ASEG-PESA 2015
Geophysics and Geology together for Discovery
24th International Geophysical Conference and Exhibition
15–18 February 2015 Perth, Western Australia

Broad-scale lithospheric structures of the Australian continent from 3-D inversion of observatory and magnetometer array

Liejun Wang
Geoscience Australia
GPO Box 378, Canberra 2601
Liejun.Wang@ga.gov.au

Adrian Hitchman
Geoscience Australia
GPO Box 378, Canberra 2601
Adrian.Hitchman@ga.gov.au

Andrew Lewis
Geoscience Australia
GPO Box 378, Canberra 2601
Andrew.Lewis@ga.gov.au

Peter Crosthwaite
Geoscience Australia
GPO Box 378, Canberra 2601
Peter.Crosthwaite@ga.gov.au

William Jones
Geoscience Australia
GPO Box 378, Canberra 2601
Bill.Jones@ga.gov.au

SUMMARY

An exploratory 3-D model of the electrical conductivity structure of the Australian continent is presented. The model is derived from the inversion of vertical magnetic-field transfer functions from the Australia-wide Array of Geomagnetic Stations.

The model reveals conductivity differences beneath Archaean cratons in Western Australia, enhanced-conductivity anomalies between Archaean cratonic regions and beneath Phanerozoic terranes in eastern Australia.

Key words: Geomagnetic induction, 3-D inversion, electrical properties, cratons, lithospheric structures.

INTRODUCTION

Geoscience Australia operates a network of ten permanent geomagnetic observatories in Australia and Antarctica. Data from these observatories are used for a variety of purposes. Their primary purpose is to monitor the very long-period geomagnetic field changes that originate in the Earth's core. These data form part of the data set used to derive reference field models such as the Australian Geomagnetic Reference Field model (AGRF), International Geomagnetic Reference Field model (IGRF) and World Magnetic Model (WMM). As such they underpin important activities such as magnetic navigation and reduction-to-the-pole techniques used in magnetic survey data analysis. Observatory data are also used in space weather analysis, as remote reference data for geophysical surveys, and as a backbone for magnetometer array studies.

Australia's geology is an assemblage of crustal blocks that can be broadly grouped into western, northern and southern cratons (Figure 1). These three major regions reflect the gross geological development of the continent and represent an evolution from Archaean in the west, through Proterozoic in the centre, to Palaeozoic–Cainozoic in the east (Myers *et al*. 1996). The solid red lines (Figure 1) represent crustal-scale conductivity anomalies identified from magnetometer array studies. The real parts of vertical magnetic transfer functions (VTF) from the 54 sites of the Australia-Wide Array of Geomagnetic Stations (AWAGS) are plotted as induction arrows at seven periods (adopted from Chamalaun and Barton 1993). Electrical anomaly code in Figure 1: C Canning Basin, E Eyre Peninsula, F Flinders, G Carpentaria, S southeast Queensland, O Otway, T Tamar.

This 3-D electrical conductivity model is derived from the inversion of multi-period VTF data from AWAGS deployed in 1989-90 (Chamalaun and Barton 1990). While, over the history of Australian magnetometer studies, data have been collected from some 600 sites, this exercise explores the sensitivity of a single, synoptic, continent-wide data set to broad-scale heterogeneous electrical conductivity structure. This approach results in a more manageable and reasonably evenly spaced data set with average of 270 km separation.

3-D ELECTRICAL CONDUCTIVITY MODEL

The 3-D model comprises a grid of 86 × 71 cells, each 55 × 55 km (approximately 0.5°), surrounded on all sides by a border of two 110 × 110 km (approximately 1°) cells, giving in total a grid of 90 × 75 cells. Horizontally, the model is bounded by longitudes 110.0°E and 157.0°E and latitudes 7.0°S and 46.5°S. Vertically, it consists of twenty-one horizontal layers to a depth of 648 km. The top five layers have thicknesses that vary progressively from 0.5 to 1.5 km to a depth of 4.5 km. The underlying sixteen layers vary progressively in thickness from 2.5 to 80 km.

Seven periods of VTF data from 388s to 9480s were modelled using the WSINV3DMT code (Siripunvaraporn and Egbert 2009). The details of the inversion procedure are reported in Wang *et al*. 2014. Four depth slices from the inverse model are presented in Figure 2 to show the broad-scale lithospheric structure of the model from 92 to 250 km.

