APPLICATION OF AUDIOFREQUENCY MAGNETOTELLURIC METHOD IN OGIRI GEOTHERMAL FIELD, SOUTHWESTERN JAPAN

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ABSTRACT

The audiofrequency magnetotelluric (AMT) method was applied in 2004, for detailed investigation of the reservoir in the Ogiri geothermal field, southern Kyushu, southwestern Japan, by Nittetsu Kagoshima Geothermal Co., Ltd. (NKG). The AMT stations were arranged with an interval of about 150 m on a grid array whose size was approximately 2.5 km x 2.5 km. The number of AMT stations was 66. This survey was targeting an eastern expansion of the currently producing geothermal reservoir. There had been conducted several stages of MT surveys in the same area by the New Energy and Industrial Technology Development Organization (NEDO), NKG and Geological Survey of Japan (GSJ) before. This report presents a trial of three-dimensional (3D) inversion of the AMT data, together with those existing MT data.

Keywords: audiofrequency magnetotelluric method, geothermal exploration, Ogiri, 3D interpretation

1. INTRODUCTION

The magnetotelluric (MT) method is now widely applied in natural resource exploration. In particular, it is a major geophysical tool in geothermal exploration. The resistivity structure of a geothermal reservoir is often characterized by a combination of a low-resistivity clay-rich cap layer on top and a relatively high-resistivity reservoir zone beneath. This resistivity structure is usually applicable when clay minerals are dominant hydrothermal alteration in a geothermal field.

To investigate the complicated geological structure in geothermal areas, 3D MT techniques have been intensively studied in the past decade (e.g., Sasaki, 1999; Mackie et al., 2001). Several case studies of 3D MT surveys have been reported in these several years. This paper describes 3D interpretation of MT and AMT data obtained in the Ogiri geothermal field, southwestern Japan, and demonstrates the effectiveness of the AMT measurement for geothermal exploration.

2. AMT AND MT SURVEYS

The Ogiri geothermal area is located in the southern part of Kyushu Island, southwestern Japan (Fig. 1). A 30-MWe geothermal power plant has been operated by Nittetsu Kagoshima Geothermal Co., Ltd. (NKG) since 1996 (Fig. 2). The neighboring Shiramizugoe field is thought to be a promising area for future expansion of steam production. The survey area is situated on a highland whose elevation is from 700 m to 900 m. The area is underlain by Quaternary volcanic rocks with a thickness of 2–3 km. Below this layer is a Mesozoic metamorphic formation that forms the basement of this region.

Three faults trending in a NE-SW direction have been identified in the survey area. From north to south they are the Sakkogawa, Ginyu, and Shiramizugoe faults. The major production zone of the Ogiri geothermal reservoir is associated with the Ginyu Fault (Goko, 2000). This geothermal reservoir is situated at a depth of 500–1500 m. A new geothermal resource is being investigated by targeting the Shiramizugoe Fault. The geothermal reservoir in this area is distributed in the Quaternary volcanic layers that mostly consist of tuff and lava erupted from young volcanoes to the east of the area, which is the Kirishima volcano. NEDO, NKG, and GSJ have conducted magnetotelluric (MT) surveys from 1996 to 2000 over the Ogiri and Shiramizugoe geothermal fields, at several stages in their exploration and development. The total number of MT stations was more than 170 (Fig. 2). A part of 2D and 3D interpretation results of these MT data was reported in Uchida (2005).

In addition to these MT data, audiofrequency magnetotelluric (AMT) data was obtained in the center of the area in 2004. An average interval of AMT sites is 150 m. The number of AMT sites is 66. This survey was aiming at the detailed structure of the eastern part of the Ginyu Fault.

