THE BERLIN GEOTHERMAL SYSTEM - FROM THE SURFACE TO THE MAGMA CHAMBER?

E.B. ANDERSON[1], H.R. JACOBO[2] AND G.N.H. USSHER[3]

[1]Senior Scientist, Geothermal Energy New Zealand Limited, Auckland, NZ

[2]Manager, Geothermal Exploration Dept., CEL, El Salvador

[3]Manager, Scientific Services, Geothermal Energy New Zealand Limited, Auckland, NZ

SUMMARY - One-dimensional analysis of a high-quality magnetotelluric survey at Berlin geothermal field, El Salvador, together with advanced data management techniques, has revealed the resistivity structure of a geothermal system. A 500m thick conductive argillitic alteration layer overlies a medium-resistivity anomaly associated with the geothermal reservoir. A deep conductive body, more than 4 km below the surface, is tentatively interpreted as the magma chamber acting as the heat source to the system.

1. INTRODUCTION

A high-quality magnetotelluric survey, comprising 57 stations, was carried out in the Berlin geothermal prospect, Usulutan province, El Salvador in early 1994. A one-dimensional analysis of the data, using the GDManager integrated data management system developed by GENZL, is presented in this paper. Two-dimensional and three-dimensional analysis by the Institute of Geological and Nuclear Sciences, Kelburn, to refine the model presented here, is currently in progress.

The Berlin geothermal field is located on the northern slopes of the Berlin-Tecapa volcano, within a 4 km wide north-northwest graben (Figure 1). This volcano is centred where the regional NW-trending fault system intersects the southern margin of the E-W trending fault system. Growth of the large basaltic-andesite composite cone during the last 1 - 2 million years has been interrupted once and probably twice by large explosive eruptions of ignimbrites, accompanied by collapse of the central cone to form the outlines of the present Berlin caldera extending from the towns of Berlin to Alegria (Naim, 1994)

Eight wells, all with temperatures above 250° C, have been drilled in the field. From the well lithology and other evidence, the northern caldera boundary is tentatively located south of the wells, while the southern boundary is assumed to be buried under the young summit cones of the Berlin-Tecapa complex. There are many areas of steaming ground and fumaroles in the borefield area, and also in the recent craters at high elevation to the south.

2. BOSTICK RESISTIVITY INTERPRETATION

The measured data quality was very high, with many soundings one-dimensional to considerable depth. At the graben margins, two-dimensional characteristics were observed, reflecting a strong resistivity boundary. As an initial interpretation, a one-dimensional analysis was carried out, using the Bostick transformation of the "effective" resistivity (the geometric average of the two principal apparent resistivities). This outlined a conductive layer within the graben and southward through the caldera, bounded by apparent extensions of the mapped graben faults. This layer is presumed to be a zone of argillitic alteration.

At deeper levels corresponding to the productive reservoir, the picture is less clear (Figure 1), with little resistivity contrast across the graben faults. Cross-sectional representations (not shown) outline the shallow alteration zone but also fail to delineate the reservoir boundaries with any precision, due to noise, static shift effects and possibly two-dimensional boundary distortions.

3. INTERPRETATION USING LAYERED MODELS

Making corrections for static shifts is a rather subjective procedure, requiring assumptions such as a particular layer has a constant resistivity, and adjusting the soundings to conform to this. However, the resistivity variations may be real, and give valuable clues to the location and nature of the geothermal reservoir. It was decided, therefore, to make layered model interpretations of all soundings using the "effective" resistivity, together with the phase to constrain the modelling, and to compare the various layers from sounding to sounding to see if a picture emerged.

All models showed a basic three-layer structure in the top 2000m, although some soundings required more actual layers to obtain a good fit. A thin high-resistivity surface layer overlies a fairly thick conductive layer, with a medium-resistivity layer below. 45 soundings also detected a very conductive layer at considerable depth, typically more than 5 km below the surface. Parameters pertaining to these four layers, such as depth, elevation, thickness, resistivity and conductance, were compared by means of contour maps to see if a coherent and understandable picture emerged.

