Proceedings **18th NZ** Geothermal Workshop **1996**

INTERPRETATION OF MAGNETIC ANOMALIES OVER THE REPOROA GEOTHERMAL FIELD, TAUPO VOLCANIC ZONE, NEW ZEALAND

S. **SOENGKONO AND** M.P. HOCHSTEIN

Geothermal Institute, The University of **Auckland, Auckland, NZ**

SUMMARY - The Reporoa geothermal field is located in an area of the Taupo Volcanic Zone (TVZ) which exhibits a complex magnetic source pattern since hydrothermally demagnetised rocks occur together with younger normally magnetised and older reversely magnetised volcanic rocks. No distinct negative residual magnetic anomalies could be observed over the central part of the prospect during our aeromagnetic survey conducted at c.760 m asl. However, when results of detailed geological studies and magnetic studies of cores are considered, it was found that the subdued magnetic anomalies over the Reporoa Field contain a small component reflecting demagnetised rocks which are surrounded, in part, by reversely magnetised rocks at the bottom of the Reporoa Caldera.

1. INTRODUCTION

Hydrothermal activity *can* cause partial or complete demagnetisation of volcanic host rocks since it alters the primary magnetic minerals (for example, magnetite) to almost non-magnetic minerals (i.e. pyrite). This is well established for geothermal systems in the Taupo Volcanic Zone (TVZ) where significant negative residual magnetic anomalies have been observed over at least ten geothermal fields which are associated with hydrothermal demagnetisation of the upper part of the reservoir (Hochstein and Soengkono, **1996).**

An aeromagnetic survey of the eastern TVZ including the Reporoa area **was** made in May **1993.** The survey was conducted along N-S oriented flight lines separated by about **1 km** at a height of c. **760** m asl (300-400 m above mean ground). No distinctive negative anomalies were observed over the Reporoa geothermal field, and in an earlier interpretation (Soengkono and Hochstein, **1996)** the effect of demagnetised rocks was neglected. Examinations of drillhole cores and cuttings from the deep Reporoa **RP1** well (e.g. Lampoonsub, **1987;** Bignall, **1990;** Nairn et al., **1994;** Wood, **1994),** however, shows that intense hydrothermal alteration had affected most rocks encountered in this well. A revised magnetic model of the Reporoa area is presented in this paper which allows for hydrothermal demagnetisation in the **RP1** well.

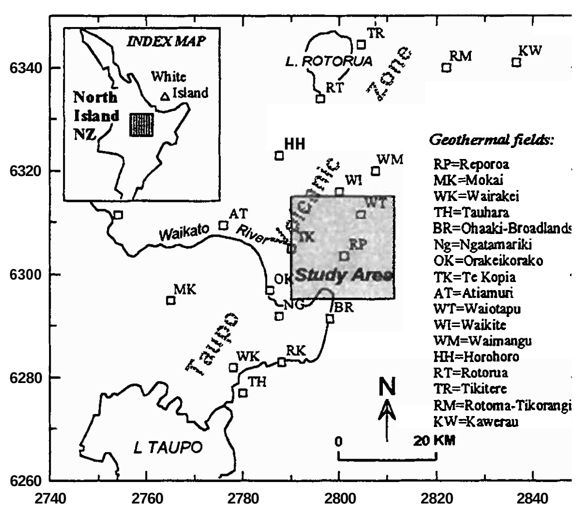

***Figure 1.** Location map of the study area in the eastern TVZ. Grid coordinutes are in term of NZ Map Grid (km).*

2. GEOLOGY

The Reporoa geothermal field lies between the already explored geothermal fields of Ohaaki-Broadlands in the SSW and Waiotapu in the NNE (Fig. 1). A simplified geological- geophysical map of the greater Reporoa area is shown in Fig. 2. It shows the main features that are relevant for

