3D MAGNETOTELLURIC SURVEYS IN HACHIJO AND MINAMI-IZU GEOTHERMAL AREAS, JAPAN

Toshihiro Uchida[1], Takumi Ueda[1], Shinichi Takakura[1], Toshio Kasagi[2]

[1] Geological Survey of Japan, AIST, 1-1-1 Higashi, No. 7, Tsukuba, 305-8567, Japan
[2] Nittetsu Mining Consultants, Co., Ltd., Tokyo, Japan
e-mail: uchida-toshihiro@aist.go.jp

ABSTRACT

We conducted three-dimensional (3D) magnetotelluric (MT) survey in two geothermal areas in central Japan in 2010 - 2012. The first area is the Hachijo geothermal field, located on a small remote island (Hachijo-jima Island), about three hundreds kilometers south of Tokyo City. A 3.3 MWe geothermal power plant has been in operation since 1999. The second one is the Minami-Izu geothermal area located at a southern part of Izu Peninsula, some 100 km southwest of Tokyo City. A goal of the research project is to understand the relation between the deep high-temperature geothermal reservoir and shallow low-temperature hot spring reservoir by an integrated geoscientific studies, including geophysics and reservoir simulation. The purpose of the MT survey was to provide a detailed electrical resistivity image around the geothermal area including surrounding hot spring sites to the base reservoir model for a geothermal monitoring study. We have applied 3D inversion to the MT data in the two areas. In the Hachijo geothermal field, the 3D resistivity model successfully correlates with the geothermal reservoir, showing low-resistivity clay cap layer and higher-resistivity reservoir core. On the other hand, we could not identify the existence of high-temperature geothermal reservoir in the Minami-Izu area from the MT model.

Keywords: magnetotelluric survey, 3D inversion, geothermal reservoir, hot spring, Hachijo, Minami-Izu

1. INTRODUCTION

When a new geothermal power development is planned in an area where utilization of hot spring water has been already established in the local community, an anxiety about possible reduction of hot spring water production due to the exploitation of deep high-temperature geothermal water is a critical discussion issue in Japan. The goal of this research is to understand the relation between the deep high-temperature geothermal reservoir and shallow low-temperature hot spring reservoir by an integrated study of geochemical, geophysical, and reservoir engineering techniques. Accurate geophysical monitoring and hydrothermal water simulation are the key elements of the current research. In order to support such integrated geothermal modeling and monitoring, we conducted magnetotelluric (MT) surveys in two test fields in the research project.

The first test field is the Hachijo geothermal field, where a 3.3 MWe power plant is in operation since 1999. The Hachijo field is located in a small remote island, called Hachijo-jima Island, approximately 300 km south of Tokyo City. The second test field is the Minami-Izu area, which is located at a southern part of Izu Peninsula, about 100 km southwest of Tokyo City. The Minami-Izu area is one of the popular hot spring resort areas in Izu Peninsula, but there is no high-temperature geothermal resource identified and no geothermal power development is planned so far. We conducted MT surveys in the two areas in 2010 – 2012, and applied 3D inversion to obtain accurate 3D resistivity models over the geothermal field and hot spring sites.

2. HACHIJO GEOTHERMAL FIELD

Hachijojima Island is a volcanic island located on the Izu Volcanic Arc. There are two volcanoes in the island, of which the western volcano (Hachijo-Fuji) is younger and has a cone-shape body, while the eastern volcano (Mihara-yama) is rather old and the volcanic body has been greatly eroded. The Hachijo geothermal power plant is located on the southern flank of Mihara-yama volcano. The power plant started its operation in March 1999, having been providing the base load electricity to the population of about 10,000 in the island. There are several hot spring sites to the south of the power plant.

MT measurement was carried out at 77 locations in 2010 (Fig. 1). High-frequency (AMT) data were obtained at all stations, while low-frequency (MT) measurement was conducted only at 24 stations out of the 77. The remote reference processing was applied to both AMT and MT data. The reference site for the MT band is about 800 km north from the island, and the reference site for AMT data is located at northwestern flank of Hichijo-Fuji volcano. AMT data acquisition was conducted usually for one night, while MT data acquisition was repeated for three nights. The target area of the study is located in a town, and most of the MT stations in the main survey area are close to houses and small power lines. Therefore, data quality, particularly at a lower frequency band, was very poor at most of the stations, even though we applied far remote reference processing and compilation of three of more nights data.

