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Delineating cobalt targets from a galvanic and inductive source Sub-Audio Magnetics (SAM) at the Carlow Castle project, Western Australia

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SUMMARY

The Carlow Castle deposit is located 40 kilometres east of Karratha, Western Australia. The deposit is shear hosted in the Ruth Well Mafic Formation, part of the Roebourne Group. It is interspersed with metagabbro intrusions and brecciated chert cataclastites. Carlow Castle contains Au, Cu and Co mineralisation. Data from a Sub-Audio Magnetic (SAM) survey was acquired in both galvanic and inductive configurations to map structural responses over known mineralisation. On-time Magnetometric Conductivity (MMC), Total Magnetic Intensity (TMI) and Off-time Galvanic Source Electromagnetic (GSEM) data were extracted from the galvanic dipole configuration. Off-time Inductive Source Electromagnetic (ISEM) data were extracted from the loop source configuration. MMC data were combined, modelled and interpreted to rank structural targets around existing Au and Cu mineralisation. This was used in conjunction with Co soil geochemistry as a vectoring tool for further cobalt mineralisation. The MMC data was successful in increasing level of detail over the project. ISEM and GSEM were also compared with previously highlighted VTEM anomalism. Five high and seven medium priority targets were identified for follow up with further drilling.

Key words: SAM, Artemis, GSEM, MMC, cobalt

INTRODUCTION

Sub-Audio Magnetics (SAM) was developed to sample both electrical and magnetic properties of the Earth and is described in Cattach et al. (1993) and Boggs et al. (1998). The method has been used in mineral exploration, environmental leaching and mapping applications, unexploded ordnance detection and archaeology (e.g. Meyers et al., 2005).

SAM methods were deployed over the Carlow Castle project, located within the Roebourne Group of the Karratha Terrane, part of the West Pilbara Superterrane (Hickman, 2016). The survey area is hosted in Ruth Well Formation and Andover mafic intrusions consisting of banded brecciated chert cataclastite, serpentinised komatiite, talc-chlorite schists and banded grey and black chert with intrusions of metagabbro. Historical mine workings litter the survey area, indicating the shallow and easy to access high grade mineralisation.

The objective of the SAM survey was to trial the effectiveness of mapping the known high-grade Co, Au and Cu mineralised structures which were expected to be oriented perpendicularly and near each other. This required orthogonal dipole orientations, with fine line spacing to provide optimal structural definition. The high spatial density SAM data was expected to add increased detail to understanding the structural complexity. The off-time GSEM data was additionally retrieved to examine the potential for mapping gold bearing sulphide structures (Wallace et al., 2015). Based off the results and due to the rapid acquisition, ISEM was attempted and compared to the GSEM results. Sixteen targets were identified consisting of five high priority targets and were selected based off association with an east-west trending conductive feature and proximity to NE fault as a host for mobile fluids. Seven medium priority targets follow similar but less well-defined conductivity pathways, also more loosely associated with Co anomalism. The four low priority targets are again associated with proximity to similar features.

METHOD

Galvanic source SAM measures the magnetic field response generated by a time varying artificial electrical signal channelled between two current electrodes. This electric current is generated by transmitting a low frequency broadband DC waveform (0.125-15 Hz) with a high-powered transmitter and is spectrally separated into several parameters. The resultant data includes; Total Field Magnetometric Conductivity (TFMMC), Total Magnetic Intensity (TMI) and Galvanic Source Electromagnetics (GSEM). TFMMC is the current channelling response through preferentially aligned geological features. In this arrangement, the GSEM response is the off-time decay of the channelled current plus the inductive component of dipole wire. In loop source deployment, TFMMC data are not recovered as no current is channelled however Inductive Source Electromagnetics (ISEM) and TMI are. ISEM data are a traditional inductive loop EM response. Both are considered SAM methods and acquired in the same fashion with Gap Geophysics TM-7 Magnetometer and Geometrics G-822A total field cesium vapour sensor.

In order to allow ease of interpretation, TFMMC data requires several corrections. TFMMC data are corrected for wire and electrode position, EM coupling overburden response and half space approximation. The primary correction includes horizontal component transformation factoring in the direction of current flow between the electrodes into a final product Magnetometric Conductivity (MMC). This is rotated for local magnetic inclination and declination similar to standard RTP magnetics.

