Application of AEM for cover thickness mapping in the southern Thomson Orogen

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SUMMARY

Regional airborne electromagnetic (AEM) surveying in the southern Thomson Orogen of southwest Queensland and northwest New South Wales highlights the efficacy of AEM for mapping near-surface Paleozoic basement rocks, the basement-cover interface, and the hydrostratigraphy of cover rocks of the Eromanga and Lake Eyre basins. Interpretations of AEM data are applied to model the basement-cover interface and answer the important question "how thick is cover" in this underexplored region, and encourage the mineral exploration industry to explore more widely. This paper shows some of the interpretation highlights from regional AEM surveys conducted in 2014 and 2016. The interpretations, when considered with regional borehole basement intersections, reduce exploration risk by demonstrating that large portions of the basement are within reach of exploration drilling.

Key words: Southern Thomson Orogen, airborne electromagnetics, mineral exploration, risk reduction, geological mapping.

INTRODUCTION

The southern Thomson Orogen is a poorly understood crustal element of northwestern New South Wales and Queensland. Geoscience Australia (GA), the Geological Survey of New South Wales and the Geological Survey of Queensland are partners in the Southern Thomson Project, which is a joint research project providing new pre-competitive geological, geophysical, geochemical and geochronological data within the region. These data are designed to improve the mineral systems and basement geological understanding of this under-explored orogen, encourage mineral exploration investment and add to the geodynamic understanding of the region. The new data were also used to help reduce the technical risk of stratigraphic drilling sites located within strategic crustal elements identified within the southern Thomson Orogen, together with pre-drilling geophysics of these proposed sites (see Goodwin, *et al.* 2018).

Geoscience Australia commissioned two airborne electromagnetic (AEM) surveys, the first in 2014 concentrating mainly on a portion of near-surface basement rocks between Hungerford and Eulo, Queensland, known as the Eulo Ridge (Roach 2015), and the second in 2016 concentrating on near-surface basement rocks in the Enngonia, Louth and Tilpa areas of New South Wales (Figure 1), as well as infilling areas of interest identified in the 2014 AEM survey. Inverted AEM data from these surveys were interpreted using available borehole data and surface geological mapping to produce a new cover thickness model of the area that was used to help advise a stratigraphic drilling campaign, and the inverted AEM data were validated by comparison to wireline geophysical logs from newly drilled boreholes and against other pre-drilling geophysical methods (see Goodwin, *et al.* 2018).

DATA ACQUISITION, PROCESSING AND INTERPRETATION

Airborne electromagnetic data were acquired using the Geotech VTEMplus® AEM system in both 2014 and 2016. In 2014 AEM data were acquired along regular east-west flight lines at 5000 m line spacing over the Eulo Ridge, and along two traverses to complement new gravity and magnetotelluric data acquisition by providing more accurate Depth To Basement (DTB) estimates to model the Thomson-Lachlan orogen boundary (Folkes 2016; Folkes 2017; Roach 2015). In 2016 AEM data were again acquired along regular east-west flight lines at 5000 m line spacing, abutting the 2014 survey data, but also as 2500 m infill lines within the 2014 survey area, as north-south lines perpendicular to the 2014 survey flight lines, and as oblique flight lines connecting proposed borehole sites to east-west flight lines or to AEM data obtained by the GA Groundwater Branch along the Darling-Paroo rivers corridor (Figure 1). Flight lines were selected over areas where legacy boreholes had identified near-surface basement, and were extended basin-wards in all directions, using the DTB model of Simpson and Cant (2013) and the legacy borehole data, to a distance where it could be reasonably interpreted that the DTB would be very much greater than the anticipated Depth Of Investigation (DOI) of the AEM system.

