RESISTIVITY RESURVEY OF SOUTHERN TAUHARA GEOTHERMAL FIELD

G.F. RISK[1], S.L. BENNIE[2] AND D.J. GRAHAM[2]

[1]Kelburn Research Centre, Institute of Geological and Nuclear Sciences Ltd, Wellington, NZ

[2]Wairakei Research Centre, Institute of Geological and Nuclear Sciences Ltd, Wairakei, NZ

ABSTRACT - Over a hundred new resistivity measurements were made throughout the southern and eastern parts of the Tauhara Geothermal Field in 1988-89 using the Schlumberger electrode array with spacings of AB/2=500 m and AB/2=1000 m. When collated with the older data measured during 1965 - 1982, the total set gives good coverage along the southern boundary of the Tauhara Field, but coverage is still sparse in several important regions including the slopes of Mt Tauhara, the foreshore of Lake Taupo and the northern parts of the field. The size of the Tauhara Geothermal Field as defined by the area totally within the new resistivity boundary is about 35 - 50 km^2, much bigger than indicated by earlier boundaries. The field extends further south and east than earlier measurements had indicated.

INTRODUCTION

The work described in this paper is aimed at providing better resistivity maps of the southern part of Tauhara Geothermal Field than have been available previously.

Growing interest in the energy potential of the Tauhara Field throughout the 1980s prompted reviews of technical information about the resource (DSIR 1988; Curtis 1989). It became evident that the coverage of the field by resistivity measurements was incomplete in some places. To redress this problem, Geophysics Division DSIR (now part of IGNS), with assistance from Waikato Regional Council, in 1988-89, undertook a resistivity survey of the southern and eastern parts of the Tauhara Geothermal Field using the Schlumberger array with fixed spacings set at AB/2=500 m and AB/2=1000 m.

RESISTIVITY EXPLORATION

Resistivity exploration has proved to be a valuable tool in the investigation of geothermal fields in New Zealand. Its usefulness results from several physical and chemical effects (involving salinity of porewater, temperature and rock alteration) which work together to cause the resistivity of rocks in a geothermal environment to be much smaller than that of the surrounding cold rocks. The results of resistivity surveys can be presented in several ways which indicate the size and extent of the field. Maps showing contours of apparent resistivity provide details of the measurements without interpretation. A simple but useful interpretation can be given in the form of a resistivity boundary zone. This is shown as an annular region separating the low resistivity rock representing the thermal ground within the field from the higher resistivity zone indicating the cold surrounding ground. Both types of presentation are used in this paper.

PREVIOUS RESISTIVITY SURVEYS

The earliest resistivity survey of the Tauhara Field was published by Banwell and Macdonald (1965) as a map encompassing Wairakei, Tauhara, Rotokawa and the surrounding regions. The part of it that covers the southern Tauhara Field is presented here as Figure 1. This work used the Wenner electrode array with the electrodes spaced at 457 m (a=1800 ft), which is nearly equivalent to the Schlumberger AB/2 = 500 m array. While this 1965 map was a pioneering work, and very useful in its time for its outline of a large contiguous area of low resistivity at Tauhara, it is now considered inaccurate and has been superseded by later work.

A revised resistivity map of Tauhara was prepared in May 1980 (letter to DSIR Geothermal Coordinator) for Land Designation purposes, but this was criticised because of the large uncertainty in its boundary location in some areas, particularly near Mt Tauhara. After this, in 1982, some extra Schlumberger measurements were made, which led to a further revision of the resistivity boundary by Geophysics Division. This revised boundary was submitted to the DSIR Geothermal Coordinator and Commissioner of Works in January 1983, and was adopted on MWD plans of the Tauhara Field in that era, but the map was never formally published.

A further revision of the data about 1985 resulted in a new version of the resistivity boundary map which Allis and Hunt (1986) presented as background material for a discussion of gravity changes at Wairakei and Tauhara. This version, which is shown here as Figure 2, was also presented in the report by DSIR (1988).

As part of a ground-water survey at Taupo, Dawson & Thompson (1981) and Dawson (1988) report the results of about 60 shallow penetrating resistivity soundings. Their appraisal of the extent of the shallow (< 100 m deep) thermal aquifers in Tauhara Field can be found in Figure 12 of Dawson & Thompson (1981) and Figure 40 in Appendix 3 of Dawson (1988).

