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PUTAUAKI (KAWERAU) MT RESISTIVITY SURVEY

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SUMMARY - New magnetotelluric resistivity soundings, supplemented by Schlumberger traversing measurements, have been collected in the vicinity of Putauaki (Mt Edgecumbe) to investigate the southern and eastern extent of the Kawerau Geothermal Field. They show that this field is associated with a large area of low resistivity totalling about 22km^2. Approximately 50% of this area is administered by the Putauaki and Te Tahuna Putauaki Trusts, and only a small portion has been tested with exploration drill holes. The volcanic peak of Putauaki itself (<5k yrs old) is on the southern boundary of the field. An association is inferred between the magma body feeding this vent and the heat source for the geothermal system (>300k yrs old). An area of particularly low resistivities (<5 ohm-m at 1km depth) and cold geothermal gas vents (H_2/Ar geothermometry >250°C) is located near the centre of the revised low resistivity anomaly, about 1.4 km east of the hottest existing Kawerau geothermal wells (KA26, KA29). From this data, a geothermal hydrological model is inferred: a deep upflow, with associated intense hydrothermal alteration, occurs on faults centered beneath the gas vents, and supplies lateral flows to the northwest into the area of present production at Kawerau, as well as to the northeast.

1. INTRODUCTION

Fluids from the Kawerau Geothermal Field have been utilised for process steam (up to 300 T/h) and electricity production (up to 8MW) by the Tasman Pulp and Paper Mill since 1957 (Bloomer, 1997). Two binary plants also generate about 6 MWe from waste brine. The existing steam field is managed by Century Resources on behalf of the New Zealand Government. The bulk of the drilling and subsequent fluid extraction took place in a 2 km^2 area at the north-western corner of the field near the largest area of thermal features (Onepu Springs) and close to the Tarawera River (Figure 1). Temperature contours, pressure contours and chloride concentrations of the discharged fluid from the existing boreholes all imply that the fluid source (hot, high pressure, saline fluid upflow) is to the southeast of the drilled area, in the direction of Putauaki (Mt Edgecumbe) (Allis et al., 1997). Two exploration wells drilled to the southeast of the Tasman Mill (KA29 and KA26) were found to be very hot (up to 310°C) but impermeable. Subsequent efforts concentrated on the more permeable outflow area of cooler temperatures to the northwest.

The known subsurface geology consists of a sequence of volcanics (rhyolites, ignimbrites, tuffs and sediments) overlying a basement of greywacke at about 1 km depth near the mill, but deepening to the northwest, and shallowing to about 700 m depth to the southeast. It was initially presumed that north-east (~45°) trending normal step faults cause this drop in basement depth towards the centre of the Whakatane Graben (Nairn, 1986). However, Wood and Brathwaite (1999) show that the most likely orientation of local basement faults, based on contours of basement elevations in Kawerau drillholes, is about 80". Indeed, about 60" (+/-5°) was the dominant trend of the most accurately measured faults in the area – an east-west zone of en-echelon fractures that ruptured just north of Kawerau geothermal field during the 1987 Edgecumbe earthquake. Furthermore, the gravity anomaly contours in the south-eastern sector of Kawerau (MacDonald et al, 1970) imply a predominantly east-west trend to the down-faulted, high-density basement.

The location of basement faults has important implications for further exploration drilling, and for management of production and injection strategies at Kawerau, because of the lack of extensive permeable stratigraphic aquifers. Where these faults pass through basement they can, in places, be highly permeable (eg. KA21), but at other places the structures are impermeable (eg. KA29). Because of large uncertainties in determining strike and dip of fault zones, and in predicting their productivity, targeting of inferred faults at Kawerau has had variable success (Wood and Brathwaite, 1999).

Some permeable aquifers do occur in the overlying volcanics to the northwest, particularly at depths above about 400 m and at about 800 m (White et al., 1997). The shallower aquifer has suffered from pressure drawdown of several bars causing inflows of cooler water from above. Calcite deposition in the well bore was also a problem, particularly in wells tapping the shallower aquifer. The deeper zone has shown little, if any, evidence of pressure drawdown after more than 25 years of exploitation. This implies that the deeper zone is recharged from a highly permeable source of hot water, and that the entire field could probably sustain a much higher rate of extraction if this source were to be tapped.

