Which anomaly should I drill? Using spatial statistics to inform exploration in covered IOCG terranes

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INTRODUCTION

The Olympic Copper-Gold Province within the Gawler Craton, South Australia (Figure 1) is the type location of the hematite-rich end-member of the iron oxide copper-gold (IOCG) family of deposits, hosting the Olympic Dam, Prominent Hill and Carrapateena deposits (Skrirrow et al., 2002; Belperio et al., 2007). There are thousands of gravity and magnetic anomalies within and adjacent to the Olympic Copper-Gold Province (Figures 2 and 3). Given that geophysics plays a major role in target generation for IOCG deposits in the region, significant benefit can be derived by an efficient method of delineating, mapping and classifying these anomalies in order to identify and prioritize potential drill targets.

This abstract provides a summary of some of the key findings regarding using spatial statistics to inform exploration in covered IOCG terranes from a paper currently in press (in Iron oxide copper-gold (Ag-Bi-Co-U-REE) and affiliated deposits, Corriveau, L., Mumim, A.H. and Potter, E.G., eds, Geological association of Canada, Short Course Note 21). Further details can be found in Katona and Fabris (2019, in press).

Potential field geophysical techniques characterize IOCG deposits as gravity highs that are spatially coincident, but often offset from an associated positive magnetic anomaly ( Gow et al., 1993; Eisdale et al., 2003; Hart and Freeman, 2003; Porter, 2010; van der Wielen et al., 2013).

These results could be used as a starting point in developing IOCG exploration strategies, due to the high number of additional untested, spatially coincident gravity and magnetic anomalies that warrant further investigation.

Key words: Gawler Craton; IOCG mineralisation; spatial statistics.

SUMMARY

This contribution presents a method for efficiently classifying geophysical anomalies and identifying regions and features that share characteristics of many known iron-oxide-copper-gold (IOCG) deposits of the Gawler Craton, and can therefore be used in drill target prioritization. Residual Bouguer gravity and reduced-to-pole total magnetic intensity grids over the Gawler Craton were transformed, generating polygon datasets representing populations of locally anomalous gravity and magnetic intensity. Taken as simple anomaly polygons, there are a very large number of features across the Gawler Craton (>39,000 TMI and >10,000 gravity). Superimposing mineral deposits over these features shows a clear spatial correlation between IOCG deposits and occurrences, and anomalies (>90% of deposits within 1,000 m of an anomaly), but leaves thousands of anomalies of varying magnitudes that cannot all be related to IOCG mineralization. Eliminating TMI and gravity anomalies with a separation of more than 1,000 m reduced the search space to ~20,000 TMI features and ~8,500 gravity features. Limiting the search to a statistically derived gravity threshold ≥0.4 mGal gravity anomalies, the exploration space is reduced to 798 gravity features with coincident TMI features within the Olympic Copper-Gold Province. The Anselin Local Morans I method was used to delineate geographic regions based upon spatial clustering of high magnitude anomalies. The spatial distribution and clustering characteristics of the gravity anomalies provide additional information and can be related to differing basement geology and deposit style. Terranes where lithologies and Cu-Au occurrences are commonly magnetite-rich show clustered high-magnitude gravity anomalies, and correlated spatially with the Mount Woods and Moonta domains within the eastern Gawler Craton. Importantly, it was found that the central, and currently most endowed, the Olympic Domain, was distinct in that it was dominated by spatial outliers (discrete high-magnitude density features).

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METHOD AND RESULTS

A residual Bouguer gravity grid with a 100 m cell size was produced (Figure 2) by subtracting a 1,000 m upward continued Bouguer gravity grid from the original Bouguer gravity grid. The same process was applied to a variable-reduced-to-pole (VRTP) total magnetic intensity (TMI) grid with an 80 m cell size (Figure 2). In each case, this processing attenuated anomalies related to deeper sources and sharpened anomalies associated with shallower sources (McCafferty et al., 2016; Katona et al., 2018).

