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DHMMR: Coming of Age

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ABSTRACT

The DownHole MagnetoMetric Resistivity (DHMMR) technique is ideally suited for detecting narrow ribbon-shaped and/or poorly conducting mineralisation. It was first suggested in the 1960s but appears to have been little used until the 1990s. It is still not been widely implemented and until recently the sensor was usually a standard downhole single (axial) component time domain electromagnetic (TEM) probe measuring dB/dt. In January 2007, a DHMMR survey was conducted in Broken Hill, NSW, Australia using a 3-component B-field probe. The survey was highly successful, delineating low conductivity narrow pipe-like zinc mineralisation in the western Zinc Lodes of the North Mine. The Zinc Lodes are directly above the main development of the North Mine orebody and directly below the North Mine infrastructure, and therefore a real challenge to isolate and energise for geophysical surveys. DHEM applied on the same targets failed to respond. The success and accuracy of this survey using new equipment is expected to lead to a better appreciation of DHMMR's potential.

DHMMR is a pseudo-DC grounded dipole geophysical survey method which allows absolute direction to a conductor from a borehole to be established. The grounded dipole channels the current through more conductive units (i.e., the mineralisation), and the down-hole survey records the magnetic field generated by these galvanic currents. This are modeled in a similar way to gravity anomalies, with the current density being the prime variable alongside anomaly location and size. DHMMR has advantages over conventional EM in that it needs lower absolute conductivity, works well for narrow pipe-like structures, has greater area of investigation around the drill hole, gives absolute direction to conductors, and is less susceptible to shielding. Until this survey, the disadvantages of lower resolution, problems with noise, lack of appropriate software, and more expensive equipment meant that DHMMR was often treated as a poor cousin to DHEM and used only as a last resort.

INTRODUCTION

With the current historically high price of zinc with few new mines on the horizon, it is not surprising that exploration for sphalerite-rich deposits is increasing worldwide. It certainly an important role in the decision of Perilya Ltd's management to investigate the 'Zinc Lodes' mineralisation directly above their North Mine main lode in Broken Hill, NSW, Australia. Whilst the North Mine main lode is mostly mined out, the western Zinc Lodes have largely been ignored.

The main style of Pb-Zn mineralisation in Broken Hill is invariably conductive enough to give good electromagnetic (EM) responses (Bishop, 1991). However, the Zinc Lodes and other lode horizons north and south of Broken Hill contain a number of sphalerite rich and galena poor zones that are much less responsive to EM. One well-documented example of this is the Potosi mineralisation, currently being mined in an underground extension from the Potosi open cut (mined by Pasminco Ltd in 1996-2000). The Potosi mineralisation averages 8.5% Zn and 2% Pb with little other sulfide and is therefore a difficult geophysical target. DHMMR was tried on this mineralisation and found to give good results, even where DHEM had failed (Bishop, 1991, Hughes et al., 1997, Bishop, 1991).

The Zinc Lodes are considered stratigraphic correlates of the Potosi mineralisation, and as such difficult targets to define both geologically and geophysically. 'Zinc Lodes' is probably a misleading name for this mineralisation, which is rarely >2m thick @ 5-10% sphalerite ± 1-2%galena, discontinuous, and seems rather to be a series of narrow ribbons than continuous sheets. In addition, the mineralisation is poorly conductive, positioned only 20-50m above massive highly conductive Pb-Zn mineralisation, and lies directly below a working mine and railway track. DHEM has been tried on the Zinc Lodes but with little success (Bishop, 1991), and the success of DHMMR at Potosi led to the logical application of this method to the Zinc Lodes.

DHMMR VS. DHEM

The prime reason for using DHMMR versus DHEM is the ability to detect low conductivity targets. This is because DHMMR requires only a conductivity contrast between the host rock and the target. Research indicates that a conductivity

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contrast of 3 between host and target is sufficient to channel the current usefully and create a good DHMMR signal (Lewis, 1998).

Another reason is that DHMMR can potentially detect extremely conductive targets, such as effectively perfect conductors (nickel deposits), where pulse type TEM establishes essentially no currents within the body and no response can therefore be observed. A third reason is the increased target detection range – the magnetic field due to current channeling decays as r-1 to r-2 (depending on source geometry), whilst most TEM methods involve r-2 to r-3 factors. Detection distance of >150m have been recorded in Broken Hill surveys (Godber unpub. report, 2006; Bishop et al., 1991).

