Three - Dimensional Magnetotelluric Analysis For the Kakkonda Geothermal Field

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Abstract

NEDO began the “Deep-Seated Geotheraml Resources Survey” in Kakkonda (Iwate, Japan) from Fiscal year 1992 and the pilot survey well WD-1a reached 3,7929m and over 500 degrees C in 1995. In1996, NEDO driiled a side-trucking well WD-1b and hit several high permeability zones. As the number of remaining shallow geothermal reserviors diminishes through exploitation, the geothermal industry must turn its efforts towards the detection and delineation of deep-seated geothermal reserviors. As part of NEDO project, an extensive tensor magnetotelluric (MT) survey was carried out over the Kakkonda area in 1998. 76 sites were arranged in four profiles to cross a major structural feature. To curtail spatial aliasing, the electric dipoles along each profile were deployed contiguously. The resistivity model within the area was derived by 3-D inversion analysis.

Introduction

From July to Octorber in 1998, MT data were collected at 76 sites along four profiles across the main geological structures of the Kakkonda area in northeastern Japan as part of a project, supported by NEDO, to assess the deep-seated geothermal potential of the region. The Kakkonda geothermal field lies in a gorge along the upper part of the Kakkonda river in the southern part of the Hachimantai volcanic field in Japan. The Hachimantai volcanic field is one of the most important regions for Japanese geothermal exploitation, and contains the Matsukawa, Onuma geothermal plants. Seismic, borehole EM, and MT data - as well as well logging- were measured in the Kakkonda area to study the main feature of regional and local structures.

One purpose of our study was to use MT method to impose geophysical constrains on the geological setting of the area. We aimed to obtain a 3-D image of the resistivity distribution in deep formation and to understand its connection with the geothermal reserviors.

Kakkonda MT Survey

Using “high-accuracy MT system” developed by NEDO, MT data were recorded at 76 locations along four profiles in the area (Fig. 1). The data were acquired in the frequency range of 125Hz to 0.001Hz, in two selected frequency bands. The measurment directions of horizontal fields were roughly N71E and N161E, in accordance with a surface geological strike. The MT time series have been processed by cascade decimation with coherency sorting algorithm (Yamane *et al*, 1998). For frequencies below than 0.01Hz, some of data

are poor, mainly near the Kakkonda geothermal plant and its associated power lines.

Figure 2 shows plot of the rotated impedance tensor components Z_{xx} and Z_{xy} at 10Hz. Patterns in the shape and orientation of these elements can be associated with one-dimensional (1-D), two-dimensional (2-D), or 3-D geoelectrical structures. Generally, Z_{xy} is larger than Z_{xx} , but at almost sites the magnitude and asymmetric form of Z_{xx} indicate 2-D or 3-D effects.

At 10Hz the depth of penetration doesn't exceed 1km (considering 30 ohm-m homogenous earth). Therefore, the direction of polar diagram is strongly influenced by the structure of Tertiary formation. The pattern (Fig. 2) at the sites along the Kakkonda river indicates a complex resistive structure oriented approximately northwest - southeast. There is clearly structural complexity in the western part of the area.

These features suggest that 3-D analysis would be preferable to a 2-D analysis. Indeed, it is believed that the structure of the area is 3-D: (1) The area presents a strong offset geometry along NW-SE, NE-SW, N-S and E-W. (2) The basement, the Kakkonda granite, must represent complex shape suggested by biotite isograd (Komatsu *et al*, 1998).

3-D MT Inversion Analysis

68 sites were selected for the inversion analysis. Due to delineate the 3-D structure, four elements of the impedance tensor were used for the inversion. We have the inverted image with the 3-D inversion program of GRRI method (Yamane *et al*, 1998) and with 3-D modelling program developed by Mackie *et al* (1993), which is based on the integral forms of Maxwell's equation.

The region of the inversion area was discretized into 24 blocks in the x -direction (N71E), 9 blocks in the y -direction (N161E), and 24 earth layers in the z -direction. Even on such grid, it is expected that the complex geometry of the area is represented. An initial model was constructed on the base of the 2-D inversion results.

Figure 3 shows the 3-D model with 8 horizontal slices. The following observations can be made from the inversion result.

- Beneath the overburden (resistivity of 10 ohm-m, thickness of 200m, associated with altered clay mineral), a several hundred meters thick formation (the resistivity of 30 ohm-m) is underlain by a more resistive basement (more than 100 ohm-m). That zone has been associated with the shallow geothermal reservoir.
- The uplift of the resistive basement is founded below the Kakkonda River, whose shape suggests that this basement is an intrusive rock.
- To the south, this resistive structure is partly limited by a conductive block.
- Below the Kakkonda River, the resistivity of the resistive basement decreases from 120 ohm-m to 50 ohm-m. Such a feature may be associated with geothermal heat source.

Conclusion

Three - dimensional inversion of MT data acquired in the Kakkonda geothermal field has led to a characterization of the resistivity structure of the middle-deeper part in the region. The inversion result indicates that there is a resistive basement at middle-deep part, and conductive zones at shallow depths in the region. The result also indicates that the shape of

the resistive basement is irregular, which is correlated with Kakkonda granite.

Reference

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Figure 1. The location of the MT sites in the Kakkonda area

Figure 2. Polar diagram of MT impedance at 10.0Hz

Figure 3. 3-D inversion result in the Kakkonda area