Three-Component Downhole TEM Surveys

A. C. Duncan and J. P. Cull

c/- Earth Sciences Dept
Monash University
Wellington Road
Clayton, Victoria 3168
Australia

Summary

Conventional downhole EM surveys measure only one component of the EM field aligned with the drill hole axis. Consequently interpretations are often inconclusive. Three-component downhole TEM surveys can overcome the rotational ambiguities associated with current filament inversions. However, suitable probes are difficult to construct. New sensors have now been developed incorporating sensitive preamplifiers. Orthogonal components can be measured sequentially and the orientation of the probe can be determined using an absolute gravity reference. The system has been tested in a ground traverse over a major conductor and the results are consistent with the response obtained using coincident loop techniques.

Introduction

Downhole EM surveys are a popular means of delineating sub-surface conductors. Normally only one component of the EM field (axial to the drill hole) can be observed. However Cull and Cobcroft (1986) have demonstrated the advantages of three-component data. They constructed a probe for use in the frequency domain and discussed the inadequacies of single axis EM logging systems.

In Australia most EM surveys are conducted in the time domain. Signal/noise ratios are greatly improved (McCracken *et al.*, 1980) and current filaments can be used to aid the interpretation (e.g. Barnett, 1984; Duncan, 1986). However, most targets are defined using surface data. Downhole TEM data are normally obtained in the later stages of exploration to verify the target geometry for further drilling.

Precision is a major factor in the interpretation of downhole TEM data. However the format of a downhole TEM survey varies considerably from a surface traverse. A downhole response can only be measured in one dimension and since drilling is expensive access is extremely limited. In these circumstances the construction of a three-component TEM probe is essential to optimise the available data allowing an improved interpretation.

Instrumentation

During the descent of a logging tool in a drill hole the probe may rotate so that its orientation is unknown. Consequently improved EM probes must include provision for establishing an absolute frame of reference. The total dB/dt vector can then be defined for any delay time at any position down the hole. This should allow a vast improvement over existing systems which measure only the projection of the vector along the drill hole.

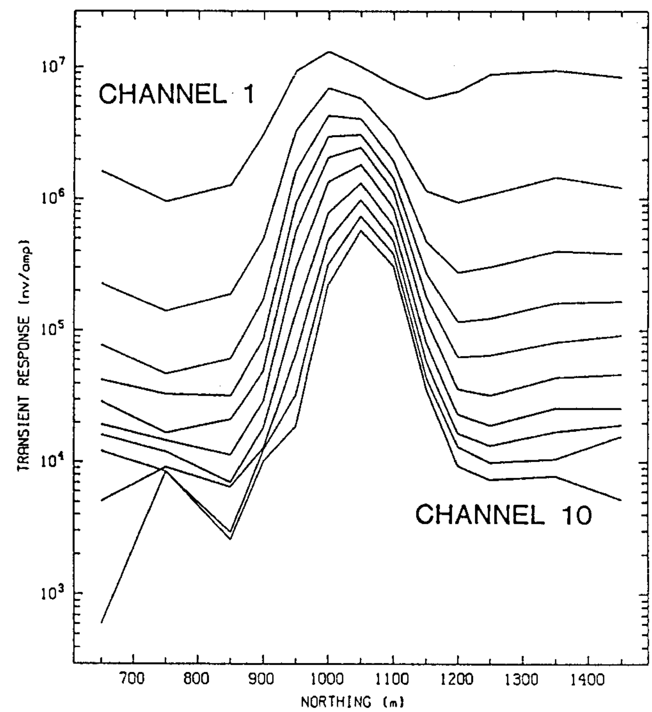

FIGURE 1
50 m coincident loop SIROTEM data over north-dipping conductor in Eastern Australia.

Hoschke (1985) has attacked the problem of measuring the orientation of downhole probes. He incorporated three orthogonal inclinometers in a three-component downhole fluxgate magnetometer probe. This method of defining orientation is complicated and expensive. A simpler alternative based on a gravity reference is preferred for the new EM probes.

Probes have now been constructed with three orthogonal sensors and sufficient effective area for routine downhole TEM logging. The logging system incorporating a sensitive preamplifier is compatible with existing SIROTEM units. Data are obtained for each component using a multiplexer to address each sensor in sequence (including the rotation meter). All signals are transmitted using a twin shielded cable and four additional conductors are included for multiplexer coding and power.