CONDUCTIVITY CONTRASTS IN THE WESTERN CRATONS

The western cratons were established by the collision of the Archaean Yilgarn Craton to the south and Pilbara Craton to the north, which were joined along the Capricorn Orogen (Myers *et al*. 1996). The model depth slices show western cratons with differing electrical structure. They suggest a low-conductivity Yilgarn Craton defined by conductivity values less than 10^{-3} S/m at crustal depths, continuing to depths beyond 250 km. By contrast, in the present 3-D model, the Pilbara Craton to the north has conductivity values a few tenths of a S/m higher continuing to below 100 km. MT data acquired in 2010 along three seismic lines in the Capricorn Orogen show a profound change in conductivity between the northern section of the orogen adjacent to the Pilbara Craton, and southern section of the orogen adjacent to the Yilgarn Craton below 10 km (Heinson *et al*. 2011). This 3-D model confirms that an enhanced conductivity anomaly is indeed present beneath the cratonic area.

DEEPER HIGH-CONDUCTIVITY ANOMALIES BETWEEN CRATONIC REGIONS

On the eastern margin of the western cratons, a linear north-south enhanced conductor A1 in Figure 2a (C in Figure 1) runs south through the Canning and Officer basins continuing to the southern edge of the continent. The deep section of A1 corresponds spatially to the collisional boundaries of three cratons during amalgamation of the Australian shield in the Proterozoic (Myers *et al*. 1996).

On the eastern side of central craton, the Carpentaria anomaly (Chamalaun *et al*. 1999; Lilley *et al*. 2003. A2 in Figure 2a and G in Figure 1) is a significant enhanced-conductivity anomaly between the Mt Isa Inlier and the Eromanga Basin (Chamalaun and Barton 1990). It extends approximately 880 km along the western margin of the inlier. The present model suggests the southwest Queensland anomaly (Woods and Lilley 1979) (S in Figure 1) and the Carpentaria anomaly form a major conductivity anomaly extending to a depth of about 100 km.

DEEPER HIGH-CONDUCTIVITY ANOMALIES IN EASTERN AUSTRALIA

The eastern continental margin is characterised by late Mesozoic and Cainozoic igneous rocks, predominantly as basic flows and basic-to-acidic shallow intrusions related to local vents and composite volcanoes (Gibson 2007), extending 4400 km from northern Queensland to Tasmania. The 3-D model suggests there are two enhanced conductivity anomalies (A3 and A4 in Figure 2a) located to the south of the Phanerozoic Lachlan and Delamerian orogens and New England Orogen.

The A3 conductivity anomaly is in a region of partial melting associated with the volcanic province in southern Victoria (Lilley 1976). The recent body wave tomographic model of Fishwick and Rawlinson (2012) identifies a clear lower-velocity anomaly in the uppermost mantle beneath the Newer Volcanics province on the eastern margin of the continent. The anomaly is interpreted as being due to elevated temperature associated with a hot source in the uppermost mantle. The A4 anomaly is mapped for the first time on the New England Orogen; it may have a similar cause to A3.

