# Imaging high quality conductors at Golden Grove

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## SUMMARY

The success of the DHEM method in detecting the Gossan Valley mineralisation, south of Gossan Hill mine, in 2008/2009 led to the systematic application of the DHEM method across the Golden Grove lease from 2011 to 2014. The method proved successful in identifying several new zones, including the Grassi resource. During these surveys it was noted that the EM method failed to elicit either in-hole or off-hole responses in a number of holes with economic intersections of lead, zinc and precious metal ore. It became clear that not all economic ore zones contained sufficient conductive sulphide to ensure detection using DHEM. This triggered an assessment of available methods to determine if other down-hole technologies could be used to complement the DHEM method.
A program of core petrophysic measurements and petro-physical borehole logging led to the realisation that because the host rocks were very resistive there existed sufficient contrast for high frequency EM imaging to be viable. This led to a trial of the Radio Imaging Method at the Xantho resource of the Gossan Hill Mine in December 2016. The results of the trial suggested direct detection of the massive sphalerite ore is possible. Further work is being undertaken to better understand the optimum survey methodology in the Golden Grove Mine environment with a view to providing specific recommendations that if approved will see the use of the method expanded on the mine leases, both at Gossan Hill and Scuddles mines, as well as on the surrounding mine leases

**Key words:** DHEM, RIM, VMS.

## INTRODUCTION

Golden Grove is an underground and open pit base and precious metals mine located approximately 56km south of the township of Yalgoo, 375 km north-northeast of Perth and 225 km due east of the coastal port town of Geraldton at lat. 28.75 º S, long 116.95 ºE.

The Golden Grove operation comprises underground and surface operations at Gossan Hill and Scuddles. Volcanogenic Massive Sulphide (VMS) mineralisation was discovered at Gossan Hill in 1971 and at Scuddles in 1979. The estimated initial in-situ mineralisation is approximately 20 Mt @ 16 % Zinc and approximately 30 Mt @ 4 % Copper based on modelling of regions using current economic cut-offs (Gellie et al, 2017, in prep).

DHEM methods have been a staple in continued exploration at Golden Grove, both within the immediate mine environments of Gossan Hill and Scuddles as well as regionally within the mining lease. The success of the DHEM method in detecting the Gossan Valley mineralisation, south of Gossan Hill mine, in 2008/2009 led to the systematic application of the DHEM method across the Golden Grove lease from 2011 to 2014. The method proved successful in identifying several new zones, including Grassi. Gossan Valley and Grassi are both blind to surface electrical methods.

During these surveys it was noted that the EM method failed to elicit either in-hole or off-hole responses in a number of holes with economic intersections of lead, zinc and precious metal ore. It became clear that not all economic ore zones contained sufficient conductive sulphide to ensure routine detection using DHEM.

A program of core petrophysical measurements and petrophysical borehole logging led to the realisation that because the host rocks are very resistive there exists sufficient contrast for high frequency EM imaging to be viable even when mineralisation had low conductivity. This led to a trial of the Radio Imaging Method (RIM) at the Xantho resource of the Gossan Hill Mine in December 2016. The results of the trial suggest direct detection of the massive sphalerite ore is possible.

**Geology and Structure**

The Gossan Hill Group consists of a succession of intermediate to felsic volcaniclastics and coherent volcanic rocks with an average thickness of 3 km and a North South strike extent of approximately 35 km. The region has undergone late stage, low-grade regional metamorphism and regional folding and faulting resulting in the stratigraphy dipping steeply to the west (Gellie, et al, 2017, in prep)

**Ore Types and Metal Zonation**

The main sulphides are pyrite, sphalerite, chalcopyrite, pyrrhotite and galena with gold occurring predominantly as electrum. Metal zonation within each deposit conforms to the typical zonation within felsic siliciclastic VMS systems. Chalcopyrite and pyrite are associated with the potentially hotter, deeper parts of the hydrothermal system, whereas higher up in the succession there is a tendency towards massive sphalerite. Both the GG5 and SC2 units have acted to cap mineralisation in the underlying units. Zonation of the different deposits are represented Figure 1.

