WA-MT: A new statewide long-period magnetotelluric survey

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SUMMARY

Regional-scale long-period magnetotelluric (LPMT) surveys are becoming more common for understating the deep lithospheric structure of the Earth, for example the USArray magnetotelluric program, AusLAMP, and a new major LPMT experiment across the state of Western Australia: WA-MT. WA remains under-imaged in LPMT data, however, WA-MT aims to remedy this by collecting data from 1468 new locations across WA. These data and data products will be made publicly available for geological interpretation of the subsurface by explorers and researchers. Outcomes of this project include: (1) increased pre-competitive geoscience data for reducing exploration risk, (2) a world-leading dataset covering the WA state to attract resource investment, (3) a lithospheric architecture model complimenting the WA Array passive seismic and GSWA deep active seismic projects, and (4) complimentary statewide conductivity data products to statewide AusAEM data. This abstract is the first publication of new survey results from WA-MT, located over the Albany-Fraser Orogen and southeastern Yilgarn Craton of WA.

Keywords: Long-period magnetotellurics, WA-MT, Albany-Fraser Orogen, Yilgarn Craton, 3-Dimensonal.

INTRODUCTION

The Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) is a national collaboration survey program that has acquired LPMT data across the Australian continent. However, few AusLAMP sites have been collected in Western Australia (WA) (Figure 1). To fill this gap, the Department of Energy Mines, Industry Regulation and Safety (DEMIRS) through the Geological Survey of Western Australia (GSWA) have established the 10-year WA-MT project. The WA-MT project will facilitate the collection of LPMT data across WA to coincide with the statewide WA Array passive seismic program. Outputs from WA Array and WA-MT will be used to image the composition and structure of the State's crust and lithosphere. Both projects are major logistical undertakings, representing one of the largest seismic and MT surveys completed anywhere in the world.

Efforts to cover the Australian continent via AusLAMP have focused on the Eastern Australian states (Figure 2). Duan et al., (2021) present 3D inversion results from AusLAMP data collected across the North Australian Craton in the Northern Territory and western Queensland which were useful for interpreting the lithospheric structures that form the main crustal sutures in the region (Figure 2(a)). Similarly, Thiel and Heinson, (2013) and Robertson et al., (2016) have inverted LPMT data as part of AusLAMP to create various 3D models across the South Australian state (Figure 2(b)). These data products were instrumental in identifying regions of potential mineral prospectivity associated with modelled 3D conductive anomaly highs. Kirkby et al., (2022) use AusLAMP data from New South Wales and Victora to demonstrate correlations between mid- to lower crustal conductors and orogenic gold, porphyry, and VHMS deposits (Figure 2(c)). In Tasmania, geothermal resources and upper crustal faults were interpreted from new 2D and 3D inversions of AusLAMP data (Ostersen, 2021) (Figure 2(d)). Due to the paucity of equivalent LPMT data, WA lacks similar models and

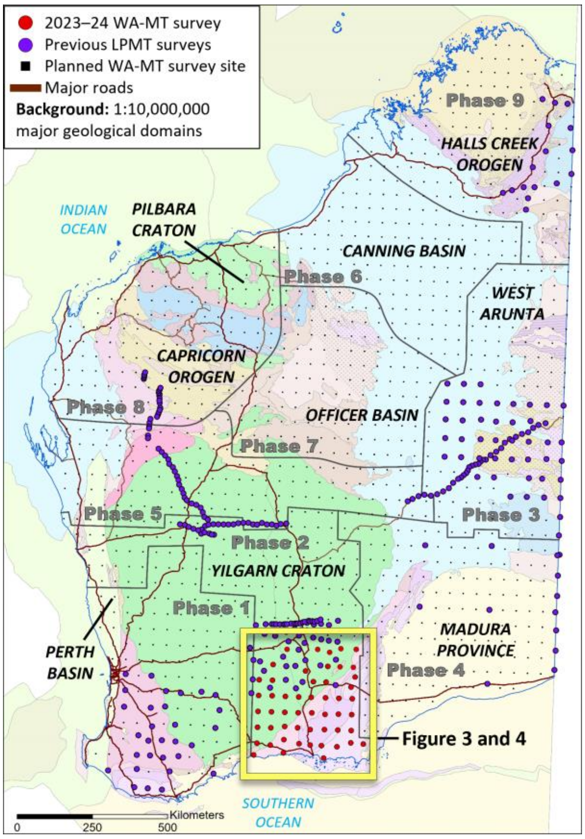

Figure 1. Map of WA-MT survey locations for each acquisition phase. Red points show the location of new LPMT sites collected in 2023–24. Small black points are the planned WA-MT survey locations.

maps of conductivity variations of the deeper sub-surface. Consequently, WA-MT aims to complete the Australian content coverage of LPMT data and produce relevant 3D conductivity models of WA.

