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AusAEM is the world's largest airborne electromagnetic (AEM) survey undertaken

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SUMMARY

Airborne electromagnetics surveys are at the forefront of addressing the challenge of exploration undercover. They have been essential in the regional mapping programmes to build Australia's resource potential inventory and provide information about the subsurface. In collaboration with State and Territory geological surveys, Geoscience Australia (GA) leads a national initiative to acquire AEM data across Australia at 20 km line spacing, as a component of the Australian government Exploring for The Future (EFTF) initiative. Regional models of subsurface electrical conductivity show new undercover geological features that could host critical-mineral deposits and groundwater resources. The models enable us to map potential alteration and structural zones and support environmental and land management studies. Several features observed in the AEM models have also provided insights into possible salt distribution analysed for its hydrogen storage potential.

The AusAEM programme is rapidly covering areas with regional AEM transects at a scale never previously attempted. The programme's success leans on the high-resolution, non-invasive nature of the method and its ability to derive subsurface electrical conductivity in three dimensions – made possible by GA's implementation of modern high-performance computing algorithms. The programme is increasingly acquiring more AEM data, processing it, and working towards full national coverage.

Key words: Airborne Electromagnetics, Exploration, Groundwater, Critical Minerals, Salt diaper.

INTRODUCTION

Pre-competitive data

Airborne, geophysical surveys have been fundamental in providing information about the subsurface. The recorded information derived from these data is particularly important in Australia, a landmass characterised by vast, remote landscapes, of which approximately 80% is under some form of cover. Over the past 50–60 years, Geoscience Australia (GA), in partnership with State and Territory government agencies, has systematically acquired and merged surveys covering the entire Australian continent. The acquisition of airborne geophysical surveys at GA builds on a long tradition of acquiring and delivering pre-competitive data to stimulate exploration and gather general geoscientific knowledge in areas with a scarcity of information.

Since the early 1950s, GA and its predecessor agencies (BMR and AGSO) have conducted regional mapping programmes to build an inventory of Australia's potential resource endowment. An organised and coordinated Continent-spanning compilation of geophysical surveying designed to serve as a baseline, combined with technological improvements over time, has led to world-class geophysical coverage of Australia. Currently, GA hosts approximately 35 million line km of magnetic-radiometric, gravity and AEM data stored in the national airborne geophysical database. This publicly available database is valued conservatively at approximately $240 M at today's acquisition prices.

GA has progressively acquired more extensive airborne electromagnetic (AEM) surveys to collect new generation geophysical datasets. AEM is a geophysical technique that unveils three-dimensional features below the ground's surface. The non-intrusive resolving capacity and investigation depth of the method have delivered very successful programs, acquiring data over extents never previously attempted. Geoscience Australia's AEM acquisition programme is as a component of the Exploring for The Future (EFTF) initiative. The programme has expanded and instigated further funding from the Geological Surveys of Western Australia and Queensland, combined with valuable in-kind support from all Australian State and Territory geological surveys. This concerted effort has yielded the world's largest AEM survey, AusAEM.

The long-lasting legacy of these datasets and the knowledge gained through them underpins the country's ability to manage energy, mineral, water and environmental resources. They provide insights into Australia's geological framework, identify potential hazards contributing to community safety, and promote Australia's global attractiveness to exploration companies.

Adjacent sections from flight lines acquired at 20 km separation (Figure 1) have provided enough detail to systematically delineate laterally continuous features, map basement topography and determine cover thickness. Models derived from AusAEM data have proven particularly useful in areas where a substantial thickness of overburden (up to 500 m) masks the underlying basement rocks that potentially host buried mineral deposits and groundwater resources. The AusAEM programme is progressively acquiring AEM data and working towards a national coverage comparable to Australia's gravity, magnetic and radiometric datasets.

