GeoConvention 2014
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Case studies from Fort Mc Murray, Horn River basin and Manitoba displaying advances in technology, new approach and updated interpretation of AEM data for unconventional hydrocarbons and groundwater mapping

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Summary

The use of Airborne Electromagnetics within the unconventional hydrocarbon world is slowly but surely on the rise, thanks also to latest advances in technology and software, smarter and more rigorous procedures being applied. The three case studies presented here report some of this development: the introduction of a new AEM system, the revisiting of existing data, the recognition of the importance of data calibration.

Introduction

Airborne Electromagnetics is starting to be recognized as an important methodology providing cost-effective, valuable information to the unconventional hydrocarbons industry. In some cases it can inform directly on the reservoir (when shallow enough), in others it can deliver vital information for groundwater modelling and/or geotechnical and engineering problems. In both cases, the level of accuracy needed to model these targets is significantly higher than what is required in the mineral exploration applications, from which AEM originated. New techniques, approaches and insight –a new focus- are being developed or adapted to these hydrocarbons and GW applications, as testified by this paper.

We present here three AEM case studies from across Canada. This first one present technological innovation and updated modelling from the Fort Mc Murray Oils sands areas. The second a revised modelling of existing data from the Horn River basin shale gas plays. The third highlights the importance of data accuracy and their consequences on derived hydrogeological models, from the Manitoba Spiritwood valley.

Theory and/or Method

Case study number 1: Fort McMurray MULTIPULSE^{TM} dataset

As described in detail by Chen et al., (2013), the MULTIPULSE^{TM} is a new system developed by Fugro Airborne Surveys aiming at combining both near surface resolution and deep penetration. It transmits multiple pulses within one half cycle. Typically the system is configured to transmit a high power half-sine pulse followed by a low power square (or trapezoid) pulse, creating a dual-pulse waveform of wider bandwidth capable of reaching both shallow and deep.

The data presented here was acquired and preprocessed by Fugro Airborne Surveys. It was then inverted using full non-linear Spatially Constrained Inversion (Viezzoli et al., 2008). Rather than modelling the response of the 2 waveforms separately and then merging them, we modelled the entire

Multipulse at once. This increases sensitivity and accuracy of the final results. The fact that we could fit the same resistivity model to both pulses at the same time proves that they are mutually well calibrated.

Case study number 2: Horn River basin SkyTEM dataset.

SkyTEM (Sorensen and Auken, 2004) is a dual moment system, combining near surface and deeper penetration. Originally developed for groundwater mapping, it has been successfully applied for this application in many projects around the world.

The data presented here had been originally acquired and processed by SkyTEM Aps, applying automated data editing and imaging techniques (Christensen, 2003).

We deploy the procedures and protocols for AEM data processing and inversions that were purposely designed for -and are enforced in- groundwater mapping in Denmark. The data was therefore reprocessed and modelled from scratch. The workflow applied entails

a) automated and manual editing of the raw navigation (e.g., altimeters, tilt meters) and EM data to remove artifacts that might arise from cultural features (coupling with metallic structures) or natural ones (e.g., canopy effects, surface water surfaces)
b) automated and manual assessment of noise and bias levels, to improve signal to noise ratio without smearing results, and to avoid artifacts in the models
c) if needed, application of calibration factors to the EM data
d) full non linear inversion (Viezzoli et al., 2008) of the EM data, based on exact (1D) solution, both multi (smooth) and few (blocky) layered
e) strong integration with GIS to evaluate inversion results, and refine step a).

Case study number 3: Manitoba VTEM dataset.

In order to improve the shallow imaging capability of the VTEM helicopter EM system, obtaining more accurate early-time data, a full waveform system was developed (Legault et al. 2012). During the fall 2011 it was tested over the Spiritwood Valley area. In particular, VTEM survey parallel 2 seismic profiles, one of which was also overlapped by an electrical tomography profile. Preliminary SCI inversion (Viezzoli et al., 2008) showed margin for improvement in the rendering of the shallowest layers. It was found that the description of the waveform used was not accurate. The modelling was therefore revisited redefining the waveform description of the VTEM data using the ERT as a reference model (Sapia et al., 2013). After this, a 3D voxel model of the VTEM survey data was realized and presented in this paper. At the same time, we present a 3D voxel model obtained with the original VTEM waveform in order to illustrate how the voxel models would have differed in terms of derived hydro\geological interpretation.