Data from the 2014 AEM survey were inverted using the GA Layered Earth Inversion-Sample By Sample (GALEISBS; see Roach 2012) algorithm and the GA Reversible Jump Markov chain Monte Carlo (GARJMCMC; see Roach 2015) algorithm, and display products included ASCII data, georeferenced raster images for display in 2D and GOCAD® objects for display in 3D. Data acquisition and processing methods used for the 2014 AEM survey are described in Roach (2015). In 2016, data from both surveys were inverted using the GA Layered Earth Inversion All At Once (GALEIAAO; see Brodie and Ley-Cooper 2018) algorithm and ASCII, georeferenced raster images and GOCAD® object interpretation products were again produced. All of the AEM data and interpretation products are available for free download from the GA website.

Data interpretation methods are described in Roach (2015) and included first using the aircraft data multiplots and GIS data to identify anthropogenic anomalies such as power lines, pipes, fences and water bores. After these were recognised, georeferenced conductivity sections were then overlain on surface geological maps and borehole information in ArcMap GIS to observe correlations between mapped surface geology, fault lines and features in the geoelectrical stratigraphy along each flight line. Lastly, 3D objects were imported into GOCAD along with borehole information including stratigraphic horizon and basement intersection picks to develop empirical rules describing the geoelectrical architecture of the subsurface and its relationship to mapped surface geology and boreholes. A 3D model of the basement-cover interface, where it was able to be interpreted above the DOI within each conductivity section, was then produced. The model was produced as a height above datum GOCAD surface, in this case the datum being Australian mean sea level.

