MODELLING OF GRAVITY DATA FROM TONGARIRO NATIONAL PARK

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SUMMARY - Data, both from previous gravity surveys and recent measurements made across the Tama Lakes Saddle, have been used to calculate a Bouguer anomaly map for Tongariro National Park. Removal of a regional field represented by a third degree polynomial produces a residual anomaly map which covers an area of 40 km x 50 km.

Two-dimensional modelling across Tama Lakes Saddle shows that the data *can* be modelled predominantly by pyroclastic material of density 1.80Mg/m^3 overlying a high density basement. A thin cover of higher density andesites exists to the west of Tama Lakes. A 2-dimensional model across Ruapehu shows three layers (andesites, pyroclastics and basement) and a low density volcanic chimney. Three-dimensional modelling of the area around Ruapehu further elucidates this structure and reveals considerable topography in the high density basement.

The possibility is raised that the high density basement beneath Ruapehu itself may actually represent an andesite sill overlying greywacke. The gravity data alone is not able to distinguish whether this is the case but it is hoped that electrical data across the Tama Lakes Saddle, where a similar *structure* may exist, will be able to detect the presence of any magmatic component.

INTRODUCTION

Mt. Ruapehu and Mt. Ngauruhoe are located in the centre of Tongariro National Park. Geologically they mark the south-western end of the Taupo Volcanic Zone (TVZ) the region which contains nearly all the main geothermal fields of the North Island of New Zealand (*Figure* 1). The TVZ extends north-east along the eastern margin of the structurally important Central Volcanic Region and is marked on its eastern edge by a line of recently active andesitic and dacitic volcanoes.

Ruapehu is a large complex andesitic strato-volcano with a single active crater (diameter about 500m) filled by an acidic lake. The temperature of the lake is generally between 20 and 40^{0}C and has a highest recorded temperature of 60^{0}C. The crater has a pattern of intermittent hydrothermal-magmatic eruptions. The last lava ejection occurred in 1945 following which there have been violent phreatic eruptions (together with lake sediments, old lava blocks, and torn and comminuted ash and mud) in 1947, 1969, 1971 and 1975.

Ngauruhoe is a young andesitic strato-volcano, only about 2500 years old, with a summit crater. Recent lava eruptions occurred in 1949 and 1954 but the volcano is continually active and regularly emits steam charged with fresh ash or comminuted vent debris.

Figure 1. Location of the Taupo Volcanic Zone.