Examples

Case study number 1: Fort McMurray MULTIPULSE^TM dataset

The test was carried out at Fort McMurray, Alberta, where previous AEM surveys were flown by Fugro, providing data for comparison. The survey area is composed of mainly layers of sand and gravel, till and silty till near surface overlying the more-conductive Clearwater shales, as per Figure 1.

We present results from two lines. The first one (Figure 2) shows the comparison between the MULTIPULSE^TM SCI results and the RESOLVE^TM conductivity depth images (CDI). RESOLVE^TM is well know for its ability to resolve the near surface , and hence provides a good benchmark for assessing the improvement provided by the MULTIPULSE^TM . The near surface is resolved by the MULTIPULSE^TM with plenty of details, similar to those obtained by RESOLVE^TM. All the main formations are clearly rendered.

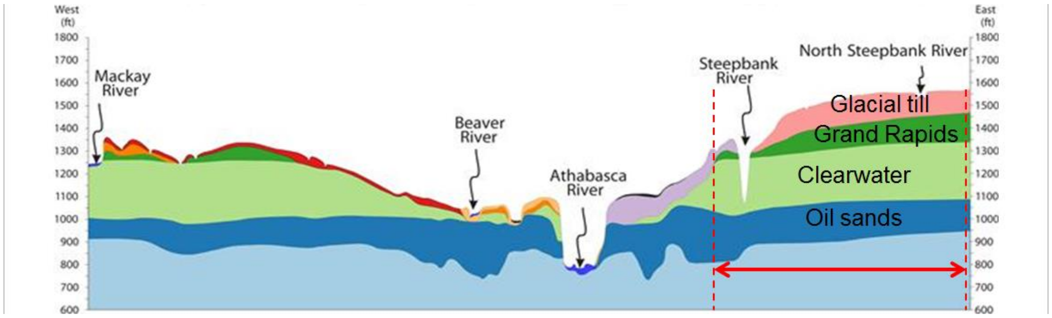

Figure 1. Conceptual geological model for the area. Readapted with permission from Chen et al., (2013)

