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Three-dimensional modelling of magnetotelluric data from the Rotokawa geothermal field, Taupo Volcanic Zone, New Zealand

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SUMMARY

The resistivity structure of the Rotokawa geothermal system in New Zealand's Taupo Volcanic Zone has been determined by 3-D modelling of data from a closely spaced (64 measurement sites) magnetotelluric (MT) survey. 3-D conductivity models were constructed using trial and error forward modelling of the phase-tensor data and 3-D inverse modelling of the impedance tensor data. Both the forward and the inverse resistivity models show good consistency. The most interesting feature of these models is a resistive (∼100 Ωm) zone within the otherwise conductive material of the geothermal system. This zone coincides with the high temperature (300–335 °C) core of the geothermal system in which seismicity induced by fluid injection occurs and may mark the zone of fracture permeability that is feeding high temperature fluid into the geothermal system from deeper levels.

Key words: Electrical properties; Magnetotelluric; Hydrothermal systems.

INTRODUCTION

The Taupo Volcanic Zone (TVZ, Fig. 1) contains all but one of New Zealand's high temperature (>200 °C) geothermal systems. These systems have been extensively investigated since the 1960's using a variety of different geophysical exploration methods (Risk 1983). The most effective exploration methods applied by far was direct current (DC) apparent resistivity mapping (Bibby 1988). These data, which provide a map (Fig. 1) of the resistivity distribution of the TVZ down to depths of ∼500 m (Bibby *et al.* 1995), played a vital role in delineating geothermal systems and in stimulating the development of New Zealand's geothermal electric power industry.

The effectiveness of the DC resistivity mapping for geothermal exploration in the TVZ arises from the large resistivity contrast between hot, hydrothermally altered material within the geothermal fields and the unaltered, young rhyolitic-volcanics that surround them. Each of the low resistivity (red) areas shown in Fig. 1 marks the near-surface expression of a large convective plume of hot water that rises to the surface from near the brittle ductile transition, ∼7–8 km below the surface. The total convective heat output discharged from the TVZ's geothermal field is 4200 MW (Bibby *et al.* 1995).

In the early stages of development, economically useful production of hot water from the TVZ's geothermal fields was obtained from production wells less than 1500-m deep, in many cases less than 1000 m. However, production from such shallow depths produces detrimental environmental effects by changing the near-surface hydrology of the geothermal systems. These effects can be mitigated to some degree by obtaining higher temperature geothermal fluid from deeper levels. This reduces the amount of fluid needed for power production and helps separate the impact of production from the near-surface hydrology.

Knowledge about the TVZ's geothermal reservoirs, i.e. the deep (>1500 m deep) high-temperature parts of the geothermal systems, comes mainly from drill holes, as geophysical exploration techniques have not been able to clearly resolve structures below this level (i.e. below ∼1500 m). For example, seismic reflection surveys that are highly successful in a sedimentary environment have been singularly unsuccessful in the TVZ because of severe attenuation and reverberation in the surface layer of recent volcanics (Bannister & Melhuish 1997).

Here we report the results of a detailed MT survey of the Rotokawa geothermal system, conducted in an attempt to explore its deeper structure. Currently Rotokawa produces 33 MW of electric power using fluid from four production wells, although the power capacity of the field is much greater. Several deep wells (>2 km) have been drilled within the geothermal field, encountering temperatures exceeding 330 °C, which are among the highest *in situ* temperatures measured in the TVZ (e.g. Hunt & Harms 1990).

Previous investigations of the deep resistivity structure at Rotokawa (Risk 2000) used long-offset bipole–dipole tensor resistivity techniques (Bibby 1986; Bibby & Hohmann 1993). In principle, the detection depth of a DC bipole–dipole measurement is determined by the source–receiver offset. In practice, the detection depth is limited by the size of the grounded-bipole source-moment and electrical noise at the receiver. Data obtained using this DC technique provided the confirmation needed that the shallow low-resistivity areas mapped in the Schlumberger surveys were not just superficial features. A further important result of the bipole–dipole surveys was the recognition that the deeper parts of the geothermal system are more resistive at depth than their upper parts, although the geothermal system as a whole is still more conductive than the surrounding material (e.g. Bibby & Risk 1973).