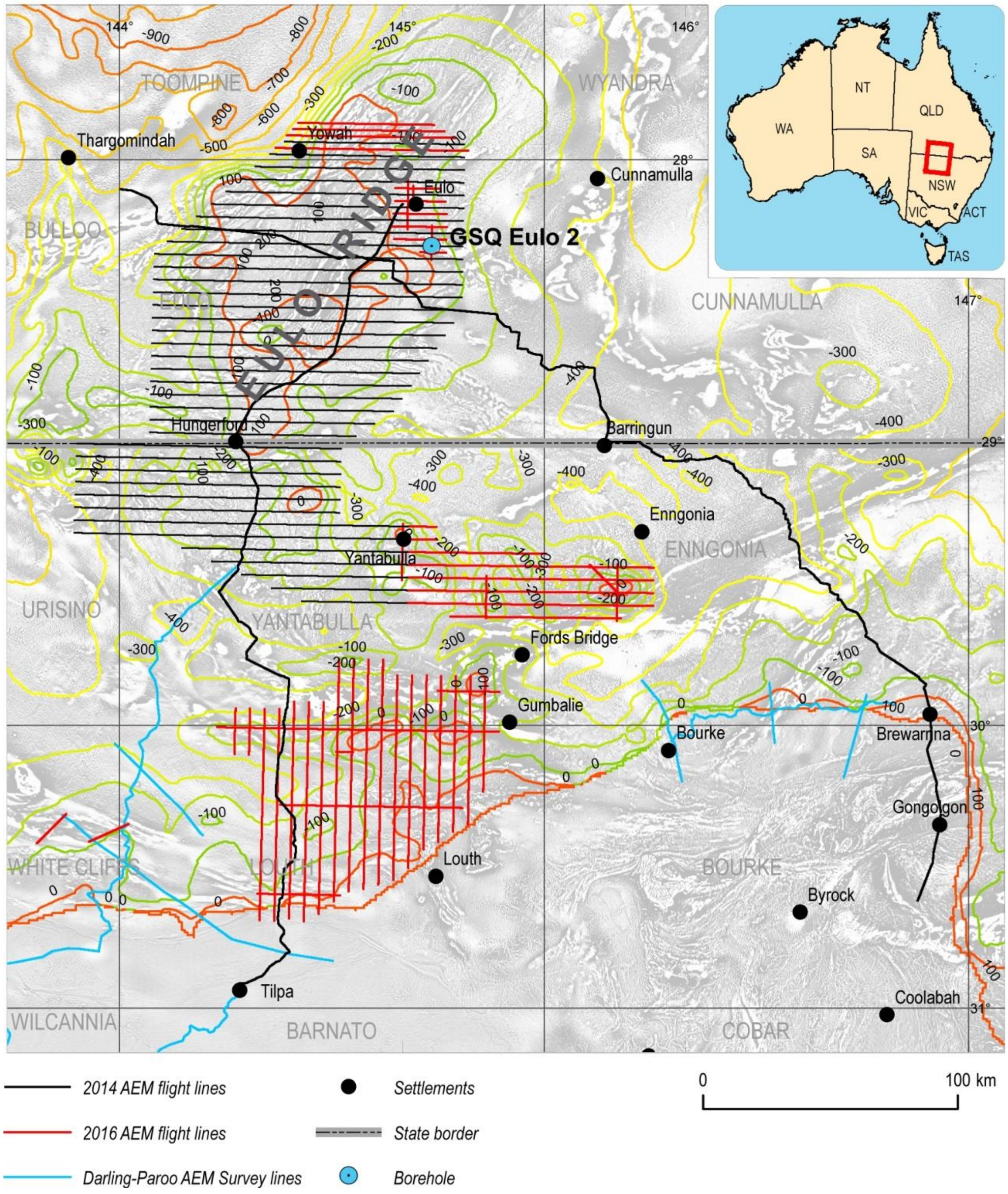

Figure 1: Location of AEM flight lines and stratigraphic boreholes drilled for the Southern Thomson Project. Background: Depth To Basement (DTB) contours for the Great Artesian Basin from Simpson and Cant (2013) over a grayscale 0.5 vertical derivative reduced to pole magnetic image.

INTERPRETATION RESULTS

Interpretation results from the 2014 AEM survey are presented in Roach (2015) and Roach (2016). The addition of the new data from the 2016 AEM survey has allowed new insights into the 2014 AEM dataset, as well as exposing new basement features in New South Wales. A basement-cover interface 3D surface was created over the Eulo Ridge area using the 2014 AEM dataset and scattered borehole basement intersections (Figure 2). New AEM data collected in 2016 allowed this surface to be revised through the use of 2500 m line spacing infill and cross-lines, to better map small basement topographic features that were observed in the 2014 AEM dataset. This includes being able to map the basement topography in the Eulo region and at the GSQ Eulo 2 borehole site (Figure 3). The ability to map some portions of basement topography in 3D highlights the fact that the basement topography of the southern Thomson Orogen in the Eulo Ridge area is more complex than has been previously interpreted; this is understandable given that a higher density of regularly collected data (i.e. evenly spaced AEM flight lines), rather than scattered boreholes, will always yield more information about the basement-cover interface than just boreholes alone. In Figure 3, a 2D basement rise is resolved into a 3D object through the use of infill and perpendicular flight lines. This basement rise is now identified as a remnant of an intermediate igneous complex, consisting of volcanoclastic conglomerates overlying sheeted ignimbrite ash flows, and is pervasively altered by pyrite (Roach, *et al.* 2017).

