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TESTS FOR RESISTIVITY BOUNDARY CHANGES AT OHAAKI NEW ZEALAND

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ABSTRACT

Close-spaced resistivity measurements along ten traverse lines crossing the resistivity boundary of the Ohaaki Geothermal Field, New Zealand, were first measured in 1975 and remeasured in 1992. The 1992 resistivity profiles were similar in shape to the original ones. On both occasions very sharp resistivity boundaries were delineated along the southern and southwestern edges of the field where apparent resistivity rises sharply over a horizontal distance of a few hundred metres from 2-5 ohm m on the inside of the field to 20-50 ohm m on the outside. On two of the southern lines the resistivity boundary appears to have moved outwards by about 100 m, which may be caused by southward movement of reinjected waste water from nearby drillholes. On the other southern lines the outward movement appears to be less than about 25 m, which is the limit of resolution of the survey.

Over the 17 year interval apparent resistivity values have dropped slightly at most measurement sites. The decrease is more pronounced on the inside of the field boundary where apparent resistivities have declined by up to about 40 percent. Some of this decrease is attributed to reinjection of conductive waste water near the field boundary causing a drop in ground resistivity. Part of this change may be due to calibration errors and measurement difficulties, including the disturbing effects of the new drillholes, steam pipes and an earthing mat that have been installed since 1975.

INTRODUCTION

As part of the exploration phase in the development of the Ohaaki Geothermal Field, New Zealand, a resistivity survey was made in 1975/76 (Risk et al, 1977) using close-spaced measurement points which had been accurately located relative to permanent benchmarks. Measurements along 10 of these lines in the south and west of the field (which had originally been measured in November-December 1975) were repeated in November 1992, 17-year years later. The aim was to determine whether the resistivity boundary zone had moved and whether any changes could be detected resulting from exploitation of the field since the commissioning of the Ohaaki Power Station in 1989. A preliminary account of this work is given in Risk (1993).

An experiment for monitoring resistivity variations in the Cerro Prieto Geothermal Field was done over a 2.5 year interval by Wilt and Goldstein (1984). They used an in-line dipole-dipole array with electrodes 1 km apart. They found a rather complex pattern of resistivity changes whose dominant feature was an annual 5 percent increase in resistivity over the production zone of the field which they attributed to dilution of reservoir fluids.

FIELD MEASUREMENTS

The transmitter and receiver sites for the part of the original survey that was repeated are shown in Figure 1. Points T1 and T2 show the locations of the current electrodes forming the transmitter; T1 is near the centre of the field, and T2 is about 2 km south of the southern boundary of the field. The transmitter location was kept constant throughout each of the surveys.

In 1992, measurements of the signal strength were made at receiver sites spaced at 50 m intervals along the lines B, C, D, E, F, G, J, K, L, N (see Fig. 1). These lines were the same (to within about 10 m) as those used in 1975, except for lines J and L which had to be moved because of the construction of the Power Station and associated facilities. The scope of the remeasurement project was insufficient to allow remeasurement of the lines to the north and east of the field, or to repeat the 1975 measurements made using the current electrode pairs T1-T3 (north-west) and T1-T4 (east).

Although the layout and method for making the measurements in 1992 was the same as used in 1975, completely different instruments were used for both transmitter and receiver. The accuracy of calibration of all the instruments is hard to assess, but it is expected that the apparent resistivities have been measured to within about 5 percent on each occasion. Thus, measured apparent resistivity differences greater than about 10 percent should represent real changes.

RESISTIVITIES

Both the 1975 and 1992 field data (currents, electric field strengths, geometric data, etc) were analysed using the same standard programs to obtain apparent resistivities at each receiver site. Figures 2 and 3 show plots of apparent resistivity versus horizontal distance from the centre of the field for eight of the ten lines.

The left of each plot corresponds to the inside of the field where the apparent resistivities are smallest (2 - 5 ohm m). Although the lines traverse only a few hundred metres into the field, measurements from other resistivity surveys (Risk et al 1970) show that a low resistivity anomaly of nearly constant value continues right across the Ohaaki Field. The resistivity boundary zone for each line is thus definable as the zone at the edge of the field over which the apparent resistivity increases above this average 'inside' level to a nearly constant larger value typifying the outside of the field. On most of the lines the apparent resistivity increases by an order of magnitude across the boundary zone and levels off on the outside of the field at values of the order of 20 - 50 ohm m.