Figure 2 shows the resistivity of the second layer, with a low-resistivity anomaly within the graben and caldera, and sharp boundaries to the west and east. Because this layer parallels the ground surface in most areas, this picture is substantially the same as that obtained with Bostick resistivity at a depth of

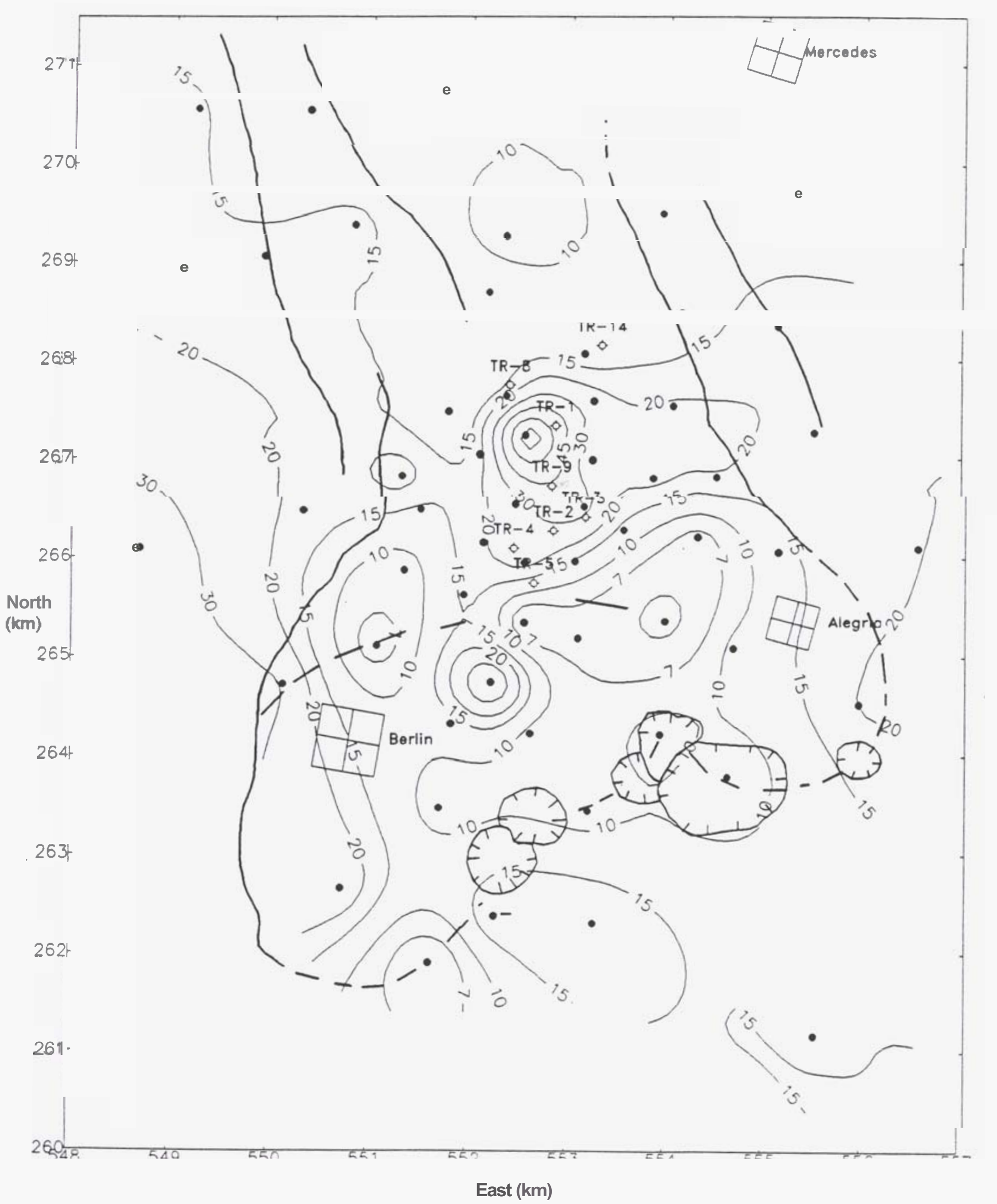

Figure 1. Bostick Resistivity (Ω-m) at a Depth of 1000m below Sea Level.

