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Structure of concealed rhyolites and dacftes in the Broadlands-Ohaaki geothermal field.

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Abstract

The structure of concealed igneous bodies in the Broadlands-Ohaaki geothermal field have been studied by analysis of seismic, gravity, and magnetic data. By using a combination of constraints imposed by borehole stratigraphy, density information, and interpretation of seismic data, 3-dimensional gravity modelling outlines concealed rhyolite and dacite flows.

The Broadlands Dacite has been intersected by nearly all wells drilled in the east of the geothermal field and extends over an area of about 16 km^2. The flow is thickest (600 m) near the eastern boundary of the field. A >120 nT magnetic high associated with this body is centred 2 km east of the productive borefield. The anomaly is attributed to the unaltered, normally magnetised (magnetisation contrast 2.5-3.0 A/m) dacite east of the resistivity boundary. This is consistent with the Broadlands Dacite inside the geothermal field having partially or wholly lost its magnetisation through a process of thermal alteration. A smaller rhyolite flow (Broadlands Rhyolite) located in the southern part of the field (magnetisation contrast - 1.0 A/m) may be associated with a poorly defined magnetic low (>-100 nT). Isopachs of the Ohaaki Rhyolite suggest that flows thicken to the northwest. On the basis of this evidence it is conceivable that the source of the rhyolite is to the west of the Broadlands-Ohaaki geothermal field and part of more extensive rhyolites outcropping to the north and west.

Introduction

Recent airborne magnetic surveys of the Maroa-Taupo region have revealed an association of geothermal fields and relative magnetic lows. The cause of the negative anomalies is a reduction in the intensity of magnetisation by the action of hydrothermal fluids. This pattern is best seen at Mokai (Soengkono, 1985) and Ngatamariki, and to a lesser extent at Wairakei, Horohoro (Allis, 1987) and Rotokawa. No clear magnetic low was observed to be associated with the Broadlands-Ohaaki geothermal field. A broad northeast-southwest trending anomaly, observed in both airborne and ground surveys (Hochstein and Hunt, 1970), is not confined to the geothermal field as outlined by the resistivity boundary (Risk et al., 1977). However, there is good evidence from susceptibility measurements on core samples that volcanic rocks inside the geothermal field are non-magnetic (Hochstein and Hunt, 1970). Furthermore, the only magnetic anomaly observed in the direct vicinity of the field is a magnetic high (>120 nT) centred east of the resistivity boundary.

Within the geothermal field the volcanic stratigraphy is well defined from the drilling of 44 deep wells (Browne, 1971; Wood, 1983) and includes lacustrine tuffaceous sediments, ash flows, pyroclastic rocks and tuff breccias. In addition, most wells have intersected concealed igneous flows and domes, including the Ohaaki Rhyolite, Broadlands Rhyolite, and Broadlands Dacite at depths between 100-600 m below the surface. Reinterpretation of published geophysical data (Hochstein and Hunt, 1970) over the Broadlands-Ohaaki field (gravity and seismic refraction) and seismic reflection data (Henrys, 1987) have provided new structural information of these rhyolites and dacites. Using this information an attempt was therefore made to quantitatively interpret the observed magnetic anomalies over the Broadlands-Ohaaki field.

Airborne magnetic data

A low-level aero-magnetic survey was undertaken by Auckland University during March 1984 in the vicinity of the Broadlands-Ohaaki geothermal field. This survey was part of a more extensive survey for the Ministry of Energy over the Maroa-Taupo region. A total of 22 cast-west flight lines (spaced 750 m apart) and 6 north-south profiles (spacing 1000-3000 m) arc shown in Figure 1. This survey covered a total area of about 180 km^2 and was flown at an altitude of 460±20 m a.s.l.(140 m above mean topographic elevation). The flight height and flight line spacing was chosen so as to provide information on shallow magnetic structures.

