Australian continental-scale multilayered chronostratigraphic interpretation of airborne electromagnetics

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SUMMARY

A key issue for explorers in Australia is the abundant sedimentary and regolith cover obscuring access to underlying potentially prospective rocks. Multilayered chronostratigraphic interpretation of regional broad line-spaced (~20 km) airborne electromagnetic (AEM) conductivity sections have led to breakthroughs in Australia's near-surface geoscience. A dedicated/systematic workflow has been developed to characterise the thickness of cover and the depth to basement rocks, by delineating contact geometries, and by capturing stratigraphic units, their ages and relationships. Results provide a fundamental geological framework, currently covering 27% of the Australian continent, or approximately 2,085,000 km^2. Delivery as precompetitive data in various non-proprietary formats and on various platforms ensures that these interpretations represent an enduring and meaningful contribution to academia, government and industry. The outputs support resource exploration, hazard mapping, environmental management, and uncertainty attribution. This work encourages exploration investment, can reduce exploration risks and costs, helps expand search area whilst aiding target identification, and allows users to make well-informed decisions. Presented herein are some key findings from interpretations in potentially prospective, yet in some cases, underexplored regions from around Australia.

Key words: AusAEM, airborne electromagnetic interpretation, Exploring for the Future

INTRODUCTION

Australia is a major producer and exporter of natural resources. However, the Australian continent is vastly (~80%) covered by regolith and sedimentary basin cover, which obscures access to the underlying prospective rocks. It has been widely recognised that one of the greatest challenges hindering resource exploration in Australia is the lack of characterisation of the thickness and composition of this cover and the accessibility to the rocks beneath.

Historically, potential field geophysics, seismic and borehole data have been used to investigate the lithology and structure of the upper-crust through the cover. However, Geoscience Australia's (GA) Exploring for the Future program, in partnership with State and Territory geological surveys, has enabled the acquisition of the nominally 20 km line-spaced AusAEM surveys (Ley-Cooper et al., 2020). These surveys shed light on the geo-electrical properties of the subsurface geology to a depth of up to ~500 m. This provides a non-invasive and cost-efficient dataset that facilitates investigations on the regional lithostratigraphy, hydrostratigraphic characteristics, groundwater quality, basin configurations, structures, and presence of prospective rocks.

The modelled regional AEM data are interpreted using the multilayered chronostratigraphic AEM interpretation workflow (Wong et al., 2022). These interpretations provide seamless consistent data to help constrain the near-surface composition and architecture across both highly-explored and under-explored regions. Interpretation lines are converted to depth estimate points, and are stored alongside multidisciplinary depth estimates in the Estimates of Geological and Geophysical Surfaces (EGGS) database (Mathews et al., 2020). These points constitute important inputs to cover modelling (e.g. Bonnardot et al., 2020) These cover models are subsequently used as inputs into mineral potential mapping (Murr et al., 2020) and a resource extraction economic viability tool (Haynes et al., 2020).

Although the multilayered chronostratigraphic AEM interpretations cover large regions with homogenous line work, metadata and depth estimates, herein, several case studies have been selected to illustrate how AEM models may be interpreted to elucidate geological features with environmental, economic or community safety implications. These case studies include: the resource potential of the 1) Willowra Suture, 2) Dulcie Trough/Syncline, and 3) palaeovalleys, in the Northern Territory; the 4) hydrogen storage potential of salt-containing basins in Western Australia; and the 5) general exploration implications in underexplored areas.

METHODS

The majority of the AEM conductivity sections currently interpreted are from the AusAEM surveys (e.g. Ley-Cooper, 2020; Ley-Cooper, 2021; Ley-Cooper & Brodie, 2018), with selected sections from other surveys also interpreted (e.g. Brodie, 2021; Costelloe et al. 2012).

The AEM data were inverted using GA's Layered Earth Inversion Sample-By-Sample Time Domain Electromagnetics inversion (Brodie, 2015). The depth of investigation varies depending on the bulk electrical conductivity, with the depth of signal penetration estimated to be up to ~500 m in electrically resistive terrains.