Figs. 2 shows examples of MT responses at very poor station and fair quality stations, respectively. Noise sources may be small power lines or some unstable electricity load at local electric facilities, but we could not identify them. Data quality is generally better at stations in the north, while it is very poor at stations in the center and southern part of the survey area.

Fig. 3 shows induction vectors at four frequencies for the main zone of the survey area. Tipper amplitude is small at frequencies higher that 1 Hz, indicating small lateral resistivity change up to a depth of several hundred meters. Induction vectors point southward at frequencies below 0.3 Hz. It is due to the sea effect: the existence of seawater in the south.

We carried out 3D inversion for the main survey area that includes the power plant and a few hot spring sites (Uchida and Sasaki, 2006). The area for 3D interpretation is approximately 2 km in E-W direction and 2.5 km in N-S direction. We utilized the MT data at 55 stations and 15 frequencies, from 0.0269 Hz to 460 Hz, for the inversion. The mesh size for the finite-difference forward modeling is 69 (x) x 73 (y) x 40 (z), and a cell at the surface has a size of 50m x 50m x 25m in x, y and z directions, respectively. Seawater that exists in the south of the survey area is approximately included in the model. We assumed that the shoreline is straight in E-W direction and is located 200 m south of the southern-most MT station.

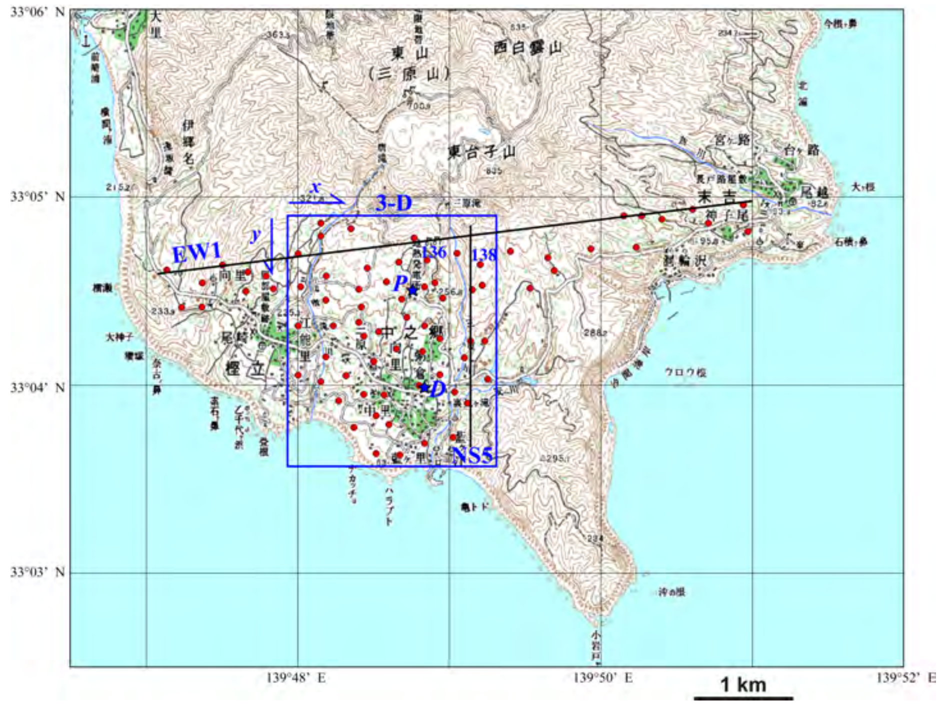

Fig. 1. MT survey stations (red dots) at the Hachijo geothermal field. "*P*" denotes the location of geothermal power plant and "*D*" indicates the location of shallow observation well drilled in this project. The blue rectangle is a zone for 3D interpretation and black line are for 2D inversion. The background map is from the topography map information by Geographical Survey Institute.