To allow testing of the sensors independently of the rotation meter the coils were used in a two-component fixed loop surface survey over a conductive target in Eastern Australia. Conventional 50 m coincident loop SIROTEM data are presented in Fig. 1 and the corresponding fixed loop data collected along the same survey line using the new sensors are given in Fig. 2. The fixed loop survey was carried out across the centre of the transmitter loop.

Channels 1, 3 and 6 of the SIROTEM response are presented for the fixed loop data for downwards (Z) and northwards (X) components. Conventional polarities are adopted with Z component responses inside the transmitter loop (shown) being positive. The stratigraphy is known to dip to the north in the area and this is demonstrated in both Fig. 1 and Fig. 2. Additional decay curves for stations on the coincident loop survey (1150 mN) and the fixed loop survey (1075 mN, Z comp.) are compared in Fig. 3.

Interpretation

Rotational ambiguities cause major non-uniqueness problems in the interpretation of axial component downhole EM data; these are particularly significant when access is limited to a single drill hole. Any current distribution can be rotated around the drill hole axis without changing its response in the drill hole. This is because of the cylindrically (or axially) symmetric nature of axial component surveys.

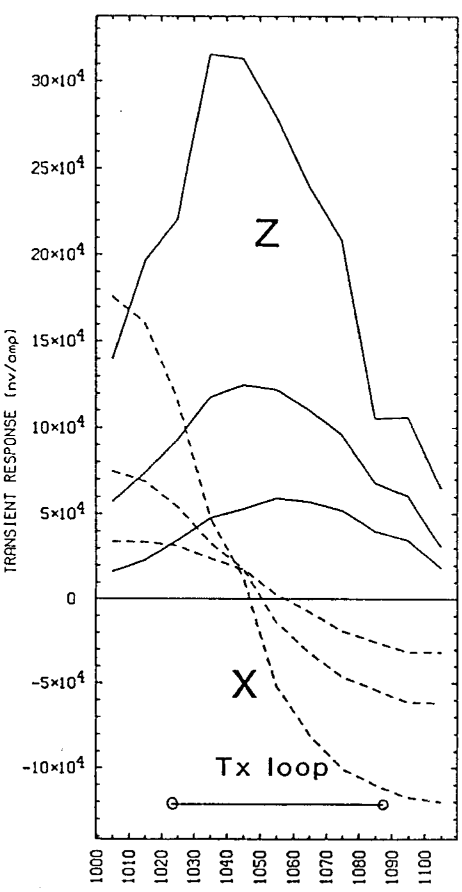

FIGURE 2
Fixed loop SIROTEM data (channels 1, 3 and 6) for same line as Fig. 1. The Z component is vertically downwards; X is horizontally northwards.

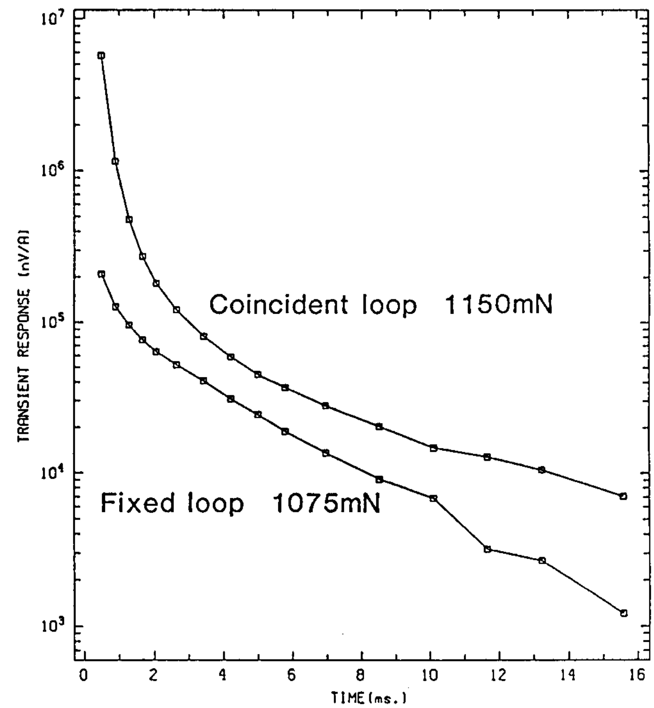

FIGURE 3
SIROTEM decay curves for coincident loop survey (1150 mN) and fixed loop survey (1075 mN, Z comp.).

Where other geological and geophysical constraints on conductivity models are not available interpretation problems may arise routinely. It may not be apparent whether current centres are above or below the hole and the direction along strike to the current centre may be unknown. The distance to the nearest part of the current distribution can not be predicted accurately from single component data unless other constraints are in place.