The natural surface heat flow from thermal activity is estimated (Allis et al., 1993) to be about 100 MW(thermal). Matahina Ignimbrite, (which occurs between about 100 m and 200 m of the surface) appears to act as a "blanket" or aquiclude, preventing upflows of hot fluid to the surface over most of the geothermal system (east of Tarawera River), but is absent to the west where the thermal features are located. An additional subsurface outflow of about 50 MW(thermal) possibly extends into the groundwaters of the Rangitaiki plains to the north and northeast, contributing to anomalously high chloride and boron concentrations in these waters.

Putauaki (Mt Edgecumbe) is a relatively young cone (mostly <5000 years old), compared to the age of the geothermal system (>300,000 years, Browne, 1979). It may be a recent extrusion from a shallow magma body that has provided a heat source for the geothermal system (Christenson, 1997). Ejecta fiom three hydrothermal eruption vents, located near Tarawera Road, north of Putauaki, have been dated at 14,500 and 9,000 years old.

Early resistivity surveys (before 1970) of Kawerau field (MacDonald et al., 1970; Studt, 1958) were shallow penetrating (to about 250 m depth) and limited in the area surveyed. They suggested a field area of 10 km^2 centred on the Tasman mill. This was the basis for the subsequent exploration drilling. Later measurements, using a deeper penetration Schlumberger traversing array (AB/2 = 1000 m), showed a much greater field area of at least 19 km^2 with a major eastward extension of the anomalously low resistivity ground (Allis et al., 1993). However, the location and cause of the north-eastem and southern resistivity boundaries, in particular, remained uncertain. The new resistivity work, reported here, allows for an improved resistivity model and an inferred hydrological model of the Kawerau field to be constructed.

2. GEOSCIENTIFIC PROGRAMME

Additional geoscientific exploration on the south-eastern side of Kawerau Geothermal Field was undertaken with the collaboration of the Putauaki and Te Tahuna Putauaki Trusts. The objective of this work was to determine the resistivity structure of this sector, to resolve uncertainties regarding the eastern boundary of the Kawerau Geothermal Field, and to provide information to assist with planning future exploration drillholes. The scope of the work included DC and MT resistivity measurements and gas analyses.

DC resistivity measurements were made using the Schlumberger array with AB/2 spacings of 500 m and 1000 m (giving nominal probing depths of up to 500 m). This helped resolve uncertainty, caused by insufficient data, regarding the eastern boundary of the Kawerau geothermal system. Magneto-telluric soundings were then sited using the traversing data as a guide. These soundings provided resistivity information as a function of depth (fiom near surface to about two kilometres), and as a function of orientation.

Gases discharging through a patch of bare ground (sometimes a shallow lake), at NZMG co-ordinates 2838433 mE, 6340600 mN, about 1.4 km east of borehole KA29, were sampled and analysed. The purpose was to determine whether these gases are of geothermal origin, and to obtain the deep temperature of origin from gas geothermometry.

Several magneto-telluric soundings were conducted around Putauaki (Mt Edgecumbe) in order to investigate the deep resistivity structure of the volcano and its relationship to the geothermal system. Soundings were also located in the vicinity of several hydrothermal eruption craters near one of the hottest Kawerau boreholes, KA26 (Figure 1).

3. RESISTIVITY AND GAS ANALYSIS RESULTS

The DC Schlumberger array measurements conducted in the vicinity of Lake Onerahi, near the eastern boundary of Kawerau Geothermal Field, reveal apparent resistivities that consistently decrease with depth (AB/2 spacings 500 m to 1000 m). They also increase from west to east (about 15 ohm-m to 45 ohm-m, at AB/2 = 1000 m). In the vicinity of Te Teko, further northeast, apparent resistivities are greater than 50 ohm-m. Figure 1 shows the revised resistivity boundary of the Kawerau Geothermal Field, incorporating these new data. The north-eastern "boundary" is actually a zone of gradual increase in apparent resistivity from 20 ohm-m to 70 ohm-m consistent with a model of outflowing, and gradually cooling, geothermal fluids. The total area of the Kawerau resistivity anomaly (defined as <25 ohm-m at AB/2 = 1000 m) is approximately 22 km^2.

