NUMERICAL MODELLING OF MAGNETOTELLURIC SOUNDINGS FROM THE CENTRAL VOLCANIC REGION

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SUMMARY - Two-dimensional numerical models have been constructed for two traverses across the eastern margin of the Central Volcanic Region. A detailed conductivity structure is required in the upper 5km to fit the observational data. The principal feature of this near surface structure is that relatively conductive material is required at 2-3km depth throughout the CVR. Crustal and upper mantle resistivity beneath the CVR is of the order of 250-1000 ohm-metres which indicates temperatures of around 1000°C at quite shallow depths. The numerical models can be correlated quite well with tectonic models of the CVR based on seismic and gravity data.

1. INTRODUCTION

Ingham (1989, 1990, 1991) has presented the results of magnetotelluric soundings of the Broadlands-Ohaaki geothermal field and of the eastern margin of the Central Volcanic Region (CVR). The purpose of these measurements is to build up a picture of the electrical conductivity structure of the region which ultimately can be related to the tectonic structure of the central North Island. Thus far data have been interpreted in a preliminary manner by means of 1-dimensional modelling of invariant apparent resistivity and phase responses (Ingham, 1990). The purpose of this paper is to present 2-dimensional numerical models constructed to fit the data from two traverses which are perpendicular to, and cross, the eastern boundary of the CVR. Although the models are non-unique they give a fit to both E and H-polarisation data from the two traverses and the conductivity structure which they show can be correlated to other geophysical evidence available from the CVR.

The locations of the sites from which data are available are shown in Fig. 1. The Kaingaroa Fault marks a major near surface boundary in the electrical structure with generally more conductive conditions to the northwest. The locations of the two traverses for which models are presented are shown as AA' and BB'. The former essentially parallels State Highway 5 and crosses the Wairakei-Tauhara geothermal field. The shorter traverse BB' is to the south of the Broadlands-Ohaaki field. Although the site is slightly off line data from BUR is included in this traverse because it is the only site in this area from which long period (T>100s) data are available.

The numerical modelling technique which has been used is the finite difference technique of Brewitt-Taylor and Weaver (1976). For a given model the E and H-polarisation responses (both apparent resistivity and phase) have been calculated for up to 14 different periods of variation and the results presented as smooth curves superimposed on the field response curves for each site. Because of quite a large degree of scatter in the data at some sites (partly due to lack of signal power in the period range 0.1-10s and partly attributable to cultural noise) a quantitative calculation of the degree of fit of any given model has not been made. Instead emphasis has been placed on how well the model response fits the general smooth trend of the data at each site. Up to periods of around 1s weight has been placed on fitting both apparent resistivity and phase responses. At longer periods, for which the phase data are poor, greater emphasis has been placed on achieving a good fit to the apparent resistivity data.

