Anisotropic forward modelling of geothermal fluid using 2-dimensional electrical anisotropy

Jake Macfarlane
University of Adelaide
The University of Adelaide, SA, AUS, 5005
jake.macfarlane@adelaide.edu.au

Stephan Thiel
University of Adelaide
The University of Adelaide, SA, AUS, 5005
stephan.thiel@adelaide.edu.au

Jared Peacock
USGS
345 Middlefield Rd Menlo Park, CA, USA, 94025
jpeacock@usgs.gov

Josef Pek
Institute of Geophysics AS CR
Bocni II/1401, Prague 4, Czech Rep.
jpk@ig.cas.cz

Graham Heinson
University of Adelaide
The University of Adelaide, SA, AUS, 5005
graham.heinson@adelaide.edu.au

SUMMARY

Electrical anisotropy, defined as the directional dependence of electrical conductivity within a medium, is an important property to consider when interpreting magnetotelluric (MT) data. We propose the use of anisotropic forward modelling to model fluid flow within a geothermal setting.

Forward models provide synthetic MT responses for hypothetical structures which are compared with measured data to obtain knowledge about the subsurface geology of a region.

Comparisons between synthetic and measured data shows anisotropic fluid volumes are acceptable approximations of fluid injected into the crust. As a result, we support the use of anisotropic forward modelling as a means of modelling fluid motion at depth within a fractured geothermal system.

Key words: Geothermal, Magnetotellurics, Electrical Anisotropy, Modelling

INTRODUCTION

Recent studies of the Paralana geothermal system (PGS) by Hasting et al. (2011) and Peacock et al. (2012) interpreted the presence of a preferentially orientated fracture network which may result in electrical anisotropy within the region. This paper demonstrates that the MT responses generated at the PGS can be adequately modelled using 2-dimensional anisotropy and suggest a new method of understanding fluid motion within a fractured geothermal system.

The Paralana Geothermal System is situated in a dilatational zone along a splay off the eastward thrusting Paralana fault system (Paul et al., 1999; McLaren et al., 2002; Brugger et al., 2005) bounding the eastern margin of the Mt. Painter Domain (MPD) (Brugger et al., 2005) in the Northern Flinders Ranges, South Australia. The MPD consists of mid-Proterozoic granites, gneisses and metasediments (Fanning et al., 2003; Kromkhun, 2010) overlain by late-Proterozoic to early-Paleozoic sediments (Foden et al., 1999; Paul et al., 1999; McLaren et al., 2002; Brugger et al., 2005; Foden et al., 2006; Wülser, 2009).

Wannamaker (2005) identified the preferential orientations of fracture porosity as a source of upper crustal anisotropy. Previous studies of the PGS which interpreted the presence of preferentially orientated micro-fractures from micro-seismic (Hasting et al. 2011) and magnetotelluric (Peacock et al. 2012) responses subsequently suggesting electrical anisotropy (Wannamaker, 2005) may be present.

In this paper, we utilise data generated from various forward models and data obtained by Peacock et al. (2012) to demonstrate that the pre- and post-fluid injection structures can be reproduced by 2-dimensional electrical anisotropy.

METHOD

The 2-dimensional synthetic models calculated using the 2-dimensional MT direct code for conductors with arbitrary anisotropy of Pek and Verner (1997) were based on a 1-dimensional, layered background chosen to be structurally similar to the geology present at the PGS. The layered background consists of a 1 km thick sedimentary layer which overlies a 6 km thick granitic layer with the remaining 410km defining the lithosphere and asthenosphere. A 600 m thick anisotropic block was introduced at 2.9 km to approximate the preferentially orientated fracture network (Figure 1). The principal resistivities for this anisotropic block were defined by the isotropic granitic layer and an Archie's law approximation of known fluid conductivity with their orientation defined by fracture orientations from Hasting et al. (2011) and Peacock et al. (2012). The resistivity (in Ωm) and orientation (in °) of each domain is displayed in Table 1.

Domain	ρ_x	ρ_y	ρ_z	α_S	α_D	α_{SL}
Sedimentary layer	10	10	10	0	0	0
Granitic layer	500	500	500	0	0	0
Half space	10	10	10	0	0	0
Anisotropic block	.01	500	.01	30	10	0

Table 1. Resistivity information for each domain defining the model of Figure 1.

RESULTS

Figure 2 displays residual phase tensor ellipses representing how the MT response calculated by forward models (a) measured by Peacock et al. (2012) (b). For periods between 0.1 second and 1 second, interpreted as the period range corresponding to the preferentially orientated fracture network, similarities in the orientation of greatest change (≈30°) and the geometric mean between the maximum and minimum phase are observed.

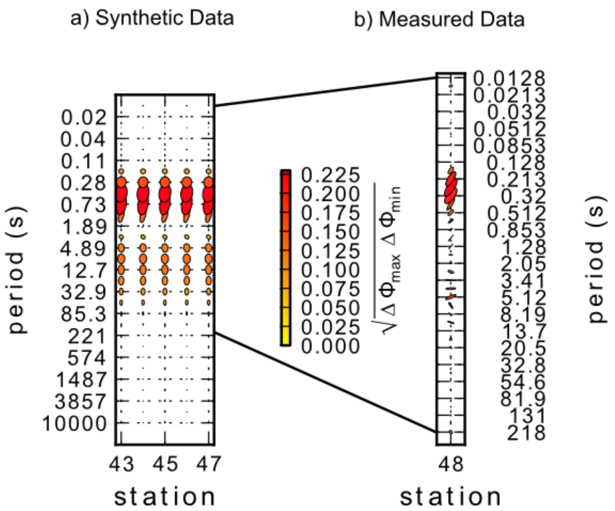

Figure 2. Graphical representation of the difference in MT response with respect to period (seconds). The colours which fill the ellipses represent the geometric mean of the maximum and minimum phase which (Heise et al. 2008).

