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Utilization of Magnetotelluric Data for Evaluation of Geothermal Reservoir Condition Associated with EGS Water Injection at the Okuaizu Geothermal Area in Japan

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ABSTRACT

Enhanced Geothermal Systems (EGS), with water injection into the geothermal reservoir is one of the effective methods to avoid superheat and following acidification and to mitigate concentration of non-condensable gases. A 5-year research project, named of “Technology Development for Geothermal Reservoir Evaluation and Management” funded by JOGMEC, Japan was started in 2013. MT survey was conducted at 116 sites and 3D inversion was performed by using the 3D inversion code WSINV3DMT. The optimum model also indicates quite a good matching with resistivity logging data in this zone. It is notable that seeking for the minimum data misfit model is not the best way to choose the optimum model probably due to the observation errors in the MT data. To evaluate the sensitivity of MT responses associated with water injection, we calculated the change of MT responses caused by water injection by using a reservoir simulator, STAR. As a result of simulation, detectable change of apparent resistivity associated with water injection is estimated at the observation sites near the injection well. The result indicates that the continuous-MT observation is effective for monitoring geothermal reservoir change associated with water injection.

1. INTRODUCTION

Imbalance between the steam production from a geothermal reservoir and natural water recharge to the reservoir causes not only shortage of steam production for electricity generation but also corrosion of surface facilities by superheated steam and highly acidic fluid produced from the geothermal reservoir. Enhanced Geothermal Systems (EGS), with artificial water injection into the geothermal reservoir is one of the effective methods to avoid these problems. A 5-year research project, name of “Technology Development for Geothermal Reservoir Evaluation and Management” funded by JOGMEC, Japan was started in 2013. The purpose of the project is to make a guideline for better understanding of the effects of artificial water injection in to a geothermal reservoir and/or a hot spring aquifer, based on numerical simulation and model verification. The test field of this project was setting at the Okuaizu geothermal area, which is located in western Fukushima Prefecture, Japan.

2. MT SURVEY AND 3D ANALYSIS

MT survey was conducted at 116 sites at the Okuaizu geothermal area (Fig.1). We performed MT3D inversion by using the 3D inversion code of WSINV3DMT (Siripunvaraporn et al., 2005a; Siripunvaraporn et al., 2005b). Data at 16 periods between 0.008 to 512 s from the 88 wideband sites were selected. The input data contained 4 components of the impedance and two components of the magnetic transfer function. The 3D calculation area consisted of cuboid cells and had dimensions of 58, 58 and 48 cells in the x-(north), y-(east), and z-(vertical) direction, respectively. The minimum cuboid cell was designed to have a horizontal 5.6 km square base with a horizontal thickness of 200m. The entire model had dimensions of 120, 120, and 100 km in the x-, y-, and z-directions, respectively. The common initial and prior models, which define the resistivities of the land as 100 ohm-m was used. We utilized 14 resistivity logging data in the area, for the selection of the optimum resistivity model, based on the RMS misfit between the logging data and the 3D resistivity model. The optimum resistivity model indicates that the shallow part around a hot spring area and along major faults in the geothermal area show low resistivity (1 to 10 ohm-m), and the main geothermal reservoir near the injection well shows medium resistivity (10 to 100 ohm-m) (Fig.2). A cross-section resistivity near the production and injection wells delineates the low resistivity at the shallow part at the geothermal area and the medium resistivity located from -2.5km to -1.0km ASL, and high temperature over 300 degree C, superheated zone over 20 degree C, and active seismicity zone are located in the medium resistivity (Fig.3, 4). We can image from the profiles that upwelling fluid flows from deeper part through faults, which shows high temprature and arise superheated zone, and active seismicity. The upwelling fluid is restricted to -1.0 km because of the cap rock located in the shallower part (above -1.0km)

The optimum model also indicates quite a good matching with resistivity logging data in this zone (Fig.5). It is notable that seeking for the minimum data misfit model is not the best way to choose the optimum model probably due to the observation errors in the MT data.

