GEOTHERMAL EXPLORATION IN ULLEUNG ISLAND, KOREA

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ABSTRACT

An integrated geothermal exploration has been performed in a volcanic island, Ulleung Island, to investigate geothermal potential. It includes a 3D MT survey to delineate the subsurface electrical structures, magnetic data analysis, and drilling two 1-km deep coring boreholes from north and south part of the island to measure the temperature and physical properties of rock cores at each depths and formations. Various well logs including temperature, caliper, gamma ray, and resistivity log have been acquired at the two boreholes to get the geothermal gradients from temperature profiles and physical properties of the formation at depths. A 3D MT survey has also been carried out to delineate subsurface structures and possible deep-seated fractures in the island. A 3-D inversion with sea-effect constraint gave reliable results and showed clear E-W trend of conductive anomaly along the connection line between the test boreholes GH-1 and GH-2, where it showed very high geothermal gradients of about 100 °C/km. Comparing with the gradients of the other two boreholes in northern and southern part of the island being lower than 80 °C/km, one can deduce that the deep circulation of convective fluid through the deeply connected fractures, say E-W trends conductive anomaly, carries the heat from the deep to near the surface. This can explain the big gradient differences from site to site in this small island.

Keywords: Geothermal exploration, Ulleung Island, 3D MT survey, Sea-effect, Geothermal gradient

1. INTRODUCTION

It was 2010 when the ‘Green Island Project’ has been started for Ulleung Island, which basically aimed to cover the whole primary energy supply in the island by renewable energy. Various renewable sources including solar and winds have been investigated. People didn’t pay much attention to the geothermal in the island, because there was no underground temperature data in the island and because there was no high enthalpy geothermal resources so far in Korea. Drilling two coring boreholes of about 500 m deep to measure the heat flows of the island was all about the geothermal within the project.

The most recent volcanic activity in the island has occurred about 5,600 years ago (Kim et al., 2014). Despite it’s a very recent volcanic activity, there was little expectation of finding remnant heat beneath Ulleung Island due to its pillar-shape and submergence in 2,000 m of cold seawater. Surprisingly, however, the bottom-hole temperatures (BHTs) were 73.8 °C at a 600 m depth (GH-1) and 66.1 °C at a 497 m depth (GH-2), corresponding to geothermal gradient readings of 94.3 and 99.2 °C/km, respectively. Given an average geothermal gradient of ~25 °C/km for the Korean mainland, the BHT measurements were very promising for geothermal energy development. A two-year geothermal exploration project was launched in 2014 for more detailed geothermal explorations. The project included a three-dimensional (3D) magnetotelluric (MT) survey to delineate the subsurface electrical structures, 3D magnetic interpretation for deep-seated heat sources, and the drilling of two additional coring boreholes in the northern and southern parts of the island for a comparison of BHTs and the physical properties of rock cores at various depths, locations, and formations. Various well logs including temperature, caliper, gamma ray, and resistivity have been acquired, so that the geothermal gradients from temperature profiles, layered structures, resistivity of each layer, and fractures intersecting the boreholes can be investigated.

2. GEOLOGICAL SETTINGS

The survey area, Ulleung Island, is located in the middle of the East Sea. It is a small island, about 12 km in length in the east-west (E-W) direction. Figure 1 shows a geological map of the study area and the location of the four coring boreholes. The topography of Ulleung Island is characterized by very steep mountains and deep valleys. A caldera, Nari, located in the northern part of the island, is covered with thick volcanic sediment. Seonginbong, the highest mountain, is located at the southern end of the Nari caldera. Seonginbong rises 984 m above sea level, within a diameter of ~10 km. Bathymetry data from the Ulleung Basin indicate sea depths of ~2,000 m, in which the island rises in a ‘pillar-like’ form.

Ulleung Island is a volcanic island; thus, various volcanic rocks such as tuff, trachyte, and basalt, are prevalent. Basalts, especially, can be found in the eastern and southern coastal areas (Figure 1). Harumoto (1970) classified the volcanic stratigraphy of the Ulleung quadrangle into five stages of volcanic activity: Stages 1, 2, and 3 correspond to stratovolcano creation; Stage 4 represents caldera formation; and Stage 5 erupting pumices. The most recent volcanic activity occurred about 5,600 years ago (Stage 5), based on an analysis of volcanic ash from the Nari caldera by Kim et al. (2014); they found that the final phreatomagmatic activity occurred first, followed by strombolian eruption and lava dome extrusion, resulting in the creation of Albong Mountain within the Nari caldera (Figure 1)

