

TDEM survey at Shea Creek uranium deposit utilising a low-temperature superconductor SQUID

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ABSTRACT

The Shea Creek uranium deposit is situated in the Athabasca basin, northern Saskatchewan, Canada. A number of TDEM (time-domain electromagnetic) profiles were surveyed in a variety of commonly used survey configurations at mainly two locations over the conductor associated with the Shea Creek uranium deposit using the IPHT - Supracon - Anglo American low-temperature superconductor (LTS) SQUID (superconducting quantum interference device). The LTS SQUID is a B-field sensor that effectively measures small secondary transient EM decays in a conductive earth due to a sudden change in the primary field of a transmitter loop located beneath, on or above the surface of the earth.

The conductor associated with the Shea Creek uranium deposit was successfully detected by the LTS SQUID TDEM profiles. The IPHT LTS SQUID behaved well in the presence of high geomagnetic activity and TDEM surveying could continue in spite of high ambient noise levels which reportedly caused other sensors to fail in the past. Given the superior sensitivity of the LTS SQUID sensor smaller transmitter loops can be used which would significantly speed-up production. Alternatively, much better signal-to-noise levels and hence penetration depths can be achieved using conventional transmitter loop sizes.

Key words: TDEM, LTS SQUID, Athabasca basin

INTRODUCTION

A low-temperature superconductor (LTS) superconducting quantum interference device (SQUID) is a very sensitive detector of magnetic flux with a very low noise floor.

A recent study in Australia comparing HTS (high-temperature superconductor) SQUID's and LTS SQUID's found that LTS SQUID signal is around 5 times better during early times and 2.5 times during late-times (Leslie et al, 2008). Macnae & Le Roux (2006) reported LTS SQUID sensors showing 4.5 times better sensitivity than HTS and about 15 times better than fluxgate B-field sensors from another comparative study. The particular LTS SQUID system developed for Time Domain Electromagnetic (TDEM) applications by the Institute for Photonic Technology (IPHT) in Jena, Germany and manufactured by Supracon, Jena under an exclusivity agreement with Anglo American Plc, achieves a noise limited resolution of less than 20 fT/ $\sqrt{\text{Hz}}$ in the laboratory.

Strong ambient noise is known to cause SQUID sensors to exceed their slew rate tolerances resulting in flux jumps or the flux trapping phenomena that causes delays in the field and renders data poor or unusable. The IPHT LTS SQUID sensors are particularly robust and the current models, resulting from recent improvements, very seldom exhibit any of these effects in the field. One of the largest constraints in TDEM data acquisition remains the dynamic range of the combined receiver system (sensor, amplifiers and analogue-to-digital converters (ADC)) due to the measurement of tiny secondary signals immediately following the very large primary fields generated by nearby transmitters. Two ploys can help to mitigate this: Measuring only in the medium to late off-time, and/or increasing the transmitter-receiver separation. The respective effects of these mitigating strategies will be to limit the interpretation of shallow horizons which reduces the confidence in the interpretation (particularly target depths), and to compromise on the spatial resolution of the target bodies.

A number of TDEM test lines were surveyed jointly by Anglo American, Discovery Geophysics and Areva

Resources Canada over parts of the Shea Creek uranium deposit in the Athabasca Basin, northern Saskatchewan, Canada in late October – early November 2008. The aim of the survey was to compare the resolving power of the Anglo American LTS SQUID EM system with previous HTS SQUID and induction coil EM work carried out by Areva and others over the conductor associated with the uranium deposit at Shea Creek.

SURVEY LOCATION AND GEOLOGICAL SETTING

The survey area was located at the Shea Creek uranium deposit situated in the Athabasca Basin, northern Saskatchewan, Canada just south of the Carswell impact structure. The area consists mainly of late Paleoproterozoic sedimentary rocks of the Athabasca Basin unconformably underlain by Archaean and Proterozoic high-grade metamorphic crystalline basement.

The brittle structures that postdate the deposition of the Athabasca Group sediments are generally considered favourable loci for exploration activity. The intersection of the early and late structures provide the necessary “plumbing” to bring uranium-bearing oxidized sandstone brines in contact with reduced basement fluids to produce the redox-related uranium deposits found in the Sea Creek area (Nimeck and Koch, 2008). At Shea Creek the Saskatoon Lake conductor (SLC) is a northwest-southeast graphitic zone that is interpreted to be a large-scale reverse (thrust) structure orientated parallel or sub parallel to the main foliation with a dip of 30 – 50 deg to the southwest (Nimeck and Koch, 2008). The Shea Creek uranium deposit is associated with the SLC, as are a number of other known deposits in the area.

