Self-organizing maps for pseudo-lithological classification of 3D airborne electromagnetic, gravity gradiometry and magnetic inversions

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SUMMARY

To improve mineral exploration success, there is an accepted need to increase the "discovery space" by exploring under cover and to greater depths using 3D geological modelling supported by multiple 3D geophysical inversions. To facilitate this approach, multi-sensor airborne platforms capable of simultaneously measuring electromagnetic, gravity, and magnetic data are now being deployed. The availability of data from such systems poses a significant challenge to the exploration geophysicist: How do you generate a shared earth model that satisfies all data? We address this with a case study from the Reid-Mahaffy test site in Ontario, demonstrating how multiple 3D inversions of MEGATEM time-domain electromagnetic, FALCON gravity gradiometry and TMI data can be analysed by the self-organizing maps (SOM) data mining approach to produce 3D pseudo-lithological models. The results of our analyses are shown to be in agreement with the known geology of the Reid-Mahaffy test site.

Key words: SOM, 3D, inversion, AEM, MEGATEM, FALCON, TMI.

INTRODUCTION

Airborne surveys often cover hundreds to thousands of square kilometres and typically contain hundreds to thousands of line kilometres of data with measurement locations every few meters. Airborne systems are now being deployed with multiple sensors (e.g., Rajagopalan et al., 2007). For example, Fugro Airborne Surveys now operate multi-sensor airborne platforms that simultaneously measure GPS position, LIDAR, radar altimetry, digital video, total magnetic intensity (TMI), gamma ray spectroscopy, FALCON gravity gradiometry, and electromagnetics (MEGATEM, TEMPEST, RESOLVE) (Figure 1). Because of the vast volumes of geophysical data produced from such surveys, most of it currently is only qualitatively analysed. This situation is a consequence of the historic lack of "inversion capacity", as geophysicists try to use existing algorithms to invert and interpret entire multi-sensor surveys with sufficient resolution and within a time-frame so as to influence exploration decisions.

In this paper, we rely exclusively on TechnoImaging's suite of large-scale 3D inversion methods for mega-cell airborne electromagnetic (AEM) inversion (e.g., Cox et al., 2010) and giga-cell potential field inversion (e.g., Wilson et al., 2011). With the availability of truly large-scale 3D inversions that enable entire surveys to be inverted to deposit-scale resolution, there is a consequent need to develop workflows for the integrated analysis and interpretation of the subsequent multiple 3D models. This study has used self-organizing maps (SOM - Kohonen, 2001; Fraser and Dickson, 2007) as a data driven computational tool to facilitate the identification of subtle correlations, trends and relationships indicative of geology, mineralization, alteration and weathering within and between the voxel elements of such multiple 3D models. Because SOM is based on the principles of vector quantization and measures of vector similarity, disparate and complex inputs can be analyzed in an exploratory fashion, without the need for *a priori* knowledge, training data or subjective inputs, which are requisite for other supervised analytical approaches (e.g., Weights-of-Evidence: Bonham-Carter et al., 1989; Fuzzy Logic: Porwal et al., 2003).

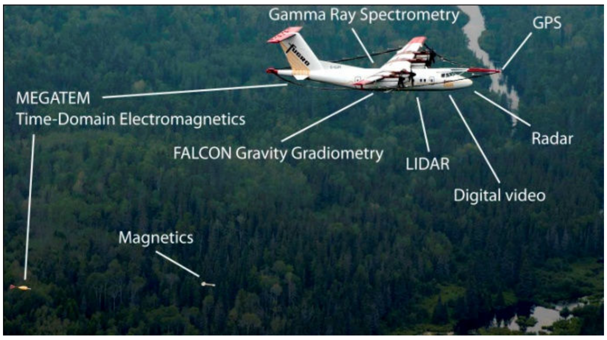

Figure 1. *Multi-sensor airborne platform operated by Fugro Airborne Surveys.*

A SOM analysis typically results in a 2D rectilinear "self organized map" that is representative of the input, multi-dimensional (nD - multi-sensor) data set. Input samples are assigned to best-matching vectors, which are defined on the basis that they represent the input data's structure and complexity. These best-matching vectors also form the nodes on the 2D map where they are arranged so that they maintain as best as possible, their nD relationships. Hence, it is possible to further group or cluster the nodes (and their representative input samples) to understand the natural domains or populations within the data set. In this study we used a Davies-Bouldin diagnostic (Davies and Bouldin, 1979) to determine an optimum number of natural groupings amongst the SOM nodes before identifying those clusters using a K-means algorithm. Ultimately, voxels are coloured according to the cluster to which their best-matching vectors (node) are assigned. The spatial coherence and distribution of the resulting domains can then have pseudo-geological significance. Previously, Fraser et al., (2008) used such an approach to identify pseudo-geological domains that are not necessarily obvious on individual, typically smooth petrophysical volumes resulting from inversion. The current study uses multiple inversion volumes as inputs over an established geophysical test-site to test and further demonstrate the SOM-based, data-domaining approach.

