MAGNETOTELLURIC, BASIN STRUCTURE AND HYDRODYNAMICS; SOUTH WEST OF WESTERN AUSTRALIA

Bibirabea Sedaghat*
PhD Candidate
Curtin University, Exploration Geophysics
bibirabea.sedaghat@postgrad.curtin.edu.au

Ralf Schaa
Lecturer
Curtin University, Exploration Geophysics
ralf.schaa@curtin.edu.au

Brett Harris
Associate Professor
Curtin University, Exploration Geophysics
brett.harris@curtin.edu.au

Andrew Pethick
Lecturer
Curtin University, Exploration Geophysics
andrew.pethick@curtin.edu.au

Alex Costall
PhD Candidate
Curtin University, Exploration Geophysics
alex.costall@postgrad.curtin.edu.au

Jingming Duan
Senior Geophysicist
Geoscience Australia
jingming.duan@ga.gov.au

Wenping Jiang
Mineral Systems
Geoscience Australia
wenping.jiang@ga.gov.au

**presenting author asterisked*

SUMMARY

A prominent TE and TM mode split is observed in magnetotelluric (MT) data below 0.5 Hz collected in the Perth Basin over the Harvey Ridge, Western Australia. We investigate the causes of mode splitting and consider implications on inversion of the MT data to subsurface electrical conductivity distribution. Twenty-five broad-band MT stations were acquired and remote reference processing was completed to arrive at a data set located midway between the Darling Fault and the Indian Ocean. We used forward modelling to test our strong suspicion that the Indian Ocean, Darling fault and architecture of the Granitic Basement were indeed the major contributors to mode splitting that we observed. Forward modelling of synthetic data was completed for comparison with the Harvey MT data. We were surprised at the match between synthetic and field data given the simplicity of the forward model and the considerable lateral distance between the MT soundings and the Indian Ocean or Darling fault. We were then able to make significant improvements to the MT inversion outcome by introducing a large scale geo-electrical architecture as the seed model for inversion. Our work demonstrates that large scale geo-electrical contrasts at considerable lateral distance from an MT transect, or the target zone need to be systematically introduced to the inversion if a quality outcome is to be achieved.

Key words: Darling Fault, Harvey Ridge, Inversion, Magnetotelluric

INTRODUCTION

Broad band magnetotelluric measurements harvest information that has contributions from hundreds of kilometres beyond the survey area itself. The ocean (~0.3 Ohm-m) and crustal scale faults that terminate basin sediments against crystalline basement are typical elements of the large scale geo-electrical architecture. The impact of the high electrical conductivity of seawater on land-based MT inversion is well known (Monteiro et al., 2001; Chave & Jones, 2012; Yang, Min, & Yoo, 2010). Several studies indicate a separation between TE and TM mode in both apparent resistivity and phase at low frequencies in proximity to the coast line (Pous et al., 2002; Lezaeta & Haak, 2003). Large scale faults also impact magnetotelluric data and inversion, and similarly many MT studies have investigated the influence of these structures (Unsworth & Bedrosian, 2004; Bedrosian et al., 2002; Wannamaker et al., 2004; Karaş et al., 2017). In most of these studies, MT data was collected across the fault zone. However the influence of large scale geo-electrical architecture on smaller scale MT surveys with a shallower local target zone is not as well studied. This is the challenge we explore. Specifically we investigate the influence of the Indian Ocean, Darling fault and the crystalline basement on measurements made in the onshore Perth Basin. MT data were collected along a ~10 km transect near the town of Harvey, Western Australia. Forward modelling has been completed to investigate the influence of the Indian Ocean, Darling fault and crystalline basement independently and when combined. To do this, synthetic data is compared with the observed data from Harvey. Finally we'll investigate impacts of large scale geo-electrical architectures on MT inversion with data limited to the onshore Perth Basin.

METHOD AND RESULTS

The Harvey Ridge is a structural high located between the shores of the Indian Ocean and the Darling Fault in Western Australia. MT data is often acquired with the objective of resolving both, the internal stratigraphy (lithologies) and the distribution (lateral and vertical changes) of solute concentration. These are key elements of basin hydrodynamics (how fluids exist and move within a basin). However the onshore Perth basin is narrow and bounded by the more than 1000 km long North South Darling Fault that separates the Perth Basin from the Yilgarn Craton and the Indian Ocean to the West.

