RESISTIVITY EVIDENCE FOR AN INDEPENDENT GEOTHERMAL FIELD AT REPOROA

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ABSTRACT - The resistivity characteristics of the Reporoa area are incompatible with the commonly accepted model in which the Reporoa geothermal waters originate as groundwater drainage from Waiotapu Geothermal Field. Resistivity mapping with the Schlumberger array shows a well defined area of low resistivity (<10 Ωm) surrounding the Reporoa thermal features. Over most of its perimeter, this low resistivity zone has sharp boundaries comparable with those of Ohaaki Geothermal Field, about 10 km to the south. Such boundaries are also *seen* in *the* deep penetration bipoledipole resistivity data. Schlumberger resistivity soundings made at Waiotapu and Reporoa show the characteristics typical of high temperature geothermal fields, and *are* quite different from those in the region between these areas. This resistivity structure is not characteristic of an outflow zone but *suggests* that an upflow of geothermal fluids occurs at Reporoa. We conclude that Reporoa is an independent geothermal field.

INTRODUCTION

The surface thermal activity at Reporoa is minor when compared with that at many other thermal areas in the Taup Volcanic Zone (TVZ). This activity consists of two small areas of thermal ground about 5 km south of Waiotapu Geothermal Field (see Fig. 1), and two low

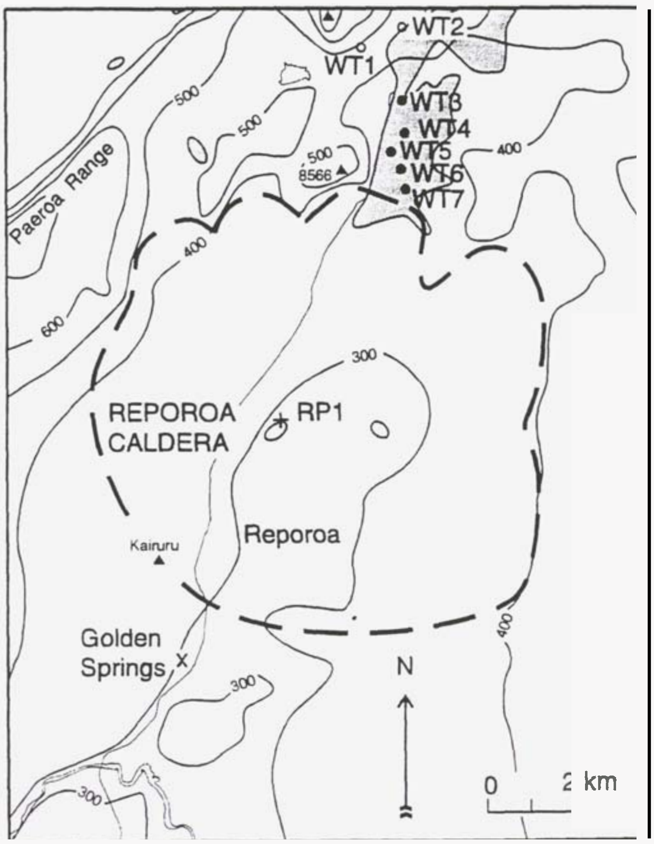

Figure 1. Shading shows distribution of thermal ground, it Reporoa and Wawtapu, *in relation to the topographic contours* (in *m*) *and locations of drill holes: Waiotapu - WT; Reporoa - RP. Reporoa caldera is marked by the solid line.*

temperature springs (Golden Springs and Butcher's Pool) a further 5 km to the south. The total heat output of the surface features, including the low temperature springs, is about 20 MW.

When electrical resistivity techniques were first *applied* to geothermal investigations (Hatherton et al 1966) the initial survey area included both Reporoa and Ohaaki (Macdonald 1967). This survey outlined substantial areas of low resistivity surrounding the thermal activity at both Reporoa and Ohaaki, an unexpected result in view ofthe small heat outputs of these areas.

