Uncovering the Musgrave Province in South Australia using airborne EM

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SUMMARY

Two airborne electromagnetic (AEM) surveys were undertaken in the Musgrave Province in South Australia in 2016 with the objective to increase knowledge about cover characteristics, thereby helping reduce exploration risks and to gain an understanding of the groundwater resource potential of the area. The Province is highly prospective for magmatic Ni-Cu-PGE and IOCG deposits, where a transported regolith imposes a significant challenge to exploration. Effective exploration through this region requires an understanding of that cover, its character and its spatial variability. This cover is also a source of groundwater that supports community and environment but our understanding of this resource is compromised by the limited information we have about it.

Two different systems, TEMPEST and SkyTEM, were used for the survey, each covering around 8000 line km with a line spacing of 2 km. The line spacing was deliberately chosen to provide a spatially coherent picture of the subsurface conductivity structure, particularly the buried palaeovalleys known to be present in the region. The two datasets were processed and inverted and the results assessed against known information from drill holes. Both systems map the palaeovalley systems in the area well and provide information about the location and geometry of these. Furthermore the results indicate that it is possible to map variability within the cover using AEM, as well as structural controls on the orientation of the palaeovalleys. Airborne electromagnetic surveys used in logistically challenging areas can therefore be a useful mapping tool for areas with varied but unknown cover sequence thickness and thereby reducing exploration risks, as well as increasing the information content about groundwater resources.

Key words: Musgrave Province, palaeovalleys, airborne electromagnetics, TEMPEST, SkyTEM

INTRODUCTION

The presence of a thick and complex cover across many parts of Australia represents an impediment to effective and efficient mineral exploration. An example of such a region is the Musgrave Province of South Australia, a terrain highly prospective for magmatic Ni-Cu-PGE and IOGC deposits. Here the transported regolith cover imposes a significant risk and challenge to explorers, and effective exploration through this region requires an understanding of that cover, its character and spatial variability. This cover is also a source of groundwater that supports community and environment but our understanding of this resource is compromised by the limited information available about it, including character and variability of aquifers, recharge rates and the quality of water they contain. The Goyder Institute's (www.goyderinstitute.org) Facilitating Long-Term Outback Water Solutions (G-FLOWS) Project was established to help address this issue.

The Musgrave Province has been subject to review from a hydrogeological perspective (see, for example, Tewkesbury and Dodds 1997; Watt and Berens 2011), and this current study is an extension of work detailed by Munday (2013) where local-scale legacy airborne electromagnetic (AEM) data, undertaken for exploration, was used to define conductive palaeovalley fill, and a complex palaeo-drainage system in the Musgraves Province. That study, which employed limited geophysics (notably airborne electromagnetic (AEM) data sets) acquired by explorers, coupled with limited exploratory drilling has confirmed the presence of a spatially complex buried inset palaeovalley system. These systems contain a groundwater resource of variable quality (100 - >20,000 mg/L TDS, with higher salinities observed in the deeper sediments of the buried palaeovalley system. Using AEM for mapping palaeovalleys is not a new concept, the technique has successfully been applied for both Uranium exploration and groundwater mapping for years (see, for example, Dentith and Randell 2003; Roach et al. 2014).

Two regional AEM surveys were undertaken across the Province involving the TEMPEST high moment fixed-wing time-domain EM system (western part) and the SkyTEM$^{312\mathit{FAST}}$ dual moment helicopter time-domain EM system (eastern part). In excess of 16000 line kilometres were acquired with a nominal line spacing of 2 km, orientated N-S. The data from the two surveys were processed and inverted using the Aarhus Workbench platform and the AarhusInv inversion algorithm (Auken et al. 2015). Analysis of the results reveals highly variable cover and a complex series of drainage systems with a notable litho-structural control on their orientation and distribution. These palaeovalleys are obscured by a valley-fill of Pliocene to Pleistocene sediments and overlying Quaternary sand dunes. In the eastern region the observed conductivity structure suggests that this fill comprises a stratified aquifer system, which is supported by drilling.