THE WA-MT PROJECT

LPMT techniques are unique in comparison to audio-magnetotelluric (AMT) or broadband magnetotelluric (BBMT) techniques as they are sensitive to electromagnetic field information useful for imaging depths of 10's of kilometers to 100's of kilometers. For LPMT surveys, the source of these electromagnetic fields comes from the interaction of the Earth's magnetic field with solar winds. Solar activity is currently increasing which is timely for the commencement of WA-MT whereby signal quality is improved. Interpretations of this deep crustal information in the form of 3D models, alongside data products from the WA Array passive seismic program will significantly add to the knowledge of WA's crust and lithosphere. In addition, the results from statewide LPMT surveys will provide new electrical conductivity models complimentary to the electromagnetic products of the continent-wide AusAEM project, and other state-wide geophysical datasets. The WA-MT products are of particular interest not only to the research community, but industry by providing first pass tools for mineral explorers looking to target deep lithospheric features linked to new mineral resources. Key outcomes of this project are models of electrical conductivity variations with a focus on mapping craton margins and deep lithospheric structures which are known to be major controls on mineralization (McCuaig et al., 2010), and understanding the influence of deep conductors and geoelectric hazards on electrical infrastructure (Cordell et al., 2021).

The WA-MT project will facilitate the collection of LPMT data on a nominal 40km x 40km spaced gird pattern with a total of 1468 new WA stations (Figure 1). Currently, LPMT data exists for 180 of these planned sites. Data collection will be completed via rolling field campaigns across nine separate phases with the aim of collecting data in each phase over a 12-month period (Figure 1). Surveying at each site consists of a 3–6-week deployment of LPMT equipment, mostly comprising a LEMI-424 fluxgate magnetometer, datalogger and non-polarizing electrodes, with the aim of calculating impendence tensors to periods $\geq 10^4$s. To date the WA-MT project has facilitated the collection of 52 new LPMT sites from the Esperance and Goldfields regions of WA. These sites fall within the 'Phase 2' region and were collected in conjunction with the WA Array program. Preliminary data from 24 of these sites are presented here. On completion of the current Esperance and Goldfields survey in early July 2024, this data will be inverted in 3D and interpreted in conjunction with new GSWA commissioned active seismic and WA Array passive seismic data.

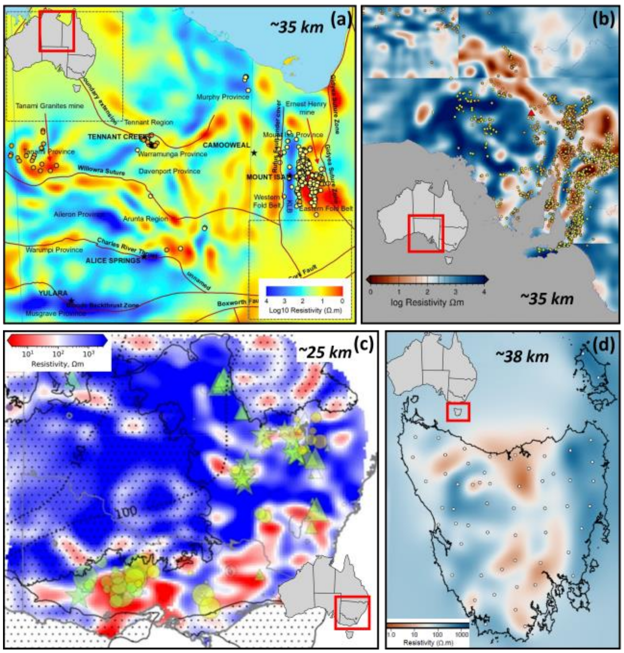

Figure 2. Example depth slices through Australian 3D LPMT resistivity models (a) Northern Australia (mod. from: Duan et al., (2021)), (b) Southern Australia (mod. from: Geological Survey of South Australia, (2023)), (c) Eastern Australia (mod. from: Kirkby et al., (2022)), (d) Tasmania (mod. from: Ostersen, (2021)).

