PRELIMINARY INTERPRETATION OF MAGNETIC ANOMALIES OVER THE WAIMANGU, WAIOTAPU, WAIKITE AND REPOROA GEOTHERMAL AREAS, NEW ZEALAND

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Abstract

The Waimangu, Waiotapu, Waikite and Reporoa geothermal areas are situated on the eastern side of the Taupo Volcanic Zone (TVZ) in the central North Island of New Zealand. An airborne magnetic survey at c. 760 m RSL (m respect to sea level) over the study area showed a complex pattern of residual magnetic anomalies reflecting a complex magnetic structure where thermally demagnetised volcanic rocks occur together with old, reversely magnetised rocks. Two outcrops of reversely magnetised rocks are marked by prominent negative residual anomalies. Preliminary interpretation of the magnetic data indicate that hydrothermally demagnetised rocks occur beneath the Waiotapu and the SW part of the Waimangu geothermal fields. Residual magnetic anomalies over the Reporoa geothermalfield are not indicative for demagnetised rocks.

1.0. INTRODUCTION

The study area is located in a region of Quaternary volcanism and geothermal activity in the central North Island of New Zealand which is known as the Taupo Volcanic Zone (TVZ). The TVZ is an anomalously high heat flow region, where more than 15 active geothermal systems occur along a 100 km segment from L. Taupo to the E of L Rotorua (Figure 1).

Most of the geothermal reservoirs in the TVZ are hosted by normally magnetised rhyolitic volcanic rocks (younger than 0.7 Ma). Study of cores from some of the TVZ geothermal drillholes (Soengkono, 1985; Lampoonsub, 1987; Morales, 1988) has shown *that* the volcanic rocks are almost completely demagnetised inside the geothermal reservoirs. Such demagnetisation of reservoir rocks is also shown by the pattern of residual magnetic anomalies over many geothermal fields. For example, large negative residual magnetic anomalies were observed over Mokai and Orakeikorako geothermal fields (Soengkono, 1985; 1993) reflecting thermal alteration in the upper 0.5 km depth of the reservoirs, as supported by the occurrence of low resistivity anomalies.

However, for the coherent Waimangu, Waiotapy Waikite and Reporoa geothermal areas in the eastern TVZ, the magnetic structure is more complex. In this area thermally demagnetised rocks occur together with older, reversely magnetised volcanic rocks. As will be shown in the following, this situation causes a complex pattern of residual magnetic anomalies which is more difficult to interpret in terms of demagnetisation associated with active geothermal systems.

2.0 GEOLOGIC SETTING

The geology of the study area has been discussed in detail by Wood (1994) and Grindley et al. (1994). The main features relevant to magnetic interpretation are shown in Figure 2, which include the principal fault zones, the Reporoa and Haroharo Calderas, the exposures of reversely magnetised rocks, the rhyolite/dacite extrusions, and the surface thermal areas of the Waimangu, Waikite, Waiotapu and Reporoa fields.

