GeoConvention
Calgary • Canada • March 7-11 2016
OPTIMIZING RESOURCES

Filling in the Gaps: Near-surface resistivity mapping using HTEM

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Summary

Heliborne time-domain electromagnetic (HTEM) systems have proven to be effective tools in mapping sub-surface resistivity. Their ability to resolve resistivity information in the near-surface (top 50 metres) is demonstrated over the Aspen Block, near Fort McMurray, Alberta. This area provided a useful setting in mapping near-surface resistivity variations, specifically the location and geometry of the Pemmican Valley aquifer. The VTEM results mapped the location of the Pemmican Valley aquifer within the Aspen Block accurately and identified an additional, previously unknown, aquifer located nearer to the surface. The 1D resistivity models match resistivity well-logs throughout the block accurately and extend to depths where conventional seismics results become more reliable.

Introduction

Onshore Oil and Gas geophysical exploration programs lack a timely, cost-effective solution to map the first 50 to 100m of geology. Filling in this gap of knowledge by accurately mapping the near-surface geology is beneficial to reduce risks associated with the exploration and production of Oil and Gas. Conventional seismics cannot resolve it due to wave energy dispersion in the top unconsolidated sediments. Although high resolution seismic surveys can be undertaken in order to overcome this problem, they can prove labor-intensive and logistically cumbersome in areas of environmental sensitivity. On the other hand, through continuous innovation, heliborne time-domain electromagnetic (HTEM) systems have expanded their ability to map geology from the surface to depths of hundreds of metres.

Heliborne Time-Domain Electromagnetics

HTEM is a controlled-source technique that maps the resistivity distribution of the subsurface by applying Faraday's law of induction. One such system, VTEM, has an excellent reputation in exploration for the mining industry due its superior signal-to-noise ratio. With the introduction of Full Waveform technology (Legault, 2012), VTEM pushes the limits of airborne TDEM's ability to map near-surface geological features. VTEM is comprised of two concentric coplanar coils of different sizes. The outer loop is the transmitter (Tx), which a nominal diameter of 26 m, and the inner loop is the receiver (Rx+backing coil) with a diameter of about 3m. Each VTEM observation station is obtained by running a time-varying current through the Tx, which generates a time-varying primary magnetic field. As this time-varying magnetic field passes through the geological medium underneath, it creates a magnetic flux which changes with time. This change in the magnetic flux will produce an electromotive force generating eddy currents that in turns create a secondary magnetic field. The secondary magnetic field is measured by the receiver coil as it decays over time.

The decay curve contains resistivity information about each of the geological units in the range of investigation depth. One of the parameters which quantify these variations in resistivity is the decay time constant (TAU). A lower TAU indicates a higher resistance and a higher TAU indicates a higher conductance. In sedimentary areas, the decay curves can be inverted to model the resistivity and thickness of the geological units.

Geology

A VTEM survey was flown over the Aspen Block which is located approximately 45 km northeast of Fort McMurray within the Athabasca oil sands deposits. The block was flown in a South-to-North direction with a line spacing of 100 metres and tie lines with spacing of 1000 metres. The sedimentary geology in this area is often subdivided into four main units from top to bottom, as shown in Figure 1a:

(1) Unconsolidated Quaternary sediments, mostly glacial till and fluvial material with localized paleovalleys that incise into the underlying formation and small pockets of sand/gravel,

(2) Grand Rapid Formation with thickness varying between 30m and 100m and dominated by two Albian sandstone units separated by a thin muddy sequence,

(3) Clearwater Formation, which is a uniform Cretaceous, marine shale unit with thickness ranging between 60m to 90m, and

(4) McMurray Formation that mostly consists of fluvial sandstones and in some regions containing important reservoirs of oil and water sands.

From the hydrogeological standpoint, all underground and surface water system appears closely linked to the shallower stratigraphic units (Figure 1b). The top Quaternary overburden contains the regional Pemmican Valley Aquifer which traverses diagonally through the Aspen block (Imperial Oil Resources Venture Limited, 2013).

