INTERPRETATION OF AEROMAGNETIC DATA OVER THE ORAKEIKORAKO GEOTHERMAL FIELD, CENTRAL NORTH ISLAND, NEW ZEALAND

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SUMMARY - The Orakeikorako geothermal field was covered by two aeromagnetic surveys which were conducted at different altitudes (760 m asl and 60 m above the ground). Interpretation of the residual magnetic anomalies from both surveys has shown that hydrothermally demagnetised rocks occur inside the Orakeikorako reservoir to about 0.6 km below sea level. The residual anomalies also indicate the presence of another concealed non-magnetic body, elongated in the SW-NE direction, that appears to be connecting the Orakeikorako field and Te Kopia prospect in the NE.

Result from topographic modelling suggests that a rhyolite dome at Trig 8571, about 5 km to the SW of Orakeikorako, is non-magnetic. The magnetic data also indicate the presence of non magnetic rocks at shallow level in the area to the NW of Trig 8571. It is possible that these non-magnetic rocks are relicts of old hydrothermal activity in the southern part of the Maroa Volcanic Centre.

1. INTRODUCTION

The Orakeikorako geothennal field is located about 17 km to the NNE of the Wairakei geothermal field in the Taupo Volcanic Zone (TVZ), New Zealand. Surface thermal activity at Orakeikorako, consisting of hot pools and springs, geysers, hydrothermal eruption craters, silica sinter deposits and acid alteration zones, has been an attraction to visitors since the end of last century. Some of the surface manifestations were flooded by the Waikato River when the Ohakuri Hydroelectric Dam was built in early 1960s. Natural heat flow of the Orakeikorako geothermal field was estimated to be about 340 MW (Lloyd, 1972). DC resistivity traversing data (Geophysics Division, DSIR, 1985) show that the geothermal field is associated with about 9 km^2 of low resistivity area (app. resistivity $\leq 20\ \Omega$-m for nominal Schlumberger array spacing of 1000 m) mainly to the E of the Waikato River (see Fig. 1). Four deep wells were drilled at Orakeikorako in the mid-1960s to a maximum depth of about 1.4 km.

Geological mapping of the Orakeikorako area was conducted by Grindley (1959) and Lloyd (1972); the geology was later modified by Wilson et al. (1984). Rhyolite domes of the Maroa Volcanic Centre occupy a large area to the W of the geothermal field and form a prominent topography with a maximum elevation of more than 700 m asl (see Figure 1). The rhyolites are surrounded by poorly welded to non-welded ignimbrites, which mostly were also erupted from the Maroa Volcanic Centre. A swarm of Cenozoic NE-SW trending normal faults cuts through the Orakeikorako area; some of the faults appear to be associated with surface hydrothermal activity (Lloyd, 1972).

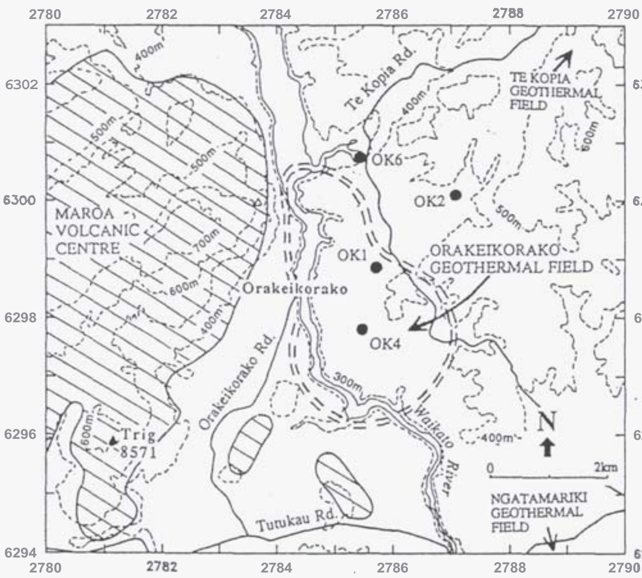

Figure 1. *Map showing the Orakeikorako field. Solid circles **mark** localities of drillholes. Topographic contours are shown by thin broken lines. Hatched pattern shows areas of exposed rhyolite domes. Double broken line indicates 20 Ω-m app. resistivity contour (AB/2 = 1000 m). Grid co-ordinates are in terms of the local NZ Map Grid (km).*

