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R.R. REEVES[1]
GNS Science, Wairakei Research Centre, Taupo, New Zealand

C.J. BROMLEY[1]
GNS Science, Wairakei Research Centre, Taupo, New Zealand

R. PAPASIN[1]
GNS Science, Wairakei Research Centre, Taupo, New Zealand

F. DELLA PASQUA[1]
GNS Science, Wairakei Research Centre, Taupo, New Zealand

J.E. HURRELL[1]
GNS Science, Wairakei Research Centre, Taupo, New Zealand

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Full addresses/phone/fax

[1]GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo 3377, New Zealand
Ph. (07) 374 8211   Fax (07) 374 8199

DELINEATION OF SHALLOW STRUCTURAL FEATURES CONTROLLING THE FLOW OF GEOTHERMAL FLUIDS AT BUTCHERS POOL, REPOROA, NEW ZEALAND

R.R. REEVES[1], C.J. BROMLEY[1], R. PAPASIN[1], F. DELLA PASQUA[1], J.E. HURRELL[1]

[1]GNS Science, Wairakei, New Zealand

SUMMARY – The shallow (<200m) resistivity structure around the "Butchers Pool" hot spring area, Reporoa, New Zealand has been determined using time domain electromagnetic soundings. A 3-D resistivity model was developed in Earthvision using 1-D inversions of TEM soundings collected at 26 sites.

The resistivity data and 3-D model suggest that Butchers Pool is an upwelling of geothermal fluids near the edge of a rhyolitic dome. The geothermal fluids penetrate a capping layer of lacustrine sediments (Huka Falls formation) and appear to pass along a NW trending corridor of higher permeability probably originating from the Reporoa geothermal system. The source of geothermal fluids from the northwest is interpreted to be from an aquifer at about 90m depth (approx. 220m RL).

1. INTRODUCTION

Identifying pathways between source geothermal fluids and geothermal surface features is important in order to assist in understanding and possibly predicting feature behaviour. Surface feature behaviour can be influenced by factors such as variations in the geothermal reservoir, groundwater systems, geology, climate, or, due to human activities such as geothermal or groundwater resource use. Understanding surface feature behaviour may be particularly important where geothermal surface features have a high cultural or community value.

The Reporoa geothermal area is located near Reporoa Township, approximately 36 km south of Rotorua. The geothermal area lies within the Reporoa Caldera which formed 0.24Ma with the eruption of the Kaingaroa Ignimbrites (Nairn *et al*., 1994). The caldera has since been in-filled with pyroclastic, lavas and breccias, tephras, alluvium and lacustrine sediments. Documented geothermal features associated with the geothermal area include springs and warm seeps (Bromley *et al*., 1993).

Regional resistivity mapping by DSIR Geophysics Division (1985), and later by Bromley *et al*. (1993) revealed an area of approximately 16 km^2 of very low apparent resistivity (<10 ohm-meters, AB/2 = 500m) centred 3 km north of Reporoa township. An extension of the low apparent resistivity anomaly(<30 ohm-meters) extending for about 6 km south is thought to represent an outflow from up-welling geothermal fluids through an aquifer (Healy and Hochstein, 1973, Bibby *et al*., 1994) Geochemical evidence (Sheppard and Robinson, 1980) suggests geothermal fluids mix with local groundwater in this area. Butchers Pool, a spring discharge, lies on the south-eastern boundary of the 30 ohm-meter anomaly. Eight Electrokinetic soundings (EKS) were conducted along a NW-SE profile near Butchers Pool in 2003 (Bromley *et al*., 2003). These suggested higher permeability liquid saturated aquifers may occur northwest of the pool in the 5-25m depth range and the 90-100m depth range. To the south-east of Butchers Pool, the shallow zone persists but the deeper zone is discontinuous.

Butchers Pool is a 43 °C spring discharging at about 40 l/s (Sheppard and Robinson, 1980). The pool area was gifted to the Reporoa community in 1927 by Mr H. R. Butcher. Ownership of the Pool was transferred to the Rotorua District Council (RDC) as a recreational reserve in 1964. Since then, RDC have developed the pool area by securing the pool sides (to prevent wall collapse), adding changing rooms/toilets and lights. The pool is used regularly by local people and tourists.