The SAM survey at Carlow Castle consisted of two galvanic dipoles with a transmitter frequency of 6.25 Hz and one inductive loop with transmitter frequency of 3.125 Hz. Galvanic dipoles G01 and G02 were orientated perpendicularly. G01 dipole was orientated north-south and G02 dipole east-

west. Survey traverses for galvanic surveys are orthogonal to current flow direction. 50 m line spacing was selected as suitable for the size of structures to be mapped, with a trial of 25 m infill performed as supplementary comparison. G03 was setup by combining the eastern and western electrodes of G02 and survey traverses acquired at 100 m line spacing.

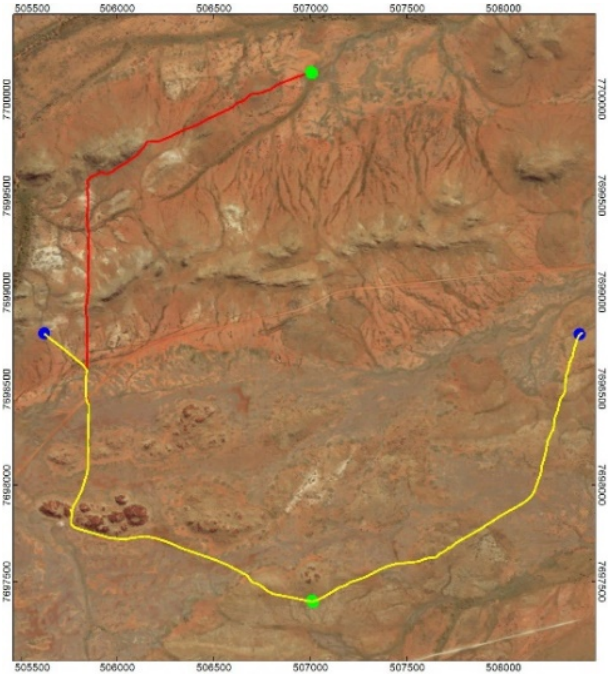

Figure 1. G01 and G02 galvanic wire paths. G01 electrodes denoted by green circle and red wire path. G02 by blue circle and yellow wire path. G03 not shown.

Due to the nature of magnetic surveying in the Pilbara, 6.25 Hz was selected as a good comprise of potentially intense variable magnetic response of host geology and successful spectral separation of the time varying SAM signal. G01 and G02 dipoles achieved 12 A and 13 A respectively transmitted current, achieving high quality signal to noise throughout the survey area. After stacking, data samples averaged 0.5m for TMI, 1-2 m for both MMC, GSEM and ISEM. The combined effort of G01, G02 and G03 was approximately 95 km of walked survey in two weeks with one acquisition team, including all electrode preparation and wire activities.

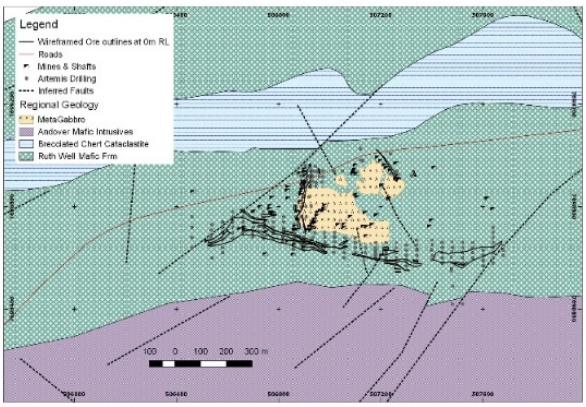

Figure 2. Carlow Castle and Quod Est ore outlines overlain with background geology.

The primary structural orientation was east-west. Some regional shearing and faulting were expected as cross cutting or oblique to this east-west structure and appear as terminations in or as weak conductors siphoning channelled signal. The north-south dipole was expected to counteract this effect and illuminate any potential dislocations or orthogonal faulting in the shearing, common in the goldfields.