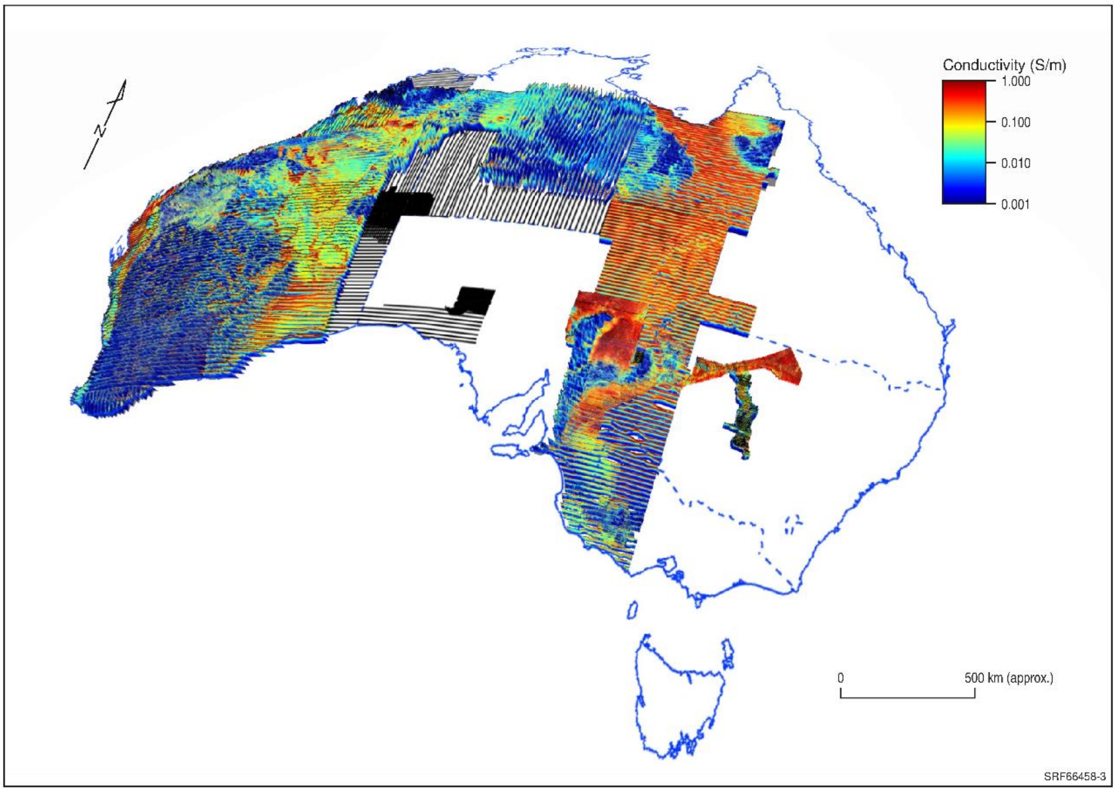

Figure 1. Conductivity-depth sections, derived from Geoscience Australia's Layered-Earth-Inversion modelling, showing the current continental coverage.

Inversion Modelling and its importance

Once the AEM data are collected, they are modelled prior to them being used for geological interpretation. AEM datasets undergo geophysical inversion, a mathematical and computational process that enables the conversion from transient electromagnetic (EM) decays in volts into profiles of subsurface EM conductivity. We use conductivity-depth values as a proxy for earth-forming materials and geological structures.

GA's open-source modelling computer code suite has evolved into more all-purpose algorithms. Inversion software built for modelling and interpretation is essential for realising the potential of AEM data. Geoscience Australia's Layered Earth Inversion Sample-By-Sample Time Domain Electromagnetics (GALEISBSTDEM) inversion codes, described in Brodie, 2016 and Brodie and Richardson, 2015, are capable of inverting data collected by most of the AEM instrument systems available.

A deterministic inversion will derive a single best-fitting solution using an optimisation technique that will update the proposed model to resemble the measured data better. This process has an inherent non-uniqueness, leaving interpreters with ambiguity, as various conductivity models can match the observed AEM data to the same quality of fit. GA has been developing the capacity to quantify the uncertainty of non-uniqueness in the process of geophysical inversion (Brodie and Sambridge, 2012; Ray et al., 2020).

Application uses and examples of AEM conductivity models

Most of the available AusAEM conductivity sections were derived from GALEISBSTDEM (Ley-Cooper and Brodie, 2020) or HiQGA (Ray et al., 2020) inversions. The conductivity-depth models derived from these inversions unveil undercover geological features that may host mineral deposits, storage reservoirs and groundwater resources (Figure 1 and 2). They enhance our capacity to derive depth-to-target information on geographical features, potential alteration and structural zones, and continue to support environmental and land management studies. The inverted AusAEM conductivity sections enable the extension of limited knowledge from surficial out-cropping geology into unexplored regions and beyond in areas undercover. These profile sections shed light on the electrical conductivity signature of the near-surface to depths of approximately 300 to 500 m below surface.

Combining these AEM inversion models with GA's national gravity, magnetic and radiometric datasets enables us to better understand the geology in 3D and determine the resource potential in frontier areas.

AEM's role in the search for critical minerals

The global energy transition will rely on our ability to explore and find critical minerals. The term refers to any mineral that is a necessary component in solar panels, wind turbines, batteries and other low emissions technologies, as well as being essential for the construction of electric motors and is at risk of supply chain disruptions. The Australian government considers 26 critical minerals based on Australia's geological endowment. This list includes chromium, cobalt, graphite, lithium, rare-earth elements, silicon, vanadium, and platinum-group elements. The complete list is available from https://www.ga.gov.au/scientific-topics/minerals/critical-minerals.