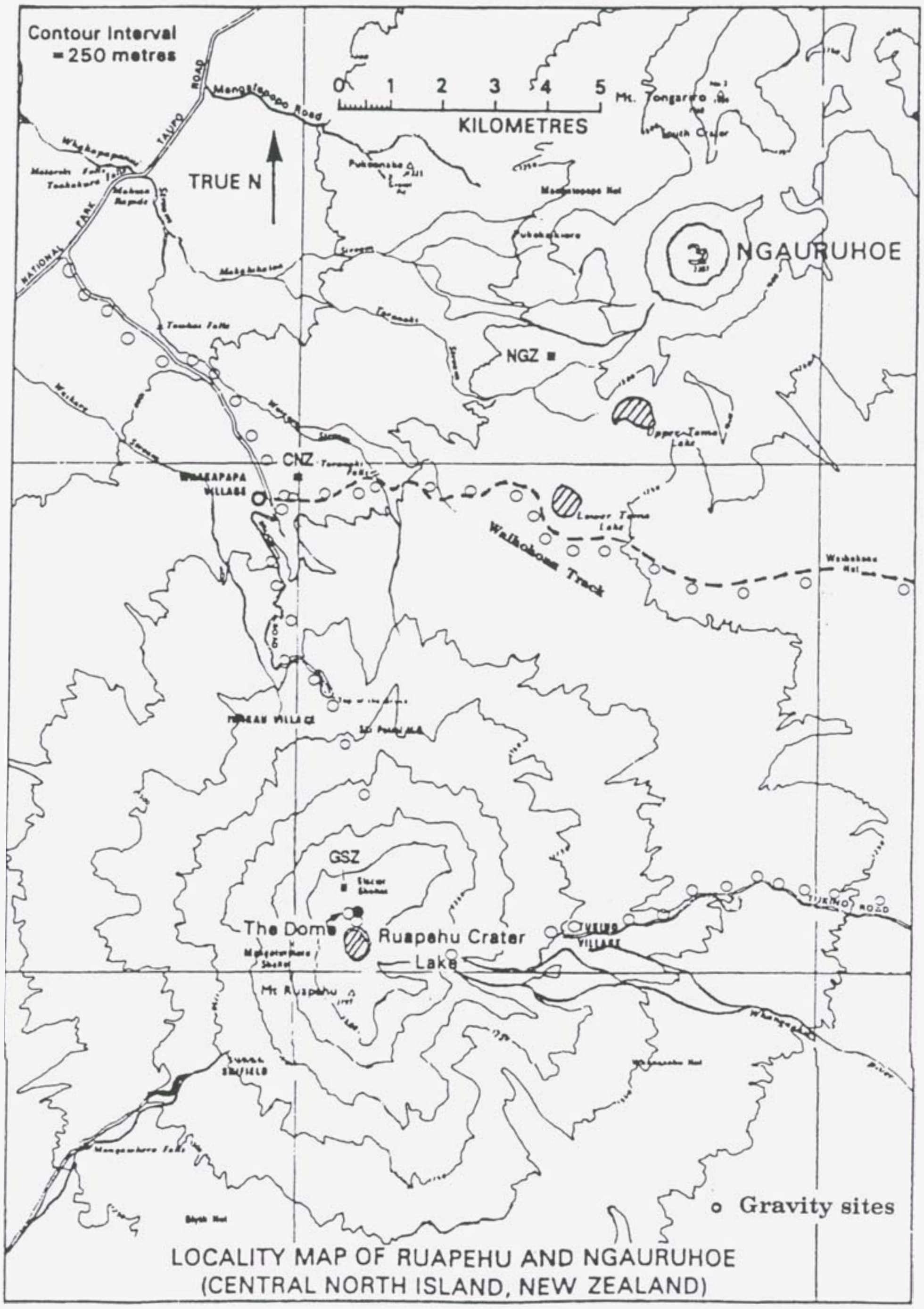

Figure 2. Location map of Tongariro National Park showing the two profiles of gravity stations discussed in the text and the locations of the permanent seismograph stations.

Previous geological and geophysical studies in the area are mostly restricted to descriptions of the surface geology and surveys of the Ruapehu crater. Early geological work mapping the surface distribution of andesite tephras and Taupo pumice was carried out by Grange & Hurst (1929), Grange & Williamson (1930) and Grange & Taylor (1931). The lava flows and lahar ring plains of the Tongariro Volcanic Centre were subsequently mapped by Grindley (1960), Grindley & Mathews (1965) and Mathews (1967). Surveys of Ruapehu's Crater Lake include work on the geochemistry (Giggenbach, 1974). bathymetry (Dibble & Christoffel, 1966) and temperature profiles (Christenson et. al., 1991). Seismic work in Crater Lake (Dibble, 1974) revealed the lake to be underlain by material with a P velocity of about 2 km/s. A more complete velocity profile through Ruapehu was obtained by Latter (1981) using the records of the three permanent seismograph stations CNZ, GSZ and NGZ (see figure 2). The focus of the earthquakes were also located with respect to depth.

Despite the existence of gravity data from around the volcanoes, and indeed. across Ruapehu, no attempt has previously been made to derive the density structure of the region. Similarly, despite the existence of eruption vents in the area, little is known of the vertical structure of the area, around the Tama Lakes, between the two volcanoes. This paper reports on new gravity data obtained through the Tama Lakes Saddle (Figure 2) and the modelling of this data, in association with older gravity measurements, in terms of the density structure both beneath Tama Lakes and across Ruapehu itself.