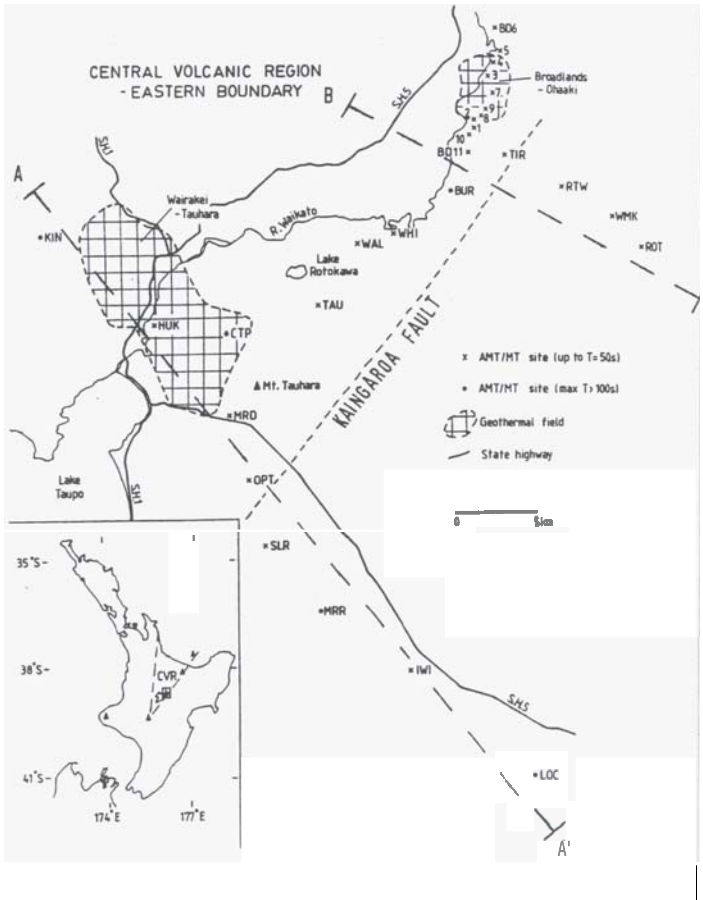

Figure 1. MT sites and traverses AA' and BB' across the eastern boundary of the Central Volcanic Region.

