GP33A-1088: Investigation of gold-bearing veins using magnetics and time domain electromagnetics

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Summary

Gold-bearing quartz-sulfide veins have been mined near Charters Towers (CT), Queensland, Australia for over a century. The gold is occurs in very small lenses that are difficult to find by drilling and standard geophysical techniques. In such granitic environments, the typical technique is IP but here we try different methods.

Ground TEM data were collected at a site at which there are two known gold-bearing structures. Airborne magnetic data at the site are also available. The purpose of our studies was to determine if these geophysical methods could locate the known structures and to better understand their geometry and thus assist in detecting the small lode structures.

Modeling of the TEM data indicates that the structures which include the mineralized veins are weakly conductive and are actually composed of multiple structures in close proximity. The TEM structural interpretation has a close correlation to linear anomalies in the magnetic data caused by low-susceptibility material. These anomaly types correlate not only at the known gold-bearing structures, but also at new structures. A summary of the exploration process to-date is presented.

1 Introduction

The CT goldfield is located in northwest Queensland, Australia (**Fig 1**). It has a long history of gold mining, dating back to the late nineteenth century. The gold ore occurs in quartz-sulfide veins, which are hosted in granitoids of the Ravenswood batholith. The veins formed in the late Silurian to early Devonian along faults and fractures (Kreuzer, 2007). The gold is found in lenses within the veins. The purpose of our work was to determine if geophysical methods could be used to identify and delineate known lode-bearing veins.

Figure 1: Location of Charters Towers [Google Earth]

The study site is near the Warrior Mine immediately south of the town (**Fig 2**). Two structures are being mined at 100-300 m depth: Warrior and Sons of Freedom (SOF). The tops of these structures are within several meters of the surface, and both structures generally dip to the north.

While IP is typically used to locate disseminated sulfides, we used a different approach: we integrated airborne magnetic data with ground TEM data to map the geometries of the gold-bearing fracture zones. TEM is advantageous because it does not involve injection of current into the ground with the uncertainty of current flow patterns in such resistive, fractured rocks. Fixed loop TEM surveying was utilized as this approach is much faster to perform than moving loop surveys. Although TEM is commonly used for mapping layered structures and strong conductors, it is much less used for detecting weak conductors, such as those found in gold exploration, contaminant plumes, or geotechnical applications. Here the fracture zones are highly weathered and wet thus producing weak conductors.

2 Magnetics

Method

1) Datasets

Airborne data were collected in 1999 by UTS Geophysics (Perth) over a large area along north-south lines with a 50 m line spacing and 5 m station spacing. The elevation of the sensor was roughly 50 m.

A high-resolution ground magnetic survey was completed in 2008 and 2010 in the Warrior area. The ground data were upward continued to a height of 50 m and compared with the airborne data. They agreed quite closely, giving us confidence in using the airborne data for detailed imaging and modeling. The 2008 data did not have sufficiently low noise levels to augment the airborne data.

2) Processing

Our interpretation focuses on the vertical derivative following reduction to pole (RTP) using specialized low latitude procedures (Keating and Zerbo, 1996). The purpose is to:

a) Better determine the position of magnetic structures
b) Improve discrimination

Results

Upon mapping the vertical derivative of the RTP magnetic data, many linear anomalies were noted, including over both mined structures. These anomalies all indicate negative susceptibility, as would be expected because the structures are depleted in magnetite with respect to the granitoids. Modeling of the RTP total field and derivatives confirms a negative susceptibility. The RTP data indicate the approximate dip, which agrees with known information.

Depth resolution is limited in standard 3D inversions, which utilize orthogonal grids with the normal axis in the vertical direction. Instead, a dipping grid which strikes and dips according to known information was used. We have obtained good results with this approach.