The geo-electrical cross-section of the area as shown in Figure 1 comprises a very thin (few cm only) practically undetectable conductive humus overburden underlain by resistive (500 – 5000 $\Omega\cdot\text{m}$) clean Athabasca Group sandstones, which in turn unconformably overlie the very resistive basement. The unconformity between the sandstone and granitic basement varies between 710 and 1000 m+ in the Shea Creek region. Alteration zones along reactivated brittle structures are associated with uranium mineralization and in places do exhibit highly conductive zones (50 $\Omega\cdot\text{m}$). In places the unconformity itself or alteration along it can be moderately conductive and appear as a conductive cover ‘layer’ that can act as a screen of the basement conductor.

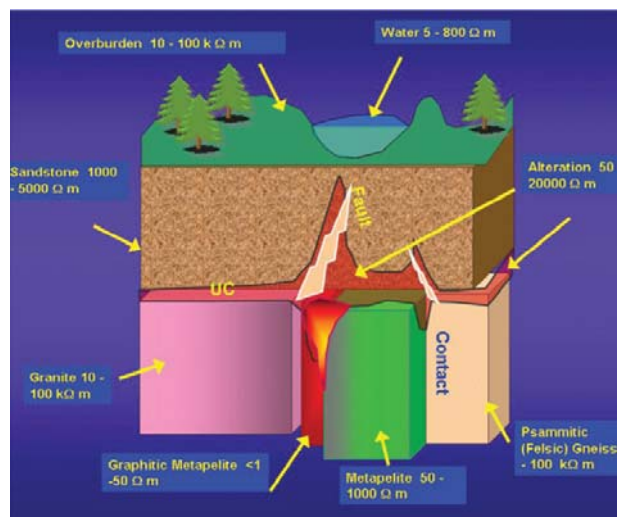


Figure 1. Geo-electrical cross-section of the Athabasca-type uranium deposits (from Nimeck and Koch, 2008)

SURVEY RESULTS AND DISCUSSION

A number of TDEM (time-domain electromagnetic) profiles were surveyed in a variety of commonly used survey configurations over the conductor associated with the Shea Creek uranium deposit. A Geonics Protem receiver and a 16 bit SMARTem receiver was used for the data acquisition. The SMARTem proved a welcome improvement on older receiver types given its clever stacking and modern acquisition software, accurate syncing with a remote transmitter and good noise rejection abilities. A Geonics TEM57 MK2 transmitter was used throughout the survey. It transmits a square half duty cycle waveform at a user selected base frequency.

A full 1-D non-linear least-squares inversion of field data provides one with a powerful tool to minimize the error between a calculated initial model response and the field data (Jupp and Vozoff, 1975). Higher order (2-D or 3-D) inversions can be done on field data but is computationally expensive and very time consuming (Wilson et al, 2007). If the target conductor is thin and steeply dipping the 1-D assumption doesn't hold and one is forced to, at the very least, consider thin plates when attempting to find a model response that resembles the field observations. Although a good fit was obtained between the field data and the model response data, depths could be erroneous where the actual geo-electric cross-section does not approximate a 1-D scenario. The problem does get worse as the Rx - Tx separation increases.

The data in Figure 2 was acquired with a 39 channel SMARTem V Receiver at a transmitter base frequency of 0.5 Hz. Approximately 15 A was injected into a single turn 400m x 400m loop used in a central loop configuration. The last Rx channel centre is at 371ms after current termination in the transmitter loop. The

profile was done at right angles to the expected conductor location.

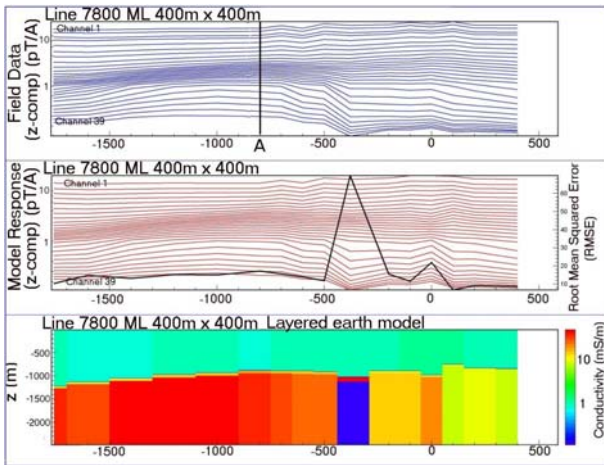


Figure 2. LTS SQUID EM data and layered earth model for Line 7800N.