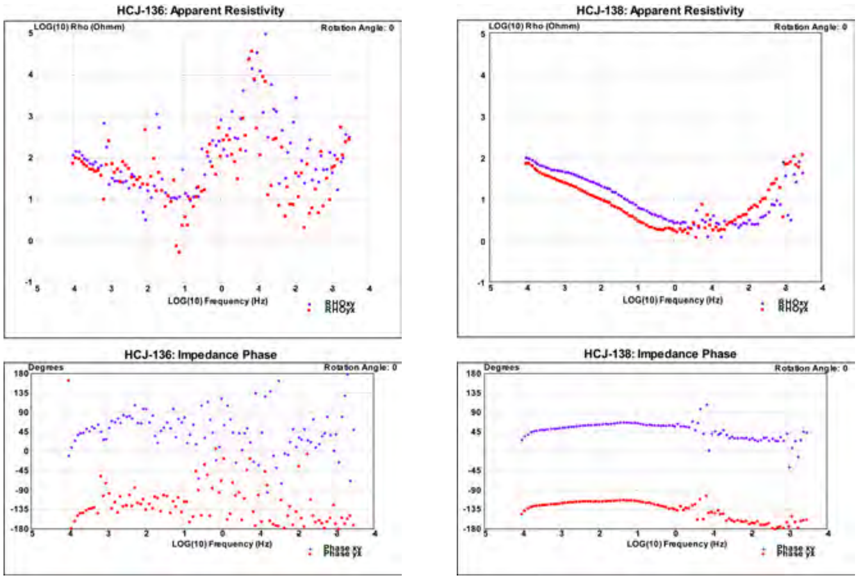

Fig. 2. Examples of apparent resistivity and phase data at (left) Station 136 and (right) Station 138. *x*-direction for the impedance rotation is north. Station 136 is one of the worst sites, while Station 138 is one of the best-quality sites. The two stations are only about 500 m apart with each other.

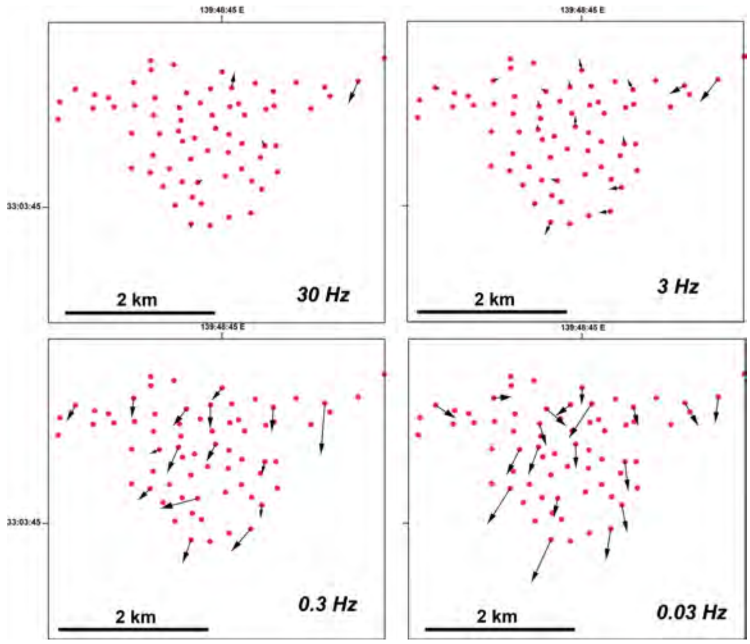

Fig. 3. Induction vectors at four frequencies in the main survey area. The vectors point toward a low-resistivity anomaly. A length of 2 km corresponds to unit amplitude of tipper.

Final 3D resistivity model is shown in Figs. 4 and 5. Figure 4 shows depth-slice sections of the 3D model. Figure 5 shows vertical cross-sections at x = 1.3 km and y = 0.7 km. Resistivity of shallow layers, up to 100m depth, is high, several hundreds of ohm-meters. This corresponds to non-altered lava layer. Below this high-resistivity layer, a low-resistivity layer expands entire survey area. Particularly, very low resistivity zone, less than 1 ohm-m, exists near the power plant in the north. This may correspond to clay-cap of the reservoir system. Below about 1 km depth, resistivity gradually increases as we go deeper. However, resistivity is not so high, about 10 ohm-meters, in the area.