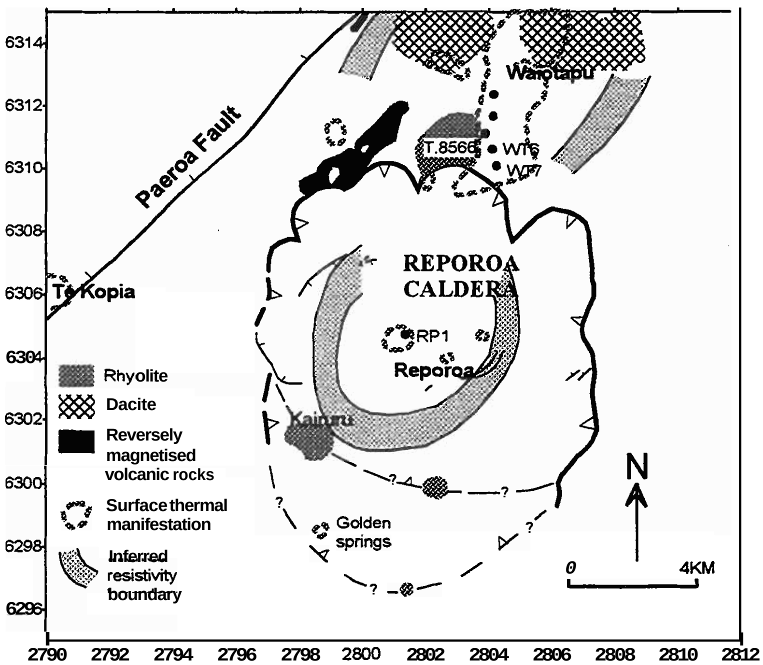

Figure 2. Simplified geological - geophysical map of Reporoa area (after Nairn et. al, 1994; Grindley et. al, 1994; Wood, 1994; and Bibby etal., 1994).

magnetic interpretation and includes major fault zones, caldera boundaries, exposures of reversely magnetised rocks, rhyolite/dacite extrusions, active surface thermal areas, and inferred resistivity boundaries.

The Reporoa geothermal field lies within the Reporoa Caldera which was only recently recognised after detailed geological investigations **(Nairn** et al., **1994).** A major eruption from this caldera occurred about **0.24** Ma ago and produced the Kaingaroa Ignimbrites (c. **100** km^3) which are widespread along the eastern edge of the TVZ and which are characterised by a large content of andesitic rock fragments. The geothermal well **RP1** was drilled to about **1340 m** depth (Fig. **3).** It penetrated **300 m** of lacustrine sediments **(Huka** Falls Formation) consisting mainly of mudstones, underlain by a sequence of rhyolite lavas **(–530 m** thick) that represent at least two episodes of dome activity (Wood, **1994).** Below the rhyolites, drilling encountered a sequence of tuffaceous sediments and tephras of the Waiora Formation **(–450** m thick) which overlay a welded part of the Kaingaroa Ignimbrites near the bottom of the hole.

Magnetisation studies of cores (Lampoonsub, **1987)** indicate that most cores are completely demagnetised although some magnetisation **(0.9** A/m remanence) occurs in a core from about 880 m depth (see Fig. **3).** A similar pattern has been observed at the Ohaaki-Broadlands geothermal field (Fig. **1)** (Hochstein and Soengkono, **1996).**