A geoprocessing routine (Katona et. al, 2018) was applied to each grid, generating GIS polygons defining localized...
geophysical anomalies (Figure. 3). The routine used distance thresholds for the maximum perimeter distance of each anomaly polygon (25 km for gravity and 50 km for TMI). All polygons were tagged with underlying grid information including minimum, maximum and mean values. Other attributes computed during the processing included the perimeter contour value of each anomaly and the “magnitude” of each anomaly which was calculated by subtracting the maximum anomaly value from the contour value. A positive geophysical anomaly was defined if the mean value within the polygon was greater than the value of the contour defining it. The offshore anomaly polygons for gravity and TMI were discarded due to the low resolution of the offshore data.

A total of 104 Gawler Craton crystalline basement hosted copper-gold deposits (Department for Energy and Mining, 2019) in the study were used as criteria to identify an association with gravity and magnetic anomaly highs, either overlapping or in close proximity to the deposits.

The evidence of spatial clustering of gravity and TMI polygons was checked using the Getis-Ord General G (Getis et. al., 1992) spatial statistics tool in ArcGIS 3D, which tests the null hypothesis that apparent clustering of high magnitude anomalies is the result of random chance. This process confirmed at a 99% confidence interval that high magnitude gravity and magnetic features cluster spatially within the area of interest.

A cluster and outlier analysis (Anselin Local Morans I (Anselin, 1995), ArcGIS 3D) was then applied separately to the gravity and TMI polygons to map each feature as clusters or outliers based on magnitude, the results indicating which high and low magnitude gravity and magnetic features are spatially clustering and which are spatial outliers. An overlay proximity analysis was then applied on the gravity and magnetic clusters and outliers to determine spatial coincidence (within 1000 m) between gravity and corresponding magnetic anomalies, with non-coincident features discarded (Figure. 4).

Within the onshore Gawler Craton there were 39,047 TMI anomalies of which 20,345 were within 1000 m of a gravity anomaly. There were 10,259 gravity anomalies in total, of which 8,510 were within 1000 m of a TMI anomaly.

Of the 104 copper-gold deposits in the region, 97% were within 1,000 m of a TMI anomaly; 93.2% were within 1,000 m of a gravity anomaly and 70.2% were within 1,000 m of a gravity anomaly that is coincident (within 1,000 m) with a TMI anomaly. These copper-gold mines and occurrences were found to cluster into three distinct groups; one located in the northwestern part of the province, with 18 deposits; one in the central part of the province, with 28 deposits; and the third in the southern part of the province, with 58 deposits (Figure. 4).

Four specific types of clusters and outliers are produced by the cluster and outlier analysis. High clusters (a statistically significant cluster of high magnitude features), high-low outliers (a statistically significant high magnitude feature, surrounded by features with low values), low-high outliers (a low magnitude feature surrounded by statistically significant high values), low clusters (a statistically significant cluster of low magnitude features) and a “not significant” class of features that satisfies the null hypothesis and displays no statistically significant clustering. High magnitude clusters, high magnitude outliers and a subset of anomalies displaying no significant clustering have been interpreted to be the most likely IOCG targets.

In addition to developing a workflow to identify semi-coincident magnetic and gravity features of interest, the cluster analysis has enabled the identification of spatial regions with similar anomaly character or texture. The distribution of high-low gravity outliers (and associated low clusters) demark the central part of the Olympic Copper-Gold Province and is the largest grouping of spatial gravity outliers in the Gawler Craton (Figure. 4). This group of gravity outliers forms the most endowed part of the Olympic Copper-Gold Province, where 23 out of the 28, basement hosted copper-gold deposits are coincident with a mapped gravity anomaly that was classified as a spatial outlier. In this region, IOCG deposits are primarily hematite-dominant, and most commonly hosted in felsic intrusive rocks of low-moderate density and magnetic susceptibility (e.g. Donington and Hiltaba suites) and therefore clear gravity outliers (high magnitude features surrounded by features with low values) are formed.

High gravity and TMI outliers common in the central Olympic Copper-Gold Province also extend through the Gawler Range Volcanics Province, potentially extending the area of prospectivity.

