Cover Page - Example

3D inversion of magnetotelluric data from the Rotokawa geothermal field, Taupo Volcanic Zone, New Zealand

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3D INVERSION OF MAGNETOTELLURIC DATA FROM THE ROTOKAWA GEOTHERMAL FIELD, TAUPO VOLCANIC ZONE, NEW ZEALAND

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SUMMARY – 3D inverse modelling of 58 magnetotelluric (MT) soundings from a high temperature geothermal system from New Zealand's Taupo Volcanic Zone has been carried out in order to investigate the deeper structure of the geothermal system. The resulting model shows that the high temperature core of the geothermal system is associated with a resistive feature beneath a cap of highly conductive clays. Phase tensor misfits were used to show the spatial distribution of the misfits and suggest that the model has captured the main features of the data.

1. INTRODUCTION

The Taupo Volcanic Zone (TVZ) in the central North Island of New Zealand is a region of young rhyolitic volcanism and rapid crustal extension. This region is characterised by an exceptionally high geothermal heat flow, 4200 MW, which is discharged through 23 high temperature (>200°C) convective hydrothermal systems.

The uppermost 1 – 2 km of the TVZ are composed of a mixture of rhyolite lavas, welded and unwelded ignimbrites and volcaniclastic sediment. This material is resistive ($\geq$ 300 Ωm) at shallow depth except where it has been hydrothermally altered. However, at deeper levels, this same material becomes conductive (10 – 30 Ωm) at low temperatures due to a diagenetic aging process in which small amounts of conductive clays and zeolites are formed within the rhyolitic volcanics. Thus, outside the geothermal systems, the conductivity-depth structure of the TVZ is characterised by a layer of young, resistive volcanics overlying a layer of much more conductive older volcanics. The basement rocks (greywacke meta-sediments) beneath the volcanics are resistive (300 - 1500 Ωm).

The near-surface low resistivities that mark the geothermal fields are caused by the combination of high temperature, saline fluid and hydrothermal alteration of the young volcanics. At depths greater than ~500 m, the resistivity values increase due to decreasing pore space and a change in the type of hydrothermal alteration products (clays) at higher temperatures.

2. MAGNETOTELLURIC DATA

Recently, an MT survey consisting of 64 broadband (0.3 ms – 2000 s) soundings was conducted to investigate the deeper structure of the Rotokawa geothermal field. The distribution of the measurement sites is shown in Figure 2. Site spacings are 200 m - 500 m in the central part of the geothermal field, (i.e. the area characterised by the low Schlumberger apparent resistivity anomaly, Figure 1).

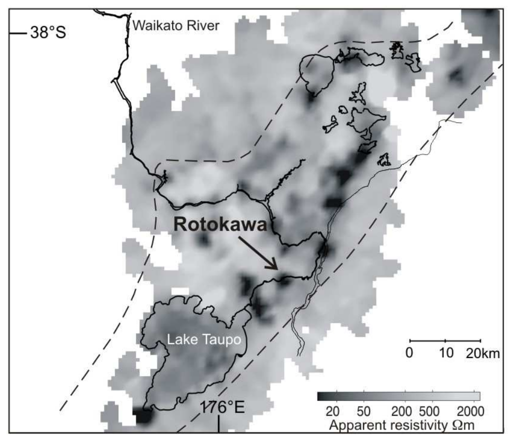

Figure 1. DC apparent resistivity map from Schlumberger array measurements made with an electrode spacing of (AB/2) 500 m. Conductive areas shown in dark (<30 Ωm) mark the geothermal systems (Bibby *et al.*, 1995).

