Evolving 3D lithospheric resistivity models across southern Australia derived from AusLAMP MT

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SUMMARY

The Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) is an eventual continent-wide deployment of long-period (10-10 000 s) magnetotelluric instruments in a half-degree interval (~55 km) grid across Australia to map the electrical resistivity structure of the continental lithosphere. AusLAMP aims to provide constraints on the tectonic evolution of the continent and the mineral exploration potential as part of the UNCOVER initiative. The coverage of sites in South Australia is nearing completion with about 350 out of 400 sites acquired to date. The survey has already provided new insights into the South Australian subsurface, and will continue to do so as the final stages of data are collected in the APY lands and modelling continues. Areas of economic potential or interest covered by the survey include the Mesoproterozoic Coompana Province, the mineral-rich Archean-Proterozoic Gawler Craton beneath cover of the Neoproterozoic Stuart Shelf, extending across to the east to cover the Neoproterozoic Ikara-Flinders Ranges and Paleo-Mesoproterozoic Curnamona Province. The central Gawler Craton is imaged as a resistive zone with conductive margins surrounding the core of the cratonic block at shallow upper mantle depths. Seismic tomography models across the almost-cratonic Curnamona Province show a fast velocity structure however very low resistivities in the crust indicate an enrichment in carbon and/or hydrogen. The most recent acquisition covers the NE of the state in the Cooper Basin and the Simpson Desert, an area that has minimal coverage by any deep-probing geophysical techniques. Preliminary results indicate the presence of a north-south trending conductor, with final modelling results presented at the AEGC 2018. The results of the inversions of the AusLAMP data highlight the correlative significance with other geochemical data and points towards MT as a geophysical fertility vector for mineral discovery.

Key words: AusLAMP, magnetotellurics, lithosphere, electrical resistivity, UNCOVER

INTRODUCTION

Almost all of the known mineral deposits to date have been found in areas of outcrop or minimal cover. Given that 80 % of Australia is under cover to some degree, a vast shift in the exploration process within Australia must occur to discover new deposits and keep up with the demand. The Australian Academy of Science's UNCOVER document (Australian Academy of Science, 2012) and the AMIRA roadmap (AMIRA International, 2015) outline the changes that need to occur, with the Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) providing great input into one of the four main themes of UNCOVER; understanding the lithospheric framework beneath Australia, and listed as a national priority in the AMIRA roadmap. AusLAMP involves the collection of long-period (10-10 000 s) magnetotelluric instruments across a half-degree interval (~55 km) grid across Australia. The goal of AusLAMP is to map the electrical resistivity structure of the continental lithosphere, thus unravelling the tectonic evolution of the continent and investigating the mineral exploration potential as part of the UNCOVER initiative. The coverage of AusLAMP in South Australia is almost complete (Figure 1) and covers the Mesoproterozoic Coompana Province, the Archean-Proterozoic Gawler Craton, the Neoproterozoic Ikara-Flinders Ranges and the Paleo-Mesoproterozoic Curnamona Province.

Given that the lithospheric mantle is responsible for the focussing of heat, fluids and metals sourced from asthenospheric depths, it makes sense that in order to fully understand the mineral deposits within the upper crust, we need to understand the entire mineral system and hence the entire lithosphere. MT is a passive electromagnetic technique capable of imaging the alteration undergone by the lithosphere with the ascent of fluids and melts. Penetration depths usually extend down to the lithosphere-asthenosphere boundary (ranging from ~100-240 km in South Australia; Kennett et al 2013) or deeper. The technique is highly sensitive to minor conducting phases, melt and temperature. Within the stable crust of South Australia, interconnected sulfide minerals and graphite in the form of interconnected grain boundary layers (stable to temperatures up to ~900 °C; Mathez, 1987) would have the greatest control on conductivity and within the mantle lithosphere, hydrogen in nominally anhydrous minerals as well as graphite are most significant.

MT images regions of enrichment or depletion, with fluids released or melts generated from subducting plates or interactions with mantle plumes increasing the conductivity. Whilst high temperature events such as high-grade metamorphism and melt events serve to deplete the lithosphere of hydrogen and carbon thus leaving a resistive lithosphere. Given the retainment of these signatures for billions of years, we have a tool capable of imaging the effects of a rich and complex tectonic history across the cratonic parts of SA (Gawler

Craton), near cratonic (e.g. Musgrave Province, Curnamona Province, Coompana Province) and younger overprinted regions (e.g. Ikara-Flinders Ranges, Stuart Shelf).

