Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

2D INVERSION OF VES AND MT DATA IN A GEOTHERMAL AREA

Keisuke Ushijima[1], Koichi Tagomori[2] and William H. Pelton[3]
[1]Earth Resources Engineering, Kyushu University, Fukuoka, Japan
[2]West JEC, Watanabedori, Fukuoka, 810, Japan
[3]Phoenix Geoscience, Inc. Denver, CO. USA

Key Words: geothermal resources, Schlumberger VES, MT, 2D Inversion, geoelectrical model

ABSTRACT

In the Hatchobaru geothermal area, various geophysical methods have been conducted for geothermal explorations by West JEC and Kyushu Electric Power Company Inc., (KEPCO). Especially, Schlumberger VES and Magneto-Telluric (MT) surveys have been used for locating promising drill sites as the most effective geophysical tools in the fractured-type geothermal resources. However, there are often inherent difficulties in determining 3D resistivity structures from a layered earth model alone in a difficult area. In order to solve this problem, Vertical Electric Sounding data with Schlumberger electrode arrangement and MT data were simultaneously interpreted by the least squares curve-fitting method based on 2D model. In the present paper, 3D resistivity structure including present production zones have been derived from 2D inversion results of VES and MT data in the Hatchobaru geothermal field in Japan.

1. INTRODUCTION

Various geophysical exploration methods have been applied to geothermal investigations in related to Sunshine Project in Japan.

However, each geophysical data has been interpreted as a layered structure. There are often inherent difficulties in determining layer thickness and resistivities from one geophysical method alone in a difficult area.

Generally, vertical electrical soundings with Schlumberger electrode array has following characteristics: (1) The depth penetration is limited (up to 1 km), (2) The equivalence problem occurs for the type curves (H and K) in multiple layers and (3) The large geometric soundings are very difficult for a topography, but the survey cost is cheaper than MT soundings.

However, MT survey in Japan has different features: (1) The depth penetration is great enough for a geothermal exploration (more than 5 km), (2) The survey cost per station is more expensive than VES method and (3) The MT method is more sensitive for conductive layers beneath thick resistive formations in a volcanic area.

Geophysical explorations for geothermal resources in Japan meets many difficult problems to be solved: (1) Field survey itself is very difficult because of steep topography and land use, (2) Large extension of survey line such as VES method is very hard to conduct, (3) The 3D interpretation derived from 2D inversion of geophysical data is an essential tool because of complex geological structures in volcanic areas.

1. COMPARISON WITH DRILLING LOGS

The Schlumberger VES data were interpreted to provide shallow resistivity information while the MT data provide deeper information.

2D inversion results were compared with drilling logs of exploratory and production wells in the Hatchobaru geothermal area. As a result of these comparisons, a geothermal reservoir indicate a geoelectrical model as shown in Figure 1.

It was evaluated that three resistivity zones correlate with three primary formations: the first, the surface high resistivity zones correlate with Kuju volcanic groups and upper Hohi sequence; the second, the intermediate low resistivity layer correlate with the section consisting of primarily of Pleistocene tuff breccia formation and the middle Hohi volcanic groups; and the third, high resistivity electrical basement appears to correlate with fractured volcanics of the lower Hohi sequence and the Usa group (Ushijima□et al.,1986).

2. 2D INVERSION OF MT DATA

In September and October 1982, Magneto-Telluric sounding surveys have been conducted on and near the property of the first Hatchobaru Geothermal Power Station (55MW) of Kyushu Electric Power Company Inc. in the north central Kyushu, Oita, Japan.

The objective of the survey was to determine if structural conditions favorable for the further development (the second 55 MW power plant) are presented to the east and southeast area of the Hatchobaru geothermal field.

The MT survey consisted of 22 sites along survey lines of b, c, d, e, and f (Figure 2).

The surveyed area includes the first production area (B12 and C15) and the all MT sites are positioned to coincide with the previous Schlumberger Vertical Electric Sounding stations with 200 m grid interval.