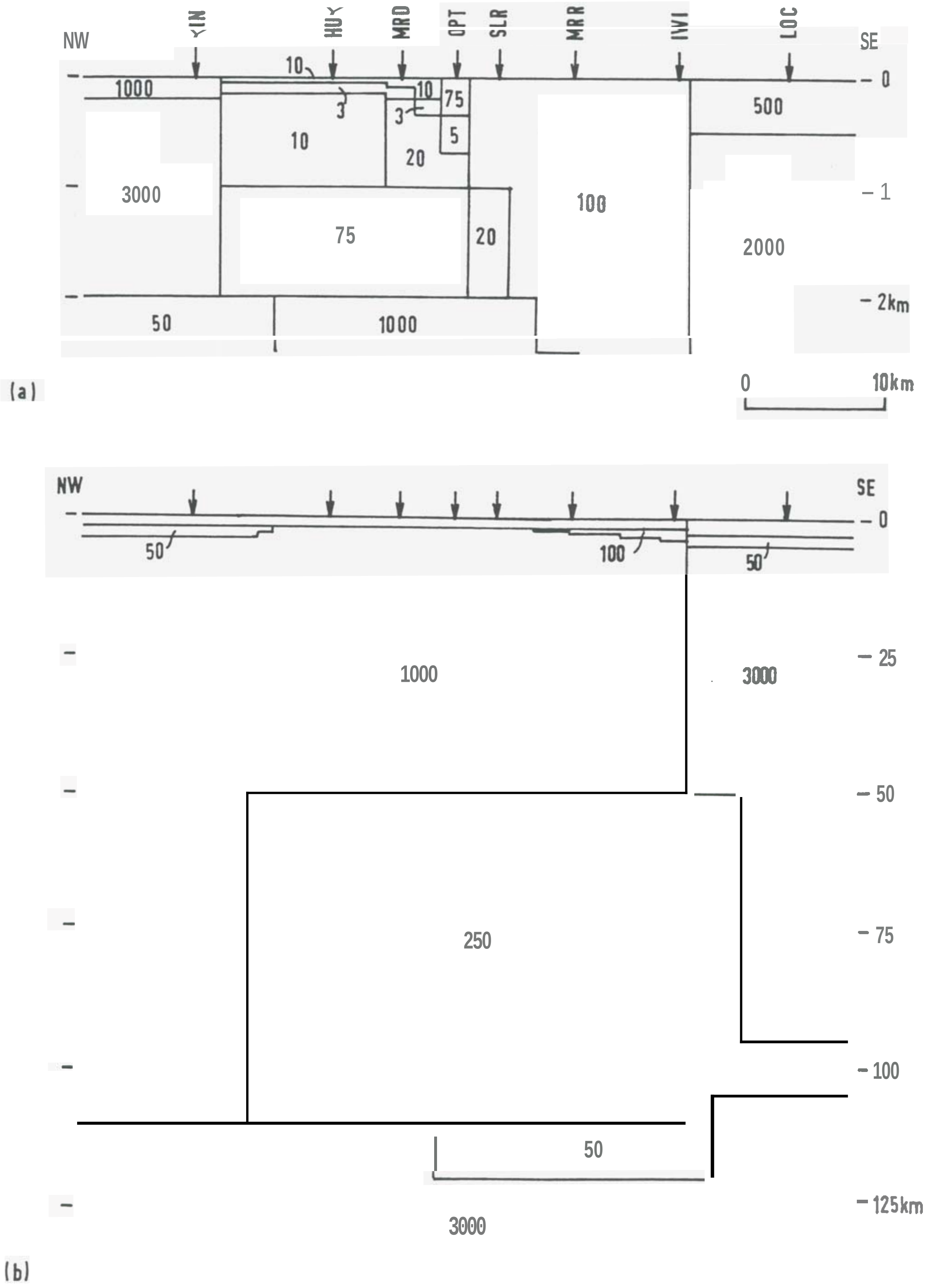

Figure 2. Resistivity model for traverse AA'.

2. TRAVERSE AA'

Shown in Fig. 2 is the electrical structure which has been found to give a fit to the data from the sites on traverse AA'. Fig. 2a shows the detailed structure of the uppermost 2.5km of the model with the deeper structure shown in Fig. 2b. The numbers shown are the resistivities of the different units in ohm-metres. The fit of this model to the data from sites MRD and OFT is shown in Fig. 3.

The following points concerning the model are worth stressing.

- A complex electrical structure is required in the upper 5km to model the great variation in responses at the different sites.

- The Wairakei-Tauhara geothermal field is represented by resistivities of 10 ohm-metres and less in the first km of depth. Beneath this a resistivity of 75 ohm-metres is modelled which should be regarded as being representative of a gradual increase in resistivity rather than an actual sharp boundary.

- Low resistivities dip to both the northwest and the southeast and are required in particular benath MRD to model the low apparent resistivity values at this site. A resistivity of 20 ohm-metres between 1 and 2km depth is required for a short distance to the east of the Kaingaroa Fault to fit the short period phase data from OPT.

- Although relatively low resistivities are modelled to 4km depth to the northwest of the Wairakei-Tauhara geothermal field, KIN is the sole site in this vicinity and the resolution of structure in this region of the model is poor. Such an increase of conductivity with depth in the first few kilometres of the earth does, however, appear to be a typical feature of sites in the CVR outside geothermal fields.

- A resistivity of 250-1000 ohm-metres has been modelled throughout the crust and upper mantle beneath the CVR. To provide greater resolution than this more long period data are necessary. At present a resistivity of either 250 or 1000 ohm-metres throughout the lower crust-upper mantle would give a similar fit to the data. Compared to "normal" crustal-upper mantle resistivities of some 1000's of ohm-metres, this resistivity beneath the CVR is atypically low.

- A conductor at about 100km depth is required to fit a flattening of the apparent resistivity curves at LOC at 100s period.

It should be noted that it has not been possible to model very long period responses (T>1000s) at LOC. Inclusion of the Pacific Ocean and the Tasman Sea as 2-dimensional features in the model confirms that at such long periods the data are sensitive to the surrounding oceans. This is also indicated by analogue 3-dimensional modelling of New Zealand reported by Chen et. al. (1990). It seems likely that the land-ocean conductivity contrast places an upper limit in period of around 100-1000s on the use of MT soundings for determining subsurface conductivity structure within New Zealand.

3. TRAVERSE BB'

The numerical model constructed to fit the data from traverse BB' is shown in Fig. 4. Fig. 5 shows the fit which the model gives to the data from BUR. The conductivity structure shown in Fig. 4 is broadly similar to that for traverse AA' in that a relatively conductive region of 10-20 ohm-metres resistivity is required in the upper 2-3km of the CVR to give a fit to the data. As for traverse AA' some extension of this structure to the southeast of the Kaingaroa Fault is indicated. Again, upper mantle resistivity is modelled as 1000 ohm-metres and, again, a model with a value of 250 ohm-metres provides an almost equally good fit to the data. As for traverse AA' a good conductor is required beneath 100km depth to give the observed maximum in the apparent resistivity curves at BUR.