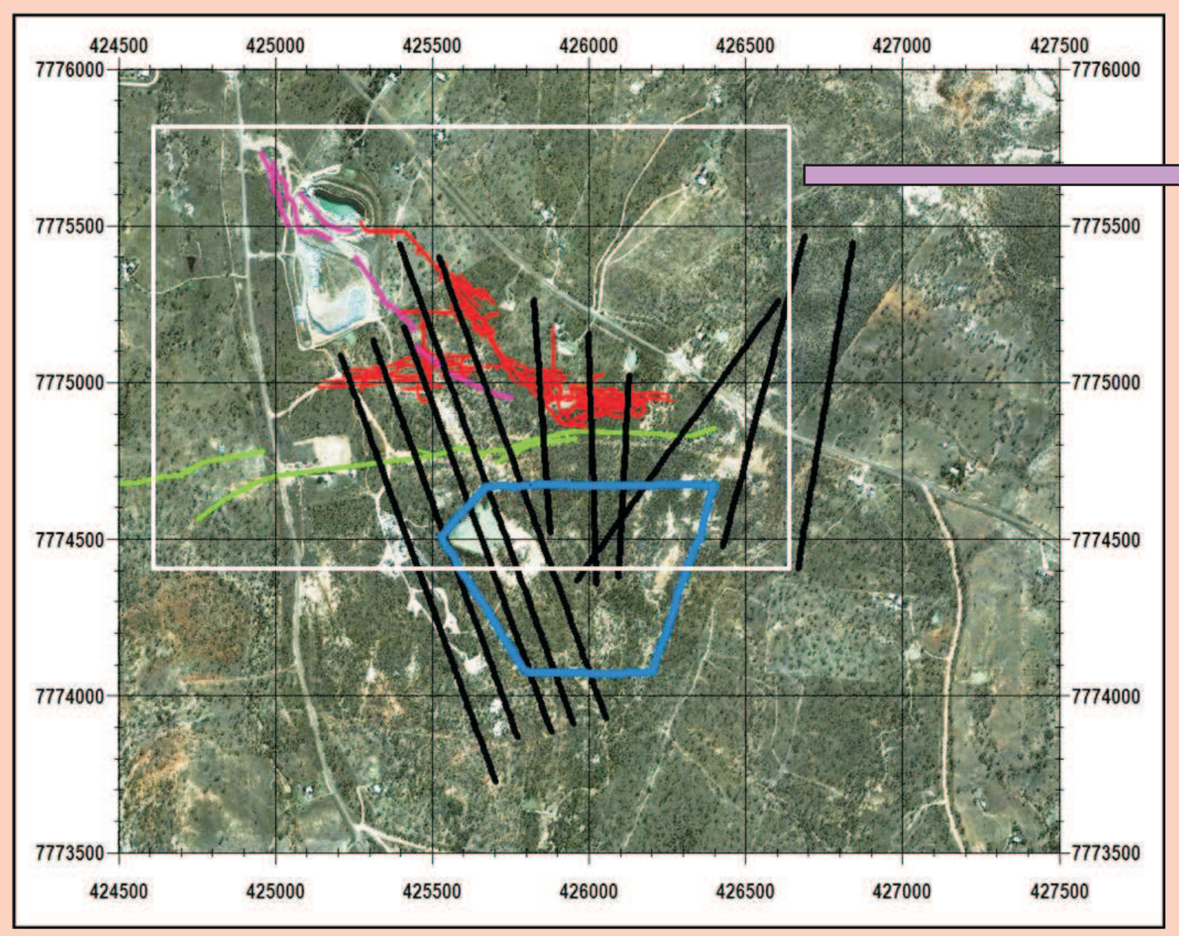

Figure 2: Map of site. TEM survey lines shown in black and loop in blue. The red lines mark the mine workings, and the green and pink are the geologists' interpretation of the tops of Warrior and Sons of Freedom.

3 Ground TEM

Method

1) Surveying

TEM surveying at the Warrior site presents challenges as there is an operating mine and other man-made features. The TEM surveys were carefully planned to minimize the impact of such features on the response.

