



Determining cover variability in the Capricorn Orogen with airborne EM

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SUMMARY

This paper focuses on elucidating cover variability throughout the Capricorn Orogen in Western Australia. We use, as a baseline, data from a widely spaced airborne electromagnetic (AEM) fixed-wing survey acquired for the Geological Survey of Western Australia in 2014. The Capricorn 2013 AEM survey is the largest AEM survey by area flown in Australia to date, covering over 146 300 km². The Capricorn Orogen is a highly mineral prospective under explored orogeny located between the Pilbara and the Yilgarn Craton. Whilst the western part of the Orogen is particularly well exposed, and as a result the surface geology, geological history tectonic setting is well understood, the north west and eastern regions are characterised by a variably thick and complex regolith. The region is relatively under-explored, although host to significant mineralisation, including mesothermal orogenic gold, copper–gold volcanogenic massive sulphides, and channel iron ore deposits. In a region of variable cover, geophysical (aeromagnetic, electromagnetic and gravity) and geochemical techniques are critical aids to the mapping of lithostratigraphic units that are covered by regolith materials, but also in providing an understanding of the regional geological factors that control the mineralisation. Here we discuss some initial results from the smooth model layered earth inversion of 30,119 line km of AEM data. We consider sections from geologically contrasting parts of the Orogen. The results show the complexity and variability of conductive cover in the region and suggest some areas in the orogen could be beneath 200m of transported and in-situ regolith cover. The regional regolith framework that is being developed from the AEM data will provide a basis for better understanding and interpreting regolith geochemistry that has been acquired across a region, particularly where outcrop is limited.

Key words: Capricorn Orogen, Airborne EM, Regolith cover, Mineral exploration.

sedimentary gneisses. In the east, the province is overlain by numerous low- to medium-grade meta-sedimentary basins. The orogen records a complex tectonic history including over one billion years of episodic reworking between two ancient cratons: the Pilbara Craton to the north and the Yilgarn Craton to the south. (Johnson *et al.*, 2013). Whilst the western and central parts of the Orogen are particularly well exposed, the north west and eastern regions are characterised by a variably thick and complex regolith, much of it transported cover (Figure 2).

Apart from the high-grade iron ore in the Hamersley Ranges (outside and to the north of the survey area), the area contains the Paulsens Gold Mine (Northern Star Resources) and the DeGrussa copper-gold deposit in Sandfire Resources' Doolgunna Project area. There are also numerous small-scale deposits that comprise a wide range of commodities and the area remains a prospective greenfields exploration region.

In complex geological settings with a variable cover, regional-scale geophysical surveys, provide a relatively rapid method for greatly increasing our understanding of these settings. Regional, precompetitive AEM surveys have been undertaken elsewhere in WA, South Australia and the NT (see Costelloe *et al.* 2013), with the aim of assisted exploration under cover, reducing economic risk and stimulating investment and promoting exploration.

This paper examines results emerging from the analysis of a regional AEM survey covering the Capricorn Orogen undertaken for the Geological Survey of Western Australia (GSWA) through Geoscience Australia (GA). The Capricorn 2013 AEM survey is the largest AEM survey by area flown in Australia to date, covering over 146 300 km² (Costello 2014). In particular we review the spatial character of the Capricorn's geo-electrical variability, to better define the causes of the modelled conductivity structure and its links to the regolith. Previous work (Munday *et al.*, 2013) and current reprocessing of existing, public domain AEM data across the Capricorn, suggests that some of the more dominant features identified in AEM data are linked to sediment filled valleys associated with palaeo-drainage systems that at some point were prevalent in the region.

