3D Modelling of magnetotelluric data acquired along the Youanmi deep seismic reflection transects in the Yilgarn, Western Australia

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SUMMARY

Geoscience Australia has been acquiring both broadband and long-period magnetotelluric (MT) data over the last few years along deep seismic reflection survey lines across Australia, often in collaboration with the States/Territory geological surveys and the University of Adelaide.

Recently, new three-dimensional (3D) inversion code has become available from Oregon State University. This code is parallelised and has been compiled on the NCI supercomputer at the Australian National University.

Much of the structure of the Earth in the regions of the seismic surveys is complex and 3D, and MT data acquired along profiles in such regions are better imaged by using 3D inversion code rather than 1D or 2D code.

Preliminary conductivity models produced from the Youanmi MT survey in Western Australia correlate well with interpreted seismic structures and contain more geological information than previous 2D models. GA has commenced a program to re-model with the new code MT data previously acquired to provide more robust information on the conductivity structure of the shallow to deep Earth in the vicinity of the seismic transects.

Key words: magnetotelluric, conductivity, resistivity, seismic, 3D, modelling

INTRODUCTION

In 2008 Geoscience Australia (GA) commenced a program of modern magnetotelluric data acquisition along deep seismic reflection transects in collaboration with the States/Territory geological surveys and the University of Adelaide. Initially this acquisition was funded by the Australian Government's Onshore Energy Security Program, which finished in 2011 (Figure 1).

During May to August 2010 MT data were acquired by GA along 690 km of the Youanmi deep seismic reflection traverses in the Yilgarn region of Western Australia (Milligan, 2012; Milligan *et al*., 2013). This acquisition was also funded by the Geological Survey of Western Australia in a collaborative project (Figure 2).

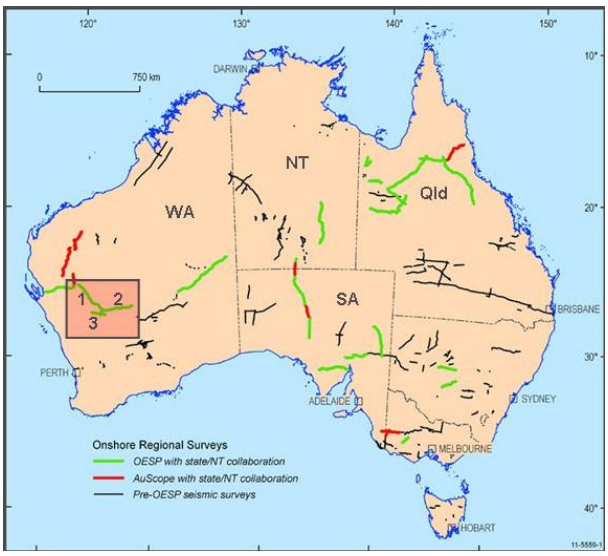

Figure 1. Location of the three Youanmi seismic and MT traverses, YU1, YU2, YU3, in Western Australia. GA has also acquired MT data along the green traverses in WA, SA, NT and Qld.

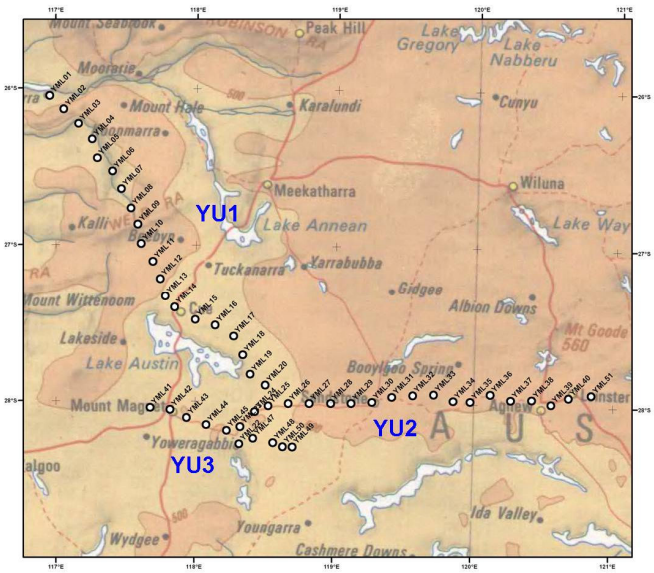

Figure 2. Long-period MT sites spaced 15 km apart along the three traverses. Broadband data infilled these sites with a spacing of 5 km.

The aim of all these MT surveys was to produce information about the electrical conductivity structure of the crust and upper mantle to complement information obtained from deep seismic reflection, gravity, magnetic and geological data. Together, these data provide new knowledge of the crustal architecture, rock properties and geodynamics of the regions, important for helping to determine the potential for both mineral and energy resources.