The total geomagnetic field, was measured using a proton precession magnetometer. The magnetometer and power supply was installed in a Cessna aircraft. The magnetometer sensor was towed 20 m behind and about 10 m below the aircraft. The magnetic field was sampled at 2 sec intervals (approximately 70-80 m horizontal distance) and recorded on magnetic tape for later processing. The horizontal position of the aircraft was determined within an error of ± 100m by using; continuous video recording of flight lines, fiducials, vertical air photos, and topographic maps. The diurnal variation was monitored throughout the survey by a proton precession magnetometer, located at Taupo Airport which digitally sampled the total geomagnetic field at 1 minute intervals.

The raw magnetic data was reduced using software written for the University of Auckland IBM 4341 computer (see Soengkono, 1985). Processing involved; decoding magnetic tape files, flight line location, correction for the diurnal variation, and the removal of a regional geomagnetic field using the equations and co-efficients from Reilly et. al. (1978).

Figure 1 shows the residual total force magnetic anomaly map in the vicinity of the Broadlands-Ohaaki geothermal field. The residual anomaly contours are observed to increase in magnitude (> 400 nT) northwest of the Broadlands-Ohaaki geothermal field and are may, in part, be caused by unaltered rhyolites (?Haparangi Rhyolite) and ignimbrites (?Oruanui Formation) cropping out north and west of the geothermal field (Figure 1). East of the geothermal field, fight lines were extended onto the Kaingaroa Plateau where greywacke basement is overlain by 200 m thick Rangitaiki Ignimbrite. A line of northeast-southwest trending magnetic highs (≈100 nT) on the Kaingaroa Plateau is considered to be associated with these ignimbrites.

The main feature in Figure 1 is the existence of a positive residual magnetic anomaly (≈150 nT) located cast of Broadlands Road. A magnetic high (200 nT) at this locality is also present in the ground-magnetic data of Hochstein and Hunt (1970) and was inferred to be unaltered Broadlands Dacite. Low-amplitude northeast-southwest trending anomalies near the geothermal field are indicative of rocks with low magnetisation. A poorly defined magnetic low (>-100 nT) southwest of the field may be associated with thick (470 m) rhyolite (Broadlands Rhyolite) encountered in three wells (Br 6, 39 and 40). The extent of this rhyolite is unknown but from gravity modelling is inferred to be a northern flow of a more extensive dome to the south that lies along an axis parallel to the trend of the magnetic low (northeast-southwest). Three-dimensional magnetic modelling of the Broadlands Dacite and Broadlands Rhyolite are described below.