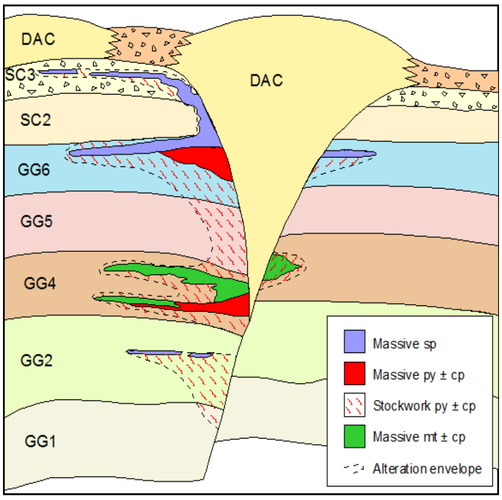


**Figure 1. Metal Zonation and Alteration schematic for Gossan Hill.**

**Gossan Hill**

Zinc mineralisation at Gossan Hill is primarily hosted within GG6 but is also present locally within SC3 and GG2. Copper mineralisation is hosted within GG6 stratigraphically below the zinc and within the GG4 and GG2 units. The primary hanging wall unit is SC2 although in some areas mineralisation has been deposited within SC3. In this instance the sulphides take the form of low-iron sphalerite and galena which contains high silver and gold.

**Scuddles**

Mineralisation is contained entirely within GG6 with the zinc stratigraphically above the copper as at Gossan Hill. No significant mineralisation has been discovered in any other unit at Scuddles.

**Gossan Valley / Southern Leases**

Mineralisation at Gossan Valley is contained predominantly within GG4 with the zinc stratigraphically above the copper. Zinc within GG4 is not present at other areas. The massive sandstones of GG5 form the hanging wall to the mineralisation at Gossan Valley and occasional zinc occurs in GG6.

## METHODS AND RESULTS

### DHEM Surveys

The following examples reflect the type of DHEM results from holes that intersect ore grade mineralisation. Data were collected in the time domain by GAP Geophysics using their higher power transmitter system tied to SMARTEM Receiver and DIGI-ATLANTAS 3 component fluxgate sensor. The transmitter field was a 50 % duty cycle interrupted square wave at base frequency of 2.5 Hz resulting in the collection of 32 channels of semi logarithmic spaced data in the off time of the transmit cycle. Transmitter loop size is 1000 m x 800 m for HIDD058 example and 800 m x 800 m for RHDD120D1. Further information regarding the DHEM method can be found in Hughes and Ravenhurst, 1996, and others.

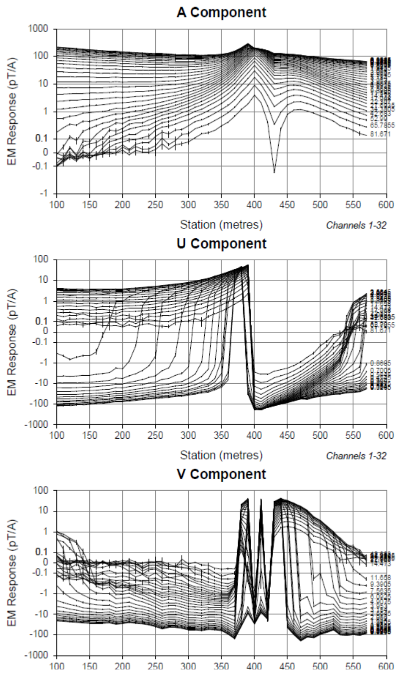


**Figure 2. DHEM results for HIDD058**

**Grassi Discovery Hole** (HIDD058)

The data from this hole display a classic in-hole response from a very good conductor intersected at a relatively steep angle in the upper portion of the mineralised zone. The early channel data reflect the influence of relatively thick (50 to 80 m) conductive cover. The calculated time constant for axial (A) component data at station 400 m for the latest 10 channels is of the order of ~19 milliseconds. Plate modelling returns a conductance of greater than 2000 Siemens. A majority of the higher grade mineralisation is in the GG4 position as shown in the assay and lithology bar chart (Figure 3). Iron assays can be used to imply presence of sulphides. Mineralisation style and zonation intersected at Grassi varies from a chalcopyrite ± pyrite, pyrrhotite and magnetite stringer footwall zone to a sub massive high iron sphalerite ± pyrite zone.

