LIGHTING UP THE REGOLITH: APPLIED POTENTIAL EXPLORATION METHODS

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ABSTRACT

The Mise-à-la-Masse (MALM) method is a cost-effective and quick method of energising conductive mineralisation, such that the data garnered will yield information on the structure and geometry of the target mineralisation. The method is adept at brownfields exploration of known mineralisation, as it can record the subsurface electrical interconnections between mineralisation in the area.

Interpretation methods for MALM are primarily qualitative, involving a plot of electrical potential data acquired from the instrument with little or no processing (Ketola 1972). Whilst this is a valid approach, it yields little depth information of the anomalous targets, and simply indicates areal extent of them. The purpose of this study is to investigate alternate means of readily interpreting the data, through three-dimensional (3D) forward modelling, simple processing, and image approximation to acquire further information, in particular, depth from the MALM dataset.

INTRODUCTION

The MALM technique is under utilised given the simplicity of the method, and the possible information that can be extracted from the resulting data. Compared to other ground geophysical methods, MALM can cover a large extent of ground in the same time it may take to do a single line of some other methods. The technique itself can be employed on pre-existing electrical geophysics equipment, such as Induced Polarisation systems, making MALM a cost-effective method.

MALM is conducted via a pole-pole array (Eloranta 1985) by placing a current electrode in contact with the conductive target, either down hole or at an outcrop. A return current electrode is placed at distance in order to simulate a point current source (Figure 1). Surface potentials are mapped using a electrode with a corresponding return electrode at distance to evaluate an absolute potential. Alternatively a pole-dipole array maybe used to determine the potential gradient fields.

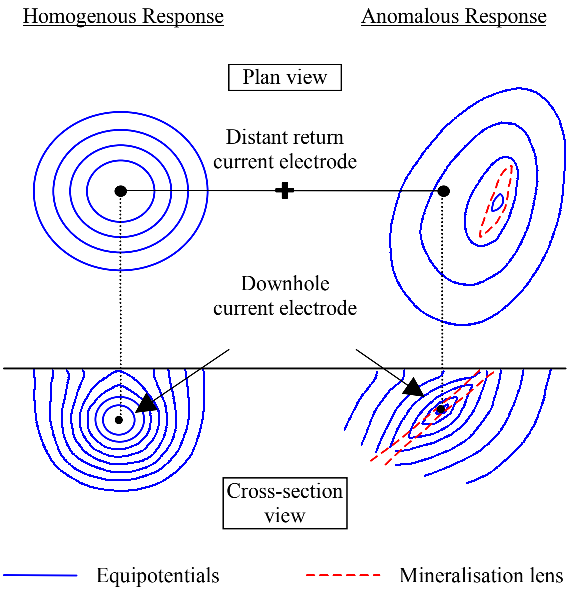

Figure 1: Homogenous media vs anomalous potential response from MALM method

Equipotentials about an energised current electrode are spherical in a homogenous and isotropic half-space. The surface response is circular (Figure 1), with the rings centred on the current electrode. If there is an anomaly within the half-space, and the electrode is electrically connected to it, the lines of equipotential are distorted and displaced from the current electrode's position, with surface measurements centred over the upper surface of the conductive body or outcrop.

Surface data from the MALM method indicates the two-dimensional (2D) extent of a conductive structure and can provide information on the continuity of ore between borehole intersections or outcrops. However, the data does not readily provide unique depth constraints to the target, as is the case with all surface potential field measurements.

LOCALE AND GEOLOGICAL DESCRIPTION

Field data used for this investigation were obtained from Newmont Australia's surveys of their Scuddles Mine, Golden Grove tenement, Western Australia (approximately 225km inland from Geraldton) (Boyd &

Frankcombe 1994). The location hosts a base metals operation involving a volcanogenic massive sulphide (VMS), with the primary target being a massive pyrite.

Covering the region is a conductive weathered overburden of variable depth of eighty to one hundred metres. The known geology indicates the target is a conductive band of eighty metre width, steeply dipping at eighty degrees to the west, striking north-south, with a plunge of five degrees to the north (Boyd & Frankcombe 1994). The conductive body has been drilled extensively and MALM surveys conducted at numerous drill holes situated in a confined area. The region is of low topographical relief with the only prominent feature being a low lying hill situated over the ore body, the aptly named Gossan Hill.