STUDY AREA

The Musgrave Province, located in the far north west of South Australia (Figure 1), is a region of Mezo-Proterozoic crystalline basement, consisting mainly of the amphibolite and granulite facies gneisses intruded by mafic – ultramafic dykes and granitoids, and dolerite dyke intrusions. East west trending major shear zones are seen throughout the area possibly occurring during the Musgravian Orogeny with later reactivation during the Petermann Orogeny (Constable et al. 2005). The Giles Complex (mafic to ultramafic layered intrusions) is the main focus for Ni-Cu mineralisation in the area where a series of vertically stacked dykes acts as potential traps for Ni-Cu sulphides (Glickson et al. 1996). Basement outcrops as isolated hills and ranges but other areas are covered by regolith. Groundwater is present in weathered and fractured basement sections, in buried palaeovalleys (sand, silts and clay), in calcretes and sediments consisting of alluvial, fluvial and Aeolian deposits (Watts and Berens 2011). The deep palaeovalley systems throughout the area (presented schematically in Figure 2) are known to be present from limited drilling. However the geometry and extent is covered by valley fill of Pliocene to Pleistocene sediments as well as overlying Quaternary sand dunes.

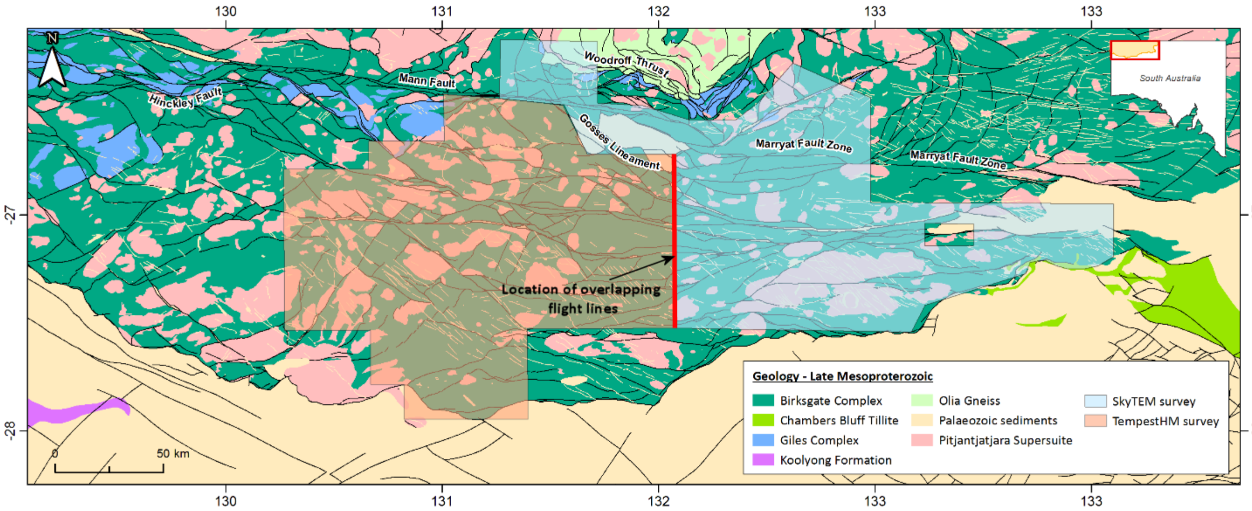


Figure 1. Location of the TEMPEST (western) and SkyTEM^{312} (eastern) surveys in the Musgrave Province that forms part of this study.

METHOD AND RESULTS

Two different AEM systems were used for the acquisition of the data in this study. The fixed-wing high moment system - TEMPEST (western part), and a heli-borne dual-moment system - The SkyTEM$^{312\mathit{FAST}}$ system (eastern part). The two surveys covered 8595 and 8800 line kilometres respectively, and were both flown N-S with a line spacing of 2 km. Where the two surveys join, one line was flown with both systems (see Figure 1 for location). The large area that these surveys cover have a varied conductivity structure as both regolith cover and outcropping basement is present. Particularly in areas of limited cover the AEM signal is disturbed by noise – i.e. the signal to noise ratio is low. This impacts the resulting conductivity-depth models as small parts of the survey area are too noisy to gain anything useful from the AEM data. Also the area is impacted by induced polarisation effects, seen quite readily in the AEM data as negative values at late times.