MT data was gathered along an East-West profile near Harvey, Western Australia in October 2016 with a combined effort from Geoscience Australia and Curtin University. More than 25 stations were collected. Some stations were omitted because of the close proximity to high voltage power lines. Sixteen (16) broad band stations were selected for the Harvey survey (Figure 1b). Robust remote reference data processing was employed which was able to reduce noise in the remaining stations. Poor quality cross-powers have been removed using the Phoenix MT-Editor software ("Data Processing User Guide," 2005).

The MT apparent resistivity and phase show similar mode splitting in all stations at frequencies lower than 0.5 Hz (Figure 1a). Initially the cause for this splitting was not clear. An isotropic 2D finite element inversion was applied via the MARE2DEM code (Key, 2016) using a half-space starting model. Despite a relatively low RMS misfit the results were not consistent with expectations from drill hole logging and seismic reflection data.

Figure 2 presents synthetic data over three (3) highly simplified large scale geo-electrical architectures that surround the survey area, where the MT survey is located in the centre of the onshore Perth Basin:

1. Ocean (0.3 Ohm-m) with constant depth, 10km basin (10 Ohm-m) over crystalline basement set to 1000 Ohm-m.
2. Fault only dividing sediment (10 Ohm-m) and crystalline basement (1000 Ohm-m)
3. Ocean (0.3 Ohm-m), sediment (10 Ohm-m) and fault, with crystalline basement (1000 Ohm-m).

Potential contributions of each element of the large scale geo-electrical architecture on the low-frequency split in TE and TM modes are shown at 4 stations: for the Indian Ocean with basin structure (Figure 2a), for the Darling Fault only (Figure 2b), and the synthesis of the basin structure with Indian Ocean and Darling Fault included (Figure 2c).

The effect of Indian Ocean and basin architecture (2a) is already considerable in all stations. The model containing the Indian Ocean and basin structure (2b) both show strong mode splitting observed at about 0.5 Hz in the target area (six km far from coast line). The Darling Fault produces a sharp TE and TM mode separation that occurs at progressively lower frequencies with distance from the fault. Synthetic data collected over the ocean, fault and highly simplified crystalline basement (2c) generate an outcome which is most similar to the observed data. Figure 3 shows a detailed comparison of synthetic and field data at Station St01.

In the next stage we used the synthetic geo-electrical model (see Figure 2c) as the seed model for 2D inversion and the result is shown in Figure 4a. The F10 fault displacement is well located and there is a good match between the 1D forward model (red line) and the 2D inversion result (blue circles), and with well log data in St08 from the nearby Harvey-1 well with depth of ~3 km (Figure 4b).

CONCLUSIONS

We have simulated onshore magnetotelluric data for a survey over simple large scale geo-electrical architectures to better understand the factors generating a significant split in the TE and TM modes seen in mid to low frequency MT data near Harvey in South Western Australia. The synthetic data derived from a combination of Indian Ocean, Darling Fault and crystalline basement that surround the Perth Basin, showing mode splitting at frequencies below ~0.5 Hz in MT apparent resistivity and phase, provides a surprisingly good match to the observed data at similarly low frequencies. It appears that the Darling Fault located about 10 km to the east of the transect is the dominating factor contributing to the separation in TE and TM mode, with the Indian Ocean to the west of the transect having a smaller but not insignificant contribution. This coarse large scale model consisting of just three conductivity values (i.e. 1. ocean, 2. Basin sediments, 3. crystalline rock) was then used as the starting model for 2D inversion to generate an improved inversion outcome. We have shown that large conductivity distributions at considerable distance beyond the transect itself must play a role in the MT response and in our example the impact commences at a surprisingly high frequency of about 0.5 Hz.

ACKNOWLEDGMENTS

The authors would like to acknowledge the contribution of an Australian Government Research Training Program Scholarship in supporting this research. We would like to thank Geoscience Australia for supporting us with equipment and staff for data collection. We also would like to thank Kerry Key for free access to the 2D inversion code MARE2DEM. Data was collected as part of a joint project between the Department of Mines, Industry Regulation and Safety (DMIRS), Curtin University and Geoscience Australia. The small pilot study consisting of several test MT sites was completed as part of the ANLEC research initiative.

REFERENCES

Bedrosian, P. A., Unsworth, M. J., & Egbert, G. (2002). Magnetotelluric imaging of the creeping segment of the San Andreas Fault near Hollister. *Geophysical Research Letters*, *29*(11), 1506. https://doi.org/10.1029/2001GL014119

Chave, A. D., & Jones, A. G. (2012). *The magnetotelluric method : theory and practice*. Cambridge University Press.