Disadvantages of DHMMR are considered to be as follows:

1. More demanding instrumentation
2. Lower signal to noise ratio.
3. Lack of readily available modeling software, and
4. Poorer resolution of target dip/distance from hole.

Whilst target resolution essentially is a limitation of using galvanic versus induced fields, the other perceived disadvantages of DHMMR are probably a result of inertia in the development of this technique. Simply put, the equipment and technology are available, but awareness and impetus have been lacking. This survey provided the opportunity to bring together the equipment, software and people to realize finally the potential of 3-component B-field probe DHMMR.

The survey was considered an excellent success given the challenging location and environment. The data was very low noise with excellent repeatability, despite proximity to the underground mine workings and the North Mine infrastructure. The model DHMMR polygons correlated very well with the known geology and expected mineralisation, as well as indicating several new untested zones.

GEOLOGICAL SETTING AND EXPLORATION TARGET

The North mine ore-body is hosted in a distinctive mine sequence comprising elements of the Broken Hill Group (Hores Gneiss and Freyers Metasediments) and the Thackaringa Group (Rasp Ridge Gneiss) of the Willyama Supergroup. There are at least six stratiform economic mineral horizons, or Lodes, known as:

Lead Lodes :	3 Lens	East
	2 Lens	
	1 Lens	
Zinc Lodes:	A Lode	
	B lode	
	C Lode.	West

The main 2- and 3- lens ore bodies (Unit 4.7 mineralisation) are isoclinally folded and plunge to the northeast at about 40-60°. The Zinc Lodes (Unit 4.5 mineralisation) locally dip ~70° north-northwest, and lie about 20-50m northwest above the main lode with parallel plunge. The steep plunge makes it difficult for a surface electrode to energise the mineralisation at depth in the northeast. This problem was solved by using an old drill hole with a Zinc Lodes intersection as the plug in point for the northeastern electrode.

The North Mine mostly mined the 2- and 3-Lens lodes with a small amount of Zinc Lodes. The major sulfides in the Zinc Lodes are marmatite (sphalerite containing up to 13% Fe) and galena. Petrophysical testing and DHEM and DHMMR surveys have shown that the mineralisation may be only weakly conductive.

METHOD

The target zone was energised with a 1Hz square wave impressed into the earth via a grounded dipole which was laid out in a 'U' shape with the holes to be surveyed within the U (to reduced the effect of the magnetic field in the wire). The dipole length was 1000m along strike with the southwestern (positive) electrode in the surface expression of the Zinc Lodes. The positive electrode was a 2x2m pit pierced by several star pickets, lined with aluminum foil, and filled with water. The dipole wire was run east out and around the North Mine waste rock dumps and back west to drill hole NM6035 (on section 2900ftN). The negative electrode was lowered down NM6035 to ~550metres in a weak (5% Zn+Pb) Zinc Lodes mineralisation intersection. In this way, the current electrodes isolated and targeted the correct mineralisation, which may otherwise have been too deep for a surface electrode to energize. A standard IP transmitter was used to produce a 7-8 amp current between the electrodes.

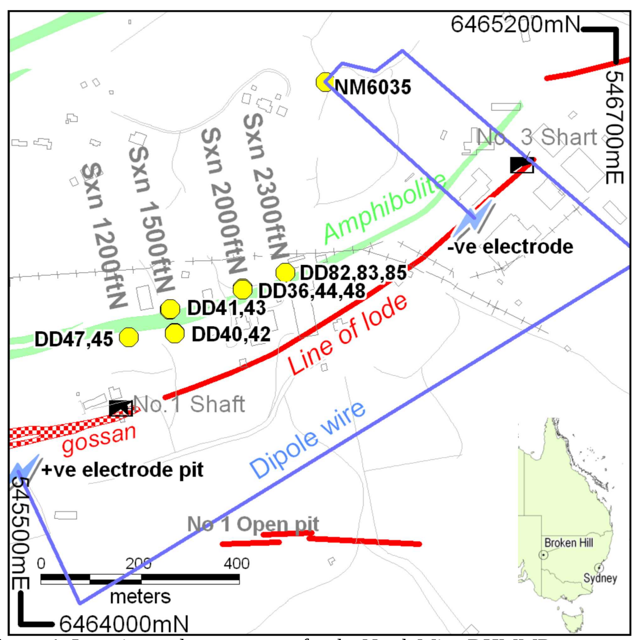

Figure 1: Location and survey setup for the North Mine DHMMR program.