Petrology of the deep wells was studied by Steiner (1965); subsurface geology and stratigraphy were described by Grindley (1965) and more recently by Bignall (1991). The wells penetrate a sequence of Quaternary pyroclastics and rhyolitic lavas which generally dip into the SE. No Mesozoic greywacke basement rocks were encountered by the drilling.

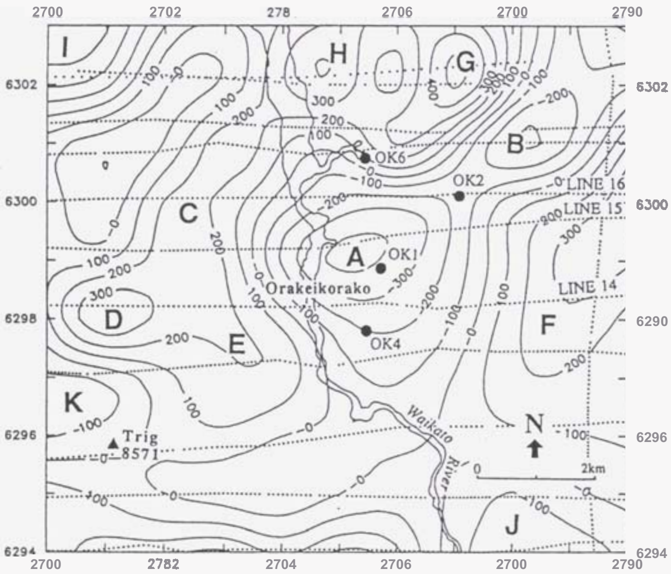

Figure 2. Second order residual anomalies at 760 m asl. Contour interval is 100 nT. Some anomaly centres are shown with capital letters.

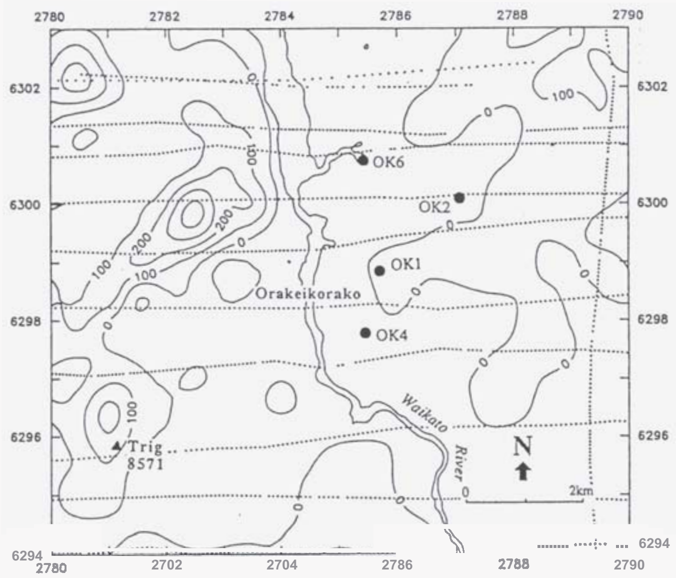

Figure 4. Magnetic effects of topography at 760 m asl, computed using a mean total magnetisation of 1.7 A/m. Contour interval is 100 nT.