The higher elevation of Waiotapu Geothermal Field, a few kilometres to the north of Reporoa, has led several authors to suggest that the thermal springs at Reporoa are merely outflows from the more substantial Waiotapu *system* (Macdonald 1967, Healy and Hochstein 1973). The temperature decrease at depths of between 300 and 600 m observed in the only well drilled in the Reporoa area (RP1, Fig. 1) and interpretations of the water chemistry (Bignall 1990) have been used as support for this interpretation. This model for the origin *of* the geothermal fluid suggests that Reporoa has only limited potential. However, several features of the resistivity data from the Reporoa area do not appear to be consistent with this origin for the Reporoa thermal springs. This paper is aimed at highlighting these discrepancies in the hope of stimulating an interest in the area and ofemphasising the need for further work to clarify the potential of Reporoa.

RESISTIVITY MEASUREMENTS

The success of electrical resistivity surveying in the delineation of the geothermal systems of the TVZ results from several factors, all of which contribute towards a reduction of the electrical resistivity within a geothermal system. Geothermal waters contain high concentrations *of* dissolved salts with chloride concentrations up to 2000 ppm. Such waters are highly conductive compared to the surrounding regions containing cold groundwater with only about 6 ppm chloride. Hydrothermal alteration of the host rock also produces highly conductive clay species, which greatly reduce the resistivity of the rock matrix (Caldwell et al., 1986). In addition, the resistivity of both the rock matrix and the geothermal fluid decrease with increasing temperature (see, for example, Quist & Marshall, 1968). These three factors all contribute towards the high contrast in electrical resistivity between the region containing geothermal fluids and the surrounding region containing cold groundwater.

Resistivity mapping

Reconnaissance DC resistivity mapping made using the Schlumberger array with spacings (AB/2) of 500 m and 1000 m now covers most of the TVZ. The measurement system and analysis techniques used are described in detail in Bibby (1988). The Reporoa area lies on the first published sheet of the 1:50000 Electrical Resistivity Map of New Zealand (Geophysics Division 1985). These data have been used together with a number of more recent measurements to produce the contour map shown in Fig. 2 (Schlumberger AB/2 = 500m). As an aid to the discussion that follows, the map area extends to include Waiotapu Geothermal Field to the north and Ohaaki Geothermal Field to the south.

Fig. 2 shows three distinct regions of (Schlumberger) resistivity less than 10 Ωm; the northern and southern areas outline Waiotapu and Ohaaki geothermal fields respectively, while the central area contains the Reporoa geothermal features. The boundaries of the Reporoa resistivity anomaly are well defined on three sides, with steep resistivity gradients similar to those observed at Ohaaki. However, on the northern side, in the region between Waiotapu and Reporoa, the resistivity values are between 10 and 15 Ωm, and are much lower than would be expected if this region contained cold water. In contrast, resistivity values between Ohaaki and Reporoa are greater than 70 Ωm.

Multiple-source bipole-dipole data

Although bipole-dipole surveying has not been made for the purpose of delineating the Reporoa resistivity anomaly, a small number of measurements have been made in the area as part of a large scale survey designed for investigations of deep regional structure (Risk et al 1993, Bibby and Risk 1992). Most of these measurements were made on a line passing through both Ohaaki and Reporoa (EE', FF' Fig. 2). This survey is discussed in detail in Risk et al (in press).

Data from bipoledipole surveys are best represented by a tensor apparent resistivity (Bibby 1986). For presentation purposes a number of tensor invariants (of averaged resistivity), which are independent of source orientation, can be used. Fig. 3 shows plots of one of these invariants (P_2) through Ohaaki and Reporoa. The Schlumberger array and bipole-dipole apparent resistivities are influenced differently by the regional resistivity structure and the values should not be directly compared.

At Ohaaki, rapid changes in the P_2 invariant (Fig. 3a) coincide with the discontinuities in the Schlumberger apparent resistivity data (Fig. 2). While the greatest contrast in P_2 apparent resistivity occurs at the southern boundary, a small but distinct step also occurs at the northern boundary. At Reporoa, the survey line crosses through the eastern side of the Schlumberger resistivity anomaly and consequently only two measurement points lie within the anomaly. The discontinuity in the resistivity is similar to that observed at the northern boundary of Ohaaki.

