Magnetotelluric Investigation Along Seismic Transect 19GA-B1

Results from Round 15 of the Geophysics and Drilling Collaborations Programme

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Map Sheet: Ranken SE53-16

Data/Projection: GDA94 MGA zone 53

Teck

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Abstract

Zonge Engineering & Research Organization (Australia) conducted a Magnetotelluric (MT) survey at the Barkly project in the Northern Territory for Teck Australia Pty Ltd. A total of 155 MT soundings were carried out, including 116 overnight Broad Band Magnetotelluric (BBMT) sites, 37 shorter duration Audio-frequency Magnetotelluric soundings (AMT), and 2 remote BBMT soundings. The objectives of this work are to better understand the nature of covered Paleoproterozoic stratigraphy by correlating MT inversion results with seismic images from 19GA-B1. The results of this work can be used to interpret major stratigraphic unit, structural features, and estimate the thickness of Cambrian cover in the Barkly Region.

Introduction

Between the 29th of September and 30th of October 2022, Zonge Engineering & Research Organization (Australia) Pty Ltd carried out a MT survey for Teck Australia Pty Ltd at the Barkly project, see Figure 1 and 2. The MT method measures natural electromagnetic fields in the Earth's subsurface and can image structures like sedimentary basins that have a different electrical conductivity compared to the surrounding rock (Chave and Jones, 2012).

The proposed programme consisted of 179 overnight BBMT soundings spaced at 500m intervals across the 19GA-B1 seismic transect. A total of 155 MT stations were collected which included 2 remote references, 116 BBMT sites acquired overnight, and 37 shorter-duration AMT sites acquired during daylight, see Table 1. The objectives of this work are to screen for conductors in Paleoproterozoic stratigraphy and integrate subsequent MT inversion results with seismic images from 19GA-B1 for enhanced interpretation of major structural features and the thickness of Cambrian cover.

Intermittent storms and inclement weather significantly reduced the productivity of the proposed survey programme with wet tracks preventing the field crew from accessing sites, sometimes for several days. To compensate for lower-than-expected production rates, Teck amended the programme to incorporate a series of AMT soundings designed to quickly fill-in gaps between 1km spaced BBMT sites in the centre of the profile. Data from these AMT soundings will enhance the quality of subsequent modelling and inversion results in the top 1 to 1.5 km below surface. Two BBMT sites were acquired during the search for a suitable remote reference site for robust data processing. These sites are located on Teck tenure near the north-eastern and south-eastern project boundaries.

To eliminate the risk of having field crew and equipment stranded on the project area by forecasted rain, Teck advised Zonge to demobilize on 30th of October 2022.

