In The Shadow Of A Headframe: Deep Exploration Using Integrated 3-D Seismic And BHEM At The Louvicourt Mine, Quebec

Erick Adam[1], Wei Qian[2], and Bernd Milkereit[3]

1. SEISServ, Quebec City, Quebec, Canada, e-mail: erick.adam@gmail.com

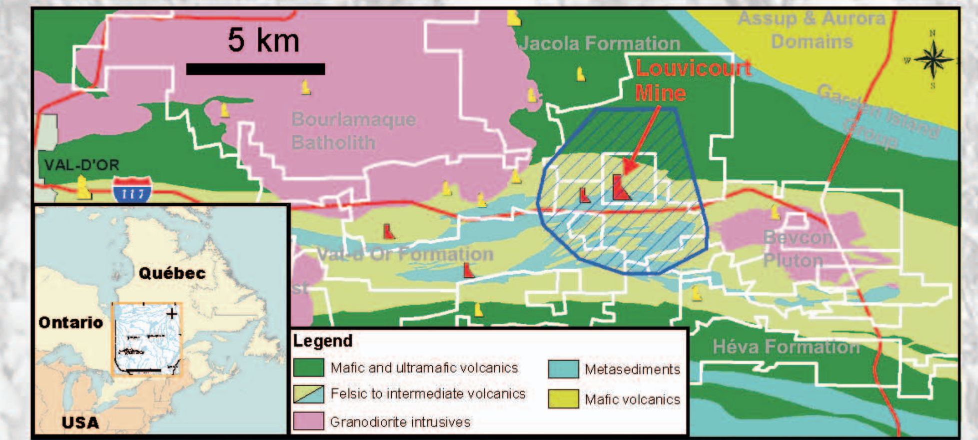
2. Geoserve Logging & Tomography, 42 Oakford Dr., Markham, Ontario, L6C 2Y8, Canada, e-mail: wei.geoserve@gmail.com

3. Department of Physics, University of Toronto, Toronto, Canada, e-mail: bernd.milkereit@gmail.com

University of Toronto

Abstract

A 3-D seismic survey was acquired in 2001 to explore for deep massive sulphide ore deposits in the vicinity of the Louvicourt mine near Val d'Or, Quebec. The seismic data was reprocessed in 2002 and the optimum imaging offsets and azimuth have been determined. The seismic stacked volume shows a detailed image of the existing mine as well as a new deep and steeply dipping reflection. A follow-up drilling program was undertaken to verify the nature of the deep seismic anomaly and BoreHole ElectroMagnetic (BHEM) data was acquired to evaluate the proximity of electrical conductors that could be indicative of a massive sulphide body. BHEM methods, although well suited for the resistive hard rock environment, are constrained by limitations of their sensitivity and resolving power of regional and local geological noise. These limitations are critical for a detailed exploration program in the vicinity of existing orebodies and mines. The interpretation of BHEM data from brown field exploration projects can be improved by both new data acquisition strategies and data processing procedures. In and within the vicinity of an existing mine, a vertical transmitter loop can sometimes provide a unique perspective for the explored volume with higher than expected data quality. The 3-D seismic volume provides geometrical information about deep impedance anomalies and can help in the design of an optimised drilling program. Forward modelling of BHEM data using potential conductor geometries derived from 3-D seismic data can then be used to guide long-term exploration strategies. The joint use of surface 3-D seismic and BHEM data has led to the identification of an extensive zone of disseminated sulphides close to the Louvicourt mine.



The Louvicourt mine is located 25 km East of Val d'Or in Quebec, Canada. The mine, which is now decommissioned, is located within a 1.5 to 5 km wide band of Archean age volcanic rocks that extend over 40 km (Pilote et al., 1998). The host rocks are subvertical are composed of felsic to intermediate volcanoclastics interlayered with andesitic flows and rhyolite domes (Pilote et al., 1998). The 15.5 Mt Louvicourt orebody is a polymetallic (Cu-Zn-Au-Ag) VMS type deposit that extends between depths of 355 and 920 m. The 3-D seismic survey acquired at the Louvicourt mine is shown by the blue hatched area.