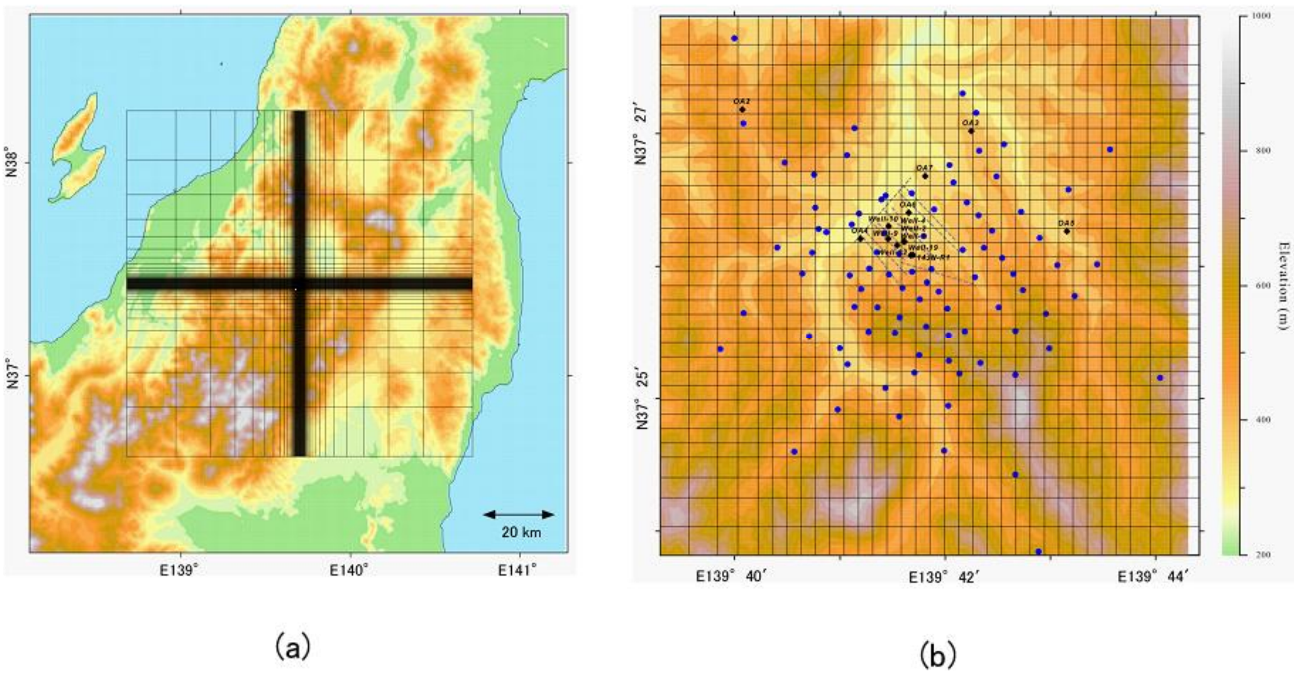

Figure 1: Grid image of MT3D analysis. Location map of the grid area of whole horizontal grid (a) and the center part (b). Blue and black dots show the MT observation points and well positions of resistivity logging, respectively.