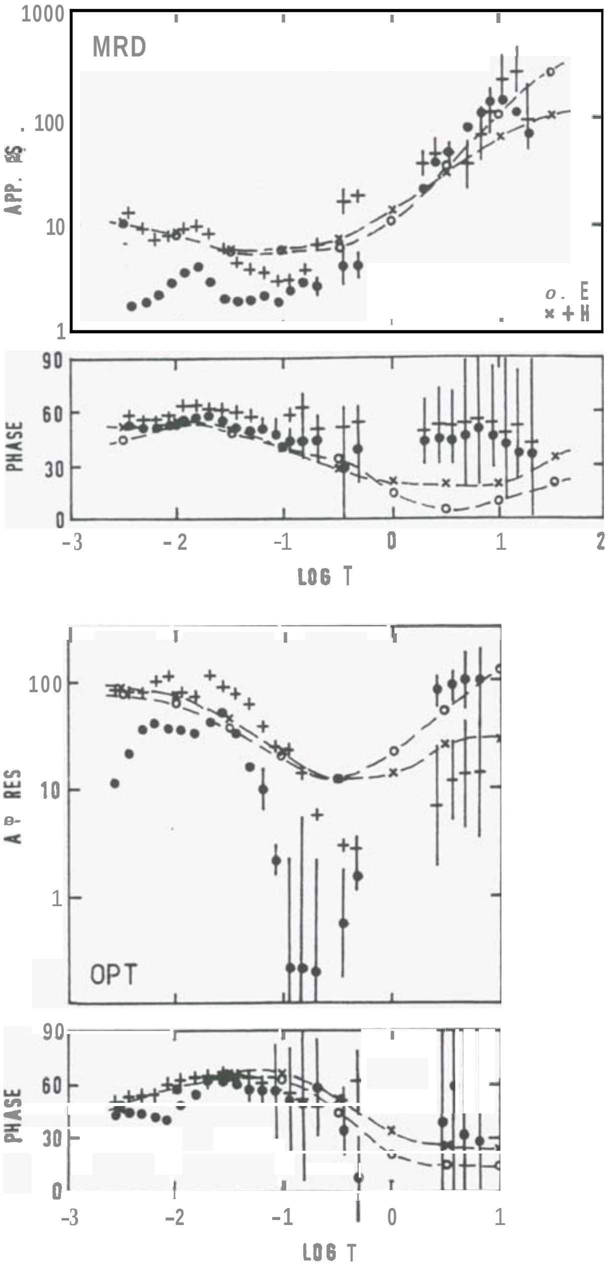

Figure 3. Field curves and model responses at sites MRD and OPT on traverse AA'.

4. DISCUSSION

A full discussion of the modelling results will be presented elsewhere, at present only the most important points and