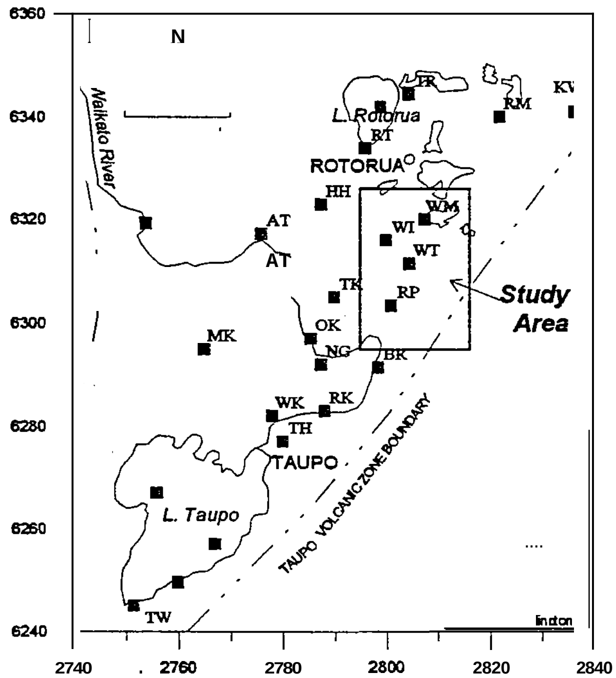

Figure 1. Location of geothermal fields in the Taupo Volcanic Zone (TVZ), Central North Island, New Zealand: TW=Tokaanu Waihi, TH=Tauhara, WK=Wairakei, RK=Rotokawa, MK=Mokai, OK=Orakeikorako, NG=Ngatamariki, BR=Ohaaki-Broadlands, AT=Atiamuri, TK=Te Kopia, RP=Reporoa, WT=Waiotapu, WI=Waikite, WM=Waimangu, HH=Horohoro, RT=Rotorua, TR=Tikitere, RM=Rotoma-Tikorangi, KW=Kawerau.

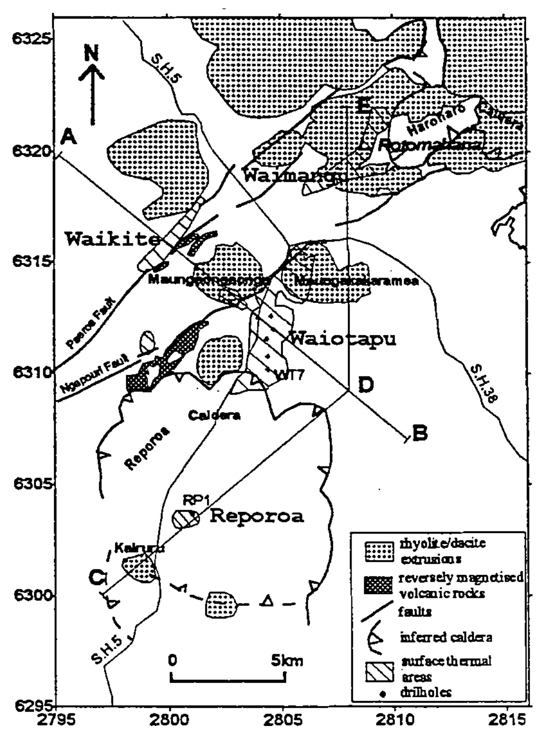

Figure 2. Map of the study area showing the principal structural elements, outcrops of older, reversely magnetised volcanic ***rocks,*** *exposed rhyolite and dacite lavas, surface thermal areas and locations of geothermal drillholes (modified* ***from*** *Wood, 1995; and Grindley et al., 1995).*

The oldest volcanic rock known in the study area is a densely welded ignimbrite which has not been found at the surface. This ignimbrite was encountered by three Waiotapu drillholes below -500 m RSL (metres relative to sea level) underlying a layer of reversely magnetised andesite lava (the Ngakoro andesite). The Ngakoro andesite, in turn, is overlain by a sequence of reversely magnetised tuffs and ignimbrites, whose upper part can be correlated with the reversely magnetised rock formations exposed to the west and north-west of Waiotapu along the Ngapouri and Paeroa fault scarps (see Figure 2).

Younger, normally magnetised ignimbrite formations erupted from various sources in the TVZ are widely exposed outside the Reporoa Caldera. The rhyolite and dacite lavas shown in Figure 2 were all extruded during the last 0.3 Ma and therefore are also normally magnetised. The Reporoa Caldera is infilled to about 300 m depth by siltstone and muddy sandstones (the Huka Falls Formation).

3.0 MAGNETIC ANOMALIES

We conducted an airborne magnetic survey at c.760 m RSL over the study area in May and November 1993. The measurement was made using an ELSEC 820 proton magnetometer along N-S flight lines at about 1 km spacing and three E-W tie lines at about 6-8 km spacing Location of flight paths was determined using a Trimble Navigation GPS Pathfinder Basic Receiver. The magnetic data was reduced using the global geomagnetic field predicted from the IGRF model (National Geophysical Data Centre, 1992) and a regional field associated with deeper-magnetic structure beneath the TVZ (Soengkono, 1995).