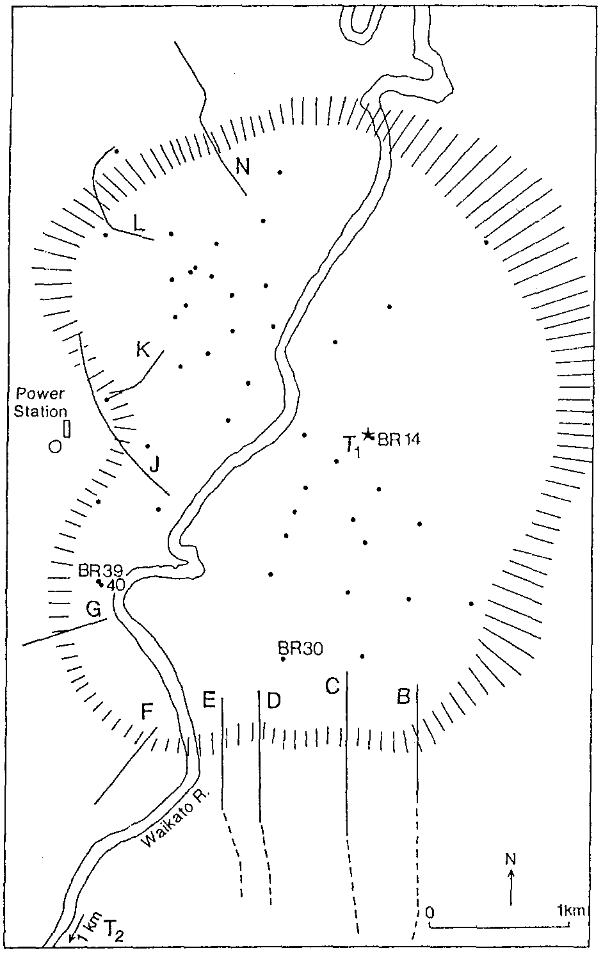

Fig. 1: Layout of multiple-source bipole-dipole array at Ohaaki. T_1 and T_2 are current electrodes. Measurements with receiver array were made along lines B, C, .. N, at 50 m intervals. Dots show drillholes.

Experiments in 1973-75 showed that some arrangements of the current electrodes allow a clearer definition of the resistivity boundary zone than others. The best electrode arrangement was found to be similar to the Schlumberger layout for which the receiver sites are near the mid-point of the two current electrodes. Thus, for the repeated part of the survey using current electrodes T1 and T2, clearest definition of the boundary was found, as expected, across the southwestern sector.

Lines B and C

Over the southern parts of these lines (Fig. 2) very little change was found between the resistivities measured in 1975 and 1992. The sharp rise in apparent resistivity over the boundary zone occurs in the same place (to within about 25 m). Thus, there has been no detectable horizontal movement of the resistivity boundary. However, on the inside of the field apparent resistivities in 1992 were significantly smaller (by up to 40 percent) than in 1975.

Lines D and E

These lines are close together and cover a small region studied in detail by separate resistivity and magnetic surveys in June 1973 (Risk, 1981). In both 1973 and 1975 the resistivity measurements near the boundary zone exhibited some unusual charateristics (i.e. electric transients, anomolous electric field directions and fine structure of the resistivity pattern). However, these unusual characteristics were no longer present in the 1992 resurvey.

Comparison of the 1975 and 1992 data shows that, in the zone where the unusual fine structure had been found in 1973 and 1975, the apparent resistivities are much smaller now (ca. 3 ohm m, Fig 2). Thus, the inside edge of the resistivity boundary appears to have moved south by about 100 m. The anomalous zone now appears to contain low resistivity material. The suggested explanation is that this region has recently been flooded with geothermal water.