500m (not shown). Maps of conductance and thickness (also not shown) of this layer, together with correlation with well lithology, support an interpretation of this anomaly being an argillitic alteration zone, similar to that shown in the generalised resistivity structure of a geothermal system by Johnston et al (1992). The lower surface of the layer, which effectively maps a temperature in the region of 180° C, points towards higher temperatures at the inferred northern boundary of the caldera.

The elevation of the third layer (Figure 3), corresponding to the base of the argillitic zone, shows a broad area above 600 m a.s.l. between the northern and southern boundaries of the caldera. The resistivity of this layer (not shown) indicates a subtle but distinct anomaly, centred on the caldera boundary and extending as far north as the northernmost wells. Within the caldera, the resistivity of this layer is typically 15 ohm-m, whereas in the borefield a higher resistivity of about 30 ohm-m is observed. These resistivities are similar to those proposed for typical propyllitic alteration expected within a reservoir (Johnstone et al, 1992).

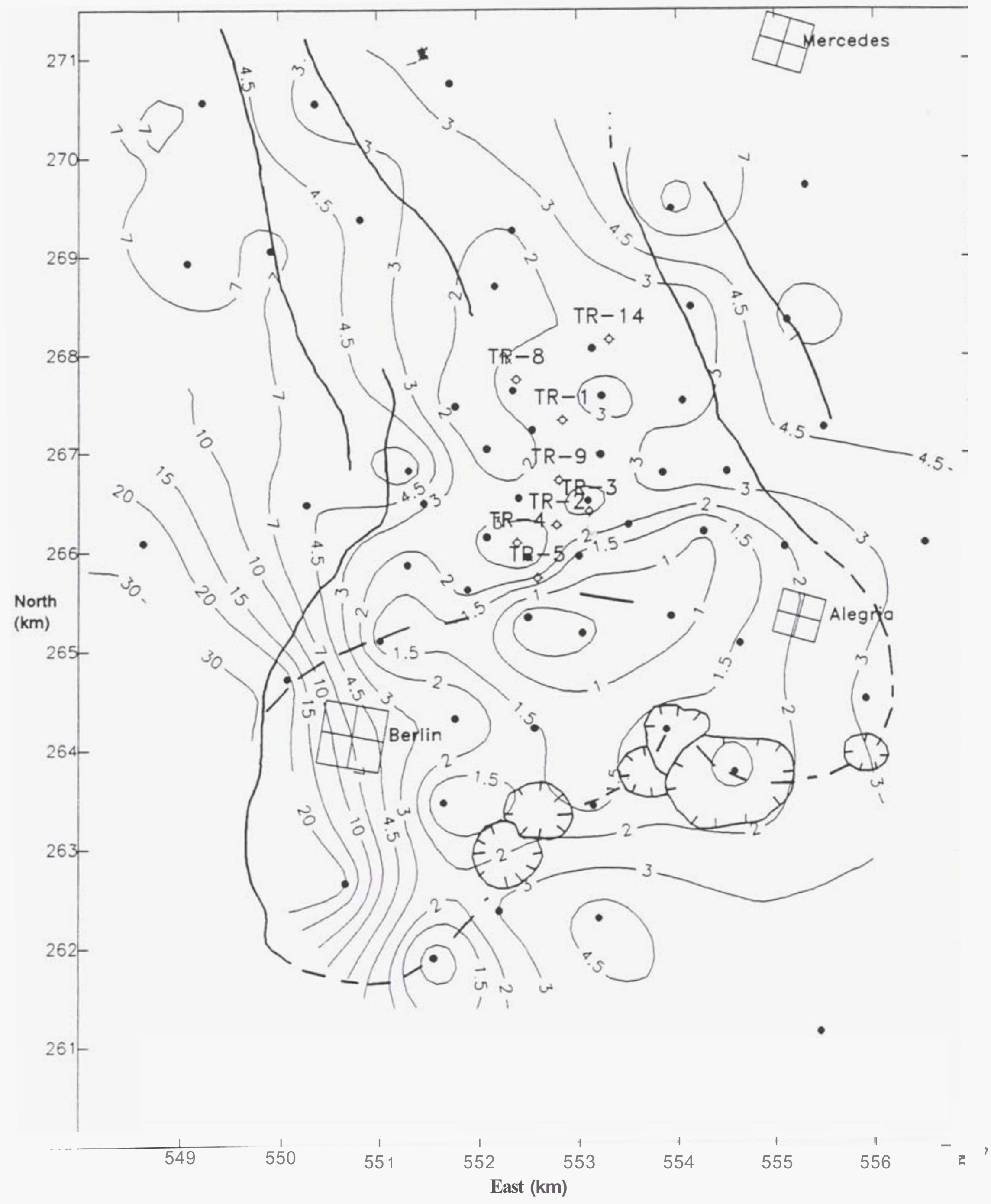

Figure 2. Resistivity (Ω-m) of the Shallow Conductive Layer.