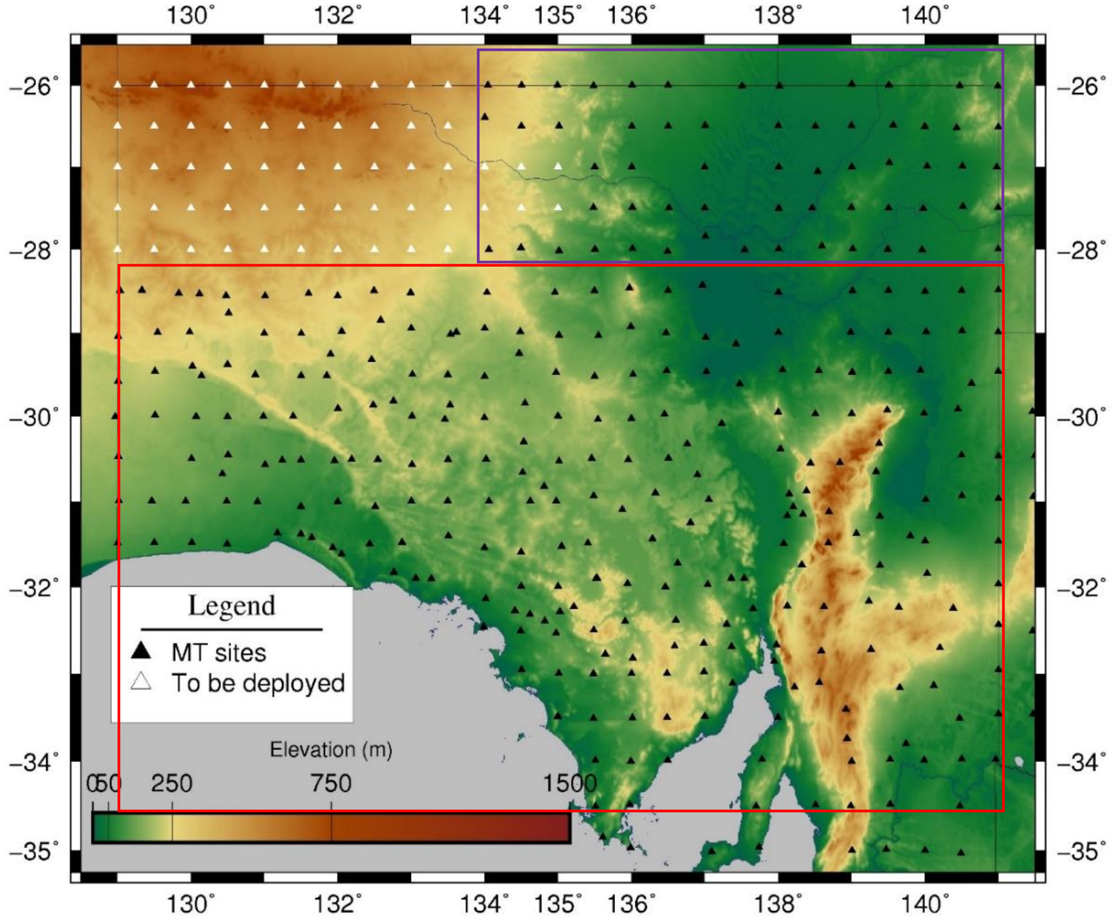

Figure 1: AusLAMP long-period MT site deployed locations (black) and intended locations (white) over topography. Model Area 1 is shown by the red rectangle and Model Area 2 is shown by the purple rectangle.

METHOD AND RESULTS

MT is a passive electromagnetic technique involving the measurement of naturally occurring magnetic and electric fields generated by a combination of the interaction of solar particles with the magnetosphere, and lightning strikes across the globe traversing within the ionosphere which acts as a waveguide. To date, a total of 350 long period (10 -10,000 s) MT sites have been collected across South Australia since November 2013. Standard long-period MT sets from the AuScope instrument pool were used, with two 50 m dipoles using Pb-PbCl non-polarizing electrodes to record the electric field in perpendicular directions (along a north-south axis, Ex and an east-west axis, Ey), and a fluxgate magnetometer to record the magnetic field in three directions (north-south, Bx, east-west, By, and vertical, Bz). Instruments recorded for at least 3 weeks unless damage was sustained in the field, but generally at least one week of recording would result in usable data. Time series data were processed to the frequency domain using the bounded influence robust remote referencing processing code of Chave & Thompson (2004) with sites that recorded simultaneously used for remote referencing to improve the signal to noise ratio of the response. With MT sounding, a more resistive subsurface and longer period measurements result in a greater penetration depth than a conductive subsurface and shorter period measurements. Generally, most sites recorded good data across a period range of about 5-10 000 s, capable of imaging the entire lithosphere across most of South Australia.