CONCLUSIONS

The observable similarities in MT responses (Figure 2) are interpreted to be caused by a modelled resistivity structure which closely approximates the structure measured by Peacock et al. (2012). This subsequently supports the proposition that 2-dimensional anisotropic forward modelling is a feasible method of modelling the flow of a fluid through a fractured geothermal system obvious applications to the geothermal industry.

ACKNOWLEDGMENTS

I would like to thank everyone involved in providing the resources used throughout this study. Furthermore, I would also like to thank the Geophysics cohort who provided numerous opportunities to discuss the issues I encountered as well as providing me with the opportunity to attend the 21st EM Induction Workshop.

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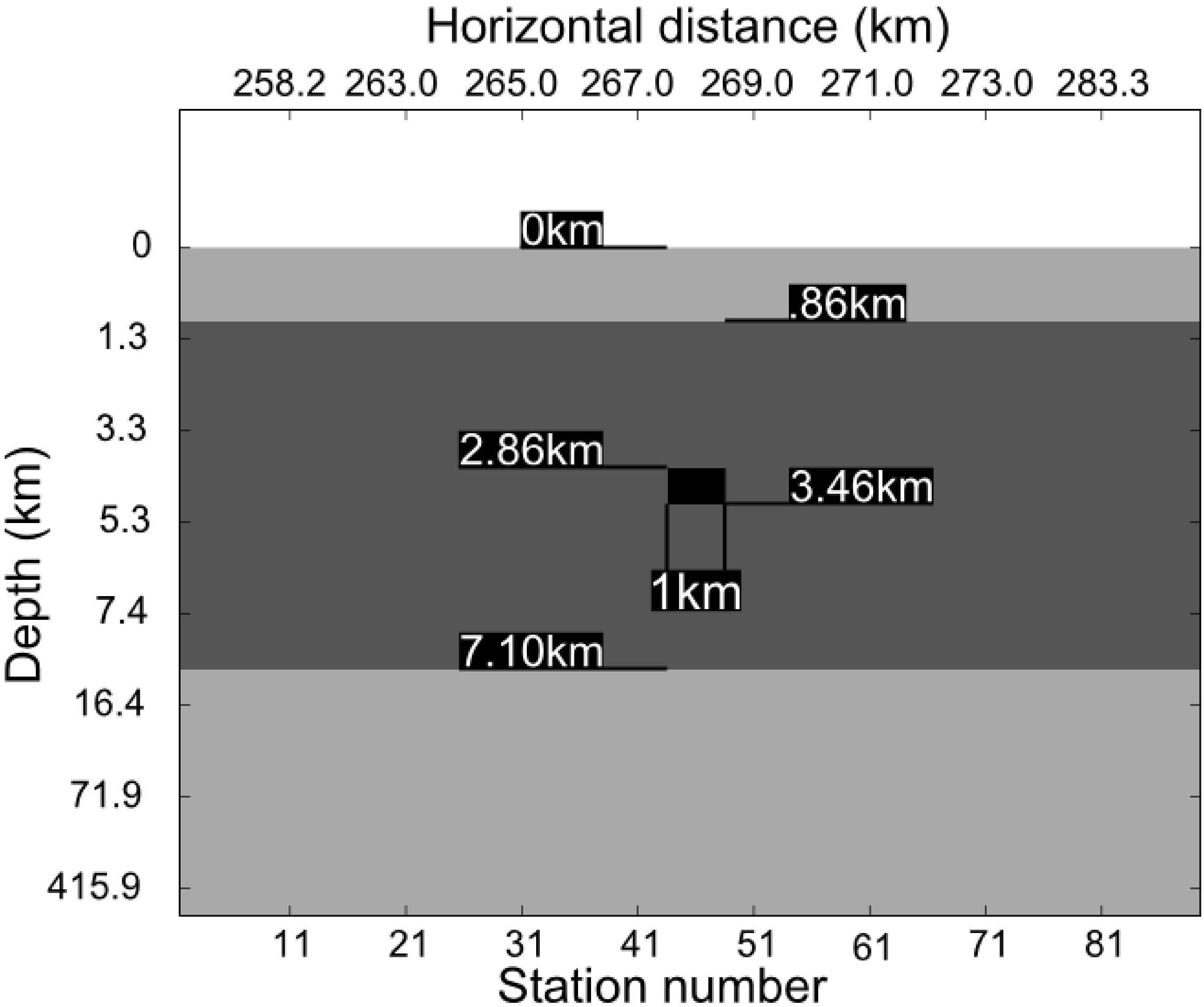

Figure 1. Model of the resistivity structure from the Paralana Geothermal System which was input into the 2-dimensional MT direct code for conductors with arbitrary anisotropy (Pek & Verner, 1997).