Electrical and Transient Electromagnetic Modelling of a Copper Prospect near Cobar, NSW

M.R.P. Tingay[a], P.I. Brooker[b] and P. Basford[c]

[a] *National Centre for Petroleum Geology and Geophysics, Adelaide University, Adelaide SA 5005, Australia (mtingay@ncpgg.adelaide.edu.au)*

[b] *Department of Geology and Geophysics, Adelaide University, Adelaide SA 5005, Australia (peter.brooker@adelaide.edu.au)*

[c] *Pasminco Exploration, Melbourne Vic 3001, Australia (BasfordP@Pasminco.com.au)*

Abstract: The electrically conductive nature of deeply weathered overburden is a significant hindrance to electrical and electromagnetic exploration. These difficulties can be greatly reduced through well-designed surveys and with modern processing and modelling techniques. Drilling and geochemical sampling in the Cobar Basin encountered a 995 ppm copper anomaly coincident with an abnormally deep weathered zone. Inverted resistivity data reveals a weakly conductive zone below the observed copper anomaly. Modelling of transient electromagnetics shows a narrow conductor with a 0.45 millisecond time constant underlying the overburden. A 60 m wide fault with a 250 Ω-m resistivity below a 40 m deep weathering trough is interpreted to be the cause of the resistivity, transient electromagnetic and copper anomalies.

Keywords: Resistivity; Transient Electromagnetics; Cobar; Weathered Terranes

1. INTRODUCTION

In 1980 the geophysics of the Elura orebody near Cobar, New South Wales was extensively discussed in a special symposium [Emerson, 1980]. The symposium investigated the response of a massive sulphide deposit located below approximately 100 m of deeply weathered and conductive overburden [Adams and Schmidt, 1980]. Transient electromagnetics [Buselli, 1980], induced polarisation [Tschaikowsky and LeBrocq, 1980] and resistivity techniques [Agostini, 1980] proved to be excellent in detecting the deposit. The results of the Elura Symposium have helped to shape geophysical exploration around Cobar and other areas of weathered terranes.

Twenty years later we use these electrical and electromagnetic techniques combined with more recent geophysical advances to investigate a copper geochemical anomaly near Elura. We show the ability of transient electromagnetics and dipole-dipole electrical methods to detect and resolve the source of the copper anomaly located beneath 100 m thick electrically conductive regolith. In particular, we highlight recent improvements in survey design, processing and software that can be used to better locate mineral deposits underneath conductive overburden.

Firstly, we summarise the difficulties associated with electrical and electromagnetic exploration in weathered terranes. We then present the geochemical and drilling results that initially highlighted the copper prospect. Finally, we show how the combined use of transient electromagnetic soundings and dipole-dipole resistivity was able to resolve a weakly conductive feature underlying the copper anomaly.

2. EFFECTS OF THE WEATHERED ZONE ON ELECTROMAGNETIC AND ELECTRIC TECHNIQUES

2. 1 Introduction

Electrical and electromagnetic geophysical techniques are used to measure variations in electrical conductivity at depth within the earth. Many types of orebody are composed of conductive minerals that can be detected and delineated by their electrical or electromagnetic signature. However, in many of Australia's mineral belts this signature may be obscured by the presence of an electrically conductive overburden.

2.2 Effects on Electrical Techniques

Two electrical surveying methods were used in our survey: resistivity and induced polarisation (IP). Resistivity techniques measure variations in the Earths' electrical resistivity (the resistance of a unit volume of material). Induced Polarisation techniques measure variations in the Earths' electrical chargeability (effectively the normalised capacitance of a material).

In both resistivity and IP surveying a current is applied to the ground by a pair of transmitter electrodes and a voltage measured across a separate set of potential electrodes. In weathered terranes the transmitted current will pass preferentially through the conductive regolith. Hence, very little current will reach an underlying orebody [Smith and Pridmore, 1989].

2.3 Effects on Transient Electromagnetic Techniques

Transient electromagnetic (TEM) techniques are based on Faraday's law that a current is induced in a conductor when the conductor is exposed to a time-varying magnetic field. A current is passed through a transmitter loop on the surface and then rapidly switched off. The "primary" magnetic field produced by the transmitter generates a voltage in any nearby conductors, which in turn generates a "secondary" magnetic field that can be measured by a receiver coil [Telford et al., 1976]. In weathered terranes the primary magnetic field must pass through a thick zone of conductive material before reaching any underlying conductive orebodies. The weathered zone also attenuates the secondary magnetic field produced by an orebody at depth [McNeill, 1995].