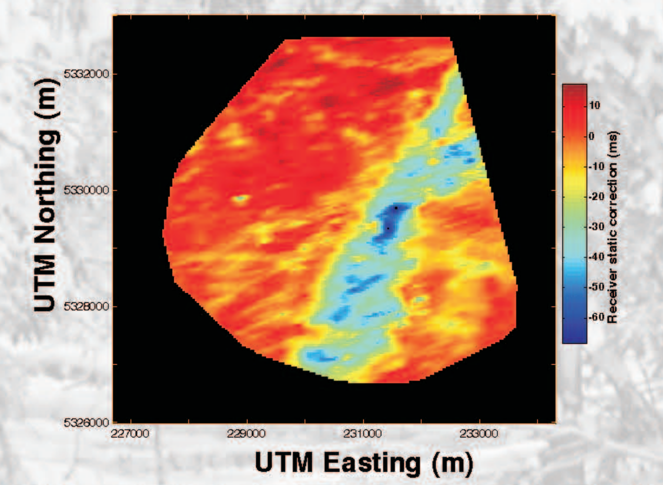
Photo by Bernard Salmon

Photo by Bernard Salmon

The Louvicourt 3-D seismic survey included 2205 explosive shots (0.454 kg geoprime) at an average depth of 6 m. The shotpoint interval was 60 m along 32 lines and were recorded by up to 2370 receivers at 30 m spacing along 28 receiver lines. The source and receiver line separations was 210 m. The recording patch, oriented in the North-South direction, consisted of 12 complete receiver lines in order to record large source receiver offsets and a wide range of azimuth. The area covered by the 3-D survey is about 28 km^2, but because of the steep dips that were anticipated, the processing grid included a buffer zone on each side of the survey. Thus, the CDP grid covers a 50 km^2 area using a 20 m square CDP bin. Because the Louvicourt mine is located in the middle of the seismic survey, the data acquisition was scheduled to take place at a time when the mill was shut down for maintenance, hence reducing the cultural noise. In general, the seismic data quality was fair to good on most of the lines, with weaker seismic energy for shots and receivers that were located in areas of thick glacial overburden (esker).

Key to Success #1:

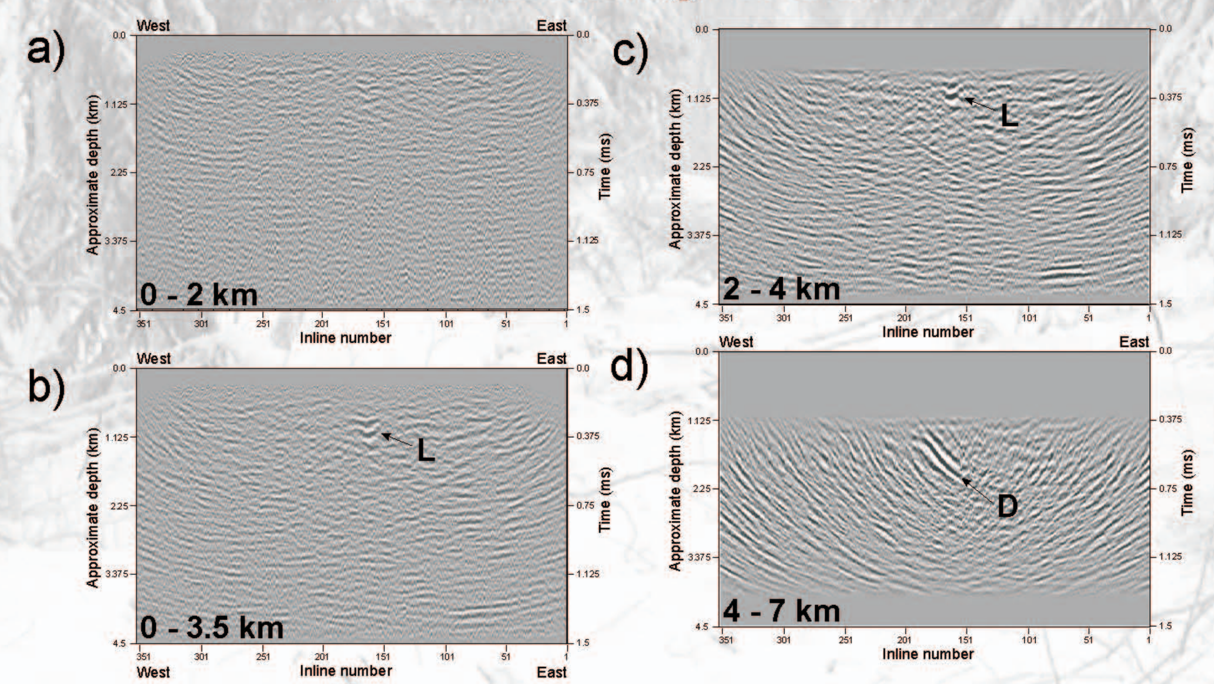
Get the refraction statics right!



