New mineral system vectors for revitalised copper-gold discovery in the Gawler Craton

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SUMMARY

Combination of a new strato-tectonic model for the Olympic Metallogenic Event (OME) and a zircon-based geochemical tool offers a significant step-change for ore target vectoring for a spectrum of IOCG and coeval copper-gold deposit styles in the Gawler Craton.

The model proposes the Paris-Nankivel epithermal-porphyry belt formed at the same time as Olympic Dam on the margins of a super caldera filled with Gawler Range Volcanics (GRV). Prior subduction tectonics produced precursor conditions suitable for the formation of epithermal and porphyry copper deposits on the southern shoulder of the caldera, whereas IOCGs formed on the northern and eastern margins with haematite- or magnetite-dominated systems respectively formed on the shoulder or in hotter more reduced conditions within the caldera. A stratigraphic marker of the OME palaeosurface and caldera formation includes volcanogenic conglomeratic facies collapsed into the IOCG pipes. The marker provides a correlation and an upper strato-tectonic limit to the OME mineralization across the craton.

The Zircon Alteration Index (ZAI = 40 – Zr/Hf) is a robust search tool that is universally applicable to the OME spectrum of deposit styles and hosts. The exclusive association of Hf with Zr in zircon enables wholerock analysis of the Zr/Hf ratio to measure the amount of hydrothermal overprinting of the inherited volcanic or detrital zircon in a host rock and hence proximity to a mineral target. ZAI targeting requires less drilling and assay samples. Comparison of downhole ZAI profiles and strato-tectonic lithologies often enables lateral or vertical target vectors to be estimated for single holes.

Vectoring with ZAI has been validated in the Stuart Shelf with a comprehensive study of 35 holes in varying proximities to known IOCG systems. Preliminary target ranges are assigned to the ZAI values and 8 holes nominated for review as being proximal to new targets.

Key words: copper, exploration, IOCG, Gawler Craton

INTRODUCTION

After the discovery of the Olympic Dam copper-gold-uranium deposit in 1975 and the subsequent recognition of the haematite iron oxide copper gold (HIOCG) class of mineral deposits, further discoveries were slow in coming until several were made in the noughties applying the paradigm of combined magnetic/gravity targeting. Discoveries again dried up as paradigm became dogma until the Oak Dam West discovery (King, 2021) affirmed the use of the mineral system approach is likely to reveal more of an expanding spectrum of copper-gold deposits in the Hiltaba Granite/GRV Super Large Igneous Province (Figure 1).

Discoveries of epithermal deposits along the southern margin of the GRV massif raised the possibility from about 1994 for a spectrum of coeval gold, silver, lead, zinc, copper and possibly nickel mineralisation (Anderson, 2016). Paris is an intermediate-sulphidation silver deposit within a 100sq km system featuring a precursor monzodiorite of the St Peters subduction suite, lithocap, advanced argillic alteration, propylitic epidote actinolite alteration and skarn copper gold mineralisation typical of the upper levels of a porphyry system (Anderson, 2017). The Paris-Nankivel system has been dated (Payne et al. 2019; Nicholson et al., 2017) within error range of the 1590Ma age generally accepted for the Olympic Dam mineralisation (Ehrig & Clark, 2019). The syn-mineralisation fluorite rhyolite dykes at Paris have unique geochemistry characteristic of intrusives associated with large mineral systems (Halley, 2020).

