High-density magnetotelluric mapping across uranium deposits highlights lithospheric controls on deposit location

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Introduction

With the Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) deployment across South Australia nearing completion (Thiel and Roberson 2017), the subsequent 3D inversion modelling of the magnetotelluric (MT) data and integration with other geophysical, geochemical and geological data will provide a new fundamental precompetitive dataset for the state. It will highlight areas of enhanced conductivity in the crust, which were shown by Thiel et al. (2017) to be a potential proxy for fertile crust, one characteristic for establishing mineral deposits.

However, with the site spacing of ~55 km for the AusLAMP grid, the resolution in the upper crust is not sufficient to confidently map the high conductivity zones extending into the surface cover sequence. Closely spaced broadband MT surveys are required to obtain greater resolution across the areas of interest identified by AusLAMP. There are already some examples across the state where this approach has been used to great benefit across known deposits such as Olympic Dam (e.g. Heinson, Direen and Gill 2006). This article summarises the results of a recently published closely spaced (1 km site spacing) broadband MT survey across the Beverley uranium deposit, located east of the northern Flinders Ranges (Fig. 1; Thiel et al. 2016). The results provide another example of how the crustal structure appears to exert a control on the location of mineral deposits.

Method

MT is a passive electromagnetic technique which involves the recording of naturally occurring magnetic and electric fields at the surface of the earth to obtain information on the electrical resistivity structure of the subsurface. During two field campaigns, MT measurements were recorded along two 35 km, ESE–WNW-oriented parallel profiles spaced 7 km apart (Fig. 1). The northern transect comprised 36 broadband (0.004–1,000 s) stations with 13 of these also recording long-period (10–10,000 s); the southern transect comprised 59 broadband stations. An additional 22 broadband MT sites along a NNE–SSW profile were used from an array of stations centred at the Paralana enhanced geothermal systems test site (Fig. 1; Peacock et al. 2012, 2013; Thiel 2017). Site spacing was 1 km across most of the profiles, extending up to 3 km at the far east of the northern profile. The data, which is overall of good quality, is predominantly 2D based on phase tensor analysis (Caldwell, Bibby and Brown 2004) with subsequent rotation to a geoelectric strike of 5° to align with surficial faults. Data from the northern and southern lines was inverted separately using the OCCAM 2D inversion code (deGroot-Hedlin and Constable 1990; Fig. 2).

Results

The resistivity structure revealed a 1–2 km thick layer of low resistivity (<10 Ωm) sediments above a highly resistive (>1,000 Ωm) ~15–25 km thick layer with a predominantly 2D structure (R1), which extends along the azimuth of the geoelectric strike to a depth of ~30 km. A subvertical mid-crustal conductor extends to about 10 km beneath the surface (C1),