DHMMR is based on the principal that 'earth return' current seeks the path of least resistance between the two dipole electrodes and thus any relatively conductive zone such as a disseminated sulphide deposit is preferentially energised. The increased current density in the target has an associated magnetic field (B) and this was monitored with a 3-componet fluxgate magnetometer probe (Atlantis probe). The station spacing was between 1 and 20m, depending upon proximity to an anomaly. The total magnetic field B (in pT/A) was reduced prior to interpretation by subtracting with the magnetic field due to the current flowing in the wire (wire response), the electrode fields, the layered earth response and the halfspace response from the total magnetic field (Btot) to get the magnetic response from the energized bodies (Bmmr). Wire response dominates the signal, so the wire was placed well away from the drill holes to reduce its influence.

Polarity and Phase

Polarity definitions are particularly important in DHMMR. The current in the ground is defined as flowing from south to north (Asten, 1988), so that a conductor beneath an easterly azimuth drill hole will produce a negative response and a positive response if above the hole. The opposite will apply for west-facing holes (Figure 2b).

The phase difference between the transmitted current and the recorded voltage was also recorded (in milliradians). This is an induced polarisation (IP) parameter, which can be used qualitatively in an interpretation, but it has not yet been incorporated into my modeling software. However, Purss et al. (2003) report a method for modeling the phase (MIP) response and apply it to some data from the Flying Doctor deposit, Broken Hill.

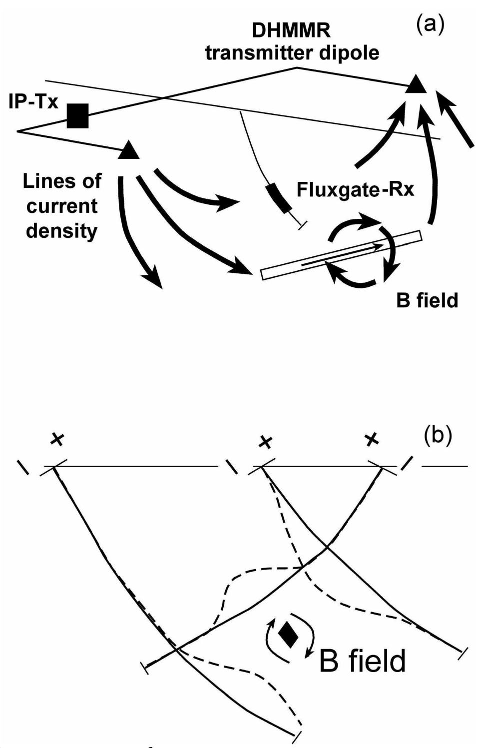

Figure 2: Sign conventions for DHMMR surveys.

Modeling

The resultant magnetic field was modeled using a combination of wire filament and current density forward modeling. The A-component was the most important match – the model fit was good for most components as long as the A-component was solved. The U-component is complimentary to the A component, whilst the V-component was useful to analyse strike/plunge information. However, since drill fans were perpendicular to strike, and the dip/plunge well constrained, the usefulness of the V-component in this particular survey was limited. It is expected that V+U component will be very useful for extending the application of MMR to targets off the drill section or striking obliquely to the drill section.

Previously, all MMR modeling was done assuming a section orthogonal to strike (2D modeling). This allows a good match to the A and U component data, but the V component is lacking. There is still development to be done in the modeling software to make a complete user-friendly 3-component package, and at the time of writing this paper some of that work is beginning.

RESULTS

12 holes on four sections were surveyed. The holes dipped 60-80° with a southeastly azimuth (Figure 1). The surveys recorded strong responses, stronger and cleaner than expected given the location. The main source of noise was very long wavelength offsets from mining vibrations and a large 50Hz signal. The noise .disappeared with stacking: 48 stacks with 2 repeats at 1Hz was sufficient to achieve noise levels well below 0.8, 2.5 and 2.9 pT/amp for the A, U, and V components respectively.