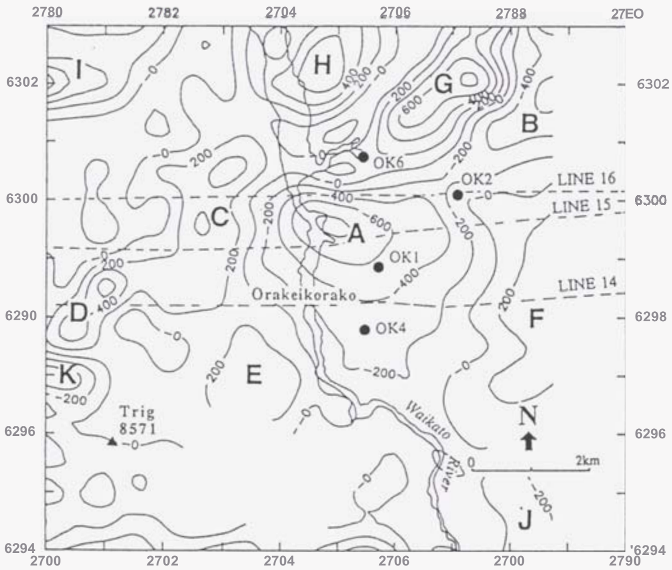

Figure 3. Second order residual anomalies at elevations of 60 m above the ground. Contour interval is 200 nT. Some anomaly centres are shown with capital letters.

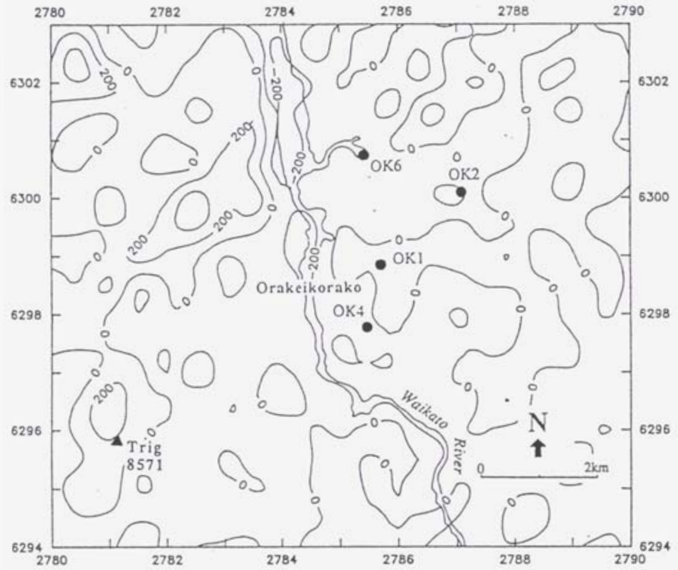

Figure 5. Magnetic effects of topography at elevations of 60 m above the ground, computed using a mean total magnetisation of 1.7 A/m. Contour interval is 200 nT.

2. AEROMAGNETIC SURVEYS AND REDUCTION OF DATA

Orakeikorako area was covered by an aeromagnetic survey at a nominal flight altitude of 760 m asl (about 350 m above the ground) conducted by staff of the Auckland University Geothermal Institute (AUGI) in May 1985. The magnetic measurement was made along mainly EW flight lines about 1 km apart. In July 1986, the Mineral Division of BP Oil New Zealand Ltd. (BPM) conducted a more detailed aeromagnetic survey (200 m flight line spacing) at 60 m above the ground (draped survey) which included a large part of the study area. Contour maps of the BPM aeromagnetic data (1:25 000 scale, 5 nT contour interval) were available from the NZ Ministry of Commerce, Wellington. For this study, the BPM aeromagnetic data were digitized using a 500 m rectangular grid.

Both sets of data from the AUGI and BPM surveys over the Orakeikorako area were reduced using the normal geomagnetic field computed from the International Geomagnetic Reference Field (IGRF) model. Effects of deep seated magnetic structure beneath the TVZ were also reduced by subtracting the first and second order long wavelength components of magnetic field over the TVZ. The first order regional