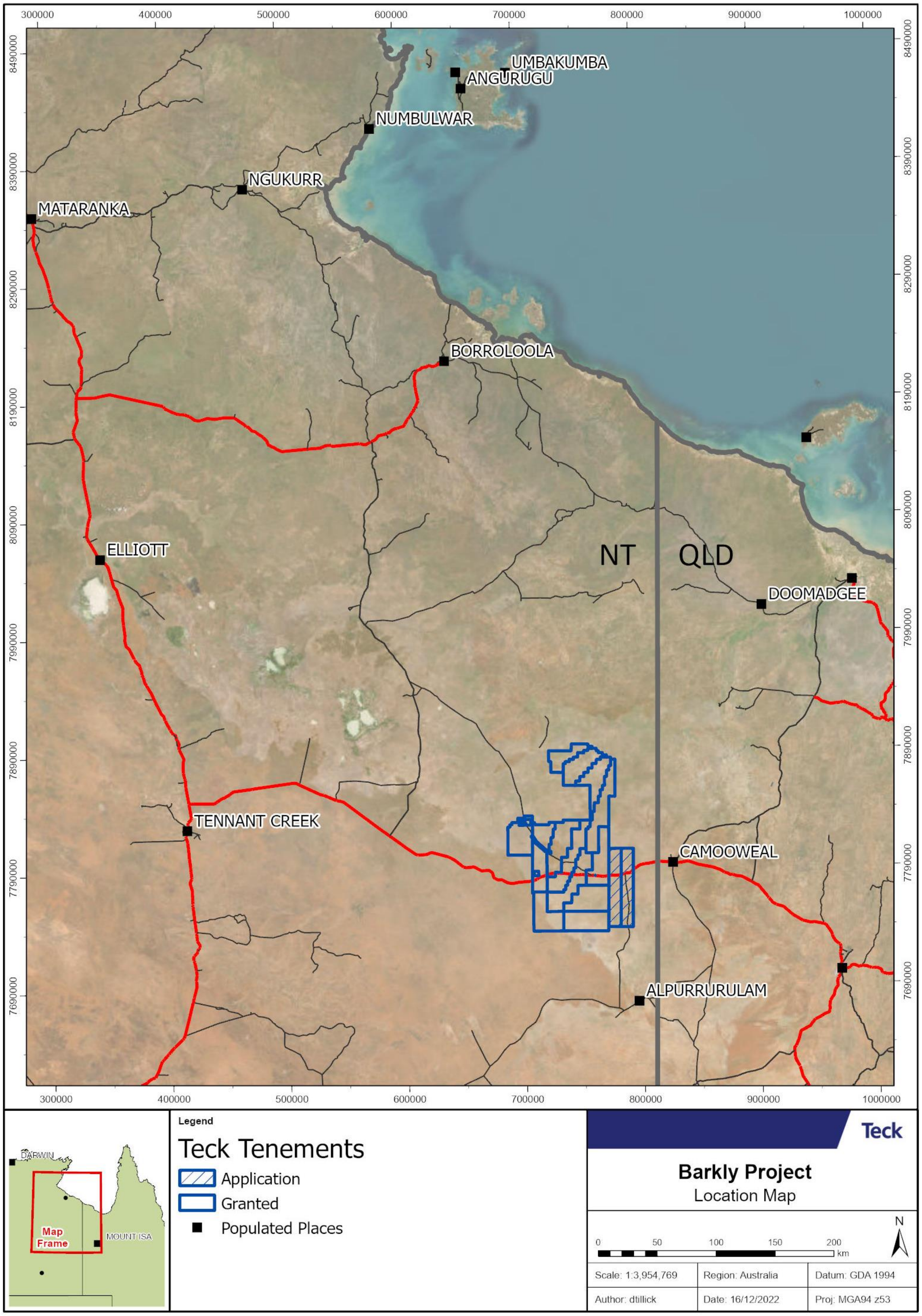

Figure 1. Location map of the Teck Barkly tenure package proximal to the NT-QLD border.

