Society of Exploration Geophysicist, November 1996

A case study on the application of the EMIGMA modelling package in interpretation of UTEM data over the Cominco Cerattepe deposit in Turkey

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Summary

This paper is part of an interpretation of UTEM data collected at the Cerattepe property in northeastern Turkey during 1992 and 1993. Three exploration targets were delineated during the survey (Figure 1), namely the Cerattepe main zone. The Cerattepe north zone., and the Kardalen target. We show that the use of electromagnetic modelling can significantly enhance the comprehension of the relation between the data and the geological structure and so affect drilling decisions.

Introduction

The Cerattepe property hosts a 1.2 MT Kuroko type stratabound massive sulphide deposit. The deposit is situated in a stratigraphic sequence which are from top to bottom basalt, pink limestone, tuffaceous sediments, hanging wall lapilli tuff, and locally silicified footwall dacite tuff . EMIGMA (PetRos EiKon, 1995) consists of three basic modules:

1. LN PRISM: models the current channelling response of 3D blocks.
2. VHPLATE: models smooth current channelling and induction responses of a thin plate.
3. Layered-Earth module: models the electromagnetic (EM) response of a halfspace or multiple layers.

The data set of the Cerattepe property, and of the Cerattepe main zone and Kardalen target in particular was selected because of the variety of types of EM responses that are observed. These types of EM responses include:

- Background response of conductive overburden or halfspace. Evidence of the conductive background is a broad series of crossovers, decreasing in amplitude and crossing over further away from the transmitter loop as a function of time.
- Current channelling responses due to regional contacts or prismatic structures such as channels or grabens.
- Induction and current channelling responses due to massive sulphides.

Method

Although more than 60 km of UTEM data were collected, this paper focuses on three profiles which show the three types of EM responses described in the above paragraph. Accordingly, the interpretation procedure contains four stages .The first three stages each focus on the three types of EM responses while the fourth brings all response types together in one single profile.

1. Layered-earth response: The stratigraphic units described above have a strong EM response and an attempt has been made to match the field data to the synthetic data profiles using the Layered-Earth module. The field data for this test is a profile which crosses over and extends beyond the Cerattepe main zone, and as such exhibits both a massive sulphide and a background (or layered-earth) response.

2. Regional contact responses: A change in a surface bedrock unit can be modelled using the Layered-Earth and LN prism modules. Thus, both the current channelling response of a block and background response are modelled. The field data for this test is away from all three targets, approximately 600 m south of the Cerattepe main zone.

3. Massive sulphide response: The main zone Cerattepe massive sulphide can be modelled using a combination of the VHPLATE and Layered-Earth modules. Thus, both the current channelling and induction of a plate and background response are modelled. The field data for this test is the same profile used to test the layered-earth response, and thus shows both a background, and a massive sulphide response.

4.. Massive sulphide in moderately conductive graben response: This is the most complicated model with all three modules used to generate the effect of a small massive sulphide unit inside a moderately conductive graben structure, all of which interact with the background. The field data for this test is a profile over the Kardelen target, located approximately 500 m northwest of the Cerattepe main zone.