3. COBAR SURVEY AREA

The Cobar Basin in central New South Wales is one of the oldest mining areas in Australia. The Cobar region is highly prospective for lead, zinc, copper, silver and gold.

Our survey area was chosen to investigate a small copper prospect located approximately 55 km north-northwest of the Cobar township. Surface geochemical sampling located an area of anomalously high copper in the soil. A line of five shallow boreholes was used to test the anomaly. Amounts of up to 995 ppm copper were found within the weathered zone. None of the boreholes penetrated deep enough into fresh rock to determine the source of the copper.

The drilling results indicate the presence of a weathering trough (a zone of abnormally deep weathering) underlying the copper geochemical anomaly. The weathering trough is at most 60 m wide and at least 30 m deep (Figure 1).

Weathering troughs are a potential indicator of an underlying orebody. Many orebodies are formed by focussing mineral-rich fluids through highly permeable features such as fractures and faults. The intense weathering associated with these highly permeable features can lead to the development of a weathering trough.

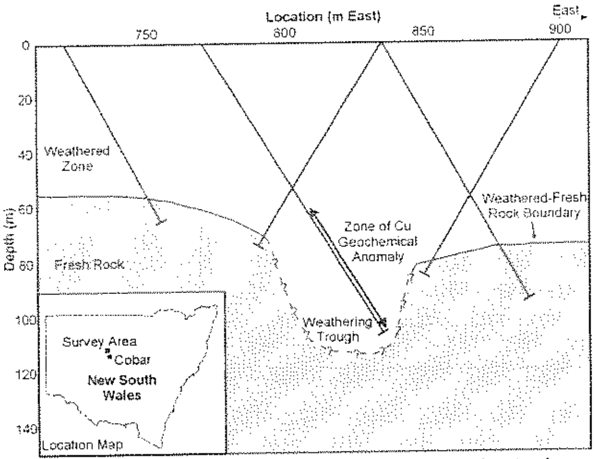


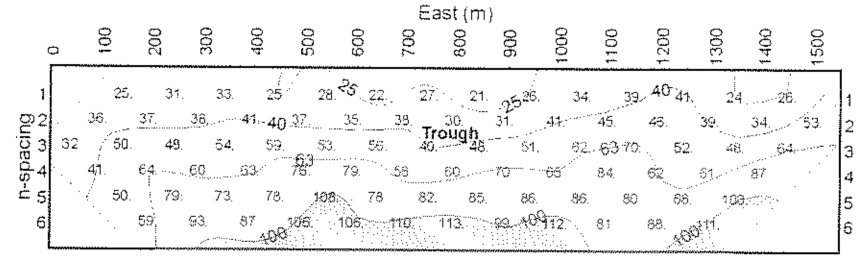
Figure 1. Cross-section of observed geological structure from five boreholes in the survey area.

4. TRANSIENT ELECTROMAGNETIC AND ELECTRICAL SURVEY

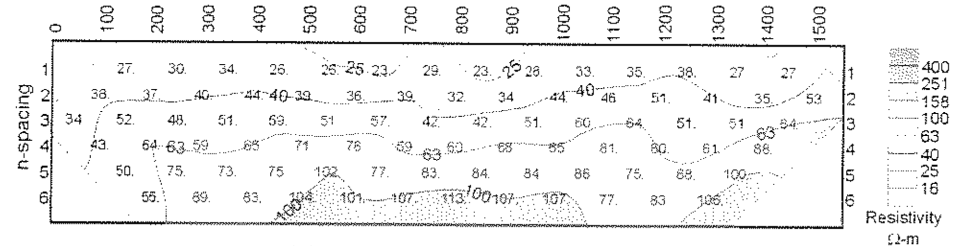
4.1 Introduction

TEM, resistivity and IP surveys were performed over the prospect to identify and delineate the origin of the geochemical anomaly and weathering trough. TEM and resistivity surveys are used to detect orebodies where the conductive minerals are predominantly in electrical contact, such as massive sulphide orebodies. The Elura Pb-Zn-Ag deposit located 12 km from our survey site is primarily a massive sulphide orebody. IP surveys are designed to detect disseminated orebodies in which the electrically conductive minerals are diffusely scattered through the orebody. The nearby Elura mine also contains zones of siliceous disseminated ore that are detectable on IP surveys [Tschaikowsky and LeBrocq, 1980].