GRAVITY DATA

During December 1992 a profile of gravity measurements was obtained along the Waihohonu Track through the Tama Lakes Saddle. Site elevations were determined using a laser theodolite and related to the closest bench mark on the Desert Road. In addition to these 29 new measurements, 208 previous gravity measurements have been selected from the New Zealand gravity database. These older data were obtained using barometric levelling and thus can be considered to have an uncertainty of about 5 m in the elevation (Woodward, 1978). Given that that the heights of the base stations used were themselves determined by barometric levelling the final uncertainty in the older data probably amounts to about 2.2 mgals compared to about 1/10 of this for the 1992 data. Consistency between the new and old data where locations had been repeated suggests that there are no systematic errors between the two sets of data. Included in the older data, and shown in Figure 2, is a traverse of measurements which follows the Bruce Road, crosses the Ruapehu summit and descends the Tukino Road to the east. This includes data originally reported by Hurst & Dibble (1974).

The observations have been used to calculate the Bouguer gravity anomaly over an area of 40 km x 50 km which includes the summits of both Ruapehu and Ngauruhoe. Considering the wide distribution of andesitic rocks in the study area a density of $2.53 Mg/m^3$ (Alder, 1989) has been used for the Bouguer plate effect and terrain correction. Terrain corrections have been applied out to zone M. The resulting Bouguer anomaly map is shown in Figure 3(a).

As can be seen from this figure a large negative anomaly (-32 mgals) is associated with Ruapehu summit (279907E, 334194N). A very rough outline of a negative anomaly also exists around the Ngauruhoe summit but better resolution is precluded by the paucity of data in this region. In the north-west and south-east of the study area NE-SW trending contours reflect the existence of basement greywacke. The torsion belt of NW-SE trending contours (of about 27 km width) almost overlays the observed distribution of andesites and pyroclastics.

Sixtyeight sites located on outcropping greywacke and tertiary sediments were used to construct the regional anomaly by means of polynomial analysis. A third degree polynomial, considered to give the best representation of the regional "trend surface", is shown in Figure 3(b). Shown in Figure 3(c) is the resulting residual anomaly obtained by removal of this regional anomaly from the Bouguer anoamly of Figure 3(a). The removal of the regional elucidates the existence of a somewhat smaller negative anomaly to the east of the main negative anomaly associated with Ruapehu. Between the two volcanoes a broad ridge of negative gravity strikes almost N-S across the area of, and to the east of, Upper and Lower Tama Lakes.

MODELLING

Both 2 and 3-dimensional modelling has been performed on the data. Density values used in the modelling are listed in Table 1,

Rock Type	Density (Mg/m^3)	Depth (km)
Andesites	2.53	0 - 0.3
Pyroclastics	1.8	0 - 0.4
Pyroclastics	2.0	0.3 - 0.8
Greywacke	2.67	0 - 3.0

Table 1. Rock densities used in the modelling.