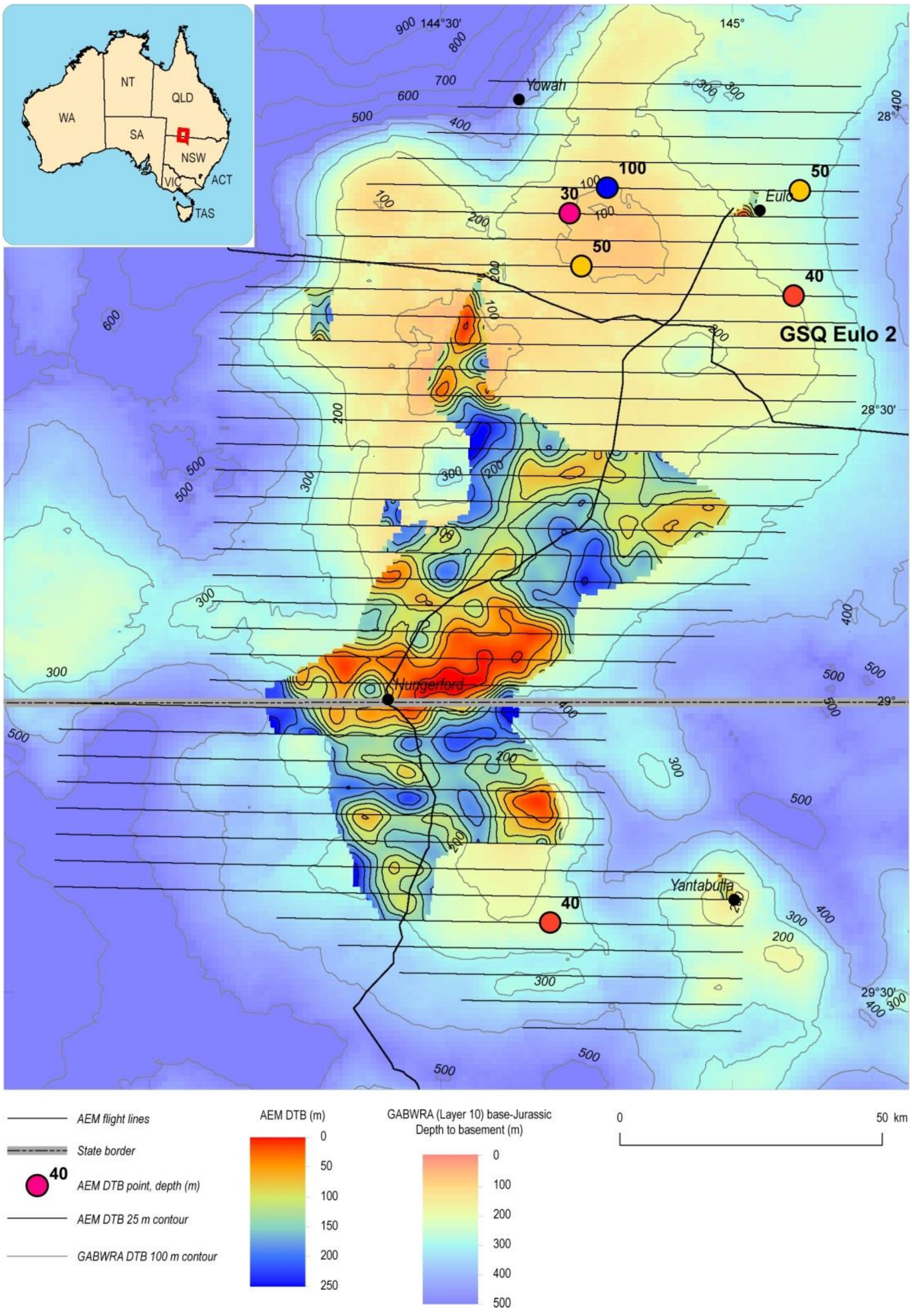

Figure 2: Depth to basement (DTB) model of the Eulo Ridge in the Southern Thomson Project area modified from Roach (2015). The model is derived from the 2014 AEM dataset and is overlain on a DTB model from Ransley and Smerdon (2012).

In New South Wales the 2016 AEM dataset has been instrumental in mapping Thomson Orogen basement topography where it occurs above the DOI, filling-in between sparse boreholes, many of which do not intersect basement. Conductivity sections from AEM flight lines between Yantabulla and Enngonia (Figure 4) reveal previously unmapped basement rises under cover of the Eromanga basin and the more recent Darling-Warrego-Paroo rivers floodplain sediments, where only limited outcrop consists solely of Cretaceous sedimentary rocks of the Eromanga Basin. In the Enngonia area near-surface basement rocks occur to within 50 m of the land surface.