Phase tensor ellipses are a useful way of viewing the data as they are unaffected by distortion and highlight regions of different electrical structure. At a period of 1000 s (Figure 2), very large scale trends become apparent in the electrical structure across the state. The Gawler Craton can be divided into two distinct zones, the central southern region has very distinct ellipses varying in orientation of NE-SW to NNE-SSW with minimum phase angles of about 45 degrees or higher and hint toward the large conductivity anomaly at mantle depths observed by Thiel and Heinson (2013). The rest of the Gawler Craton is defined by phase angles less than 45 degrees and occur on the outer edges of the Gawler Craton, with the exception of the high phase angle circular ellipses of the Eyre Conductivity Anomaly. Across the geologically complex Ikara-Flinders Ranges the ellipses vary substantially and highlight the Flinders Conductivity Anomalies with high minimum phase angles through the Curnamona Province and parts of the southern Ikara-Flinders Ranges, as imaged in Robertson et al. (2016). The NE of the state is relatively coherent with ellipses NNE-SSW to NE-SW and all have low minimum phase angles indicating that the subsurface is becoming more resistive with depth. Only the very eastern part of the

Musgrave Province is covered by the AusLAMP array so far, but the change in ellipse orientation and minimum phase angle in the Musgrave Province shows a change in electrical structure.

