MAGNETOTELLURIC SOUNDINGS ALONG A TRANSECT OF THE CVR

M. INGHAM

Institute of Geophysics, Victoria University of Wellington, Wellington

SUMMARY – New broadband magnetotelluric soundings have been made along a transect of the CVR to the south of Lake Rotorua where the CVR has a width of about 75km. Data from the eastern end of the line are strongly 2-dimensional in character and indicate an orientation of electrical strike that is consistent with the gross tectonic strike of the eastern margin of the CVR and Taupo Volcanic Zone. 2-dimensional inversion of apparent resistivity and phase data from the easternmost 5 sites yields a resistivity structure which is consistent with previous deep dc measurements and suggests that low resistivity exists to depths of at least 10km and, below 5km, depth possibly extends further to the west than has previously been identified. In contrast data from close to the western margin of the CVR is much more complex and exhibits 3-dimensional characteristics which suggest that the data may be influenced by the SSE-NNW trending Hauraki Rift just to the north of the western end of the transect.

1. INTRODUCTION

The Central Volcanic Region (CVR) of the North Island of New Zealand is a wedge shaped area which has been interpreted (Stern, 1985,1987) as being an active back-arc basin forming within continental lithosphere behind the Hikurangi subduction zone off the east coast of the North Island. The Taupo Volcanic Zone (TVZ) lies in the eastern part of the CVR and is a region of active volcanism and rapid extension which contains the majority of the high temperature geothermal fields in New Zealand.

Previous geophysical studies of the CVR and TVZ have largely concentrated on the identification and study of the geothermal fields. Extensive dc resistivity measurements (eg. Risk et al., 1993, 1994) and early magnetotelluric soundings (eg. Ingham, 1990, 1991, 1992) have shown that within the geothermal fields there is a general increase in resistivity, while outside the geothermal fields relatively low resistivity (~10-20Ωm) occurs at about 1km depth. The eastern margin of the CVR/TVZ has been modelled in detail from seismic, gravity (Stagpoole, 1994) and dc electrical studies (Risk et al., 1993, 1994) as a series of downstepping normal faults. However, the western margins of the TVZ and CVR have not been studied in detail by geophysical techniques. Within the CVR, early seismic studies (Stern & Davey, 1987, Stern et al., 1987) identified an anomalous upper mantle and a crustal thickness beneath the TVZ of about 15km. Further west the crustal thickness was interpreted as being some 10km greater. Recent long period MT data (Ogawa et al., 1999), from a transect of the TVZ just to the north of Lake Taupo, suggest a conductor at 15km depth and a relatively conductive upper mantle.

A new multi-technique geophysical study of the CVR is now under way, with the objective of clarifying the deep structure of the region. As part of this study, preliminary results are presented in this paper from a new MT study across the CVR some 10km to the south of Lake Rotorua.

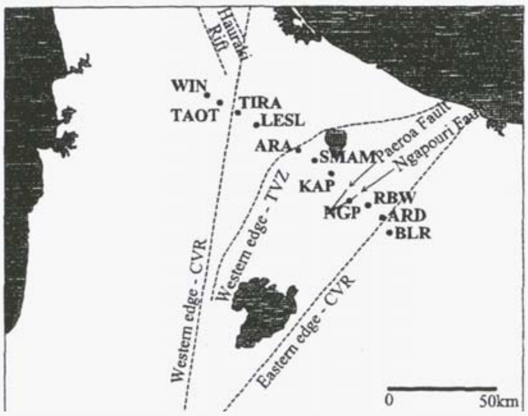

Figure 1 – Location of MT sites and features of the CVR/TVZ mentioned in the text.