Apart from one sounding at Station -400, where the measurement was unknowingly taken close to a borehole casing, a relative good fit was obtained between the field data and the 1-D layered earth inversion model response, as indicated by the RMS error shown in Figure 2. The decay curve at Station -800 is shown in Figure 3. The decay curve clearly shows the exponential decay associated with the conductor out to 371 ms after current termination. The conductor manifests itself by a late-time Tau value of 60 ms.

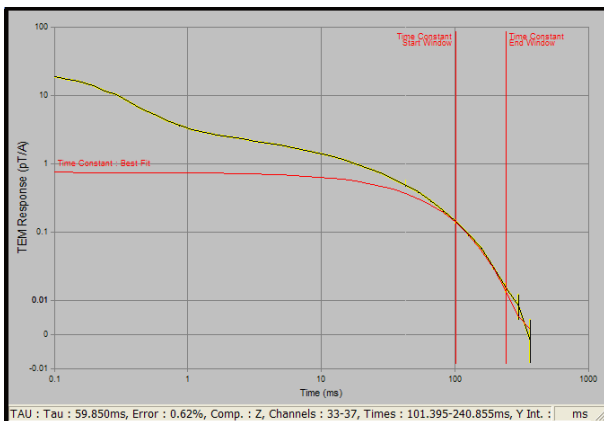


Figure 3. Decay curve for Station -800, Line 7800N (position A (Figure 2)).

Once the exact location of the conductor was known an 800m x 800m fixed loop was laid out and a number of profiles were surveyed over the loop. The position of the loop was chosen so as to maximize the coupling between the transmitter and the target conductor, given the practical limitation imposed by terrain relief.

The data in Figure 4 was acquired with a Geonics Protem receiver at a transmitter base frequency of 3 Hz.

The last receiver channel centre is at 69.8 ms after current termination in the transmitter loop. The profile was done at right angles to the conductor location at a station spacing of 200m with some additional 100m infill stations. An 800 m x 800 m fixed-loop was used with the loop position indicated in Figure 4.

Given the complexity of the geo-electrical model, the data was modelled using the newly released Leroi code developed by CSIRO through the P223F AMIRA project. Leroi can accommodate any number of horizontal layers with any number of dipping thin plates residing in any of the horizontal layers. The computing time does become excessive if there are many plates or if the plates become big.

A simplified model was attempted on the data acquired along Line 8000N. The overburden was modelled with a single layer of 600 m thickness with a resistivity of 400 $\Omega\cdot\text{m}$. The thin plate conductor (red) was modelled with a conductance of 420 siemens, a dip of 10° W and a strike length of 1000 meters. The results suggest that the actual geo-electrical model might be somewhat more complex although the main features have been captured. The slight discrepancy between the conductor depths obtained with the 1-D layered earth inversion (Figure 2) and the thin plate model in Figure 4 can be ascribed to an invalid 1-D assumption made during the layered earth inversion.