The locations of all the magnetotelluric soundings around Putauaki are shown in Figure 1. Wherever possible, the orthogonal sounding arrays were oriented NE (Ex) and NW (Ey), using 50 m electric field dipoles and perpendicular magnetic coil antennas. A measurement frequency range of 8 kHz to 0.02 Hz provided penetration depth range from near surface to about 3 km. Notch filtering at 50 Hz was required because of nearby high voltage powerlines. Natural signal strengths in the frequency bands near 1 Hz and 2 kHz, were, as usual, very low, resulting in some noisy portions of the sounding curves containing poorly correlated data.

Layered interpretation of the filtered and smoothed apparent resistivity curves was undertaken using an automated iterative process. The best fitting models, although subject to some uncertainty, have been combined into cross-sections (see Figure 2) in order to assist with geothermal interpretation. Several soundings show evidence of distortions, particularly at low frequencies, that are probably caused by 3-dimensional structure. Several others show evidence of static shift effects (frequency independent displacement of the sounding curves in the Ex and Ey directions). These are probably caused by near surface inhomogeneities. To resolve some of these uncertainties would require a more detailed MT survey of the area backed up by co-located TEM soundings to account for static shift effects.

The cross-sections presented in Figure 2, however, are reasonable interpretations of smoothed subsurface resistivity structure. They reveal several new features related to the gross structure of the geothermal system. Sections A-A' and B-B' (Figure 2) show that the peak of Putauaki is located above the boundary of the low resistivity anomaly associated with the geothermal system. On the northern side of the volcano, the low resistivity layer extends from at least 2 km depth to within about 100 m depth. Further northeast, (beyond the 20 ohm-m contour of Figure 1) the low resistivity is confined to a layer between about 200 m depth and about 1 km depth, with an underlying resistive basement (presumed to be relatively unaltered, and cool, greywacke). This resistivity structure is consistent with a hydrological model of upwelling geothermal fluids feeding a north-eastern fluid outflow through permeable volcanic formations. These fluids have probably generated intense hydrothermal clay alteration.

To the north-west, it is possible to compare interpreted resistivities along sections B-B' and C-C' with nearby borehole geology and temperatures (KA34, KA26, and KA29). These comparisons suggest that the shallow low resistivity anomaly, in this area, is caused by intense smectite alteration at temperatures of about 100°C, occurring within porous volcanic units. The underlying moderate resistivity layer (about 30 ohm-m) coincides with greywacke at high temperature (>280°C), but relatively low permeability, and moderate illite/chlorite type alteration. In the central area of the anomaly, low resistivities (<5 ohm-m) are found at depths of 1.2 to 2.5 km. This is beyond the depth of the nearest well KA26, and the cause is unknown, but may be related to a local increase in alteration intensity associated with basement fracturing.

The sampled gas vent (within the former Lake Waimangau), lies at the centre of this low resistivity anomaly. It is aligned with a probable fault structure, oriented at 80°, that links other nearby patches of hydrothermally altered ground. The results of the compositional analysis of this gas show that it is a typical geothermal gas sample. Concentrations are given below in millimole/mol (dry gas):

$CO_2 = 853$, $H_2S = 6.52$, $He = 0.031$, $H_2 = 6.2$, $O_2 = 0$, $N_2 = 58.8$, $CH_4 = 75.2$, $Ar = 0.52$

The H_2/Ar gas geothermometer produces a minimum subsurface temperature of 250°C for the deep source of this gas (Christenson, pers. comm.).

4. CONCLUSIONS

The resistivity and gas chemistry results reported here strongly support the conclusion that most of the Putauaki Trust block (approximately 10 km^2) and the Te Tahuna Putauaki blocks (1.3 km^2) are contained within the boundaries of the Kawerau Geothermal Field, which has a revised estimated total area of 22 km^2. A subsurface outflow of cooling geothermal fluid is inferred to extend several kilometres to the north and north-east, causing a more diffuse resistivity boundary in this direction. The low resistivity anomaly also extends to the south, as far as Putauaki itself. In the vicinity of the four existing south-eastern Kawerau boreholes (KA34, KA25, KA26, KA29), where the greywacke basement has high temperatures (over 280°C), we found an intermediate basement resistivity (30 ohm-m). But about 5 km to the north-east, the underlying greywacke has a much higher resistivity (several hundred ohm-m). Here it presumably forms a cooler, unaltered basement to the northern lateral outflow.