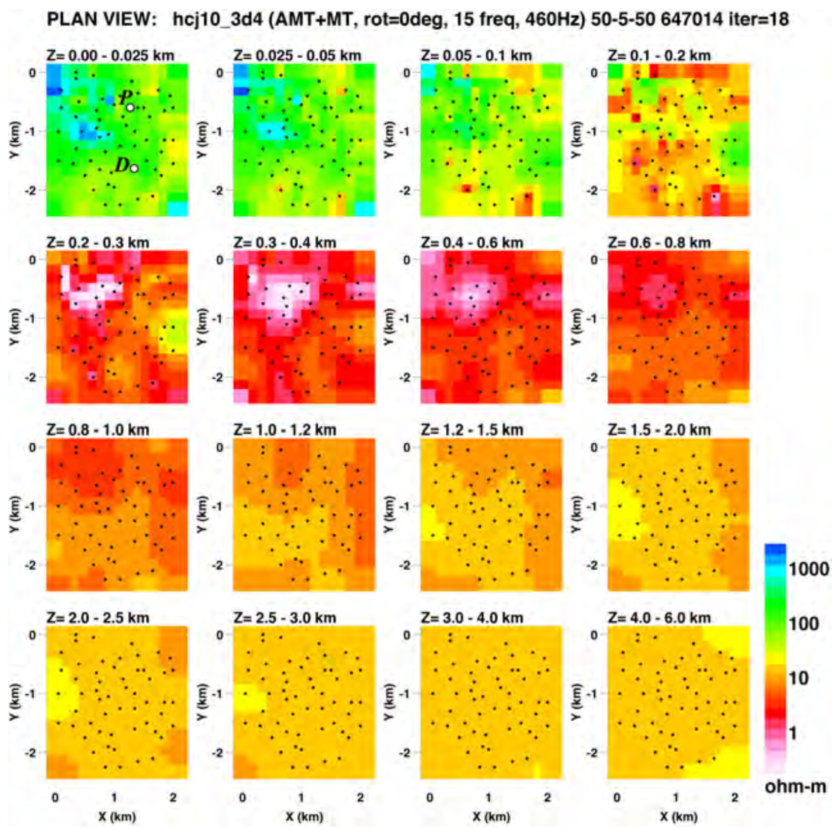

Fig. 4. Depth-slice sections of the 3D resistivity model. Open circles *P* and *D* on the top-left panel indicate location of Hachijo Power Plant and the observation drilling, respectively.

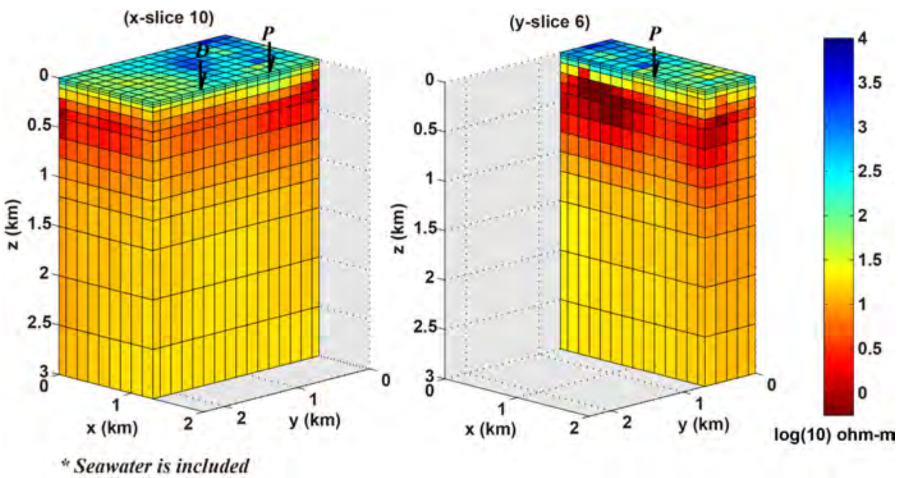

Fig. 5. 3D resistivity model, looking from southeast. Cross sections at (left) x=1.3 km and (right) y=0.7 km are shown. Arrows *P* and *D* indicate location of Hachijo Power Plant and the observation drilling, respectively.