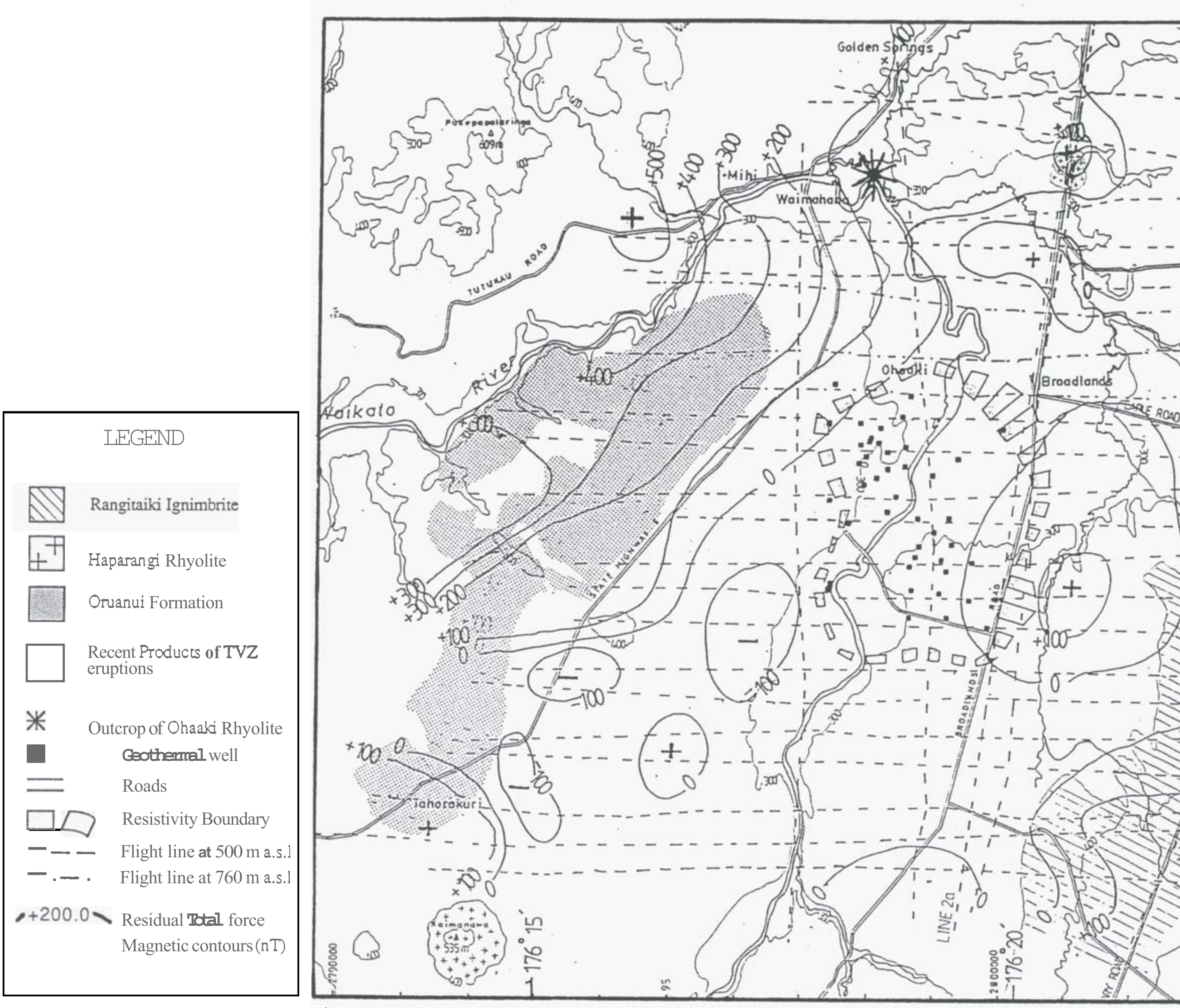

Figure 1
Residual total force magnetic anomaly map. **Contour** interval is **100** nT. Overlain is a simplified geology **from** Grindley **(1961) and** Wilson (pers comm., 1986). The resistivity boundary is **from Risk** et al. (1977). Map co-ordinates are from New Zealand metric grid.

Magnetisation

The quantitative modelling of magnetic anomalies requires estimates magnetic properties. Susceptibility measurements of core samples from Broadlands-Ohaaki wells have values $<10^{-6}$ (SI units) which is equivalent to a having zero magnetisation; no wells have been drilled outside the resistivity boundary. Only in well Br 5 are there any significant values of susceptibility recorded (290×10^{-5}). One sample only in Br 16 has susceptibility of 850×10^{-5}; base-metal sulphides are known to abundant in Br 16 (Browne, 1986). To date, only a few measurements of total magnetisation (remanent plus induced) have been made on volcanic rocks within the Taupo Volcanic Zone (TVZ) and outside the geothermal fields. Studies by Modriniak and Studt (1959), Hunt and Smith (1981), Whiteford and Lumb (1975a, b, c), and Rogan (1980) indicate that intensities of magnetisation for rhyolites range from <1 A/m to 7 A/m and have a mean of 2.5 A/m. Furthermore, magnetisation values between 2.3 and 2.5 A/m have been determined by modelling the topographic effect of rhyolitic domes within the Okataina Volcanic Centre (Rogan, 1980) and a rhyolite dome (Kaimanawa) south of Broadlands-Ohaaki (Figure 1). Dacites within the TVZ range from 1 to 3.3 A/m (Whiteford and Lumb; 1975a, b, c). Assuming tuff breccias, ash flows, and volcanic sediments have magnetisations of <0.5 A/m (Rogan, 1980), the magnetisation and magnetisation contrasts adopted for this study are listed in Table 1. It was also assumed that all rocks are normally magnetised (inclination -60°) and the mean declination of the magnetisation to be 0°. The effect of possible variations in the declination of up to ±20° in modelling the observed residual anomalies, discussed later, is found to be small.