The AEM models are interpreted in 2D space and then validated, and converted to 3D space and points, using code developed at GA (Wong et al., 2022). This workflow facilitates attribution of each interpretation line or point with large amounts of interpretation-specific metadata such as stratigraphic units, confidence and links to supporting datasets. Outputs meet strict EGGS database structure requirements and are available in multidimensional non-proprietary formats across various delivery platforms. Integrated interpretation of AEM models with potential fields, boreholes, seismic sections and interpretations, surface and solid geology maps, ensures production of well-informed interpretations and confidence attribution.

RESULTS AND DISCUSSION

Chronostratigraphic interpretations produced by GA and its collaborators currently cover ~110,000 line km of AEM-derived conductivity sections, covering an area ~2,085,000 km^2 to a depth of up to ~500 m (Figure 1). . These interpretations have produced ~600,000 attributed depth estimate points, with ~300,000 already available through EGGS on the GA Portal (https://portal.ga.gov.au/).

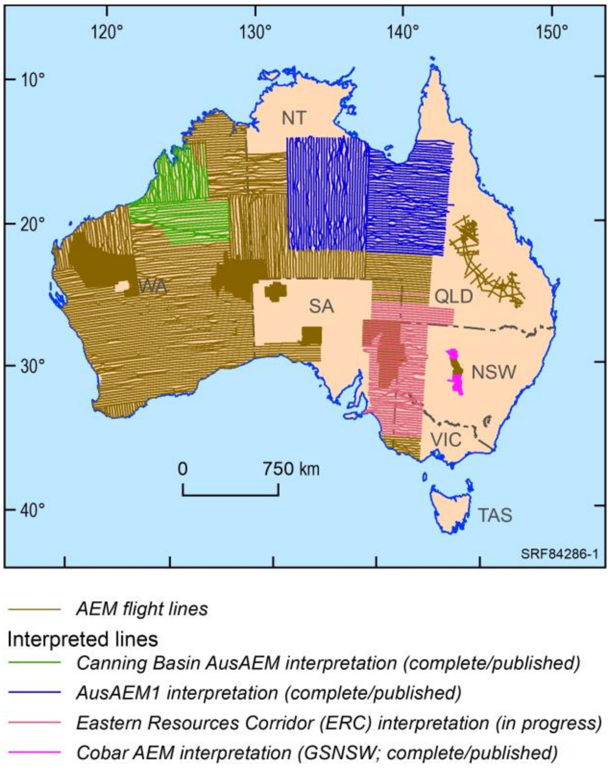

Figure 1 Current coverage of AEM interpretations made using the multilayered chronostratigraphic AEM interpretation workflow. Canning Basin AusAEM interpretation (Connors et al., 2022; Vilhena et al., 2023); AusAEM1 interpretation (Wong et al., 2020; Wong et al., 2021); Cobar AEM interpretation (Folkes et al., 2022; GSNSW = Geological Survey of New South Wales).

First-order structures and palaeovalleys

One key finding from the interpretation of regional AEM surveys is their ability to reveal first-order geological structures. In the central Northern Territory, the contact between the Proterozoic Aileron Province and the adjacent Paleozoic Lander Trough has been interpreted in the AusAEM models as a large-scale faulted contact (Figure 2a). This contact can be confidently mapped for hundreds of kilometres beneath thin (~5-10 m) Cenozoic cover. The location of the Willowra Suture (Korsch & Doublier, 2015), a south-dipping crustal-scale boundary that resulted from the collision of the Aileron and Tanami provinces at 1864-1844 Ma (Goleby et al., 2009; Korsch et al., 2011; Korsch & Doublier, 2015), correlates extremely well with this fault, suggesting that the interpreted fault is the near-surface expression of the Willowra Suture. Besides a change in the age of rare small scattered outcrops throughout the region, the presence of a major fault or the extent of the Willowra Suture reaching the near-surface was unknown. The near-surface geometry and distribution of this feature can now be well-constrained using AEM models.

