Magnetotellurics and Airborne Electromagnetics – a combined method for assessing basin structure and exploring for unconformity-related uranium

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SUMMARY

Unconformity-type uranium deposits are high-grade and constitute over a third of the world's uranium resources. The Cariewerloo Basin, South Australia, is a region of high prospectivity for unconformity-related uranium. An airborne electromagnetic (AEM) survey was flown in 2010 using the Fugro TEMPEST® system to delineate the unconformity surface at the base of the Pandurra Formation. However highly-conductive regolith attenuated the signal in the northern and eastern regions, requiring application of deeper geophysical methods. In 2012 a magnetotelluric (MT) survey was conducted along a 110 km transect of the north-south trending AEM line.

MT data were collected at 29 stations and successfully imaged the depth to basement, and additionally providing evidence for deeper fluid pathways. The AEM data were integrated into the regularisation mesh as a-priori information generating an AEM constrained resistivity model and also correcting for static shift. The AEM constrained resistivity model best resolved resistive structures, allowing strong contrast with conductive zones.

Key words: Magnetotellurics (MT), electromagnetic induction, airborne electromagnetic (AEM), Cariewerloo Basin, uranium, unconformity

INTRODUCTION

Magnetotellurics is a passive, ground-based EM technique used to image the physical state of the crust and upper mantle, with relatively low-spatial sampling (Simpson and Bahr 2005, Chave and Jones 2012). Airborne Electromagnetics (AEM) has high-spatial sampling, and can resolve resistivity structures in detail to a depth of several hundred metres. However AEM inducing signals are strongly attenuated in regions of highly-conductive cover, reducing the depth to which resistivity structures can be imaged.

The Cariewerloo Basin, South Australia is prospective for unconformity-related uranium, in a style that is analogous to some of the world's largest deposits in the Athabasca Basin, Canada (Jefferson et al., 2007, Wilson et al., 2010). Such similarities include Palaeo-Mesoproterozoic unmetamorphosed sedimentary rocks which unconformably overlie deformed and metamorphosed Palaeoproterozoic and Archean basement; reactivated basement faults; and elevated uranium concentration in basement rocks (Cowley 1991, Jefferson et al. 2007). The Cariewerloo Basin displays the three criteria considered essential for unconformity related uranium mineralisation; U-rich Hiltaba Suite granites; oxidised red bed sandstone; and reactivated basement faults.

In 2010, four AEM survey lines were flown using the Fugro TEMPEST® system that successfully mapped areas of basement (down to 300 m) (Hutchinson and Costelloe 2010). However, in the northeast of the AEM survey area, significant amounts of conductive cover attenuated signal, leaving depth to basement unknown (Dhu, 2010). In this paper we show that the depth to basement and consequently the unconformity surface can be mapped using broadband MT, and that the resistivity models can be further enhanced by constraining the MT-derived resistivity values with the AEM inversion results from the top 300 m.

GEOLOGICAL SETTING

The Cariewerloo Basin (Figure 1) is a Mesoproterozoic intra-continental sedimentary basin which unconformably overlies the eastern margin of the Gawler Craton. The basin hosts the prospective Pandurra Formation; a thick succession of Mesoproterozoic unmetamorphosed and undeformed fluvial redbed sediments, overlain by Adelaidean sequences including the Tapley Hill Formation, Whyalla Sandstone and Quaternary Sediments which thicken towards the north (Cowley 1991).

METHOD

The MT method simultaneously records naturally-occurring time-dependent magnetic field fluctuations and the associated induced orthogonal electric current at the surface of the Earth (Simpson and Bahr 2005, Chave and Jones 2012). Electromagnetic responses can be recorded over a broad frequency range of 10^4 Hz to 10^{-4} Hz, dependant upon external quasi-uniform natural sources.

In 2012, 29 stations were deployed in a north-south transect extending for 110 km at the northern end of the AEM line 7000201 (Figure 1). The majority of the stations were spaced 1 km apart with six outer stations spaced 10 km. The geomagnetic north and east components of the electric and

magnetic fields were recorded for two days at a sample rate of 1000 Hz. Two orthogonal induction coils placed in a geomagnetic north-south and east-west arrangement recorded the magnetic field data. The electric field data were captured by an L-shape dipole configuration using three non-polarising Cu-$CuSO_4$ electrodes with an average dipole length of 50 m which were aligned to geomagnetic north and east.

