Case study on the application of EMIGMA to the Lac Volant data

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A case study on the application of the EMIGMA modelling package to Crone data over the SOQUEM Lac Volant Region, Sept-Îles, Quebec

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Summary

This paper is part of an interpretation of Crone and Max-Min data collected at the Lac Volant property in Sept-Îles, Quebec during the fall of 1996. Two conductive targets were delineated (Figure 1). We show the use of electromagnetic modelling to enhance the comprehension of the relation between the data and the geological structure and so affect drilling decisions. In this case, the Lac Volant anomaly was determined to represent a spatially limited massive sulfide target despite the significant base metal values and the hope generated by the discovery.

Introduction

In the summer of 1996, a significant Ni-Cu surface showing was discovered by geologists of the Ministere Des Resources Naturelle De Québec (MRDQ) in the area of the Lac Volant. Two mining companies (Falconbridge Ltd. and WMC International Ltd.) were authorized to carry out a HEM Max-Min (APEX Parametrics) and Fixed Loop DEEP-EM (Crone Geophysics) survey over the showing. A significant anomaly on surveys sparked interest for a modelling project to help delineate a massive sulfide conductor. The initial surveys were designed to evaluate the physical characteristics and the possible extension of a nickel-copper showing. The survey=s purpose was to test in the nearby area for the possible presence of other mineralized lenses for WMC and Falconbridge. The survey area is covered by a group of 94 contiguous claims registered with the MNRQ and transferred to the Société Québécoise D=exploration Minière (SOQUEM).

In February, 1997, SOQUEM contracted *PetRos EiKon Inc.* to interpret 10 lines of Crone Pulse EM data and 15 lines of Max-Min data from two surveys conducted by VAL D=OR SAGAX. There was significant anomaly showings on five of the Crone and Max-Min data lines: 0N, 50N, 100N, 150N and 200N with the response strongest on lines 0N, 50N and 100N. The response is much weaker on lines 150N and 200N and has disappeared by lines 50S and 300N.

In order to delineate the suspected conductive target a series of models were run to match the main aspects of the data with modelled data using *PetRos EiKon=s* forward, 3D electromagnetic modelling software, **EMIGMA** (1997).

Data presentation

Max-Min Survey:

A Max-Min APEX II system was used. This is a moving source, horizontal-loop system measuring the ratio of the vertical secondary fields to the vertical primary magnetic field for both In-Phase and Quadrature with the data being normalized to a ratio in percent. The TX and RX coils are coplanar with a 100m separation. Readings were taken every 12.5 m with 3 frequencies 444 Hz, 1777 Hz and 3555 Hz.

Crone Survey:

10,500 km of high power Crone Pulse-EM survey data with a base frequency of 30.01 Hz were collected. A line spacing of between 25 and 100 metres was used and readings were taken at a measurement spacing of 25m. An 8.33 millisecond time-base was used for 16 channels with a 1 msec linear ramp cut-off. Transmitting loops of dimensions 500m x 800m were used. Two components of total field magnetic data, unormalized, are shown for both field and synthetic data. The Hx component is the horizontal component parallel to the survey line. Although Crone Pulse EM System 16 channels of data were collected, only the last 7 channels are used due to an apparent oscillation in the sensor which was not noticed at the time of the survey.

Data Interpretation:

The interpretation procedure consisted of 4 stages.

I. Calibration of Crone and Max-Min Data: An essential step in modelling any survey is to carefully calibrate the data and check for inconsistencies in data collection procedures and\or equipment problems.

II. Background Response: It is necessary to ascertain the nature of the background to ensure that the host rock is modelled correctly.

III. Max-Min Models of Targets A and B: The Max-Min model that was best able to match the characteristics of both the In-Phase and Quadrature response of the data was a thin sheet.