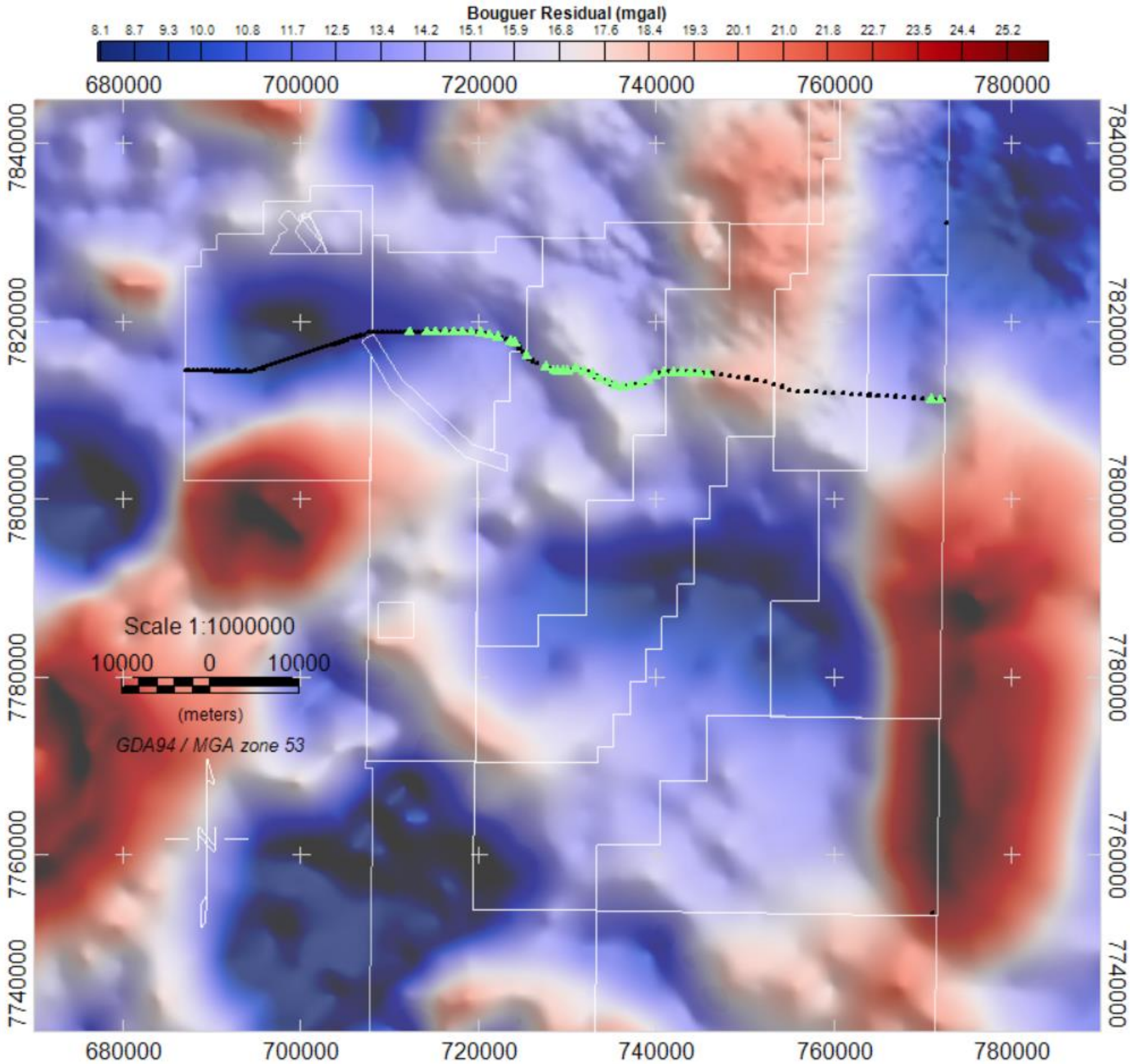

Figure 2: Plan showing MT coverage overlain on an image of the Bouguer gravity residual. Teck tenements (white) are shown with BBMT (black squares) and AMT (green triangles) soundings.

Table 1: MT sounding summary.

Sounding Type	Completed	Incomplete	Proposed
BBMT	116	26	179
AMT	37	0	
Remote BBMT	2	0	0
Total Acquired	**155**		

Regional Context

The Barkly Project spans the eastern portion of the Barkly Tablelands, between the Soudan and Avon Downs homesteads, with the Barkly Highway transecting the central portion of the tenure. Much of the geological understanding of the region comes from government datasets including the Geoscience Australian seismic transect (19GA-B1), NTGS regional aeromagnetic surveys and the recent Brunette Downs ground gravity survey (Wynne, 2022).

Outcropping geology within the project area is limited to Cryogenian to Devonian sedimentary rocks of the intra-cratonic Georgina Basin, which is likely to be locally intruded by mafic units belonging to the Kalkarindji Large Igneous Province. Proterozoic rocks are not exposed in the project area, however, recent (Gibson and Edwards, 2020; Connors et al., 2022) interpretations of the 2D seismic profile 19GA-B1 indicate that Isan-aged Proterozoic stratigraphy extends westward under the Georgina Basin, from the Mount Isa Inlier into the Barkly Tablelands.

Regional geophysical datasets, including magnetics and gravity, support the presence of non-magnetic and relatively low-density basin sediments overlying a generally denser and more magnetic crystalline basement comprising volcanics and/or metamorphic rocks that appear to be a continuation of the East Tennant Creek terrane. Magnetic responses are broad and diffuse in the project area, attesting to a relatively deep source rock. Structure within the basement and overlying sedimentary basins are currently poorly understood.

In 2019, Geoscience Australia undertook an MT survey in the eastern region of the Tennant Creek inlier as part of its "Exploring for the Future" program (Jiang et al., 2022). The goal was to improve the understanding of basement architecture and its impact on mineral potential by mapping the Tenant Creek basement as it plunges beneath the southern McArthur super basin. The Barkly MT survey starts approximately 40 km east of the East Tennant Creek survey and potentially maps the continuation of Tenant Creek basement beneath the Barkly project.

NTGS drilling in 2000-2001, which straddled Teck's Barkly project (NGTS00_01 and NTGS01_01), intersected Proterozoic South Nicholson Group but fell short of intercepting underlying prospective units. MinEx CRC hole NDI Carrara-1 intersected a thick package of Proterozoic carbonates, shales, and siliciclastics, within the newly identified Carrara Sub-basin and Teck is targeting the same, or age-equivalent, stratigraphy within the Barkly project.

