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ELECTRICAL CONDUCTIVITY STRUCTURE OF THE EASTERN MARGIN OF THE CENTRAL VOLCANIC REGION

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Abstract

AMT/MT soundings have now been made at a total of 17 sites along a NE-SW line from the Broadlands-Ohaaki to Wairakei-Tauhara geothermal fields. The data have been modelled in terms of a resistivity structure which shows the geothermal fields to be characterised by very low resistivities (of order 5 ohm-metres) at shallow depths, underlain by resistivities of less than 100 ohm-metres which extend to depths of several kilometres. Between the fields a moderately conductive layer of 10-20 ohm-metres exists at around 1-2 km depth and overlies resistivities of some hundreds of ohm-metres. The extension of this feature to the south-east has been gauged from measurements at four locations on a NW-SE line which crosses the eastern edge of the Central Volcanic Region. These data suggest that, although resistivity values remain relatively low in continental terms, the conductive layer loses its identity some 10km to the south-east beneath the Kaingaroa Plateau.

Introduction

Ingham (1989,1990) reported the results of an audiomagnetotelluric (AMT) / magnetotelluric (MT) survey of the Broadlands-Ohaaki geothermal field. The main result of this survey was the delineation of a layer of very low resistivity which could be identified with the upper aquifer of the geothermal reservoir. Within the known geothermal field this was found to be underlain by slightly more resistive material extending to several kilometres depth. More controversial, however, was the indication that to the south of the field the very low resistivity layer, now apparently underlain by much more resistive material, could still be traced at a depth of around 1-2 km.

With a view to determining whether or not such a low resistivity layer really does exist to the south of the field, the original line of 11 sites has now been extended 20km to the south to include a further 6 sites. The two most southerly of these (Fig. 1) are within the Wairakei-Tauhara geothermal field with the other four sites being between the Wairakei-Tauhara and Broadlands-Ohaaki fields. At all 6 sites AMT/MT data have been obtained in the period range 0.001-50s, whilst at two locations, CTP and BUR, much longer period data, giving information about the deeper resistivity structure, have also been recorded.

To investigate any lateral variations in resistivity structure across the eastern boundary of the Central Volcanic Region (CVR) measurements have also been made at four locations on a NW-SE line originating just to the south of the Broadlands-Ohaaki geothermal field and extending up onto the Kaingaroa Plateau. Further measurements, which are not discussed here, have been obtained at 7 additional sites along a parallel line to this, roughly along State Highway 5, extending from Kinloch (north-west of Taupo) to Rangiteiki.

Broadlands-Taupo line

Smoothed curves of E and H-polarisation apparent resistivities and phases from 8 sites along the Broadlands-Taupo line are shown in Fig. 2. Analysis of AMT/MT data produces an impedance tensor which is a function of the period of the variations of the measured magnetic and electric fields. For any particular period of variation the principal axes of the tensor generally define the directions which are parallel and perpendicular to major lateral variations in electrical resistivity. The principal impedances are used to calculate two apparent resistivities and their

