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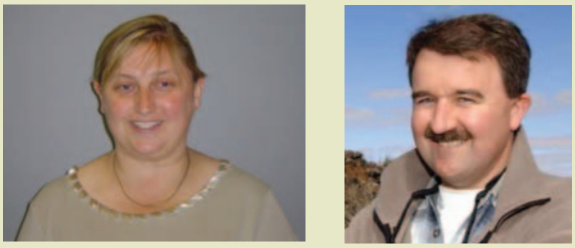
The Frome airborne electromagnetic survey: uncovering 10% of South Australia



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Introduction

The Frome airborne electromagnetic (AEM) survey was acquired by Geoscience Australia (GA) under the Australian Government's Onshore Energy Security Program (OESP). This area is considered to have great potential for uranium mineralisation and includes Australia's only two producing *in situ* leach uranium mines, Beverley and Honeymoon. In contrast to deposit-scale investigations carried out by industry, the Frome AEM survey was designed to reveal new geological information at a regional scale, reducing exploration risk, stimulating exploration investment and enhancing the prospectivity within the region primarily for uranium, but also for other commodities including copper, gold, silver, lead, zinc, iron ore, coal and groundwater. The Frome AEM survey (Figure 1) was flown by Fugro Airborne Surveys for GA, using the TEMPEST™ time-domain AEM system.

In this article we discuss a selection of the Geoscience Australia Layered Earth Inversion (GA-LEI) products that are now available from the GA website free of charge. The inversion data and derived products reveal new geological information including facies changes associated with uranium mineralisation, structures related to uranium and gold mineralisation, palaeovalley architecture, geological surfaces and geology 'under cover'.

AEM system selection and survey design

Geoscience Australia selected the TEMPEST™ system to fly the Frome AEM survey from the various candidates submitted by members of the Panel of AEM contractors after an assessment of the probability of detecting 'type' geological targets in the presence of typical background geology. In this methodology (Green and Lane, 2003) a geological scenario representing the likely background and target conditions is defined and then transformed into an equivalent geo-electric model. From forward model responses, with and without the target unit present, an anomalous response is determined. Then, using the estimated system noise levels, the anomalous response is converted to an anomaly-to-noise ratio, from which a probability of detecting the presence of the target can be derived.

While the usefulness of this method is strongly dependent on the assigned conductivities and system noise levels, it does give an objective measure of system suitability for a particular exploration task. The assigned system noise levels for each AEM system were those specified as maximum allowable noise levels in the Deed of Standing Offer with the GA AEM panel contractors. These are determined from sample high-altitude and repeat-line data (Green and Lane, 2003) provided to GA as part of the requirement of becoming a member of the contractor panel. The geo-electrical models were synthesised from prior knowledge of conductivity ranges for the targeted geological units.