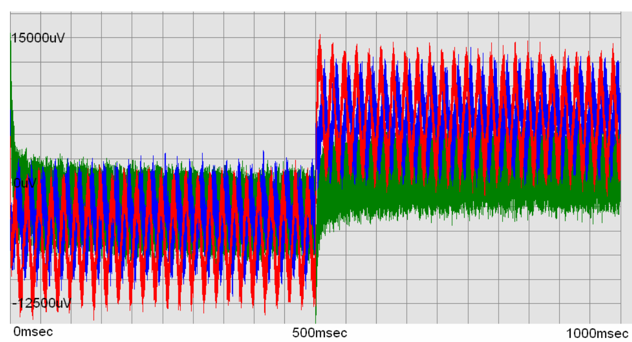

Figure 3: Raw signal from Atlantis fluxgate probe from A (red), U(blue) and V(green) component data.

The comparison between the Sirotem and Atlantis probes indicates that the Atlantis is more sensitive to off-hole anomalies, and has much less noise. The full reason for the differences between the results is still being investigated.

DHMMR was modeled on a section-by-section basis. The 2D-polygons from this modeling were extended 50m up and down-plunge to create 100m strike-length polygons. These were incorporated into the mine resource modeling software (Vulcan) as the best way to visualize the relationship between the model results and the known mineralisation (Figure 5). The primary concern was that the current had short-circuited through the

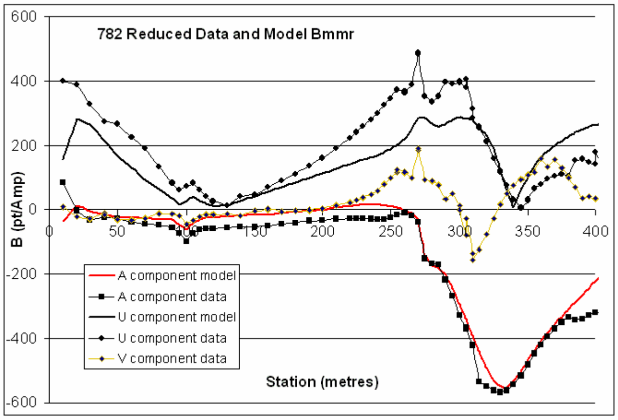

Figure 4: Hole 782 data and model Bmmr for A+U components, and Bmmr for V-component.

nearby highly conductive North Mine main lode; however the plotting of the model results soon proved that the models were in the correct stratigraphic position.

The modeling indicates to two types of mineralisation (Unit 4.5 and Unit 4.7) defined by different current densities. This variation is primarily a function of the pyrrhotite composition of the two units, manifesting as current densities of 1 mA/m2 for Unit 4.7 to 0.1mA/m2 for Unit 4.5. This supports previous experience that Unit 4.7 mineralisation is generally quite conductive and Unit 4.5 is much less so.

DISCUSSION

This survey represents the first use of a 3-component fluxgate probe in a DHMMR survey at Broken Hill, and one of the first examples Australia-wide. Previous surveys have used single component TEM induction coils as the down-hole sensor, which only record the induced field (dB/dt). There are a number of issues associated with the use of TEM probes for DHMMR surveys that compromise the quality of the data acquired. Of these, the two main limitations are (1) TEM probes measure dB/dt rather than the B-field directly (thus requiring manipulation of the data to arrive at the mathematical equivalent of the B-field), and (2) while TEM probes, in general, are well suited and calibrated for downhole time-domain EM surveys (with source frequencies generally greater than 10Hz) the output signal from the receiver coils at low frequencies (e.g., 1Hz) is greatly affected by the background noise level. The use of 3-component TEM probes have been investigated (Elders and Asten, 2004), but the smaller coil area for 3-component TEM probes meant that they suffer from problems with noise. Using a B-field probe effectively allows the entire time signal (minus the inductive spike) to be averaged to create a better result with