Several fixed-loop surveys were performed in 2010 with Crone Pulse Equipment with three different loops between 200 m x 500 m and 600 m x 700 m in size. One of these surveys (Loop I) is illustrated on the map in **Fig 2**. In all cases, both vertical (Hz) and in-line (Hx) components were collected at a base frequency of 25 Hz. Station spacing was 10-25 m.

2) Modeling

Forward modeling was performed in EMIGMA, using an inductive plate algorithm based on the formulation of Annan (1974). An inductive algorithm is appropriate in this environment as the host granitoids have a very high resistivity. The data indicate a resistive background with a very thin conductive overburden. Our adaption of the original algorithm by Annan allows for an inductive response in an arbitrary background, allowing us to model both the inductive effect of the targets and the effect of the relatively conductive overburden caused by weathering of the granitoids.

We consider the response at the receiver to be a convolution of the response of the ground with the current input function, and the system response of both the transmitter and the receiver. Simulations are performed in the frequency domain and transformed to time domain.

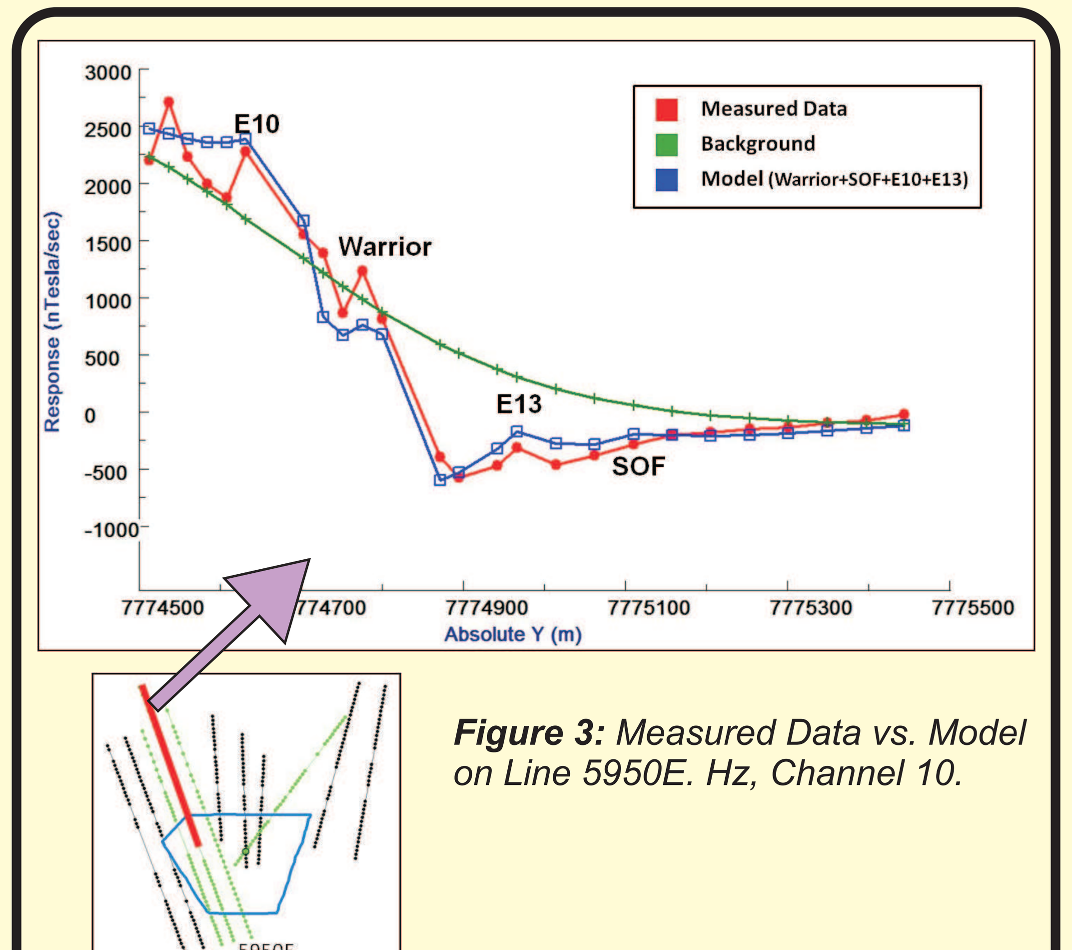

Figure 3: Measured Data vs. Model on Line 5950E. Hz, Channel 10.