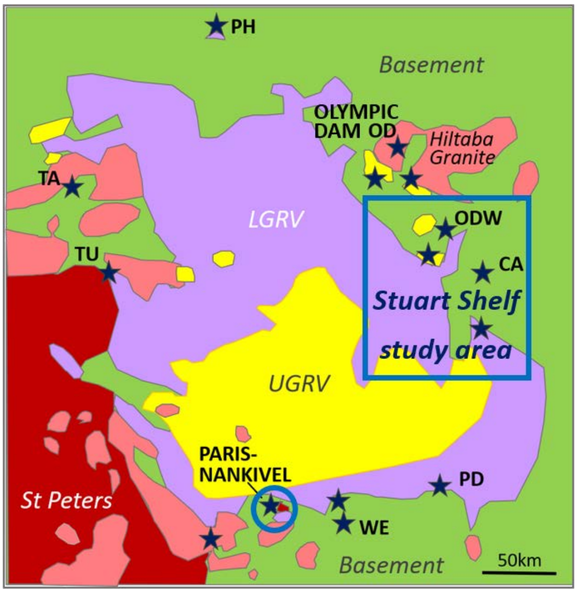

Figure 1. Geological interpretation plan of the Hiltaba-GRV SLIP showing key mineral deposits as stars.
IOCGs: ODW – Oak Dam West, CA – Carrapateena, PH – Prominent Hill; **Epithermal & other gold occurrences**: PD - Parkinsons Dam, WE – Weednanna, TU – Tunkillia, TA – Tarcoola

During the last decade, a mineral systems approach has been increasingly applied to targeting research in particular seeking mineral and geochemical pathfinders using new spectral and 4-acid ICP technologies. This included studies in the Stuart Shelf district (Figure 1) by the Geological Survey of South Australia (GSSA) (Fabris et al., 2013).

A long proponent of mineral system exploration, the author integrated 30 years' experience of exploration/collaborative research in the craton with others' research outcomes in the search of breakthroughs to improve waning exploration and copper discovery rates in South Australia (Anderson, 2017; 2020). With the aim of opening up the discovery space and producing better predictors of copper deposits, several concepts developed during 1994 to 2019 were tested and validated in the relatively well-drilled and data-dense Stuart Shelf district.

NEW CONCEPTS

Super Caldera & Precursor Subduction

To explain the rapid co-formation of belts of IOCGs, epithermal precious metals and potential porphyry-skarn copper deposits, a revised tectono-metallogenic model is proposed (Anderson, 2016, 2020). Parallel epithermal/porphyry and IOCG belts are both fluorine anomalous, associated with low εNd granites and connected by a conductive magneto-telluric (MT) corridor possibly representing a fossil transfer fault and metal source along the mantle interface. Analogy with the belt polarity of the coastal batholith of Chile places a subduction front to the northeast of the current Gawler Craton consistent with the preceding collision of the North Australia Craton. With subduction also indicated by the St Peters Suite on the southern side of the Craton, a double-subduction hypothesis of extreme mantle metasomatism would explain the super-sized Olympic Metallogenic Event (Anderson, 2017). Others have proposed elements of the subduction setting for the IOCG deposits (e.g. Tiddy & Giles; 2020). Fluids and metals were rapidly released on extension and collapse of the Gawler Caldera between the deposition of the Lower and Upper GRV. Precursor subduction conditions varied around the caldera producing different metallogenic environments with IOCGs to the north and epithermal-PCD potential in the south (Figure 2).

OME Deposit Spectrum

This elevates the potential for a spectrum of deposit styles that formed during the OME, some of which will not have the density contrast relied on to delineate deeper and more subtle gravity signatures in recent times. Exploration is revitalised both for parts of the craton remodelled for the OME and for brownfields IOCG areas where prior dogma has limited testing with even shallow potential remaining. Potential for hybrid deposits should also be considered in the transition zones between the IOCG and epithermal belts.

Mid-GRV Marker (MGRVM)

Recognising the potential for a spectrum of coeval deposits, the author postulated a mid GRV stratigraphic marker (MGRVM) in the nineties. The MGRVM was first identified regionally in historic drill holes during 2015 and supported by precise dating of the GRV stratigraphy (Jagodzinski et al., 2016). Variants of the MGRVM are identified as stratigraphic correlates of the OME across the caldera (Figure 2). First recognised outside Paris as a volcanogenic quartz conglomerate at Red Lake separating the LGRV and UGRV within the caldera, the MGRVM is now correlated with the thin remnants of the Bitalli Rhyolite on the southern shoulder, an advanced argillic cap of alunite, pyrophyllite, dickite and topaz at Nankivel Hill and ferruginous maar-like sediments on the eastern and northern shoulder of the caldera. These sediments collapsed into the underlying HIOCG breccias at Olympic Dam, Oak Dam West and Emmie Bluff (Figure 4). Volcanogenic quartz conglomerates are also preserved in the eroded Khamsin and Carrapateena breccia pipes (Neumann, 2019).