Case study on the application of EMIGMA to Cerattepe data

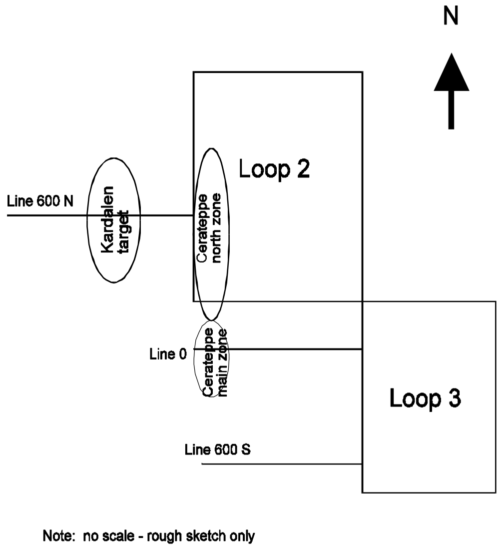


Figure 1.1 Sketch showing Loop, Line and target positions

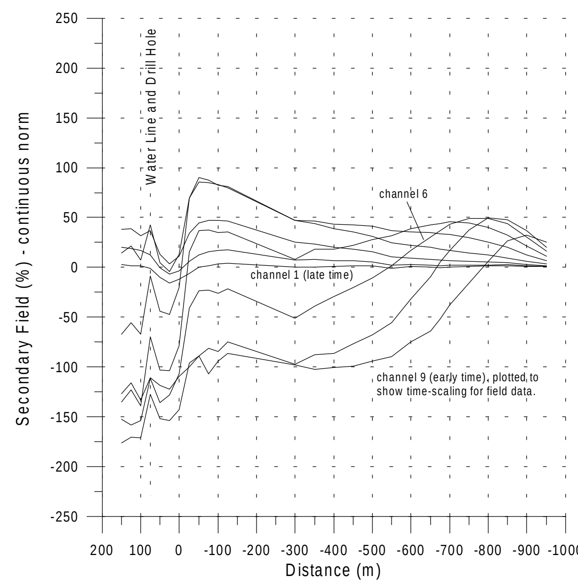
Data presentation

Secondary field data, continuously normalized as a percentage of estimated freespace, are plotted for both field and synthetic data. Although the 26 Hz base frequency UTEM system produces 10 channels of data, only the last eight are plotted. The first two channels tend to be extremely noisy, often because of cultural noise or instrument timing problems.

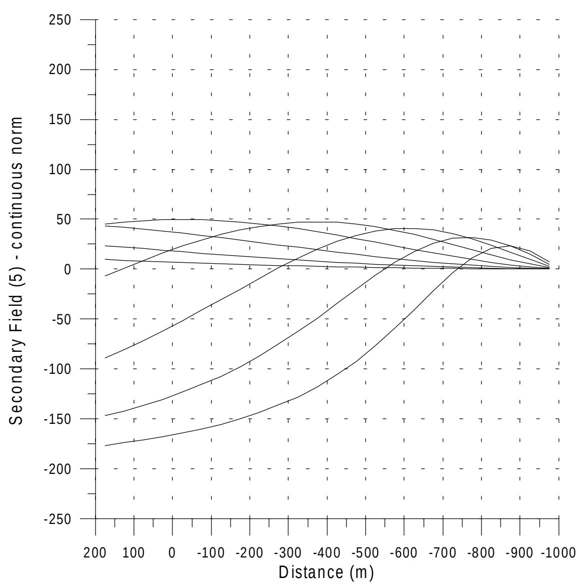
Layered Earth response

One of the first steps in interpreting EM data is to determine the characteristics of the background response. Once the background characteristics are estimated, more complicated models can be evaluated by adding plates or prisms to the synthetic environment. For example, determining background characteristics is critical in evaluating the relative proportion of current channelling to induction in a target. For the Cerattepe data, we wish to distinguish between a halfspace response and a conductive overburden over resistive basement response.

Matching the field data to the synthetic data relies mostly on matching the crossover position of each time channel. The conductivity of the earth is crucial in determining the distance and depth of current penetration and thus for interpreting structure.



The distances from the loop to the positions of two successive time-channel crossovers are another measure used in interpreting the field data. Because UTEM time channels are measured on a binary log scale (i.e. channel n is twice as late and twice as long as channel n+1), simple time scaling can be used to determine if data fits a halfspace model or not.



Remembering the scaling relationship:

$$\sigma \mu L^2 \quad \sigma' \mu' L'^2$$

where the prime (>) indicates that the variables σ, μ, L and t are scaled. Fixing the loop size and position but scaling loop-receiver separation, crossover positions for the halfspace model and for all time channels can be predicted based on single time channels. For example, a change in t by a factor of two corresponds to a change in L= by a factor of $1/\sqrt{2}$ The field data in Fig 2 shows 3 crossover positions, and a table can be used to compare the actual crossover positions to predicted crossover positions. The difference between the actual and the predicted crossover positions is a measure of how close the data represents a halfspace model. EMIGMA is then used to confirm or deny the halfspace hypothesis and assign resistivities. To confirm that

the field data shows a halfspace, not a multi-layered response, two basic types of synthetic models were calculated: Overburden over a resistive basement model: (a) Air, (b) 50 m thick overburden and (c) resistive (10^9 ohm-m) basement. Overburden resistivities ranging from 10 ohm-m to 500 ohm-m were modelled. With such modelling, the background EM response can be positively identified as resulting from a halfspace model and not an overburden mode as summarized in Figure 2.