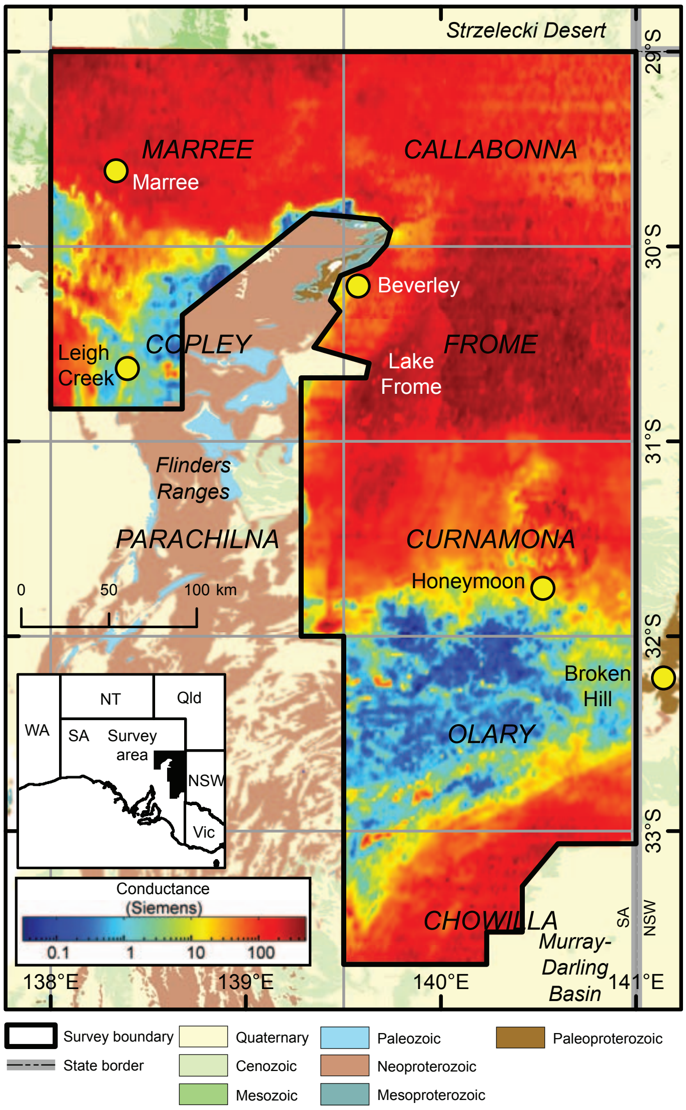

Fig. 1. *The Frome Survey area highlighted with an image of the estimated conductance to 200 m depth and 1:250 000 map sheet names. Geoscience Australia funded 5000 m line spacing across the entire survey and a large infill area at 2500 m line spacing. The Department of Manufacturing, Innovation, Trade, Resources and Energy South Australia (DMITRE) and a consortium led by Callabonna Uranium Ltd. funded infill areas at 2500 m line spacing.*

The geological scenarios representing the aims of the survey can be grouped into three main geo-electric models:

1. Model 1: Sandstone Systems – Paleochannel style; mapping paleovalley architecture.
2. Model 2: Structures – mapping offsets between rock units particularly associated with uranium or other mineralisation.
3. Model 3: Depth of cover – mapping depth to 'mineralised units' and depth to basement.

When all scenarios were deemed of equal relevance, and when other survey factors were taken into account (such as survey logistics, availability, safety and cost), the TEMPEST™ system was assessed as most likely to be effective in the Frome AEM survey area.

Survey boundaries were determined by considering cultural, geological, geophysical, remote sensing and topographic data with the forward-modelling results. Flight line spacing was determined by assessing the extents of known geological units, structures and mineralisation and by assessing the expected footprint of targets. The Frome survey was flown with east–west flight lines spaced at 2500 m and 5000 m, at a nominal 100 m above ground level totalling 32 317 line km of data. The completed survey area was 95 405 km^2, covering 10% of South Australia.

The GA-LEI results

The data from the Frome AEM survey were inverted using the GA-LEI (Brodie and Sambridge, 2006) to create subsurface conductivity models and products, referred to as Phase-2 data (Hutchinson *et al.*, 2011). In previous GA regional AEM surveys, such as Paterson (Roach, 2010) and Pine Creek (Craig, 2011), the data were inverted solely using a GA-LEI sample-by-sample (SBS) inversion algorithm, which inverts each sample independently of its neighbours. For the Frome AEM survey, GA released conductivity models using both the GA-LEI SBS inversion and a laterally constrained line-by-line (LBL) inversion. A detailed description of the LBL inversion algorithm can be found in Brodie and Sambridge (2009) and Brodie (2010). A brief explanation is given below.

The LBL inversion algorithm is based on the same layered earth structure as the SBS inversion, but applies additional lateral constraints. The LBL inversion uses the principle of fitting layered earth conductivity values to match the measured AEM data including the vertical smoothness and reference model constraints. However, a whole line of data is inverted at once using a cubic-spline parameterisation of the conductivity of each layer and each system geometry parameter. This allows along-