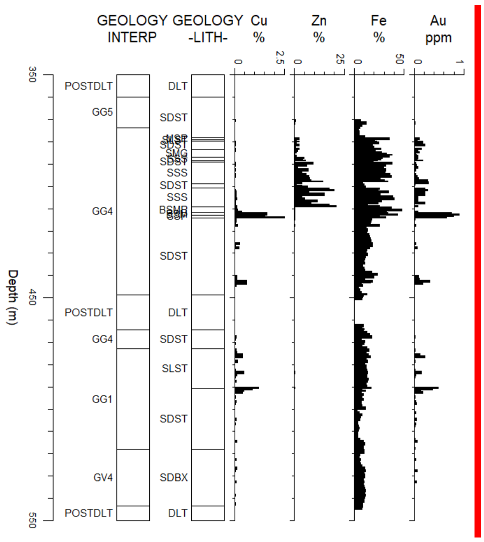


**Figure 3. Geology and assays for HIDD058**

**Xantho (Gossan Hill) ore intersection** (RHDD120D1)

The data from this hole is dominated in the late time by a regional banded iron formation (BIF) located to the west of the mine, resulting in the long wavelength cross-over response seen in the axial (A) data. At earlier delay times the responses are a complex interplay between BIF, cover, and hole trajectory, as well as local conductive responses. A localised response is noted at the Xantho mineralisation position (910 m to 920 m) in the earlier channels that relates to the mineralisation, but it is difficult to construct a model with confidence that reflects the extent and continuity of the zone. Figure 7 shows the location of the Xantho zone (as represented by the >3 % Zn iso-surface) relative to the drill-hole EM under discussion (bottom hole). A significant issue in working in a mine environment is being able to position transmitter loops to optimally couple with targets of interest and minimise coupling to regional or other conductors. Even though the coupling to the horizon of interest is excellent the optimal position is likely to the east to minimise coupling to the BIF. Because the dominant mineralisation intersected in the hole has low conductance the influence of the cover (at 3 to 5 Siemens) masks the response and needs to be taken into consideration in any modelling. Mineralisation style and zonation intersected at Xantho in RHDD120D1 includes a stringer high iron sphalerite +-pyrite footwall zone, transitioning to sub-massive to massive low iron sphalerite and galena +- pyrite main zone. Lower down in the stratigraphy a stinger to sub-massive pyrite zone is intersected.