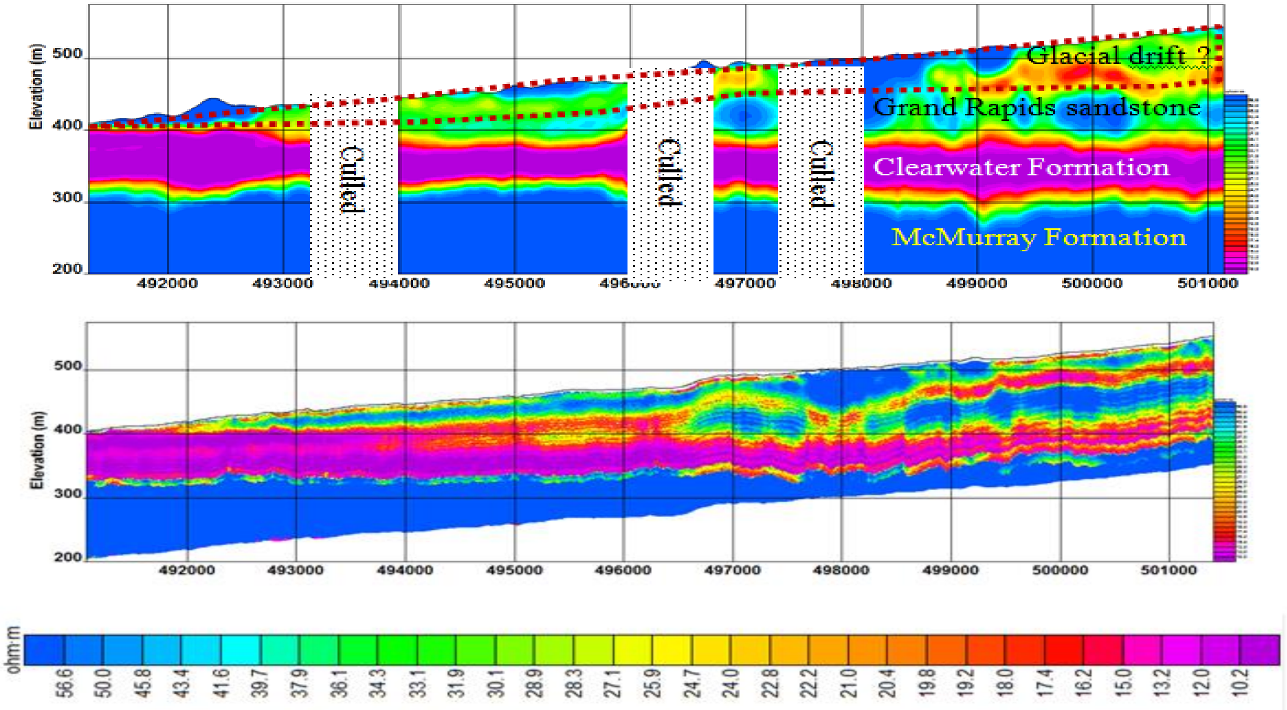

Figure 2. MULTIPULSE^{TM} SCI (top) versus RESOLVE^{TM} (bottom) CDI sections over coincident flight lines, Fort Mc Murray Oil sands area. Adapted with permission from Chen et al. (2013)

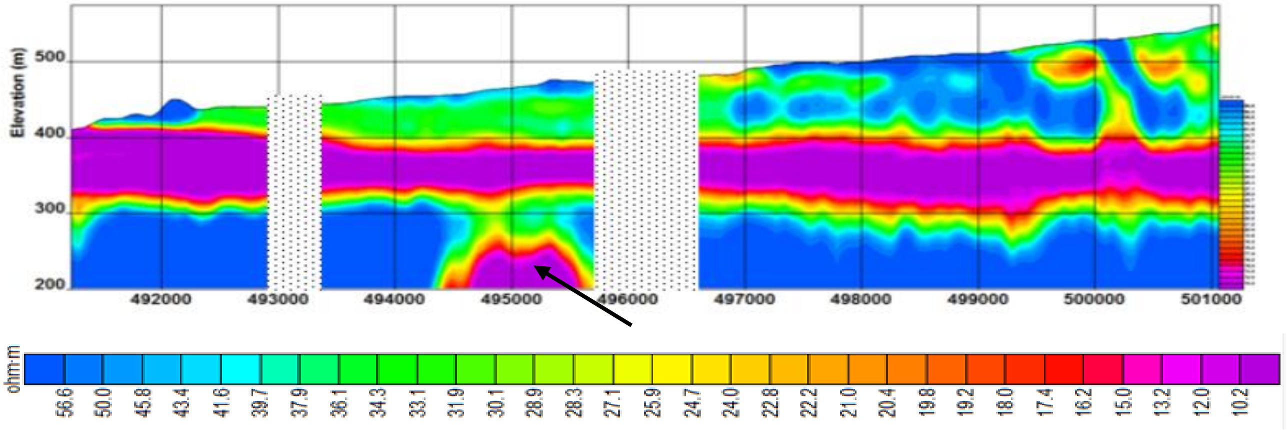

Figure 3. MULTIPULSE^{TM} SCI resistivity section, for another line of data. Notice the deep, well defined conductor within the Mc Murray formation (Oil sands), possibly saltwater seeped through underlying limestone. Adapted with permission from Chen et al. (2013)

In Figure 3, showing another line of the test survey, an interesting conductive feature is evident within the Oil sands. The feature is not due to cultural effects, and is confirmed also by other data. Potentially it could be caused by the saltwater seeped into the formation through the sinkholes in the underlying limestone. To this date, however, this tentative geological interpretation is not confirmed.

Case study number 2: Horn River basin SkyTEM dataset.

The results presented here are obtained re-processing and re-inverting a SkyTEM publicly available dataset, which had been acquired as part of a collaborative project aimed at undertaking baseline research on water resources in the Horn River Basin.