Zircon Alteration Index (ZAI) tool

During a geometallurgical study by CSA Global, Scott Halley pointed out the highly prospective wholerock Zr/Hf ratio of 20 in the late mineralizing dyke phase at Paris. The precursor subduction intrusives and early Hiltaba granites have ratios of about 38. The Paris breccia ore shows mixing values between the end members of 38 and 20. Schlegel et al., 2016 confirmed the connection of IOCG sulphur to magmatic Hiltaba sources. Studies of igneous and detrital zircon compositions around IOCGs support the concept of hydrothermal overprinting with decreasing Zr in altered zircons (e.g. Courtney-Davies and Verdugo-Ihl, 2019).

A **universal geochemical model** is therefore proposed for the OME (Anderson, 2020) (Figure 3). The exclusive association of Hf with Zr in zircon enables the wholerock Zr/Hf ratio to measure the amount of hydrothermal alteration of host rock zircon and hence proximity to a mineral target. The **Zircon Alteration Index (ZAI = 40 minus Zr/Hf)** is a simplified alteration metric of 0 lowest to 20 highest.

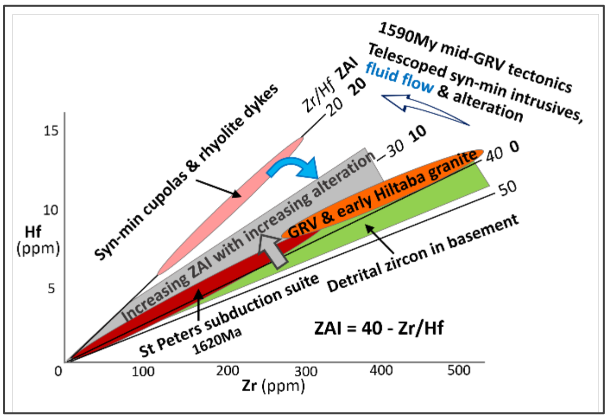

Figure 3. Geochemical Model for the 1590Ma Olympic Metallogenic Event. The overprint of zircons by hydrothermal fluids derived from fractionated ("mineralisisng") 1590Ma Hiltaba intrusives is agnostic to whether these are primary igneous zircons or inherited detrital zircons in metasediments. Data from Paris and Stewart and Foden (2003) show consistent "starter" wholerock Zr/Hf values of around 38 for the Hiltaba and St Peters Suite. As metasedimentary zircon can range higher, a Zr/Hf ratio of 40 (ZAI = 0) is selected as the nominal wholerock signature for unaltered rocks.

VALIDATION FOR STUART SHELF IOCGS

The prior study by the GSSA provided an excellent platform for evaluation of the strato-tectonic concepts and ZAI tool. The GSSA re-assayed thirty-five exploration holes (Figure 5) for a pathfinder suite with 4-acid/ICP and established a Pathfinder Prospectivity Index (PPI) using an algorithm of eleven widely-accepted pathfinder elements. The GSSA assay data were used to assess the viability of the ZAI geochemical model in the context of the proposed caldera setting.

The caldera model is supported by the distribution of haematite IOCGs up on the shoulder whereas the magnetite IOCG (MIOCG) deposits are situated within the caldera (Figure 5) presumably due to hotter, more reduced conditions. Outside the study area, Acropolis is another example of an MIOCG in a local graben adjacent to the Olympic Dam HIOCG deposit previously interpreted to be on a horst (J. Hronsky, pers. comm.). The HIOCGs possibly formed beneath the more oxidised palaeosurface in half grabens behind a series of normal faults at the caldera margin.