Long-period magnetotellurics (MT) models have identified a major conductive zone at depth along this feature (Duan et al., 2019; Figure 2b). This significant crustal/mantle-scale feature could represent metasomatism along a major fluid flow pathway (Duan et al., 2022). Duan et al. (2022) noted that Au mines and deposits associated with the Tanami orogenic Au system are located directly above a conductivity anomaly, whereas Korsch & Doublier (2016) indicated that major crustal boundaries, such as the Willowra Suture, are conduits for mineralising fluids to upper-crustal levels. Structures potentially linked to these deeper fertile zones can now be mapped in the near-surface, and under thin cover, using AEM models, providing explorers additional data to refine and focus their exploration efforts.

Additionally, there is a significant elevation offset across this feature (Figure 2c), suggesting geologically recent movement, with the Aileron Province displaced upwards relative to the Lander Trough. This improved ability to precisely map the distribution of neo-tectonic structures allows for enhanced hazard mapping and community safety assessments.

Integration with palaeovalley maps (e.g. Bell et al., 2012) demonstrated that the regional AEM surveys are a powerful tool to refine such maps, by improving the capability to approximate under cover palaeovalley distribution and connectivity. Furthermore, these surveys can also be used to discover undocumented palaeovalleys. Importantly, the interpretations provide a depth dimension, which can be used to gauge thicknesses and volumes of the palaeovalley fill (Figure 2a). Determination of these properties is vital for explorers, land users and governments to make informed decision on policy, management of groundwater extraction, and management of groundwater dependent ecosystems.

Multilayered chronostratigraphic interpretation for resource exploration

The Dulcie Trough/Syncline in the central Northern Territory is an asymmetrical syncline with Neoproterozoic-Paleozoic Georgina Basin rocks in the hinge of the fold overlying Paleoproterozoic basement (Kruse et al., 2013). The Neoproterozoic-Paleozoic units are sedimentary fill of a Neoproterozoic depocentre, with the geometry of this structure being amplified by Upper Ordovician to Carboniferous Alice Springs Orogeny folding (Dunster et al., 2007; Kruse et al., 2013).

Interpretation of the AusAEM models has constrained the under cover geometry of the syncline by showing the thickness of the trough fill and depth to the underlying basement, as well as revealing internal structures, such as potential parasitic folding, faulting and/or separated depocentres (Figure 3). These observations have the potential to aid exploration, as the trough/syncline region is prospective for Au, base metals and phosphate (Huston et al., 2021; Kruse et al., 2013; Dunster, 2015).

In this example, as Au and base metal occurrences exist at or near the trough-basement boundary, the conductivity contrast between moderately conductive trough fill and resistive basement can help to extrapolate the distribution and depth of prospective stratigraphy under cover. Delineation of this contact also helps to determine the thickness of overburden and the depth to prospective rocks. Similarly, the Georgina Basin stratigraphy is prospective for and hosts significant phosphate deposits. These deposits are typically covered by surficial sediments, are commonly situated on the Neoproterozoic-Paleozoic basin peripheries, and can occur proximal to palaeo-topographic highs (Khan et al., 2007; Howard, 1990). McCrow (2008) suggested that improved targeting of phosphate deposits would require additional structural interpretations, including identifying palaeo-topographic highs and embayments. Therefore, utilising AEM models to refine the basin boundary geometries, to identify the palaeo-topographies (e.g. the ridges separating possible depocentres in the Georgina Basin) and to develop the structural framework of the near-surface geology, is highly valuable in the design of exploration projects targeting phosphate deposits.

