IDENTIFYING LITHOSPHERIC BOUNDARIES AND THEIR IMPORTANCE FOR MINERAL DISCOVERY

Stephan Thiel*
Geological Survey of South Australia
Department of the Premier and Cabinet
Adelaide, SA 5000
Stephan.Thiel@sa.gov.au

Stacey Curtis
Geological Survey of South Australia
Department of the Premier and Cabinet
Adelaide, SA, 5000
Stacey.McAvaney@sa.gov.au

Anthony Reid
Geological Survey of South Australia
Department of the Premier and Cabinet
Adelaide, SA, 5000
Anthony.Reid@sa.gov.au

Graham Heinson
The University of Adelaide
School of Physical Science
Adelaide, SA, 5005
Graham.Heinson@adelaide.edu.au

Kate Robertson
Geological Survey of South Australia
Department of the Premier and Cabinet
Adelaide, SA, 5000
kate.robertson2@sa.gov.au

**presenting author asterisked*

SUMMARY

Major lithospheric boundaries under cover have commonly been recognised through tracing of potential field anomalies, such as extensive magnetic boundaries representing margins of upper crustal packages in conjunction with density contrast. Here, we extend the investigation of domain mapping to include isotope geochemistry and deep-probing magnetotelluric data, which are able to map the deeper crustal and mantle lithosphere. We demonstrate with examples across the Kalinjala Shear Zone, South Australia, and the Eastern Gawler Craton, that major lithospheric domain boundaries exert a primary control on the location of mineral deposits near the surface.

We show examples of correlating magnetotelluric models derived from the Australian Lithospheric Magnetotelluric Project (AusLAMP) and higher density broadband magnetotelluric deployments along profiles with isotope geochemistry across major lithospheric boundaries in South Australia. As one example, the Kalinjala Shear Zone in the southern Gawler Craton can be better constrained using the additional geochemical and magnetotelluric data sets and solve a long-standing debate about the northern extension of the Kalinjala Shear Zone towards the prospective Olympic Province, which hosts, major IOCG deposits. These insights have led to the development of future exploration programs which focus on in-fill broadband deployments for MT and isotope mapping to trace major lithosphere boundaries to the surface, reducing risk for mineral exploration.

Key words: AusLAMP, magnetotellurics, lithosphere, electrical resistivity

INTRODUCTION

Cover remains one of the main impediments to mineral exploration in Australia. With a lack of conclusive mineral indicators from upper crustal and near-surface geophysical techniques, such as potential field methods, the push to understanding mineral systems across the entire lithospheric column provides a promising addition to the methodology employed by mineral explorers. Additionally, the constraints on lithospheric architecture and insights into composition shed a crucial light on the tectonic setting and mineral fertility corridors. With an increased understanding of a whole lithosphere approach to exploration, deep probing geophysical techniques such as magnetotellurics (MT) (Heinson et al., 2006; Thiel and Heinson, 2010; Thiel and Heinson, 2013) seismic tomography (Rawlinson et al., 2014) as well as geochemical sampling of the sub-continental lithospheric mantle (SCLM) (O'Reilly and Griffin, 2010) will play an increasingly important role in terrane-to-province selection of target areas for mineral exploration.

Major lithosphere boundaries play a seemingly important role for the location of the deposits at the surface. Traditionally, potential field methods are employed to infer large-scale boundaries beneath cover. However, the limited depth constraint of these methods means that they are unable to provide insights into the transition from regional scale (several 100 km) prospectivity to the camp scale prospectivity (<10 km). Here, we show examples of the integration of magnetotelluric data and isotope geochemistry to constrain the location of crustal scale boundaries. We find that the upper crustal location of large-scale boundaries identified from potential field methods do not necessarily reflect the insights from MT and geochemical data.