Results

1) Initial data for Warrior

An EM response over Warrior was clearly observed in Hz and Hx using Loop I (Oct. 2010). A 3D model of Warrior based on drill log intersections was constructed, and then used to design a starting point for plate modeling of the EM data. The simulated data were iteratively compared with the measured data. Adjustments were made to the depth extent, depth to top, conductance, and position of the plate until the synthetic data fit the measured data sufficiently with respect to the both the profile and the decay responses. Hx was particularly useful for finding the strike and position of the structure, and Hz was useful for study of the decays.

We identified another structure about 75 m south of Warrior (E10), roughly parallel to Warrior. Due to the proximity of these structures and the survey design, we were unable to resolve the details of this structure.

2) Further data

Data were collected using Loops I, II, and III later in 2010, and our models of Warrior and E10 were adjusted based on these data (**Fig 3**). These surveys also enabled study of Sons of Freedom.

E10 was split into three structures (east, central, and west) with slightly different strikes and conductances. Earlier data did not enable us to determine its strike and extent. But with the addition of seven lines from of Loop I, we could track the changes in strike direction across its length.

In addition to E10, two other anomalies were identified in this data (E11 and E13). These anomalies do not correspond with known structures but are consistent with magnetic anomalies (**Fig 5**). Modeling indicates the structures causing these anomalies have similar properties to Warrior and Sons of Freedom.

In a later 2011 survey, eight 100 m x 100 m loops were utilized to examine the details of the structures, particularly the central section of the Warrior structure. These loops were located close to or over the structure. We found that Warrior is more complex than initially thought: the data indicate that it is comprised of several structures. However, it is possible from the data to determine if the structures converge at depth.

4 Integration of TEM and Magnetics

The tops of the structures interpreted from the TEM are mapped in **Fig 5** with the magnetic data. The RTP data indicate the approximate dip but provide limited depth interpretation. There is a strong correlation between the TEM structures and the magnetic highs, not only at the mined structures, but also over the three new structures.

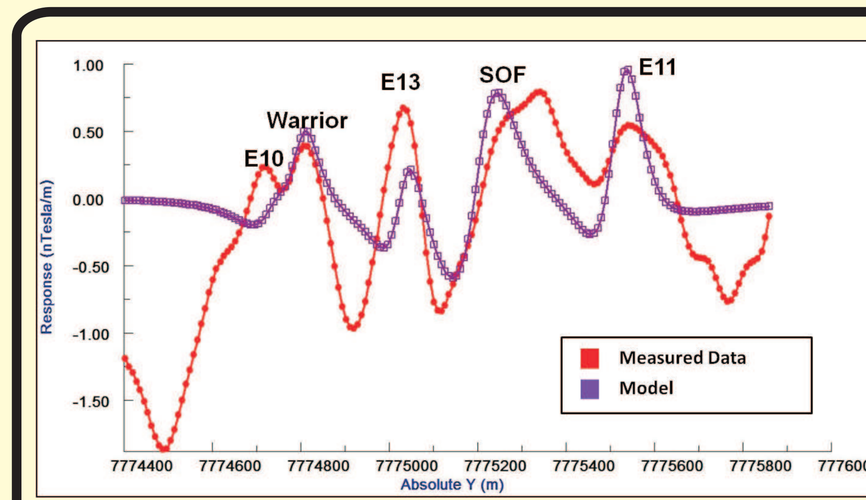

Figure 4: Measured vs. simulated magnetic data for all structures, RTP Btz on Line 35 (425420E).