(a) Observed Apparent Resistivity



(b) Calculated Apparent Resistivity from Inversion



(c) Smooth-model Inverted Resistivity

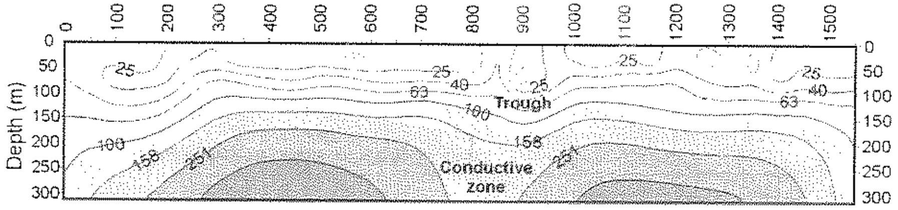


Figure 2. Resistivity results and inversion.

4.2 Electrical Surveys

A single 1.5 km line of resistivity and IP was collected along the same line as the exploration boreholes. Both the resistivity and IP were measured using a dipole-dipole configuration with 100 m dipoles. A large high current transmitter dipole was used, allowing current to more effectively penetrate through conductive overburden [Smith and Pridmore, 1989].

4.3 Transient Electromagnetic Survey

Three 1000 m lines of TEM were collected over the prospect. The central line was measured along the same line as the five exploration boreholes. TEM were also measured 250 m north and south of the central line. The TEM was measured with a SIROTEM MKIII system using in-loop soundings and 100 m transmitter loops. TEM surveys with large transmitter loops and high transmitter currents are the best survey design for detecting orebodies under thick conductive regolith [Lowrie and West, 1965; McNeill, 1995]. A similar survey design produced excellent results over the nearby Elura orebody [Busselli, 1980]. Both the vertical (Z) and east-west (X) components of the secondary magnetic field were measured.

5. RESISTIVITY AND INDUCED POLARISATION RESULTS AND MODELLING

5.1 Resistivity Results

The dipole-dipole resistivity measurements suggest that resistivity is approximately 30 Ω-m near the surface and increases with depth. The resistivity psuedosection indicates there is a deeper zone of conductive material at the location of the weathering trough (Figure 2a).

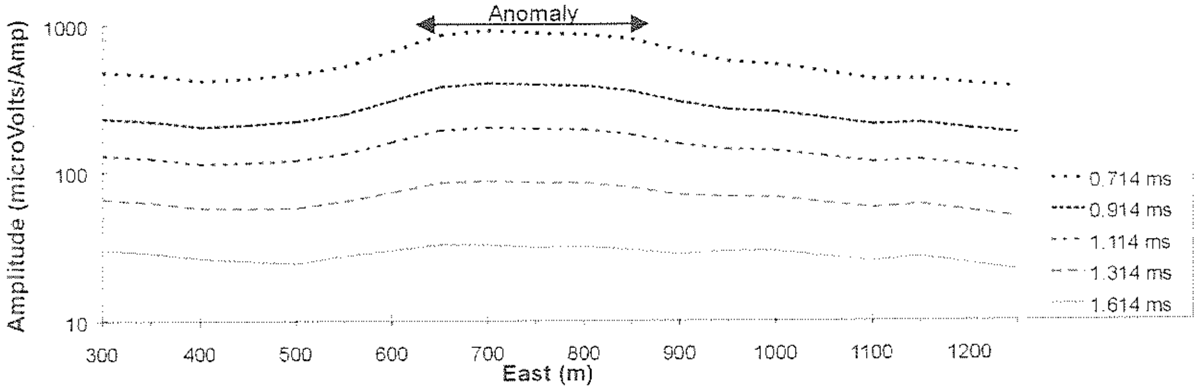
5.2 Induced Polarisation Results

The IP results show very low values for chargeability. This suggests that there are no chargeable bodies underneath or within the weathered zone. Hence, there is unlikely to be any disseminated mineralisation associated with the weathering trough.

5.3 Resistivity and IP Modelling

Resistivity was inversely modelled using the Zonge Engineering TS2DIP 2D smooth model inversion program. No constraints were placed on the inverse model solution. The inverse modelled resistivity is