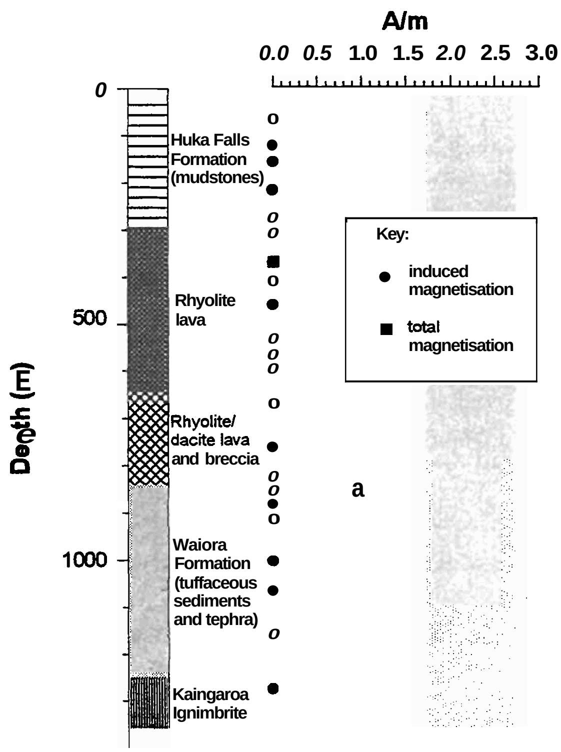

Figure 3. Geological log (Wood, 1994) and magnetisation of cores (Lampoonsub, 1987) of drillhole RP1. The shaded area represent the range of the magnetisation magnitude of unaltered volcanic rocks in the TVZ (Hochstein and Soengkono, 1996).

3. GEOTHERMAL ACTIVITY

Small areas with active Surface manifestations (mainly thermal ground) occur over the Reporoa geothermal field (see Fig. 2). In addition, two low temperature springs (Golden Springs) occur 6 km to the SSW from the centre of the field. All Surface manifestations have a rather small total heat output of about 20 MW (Bibby et al., 1994a).

Resistivity surveys with fixed Schlumberger arrays (Bibby et al., 1994a,b) shows that the Reporoa field is associated with a low resistivity area (< 10 ohm-m apparent resistivity for an array spacing of AB/2 = 500 and 1000 m). A discontinuity of apparent resistivity occurs to the east and west of the Reporoa resistivity low, but not towards the Waiotapu field in the north-east. Healy and Hochstein (1973) suggested that the thermal activity at Reporoa is caused by a concealed outflow from the Waiotapu geothermal field which lies upstream in the Reporoa-Waiotapu catchment. Although the temperature profile in well RP1 shows a temperature inversion below 500 m depth and the well has lower temperatures than those measured, for example, in well WT7 (Waiotapu) at similar depths, these features do not necessarily support an outflow model since significant downflow of cooler fluids has been observed in the RP1 well. A chloride flux study gave no evidence for any concealed outflow of fluids from the Reporoa field into the Waikato River (Hochstein et al., 1992). From the pattern of resistivity data (Schlumberger traversing and vertical electrical sounding surveys) across the Reporoa and Waiotapu areas, Bibby et al. (1994a,b) inferred that the Reporoa field is a separate and independent geothermal field.

4. RESIDUAL MAGNETIC ANOMALIES

The residual magnetic anomalies (Soengkono, 1992) over the Reporoa area obtained from our 1993 aeromagnetic survey are shown in Fig. 4. The uplifted Paeroa Fault Block in the north-western part of Fig. 4 is associated with distinct SW-NE trending, positive residual magnetic anomalies whereas significant negative anomalies occur over the Te Kopia geothennal field along the same fault zone. No distinctive magnetic anomalies are associated with the two dacite domes in the northern part of the figure (the Maungaongaonga Dome in the west and the Maungakakaramea or Rainbow Mountain in the east), indicating that these features have been demagnetised by hydrothermal alteration during past activities of the Waiotapu geothermal system.

Negative residual magnetic anomalies near the north-western margin of the Reporoa Caldera are clearly associated with exposed, reversely magnetised rocks. Subdued negative residual magnetic anomalies also occur over the Waiotapu geothermal field to the northeast of Reporoa although only a small portion of these anomalies is shown in Fig. 4. The rhyolite dome to the west of the Waiotapu bore field (Trig. 8566) is associated with a positive anomaly, indicating that the dome has not been affected by demagnetisation. Pronounced negative residual anomalies near the eastern and north-eastern edge of the Reporoa Caldera were interpreted to be caused by remnants of a large, buried andesite volcano (Soengkono and Hochstein, 1996) whose existence is indicated by lithic fragments of andesitic rocks found in the Kaingaroa Ignimbrites (Nairn et al., 1994).

