Magnetotelluric investigation complement multi-disciplinary geophysical data

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SUMMARY

As part of the Australian Government's Onshore Energy Security Program, Geoscience Australia has acquired magnetotelluric data along 12 deep crustal seismic reflection transects in Australia.

The magnetotelluric projects, which total more than 640 stations over 3700 km in distance, have been undertaken by Geoscience Australia in collaboration with state and territory geoscience agencies. Broadband and long period MT data have been acquired for investigating geological structures from the shallow surface to upper mantle.

These data, along with the deep seismic reflection, magnetic, gravity and geological data form the basis for multi-disciplinary investigations of crustal architecture, and energy and mineral potential, providing pre-competitive information to industry and researchers.

Key words: magnetotelluric, multi-disciplinary, energy, mineral, Australia

INTRODUCTION

The Australian Government's Onshore Energy Security Program (2006-2011) was completed recently by Geoscience Australia (GA). The five year program provides pre-competitive geoscience data and value-added products for assessment on hydrocarbon, uranium, geothermal energy and mineral resource potential. As part of the five year program, Geoscience Australia has acquired magnetotelluric (MT) data along 12 deep crustal seismic reflection transects across potential mineral provinces and frontier sedimentary basins in Australia (Figure 1). MT data were collected using AusScope instrumentation through ANSIR (National Research Facility for Earth Sounding) agreement and by contract. Broadband and long-period MT data were acquired at more than 640 stations over 3700 km in distance along these seismic transects in collaboration with state and territory geoscience agencies and the University of Adelaide.

The MT method complements the deep seismic reflection method by providing information of Earth electrical resistivity (or conductivity) distribution from near-surface to upper mantle. The MT data, along with deep seismic reflection data, potential field data of magnetic and gravity, and geological data have provided multi-disciplinary investigations of crustal architecture, and energy and mineral potential. These geophysical data have significantly improved the quality of regional geological interpretations. They have enabled a new understanding of the crustal architectures and geodynamics, as well as the mineral and energy potential in these regions.

The MT and seismic data are available from GA's website (http://www.ga.gov.au/minerals/projects/current-projects/seismic-acquisition-processing.html)

The results and interpretations of the seismic and MT surveys are available in several workshop reports.
(http://www.ga.gov.au/minerals/projects/current-projects/onshore-energy-geodynamic-framework.html)

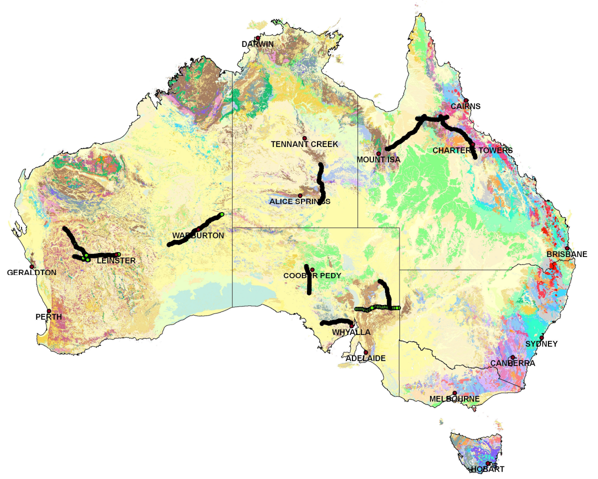

Figure 1. The location of MT surveys (black lines) on a surface geological map of Australia.

METHOD AND RESULTS

The MT method utilises time-dependent variations of the Earth's natural magnetic and electric fields to infer Earth's interior resistivity distribution from depths of tens of meters to hundreds of kilometers (Tikhonov, 1950; Cagniard, 1953; Vozoff, 1991). The variations of Earth's natural magnetic fields over a range of frequencies diffuse into the Earth and induce electric fields over a range of depths, which have characteristics depending upon the frequencies and the resistivity distribution of the Earth. The variations of the magnetic field are measured simultaneously by two or three orthogonal induction coils and a three component fluxgate magnetometer, while the electric field responses are measured by orthogonal pairs of electrodes.

Broadband data were measured with a frequency bandwidth of 0.01 Hz to 250 Hz for gaining information within the upper crust. Long-period data were measured with a frequency bandwidth of 0.1 Hz to 0.0001 Hz for identifying features in the lower crust and upper mantle.

MT time series data were processed using the robust algorithm BIRRP (Chave, 1987; Chave, 2004) with remote reference data when available. The aim of the process was to remove outliers in the time series measurements, produce a robust estimation of the transfer function, and obtain a series of power spectral estimates of the electric and magnetic fields. Finally, the apparent resistivity and phase as a function of frequency were calculated. The broadband and long-period data from coincident locations were merged into single responses, which were covering periods of about 0.004 s to 10,000 s (Figure 2). The processed data is available in industry standard Electrical Data Interchange (EDI) file.

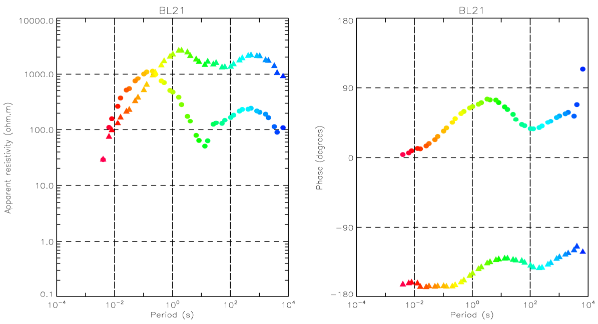

Figure 2. An example of merged apparent resistivity and phase curves of TM mode (triangle) and TE mode (circle).