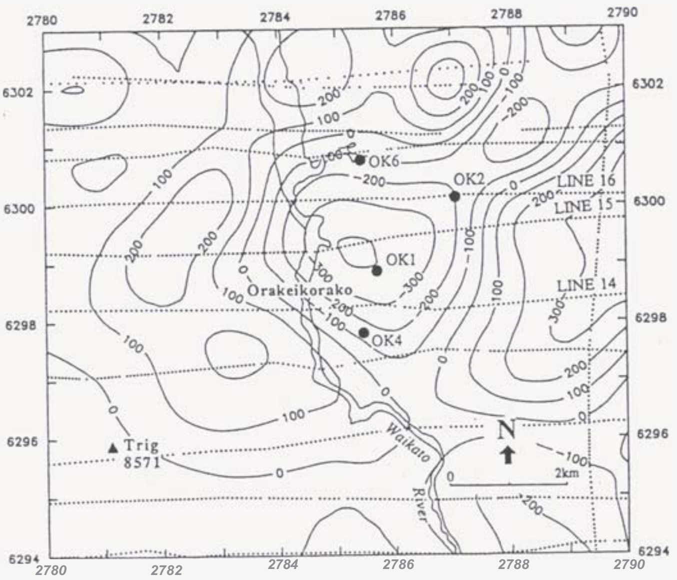

Figure 7. *Computed magnetic effects of models at 760 m asl. Contour interval is 100 nT.*

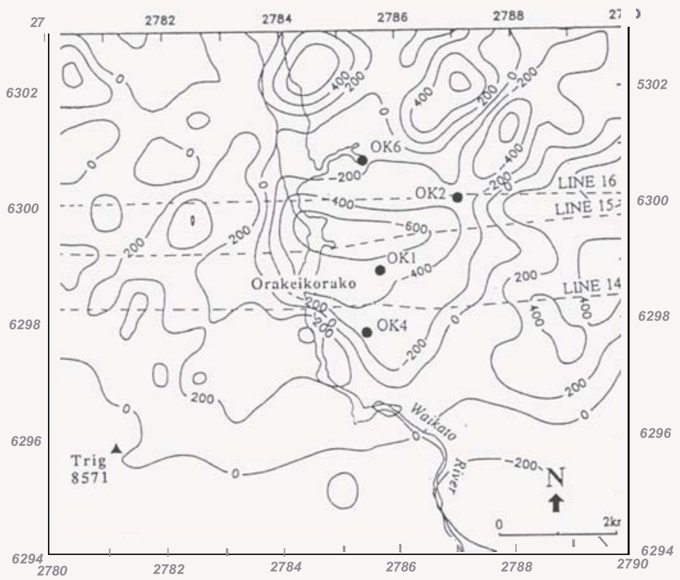

Figure 8. *Computed magnetic effects of models at elevations of 60 m above the* ***ground.*** *Contour interval is 200 nT.*

field was determined by polynomial fitting of the magnetic anomalies over outcropping non-magnetic greywacke basement; the second order long wavelength component was obtained by modelling of deep seated magnetic masses beneath TVZ using upward-continued magnetic data at 5000 m asl and computing effects of the deep models at actual flight altitude of the aeromagnetic surveys (Soengkono, 1990). The same reduction procedure has been used to isolate local magnetic anomalies (termed the second order residual anomalies) over nearby Rotokawa, Wairakei and Ngatamariki geothermal fields (Soengkono et al., 1991; Soengkono and Hochstein, 1992; and Soengkono, 1992).

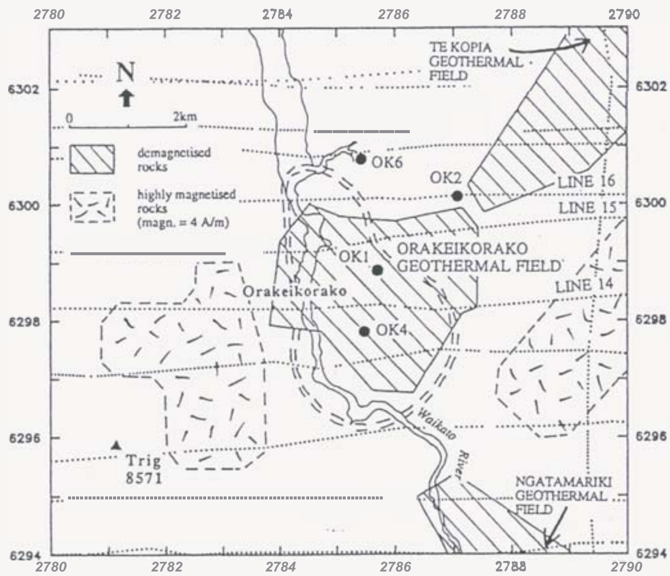

Figure 6. *Map showing the lateral extent of demagnetised rocks and the inferred highly magnetised bodies (magnetisation of 4 A/m) in the Orakeikorako area.*