2. MTDATA

MT soundings have been made at 11 locations on a line of length approximately 100km (Fig. 1) that extends from the region west of the CVR to just east of the eastern boundary of the CVR/TVZ. Data were collected using two different systems. Data at sites with 3-letter acronyms were collected using the VUW MT

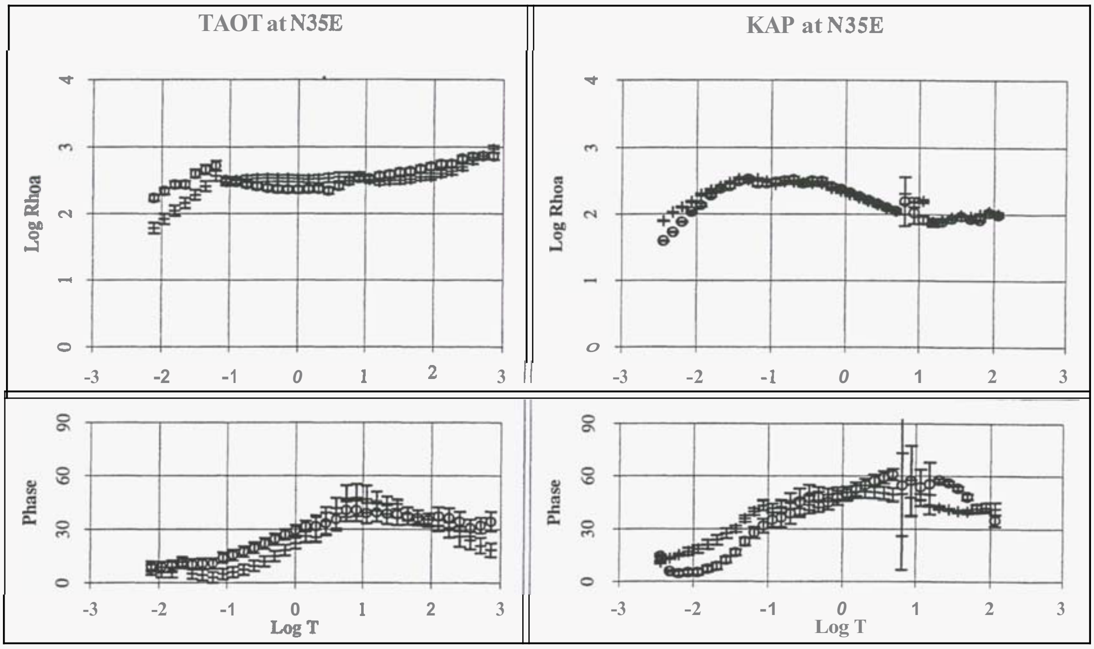

Figure 2 – Apparent resistivity and phase curves rotated to orientations parallel (circles) and perpendicular (crosses) to N35°E.

system in the nominal period range from 0.002-300s. Sites with 4-letter acronyms refer to data collected with with a SPAM Mark III system on loan from the Dept. of Geology & Geophysics, University of Edinburgh. Data quality was variable as the CVR is a region of extensive cultural noise. In particular, widespread electric fence noise caused severe distortions in the data at some sites (TIRA, LESL and SMAM) along the western part of the line. Examples of apparent resistivity and phase data (rotated to orientations parallel and perpendicular to N35°E) from both sets of equipment are shown in Fig. 2. Pseudosections of apparent resistivity and phase in the measurement co-ordinate system (magnetic NS-EW) for the entire line of