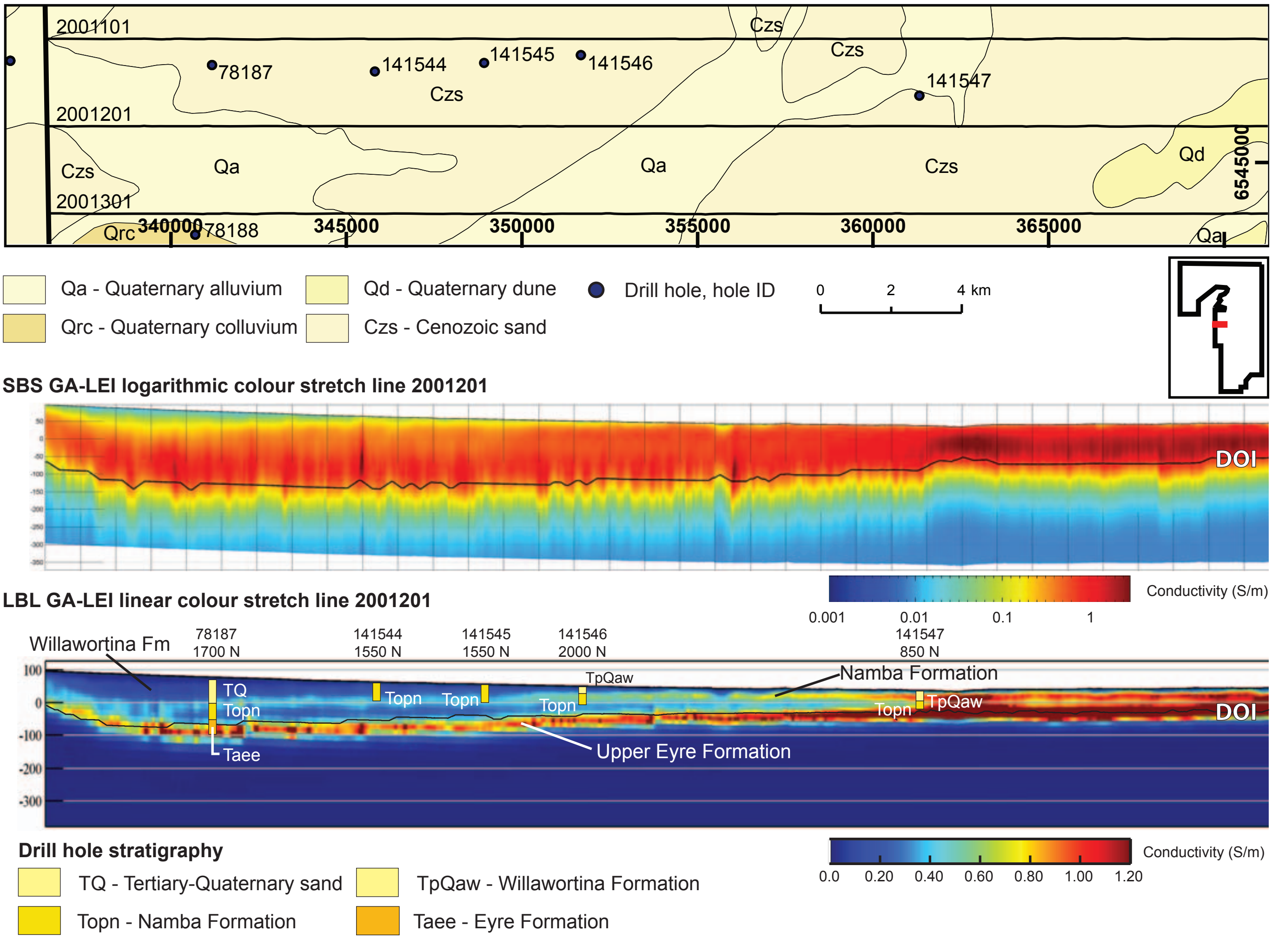

Fig. 2. *Example of surface geology (top), sample-by-sample (SBS) (middle) and line-by-line (LBL) (bottom) inversion products for line 2001201 in the southwestern Lake Frome area. Here, relatively weak to moderate conductors (Namba and Eyre formations) overlie resistive Cambrian basement. The linear colour stretched LBL inversion conductivity section defines the different units in the stratigraphy much more successfully than the logarithmic colour stretched SBS inversion conductivity section, as shown by drill hole logs on the LBL inversion conductivity section (bottom). Drill hole stratigraphic logs are marked with the SARIG drill hole ID and distance in metres north (N) of the flight line.*