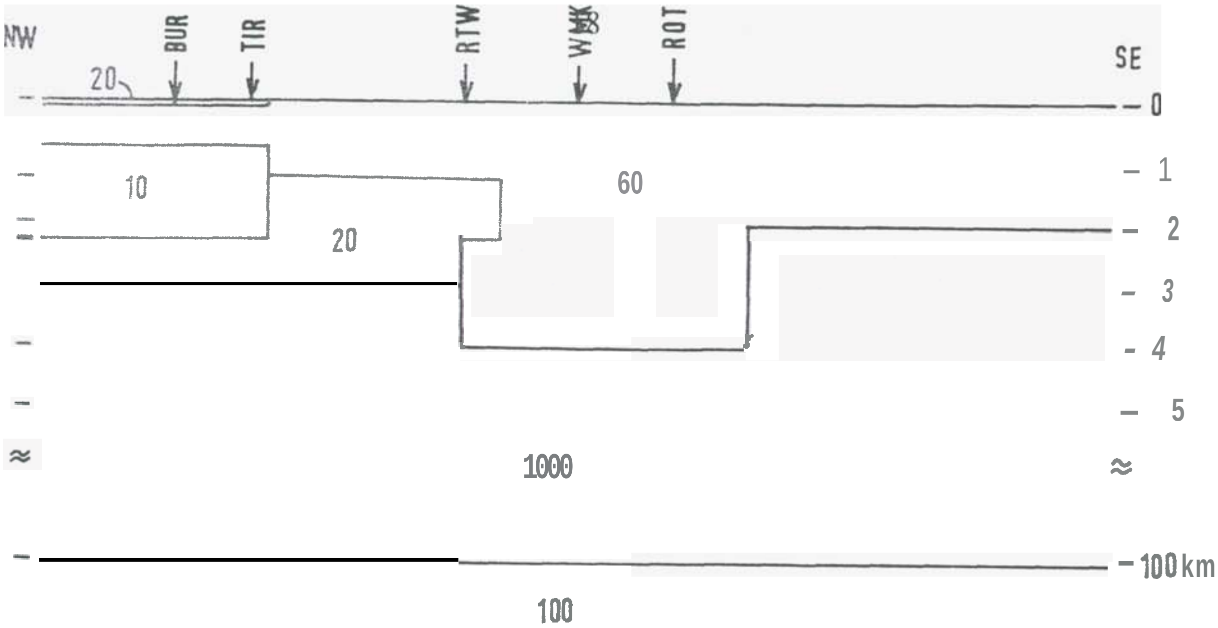

Figure 4. Resistivity model for traverse BB'.

comparisons with recent tectonic models for the CVR will be mentioned. Recent models of the tectonic structure of the CVR have been presented by Reyners **(1980)**, Stern and Davey **(1987)** and Smith et. al. **(1989)**. These have been based largely on seismic, gravity and heat flow data and indicate a crustal thickness of around **15km** beneath the CVR. To the northwest the crust is also thinner than normal continental crust with a thickness of some 25km. Southeast of the CVR more normal thicknesses prevail. Of importance with regard to electrical conductivity, Stem and Davey **(1987)** suggest the existence of partial melt within the upper mantle beneath the CVR. *An* earlier interpretation of the conductivity structure beneath the CVR (Ingham, **1987)** suggested that low resistivities, which could result from partial melt, do indeed exist at the appropriate depths.

The present modelling results, **as discussed** above, confirm that the resistivity throughout the crust and upper mantle, although not well resolved, is of the order of **250-1000 ohm**-metres. Given typical crustal and upper mantle constituents, laboratory studies of electrical conductivity (e.g. **as** summarised by **Haak, 1980)** indicate that temperatures of the order of **1000°C** are necessary to produce such resistivities. Stern et. al. **(1987)**, quoting Pandey **(1981)**, suggest that to the northwest of the CVR temperatures probably reach this value at around 30-35km depth. Given the much higher heat flow within the **CVR** such temperatures are likely to prevail at even shallower depths. Furthermore, models of the conductivity of mixtures of solid and liquid phases suggest that only very small amounts of partial melt **are** necessary to significantly lower the bulk resistivity. The reduction of melting point required to produce melt **at** lower temperatures can be brought about by the presence of water in the upper mantle. Electrical studies of the Juan de Fuca subduction system (e.g. **Kurtz** et. al., **1986)** have suggested that water can be introduced into the mantle by the subduction of saturated sediments. In the present case it is interesting to note that the depth of 100km to the conductor required to fit the data at LOC is approximately the same **as** the depth to the subducted plate **as** interpreted by Reyners **(1980)**, Stem and Davey **(1987)** and Smith *et.* al. **(1989)**.