NEW RESISTIVITY MEASUREMENTS

New resistivity measurements were made in 1988-89 at 122 sites in the Southern part of the Tauhara Geothermal Field using the Schlumberger electrode array with spacings of AB/2=500 m and AB/2=1000 m. These data give approximate average ground resistivities to depths of about 250 m and 500 m, respectively.

Several measurement problem were experienced. Laying out the 1000 to 2000 m of cable in a nearly straight line as is needed to form the arrays proved to be impossible is some areas, particularly near Mt Tauhara and in the highly built-up parts of Taupo town. Thus, gaps in the data set have resulted. To fill in these gaps will require some other measuring method which uses a smaller receiving array. Interference from industrial electrical *sources*, 50 Hz mains and buried pipes proved troublesome in some parts of the built-up areas in Taupo town and along highway SH1 at Waipahihi.

To identify unreliable and suspect data, the measurements at each site were examined for self-consistency by using the method given in Bibby (1988). Measurements at just 10 of the 122 new sites were judged to be erroneous, but a greater fraction of the old data failed the test.

Figures 3 and 4, which show the data for AB/2=500 m and AB/2=1000 m, respectively have been complied using only the most reliable data Dots on these *maps* show the measurement sites. The most reliably drawn contours are shown as *solid* lines. where there is less reliability because of a shortage of data or because: conflicts exist between adjacent sites, the contours *are* dashed. Where there is a serious lack of data or no data at all, question marks are used to indicate the likely trends of the contours. In the worst cases, no contours are drawn. Within the Tauhara Field., as is found within many other fields, the apparent resistivity values scatter over a considerable range (2 to 20 Ωm). Since this makes it almost impossible to draw reliably *contours*, the lowest contour value shown is 20 Ωm.

In Figure 5 a hatched annulus has been drawn to indicate the inferred position of the lateral resistivity boundary zone of the Tauhara Geothermal Field to depths of approximately 500 m. This has been constructed mainly from consideration of the deeper penetrating data *of* the AB/2=1000 m survey.. The region inside the hatching is inferred to contain very low resistivity rocks (<20 Ωm) while the outside region contains very high resistivity material (>70 Ωm). Within the hatching itself, intermediate values are inferred. The width of the hatching, which varies from about 0.5 to 2 km indicates the accuracy with which the resistivity boundary has been delineated.

DISCUSSION

By concentrating the new measurements in the Southern part of the Tauhara Field, a *good* definition has been obtained for the southern boundary. *Comparison* of the new boundary in Figure 5 with the earlier boundaries, particularly the recent one in Figure 2, shows that the field extends more than 2 km further to the south and south-east than was previously thought, adding about 5 km^2 *to* the inferred *size* of this part of the field.

The main areas of thermal ground at Tauhara, as mapped by Fisher (1965), are shown in Figure 1, while more detailed thermal maps *can* be found in Allis *et. al.* (1989) and DSIR (1988). Schlumberger resistivity measurements made over these thermal zones all yielded very low resistivities (Figs. 3 & 4). In particular, low resistivities were found over the patches of thermal ground on the south side of Mt Tauhara near highway SH5 (*see* Fig. 1), which had previously been shown as outside the low resistivity region.

The presence of Mt Tauhara on the eastern si& of the field has resulted in a *gap* in the data set where the terrain is too rugged to allow measurements using the Wenner and Schlumberger methods to be made. In the past this data *gap* has been the cause of considerable doubt about the *correct* position of the boundary of the field in this vicinity. There has long been debate about whether or not the field extends beneath Mt Tauhara. Since no new measurements have been made on Mt Tauhara itself, these data do not resolve the question. However, comparison of the data close to Mt Tauhara on Figures 3 and 4 *suggests* that the very resistant near-surface volcanic rocks may be underlain by low resistivity rock at least over the western part of the mountain. Deeper penetrating surveys will be needed to fully resolve this issue.

Several *small* warm springs were found on the banks of the Pueto Stream at a point about 3 km east of Mt Tauhara (*see* Fig. *5*). The largest springs were estimated (4 October 1989) to have a flows *of* about *5 - 10* l/s. Their temperatures were 16°C to 18°C, compared with the (upstream) Pueto Stream temperature of 12.0°C. Conductivities were up to 180 µS/cm, compared with values of about 100 µS/cm measured in the *stream*. The site is at an elevation of about 350 m above sea level, similar to that of Lake Taup. Schlumberger resistivities in the area are quite high (> 70 Ωm), but the measurements show that resistivity decreases with depth.