The most interesting part of the resistivity anomaly lies at its centre, near an area of cold gas discharge (former Lake Waimangau). Several soundings in this area reveal very low resistivities (less than 5 ohm-m) at drillable depth range (1 km to 2.5 km). Based on simple extrapolation of lateral temperature gradients, very high

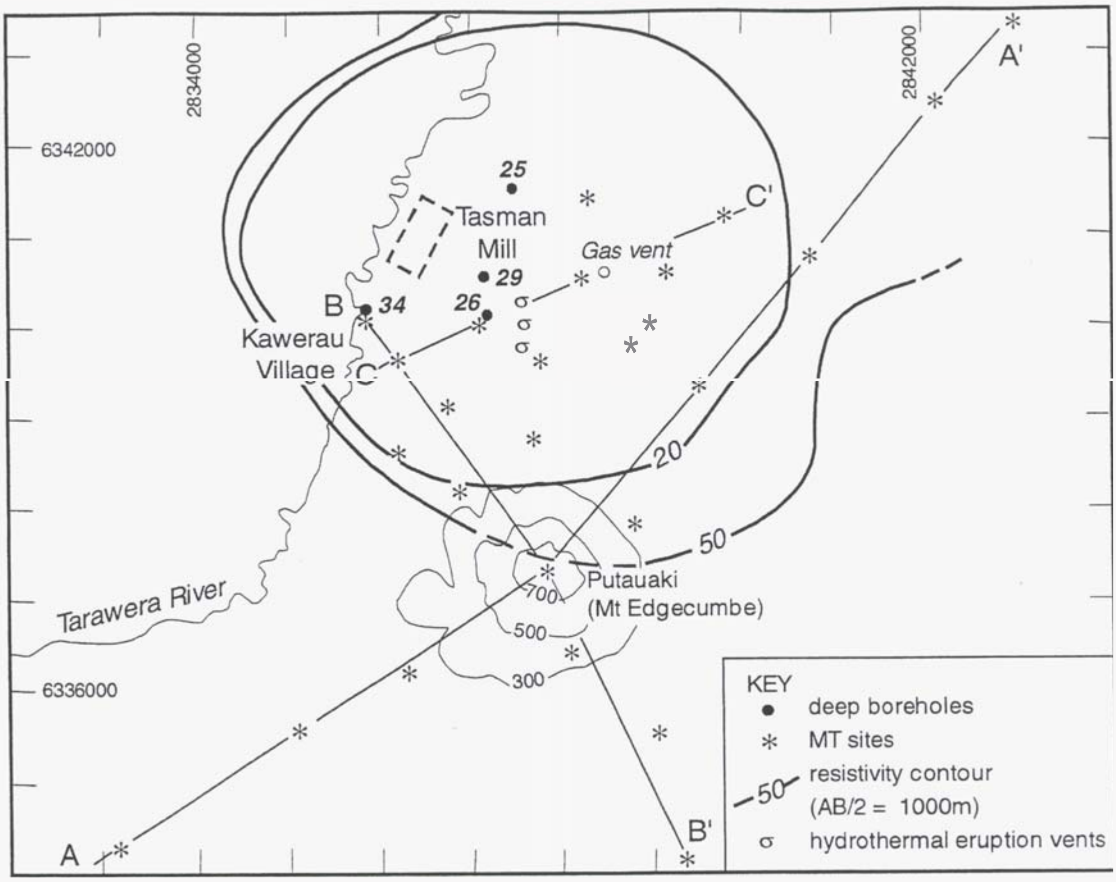

Figure 1. Kawerau Geothermal Field: resistivity boundary, magneto-telluric resistivity (*) **and** cross-section locations, boreholes (•) and gas vent (o).