The EM models were converted to magnetic models with thicknesses of 5 m and susceptibilities between -0.1 and -0.05 (SI). The simulated magnetic response was found to be in good agreement with the measured data (**Fig 4**). The rather large negative susceptibilities indicate a larger volume than can be explained by individual veins alone indicating groups of veins. However, we can conclude that the weak conductors causing the EM anomalies are associated with low magnetic susceptibility. Note that in the Warrior area, we do not observe any magnetic anomalies that are not associated with an EM anomaly.

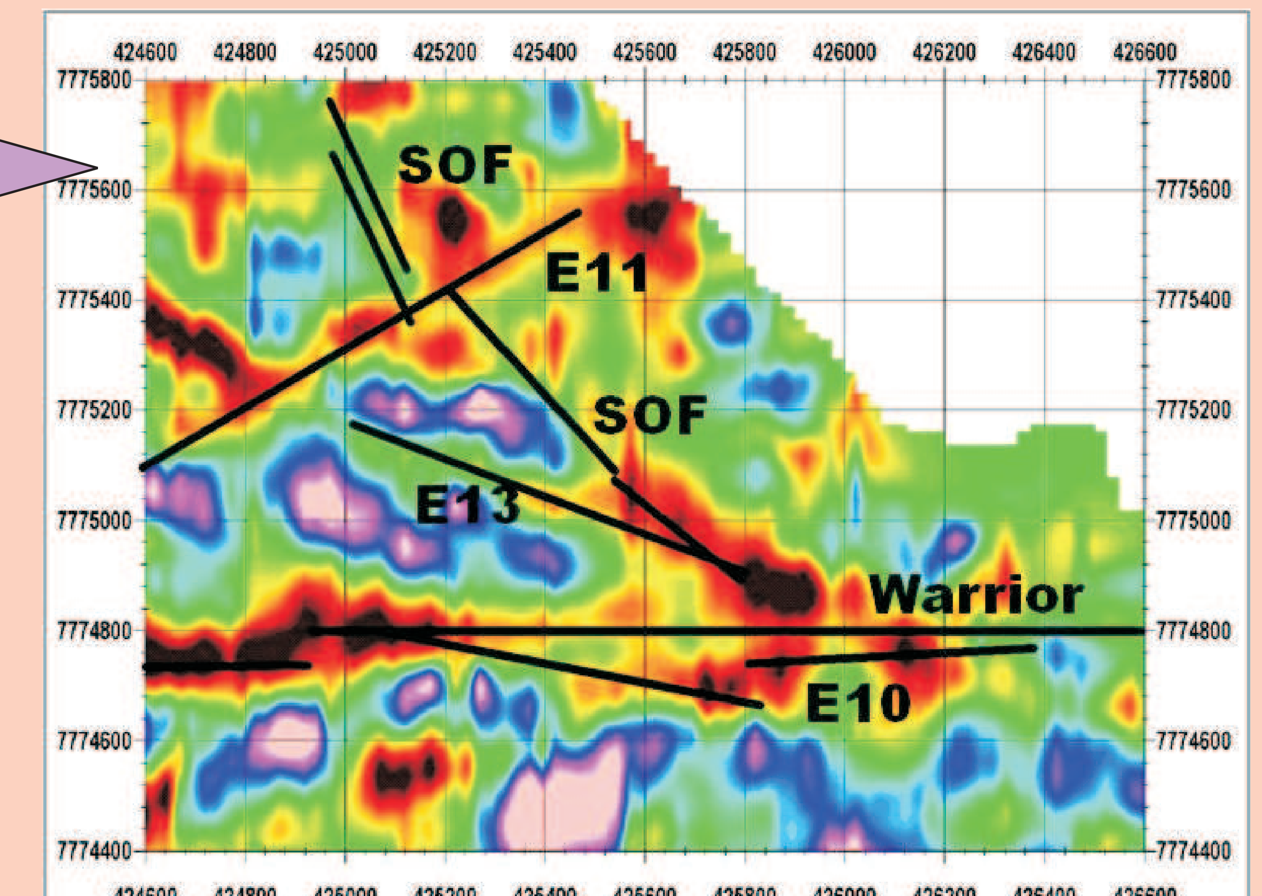

Figure 5: Map of the contoured RTP vertical derivative, with interpreted structures from the TEM shown in black. Warrior and Sons of Freedom (SOF) are the known gold-bearing structures; E10, E11, and E13 are interpreted from the data.

5 Borehole TEM

From the magnetic and ground TEM results, the obvious next step is borehole TEM surveying. More than ten holes were read with TEM in 2008-2010; however, the data were inconclusive. As a result, some tests were performed near Warrior at surface utilizing both surface and borehole coils. It was found that