ZAI Study

With the possibility the Paris ZAI signature was solely due to physical breccia mixing, a rare drillhole with dykes associated with magnetite-hosted mineralisation was first selected at Winjabie for study as the closest hydrothermal analogy to the Paris. The hole showed the predicted Zr/Hf variations as alteration and mineralisation increased towards the mineralising dykes which have ZAI as high as 17, close to the ZAI signature of 20 for the Paris syn-min dykes. Comparison of downhole ZAI values with more usual pathfinder elements and derivative algorithms such as the GSSA PPI show ZAI has more consistent values and informative profiles.

The next step was comparison of ZAI profiles with stratigraphy particularly for the MGRVM as the proposed upper limit to OME mineralisation. Two test scenarios were selected, one within the caldera and one on the shoulder. The MGRVM was mapped in the caldera at Red Lake (Figure 5) as separating the UGRV with consistently low (unaltered) ZAI, from the LGRV with an erratically higher ZAI reflecting sporadic alteration including fluorite and tourmaline characteristic of the OME. This is underlain by mineralised basement with a consistent high ZAI signature of alteration. For the shoulder trial at Chianti, the ZAI shows the MGRVM is altered with decreasing ZAI downhole into the basement. This profile is interpreted as showing the MGRVM is proximal in a lateral direction to known haematite/bornite mineralisation.

The holes around Emmie Bluff, Khamsin, Carrapateena and Punt Hill show the same consistent ZAI variations approaching their respective deposits and were accordingly used to establish a **Target Proximity and Vector Template** (Figure 4). Despite the limited coverage of the study holes, comparison of the results for different prospects enabled an initial estimate of the target range for holes with a Proximal rating (ZAI = 4-5) as 500m to 5km and for the Distal rating (ZAI = 2-3) as 5km to 8km. The validation warrants research on more holes adjacent to deposits to refine the target ranges of the strato-tectonic/ZAI template.

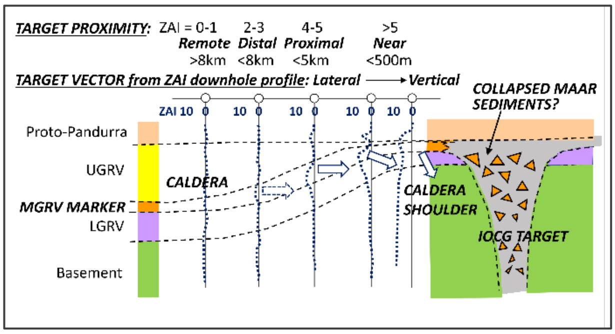

Figure 4. Target Proximity and Vector Template for the strato-tectonic model placing haematite IOCGs on the shoulder of the Gawler Caldera.

Figure 4 also shows the Pandurra (Sandstone) Formation transitionally overlying the MGRVM as described by early loggers in the Emmie Bluff district. This raises the possibility of a proto-Pandurra having an early age of 1587Ma. Positive ZAI signatures would therefore represent primary OME alteration rather than the secondary physical dispersion in Pandurra cover interpreted elsewhere. This has significant exploration ramifications.

Target Vectoring

The shapes of the profiles as summarized in Figure 4 may also provide two-dimensional target vectors for a single hole; i.e. downwards or laterally in an unspecified direction away from the hole. Three-dimensional vectors can be attained by adding the ZAI intensity of adjacent holes, relative position on the caldera margin and other mineral system inputs such as the mapping of fluid/metal pathways with gravity gradient strings and magneto-tellurics (MT). Emmie Bluff Deeps is an example where steepening ZAI vectors point downwards through increasing haematite and brecciation towards an MT conductive pipe. This analogy to the MT signature (Thiel et al., 2019) and setting at Oak Dam West warrants deeper drilling.

Such integrated proximity/vector analyses were undertaken for the balance of the 35 holes in the study area (Figure 5). Including Emmie Bluff Deeps, eight prospects are recommended for reappraisal by the tenement holders.

