Magnetic Induced Polarization - using new technology for greater detection capability of deep and elusive mineralization

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SUMMARY

The Magnetic Induced Polarization (MIP) method uses the measurement of magnetic fields to directly detect internal and external current flow from IP-generating targets, rather than the resultant surface currents as with conventional Electric Induced Polarization (EIP). Magnetometric Resistivity (MMR) measures the magnetic field produced by galvanic current flow to detect horizontal variations in resistivity. We focus primarily on the MIP method but since MIP and MMR data are collected simultaneously, we will treat them together where appropriate. MIP/MMR is insensitive to horizontal layering, and is especially suitable for regions with highly conductive cover where EIP and resistivity responses are sharply attenuated. Magnetic fields easily propagate through such conditions; therefore MIP/MMR is minimally impacted by conductive cover. The other major advantage of MIP/MMR, over traditional electrical IP and resistivity, is that it completely eliminates the need for measurement electrodes. Hence, it is effective in difficult ground contact conditions such as dry sandy soils, frozen ground, and rocky scree slopes. For inversion purposes, MIP has an additional benefit that magnetic fields can be measured in all three axes simultaneously, which provides significantly more information about target position and attitude. By using SQUID technology and remote referencing, we are able to improve the data quality and extract useful three component MIP and MMR data. We present a number of field trials using both frequency and time domain methods to analyze the MIP and MMR responses from porphyry copper, and unconformity uranium ore bodies.

Key words: MIP, MMR, Remote Referencing, IP, SQUID

INTRODUCTION

These techniques, in particular MIP, have seen limited commercial application over the past 40 years, in part due the inherent difficulties in measuring very small magnetic fields at the low frequencies necessary for MIP/MMR. A further complication is the presence of magnetic noise from both natural and synthetic sources which can make it difficult to distinguish the very small MIP/MMR magnetic fields from the background noise. With the relatively recent availability of SQUID magnetometers, it is possible to measure low frequency, three component, magnetic fields with very high sensitivity. By utilizing two SQUIDS, one for measuring over the target area and a second which serves as a remote reference station, we are able to significantly increase the signal to noise ratio allowing for the accurate calculation of IP and resistivity values at the measurement point.

Similar to traditional electrical IP and resistivity, MIP/MMR has particular application for sulphide-associated, disseminated and gold and base metal deposits. However, the higher sensitivity of SQUID MIP and MMR, and the inherent ability of MIP/MMR to see through conductive cover, means that it can detect these deposits to greater depth, in more difficult environments, and with greater resolution and discrimination.

MIP METHOD

The MIP method detects the presence of geologic materials of anomalous induced polarization through the measurement of the magnetic fields associated with subsurface polarization currents, rather than the measurement of their resultant surface electric fields, as is customary in the traditional EIP approach. The theory of the MIP method and some MIP field case histories, are presented in Seigel, 1974, Howland-Rose et al, 1980 and Seigel and Howland-Rose, 1983. Whereas the MIP and EIP methods are both based on the measurement of IP effects in the earth, they differ in important respects, including field operations; in the response to the IP and resistivity characteristics of the earth; and in the processing and the interpretation of the measurements.

MIP can be calculated from a 100% duty cycle square wave in the frequency domain or from a 50% duty cycle in the time domain. In the frequency domain, MIP can be represented as Percent Frequency Effect (PFE) or Relative Phase Shift (RPS). In either case, the recorded magnetic field and the current records are converted to the frequency domain. The square wave signal contains amplitude at the fundamental frequency and each of the odd harmonics. A deconvolution is performed to normalize the amplitudes at each of the frequencies of interest. The ratio of the fundamental frequency to the first harmonic is PFE and without the presence of a chargeable body will be 1. RPS is calculated in the same way but uses the imaginary component of the frequency domain rather than the real. In time domain measurements, the IP effect is calculated by integrating the magnetic field over a given time period.