Table I

Magnetisation and magnetisation contrast of rocks from the Taupo Volcanic Zone and the Broadlands-Ohaaki region

Rock type	Mean Magnetisation (A/m)	Magnetisation contrast with respect to non-magnetic tuffs, ash flows, and sediments (A/m)
tuff breccias ash flows volcanic sediments	<0.5	0.0
rhyolite (Ohaaki Rhyolite) (Broadlands Rhyolite)	2.3-2.5	> 1.8-2.0
dacite (Broadlands Dacite)	3.0	2.5-3.0

Broadlands Dacite

Isopachs of the Broadlands Dacite are shown in Figure 2. These contours were constructed using a combination of constraints imposed by borehole stratigraphy, and interpretation of seismic and gravity data (Henrys, 1987). The Broadlands Dacite has been intersected by nearly all wells drilled in the east of the geothermal field and extends over an area of about 16 km². The base of the dacite dome is assumed to be a horizontal plane lying at 300 m b.s.l., the top of the dome comes within 120 m of the surface near Br 16 (Figure 2) where it intersects the resistivity boundary. The resistivity boundary zone is taken to represent the near vertical limit of the hot water reservoir down to about 1 km depth (Risk et al., 1977).

Theoretical magnetic anomalies of the dacite were computed using the method of Barnett (1976). In this method the 3-dimensional dacite body are represented by polyhedrons composed of triangular facets. Best fit models were computed for 5 sections, 3 of which are shown in Figures 3, 4 and 5 (Lines 12, 13, and 2a of Figure 1). initially it was assumed that the dacite body is composed of uniform magnetisation contrast of 2.5-3.0 A/m (i.e. no part of the body is demagnetised). Cross sections corresponding to the dacite body are outlined in the thick line type in Figure 3, 4, and 5. The maximum calculated anomaly for such a body is 375 nT compared to the observed maximum of 150 nT (observed data are displayed as filled boxes). By truncating the Broadlands Dacite and only computing the effect of the body lying east of the resistivity boundary (shown by the stippled pattern in Figures 3 and 4); i.e. the body outlined in the thinner line, we obtained an independent check on the total magnetisation of the dacite. Anomalies computed with a

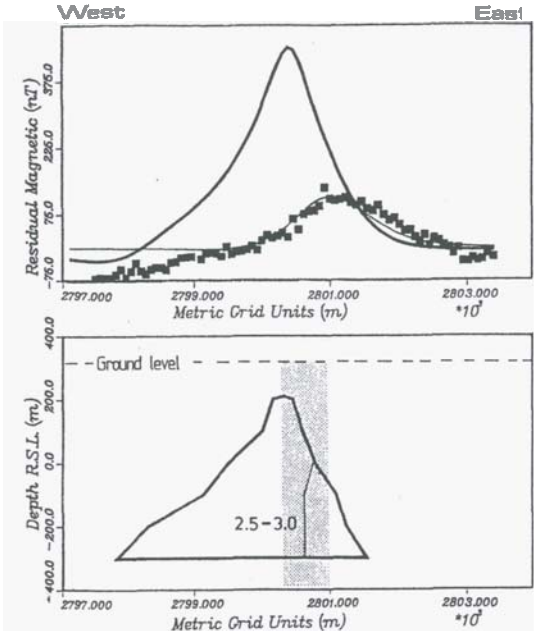

Figure 3
Observed. computed residual magnetic anomalies and interpreted cross section along cast-west flight line 12 (Figure 2). Observed magnetic values are shown by the filled boxes. The thick solid line is the computed magnetic anomaly corresponding to the body outlined in the thick line type. The thin continuous line is the computed magnetic anomaly corresponding to the body outlined in the thin line type. Figures in the section denote the magnetisation contrast (in A/m). The vertical resistivity boundary is shown by the stippled pattern.

