Layered Model Inversion of Central-Loop E M Soundings near a Geological Contact

M J Wilt
Department of Material Science & Mineral Engineering
University of California, Berkeley CA 94720 USA

J P Williams
Department of Applied Geology
Queensland University of Technology
Brisbane Qld 4001 Australia

Abstract

Central-loop time-domain EM is a widely used method for depth sounding due to its relative insensitivity to lateral changes in conductivity. Near a geological contact, however, this method produces distortions which are not easily distinguished from the layered-model response that is sought by inversion. In this paper we examine this problem for a simple two-dimensional model. Central-loop TDEM data were collected over a vertically dipping quarter-space model using a scale model system developed at U C Berkeley. Both vertical and horizontal magnetic field measurements were made within 250m radius loop transmitters with soundings spaced from 50 to 200m apart along a profile orthogonal to the contact. The sounding data from individual stations were then fitted to layered models using a standard least squares algorithm and the resulting layered models were plotted as a pieced-together cross-section. For the vertical field data the contact effect appears as a loss in field strength at lag times that depend on the distance from the contact and the conductivity of the quarter-space. At stations more distant from the edge the fields are reduced only at later times, whereas closer to the contact the effect shifts to earlier times and increases in magnitude. The layered model inversions seem to interpret this distortion as a fictitious resistive layer that grows more shallow and more resistive as the contact is approached. For stations within one loop radius of the contact the entire sounding is affected and the layered model inversions show little similarity to the true section. The scale model data also indicate that horizontal magnetic fields in the centre of the loop are diagnostic of the contact effect. These data may be used to determine which parts of a sounding may be confidently used for inversions. We have empirically found that for values of the TDEM tipper (H_x/H_z) greater than 0.5 the layered-models produce unreliable results.

Key words: E M Soundings; Layered inversion; geological contact.

Introduction

For homogeneous or layered models, a step change in transmitter current from a loop source induces azimuthally symmetric eddy currents with respect to the source, whereas the magnetic field at the centre of the loop is vertical. Near geological inhomogenieties, however, the current is not symmetrical. The vertical field becomes weaker, and the field at the centre of the loop develops a horizontal component that is directed towards the structure.

A series of central-loop TDEM soundings were collected along a single profile over a quarter-space which was a 4.0 ohm.m

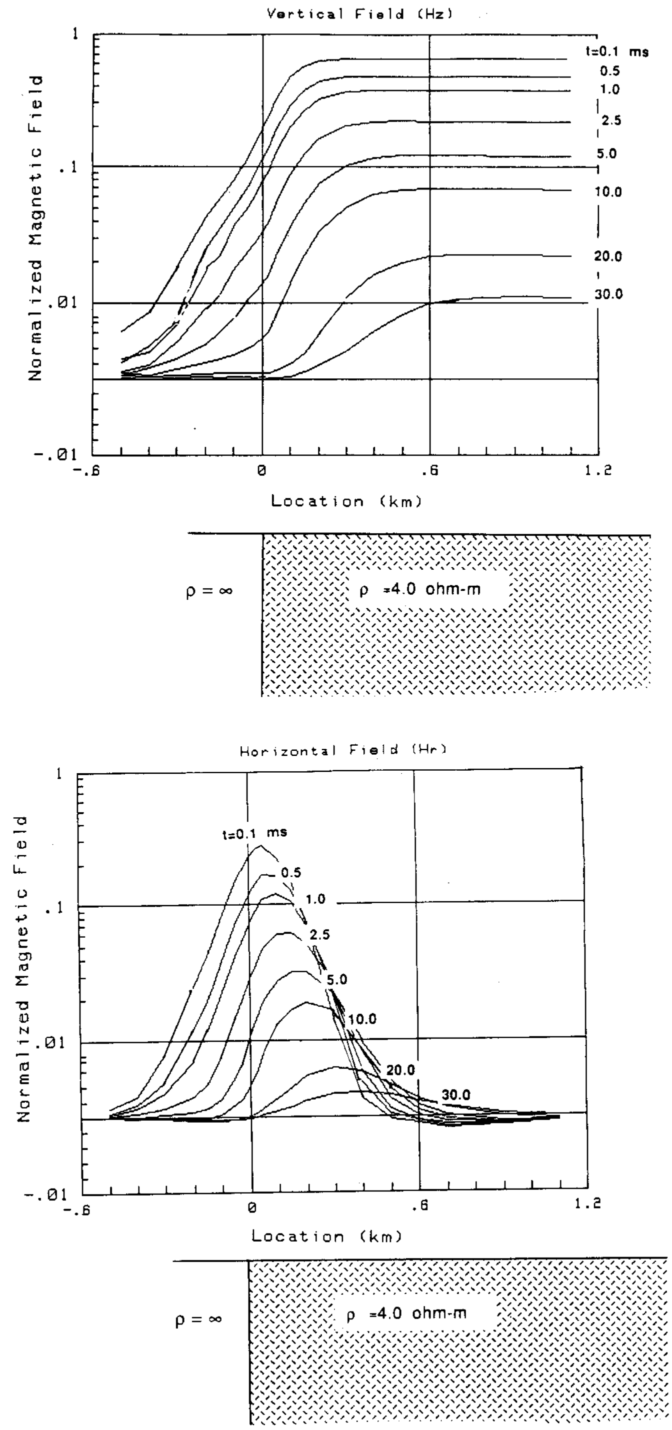

FIGURE 1
Vertical and horizontal magnetic field profiles over a quarter-space for various lag times after transmitter cut off.