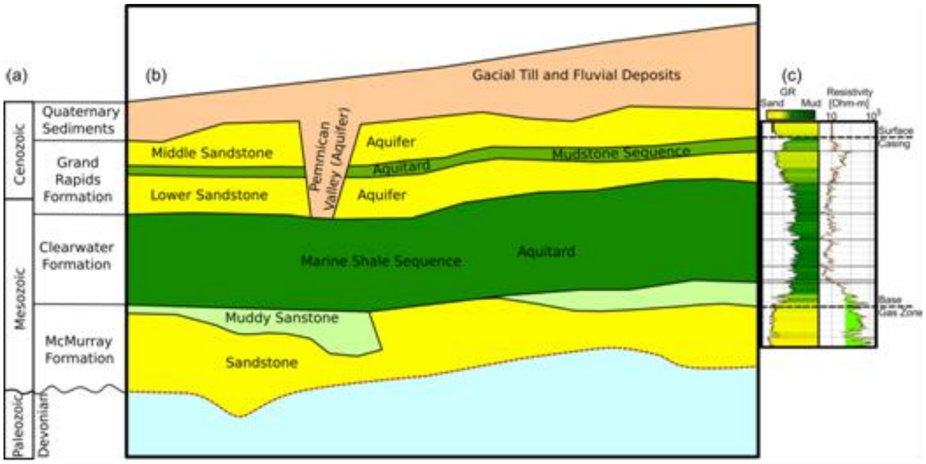

Figure 1: A composite schematic of the near surface stratigraphy within Aspen block, Fort McMurray. a) stratigraphic column, b) simplified geological cross-section, c) a typical resistivity well log (modified after Imperial Oil Resources Venture Limited, 2013)

The main stratigraphic sequences are well characterized geoelectrically as shown by the resistivity well log (Figure 1c). In the Grand Rapids Formation, the alternation between sand and muddy units correspond with moderate resistivity values around 50 Ohm-m and 10 Ohm-m, respectively. The Clearwater Formation is very distinctive with resistivity values generally below 10 Ohm-m. At the base, the McMurray Formation is signaled by a sharp resistivity increase reaching anomalous values close to 500-1000 Ohm-m, possibly associated with oil/water sands. The Pemmican Valley aquifer traverses through the Aspen Block diagonally from the northeast corner to the southwest corner and cuts through the Grand Rapids Formation which is represented in Figure 1b.

Results from Tau Analysis and 1D Inversions

The analysis of the Aspen block dataset started by calculating the TAU on a subset of early time channels to extract information about the varaiation of the resistivity in the near surface. The results of this early time TAU analysis is shown in Figure 2 along with the known location of the Pemmican Vally aquifer. There is an excellent correlation between the Pemmican Valley Aquifer with the most resistive (white) lineaments observed in the southwestern corner of the TAU maps. However, in the northwest section of the block, the TAU maps indicate that the location of the aquifer takes a more northerly path compared to what is known. Based on the linear trajectory for the northern section of the aquifer, compared to the snaking path it has in the southwest, it likely indicates a looser control on the aquifers exact location. Additionally, the TAU analysis shows another resistive unit running in an east-west direction. This resistive unit indicates the location of a previously unknown aquifer.

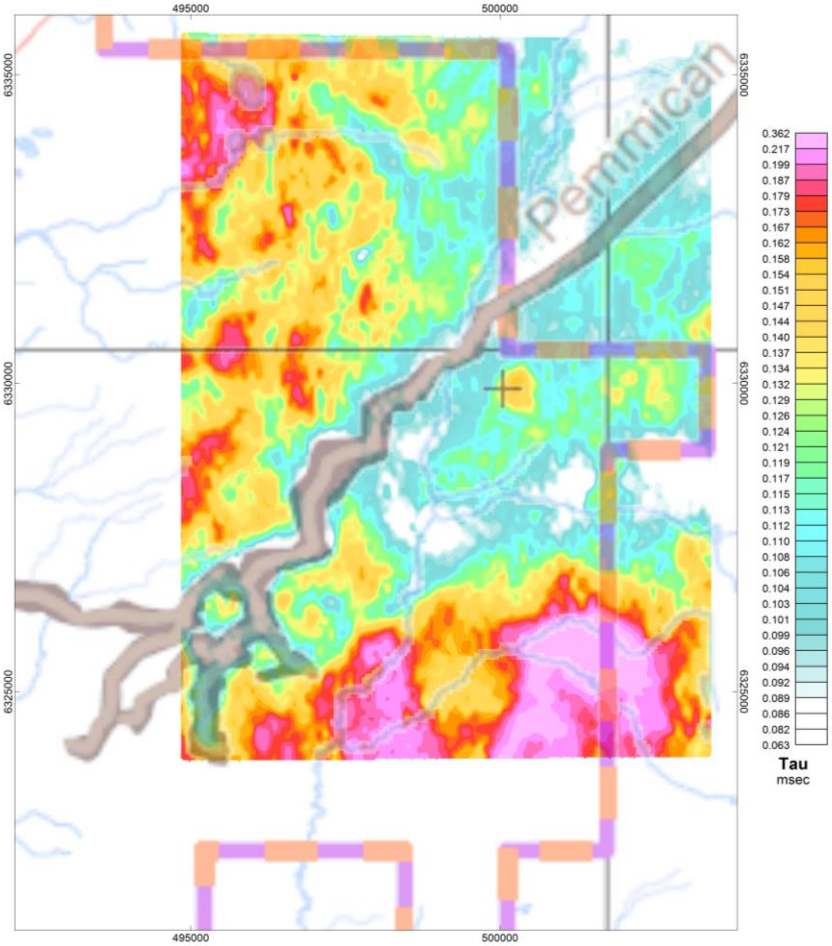

Figure 2: Early-time Tau constant map overlain by Pemmican Valley aquifer location. The trajectory of the Pemmican Valley aquifer was taken from Imperial Oil Resources Venture Limited (2013).