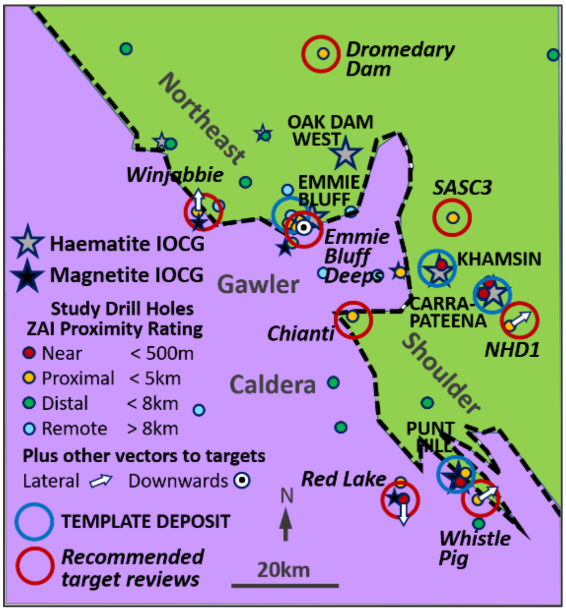

Figure 5. Stuart Shelf Study Area – Plan of the interpreted margin of the Gawler Caldera: Summary of ZAI hole analysis showing deposits used to establish a template for target proximity estimates. The template was used to determine other holes with potential for proximal copper-gold targets.

CONCLUSIONS

The Zircon Alteration Index potentially offers a simpler, more reliable and further seeing measure of target proximity that requires less drilling and assaying compared with prior pathfinders. Comparison of downhole ZAI profiles with reinterpreted strato-tectonic geology may enable 2-dimensional target vectors and target distances to be estimated for single holes requiring minimal penetration of the basement prior to deeper drilling decisions. Stronger 3-dimensional vectors can be obtained by either ZAI analysis of adjacent holes or other supporting mineral system vectors such as upwards mapping of interpreted fluid pathways by MT and gravity gradient strings.

This study and the target recommendations are limited to Stuart Shelf holes with the required 4-acid ICP analyses. Geological reinterpretation and re-assaying of any adjoining holes and more regional holes are warranted to build the ZAI analysis, research and targeting throughout the caldera particularly where prospective gravity, structural and MT features are evident. Additional MT surveying and strategic drilling are also desirable to extend and integrate the new mineral system inputs in advancing the search for deposits with and without the potential field signatures used in past IOCG exploration.

ACKNOWLEDGMENTS

Graham Heinson for the MT models around Emmie Bluff. OZ Minerals Ltd., Department of Mining and Energy South Australia and Unearthed for the incentives of their 2019 and 2020 crowd-sourced competitions to consolidate and advance these ideas. Colleagues at the Australian Institute for Machine Learning/DeepSightX team in achieving second prize in the Explorer Challenge. And Investigator Resources colleagues who contributed to the discovery or drill-out of Paris.

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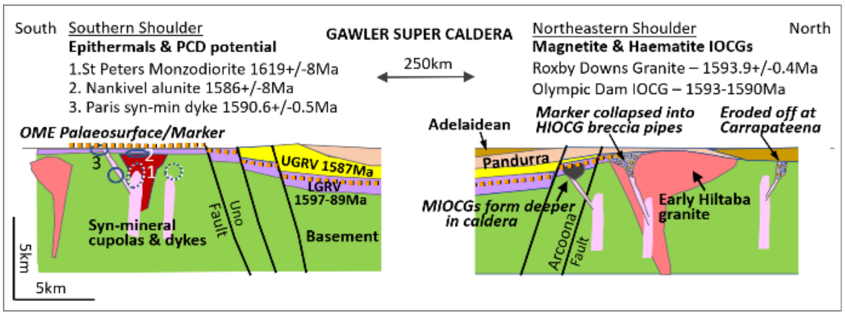

Figure 2. Regional Long Section looking west across the proposed Gawler Super Caldera with different copper gold deposit styles determined by precursor subduction preparation.