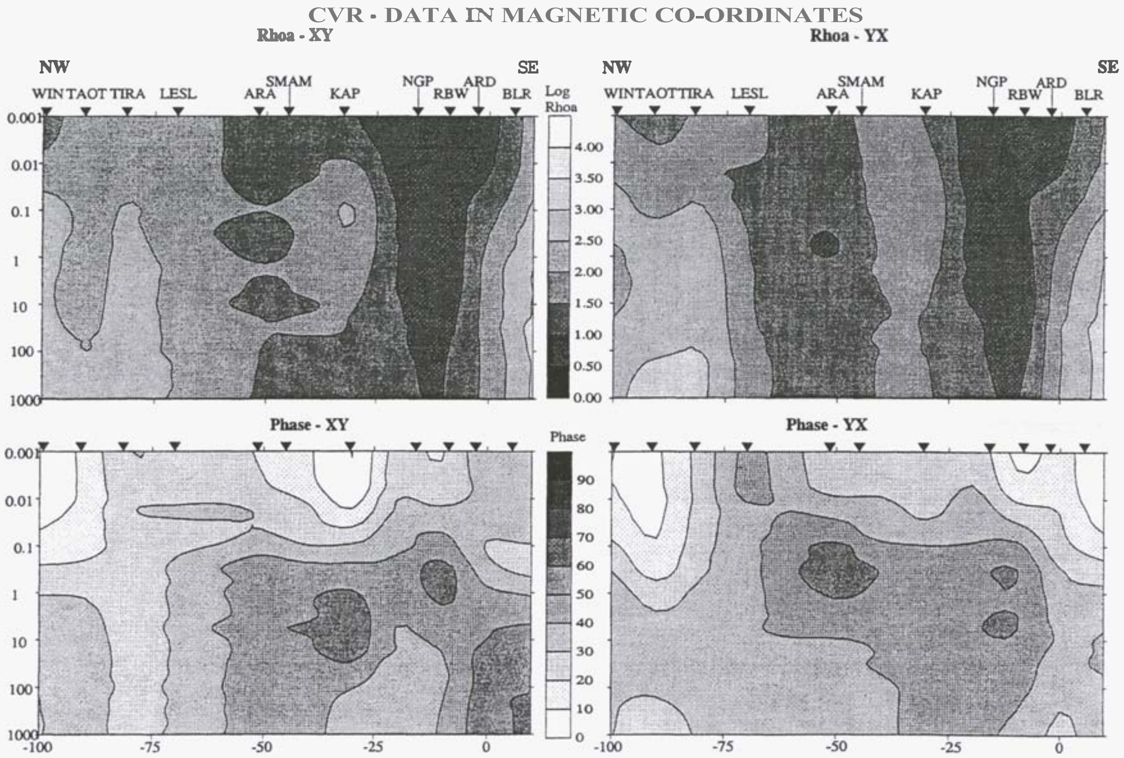

Figure 3 – Apparent resistivity and phase data from all 11 MT sites.

sites are shown in Fig. 3.

The most marked feature of the data pseudosections is the low apparent resistivity throughout the entire period range of the data in both polarisations of data from sites NGP and RBW. These sites are located where the transect passes just to the north of the Waiotapu geothermal field and Rainbow Mountain. Between ARD and BLR the eastern margin of the CVR/TVZ is marked by a rapid rise in apparent resistivity. Similarly low phases at short period are observed on the western margin of the CVR at TAOT and WIN, but are not accompanied by a significant increase in apparent resistivity.

3. REGIONAL STRIKE DIRECTIONS

Prior to modelling of MT data it is useful to have a good working hypothesis of the complexity of the data. For example, although electrical structure in the earth is in reality 3-dimensional, in some cases it is possible to obtain meaningful models of MT data in terms of a simple variation of electrical resistivity with depth. Similarly, largely as a result of the fact that many parts of New Zealand exhibit a well-defined tectonic trend, in many situations in New Zealand it has been found possible to model MT data in terms of 2-dimensional structure. The case of the CVR however is, at first sight, more complex.

To investigate the dimensionality of the MT data a distortion analysis using the technique of Groom & Bailey (1989) has been carried out to attempt to isolate the regional strike direction for the data from each site. The methodology of the Groom-Bailey technique has been widely discussed (eg. Groom & Bahr, 1992) and it has been shown to be capable of isolating the orientation of the regional electrical strike in cases where the measured electric fields are distorted due to near surface 3-dimensional structure. The technique attempts to model MT data in terms of a regional 2-dimensional impedance, which is distorted by the operation of period independent twist, shear and splitting parameters.

Data from each site has been initially decomposed without constraints to find as a function of period the values of twist, shear and regional strike which best model the data. Based on the results of this decomposition the best period independent values of the twist and shear parameters have been determined and the decomposition has been repeated with these values held fixed.