(a) Z-component TEM response



(b) TEM response after overburden stripping

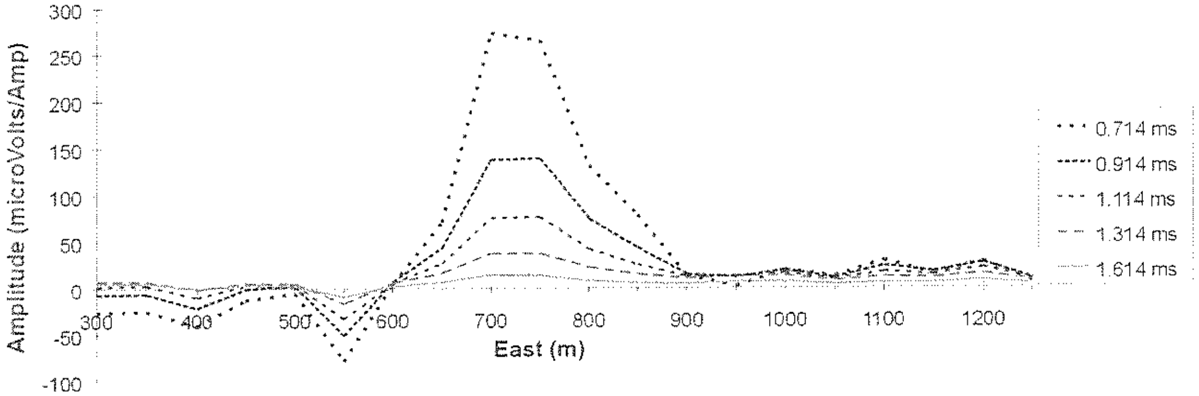


Figure 3: Observed TEM response and TEM response after overburden stripping.

an excellent fit to the observed resistivity (Figure 2). The nature of the smooth model inversion makes it difficult to determine diagnostic information about the weathering trough and conductor, in particular width and depth. However, the inversion gives a good impression of the general resistivity structure. The calculated model suggests:

- A 60 m thick, 25 Ω-m weathered zone.
- At most 100m wide, 60 m deep and 20 Ω-m weathering trough.
- An underlying 200 Ω-m weakly conductive zone up to 150 m wide.

6. TRANSIENT ELECTROMAGNETIC RESULTS AND MODELLING

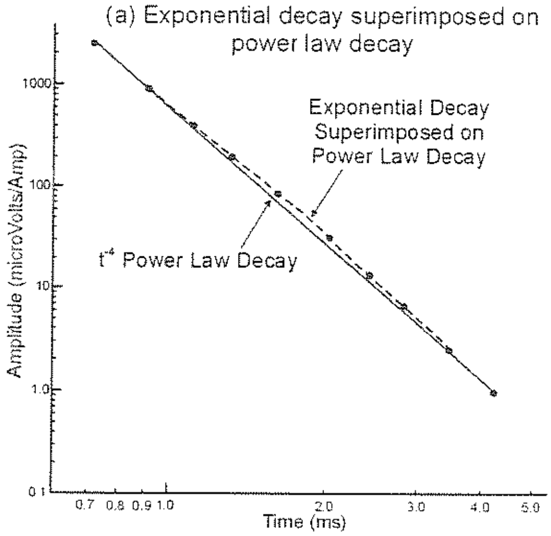
6.1 TEM Results

The central and northern survey lines exhibited high amplitude Z-component TEM responses over the location of the weathering trough. The TEM response is observed on time channels between 0.714-1.614 milliseconds (Figure 3a). Delay times are approximately proportional to the depth of the conductor. The TEM response was recorded up to 11.814 milliseconds. Hence, the observed delay times indicate a conductive body at shallow to moderate depth.

The X-component TEM measurements showed a positive-to-negative cross-over at the approximate location of the weathering trough. This result is consistent with forward modelling of a conductor underneath the weathered zone.

Asten [1992] showed that the Z-component TEM response of the weathered zone can be "stripped" away to highlight conductive bodies at depth. The TEM response of conductive overburden can be approximately modelled by a thin horizontal sheet and will have a t^{-4} decay on TEM soundings [Kaufmann and Keller, 1983]. Stripping involves subtracting the power law overburden response away from the total TEM response. The remaining residual is the inductive response of an underlying conductor plus background noise and any errors arising from the stripping process [Asten, 1992]. When the overburden response was removed from our data the response of the underlying conductor was greatly enhanced (Figure 3b). Stripping reveals that the underlying conductor has an exponential time decay with a time constant of

0.45 milliseconds (Figure 4). A good conductor would show a time constant of at least 1.0 milliseconds [McNeill, 1995]. Hence, a 0.45 millisecond time constant indicates the underlying body is moderate to weakly conductive.