METHOD

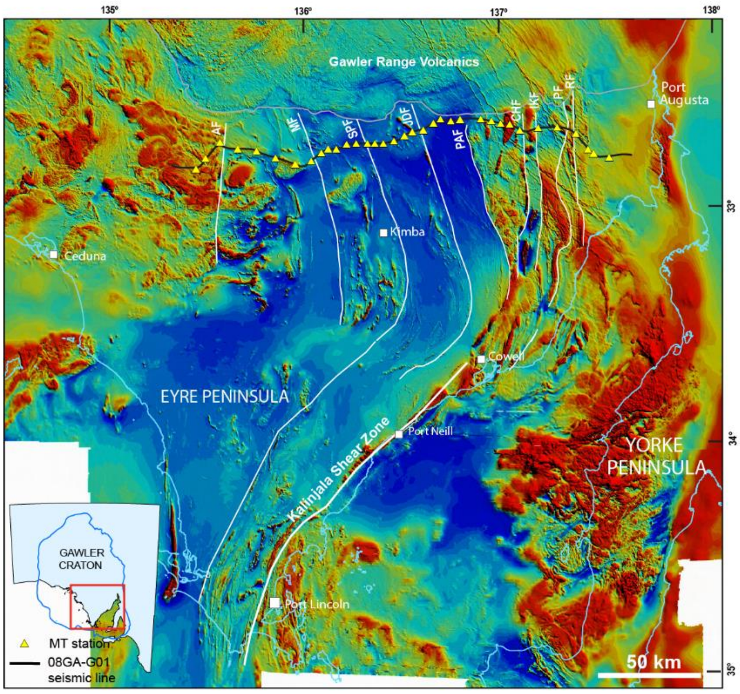

Figure 1: TMI image of the southern Gawler Craton, showing the major fault structures. AF=Allalone Fault, MF=Melaleuca Fault SPF=Shoal Point Fault, JDF=Jungle Dam Fault, PAF=Pickaxe Fault, CHF=Camel Hill Fault, IKF=Iron Knob Fault, PF=Pankalla Fault, RF=Roopena Fault

Magnetotellurics

The Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) uses long-period (5-20,000 s) (MT) data spaced every half degree latitude and longitude to map the electrical resistivity of the crust and mantle lithosphere. The project is designed to improve the understanding of the lithosphere as a primary control for mineral deposits. It is widely accepted that varying lithospheric strength plays a key role in localisation of deformation and channelling of magmatism and fluid flow in the crust and mantle.

Magnetotellurics is a passive electromagnetic technique measuring natural variations of the Earth's magnetic and electric field at the surface of the Earth (Cagniard, 1953). Interactions between the solar plasma with the Earth's ionosphere and magnetosphere (Frequency f< 10 Hz or its inverse period T>10 s) or global lightning activity (f>10 Hz) cause magnetic field variations, which act as a source for the induction of electric eddy currents in the Earth.

In the field, the MT systems sample time series of the horizontal electric field (E_x, E_y) and the three-component magnetic field (B_x, B_y, B_z), with (x, y, z) denoting geographic north, east, and vertically down, respectively. The time series is converted into the frequency domain using robust remote referencing processing schemes (Chave and Jones, 2012; Chave and Thomson, 2004). The frequency of the signal as well as the bulk resistivity of the subsurface determines the penetration depth δ of the signal via the skin-depth relationship (in m):

$$\delta = 503\sqrt{\rho \cdot T}$$

The complex ratio of the horizontal electric to magnetic field, as a function of period T, yields the impedance tensor Z via:

$$[E_x \quad E_y] = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix} \cdot \begin{bmatrix} B_x \\ B_y \end{bmatrix}$$

Each component of $Z = X + iY$ can be expressed as a magnitude ρ_a and phase ϕ as follows:

$$\rho_a = \frac{1}{\omega\mu_0}\left|Z_{ij}\right|^2$$

Where ω denotes the angular frequency, and μ_0 the magnetic permeability.

$$\phi = \tan^{-1}\frac{\Im Z_{ij}}{\Re Z_{ij}}$$

Where I and R denote the imaginary and real part of Z_{ij}, respectively.

Isotope mapping

Whole rock Nd isotope values of peraluminous granitoids derived from continental crust and metaluminous granitoids which assimilate material from the lower and mid-crust, can be used as a sampling tool to estimate the approximate age of the mid- to lower crust. The Nd model age T_{DM}(Ga) is a measure of the average length of time that a sample has been separated from the mantle. For a granitoid derived from the mantle, the model age gives the time of mantle fractionation of the mafic precursor. For a granitoid derived from a crustal source, the model age gives the average age that the precursor crustal material was derived from the mantle. For granitoids with a mixed source, the mantle model age is a mixing age of both the mantle and crustal components.