At all of the sites along the eastern half of the MT line such a procedure strongly indicates that

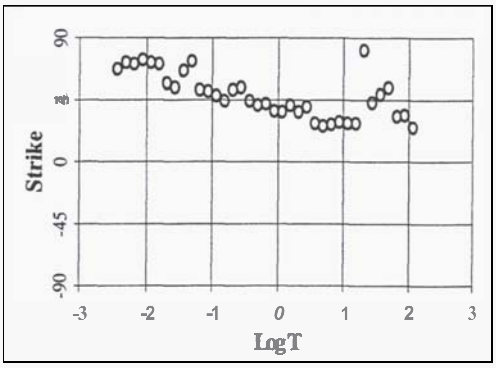

Figure 4 – Regional strike angle as a function of period for site NGP determined from Groom-Bailey decomposition.

long period values of regional electrical strike are very close to the observed tectonic strike (~N35°E) of the eastern margin of the CVR/TVZ (eg. Fig. 4). This is consistent with the results of Ogawa et al. (1999) from further south in the TVZ. At the sites at the western end of the line, however, the resulting regional strike determination is significantly different from this and is much closer to values between N60°E and N80°E (Fig. 5). The strike of the western boundary of the CVR is close to N10°E and apparently unrelated, therefore, to the predominant electrical strike at these sites.

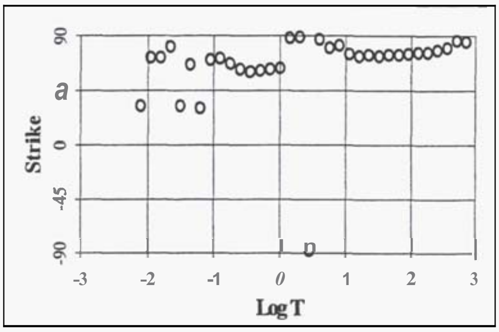

Figure 5 – Regional strike angle as a function of period for site TAOT determined from Groom-Bailey decomposition.

This complexity in the MT data from the western end of the line is also reflected in the fact that for these sites apparent resistivity and phases curves calculated from the determinant impedance cannot be modelled successfully with a 1-dimensional resistivity structure. In contrast 1-dimensional modelling of the determinant parameters is successful for all the sites close to the eastern boundary of the CVR/TVZ. The determinant impedance is invariant with rotation angle of the MT impedance tensor and generally proves to be of use in determining resistivity-depth variations even in localities where structure is 2 or 3-dimensional. Use of an alternative decomposition scheme for MT data based on the Mohr circle representation of a 2x2 tensor

(Lilley, 1993, 1998) suggests that the most appropriate strike angle for sites at the western end of the line may in fact vary with period.

One possible explanation for this is that the MT data at the western end of the line are affected by the electrical structure associated with the Hauraki Rift (Fig. 1). The Hauraki Rift is regarded as an magmatic intra-continental rift of Miocene-recent age (Hochstein & Ballance, 1993) and strikes **NNW-SSE,** much more commensurate with the long period strike determinations from TAOT and WIN from the Groom-Bailey decomposition. The rift is largely filled with Quaternary sediments at the surface and bounded to the west by greywacke outcrops and on the east by the andesitic volcanics of the Coromandel Peninsula. At shorter periods it may be that the MT data reflect more strongly the coupled effect of both the electrical structure of the Hauraki Rift and structure associated with the western boundary of the CVR.

4. 2-DIMENSIONAL INVERSION.

The sites from the eastern part of the MT line show a well defined strike orientation on decomposition that is consistent with the observed strike of the eastern boundary of the CVR/TVZ. To recover more detail of the structure across this boundary 2-dimensional inversion of the decomposed MT data has been carried out.

Shown in Fig. 6 is the resistivity structure obtained from a joint inversion (Smith & Booker, 1991) of the TE and TM mode decomposed apparent resistivity and phase responses from KAP, NGP, RBW, ARD and BLR. Shown in Fig. 7 is the fit of the forward responses of this structure to the decomposed data.

As was indicated in the original data pseudosections, the eastern edge of the CVR/TVZ is marked by a sharp resistivity contrast between the much more conductive structure of the TVZ and the ignimbrite/greywacke terrain to the east. Within the TVZ conductive structure appears to exist to a depth of at least 10km, although simple skin-depth calculations suggest that in this region penetration is probably not as deep as is indicated in Fig. 6. Inversion of only the TM mode data in fact yields a somewhat shallower thickness of conductive material.