3. RESIDUAL MAGNETIC ANOMALIES OVER THE ORAKEIKORAKO AREA

Figures 2 and 3 show contours of the second order residual magnetic anomalies over Orakeikorako area from the AUGI and BPM surveys, respectively. It can be seen from these maps that the two sets of residual anomalies (measured at different levels) have a similar pattern. Both maps show a prominent centre of negative anomalies over the Orakeikorako geothermal field (anomaly A). There is another centre of strong negative anomalies (anomaly B) lying to the NE of anomaly A. Anomalies A and B are surrounded by several distinctive centres of positive anomalies (anomalies C, D, E, F, G, and H). Another centre of positive anomalies occurs in the NW comer of Figures 2 and 3 (anomaly I). A magnetic low in the SE comer of the maps (anomaly J) is a part of a larger negative anomaly centre to the S that has been interpreted to be associated with the Ngatamariki geothermal field (Soengkono, 1992). The data in Figures 2 and 3 also show a short wavelength negative anomaly to the NW of Trig. 8571 (anomaly K).

4. MAGNETIC MODELLING OF TOPOGRAPHY

Steep volcanic topography can produce a significant short wavelength magnetic effects at low altitude, and therefore needs to be included in an interpretation of low level aeromagnetic data. Topographic effects can be estimated by calculating the effects of a model constructed from topographical maps, using a magnetisation value which represents the bulk average magnetisation of the volcanic rocks forming the

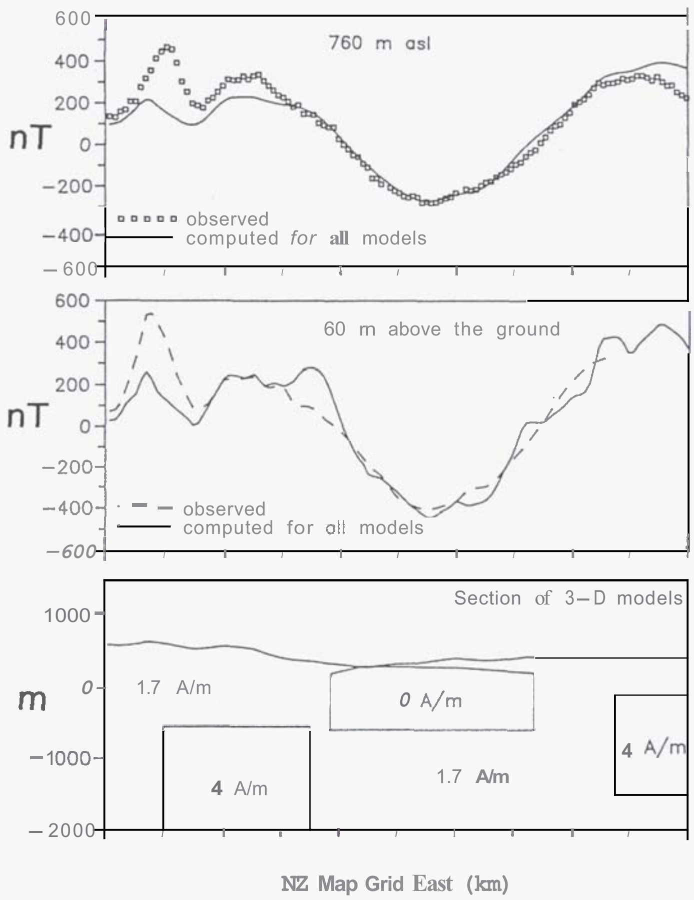

Figure 9. Observed and computed residual magnetic anomalies along flight line 14 at 760 m asl (upper profile), and at elevations of 60 m above the ground (middle profile). A section of the 3-D magnetic models is shown in the lower profile. The flight line is shown in Figures 2 and 3.