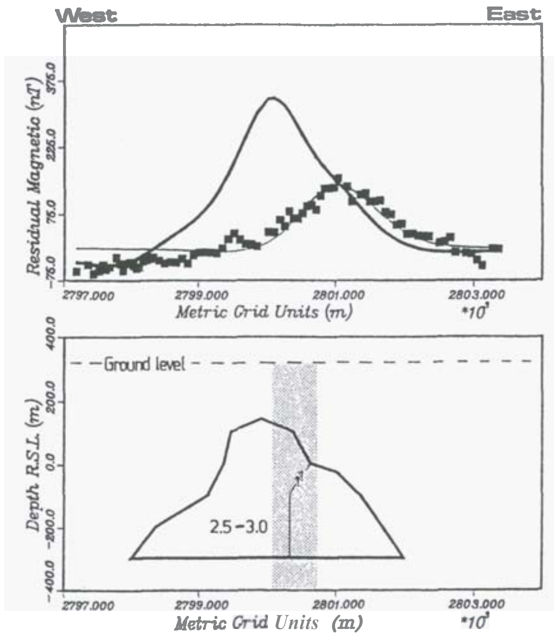

Figure 4
Observed, computed residual magnetic anomalies and interpreted cross section along cast-west flight line 13 (Figure 2). Details are the same as Figure 3.

magnetisation contrast of 2.5 A/m match both the observed low-level airborne and the ground level data.

The some of the dacite is considered to lie close to the margin of the geothermal field; where the flow is thickest, and may be associated with fault structures in the basement (Henrys, 1987). Delineation of feeder dykes is beyond the resolution of seismic reflection data (>100 m) acquired over the Broadlands-Ohaaki geothermal field.

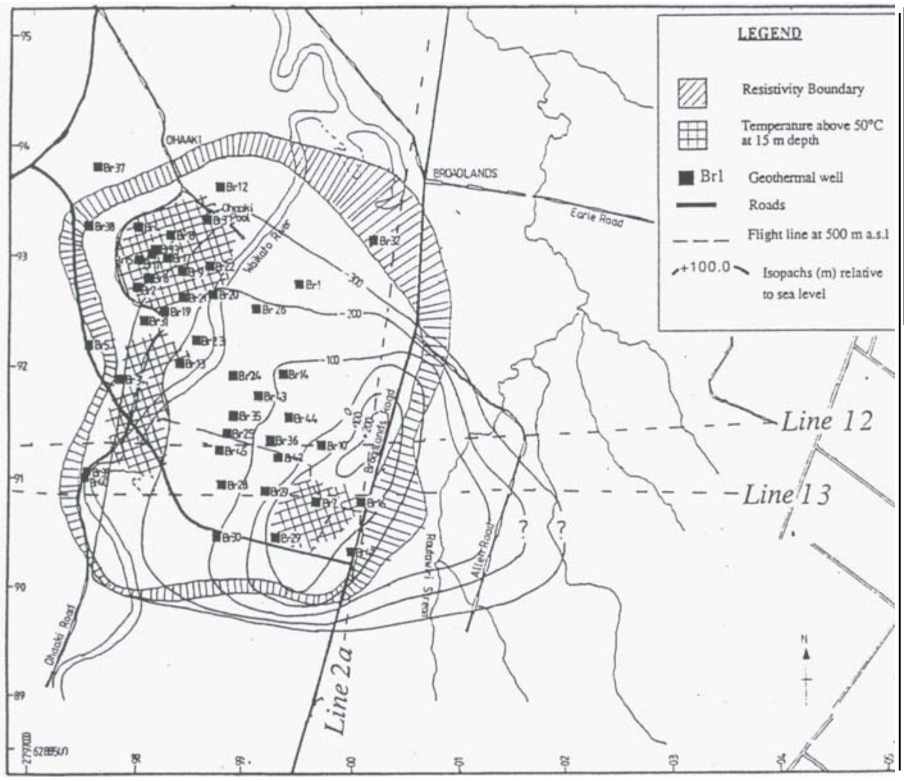

Figure 2
Isopachs of the Broadlands Dacite. Contours are consnucted from constraints imposed by bore hole stratigraphy, seismic, and gravity data. The resistivity boundary is from Risk et al. (1977).