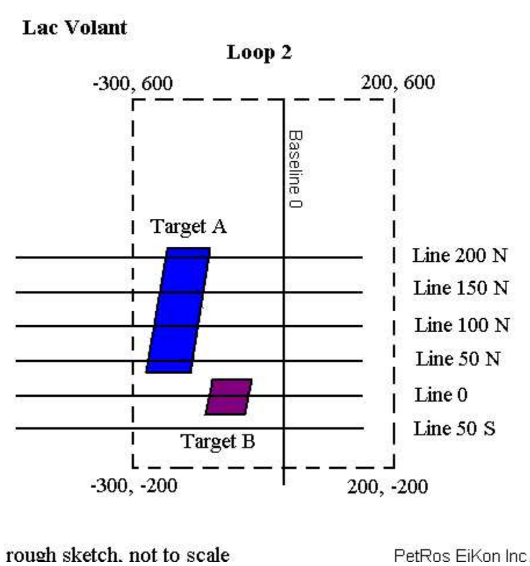
IV. Crone Models of Targets A and B: Massive sulphide targets A and B (Figure 1) can be modelled using either the VHPLATE or ILN-PRISM (I. Murray, 1997) algorithms. The ILN-PRISM algorithm was used to accurately simulate a volume inductive target. A good match to the shape and amplitude of both the vertical and horizontal components of the Crone data was produced by placing two conductive ILN prisms into a 5000 ohm-m halfspace.

Calibration of Data

Certain problems were found with both the Max-Min and Crone data sets which had to be corrected prior to modelling.

APEX Max-Min System

The Max-Min equipment was inadequately calibrated. The data was corrected by removing the average residuals at positions remote from the anomaly for each line and for each frequency.



Inconsistencies were found in the of the Hx dipole orientation resulting in sign inconsistencies within the data. The resulting sign corrections produced consistent data for both components and both loops**.** The Crone data was reduced to assume a 1 Amp current to match the units produced from EMIGMA

It was determined that for lines away from the anomalies, clear cross-overs were found across the loop as late as Channel 8 (.64msec) and likely up to Channel 10 (.95 msec after the end of the ramp). The manufacturer attributes the oscillating behaviour of the sensor to underdamping which results when the coil is out of calibration. This is a reasonable explanation. We can model the response of a standard, critically damped Crone sensor, but this sensor was underdamped and we did not attempt to model channels 1-10.

Background response
The host rock is a resistive gabbronorite gneiss. Due to the shallow nature of the target, the basement does not affect the response. The possibility of a conductive overburden was tested and rejected and thus the a simple resistive half space was assumed with resistivity of 5000 ohm-m. A good match was found between the primary pulse of the Hz component of the simulated data versus the field data with this background, see Figure 2. Note that the accuracy of the primary pulse of the data on the two positions on either side of the loop (-275 and -325) is suspect as indicated by the surveyor and thus we did not try to math the response at these positions.

Max-Min Model of the Massive Sulfide Targets:
Since the Max-Min data does not have the same calibration issues as the PEM data and as frequency data is faster to model, simulation began with the Max-Min data. As the target was quite shallow and as the Max-Min system is limited in its depth of penetration, it was felt that a plate would give an adequate response to begin delineation of the target. Initially, the characteristic double negative peak shape of the Max-Min responses were matched with two non-interacting vertical or sub-vertical plates but the amplitudes of the modelled responses were too small. A better response with higher amplitudes was found with a horizontal or subhorizontal plate, although a few characteristics of the response were lost. In particular, the positive saddle between the two negative peaks was not accurately reproduced. A suite of models was then computed to test the effect of varying strike to width ratios, thicknesses, depths and conductivities.

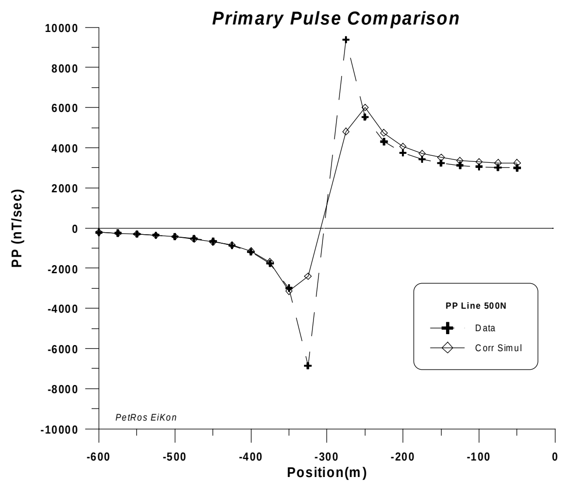
Depth: In order to produce the high amplitudes seen on Lines 0, 50N and 100N, it was necessary to keep the plate quite shallow with depths to top between -5 and -10 metres. Plates buried deeper (20-30 metres) result in amplitudes closer to Lines 150N and 200N.