REID-MAHAFFY TEST SITE

Terranes overlain by conductive near-surface geology effectively distort if not mask the AEM response of the more resistive basement and deeper conductive targets that contain potential economic geology. For example, AEM-led exploration for Archean bedrock conductors in Ontario (e.g., Kidd Creek analogues in the Abitibi greenstone belt) is often hindered by a conductive near-surface layer. The Reid-Mahaffy area is representative of Abitibi Archean terranes in that it has a moderately conductive overburden overlying a resistive basement containing a number of conductive graphites and other bedrock conductors. At just 90 line km, the test provides a good opportunity to test our 3D inversions and SOM analysis at deposit-scale resolution.

Reid-Mahaffy is located in the Abitibi Subprovince, immediately east of the Mattagami River Fault. The area is underlain by Archean (~2.7 Ba) mafic-to-intermediate metavolcanic rocks in the south, and felsic-to-intermediate metavolcanic rocks in the north, with a roughly EW-striking stratigraphy. Narrow horizons of chemical metasedimentary rocks and felsic metavolcanic rocks have been mapped, including a mafic-to-ultramafic intrusive suite to the southeast (Figure 2). NNW-striking Proterozoic diabase dikes are evident from the aeromagnetic data. Copper and lead-zinc vein/replacement and stratabound, volcanic-hosted massive sulphide (VMS) mineralization occur in the immediate vicinity. For example, the world-class Kidd Creek VMS deposit occurs within the Timmins area.

First, we performed a 3D joint inversion of the inline and vertical components of the MEGATEM II dB/dt data as per Cox et al. (2010) (Figures 3 and 4). Second, we performed a 3D inversion of the IGRF-reduced total magnetic intensity (TMI) data as per Wilson et al. (2011) (Figure 5). Third, we performed a 3D joint inversion of all 2.67 g/cm^3 terrane corrected gravity gradient components as delivered by FALCON as per Wilson et al. (2011) (Figure 6). As shown in Figures 3 and 4, the 3D MEGATEM inversions recovered a 3D conductivity model as per our expectations. That is, sub-vertical basement conductors in a resistive host beneath a variable conductive overburden. At Reid-Mahaffy, the volcanic host rocks are very resistive and can't be discriminated using electromagnetic methods. As shown in Figure 5, the diabase dykes have been recovered quite well. These dykes have no conductivity contrast with the host, which is why they don't appear in the MEGATEM inversion. In Figure 6, basement structures of subtle density contrasts are identified from the FALCON inversion that are not apparent in either the MEGATEM nor TMI inversions.

The challenge for an interpreter is to now reconcile these multiple 3D inversions to produce a self-consistent 3D geological model. In response, we applied SOM to the 3D conductivity, susceptibility and density model volumes and segmented the data into eight SOM-based clusters (Figures 7 to 9). As shown in Figures 7 to 9, the 3D model with voxels coloured by their SOM cluster colour was coherent and considered indicative of geology.