The simplified geological setting of the Horn River basin consists of a) Quaternary glacial deposits: thickness= 100-150 m (generally conductive) with b) Possible aquifers within buried glaciofluvial channels (sands and gravels): conductive response due to highly mineralized water (more than 5 g/l ?), c) Dunvegan sandstones-conglomerates: resistive lenses, d) Buckinghorse shales: conductive, e) Debolt/Rundle aquifer: limestones (too deep for AEM).

A tentative, comparison between the revised geophysical section and available schematic geological section (Petrel Roberson, 2010) is shown in Figure 4.

Notice the good resolution of the conductive aquifers, saturated by mineralized waters, at the bottom of the buried fluvio-glacial valleys (clearly imaged on plane by the resistivity slices in elevation), and the better definition of the Dunvegan aquifer, characterized by resistivity of 30-40 ohm-m.

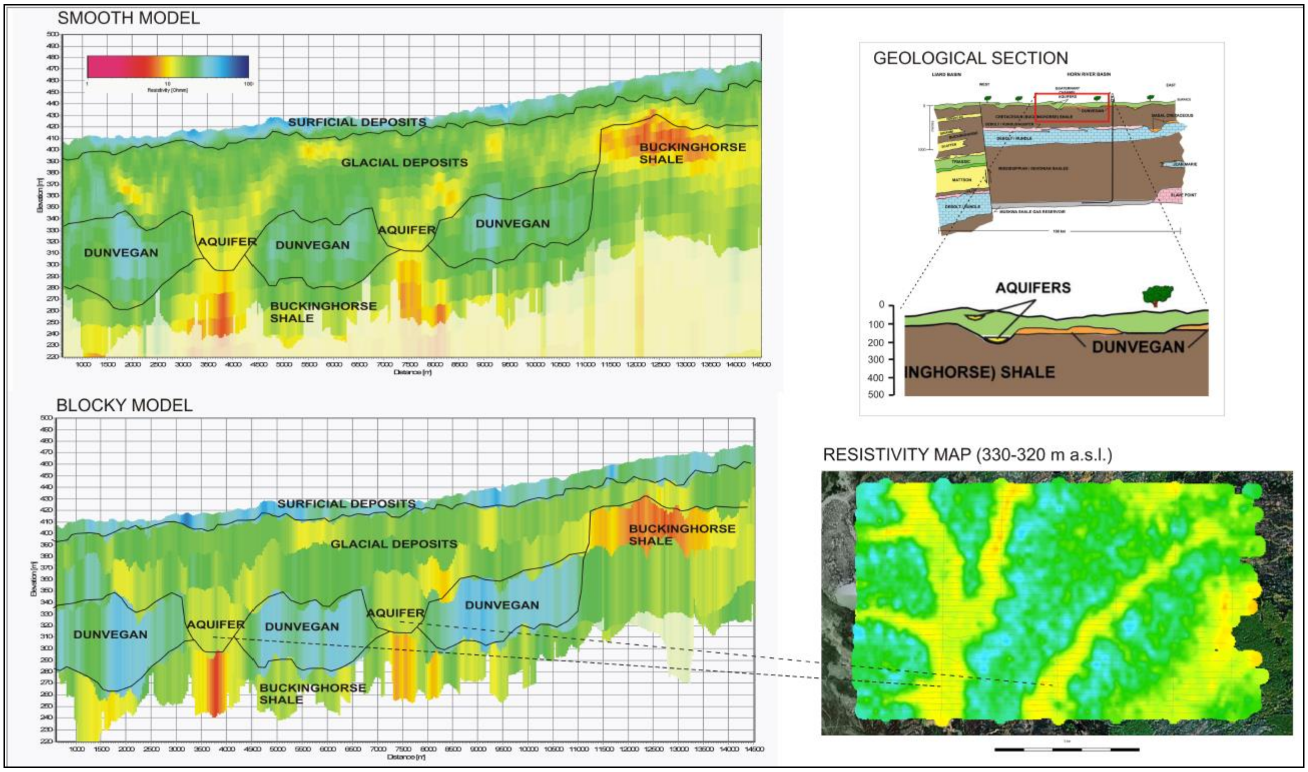

Figure 4: Tentative comparison between geophysics and geological information present in the area (adapted from Petrel Robertson, 2010).

Case study number 3: Manitoba VTEM dataset.