Negative residual magnetic anomalies cannot be recognised over the low resistivity structure of the Reporoa field. An area with positive residual anomalies occurs towards the south-west, straddling the inferred boundary of the Reporoa Caldera near the Kairuru Dome in Fig. 4; they extend towards the Reporoa resistivity low. The eastern extension of these positive anomalies can also be recognised in the pattern of a map of Bibby et al. (1994a,b) showing detailed, low level (60 m above ground) aeromagnetic data in that area. The Kairuru rhyolite dome occurs in the south-eastern part of the area with positive anomalies. It has been suggested by Bibby et al. (1994a,b) that the magnetic high is caused by buried rhyolite domes which can be correlated with the sequence of rhyolites encountered in well RP1 and at the Kairuru Dome.

5. INTERPRETATION OF MAGNETIC ANOMALIES

The Reporoa geothermal reservoir lies in an area with a complex magnetic source pattern because hydrothermally demagnetised rocks occur together with normally and reversely magnetised volcanic rocks. A preliminary interpretation of the Reporoa magnetic anomalies has been presented by Soengkono and Hochstein (1996) who also gave a preliminary interpretation for the magnetic anomalies over the Waiotapu, Waimangu and Waikite fields. Possible effects resulting from concealed, demagnetised rocks at Reporoa were neglected in the earlier study because of the lack of a distinct negative magnetic signature over the Reporoa field.

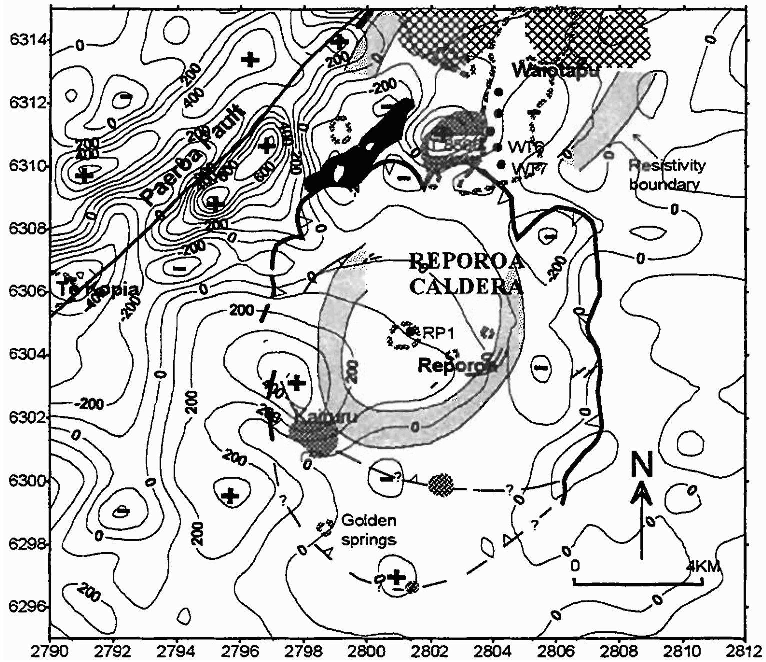

Figure 4. Residual magnetic anomalies over the Reporoa ***area*** *at c. 769 m asl. Contour interval is 100 nT.*

