An Interpretation Study of Pulse EM Reconnaissance Data from the Raglan Belt of Northern Canada - 3D Symposium, Utah, 1999

R.W.Groom, I. R. Murray, C. Alvarez, PetRos EiKon Incorporated and Jon North, Dumont Nickel Inc.*

Summary

Several stages of interpretation of pulse EM data over a relatively complex geological setting are presented. Simulation of the electromagnetic data was critical to understanding the electromagnetic data. This simulation required the accurate reproduction of several physical mechanisms not to our knowledge previously available. These studies led to a better understanding of some basic physical responses potentially present in many data scenarios.

Introduction and Background

Research has continued for several decades to develop modelling software for electromagnetic data collected for mining exploration surveys. However, very few case studies have been presented particularly in environments which provide a combination of inductive and current channelling responses (Lajoie, *et al.* [1], Parker, *et al.* [2]).

In the exploration area within the Raglan belt of Northern Quebec, pockets of volcanic sediments are distributed in a resistive host rock which is permanently frozen at surface. Intruding into the host rock are large peridotite structures which contain deposits of sulphide ore either in a disseminated or massive form. The data, presented and interpreted here, consists of two magnetic components utilizing a 20 channel Crone Geophysics pulse EM system collected at a base frequency of 15Hz. Twenty lines of data were collected at 50m stations within a large loop, 1.1 by 2.2km. Initially, contouring of the vertical data (Figure 1a) indicated three areas of mid-time anomalies within the survey region. The relative strength, size and persistence into the mid-times of the anomalies indicated the potential for the presence of an ore concentration of interest to the exploration company, Dumont Nickel Inc. We chose to investigate the easternmost anomaly for evidence of ore.

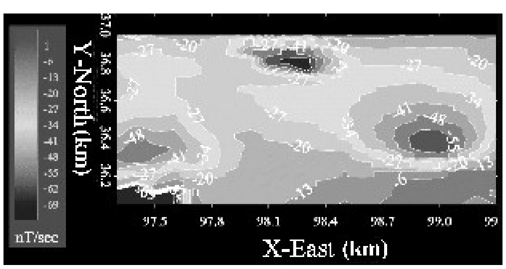

Figure 1a: Channel 12, Hz

Initial Data Analyses

Early time channels for Hx and Hz (Figures 1b,1c) indicated long east-west structural trends confirmed in the central region by a long magnetic anomaly striking roughly east-west**.**

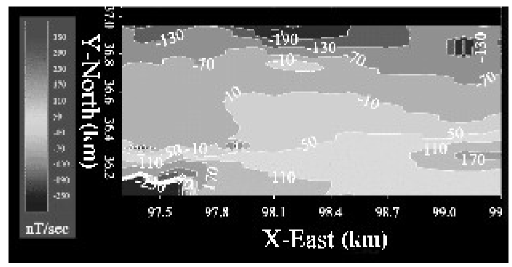

Figure 1b: Channel 4, Hx

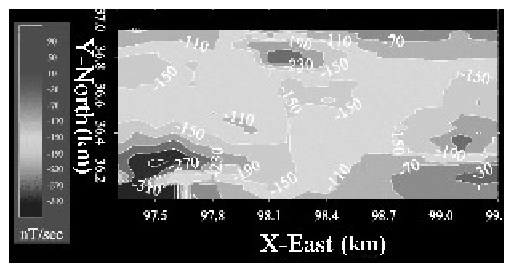

Figure 1c: Channel 4, Hz

As the Hx component for the mid-time channels (Figure 1d) continued to indicate these long east-west structures, it was decided to first investigate the electromagnetic cause of these anomalies. In particular we concentrated on an interpretation of the anomaly in the southeast corner of the survey.

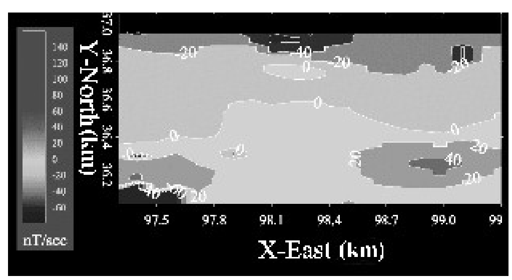

Figure 1d: Channel 12, Hx

Calibration Issues

The modelling or simulation software (**EMIGMA**) employs a suite of frequencies over a wide frequency band to create the impulse response of the model in frequency domain. The frequency data is then transformed convolving the known waveform with the impulse response and determining the simulated time domain data at the centre of the time windows. (Although the transformation software can integrate over the time windows, it was not necessary in this case to do so.) Figure 2 shows comparisons between the on-time channel (the so-called primary pulse) for the data and simulated model for two lines, one near the centre of the loop and one near the east end of the survey. The pulse channel is primarily the free-space response and is only slightly effected by the conductivity structure in the Hz component. Thus this channel and component can be used to calibrate the simulation with the data.