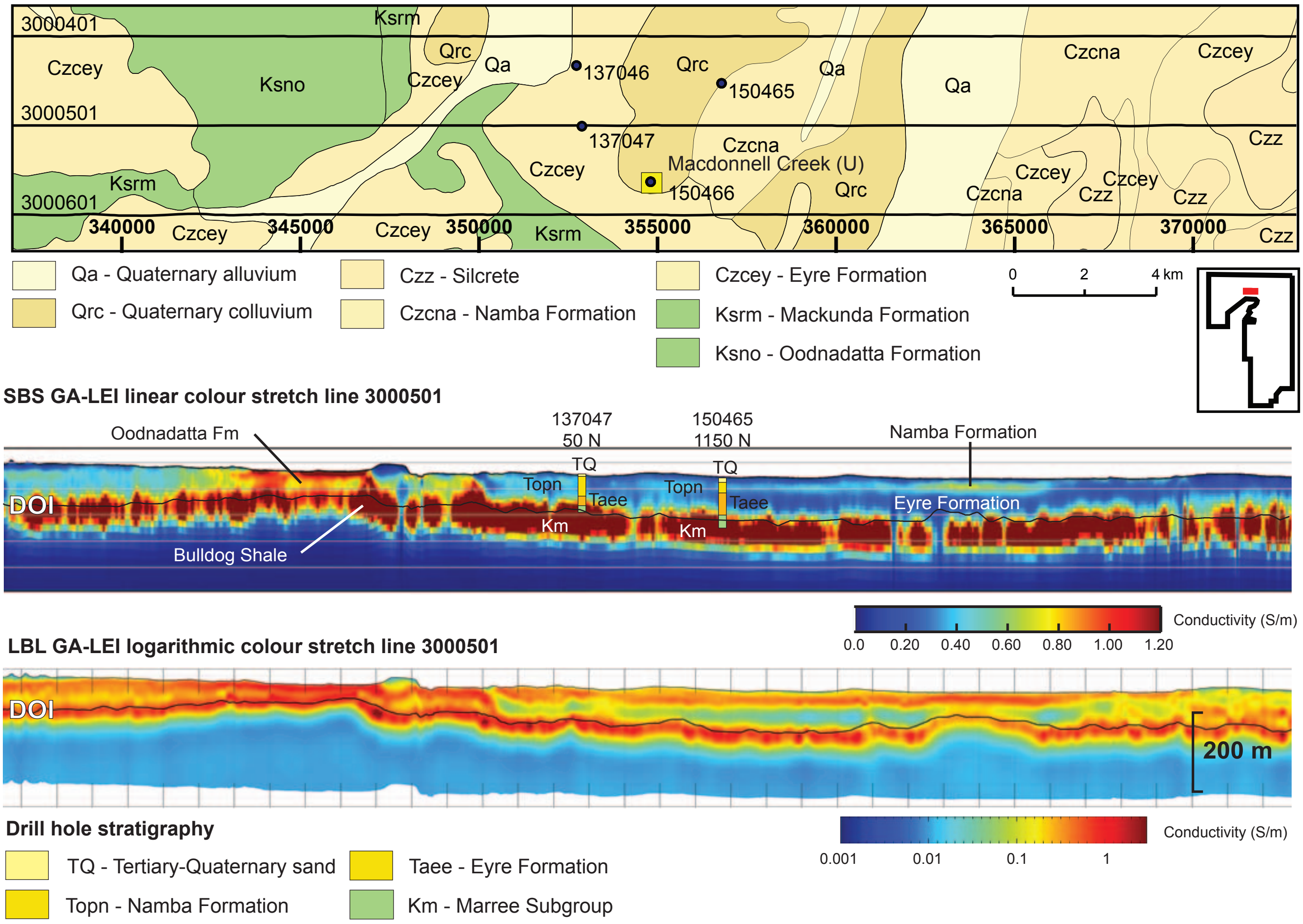

Fig. 3. *Example of surface geology (top) sample-by-sample (SBS) (middle) and line-by-line (LBL) (bottom) inversion products for line 3000501 on the flank of the northern Flinders Ranges. Here, relatively weak to moderate conductors (Namba and Eyre formations) overlie highly conductive Mesozoic basement (Marree Subgroup, including the Bulldog Shale, Mackunda Formation and Oodnadatta Formation). The linear colour stretched SBS inversion conductivity section has been used here to map the top of the Bulldog Shale (basal conductor) and distinguish it from the overlying Oodnadatta Formation. The linear colour stretched LBL inversion can be used to define the top of the Marree Subgroup and top of the Eyre Formation. Drill hole stratigraphic logs are marked with the SARIG drill hole ID and distance in metres north (N) of the flight line.*

line smoothness and continuity constraints to be applied. The solution at a particular sample is influenced by its neighbours.

The horizontal smoothness of the model has the advantage of enhancing layered geological features, making such features more continuous and clearly defined. This smoothing also helps to reduce the one-dimensionality of the SBS inversion, and allows the model to give appropriate weighting to data trends in either a vertical or horizontal direction. Likewise, horizontal smoothing can effectively attenuate discontinuous features in the data, such as discrete conductors. Discontinuous features may still be present in the data, but their magnitudes will be underestimated because of the numerical tendency to reduce the conductivity gradient between neighbouring data points. Examples of SBS and LBL conductivity sections are given in Figure 2 and 3, highlighting the efficacy of each in different parts of the survey area. Figure 2 shows the LBL defining the target stratigraphy more successfully than the SBS inversion. Figure 3 shows the SBS defining the target unit more effectively.

The maximum depth at which the inversion is influenced more by the conductivity data than the reference model is known as the depth of investigation (DOI). The DOI for the SBS inversion was calculated using a variation on the method of Christiansen and Auken (2010). The LBL inversion DOI was calculated based on the method of Oldenburg and Li (1999). The DOI is represented as a black line in the Phase-2 conductivity section products and is utilised as a reliable depth of conductivity results in interpretations. The DOI is also gridded (see Hutchinson *et al.*, 2010) and used as a cutting tool to null data below the DOI in depth and elevation slices to avoid over-interpretation.