Conductance: Plate models with conductances between 100 to 1000S were computed. Reasonably close comparisons were obtained with conductances in excess of 300S. Very little difference was found in the In-phase response when the conductance was increased to 1000 Siemens. In the data, as the frequency was increased, the Quadrature response increased only slightly. However, the In-phase response remained essentially constant.

Strike to Width Ratios: An initial strike of 200m was chosen because it roughly corresponded to the data anomaly length (Line 0 to 200N). Widths were varied from 20m to 100m with the best match amplitudes occurring with a plate 100m wide. Although the approximate strike of the body could be seen in the data, there was the possibility of a plunge to the north due to the fall off of the response in the northerly lines. These aspects were not examined at this initial stage.

Some of the sharper edge effects in the data on the northerly lines could not be produced by a horizontal plate. It was thought at this stage that the most likely match to the data was with two vertical plates with a subhorizontal plate sandwiched between them. Thus, a fully three dimensional object with significant volume was implied.

Crone Model of the Massive Sulfide Targets

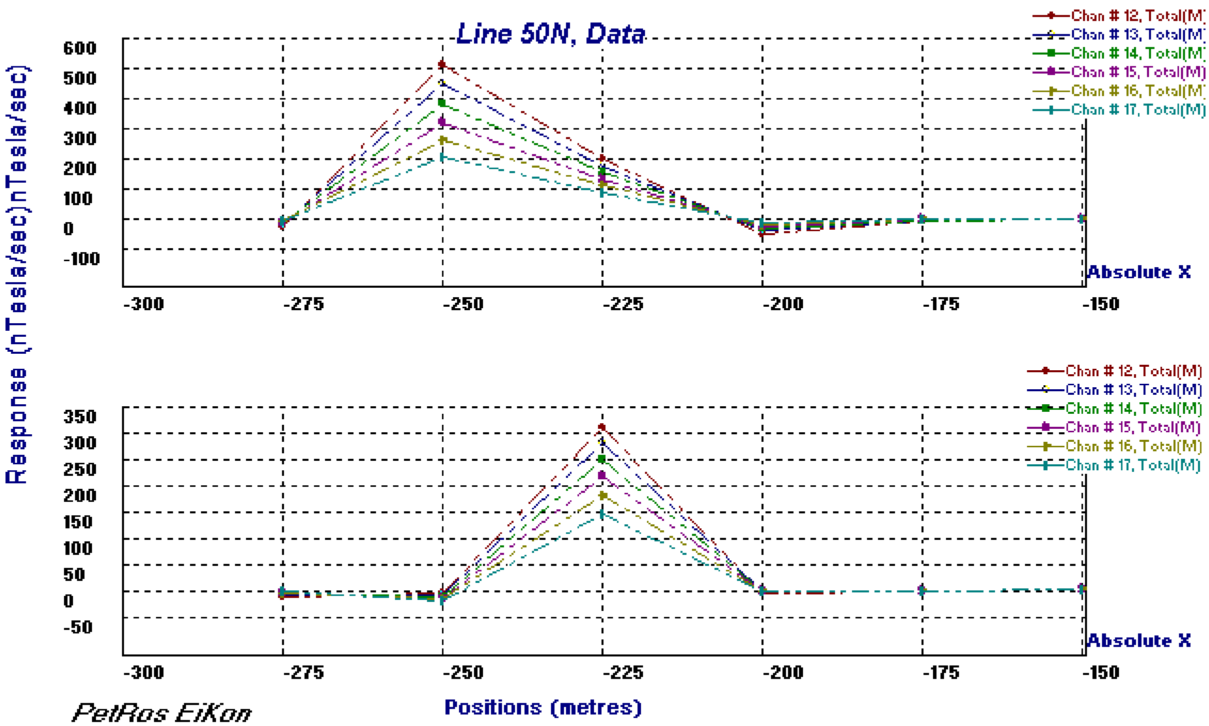


Depth and Plunge of Target :
Initial modelling of the Crone data with a thin-sheet, as indicated from the Max-Min model, determined that the target required a volume. It was found that some of the characteristics seen in the data could be matched with a horizontal plate model and that a vertical target did not give the desired response for either the vertical or horizontal components. (A vertical target does not couple well with the source field in the interior of the loop unless it approaches the wire). Although the Hz component could be reasonably matched with a horizontal plate, the Hx response could not be reproduced. We turned to use of the new ILN algorithms (Murray, 1997) to model highly conducting prism but still utilizing some of the information from the earlier plate modelling of the Max-Min data.