INTRODUCTION

The Capricorn Orogen, spanning an area of ~200,000 km² in Western Australia is a complex zone, comprising a range of variably deformed and metamorphosed igneous and sedimentary rocks. In the west, the Gascoyne Province, which forms the core of the Orogen, is dominated by medium- to high-grade metamorphic rocks, including granitic and meta-

THE CAPRICORN OROGEN AEM SURVEY

In 2014 the Geological Survey of Western Australia designed and contracted (through Geoscience Australia) a regional AEM fixed-wing survey across the Capricorn Orogen with a TEMPESTTM system (Lane *et al.*, 2000). It was developed, in consultation with its research partners and input from the

exploration industry, to provide broad-acre, wide line-spacing, airborne electromagnetic (AEM) data that could be used to:

- determine trends in regolith conductivity and thickness;
- map regional variations in bedrock conductivity;

The survey acquired over 190 flight lines, composed by more than 2,155,000 data points (or soundings), for a total of 30,119 line km of data (Costello 2014). The separation between lines is of 5 km, covering the near-full extent of the Orogen.

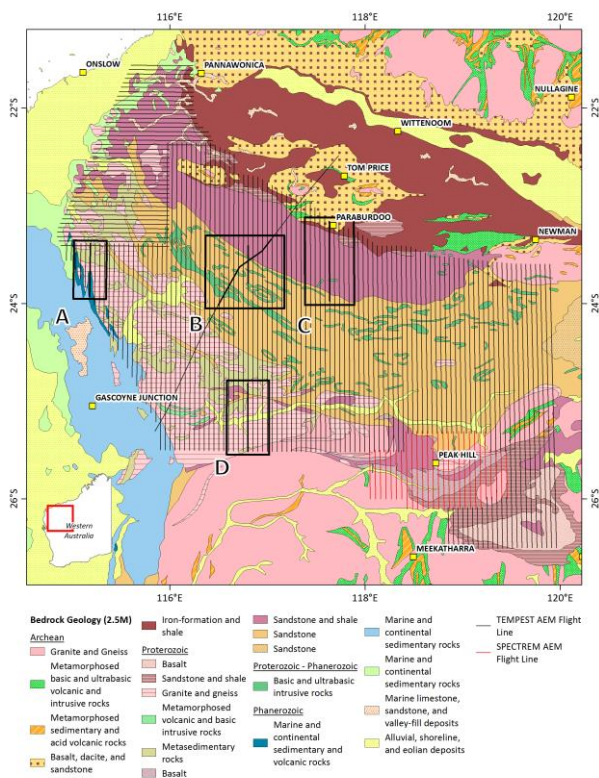


Figure 1. Map of the TEMPEST and SPECTREM flightline coverage of the Capricorn Orogen over a map of the regional geology of the region.

INVERSION, RESULTS AND INTERPRETATION

Inversion

The survey data were inverted using Geoscience Australia's Layered Earth Inversion (GA-LEI) algorithm originally conceptualised by Lane et al. (2004) and further developed by Brodie (2012). In first instance the algorithm reinstates the total field (primary + secondary), and then solves for conductivity and for system geometry. The relative position between the transmitter and receiver (Tx-Rx) coils will vary throughout the survey, solving for this improves the algorithm's ability to model the near surface as shown in Ley-Cooper and C. Brodie (2013). The process implemented on NCI supercomputer facilities took approximately 18 hours on 160 CPUs, which equates to a CPU time of close to 277 hrs, whilst solving for 40 parameters per station. The dataset we inverted on a sample-by-sample basis, which means data has not undergone any further decimation.