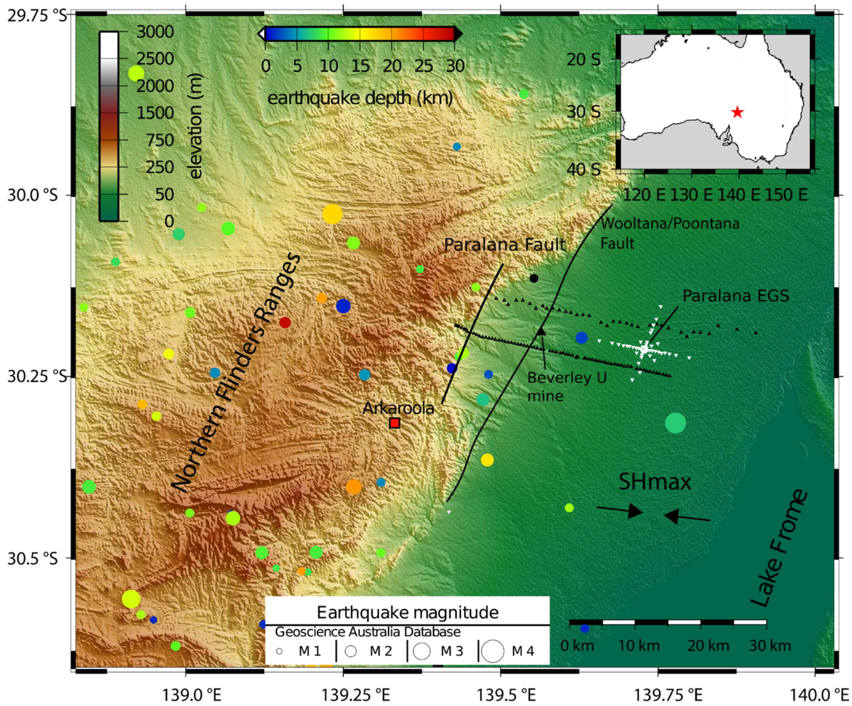

Figure 1 MT stations (black triangles, this study; white triangles, Peacock et al. 2013) over topography. Coloured circles denote earthquake epicentres and magnitudes across the survey area although depths are poorly constrained. Reprinted from Thiel et al. (2016; fig. 1) with permission from the American Geophysical Union.

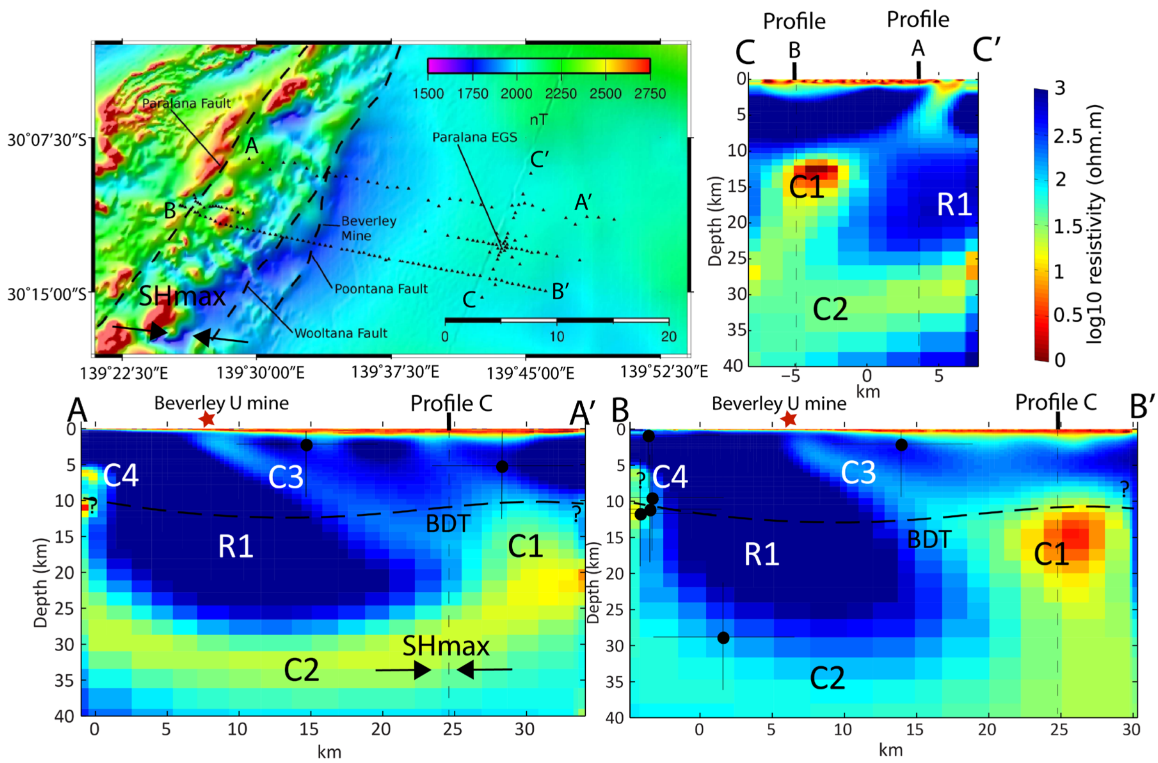

Figure 2 Two-dimensional resistivity models of the MT profiles obtained using the 2D OCCAM inversion of deGroot-Hedlin and Constable (1990). The models show increased conductivity in the lower crust at around 30 km (C2). Localised near-vertical zones of higher conductivity extend to the brittle–ductile transition (BDT) at around 10 km depth (C1). Lower conductivities extend to the surface along faults at 45° angle. Earthquake locations in the vicinity of the profile were projected along strike onto the nearest MT profile (black dots). Hypocentres are poorly constrained, and we assign a generic 15 km error. There is generally higher uncertainty in the E–W direction of epicentres due to the seismometer network geometry. Reprinted from Thiel et al. (2016; fig. 2) with permission from the American Geophysical Union.