These springs would appear to be part of an eastward thermal outflow from Mt Tauhara. If this is true it would support the earlier suggestion of geothermal conditions under Mt Tauhara. There may also be other unrecognised outflows. It is also interesting to observe that the section of highway SH5 due south *of* Mt Tauhara lies *on* a ridge (at elevation *580 - 600* m) forming the watershed between streams flowing south-west to Lake Taupo and others flowing north-east into Pueto Stream. This suggests that there is *some* likelihood that the small surface thermal features to the south *of* Mt Tauhara (and the southern part of the resistivity low) may represent an outflow from a centre under Mt Tauhara.

The *size* of the Tauhara *Geothermal* Field as defined by the area totally within the *new* resistivity boundary zone in Figure 5 is about 35 - 50 km^2, almost twice the size indicated by the earlier boundary in Figure 2. This is much

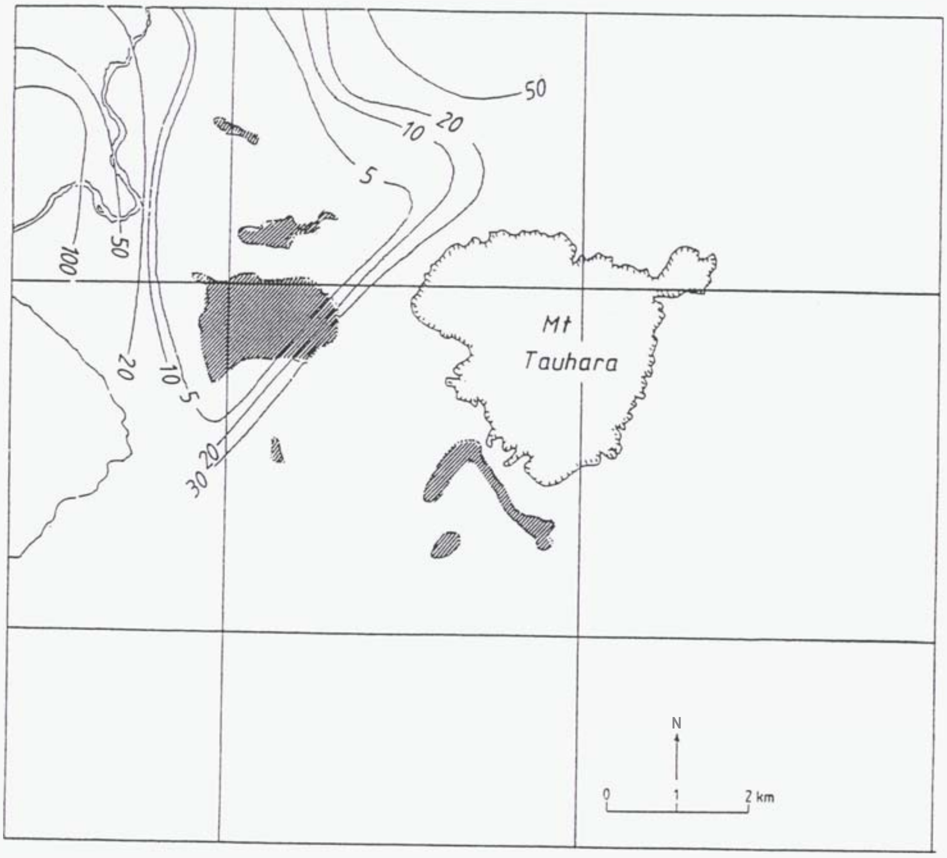

Figure 1: Original apparent resistivity contour map (in Ωm) of Tauhara Geothermal Field, obtained using a Wenner array with electrodes spaced at 457 m (Banwell and Macdonald, 1965). Shading shows main areas of thermal ground.