Figure 3 shows the residual magnetic anomalies over the study area A simplified contour map of Schlumberger apparent resistivity (AB/2=1000 m) of the same area is presented in Figure 4, which also shows the likely extent of the electrically conductive reservoir rocks (Bibby et al., 1994). The resistivity data indicate a continuous zone of low resistivity ground (*app.* resistivity ≤ 15 ohm-m) extending from Reporoa to Waimangu. A comparison between Figures 3 and 4 suggests that there are as many magnetic lows over high resistivity ground as there are over thermally altered, low resistivity ground Individual magnetic anomalies are associated with demagnetised reservoir rocks (D), reversely magnetised rocks (R), the topography of normally magnetised volcanic rocks (TN), and concealed lava domes (CR).

4.0 QUANTITATIVE MAGNETIC INTERPRETATION

We have found that quantitative interpretation of magnetic anomalies over geothermal reservoirs hosted by Quaternary volcanic rocks is best &ne by comparing the observed residual anomalies with theoretical data obtained from a three-dimensional (3-D) computer model representing the ground magnetic structure, including the topography formed by magnetic rocks. We also found that a simple model that reproduces the main features of the observed anomaly pattern is usually more representative than any detailed model which can be biased

A preliminary quantitative interpretation of the residual magnetic anomalies over the study area was conducted using available geological and resistivity constraints. In this interpretation, it was assumed that the average magnetisation of normally magnetised volcanic rocks in the study area is the same as that of the whole TVZ which is 1.7 A/m (Soengkono, 1995). Two interpretation profiles along lines A-B and C-D-E (see Figures 2 and 3) are presented in Figures 5 and 6. The lower profiles in these figures are cross-sections of a 3-D model used to produce the computed anomalies shown as solid lines in the upper profiles. It can be seen in Figures 2 and 3 that the magnetic model reproduces the main features of the

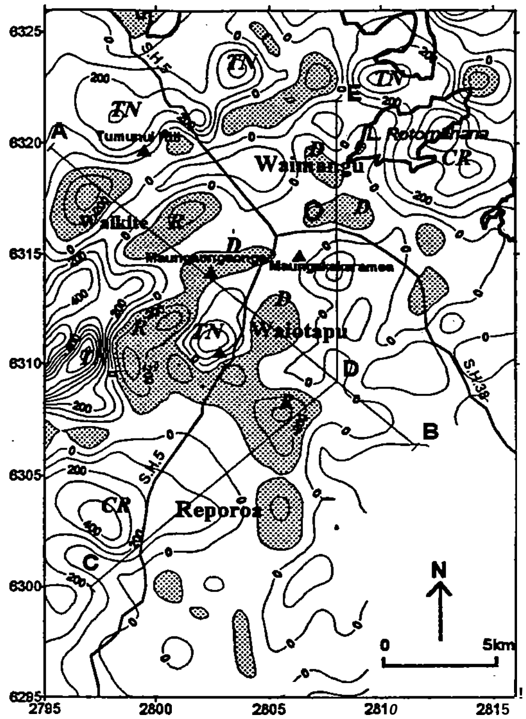

Figure 3. Residual total force magnetic anomalies at **c.** *760 m RSL over the study area. Contour interval is 100 nT. Areas* ***with*** *residual magnetic anomalies* **I-200** *nT are shown (stippled). See text* ***for*** *the discussion.*