METHODS

Data Collection and the Near-Miss Scenario

In collecting the data, a current electrode was placed down hole at the depth of lowest resistivity for the target formation to ensure a good coupling to the conductive body. The area surveyed measured 750 metres by 1 kilometre. The transmitter used was an Iris VIP-4000 that supplied between two to five amps on a two second cycle at 200 volts. The receiver used was an Elrec 6 IP receiver. The distant return electrodes were placed more than two kilometres from the survey area.

Most surveys were conducted in the conventional pole-pole manner with the current electrode placed in contact with the conductive body. Several surveys were also conducted in a near-miss/barren hole configuration where the current electrode was not placed in contact with the target, but rather outside the target formation's known depth, identified from drill logs.

3D Forward Modelling

Using a 3D Finite Element Method (FEM) forward modeller (Zhou & Greenhalgh 2001), a simple block model of resistivities was defined to reflect the MALM responses using an inhomogeneous, isotropic half space. The conductive body, with geometries and positioning estimated from the described geology, was located within the half-space. The program allowed for simulated source electrodes to be placed in locations about the model body to correspond to those in the two surveys described. The aim of this modelling was to numerically replicate the MALM responses seen from the conventional and near-miss surveys.

Electrode Effect Removal

Electric potential fields caused by a buried current electrode inside any complex geologic resistivity structure can be described as part of a geoelectric construct, where spatial variations in the potential field are due to point current sources and/or sinks (Keller & Frischknecht 1966):

$$U(P) = \frac{1}{2\pi}\left[\int_V \frac{\rho \operatorname{div}\mathbf{J}}{r}\,dV + \int_V \frac{\mathbf{E}\cdot \operatorname{grad}\rho}{\rho r}\,dV\right] \qquad (1)$$

The above equation is the geoelectric potential U at point P where J and E are the applied current density and electric vectors, r is the distance from point P, to the volume element dV, and ρ is the resistivity function. The first integral is the primary input to $U(P)$, from the current electrode, the second integral is the secondary input to the total geoelectric potential at P, caused by variations of resistivity within the volume V.

Equation 1 assumes that volume V consists of blocks of isotropic material and the resistivity gradient gradρ, is only across surfaces of resistivity discontinuity at the interface between these blocks. In the first integral, the potentials due to current sources can be removed, thus leaving the second integral describing charges at resistivity boundaries. The image-current technique (e.g Telford *et al.* 1990) numerically calculates the potential field from a buried electrode in a homogenous half-space and subtracts it from the total electric potential, U. The resultant residual potentials are reflective of the subsurface resistivity boundaries.

EXAMPLES

3D Forward Modelling

A particular drill hole had several surveys conducted in the same area with the current electrode positioned at differing depths in order to have one conventional and a near-miss scenario. Set-up A (Figure 2) is the surface potential response from a MALM survey conducted with the current electrode in contact with the conductive massive pyrite body at a depth of seven hundred metres. The equipotentials are elongated in the north-south direction, following the strike of VMS deposit.

In the same drill hole, two more set-ups were conducted, both of the near-miss type with the current electrode out of the known target mineralisation depth. Set-up B (Figure 3) is the shallower survey with the downhole electrode at a depth of four hundred and eighty metres. The peak anomaly is still in the same approximate position as that of the in-mineralisation case and it is still elongate according to strike. However, the shape of the anomaly is much broader and the maximum value is considerably lower despite the electrode being closer to the surface.

The forward model consisted of a homogenous half-space of 1000 Ω.m resistivity and a conductive of body of 0.1 Ω.m. The body created strikes north-south with an eighty degree dip to the west. The upper surface of the body plunges to the north and has a minimum depth of one hundred metres. The body is separated from the cover by twenty metres of resistive host material and has a width of eighty metres. The simulated cover of 10 Ω.m resistivity was 100 metres thick.

