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3D modelling and 1D inversion of synthetic and real airborne time-domain electromagnetic data for uranium exploration in the McArthur River area, Athabasca Basin, Canada

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Introduction

Uranium deposits in the Athabasca Basin, Canada, are often found in the vicinity of conductive graphitic fault zones in the basement rocks that are unconformably overlain by sandstones in the basin. Also, the area is covered by an overburden of glacial sediments which can have a conductivity contrast with the sandstones (Jefferson et al., 2007). These two conductive features are considered to be easy targets for electromagnetic (EM) methods. However, in the parts of the Athabasca Basin undergoing active exploration, the graphitic fault zones (and associated uranium deposits) are found at depths of approximatly 500m, and it is unclear how easily these fault zones can be imaged given their depth and potential masking by a conductive overburden. Here, time-domain EM (TDEM) data, specifically from the helicopter-borne VTEM system, are investigated. Synthetic data were computed for a 3D representative model including topography. The modelling was performed using the code of Ansari and Farquharson (2014), which uses unstructured tetrahedral meshes to discretize the computation domain. Then, 1D inversions (using the code EM1DTM, Farquharson and Oldenburg, 2006), were done on the synthetized data and the accuracy of the constructed sections assessed. Finally, 1D inversion was also applied to real VTEM data from the Athabasca Basin. This study was focused on the area around the McArthur River mine. This is the largest, high-grade uranium deposit in the world, which is at a depth of about 500 m below surface on a structure called the P2 Fault.

Geological setting

In the Athabasca Basin (Figure 1), uranium deposits are often located at or close to the unconformity between Proterozoic sedimentary rocks and the Archean and Paleoproterozoic metamorphic basement in the vicinity of conductive graphite that often define faults in the basement intersect the unconformity. The basement is tectonically interleaved Paleoproterozoic metasedimentary and Archean to Proterozoic granitoid rocks which were last metamorphosed at 1800 Ma by the Trans Hudson Orogen. Many of the faults developed during this orogenic event, and were then reactivated after the deposition of the sediments in the basin prior to the formation of primary uranium mineralization along these faults at ca. 1.6 Ga (Jefferson et al., 2007; Alexandre et al., 2007). The sedimentary rocks are unmetamorphosed strata which are covered by Quaternary glacial deposits (Figure 2).

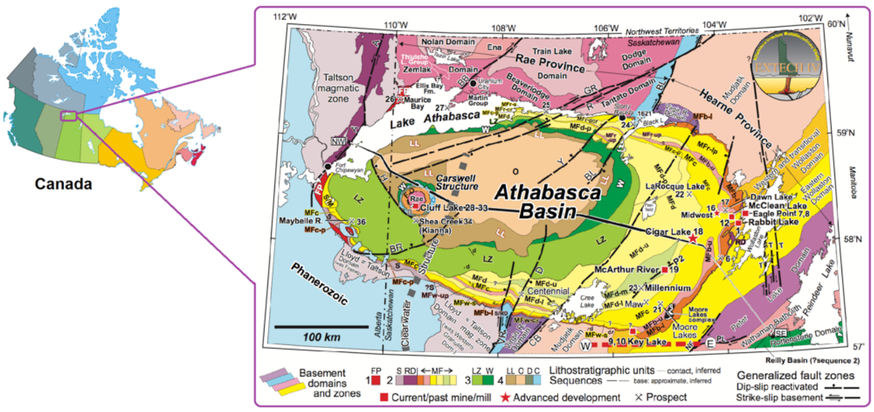

***Figure 1** Geology of the Athabasca Basin (adapted from Jefferson et al., 2007).*

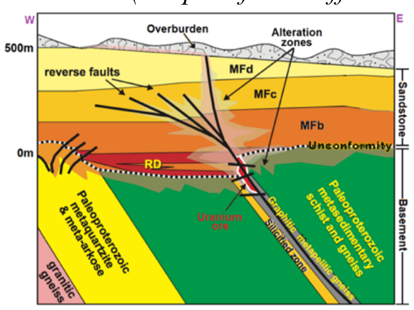

***Figure 2** Generic model of an unconformity type uranium deposit in the Athabasca Basin (adapted from Jefferson et al., 2007).*

The overburden of the Athabasca Basin is a product of the advance and retreat of the last ice sheet belonging to the Late Wisconsinan. Deglaciation of the eastern Athabasca Basin began in the southwest around 9000–8700 BP (Before Present), and it was completely ice-free by 8200 BP. The thickness of glacial deposits is variable and ranges from 0 up to 100 m. The presence of water in the unconsolidated materials of overburden can decrease the resistivity.