there were significant discrepancies in the nature of the decay (**Fig 6**) between different coils. The borehole sensors show a much slower late-time decay, which is inconsistent with surface probe, drilling and mining results. Our conclusions were that this borehole data could not be used, but borehole data were later collected in 2012 with different equipment (UTEM4).

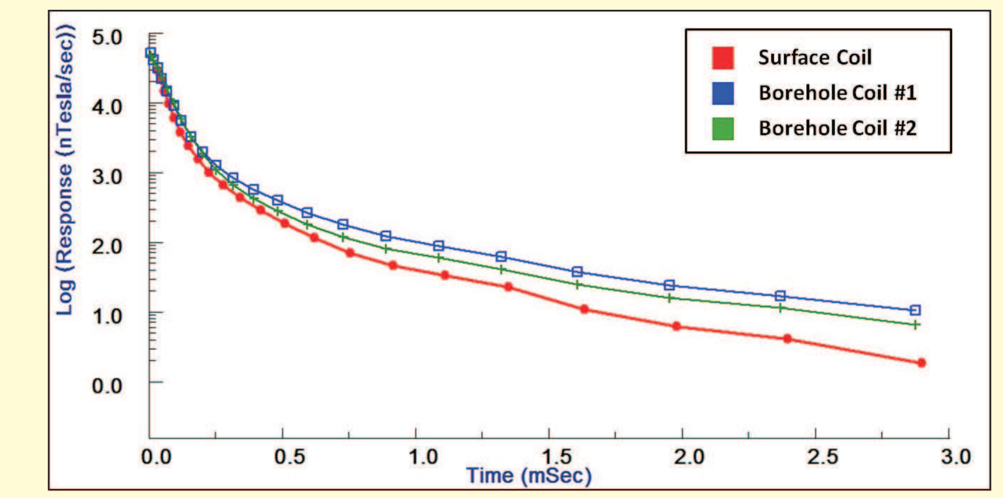

Figure 6: The decays at an in-loop station for three different coils, up to 3 ms after the end of the pulse.

The general trend and amplitude of the measured UTEM4 response down the hole is consistent with the simulation of a background model for the two principle components (**Fig 7**); this was not the case for the previous borehole data. This agreement gives us confidence in the data. The UTEM system measures the step response, and at late times, the total measured response is primarily freespace, which is dependent primarily on geometry supporting the actual measurements..

While careful study of the UTEM data has yet to be performed, initial analyses indicate that the measured response is reasonable, and it is our belief that it will be useful in understanding the structures.