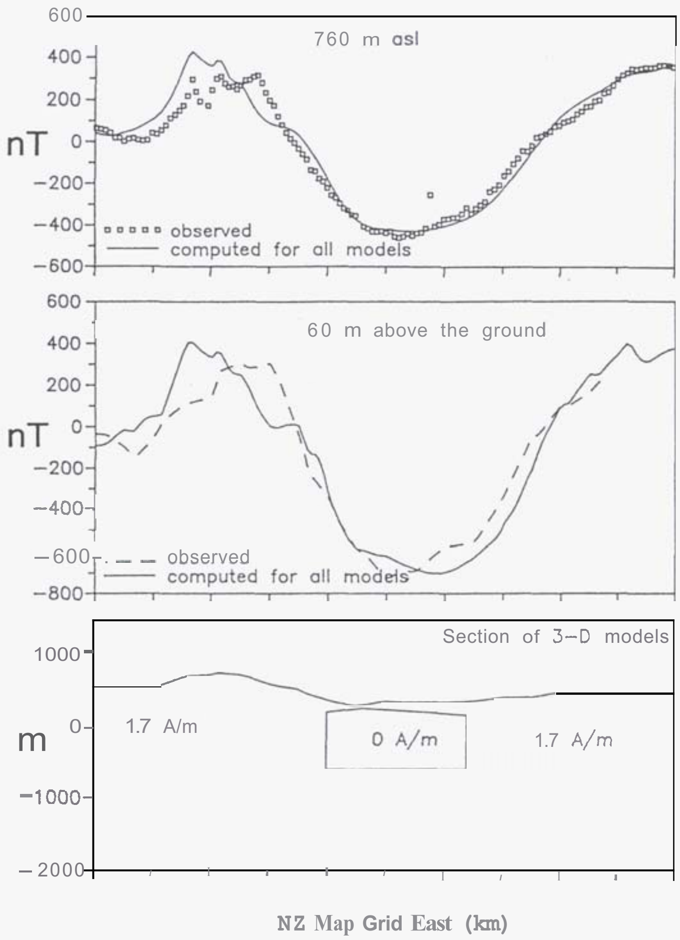

Figure 10. Observed and computed residual magnetic anomalies along flight line 15 at 760 m asl (upper profile), and at elevations of 60 m above the ground (middle profile). A section of the 3-D magnetic models is shown in the lower profile. The flight line is shown in Figures 2 and 3.

topography. For this study, topographic model of the Orakeikorako area was constructed by digitizing a 1:50 000 scale topographic map using a grid spacing of 500 m. A total magnetisation of 1.7 A/m with inclination of -62° and declination of 0" (i.e. mean values for magnetisation of most surface rocks in the TVZ; Soengkono, 1990) was used to compute theoretical topographic effects. The computation was made using a 3-D magnetic modelling algorithm introduced by Barnett (1976).

Theoretical magnetic effects of topography over the study area, computed at 760 m asl and at draped elevations of 60 m above the ground, are shown in Figures 4 and 5, respectively. Both figures show a centre of positive effects over the area to the NW of Orakeikorako, indicating that the residual anomaly C (see Figures 2 and 3) is mainly caused by topographic effects. Results of topographic modelling also show that the positive anomaly I in the NW comer of Figures 2 and 3 is partly caused by topographic effects.

A more interesting result from the topographic modelling is the presence in both figures 4 and 5 of a distinctive centre of theoretical positive topographic effects near Trig 8571 in the south-eastem part of the Maroa Volcanic Centre. The absence of any significant observed positive residual anomalies in this area in Figures 2 and 3 clearly indicates that the exposed rhyolite dome of Trig 8571 (see Fig. 1) is non-magnetic. It also appears that non-magnetic rocks are present at shallow level to the NW of the Trig 8571 rhyolite dome, as indicated by the negative residual anomaly K (see Figures 2 and 3). It is interesting to note that an interpretation of aeromagnetic data over the Mokai area has also indicated the presence of two other non-magnetic rhyolite domes in the south-western part of the Maroa Volcanic Centre, i.e. the Pukemoremore and Maroanui domes (Soengkono, 1985).