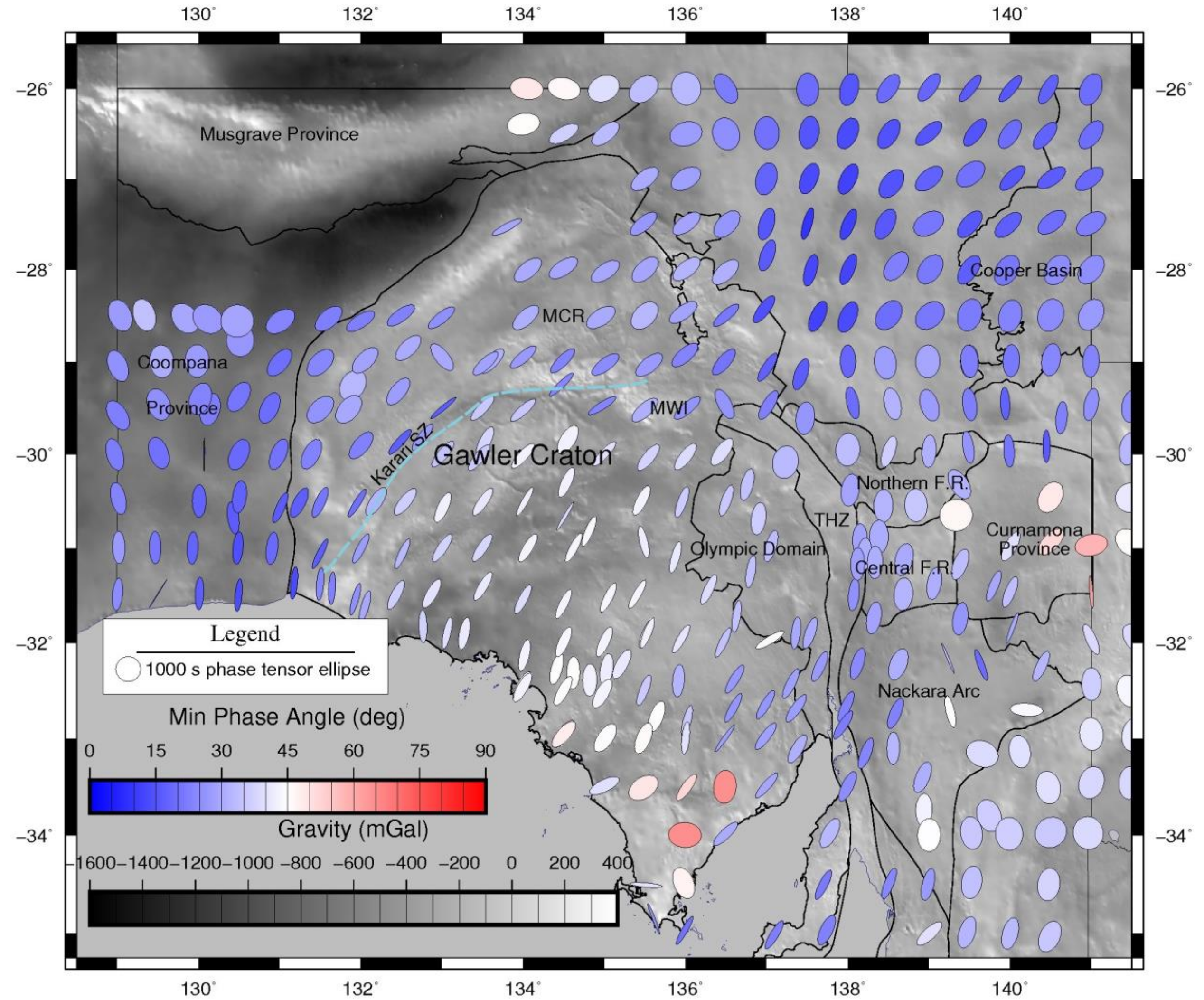

Figure 2: Ellipses are shaded by the minimum phase angle which for interpretation gives an indication of how the resistivity structure changes with depth (angles less than 45 degrees shows resistivity is increasing with depth, greater than 45 degrees shows resistivity is decreasing with depth). A circle shows a one-dimensional resistivity structure (varying only with depth) and an ellipse is 2- or 3-D resistivity structure. The major or minor axis points along the direction of current flow (a 90 degree ambiguity exists- resolved by matching to geological strike). MWI= Mt Woods Inlier, MCR= Mabel Creek Ridge, blue dashed line= Karari Shear Zone.

Models of subsets of AusLAMP SA have already been presented (Robertson et al 2016, Thiel et al 2016), however final stages of modelling are currently underway to incorporate these smaller subsets into a model space covering almost all of South Australia and will be presented in full at the AEGC in February, 2018 (Model Area 1, red rectangle, Figure 1) along with new results from the northeast SA area (Model Area 2, purple rectangle, Figure 1). Modelling is conducted using the ModEM software package (Egbert & Kelbert, 2013; Kelbert et al., 2014) for the full impedance tensor and the tipper.

Model Area 1 has a total model space including boundary padding of 2700 x 3150 x 2350 km with 101 (north-south) x 142 (east-west) x 82 (vertical) cells and incorporates the ocean into the model. Inner grid cell spacing is 10 km x 10 km, increasing outside of the survey area. Preliminary models reveal a very resistive Archean core of the western to central Gawler Craton. A conductive band appears down the eastern margin of the craton at depths of 20 km and greater, coinciding with the Olympic iron oxide-copper-gold (IOCG) province, containing the world class Olympic Dam deposit, along with other IOCG deposits and prospects (e.g. Carapateena, Punt Hill). This conductor is known to connect to the surface at these deposits (Soeffky et al., 2016; Heinson et al., 2006). At a depth of 50 km this conductor extends around to link the Olympic Domain to the Mount Woods Inlier, (host to the Prominent Hill Cu-Au-Ag mine), the Mabel Creek Ridge and the NE-SW Karari Shear Zone, almost reaching the coast just to the east of the Coompana Block. This conductive ‘horseshoe’ extends down to depths of over 100 km. It is too conductive for the sole cause of the conductor to be a result of hydrogen diffusion (< 10 Ohm.m to depths of perhaps up to 200 km) thus other conduction mechanisms must be attributed as well. The Eyre conductor is observed as a mid-upper crustal conductor spanning depths 5 to 10-15 km, in agreeance with observations by White and Milligan (1984) and Thiel et al. (2005) and is interpreted to be related to a major fracture or shear zone located within the top 10-15 km of the crust that is filled with saline fluids, graphite, or a combination of the two. The Ikara-Flinders Ranges and Curnamona Province exhibit several major conductors within the crust of the Curnamona Province (likely graphite from subduction associated fluid alteration), and the shallow upper mantle of the Ikara Flinders Ranges (interpreted as the alteration pathway of carbon-rich kimberlite bearing melt on its ascent through the lithosphere; Robertson et al 2016).

Model Area 2 contains all new data collected over the first half of 2017 and covers the Simpson Desert and a region of overlaying sedimentary basins including the Cooper, Eromanga, Great Artesian and Warburton basins. The total model space is 2900 x 3250 x 2500 km with dimensions of 54 (north-south) x 104 (east-west) x 75 (vertical) cells with a cell size of 7.5 km x 7.5 km. Models of this area are still in early stages but as expected from investigating phase tensor ellipses and induction arrows (ratios of horizontal to vertical magnetic fields represented as vectors which point toward directions of increasing conductivity), the central region of the model contains a large north-south conductor separating otherwise mostly resistive lithosphere.

