Three-dimensional magnetotelluric inversion of large data sets: Case study of Pasfield Lake (Saskatchewan) for mineral exploration

*Sophie Hautot *, Imagir, David Goldak, EMpulse Geophysics, Pascal Tarits, Imagir/IUEM, and Peter Kosteniuk, Kosteniuk Consulting*

Summary

We present a case study of three-dimensional inversion of a large set of transient audio magnetotelluric (~500 sites) data acquired in the Athabasca Basin of northern Saskatchewan as part of an uranium exploration program at Pasfield Lake along seven lines. Previous studies revealed a complex structural setting near the line extremities with a large conductive uplifted block in central portions of the lines. Previous 2D and 2.5D inversion of the AMT data have been carried out along the lines to capture the most salient shallow geological features. Here, we applied a full 3D inversion to recover the deep part of the geological structures. The preliminary inversion results reveal shallow features in better agreement with 3D potential field data than previously obtained.

Introduction

Transient audio magnetotelluric (TAMT) data were collected in the proterozoic Athabasca Basin of northern Saskatchewan (Figure 1), at Pasfield Lake, as part of a uranium exploration program. The Athabasca basin consist of sediments of 800-1000 m thickness overlying the crystalline basement comprised of felsic gneiss, metavolcanic rocks and graphitic pelitic shist (Leppin and Goldack, 2005). Basement structures are usually near vertical due to the intense deformation that occurred during the Hudsonian orogeny. EM techniques are used to map electrical conductors in the basement, that are usually associated with graphitic shist, favorable to uranium mineralization. Airborne total field magnetic and airborne gravity gradient surveys evidenced an uplifted basement under Pasfield Lake with a roughly circular anomaly, possibly the consequence of an explosive event such as a meteorite impact or a volcanic intrusive (Goldak et al., 2010).

The TAMT survey was carried out in order image subsurface structure down to the basement. Five-hundred and fourty five were collected on seven parallel lines, with a station spacing of 125-250 m (Figure 2). The distance between the lines is approximately 1.5 km. The frequency range is 5-31000 Hz (Goldak et al., 2010). The data indicate a high level of structural complexity.

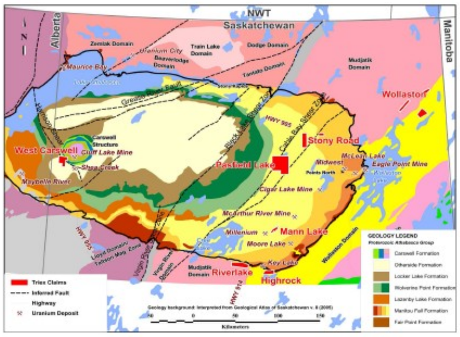

Figure 1: Structural map of the Athabasca Basin. After Goldak et al. (2010).

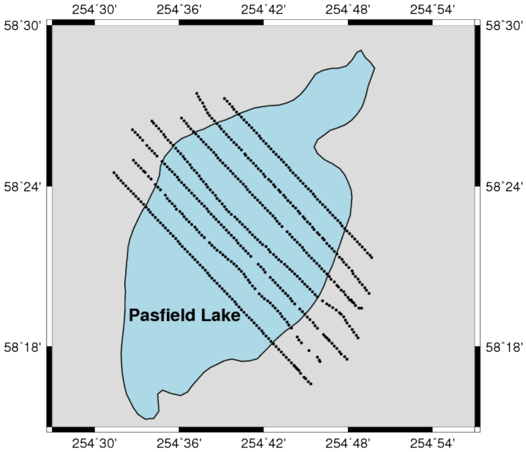

Figure 2: Location of the seven TAMT profiles carried out at Pasfield Lake. Black dot: TAMT site.

The data set was previously inverted using 2.5D with the WSINV3DMT code (Siripunvaraporn et al., 2005). Because of limited capacities to handle large data set at that

GEM Beijing 2011: International Workshop on Gravity, Electrical & Magnetic Methods and Their Applications
Beijing, China. October 10-13, 2011.

time, each line was inverted individually with the 3D inversion code and the results wee combined in order to provide a 3D model of the surveyed area (Goldak et al., 2010). The results were in good agreement with drill holes information and the potential field data. Most of the conductive anomalies could be associated with zones of brecciation and fracturing but also with graphitic pelites in the uplifted basement. However, the scale of some of the geological features encompasses the distance between lines, preventing the 2.5D models to recover correctly the structures. Furthermore, even at depth less than the distance between profiles, large scale 3D structures could be biased by the 2.5D inversion. Full 3D inversion of a data set distributed all over the surveyed area is therefore needed.