GEOLOGICAL BACKGROUND

Of the 24 preliminary LPMT sites, 15 are located over the Albany Fraser Orogen (AFO), and nine are in the southeastern Youanmi Terrane (SEYT) of the Archean Yilgarn Craton (Figure 3(a)). The SEYT comprises mostly granitic units and some minor metasedimentary and metamorphosed volcano-sedimentary units (Dentith et al., 2013; Kirkland et al., 2011). The AFO records a long Paleo- to Mesoproterozoic history of extension and thrust tectonics and is largely a product of reworking of the southern and southeastern Yilgarn Craton (Spaggiari et al., 2015; Spaggiari et al., 2014). AFO is a northeasterly trending belt that is subdivided into several geological zones and provinces, with the Biranup and Nornalup Zones being the two main zones covered by new LPMT data. The Nornalup Zone comprises metagranites and meta-monzogranitic gneisses intruded by the granites of younger suites, and the Biranup Zone comprises metamorphosed gneisses at upper amphibolite- to granulite-facies (Spaggiari et al., 2014).

Two tectono-thermal stages define the early deformation of the AFO: felsic and mafic magmatism accompanied by high-temperature metamorphism, folding, thrusting and shearing in Stage I (1330 and 1260 Ma), and intracratonic reactivation and voluminous magmatism and craton-vergent thrusting in Stage II (1225–1140 Ma)

(Kirkland et al., 2011; Sippl et al., 2018; Spaggiari et al., 2015; Spaggiari et al., 2014). The AFO is separated into several internal zones and provinces by northeast to southwest trending faults, some of which form large scale sutures and interpreted zones of crustal weakness for the emplacement of magmatic intrusions (Spaggiari et al., 2014). Identifying these deep penetrating faults is important as they may form conduits for metal-bearing magmas and brines from the deep crust and mantle (McCuaig et al., 2010). Such faults can be mapped using inversions of LPMT data where a resistivity contrast can be identified between the SEYT and geological domains of the AFO.

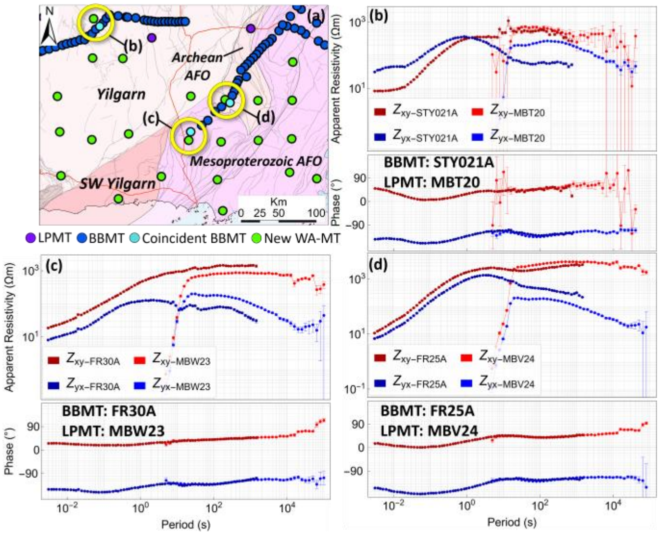

Figure 3. (a) GSWA 1:2,500,000 tectonic units and 1:500,000 structures, and new LPMT WA-MT and 2012-13 BBMT locations. (b)-(d) Apparent resistivity and phase plots for three WA-MT sites and coincident 2012-13 BBMT.

FIRST LOOK: NEW WA-MT DATA

The geological complexity of the SEYT margin with the AFO is reflected in the new LPMT data. Figure 4 shows the dimensionality of the data and induction arrows directed towards regions of conductive anomalies at selected periods plotted following Caldwell et al., (2004) and the Parkinson method (Parkinson, 1959), respectively. At all periods the data are dominantly 3-dimensional having elliptical phase tensor ellipses with skews greater than ±3^{o} for all periods. Unsurprisingly, the ellipticity of the phase tensors increase for data over the highly deformed AFO compared to data over the comparatively less deformed granites of the SEYT. Between ~10^{2}s–10^{4}s the geoelectric strike is relatively consistent for each site with increasing period. For periods >10^{4}s, synonymous with very large depths (much greater than 100km depth), there is a slight shift in the orientation of the geoelectrical strike, and a significant change in the orientation and size of the induction arrows which predominantly point towards a conductive anomaly in the southwest. For periods ≤10^{2}s, synonymous with shallower depths, induction arrows are mostly variable with a weak north–northeastern trend.