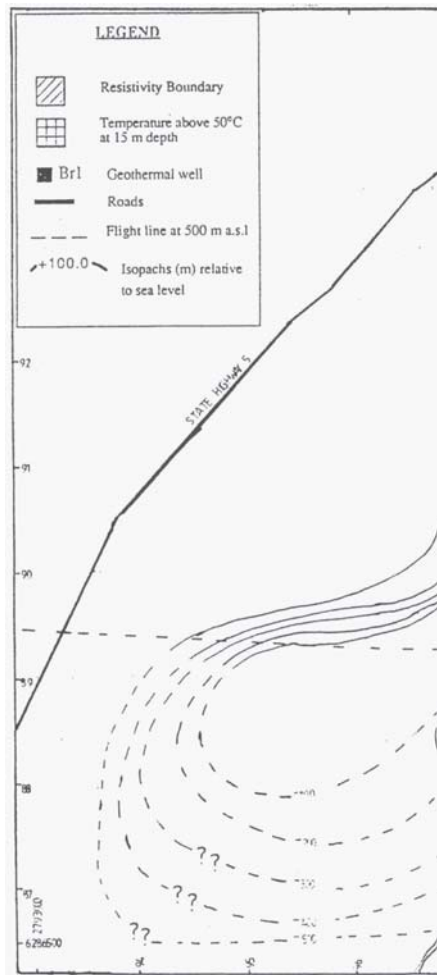

Figure 6
Isopachs of the Broadlands Rhyolite. Con
constraints imposed by bore hole stratigraphy,
resistivity boundary is from Risk et al. (1977).

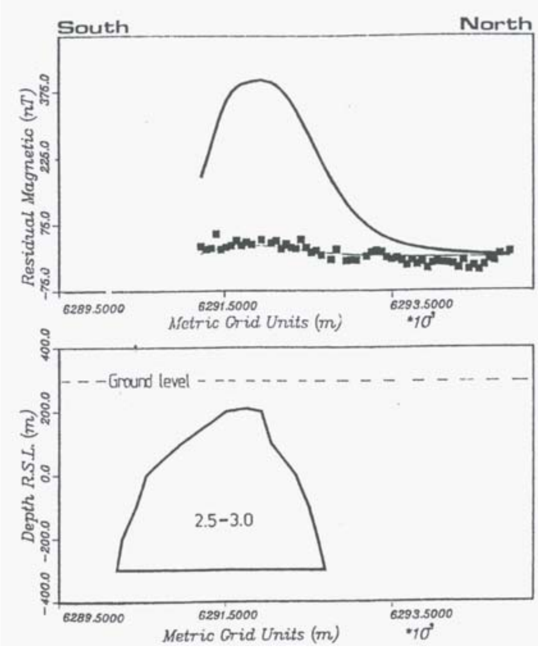

Figure 5
Observed, computed residual magnetic anomalies and interpreted cross section along north-south flight line 2a (Figure 2). Details are the same as Figure 3.

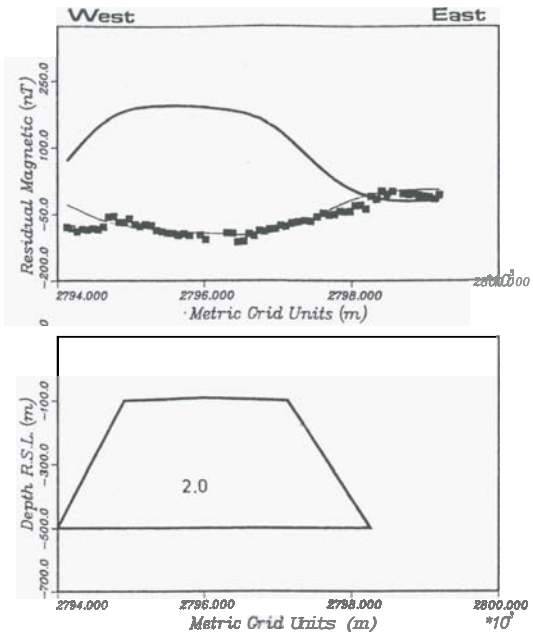

Figure 7
Observed, computed residual magnetic anomalies and interpreted cross section along east-west flight line 16 (Figure 6). Details are the same as Figure 3.