Several techniques have been used for the dimensionality and geoelectric strike analysis. The WALDIM method (Marti, 2005) was used to examine the statistical distribution of dimensionality and distortion. The phase tensor approach (Caldwell, 2004) was also used to determine the spatial correlation, period consistency of the strike and the dimensionality (Figure 3). The induction arrows or Parkinson Arrows (Parkinson, 1959) were calculated from the complex ratio of vertical to horizontal magnetic fields in the frequency domain. They provided information for lateral geological structures and information of geoelectric strike.

Two dimensional MT inversion used the non-linear conjugate gradient algorithm of Rodi (2001) to produce the MT resistivity models. The resistivity characteristics from these models have been used to extract geological structural information of the continental lithosphere. They have provided complementary information for the multi-disciplinary geological interpretations based on the seismic reflection data. The joint interpretation reduced the ambiguity of one type dataset and produced a more consistent and reliable interpretation, especially, for regions that have complex geological structures.

Multi-disciplinary investigations are demonstrated by data acquired in Queensland across the eastern Mt Isa region; in South Australia across Gawler Craton, Officer Basin, Musgrave Province, Amadeus Basin (GOMA survey); and in Georgina-Arunta region of Northern Territory. Significant correlations were apparent between the different geophysical data for mapping geological structures and in the assessment of energy and mineral potential.

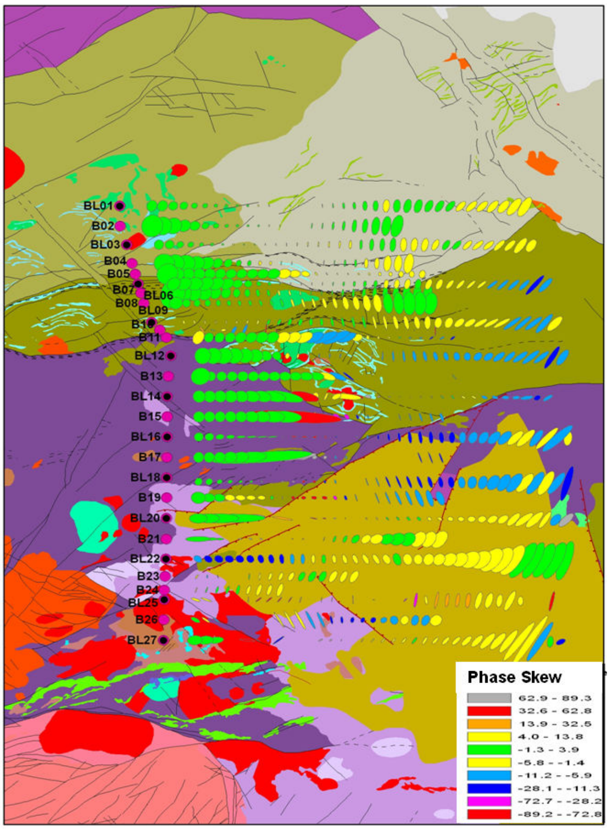

Figure 3. Phase tensor ellipse plots for each site from GA08-OM1 GOMA MT survey on a solid geological map, highest frequency closest to the site. The ellipses are invariant representation of phase values (size), skew values (colour) and direction of current flow (axis).

For example, in the Georgina-Arunta survey (Figure 4), spatially correlated geological features have been suggested by both the seismic image and the MT model (Korsch, 2011). First, the Amadeus Basin and the Georgina Basin have been well defined by the seismic image as well as the MT model, which shows high conductive zones of these Basins. Secondly, some geological boundaries are clearly seen in the MT model as well as in the seismic image, e.g., the boundary between the Aileron Province and the Davenport Province at about CDP 7000, and the boundary between the Aileron Province and the Irindina Province at about CDP 10000. The south dipping crustal resistivity structure matches a south dipping seismic structure. Gravity and magnetic anomalies from this region correlate with this feature. Thirdly, the MT model and seismic image indicate that the crust of Davenport Province can be divided into three regions: the Georgina Basin down to about 2.5 km in the MT model; a low seismic reflectivity zone corresponds to the high resistivity zones from about 2.5 km to about 15 km; and a high seismic reflectivity zone is coincident with a conductivity zone from about 15 km to 40 km in depth.

The MT model provides additional information for understanding the geodynamic, and energy and mineral potential. For instance, the MT model appears two larger crustal conductivity anomalies at about CDP 7000 and CDP 16000. Even though the significance of these anomalies is not fully understood yet, it may have mineral resource and hydrocarbon implication.

CONCLUSIONS

Broadband and long-period MT data have been acquired by Geoscience Australia along deep seismic reflection transects in Queensland, South Australia, Northern Territory, and Western Australia. Data have been processed and released to the public. These data provide pre-competitive information to industry and researchers for multi-disciplinary geological interpretations. The joint interpretation approach which utilises the different geophysical data provides an effective and reliable tool for interpretation.

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Figures 4. Two dimensional MT preliminary model with geological interpretation and seismic reflection image from Georgina-Arunta survey (Line 09GA-GA1)