The MT method uses natural time variations of the geomagnetic field over a range of frequencies to provide electrical conductivity information at varying depths within the Earth by measurement of induced electric currents and magnetic fields (Chave and Jones, 2012). Recently acquired 3D inversion software is producing more realistic images of the subsurface electrical conductivity structure from such data than has been possible in complex geological regions with 2D code. Examples of inversions of the Youanmi MT data provide evidence of this, and model results are compared with seismic interpretations and other geophysical data.

METHOD

MT measurements are made at field sites by recording two orthogonal horizontal components of the geomagnetic field and the electric field. The horizontal magnetic variations are the source signal and the electric components are the induced Earth signal. Vertical magnetic field variations are also acquired as an induced component (Chave and Jones, 2012).

For the Youanmi survey, two sets of instruments were deployed; broadband measurements were made at sites spaced 5 km apart, while long-period three-component measurements were made at sites spaced 15 km apart (Figure 2).

Raw MT time-series data recorded at each site were processed in the frequency domain using the Bounded Influence Remote Reference Processing (BIRRP) robust algorithm of Chave *et al*. (1987) and Chave and Thomson (2004) and incorporating remote referencing with data from other sites wherever possible. The resulting spectral estimates were combined into complex frequency-dependent elements of the MT impedance tensor.

The impedance values are the primary input to modelling programs after analysis of the data, which includes study of the distortion and dimensionality. Attempts are usually made to model MT data acquired along profiles in 1D and 2D by removal of individual frequency impedance tensor estimates analysed to be not 1D or 2D. Phase tensor analysis of the Youanmi data indicates that they are mostly 3D (Caldwell *et al*., 2004). If data are 3D, then such modelling attempts will not produce realistic results, and 3D modelling code must be used, even if the data are acquired along profiles (e.g. Patro and Egbert, 2011). This has been undertaken for the Youanmi MT data using ModEM code (Egbert and Kelbert, 2012).

ModEM has 2D and 3D electromagnetic inversion components written in Fortran 95 and parallelised using MPI controls so that it executes efficiently on large cluster computer systems. GA has compiled the code on the Vayu Sun Constellation Cluster at the National Computational Infrastructure (NCI) Facility, which has 1492 nodes each containing two quad-core CPUs. To make efficient use of this system, local PC-based software has been written to pre-process the data into the required formats and generate a finite difference model mesh. Output models are manipulated with local software to provide visualisations in either Gocad™ or ArcGIS™ formats.

3D meshes used in inversion runs are tailored to the spatial locations of the data so that each MT site is located within its own mesh cell (Figure 3). The input data consists of both broadband and long-period values, with the broadband values culled so that there is no frequency overlap with the long-period values. Conservative error estimates are applied, and frequencies with significant error outliers are removed. The mesh is well-padded with extra cells around the edges to avoid edge-effects in the models.

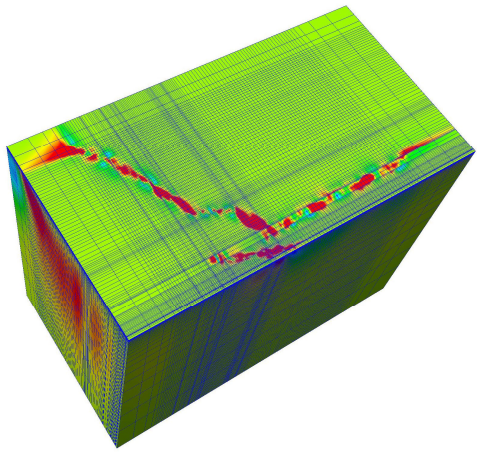

Figure 3. An example 3D finite-difference model mesh for the Youanmi MT data.

To conveniently display model data in Gocad or ArcGIS format, values within the model volume are interpolated onto vertical Gocad Sgrid meshes computed at the common depth point (CDP) locations of the seismic profiles. This ensures that the best model information from directly beneath the MT sites is displayed (Figure 4).

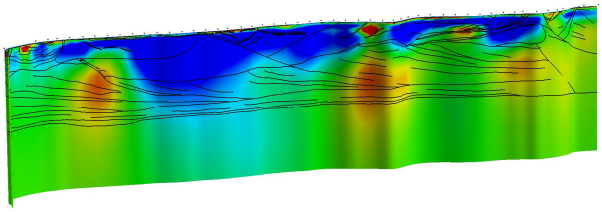

Figure 4. An example conductivity image of data extracted directly beneath the YU2 transect from the 3D model volume and overlaid with the seismic interpretation.

Seismic images and interpretations and magnetic and gravity images are also displayed in the Gocad 3D environment, and this enables an exact comparison of the different data types.

RESULTS

Example inversion results and the corresponding seismic image for line YU2 are shown in Figure 5, both overlaid with the seismic interpretation linework. The conductivity features broadly follow the major trends in the seismic interpretation with the upper crustal layers and granite plutons generally

resistive. The deepening trend of the upper crustal layer to the west corresponds with thickening of the resistive layer until an abrupt change in the depth of the lower crustal layer and thinning of the upper crustal layer in the west where the Windimurra Complex resides. Induction arrows derived from the vertical magnetic field transfer functions, but not shown here, also support this hypothesis.