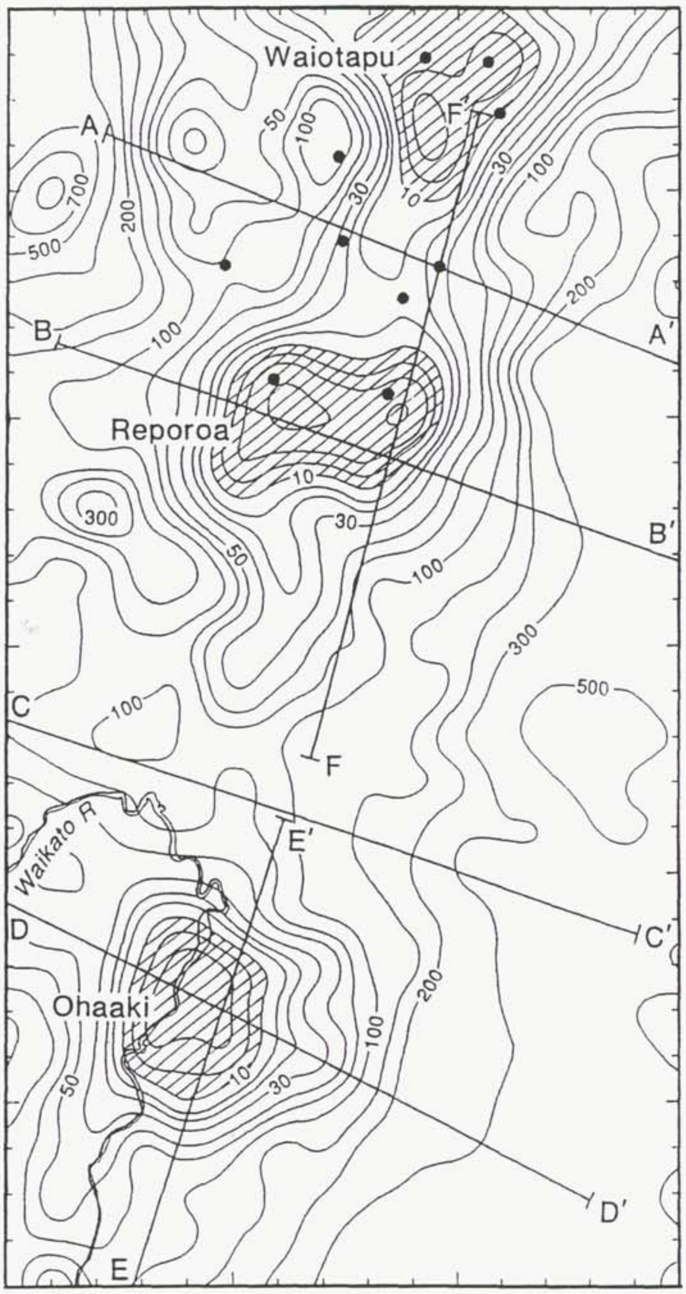

Figure 2. Contours of apparent resistivity for the Schlumberger array with (nominal) spacing of 500 m. The logarithmically spaced contours are based on griding of data on a 1 km interval using the technique of Bibby (1988). Values are in Ω m. Lines show locations of the cross sections of Figs. 3 and 5. Dots show sounding sites.

soundings

Ten Schlumberger **resistivity soundings** have been **made** in **the vicinity of Waiotapu** and **Reporoa.** Fig. **4** shows typical curves **from** within Waiotapu Geothermal Field, from within **the** Reporoa anomaly and **from the region** between the **two.** Inferred resistivity-depth **sections are** also shown.

Below **the** *surface* **layers,** about 100m thick, soundings at **both Waiotapu** and Reporoa *show* low **resistivities** (<5 Ω m). Such **low resistivities,** which **are** a characteristic *of* all the high **temperature** geothermal *systems* of **the** TVZ, **are** caused by *the* presence *of* hydrothermal alteration products (illite-smectite) and conductive **geothermal** waters. It is **this** layer that **produces** the low **resistivity anomalies** in Fig. **2.** **Below this** conductive layer, **resistivity increases at both Waiotapu and Reporoa.** In **particular at Reporoa this increase** occurs at depths **between** 200 and 400m. The increase **of resistivity** with depth is also **a characteristic of** high **temperature** geothermal *systems* and is believed to **be linked to the** change in mineralisation *from* **the** conductive **illite-smectite** to a **predominance** of **the more resistive** chlorite **species with increasing** temperature (>150 °C) (Bjornsson *et* al **1986,** Bibby *et* **al 1992).** In **contrast,** between Waiotapu **and** Reporoa, **the** very low **resistivity** near surface **layer** is absent. **Instead,** resistivity slowly decreases with increasing depth.