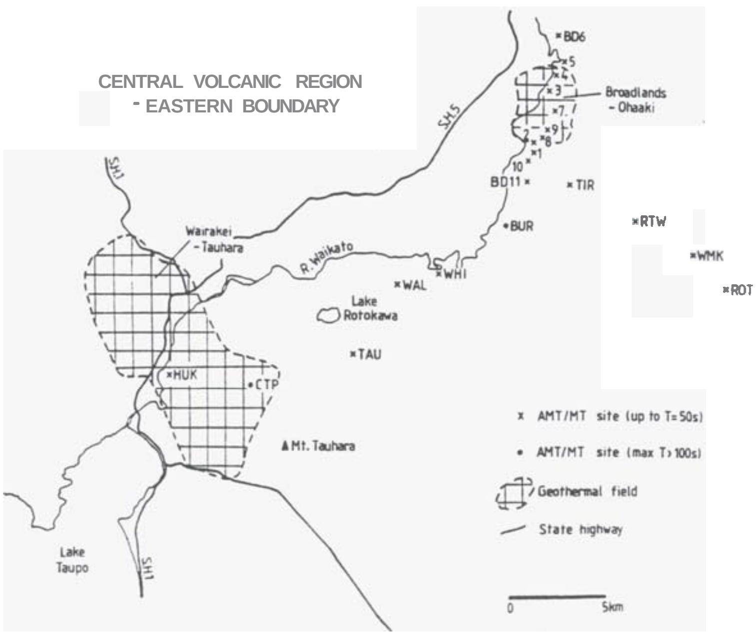

Fig. 1. Location of AMT/MT sites along the eastern margin of the Central Volcanic Region.

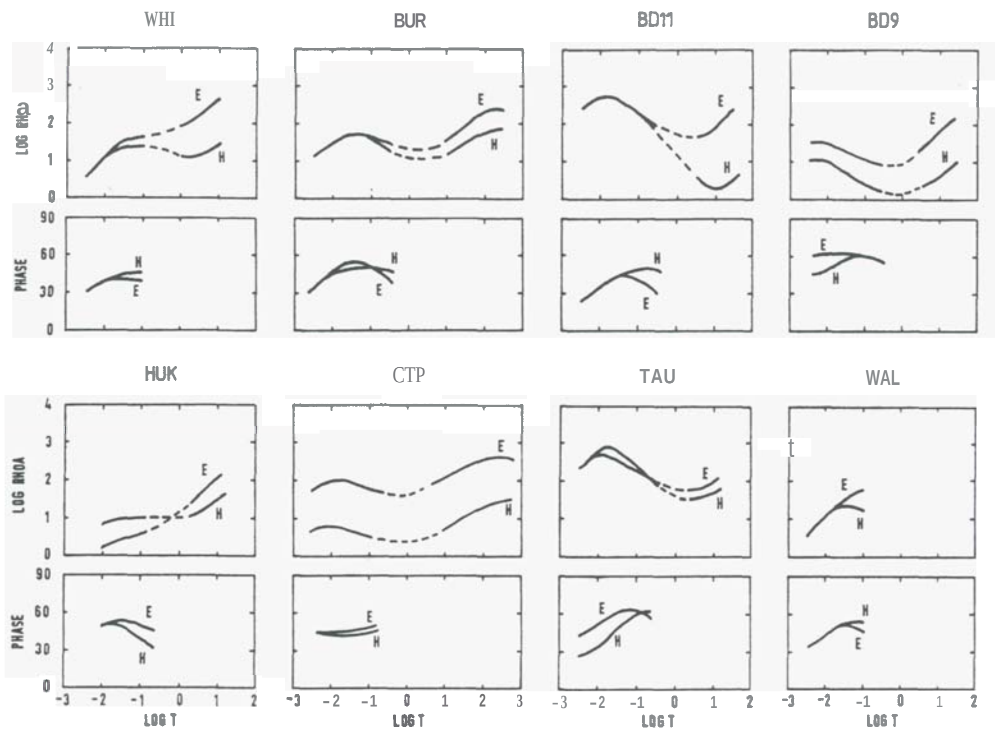

Fig. 2. Smoothed E and H-polarisation apparent resistivity and phase curves for sites along the Broadlands-Taupo line.

associated phases which are indicative of the electrical resistivity structure beneath and around the measurement site. At all sites reported here the principal axes of the impedance tensor are close to parallel and perpendicular to the eastern boundary of the CVR. E-polarisation therefore refers to an orientation of approximately SW-NE and H-polarisation to an orientation NW-SE.

Data quality is good up to a period of 0.1s with interference from 50Hz and its harmonics removed by analogue and digital notch filtering. In the period range 0.1-10s the natural signal level is very low and the problem of obtaining good data in this period range is further complicated by the occurrence of leakage of currents into the ground from the mains system. As a consequence, as indicated by the dashed portions of the apparent resistivity curves in Fig. 2, little useable data was obtained between 0.1 and 10s period. For longer periods of variation consistent apparent resistivity values have been obtained but phase values are very scattered. For this reason no attempt has been made to indicate the form of the phase curves beyond about 0.3s period.