Regional Contact Response: LN prism and Layered-Earth models

In this section, LN (Non-Linear Approximator) prisms are added to the 200 ohm-m halfspace to produce current channelling responses. Current channelling responses can represent a significant portion of the total EM response when the background conductivity is sufficiently high, as it is at the Cerattepe property. Current channelling responses are enhanced by elongated geological features such as regional contacts, dykes or narrow graben or channel features. The LN prism module of EMIGMA models the current channelling response of rectangular prisms, and as such is ideally suited to model elongated geological structures.

Contact type responses are interpreted by Cominco throughout the Cerattepe property. In particular, strong contact type responses are interpreted on Line 600S for Loop 3 (Fig 4). This is the same loop used in the previous section, but for a line 600 m south. Because this line is far away from the main zone Cerattepe deposit, the regional contact response is probably not contaminated with inductive massive sulphide responses, thus simplifying the model.

In the following figures, the 200 ohm-m halfspace is the basis of a model onto which is added a LN prism with the following characteristics:

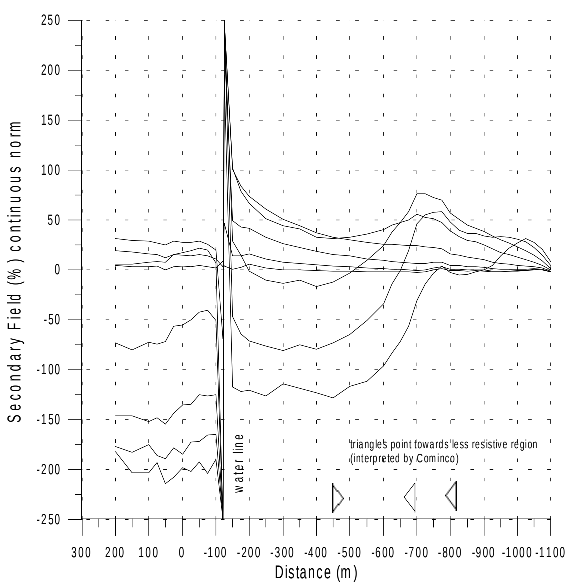
! 200 m along profile,

! 100m thick (along depth),

! 400m across the profile (300 S to 700 S). This dimension is parallel to the loop front. Therefore the prism Achannels@ the current parallel to loop front.

! Resistivity of the prism varied from 20 ohm-m to 1000 ohm-m. For values below 200 ohm-m (halfspace resistivity), the prism is considered to be a conductor, above 200 ohm-m the prism is considered to be a resistor.

The original Cominco interpretation (see Figure 4) suggested the presence of a conductive zone extending from -450 to -825. Interpretation using the LN prism module confirms that this zone is conductive, but places the zone from -700 to -900.



The subtle response of the resistive prism illustrates why magnetic field measurements are seldom used to map resistive features. Electric field measurements show much more rapid changes over resistive features, and as such are often used to map resistive units such as quartz veins, useful in delineating gold prospects. Although not shown here, EMIGMA can also be used to profile electric field measurements.

Assigning resistivity values to certain geological units is important in correlating and interpolating these units between survey lines or even different sections of the survey region. EMIGMA, with the LN prism module is successfully used here to define a conductive zone. This zone coincides with the lower portion of a valley suggesting perhaps that the erosional features (i.e. deeper sediments) of this region can be correlated to certain geologic units. It is not unusual that softer more eroded rocks tend to be also more conductive.

Massive Sulphide Response: VH Plate and Layered-Earth model.

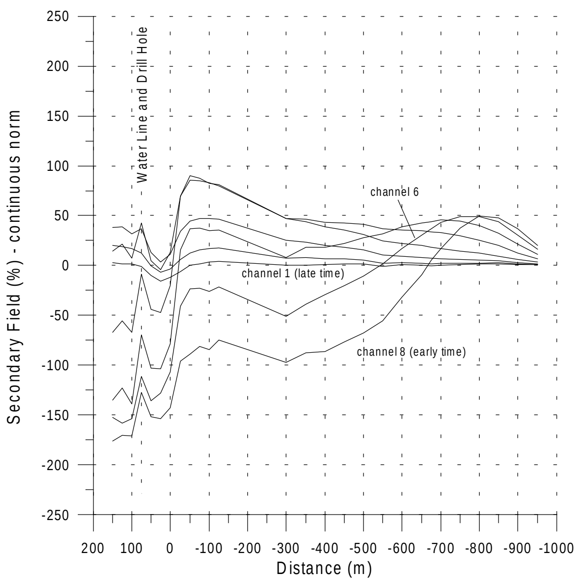
A highly conducting plate (VHPLATE) is added to the 200 ohm-m halfspace to simulate the Cerattepe main zone massive sulphide. The VHPLATE module calculates both the inductive and galvanic response of a thin conductive plate in a layered medium. This is why VH Plate is referred to as a Arobust@ algorithm.