DISCUSSION

The thermal springs at **Waiotapu** *are* about 100 **m** higher **than** the **Reporoa springs. Thus,** the **outflow of Waiotapu** geothermal waters would be expected to pin **the natural groundwater** drainage flowing to the **south.** Analysis **of** the **resistivity data** at Waiotapu (Bibby **et al** in **press) suggests** that **this** movement *of* geothermal **water occurs** over **a** wide front.

The **patterns** of resistivity **mapped** over other drainage features in the **TVZ (Mokai** far example, Bibby **et** al **1984) show such flows** *can* **be identified** by their **low resistivity signatures. The** resistivity *of* such **outflows** systematically **increases** along **the paths** as **dilution reduces** the concentration *of* **the** dissolved **salts and the** fluid **temperatures. Hydrothermal alteration** will also diminish. **These** characteristics **are** not *observed* southward **from** Waiotapu. **Fig.** *5* **shows cross sections of measured** apparent resistivity (AB/2 = **500** m) **at increasing distances** *from* **Waiotapu (locations shown** in Fig. *2).* The section **through Reporoa (Fig. 5b)** is **quite** distinct from those **to the north** (Fig. 5a) **and south** (Fig. **5c).** Abrupt **resistivity changes,** *of* an *order of* magnitude, **mark the** east **and** west edges **of the** Reporoa **anomaly.** Although relatively low **resistivity** values (<30 **Ωm)** *are* **observed** to **the north** (Fig. **Sa),** they **are not as low as at Reporoa and they occur over** a much broader **front. The** data **on the northern** profile (Fig. Sa) **are consistent** with **subsurface** *drainage* **from Waiotapu.**

If **this flow** were **to** continue southward, with **no** other source of **geothermal fluids,** a southward **increase** in resistivity would **be** expected in Fig. **5b.** **Instead,** a low resistivity anomaly **occurs** at Reporoa. **Within** this anomaly resistivity **soundings** *show* the characteristics normally associated with a high **temperature geothermal** system. Furthermore, the **shallow penetration** Schlumberger resistivity measurements **as** well **as** the deep penetration bipole-dipole **survey** *show* *abrupt* **and** well **defined boundaries to the low resistivity anomaly at Reporoa.** These characteristics **are inconsistent** with a model having **only** subsurface **flow from Waiotapu.** They **are,** however, **the** characteristics of an independent **geothermal system.**

Comparison *of* **Ohaaki** and Reporoa resistivity **anomalies** *supports* *this* view. **The** near **surface geology and the resistivity signatures** *of* **Ohaaki** and Reporoa **are similar.** Resistivity changes **across the boundaries** to **the east** and west (Fig. 5b,d) have **matching shapes** and magnitudes.