Coherent time series windows were selected and processed using a robust, remote-referencing code (Chave and Thomson 2004). Impendence tensors were generated for 46 frequencies over a bandwidth of 200 Hz to 0.002 Hz, which were then used to calculate apparent resistivity and phase curves. The data produced were continuous, consistent and of good quality, relatively free from cultural noise. At some locations, noise was evident at 50 Hz and harmonics, which have been correlated with domestic electric fields from generator and/or powerlines. These noise sources have been removed using notch filters.

Strike analysis of the sub-surface electrical current indicated two dominant bandwidths. Shorter periods were randomly orientated, showing no clear correlation. This is typical of a 1D environment. Longer periods exhibited geoelectric strike converging at 45° or 135° east of geographic north (there is a 90° ambiguity). Since the observed geological strike of the eastern margin of Gawler Craton is 135° east of geographic north, data were processed with the geoelectric strike at 135°.

Phase tensor pseudosections, not susceptible to near surface distortion, appeared to divide the data into three horizontal regions. Short periods demonstrated little skew and ellipiticity indicating a 1D environment, long periods (0.853-20.5 s) showed elongated ellipses suggesting conditions became more 2D and possibly 3D at depth. Further analysis of the longer periods show the skew is generally ~3° and ellipticity less than 0.1 indicating mostly 2D effects with some minor 3D effects at very long periods. These findings for long period are consistent with the strike at the edge of the eastern Gawler Craton, representing the contact between the resistive Archaean core and the more conductive Proterozoic fold belt (Heinson et al. 2006). For the majority of the bandwidth, data are consistent with shallow 1D structure with some 2D effects caused by basin sediment and basement topography, indicating 2D analysis is valid.

RESULTS

The Cariewerloo MT data set was inverted and modelled using the OCCAM2D algorithm of de Groot-Hedlin and Constable (1993) which uses an over parameterised model scheme seeking the smoothest possible model at a given level of misfit. It uses the finite element forward code of Wannamaker et al. (1987) for 2D MT modelling.

The MT inversion model has an RMS error of 2.74 and roughness of 575. The inverted AEM data were incorporated as a-priori information into the MT model before the inversion process in the form of a prejudice file. Various inversions were run incorporated the AEM data at varying depths and weightings. The optimal parameters were determined to be a depth of 500 m and a weighting (tau value) of 1 producing a model with an RMS misfit of 2.5 and roughness of 167.

DISCUSSION

Figure 2 shows the AEM constrained MT inversion. It shows good agreement between the MT and AEM with both showing similar conductivity values. The MT model provides new information about the conductivity structure below the AEM line. The AEM-MT model in Figure 2 shows a conductive surface layer ~50 m thick; a resistive intermediate layer of varying thickness 30-500 m; and a basal more-conductive layer over significantly more resistive basement. Two vertical regions of lower conductivity correlate to regions in the AEM data interpreted as faults.

A geological interpretation, constrained by drill hole data, is superimposed on the AEM-MT model in Figure 2. The surface layer is interpreted to be a combination of Quaternary and Adelaidean sediments which are conductive due to the high salt content and pore fluids. The intermediate resistive layer below this correlates to the Pandurra Formation which increases in thickness as it gently dips towards the north. The basal conductive layer is associated with an alteration zone at the base of the Pandurra Formation which is interpreted to be the unconformity surface.

The MT models identify the unconformity surface and two faults which are potential fluid pathways. However the mesh cell size of 40 m is too large to identify potential alteration halos which are on the order of 25 m (Tuncer et al., 2007). Closer spaced stations such as that of 300 m used by Tuncer et al. (2007) in the Athabasca Basin provided much finer spatial resolution compared to the 1000 m station spacing used here. However as a greenfields exploration, MT and AEM datasets identified the unconformity surface and faults and highlighted areas for further investigation.

The highly conductive upper crust overlying a resistive basement and is consistent with previous deep MT soundings in the Gawler Craton (Heinson et al. 2006, Maier et al. 2007, Thiel and Heinson 2010). Structures in the deeper crust suggests the presence of highly resistive (>10 000 Ω.m) crustal blocks divided by marginally less resistive regions. These higher conductivity regions are possibly the basement expressions of faults, and alteration due to prior fluid flow events. The intersection of these potential flow paths with the sediments may be potential targets for uranium exploration.

CONCLUSION

MT is an effective tool for mapping depth to basement in regions of conductive cover. The MT model has good agreement with the AEM resistivity model indicating the two can be successfully integrated. The AEM-MT model was considered the most geologically plausible. The models showed a highly conductive layer at ~500 m associated with the unconformity surface. Two fault structures offset the resistivity layers, providing potential fluid pathways. Additionally, MT data provided new information about deeper crustal heterogeneity, showing highly resistive blocks bordered by less resistive zones indicative of fossil fluid pathways.