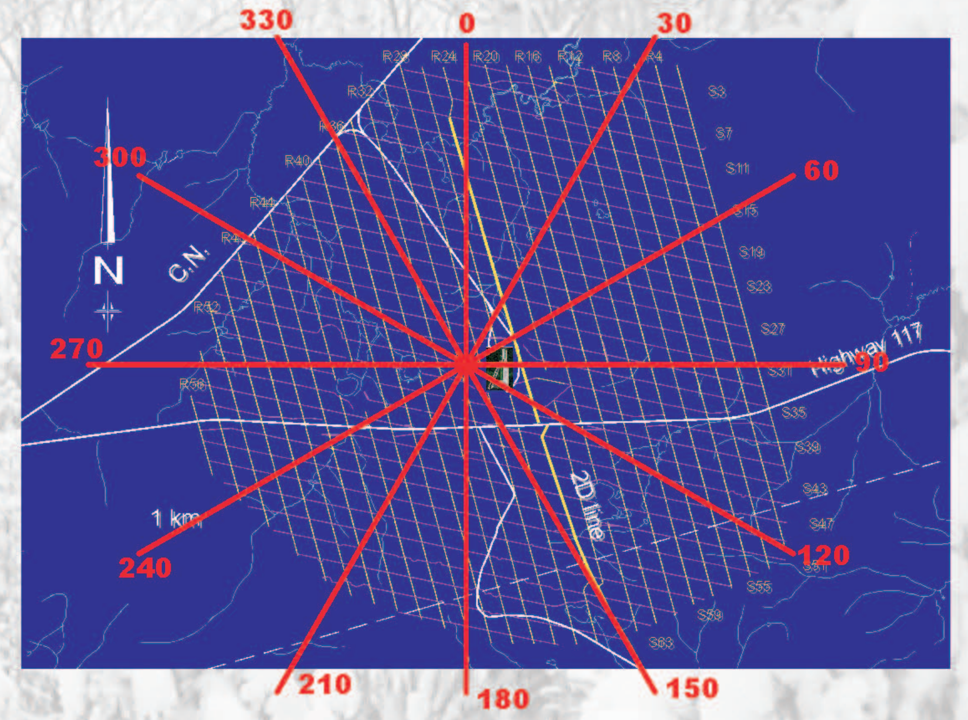
The seismic data acquired in the hardrock environment are strongly affected by time delays caused by low-velocity overburden of variable thickness. The importance of the refraction static correction is due to the high bedrock velocity (>5.5 km/s) and the low overburden velocity (< 1.5 km/s), the absence of a regolith and the poor performance of residual static correction as the lithological contacts have relatively low reflection coefficients in the hardrock environment. At Louvicourt, the shot refraction static and datum corrections (datum is at 400 m above sea level) range between -61 and +16 ms. The receiver refraction static and datum corrections show similar amplitude variations ranging between -71 and +18 ms. The large refraction static correction are oriented in the SW-NE direction and correspond to an esker (indicated by the blue color). The shotpoints and receivers that were placed on this esker generally show lower energy levels. The large amplitude of the shot and receiver static correction, a maximum of -132 ms (the sum of the maximum shot and receiver static correction), is in the same range as the target time (e.g. 400 m or ~140 ms).