Data Processing User Guide. (2005). Retrieved from http://www.phoenix-geophysics.com/Support/user_guides/guides/data-proc-v.3-online.pdf

Karaş, M., Tank, S. B., & Özaydın, S. (2017). Electrical conductivity of a locked fault: investigation of the Ganos segment of the North Anatolian Fault using three-dimensional magnetotellurics. *Earth, Planets and Space*, *69*. https://doi.org/10.1186/s40623-017-0695-2

Key, K. (2016). MARE2DEM: A 2-D inversion code for controlled-source electromagnetic and magnetotelluric data. *Geophysical Journal International*, *207*(1), 571–588. https://doi.org/10.1093/gji/ggw290

Lezaeta, P., & Haak, V. (2003). Beyond magnetotelluric decomposition: Induction, current channeling, and magnetotelluric phases over 90°. *Journal of Geophysical Research: Solid Earth*, *108*(B6), 1–20. https://doi.org/10.1029/2001JB000990

Monteiro Santos, F. A., Nolasco, M., Almeida, E. P., Pous, J., & Mendes-Victor, L. A. (2001). Coast effects on magnetic and magnetotelluric transfer functions and their correction: Application to MT soundings carried out in SW Iberia. *Earth and Planetary Science Letters*, *186*(2), 283–295. https://doi.org/10.1016/S0012-821X(01)00237-0

Pous, J., Heise, W., Schnegg, P. A., Muoz, G., Martí, J., & Soriano, C. (2002). Magnetotelluric study of the Las Canadas caldera (Tenerife, Canary Islands): Structural and hydrogeological implications. *Earth and Planetary Science Letters*, *204*(1–2), 249–263. https://doi.org/10.1016/S0012-821X(02)00956-1

Unsworth, M., & Bedrosian, P. A. (2004). On the geoelectric structure of major strike-slip faults and shear zones. *Earth Planets Space*, *56*, 1177–1184. Retrieved from https://www.terrapub.co.jp/journals/EPS/pdf/2004/5612/56121177.pdf

Wannamaker, P. E., Caldwell, T. G., Doerner, W. M., & Jiracek, G. R. (2004). Fault zone fluids and seismicity in compressional and extensional environments inferred from electrical conductivity: the New Zealand Southern Alps and U. S. Great Basin. *Earth Planets Space*, *56*, 1171–1176. Retrieved from https://earth-planets-space.springeropen.com/track/pdf/10.1186/BF03353336?site=earth-planets-space.springeropen.com

Yang, J., Min, D. J., & Yoo, H. S. (2010). Sea effect correction in magnetotelluric (MT) data and its application to MT soundings carried out in Jeju Island, Korea. *Geophysical Journal International*, *182*(2), 727–740. https://doi.org/10.1111/j.1365-246X.2010.04676.x

FIGURES

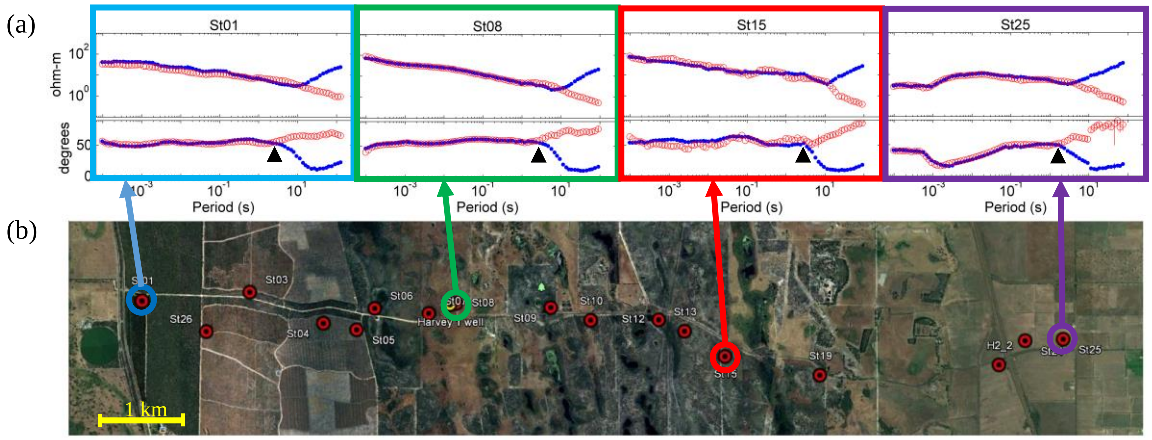

Figure 1: The location and AMT and MT observed responses in Harvey Ridge. (a) Apparent resistivity and phase for six stations along the profile. TE and TM mode splitting can be seen in all stations at 0.1 Hz. (b) the location of measured stations on Google Earth.

