography (to correct gravity and magnetic data) and the velocity of the lithology at the top of basement. The velocity contrast between iron oxide alteration and unaltered granite, in this instance, means velocity variation is a proxy that maps the extent of the IOCG alteration.

Mapping of the basement-cover contact will provide the single biggest step forward in exploring for IOCG mineralisation undercover. Resolving this interface will improve confidence in geophysical interpretations and make geophysical vectors more reliable.

DEPOSIT SCALE VECTORS

More detailed gravity and magnetic surveys are often first completed after the intersection of iron oxide alteration. At Prominent Hill, the improved resolution shows the density correlates with strong silica-hematite +/- gold alteration more than the copper-rich hematite breccia's. At Olympic Dam, drillholes RD6, RD7 and RD 17 tested the centre of the known gravity anomaly and intersected barren hematite quartz rocks (Esdale et al., 2003). Also, the centre of the density anomaly at Carrapateena occurs immediately to the north-east of the copper-gold rich zone. Drilling the highest gravity anomalies is not a vector to the highest grade. Petrophysical studies support this conclusion at Prominent Hill where the densest rocks, with greater than 25wt% iron (Fe), are predominantly barren.

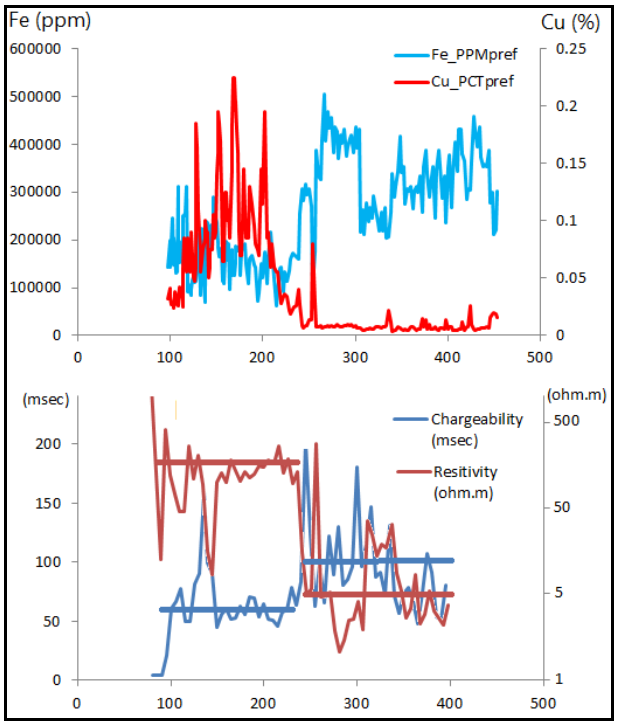

Figure 4. Downhole assay data and IP results from drill hole DP002 at Prominent Hill. IP trend lines show a stepped response related to iron content and not copper.

Magnetic anomalies commonly contain low grade (.1-.2%) copper mineralisation. Deposits with offset magnetic responses predominantly show low grades associated with magnetite. The best grades occur where magnetite is absent, occurring in association with haematite and sericite alteration. These high grade zones generally occur immediately above, adjacent to or both, from the low grade magnetite mineralisation. Magnetic anomalies are not a direct vector to mineralisation but their margins may be favourable.

Resistivity and chargeability has been completed within drillholes and on drillcore samples at Prominent Hill (Hart and Freeman, 2003) and Carrapateena (Vella and Cawood, 2012). The results show that chargeability and resistivity at both deposits is directly correlated with iron content and not copper or gold (Figure 4). Anecdotal evidence suggests specular hematite and crystalline dark grey hematite are the mineral pseudomorphs most responsible for the chargeability response. Downhole surveys at Prominent Hill show variation from conductive hematite alteration zones to resistive silica-hematite alteration within the broader conductive regime.

Surface and downhole EM, IP, CSAMT and mise a la masse has not distinguished mixed sulphide and iron oxide from barren iron oxide alteration at Carrapateena, Prominent Hill or from the work of Esdale et al (2003) work at Olympic Dam. The electrical response of the iron oxides dominates that of the sulphides rendering electrical methods ineffective for the direct detection of mineralisation within a hematite IOCG system.