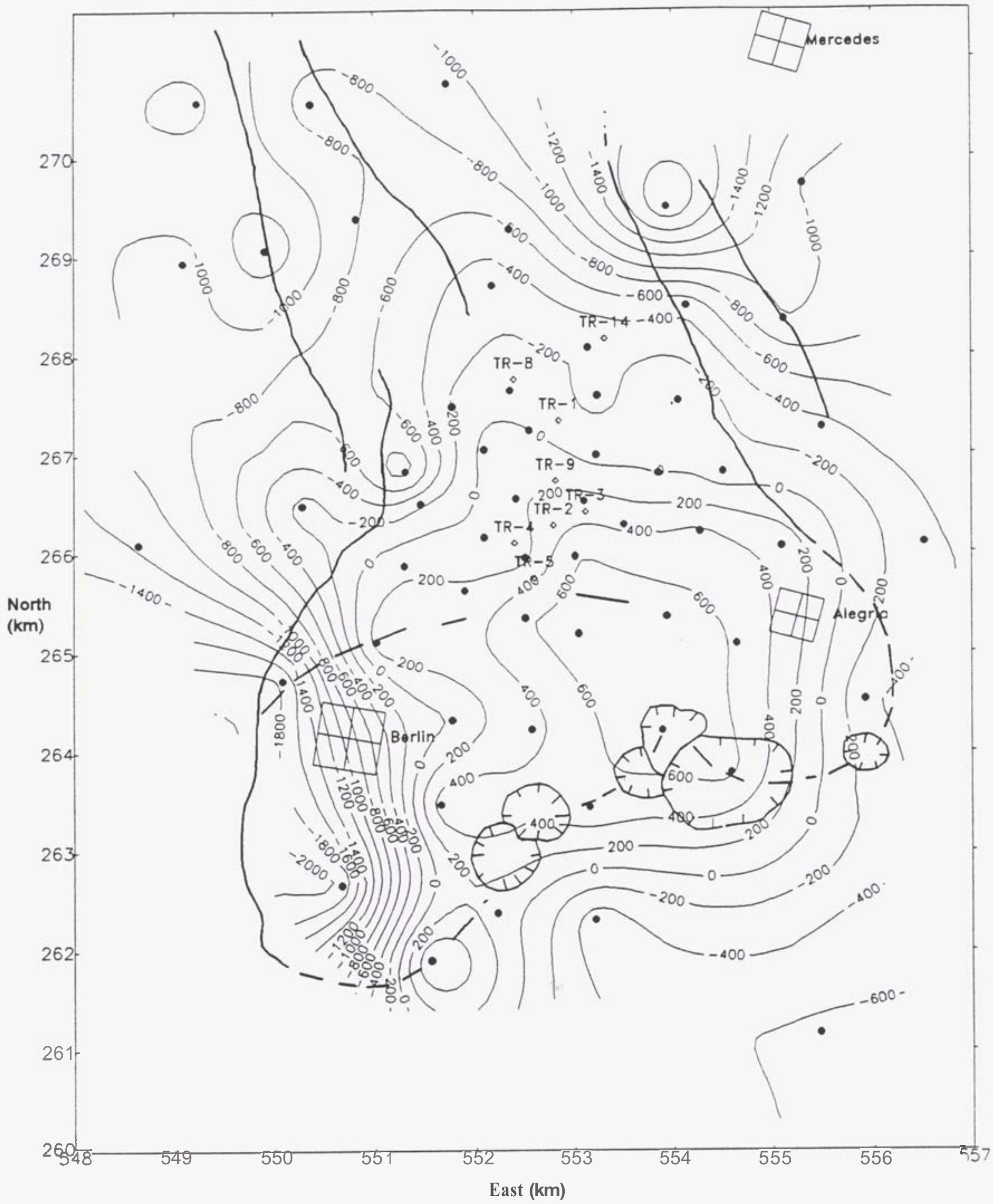

Figure 3. Elevation (m) of the Layer beneath the Shallow Conductive Layer.

Analysis of these maps, together with information from geology, chemistry and the wells, strongly suggests that this layer does represent the geothermal reservoir. Upflows of the system are located on both the northern and southern boundaries of the caldera, with a major outflow to the north through the borefield. Minor outflows are also observed to the west and the southwest, with continued tectonic activity keeping the flow paths open. Wells TR-8 and TR-14 are at the northern limits of the productive zone. The lower resistivity in the caldera may be a result of enhanced porosity in the ignimbrites infilling this zone.

Modelling by Newman et al (1985) has shown that a typical mature low resistivity magma body should be detectable by MT surveying. The resistivity of the very deep conductive layer is shown in Figure 4, with a distinct anomaly lying east-west along the northern caldera boundary. Figure 5 shows the elevation of this layer, rising to less than 4 km below sea-level on a similar trend slightly further south in the caldera. Although it is acknowledged that the soundings are strongly three-dimensional at this depth, the striking pattern observed and the correlation with the inferred model suggests that this anomaly represents the remnant of the dacite magma body associated with the recent (100,000 years) ignimbrite eruption and caldera formation.