RESULTS

The MMC data is shown to have successfully highlighted the zones of interest, in both orientations. The strong southern east-west trending conductive zone over Carlow Castle West and East are prominently displayed in Figure 3 and Figure 4. Broad MMC responses are interpreted to be areas of weathered structure, due to the shallow nature of MMC data. They can also be indicative of drainage or paleochannels. Sharper responses can be attributed to zones that are less weathered unaltered rock. It must also be stated that there are fences in this area that have channelled signal, particularly in the north east part of the survey area. This is also evident potentially in the early off-time GSEM data and is proposed to be carefully interpreted.

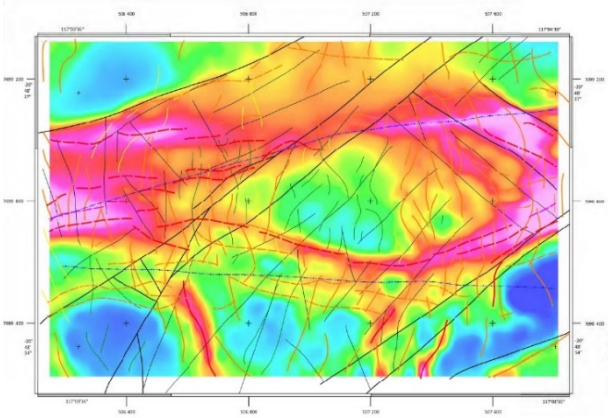

Figure 2. G01 and G02 averaged galvanic MMC interpretation.

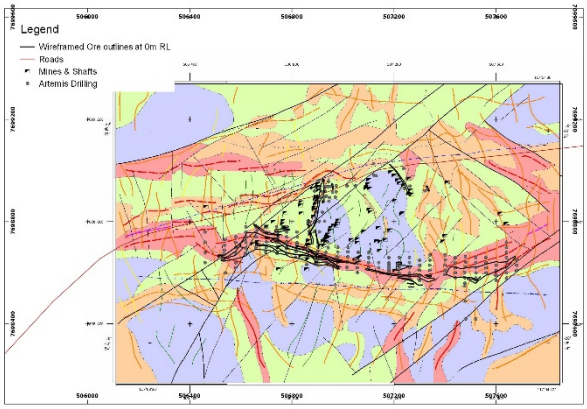

Figure 3. Interpreted structural plot from MMC overlain with averaged MMC, ore outlines and drilling.

Overlain with regional geology, MMC resistive zones (blue lows) are coincident with metabasalt intrusions. Komatiite correlates well with conductivity highs (red), reflecting weathering to clay mineral assemblages. The broad conductivity high is coincident with a chert ridge to the north of the survey grid. Figure 4 displays the merged TMI reduced to pole (RTP) dataset. In this survey area, mapped magnetic

regions are associated with the weakly magnetic komatiite ridge in the north of the survey area or a potentially deeper source. The ridge has been highly faulted in both NE and NW orientations, clearly mapped in the averaged MMC data.

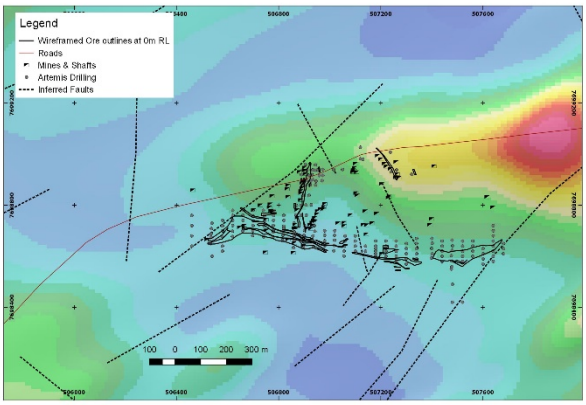

Figure 4. Merged TMI reduced to pole with north shading applied.

ISEM AND GSEM

Electromagnetics from both inductive and galvanic source data were extracted and compared in Figures 5 to 9. G01 and G02 galvanic dipoles were averaged. Early off-time data is comparable to conductivity MMC data, as expected due to shallow nature of current flow. Later time anomalies are apparent in the ISEM, although early time response is compromised by fence location.