RESULTS

Areas of low mantle resistivity (<10 Ωm) at depths greater than 100 km occur beneath the Gawler Range Volcanics, a package of Mesoproterozoic volcanic rocks in the central Gawler Craton which are temporally and genetically linked to the IOCG deposits in the Olympic Province. This low resistivity anomaly suggests that widespread fertilisation of the inferred Archean-Proterozoic lithospheric core of the Gawler Craton has occurred. The lithosphere-asthenosphere boundary (LAB) beneath the Gawler Craton, derived from P- and S-wave arrivals, is on the order of ~200 km. A reduction in resistivity due to asthenosphere melts is not expected at the depth of the anomaly, and temperatures are not high enough for partial melts to occur. Instead a minor conductive phase in nominally anhydrous mantle rocks is the likely cause for a reduction in resistivity. The low resistivity region connects to the surface beneath/adjacent to the Olympic Province in the eastern margin of the Gawler Craton, and may represent a major lithospheric boundary. The Olympic Province is a region which hosts a number of IOCG deposits, including Olympic Dam, and, the conductivity anomaly suggests a causal link between mantle fertilisation and mineral enrichment in the crust.

In contrast, beneath the south-western region of the craton the electrical resistivity is high (>1000 Ωm) to depths exceeding 200 km. If the inferred mantle fertility beneath the central-eastern Gawler Craton is due to metasomatic input from an Archean or Proterozoic subduction setting, it did not have a pervasive effect on the SCLM of the western part of the craton. There is uncertainty about the location of the southern extension of this major lithospheric boundary on Eyre Peninsula, which has implications for the IOCG prospectivity of this region. A higher resolution analysis using the broadband MT transect 08GA-EG1 across the northern Eyre Peninsula reveals that the Mesoarchean basement of the Gawler Craton extends underneath the Hutchison Group located in the central Eyre Peninsula, which has embedded upper- to mid-crustal conductivity anomalies associated with the overlying Hutchison Group sediments. The discrete subvertical conductive fault structures in the upper and mid-crust connect to a conductive west-dipping decollement fault at depth, and is interpreted to represent an east-verging thrust system formed during the Kimban Orogeny. Based on the Nd isotope data the model ages of Palaeoproterozoic to Mesoproterozoic igneous rocks to the east of the Roopena Fault are significantly younger than those to the east of the Camel Hill Fault, predominantly ranging from 2.0 to 2.5 Ga, similar to the range of Nd model ages of Palaeoproterozoic igneous rocks to the east of the Kalinjala Shear Zone, which have Nd model ages of 2.0-2.9 Ga. The Roopena Fault is thus interpreted to represent the northern extension of the Kalinjala Shear Zone, separating a palaeo-suture juxtaposing a c. Mesoarchaean terrane from a c. younger terrane, and coincides with the western boundary of the Olympic Province.

CONCLUSIONS

We show that the location of mineral deposits is controlled by the lithospheric architecture in addition to near surface processes and fluid fluxes. In order to estimate the location of lithospheric boundaries controlling magmatic and fluid flux.

Taken together, these data support a hypothesis that links (i) magmatism derived from a metasomatically enriched, and therefore more evolved mantle, (ii) large-scale crustal contamination of syn-mineralisation mantle melt, and (iii) large-scale regional fluid pathways revealed in the 3D MT data to the IOCG mineralisation prevalent along the eastern margin of the craton.

ACKNOWLEDGMENTS

AusLAMP in SA is a collaborative project between the GSSA, the University of Adelaide and Geoscience Australia with funding from the GSSA's PACE Copper initiative, Geoscience Australia and NCRIS. Thank you to the core field team Philippa Mawby, Bruce Goleby and Geoff Axford and all other field crew for collecting the data, and to Goran Boren for instrument maintenance. The instruments were provided by the AuScope instrument pool. Thanks to landholders and traditional owners for allowing access to the lands and to Naser Meqbel for providing 3D grid software.

REFERENCES

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

O'Reilly, S.Y. and Griffin, W.L., 2010. The continental lithosphere-asthenosphere boundary: Can we sample it? Lithos, 120(1â€“2): 1-13.

Rawlinson, N., Salmon, M. and Kennett, B.L.N., 2014. Transportable seismic array tomography in southeast Australia: Illuminating the transition from Proterozoic to Phanerozoic lithosphere. Lithos, 189(0): 65-76.

Thiel, S. and Heinson, G., 2010. Crustal imaging of a mobile belt using magnetotellurics: An example of the Fowler Domain in South Australia. Journal of Geophysical Research, 115(B6): B06102-B06102.

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