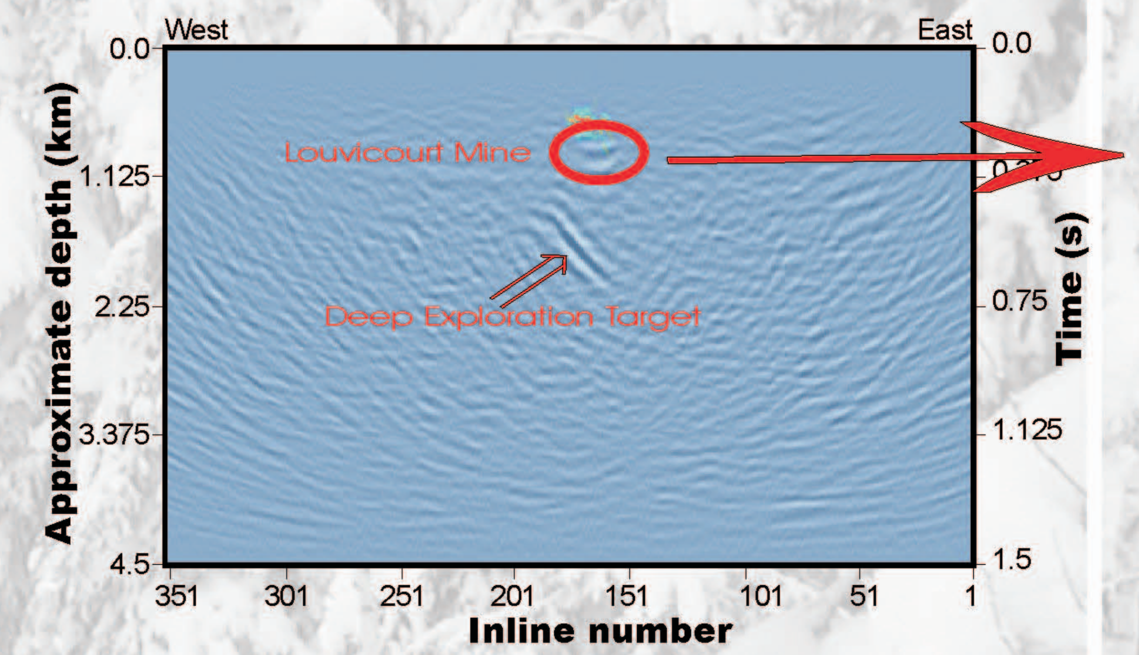
Key to Success #2:

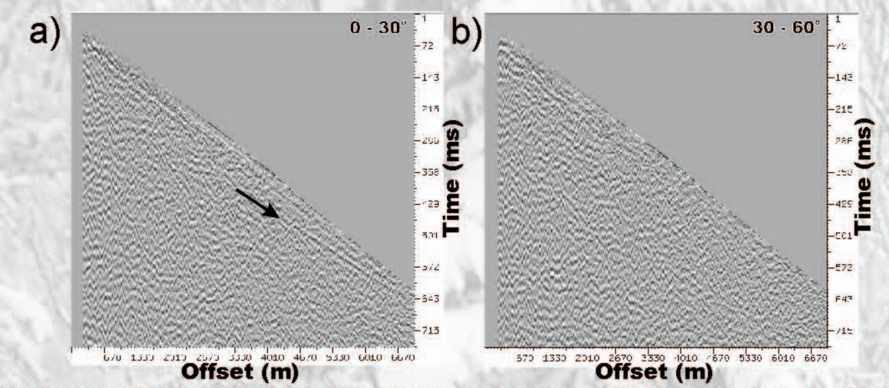
Find the useful range of offsets!