In other parts of study area, a comparison between the computed topographic effects (Figures 4 and 5) and the observed residual data (Figures 2 and 3) shows that the

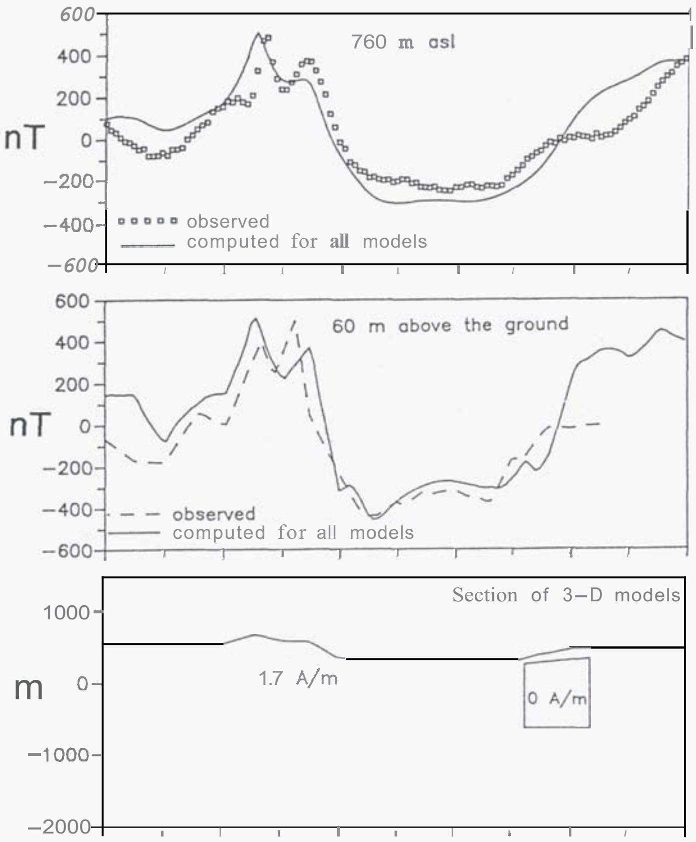

Figure 11. Observed and computed residual mgnetic anomalies along flight line 16 at 760 m asl (upper profile), and at elevations of 60 m above the ground (middle profile). A section of the 3-D magnetic models is shown in the lower profile. The flight line is shown in Figures 2 and 3

bulk of both negative anomalies A and B, and the positive anomalies E, F, G and H, are not caused by any topographic effects.

5. INTERPRETATION OF CONCEALED MAGNETIC BODIES

The interpretation was mainly aimed to explain the negative anomalies A and B. Prominent residual negative magnetic anomalies have also been observed over several other geothennal fields in the Taupo Volcanic Zone, and were interpreted in terms of non-magnetic rocks inside the reservoirs caused by hydrothermal demagnetisation (Ignacio, 1985; Soengkono, 1985, 1992; Henrys and Hochstein, 1990; Soengkono et. al, 1991; Soengkono and Hochstein, 1992). Result of magnetisation measurement of drillhole cores from the Mokai and Wairakei fields supports the assumption that demagnetized volcanic rocks are present inside the geothermal reservoirs, although at deeper levels the cores seemed to retain most of their magnetisation. It is therefore also assumed that the Orakeikorako magnetic low (anomaly A) and the negative anomaly B (lying between the Orakeikorako field and Te Kopia prospect in the NE) are also caused by demagnetized rocks associated with hydrothermal alteration process. For interpretation, theoretical anomalies of a set of simple demagnetised models were computed at the actual flight heights using the 3-D magnetic modeling algorithm of Barnett (1976). The same magnetization value of 1.7 A/m (declination=-62° and inclination=0°) as that used for the topographic modelling (section 4) was also used to represent the average bulk magnetisation of the unaltered volcanic rocks outside demagnetized zones.