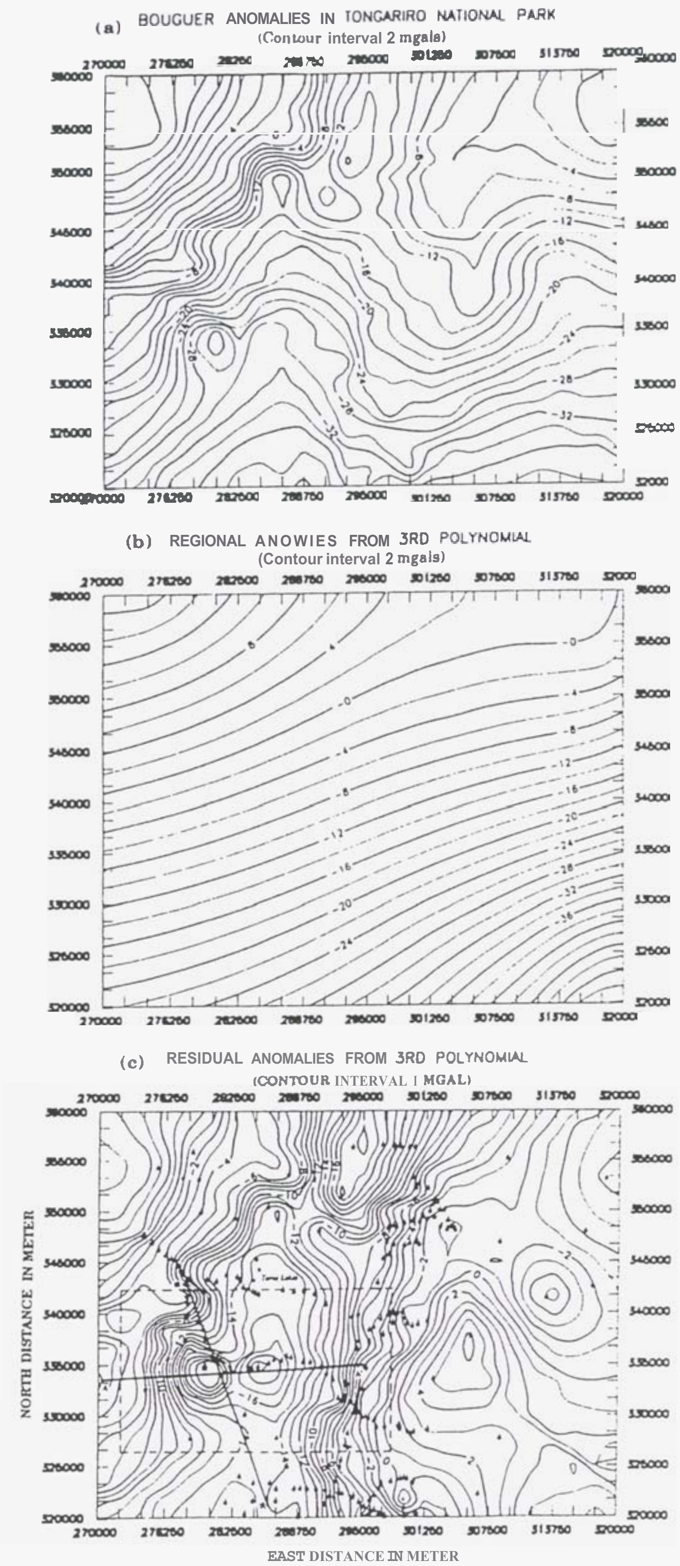

Figure 3. (a) Bouguer anomlies within Tongariro National Park. (b) 3rd order regional surface fitted to the data. (c) Residual Bouguer anomalies after subtraction of the regional. The dashed **box** shows the area of 3-D modelling. *Also* shown are the orientations of the two cross-sections discussed in the text.

and correspond to values obtained **by** Alder (1989) and the density change **of** volcanic **rocks** with depth as illustrated from boreholes in the Wairakei region (Hunt & **Harms,** 1990; **Stem, 1982).** For example the **mean** density value **of** pyroclastic **material was observed** by Alder to be $1.8 Mg/m^3$ whilst **tuff** densities increase **from** $1.7 Mg/m^3$ **at** the surface to approximately $2.2 Mg/m^3$ at **a** depth **of** 1 km.

A 2-dimensional model **which** provides **a** fit to the gravity data through **the Tama** Lakes Saddle is shown in Figure **4. This** is the region **of** the broad N-S **trending ridge observed** in **Figure** 3(c). The model **suggests** a **maximum** thickness of about 460m of pyroclastic and volcanic debris which extends some 20km to the east to where greywacke outcrops. To the west of Tama Lakes the pyroclastic debris is somewhat thinner **and is** overlain by about 100m of andesites. Although **greywacke** outcrops in the east and the density of $2.67 Mg/m^3$ is seen to form **a** continuous basement **beneath** Tama **Lakes, as is** discussed below, **this** does not preclude the possibility **that** under **the Lakes** themselves the higher density material may actually represent a magmatic intrusion.