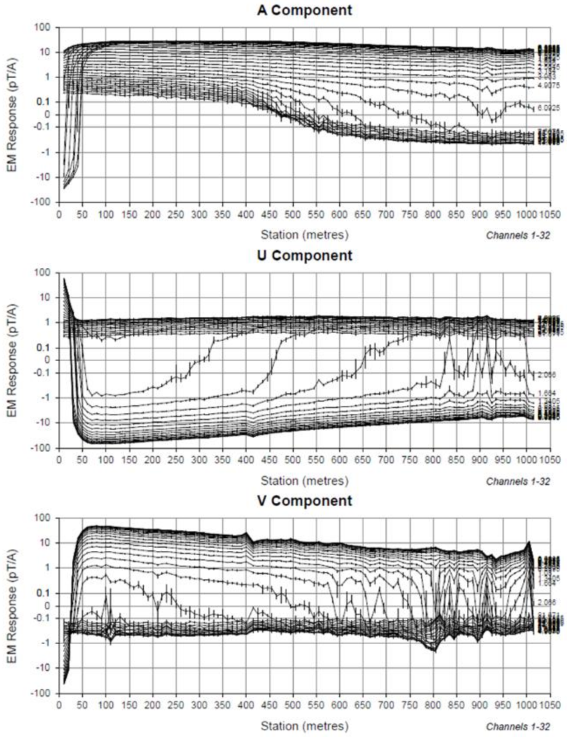


**Figure 4. DHEM results for RHDD120D1**

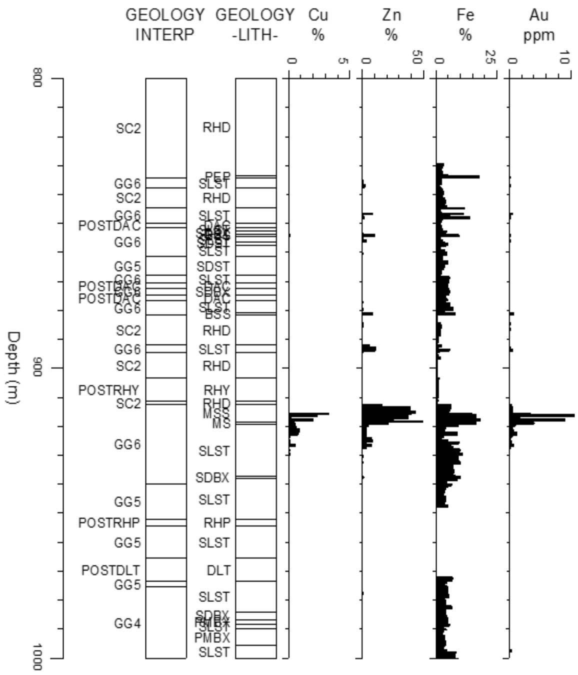


**Figure 5. Geology and assays for RHDD120D1**

## Petrophysics

Petrophysical testing of a limited number of hand and core samples from the Gossan Hill mine indicated that there exists a significant contrast in resistivity between zones of mineralisation and host. Apart from sample 6, none of the other samples would be considered a good conductor. These results were followed up with borehole conductivity logging in a limited number of underground and surface holes that covered the full range of host and mineralisation styles and positions. It should be noted that a limited program of petrophysical sampling and logging had been undertaken in Scuddles mine as part of the AMIRA P436 project (Fullagar et al, 1996) that also indicated the host rocks are very resistive.

Analysis of the core and hand samples were undertaken by Don Emerson of Systems Exploration (NSW) Pty Ltd. Table 1 shows sample description and saturated resistivity value.

**Table 1. Hand/core petrophysical resistivity results**

| Sample Description | Rho 1kHz (sat) ohm-m |
|---|---|
| Massive low iron Sphalerite and Galena | 0.7, 3.0 |
| Barren SC3 chloritic SLST | 12932 |
| Barren SC3 sericitic breccia | 26030 |
| 30% sphalerite stinger 10% galena in sericitic SC3 SDST | 1429 |
| 15% stinger sphalerite with minor Galena, in weak chlorite/sericite pumice breccia | 4179 |
| Massive Sphalerite and Galena | 0.08 |

Conductivity logging was undertaken using a Mt Sopris system employing a 2HIA-1000 (W-R HII 453) dual induction probe. The stated conductivity measurement range is 1 mS/m to 3 S/m. After calibration and logging of 4 underground holes it was found a majority of background readings clustered around 0 with a spread of ±4 mS/m which appears in accordance with the stated accuracy for the instrument for measurements less than 100 mS/m. The aim of the logging was to gauge the relative conductivity of mineralised zones against general host lithology. The logging system used did not have the depth capability to log RHDD120D1 to depths of interest but conductivity logging results for underground hole G14/436 (Figure 6) are thought generally representative for similar units and mineralisation in and around Gossan Hill.