Target A. A series of prism models were computed attempting to match the response of the data. Because the response of target A is significant on Lines 50N to 200N, a prism with a strike extent of 150 metres, extending from 50N to 200N, was used as an initial model. The prism was centred at 125N, 210W and buried with a depth to top of 5 metres. In order to match the strike of the data anomaly, the plate was given a initial strike of 15ENNE. Initial thicknesses of 15m and 30m were chosen with an integrated conductivity of 300 Siemens. Initially, no plunge was used.

Width of Target The best match to the width of data response was found with a prism 30 metres wide. A wider plate resulted in too broad of a response.

Thickness of Target: The thickness of the body affects the width of the response as well as the amplitude. Generating the inductive response from a body that has depth extent with the ILN algorithms, we were able to simulate the characteristic Hx and Hz shapes of the data. A 20 metre thickness produced a response that best matched both the data width and amplitudes.



It was known that the target was outcropping around Line 50N. The decrease in the response of the data as one moves North is likely caused by an increase in depth of burial implying that target A was plunging to the North. Non-plunging models at varying depths determined that a depth to top of about 30m at Lines 150N and 200N produced reasonable amplitudes for both the Hx and Hz components. Models were computed for a series of plunges where the target was essentially at the surface on Line 50N plunging North along strike. A plunge of 8E was found to bring the target deeper at lines 150N and 200N while maintaining the right range of decays.

Decay Rates and Conductance It was immediately obvious that the simulated responses were decaying too quickly with a conductance of 300S. A decay rate of about 2.5msec was produced with a 600S prism closely matching the decay rate of the data. Two decay rates were observed in the data channels available for analysis. There appears to be a short-wavelength response which is responsible for the decay on channels 11-13 and an underlying long-wavelength response which slows down the decay at the late times (channels 14 to 16). The average decay rate ranges from about 2-2.5msec and is generally consistent on all lines, except line 50 N which shows a decay of 4msec. Later the integrated conductivity was lowered to 500S.