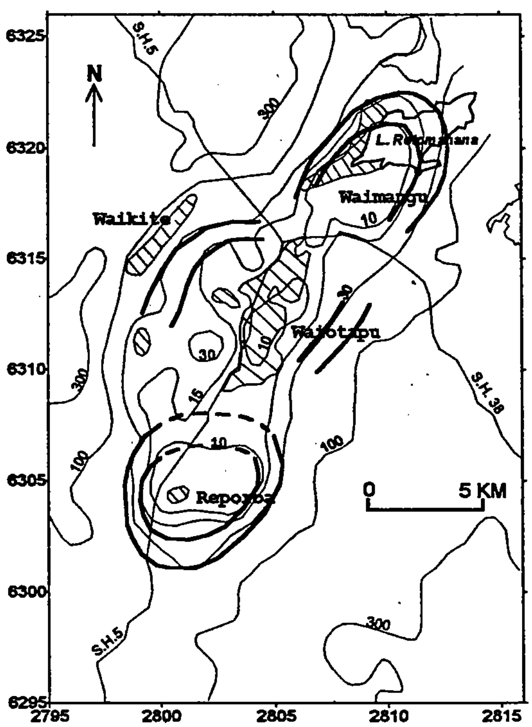

Figure ***4.*** *Map showing approximate extent* ***of*** *the Waimangu, Waiotapu, and Reproa geothermal systems (thick double lines) derived from resistivity data by Bibby et al. (1995). The thin contour lines show the Schlumberger apparent resistivity (ohm-m) measured* ***using*** *AB/2=1000 m.*

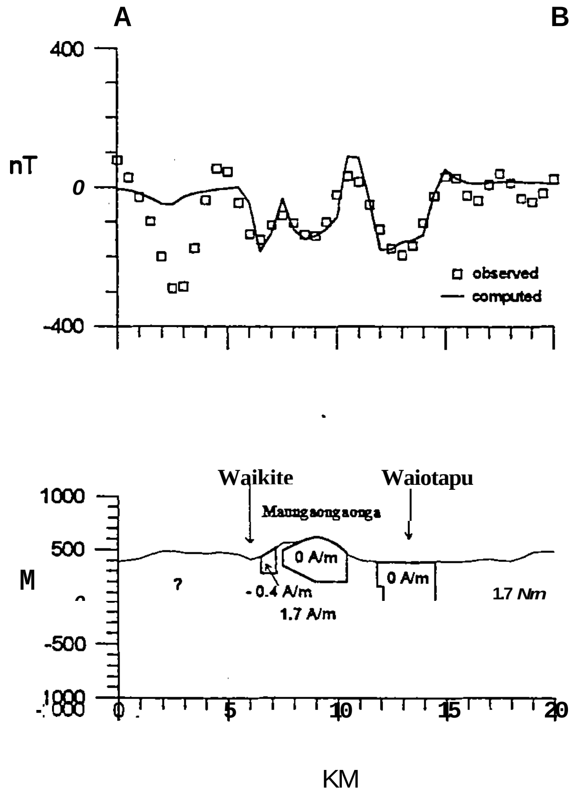

Figure 5. Magnetic interpretation along line A-B. Location of profile is shown in Figures 2 and 3. See text for the discussion.