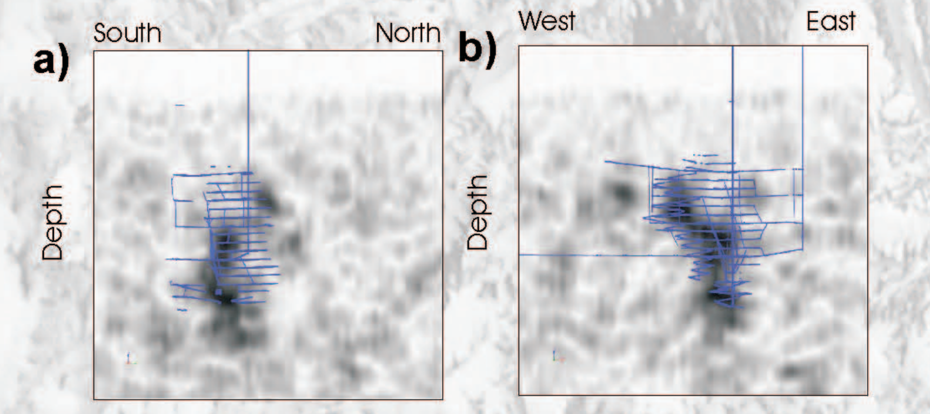
The steeply dipping reflectors are best imaged with large source-receiver offsets relative to their depth. Hence, for a given target dip and depth, there is a corresponding source-receiver offset range that will produce the optimum seismic image of that reflector. For example, sub-horizontal reflections are better imaged at small source-receiver offsets while steeply dipping reflections are more visible with large source-receiver separations. Consequently, offset-limited seismic stacked sections offer a simple way to enhance reflections that may otherwise stay unnoticed or buried in noise. This figure shows one crossline on which a package of reflections that are from the vicinity of Louvicourt are seen for shot-receiver separation of less than 4000 m (Figures a, b, and c). A deep (1.4 - 1.8 km) and steeply dipping (~50°) reflection is clearly identified by shot-receiver separation exceeding 4000 m (Figure d). By limiting the shot-receiver offset to less than 4000 m (the conventionally processed data was limited to 3500 m) does not allow the detection of the deep/steeply dipping reflection even if it is stronger than the seismic anomaly associated with the Louvicourt deposit.