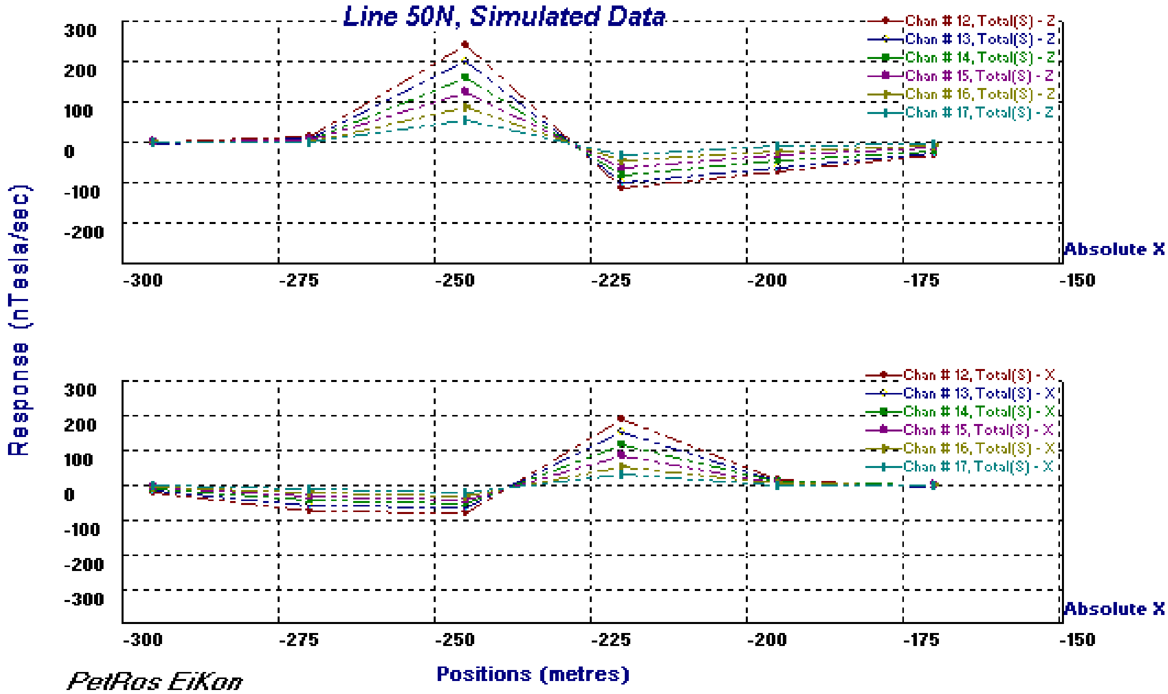
Dip: Flat lying targets could not reproduce the shape of the Hx component nor the symmetry of the Hz component. This is evident from the broadened shoulders in the data away from the wire as opposed to those of flat lying models which produce broader shoulders on the wire side of the target. This was seen particularly for Lines 50 and 100N. It was determined that the correct shape is generated with a target dipping at about 23 degrees towards the loop. This was derived primarily from lines 50N to 100N which are less affected by the plunge than more northerly lines which in turn are less affected by the dip (Figures 3 and 4)

Strike Extent It was necessary to increase our strike extent North was necessary to prevent overly long and smooth in both the North and South directions. An extension to 210 responses on Lines 150N and 200N. This also decreases the response generated at 100N by decreasing its proximity to the centre of the body over which the response is maximized. The strike extension to 35N effectively rids the model of an edge response on Line 50N and increases the amplitude on this line.

The resulting simulated data was able to duplicate the characteristic Hz response of a large positive peak with two smaller negative peaks on either side. The simulated data was also able to generate the characteristic Hx response which has a sharp negative peak that crosses over to a sharp positive peak asymptoting to zero on either side of the anomaly. Examples are shown for Line 50N in Figures 3 and 4. The simulated data and the field data are not exact duplicates. However given the lack of spatial data sampling resulting in imprecision in the position of the peaks and also the exact waveform calibration, the degree of reproduction seems quite startling.

Target A is a shallow sub horizontal target which plunges to the North with the following characteristics: strike extent of 175 m, (35 N to 210 N), width of 30m, thickness of 20m, approaching the surface at line 50N and plunging to the NE at an angle of 8 degrees and having a conductance of 500S. Target B is very difficult to delineate due to its appearance on only one line. However, its response on Line 0 is so similar to the response of Target A on line 50N, although offset to the east by 50m, that it likely has many of the same characteristics as Target A but with a shorter strike extent. Modelling confirmed this hypothesis but was indeterminate.

Unresolved Issues with Crone Data Models: Amplitudes generated with the Crone models were slightly smaller on line 50N and slightly higher on Lines 100N, 150N and 200N. Both problems can likely be explained by the insufficient spatial sampling in the data resulting in an ambiguity in the positions of the peaks. The response of Target A on Line 0 for our final model is too large compared to the data. One possibility is that target A is actually thinner around 50N.



Max-Min Confirmation: Max-Min data was re-modelled to confirm that the target A model that matches the Crone data also reproduces the main features of the Max-Min data (e.g. Figure 5). To model the Max-Min data it again was sufficient to use a thin-sheet as the data gave no information on depth extent. A thin sheet with a strike length of 180m (30 N to 210 N) was used having a dip extent of 30m, a conductance of 600S, striking at 14.5 degrees East of North and plunging 8 degrees to the North. The simulated response is able to match the characteristic double negative peak (e.g. Fig. 6, Line 100N).