Multilayered chronostratigraphic AEM interpretations are currently occurring in the Eastern Resources Corridor of the Exploring for the Future program. These interpretations are providing a geological framework in areas including the Curnamona Craton, which hosts the world-class Broken Hill Pb-Zn-Ag deposit, as well as the Delamerian Orogen, which is prospective for Au, Cu, Pb, Ag, Ni, Zn and PGEs. These interpretations are also providing geological insight in agricultural areas in the western Murray Basin that rely heavily on groundwater resources. The AEM interpretations have been utilised in drilling programs to estimate cover thicknesses and identify basement highs. They help to support groundwater investigations by refining the subsurface basin boundaries and distribution of stratigraphic units. The interpretations are also crucial inputs into cover thickness modelling, and will be released as precompetitive data across various platforms.

The workflow has facilitated the delineation of individual stratigraphic units, by the interpretation of changes in electrical conductivities in the subsurface. The results can be extended to infer lithostratigraphic or hydrostratigraphic properties important to groundwater or hydrocarbon exploration, such as the presence or extrapolation of traps, seals, reservoirs and source rocks, and/or aquifers and aquitards.

Salt deposits

The AusAEM dataset has presented opportunities for using AEM models in unconventional ways to support exploration of subsurface salt deposits. Integration of the AEM models with a range of supporting information and datasets provided insight on the distribution of salt within various basins. This is important, as caverns made in underground salt deposits are cost effective storage sites for large quantities of hydrogen. New studies were undertaken to understand salt distribution in the Canning (Connors et al., 2022; Vilhena et al., 2023; Zhan, 2022) and Officer (Bradshaw et al., 2023) basins, in Western Australia, which are known for thick onshore salt accumulations. The multilayered chronostratigraphic AEM interpretation revealed disruption of the electrical conductivities in the shallow stratigraphy, likely caused by movement or dissolution of the salt at depth. As a result, the AEM models were found to be a powerful tool for targeting near-surface salt diapirs, and for mapping the regional distribution of bedded salt horizons under cover. Therefore, these studies provide insights into the geological hydrogen storage potential of the salt deposits within these basins by refining search areas.

CONCLUSIONS

Multilayered chronostratigraphic interpretations of regional AEM surveys have led to significant improvements in the understanding of near-surface geology in Australia. They help characterising the thickness and composition of the expansive cover, whilst providing insight into the underlying rocks at an unprecedented scale. They provide a foundational dataset that informs on Australia's subsurface geology and assists a variety of users in academia, government, industry and the public with environmental management, resource exploration and hazard mapping

The development of the integrated workflow presented here facilitates large quantities of interpretation-specific metadata to be captured and attributed to 2D and 3D line work and points. Large regions of Australia are now covered with precompetitive multidimensional interpretation data in non-proprietary formats, which are accessible across a variety of platforms.