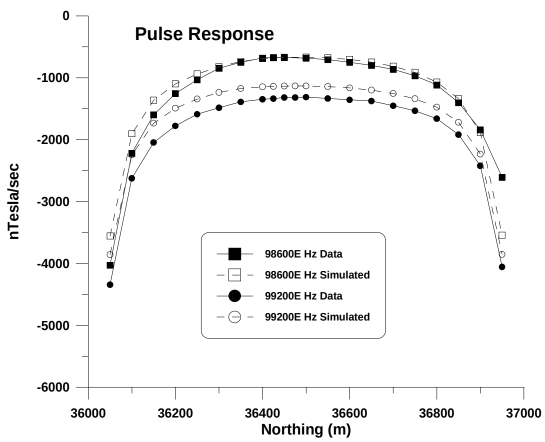

Figure 2: Pulse Response vs Simulation

As can be seen in Figure 2, the simulated and measured data match very well on Line 98800E in the centre of the loop except at the north end of the line. For line 99200E, farther to the east, the agreement is not as good. These discrepancies, likely due to loop positioning, could be improved but we did not find it imperative to do so.

Initial Model Investigations

Initially, it was necessary to examine whether the complicated host rock, containing small random distributions of volcanic sediments, could be approximated by a simple bulk resistivity. If the small scale variations in the host material created a distribution of very local anomalies then the task of interpretation through forward modelling would indeed have been extremely difficult. However, comparison models against layered forward models indicated that the general decay behaviour of the 8 easterly lines could, initially, be roughly approximated with a half-space resistivity of 300 Ohm-m. This model broadly approximated the decay of these 8 lines of data. Early time responses were somewhat high and late time responses too small but the overall half-space response satisfactorily followed the decays of the data and spatial variations due to the source loop for our initial 3D modelling investigations. In particular, this half-space resistivity (300 Ohm-m) allowed us to examine the basic geometry and response of an intrusive peridotite in the eastern region of the survey over lines 98600E to 99300E.

The decay of the data over the entire 8 lines was similar at all locations in the first 10 channels. This was true even over those portions of the lines where there were strong spatial anomalies in a given time window, and indicated the strong possibility of a current channelling response over large portions of the region of interest (at least in the earlier time channels). This was consistent with aspects of the geology.

Comparison of this layered simulation to data indicated a major anomaly over a large region with rapid spatial variations in the south followed by a long northerly tail. The peridotite was exposed at surface and there was some geological information for the dip. Early time data provided indication of strike. A series of modelling studies derived the basic geometry of the peridotite, and data analyses and modelling revealed that the response was primarily current channelling. As such, it was possible only to derive a range of resistivity for the peridotite.

The peridotite was exposed at surface in the eastern region and the geology indicated an approximate east-west strike and an approximate 30 degree dip for the structure. It was expected that the peridotite was more than a kilometre in depth extent. Although generally a peridotite structure need not be conducting, in this region there was a likelihood for a weak bulk conductivity from several possible causes including a weak dissemination of sulphide mineralization. The indications from the initial layered-earth modelling of the host conductivity would allow for the presence of induced currents flowing within it at early times. This induced current would then act as a source for a current channelling magnetic field response from the peridotite.

We therefore calculated a number of models using the LN algorithm for a prism (Groom, *et al.* [1], Habashy, *et al.* [3]). As this algorithm only simulates the galvanic response, this allowed us to investigate the nature of the current channelling response for the peridotite. Resistivity, strike angle and length, dip angle and length, thickness and plunge of the prism were varied through a suite of models. The rapid calculation time of the LN algorithm allowed us to derive upwards of 50 models in a relatively short time.

Curve matching of the data to the simulated models, particularly channels 5 through 8 for both Hx and Hz, led us to an initial model for the peridotite geometry which utilized a simple prism with strike 872m, depth extent 1480m and thickness 110m. The strike angle was 94 degrees east of north and the dip angle was modified to 25 degrees. Since the response was current channelling, the resistivity could not be resolved accurately but a lower limit was placed at about 10

Ohm-m. The lower bound was found by comparison with an inductive LN algorithm (Murray [4]). Above this range an inductive response was seen which no longer had the principal spatial shape of the data.