ACKNOWLEDGMENTS

The author would like to acknowledge the advice and support received from the University of Adelaide geophysics staff and students, in particularly Dr Jared Peacock for his assistance in fieldwork and MT processing. From the Geological Survey of South Australia, Tania Wilson for the access to resources. Published with the permission of the Chief Executive Officer, Geoscience Australia.

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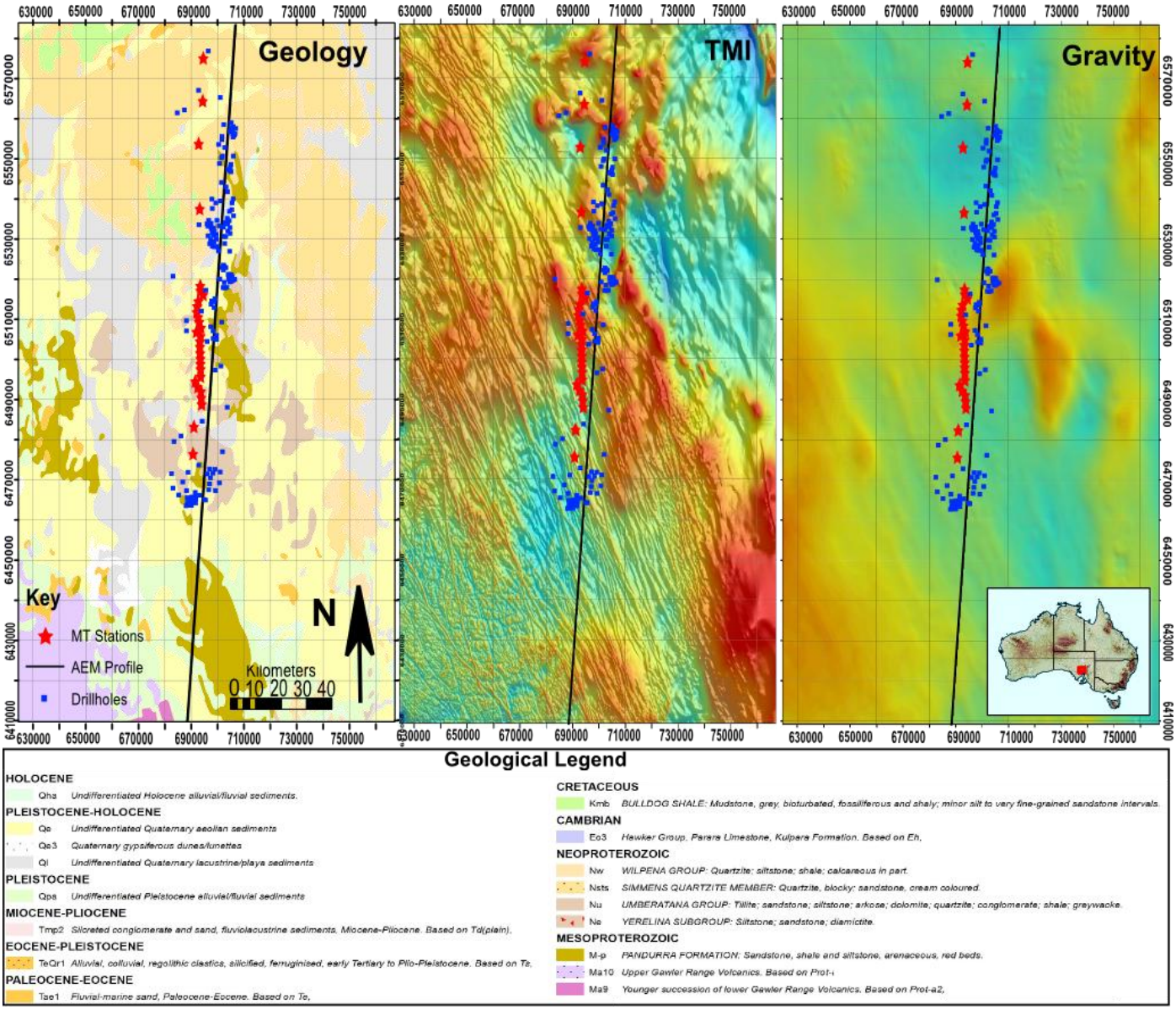

Figure 1 Geological, gravity and magnetic (TMI) maps of the Cariewerloo Basin, South Australia, overlain with AEM survey line 700201 (black line), 29 MT stations (red stars), drill holes within a 13km radius of the AEM line (blue dots). The MT survey line consists of 29 broadband MT stations recording at 1000 Hz for two days. Inset: Map of Australia showing the map extent in red.