An initial 2-dimensional model **has** also been constructed to give **a** fit to the data **observed** across the summit of **Ruapehu. This** model is shown in Figure 5. The main outline of the **Ruapehu** volcanic structure **has** previously been determined by Latter (1981) **using** seismic data from the three permanent seismograph **stations** GSZ, CNZ, NGZ. As can be seen from Figure **5**, the gravity model **fits with** the basic **structure suggested** by Latter. Three **main** layers form the strato-volcano. The top layer is andesitic lava with **a** thickness of about 200 m which overlies a much thicker layer of pyroclastic and laharic material. Again the pyroclastic material is asymmetric with greater thickness to the east. The The underlying **high** density layer **was** interpreted by Latter to be either greywacke or **tertiary** sediments and can be Seen to have **a marked** uplift beneath the summit of the volcano. Above **this, a** low density volcanic neck dike rises about 1 km to connect to the crater.

In an attempt to derive information on the possible 3-dimensional ***structure*** associated with Ruapehu a 3-dimensional gravity model has been fitted to the Bouguer residual anomalies shown in **Figure** 3. This **has** concentrated on the area surrounding Ruapehu and covers only about the south-westem 25% of the **area** shown in **Figure** 3. The 3-dimensional gravity result **calculated** from the model is shown in Figure 6 **whilst** the model itself is presented in the form of approximately **N-S and** E-W cross-sections (locations **marked** on **Figure** 3(c)) in **Figures** 7(a) and 7(b). Not

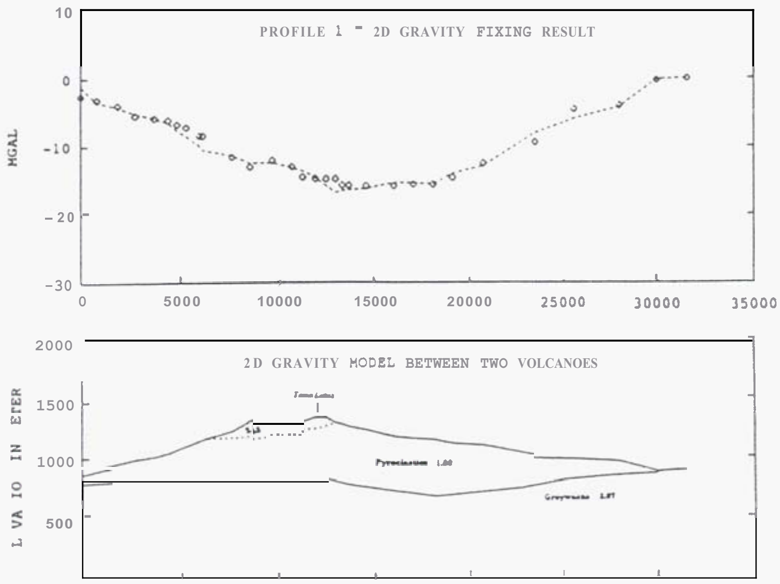

Figure 4. 2-D gravity model across Tama Lakes Saddle.