Detailed Modelling of the Host and the Peridotite

The simulated data from the above model did not produce amplitudes in channels 10 to 15 comparable to the data, although the shape and amplitudes in channels 5 to 8 did closely match. The half space of 300 Ohm-m also did not generate amplitudes large enough at late time. It was therefore necessary to further detail the bulk response of the host.

A series of additional layered earth modelling exercises indicated a basement contact at 350m with a conducting basement of about 80 Ohm-m beneath 750 Ohm-m material. The basement contact subsequently was revealed as the permafrost boundary and thus was the likely cause for the increased conductivity in the basement.

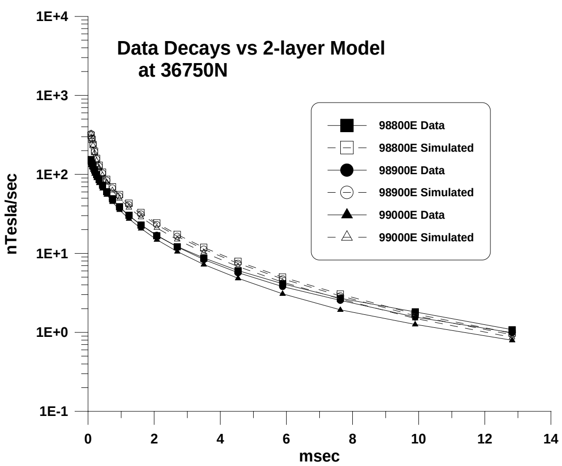

Figure 3: Decay Curves; Data vs Layered Simulation

Figure 3 shows decay curves on 3 lines at station 36750N on the north end of the survey in the central region. The simulated data is shown with broken lines and open symbols and indicates a close comparison with the decays of the data. Matching of decay curves was done on the north end of the lines as it appeared that the response of the peridotite was weakest in this area.

Detailed Simulation of the Peridotite Structures

Several problems arose in simulating the response of the peridotite. The relatively high conductivity of the basement causes a slow outward and downward migration of the currents while the peridotite clearly plunges deep into this basement. Thus, the peridotite should continue to be excited relatively late in time. It would be expected that this late-time excitation, at depth, would produce later time anomalies from portions of that structure nearer surface as the currents should flow up the peridotite towards the top. To reproduce this, it was necessary to utilize extended developments in our simulation algorithms (Murray, *et al.* [6]).

The prismatic peridotite had first to be split into two polyhedra at the host unconformity to maintain the exact geometry; current was then forced to flow continuously between the two partitions of the peridotite through the multiple interaction functions of the simulation algorithms. An extension of the basic LN technique is used to reproduce this scattering phenomena as if the two polyhedra components of the original component where part of one integral structure. The resulting current distributions are propagated to the receivers through the layered earth Green s functions. This process is performed automatically in the software relieving the user of forming the polyhedra primitives that are required.

This resulting simulation reproduced the data responses remarkably accurately. Figure 4 shows comparisons for the horizontal component on line 99200E for 3 time windows. The resulting simulations produced anomalies matching the data well into the late time over the entire structure. Figure 5 shows the vertical component for the same line and windows.

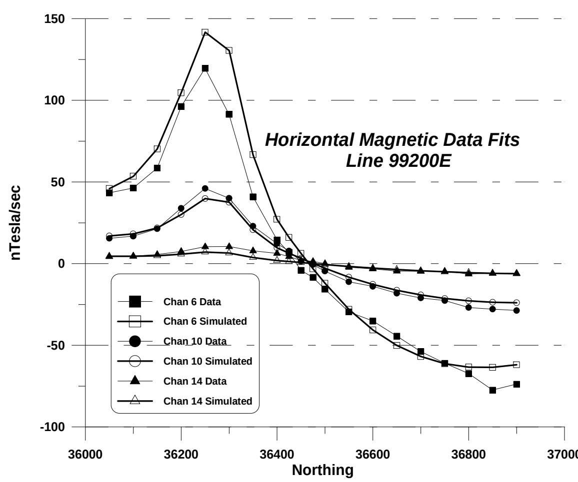

Figure 4: Simulated Hx Response for the Peridotite:

As the peridotite was potentially magnetic, another extension of the LN technique (Murray, *et al.* [6]) was used to investigate potential magnetic effects in the EM data. These models indicated that no strong magnetic effects appear in the EM data over the eastern peridotite structure. Finally, contouring of the simulated Hz component showed a similar shape as the data of quite comparable amplitudes even beyond Channel 12 as late as Channel 16. Thus, if there was any indication in the data of a response from ore it would have to be in the very late times.