Lines F and G

For these lines in the southwest corner of the field, the curves show large, sharp steps in resistivity across the resistivity boundary. The 1992 curves are similar in shape to the 1975 ones, but are slightly offset, implying that the 1992 resistivities are about 10 - 20 percent smaller than the 1975 values. The boundary appears to have moved southwards by a small amount (up to 20 m), but as this is about the same as the resolution of the survey, the movement is not certain. Near the outside of

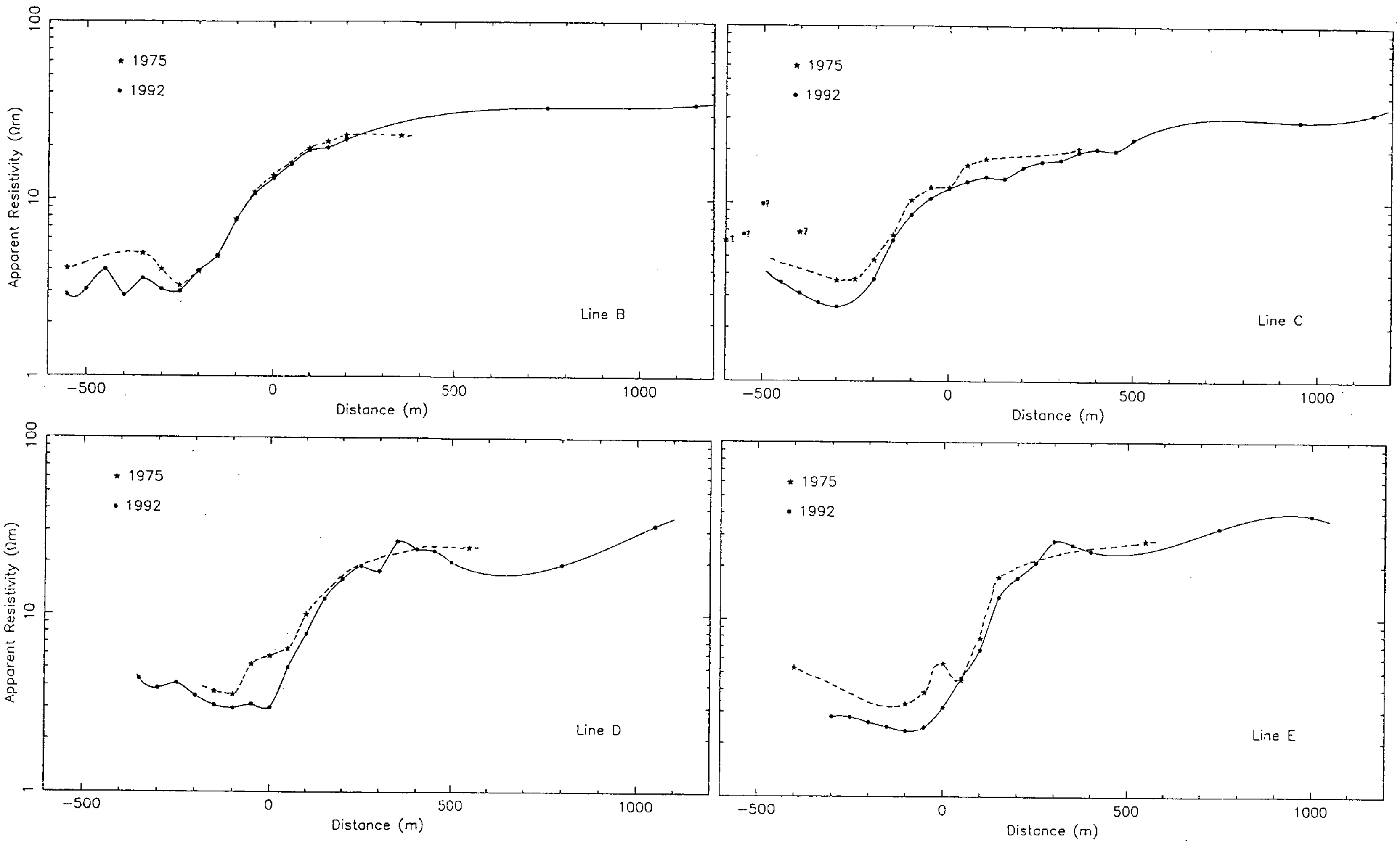

Figure 2: Apparent resistivities measured along lines B, C, D and E in 1975 and 1992. Centre of Field is at left.