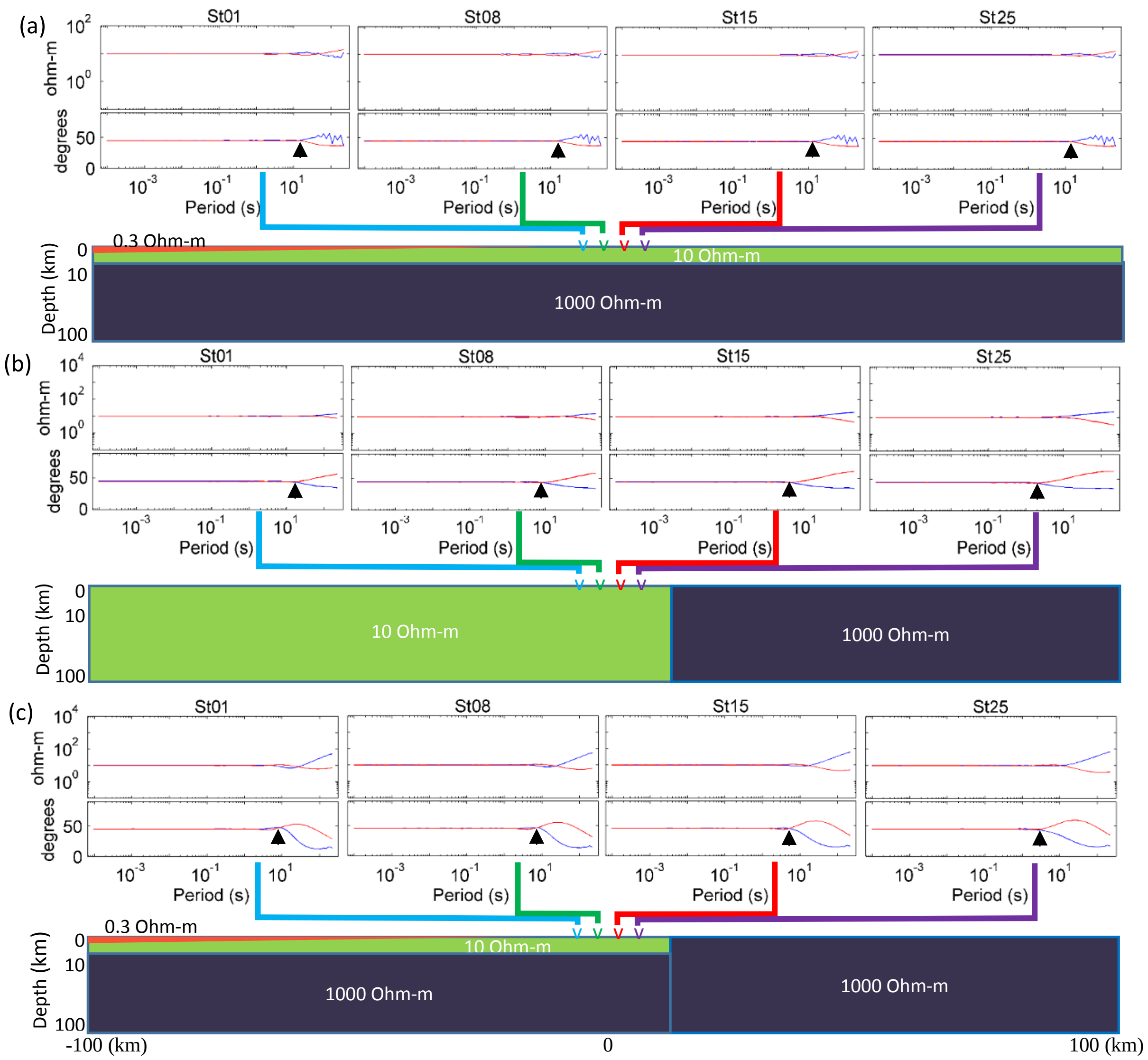

Figure 2: The forward models and synthetic data generated from three basic models: (a) Indian Ocean and basin architecture, (b) Darling Fault, (c) Combination of Indian Ocean, darling Fault and Perth basement. The synthetic data from model (c) has the best match with observed data in low frequencies and it could rebuild the observed mode splitting.