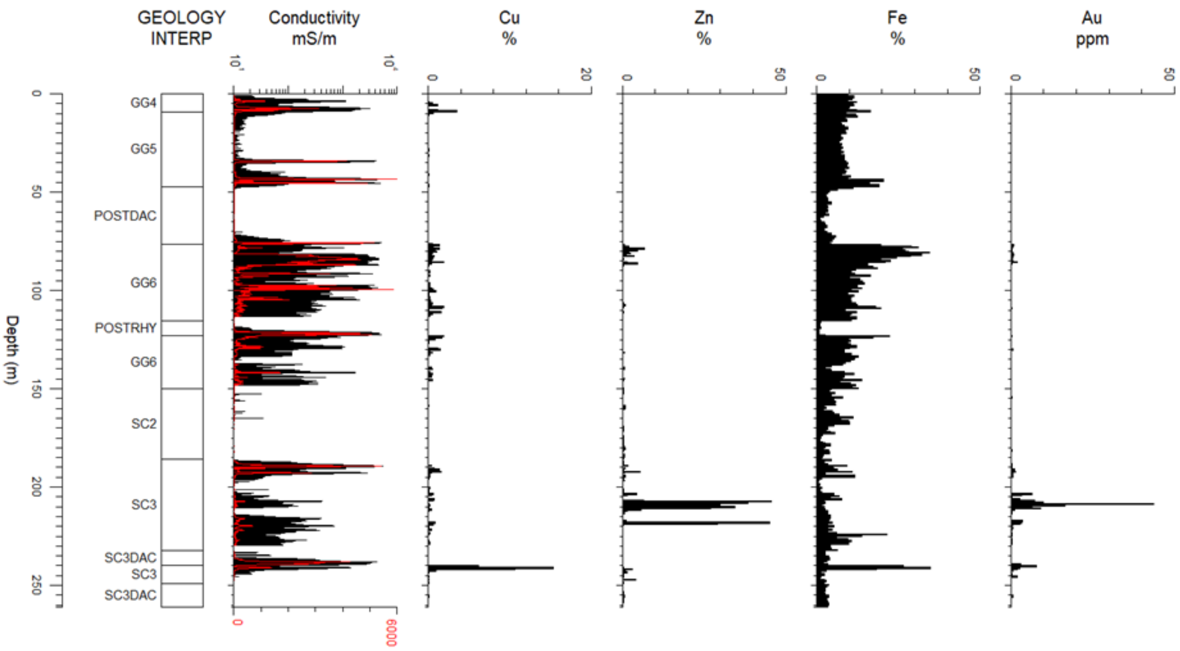


**Figure 6. Geology, assay and conductivity log for G14/436**

General comments regarding the results:

- Barren GG4, GG5, SC2, POST DAC and RHY lithologies all yield negligible responses.
- Golden Grove Formation sediments that contain only trace disseminated quantities of ore sulphides have negligible survey response
- GG4 chalcopyrite constituting high grade Cu (2 m @ ~4 % Cu) has a high amplitude (≥3000 mS/m) response
- GG6 sub-massive to massive pyrite and chalcopyrite have prolonged high amplitude responses over the full length of the intersect, with internal variation attributable to sulphide content.
- GG6 magnetite caused a 'false positive' response This may be a relatively minor concern given the frequency with which magnetite is associated with sulphide mineralisation.
- Connected bands of pyrite (eg. '30 cm thick bands) in otherwise un-mineralised stratigraphy result in significant high amplitude responses.
- SC3 stringer sphalerite and pyrite cause a high amplitude response, whereas SC3 massive sphalerite (high grade Zn) has a much more attenuated response (noted comparison in one hole).
- Barren SC3 sediments do not cause any significant response and are indistinguishable from other barren lithologies.

## RIM Trial

Down-hole radio wave imaging (RIM) was undertaken by Stolar Global using a RIM-6 system in 7 drill-holes at the Gossan Hill mine A total of 10 cross-hole tomographic data sets were collected. Data processing and refinement is still being undertaken (Fullagar, 2017). An example of the results of processing of the data is presented for the Xantho area for the hole pair RHDD119 and RHDD120D1.

A review of the RIM method can be found in Stolarczyk, 2012, Stevens et al, 2000, Zhou, et al, 1998, Fullagar, et al, 1996, and others. The basic premise for the RIM method is to measure the amount of signal attenuation (or absorption) from an active transmitter in one hole and receiver in another, after correction for source – receiver geometry, radiation pattern and source strength (Zou et al, 1998). An increase in attenuation indicates a zone of higher conductivity between the TX and RX along that ray path. By varying the transmitter and receiver positions in the drill-hole pair a tomographic image of the intervening space can be created. The corrected data is suitable for submission to a tomographic reconstruction algorithm; the results of which can be converted to an image of conductivity.

Data for the RHDD119 /RHDD120D1 hole pair was collected at a frequency of 890 kHz using a 0.5 m sample interval. Good signal detection was achieved over distances of 250 m to 300 m (Fullagar, 2017). The Simultaneous Iterative Reconstruction Technique (SIRT) reconstruction algorithm was used to create the absorption (attenuation) image using a 2m pixel size (Fullagar, 2017).

An image of the finalised conductivity derived from SIRT tomogram is provided in Figure 8. In the lower part of the panel the Xantho mineralised zone and a lower foot wall pyrite zone are clearly imaged. Both zones are shown as steeply dipping in accord with mapped geology. Limited tomographic surveying was undertaken in the upper portion of the hole pair as this is not an area of immediate interest.