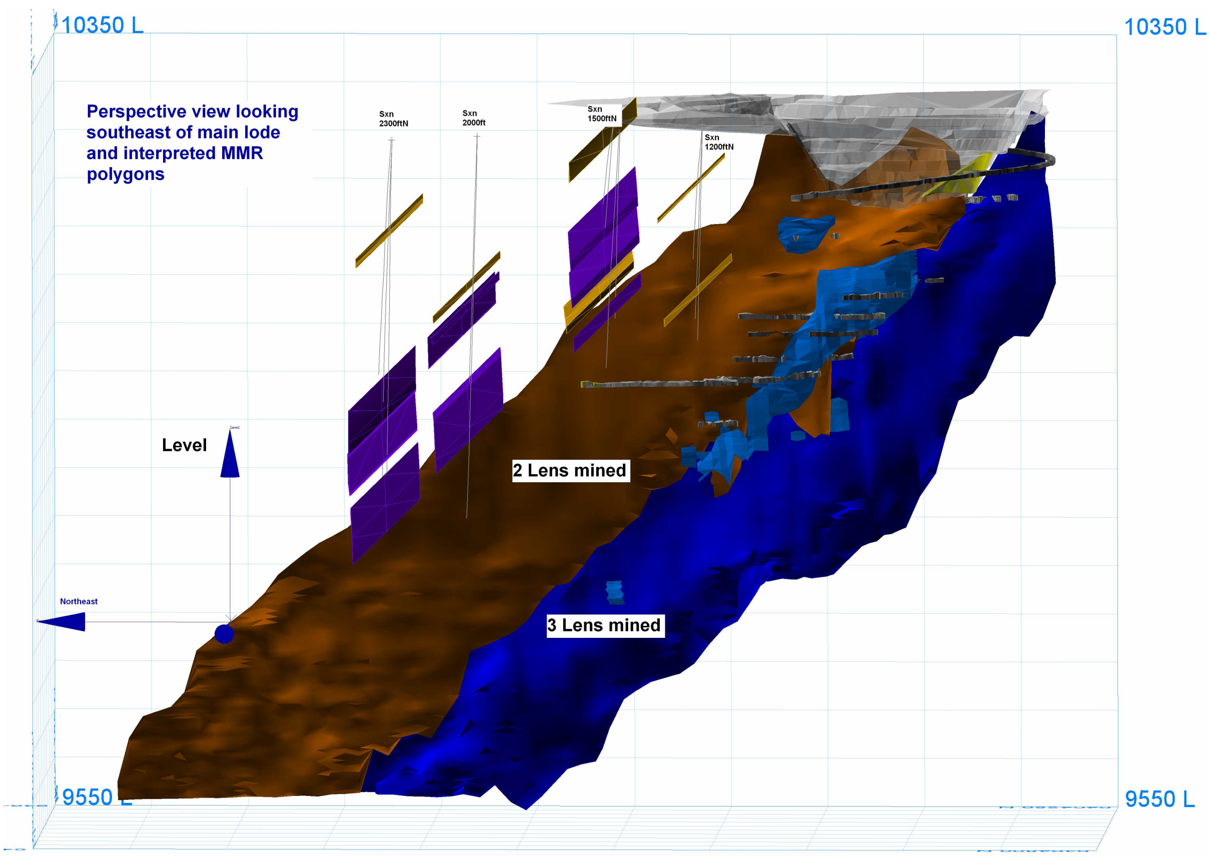

Figure 5: Perspective view looking south east of 3D DHMMR polygons and drill hole traces with 3-Lens and 2-Lens orebodies.

much lower noise components. In the high noise environment next to the North Mine it was considered worthwhile to promote a B-field probe to try to eliminate or at least reduce the mine noise. To document the effectiveness of the B-field probe and work out the transmitter frequency/number of stacks required, one hole was repeated with the Sirotem probe. This showed much lower noise and better anomaly definition in the B-probe data despite fewer stacks, not to mention the addition U, V and raw magnetic field data.

The survey was considered a success, particularly given the excellent data quality underneath the North Mine infrastructure and the accurate delineation of the low conductivity Zinc Lodes so near to the high conductivity 3 lode mineralisation. The modeled polygons define nearly continuous ribbons west and above the main lode (Figure 5) with different current densities associated with different types of mineralisation. The main limitation of the software surfaces when one considers that the drill holes are required to be on the same section to be realistically jointly modeled, however it is expected that this limitation will be overcome in the next few months.

CONCLUSION

The comparison between the modeling and the interpreted geology of the North Mine provides a very strong case for the use of DHMMR to delineate low conductivity ore in this challenging setting. In addition, the depth of investigation of DHMMR (when a down-hole source electrode is used) does not seem to be limited by any physical constraint other than drill hole depth. The success and accuracy of this survey using new equipment is expected to lead to a better appreciation of DHMMR's potential.

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