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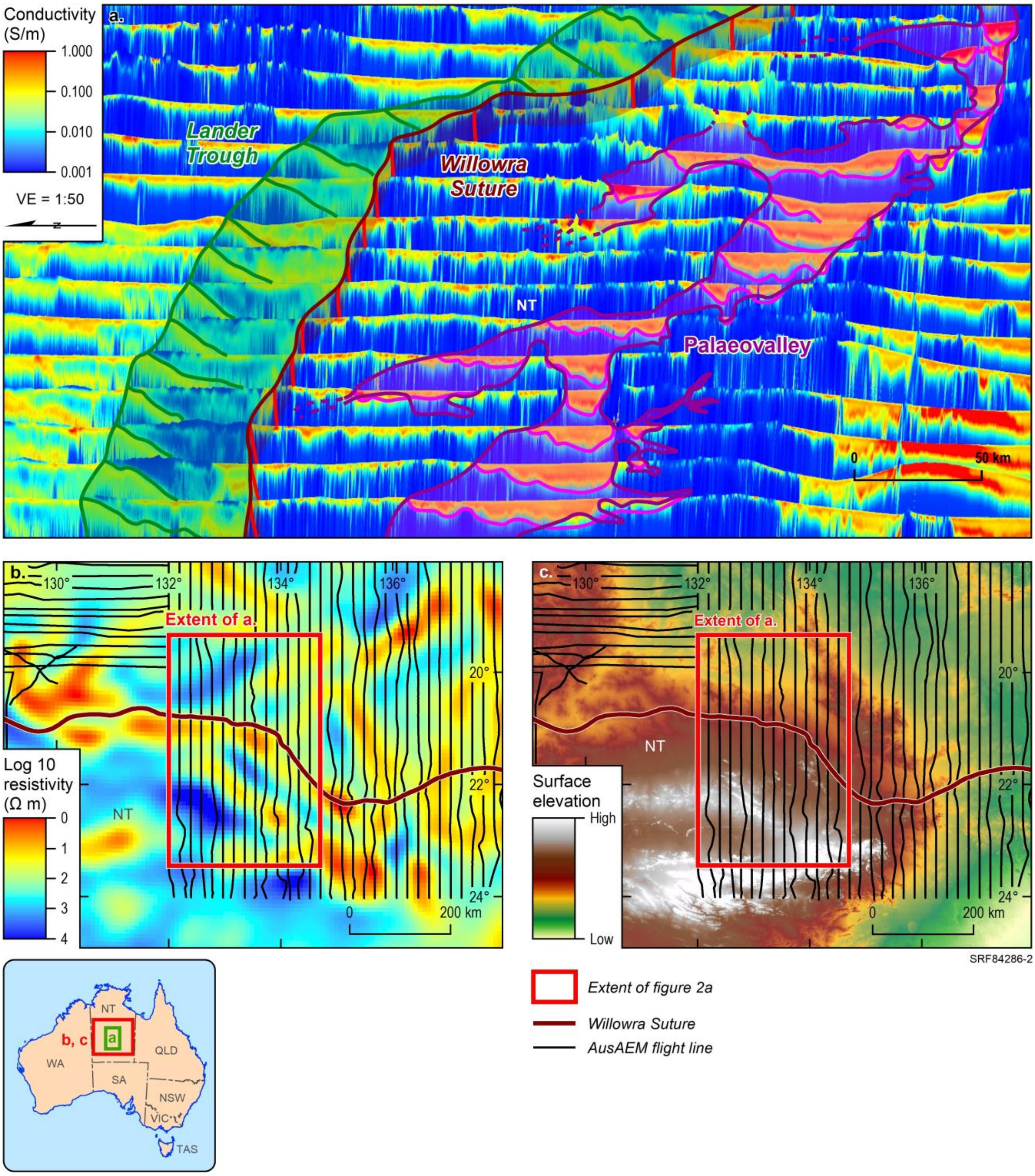

Figure 2 Palaeovalleys, first-order geological structures and sedimentary basins – examples of interpreted features in broadly-spaced AEM. a) Oblique view (looking east) of AusAEM conductivity sections (Ley-Cooper & Brodie, 2018) showing lithostratigraphic units in the Lander Trough of the Paleozoic Wiso Basin, first-order structural features, such as the near-surface expression of the Willowra Suture, and the connectivity and 3D geometry of palaeovalleys. b) AusLAMP long-period magnetotelluric 36 km depth slice (Duan, 2019) showing a deep conductivity anomaly that correlates with the distribution of the Willowra Suture. c) Digital elevation model (Geoscience Australia, 2017) illustrating a surface expression of the Willowra Suture. NT = Northern Territory