Representation of the data as phase tensor maps (Caldwell *et al.*, 2004) provides a distortion free method of visualizing the conductivity gradients of the data and allows identification of main features of the conductivity structure prior to modelling. Phase tensor ellipses at different periods are shown in Figure 2. For periods between 0.1 s and 1 s the mean phase averaged over polarisation direction Φ_2 in the centre of the geothermal system is >45º indicating increasing resistivity with depth. At periods >3s the major axis of the phase tensor ellipses become aligned to the NE striking regional conductivity structure known from long offset resistivity studies (Bibby *et al.*, 1998; Risk, 2000) and regional MT studies (Ogawa *et al.*, 1999; Heise *et al.*, 2007). The conductivity structure producing this alignment reflects the down faulting of the greywacke basement along the SE margin of the TVZ.

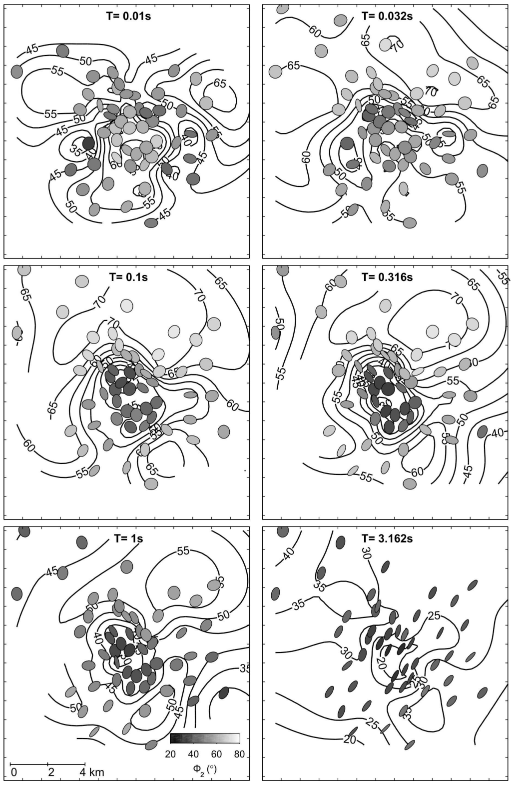

Figure 2. Normalised phase tensor ellipses at each measurement site for periods between 0.01 and 31s. The ellipses are normalised by Φ_{max} and the colour scale shows the geometric mean $\Phi_2 = \sqrt{\Phi_{max}\Phi_{min}}$ which measures the mean phase averaged over polarisation directions. The high values of Φ_2 outside the geothermal system indicate decreasing resistivity. Note the low phase values in the centre of the geothermal system for 0.31 s indicating a resistor at depth.

3. 3D MODELLING

3D inverse modelling was carried out using the code WSINV3DMT described by Siripunvaraporn *et al.* (2005). For the inversion, the data at 58 sites was interpolated at 2 points per decade for a period range of 1-30s. Data was selected carefully, omitting noisy soundings (e.g. sites affected by electric fences) and obvious outliers from the soundings retained for the inversion. A uniform 5 % error was assumed for all impedances. For soundings where the phase tensor analysis identified a 1D section of the sounding curve at short periods, galvanic distortion was removed using the method of Bibby *et al.* (2005). This method retrieves the shape of sounding curves. The scale of the sounding was set by comparison with TEM soundings made at each location and comparison with the Schlumberger apparent resistivity data.

Discretisation in the central part of the model was regular with a cell width of 400m. The inversion reached a minimum rms 5.77 after 6 iterations. Computation time was 8 days on the workstation (Sun Fire X2200 M2 with two Dual-Core AMD Opteron 2214 processors and 12 GB of RAM).

The degree and spatial distribution of misfit can be assessed from the phase misfit tensors in Figure 3,

$$\mathbf{\Delta} = \mathbf{I} - (\mathbf{\Phi}_{obs}^{-1}\mathbf{\Phi}_{mod} + \mathbf{\Phi}_{mod}\mathbf{\Phi}_{obs}^{-1})/2\,, \qquad (1)$$

where **I** is the identity matrix. The magnitude of the misfit is indicated by both the size of the ellipse and the colour used to fill the ellipses which indicates the mean of the absolute value of the residual tensor principal axes

$$(|\Delta_{max}| + |\Delta_{min}|)/2 \qquad (2)$$

The ellipse orientation indicates the polarisation direction in which the maximum difference occurs. Figure 4 shows a 3D view of the resulting conductivity model.