Previous Exploration

Historically, the Barkly project has been explored for manganese, uranium, and phosphate hosted within the Georgina Basin. Additionally, Devonian kimberlite pipes were popular exploration targets for diamonds. Historical exploration for Proterozoic sediment-hosted massive sulphide (SHMS) styles was limited due to the thick cover being considered prohibitive. There is no drilling within the project tenure that has effectively tested for SHMS potential.

Exploration Concept

The Barkly project is prospective for SHMS Zn-Pb-Ag mineralisation, comparable to the world-class systems hosted in the ~1.6 Ga Proterozoic McArthur Basin (McArthur River) and Isa Super-basin (e.g. Century, Mt Isa, George Fisher). These deposits are all hosted within carbonaceous, pyritic, and dolomitic siltstone/shale units deposited during the sag phase of the rift cycle. These lithologies are typically more conductive than carbonate and sandstone facies and should respond more favourably to electrical geophysical methods.

Evidence from drilling (NDI Carrara-1) and seismic (17GA-SN1, 17GA-SN5, 19GA-B1, and 19GA-B2) suggests that the McNamara Group (Lawn Hill Platform), which hosts the Century Zn-Pb deposit, extends under cover into the Barkly Tablelands and potentially into the project area. The proposed MT survey will test for a continuation of conductive stratigraphy within the project area and may also help define major basin-bounding or intra-basin growth faults.

Details of the Collaborative Programme

Zonge carried out a 90-line-km MT traverse coincident with a portion of seismic line 19GA-B1. The traverse extended from 697661 mE, 7816520 mN in the west to 764986 mE, 7795950 mN (MGA 53) in the east. Using the Phoenix MTU5-C system (Figure 3), we acquired data with a station spacing of 500m to resolve lateral changes in conductivity in the top 1 km of the crust.

Figure 3: Equipment used in the Barkly MT survey.

The sounding duration and signal frequency varied across the survey, with AMT soundings typically lasting between 20 and 120 minutes and sampling frequencies from 7 to 10,000 Hz, and BBMT soundings lasting between 16 and 20 hours and sampling frequencies from 0.001 to 10,000 Hz. By interspersing AMT and BBMT sites, we ensured uniform depth of investigation from the surface to depths beyond 100 km. BBMT data was acquired using non-polarizing electrodes, while some AMT sites utilized stainless steel stakes.

Zonge processed data from raw time series format into EDI files using software EM Power. Data were acquired with the x-components directed north (0°) and y-components directed east (90°) using a geomagnetic coordinate system. Zonge applied corrections for geomagnetic declination (approximately 4.8° East). We edited the apparent resistivity and phase data on a frequency-by-frequency and station-by-station basis to remove spurious points, improve data quality, and increase the reliability of subsequent 2D inversion results. After editing, we created a series of MT parameter plots including tipper vectors (Jones, 1986) and phase tensor ellipses (Caldwell et al. 2004) for the entire BBMT frequency band, see. Figure 4.