Starting from the north-east end of the line of sites, BD9 is a site close to the centre of the Broadlands part of the Broadlands-Ohaaki geothermal field. It shows E and H-polarisation apparent resistivities which are displaced vertically with respect to each other and have low values around 1s period. BD11 was the southernmost site reported by Ingham (1989,1990) which gave the interpretation of low resistivity at 1-2km depth. The highly anisotropic apparent resistivity curves at periods greater than 1s are indicative of a lateral variation in electrical resistivity close to the site - assumed to be the southern boundary of the geothermal field. The low H-polarisation apparent resistivity at periods close to 10s is the principal reason for the interpretation of very low resistivity at about 1.5km depth.

A relatively consistent picture can be drawn from the results for BUR,WHI,WAL and TAU, the next four sites to the south-west. Such anisotropic apparent resistivities as seen at BD11 do not occur and although the curves do show minima around 1s period they are much less prominent and have values greater than 10 ohm-metres. The longer period results from BUR start to suggest a maximum in the apparent resistivity curves but do not clearly define such a feature.

Sites CTP and HUK are within the Wairakei-Tauhara geothermal field and exhibit significantly different apparent resistivity curves to these four sites. At CTP, as at BD9, there is a period independent shift along the apparent resistivity axis between the E and H-polarisation curves. This may well be due to static-shift, the effect of very localized near-surface inhomogeneities. However, the longer period data were actually recorded at a slightly different location to the high frequency data yet show the same shift, thus it is not clear that this is the case. At HUK the short period apparent resistivities are very low and the H-polarisation values are greater than the E-polarisation ones. This may well simply reflect the fact that HUK is relatively close to, and on the conductive side of, the NW-SE trending boundary of the geothermal field. Elsewhere along this Broadlands-Taupo line of sites the E-polarisation apparent resistivities are greater than the H-polarisation values, an observation which is consistent with the sites being on the conductive side of a resistivity boundary parallel to the edge of the CVR.

To gain some insight into the actual resistivity structure along the line of sites, one-dimensional modelling of the determinant apparent resistivity and phase at each site has been carried out. These parameters are the apparent resistivity and phase derived from the determinant impedance defined by Ranganayaki (1984) and do not depend upon the orientation of the axes of the impedance tensor. For one-dimensional structures the apparent resistivity and phase curves at a site are related by dispersion relations. Thus, as the phase estimates are generally

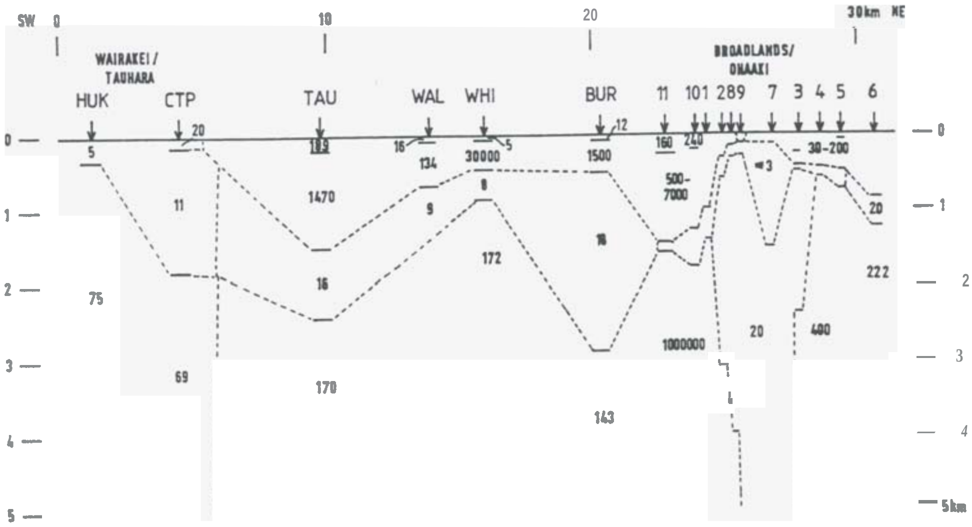

Fig. 3. Compilation of one-dimensional models for the resistivity structure at each site. Resistivities are in ohm-metres.

quite scattered for periods greater than 1s, the dispersion relations have been used to calculate theoretical phase values from the measured determinant apparent resistivities. As suggested by Fischer and Schnegg (1980) the theoretical phase curve so obtained has then been averaged with the measured phase curve to give resultant phase values which, with the measured apparent resistivities, have been modelled using the technique described by Fischer et. al. (1981) and Fiscner and Le Quang (1981).