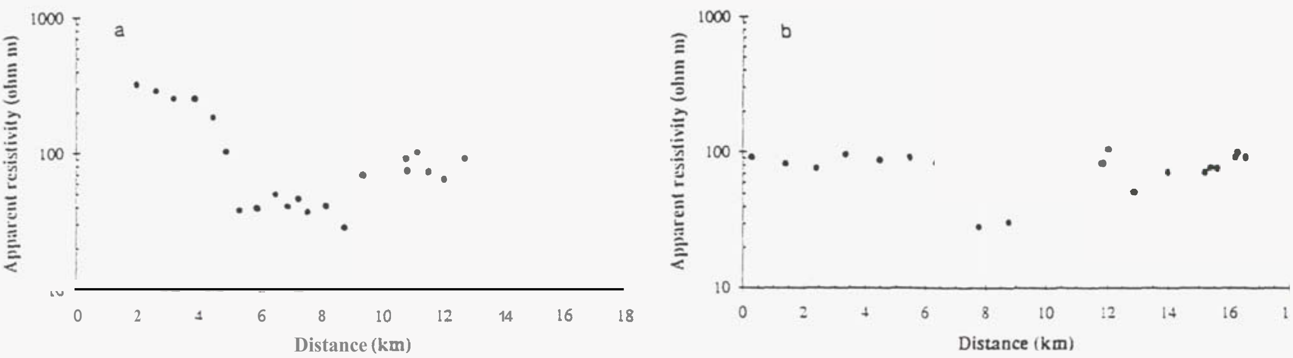

Figure 3. Bipole-dipole data in the Reporoa area, from Risk et al (in press). Current transmitter is located on the Kaingaroa Plateau to the east. Values are in Ω m.
a. Profile along line EE' (Fig. 2) passing through Ohaaki Geothermal Field.
b. Profile along line FF' (Fig. 2) passing through the Reporoa resistivity anomaly.

The change in the bipoledipole data across the northern boundary of Ohaaki Field (Fig. 3a) is similar to that *observed* at of the Southern boundary of the Reporoa anomaly (Fig. 3b). The resemblance of these two anomalies suggests the Same processes are responsible for both.

The major difference between the Ohaaki and Reporoa anomalies *occurs* at the northern boundary of Reporoa where only a small contrast in the resistivity is observed. In this region southward drainage of geothermal fluids from Waiotapu masks the deeper boundary and reduces the *observed* resistivity contrast.

Between Reporoa and Ohaaki, subsurface drainage would be expected to flow northwest from Ohaaki, and south from Reporoa, in the direction of the Waikato River. The intermediate resistivity values measured in this area (Fig 2, 5d) are consistent with such a drainage pattern.

Temperature measurements in the Reporoa drill hole (RP1, Fig. 1) *show* a large temperature reversal in the upper 900 m. This temperature inversion is perhaps the strongest evidence far the drainage model of Reporoa geothermal springs. A comparison of the stratigraphy of RP1 with the temperatures shows that the temperature reversal *occurs* within a rhyolite. High resolution aeromagnetic data (centre of Fig. 6), acquired as part of a mineral exploration programme, suggest that this rhyolite is extensive. These magnetic data show a local high about 2 km to the south of RP1, with a very much larger anomaly to the west, farther from RP1. Thus, it appears that the rhyolite encountered in RP1 is shallower some kilometres to the west and may be related to the two rhyolite domes (Karuru and Pukekahu) to the southwest of RP1. In other geothermal fields in the TVZ, the outer margins of large rhyolites often have high permeability and contain flows of cold water. At Ohaaki, for example, cold water, enters the field through the Ohaaki rhyolite, and gradually increases in temperature towards the centre of the field. Thus, we suggest that the rhyolite to the west of Reporoa provides a natural conduit by which cold water enters the geothermal *system* from higher ground. Such an inflow would also account for the dilute water found in the well. The rhyolite clearly retains most of its magnetisation, and thus cannot have been subjected to extensive demagnetising effects of hydrothermal alteration. The presence of a flow of cooler water within the rhyolite may also provide an explanation far the retention of its magnetisation.