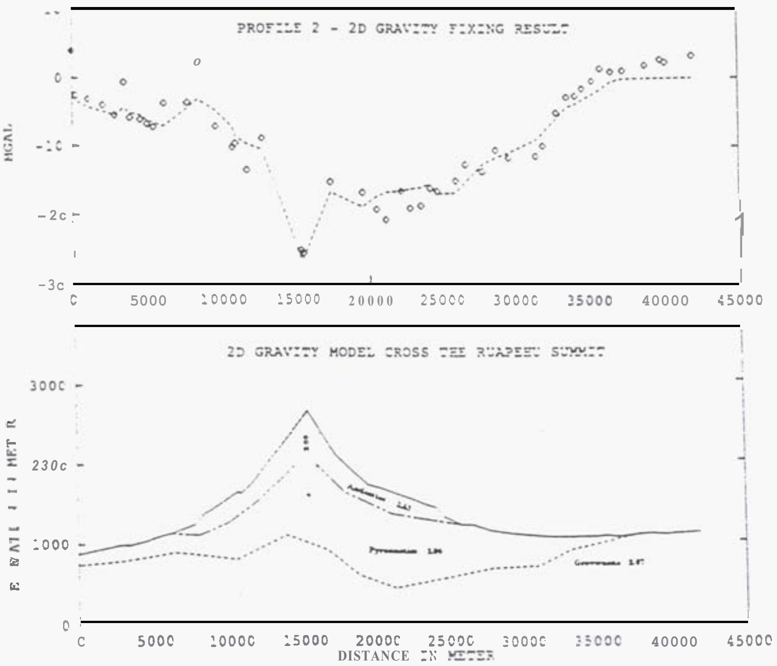

Figure 5. 2-D gravity model across Ruapehu.

shown in these cross-sections is the cylindrical plug of diameter 500m and density $2.23 Mg/m^3$ which models the volcanic chimney connected to the crater itself.

The 3-dimensional model successfully reproduces both the main negative anomaly associated with Ruapehu and the secondary negative anomaly to the east. Similarly the tongue of higher gravity immediately to the north of the volcano is also modelled. The model cross-sections show the thickness of low density material (i.e. pyroclastics and laharic material) to be about 1000 m beneath the summit. The andesite cover is about 650 m thick at the summit but thins markedly on the slopes. The andesites appear to be generally thicker to the north and south (Figure 7(a)) than to the east and west (Figure 7(b)). The uplift of denser material at depth is much smoother in the N-S direction than in the E-W direction. In this latter orientation there is an apparent basement uplift of about 500 m with a width of about 10km. Associated with this is a depression in higher density material immediately to the east of Ruapehu (Figure 7(b)).

DISCUSSION

The very small difference in the rock density between greywacke ($2.67 Mg/m^3$) and andesite ($2.53 Mg/m^3$)

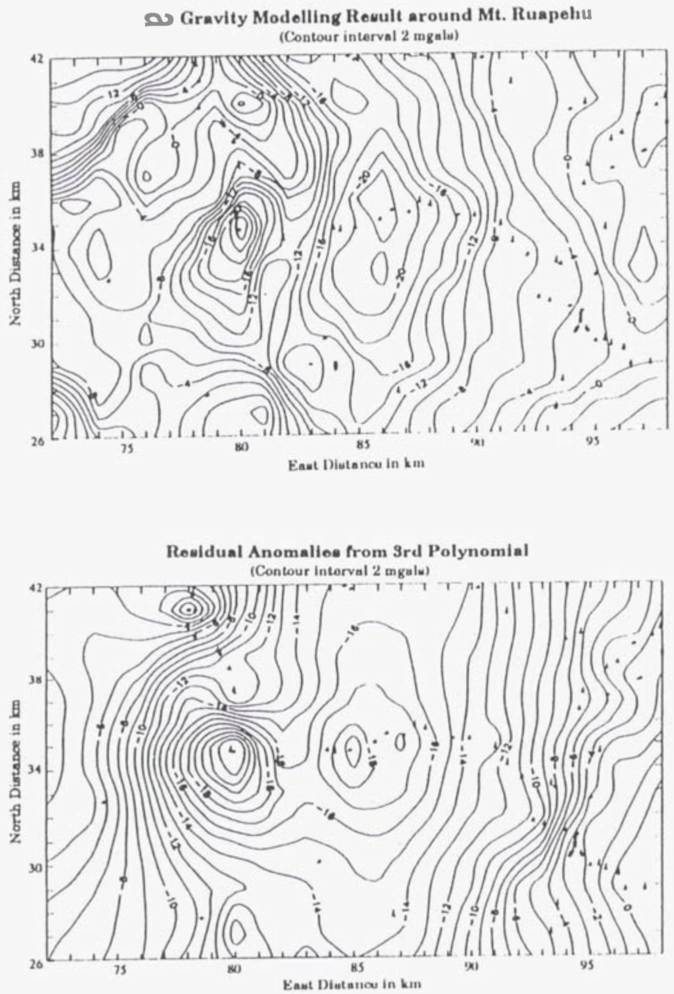

Figure 6. Observed residual Bouguer anomalies from the area around Ruapehu and the result of 3-D gravity modelling of this area.