Shown in Fig. 3 is a compilation into a two-dimensional section of the one-dimensional structures obtained for each of the sites along the Broadlands-Taupo line. The resistivity values shown are those pertaining to the one-dimensional model which gives the best fit to the modelled data at each site. However, the models obtained are non-unique and, to indicate the

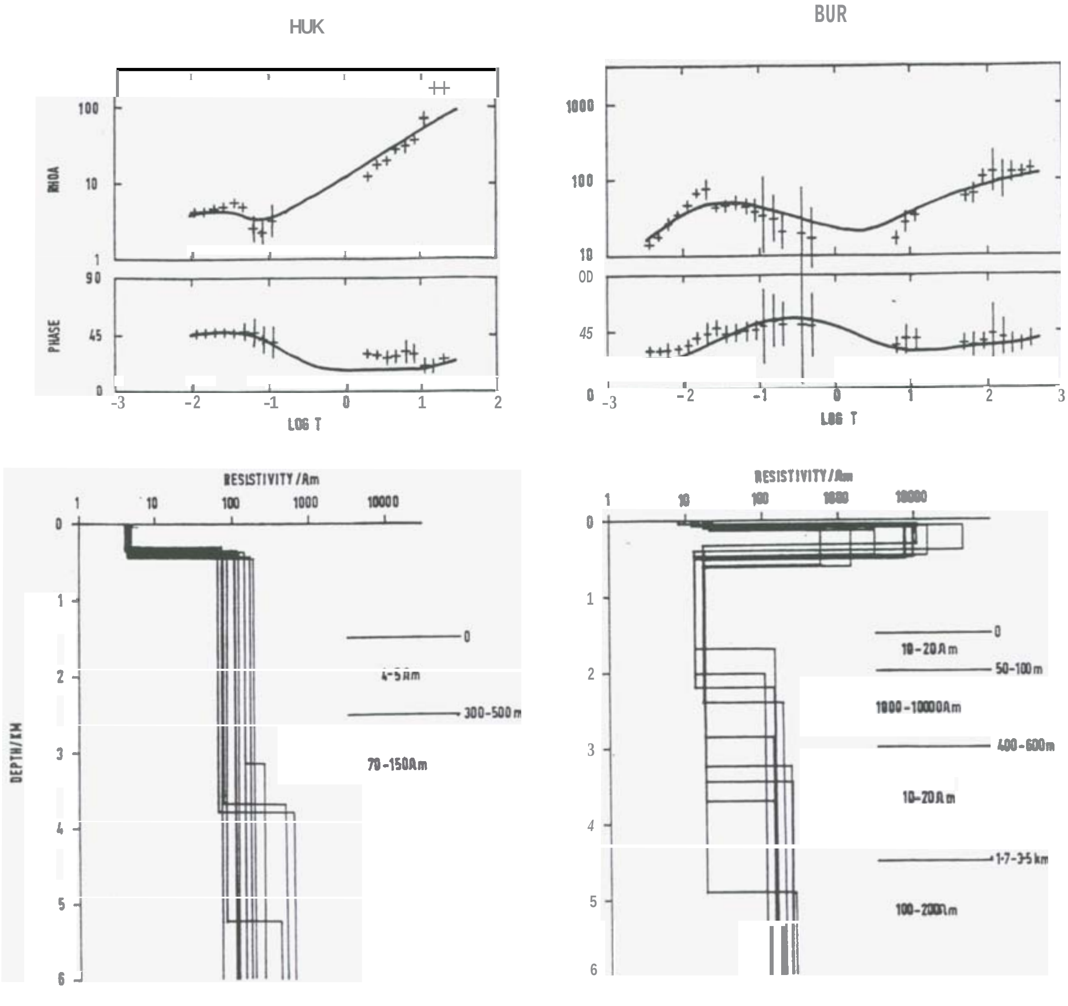

Fig. 4. Range of the 10 best fitting models at the sites HUK and BUR, and the fit to the data of the best model at each site.