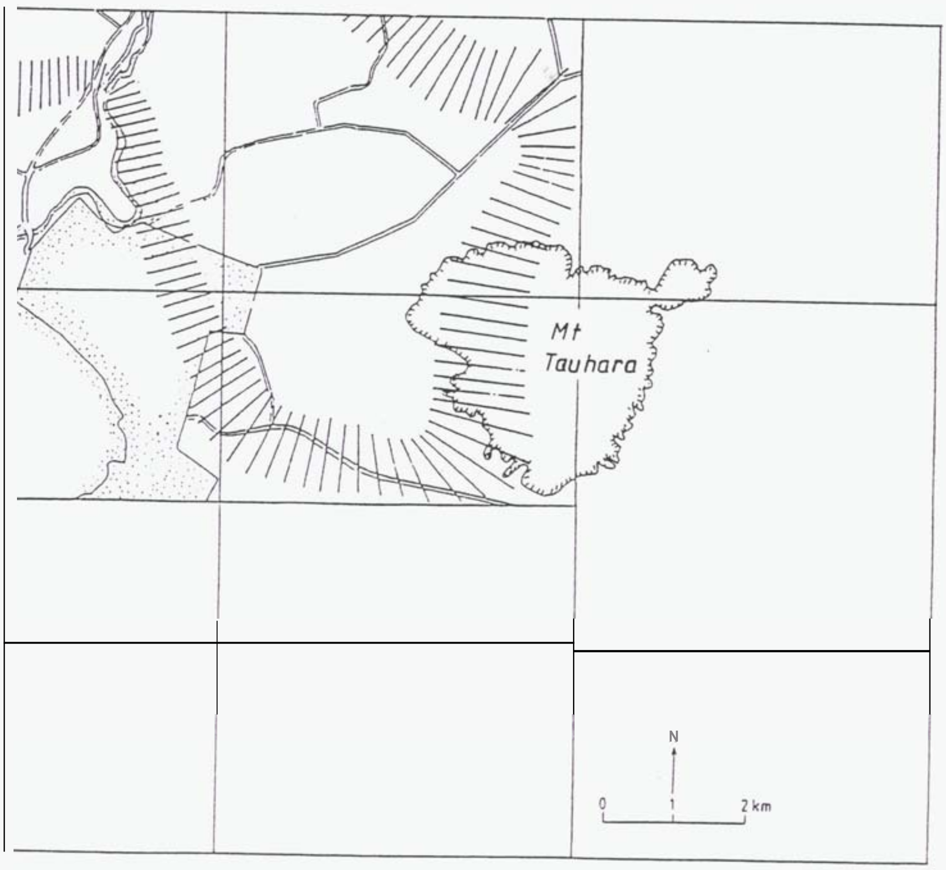

Figure 2: Lateral Resistivity Boundary Zone of the Tauhara Geothennal Field as given by Allis and Hunt (1986) and DSIR (1988).