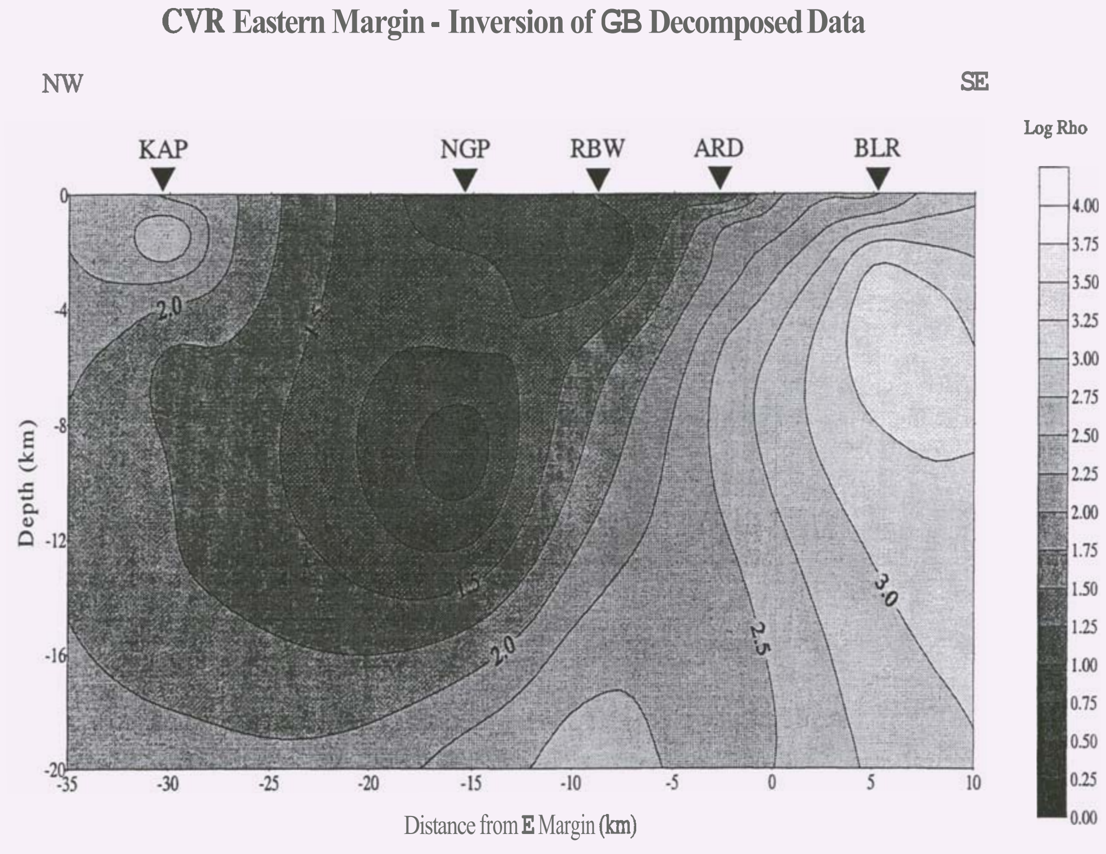

Figure 6 – 2-dimensional resistivity model of the eastern part of the MT line derived from joint inversion of TE and TM mode apparent resistivity and phase data.