In order to determine the three-dimensional resistivity structure of the known geothermal reservoir, the VES and MT sounding data were interpreted by the constrained 2D inversion as shown in Figure 3.

A geoelectrical model for the hydrothermal system of fractured type of geothermal reservoirs was already derived from the comparison of inversion results and drilling data over the production zones in Hatchobaru area.

Therefore, it was evaluated that the geothermal reservoir itself exist in resistive Usa formation called as an electrical basements beneath low resistivity zones (hydrothermal alteration zones) where sufficient faultings has allowed geothermal fluids to migrate upward from deep heat sources to economically drillable depths.

The 2D inversion results have outlined several promising areas of low resistivity less than 5 ohm-m coinciding with the known geothermal reservoirs that provide steam and hot water mixtures for the Hatchobaru geothermal power plants (110MW).

3. EXPLORATORY DRILLING

The geologic correlation of MT data was in part developed through comparison of the inversion results at the present production zones with well logs of production wells and to cross-sections derived from 2D inversion of both VES and MT data as illustrated in Figures 4 and 5.

However, well-to-well correlation is difficult due to complex stratigraphy, highly variable volcanic formations, and geothermal environment.

Therefore, we have applied a geoelectrical model for fractured type geothermal reservoir in order to locate drill sites in a virgin geothermal area. Three exploratory boreholes were drilled to a virgin area of survey line-d in the Hatchobaru geothermal field.

Figures 6 shows 3D geoelectrical sections derived from 2D inversion of MT data of b-, c-, d-, e-, and f- lines. It was recognized that the electrical discontinuity determined from 2D inversion results coincided with the lost circulation zones identified during drilling operations.

Three exploratory wells, HT-12, HT-13, and HT-11 were planned to drill near the D17 station of the line-d because a promising geoelectrical structure existed around Mt. Goto.

In addition, the very low resistivity zones appear to lie below D18 station of the line d- suggesting that the hydrothermal alteration is very intense around these sites (Figure 7).

Three exploratory drilling have been conducted on the promising site of the line d. Two wells, HT-12 and HT-13, were quite successful and have been producing steam-water mixtures of 9 and 10 MW capacity each.

However, another one exploratory well (HT-11) was not productive, because this borehole was planned to drill in the resistive site of MT sounding data in order to confirm marginal geothermal effects in the southern area.

4. CONCLUSIONS

The repeated Schlumberger VES and MT sounding surveys extended the anomalous zones at the known geothermal area (B-12 and C-15), over the present Hatchobaru geothermal field.

The MT sounding survey also located several other promising areas in addition to production zones of two geothermal power plants (55MW x 2 units).

The joint application of Schlumberger VES and MT sounding clearly demonstrate that MT method could be used to determine areas of anomalously low resistivity that are the most important indicator of potential geothermal reservoirs beneath the thick volcanics that covers the Hatchobaru geothermal area.

In addition, the location of faulting and increased fractures determined by MT sounding surveys have been confirmed by the resulting exploratory wells (HT-12 and HT-13) drilled in a new area (Ushijima, 1986).

The drilling success proved the existence of exploitable potential geothermal reservoirs at the southeast and southwest parts in the Hatchobaru geothermal area.

ACKNOWLEDGEMENTS

The authors are grateful to KEPCO for carrying out Schlumberger VES and MT sounding surveys in the Hatchobaru geothermal area. We thank PHOENIX Geophysics Inc. for their help of MT field works. We also thank Dr. T. Uchida of Geological Survey of Japan for his valuable technical assistance for the interpretation of geophysical data.

REFERENCES

Constable, S. L. et al., 1987, Occam's inversion: A practical algorithm for generating smooth models from EM sounding data, *Geophysics,* Vol.52, pp.289-300.