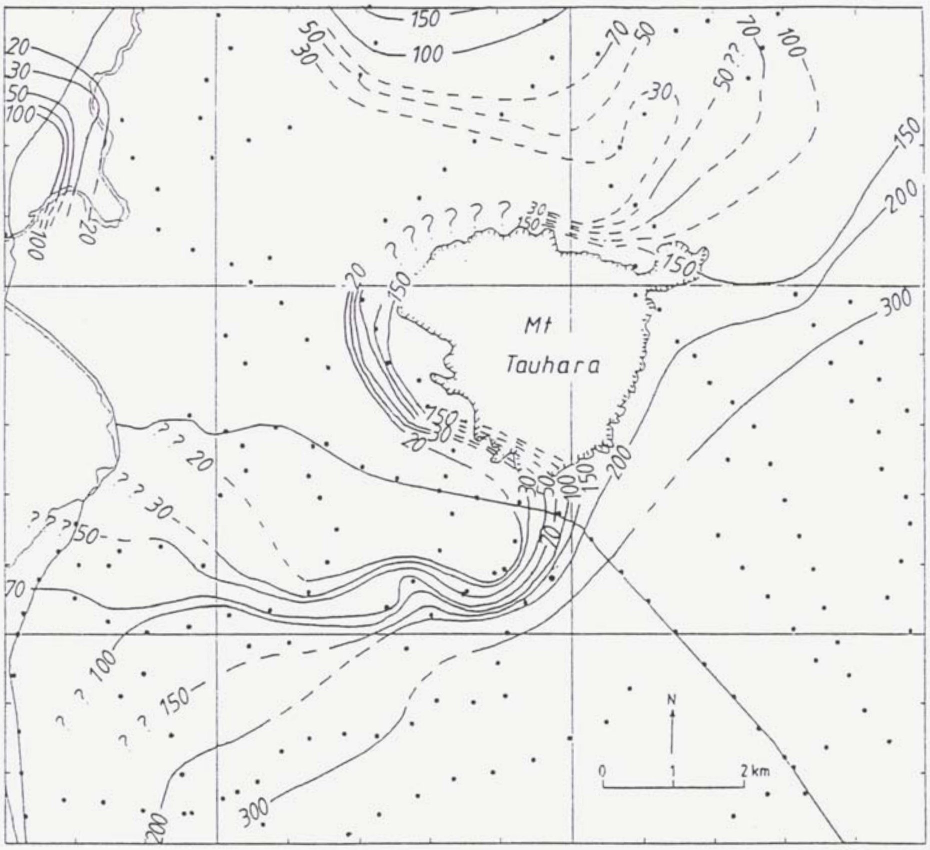

Figure 3: **Contours** *of apparent resistivity (in* Ωm*) measured with the Schlumberger array of spacing AB/2=500 m. Dots show measurement sites. All available reliable data were used in drawing the contours.*

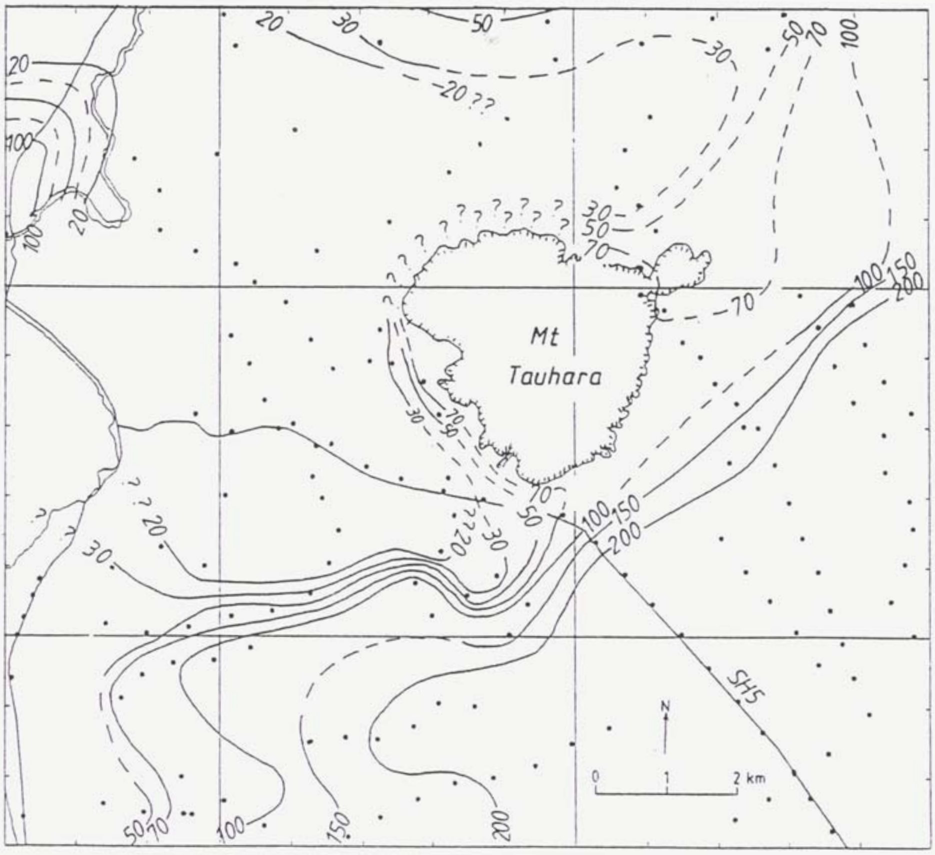

Figure 4: Contours of apparent resistivity (in Ωm*) measured with the Schlumberger array of spacing AB/2=1000 m. Dots show measurement sites.*

larger area than most other fields in New Zealand which average about 15 km^2. The large uncertaintyrangeofthis estimate reflects the doubt remaining about the correct boundary position in the Mt Tauhara vicinity, the north-east, and along the Lake Taupo foreshore.