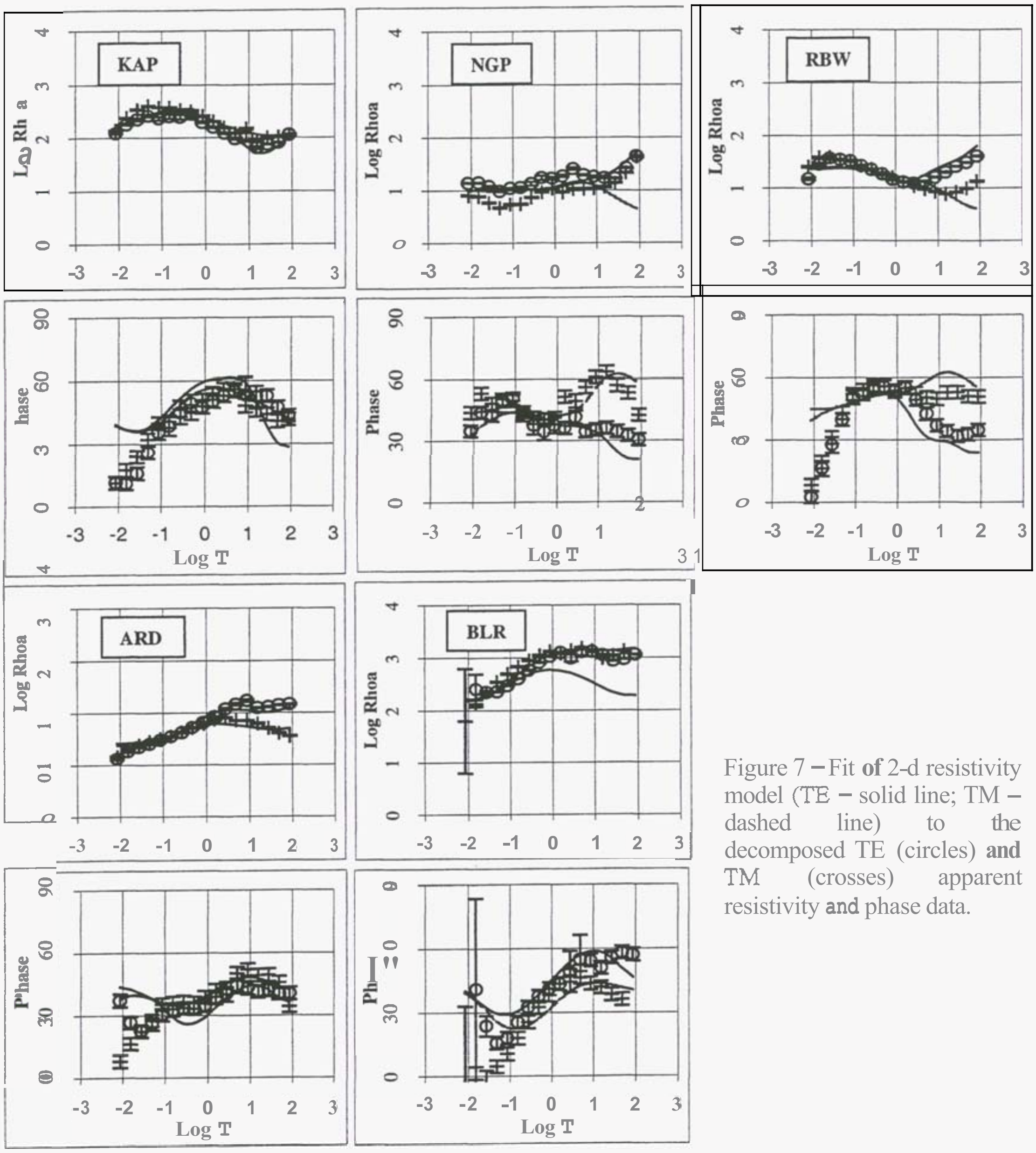

Figure 7 – Fit of 2-d resistivity model (TE – solid line; TM – dashed line) to the decomposed TE (circles) and TM (crosses) apparent resistivity and phase data.

The derived structure is extremely similar to that presented by Risk et al. (1994) who modelled bipole-dipole dc resistivity data along part of the same line. The downstepping nature of the eastern boundary of the CVR/TVZ is clearly reproduced in the upper few kilometres of the model, whereas the low near surface resistivity beneath NGP and KAP may be associated with their proximity to the Waiotapu geothermal field.

The Paeroa Fault (Fig. 1) occurs between NGP and KAP and may be associated with the rise in resistivity which occurs between these two sites. The exact location, and sharpness of this rise, is poorly constrained by the site spacing of nearly 15km. The Paeroa Fault was modelled by Risk et al. (1994) as a vertical interface between two similar resistivity blocks. The MT data suggests that at greater depth conductive material extends west of the fault beneath KAP and this may correlate with suggestions that slightly further to the south conductive ignimbrites occur at depth (Allis et al., 1987; Risk et al., 1994).

To the east of the Paeroa Fault., the Ngapouri Fault (Fig. 1) was suggested by Risk et al. (1994) to significantly affect the dc electrical data. There is no evidence of any corresponding influence on the MT data.