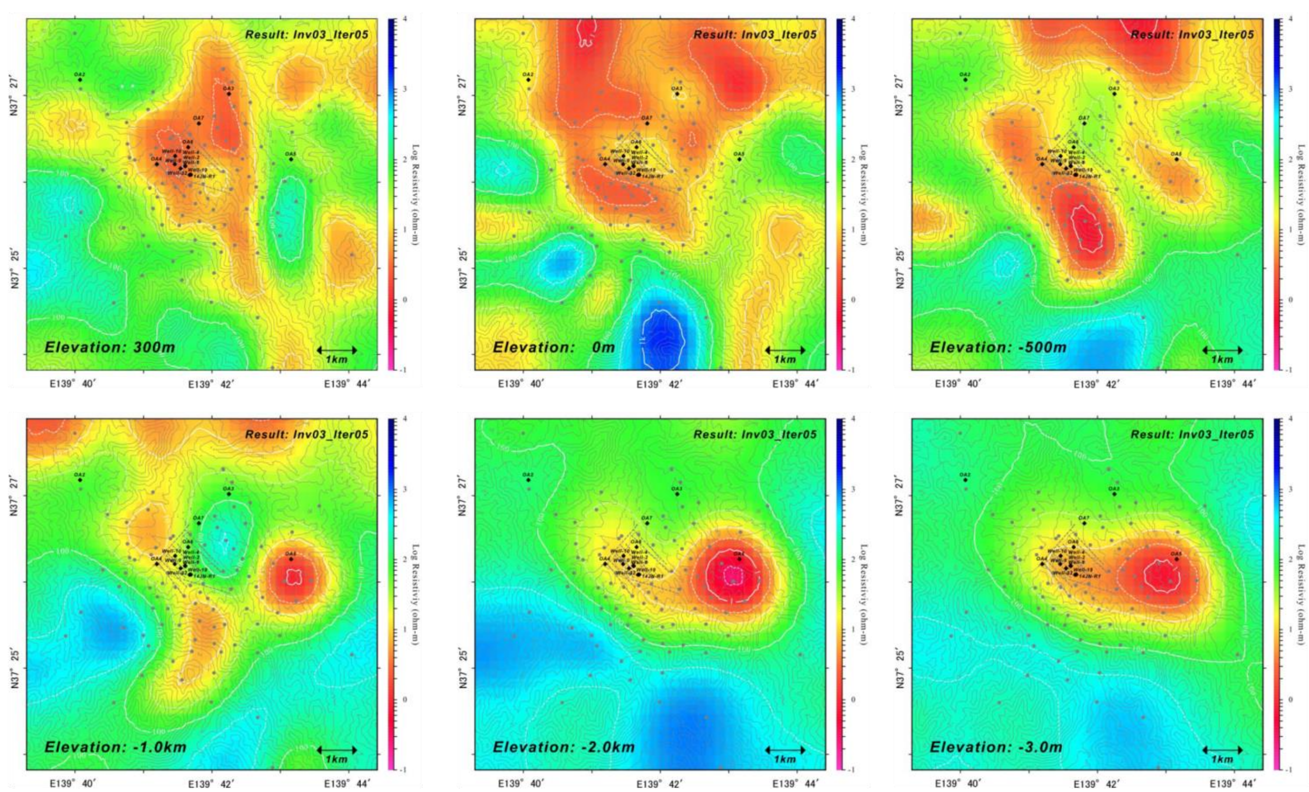

Figure 2: Horizontal resistivities of the optimum model. Gray and black dots show MT observation points and well positions of resistivity logging, respectively

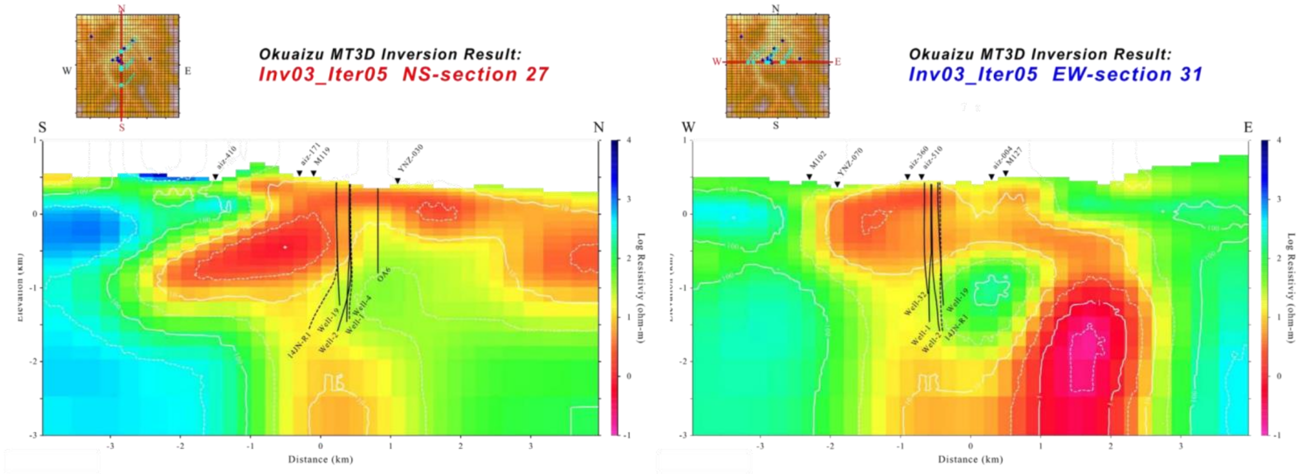

Figure 3: Cross-sections of the optimum model's resistivity. The left and right figures show the cross-section resistivity of NS and EW, respectively. Black triangles show MT observation points. Solid and dot lines show well paths. Each upper left map shows the position of the cross-section in the horizontal map.