Pelton, W. H. et al., 1985, Magnetotelluric interpretation of Hatchobaru Geothermal area, Japan, *Geothermal Resources Council Trans.,* Vol.9 (II), pp.45-48.

Petrick, W.R. et al., 1977, Ridge regression inversion applied to crustal resistivity sounding data from South Africa, *Geophysics,* Vol.42, 995-1005.

Uchida T., 1991, Two-dimensional resistivity inversion for Schlumberger sounding, *Geophy.Explor. of Japan(Butsuri Tansa),* Vol.44, pp.1-17.

Ushijima, K. et al., 1986, Joint interpretation of MT and dc resistivity data at Hatchobaru geothermal area, *Expanded Abstracts, 56th SEG Meeting,* pp.216-219.

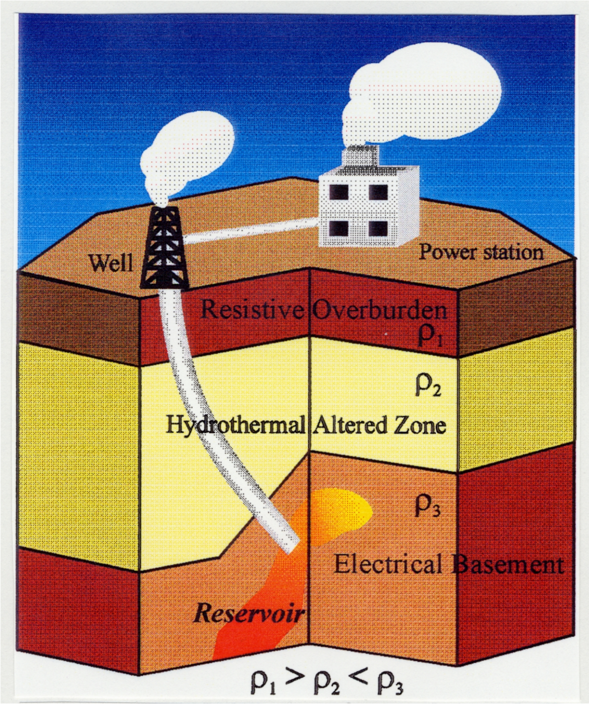

Figure 1. Geoelectrical model for a geothermal reservoir.