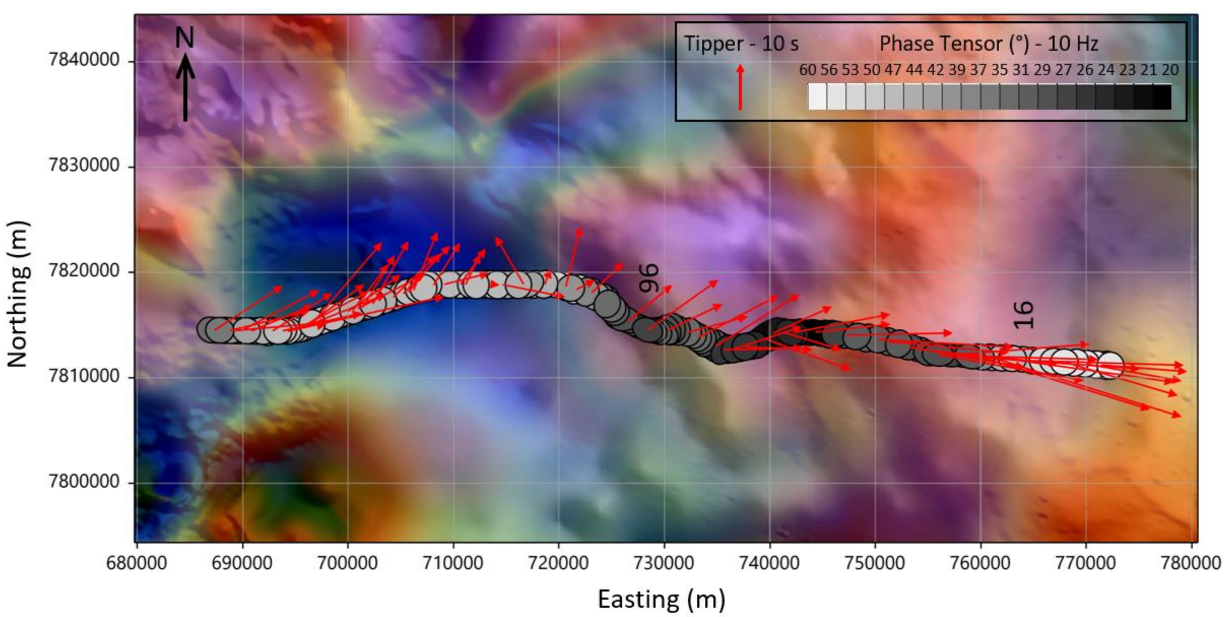

Figure 4:Plan showing phase tensors (10 Hz) as grey ellipses and tipper vectors (0.1 Hz) as red arrows on a composite image of gravity and magnetic data using a rainbow colored gaussian stretch.

The phase tensors were calculated at 10 Hz and graphically represented on Figure 4. Lighter-shaded ellipses indicate conductive rocks, while darker-shaded ellipses indicate resistive rock. The near-circular ellipses observed across the profile indicate the isotropic conductivities. Above 10 Hz, phase tensors demonstrate mild preference for electrical currents to flow to the north. Tipper vectors calculated at 0.1 Hz (also shown on Figure 4), which are displayed as red induction arrows, point towards conductors, and help us visualize the direction and magnitude of electrical current flow in the subsurface. To the west of the profile, tipper vectors point north towards a gravity and magnetic low, likely indicating a conductive structure buried at a depth of approximately 20 km. Further 3D Magnetotelluric surveying with 3D inversion are required to better image this feature. To the east, relatively long tipper vectors demonstrate the presence of a major crustal structure located east of the survey area by possibly tens of kilometers.

To visualise conductivity structure and identify areas with contrasting electrical properties, we compared processed MT data from two sites, 96 and 16, located in the center and east of the profile, respectively (Figure 5). At station 96, we observe an apparent resistivity curve that starts at 10 Ω.m at high frequency, increasing monotonically to 1000 Ω.m at around 10 seconds. This demonstrates a conductive layer at shallow depths that transitions to a resistive layer at depth.

At station 16, however, we observe distinct differences in response. A deep trough in apparent resistivity is noted at around 5 Hz, with a coincident positive-to-negative phase crossover. This suggests the presence of a conductive layer at depth. The split of the xy and yx curves (red and blue, respectively) beginning at several seconds highlights that the deep subsurface is anisotropic here, meaning conductivity varies in different directions. Polar plots show the strike of this deeper feature is approximately NNW. Also displayed on Figure 5 are 2D model responses, which produce a highly accurate fit to the apparent resistivity and phase curves.

