MAGNETOTELLURIC IMAGING OF CONVENTIONAL AND UNCONVENTIONAL GEOTHERMAL RESOURCES

A dissertation presented

by

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In fulfilment of the requirements
for the degree of

Doctor of Philosophy
in the subject of
Geophysics

THE UNIVERSITY
of ADELAIDE

Submitted to the

Department of Earth Sciences,

School of Physical Sciences, Faculty of Sciences

Adelaide, January 2016

Dedication

To my parents

Lemma Didana and Damench Abebe

without whom none of my success would be possible

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ABSTRACT

This thesis presents magnetotelluric (MT) imaging of the Tendaho conventional geothermal system in the Afar Depression in north eastern Ethiopia and the Habanero Enhanced Geothermal System (EGS) in the Cooper Basin in South Australia. The aims of this dissertation are twofold. The first was to characterize the resistivity structure of the Tendaho conventional geothermal system. This includes delineating fluid pathways and heat sources and determining the connectivity of geothermal localities in the Tendaho field using 2D and 3D resistivity models. The second aim was to investigate the viability of MT to monitor permeability enhancement in an unconventional EGS reservoir during fluid injection using continuous MT measurement at Habanero EGS in the Cooper Basin, South Australia.

The 2D and 3D resistivity models of the Tendaho high temperature field reveal three main resistivity structures to a depth of 20 km. The surface conductive structure (typically $\leq 10\,\Omega\,$m and $>1\,$km thick) is interpreted as sediments, geothermal fluids or hydrothermally altered smectite clay. The underlying high resistivity structure is interpreted as Afar Stratoid Series basalts or chlorite-epidote alteration mineralogy. At a depth greater than 5 km, low resistivity is observed across the whole of the Tendaho geothermal field. This structure is inferred to be the heat source of the geothermal system. Based on geochemical and borehole information and a bulk resistivity from the resistivity model, a melt fraction of about 13% by volume has been estimated for the structure. The most striking feature in the 2D and 3D models is a conductive fracture zone in the basalts, which is likely to increase the permeability and temperature of the deep reservoirs in the basalts and provide an upflow zone. Analysis of 3D resistivity models and the geochemistry of geothermal fluids sug-

gests that the Dubti and Ayrobera geothermal localities at the Tendaho field are not connected. The inferred presence of a conductive fracture zone and shallow magma reservoirs make the Tendaho geothermal field a promising prospect for geothermal power development.

An MT survey was conducted at Habanero EGS during stimulation of the Habanero-4 well, where 36.5 ML of water with a resistivity of 13 Ω m (at 25 ℃) was injected at a relatively continuous rate of between 27–53 L/s into the EGS reservoirs at a depth of 4077 m. Analysis of pre- and post-injection MT responses showed possible conductive fractures oriented in a N/NNE direction. Apparent resistivity maps also revealed that the injected fluids likely propagated towards N/NNE direction. This result is consistent with the propagation direction of the dominant microseismic events, as well as the orientation of pre-existing N-S striking sub-horizontal fractures susceptible to slip on stimulation. The MT responses close to the injection point show on average a 5% decrease in apparent resistivity for periods >10 s. The main reasons for detecting only subtle changes in resistivity at the Habanero EGS is the screening effect of the conductive thick sedimentary cover (about 3.6 km thick) and the presence of pre-existing saline fluids with resistivity of 0.1 Ω m (equivalent to a salinity of 16.1 g/L at 240 ℃) in the natural fractures in the EGS reservoirs. This is further compounded by the physics of the problem, that is, the small volume of injected fluid compared to the large volume averaging by an MT sounding at the depth of interest. For MT sites close to the EGS well, the analysis of time-lapse inversion models indicated an increase in total cumulative conductance of about 25 S over a depth range of 2–5 km in the N-S direction compared to the E-W direction. This likely indicates anisotropic permeability generated by the hydraulic stimulation. Overall, the MT monitoring at Habanero EGS highlights the need for favorable geological settings and/or controlled source methods and down-hole methods to measure significant changes in resistivity in EGS reservoirs.

STATEMENT OF ORIGINALITY

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ACKNOWLEDGEMENTS

First and foremost I want to thank my supervisors professor Graham Heinson and Dr. Stephan Thiel. I appreciate all their contribution of time, ideas, effort and patience to make my PhD research experience productive and exciting. Their guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better supervisors and mentors for my PhD research.

I gratefully acknowledge the funding source from the Australian Geophysical Observatory (AGOS) through the South Australian center for Geothermal Energy Research (SACGER) for the Habanero EGS MT survey. Thanks to Geodynamics Ltd for providing access to the Habanero EGS project area to collect MT data. I am grateful to Heinz-Gerd Holl and Andrew McMahon from Geodynamics Ltd for valuable discussions about the Habanero EGS project. Special gratitude to the Geological Survey of Ethiopia for providing MT and magnetics data of the Tendaho conventional geothermal field. Without the scholarship from the University of Adelaide, I would have never completed my post-graduate research. Many thanks go in particular to all PhD geophysics candidates for sharing their expertise in MT and friendship. Special thanks for Lars Krieger and Jared Peacock for insightful discussions and reviews.

Lastly, I would like to thank my family for their encouragement and moral support through my PhD journey.