Allis et. al. (1989) note that there are differences in drawdown, thermal features and chemical signatures between the main part of the Tauhara Field near the Waikato River and the southern part. This led them to suggest that there may be two separate geothermal circulation systems at Tauhara. The resistivity data show a single contiguous resistivity low throughout the field with no detectible zone of significantly higher resistivity between the northern and southern parts. This appears to suggests that Tauhara has only one thermal circulation system, but it would be possible that a permeability barrier of low resistivity material might exist between the two regions. The unusually large area inferred for the Tauhara Field may be considered evidence indicating that the field contains more than one circulation system, but, this could alternatively be caused by the presence of several outflow zones, as suggested above. Measurement of resistivity at deeper levels may help resolve this question.

The triangles on Figure 5 show the three main peaks of Mt Tauhara and the small volcanic peak of Maunganamu in the south of the survey area. The Maunganamu peak, the eastern Tauhara peak and the small thermal area on the south of Mt Tauhara appear to align with the eastern side of the resistivity boundary on Figure 5. This suggests that the volcanism may in some way be related to the source ofthe thermal features, although in the vicinity of Maunganamu, resistivities are high and there is no sign of thermal activity. The Kaingaroa Fault which marks the eastern margin of the Taupo Volcanic Zone is aligned in the same direction but, as mapped by Grindley (1961), it lies about 4 - 5 km to the east of the volcanic alignment. While the importance of these alignments remains unclear, the eastern edge of the revised resistivity anomaly matches better with these volcanic and structural features than did the earlier version shown in Figure 2.

CONCLUDING REMARKS

There is a clear need for deeper penetrating resistivity surveys at Tauhara. Many drillholes in other New Zealand geothermal fields have penetrated to more than 2500 m depth and have found permeable aquifers at levels deeper than can be probed (750 m max.) by the Schlumberger surveys reported here. In several other N.Z. fields (Wairakei, Ohaaki, Mokai, Ngatamariki, Rotokawa and Ngawha) resistivity surveys have been done using the deeper penetrating multiple-source bipoledipole technique which can yield resistivity information to depths of about 1000 - 2000 m. Such surveys have never been done at Tauhara, but if developments are envisaged which propose to extract fluids from the deeper levels mentioned, deep

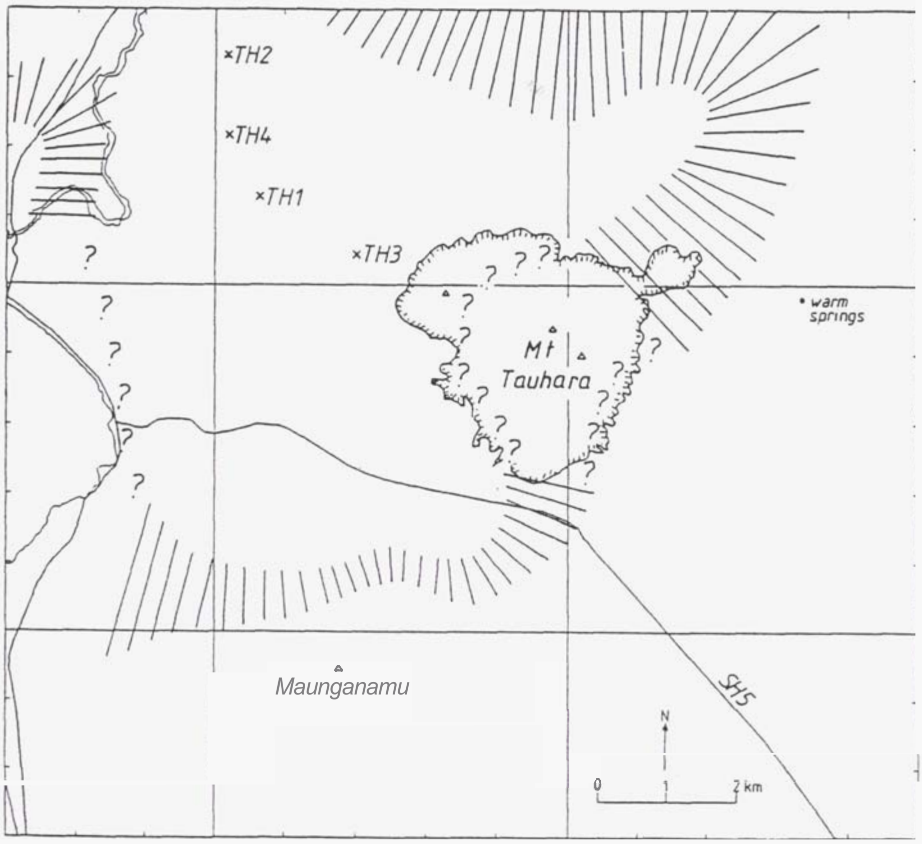

Figure 5: Inferred resistiviry boundary zone for the Tauhara Geothennal Field as approximately 500 - 750 m depth. Triangles show main volcanic peaks. Crosses show drillholes and the dot shows a warm spring.