interpreted as a signature of fluid ponding beneath the brittle–ductile transition, which tends to resist the passage of fluids (Connolly and Podladchikov 2004). Narrow, 45°-angle conductive faults extend to the surface. The eastern mid-crust conductor beneath the Paralana enhanced geothermal system (C1) has a maximum width of about 10 km. The western region of the profiles contains very resistive (10,000 Ωm) unfractured basement rock. Along the western edge of both profiles in the mid-crust is a conductor (C4) that aligns with the range-bounding Paralana Fault (Fig. 1). The NNE–SSW profile ties in with the results of the main profiles with a lower crustal conductor and a subvertical low-conductivity extension into the mid-crust below the brittle–ductile transition (Fig. 2).

Conductivity anomalies within a few hundred kilometres of the survey area are associated with Mesoproterozoic magmatic events along the margin of the Archean–Proterozoic Gawler Craton to the west (Heinson, Direen and Gill 2006; Thiel and Heinson 2013). To the south, Delamerian-subduction associated serpentinisation and resultant enhanced magnetite within mafic and ultra-mafic rocks is interpreted to cause higher crustal conductivity (Robertson et al. 2015; Robertson et al. 2017). Low resistivity in the lower crust and upper mantle beneath the Newer Volcanic Province to the south is a result of recent decompressional melting within a lithospheric step (Aivazpourporgou et al. 2015). Recently, long-period MT AusLAMP data revealed a pervasive lower crustal conductor of the Curnamona Province and isolated conductors within the Nackara Arc province of the Ikara-Flinders Ranges (Robertson, Heinson and Thiel 2016; Robertson, Heinson and Thiel 2017). Both present and fossil crustal fluids may result in enhanced conductivity through precipitation of sulfides, graphite or magnetite on interconnected grain boundaries under the right conditions (Nover 2005; Thiel, Heinson and White 2005).

The coincident position of enhanced conductivity in the lower crust (C2; Fig. 2) and enhanced strain derived from geodynamic modelling (Célérier et al. 2005) beneath the area of maximum topographic flexure is suggestive of a connection between neotectonic uplift of the Flinders Ranges and reactivation of the lower crust beneath the survey area. The horizontal geometry of the lower crustal conductor (C2; Fig. 2) does not appear to have mantle connections; however, mantle resolution is limited due to the small profile aperture (~40 km). It is unlikely that the fluids are entirely meteoric due to the fluid flow resistant brittle–ductile transition (Connolly and Podladchikov 2004; Raimondo et al. 2013); a potential additional fluid source is geologically recent fluid release from metamorphism of lower crustal rocks.

The westernmost upper crustal pathway that branches up from C1 reaches the surface beneath the Wooltana–Poontana Fault (which has most likely been active since the Pliocene, Wülser et al. 2011) and the Beverley uranium mine (Fig. 2). The crustal architecture may therefore have some control on the location of uranium in near-surface sedimentary layers. Mobile reducing fluids may provide the required redox conditions near the neotectonic displacement along the Wooltana–Poontana Fault for uranium emplacement. The results indicate the significance of understanding the full crustal architecture when exploring for near-surface economic mineral deposits.

Conclusion

This study is another example of how geophysical surveys contribute to the scale-reduction process that is critical for mineral exploration success (e.g. McCuaig, Beresford and Hronsky 2010). Starting from the regional scale of the AusLAMP surveys, the follow-up high density MT surveys, such as that over the Beverley uranium mine, resolve crustal-scale faults that can control the location of mineral deposits.

As an outcome of the insights gained from this study and the AusLAMP survey, $500,000 will be invested through the *PACE* Copper initiative to acquire over 300 broadband MT stations across the Olympic Domain. The site layout will cover a 100 x 100 km area to map low conductivity zones to the surface in 3D. The data collection will likely commence in October/November 2017. Further in-fill surveys are planned to maximise the impact of MT methods in the process of unlocking the mineral potential of South Australia.

Acknowledgements

Petratherm provided MT data for the southern profile. Heathgate provided logistical support during the data acquisition of the northern profile. Anthony Reid (Geological Survey of South Australia) reviewed the article.

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FURTHER INFORMATION

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