Using two very different AEM systems in the same area does raise the question whether outputs from these systems are comparable. The overlapping line (see Figure 1 for location), where the two surveys meet, provides an opportunity to assess whether data from two different systems give similar conductivity-depth models. Here we have used AarhusInv (described by Auken et al. 2015), a full non-linear inversion algorithm, for the inversion of data from each systems using a smooth layered conductivity-depth structure. More specifically a 30 layer model with layer thicknesses logarithmically increasing, starting at 2m to a depth of 300m. Before the inversion of the data a full processing and assessment of the data was undertaken using the Aarhus Workbench software package. This allows a thorough investigation of the data, noise assessment and removal, and applying filters to the data if needed.

The models from the two systems (Figure 3) for the overlapping line shows very similar results in terms of mapping of the location and geometry of the palaeovalley systems for this particular line. The relatively high conductivity of the palaeovalley fill compared to the surrounding bedrock makes these good AEM targets. The main difference between the two sections are observed in mapping of the variation within the paleovalleys themselves. Both systems identify the extent and depth of the conductive cover, but the results from the SkyTEM survey indicates that the fill is not one homogeneous layer but that it contains variations relating to lithology changes (Figure 3; 8000m – 14000m), something that information from drilling also confirms in other parts of the survey area (Figure 4).

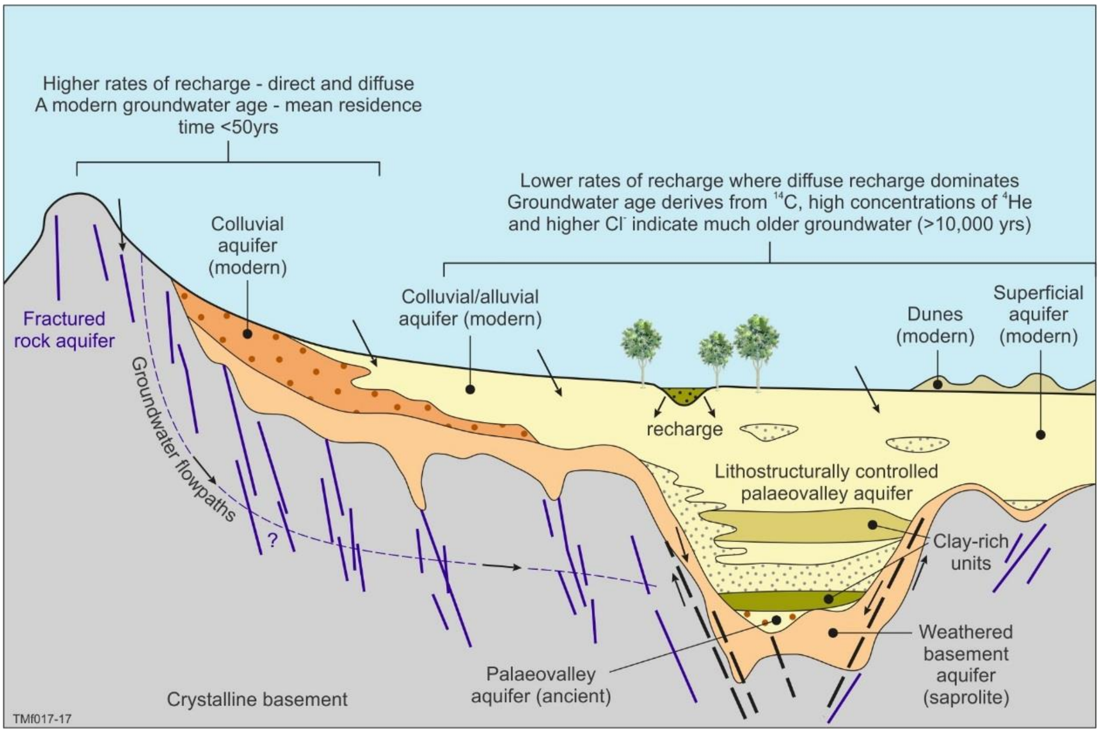
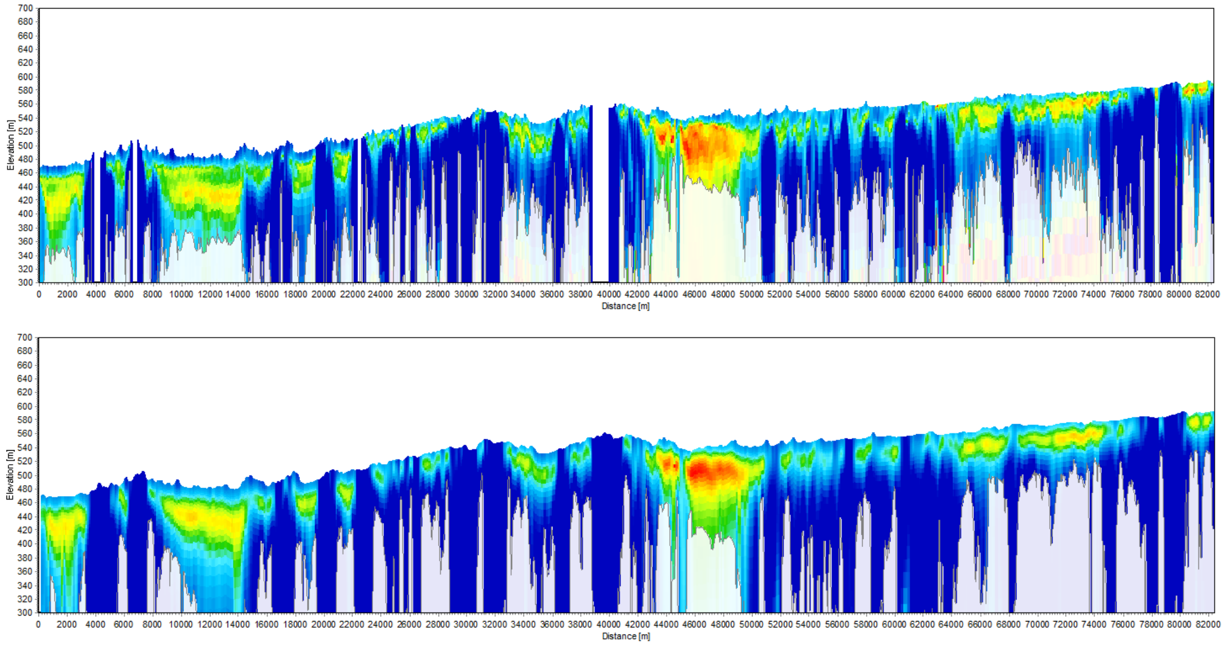