Electrical resistivity techniques (e.g., Schlumberger array DC resistivity, magneto tellurics and bipole – dipole surveys) have been used extensively to help delineate geothermal fields in New Zealand (e.g., Geophysics Division, DSIR, 1985, Bibby *et al*., 1994). These techniques help to delineate the boundaries and layered resistivity structure of deeper geothermal systems, but are less efficient and have limited application where detailed shallow resistivity structure is required, such as the subsurface environment of an individual hot spring.

Time domain electromagnetics (TEM) is a resistivity sounding technique that is better suited to efficient lateral and vertical resolution of shallow resistivity structure. The method (e.g., Nabighian and Macnae, 1991) involves measuring the decay of the vertical magnetic field over time from a pulse of electric current applied through a loop of wire. Pulses are repeated, typically at rates of 32 Hz to 8 Hz, and stacked to reduce the effects of electrical noise. The rate and size of the changes in the magnetic field are related to both the applied electrical current, the frequency of the pulses, and the resistivity structure of the earth beneath the loop of wire. Generally, low resistivity values are correlated with the presence of thermal fluids, intense clay-alteration, saturated porous formations and/or high-salinity fluids. The penetration depth of the technique depends on the amount of current used in the loop, the size of the loop and the resistivity structure of the earth beneath the loop. A typical maximum penetration depth for a battery operated TEM transmitter and a 100m per side square loop is about 200 – 300m.

The objective of this study was to delineate the shallow (<200m deep) resistivity structure around Butchers Pool to investigate the source of geothermal fluids to this feature. The TEM resistivity method was used because of its ability to efficiently obtain a high lateral resolution of the resistivity structure from a high density of measurement sites.

2. METHODS

2.1 Site Selection

Twenty eight sites were selected to cover the Butchers Pool area (Figure 1) in a grid pattern in order to make line traversing and interpolation between sites easier. Five approximately north/south oriented lines were selected with Butchers Pool in the centre of the survey area. Sites were nominally spaced about 200m apart, except for Line 1 (western line), which had a site spacing of between 100m to 200m. A closer spacing between sites was used in areas where more detail was thought to be required. The survey area is on relatively flat farmland. Exact site selection depended on a number of constraining factors such as: to avoid stock, to minimize the number of fences that crossed the current loop, to avoid crossing roads, and to maximize the distance from noise sources such as power lines.

Electric fences can also introduce electrical noise to TEM soundings. The farmers in the survey area make extensive use of electric fencing to control stock. The electric fences were turned off in the area of interest prior to recording data. However, this was only possible at farms that were occupied during the survey. Electric fences on neighbouring farms were not turned off during data collection.

2.2 TEM Measurements

The TEM current loops were typically arranged in a square, with 100m sides aligned north/south and east/west. The loop was connected to a battery powered Zonge NT-20 multi-purpose TEM transmitter placed approximately 10m outside one corner of the loop. A TEM3 magnetic receiver coil was placed vertically in the centre of the loop ("In-loop" sounding). Shielded cable was used to connect the TEM3 coil to a Zonge GDP-32 receiver placed close to the NT-20 transmitter.

Data were collected using 8 Hz, 16 Hz and 32 Hz switching rates at most sounding sites. Three frequencies were recorded so they could be compared to ensure data quality. 32 Hz data is used to develop the resistivity models at each site. Two blocks of averaged coil voltage decay data consisting of up to 8000 stacks each were collected at each frequency to ensure that any magnetic data affected by noisy spikes could be discarded. Data quality was checked on the GDP-32 receiver before moving to the next site.