Figure 4 gives an example of artificial three-component data calculated for a hole plunging 60 degrees and drilled perpendicular to the strike of stratum containing a planar conductor. The Z component is the conventional axial component. The signals measured by the two sensors orthogonal to the drill hole axis are resolved into directions parallel (X) and perpendicular (Y) to the strike direction. The usual convention of polarity is adopted; a positive Z response would occur with the probe inside the transmitter loop.

The X, Y and Z directions form a right-handed axes set (Fig. 4); X is horizontally northwards, Y is directed upwards and to the east and Z is down the drill hole. The symmetry of the Z component shows that the drill hole is approximately perpendicular to the plane of the conductor. Qualitative analysis of the transverse components shows that the current centre is below and slightly to the north of the hole.

Discussion

Filament inversion can provide a good indication of how much 'information' is contained within a downhole TEM data set. Filament inversion of axial component data from a single drill hole can not be carried out without the application of

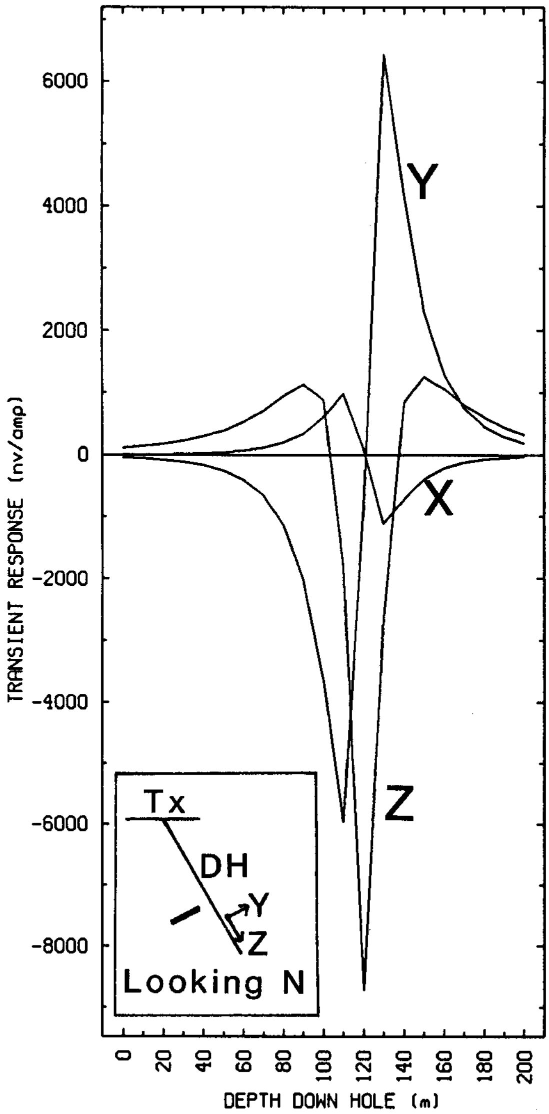

FIGURE 4
Artificial three component TEM data for hole perpendicular to plane of tabular body (inset). The Z component is down the drill hole, X is horizontally northwards and Y is upwards and to the east.

geological constraints such as strike, dip and/or surface projection of conductive bodies.

On the other hand no constraints are required to carry out a filament inversion of a three-component data set from one hole. Non-uniqueness problems are far less severe. Inversions on axial component data sets are quite sensitive to the amount of noise present on the signal. Tests using artificial data sets have demonstrated that this is not the case for three-component data sets. Inversions with multi-component data converge much more rapidly than those with axial component data.

With a complete data set the geophysicist can use more complex models for sub-surface current distributions. Current channelling and host rock responses should be much more obvious where the magnitude and direction of the dB/dt vector are known. The use of three-component downhole TEM surveys should allow more confidence in the placement of further drill holes.

References

Barnett, C. T. (1984)—'Simple inversion of time-domain electromagnetic data', *Geophysics* **49**, 925–933.
Cull, J. P. & Cobcroft, R. (1986)—'Omni-directional downhole EM probes', *Geophysical Prospecting* **34**, 569–579.
Duncan, A. C. (1986)—'Filament inversion of fixed-loop TEM data', unpublished Monash University honours thesis.
Hoschke, T. (1985)—'A new drill hole magnetometer: preliminary results from the Tennant Creek area', *Exploration Geophysics* **16**, 365–374.
McCracken, K. G., Hohmann, G. W. & Oristaglio, M. L. (1980)—'Why time domain?', *Exploration Geophysics* **11**, 318–321.