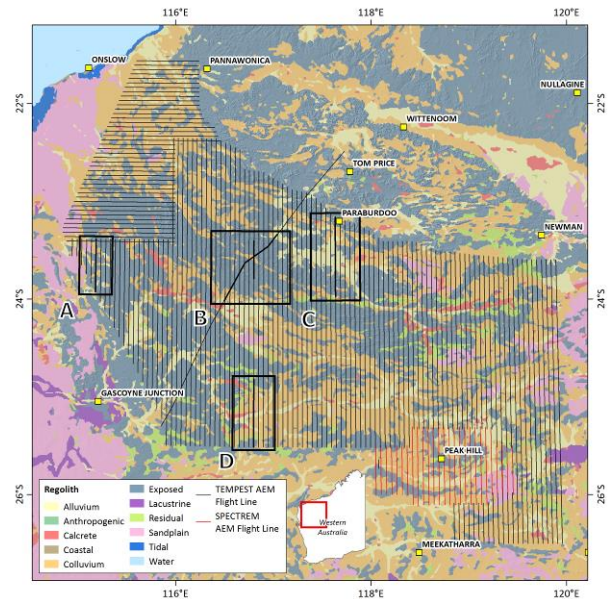


Figure 2. Map of the regional flightline coverage over GSWA's mapping of regolith materials. The coverage of the Bryah Basin survey flown in 2013 is also shown.

The large spatial extent and wide variability of ground conditions the survey has justified the time spent exploring the dataset through different inversions. We have varied parameters such as; reference and noise models, numbers of layers, constraints and regularisation values. As a result, there are a wide range of models that fit the data. Current work is concerned with understanding the suitability of these at different scales and over different regions of the Capricorn.

Results

Figure 3 and 4 show a 15 to 20m inverted conductivity-depth interval for the combined Capricorn TEMPEST™ survey flown in 2014 and Bryah Basin SPECTREM™ survey (Munday et al., 2013) flown in 2012. In Figure 3, the conductivity-depth interval is plotted over a 1st vertical derivative of the regional magnetics. In Figure 4, the same interval is plotted over a terrain index (mrVBF) which shows the varying degree of slope across the Capricorn. Considering these data were acquired with two systems at different times, it is worth noting how spatially contiguous the conductivity structure appears. No levelling, calibration, or post processing was applied for the images to match. Figure 5 shows a series of representative conductivity-depth sections from across the Orogen. The section lines are also shown plotted against surface regolith geology and bedrock geology mapping.

Interpretation

The relatively shallow interval conductivity images from the gridded AEM data sets show how the more conductive areas are largely confined to the lower-flatter parts of the landscape (Figure 4); areas that are mapped as being characterised by alluvium and colluvium (Figure 2 and Figure 5). We use the valley flatness index (MrVBF) algorithm developed by Gallant and Dowling (2003) understanding these relationships better. We interpret these conductive linear features as being associated with sediment filled palaeovalleys that are developed across the region. In many places the contemporary drainage is aligned with these palaeovalleys. They also show a strong lithostructural control on their orientation, control which is supported in an analysis of the conductivity over the magnetics

(Figure 3). In places the AEM data indicates these valleys are in excess of 300m deep, can be of several kilometres wide and have little or no expression at surface. Some of these sediment filled drainages are prospective for both uranium and channel iron deposits. The regional AEM survey has enabled the mapping of their geometry and has also highlighted some of the internal variability of these valleys. Understanding the location of these systems has the potential to better inform the analysis of the regolith geochemistry that has been determined for significant parts of the region. This presents an opportunity to further unlock the prospectivity of the region and reduce exploration risk.

The conductivity-depth sections shown in Figure 5 shows that the region exhibits a variable conductivity structure, with the more conductive areas being related to conductive lithological units (carbonaceous shales, sediments etc), and to a conductive regolith (both in-situ and transported in nature). Section A shows the southern part of the section dominated by a conductive sedimentary package associated with marine sediments of Devonian age. The northern half of this section shows some shallow conductors related to transported sediments occupying shallow palaeovalleys. The conductivity-depth section for line 1016701 in B (which follows a seismic line), shows deep bedrock-related conductors associated with Mesoproterozoic shales and sandstones in the southern section of the line. In the older Palaeoproterozoic sediments to the north these conductive units are no longer present. At the northern-most part of the line, a near surface conductor associated with palaeo-valley fill is apparent. A similar set of characteristics are observed in the conductivity-depth section for line 1003901 (Section B).