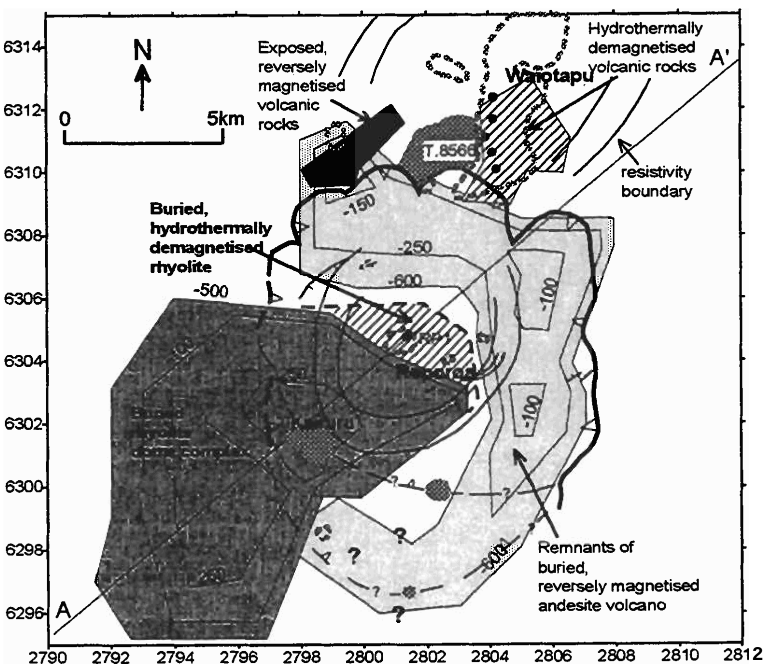

Figure 5. Map showing the extent of a 3-D magnetic model of the Reporoa area. Polygonal lines represent contours (in metres) of the upper part of the rhyolite dome complex and reversely magnetised andesite.

A reinterpretation of the residual magnetic data over the Reporoa **area** was therefore attempted. It was conducted following the method outlined by Soengkono **(1992)** and using all constraints given by available surface geological investigations, the geological log of **RP1**, and the magnetic measurements of cores from that well. We assumed that the average total magnetisation of normally magnetised volcanic rocks in the study **area** outside the geothennal reservoirs is of the same order of magnitude **as** that of unaltered rocks in the greater TVZ which is c. **1.7** A/m (Soengkono, **1995).** The shaded vertical band shown in Fig. 3 represents the range of the magnitude of magnetisation (median values) of unaltered volcanic rocks in the TVZ, taken from Hochstein and Soengkono **(1996).**

The reinterpretation started with the 3-D model constructed by Soengkono and Hochstein **(1996)** which already included normally magnetised bodies representing the north-eastem part of the concealed rhyolite dome complex south-east of Reporoa (magnetisation **2.5** A/m), reversely magnetised andesite bodies concealed beneath the western and north-westem part of the Reporoa Caldera (total magnetisation of **-1.8** A/m), a shallow infill (upper 300 m) of the Reporoa Caldera representing the

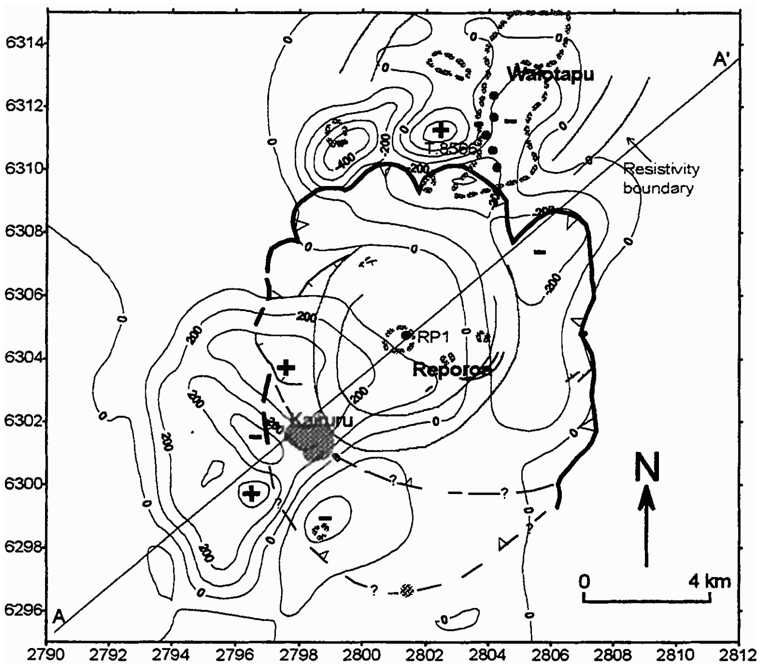

Figure 6. *Magnetic anomalies computed* ***from*** *the model shown in Fig.* ***5.*** *Contour interval is 100 nT.*