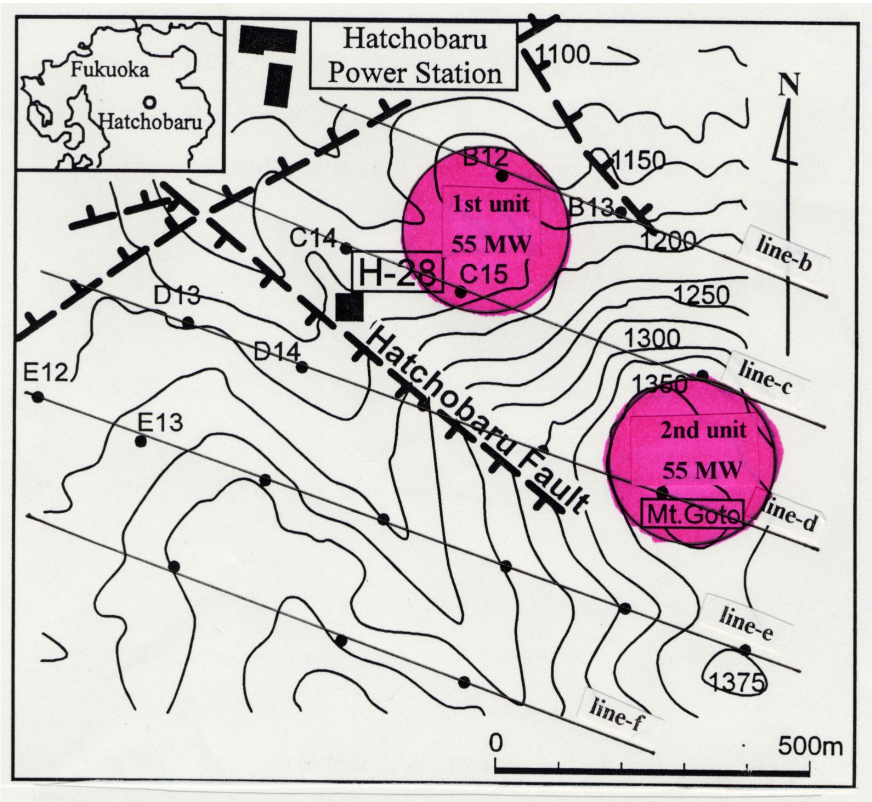

Figure 2. Schlumberger VES and MT survey lines in Hatchobaru area.