Synthetic modelling and inversion

For the 3D forward modelling, a model was made for the McArthur River area (Figure 3) for which real VTEM data were available. The main geological structures in this model are overburden, sandstone, alteration zone, pelite, psammite, quartzite, granitoid gneiss and graphitic fault. Synthetic VTEM data were calculated along a profile with a station spacing of 100m and an EM sensor height of 30m using the code CSEM3DFWD (Ansari and Farquharson, 2014). Time-domain voltages were calculated from the computed frequency-domain fields via Fourier transformation using 160 frequencies over a range from 1 Hz to 30 MHz. Since the data were simply transformed from the frequency domain to the time domain, the current waveform for these synthetic data corresponded to a step off. The width of the transmitting time is 5.74 ms, and the earliest time datum is 21 μs after turn off. A variable range of noise from 0.5% (for early times) to 100% (for late times) was added into the data-set to be inverted. 1D inversions were applied to the synthetized data using the program EM1DTM. Figures 4 shows the synthetic noisy data as well as the inversion results. The inversion result shows that the VTEM method can be used to see the conductive anomalies to a certain depth and with a certain conductivity contrast, as the conductive overburden can be seen in this synthetic modelling but not the conductive graphite. For this modelling, only a depth of 200m is considered for mapping the depth of inversion results.

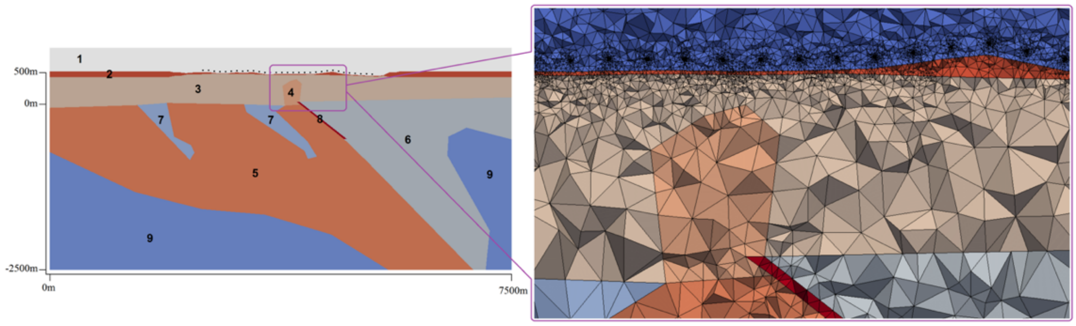

Figure 3 *Constructed 3D geological structure under the schematic profile (left), and tetrahedral mesh (right). Numbers 1, 2, 3, 4, 5, 6, 7, 8 and 9 indicate: air (10^8 Ohm-m), overburden (500 Ohm-m), sandstone (2000 Ohm-m), alteration zone (1000 Ohm-m), pelite (800 Ohm-m), psammite (6000 Ohm-m), quartzite (10,000 Ohm-m), graphitic fault (50 Ohm-m) and granitoid gneiss (70,000 Ohm-m), respectively.*

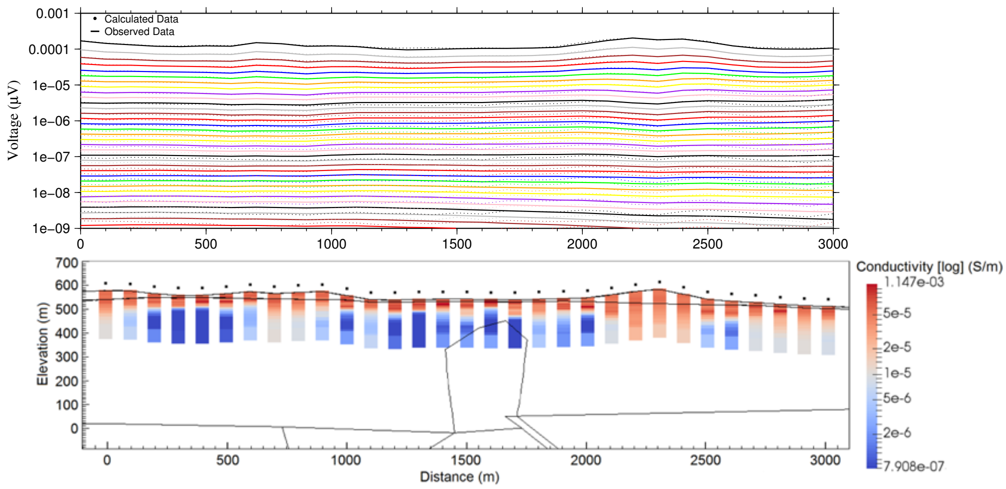

Figure 4 *Top: observed and calculated VTEM data. Bottom: true model (black lines), and 1D inversion results for each station (black dots) along the profile.*

Inversion of real data

A VTEM airborne geophysical survey was carried out by Geotech Ltd. for Cameco Corporation over the McArthur River area in December 2013. The survey coverage consisted of approximately 889 line-km with a line spacing of up to 300 metres and a station spacing of around 2.5 m, and with an EM sensor height of approximately 31 metres (Figure 5; Geotech Ltd., 2013). The VTEM system measures voltages (dBz/dt) at 44 off-time channels which were processed by Mir (2016). 1D inversion was applied to the real VTEM data along a profile with around 1200 stations (Figure 6).