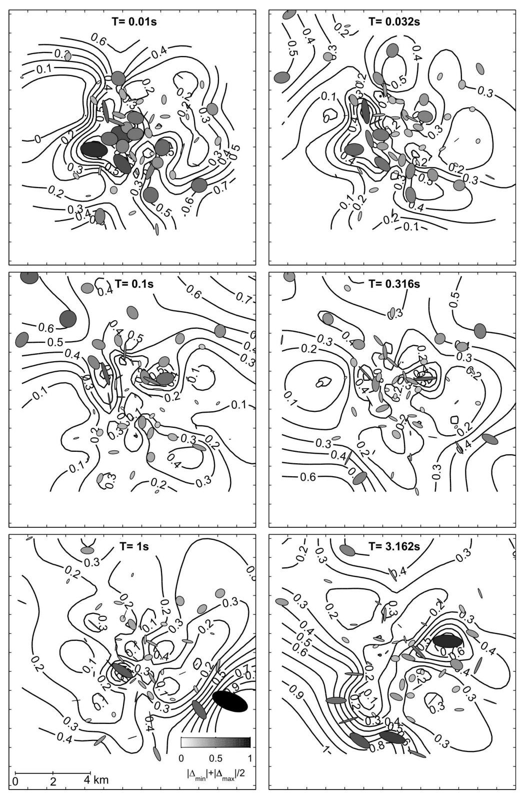

Figure 3. Phase misfit tensor at periods between 0.01 and 31s for the model shown in Figure 4.

4. RESULTS AND DISCUSSION

At shallow depth (15 m - 200 m) the geothermal field is characterised by low resistivities (2 - 5 Ωm) caused by relatively high temperatures and conductive clays (smectites) which are the hydrothermal alteration products at these temperatures (~100ºC). With increasing depth the resistivity increases to ~30 Ωm and then decreases again to 10 Ωm at depth >500 m. These changes in resistivity are interpreted to result from the interplay of temperature, fluid chemistry and porosity which control the nature of the alteration products (clays) inside and at the margins of the geothermal system.

Outside the geothermal system the top 500 m of young volcanics are resistive (>300 Ωm) but become more conductive (30 -10 Ωm) below about 600 m.

At depths of ~1200 m within the geothermal field the resistivity increases rapidly to values >100 Ωm. This high resistivity body corresponds with the hottest part of the geothermal system, known from drilling. At high temperatures the alteration products formed are less conductive illitic and chloritic clays.

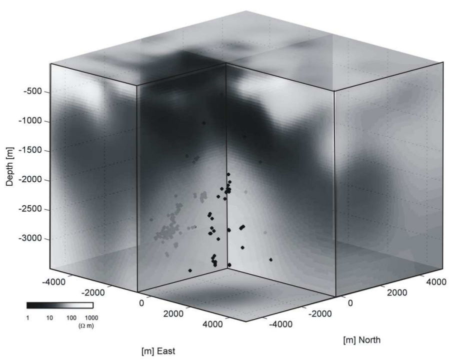

Figure 4. 3D inversion model of Rotokawa geothermal system. Earthquake hypocentres (Bannister unpublished data) shown as black dots correlate with the high resistivity body.

5. CONCLUSIONS

The 3D inversion code WSINV3DMT by Siripunvaraporn et al. (2005) applied to a dense MT dataset gives a geologically consistent model of the conductivity structures. Representation of the model's misfit as phase misfit tensors shows that the main resistivity features of the data are explained by the model.

The most interesting feature of the modelling is the high resistivity body in the central part of the geothermal field. This feature correlates spatially with the area of highest temperature. Earthquake hypocenters concentrate along the margins of the resistive body. Thus it appears that the resistive high temperature (>300ºC) core of the geothermal system imaged by MT also corresponds to relatively strong material which supports brittle failure.

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