5. CONCLUSIONS.

The present dataset represents only the preliminary stage of a much more extensive electrical investigation of the structure of the

CVR. As such it provides some important pointers for the direction of future work.

The structure of the eastern margin of the CVR/TVZ appears to quite well understood. In contrast, however, the complexity of the MT responses from the western boundary of the CVR indicate that considerable emphasis needs to be placed on acquiring additional data from this region.

Although long period data have been obtained fiom two sites (TAOT and ARD) at either end of the line, it is apparent from the 2-dimensional inversion that in the central part of the line, the present data do not extend to sufficiently long periods to penetrate through the low resistivity upper-middle crust. Consequently little can thus far be said concerning deeper structure. Much more closely spaced sites will also allow resolution of finer detail.

6. REFERENCES.

Allis, R.G., Bennie, S.L., Dawson, G.B., Graham, D.J., Kenelly, M., Rayner, H.H. and Stagpoole V.M. **(1987).** In: R.G. Allis (compiler), Geophysics and geochemical investigations of the Horohoro geothermal prospect. Report **213,** Geophysics Division, DSIR, Wellington, **12-20.**

Groom, R.W. and Bahr, K. **(1992).** Corrections for near surface effects: decomposition of the magnetotelluric impedance tensor and scaling corrections for regional resistivities: a tutorial. Surv. Geophys., Vol. **13,341-379.**

Groom, R.W. and Bailey, R.C. **(1989).** Decomposition of the magnetotelluric impedance tensor in the presence of local three-dimensional galvanic distortion. J.Geophys. Res., Vol. **94, 1913-1925.**

Hochstein, M.P. and Ballance, P.F. **(1993).** In: Ballance, P.F. (editor), Sedimentary Basins of the World. Elsevier.

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.**

Ingham, M. **(1992).** Numerical modelling of magnetotelluric soundings fiom the central Volcanic Region. Proc. 13th NZ Geothermal Workshop, **15-19.**

Lilley, F.E.M. **(1993).** Magnetotelluric analysis using Mohr circles. Geophysics, Vol. **58, 1498-1506.**

Lilley, F.E.M. **(1998).** Magnetotelluric tensor decomposition: Part I, Theory for a basic procedure. Geophysics, Vol. **63, 1885-1897.**

Ogawa, Y., Takakura, S., Uchida, T., Matsushima, N., Tosha, T., Nishi, Y., Caldwell, T.G., Bibby, H.M. and Bennie, S.L. **(1999).** Implications of deep resistivity structure of the Taupo Volcanic Zone, New Zealand. Paper presented at 22nd Assembly IUGG, Birmingham, UK, July **1999.**

Risk, G.F., Bibby, H.M. and Caldwell, T.G. **(1993).** Dc resistivity mapping with the multiple-source bipole-dipole method in the Central Volcanic Region, New Zealand. J. Geomag. Geoelectr., Vol. **45,897-916.**

Risk, G.F., Caldwell, T.G. and Bibby, H.M. **(1994).** Deep resistivity surveys in the Waiotapu-Waikite-Reporoa region, New Zealand. Geothermics, Vol. **23,423-443.**

Smith, J.T. and Booker, J.R. **(1991).** Rapid inversion of two- and three-dimensional magnetotelluric data. J. Geophys. Res., Vol. **96, 1168-1171.**

Stagpoole, V.M. **(1994).** Interpretation of refraction seismic and gravity data cross the eastern margin of the Taupo Volcanic Zone, New Zealand. Geothermics, Vol. **23,501-510.**

Stem, T.A. **(1985).** A back-arc basin formed within continental lithosphere: the central Volcanic Region of New Zealand. Tectonophysics, Vol. **112, 385-409.**

Stem, T.A. **(1987).** Asymmetric back-arc spreading, heat-flux and structure associated with the Central Volcanic Region of New Zealand. Earth Planet. Sci. Lett., Vol. **85, 265-276.**

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

Stem, T.A., Smith, E.G.C., Davey, F.J. and Muirhead ,K.H. **(1987).** Crust and upper mantle structure of the northwestern North Island, New Zealand. Geophys. J.R. Astr. Soc., Vol. **91, 913-936.**