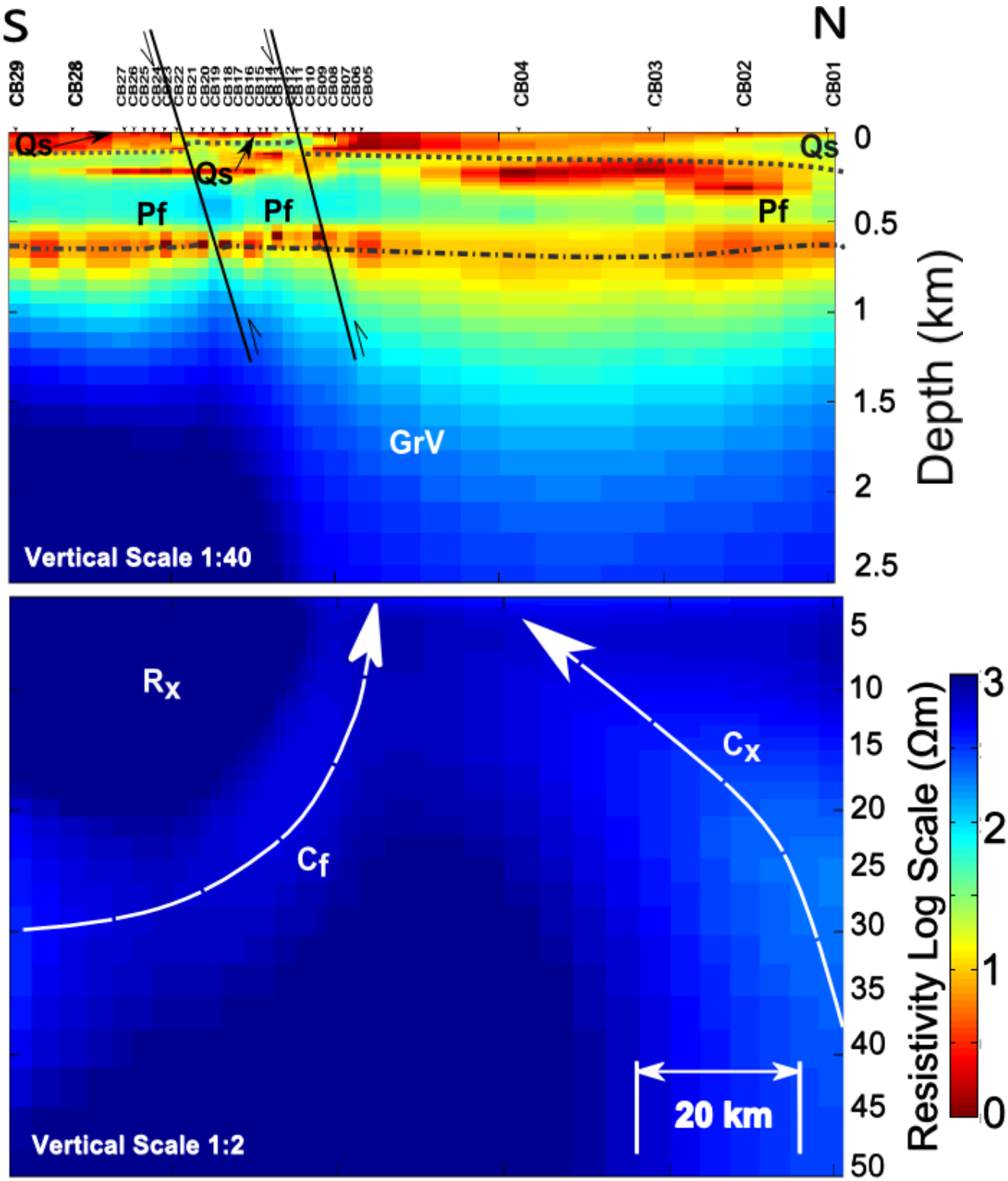

Figure 2 A geological interpretation overlain onto the AEM constrained MT model which uses the AEM as a-priori information. The shallow interpretation consists of conductive layer, Qs, which are the Quaternary sediments and Adelaidean Sequences which contain high amounts of salt. Pf is the Pandurra formation which is resistive sandstone, GrV are the resistive Gawler Range Volcanics and also includes deeper crystalline basement. Rx is an anomalous resistive body and Cf and Cx are regions of lower resistivity thought to be palaeo fluid paths. Two thrust faults are observed, F1 and F2, which offset layers Cs1 and Pf. The unconformity surface is highlighted by the dashed line.