Broadlands Rhyolite

Isopachs of the Broadlands Rhyolite are shown in Figure 6. Although well constrained by gravity and seismic data in the north, contours defining the southern boundary are considered unreliable. Theoretical anomalies for this body were computed for 6 east-west profiles one of which is shown in Figure 7 (Line 16 in Figure 1).

Using a magnetisation contrast of 1.5-2.0 A/m (see Table 1) for the rhyolite will give the computed positive anomaly shown by the thick line in Figure 7. In order to fit the observed magnetic low on all profiles a contrast of about -1.0 A/m was required which indicates:

1. The rhyolite might be reversely magnetised,
2. The surrounding volcanics rocks have a magnetisation of >3.0 A/m (assuming that the magnetisation of rhyolites is 2.0-2.5),
3. The magnetisation of the Broadlands Rhyolite is about 0.5 A/m and surrounding rocks have magnetisation of 1.0-1.5 A/m.

Radiometric dating of the stratigraphically older Rangitaiki Ignimbrite gives an age of 0.23-0.36 m.y (Wilson et al., 1986) and lies within the period of dominantly normal polarity (Matuyama-Brunhes). In addition magnetic measurements made on samples of Rangitaiki Ignimbrite (Cox, 1971) indicate that it is indeed normally magnetised making it very unlikely that the overlying Broadlands Rhyolite is reversely magnetised. Given that the stratigraphy at Broadlands-Ohaaki is dominated by tuff and tuff breccias then it is also considered unreasonable for lithologies surrounding the Broadlands Rhyolite to have a magnetisation of >3.0 A/m. For this reason we believe that the magnetisation of the Broadlands Rhyolite is low *(0-0.5* A/m) compared to the average magnetisation of rhyolites within the TVZ (2.5 A/m).

Ohaaki Rhyolite

No attempt was made to quantitatively interpret magnetic anomalies northwest of the Broadlands-Ohaaki field since seismic and gravity data in the area are limited. The magnitude (>400 nT) and wavelength (>4 km) of these anomalies indicates that they are associated with a thick sequence of magnetic rocks. Unaltered ignimbrites and rhyolites of unknown thickness outcropping to the north and west of Broadlands-Ohaaki (Figure 1) may, in part, contribute to the observed anomaly. However, isopachs of the Ohaaki Rhyolite in the vicinity of the geothermal field have been constructed (Henrys, 1987) and are shown in Figure 8. The upper surface of the Ohaaki Rhyolite is known to reach an elevation of 340 m a.s.l near the power-house site. The top surface of this layer dips away to the north, east and south, suggesting that the highest point is west of this point. A local high point of the Ohaaki Rhyolite known from drilling in the vicinity of Br 17 occurs at an elevation of 246 m a.s.l. This high has in the past been interpreted as the centre of a dome overlying the source of the Ohaaki rhyolite. Gravity modelling and interpretation of seismic refraction data suggests that this area is within the thickest part of the rhyolite that continues to the northwest. An outcrop of rhyolite at Mihi (Figure 1) is lithologically and petrograhically similar to the Ohaaki Rhyolite (Grindley pers comm., 1987) On the basis of this evidence and separate seismic refraction studies near the power-house (Hicks, 1982) it is conceivable that the s o m e of the rhyolite is to the west of the Broadlands-Ohaaki geothermal field and part of more extensive rhyolites outcropping to the north and west.