Australia currently supplies around 55% of the world's lithium; by 2040, its global demand is expected to be 40 times bigger than in 2020 levels. Demand for graphite will be 25 times more considerable and 21 times more significant for cobalt. Mineralisation associated with mafic intrusions in Precambrian magmatic systems is an important world source of critical minerals. This is important in the Australian context since approximately 60% of the western part of Australia is composed of Precambrian rocks (Uwe et al., 2021). Exploration for mineral deposits in these systems can be daunting since they can occur as intrusions in a stack of thick cumulates ranging from a few meters to thousands of metres, in an area of several hundred square kilometres.

Collecting geophysical data and applying new approaches for revealing the details of the geologic environment in less explored environments where critical minerals might be found is crucial. The AusAEM programme has proven instrumental at the different stages of critical mineral search in Australia, from project generation, area selection, targeting and drilling. Data is used by GA, industry, CSIRO and other government organisations to progress exploration for less-conventional environments and rocks which host critical minerals such as pegmatites and rare earth element-bearing clays.

Geophysical methods play an important role in mineral resource exploration. However, compared with bulk minerals, there are many differences in physical properties, reserves, and occurrence of critical minerals.

Hydrogen Storage

AusAEM has confirmed the existence of previously known salt diapiric structures and revealed potentially new ones, features which are being analysed and further investigated for their hydrogen storage potential.

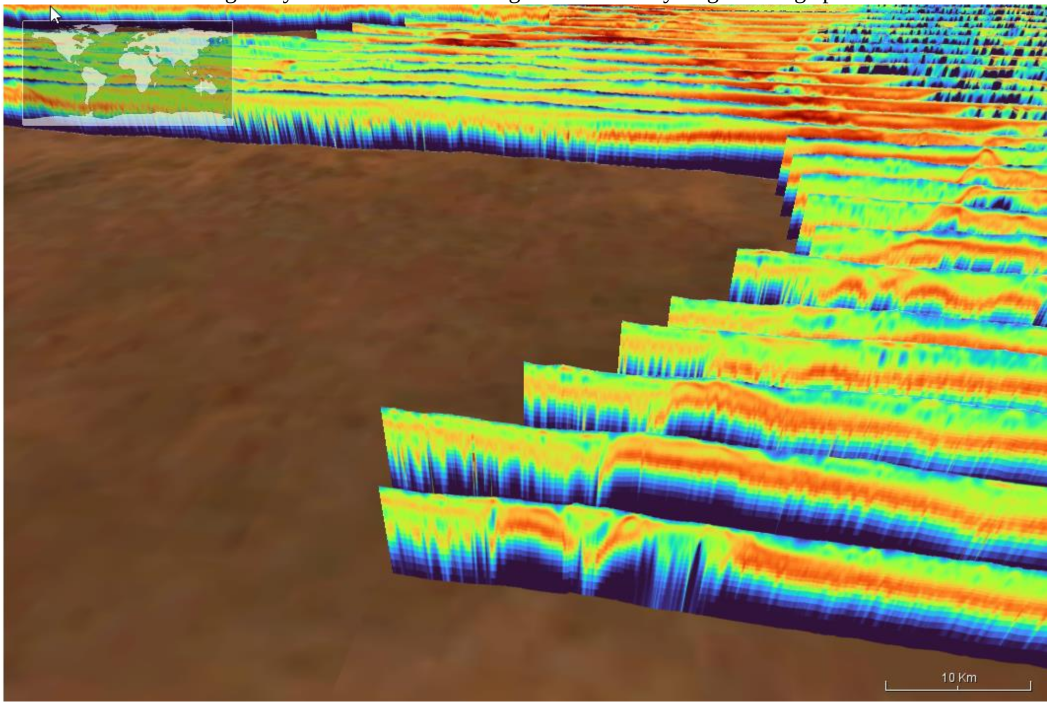

Figure 2. View looking to the East at the of north-south flown conductivity-depth sections, derived from Geoscience Australia's Layered-Earth-Inversion modelling. The cross-sections highlight disruption in conductive stratigraphy related to localised movement.

Salt diapirs in the AusAEM profiles, such as those described by Connors et al., 2022 in the Canning basin area, appear as prominent anomalous structures disrupting the laterally continuous background of basin strata. These features disrupt the continuity of overlying layering as shown in Figure 2. Efforts to understand the near-surface disrupted geology by the dissolution or movement of salt structures have focused on areas where salt-related structures are known to occur. The potential variation in salt geometry inferred from observed variations in the shallow conductive units is evident in the AEM sections.