In the Louth area, a large region of resistive basement occurs to within < 150 m of the surface (Figure 5A, B) and a sharp contrast between resistive basement and juxtaposed Eromanga Basin sedimentary rocks highlights the location of the Mount Oxley Fault, which is a major crustal element visible in magnetic imagery. Where possible, the interface between resistive basement and overlying conductive cover has been mapped and used to construct a basement elevation model, which is coloured by the calculated cover thickness in Figure 5B.

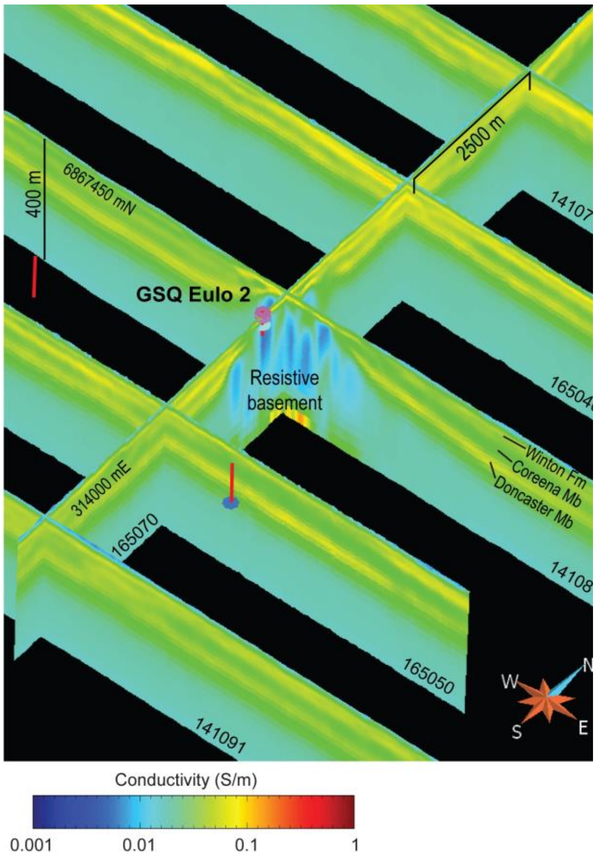

Figure 3: A GOCAD oblique view of a resistive basement rise identified in the 2014 AEM survey (lines labelled starting with "14"), which was overflown in 2016 (lines labelled starting with "16") with 2500 m line-spaced east-west infill, and a north-south flight line. Data reveal the 3D topography of the rise, which was a ~900 m diameter island in the Cretaceous sea. The GSQ Eulo 2 (Roach, et al. 2017) borehole was drilled on the southwest side of the basement feature.

CONCLUSIONS

Regional AEM survey data have been immensely useful in mapping the basement-cover interface, and thus the DTB, in the southern Thomson Orogen study area. This knowledge, constrained by sparse legacy borehole basement intersections and more detailed pre-drilling geophysical techniques (see Goodwin, *et al.* 2018), has provided more surety in planning the location of stratigraphic boreholes to test solid geological models of the Paleozoic basement rocks of the Thomson Orogen. The new AEM data have reduced exploration risk by ensuring that the targets are within reachable depths of more economical multi-purpose drilling rigs, and have also reduced the technical risk of drilling by being able to map near-surface aquifers to the limits of the DOI, ensuring the technical success of boreholes in this artesian groundwater-dominated terrain.

Flights lines at 5000 m spacing are shown to provide sufficient detail to map much of the basement topography, to the limits of the DOI, in sufficient detail to provide surety to drilling campaigns. Smaller basement features, such as the rises identified in this work, need higher-density data collection to reveal their 3D nature; the example shown here in Figure 3 is revealed by 2500 m line-spaced infill and a perpendicular flight line, to be a relatively small object < 1 km diameter. These may be mapped in more detail by infill AEM flight lines after initial data are collated, or by a ground-based technique, to provide more surety for subsequent drilling campaigns.