2.3 Data Processing

The Zonge software programs Shred362 and TEMAVG (version 7.63) were used to process the raw TEM data. The TEMAVG software was used to average the two data blocks at each switching frequency at each site. A one dimensional (1-D) inversion was performed on the measurements of the vertical magnetic field using the Zonge software STEMINV version 3.20f. Noisy data were deleted before 1-D modelling of the 32 Hz data. The 1-D modelling software STEMINV outputs a plot and listing of smooth modelled resistivity with depth. Interpretations were limited to 220m depth at each site to limit the possible geometric distortion effects on deeper resistivities obtained using the 100m sided array.

Resistivity with depth results from the 1-D modelling were spatially modelled (3-D minimum tension gridding) and visualized in Earthvision software. Elevations at each sounding site were estimated from a 1:50 000 topographic map (20m contour interval) to obtain relative levels for the resistivity data and develop a local digital terrain model (DTM). Resistivity data were modelled using a 100m x 100m x 20m (x, y and z) grid. The grid was bounded by the DTM on the top surface, the DTM – 220m on the bottom surface, and the outer extent of the sites. This restricts the grid to interpolation between valid data only, without requiring extrapolation.

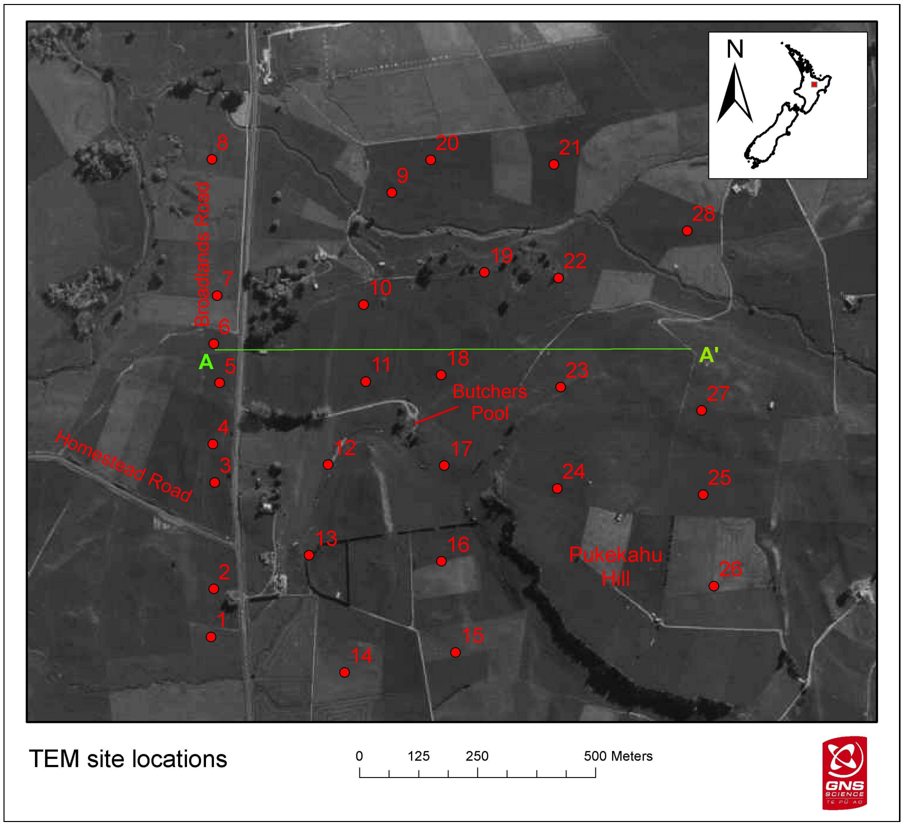

Figure 1. Site map of the study area.

3. RESULTS AND ANALYSES

TEM measurements were made at 28 sites (Figure 1) with a 100m loop size in the Butchers Pool area, Reporoa, between 19/3/2007 and 4/4/2007. Data at two sites (26 and 27) were not used in the visualization or interpretation due to poor data quality. Both of these sites are on Pukekahu Hill (an exposed portion of a partly buried rhyolite dome, centred southeast of Butchers Pool). Good smooth 1-D model inversions were obtained for data collected from the other 26 sites. Late-time TEM arrival data (deeper penetration) at most sites was noisy, and needed to be edited prior to 1-D modelling. Inversion modelling of the TEM data show apparent resistivities range widely, from 2 ohm-meters to nearly 4000 ohm-meters at depths of up to 220m.