Analyses of the acoustic properties of four mineralised and six non-mineralised hematite breccia hand samples at Prominent Hill suggest both are indistinguishable with velocities between 4500-5650ms^{-1}, attenuations of 140-360Vm^{-1} and acoustic impedances ranges of 17100-22600.

CONCLUSIONS

Geophysics is the primary exploration tool for IOCG exploration in the Gawler Craton due to the widespread cover over the prospective rocks. Gravity, magnetics and seismic are vectors at the terrane scale. Interpreting geology, mapping the basement topography, gravity highs +/- associated offset magnetic responses, chargeability highs and resistivity lows are vectors at the tenement scale. Though at the deposit scale these techniques fail to directly detect, or provide vectors to mineralisation within an IOCG deposit.

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REFERENCES

Austin, J., Foss, C., 2012, Rich, attractive and extremely dense: A geophysical review of Australian IOCGs, ASEG Extended Abstracts 2012 , 1–4.

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; conomic Geology, v. 102, 1415-1440.

Belperio, A., Flint, R. and Freeman, H., 2007 - Prominent Hill: A Hematite-Dominated, Iron Oxide Cu-Au System; Economic Geology, v. 102, 1499-1510

Davidson, G.J., Paterson, H., Meffre, S. and Berry, R.F., 2007, Characteristics and origin of the Oak Dam East breccia-hosted, iron oxide-Cu-U-(Au) deposit: Olympic Dam region, Gawler craton, South Australia; Economic Geology, v. 102, 1471-1498

Drexel, J.F., Preiss, W.V. and Parker, A.J., 1993, The Geology of South Australia, Vol 1, The Precambrian, South Australia, Geological Survey, Bulletin 54.

Esdale, D., Pridmore, D.F., Fritz, F., Muir, P., Williams, P., Coggon, J., (2003) The Olympic Dam copper-uranium-gold-silver-rare earth element deposit, South Australia: A geophysical case history.ASEG Extended Abstracts 2003 , 147–168.

Gow, P. A., Wall, V. J., and Valenta, R. K., 1993, The regional geophysical response of the Stuart Shelf, South Australia: Exploration Geophysics, v. 24, 513-520.

Groves, D.I., Bierlein, F.P., Meinert, L.D. and Hitzman, W.M, 2010, Iron Oxide Copper-Gold (IOCG) Deposits through Earth History: Implications for Origin, Lithospheric Setting, and Distinction from Other Epigenetic Iron Oxide Deposits: Economic Geology, 105, 641-654.

Harris, T.M., Funk, C.W., Murphy, F.C., Betts, P.G., submitted, Mt Woods 2D Seismic Reflection Survey, Gawler Craton, South Australia: An Integrated Minerals Exploration Case Study. Australian Society of Exploration Geophysicists, Extended Abstract

Hart, J. and Freeman, H., 2003, Geophysics of the Prominent Hill prospect, South Australia; in Dentith, M.C., (ed.), Geophysical Signatures of South Australian Mineral Deposits, Australian Society of Exploration Geophysicists, Special Publication 12, 93-100.

Heinson, G.S., Direen, N.G., Gill, R.M., 2006, Magnetotelluric evidence for a deep-crustal mineralizing system beneath the Olympic Dam iron oxide copper-gold deposit, southern Australia, Geology. 34(7), 573-576

Reynolds, L.J., 2000, Geology of the Olympic Dam Cu-Au-Ag-REE deposit, in Porter, T.M., ed., Hydrothermal iron-oxide copper-gold and related deposits: A global perspective: Adelaide, Australian Mineral Foundation, v. 1, 33–48.

Smith, R.S., 2002, Geophysics of Iron-Oxide Copper-Gold Systems, in - Porter, T.M. (Ed), Hydrothermal Iron Oxide Copper-Gold and Related Deposits: A Global Perspective, PGC Publishing, Adelaide, v.2, 357-367.

Vella, L., 1997, Interpretation and modelling, based on petrophysical measurements, of the Wirrda Well potential fi eld anomaly, South Australia; Exploration Geophysics, v. 28, 299-306.

Vella, L. and Cawood, M., 2012, Geophysical Characteristics of the Carrapateena Iron-Oxide Copper-Gold Deposit, ASEG Extended Abstracts, Vol. 2012 No. 1, 1-4.