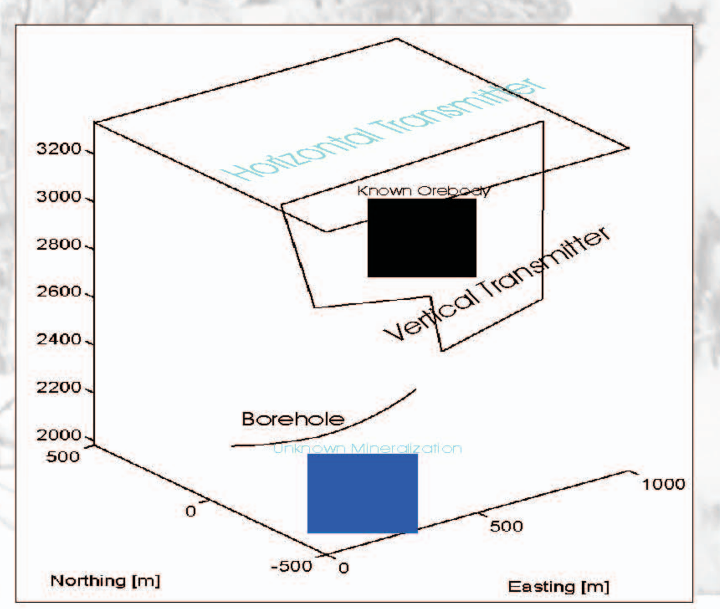
A steeply dipping reflection will reflect seismic waves in a preferred direction, it is thus possible to enhance such a reflection by stacking only traces that are located in the preferred azimuth. This Figure shows the results of the azimuthal analysis for shotpoints located around the center of the deep anomaly. Most shotpoints do not contribute to the deep anomaly (Figure b) except those located between 0 and 30° (Figure a) (i.e. Northeast) and between 120 and 150° (not shown here). The strongest amplitudes (arrow on Figure a) are observed from shotpoints located in the Southeast. These findings are consistent with a steeply east-dipping reflector. The deep anomaly can be enhanced by limiting the shot azimuth to the two ranges for which a reflection is observed. The azimuthal selection applied to the shotpoint was also tested on the receivers, the midpoints, and the shot-receiver azimuths. There is an advantage in filtering azimuths based on the midpoints since only one range shows the reflection from deep anomaly. The analysis of the shot-receiver azimuths, using the shot location as the reference, is also consistent with the other results: the anomaly is imaged for shot-receiver azimuths in the 330-360° and 150-180° ranges. We estimate that about 5% of the seismic traces are creating the deep steeply dipping seismic anomaly. Again, these results are consistent with a steeply east-dipping reflector.

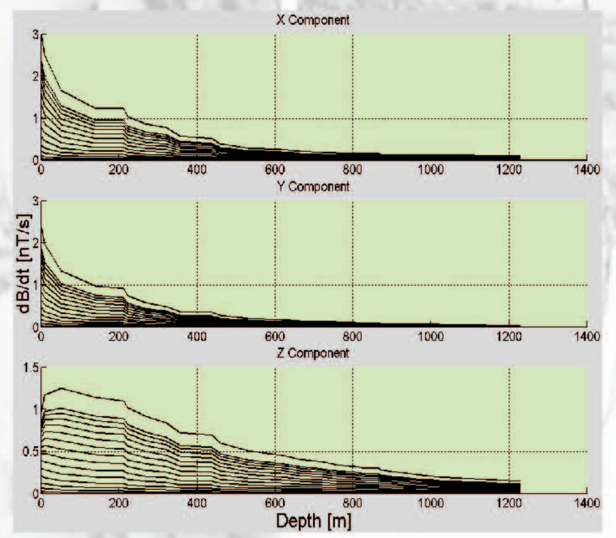


3-D seismic response in the Louvicourt mine.

Key to Success #3:

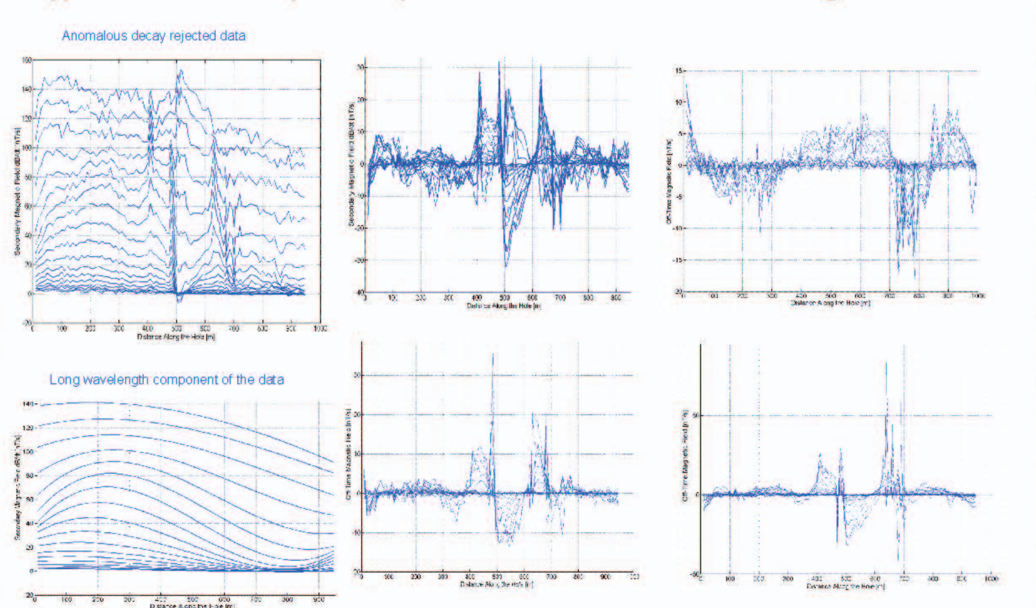
Identify the contribution of known conductors!