For line 1005601 (Section C), which is principally over Palaeoproterozoic sediments of the Wyloo Group, the conductivity structure is dominated by near surface conductors interpreted as being related to palaeo-valley fill and adjacent areas of transported cover. A similar interpretation is made for line 1003901, which straddles the course of the present day Gascoyne River. Immediately beneath the present channel of the river is a thick (~200m) conductor which we interpret to be conductive Cainozoic valley fill. Relatively thick (~50m+) sequences of conductive transported cover are interpreted to extend across other parts of this line.

CONCLUSIONS

We have inverted the entire regional AEM data set flown over the Capricorn orogen. From the inverted EM data we have now a better understanding of how some of the main geo-electrical features vary across the Orogen and how they change with depth. Despite using different AEM systems for data acquisition across the Bryah Basin and the Capricorn, the inversion of the resulting data using a common inversion kernel (GA's LEI) we have been able to generate relatively seamless maps of conductivity. This is despite differences in sampling widows, transmitter waveforms and peculiarities relating to system configuration. We contend that the full inversion of fixed-wing TDEM data, taking account of system geometry and the total field, yields a more robust estimate of the ground conductivity.

Previous work (Munday *et al.*, 2013) and current reprocessing of existing, public domain AEM data across the Capricorn, suggests that some of the more dominant features identified in

AEM data are linked to sediment filled valleys associated with palaeo-drainage systems that at some point were prevalent in the region. However, the conductivity-depth sections indicate that there are areas where bedrock (lithology-related) conductors are commonplace. There are a wide range of materials with similar conductive responses, emphasising the importance of taking an integrated approach to the interpretation of the AEM is critical, particularly to elucidate the cover story. This should involve interpretation with ancillary data and an understanding of the local geological and geomorphological context.

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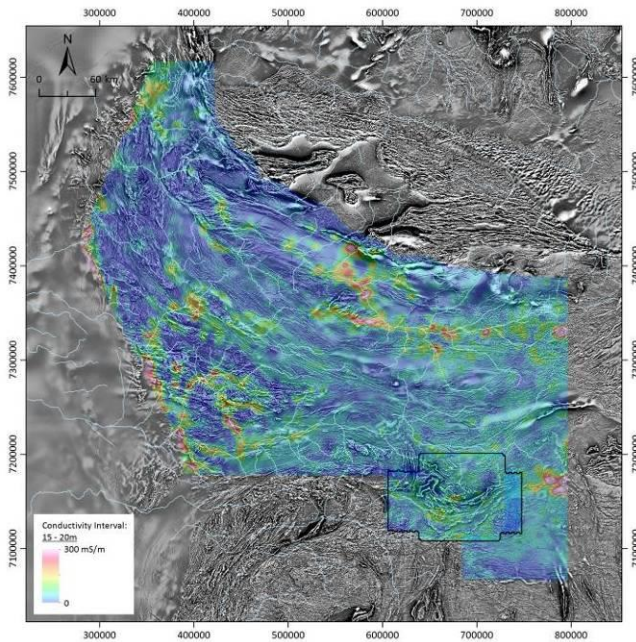


Figure 3. Inverted conductivity-depth slice (in colour) from the combined TEMPEST and SPECTREM AEM data sets for a depth interval from ~15 to 20 m overlain on 1st vertical derivative of the regional magnetics (gray scale image).