With this model, we are able to generate the correct width of the response (–100 metres) confirming the 30m width of the target, correct centre position of the response confirming a strike of –14.5 degrees, correct strike length of the target, the right fall-off of amplitudes for lines 50N to 200N, indicating that 8 degrees is a reasonable plunge. Reasonable amplitudes of the simulated Max-Min responses on Line 200N give additional confirmation to the strike length and the dip angle.

The phase angle (the ratio of In-phase to Quadrature) of the simulated data does not completely fit the data. There is an indication that the phase angle in the data is changing as a function of frequency where it is not in the models. This implies that we have reached the inductive limit in the simulation. Computing the same model with a decreased conductance of 500S probably gives better phase characteristics. This conductance does not dramatically effect the decays rates of the late time Crone simulations.

The differences between the simulated and filed data of the Max-Min may be due to slight inaccuracies in the depth of burial. However with a thick body as indicated by the Crone data, trying to find a better fit with a thin sheet model would be futile and the ILN routines were at the time unable to accurately model rapid gradients in the source field as produced by the moving Max-Min system.

Conclusion

The fact that the Crone sensor was out of calibration as indicated by the oscillating behaviour of the response up to at least channel 8 is not necessarily a problem from a modelling perspective so long as the exact specifications of the sensor response are known. Since we could not determine this, we were not able to model the early channels, but we were able to match the primary pulse and successfully model the late time channels.

The results from this modelling work shows that EMIGMA is useful in modelling both FEM and TEM surveys over the same target. Valuable insight was gained into the geological properties of the earth by using 3D electromagnetic modelling and we were able to build a model that represents the true target bodies as evidenced by the reasonable match to both the Crone and Max-Min data.

Figure 5

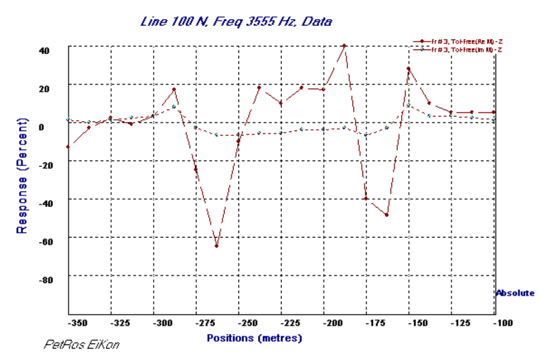
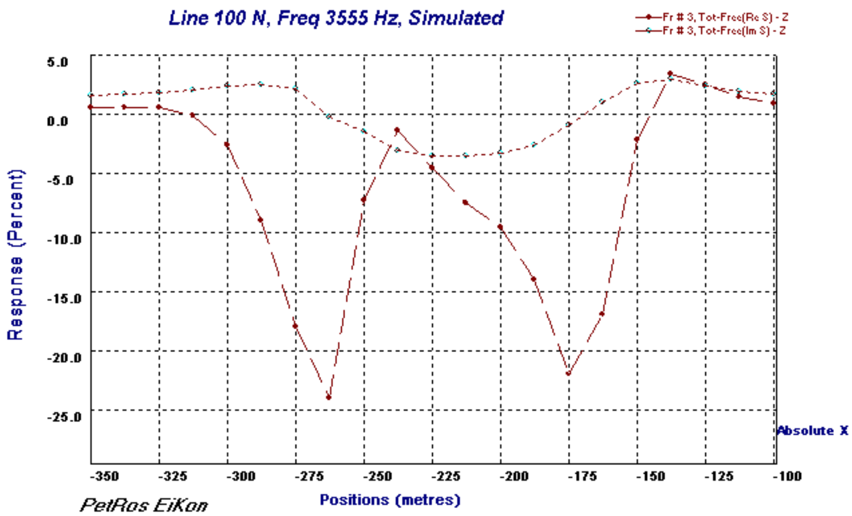


Figure 6


Line 100 N, Freq 3555 Hz, Simulated
Fr # 3, Tot-Freq(Re S) - Z
Fr # 3, Tot-Freq(Im S) - Z
Response (Percent)
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
Absolute X
-350
-325
-300
-275
-250
-225
-200
-175
-150
-125
-100
Positions (metres)
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