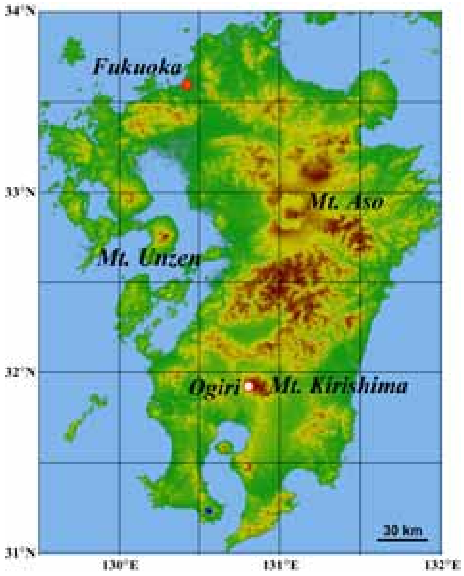

Fig. 1. Location of the Ogiri geothermal field southern Kyushu, southwestern Japan. The background is topography contour.

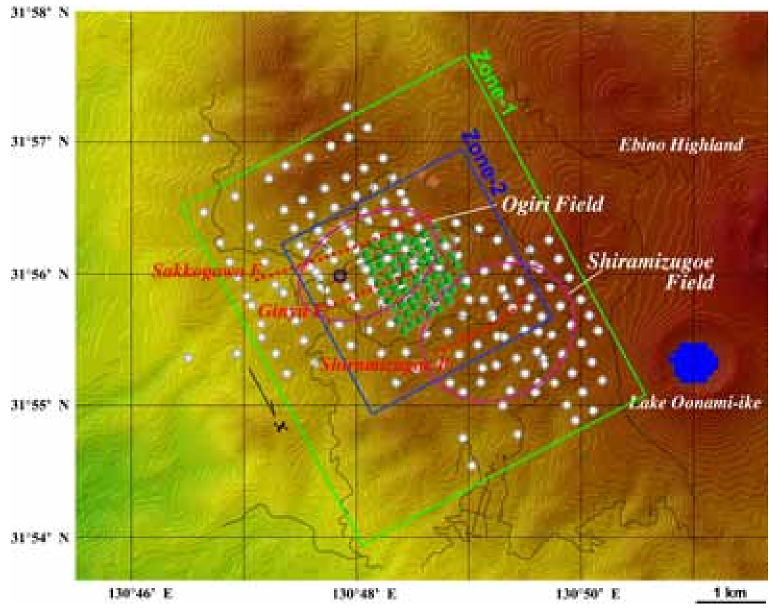

Fig. 2. AMT (green dots) and MT (white and orange dots) stations in the Ogiri geothermal field. The background is topography contour. Red dashed lines are estimated faults; large pink ovals indicate areas of geothermal reservoirs; black open circle indicates location of the power plant; large rectangles are zones for 3D interpretation.

3. 3D INTERPRETATION

A 3D inversion using the MT data at almost all stations was first conducted (Uchida, 2005). The region of the 3D modeling is shown as Zone-1 in Fig. 2. The MT impedance was rotated to the direction of the survey lines. Directions of x- and y-axes were 150 and 60 degrees clockwise from north, respectively. Off-diagonal components of the MT impedance (apparent resistivity and phase) were used as the observed data. The inversion scheme was based on the 3D finite-difference forward modeling and the linearized least-squares inversion. Topography was not included in the modeling. Static shifts can be solved simultaneously in the inversion.

The numbers of MT stations and frequencies used for the inversion were 158 and 11 (from 0.0703 Hz to 72 Hz), respectively. The total number of observed data was 6912. The cell size of the finite difference mesh in the interpretation zone was 150 m horizontally. The number of cells in the whole mesh was 68, 62, and 33 in x, y, and z directions, respectively. The noise floor was assumed as 1%. A final 3D model is shown in Fig. 3.

The resistivity distribution in the shallow layers (200 m depth) shows a clear contrast between the high-resistivity zone in the northern half of the survey area and the low-resistivity zone in the southern half. We can recognize low-resistivity anomalies associated with the two faults, Ginyu and Shiramizugoe, which strike in a NE-SW direction. The low-resistivity anomaly is very wide around the Shiramizugoe Fault. These anomalies can be interpreted as a zone of intensive clay alteration. On the other hand, the Sakkogawa Fault does not show a significant low-resistivity anomaly. The shallow high-resistivity zone in the northern side of the Sakkogawa Fault seems to be due to unaltered young lava layer.