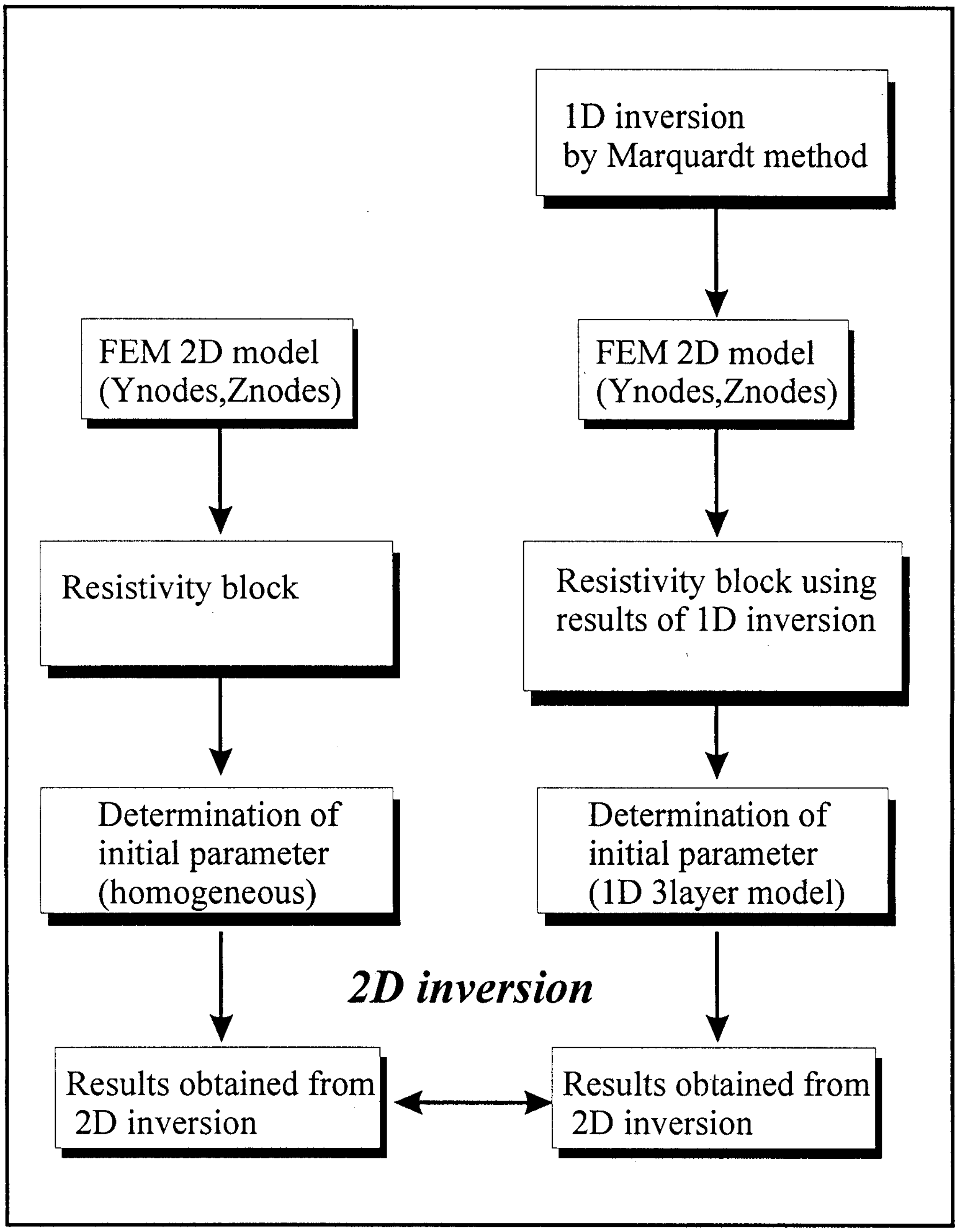

Figure 3. Flow chart for 2D inversion of VES and MT sounding data.

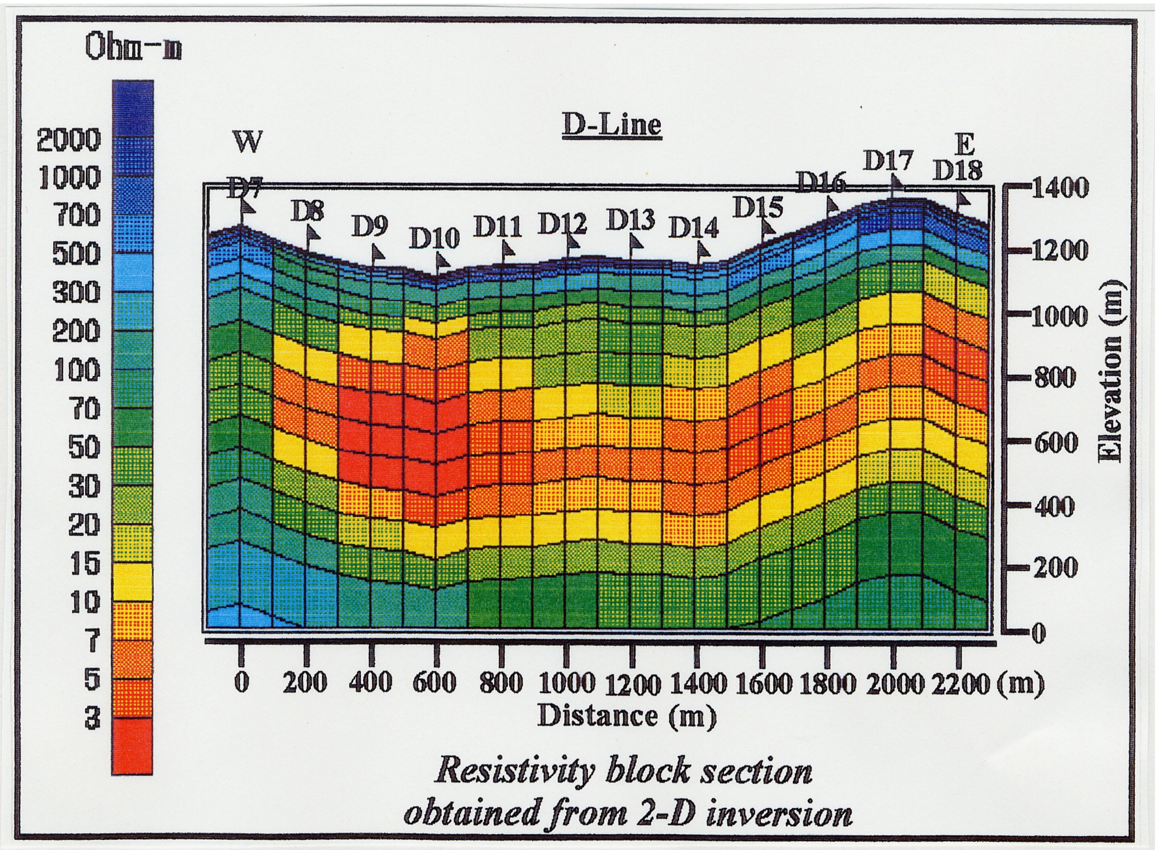

Figure 4. Resistivity section derived from 2D inversion of VES data (line-d).