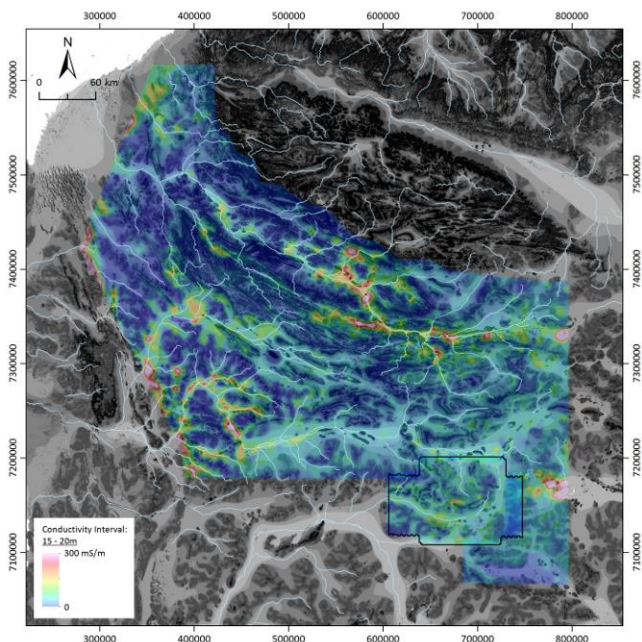


Figure 4 Inverted conductivity-depth slice (in colour) from the combined TEMPEST and SPECTREM AEM data sets for a depth interval from ~15 to 20 m overlain on a terrain index (the MrVBF valley flatness index). The paler grey colours are indicative of low flat areas in the landscape. Dark areas are where landscape steepens and outcrop is more likely.