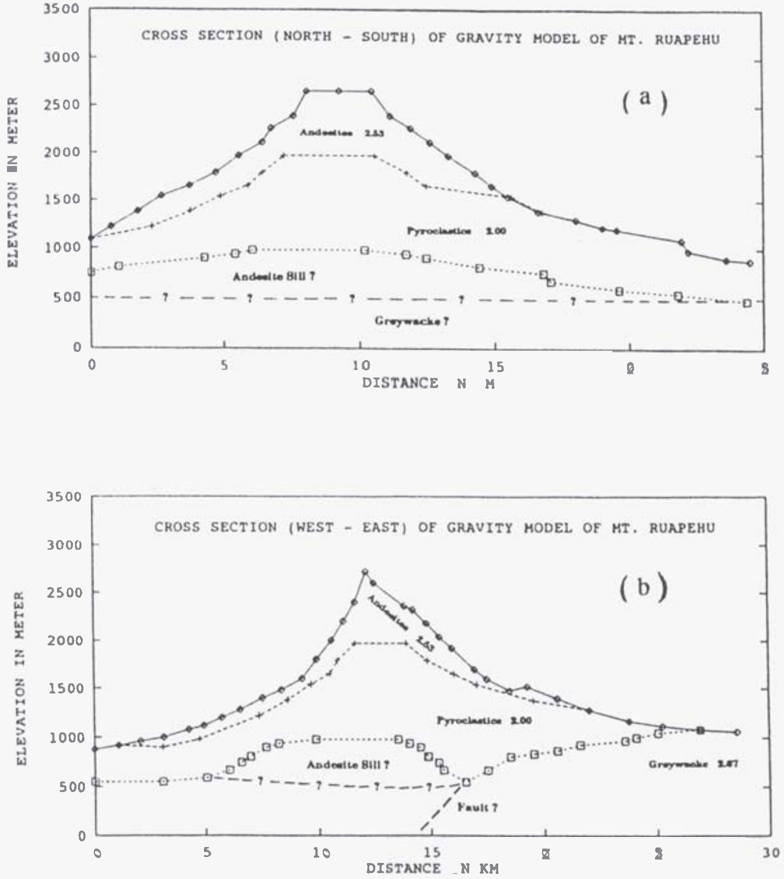

Figure 7. (a) NS cross-section (A-A') through 3-D gravity model. (b) EW cross-section (B-B') through 3-D gravity model.

means that they cannot be readily distinguished using gravity data alone. This raises the possibility that in all of the gravity models the high density "basement" layer may not necessarily represent a continuous greywacke basement. A possible indication that this is in fact not the case is provided by the published petrology of ejecta from previous eruptions of Ruapehu. In the April 24, 1975 eruption of Ruapehu the ejecta were reported (Nairn et. al., 1979) to consist of lake sediments, andesite and breccia fragments, plagioclase and pyroxene crystals. Ballistic ejecta collected from the summit area included scoriaceous blocks up 25 cm across. The eruptions of June 21 1969 and April 23 1975 included lake sediments, solidified andesite and fresh magma. No reports exist of greywacke as a content of eruptions suggesting that none may exist in the proximity of the eruption channel.

The E-W cross-section shown in Figure 7(b) shows considerable topography in the high density basement. From its outcrop in the east the greywacke basement dips at about 2^0 up to a point about 6 km east of Ruapehu. At this point the dip increase sharply and may indicate the presence of faulting associated with volcanic subsidence. The rise in high density material to the west of this point might then be due to the presence of an andesite sill resulting from lateral migration of magma. Volcanic seismicity at Ruapehu has shown a lateral distribution of microearthquakes beneath the pyroclastic material at locations where no vent is in existence(Latter, 1981). This may well indicate the presence of magmatic intrusions at depth.