The original Cominco interpretation of the data shown in the figure below (see Figure 5) defined the Cerattepe main zone conductor with

the following characteristics, modelled in Figure 6:
- ! Excess of 500 S conductance ! Depth to top of 30 m
- ! Shallow westerly dip (west is negative) ! Depth extent of 200 m

Note the following two cultural anomalies seen in the field data (Figure 5):
1. Spike caused by drillhole (DH) and water line, both at +75.
2. Abrupt changes in response at -300 m and -125 m.

This is caused by lack of measurements because of a cliff situated between those two points. Size, depth of burial, conductance and dip of the plate were varied until a suitable match was obtained. Comparison is based on matching amplitudes and shape of all channels, but particular attention is focussed on matching the latest time channel (Ch. 1) as its response discriminates easily between good and very good conductors. The best match is obtained with a plate with the following characteristics (see Figure 7) and differs from Figure 6, the model of the interpreted structure.

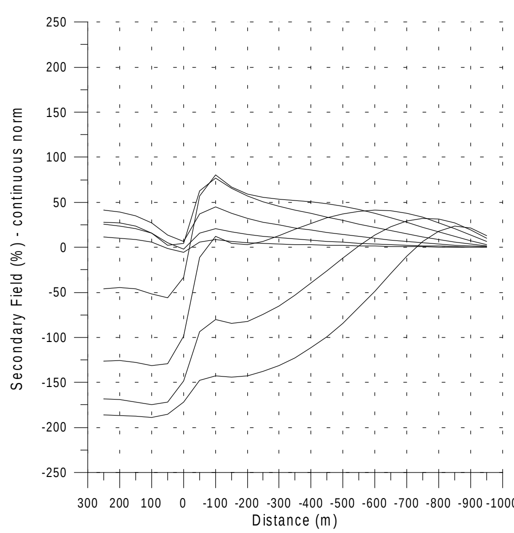


- ! Conductance of 2000 S ! Depth to top of 50 m
- ! Shallow 30E westerly dip ! Depth extent of 100 m, strike extent of 400 m

The differences between the conductor interpreted by Cominco and the one modelled by EMIGMA are small. It is worthwhile noting that the induction number, $\sigma\mu L^2/t$, of both interpreted models is the same. However, EMIGMA shows that in spite of two similar induction numbers (see figures 5 and 6), the response of the two models is substantially different. Both the channel 1 amplitude (reflecting conductance, size, depth of burial), and decay characteristics (reflecting mostly size and conductance) are almost identical to the field data. From an exploration geophysics perspective, differences in conductance between 500 S and 2000 S are unlikely to affect drilling decisions, but it is likely that a depth extent of 200 m versus 100 m would influence collaring of drillholes and the fiscal attractiveness of the target.

Conclusion

We have highlighted several possibilities and advantages of using EMIGMA. Namely that is useful in modelling a wide variety of exploration targets and geological environments. These include the following types of models for any EM exploration system:
1. Halfspace or layered-earth response C Layered-earth module.
2. Contact, regional contact or trough with background response C LN prism and Layered-earth modules.
3. Massive sulphide with background response -VH and Layered modules.
4. Combination response which includes response of background, regional trough and massive sulphide C LN , VH and Layered-earth.



EMIGMA works well in these tests to provide quick "what if" scenarios, and can easily be used to confirm previous interpretation. Models that contain layered earth objects and LN prism objects can be generated within fifteen minutes on a modest PC machine, models that contain VH plate objects are slower to generate and can take four to five hours. These stated times are for profiles with 25 stations, run on a 486 DX2, 66 MHZ machine with 8 Meg of RAM.