3. MINAMI-IZU GEOTHERMAL AREA

The Minami-Izu hot spring area is located at a southern end of Izu Peninsula. It is one of the popular hot spring resorts in the Peninsula. There are tens of hot spring wells in the area, either naturally flowing out or artificially pumped out. The highest temperature of hot spring water in the area is approximately 100 degrees Celsius. Our study aimed at to examine the existence of deep high-temperature geothermal reservoir beneath shallow hot spring resource.

In the Minami-Izu area, we conducted MT measurement at 43 locations in 2011 and 2012 (Fig. 6). Low-frequency (MT) data were obtained at 22 stations, while AMT data were obtained at all stations. The remote reference site for low-frequency MT data was the same as the one for the Hachijo MT survey. The remote reference site for high-frequency AMT data was located about 10 km northwest of the survey area. Since a DC-powered train system is located several kilometers to the east of the survey area and an industrialized area as well as the main bullet train line in Japan are only a few tens of kilometers north, we had expected that the MT data would be miserable before the field work. However, with a careful measurement and a far remote reference processing, we were able to obtain moderately good-quality data.

We applied the 3D inversion to all stations in the area. The size of the 3D interpretation zone is approximately 3.5 km in E-W direction and 3 km in N-S direction. Fifteen frequencies, 0.054 - 900 Hz, were utilized for the inversion. The mesh size is 92 (x) x 83 (y) x 39 (z) in cell numbers, and the cell size at the surface is 50m (x) x 50m (y) x 25m (z).

The final 3D resistivity model is shown in Figs. 7 and 8. Fig. 7 shows depth-slice sections and Fig. 8 vertical cross-sections at x=1.15 km and y=1.5 km. Resistivity distribution at the surface is very complicated; a low-resistivity zone near the drilling site corresponds to clay alteration zone and high-temperature hot spring wells. From 100 m to 600 m depth, low-resistivity zones are dominant in the center of the survey area. It has a weak trend of NW-SE direction.

Fig. 9 compares the 3D MT model with the resistivity logging data in the observation well. The general trend of the resistivity profile by the MT model correlates with logging data very well. According to the catting sample analysis, concentration of smectite is high from the surface to about 150m depth. This zone corresponds with low-resistivity layer both in the MT model and the logging profile.

Fig. 10 compares depth-slice resistivity section with surface geology. At depth between 50m and 100m, low-resistivity anomaly is located in the center of the survey area. This corresponds to the location of hot spring wells in the area. They are also mostly located in a marine sedimentary formation (including volcanic rocks) in Tertiary time. High-resistivity anomaly in the west of the drilling site corresponds with Tertiary dacite formation, which overlies the marine sedimentary formation. At depth of 300m - 400m, low resistivity zone correlates with the marine sedimentary formation.