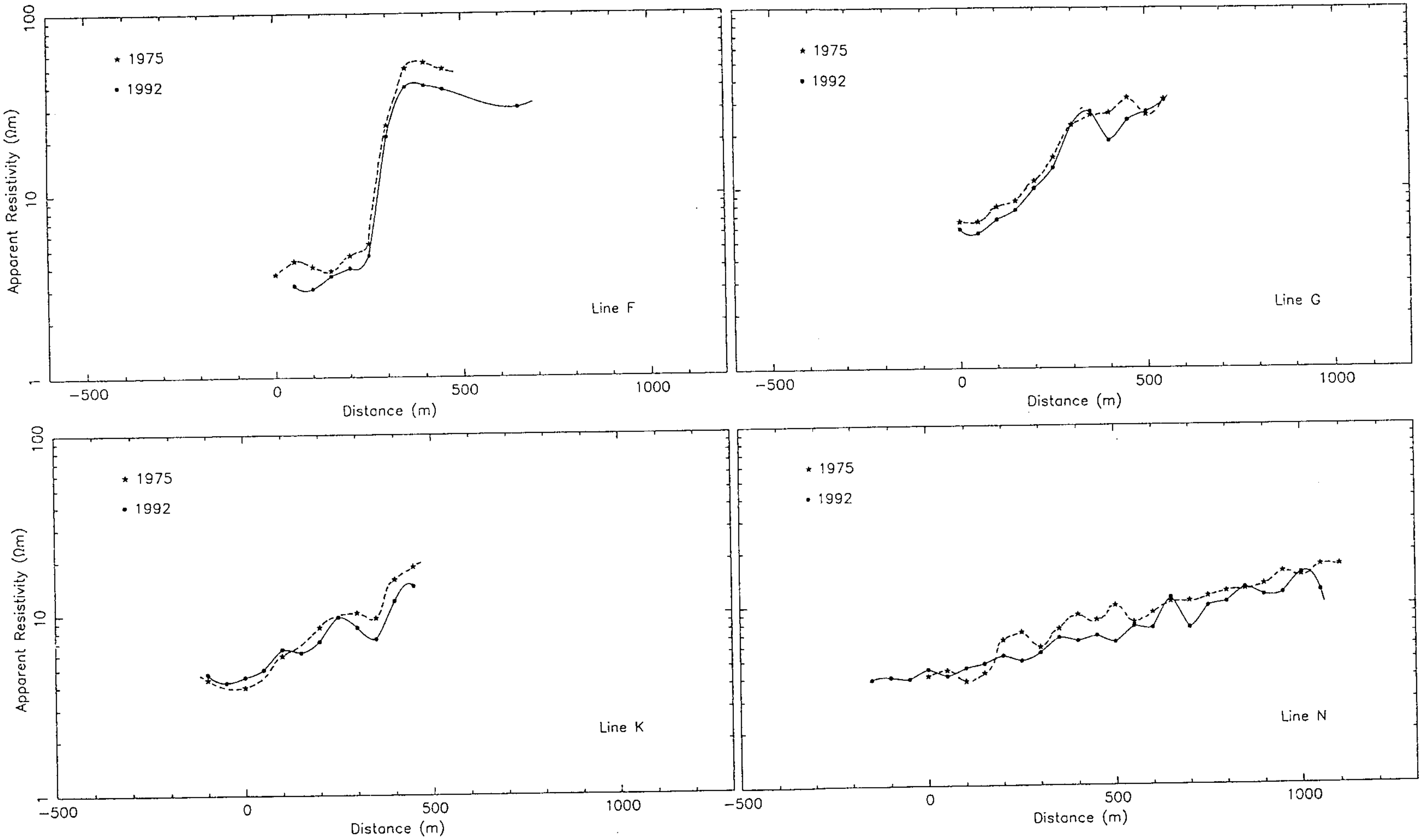

Figure 3: Apparent resistivities measured along lines F, G, K and N in 1975 and 1992. Centre of Field is at left.

line G, the 1992 measurements are disturbed by the presence of the shallow well BRM9, which was not there in 1975.

Line J

Since the original line J (1975) could not be remeasured because it now runs through the Power Station, a new line J, further north, was measured in 1992. The measurements were found to be very irregular. This is attributed to disturbances caused by the presence of the earth mat at the Power Station, the network of pipes, and other grounded conductive structures near the line.