The inverted AEM models have been a nodal dataset to support resource exploration and environmental management in the study area, as well as recommendations on the potential of the area to host salt structures for hydrogen storage.

Mapping Palaeovalleys and delineating groundwater aquifers

Palaeovalleys are commonly filled with Cenozoic and Mesozoic sedimentary sequences incised into older underlying units in Australia. These Palaeovalleys usually take the shape of elongated basins or low-relief valleys and can usually be traced over tens of kilometres across multiple AusAEM conductivity sections.

Palaeovalleys can typically be recognised by a sharp contrast between electrically high resistive underlying units and electrically conductive sedimentary infill. Palaeochannels usually contain porous sediments and have good aquifer storage and migration potential. Less porous rocks underlying and surrounding palaeovalleys may act as aquitards that limit infiltration to greater depths or constrain lateral migration of groundwater, which allows the palaeovalleys to act as conduits for groundwater flow. Interpreting AusAEM data has greatly improved knowledge of the potential locations of near-surface groundwater systems through the broad-scale mapping of the old river channel networks.

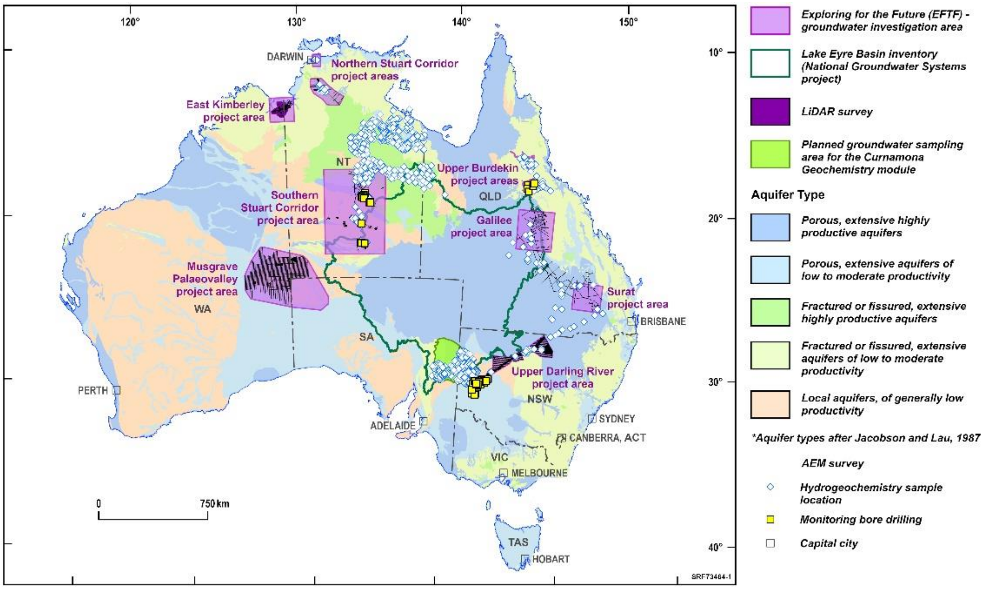

Figure 3. High resolution GA managed groundwater AEM surveys over map of known national aquifers.

AEM conductivity data and its associated byproducts are crucial to accurately assess the impacts caused by land use changes and groundwater pumping. This leads in whole, to a better understanding on the impact, the structure and composition of Australia's groundwater systems (Symington et al., 2021; Buckerfield et al., 2022). Figure 3 shows the location of some of GA's AEM surveys designed around the targeting of ground water resources.

CONCLUSIONS

Australia has some of the finest national collections of legacy geophysical datasets in the world acquired through coordinated geophysical surveying, organised and compiled over 70 years. These datasets allows for data driven decision making, turning it into one of the preferred destination places for natural resource exploration and investment. Approximately seventy per cent of the Australian continent is currently covered with broad reconnaissance 20 km spaced AEM line data.

The AusAEM survey images subsurface structures down to 500 m through lateral and vertical electrical conductivity variations. These variations add extra information for deep stratigraphy and structure mapping, especially in areas lacking drill-hole and outcrop data. Conventional bump finding is now enhanced by modelling and inversions, which has extended the use of AEM models to more quantitative applications.

Many features observed in the AEM models have provided insight into potential salt distributions for hydrogen storage studies. A growing number of documented examples using the AusAEM dataset have mapped known and new groundwater features such as palaeo-drainage, aquifers, and fresh-saline groundwater interfaces.

AusAEM provides a new semi-continuous, 3D regional picture of near-surface geology in Australia. Continuing interpretation has provided regional-scale depth to the chronostratigraphically important boundaries; helping to re-evaluate the distribution and thickness of basins. This ultimately improves our understanding of groundwater, mineral and energy systems in Australia.

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