Conclusions

The interpretation of residual magnetic anomalies over the Broadlands-Ohaaki geothermal field using constraints imposed by bore hole stratigraphy, seismic, and gravity data provided the following structural and rock properties information for the Broadlands Dacite, Broadlands Rhyolite, and Ohaaki Rhyolite:

1. The Broadlands Dacite dome extends over an area of about 16 km^2. The source of the dacite is considered to lie close to the margin of the geothermal field and may be associated with fault structures in the basement. A magnetic high associated with the Broadlands Dacite is attributed to the unaltered, normally magnetised (magnetisation contrast 2.5-3.0 A/m) dacite east of the resistivity boundary. This is consistent with the Broadlands Dacite inside the geothermal field having lost its magnetisation through a process of alteration.

2. The Broadlands Rhyolite located in the southern part of the field is associated with a poorly defined magnetic low (>-100 nT) extending to southwest. Modelling of this anomaly requires that the magnetisation of the rhyolite to be very low (0-0.5) This body is postulated to be a tongue of a dome that lies south of the Broadlands-Ohaaki geothermal field.

3. Isopachs of the Ohaaki Rhyolite suggest that flows thicken to the northwest. On the basis of this evidence the source of the rhyolite is likely to be west of the Broadlands-Ohaaki geothermal field being part of more extensive rhyolites outcropping to the north and west.

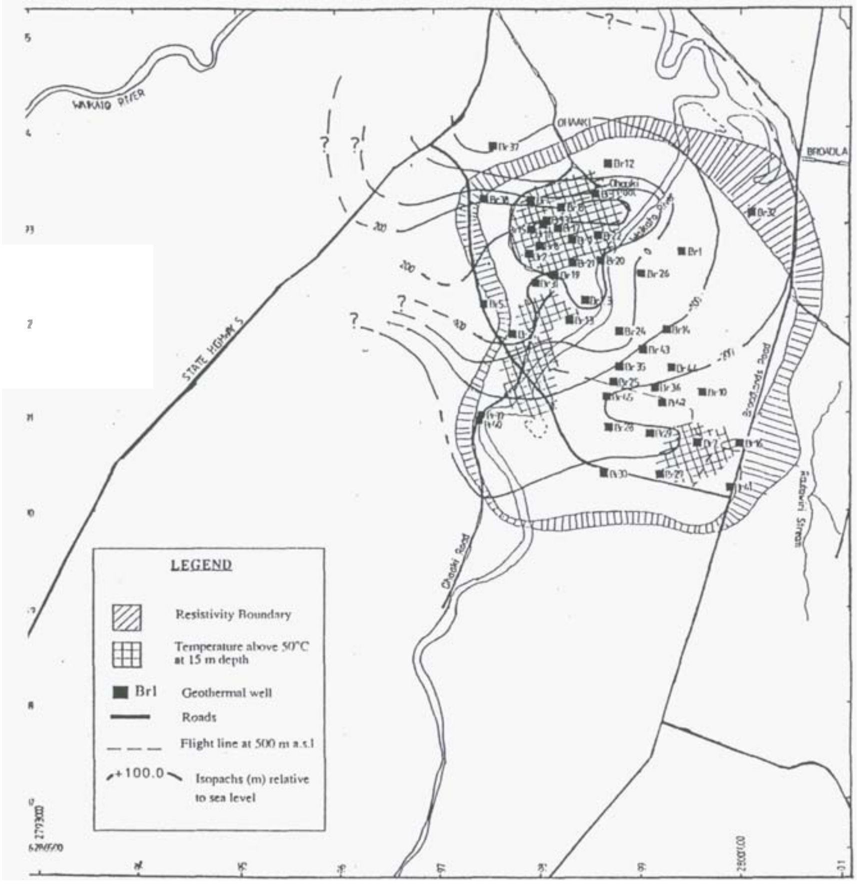

Figure 8
Isopachs of the Ohaaki Rhyolite. Contours are constructed from constraints imposed by bore hole stratigraphy, seismic, and gravity data. The resistivity boundary is from Risk et al. (1977).

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