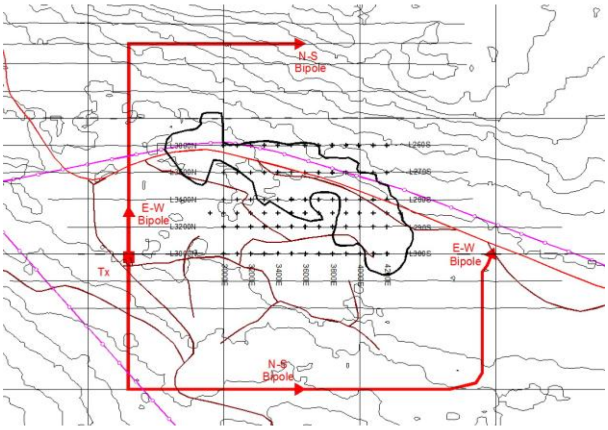

Figure 1 - Highland Valley JA Deposit - Survey Plan

SURVEY DESIGN

Figure 1 shows a typical MIP/MMR survey design with two sets of current electrodes at orthogonal angles. The opposing electrodes are energised in pairs to produce current flow through the survey area. Using two current paths produces a second dataset to aid in inversion and interpretation. Station intervals on these lines are typically 50m – 100m and the line spacings are 100m – 500m depending on the required spacial resolution, which is largely determined by the expected depth and size of the geologic targets. While two orthogonal current directions are used, it is typically the along strike current that produces the best results as it preferentially excites structures which are elongated in that direction. The cable connecting the electrodes is ran in a "U" shape to reduce vertical magnetic fields and inductive effects in the survey area.

FIELD MEASUREMENTS

At each station the magnetic field B will be digitally recorded, continuously, together with GPS timing, for one or more minutes, depending on ambient noise levels. The GPS coordinates of the station will likewise be recorded. A second magnetic field sensor, suitably located where the normal B field from the current electrodes is substantially reduced, continuously records the ambient noise, in digital form. Placement of this remote reference station can be somewhat problematic as it is desirable to keep it as close to the survey area as possible while simultaneously minimizing the source signal from the survey. It is beneficial to have a general knowledge of the local conductors to avoid placing the reference station on a conductor that continues into the survey area. The two magnetic sensors are time synchronised, using GPS time signals, to permit the ambient noise removal. The resultant signal has significantly less telluric noise which improves the accuracy of MIP/MMR measurements.

Full waveform records of the current are obtained by using a third recorder in combination with a current measuring device. This data also contains GPS timing information so that it can be synchronized against the rover and base records.

NOISE SOURCES

To accurately remove noise from the record it is necessary to understand the sources and frequencies of noise involved. Broadly, these can be placed into three categories. First, local lightning strikes cause very high frequency noise "bursts". Remote referencing has not been effective in removing this high frequency noise. The difficulty is that there is a phase shift between the two signals which is related to their separation. Attempts to use cross correlation to shift the signals into alignment have also been unsuccessful as each event may have a different orientation to the receiver array and therefore the phase shift is not consistent. Global lightning or sferic noise is best removed through the use of a wavelet based sferics filter and by stacking. The second source of noise to consider is telluric noise, caused by solar energy. It is mostly of quite low frequency (<1 Hz) and causes substantial error in the MIP calculations. While modern stacking methods can reduce error from slow linear drift, inflection points or higher frequency oscillation is still a significant source of noise which is best addressed through remote referencing. A third source of noise is man-made or "cultural" such as power lines and often has a fixed frequency and can be suppressed by signal processing. Other, short duration, noise can be dealt with manually by viewing the records and removing the bad data before stacking. We have developed a software tool for this purpose.