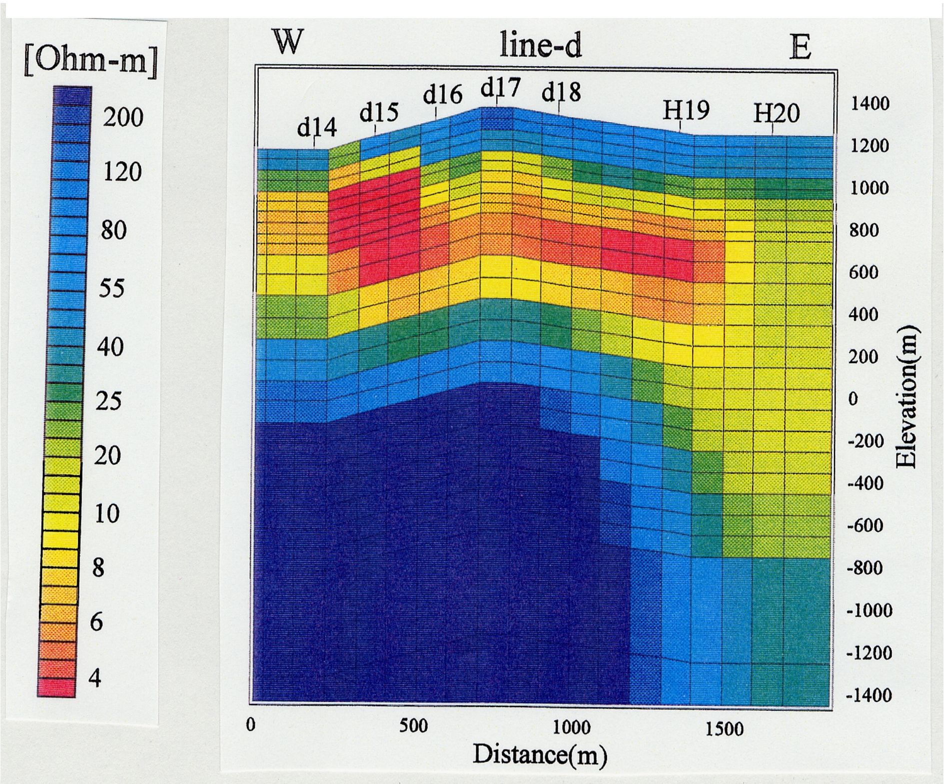

Figure 5. Resistivity section derived from 2D inversion of MT data (line-d).