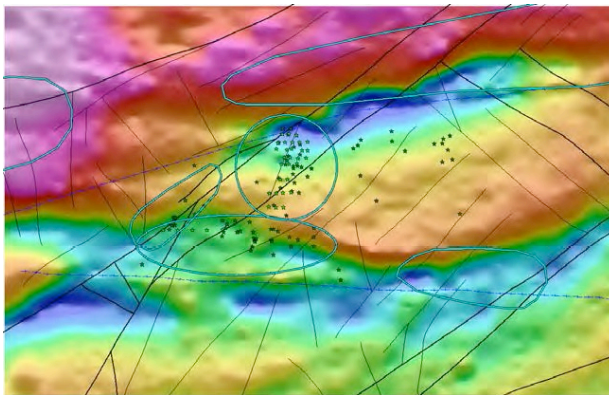

Figure 5. G01 and G02 Averaged GSEM, channel 1 – 1ms, overlain with 2017 and pre 2017 drill locations.

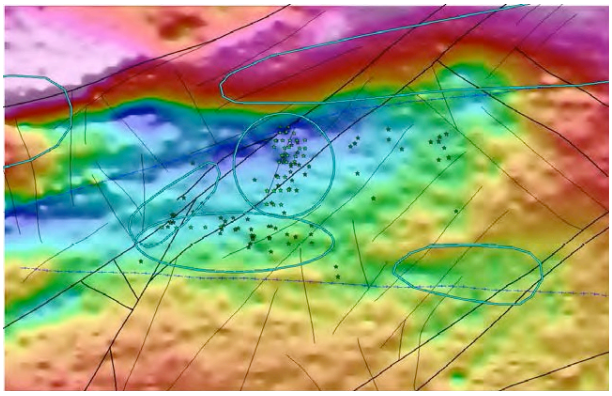

Figure 6. G01 and G02 Averaged GSEM, channel 8 – 5.5ms, overlain with 2017 and pre 2017 drill locations.

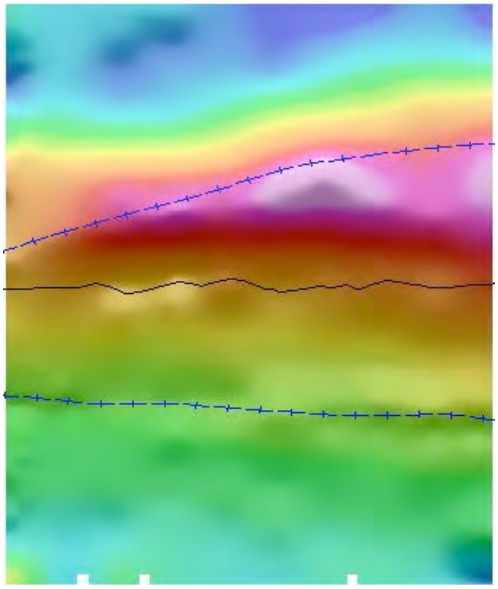

Figure 7. G03 ISEM channel 10 – 8 ms, with previously modelled VTEM plates overlain

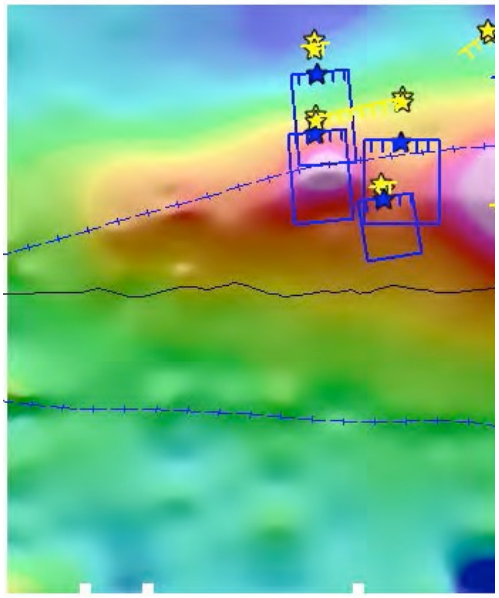

Figure 8. G03 ISEM channel 18 – 45 ms, with previously modelled VTEM plates overlain

GEOCHEMISTRY

Cobalt soil geochemistry was collected and compared to the MMC, GSEM and TMI datasets. Zones of MMC highs correlated well with Co anomalism shown in Figure 9 as contours. Co anomalism was found to be present in areas near highlighted new features, suggested transported cover away from conductive zones along the major NE trending structure.