Low resistivities (<10 ohm-meters) occur in two distinct sections of the 3D Earthvision model. Firstly, a small volume of low resistivity is modelled close to Butchers Pool (at site 18, approximately 150m north-east of the pool) below 160m RL (140m depth). The extent of this anomaly is limited given that it is dominated by data from one site (site 18). Secondly, a large volume to the north-west of Butchers Pool extends from 250m RL to the bottom of the model. This anomaly splits into 2 layers to the southwest. The top low apparent resistivity layer forms a thin wedge (Figure 2) occurring at about 230 - 250m RL (between 50m and 70m depth) and extends to about 250m north of Butchers Pool. The deeper low resistivity layer appears to be strongest to the west of Broadlands Road. The low resistivity layers are interpreted to be predominantly caused by hot geothermal fluids in shallow aquifers, and associated hydrothermal clay alteration. However, clay rich sediments may also be contributing to the low resistivity anomalies.

High resistivities (>250 ohm-meters) occur in the eastern part of the study area in two sectors. Firstly, a large high resistivity volume occurs to the east and south east of the study area from below about 220m RL (90m below ground level). An approximately northwest/southeast trending lower resistivity volume splits the high resistivity anomaly into a northern and a southern lobe (Figure 3). Both high resistivity lobes are in the vicinity of the Pukekahu rhyolite dome. This high resistivity area is interpreted to be due volcanic deposits associated with the rhyolitic dome. Secondly, a small (100m radius) high resistivity anomaly occurs at site 19 at a depth of 280m to 300m RL. This may also represent a local shallow deposit of unaltered rhyolite lava or a buried sinter deposit. A small sinter deposit can be seen at nearby site 22, which used to be a small discharging hot spring.

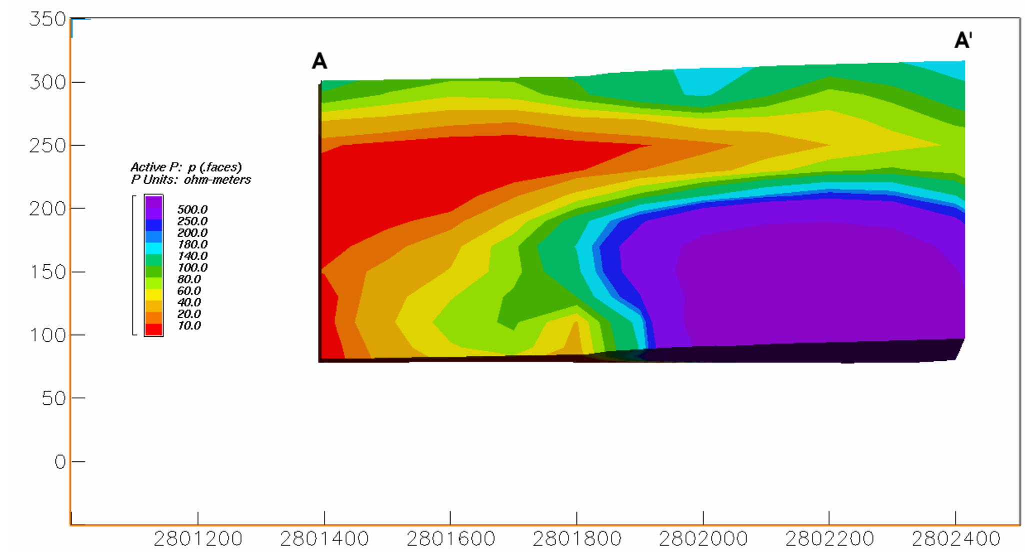

Figure 2. West – east cross section across the resistivity model.