The 3D Inversion Technique

In general, 3D MT inversion methods are based on numerical solutions of the Maxwell equations with techniques involving a very large number of parameters, sometimes with the computation of the Jacobian matrix, and strong smoothness constraints (eg: Newman and Alumbaugh, 2000; Mackie et al., 2001; Siripunvaraporn et al., 2005). These methods perform well but require huge amount of computer memory.

Here, we developed a 3D inversion code that allows to invert large sets of MT sites with a number of parameters commensurate with the number of data. Our inversion method is based on a downhill descent technique. An iterative procedure was developed to minimize a misfit function between the observed data and the model response using a non-linear steepest gradient method with a regularization term (Hautot et al., 2000). The data is the MT tensor (the four complex components) at all available frequencies. The code was recently implemented to include also the tipper when available. The 3-D model is parameterized by blocks in the x,y,z directions. The size and the initial meshing of the 3D volume are determined according to the MT sites distribution and the depth of investigation of the data. The 3D grid used for the inversion is different from the grid used for the forward calculation. In the uppermost layers of the model, the size of the blocks increases with the distance from the MT sites. In the deeper layers, the size of the blocks is larger in order to take into account the resolution decreasing of MT data with depth (Hautot and Tarits, 2009). The model parameters for inversion are the resistivity of each block. The gradient with respect to the parameters is not calculated but at the cost of a large number of calls to the solver (about 10 times the number of parameters). The inversion starts with a homogeneous half space although this is not required. Once a good agreement is obtained between the 3D model response and the data, a regularization factor is added to the error function and a new solution is searched again. The regularizing term controls the resistivity contrast between blocks and is the sum over all vertical and horizontal squared differences in the logarithm of the resistivity between two adjacent blocks. The grid may be updated during the inversion. It may be refined around sites that show large misfits and enlarged in areas or between layers that are not well resolved by the data. The minimization stops when excess of regularization makes the misfit increase.

3D Inversion Results

We applied our 3D inversion code to the TAMT Lake Pasfield data set in order to test its capability when dealing with a large data set collected in a complex structural environment, but also to use advantage of a comparison with independent 2.5D results, obtained here with the WSINV3DMT code (Goldak et al. 2010).

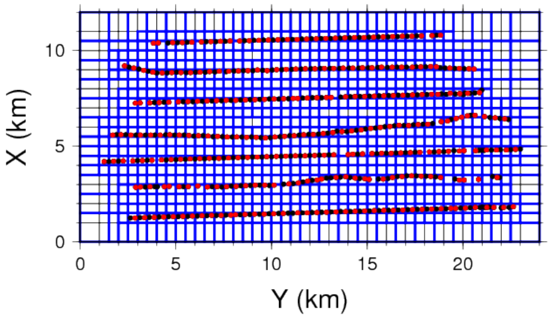

Figure 3: Horizontal grid used for the full 3D inversion. The thin black line show the grid used for the forward calculation (here, the minimum size is 500 m). The blue lines show the grid used for the inversion in the uppermost layers. Cells that are not in the neighboring of TAMT sites are grouped together. Black dots: TAMT sites. Red dots: TAMT sites automatically selected for the inversion of this 3D grid.

For a full 3D inversion of the 545 MT sites, with a mesh size of 250 m, a grid of 41x90x11 cells is generated. The number of calls to the forward solver required to get a satisfying result was too long to present results in this abstract. Hence meanwhile, we generated a grid with a minimum mesh size of 500 m. A grid of 22x46x11 cells is generated and a new data set of 272 MT sites, with a spacing of about 500 m is automatically selected for the inversion (Figure 3). The grid is orientated so that the y direction is parallel to the lines. The grid encompasses all the lines. The inversion and the forward calculation grids are shown in Figure 3. The size of the grid for the forward calculation is 11132 cells while there are 8762 unknown for the inversion. The initial model is a 200 ohm-m homogeneous half-space. The data are the four components of the MT tensor.