ACKNOWLEDGMENTS

ICR acknowledges the invaluable input of colleagues from Project Partners the Geological Survey of New South Wales and the Geological Survey of Queensland: Rosemary Hegarty, David Purdy and Dominic Brown. ICR also gratefully acknowledges the input of colleagues from GA (in no particular order): Michael Doublier, James Goodwin, Andrew McPherson, David McInnes, Millicent Crowe and Ross Brodie, and review by Yusen Ley-Cooper. This work is published with the permission of the CEO, Geoscience Australia.

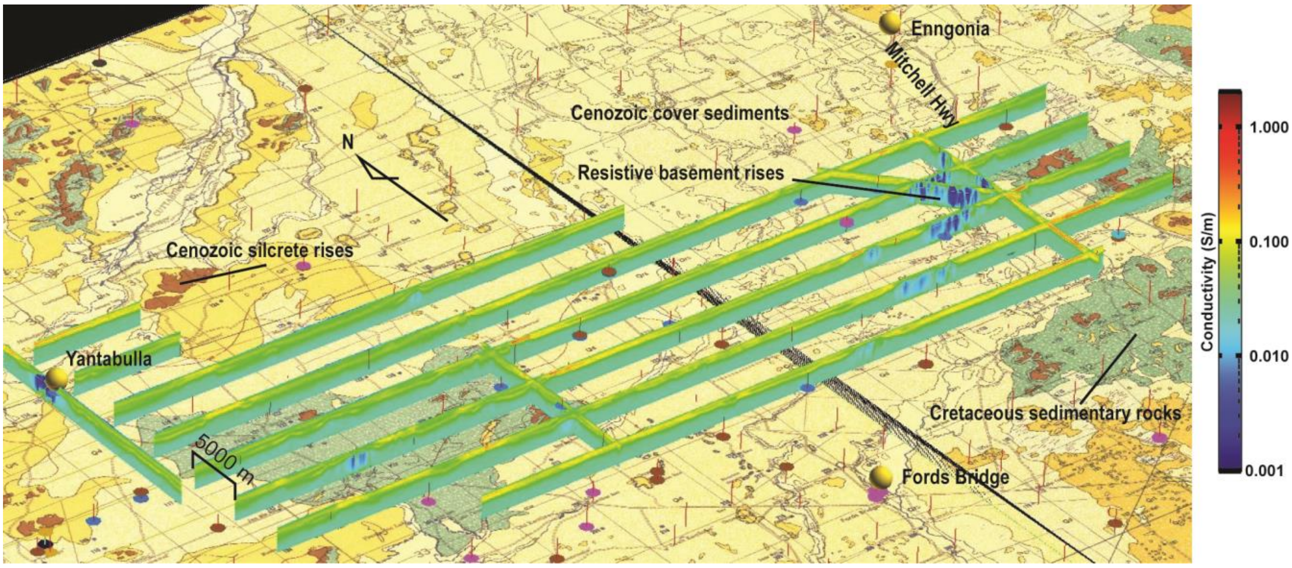

Figure 4: A GOCAD oblique view of AEM conductivity sections in the Yantabulla-Enngonia region of New South Wales highlighting the relatively flat-lying Eromanga Basin sedimentary rock sequence. Resistive basement rises (dark blue) are visible in some conductivity sections at Yantabulla and especially southwest of Enngonia, with Eromanga Basin rocks draped over them. The conductivity sections are overlain on the YANTABULLA and LOUTH 1:250,000 geology maps, highlighting the paucity of outcrop and the model includes basement intersections in boreholes (sticks and discs).