WA presents a unique opportunity for understanding the WA lithosphere at a range of depths. Various publicly available AMT and BBMT surveys from across WA can be integrated with the new WA-MT data to produce models of the shallow to very deep subsurface. Spratt et al., (2019) previously inverted BBMT data collected in 2012-13 in 2-dimensions from the AFO. For three of the new WA-MT sites the LPMT apparent resistivities and phases have been plotted with approximately coincident 2012-13 BBMT data in Figure 3(b)-(d). The magnitude of the LPMT Z_{XY} component apparent resistivity data is generally consistent with the BBMT data at the same periods, however, across all sites there is a shift in the magnitude of the LPMT Z_{YX} component apparent resistivity data compared to the BBMT data. Separately, data are spurious at the limits of the LPMT instrument sensitivity (recording rates at 1Hz), for example, at the shortest periods and periods approaching 10^{5}s the LPMT data are ‘noisy’ and inconsistent with equivalent BBMT data. All phase data are consistent across the 2 surveys.

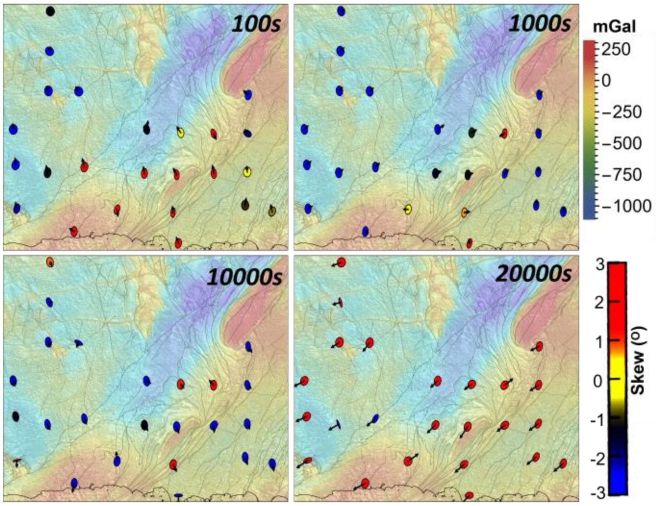

Figure 4. Transparent pseudocolour 400m Bouguer gravity anomaly grid over grey scale with 45^{o} sun shading 20m RTP magnetic anomaly grid overlain by 1:500,000 GSWA structures. Phase tensors and induction arrows pointing towards conductive regions are shown for select periods.

The LPMT apparent resistivities typically decrease with increasing period suggesting there may be a deep source of conductivity at great depths not previously detected by the BBMT survey. Holistically viewing the BBMT and LPMT apparent resistivities between periods ~10^{-2}s–10^{2}s, the data indicate the near surface is conductive and that with increasing depth the subsurface becomes more resistive (apparent resistivities up to 1000Ωm for mid-range periods), consistent with a potentially conductive cover sequence overlying the resistive granites and gneisses of the SEYT and AFO, respectively. The longest period apparent resistivities for site MBT20 have large errors, and phases are out of quadrant (POQ) in the Z_{XY} component. While POQ are a real phenomenon in complex geological terranes (Piña-Varas and Dentith, 2018), with limited data from surrounding sites, it is inconclusive whether these POQ data are related to the geology or a byproduct of a poorer quality site recording.

CONCLUSIONS

The WA-MT experiment is one of the largest MT surveys attempted in Australia, and in conjunction with the WA Array program, aims to image the very deep lithosphere. The project offers the opportunity to fill the gap in lithospheric scale LPMT information across WA which will feed into the AusLAMP project for the Australian continent, completing one of the largest continent-wide LPMT surveys in the world. The data collected at the proposed sites will be made publicly available whereby: (1) mineral explorers can make informed decisions on procuring or retaining tenements, and (2) appropriate plans and standards can be developed for electrical infrastructure that may be impacted by induced currents from geomagnetic disturbances. On completion of the latest WA-MT survey in July 2024, the new data will be inverted in 3-dimensions to produce new models of the Earth’s conductivity variations across the SEYT and AFO of WA.

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