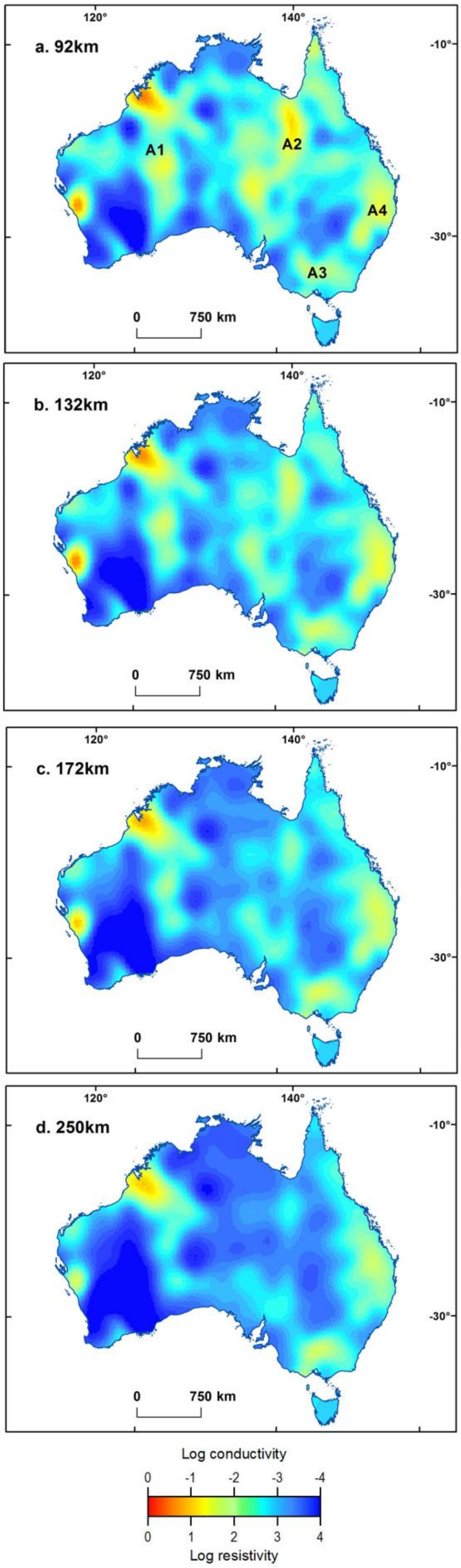

Figure 2. Depth slices of the 3-D conductivity model derived from the inversion of AWAGS VTF data.

CONCLUSIONS

The broad geological blocks from Archaean in the west, through Proterozoic in the centre, to Palaeozoic–Cainozoic in the east, are well presented in the model as simple lower conductivity structures. In addition, the model shows conductivity contrast in the western craton, characteristic of enhanced conductivity structures which separate the cratonic blocks, and enhanced conductivity anomalies presented in eastern Australia.

ACKNOWLEDGMENTS

The authors thank François Chamalaun and Charlie Barton for instigating the AWAGS experiment and making its dataset available for investigation.

REFERENCES

Chamalaun, F.H. and Barton, C.E., 1990, Comprehensive mapping of Australia's geomagnetic variations, EOS, Trans. Am. geophys. Un., **71,** 1867, 1873.

Chamalaun, F.H. and Barton, C.E., 1993, Electromagnetic induction in the Australian crust: results from the Australia-wide Array of Geomagnetic Stations, Exploration Geophysics, **24**, 179–186.

Chamalaun, F.H., Lilley, F.E.M. and Wang, L.J., 1999, Mapping the Carpentaria conductivity anomaly in northern Australia, Physics of the Earth and Planetary Interiors, **116**, 105–115.

Fishwick, S. and Rawlinson, N., 2012, 3-D structure of the Australian lithosphere from evolving seismic datasets, Australian Journal of Earth Sciences, **59**, 809–826.

Gibson, D.L., 2007, Potassium-Argon Ages of Late Mesozoic and Cainozoic Igneous Rocks of Eastern Australia, CRC LEME Open File Report, **193**, Cooperative Research Centre for Landscape Environments and Mineral Exploration, Perth, 53 pp.

Lilley, F.E.M., 1976, A magnetometer array study across southern Victoria and the Bass Strait area, Australia, Geophysical Journal of the Royal Astronomical Society, **46**, 165–184.

Lilley, F.E.M., Wang, L.J., Chamalaun, F.H. and Ferguson, I.J., 2003, Carpentaria electrical conductivity anomaly, Queensland, as a major structure in the Australian Plate, in Evolution and Dynamics of the Australian Plate, pp. 141–156, ed. Hillis, R.R. and Muller, R.D., Geological Society of Australia Special Publication **22** and Geological Society of America Special Paper **372**.

Heinson, G., Boren, G., Ross, J., Campanya, J., Thiel, S. and Selway, K., 2011, The Capricorn Orogen magnetotelluric (MT) transect, in Capricorn Orogen seismic and magnetotelluric (MT) workshop 2011: extended abstracts, pp. 75–100, ed. Johnson, S., Thorne, A. and Tyler, I., Geological Survey of Western Australia Record, 2011/25.

Myers, J.S., Shaw, R.D. and Tyler, I.M., 1996, Tectonic evolution of Proterozoic Australia, Tectonics, **15**, 1431–1446.