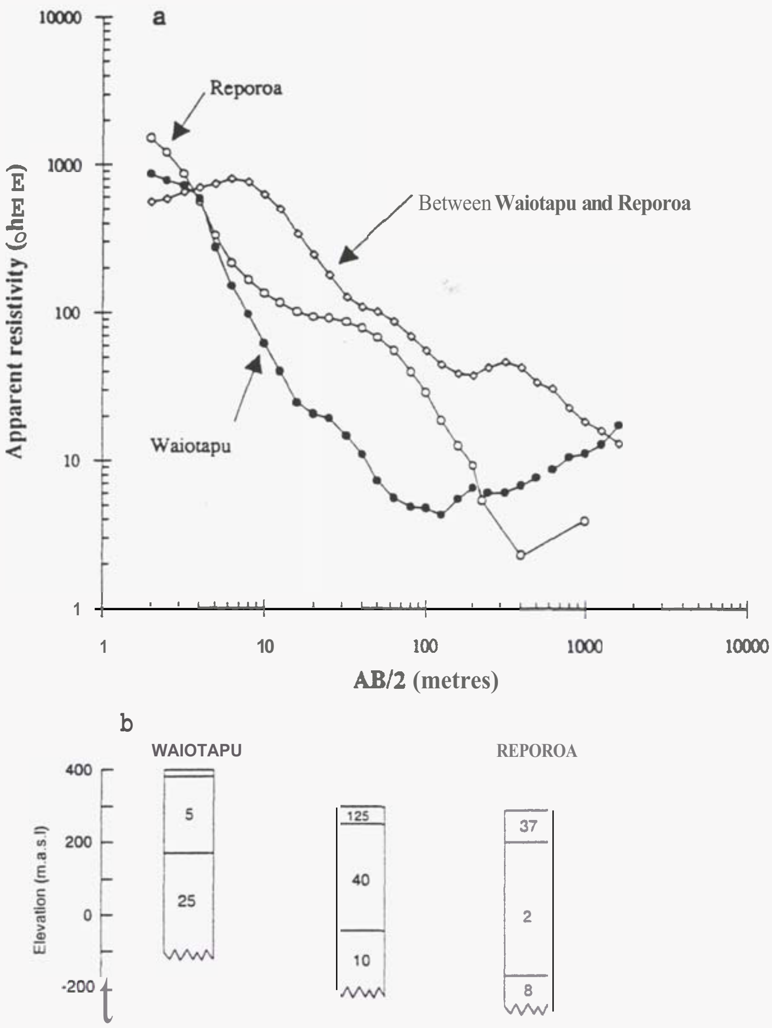

Figure 4. Three typical resistivity soundings from Reporoa, Wawtapu and the area between them.
a. Measured sounding curves for the three different regions discussed in the text. Values are in Ω m.
b. The interpreted resistivity-depth sections for these curves.