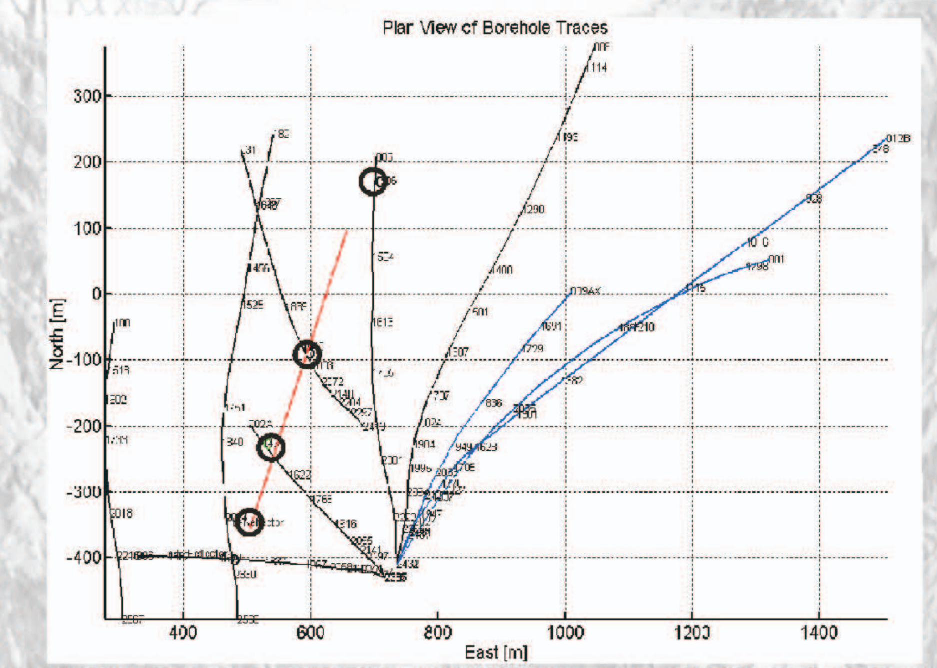


Brown field exploration scenario: BHEM response of the unknown mineralization is masked by responses of the orebody (long wavelength) and stringer sulfides zones close to the borehole (spikes). The left panel of the figure shows the response of the known orebody.