Executing the model, with the current electrode in the mineralisation as with Set-up A, shows the mineralisation is energised by the electrode with the upper surface of the conductive body underlying the position of the peak surface anomaly (Figure 2). The model cut away shows a potential halo surrounding the model body; this is equally distributed, as the body is electrically homogeneous and isotropic. This model was also used with the current electrode in the near miss positions outside of the mineralisation. In the shallow position of Set-up B, the model (Figure 3), shows that highest potentials in the volume occur about the current electrode's position. However, the conductive body is drawing current closer to the surface, hence, the epicentre of the surface potentials are situated above the uppermost part of the conductive body.

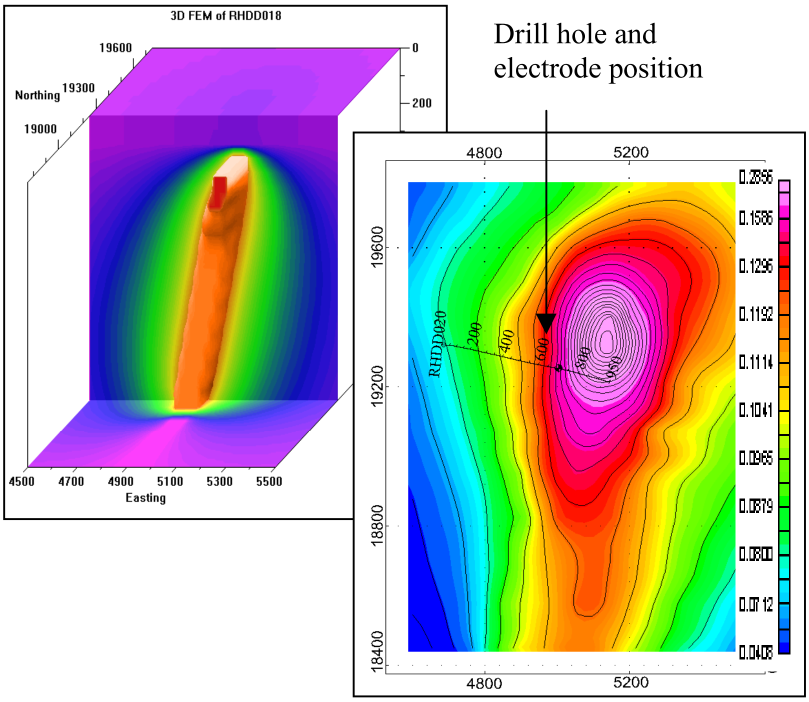

Figure 2: Left: 3D model cross-section. Right: Surface potentials and electrode position.The MALM surface data for Setup A (right), with its corresponding electrode position, is shown to energise the conductive body in the 3D forward model (left). The peak surface anomaly is centred over the upper portion of the body.