range of models which typically give almost equally good fits to the data, the ten best fitting models for the sites HUK and BUR, obtained by a Monte-Carlo search of model space, are shown in Fig. 4. The best fit to the data at these sites is also shown. At BUR, for example, it is clear that a layer of resistivity 10-20 ohm-metres exists at a depth of around 500m. The thickness of the layer is, however, poorly constrained. Similarly, a wide range of values are acceptable for the resistivity of the overlying layer.

In Fig. 3 the structure shown for the Broadlands-Ohaaki geothermal field is that obtained previously (ingham, 1989,1990). From the figure it is now apparent that a moderately conductive layer, such as indicated above for BUR, exists at around 1-2km depth along the whole of the line between Broadlands-Ohaaki and the Wairakei-Tauhara geothermal fields. The very low resistivities (less than 3 ohm-metres) suggested by the earlier work do not occur and can probably be attributed to the inadequacy of the one-dimensional modelling close to the boundary of the geothermal field. Likewise, the highly resistive structure obtained beneath this layer at BDlO and BDll is probably an overestimate of the true resistivity. As can be seen from Fig. 3, away from the boundary of the field, more moderate resistivities of some 100's of ohm-metres are obtained.

The resistivity structure obtained for the two sites within the Wairakei-Tauhara geothermal field bear certain similarities to that found for Broadlands -Ohaaki. A low resistivity (5 ohm-metres at HUK) is underlain by a slightly higher value which apparently extends to considerable depth. It is this near-surface low resistivity coupled with the persistence of resistivities of less than 100 ohm-metres to an indeterminate depth which appears to distinguish the geothermal areas. The higher value of around 10 ohm-metres found for the more conductive layer at CTP is possibly an indication that the E-polarisation apparent resistivity curve shown in Fig. 2 has indeed been affected by static-shift.

It should be pointed out that the deepest resistivities of 100-200 ohm-metres obtained at TAU, WHI and BUR, although much higher than those values associated with geothermal fields, are low when compared to more normal values for continental crust. Furthermore, the long period data available from BUR indicate that these values exist to depths of at least lOkm and that the structure may then in fact become less resistive. This suggests that hiqh temperatures exist at relatively shallow depths and it could be argued that this lends support to the proposition of Giggenbach (1989) that along the eastern margin of the CVR a considerable magmatic component exists in the crust at such depths.

Broadlands-Kaingaroa Plateau 1ine

Smoothed E and H-polarisation apparent resistivities and phases for the line of sites from just south of the Broadlands-Ohaaki geothermal field onto the Kaingaroa Plateau are shown in Fig. 5. BD10, like BD11, is one of the sites to the south of the field which in the results of the earlier work suggested the existence of resistivities of less than 3 ohm-metres at a depth of about 1.5km. As can be seen from Fig. 5 the apparent resistivity curves at BDlO show similar features to those at BD11.

The results from the 4 new sites along this line are very consistent and suggest that as the boundary of the CVR is crossed the apparent resistivity curves start to exhibit less long period anisotropy and a much less pronounced minimum. The E-polarisation values do, though, reniain higher than the tl-polarisation values suggesting that even at ROT no major lateral resistivity boundary has been crossed. The apparent shift to longer period, at TIR, of the minimum in apparent resistivity is probably not real. The quality of the data obtained at this site was poor even at the shortest periods and considerable uncertainty exists in the smoothed curves shown.