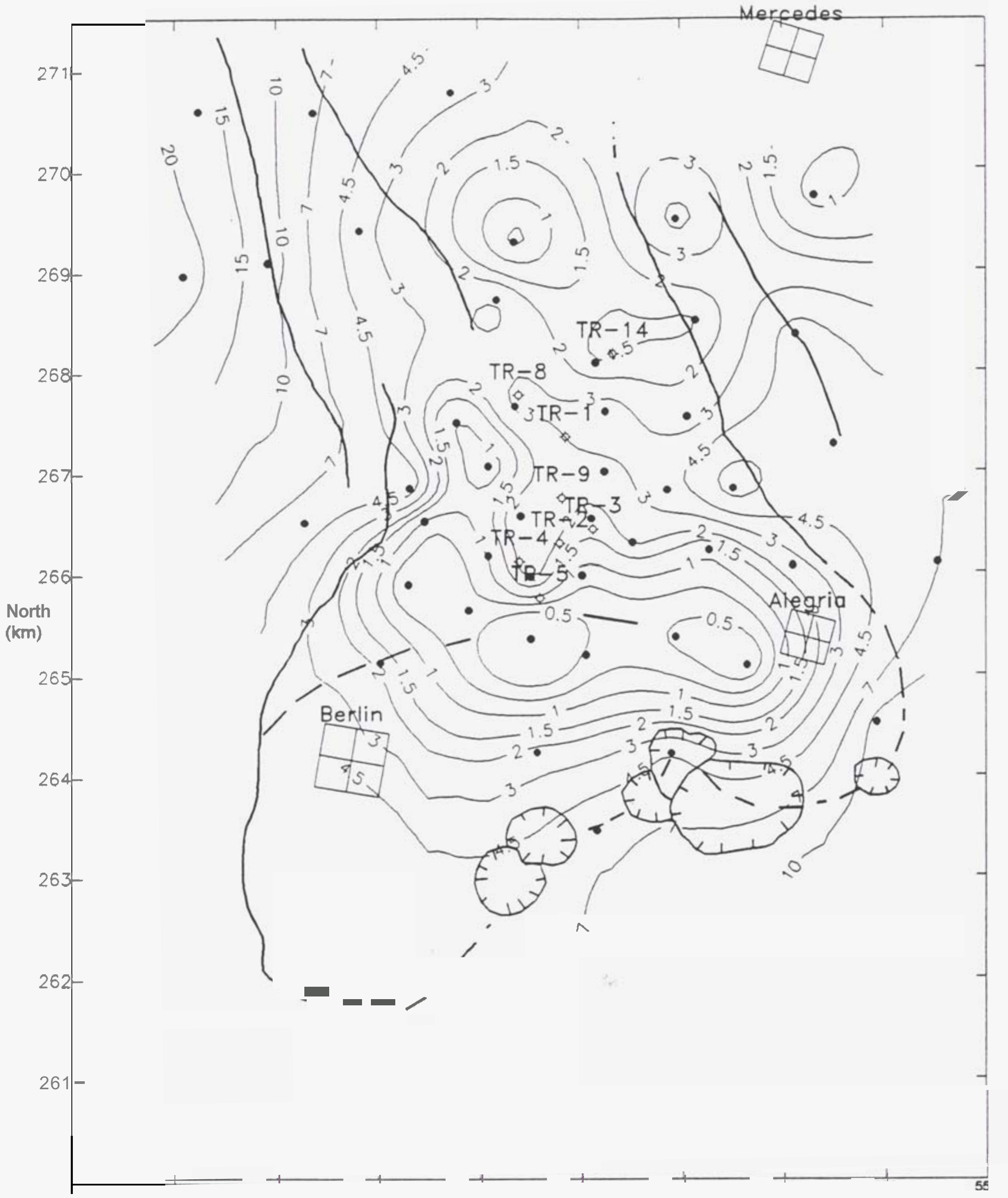

Figure 4. Resistivity (Ω-m) of the Deep Conductive Layer.

4. Discussion

Analysis and interpretation of magnetotelluric data is not an easy task, in view of the effects of shallow inhomogeneities, two and three-dimensional structures, and the ever-present noise in the data. This paper shows that a convincing model can be obtained with one-dimensional analysis (assuming that there is comprehensive coverage of the survey area with high data quality) as long as tools are available to select, manipulate and transform data rapidly, to aid in the search for meaningful and self-consistent interpretations.

The considerable penetration of the magnetotelluric method means that the bottom of the argillitic zone can be comprehensively mapped, giving a probable temperature distribution at depth, and the true resistivity of the geothermal reservoir can be measured. The detection of a possible magma chamber at depth is an additional bonus to aid in the interpretation of the geothermal system.

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Acknowledgements

The authors gratefully thank Comision Ejecutiva Hidroelectrica del **Rio** Lempa (CEL) for permission to publish this paper, Phoenix Geophysics Limited for collecting high-quality MT data, and Grant Caldwell and Hugh Bibby of IGNS for stimulating and helpful discussions.