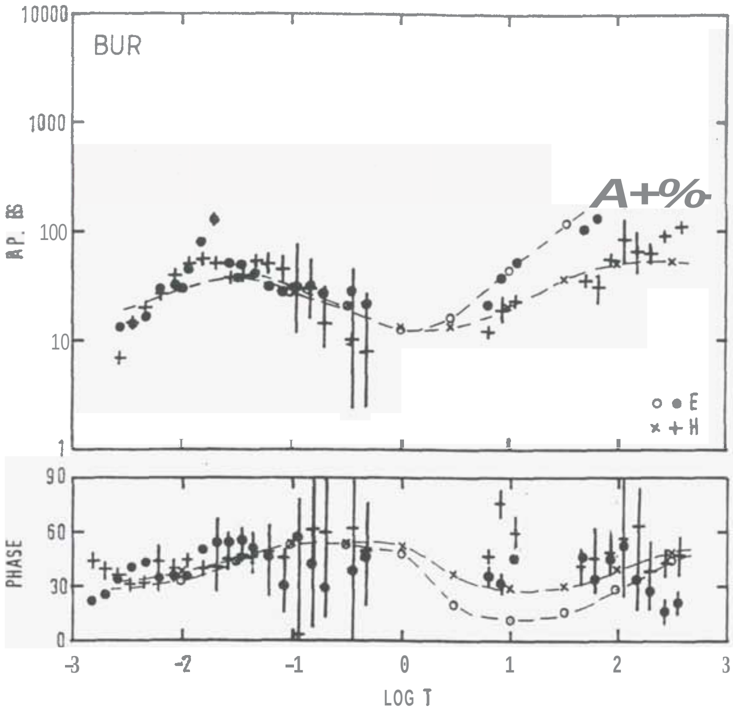

Figure 5. Field curves and model responses at site BUR on traverse BB'.

The lack of a conductivity **boundary** which can be correlated with the base of the crust beneath the **CVR** is not surprising. Electrical conductivity is primarily responsive to temperature rather than rock **type** and it is likely that there is a gradual change in resistivity with depth rather than a discontinuity.

At shallower depths the conductivity structure is very detailed but, generally, can be quite well modelled 2-dimensionally. It seems clear that at the **eastern** margin of the CVR the Kaingaroa Fault marks a boundary to the northwest of which conductive material exists at 2-3km depth. This apparent structural difference is probably the result of temperature differences but whether it is a feature which is associated with the CVR as a whole, or only the Taupo Volcanic Zone along the eastern edge of the CVR, is still to be determined. Similarly the more resistive material at depth at the eastern end of traverse AA' can most likely be attributed to a different thermal regime but requires further data to better resolve the structure.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Brewitt-Taylor, C.R. and Weaver, J.T. (1976). On the finite difference solution of two-dimensional induction problems. ***Geophys. J.R. astr. Soc.***, Vol. 47, 375-396.

Chen, J., Dosso, H.W. and Ingham, M. (1990). Electromagnetic induction in New Zealand analogue model and field results. ***Phys. Earth Planet. Int.***, Vol. 63,257-270.

Haak, V. (1980). Relations between electrical conductivity and petrological parameters of the crust and upper mantle. ***Geophysical Surveys***, Vol. 4, 57-69.

Ingham, M. (1987). Lower crustal and upper mantle electrical conductivity contrasts in the central North Island of New Zealand. ***Phys. Earth Planet. Int.***, Vol. 49,304-313.

Ingham, M. (1989). Audiomagnetotelluric/magnetotelluric soundings of the Broadlands-Ohaaki geothermal field ***Proc. 11th NZ Geothermal Workshop***, 39-44.

Ingham, M. (1990). Electrical conductivity structure of the eastern margin of the Central Volcanic Region. ***Proc. 12th NZ Geothermal Workshop***, 77-81.

Ingham, M. (1991). Electrical conductivity structure of the Broadlands-Ohaaki geothermal field, New Zealand. ***Phys. Earth Planet. Int.***, Vol. 66, 62-75.

Kurtz, R.D., DeLaurier, J.M. and Gupta, J.C. (1986). A magnetotelluric sounding across Vancouver Island detects the subducting Juan de Fuca plate. ***Nature***, Vol. 321,596-599.

Pandey, O.P. (1981). Terrestrial heat flow in New Zealand. ***Unpublished PhD Thesis***, Victoria University of Wellington.

Reyners, M. (1980). A microearthquake study of the plate boundary, North Island, New Zealand. ***Geophys. J.R. astr. Soc.***, Vol. 63, 1-22.

Smith, E.G.C., Stem, T. and Reyners, M. (1989). Subduction and back-arc activity at the Hikurangi convergent margin, New Zealand. ***Pure and Applied Geophs.***, Vol. 129, 203-231.

Stem, T.A. and Davey, F.J. (1987). A seismic investigation of the crustal and upper mantle structure within the Central Volcanic Region of New Zealand. ***New Zealand Jl. Geol. Geophys.***, Vol. 30,217-231.

Stem, T., Smith, E.G.C., Davey, F.J. and Muirhead, K.J. (1987). Crustal and upper mantle structure of the northwestern North Island, New Zealand, from seismic refraction data. ***Geophys. J.R. astr. Soc.***, Vol. 91,913-936.