The Broadlands-Kaingaroa Plateau line of sites, being perpendicular to the tectonic grain of the North Island, is eminantly suitable for two-dimensional modelling of the resistivity structure. As an initial indication of structure,prior to such modelling, the same type of one-dimensional modelling as discussed above for the Broadlands-Taupo line has been carried out. The results of theis procedure, again in the form of a two-dimensional compilation of one-dimensional models, is shown in Fig. 6.

Allowing for the reservations concerning the data quality at, and consequently the structure obtained for, TIR, it is apparent that the moderately conductive structure at a depth of 1-2km observed along the Broadlands-Taopo line also appears along this second line. The structure'persists to the south-east as far as RTW and then appears to peter out beneath WMK and loses its identity completely beneath ROT. To further illustrate this, Fig. 7 shows the range of models obtained for ROT which give a satisfactory fit to the data. As can be seen, no clear conductive layer is present in all of the models.

The deeper resistivity beneath the Broadlands-Kaingaroa Plateau 1ine is around 300-500 ohm-metres (the high value beneath RTW is poorly defined). This value is somewhat higher than the 100-200 ohm-metres found beneath the central part of the Broadlands-Taupo line and may indicate a lowering in crustal temperature as the eastern boundary of the CVR is

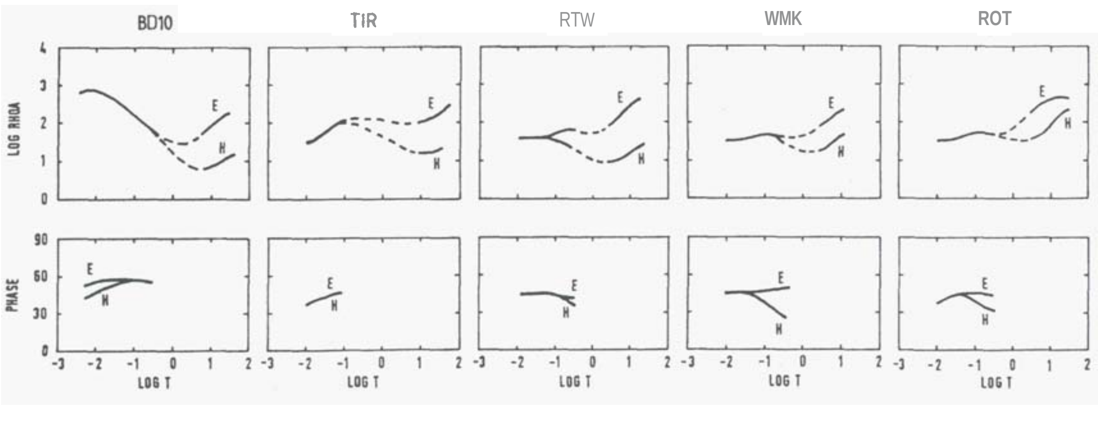

Fig. 5. Smoothed E and H-polarisation apparent resistivity and phase curves for sites along the Broadlands-Kaingaroa Plateau line.

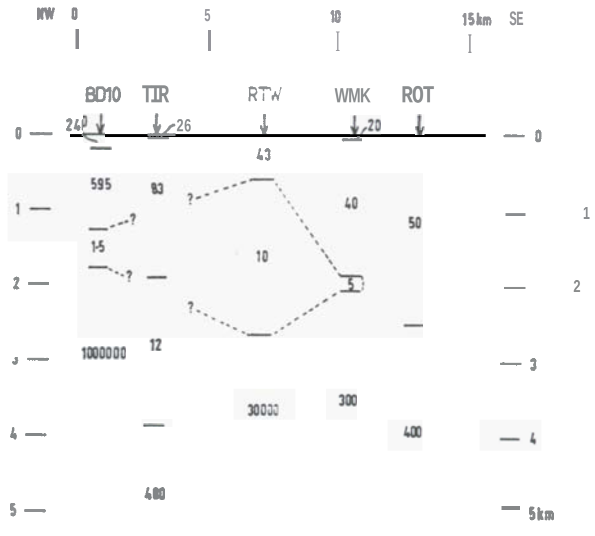

Fig. 6. Resistivity structure along the Broadlands-Kaingaroa Plateau line. Resistivities are in ohm-metres.