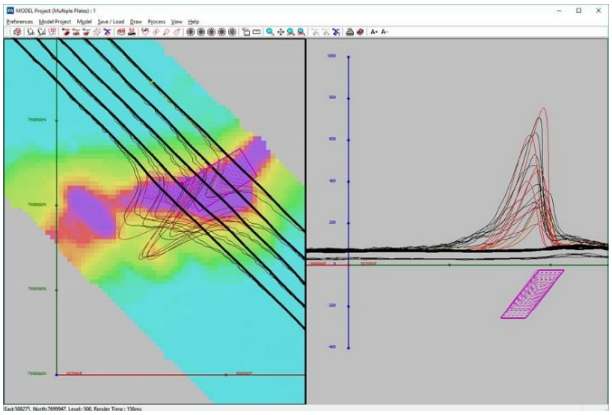

Figure 9. VTEM modelling over Carlow Castle bedrock conductors. Indicated as shallow south dipping features and supported in the ISEM data.

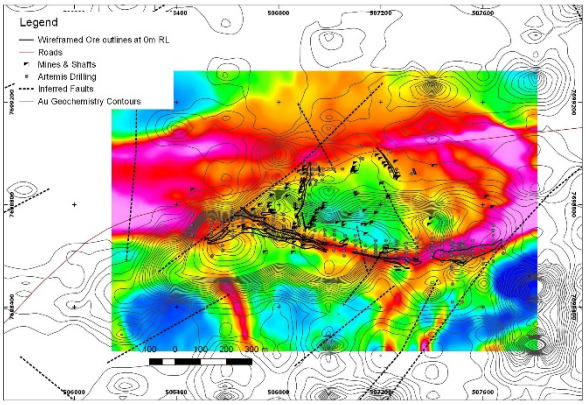

Figure 10. Co soil anomaly contouring overlain with averaged MMC conductivity.

DRILLING

Prior to this survey, drilling occurred pre 2018. Post-survey, sixteen16 targets were identified based off the successful delineation of the MMC structural mapping. Targets CC01 to CC05 were considered high priority and focused on regions coincident with known mineralisation, MMC conductivity highs and surface Co anomalism. Targets also factored in mobilisation of pore fluids along the large NE fault structure cross cutting conductivity features.

Targets CC06 to CC12 were also selected based on proximity to new mapped structures and zones of moderate MMC conductivity. Targets CC13 to CC16 were weaker extensions of mapped structure.

CONCLUSIONS

The SAM MMC data provided the most detail and was used in the generation of several high quality follow up targets related to existing mineralisation and Co anomalism. Averaged MMC also highlighted several moderate conductors and extensional zones of interest. Some interference from fences was noted in the north of the survey area, evident in the MMC and early off-time GSEM datasets, diluting by late time. TMI RTP provided little new information that was not evident in EM or MMC datasets. However, the simple fact of being able to simultaneously acquire MMC, TMI and GSEM cannot be overstated for efficiency sakes and logistical simplicity.

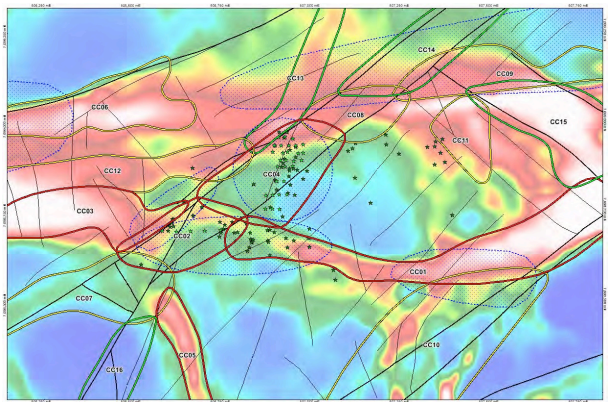

Figure 11. Carlow Castle targets shown in red (Priority 1), yellow (Priority 2) and green (Priority 3) outlines, over MMC image with structures (black), Co soil anomalies (blue hashed), 2017 drilling (light green) and pre-2017 drilling (dark green).

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