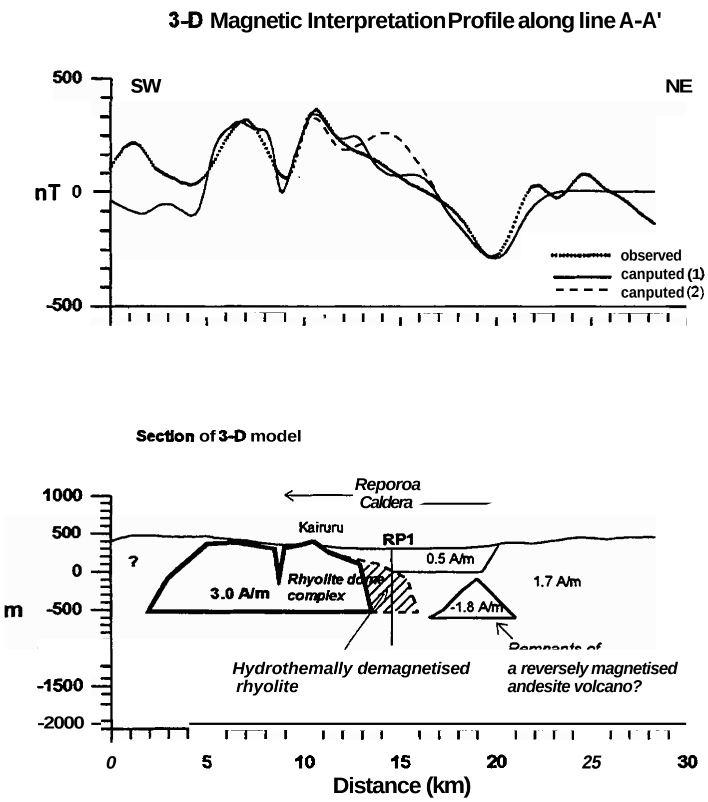

Figure 7. *3-D magnetic interpretation profile along line A-A'. The computed magnetic anomalies shown in the upper section are* ***from*** *the model with the rhyolite body terminated south-west* ***of RPI*** *(I), and with the rhyolite body extending to the northeast of* ***RPI*** *(2).*

mudstones of the Huka Falls Formation (with a total magnetisation of 0.5 A/m), and hydrothermally demagnetised rocks of the upper part of the Waiotapu reservoir near the northern **rim** of the Reporoa Caldera. New magnetic bodies were added to that model representing the reversely magnetised rocks north-west of the Reporoa Caldera and the normally magnetised rhyolite dome (at Trig. 8566). The model **was** further modified by assessing the effect of demagnetised rocks **as** observed in the RP1 well.

Our best fit 3-D model is shown in Fig. ***5*** and the magnetic effects computed from that model are presented in Fig. 6. We found that the representative total magnetisation for the body representing the buried dome complex south-west of Reporoa had to be increased to about 3.0 A/m. More significantly, we also found that this magnetic body **has** to be terminated south-west of RP1 in order to obtain a good fit between the computed magnetic effects and the observed residual magnetic anomalies in the central part of the Reporoa field (see Fig. 7). The comparison shows that the sequence of rhyolite lavas penetrated by well RP1 is part of the same rhyolite dome complex that has been hydrothermally demagnetised. Our magnetic interpretation is therefore consistent with intense hydrothermal alteration of rocks found in this well from examinations of cores and cuttings (e.g. Bignall, 1990; Nairn et al., 1994; Wood, 1994), supported by results (see Fig. 3) of magnetic measurements of cores (Lampoonsub, 1987).