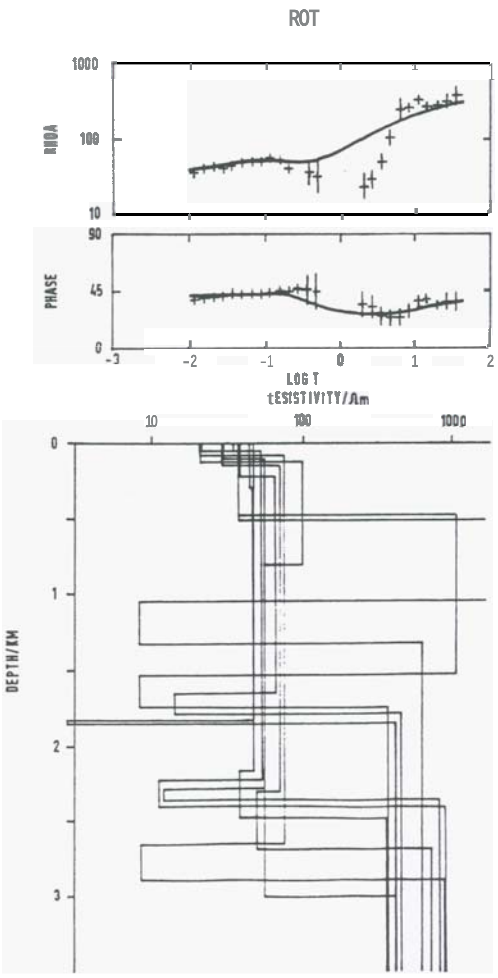

Fig. 7. Range of 10 best fitting models at ROT showing no clear definition of a low resistivity layer.

Only limited two-dimensional modelling has been carried out to date. What is clear from the results obtained is that the lateral variations in the apparent resistivity and phase curves shown in Fig. 5 do not arise from topographic effects caused by the approximately 350m height difference between BD10 and ROT.

Summary

AMT/MT soundings along and across the eastern boundary of the CVR suggest the existence, outside of the geothermal fields, of a moderately conductive layer of 10-20 ohm-metres resistivity at a depth of 1-2km. This is apparently underlain by resistivities of a few hundred ohm-metres which persist to at least 10km depth. The conductive layer loses its identity some 10km to the south-east of a line joining Broadlands and Taupo, at the edge of the CVR. The existence of such relateively low resistivities suggests high crustal temperatures and possibly a significant magmatic component within the upper 10km. Analysis of additional data along a second traverse crossing the eastern boundary of the CVR and two-dimensional modelling of the resistivity structure should help to clarify the situation further.

Acknowledgements

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References

Fischer, G. and Schnegg, P.A., 1980. The dispersion relations of the magnetotelluric response and their incidence on the inversion problem. Geophys. J.R. astr. Soc., 62: 661-673.

Fischer, G., Schnegg, P.A., Peguiron, M. and Le Quang, B.V., 1981. An analytic one-dimensional magnetotelluric inversion scheme. Geophys. J.R. astr. Soc., 67: 257-278.

Fischer, G. and Le Quang, B.V., 1981. Topography and minimization of the standard deviation in one-dimensional magnetotelluric modelling. Geophys. J.R. astr. Soc., 67: 279-292.

Giggenbach, W., 1989. The chemical and isotopic position of the Ohaaki field within the Taupo Volcanic Zone. Proc. 11th N.Z. Geothermal Workshop: 73-79.

Ingham, M., 1989. Audiomagnetotelluric/magnetotelluric soundings of the Broadlands-Ohaaki geothermal field. Proc. 11th N.Z. Geothermal Workshop: 39-44.

Ingham, M., 1990. Electrical conductivity structure of the Broadlands-Ohaaki geothermal field, New Zealand. Phys. Earth. Planet. Int., in press.

Ranganayaki, R., 1984. An interpretive analysis of magnetotelluric data. Geophysical Journal, 92: 1730-1748.