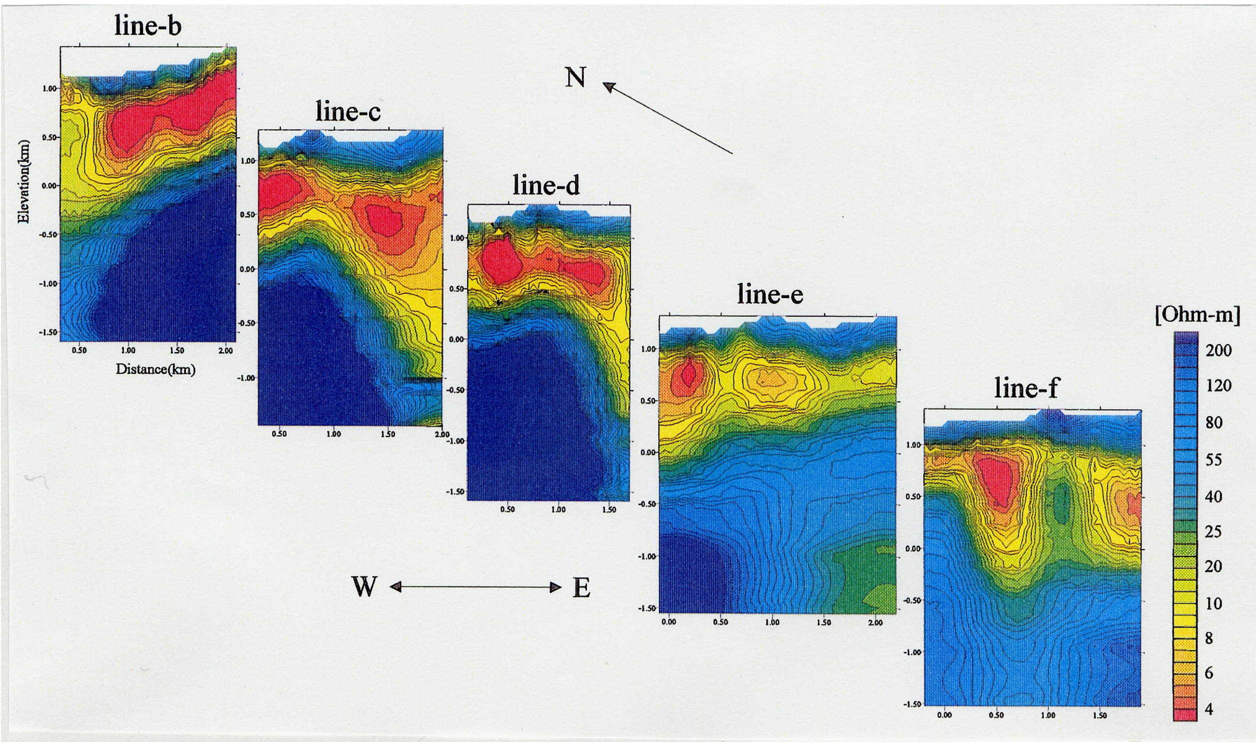

Figure 6. Resistivity section from 2D inversion of MT data in Hatchobaru area.

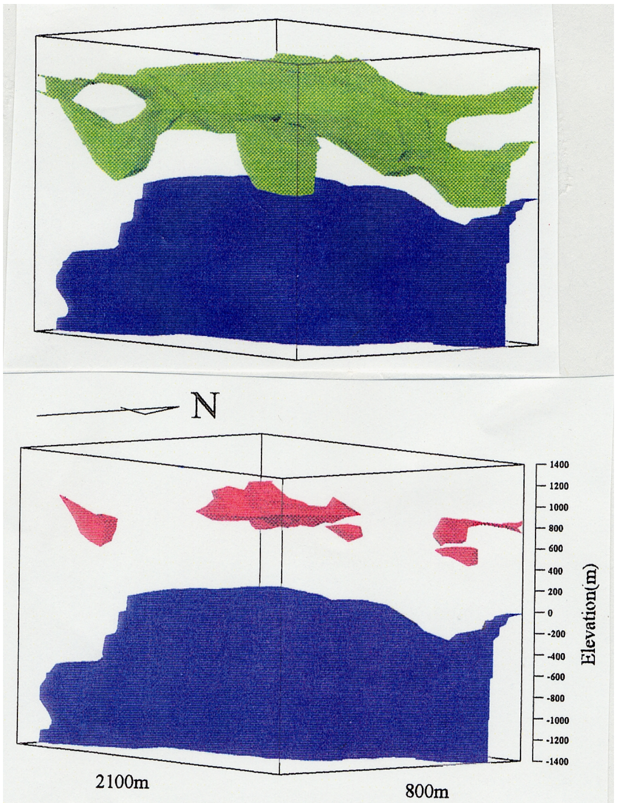

Figure 7. 3D distribution of low resistivity zone over an electrical basement.
(above: 10 Ωm distribution; below: 3 Ωm distribution)