Siripunvaraporn, W. and Egbert, G., 2009, WSINV3DMT: Vertical magnetic field transfer function inversion and parallel implementation, *Physics of the Earth and Planetary Interiors*, **173**, 317–329.

Wang, L., Hitchman, A.P., Ogawa, Y., Siripunvaraporn, W., Ichiki M. and Fuji-ta, K. 2014, A 3-D conductivity model of the Australian continent using observatory and magnetometer array data, Geophysical. Journal. International., 198 (2): 1143-1158. doi: 10.1093/gji/ggu188.

Woods, D.V. and Lilley, F.E.M., 1979, Geomagnetic induction in central Australia, Journal of Geomagnetism and Geoelectricity, **31**, 449–458.

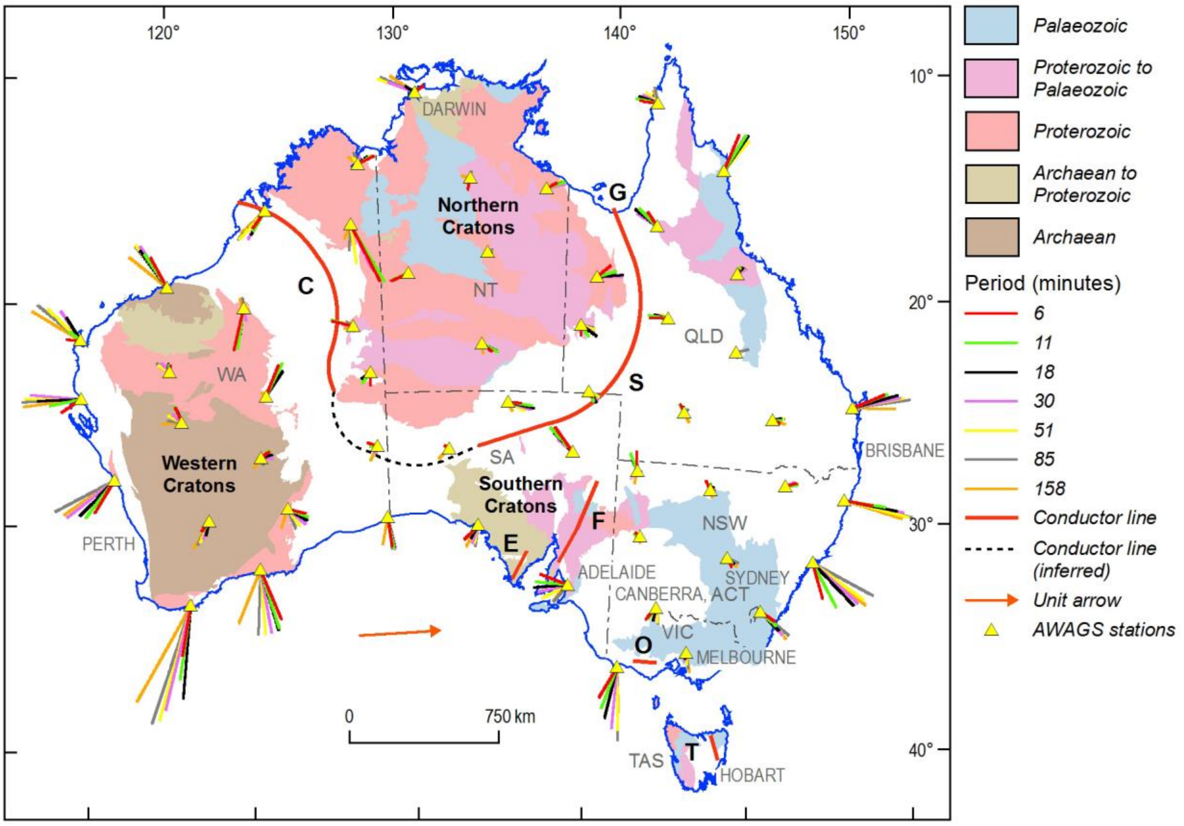

Figure 1. Australian geological setting and vertical magnetic transfer functions (VTF) from the 54 sites of the Australia-Wide Array of Geomagnetic Stations (AWAGS).