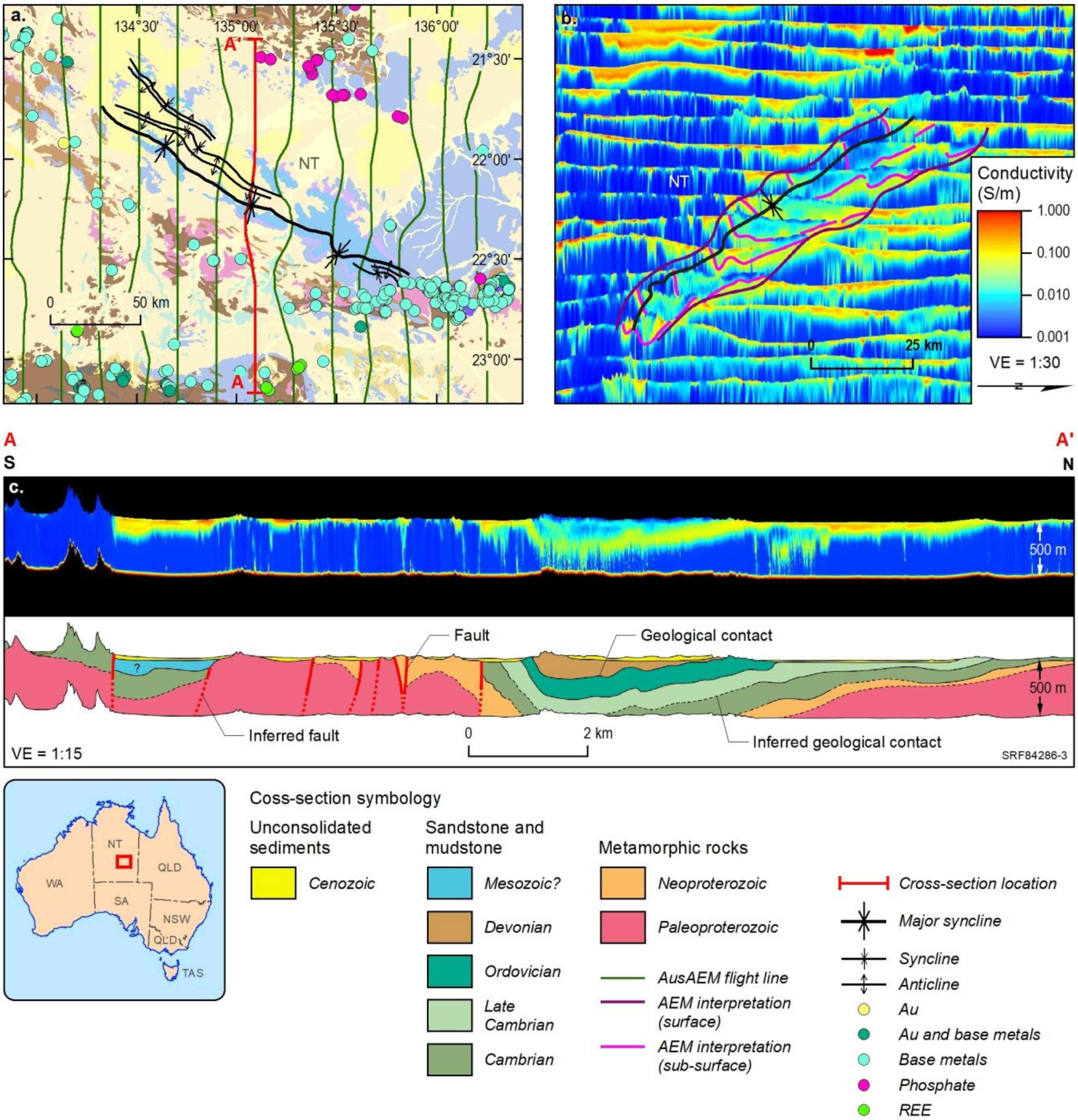

Figure 3 AusAEM interpretation in the Dulcie Trough/Syncline area. Internal structural geometries can be interpreted within the trough/syncline in the AEM. a) Map of the Dulcie Trough/Syncline area with interpretation of the major and minor fold axial traces observed in the AEM. The newly discovered minor folding in the northwest are examples of how the AEM can be used to refine 2D and 3D geological maps. b) Oblique view (looking west) of AusAEM conductivity sections (Ley-Cooper & Brodie, 2018) in the Dulcie Trough/Syncline area with basic interpretation delineating the conductivity contrast between Ordovician and Devonian stratigraphic units. This demonstrates the level of structural geometry that can be interpreted with the broadly-spaced surveys. c) Chronostratigraphic cross-section illustrating the level of detail that can be interpreted in this area, as a result of integrating the AEM with supporting geological and geophysical datasets. NT = Northern Territory