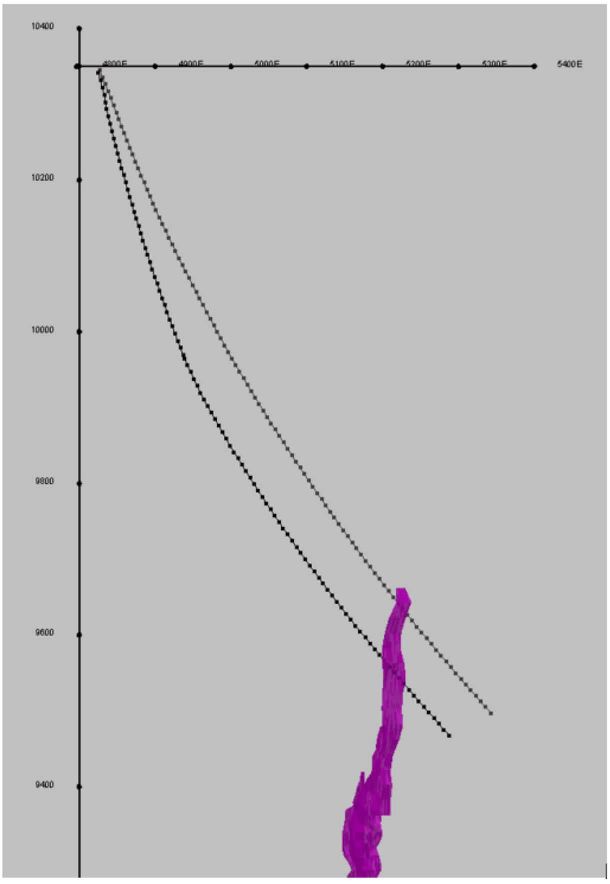


Figure 7. HDD120D1/RHDD119 and (>3%Zn) Xantho ore lens

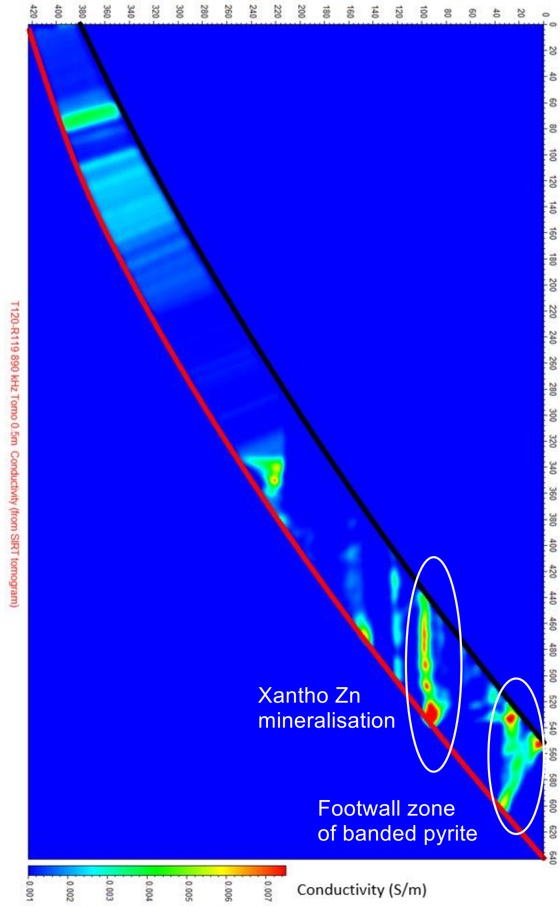


Figure 8. Conductivity for RHDD120D1/RHDD119

## CONCLUSIONS

At Golden Grove economic mineralisation styles encompass a wide range of resistivities, from highly conductive at Grassi to the barely detectable at Xantho. Methods for detection of highly conductive mineralisation is well established and has been very successful. Detection and imaging of poorer conductors, that may reflect high grade, economic zones in this environment is much more problematic. When undertaking DHEM surveys this include having to account for masking effects of regional conductors and thick and variably conductive cover as well as the masking effect of other local conductors. Under these conditions it is not difficult to imagine a class of mineralisation that would be transparent to current DHEM methods; be that due to masking effects from other conductive features or limitation of equipment. A limited course of petrophysical sampling of core and logging, together with historically available information indicates that the host sequence at Golden Grove, regardless of geology, is general highly resistive with very low porosity. This affords the opportunity of using high frequency cross hole EM methods to both detect and image poorly conducting mineralised zones. The RIM method, as with traditional DHEM, can be used to explore areas of high structural complexity where depending on geology alone may result in missed opportunity. Cross hole tests at lower frequencies indicate that useful signals can be detected up to 500 m (Fullagar, 2017) which may help to significantly expand the search space between widely spaced drill holes. As with most EM methods there is always the issue of false positives; as indicated with the lower footwall pyrite zone imaged in the RIM survey below the Xantho zone.

It may be too early to tell whether routine use of RIM will provide high definition imaging in the mine environment as well as distal detection of yet undetected ore zones along prospective horizons within the mine lease but tied with the continued use of DHEM methods the combination appears well suited to detection and imaging the VMS deposits commonly found in the Golden Grove environment.

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