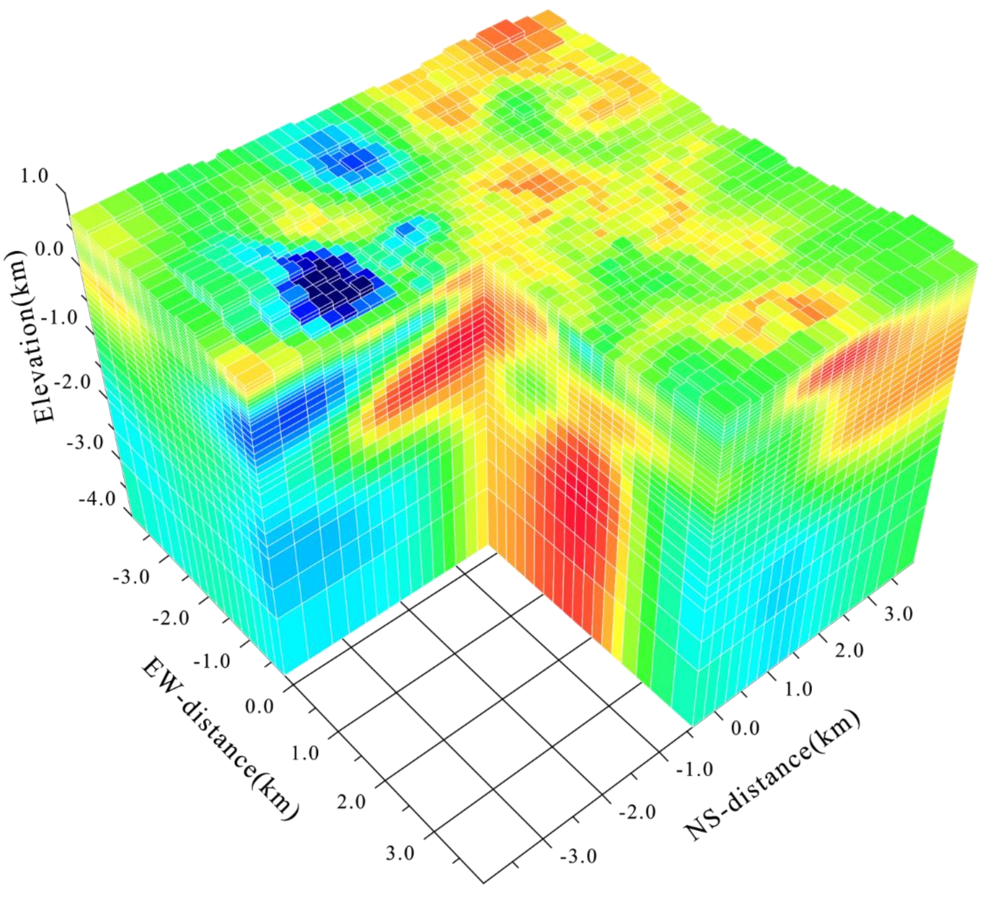

Figure 4: A bird's view of the optimum model's resistivity

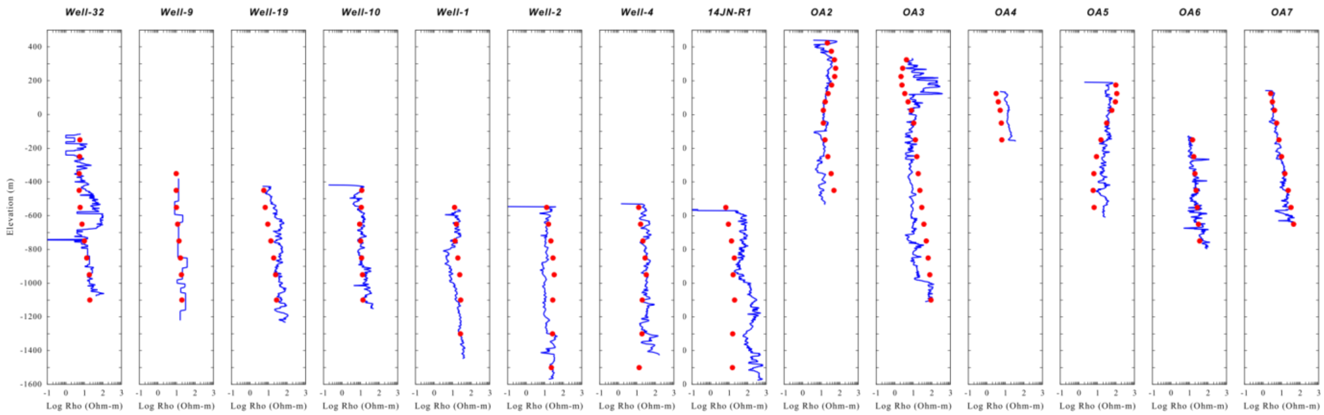

Figure 5: Resistivity profiles of well-loggings and the optimum model. Blue solid lines show well-logging resistivity and red dots show model's resistivity.