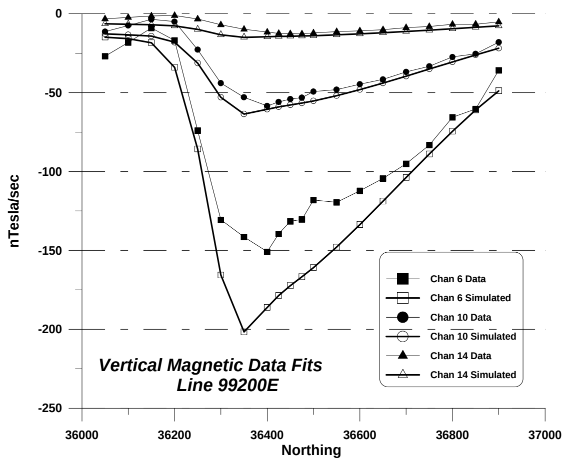

Figure 5: Hz comparisons for the Peridotite Structure

Simulation Issues for an Ore Zone

Having identified the structure and the response of the host and the regional geology, we were able to investigate the possibility of an ore deposit. First, a possible size of target zone at a suitable depth was modelled alone in the 2-layered background using a conductance in the lower range of interest. This reproduced a response of a quite different character than the peridotite especially at very late times.

The ILN technique (Murray [4], Murray, *et al.* [6]) is needed to model the sulphide ores since, through modelling, we determined that the response of such targets was caused both by induction and galvanic current channelling. The simulation primitive for this case was again a prism although the algorithm can use a polyhedral primitive. The response was calibrated against a thin-sheet algorithm (Walker and West [5]). Comparisons were good with expected variations caused by enhanced current channeling from the prism model.

The sulphide ore model was then incorporated into the combined model and the effects of the ore in contact with the peridotite were investigated. Single backscatter multiple interaction (which we term *Far Field* interactions) was used to simulate lack of contact and (what we term) *Near Field* interactions, as described above, were invoked to simulate electrical contact with the peridotite.

These modelling studies posed several questions with regard to such EM responses and the modelling capabilities of software. When the ore zone was in contact with the larger structure, if the ore conductance was too weak it could not be observed at all in the simulated data. Whereas, for the same conductance and size, it could be observed when not in contact. Our inference was that if the conductor was in contact then the additional induced currents in the ore zone leak into the peridotite and subsequently flow throughout it. This leakage into the weakly-conducting structure diffuses the response such that it cannot be observed. If the ore zone is not in contact with the larger structure, this leakage does not occur and the conductor can be seen. If the conductance is increased in contact, then eventually the conductor can be observed. However, the weakness of this tertiary response in the data, compared to the simulated response of the two-layer host and channelling response of the regional conductor, makes the determination of a possible ore zone extremely difficult.

Conclusions

The study concluded that the strong excitation of the regional geology from the large loop and its lack of focus on the target region did not provide sufficient resolution to confirm a deposit. Recommendations were made for a follow-up survey using a small source concentrating on the regions of interest identified from the larger reconnaissance survey. Model studies indicate that discrimination of possible ore zones was much more likely with such a survey.

References

[1] R. W. Groom, C. H. Hyde and J. Lajoie, *A case study of the application of the EMIGMA modelling package in interpretation of UTEM data over the Cominco Cerattepe deposit in Turkey*, Extended Abstracts, 66th SEG Conference, Denver, Colorado (1996).

[2] D. H. Parker, M. Boivin, I. R. Murray and R. W. Groom, *A case study on the application of the EMIGMA modelling package to Crone data over the SOQUEM Lac Volant Region, Sept-Îles, Quebec*, Extended Abstracts, 67th SEG Conference, Dallas, Texas (1997).

[3] T. M. Habashy, R. W. Groom and B. R. Spies, *Beyond the Born and Rytov Approximations: A Nonlinear Approach to Electromagnetic Scattering*, J. Geo. Res., *98*, no. B2 (1993).

[4] I. R. Murray, *On Extending the Localized Non-Linear Approximator to Inductive Modes*, Extended Abstracts, 59th EAGE Conference, Geneva, Switzerland (1997).

[5] P. W. Walker and G. F. West, *A robust integral equation solution for electromagnetic scattering by a thin plate in conductive media*, Geophysics, *56*, 1140-1152 (1991).

[6] I. R. Murray, C. Alvarez and R. W. Groom, *Modelling of complex electromagnetic targets using advanced non-linear approximator techniques*, Extended Abstracts, 69th SEG Conference, Houston, Texas (1999).