Lines K and L

Lines K and L also lie close to the Power Station (Fig. 1). The apparent resistivity curves from line K (Fig. 3) for 1975 and 1992 have similar shapes, but the 1992 curve does not rise as steeply as that for 1975. The differences are more likely to be due to the disturbing effects of conductors associated with the Power Station than to movement of the boundary. Results from Line L are similar.

Line N

Signal levels were smaller on line N and it was difficult to lay out the 50m x 50m receiver array because of the scrub and blackberry on both sides of the line. This appears to have caused larger-than-usual measurement errors on both surveys and accounts for the scatter of data. On average, the 1992 data are about 20 percent smaller than the 1975 data, and the curves have similar shapes suggesting little change of the resistivity boundary since 1975. However, on line N the resistivity boundary zone is not well delineated by either survey. This appears to be because the (T1-T2) transmitter orientation is not appropriate for this line.

COMPUTER MODELING

The nearly circular shape of the Ohaaki Geothermal Field as well as the geometric arrangement of electrodes, with one electrode at the centre and the other well outside the field, makes this problem well suited to computer modeling analysis using axially symmetric models (Bibby 1978). With this kind of modeling, the field is simulated as a stack of (up to 100) concentric annular shaped rings. An example of such a theoretical model is given in Figure 4a which shows a radial cross-section. The centre of the field is at the left-hand side, with the boundary of the field at ca. 2 km from the centre.

This model tests the basic premise underlying the use of this resistivity resurveying method; i.e. whether it is possible to detect lateral movements of a vertical resistivity boundary. The model simulates boundary movements and assesses the resulting effects on the apparent resistivity profiles. This is illustrated in Figure 4. Model (i) has the (vertical) boundary in its initial position, while in models (ii), and (iii) it has been moved, respectively 100m and 200m, away from the centre of the field. Corresponding outward movements of the theoretical apparent resistivity curves can be seen, verifying the viability of the method (Fig. 4b).

Other more complex models were also run. These included sloping boundaries and simulating a gradual increase in resistivity across the boundary zone. Various different resistivity-depth profiles were also investigated. This work indicates that shallow structures dominate the apparent resistivity pattern and that many alternative resistivity structures are possible. Thin deeply buried formations are unlikely to be detected.

DISCUSSION

The eight resistivity profiles remeasured at the same sites in 1992 are all similar in shape to those of the original survey in 1975. Sharp steps of an order of magnitude in apparent resistivity were found on both occasions in the south and south-west of the field. This degree of repeatability suggests that the Schlumberger-like electrode arrangement is appropriate for monitoring the resistivity boundary. The pattern of changes is simpler than that found at Cerro Prieto with the in-line dipole-dipole array (Wilt and Goldstein 1984).

The modeling shows that any large-scale lateral movement of the boundary of the hydrothermal reservoir is expected to be reflected as a movement in the place where the sharpest rise in apparent resistivity occurs. The lines in the south and south-west of the field show sharp resistivity boundaries for which lateral movements of more than 20 - 50 m should have shown up. Such movements between 1975 and 1992 were detected on only lines D and E where the resistivity boundary appears to have moved outwards by about 100m. However, very little outward movement is evident on lines F and G.

In the south of the Ohaaki Field, most of the reinjection of waste water has been into drillholes BR39 and BR40, with a smaller amount going into BR30 (Fig. 1). Since the temperature of this water is about 145 - 150C with chloride concentrations of about 1500 mg/kg, the resistivity of the water would be about 0.5 ohm m. The water is mostly injected into the Broadlands Rhyolite formation at about 500 m depth, and some of it appears to flow south across the resistivity boundary. This probably explains the small southward movement of the resistivity boundary on lines D and E. However, it is not consistent with the lack of any significant southward movement in the resistivity patterns on lines F and G, which are closer to the main injectors (BR39, BR40). Possible explanations are that the reinjected water is flowing outward in thin aquifers, too deep to give an unambiguous apparent resistivity change or that there has been insufficient time for the effects to show up.