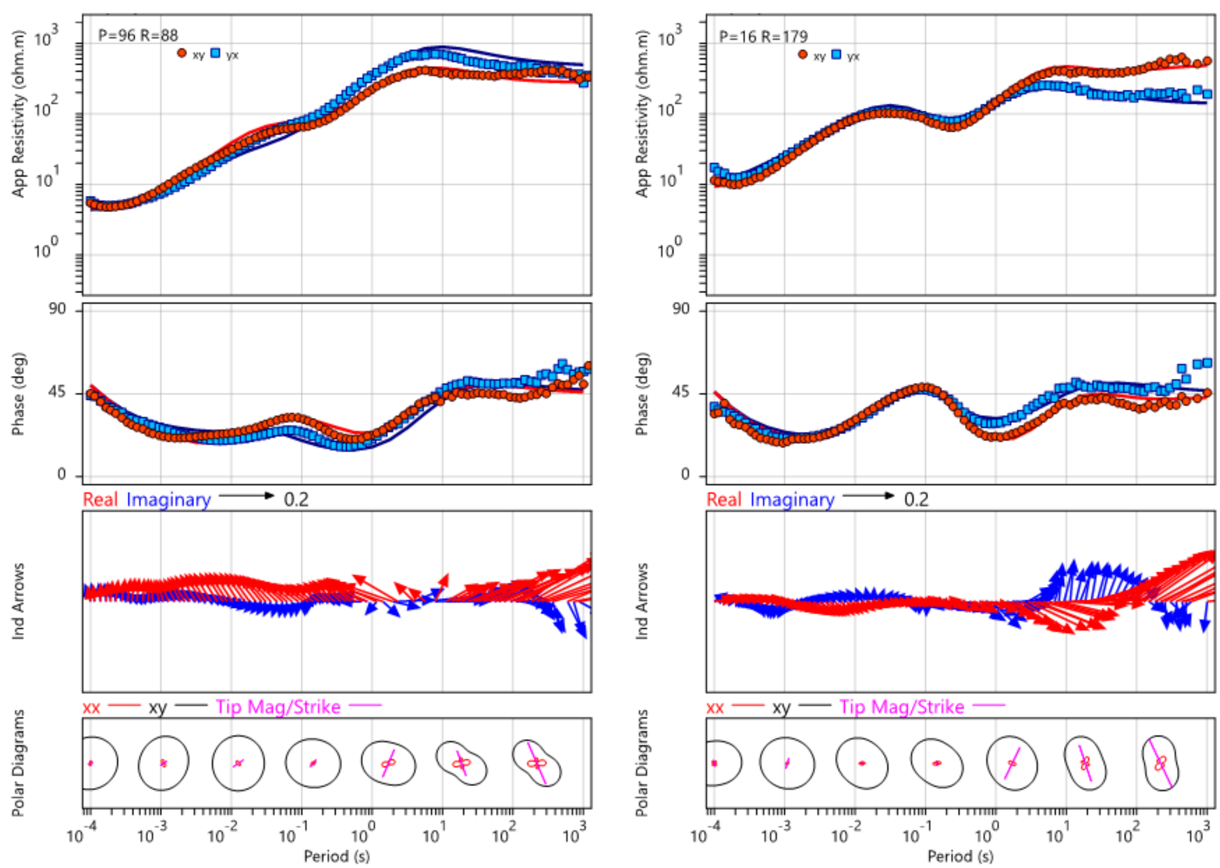

Figure 5: 2D modelling of apparent resistivity and phase curves at stations 96 (center) and 16 (east), with real (red) and imaginary (blue) induction arrows and polar diagrams showing dimensionality and directionality.

Results and Interpretations

We used the program Geotools to carry out 2D inversion of the entire Barkly MT profile. The 2D code, based on work by Rodi and Mackie (2001), was applied to un-rotated data and used regularization parameters that favoured horizontally smooth structures, as expected in a sedimentary basin.

A cross-sectional representation of the 2D inversion results (Figure 6), depict a sequence of horizontally layered conductors that overlie a resistive basement. The conductive strata, identifiable as warm-colored horizontal layers, are primarily concentrated within the upper 2000 m’s beneath the surface. At surface, a 20-m-thick Cenozoic black soil layer has a resistivity of 10 Ω.m and a conductivity-thickness product (conductance) of 2 S. These cover conditions are favorable for MT and allow us to confidently and accurately image deeper stratigraphic conductors where their conductance values are greater than 2 S. A deep crustal conductor is imaged at approximately 20 km depth on the western end of the profile and is corroborated by a strong tipper response pointing north towards the conductor.