The central resistive layer between sites YMB077 and YMB094 may represent the old heart of the Archaean Craton. In the east the gradient in conductivity follows well with the bottom of the mid-crustal layer, which contains within, and also at the bottom, mafic sill material. Mafic dykes at site YMB106 are conductive at about 8 km depth. The non-conductive nature of the granites is emphasized at about 10 km depth between sites YMB108 and YMB112 in the vicinity of the Leinster anticlines. The surface mafics at sites YMB113 and YMB114 have a more conductive expression, and generally east of here the region is more conductive to the Moho.

CONCLUSIONS

Broadband and long-period MT data have been acquired along the three Youanmi deep seismic reflection transects, and the data have been processed in the frequency domain to produce full complex impedance tensor estimates and magnetic vertical-field transfer functions.

Phase analysis of the impedance tensor estimates shows that the data mostly represent three-dimensional earth conductivity distributions; therefore, one- and two-dimensional modelling is unlikely to be successful. Three-dimensional modelling code, ModEM, has recently been made available to GA, and this has been trialled on the Youanmi data to produce preliminary volumes of conductivity from which the values can be extracted along vertical sections defined from the seismic transect CDP positions.

Conductivity values imaged along the three transects show features that correspond with interpretations of the seismic section images, thus adding confidence to the reliability of the modelling. Induction arrows that change orientation from west to east at shorter periods correspond with a resistive region of the crust along line YU2 which may represent the resistive core of the Archaean craton.

It should be noted that the models presented are preliminary, and that the model space requires further investigation. Inversion modelling with no geological constraints is inherently non-unique, although it is pleasing that first-pass models from the new code provide conductivity sections that relate so well to other independent information.

ACKNOWLEDGMENTS

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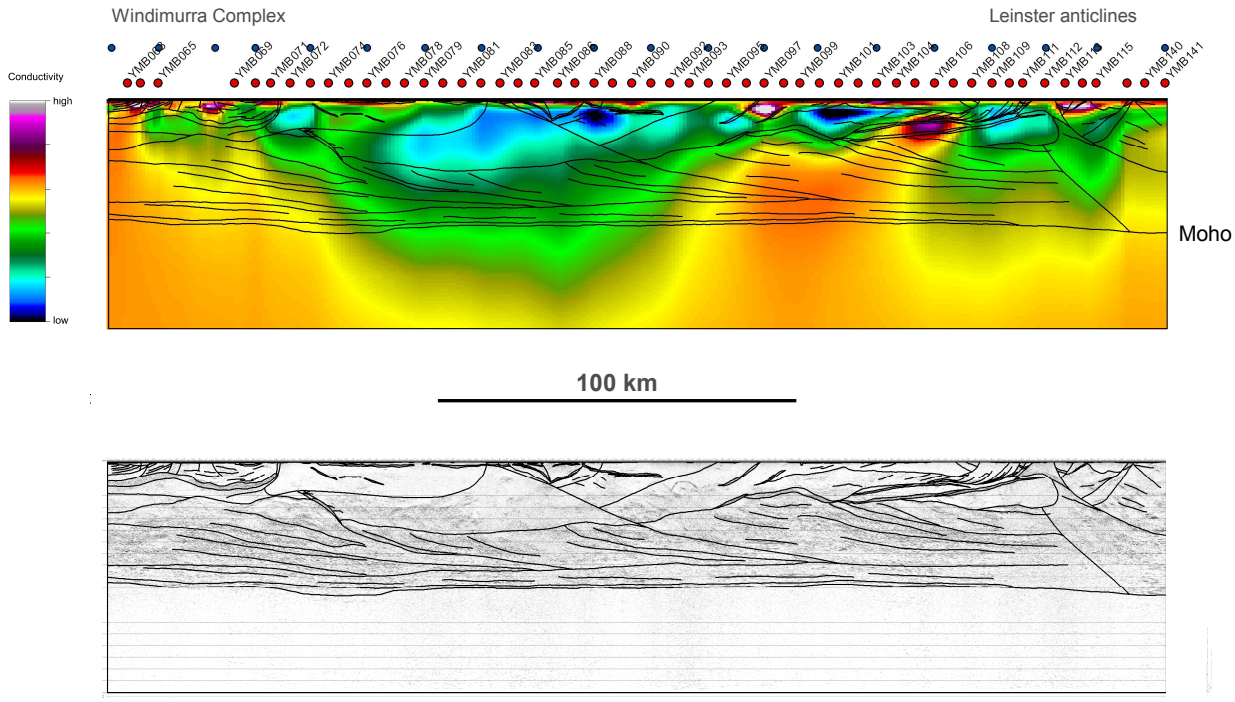

Figure 5. MT inversion model (top) and seismic section (bottom) for line YU2, both overlaid with seismic interpretation linework. Depth of the section is ~60 km. The broadband sites in red are labelled and referred to in the text. The long-period sites are in blue.