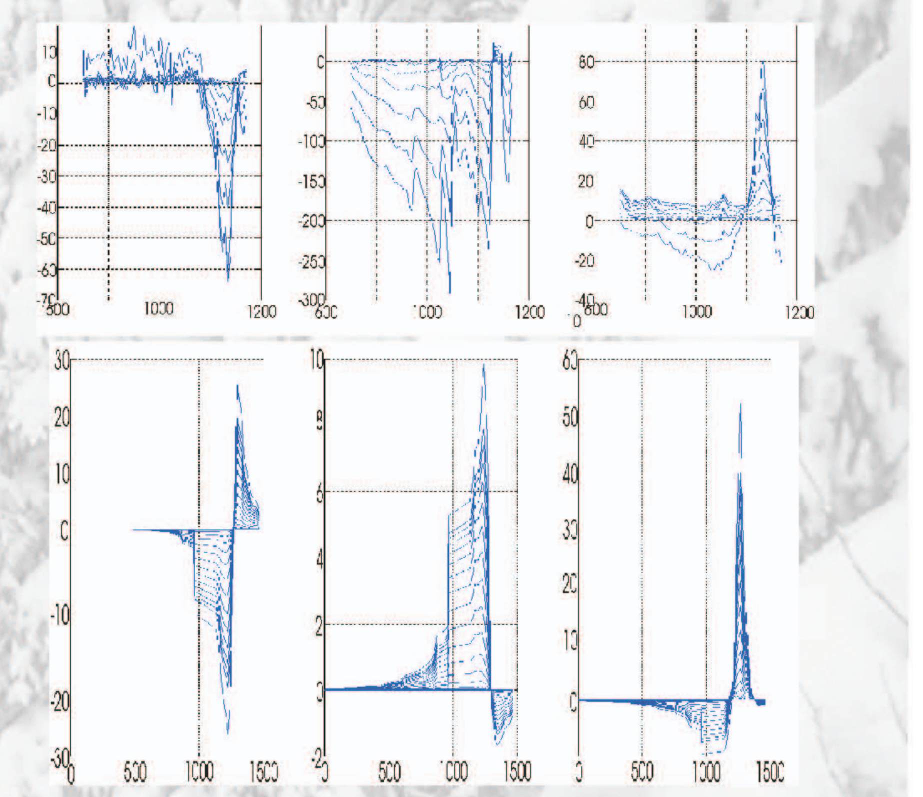
A typical brown field exploration problem: remove the effect of the regional conductor



Long wavelength trend removed and anomalous decay rejected BHEM data for 4 boreholes. The remaining responses show a consistent decay and the conductor locations indicated by these 4 data sets define a fairway in space described below.



The processed BHEM data defines a conductive fairway consisting small conductors located close to the borehole. This fairway is in good agreement with a prominent 3D seismic reflector. This fairway probably represents an alteration system with very heterogeneous conductivity enhancement. BHEM data in each borehole responds to this big patchy conductor in a localized manner. With the underground vertical transmitter loop excitation, the BHEM shows superior quality. In one borehole, this response indicates a large inductive eddy current system. This response can be easily modeled by a plate conductor marked in red color in the figure below. The first eigen-mode time constant for this conductor is 1.5 ms. To match the early time amplitude response, this conductor has to be fairly big (~ 500 X 500 m) and moderately conductive (~ 10 S). This conductor has a near vertical dip (~ 70 degrees). This conductor lies on top of the fairway. The software used in the modeling is developed by Qian et al. (2002).



Measured and modeled three component BHEM responses of the red plate conductor with the underground vertical loop transmitter excitation. Both amplitudes and decay are matched very well.

Conclusions

This study shows that it is possible to enhance the reflections from steeply dipping contacts in 3-D seismic data. In order to obtain a seismic image from steeply dipping reflectors, recordings with large sources-receiver separations are necessary and must be preserved during data processing. By limiting the migration aperture or the offsets during prestack migration the processing time is reduced but target reflections can effectively be destroyed. BHEM measurements acquired in all exploration wells should be filtered to remove contribution from known conductors. Furthermore, the BHEM transmitter loop position must be optimised by using modelling software that can simulate all possible deployment scenarios including the underground development. In cases where the geometry of potential conductors is known by seismic methods, the forward modelling of BHEM can be use to effectively test the possibility of a conductor also being a seismic reflector. This key information can be crucial in the decision to focus exploration in an area where large targets are indicated from the surface seismic data. By measuring the electrical and acoustical properties the approach could become quantitative and even more useful.

Acknowledgements

The authors thank Aur Resources, Novicourt, and Teck-Cominco for providing the seismic data. Aur Resources provided research funds, offered support and feedback. The Louvicourt seismic data was partially processed using software developed by BP America Inc. and its contributors.