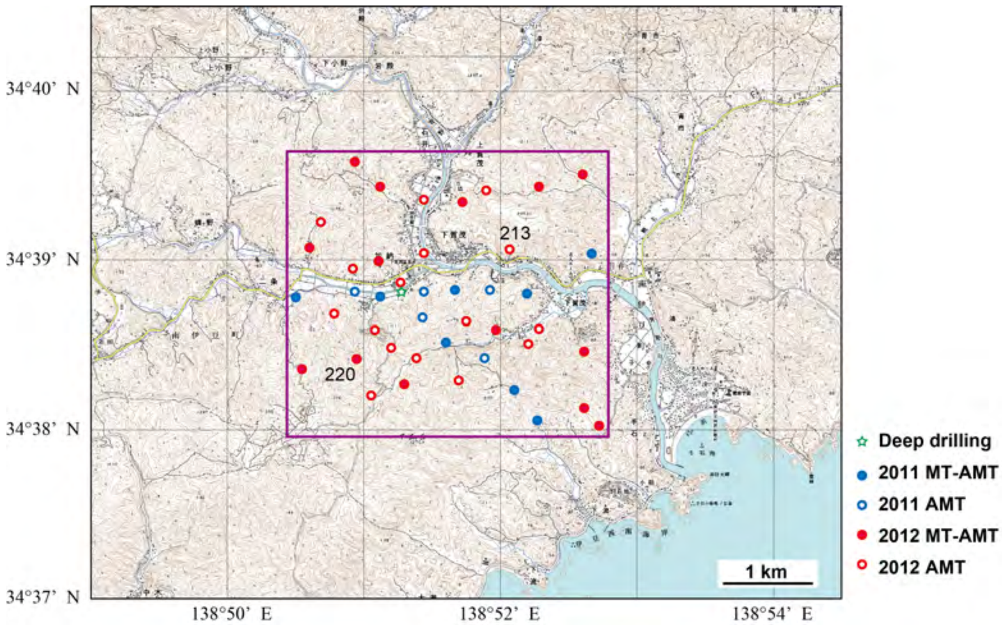

Fig. 6. MT survey stations (circles) at the Minami-Izu geothermal area. The star indicates location of drilling site in this study. The purple rectangle is a zone for 3D interpretation. The background map is from the topography map information by Geographical Survey Institute.

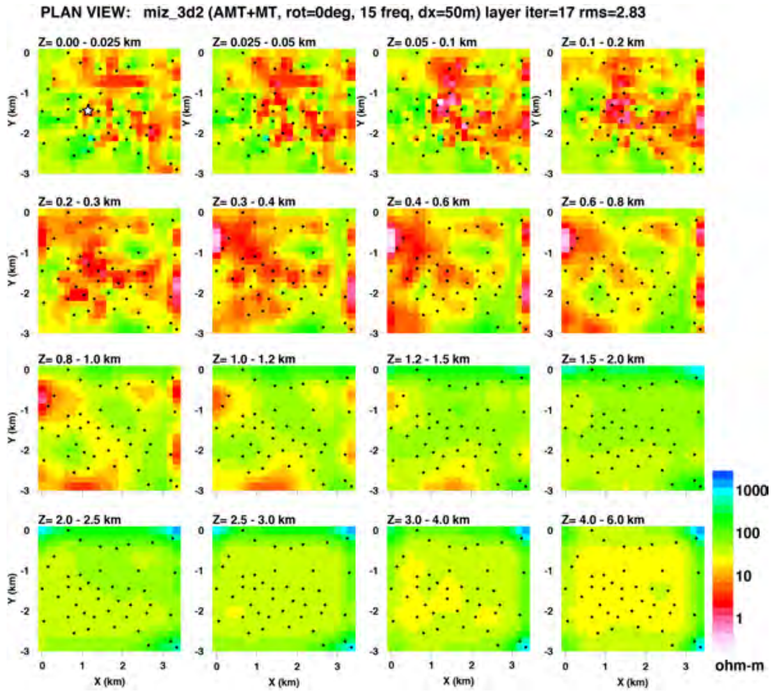

Fig. 7. Depth-slice sections of the 3D resistivity model. The star on the top-left panel indicate location of observation drilling of about 700 m depth.