A voxel approach allows a quantitative understanding of the hydrogeological setting of the area, and it can be further used to estimate the aquifers volumes (potential amount of groundwater resources) as well as hydrogeological flow model. The voxel discretization is 100 × 100 m in the X–Y direction and 5 m in the Z direction. The 3-D modelling was carried out in two steps: first, 3D surfaces were previously interpreted and interpolated based on AEM (VTEM) resistivity grids and, subsequently, those surfaces were used to constrain the 3-D lithological model. Since different resistivity values are due to variations in filling materials (higher resistivity for coarse-grained materials and lower resistivity for finer-clayey ones), each lithology were interpreted based on picked resistivity values directly from the VTEM resistivity grids. Figure 5 reports the geological models derived from the original and the revisited VTEM waveform, over the same volume of the subsurface.

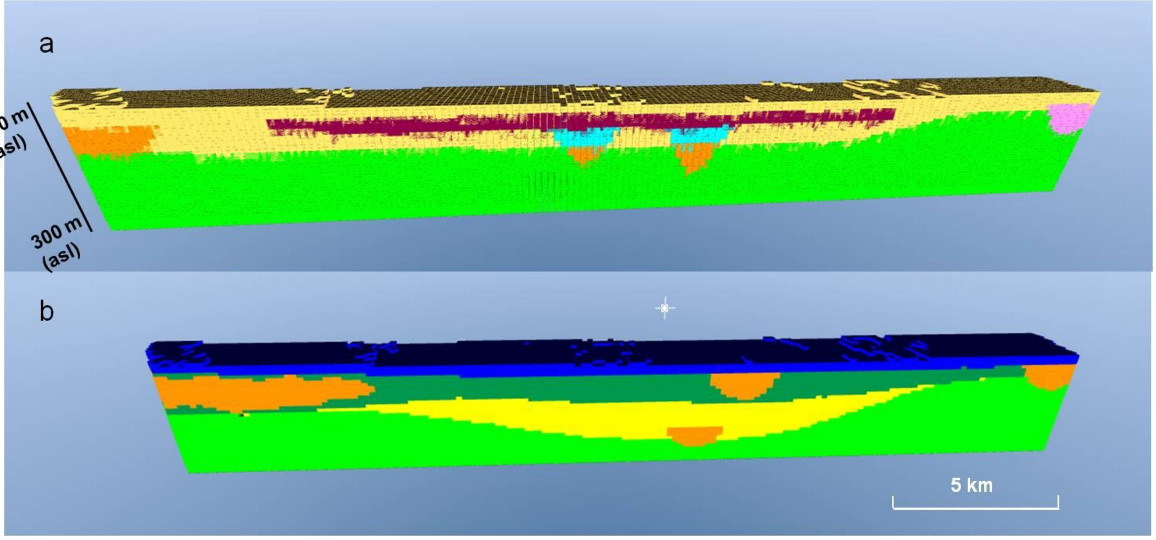

Figure 5. Voxel based geological models derived from ERT-based revisited VTEM waveform (top) versus preliminary waveform (bottom). Different lithologies are rendered with different colors (e.g., sandy aquifers cyan, gravel aquifers orange, shale bedrock green, clay blue and purple).

The differences in the geological models are evident. The top model matches all available ancillary information (ERT, seismic, boreholes, priori geological knowledge- and the AEM data). The bottom version is inaccurate for many reasons, including a) artificial ubiquitous shallow clay cap cover that would prevent surficial recharge, shows, b) erroneous depth estimate of buried valleys, c) overestimation of aquifers porosity. Extraction or management of the GW resources based on this model would most likely bring unwelcomed consequences.

Conclusions

Ongoing development within the AEM world is increasing the value, relevance and applicability of this methodology with the unconventional hydrocarbons applications. Improvements or revisiting of hardware, modelling, procedures deployed for the task and interpretation, they are all contributing towards this result.

Acknowledgements

We would like to thank: a) CGG/Fugro Airborne Surveys for the permission to show the MULTIPULSE^{TM} data, the support in the work and interpretation, b) Geoscience BC for the interest in the Horn River Basin work, and SkyTEM Aps for providing the raw data, c) Geotech for providing the Spiritwood data, the Canadian Geological Survey and GEUS for the cooperation in the interpretation.

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