The Tama Lakes Saddle model (Figure 5) might be interpreted similarly. From its outcrop in the east the basement shows a similar westward dip, although without the marked change in slope observed in Figure 7(b). However, a similar rise in the high density layer occurs beneath Tama Lakes themselves. In this region of less extreme topography determination of the electrical resistivity structure might provide a means of testing the different possibilities. A purely greywacke basement would be expected to have considerably higher resistivity than would be found should a magmatic component be present.

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REFERENCES

ALDER, G.F., 1989. Seismic and gravity studies of Tokoroa gravity anomaly, North Island, New Zealand, Unpublished MSc thesis, Victoria University of Wellington.

CHRISTENSON, B.W., BLICK, G.H. & CRUMP, M.E. 1991. Ruapehu Crater Lake bathymetry, temperature profile and water column chemistry, Febuary 1991, Unpublished Report, Institute of Geological and Nuclear Sciences.

DIBBLE, RR. 1974. Seismic explosion in Ruapehu Crater Lake on 13 April 1974, *New Zealand Volcanology Record* No.4, Volcano and Geothermal Observations 1974.

DIBBLE, R.R. and CHRISTOFFEL, D. 1966. Temperature and depth of Crater Lake, Unpublished report, Victoria University of Wellington.

GIGGENBACH, W. 1974. The chemistry of Crater Lake, Mt. Ruapehu (New Zealand) during and after the 1971 active period, *New Zealand* Journal of *Science,* Vol. 17, pp. 33 - 45.

GRANGE, L.I. and HURST, J.A. 1929. Tongariro subdivision, *NZ. Geological Survey* 23rd Annual Report: 5 - 8.

GRANGE, L.I. and TAYLOR, N.H. 1931. Reconnaissance soil survey of the central part of the North Island, *N.Z. Geological Survey* 25th Annual Report: 7 - 8.

GRANGE, L.I. and WILLIAMSON, J.H. 1930. Tongariro subdivision, NZ. *Geological Survey* 24th Annual Report: 10 - 3.

GRINDLEY, G.W. 1960. Sheet 8 Taupo. "Geological map of New Zealand 1:250000." N.Z. Department of Scientific and Industrial Research, Wellington.

GRINDLEY, G.W. and MATHEWS, W.H. 1965. Geological map of National Park volcanoes. In New Zealand volcanology - Central Volcanic Region. N.Z. Department of Scientific and Industrial Research Information Series 50.

HUNT, T. M. and HARMS, C. (1990): Gravity survey of the Rotokawa Geothermal Field, *Proceedings of the 12th New Zealand Geothermal Workshop*, pp. 91-92.

HURST, A.W. & DIBBLE, R.R., 1974. Repeat gravity surveys on Ruapehu, 1970-1974. Report no. 100, Geophysics Division, DSIR.

LATTER, J.H., 1981. Volcanic earthquakes, and their relationship to eruptions at Ruapehu and Ngauruhoe volcanoes, New Zealand, *Journal of Volcanology and Geothermal Research,* Vol. 9, pp. 293-309.

MATHEWS, W.H. 1967. A contribution to the geology of the Mount Tongariro massif, North Island, New Zealand, *NZ Journal of Geology and Geophysics,* Vol. 10, No.4, pp. 1027-38.

NAIRN, I.A., WOOD, C.P. & HEWSON, C.A., 1979. Phreatic eruptions of Ruapehu: April 1975, *NZ Journal of Geology and Geophysics,* Vol. 22, pp. 155-73.

STERN, T.A., 1982. Seismic and gravity investigations of the Central Volcanic Region, North Island, New Zealand. Unpublished PhD thesis, Victoria University of Wellington.

WOODWARD, D. J. and HICKS, S. R. (1978): Gravity models of the Wairarapa region, New Zealand, *NZ Journal of Geology and Geophysics,* Vol. 21, No. 1, pp. 539-44.