In the north-western end of the Olympic Copper-Gold Province, 14 of the 18 deposits and occurrences (including the Prominent Hill mine) are coincident with gravity anomalies, however these are of the high cluster type of gravity anomalies (i.e. statistically significant spatial cluster of high magnitude features). The extent of the region identified by the cluster analysis of both gravity and magnetic data coincides with relatively shallow (<150 m), high metamorphic grade rocks of the Mount Woods Inlier, Coober Pedy and Mabel Creek ridges where basement rocks are generally magnetite-stable and include alternative gravity and magnetic sources to IOCG deposits, such as iron formation and magnetite-bearing orthogneiss (Chalmers, 2007).

The southern-most part of the Olympic Copper-Gold Province, exposed on the Yorke Peninsula, is also dominated by gravity high clusters. Only 17 of the 58 copper-gold deposits are located over a gravity anomaly, however, 42 are in close proximity with gravity high-clusters, indicating some spatial association with high density sources. The remaining 16 deposits are associated with gravity features in the non-significant clustering class. Unlike the central eastern Gawler Craton where many of the copper-gold occurrences relate to discrete, pipe-like magnetic and high gravity bodies, much of the metamorphic Fe in the Moonta Domain is structurally controlled and located along shear zones. In addition, as in the northern Olympic Copper-Gold Province, iron formations in the region present an alternative source of geophysical features.

**CONCLUSIONS**

Mineral exploration relies upon accurate drill targeting, especially in terranes with significant barren cover. The application of potential field geophysical methods to characterize rock packages beneath barren cover is a critical element in any mineral exploration workflow.

The conversion of residual TMI and gravity data to vector GIS layers assist the joint interpretation of complex TMI and gravity grids. High magnitude spatial outliers of residual gravity delineate IOCG deposits within the Olympic Copper-Gold
Province and suggest the existence of a significant number of un-explored or under-explored gravity anomalies of similar tenor to those that host IOCG deposits.

The workflow described in this contribution is regarded as a useful way of identifying potential IOCG targets across the Gawler Craton. In addition, the way in which the gravity anomaly clusters are spatially distributed, relate to differing basement geology and deposit style. Importantly, the geophysical characteristics of hematite-rich deposits can typically be distinguished and mapped based on the spatial distribution of gravity and magnetic features.

The use of gravity and magnetic anomaly classification and cluster analysis has also been shown to be useful for defining geological terranes with similar geophysical character, related to a shared tectonic history and basement geology (Figure 4). Since these factors may influence the style of mineralization, spatial clustering provides an additional means of regional exploration area selection.

The spatial clustering of gravity (and to some degree TMI) anomalies has helped define three sub-regions of the Olympic Copper-Gold Province whose geophysical character are explained by corresponding changes in the fundamental geology within the sub-regions. The main group of high magnitude gravity outliers suggests that the style of high-density sources found in the central part of the province extends beyond the Olympic Domain and includes large portions of the Gawler Range Volcanics Province. Exploration strategies for each of the three sub-provinces should be considered separately, to maximize the chance of success within each region.

This type of analysis and interpretation is an early step in identifying possible location of copper-gold mineralization. A thorough understanding of the specific style of IOCG system should be coupled with analyses such as this in order to identify appropriate relationships between potential deposits and magnetic and gravity data and subsequently identify plausible IOCG targets.

REFERENCES


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Figure 1. Simplified Gawler Craton geology showing the extent of the geological domains in and around the Olympic Copper-Gold Province, South Australia. (Modified from Katona and Fabris 2019, in press.)
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Figure 2. Residual gravity (left) and residual VRTP TMI (right) used to generate polygons of anomalous potential field response, with IOCG deposits and occurrences superimposed. (Modified from Katona and Fabris 2019, in press.)
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Figure 3. Gravity (left) and magnetic (right) anomaly polygons produced from residual grids. (Modified from Katona and Fabris 2019, in press.)
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Figure 4. Spatial clustering of residual gravity (left) and magnetic (right) anomalies. (Modified from Katona and Fabris 2019, in press.)