Implications for exploration

The outcomes of the Frome AEM survey include mapping of subsurface geological features that are associated with uranium mineralisation including sedimentary facies changes, palaeovalley and basin architecture, faults involved in preserving uranium deposits and depth of cover. The products are also suitable for interpretation focussed on other commodities including metals, coal and groundwater, as well as for landscape evolution studies. The improved understanding of the regional geology for an area that covers approximately 10% of South Australia will be of considerable benefit to mining and mineral exploration companies.

The Frome AEM survey results illustrate a significant improvement in mapping conductivity in greater detail and identifying features such as unconformities (e.g. Benagerie Ridge surface), paleovalleys (e.g. Yarramba and Billeroo palaeovalleys) and major structures (e.g. range front faulting around the northern Flinders Ranges and the Redan Fault Zone in the Murray-Darling Basin) in the Lake Frome area at much greater extent than previously realisable. The Frome AEM survey results demonstrate the effectiveness of AEM for regional geological mapping.

Geoscience Australia Frome AEM survey data releases

Frome Phase-1 TEMPEST™ data and processing report. The complete TEMPEST™ data set and processing report are available for download from the web:
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71624

Frome Phase-2 TEMPEST™ GA-LEI 30 layer inversion data and products to 400 m are available for download from the web:
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=72589

Frome Phase-2 TEMPEST™ GA-LEI 30 layer inversion data and products to 200 m are available for download from the web:
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=73838

Frome Embayment AEM Phase-1 and Phase-2 TEMPEST™ data for the Callabonna Uranium infill area, SA are available for download from the web:
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=73839

Frome Interpretation Report. An interpretation report (Roach, 2012) released at the AusIMM Conference in June 2012 is now available for download from the web:
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=73713

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