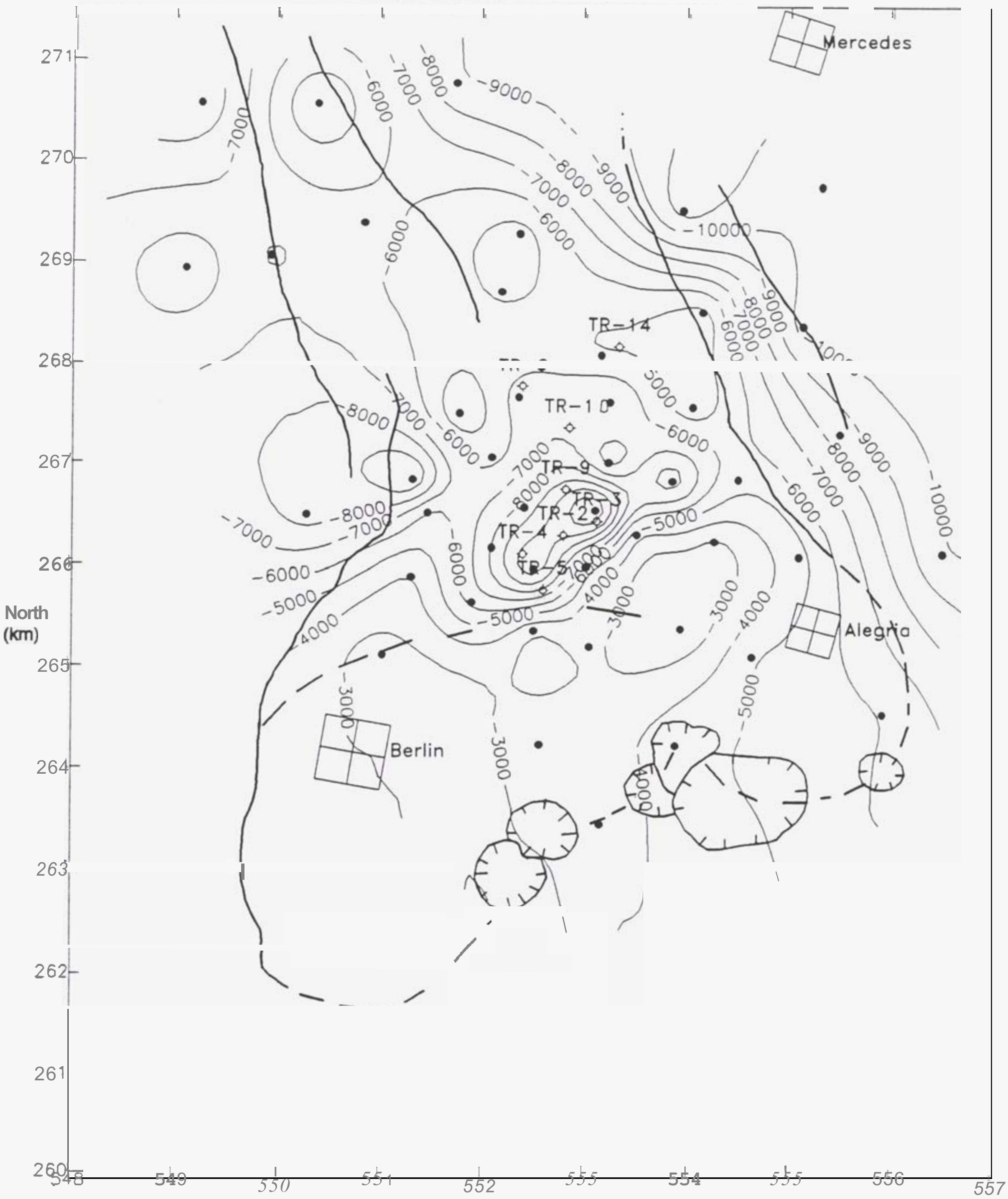

Figure 5. Elevation (m below sea level) of the Deep Conductive Layer.