Figure 4 compares two vertical sections of the 3D model: a x-slice at x = 2.4 km (which is almost along the Ginyu Fault), and a y-slice at y = 2.1 km. We can recognize that the low-resistivity second layer is widely distributed. This corresponds to a clay-rich layer in which smectite is abundant. The high-resistivity third layer may correspond to geothermal reservoir zones. The third layer is shallow at the center of the x-slice section, while it has two shallow anomalies in the y-slice section. The left (northern) anomaly corresponds to the location of the Sakkogawa and Ginyu faults, and the right (southern) one to the Shiramizugoe Fault. This indicates that the high-temperature reservoir is shallower beneath these faults.

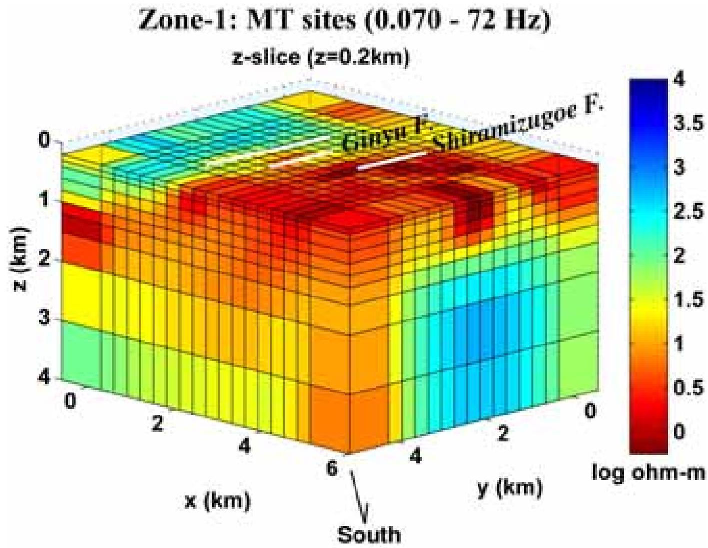

Fig. 3. 3D view of the resistivity model by 3D inversion of MT data in Zone-1. Shallow blocks up to 200 m depth are omitted. Thick white bars indicate projected locations of faults.

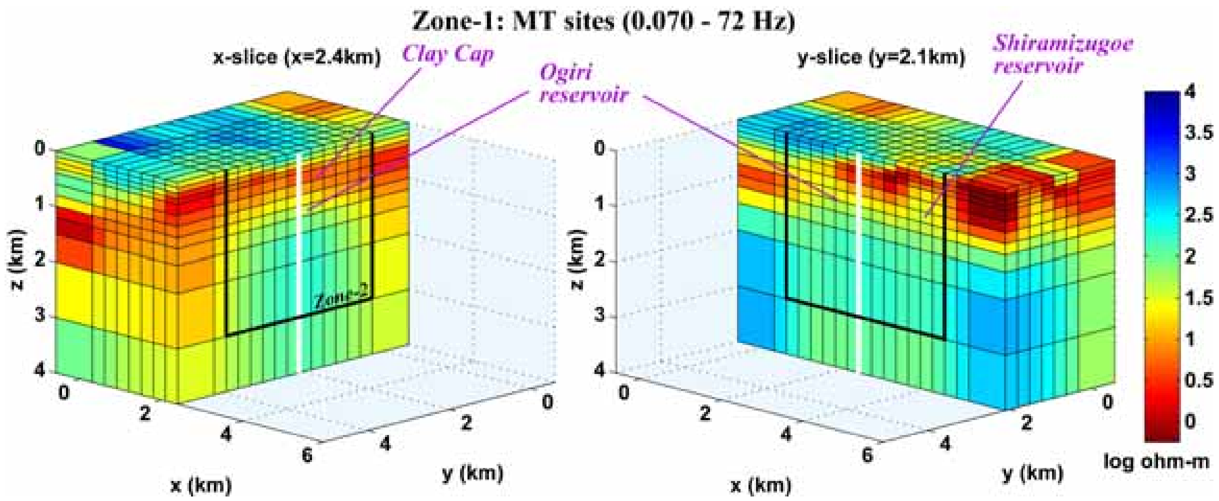

Fig. 4. Vertical slice sections of the 3D MT model in Zone-1: (left) x-slice along the Ginyu Fault and (right) y-slice. White vertical lines are locations where two sections intersect. Thick black lines indicate the area where the model in Fig. 5 shows.