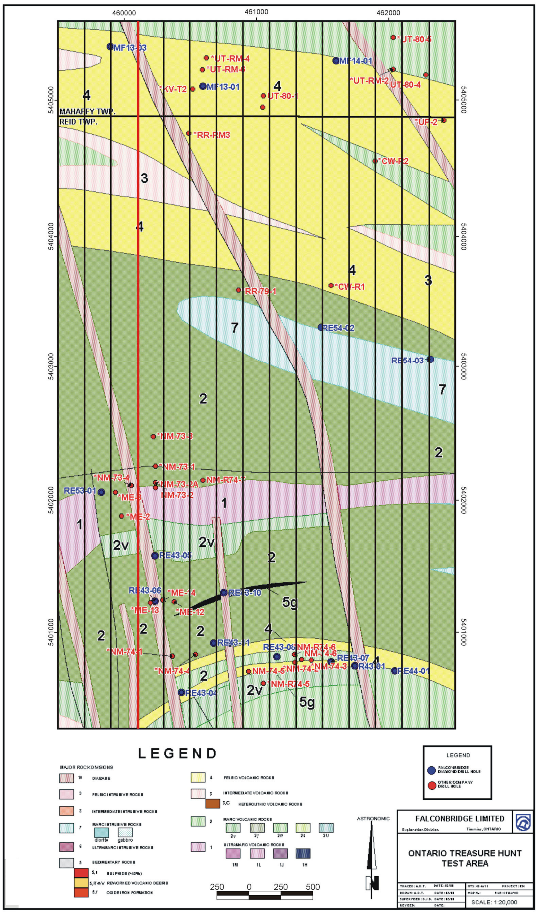

Figure 2. *Surface geology of the Reid-Mahaffy test site. Line L50 is shown in red.*

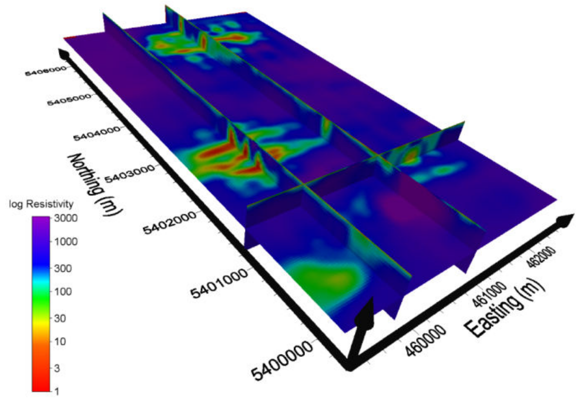

Figure 3. *Perspective of the 3D resistivity model obtained from 3D inversion of MEGATEM II dB/dt data. Sub-vertical bedrock conductors beneath line L50 can clearly be seen.*

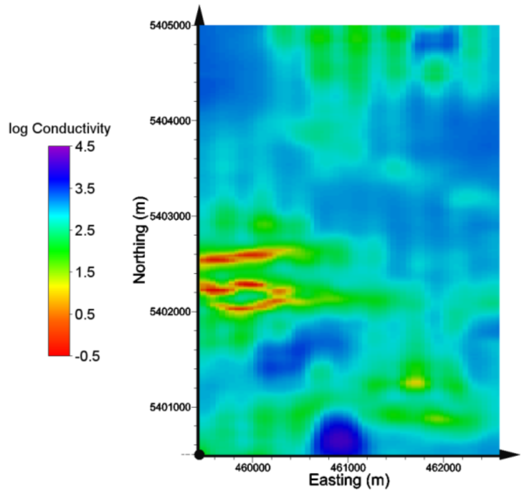

Figure 4. *Horizontal cross-section of conductivity obtained from 3D inversion of MEGATEM II dB/dt data. The sub-vertical bedrock conductors beneath line L50 can clearly be seen.*

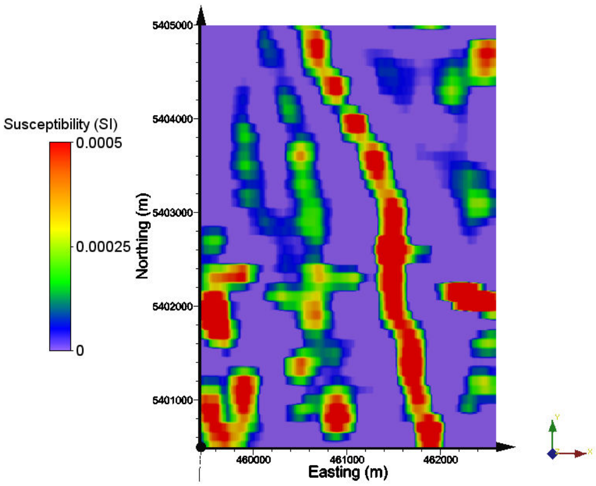

Figure 5. *Horizontal cross-section of magnetic susceptibility obtained from 3D inversion of total magnetic intensity (TMI) data. The diabase dykes are clearly seen in these results.*