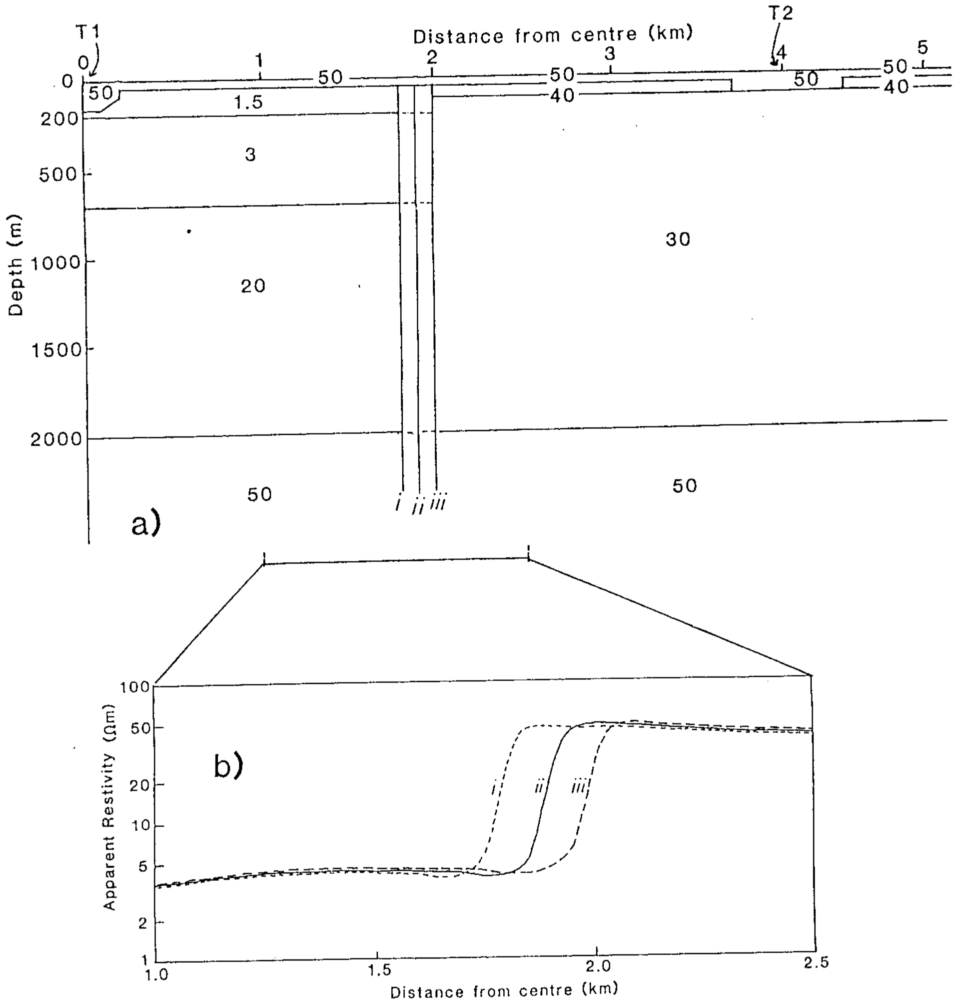

Figure 4: a) Section along a radius of axially symmetric resistivity models of Ohaaki Geothermal Field. Models have vertical boundaries at the edge of the field at distances from the centre of:
(i) 1.8 km, (ii) 1.9 km, (iii) 2.0 km.
b) Apparent resistivity curves for models (i) (ii) and (iii).

Over the 17 years between 1975 and 1992 apparent resistivity values have dropped in most places. The decrease is more pronounced on the inside of the field where apparent resistivities have declined by up to about 40 percent. A large part of this drop is thought to be caused by the redistribution of the conductive reservoir fluids which are being extracted from the centre of the field and reinjected near the southwest edge. This would raise the watertable in the boundary region and decrease the formation resistivity over the south of the field.

However, other causes for the resistivity drop are possible. Calibration and measurement errors may account for up to 10 percent of the drop. There has also been a major change, between the surveys, in the number of drillholes in the field and in the installation of steam pipes and other metal structures at the surface. The new pipework near electrode T1 would be expected to affect the measurements. The biggest change here is that nearby drillhole BR14 is now connected by steam pipes to the other neighbouring bores. A low resistance was measured between electrode T1 and BR14. Thus, in 1992 but not in 1975, some of the current will have entered the ground through bores BR43 and BR44. This increases the effective size of the electrode. The implications of these effects have not yet been fully examined.

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