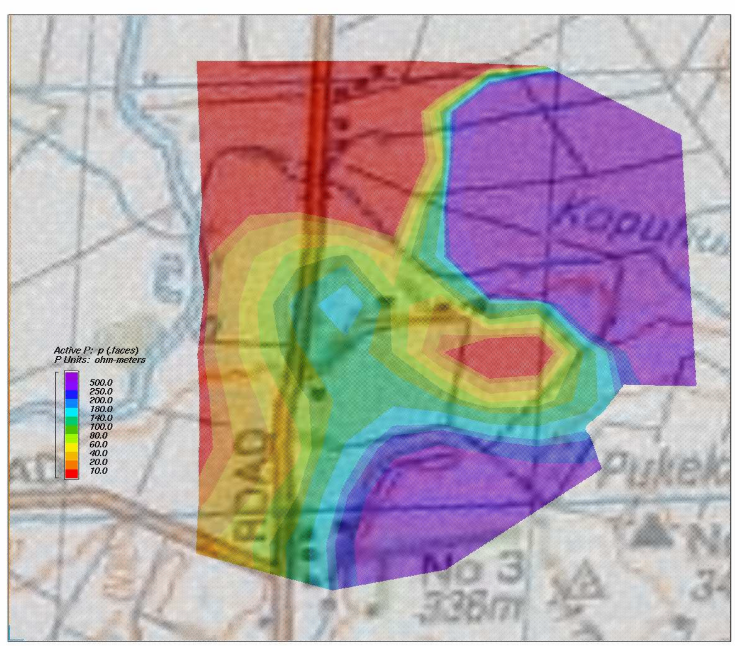

Figure 3. Horizontal cut across the resistivity model at 110m RL.

4. SUMMARY

3-D modelling of the 1-D TEM resistivity data infers a northwest/southeast trending lower apparent resistivity trend linking a low apparent resistivity adjacent to Butchers Pool to a low apparent resistivity anomaly approximately 300m northwest of Butchers Pool. These areas are in line with a scarp on the side of Pukekahu Hill. This could be an area of higher permeability, such as a fault, enabling hot geothermal fluids to flow from the northwest to the southeast. Fluids then encounter the high permeability margins of the rhyolitic dome, allowing the hot fluids to rise, and discharge at the hot spring.

5. REFERENCES

Bibby, H.M., Bennie, S.L., Stagpoole, V.M., Caldwell, T.G. 1994. Resistivity structure of the Waimangu, Waiotapu, Waikite and Reporoa geothermal areas, New Zealand. *Geothermics Special Issue*, Vol. 23, No. 5/6: 423-444.

Bromley, C.J., Bennie, S.L., Graham, D.J. 1993. *Reporoa Geophysical Survey.* Institute of Geological & Nuclear Sciences confidential client report 723306.11/A.

Bromley, C.J., Carrington, L., Bennie, S., Graham, D. 2003. Electrokinetic Soundings-application of a novel groundwater exploration method to hot water. *Extended abstracts of Annual Hydrological Society Conference, Taupo*, November 2003.

Geophysics Division, DSIR, 1985: *Sheet U17 – Wairakei. Electrical resistivity map of New Zealand 1:50 000. Nominal Schlumberger array spacing 500m.* Wellington, New Zealand. Department of Scientific and Industrial Research.

Healy, J. and Hochstein, M.P. 1973. Horizontal flow in hydrothermal systems. *J. Hydrology* 12, 71-82.

Nabighian, M.N. and Macnae, J.C. 1991. Time domain electromagnetic prospecting methods, in Nabighian M.N. (Ed) *Electromagnetic Methods in Applied Geophysics.* Vol. 2, Soc. Exploration Geophysics.

Nairn, I.A., Wood, C.P., Bailey, R.A. 1994. The Reporoa Caldera, Taupo Volcanic Zone: source of the Kaingaroa Ignimbrites. *Bulletin of Volcanology*, v. 56, p. 529-537.

Sheppard, D.S., Robinson, B.W. 1980. *A chemical and isotopic survey of the Waiotapu, Reporoa and Waikite hydrothermal discharges.* DSIR Geothermal circular CD 30/555/6 DSS-4.

6. ACKNOWLEDGEMENTS

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