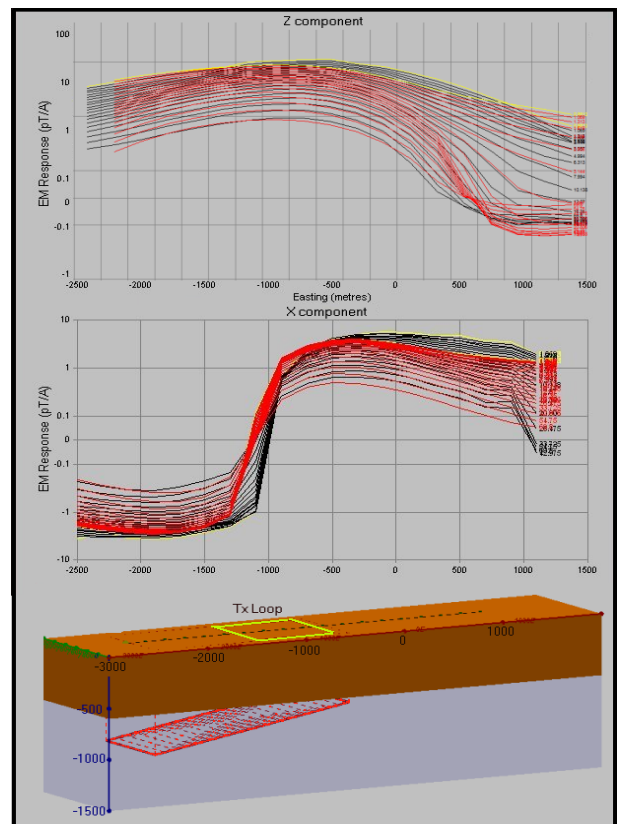


Figure 4. LTS SQUID EM data (black), Leroi thin plate model response (red) and layered earth thin plate model for Line 8000N.

Induction coil measurements were also made along Line 8000N using a single component 100 m² Geonics receiver coil with the same survey configuration as described for Figure 4. The results are shown in Figure 5. Although the presence of the conductor is visible, the only parameter that can be resolved with confidence from the coil data is the conductivity of the Paleoproterozoic sandstone above the unconformity.

CONCLUSIONS

The conductor associated with the Shea Creek uranium deposit was successfully detected by the LTS SQUID TDEM survey. In places the conductor was detected under moderately conductive cover at depths of over 1000 meters. The IPHT LTS SQUID behaved well in the presence of high geomagnetic activity and TDEM surveying could continue in spite of high ambient noise levels which reportedly caused other sensors to fail in the past. Given the superior sensitivity of the LTS SQUID sensor smaller transmitter loops can be used which would significantly speed-up production. Alternatively, much better signal-to-noise levels and hence penetration depths can be achieved using conventional transmitter loop sizes. Post processing of field data with data collected at a remote reference station could be done if the respective time series have an accurate GPS time-stamp. Remote reference processing would improve the signal to noise characteristics of the field data and hence the effective penetration depth.

ACKNOWLEDGMENTS

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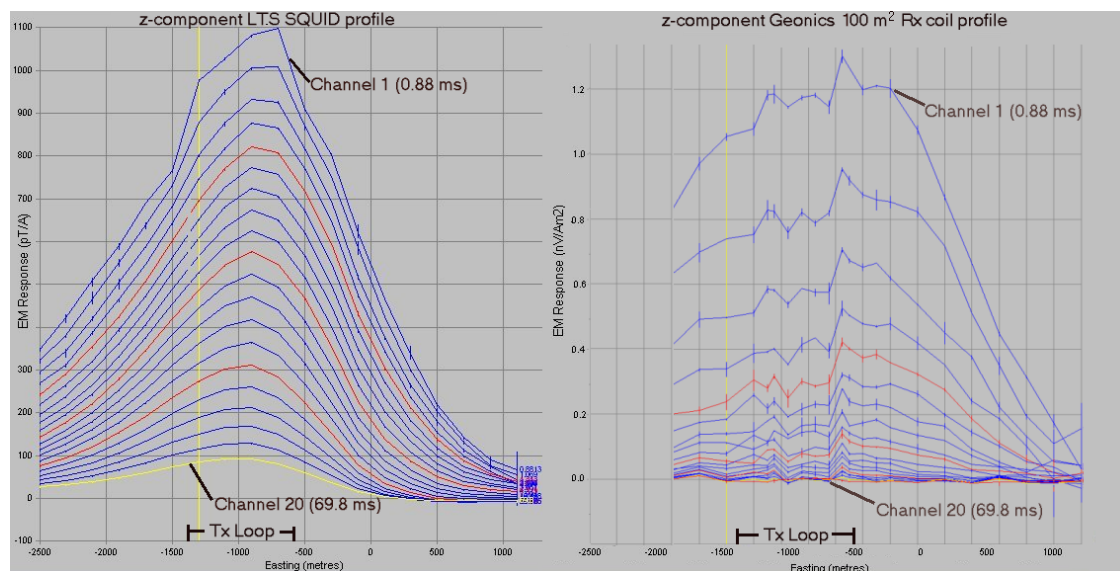


Figure 5. Z-component LTS SQUID data and Geonics coil data for Line 8000N (800 m x 800 m fixed-loop configuration).