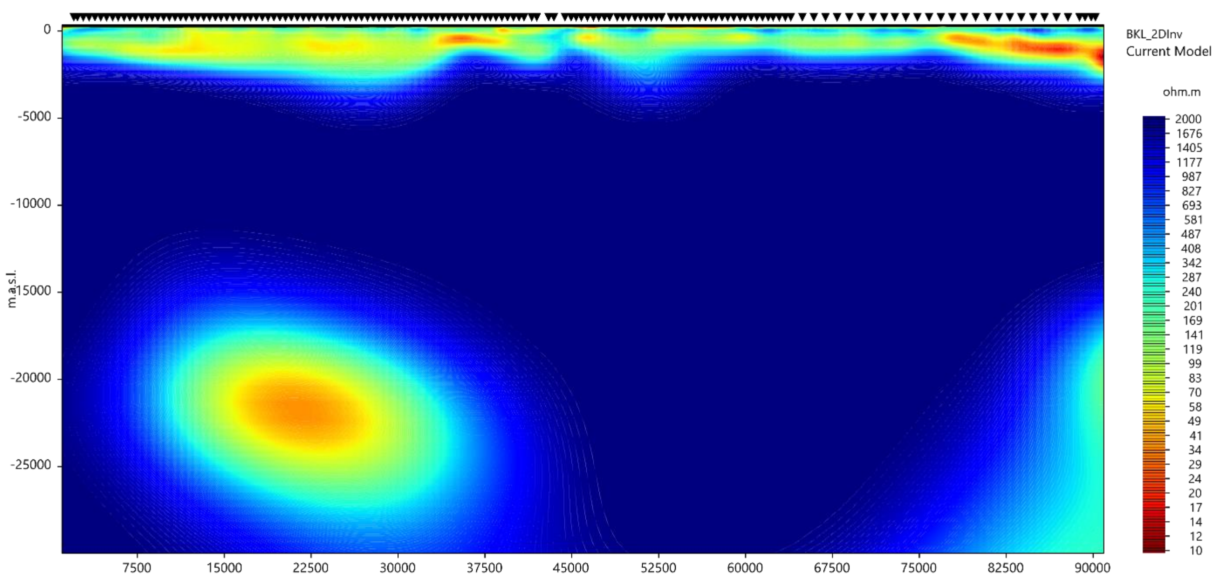

Figure 6: 2D MT inversion results from surface to 30 km depth shown using a logarithmic color stretch from 10 to 1000 Ω. The horizontal axis measures distance along the profile in metres.

Overlying the 2D MT inversion data with the depth migrated seismic images (Figure 7), show two faults (black lines) divide the image into three domains and correspond to variations in the appearance of the stratigraphy including differences in conductivity, thickness, and the number of conductive strata. The three domains are spatially consistent with the approximate location of major structures identified in seismic images from 19GA-B1 (Figure 7).

The Western and Central domains (Figure 7) show conductivities ranging from 60 to 600 Ω.m, likely sourced by mudstones, sandstones, and limestones with and without the presence of saline aquifers. A discrete conductor is perched at the transition between the Western zone and the Central domain. The Central domain appears upthrown with respect to the Western and Eastern segments. This is consistent with the possibility of an inverted depocenter; however, a distinct number of strata is observed in each domain. For example, 5 distinct formational features can be observed to the west, whereas only 3 are observed to the east.

The Eastern domain (right of Figure 7) hosts the most conductive (10 Ω.m) and thickest (~800 m) package observed in these data. This feature is observed shallowly dipping to the east and is spatially coincident with a package of dipping seismic reflectors.

Integrating the 2D inversion section with a greyscale image of depth-migrated seismic data, and results from geological modelling of potential fields (Figure 8), the modelled Eastern Tennant Creek basement and Calvert Supergroup, can be observed underlying the Barkly Tablelands (shaded polygons). A thin horizontal black polygon corresponds to a strong reflector observed in the Calvert group and is interpreted as a dense and highly magnetic basalt flow analogous to basalts of the Eastern Creek Volcanics.