block in contact with an infinitely resistive host (air). These data were individually fitted to layered models to determine how the actual contact effect is manifest in routine sounding interpretation. Soundings were made within 250m radius loops spaced from 25 to 200 metres apart along a single profile measured orthogonal to the contact.

Vertical and horizontal magnetic fields are shown as a series of profiles at various times after current extinction in Figure 1. Note that the horizontal fields have a negative polarity. For the central-loop vertical fields, the contact effect is basically a level adjustment between the fields on either side of the edge. The adjustment distance increases in proportion to the lag time and at the latest times shown, some recognizable contact anomaly is observed at a distance of more than four loop radii from the edge. The central loop, horizontal field contact effects are sharply peaked anomalies centred near the edge on the conductive side. The peaks are larger and located closer to the contact at the earliest lag times, and gradually diminish in amplitude, broaden and move inwards from the edge at later times.

The table top modelling system was developed at the University of California, Berkeley. The transmitted waveform is triangular rather than square, and the receiver measures the time derivative which is equivalent to the step response of the magnetic field. The system is scaled to 1:10,000 and computer controlled. The model was an aluminium block with a scaled thickness of 760 metres.

Layered Model Inversion

The transients at each station were fitted to a layered model using an inversion algorithm of Anderson (1982). A three-layer model consisting of two 100m thick, 5 ohm-m layers overlying a 5.0 ohm-M basement was used as first estimate for the inversion. One problem encountered was that with the scale model system magnetic fields are measured, but the computer program requires an impulse response input (i.e., the time

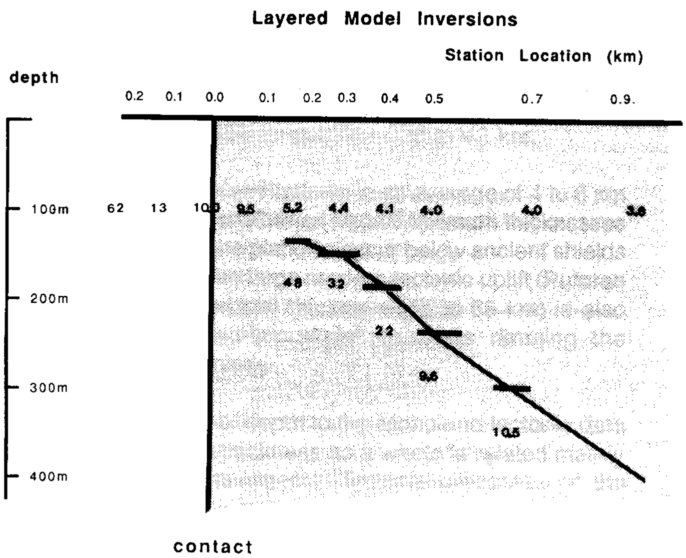

FIGURE 2
Layered model inversion results from central loop vertical field transients over a quarter space.

derivative of the field). To satisfy this requirement the scale model data were differentiated numerically using a central difference scheme. Although this added another layer of processing it probably did not introduce significant noise or bias into the results.

The layered model inversion results of 18 stations are plotted in a profile in Figure 2. For each sounding the resistivities are plotted beneath the centre of the loop at the centre of the layer. The layer boundaries are marked with a thick line. Note that none of the soundings actually resolved a three layer model. This is not surprising for this model, as Newman *et al.* (1989) also found that layered earth interpretations were unreliable for estimating depth extents for a 3-D body.

For soundings located further than 700m from the contact the quarter-space resistivity was correctly determined (within 2 percent) from the inversion. Closer to the edge the inversions begin to detect a resistive layer at depth. The sounding at 700m from the contact detects a 10 ohm-m layer at a depth of 280 metres. At 500 metres from the edge the resistive layer is 10 ohm-m and it is detected at a depth of 240 metres, and at 300 metres from the edge the layer is 20 ohm-m and only 170 metres deep. For soundings taken within 100 metres of the contact, part of the transmitter loop extends over the edge and even the resistivity at the surface is incorrectly determined. Across the contact the layered models approximate a homogeneous halfspace that progressively becomes more resistive as the soundings are taken further from the edge. At a distance of 300 metres away from the edge the inversion code could not fit the data to any layered model. Note that because the vertical fields are smoothly varying across a contact it is difficult to determine accurately the position of the contact on the basis of the layered model inversion results.