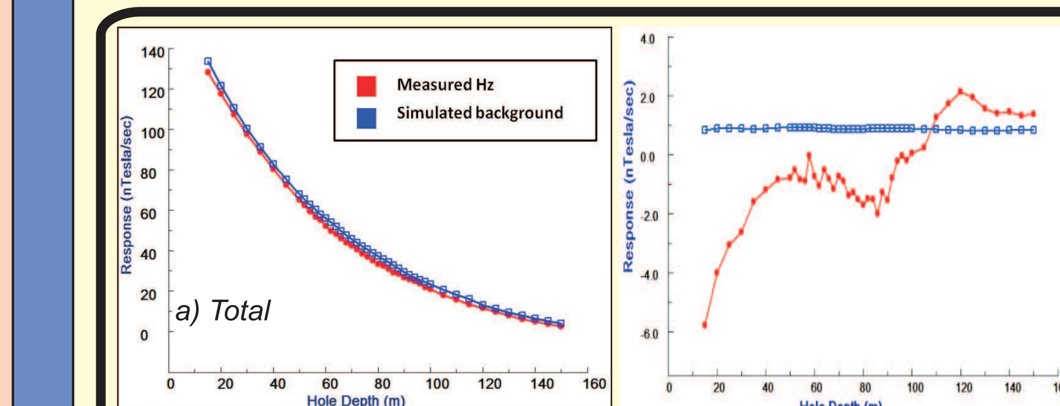

Figure 7: Hz (axial), late time in CT8011. Measured data vs. simulated 1D
a) Total response. Simulated and measured data in excellent agreement.
b) Total - Freespace indicating short wavelength conductor

6 2012 Exploration

New boreholes were designed to investigate the structures identified by the geophysics. While drilling is still in progress, borehole CT8002 did intersect E10 at depth. Thus, the drilling result to date have confirmed the ability of TEM and magnetic to locate potential lode-bearing structures.

Further ground data were also collected with the UTEM3 system. Several of the ground lines were designed to investigate anomalies in the vertical derivative of the RTP aeromagnetic data. Detailed analyses have yet to be performed, but there is an anomaly in the TEM data 1500 m south of Warrior that corresponds with one such magnetic anomaly. This approach of using the aeromagnetic data to identify areas of interest for TEM will be used in further exploration.

7 Discussion

We believe that the source of the weak conductivity is the clays in the alteration zone around the veins, and the sulfides.

Kreuzer (2007) suggests that the negative susceptibility is due to pyrite and other secondary minerals replacing the magnetite in the granitoids. While this may be a partial explanation, we believe it is insufficient to explain the strong anomalies observed. We would expect an upper limit on the susceptibility of the granitoids to be 0.003 (SI). Using this as an upper limit for the susceptibility of the structures requires a much larger volume than can be explained by the veins.

One possibility is that, if the altered and weathered granite is included, the thickness of the structure could be of sufficient volume to provide a more reasonable susceptibility contrast. We would expect the alteration and weathering processes to remove the susceptibility from the granite. Another possibility is that there are multiple non-magnetic structures. In the modeling of small-loop TEM data collected in 2011, we found that Warrior was composed of several proximate structures. Perhaps the combined volume of the multiple structures would add sufficient volume, but still be observed as a single anomaly in the airborne data. Further, more accurate ground data would be required to answer this question.

8 Conclusions

Two known lode structures at Charters Towers are associated with both magnetic and EM anomalies. These structures were found to be weakly conductive, and the magnetic response over these structures indicates a negative susceptibility contrast with the host rock.

The structural interpretation of the EM data also resolves three similar anomalies in the immediate vicinity, which correlate with magnetic anomalies. Due to their favorable geophysical response in comparison with the known gold-bearing structures, these are of interest for further exploration, and drilling has commenced.

This approach will be used to find potential lode-bearing structures in the Charters Towers goldfield. Areas of interest can be first identified in the magnetic data based on the RTP vertical derivative, and then TEM will be performed at these sites. Such work has already begun in Fall 2012. We have demonstrated that, through careful modeling, TEM can be used to understand the geometry of weak conductors.

We expect to use direct electrical excitation of the fracture zones accompanied by measurements with a magnetometer in boreholes to directly detect the highly conductive sulfide lenses.

References

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