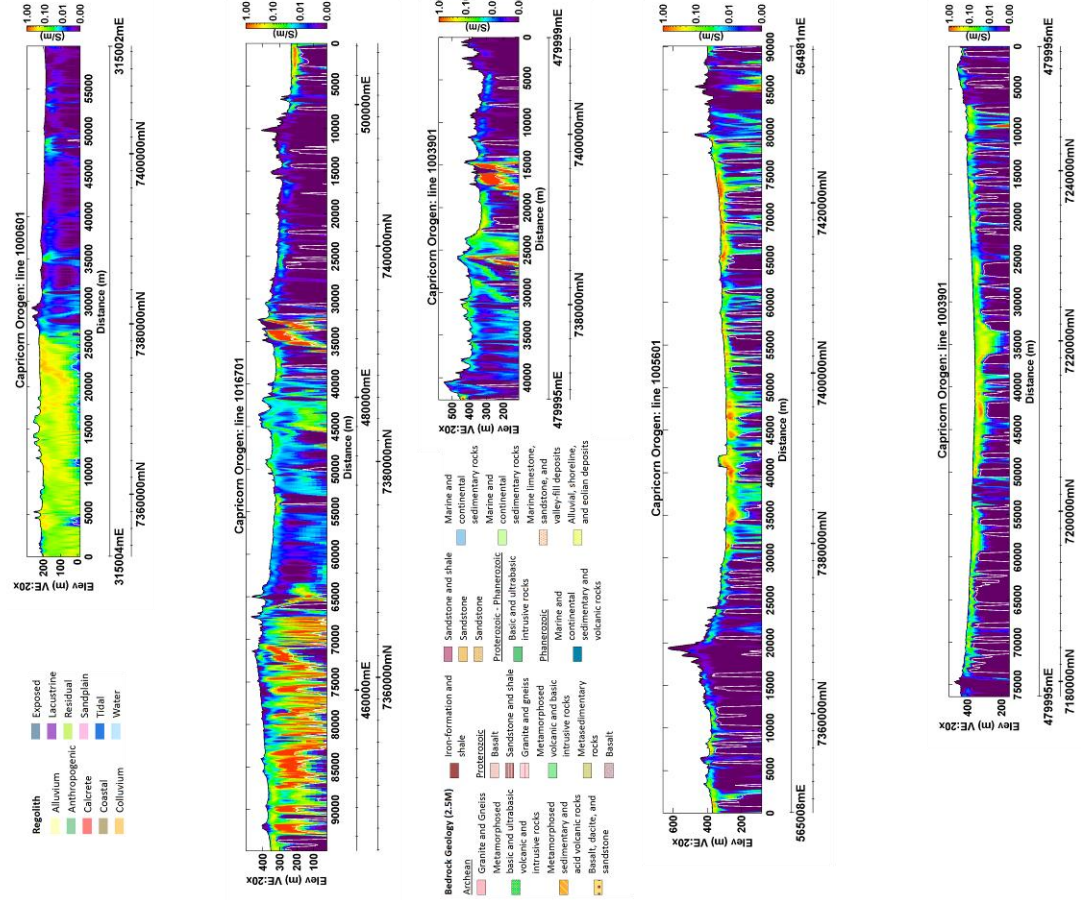
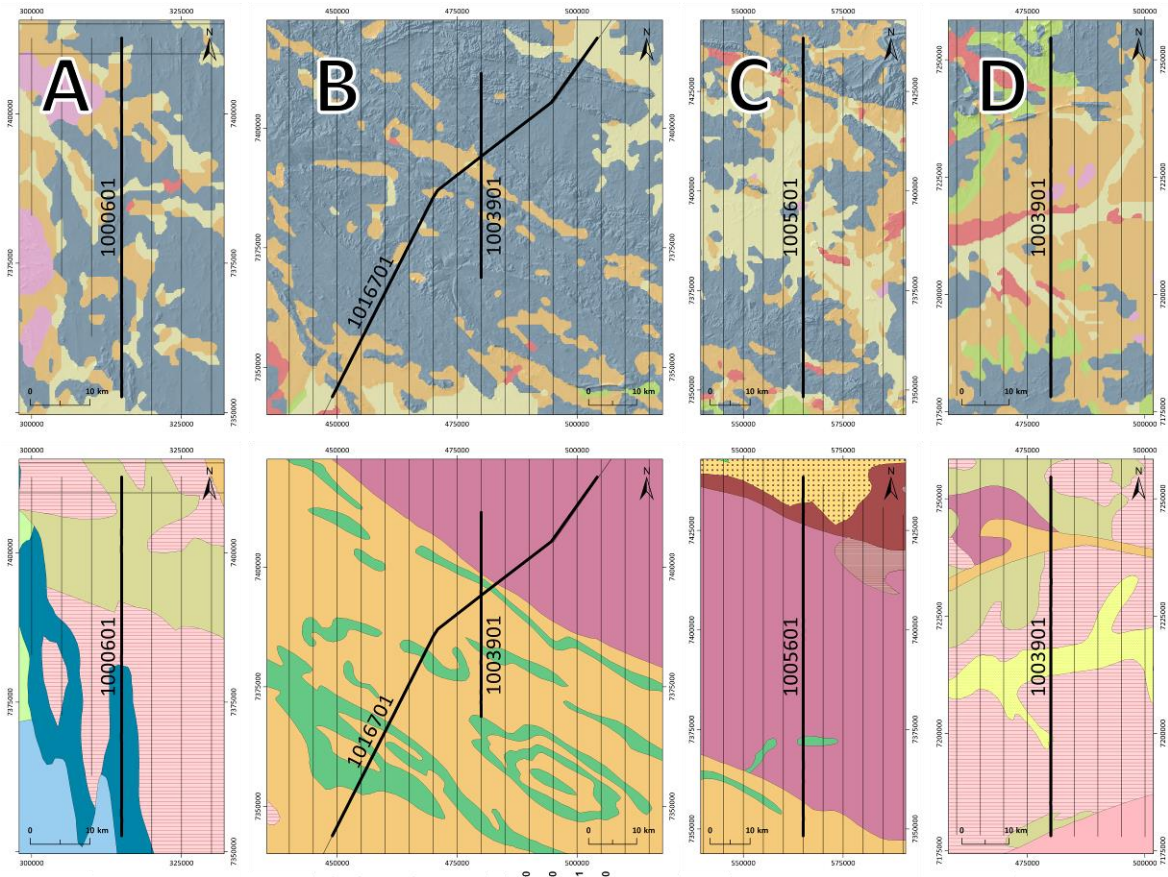


Figure 5: Representative conductivity-depth sections from a smooth model (30-Layer) inversion of TEMPEST data for subsets of data acquired across the Capricorn Orogen. Their locations relative to the mapped surface regolith and basement geology are also shown. The top panel of maps shows the regolith, and the middle panels - the bedrock geology.