Figure 2. Schematic hydrogeological conceptual model showing a typical palaeovalley drainage system in the Musgraves (adapted from M. Gogoll, DEWNR).



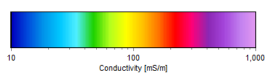


Figure 3. Conductivity-depth sections for the coinciding line of SkyTEM (top) and TEMPEST (bottom), displayed from South to North. Greyed out areas indicate the defined depth of investigation (DOI) determined through the inversion process.

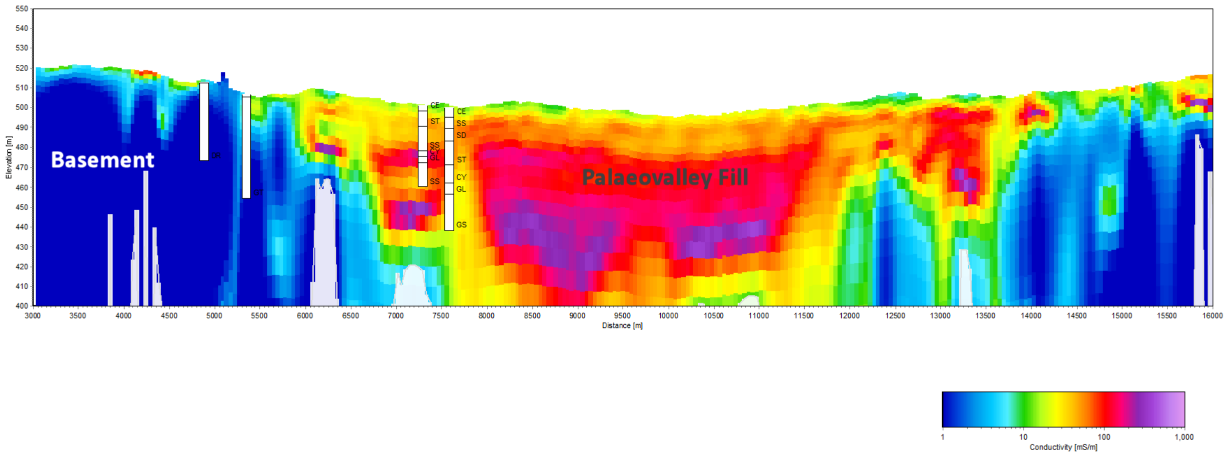


Figure 4. SkyTEM line shown with existing lithological drill hole information. The variation detected by the SkyTEM system within the palaeovalley fill is also seen in the lithological logs. The high conductivities correlate with clays and gravel in the logs.

CONCLUSIONS

Data from two AEM surveys acquired in the Musgrave Province in South Australia have been inverted using the same inversion platform (AarhusInv) for both surveys. The results from the inversion of each of the TEMPEST and the SkyTEM dataset indicates that both effectively define the cover, which is relatively conductive, and map palaeovalley systems in this area, particularly the location and geometry of these systems. The spatial complexity in the cover of the Musgrave Province can to some extent be mapped with the techniques (not shown here) and these can therefore assist in providing an effective framework for significantly enhancing our understanding of the region's groundwater resource potential; important for communities, industry and the environment. The potential to map variations within the palaeovalley itself can also be useful for assisting in locating compartmentalised aquifers particular in areas with limited drilling, due to remoteness and high mobilisation costs. Gaining an understanding of the cover thickness and spatial variability will also help reduce exploration risks in the area.

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REFERENCES

Auken, E., Christiansen, A. V., Kirkegaard, C., Fiandaca, G., Schamper, C., Behroozmand, A. A., Binley, A., Nielsen, E., Effersø, F., Christensen, N. B., Sørensen, K. I., Foged, N., and Vignoli, G., 2015, An overview of a highly versatile forward and stable inverse algorithm for airborne, ground-based and borehole electromagnetic and electric data. Exploration Geophysics, 46, 223-235.

Constable, S., Fairclough, M. and Gum, J., 2005, Nickel mineralisation models in the Fowler Domain and Musgrave Province – applying the Thompson Nickel Belt as an analogue. MESA Journal, 39.

Dentith, M. and Randell, M., 2003, Sandstone-type uranium deposits in South Australia and North America; a comparison of their geophysical characteristics. In "Geophysical signatures of South Australian mineral deposits" edited by Dentith, M.C., University of Western Australia, Centre for Global Metallogeny, 31, 233-247.

Glickson, A.Y., Stewart. A.J., Ballhaus, C., Clarke, G.L., Feeken, E.H.J, Level, J.H., Sheraton, J.W. and Sun, S.S., 1996, Geology of the western Musgrave Block, central Australia, with particular reference to the mafic-ultramafic Giles Comlex. AGSO Bulletin, 239.

Munday, T., 2013, The role of airborne geophysics in facilitating long-term outback water solutions to support mining in South Australia. ASEG Extended abstracts.

Roach, I.C., Jaireth, S. and Costelloe, M.T., 2014, Applying regional airborne electromagnetic (AEM) surveying to understand the architecture of sandstone-hosted uranium mineral systems in the Callabonna Sub-basin, Lake Frome region, South Australia. Australian Journal of Earth Sciences, 61, 659-688

Tewkesbury, P. and Dodds, A.R., 1997, An appraisal of the water resources of the Musgrave Block, South Australia, Dept. Mines and Energy Resources Geological Survey South Australia Report Book 97/22.

Watt E.L. and Berens V., 2011, Non-prescribed groundwater resources assessment – Alinytjara Wilurara Natural Resources Management Region. Phase 1 – Literature and Data Review, DFW Technical Report 2011/18, Government of South Australia, Department for Water, Adelaide.