Next, the VTEM data over the Aspen block was inverted in 1D using the AirBeo algorithm by CSIRO (Raiche, 1998). These 1D models were stitched together to create a 2D cross-sectional image of the resistivity variation from the surface to the base of the Clearwater formation as seen in Figure 3a. The cross-sections map a resistive unit at the location of the Pemmican Valley aquifer along each of the lines. These resistive units also extend to the Clearwater formation as is indicated in the geological model (Figure 1).

Several resistivity well-logs have been collected within the Aspen block. The results of the 1D inversion models accurately reflect the resistivities of the well logs as displayed in Figure 3b. The 1D inversions accurately resolve the Clearwater formation near the location of Well A and B. Figure 3c shows planar slices compiled from the 1D resistivity models. Geoelectrical Layer 2 lies between 30-60 metres in depth while Geoelectrical layer 3 is deeper, between 60-100 metres. Each of the layers outline the two aquifers indicated by the TAU results.

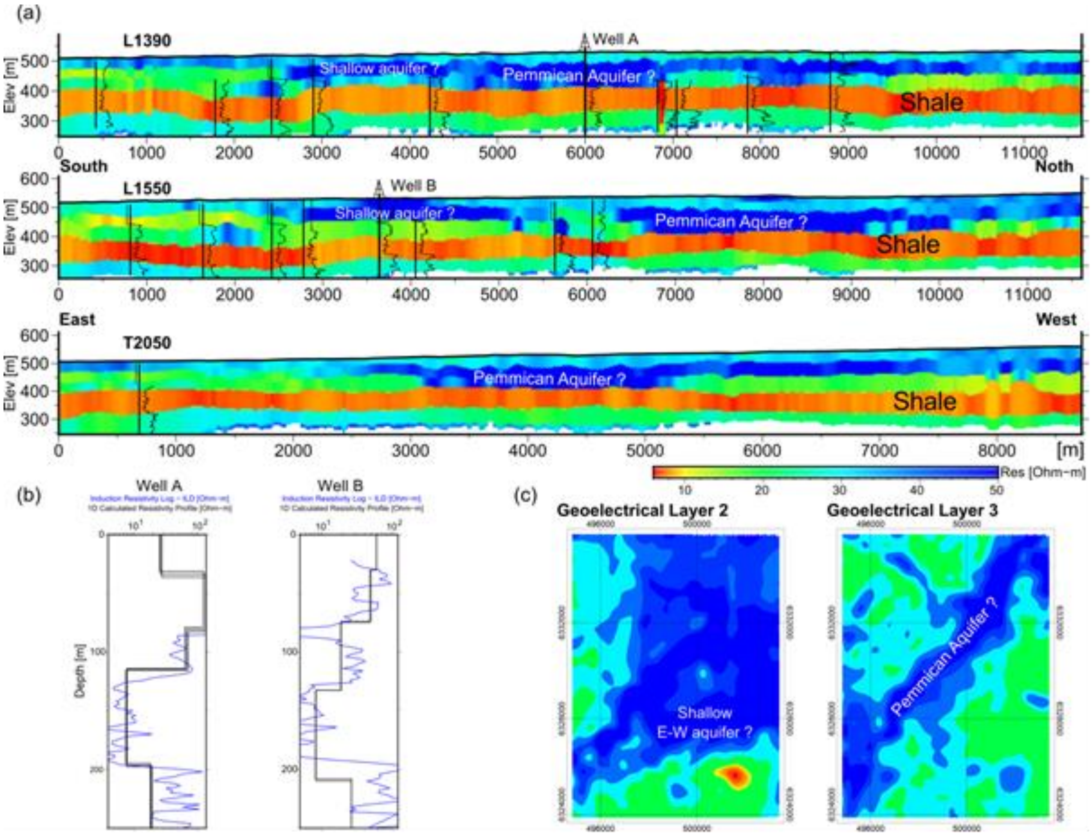

Figure 3: a) 1D Stitched inversion cross-section, b) 1D inversions with well-log resistivity data, c) Layer resistivity maps from 1D inversions

Conclusions

Over the Aspen block, VTEM has proven to be an effective solution to mapping the near-surface geology and detecting variations in the resistivity within it. The Tau constant maps provide useful information in mapping the locations of aquifers including previously unknown ones. The 1D resistivity inversion models are able to determine the depths of the top and bottoms of those aquifers. When compared against resistivity well-logs, the 1D model accurately resolves the resistivity variations with depth while containing information of the resistivity in the top 50 metres. The VTEM data contains the resistivity data in the near-surface and extends to depth where well-log and seismic results become more reliable.

Acknowledgements

The authors would like to thank Imperial Oil and Geotech Ltd. for allowing us to show the VTEM results over the Aspen block.

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