(a) Exponential decay superimposed on power law decay

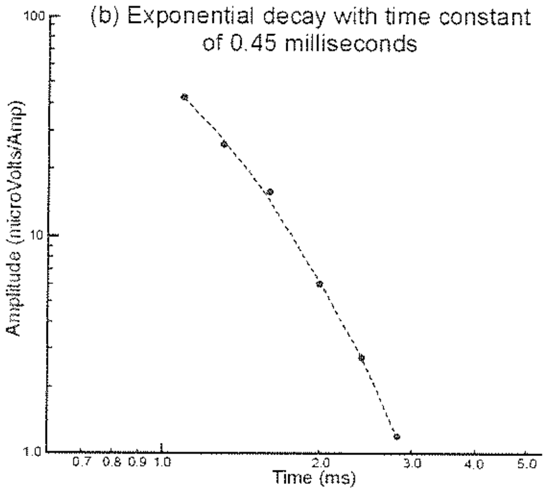

(b) Exponential decay with time constant of 0.45 milliseconds

Figure 4: Stripping away the t^{-4} overburden response reveals an underlying conductor with an exponential decay.

6.2 TEM Modelling

The observed TEM response of the underlying conductor was modelled using the 3D modelling software SAMAYA produced by the Co-operative Research Centre for Australian Mineral Exploration Technologies. SAMAYA allows the modelling of simple 3D rectangular prisms in a resistive halfspace underneath a conductive surface layer.

The model was constrained using the known information from the five boreholes and from petrophysical measurements of the weathered zone and underlying fresh rock. The general resistivity structure from the resistivity inversion was used to first approximate the model. Hence, the model consisted of a 60 m thick weathered zone overlying fresh rock of 1500 Ω-m resistivity [Emerson, 1980]. The weathering trough is known to be a maximum of 60 m wide and at least 30 m deep. A conductivity log run in one of the boreholes indicates that resistivity in the weathered zone is on average 30 Ω-m but decreases in the weathering trough to approximately 20 Ω-m. The underlying conductor is at most 150 m wide and appears to have a resistivity of approximately 200 Ω-m.

The forward model that accurately fit the observed TEM results is comprised of a 60 m wide, 40 m deep and 20 Ω-m weathering trough underlain by 100 m deep, 60 m wide weakly conductive (250 Ω-m) rectangular prism. The combined response of these two bodies is an exponential decay of similar amplitude to the observed with a 0.42 millisecond decay constant (Figure 5).

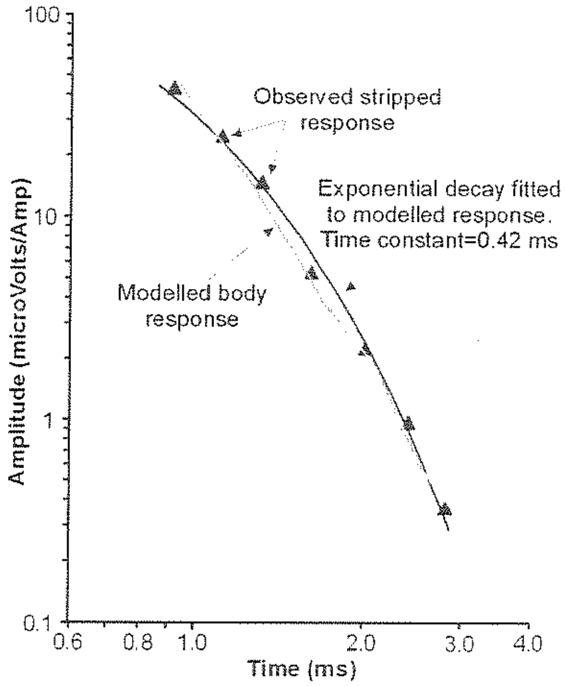


Figure 5: Modelled TEM response and exponential fit to the modelled response.

7. DISCUSSION

The combined use of all the TEM, resistivity and IP information can be used to reliably estimate the size of the weathering trough and underlying conductive zone. The resistivity inversion yields a good impression of the conductivity structure. The

TEM was used to better refine the underlying geology and delineate rock properties.

The lack of any IP response combined with the observed TEM and resistivity response suggests that the conductive body is composed of material that is in direct electrical contact. However, the underlying body is composed of only weakly conductive material (250 Ω-m) when compared with samples from the nearby Elura orebody that show resistivities of 0.1-35 Ω-m [Emerson, 1980]. Hence, the underlying body is unlikely to contain economic mineralisation. One possible scenario is that the underlying body is a fault zone that has acted as a conduit for fluids containing weak amounts of copper in solution. Hydrous materials in the fault zone could cause the weakly conductive nature of the body. The weathering trough has most likely formed by the higher fluid flow from the fault zone.

The combined use of electrical and TEM techniques are a powerful and inexpensive mineral prospecting method. Whilst electrical and electromagnetic prospecting is hampered in weathered terranes such as the Cobar Basin, many of these difficulties can be overcome by utilising modern enhancement and modelling techniques such as overburden stripping, modelling and inversion software.

8. AKNOWLEDGEMENTS

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