6. SUMMARY AND DISCUSSION

Our reinterpretation of magnetic anomalies over the Reporoa Caldera has shown that some hydrothermally demagnetised rocks occur at depth in the central part of the Reporoa geothermal reservoir. The magnetic signature of this effect is masked by strong positive magnetic anomalies caused by a large, concealed rhyolite dome complex beneath the south-western part of the Reporoa Caldera, and also by negative anomalies caused by remnants of an older, buried, reversely magnetised andesite volcano beneath the eastern and north-eastern part of the caldera. In comparison with the magnetic structures of other high temperature systems in the TVZ which have been studied in detail (summarised recently, for example, by Hochstein and Soengkono, 1996), the structure of the Reporoa system is unusual since the extent of the demagnetised rocks at depth is significantly smaller than the extent of near-surface rocks with low resistivity.

If the north-eastern part of the rhyolite dome complex has been hydrothermally demagnetised by fluid/rock interaction in the Reporoa geothermal reservoir, it can be inferred from our model that hydrothermal demagnetisation has only affected a rather limited portion of the northern edge of the dome complex which appears to cover less than, say, 5 km^2 at 800 m depth. The low resistivity rocks in the upper 300 m cover an area of at least 15 km^2. If the deeper reservoir were of smaller extent, this could explain the rather small natural heat output of the prospect. It is also possible that a cold water inflow from the south-east, as has been suggested by Wood (1994), has prevented demagnetisation to expand.

REFERENCES

Bibby, H.M., Caldwell, T.G. and Risk, G.F.(1994a). Resistivity evidence for an independent geothermal field at Reporoa. ***Proceedings of the 16th NZ Geothermal Workshop,*** 133-138.

Bibby, H.M., Bennie, S.L., Stagpoole, V.M., and Caldwell, T.G. (1994b). Resistivity structure of the Waimangu, Waiotapu, Waikite and Reporoa geothermal areas, New Zealand. ***Geothermics*** Vol. 23, No 5/6, 445471.

Bignall, G. (1990). Hydrology and hydrothermal alteration, Reporoa well (1), Reporoa, New Zealand. ***Proceedings of the 12th NZ Geothermal Workshop,*** 257-264.

Grindley, G.W., Mumme, T.C., and Kohn, B.P. (1994): Stratigraphy, palaeomagnetism, geochronology and structure of silicic rocks, Waiotapu/Paeroa Range area, New Zealand. *Geothermics* Vol. 23, No 5/6, 473499.

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

Hochstein, M.P., Simmons, S.F., Maggs, G.R. and Newson, J. (1992). Assessment of thermal water input into the Waikato River - results of a test study. ***Proceedings of the 14th NZ Geothermal Workshop,*** 51 - 56.

Hochstein, M.P. and Soengkono, S. (1996). Magnetic anomalies associated with high temperature reservoirs in the Taupo Volcanic Zone (New Zealand). ***Geothermics*** (in press).

Lampoonsub, K. (1987). Magnetic properties from Wairakei, Orakeikorako, Te Kopia and Reporoa geothermal fields. ***Geothermal Institute Report 87.13,*** The University of Auckland, New Zealand.

Nairn, I.A., Wood, C.P., and Bailey, R.A. (1994). The Reporoa Caldera, Taupo Volcanic Zone: source of the Kaingaroa Ignimbrites. Bull. ***Volcanology,*** Vol 56, 529-537.

Soengkono, S. (1992). Magnetic anomalies over the Ngatamariki geothermal field, Taupo Volcanic Zone, New Zealand. ***Proceedings of the 12th NZ Geothermal Workshop,*** 241-246.

Soengkono, S. (1995). A magnetic model for deep plutonic bodies beneath the Central Taupo Volcanic Zone, North Island, New Zealand. ***Journal of Volcanology and Geothermal Research,*** Vol68, 193-207.

Soengkono, S. and Hochstein, M.P. (1996). Preliminary interpretation of magnetic anomalies over the Waimangu, Waiotapu, Waikite and Reporoa geothermal areas, New Zealand. ***Proceedings of the 17th Annual PNOC-EDC Geothermal Conference,*** Philippines, 197-203.

Wood, C.P. (1994). Aspects of the geology of Waimangu, Waiotapu, Waikite and Reporoa geothennal systems, Taupo Volcanic Zone, New Zealand. ***Geothermics*** Vol. 23, No 5/6, 401-421.