REMOTE REFERENCING

Since SQUIDS have an unknown offset in the produced signal, a simple subtraction between the base and rover cannot be used for remote referencing. A further complication is that even small rotational errors in the positioning of the SQUIDS introduce significant error into the noise cancellation (Nichols *et al*, 1988). Nichols *et al*. suggests using a matrix to calculate coherence between different axes to aid in cancellation. In practice, this was not effective as the least squares fitting tended to fit residual primary in the base station to the rover and remove the signal of interest. The solution was to first remove the primary signal from the base station by fitting the current recording to the base records and then subtracting (Figure 2). This must be done on each individual cycle, as

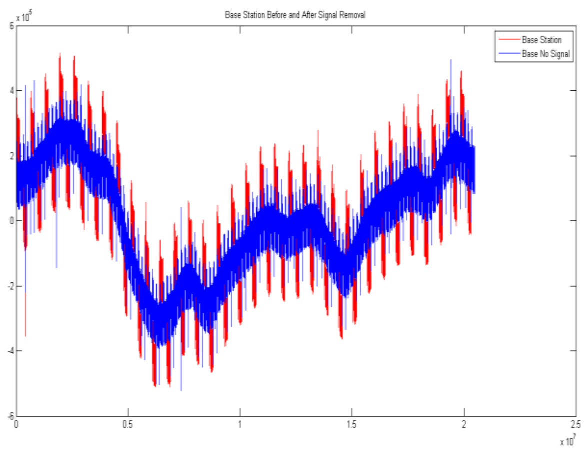

Figure 2 – Base station before and after primary signal removal

telluric noise causes drift in the base station that can be much larger than the recorded signal. A multi-component least squares fit can then be performed using the base record which does not contain the primary signal.

CASE STUDY

Recently, several MIP/MMR surveys using SQUIDS were performed. A survey over an unconformity Uranium deposit produced limited MIP effect though MMR results were encouraging. Another MIP/MMR survey was conducted over Teck's Highland Valley JA porphyry copper deposit in British Columbia, Canada (figure 3). The area is known for having condutive overburden that has made EIP surveys difficult (figure 4). Supracon's Jessy Deep High Temperature SQUIDS were used for both the survey measurements and the reference station. A base frequency of 0.25 Hz was used with a 50% duty cycle. After referencing and stacking, the amplitudes were averaged over the time period from 442ms to 992ms. Figure 5 shows the MIP results plotted with the approximate outline of >0.2% Cu.

CONCLUSIONS

As predicted by Seigel (1974), the MIP effect can be seen from chargeable bodies at significant depth and is far less sensitive to overburden than conventional EIP. MIP is a useful tool for the detection of porphyry copper deposits in difficult conditions. The use of remote referencing and SQUID technology can provide accurate, three component MIP data.

ACKNOWLEDGMENTS

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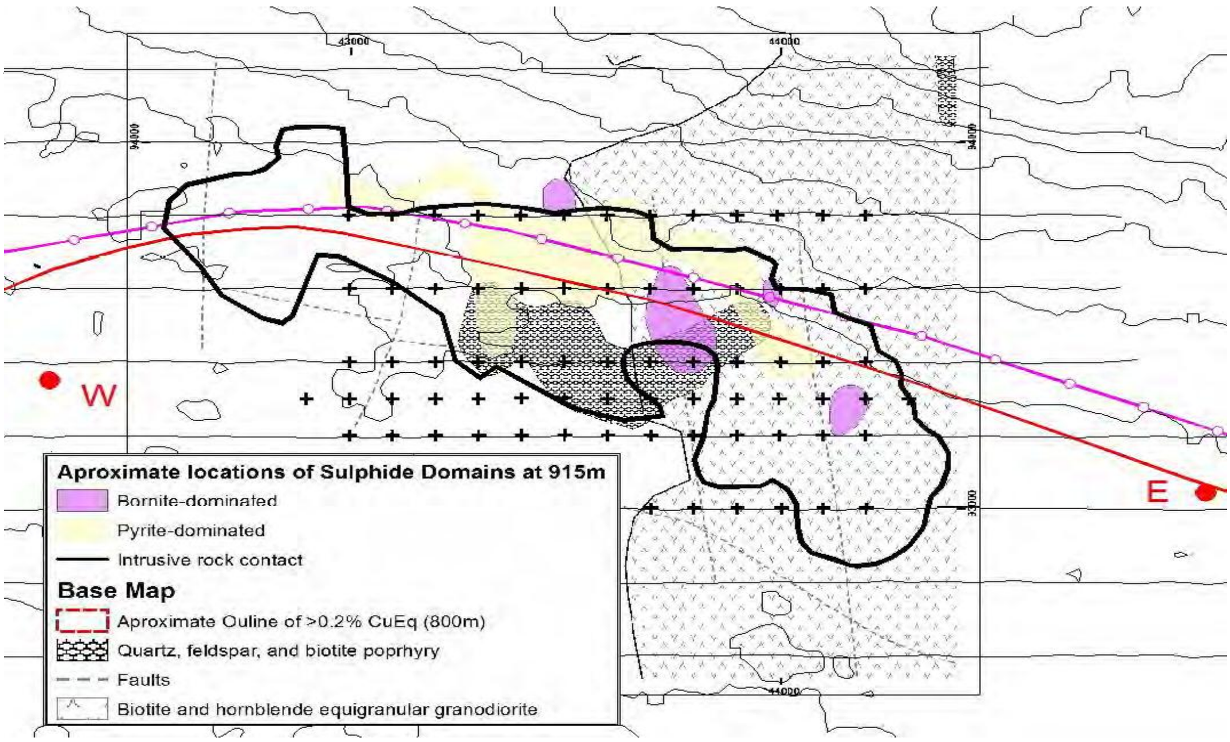