As shown above, for stations far from the edge, the contact effect is not evident until later times. For stations closer to the contact, the edge effect appears at earlier times and, if part of the transmitter loop extends over the edge, the entire transient is affected. This behaviour is explained by invoking Nabighian's 'smoke ring' analogy. For stations some distance away from the contact, the induced current is initially a symmetrical ring that propagates away from the source. When part of the current has reached the edge, the symmetry is lost since this current cannot propagate further. At this time some of the field that normally belongs in the vertical component begins to appear in the horizontal component. For stations closer to the edge, the induced current reaches the contact sooner and the contact effect appears earlier in time. The weakening of the vertical field (and development of the horizontal component) therefore occurs progressively earlier in time as the soundings are made closer to the edge. The layered model inversion interprets this effect as a (fictitious) resistive layer that becomes more shallow and more resistive for transmitters closer to the edge.

Recognizing a Contact Effect

Although the contact effect is relatively benign with the central-loop system as compared with other configurations (Wilt, *et al.* 1986) the distortion may still have a profound effect on

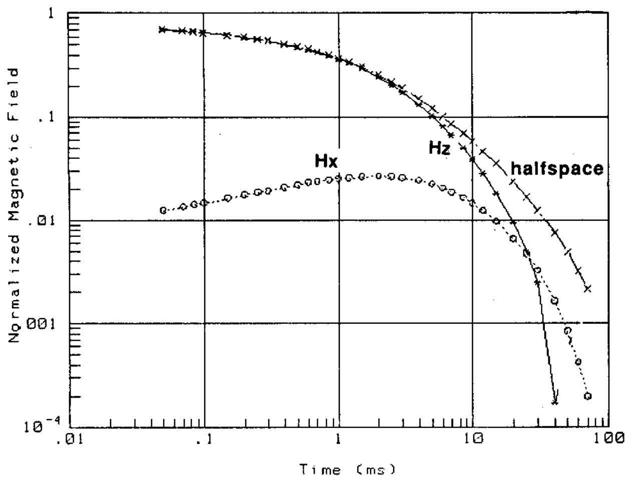

FIGURE 3
Vertical and horizontal transients 300 metres inside the contact; and the transient for a homogeneous half space.

interpretation. For example, a contact anomaly might mask a conductive target located near a geological boundary or distort a structural interpretation. It is therefore important that one recognizes the field signature of a contact before an interpretation is made.

The horizontal fields are a very good indicator of the presence of a nearby contact. Large horizontal fields strongly suggest that a layered interpretation should not be trusted. During lag times when the horizontal field is small, however, the vertical field data are not distorted and may be confidently fitted to layered models. As an example, the horizontal and vertical field for the sounding 300 metres from the edge are shown in Figure 3 together with the transient for the homogeneous half space. These transients show that the horizontal field begins to develop at a lag time of about 3 m which is during the time that vertical field transient begins to depart from the homogeneous half-space curve. By observation we empirically found that, when the ratio H_x/H_z (which has been referred to as the TDEM tipper (Spies, 1988) exceeded 0.5 the vertical field transient data could not be confidently used in obtaining layered models. H_x values below this level will generally be noisy and meaningless, indicating that there are no lateral changes in proximity. Hence inversion of H_z values can be carried out confidently.

Central loop field H_z observations over a contact between resistive and conductive (cindered) coal (Asten, 1987) yielded depths that are too shallow due to the 3-D geometry. It follows that the measurements of H_x are warranted, even if apparently useless, to assess the reliability of H_z layered inversions. Newman *et al.* (1987) also noted their value in mapping 3-D structures, in their case, using synthetic data.

References

Anderson, W. L. (1982), 'Nonlinear least-squares inversion of transient soundings for a central induction (Program NLSTCI)'. USGS Open File Report 82–1121.

Asten, M. W. (1989), 'Full transmitter-waveform transient electromagnetic modelling and inversion for soundings over coal measures, *Geophysics* **52**, 274–288.

Newman, G. A. Anderson W. L., and Hohmann, G. W. (1987), 'Interpretation of transient electromagnetic soundings over three dimensional structures for the central loop configuration', *Geophys. J. R. Astr. Soc.* **89**, 889–914.

Spies, B. R. (1988), 'Local noise prediction filtering for central induction transient electromagnetic sounding'. *Geophysics* **53**, 1068–1080.

Wilt, M. J., Becker, A. and Morrison H. F. (1986), 'Effects of vertical contacts on time domain electromagnetic sounding', Extended abstracts; Society of Exploration Geophysicists annual meeting Houston, Texas 177–180.