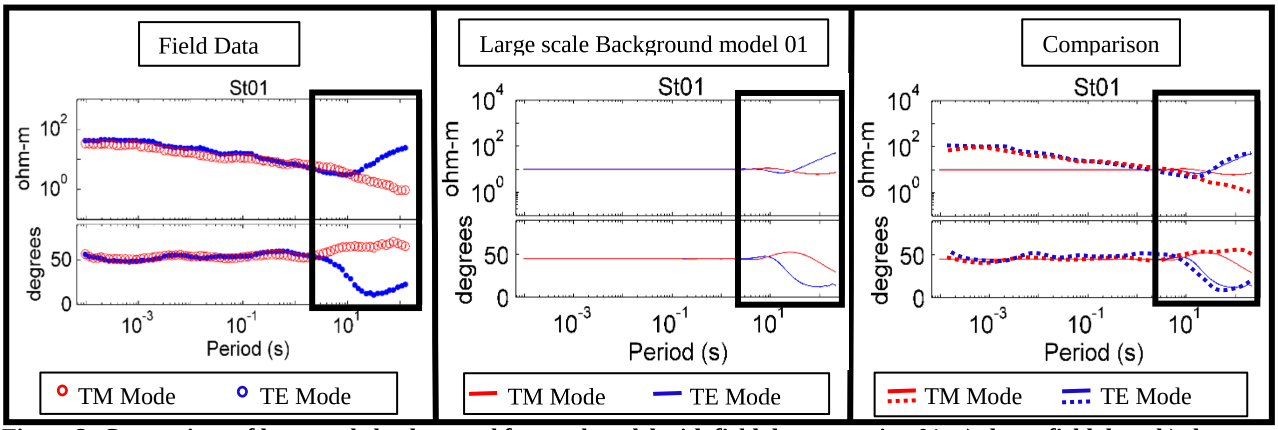

Figure 3: Comparison of large scale background forward model with field data at station 01. a) shows field data, b) shows large scale background model as in Figure 2d, c) zoomed in comparison for mode splitting for field and large scale background model. Comclusion is clear. The large scale picture has a significant impact on MT data.

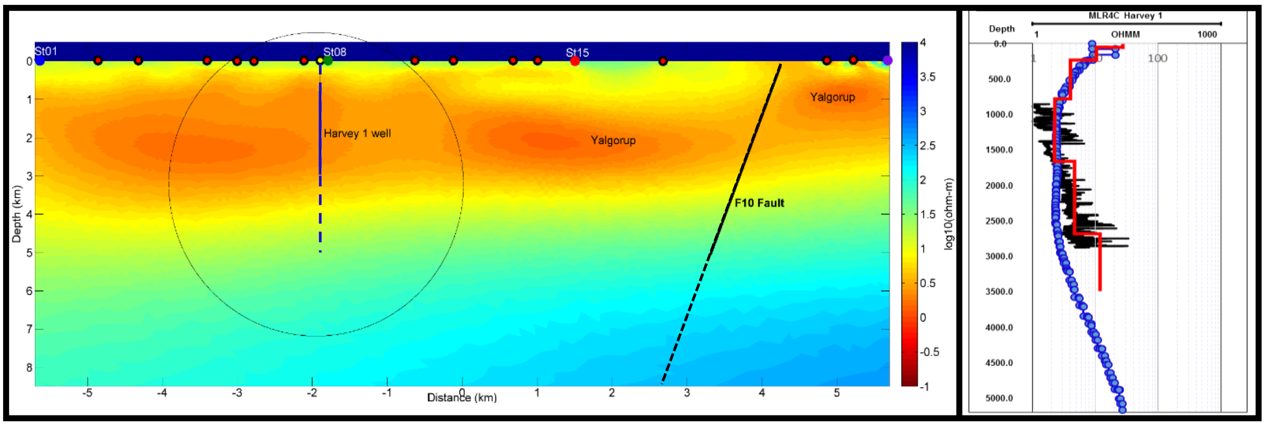

Figure 4: The 2D inversion result. (a) 2D inversion result after including Indian Ocean, darling Fault and Perth basement, (b) Comparison of Harvey 1 well log (black line), 1D forward model (red line) and 2D inversion result (blue circles) at St08. The location of the F10 fault is well defined and conductivity structures are following the well log data.