Figure 3 – Geology of the Highland Valley JA Deposit

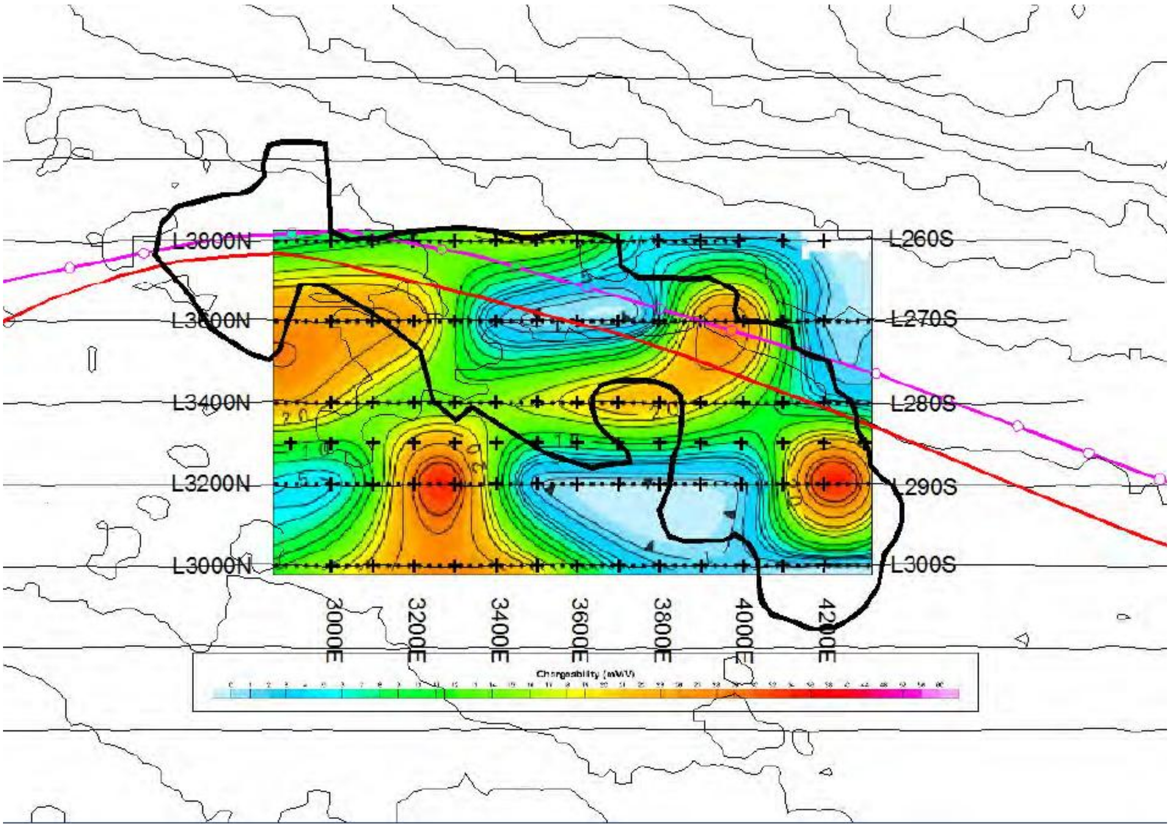

Figure 4 – Chargeability Inversion at 500m