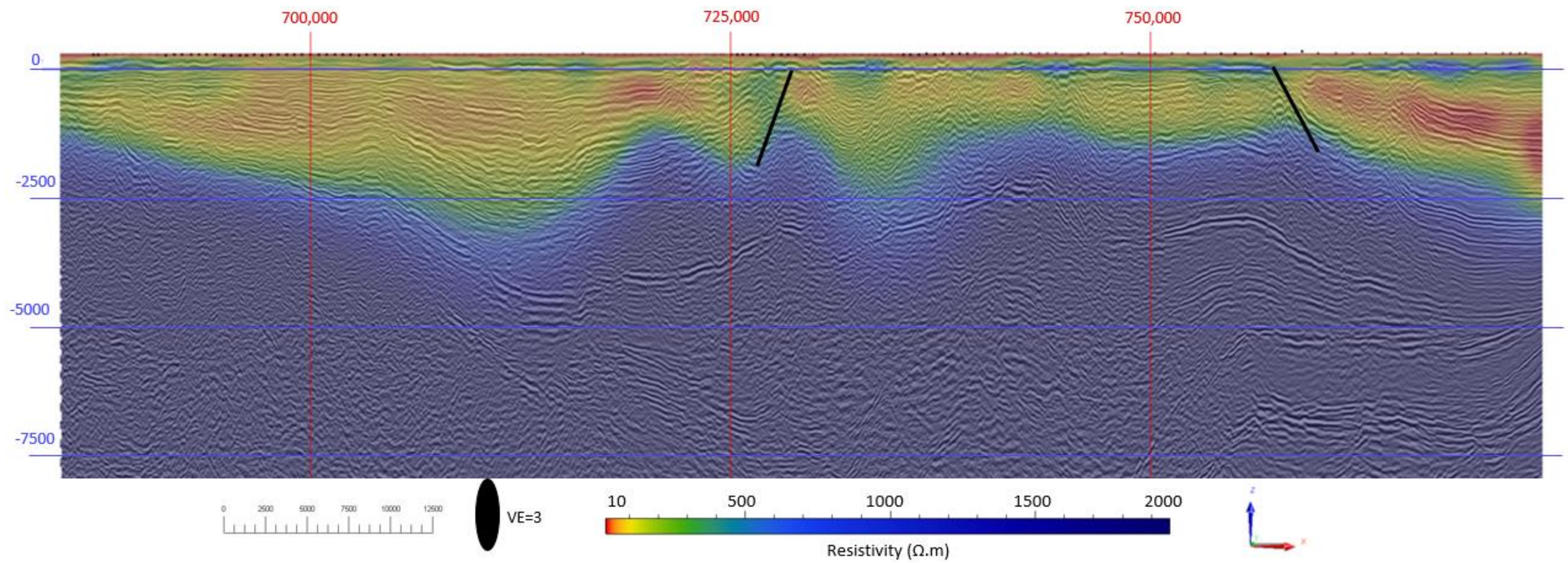

Figure 7: 2D MT Inversion overlain on a greyscale image of depth migrated seismic from 19GA-B1. Two major faults (black lines) separate the section into three domains and coincide with marked changes in conductivity, thickness, and the number of layers in the stratigraphic sequence.

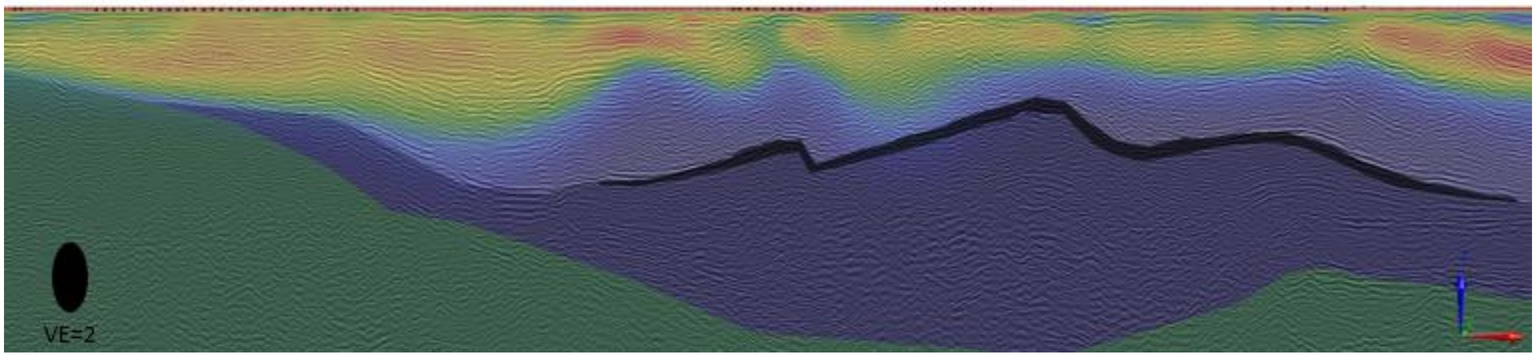

Figure 8: 2D MT Inversion section (looking north) overlain on the depth migrated seismic from 19GA-B1. The shaded green polygons outline the interpreted East Tennant Creek basement as defined by GM-Sys Magnetic and Gravity forward modelling. The thin black polygon conforms to a strong reflector and is interpreted as a dense and highly susceptible basalt flow analogous to the Eastern Creek Volcanics. Field of view is approximately 90km wide.

Conclusions

We carried out a 2D interpretation of geology of the Barkly Tablelands using MT data, depth migrated seismic images, and geological modeling of underlying Proterozoic basement. Our results showed the presence of horizontally layered conductors within the top 2 kilometers of crust. By overlaying the MT data with seismic images, we revealed two major faults that divide the are into three domains with varying conductivities, thicknesses, and number of conductive strata. Further interpretation is required to determine what causes the varying conductivity in the three domains and if the McNamara Group is present across the Barkly Tablelands.

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