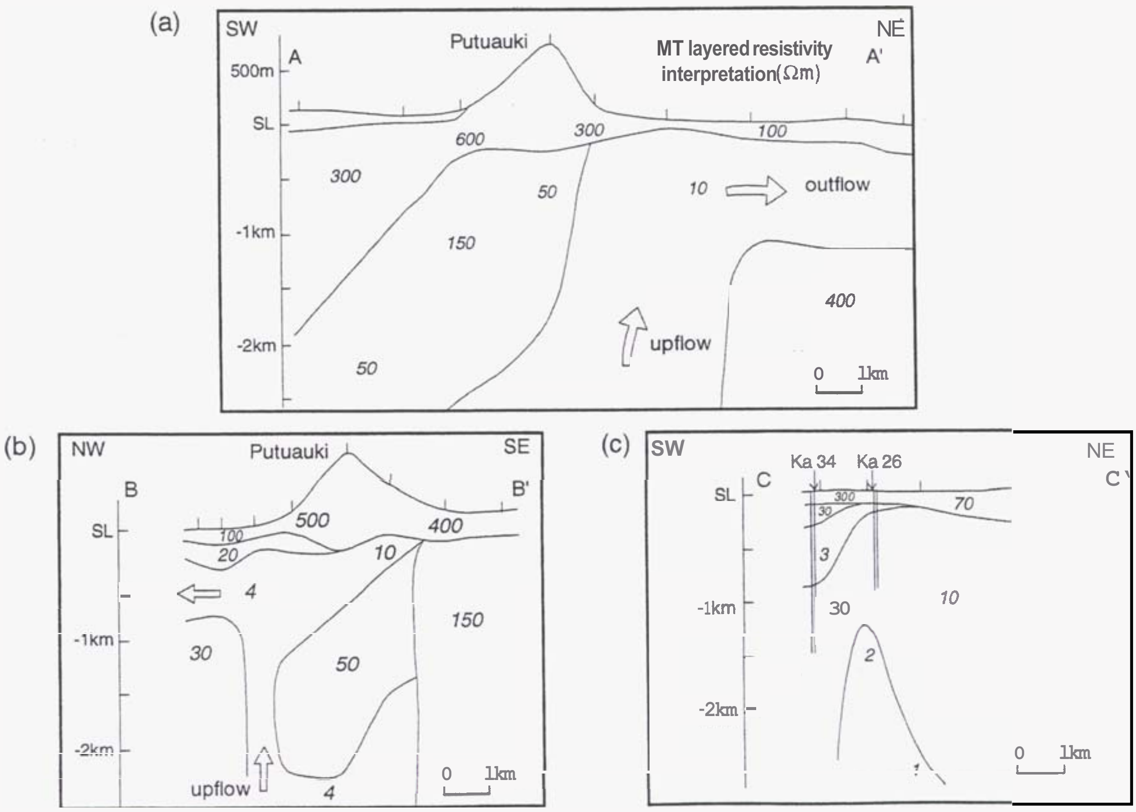

Figure 2. Putauaki magneto-telluric resistivity interpretation. Cross-sections **A-A'**, B-B' and **C-C'**, showing layered resistivity models and inferred hydrological flows.

temperatures can also be expected in this area east of KA29. The low resistivities possibly indicate more favourable basement permeability (associated with highly fractured and intensely altered zones) than at KA26 and KA29.

A sounding located adjacent to one of the large hydrothermal eruption craters reveals a localised high resistivity layer that may indicate the presence of a relatively young and unaltered intrusive dyke or sill under the eruption vent.

Analysis of the gas from the Putauaki vent confirms that it is geothermal in origin and has a source temperature of at least 250°C.

Based on the area of the resistivity anomaly, and the production history of the existing development, the potential sustainable production capacity of the Kawerau field is likely to be in excess of 100 MW (e). The new results, when combined with the knowledge from existing Kawerau wells, which indicate a south-eastern direction for the origin of the deep recharging fluids (high temperature, high pressure and high chloride), confirm that a deep exploration borehole should be drilled in the area of the gas vents, where high temperatures and permeability can be anticipated at depths of 1 to 2 km.

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