resistivity surveys will be essential for orderly planning of the development and for wise management of the resource.

The compact receiver arrays used in multiple-source bipole-dipole surveys would allow measurements to be made closer to Mt Tauhara, which should provide useful data bearing on the questions of whether the Tauhara Field extends under the mountain and whether any thermal outflows can be identified. Better quality measurements would also be expected in Taupo town and at Waipahihi with the greater immunity to electrical noise afforded by the compact receivers used with that method.

The northern part of the Tauhara Field has not been investigated in this study. As the public domain resistivity data in this region do not give a very sharp delineation of the resistivity boundary more resistivity work needs to be done. The north-east comer of the field needs better delineation, and possible connections between the Tauhara and Rotokawa Fields warrants investigation. The important problem of investigating the nature of the connection between the Tauhara and Wairakei Fields also needs attention, particularly to check the validity of previous resistivity interpretations (Risk *et. al.* 1984; Allis *et.al.* 1986; ECNZ 1992).

ACKNOWLEDGMENTS

Support from Waikato Regional Council allowed this field programme to be undertaken. We thank R.G. Allis and H.M. Bibby for assistance in planning the work, T.G. Caldwell for making helpful comments on data interpretation and H.H. Rayner for making some of the field measurements. Many Tauhara land owners have generously allowed our field teams access to their lands.

REFERENCES

Allis, R.G. and Hunt, T.M. (1986). Analysis of exploitation-induced gravity changes at Wairakei Geothermal Field. *Geophysics. 51:* 1647-1660.

Allis, R.G.; Mongillo, M.A. and Glover, R.B. (1989). Tauhara Field - Two geothermal systems? *Proceedings 11th N.Z. Geothermal Workshop 1989.* University of Auckland, pp. 95 - 100.

Banwell, C.J. and Macdonald, W.J.P. (1965). Resistivity surveying in New Zealand thermal areas. *Proceedings of the 8th Commonwealth Mining and Metallurgical Congress, 7:* paper 213. 7p.

Bibby, H.M. (1988). Electrical resistivity mapping in the Central Volcanic Region of New Zealand. *N.Z. Journal Geology and Geophysics, 31*: 259-274.

Curtis, R.J. (1989). Upper Waikato Catchment: Tauhara Geothermal Field and related water resources. *Waikato Catchment Board Technical Report 89/8*, 51p.

Dawson, G.B. (1988). Ground water survey at Taupo. Part 2 Relationships: Geophysical, Geological, Geochemical. *Research Report No. 219,* Geophysics Division, DSIR, Wellington, 31p and separate volume of appendices.

Dawson, G.B. and Thompson, G.E.K. (1981). Ground water survey at Taupo. Part 1: Physical data and hydrology. *Research Report No. 153,* Geophysics Division, DSIR, Wellington, 19p, 59 figs.

DSIR, (1988). Assessment of development impacts and reservoir response of Tauhara Geothermal Field. Unpublished report to the Waikato Valley Authority. DSIR, Wellington, 170p.

ECNZ (1992) Resource consent application for reinjection. Application for water rights to Waikato Regional Council. 209p.

Fisher, R.G. (1965). Shallow heat survey of Taupo Borough and adjacent country. *N.Z. Journal of Geology and Geophysics 8* (5): 752-71.

Grindley, G.W. (1961). Sheet N94 Taupo (1st Ed.) Geological Map of New Zealand 1:63360 DSIR, Wellington.

Risk, G.F.; Rayner, H.H.; Stagpoole, V.M; Graham, D.J.; Dawson, G.B. and Bennie, S.L. (1984). Electrical resistivity survey of the Wairakei Geothermal Field. Research *Report No 200,* Geophysics Division, DSIR, Wellington, 70p.