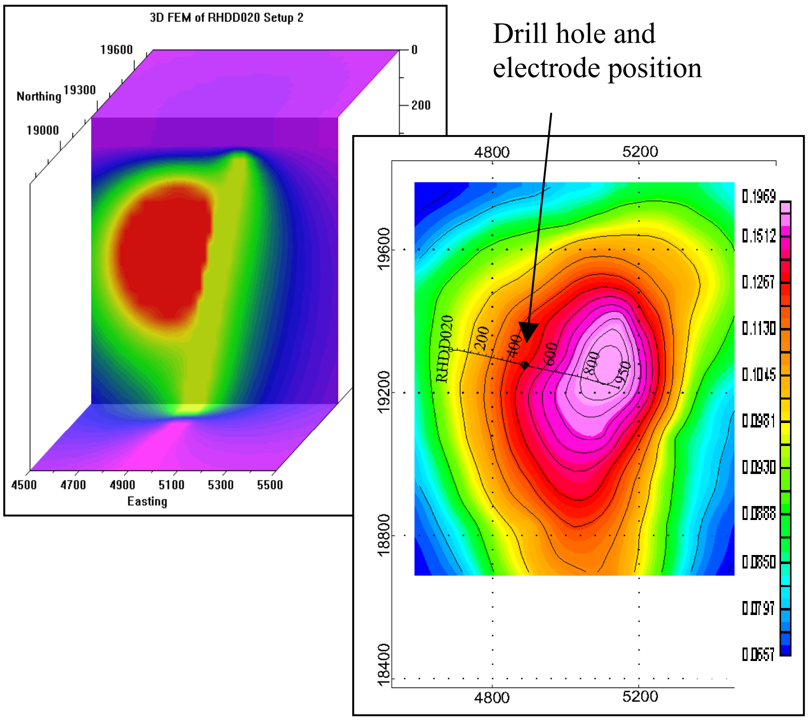

Figure 3: Left - 3D model cross-section. Right - Surface potentials and electrode position. Setup B surface data (right) is similar to Setup A, however in the 3D model cross-section (left), the electrode is outside of the conductive body but charge is still carried closer to the surface by the conductive body.

Electrode Effect Removal

This technique was applied to two different sets of data from the same drill hole but at different depths, 450 metres and 850 metres. The responses from the shallow MALM survey, Hole 1a (Figure 4), are significantly different to that of the deep survey, Hole 1b. The shallower response is a broad anomaly with the highest values to the south east of the current electrode's position. The deeper response shows that the highest values are far to the south of the current electrode and the shape of the peak is very different in comparison to the shallower survey.

The current electrode's position was modelled for each of the respective data sets in a half-space of 1000 Ω.m, and the modelled surface potentials were subtracted from the acquired MALM data. Residual potentials are very similar in appearances juxtaposed to the data they were derived from.

Residuals from Hole 1a (Figure 4) no longer have the peak anomaly centred in the survey area: maximum potentials now occur on the southern border of the survey, similar to the field data collected in the deeper electrode position. There appears to be minimal change to the data of Hole 1b upon application of the electrode removal technique.

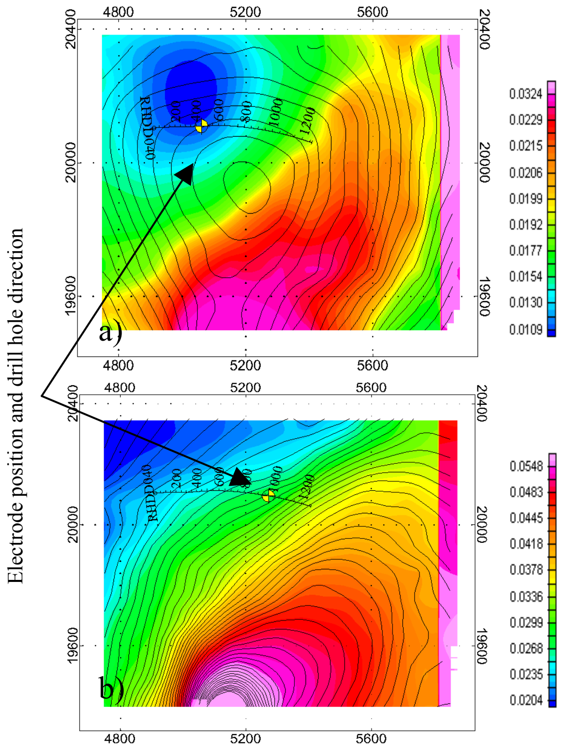

Figure 4: a) Contours of original MALM data (Hole 1a) and colour map after the removal of the electrode effect. (Above): b) as for (a) but for electrode in Hole 1b.

DISCUSSION AND CONCLUSION

It has been shown that MALM data provide a means of constraining resistivity variations in the subsurface. From the near-miss surveys conducted at Golden Grove, near-miss MALM data contains information that is useful despite being in a barren hole. This implies that similar holes without mineralisation intersections can still be investigated for pertinent information.

The use of plots of potential is outmoded and insufficient, as the potential field due to the electrode can significantly distort and dominate the surface response. Using an image current approach, it is very easy to remove the electrode potential. The resulting potential map is a better representation of the subsurface charge distribution that occurs at resistivity boundaries. Rather than 3D forward and inverse modelling, we recommend an alternative approach of defining a 3D scanning function and determining a spatial correlation with the measured fields. As targets are bounded by changes in resistivity, it is of interest to know where charges are located spatially rather than in terms of their electrical potential response. More details of the method are given by Carey (2003).

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