Preliminary work on the near-statewide AusLAMP dataset shows that tectonic provinces with varying tectono-thermal histories are imaged by a change in electrical resistivity structure, with parts of the lithosphere enriched in graphite, carbon and sulphides (such as the margin of the Gawler Craton and the crust of the Curnamona Province), whilst depleted regions such as the interior core of the Gawler Craton appear resistive. Regions of anomalous conductivity may underlie regions of mineralogical potential such as that which occurs along the IOCG belt in the Olympic Domain (Heinson et al 2006) and the Beverley Uranium mine (Thiel et al 2016b). Finalising of models in the coming months will further illuminate conductive regions that can be targeted for future infill surveys at higher resolution. Higher resolution surveys are capable of imaging fluid delivery pathways of the mineral system throughout the entire lithosphere to the surface and may provide a vector toward mineralisation.

CONCLUSIONS

AusLAMP is nearing completion across South Australia with approximately 10 % remaining to be covered in the northwest of the state. A total of 350 long-period MT sites reveal distinct large scale changes in the electrical structure across the state and for the first time we have shown data and described preliminary modelling results of the northeast of South Australia, a region that until now has very little known about the lithosphere. Major features observed across the state include a resistive interior core of the Gawler Craton surrounded by a conductive margin, a resistive Ikara-Flinders Ranges with the exception of two conductive anomalies and a conductive crust of the Curnamona Province. Modelling continues and final results and full interpretations will be shown at the AEGC in February 2018.

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REFERENCES

Australian Academy of Science, 2015, UNCOVER, Searching the deep earth: A vision for exploration geoscience in Australia.

Amira International, 2015, Final Report- Unlocking Australia's hidden potential. An Industry Roadmap – Stage 1, P1162.

Chave, A.D., and Thompson, D.J., 2004, Bounded influence magnetotelluric response function estimation: Geophysical Journal International, 157, 988-1006.

Egbert, G.D., Kelbert, A., 2012, Computational Recipes for Electromagnetic Inverse Problems: Geophysical Journal International, 189, 251-267.

Kelbert, A., Meqbel, N.M., Egbert, G.D., and Tandon, K., 2014, ModEM: A modular system for inversion of electromagnetic geophysical data: Computational Geoscience, 66, 40-53.

Kennett, B., Fichtner, A., Fishwick, S., and Yoshizawa, K., 2013, Australian Seismological Reference Model (AuSREM): Mantle Component: Geophysical Journal International, 192, 871-887.

Heinson, G., Direen, N., and Gill, R., 2006, Magnetotelluric evidence for a deep-crustal mineralizing system beneath the Olympic Dam iron oxide copper-gold deposit, southern Australia: Geology, 34(7), 573-576.

Mathez, E.A., 1987, Carbonaceous matter in mantle xenoliths—composition and relevance to the isotopes: Geochim Cosmochim Acta, 51(9), 2339–2347.

Robertson, K., Heinson, G., and Thiel, S., 2016, Lithospheric reworking at the Proterozoic–Phanerozoic transition of Australia imaged using AusLAMP Magnetotelluric data: Earth and Planetary Science Letters, 452, 27-35.

Soeffky, P., Heinson, G., and Thiel, S., 2016, The electrical resistivity of the Australian lower crust: AESC 2016 Abstracts, 489. http://aesc2016.gsa.org.au/assets/AESC-2016-Abstract-Book-as-at-070716-opt.pdf

Thiel, S.; Heinson, G. & White, A., 2005, Tectonic evolution of the southern Gawler Craton, South Australia, from electromagnetic sounding: Australian Journal of Earth Sciences, 52, 887-896.

Thiel, S., Heinson, G., 2013, Electrical condcutors in Archean mantle- Result of plume interaction?: Geophysical Research Letters, 40, 2947-2952.

Thiel, S., Heinson, G., Reid, A. and Robertson, K., 2016, Insights into lithospheric architecture, fertilisation and fluid pathways from AusLAMP MT: ASEG Extended Abstracts.

Wessel, P., Smith, W.H.F., Sharroo, R., Luis, J. and Wobbe, F., 2013, Generic Mapping Tools: Improved Version Released: EOS Transactions. AGU, 94(45), 409-410.

White, A., and Milligan, P.R., 1986, Geomagnetic variation anomaly on Eyre Peninsula, South Australia: Exploration geophysics, 17, 32