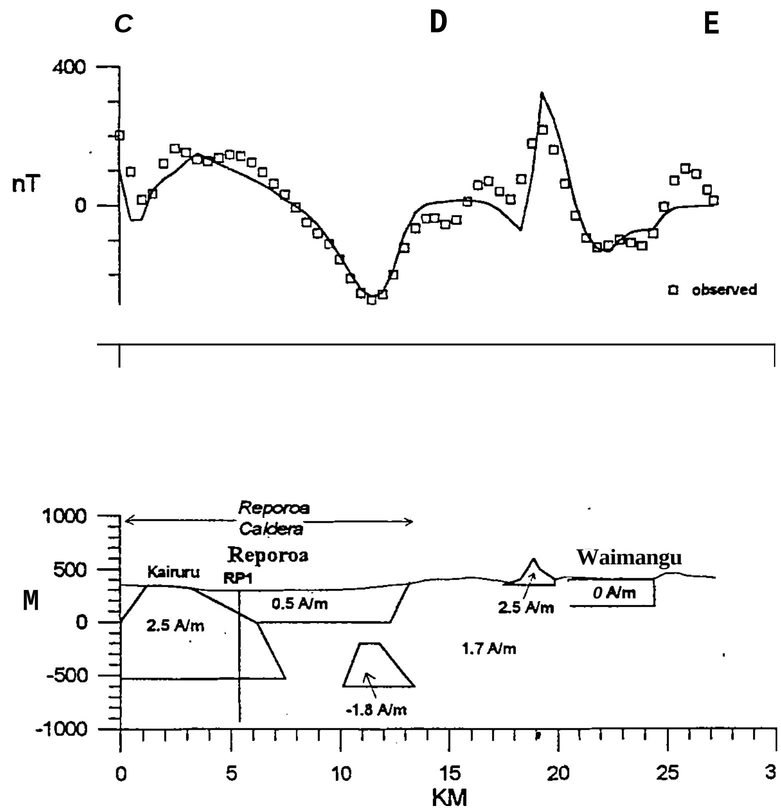

Figure 6. Magnetic interpretation along line C-D-E. Location of profile is shown in Figures 2 and 3. See text for the discm'on.

observed anomalies (shown by open boxes) along lines **A-B** and **C-D-E**. However, it is important to note that the model shown in these figures is not a unique solution for the observed residual anomalies.

Line A-B

The magnetic interpretation along this line (Figure 5) shows that thermally demagnetised rocks (magnetisation = 0 A/m) extending to more than 300 m depth beneath the Waiotapu and the Maungaongaonga dome. Demagnetised rocks are absent beneath the Waikite thermal manifestations. The -0.4 A/m body shown to the right of Waikite represents the reversely magnetised rocks which crop out along the Paeroa fault scarp (see Figure 2).

The magnetic interpretation along line **A-B** is consistent with the inference that the Waikite thermal manifestations are the result of a concealed thermal outflow from the east (Bibby et al., 1994). The magnetic model suggests that the demagnetised rocks beneath Maungaongaonga and those beneath Waiotapu are separated. It is not known whether this separation also represents a hydrologic barrier and, therefore, prevents any shallow thermal outflow from the Maungaongaonga area to Waiotapu.

Line C-D-E

The large, mostly concealed magnetic body (2.5 A/m) at the left end of the lower profile in Figure 6 represents an inferred buried rhyolite dome complex beneath the SW side of the Reporoa Caldera, as indicated by a sequence of rhyolite lavas penetrated by drillhole RP1 at about 0 to -530 m RSL (Wood, 1994). No demagnetised body is shown at Reporoa. The stronger positive anomalies caused by the (inferred) buried rhyolite dome complex may have masked weak negative anomalies associated with any thermal demagnetisation of the weakly magnetised Huka Fall Formation (represented by the 0.5 A/m body in Figure 6).

The -1.8 A/m body beneath the NE side of the Reporoa Caldera probably represents buried remnants of an older andesite strato volcano, whose existence was predicted from the abundant andesite blocks found in ignimbrites erupted from the Reporoa Caldera (Nairn et al., 1994). The andesite volcano has been correlated with the reversely magnetised Ngakoro andesite penetrated by three Waiotapu drillholes (Wood, 1994).

The magnetic interpretation along line **C-D-E** also suggests that demagnetised rocks occur beneath the SW **part** of the Waimangu geothermal field to about 250 m depth. The magnetic profile in Figure 6 clearly shows that the small rhyolite dome SE of the thermally altered Maungakakaramea has retained its magnetisation (see the 2.5 A/m body south of Waimangu) and therefore has not been affected by hydrothermal demagnetisation.

5.0 CONCLUSIONS

The occurrence of older, reversely magnetised rocks can complicate the interpretation of magnetic anomalies over geothermal fields in a Quaternary volcanic setting. As shown by the preliminary interpretation of residual magnetic anomalies over the Waimangu, Waiotapu, Waikite and Reporoa geothermal areas discussed in this paper, detailed information about the geologic, volcanic stratigraphy and resistivity structure **of** the area is required prior to a magnetic interpretation for investigation of thermally demagnetised rocks associated with geothermal activity. On the other hand, this study shows that the interpretation of the magnetic data can still provide significant information about the existing reservoir models as well as the gross volcanic structure of the area.

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