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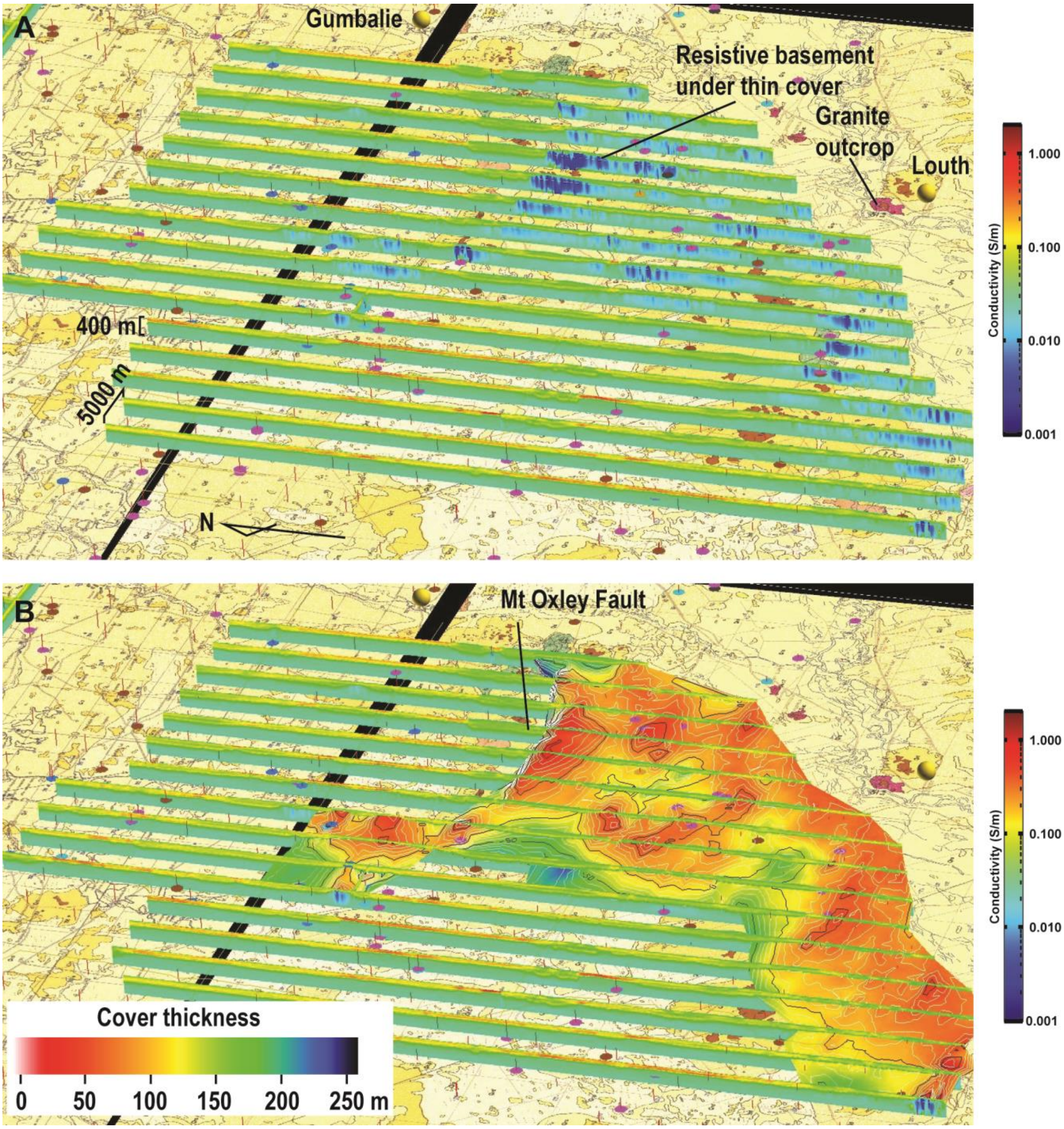

Figure 5: A GOCAD oblique view of AEM conductivity sections in the Louth area of New South Wales. Figure 5A shows the conductivity sections and Figure 5B shows a basement elevation model, coloured by cover thickness. The conductivity sections are overlain on the LOUTH and YANTABULLA 1:250,000 geological maps highlighting the paucity of outcrop in the region.