3. ESTIMATION OF MT RESPONSES ASSOCIATED WITH WATER INJECTION BY USING STAR SIMULATOR

In order to perceive the change of the geothermal reservoir condition associated with water injection, we plan to conduct a continuous-MT monitoring at the Okuaizu geothermal area from August 2016. To evaluate the sensitivity of the survey, we calculated the change of MT responses caused by water injection by using a reservoir simulator, STAR (Ishido, T and Pritchett, J. W., 1999; Pritchett, J. W., 1995). STAR can calculate not only resistivity change of each grid associated with water injection but also apparent resistivity and phase at each observation site on the surface grid. As a result of simulation, detectable change of apparent resistivity associated with water injection is estimated at the observation sites near the injection well (Fig.6). The result indicates that the continuous-MT observation is effective for monitoring geothermal reservoir associated with water injection.

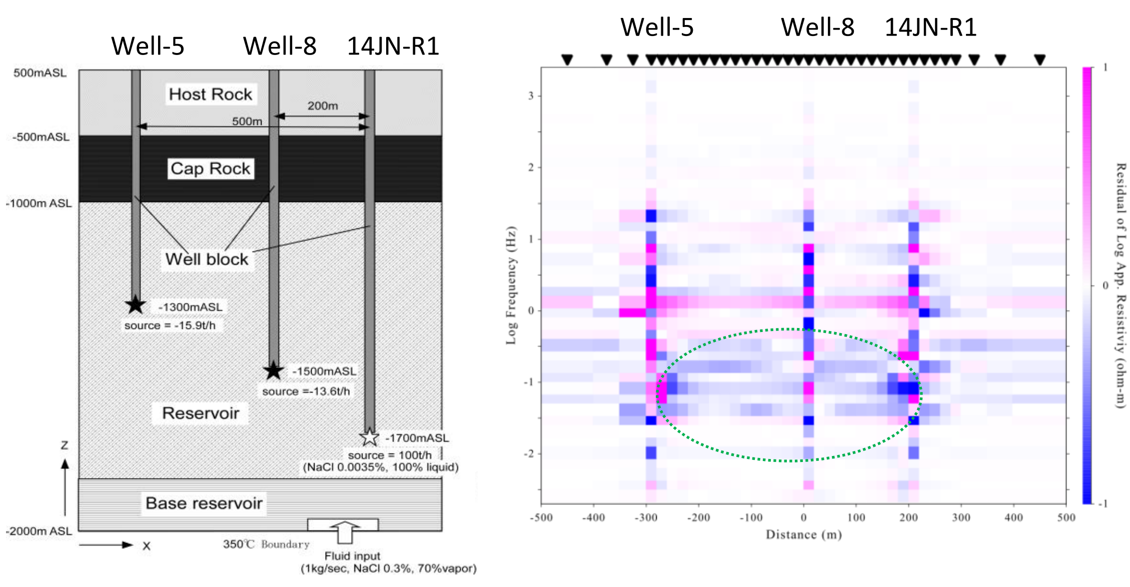

Figure 6: Grid setting image of the STAR simulation (left figure) and the estimated apparent resistivity change by EGS water injection (right figure).

4. SUMMARY

We conducted 116 sites of MT survey and performed 3D inversion analysis at EGS site in Japan. The optimum resistivity model indicates that the shallow part around a hot spring area and along major faults in the geothermal area show low resistivity (1 to 10 ohm-m), and the main geothermal reservoir near the injection well shows medium resistivity (10 to 100 ohm-m). The optimum model also indicates quite a good matching with resistivity logging data in this zone. To evaluate the sensitivity of MT responses associated with water injection, we calculated the change of MT responses caused by water injection by using a reservoir simulator, STAR. As a result of simulation, detectable change of apparent resistivity associated with water injection is estimated at the observation sites near the injection well. The result indicates that the continuous-MT observation is effective for monitoring geothermal reservoir change associated with water injection.

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