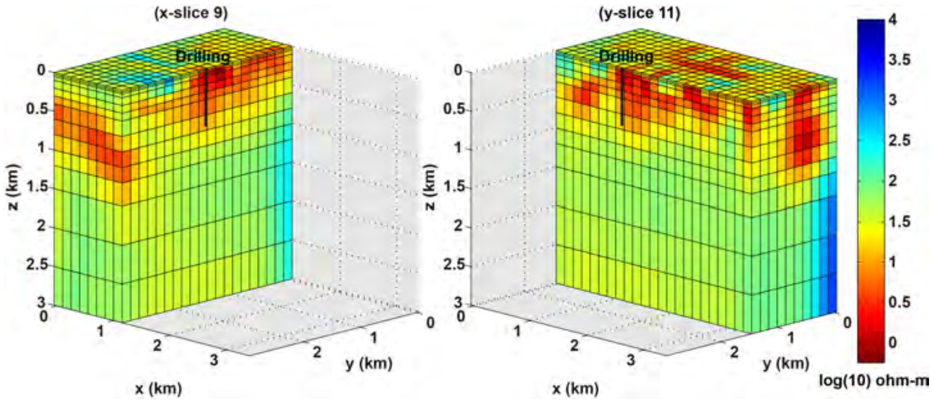

Fig. 8. 3D resistivity model, looking from southeast. Cross sections at (left) x=1.15 km and (right) y=1.5 km are shown. The back bar shows an approximate trace of the drilling.

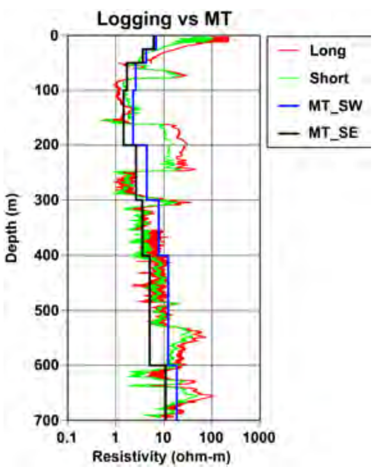

Fig. 9. Comparison of depth profiles of the 3D MT resistivity model with the resistivity logging data in the observation well. Resistivity values of the two neighboring blocks near the borehole are shown.

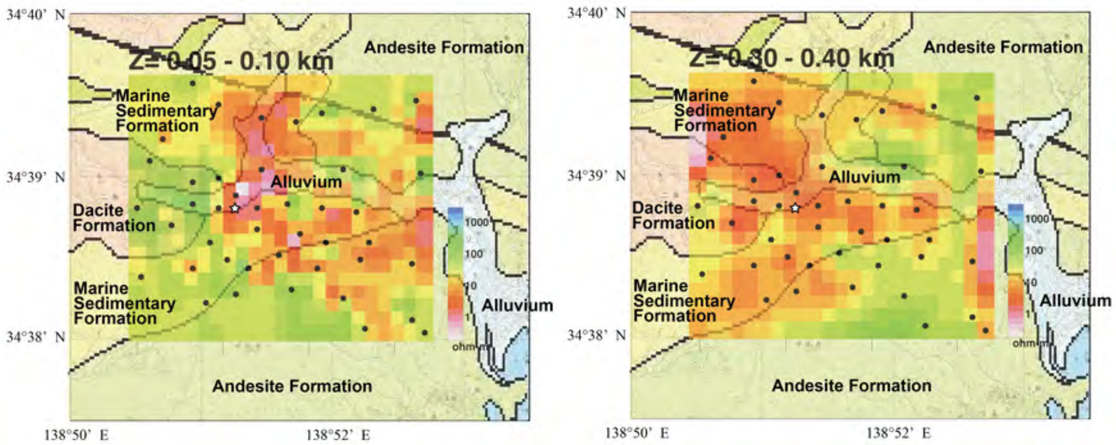

Fig. 10. Comparison of depth-slice resistivity sections of the 3D MT model with surface geology. (left) depth of 50 to 100m, and (right) depth of 300m to 400 m.

5. SUMMARY

3D MT survey was carried out in the Hachijo geothermal field and Minami-Izu geothermal area. In the Hachijo field, the 3D resistivity model indicates high-resistivity unaltered lava formation in the shallow zone and a low-resistivity anomaly probably associated with the cap rock of the geothermal system around the power station. Resistivity of the reservoir zone is not so low, approximately 10 ohm-m. Because the Minami-Izu area is recognized as a hot spring area, we could not obtained a resistivity model that indicates high-temperature geothermal reservoir with a combination of shallow low-resistivity layer and deep high-resistivity core.

ACKNOWLEDGEMENTS

This study was conducted under a project "Development of an advanced geothermal reservoir management system for the harmonious utilization with hot spring resources" in FY 2010 – FY 2012, funded by the Ministry of Environment.

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