As an illustration of our preliminary results, Figure 4 depicts the plan view of the layer 270-430 m. Compared to the results from 2.5D inversion (Figure 5), the NE-SW trend induced by the inversion per profile has disappeared. The limit of the circular conductive structure observed in the 3D MT model (Figure 4) is in better agreement with the potential field anomaly (Goldak et al., 2010) than in the 2.5D model (Figure 5).

Conclusions

The complete elimination by the 3D inversion of the biased structural trend generated by the inversion of each profile individually is an encouraging result. The current work is to extend the data set to the full number of sites, and to include also the tipper. Our algorithm is quite sensitive to the data quality. Editing the data set is mandatory to obtain fast and accurate results which needs to be done for the rest of the sites.

Acknowledgments

We thank Canterra Minerals Corporation and Thelon Ventures Ltd. for agreeing to release this data for the purpose of 3D inversion and for presentation.

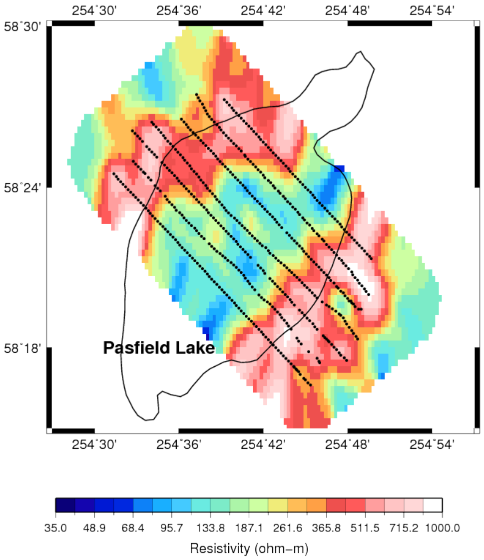

Figure 4: Plan view of the 3D resistivity model between 270-430 m depth.

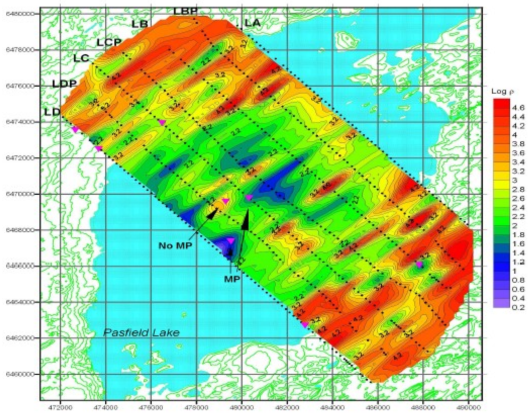

Figure 5: 300 m plan view obtained from 2.5D inversion (Goldak et al., 2010)

References

Goldak, D., K. Witherly, and P. Kosteniuk, 2010, Three-dimensional inversion of transient magnetotelluric data at Pasfield Lake, Saskatchewan: 80th Annual International Meeting, SEG, Expanded Abstracts, **29**, 859-863.

Hautot, S., P. Tarits, K. Whaler, B. Le Gall, J.-J. Tiercelin, and C. Le Turdu, 2000, The deep structure of the Baringo Rift basin (central Kenya) from 3-D magnetotelluric imaging : Implications for rift evolution: Journal of Geophysical Research, **105**, 23493-23518.

Hautot, S., and P. Tarits, 2009, A new coarse-to-fine 3D magnetotelluric inversion method: Application to field data for hydrocarbon exploration: 71st EAGE Conference and Exhibition, Extended Abstracts.

Leppin, M., and D. Goldak, 2005, Mapping deep sandstone alteration and basement conductors utilizing audio magnetotellurics: Exploration for uranium in the Virgin River area, Athabasca Basin, Saskatchewan, Canada: 75th Annual International Meeting, SEG, Expanded Abstracts, **24**, 591-594.

Mackie, R.L., W. Rodi, and M.D. Watts: 2001, 3-D Magnetotelluric Inversion for Resource Exploration: 71st Annual International Meeting, SEG, **20**, 1501–1504.

Newman, G.A, and Alumbaugh, D.L., 2000, Three-dimensional magnetotelluric inversion using non-linear conjugate gradients: Geophysical Journal International, **140**, 410-424.

Siripunvaraporn, W., G. Egbert, Y. Lenbury, and M. Uyeshima, 2005, Three-dimensional magnetotelluric inversion: data-space method: Physics of the Earth and Planetary Interiors, **150**, 3-14.