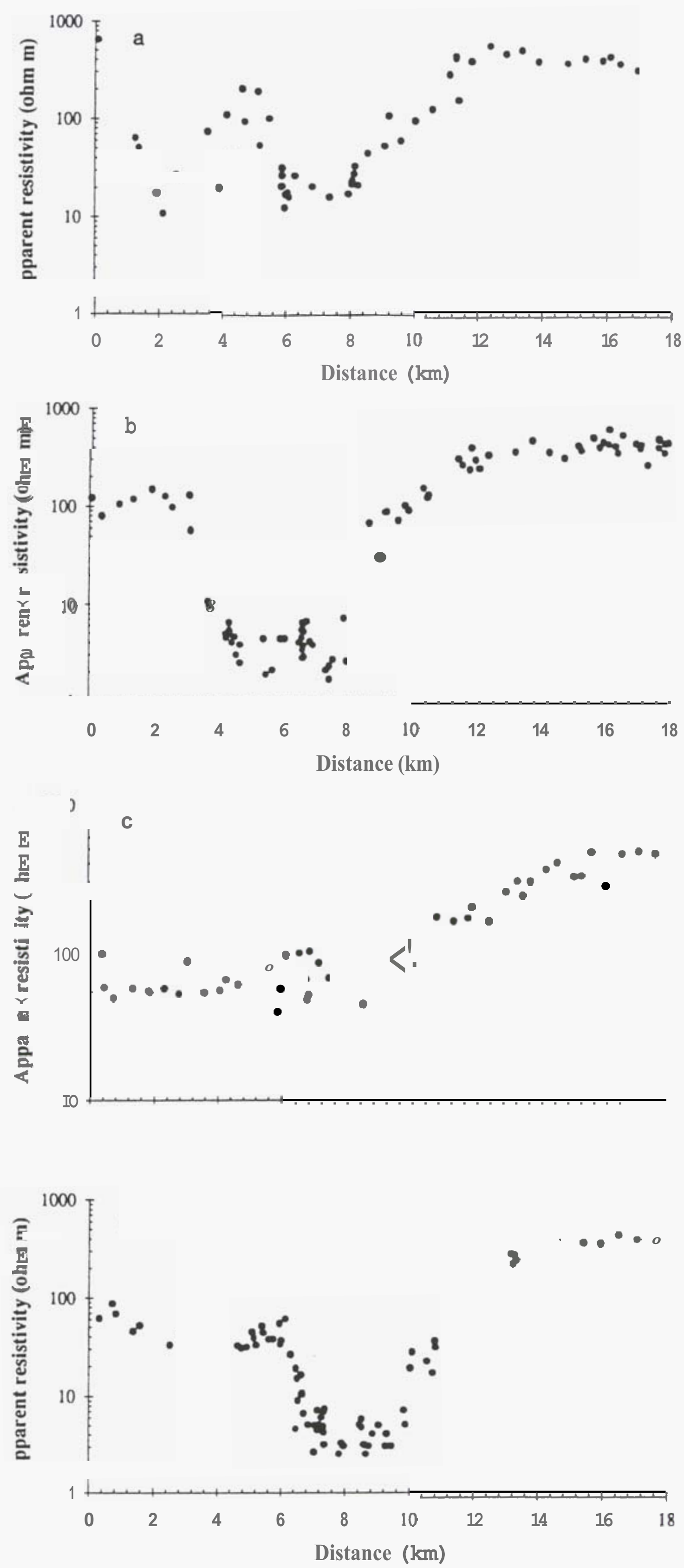

Figure 5. Profiles of Schlumberger apparent resistivity at increasing distances from Waiotapu Geothermal Field.

a. Data along line AA' (Fig. 2) between Waiotapu and Reporoa.

b. Data along line BB' (Fig. 2) passing through Reporoa resistivity anomaly.

c. Data along line CC' (Fig. 2) passing to the south of Reporoa resistivity anomaly.

d. Data along line DD' (Fig. 2) passing through Ohaaki Geothennal Field.

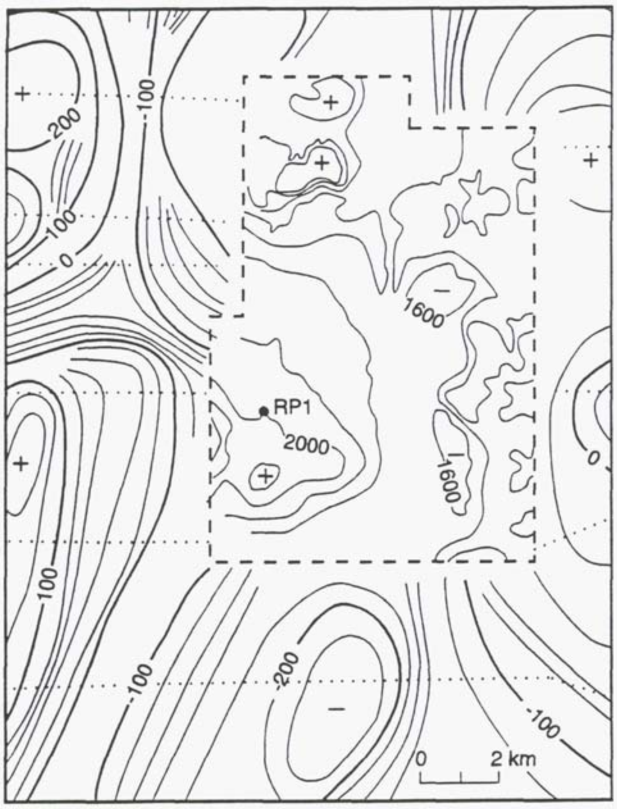

Figure 6. Aeromagnetic anomalies (nT). Data are from the survey of Gerard and Laurie (1955). In the central region, recent high resolution data are shown (60 m terrain clearance, 200 m flight line spacing).

CONCLUSIONS

The electrical resistivity data in the Reporoa area are not consistent with the drainage model for the origin of the hot springs at Reporoa. The sharp boundaries, and the change in resistivity with depth are similar to those measured in other high temperature systems in the TVZ and suggests that the resistivity anomaly at Reporoa outlines an independent geothermal field. The area of the resistivity anomaly is comparable with those of other geothermal systems which suggests that extensive hydrothermal alteration has taken place in the upper portion of the geothermal field. In view of the low natural heat output from the Reporoa area it is possible that the heat output of the system may have been much greater in the past

The lack of attention that Reporoa has received in the past maybe the result ofthe belief that this thermal area is a drainage feature with only a limited potential as an energy source. Clearly, further investigations are warranted.

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