Small complementary negative effects of surrounding positive (dipolar) anomalies would increase slightly the amplitude of negative anomalies A and B. To allow for these additional negative effects, the observed positive anomalies E, F, G and H shown in Figures 2 and 3 were modelled using some inferred bodies with a high magnetisation lying at various depths. It was found that a magnetisation of about 4 A/m was required for the bodies in order to explain both sets of positive residual anomalies observed at different levels.

Interpretation of the demagnetized rocks was made using a trial and error approach; theoretical anomalies of models were computed until a simultaneous acceptable fit with both sets of residual data was obtained. The inferred highly magnetised bodies outside the Orakeikorako field were included in the interpretation. It was found that the use of two sets of residual anomalies observed at different altitudes increased the sensitivity of modelling with respect to the depths of the models.

The lateral extent of hydrothermally demagnetised rocks in the Orakeikorako area, together with that inferred for some highly magnetised bodies outside the Orakeikorako field, are presented in Fig. 6. Theoretical anomalies of all models (including effects of a complex set of shallow, highly magnetised bodies in the N of Orakeikorako which are not shown in Fig. 6) and topographic effects (excluding that of the non-magnetic Trig 8571 dome) computed at 760 m asl and at 60 m above the ground are presented in Figures 7 and 8, respectively. Observed and computed anomalies along flight lines 14, 15 and 16, together with sections of the 3-D models are shown in Figures. 9, 10 and 11.

It can be seen from Figures 9, 10 and 11, and from a comparison between Figures 7 and 8 and Figures 2 and 3 that, overall, an acceptable fit has been achieved. The interpretation result in Figure 6 shows that inside the northern and south-southeastern parts of the Orakeikorako low resistivity area, the rocks are still magnetic; however, demagnetised rocks extent laterally to the NE beyond the 20 Ω-m contour of apparent resistivity (Schlumberger array, nominal AB/2=1000 m). The results also indicate a connection between the

Orakeikorako field and the Te Kopia prospect in the NE, represented by an SW-NE elongated demagnetised body.

6. CONCLUSIONS

Compatible sets of residual magnetic anomalies were obtained from two different aeromagnetic surveys conducted over the Orakeikorako area by the Auckland University Geothermal Institute (760 m asl) and by the Mineral Division of British Petroleum NZ Ltd. (60 m above the ground surface). The availability of two magnetic data sets observed at different levels has increased the sensitivity of interpretation with respect to depths of upper boundary of the models. On the other hand, it was also found that no more significant additional information about the magnetic structure of the Orakeikorako system than that already indicated by the survey at 760 m asl, is provided by result from the detailed survey at 60 m above the ground.

The Orakeikorako geothermal field is associated with a centre of strong negative anomalies which were interpreted in terms of hydrothermally demagnetised rocks inside the geothermal reservoir, down to about 0.6 km below sea level. Laterally, the demagnetised body extends to the NE beyond the 20 R-m contour of apparent resistivity (Schlumberger array, AB/2=1000 m). The residual magnetic data also indicate the presence of another concealed non-magnetic body, elongated in the SW-NE direction, that appears to be connecting the Orakeikorako field and Te Kopia prospect in the NE.

Results from topographic modelling of the residual magnetic data indicates that the rhyolite dome at Trig 8571, about 5 km to the SW of Orakeikorako, is non-magnetic. The magnetic data also indicate the presence of non magnetic rocks at shallow level in the area to the NW of Trig 8571. It is possible that these non-magnetic rocks are relicts of old hydrothermal activity in the southern part of the Maroa Volcanic Centre.

The residual magnetic data over Orakeikorako area also indicate the presence of concealed bodies with a magnetisation of about 4 A/m around the Orakeikorako geothermal field. These inferred highly magnetised bodies may represent concealed andesitic lavas.

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