depth from EIP survey

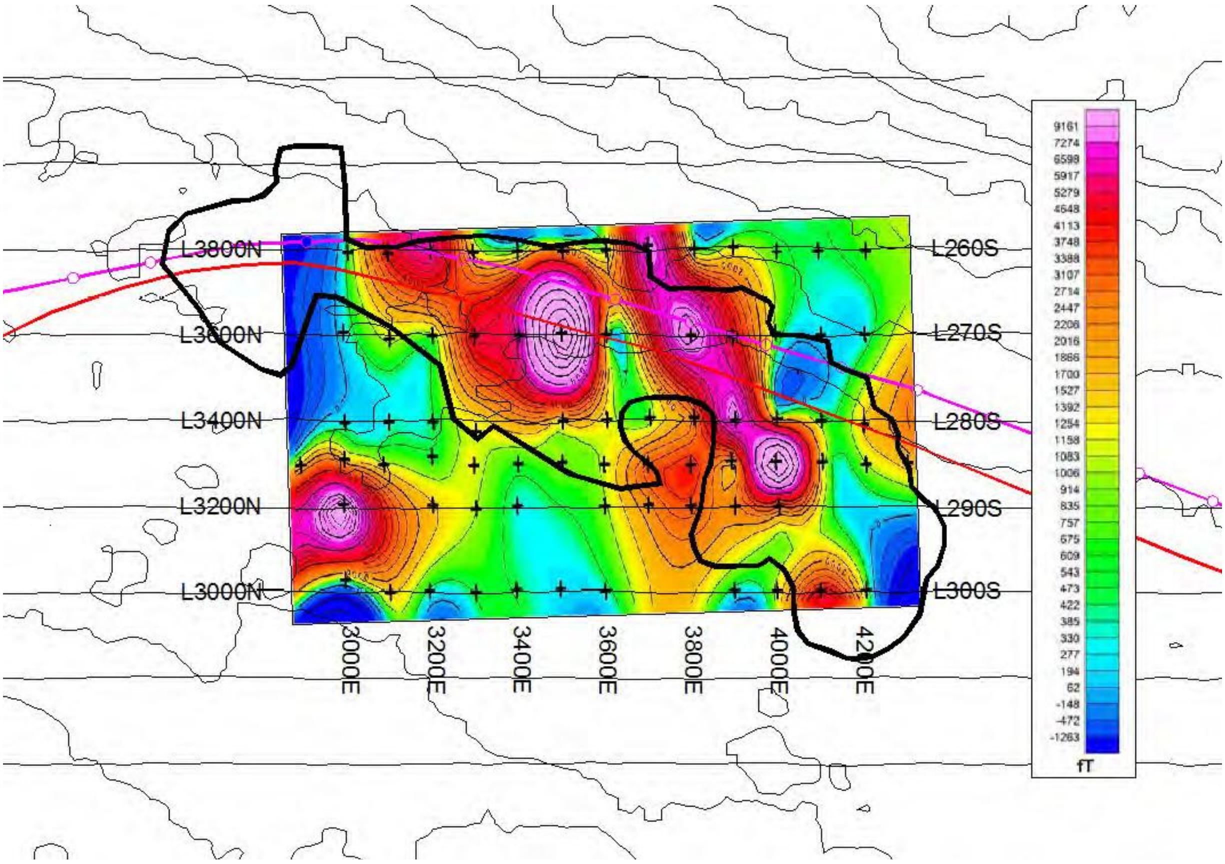

Figure 5- Highland Valley JA - X Axis - MIP response using N-S Electrodes