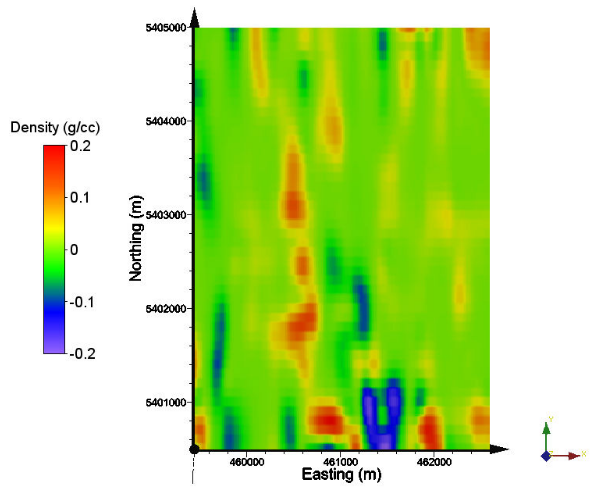

Figure 6. *Horizontal cross-section of density contrast obtained from 3D inversion of multiple tensor component FALCON gravity data.*

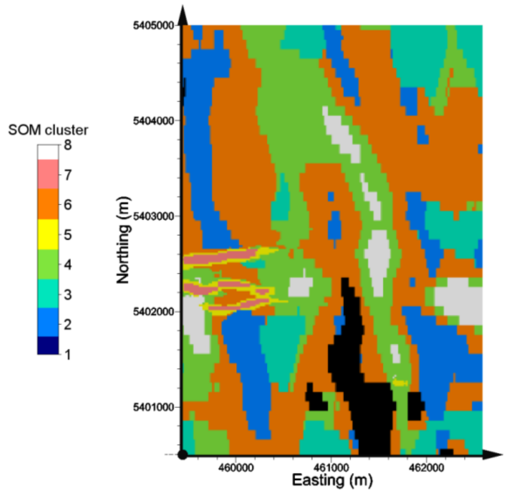

Figure 7. *Horizontal cross-section of pseudo-lithological domains obtained from self-organized map of 3D conductivity, magnetic susceptibility and density models.*

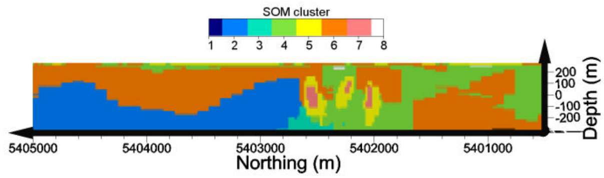

Figure 8. *Vertical cross-section along line L50 of pseudo-lithological domains obtained from self-organized map of 3D conductivity, magnetic susceptibility and density models.*

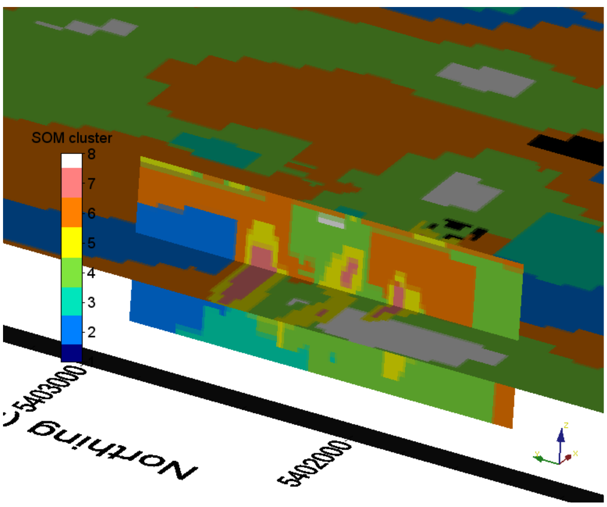

Figure 9. *3D perspective view of the pseudo-lithological domains obtained from self-organized map of 3D conductivity, magnetic susceptibility and density models. Vertical cross section for line L50 is shown.*

CONCLUSIONS

Multi-sensor airborne geophysical surveys can produce vast amounts of data and computational methods are needed to ensure that such data are analyzed and interpreted in a timely, quantitative fashion. In this study we have demonstrated how a self-organizing maps (SOM) domaining approach can be used to produce 3D pseudo-lithological models from independent 3D inversions of airborne electromagnetic, gravity gradiometry, and magnetic data. To emphasize the robust nature of the approach, neither the 3D inversions, nor the SOM analysis require the use of any *a priori* information, yet we are able to produce 3D pseudo-lithological models of the Reid-Mahaffy area that compare well with the known geology as inferred from drilling. The SOM-based domaining approach appears to be a valuable computational tool to assist in the integrated analysis and interpretation of petrophysical voxel volumes, which bodes well for future 3D integrated interpretations of 3D petrophysical volumes resulting from multi-sensor airborne geophysical surveys.

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