The 3D inversion was also applied to the AMT data. Here, a joint inversion result using both AMT and MT sites in the Zone-2 (Fig. 2) is presented. Ten frequencies from 1.17 Hz to 640 Hz were used for the inversion. The numbers of AMT and MT sites used were 66 and 84, respectively. The cell size of the finite difference mesh was

100 m horizontally. The number of cells in the whole mesh was 62, 61, and 37 in *x*, *y*, and *z* directions, respectively. This mesh created the maximum numerical error of about 2 % in apparent resistivity for a 100 ohm-m homogeneous earth. The final 3D model of Zone-2 is shown with two vertical sections in Fig. 5: x-slice at x = 1.5 km (which is almost along the Ginyu Fault), and a y-slice at y = 1.5 km. Because we used higher frequency data with dense AMT sites, the resistivity model shows more complicated structure than the one in Fig. 4. The boundary between the low-resistivity second layer and the high-resistivity third layer has a rough surface. Although the 3D inversion of the AMT data is still preliminary, it may provide higher resolution on the resistivity structure down to a depth of 1 km.

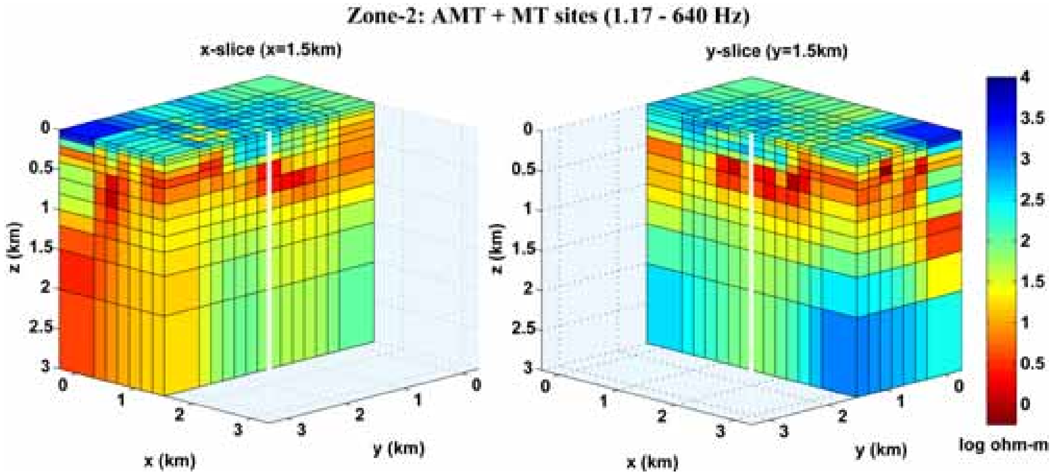

Fig. 5. Vertical slice sections of the 3D inversion model of AMT and MT sites in Zone-2: (left) x-slice along the Ginyu Fault and (right) y-slice. The frequencies used were in the AMT band. White vertical lines are locations where two sections intersect.

4. SUMMARY

A dense AMT measurement was conducted in 2004 in the Ogiri geothermal field within a area of 2.5 km x 2.5 km. The 3D inversion was applied to the AMT data as well as the existing MT data. The resultant 3D models are consistent with the Mt models reported before. The boundary between the low-resistivity cap layer and the high-resistivity reservoir zone is more complicated in the AMT model than the MT models. This may indicate a capability of high-resolution survey by the AMT method.

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