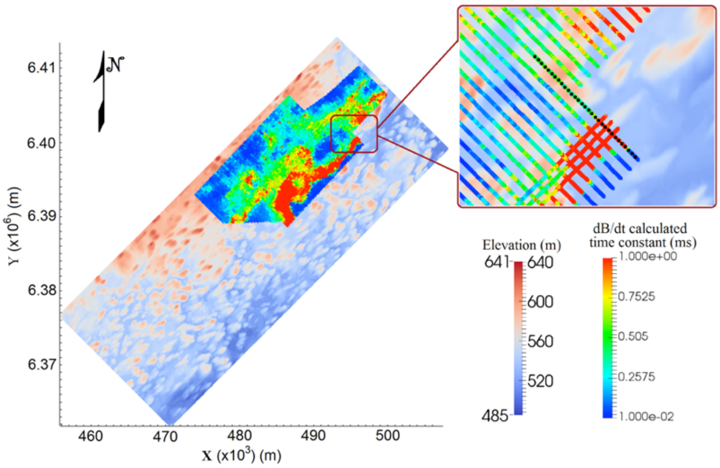

Figure 5 *VTEM data for the time gate number 10 over the McArthur River area. Inset shows location of survey line (black dots) chosen for 1D inversion.*

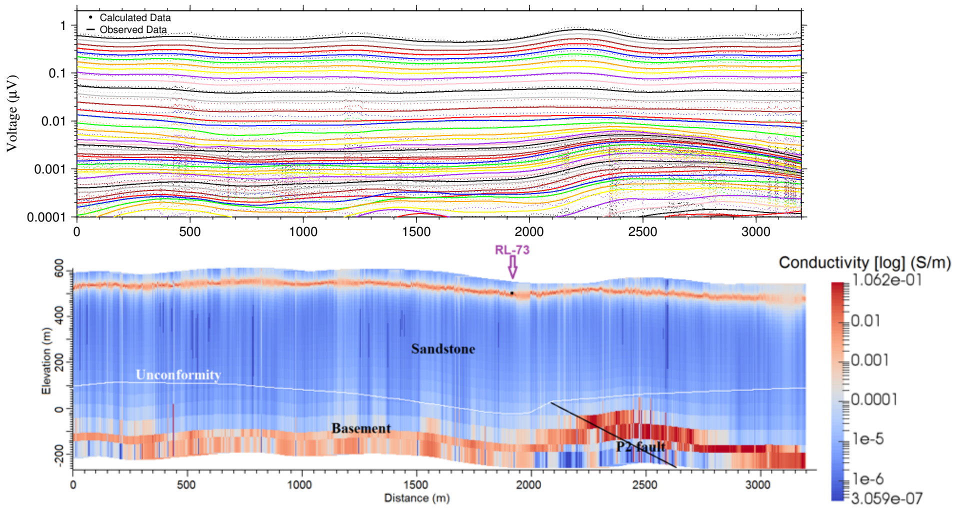

Figure 6 *Top: observed and calculated data. Bottom: 1D inversion results. White line: approximate location of unconformity; black line: approximate location of P2 fault; back dot: true location of the base of overburden from drill-hole RL-73.*

The 1D inversion result shows three main structures. The first one is a conductive layer consistent across the bottom of the whole model below -100m elevation, which is almost certainly due to noise in the late-time measurements. This can be explained as follows. An increase in conductivity at depth tends to increase the late-time measurements. But the noise in the data acts to increase the measured values at the late times in a way similar to the effect of a deep conductor. Thus, in order to make the calculated data fit the observed data at late times, the inversion shifted the calculated data up at late times by introducing a (fictitious) conductive layer at depth. The second feature is a conductive zone starting from a depth of 0m in the right side of the model between 2000m and 3000m. This zone is located around the P2 fault; thus this could be a signature of the graphitic zone. The third feature is a narrow conductive layer close to the surface. The real location of the interface between overburden and sandstone in shown with a black dot using the data from drill-hole RL-73. Although this conductive layer is close to the interface between overburden and sandstone, there is not a certain geological interpretation for this as there is not a good contrast between the overburden and sandstone in the McArthur River area. Also, it seems too consistent all the way along the profile to be considered as, for example, a water table.

Conclusions

The electromagnetic method can be used for a wide range of subsurface explorations. The synthetic examples considered here for the Athabasca Basin confirm that the airborne time-domain method can detect conductive layers such as the overburden. 1D inversion was applied to real VTEM data from the McArthur River area. This showed a conductive zone close to the known location of the P2 fault, suggesting that this data-set can indeed see the deep graphitic fault zones that are associated with the uranium mineralization in the area.

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