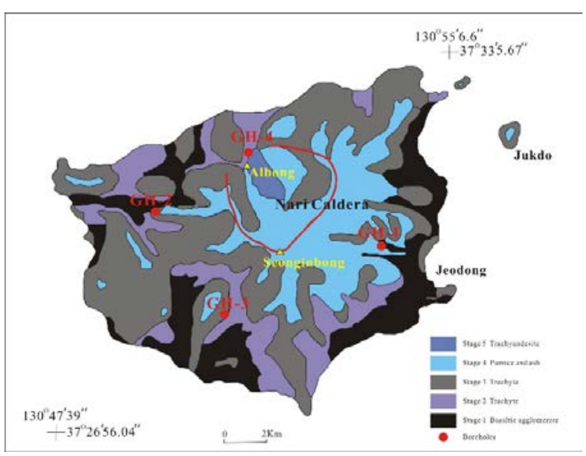


Fig. 1. Simplified geological map of Ulleung Island (modified from Kim et al., 1999; Figure 2)

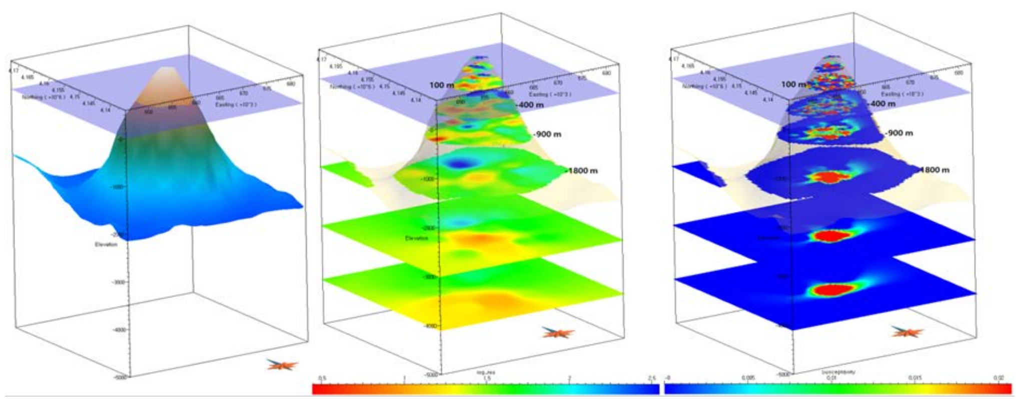
The locations of the test boreholes are also shown in Figure 1. The geothermal gradient at borehole GH-4, located in the northern part of the island is less than 80 °C/km; an even lower reading is recorded at GH-3 to the south. It is noteworthy that the temperature gradient differed considerably among sites.

3. GEOPHYSICAL SURVEYS

A 3D MT and 3D magnetic interpretation has been performed to investigate possible deep-seated fractures that can be a conduit of geothermal water and possible deep-seated heat source, respectively. Figure 2 compares 3D MT and 3D magnetic interpretation results. Because the island is surrounded by very conductive sea water down to roughly about 2 km deep (Figure 2a), MT data are definitely affected by the nearby sea water. A 3D MT modelling showed that the conductive seawater affects the low frequency MT data, especially below 10 Hz, depending on the distance from the seashore.

Two kinds of 3D inversion have been performed with the MT data observed from the area; ordinary 3D inversion, and inversion including the sea as a constraint. The sea-effect constraint inversion gave more reasonable and reliable results and showed clear E-W trend of conductive anomaly along the connection line between the boreholes GH-1 and GH-2 (Figure 2b).

The 3D inversion of magnetic data used the 3D MT inversion results as a constraint (Figure 2c). It shows very definite high susceptibility anomaly from the bottom (~ 5 km), which can possibly be a deep-seated heat source related to the past volcanic activities.



(a) **(b)** **(c)**

Fig. 2. 3D views for terrain (a), 3D MT interpretation with sea-effect constraints (b), and 3D magnetic inversion results (c).

4. DISCUSSIONS

According to the geothermal exploration of Ulleung Island so far, major finding are as follows;

1) Geothermal gradients of the island show high (~ 100 °C/km) in eastern and western part, while less than 80 °C/km in south and north parts.
2) 3D MT inversion results show a conductive structure running E-W direction at about 1 ~ 2 km

depth, and connecting GH-1 and GH-2.

3) Possible heat sources in volcanic origin at depth from 3D magnetic inversion result.

One of the possible explanations of these results can be the convection of hot water through the big conductive structures running E-W direction, which are shown from the 3D MT inversion result. The convection of fluid (water) can carry the heat at depth to near surface, which may cause the different geothermal gradients from site to site within this small island (Figure 3).

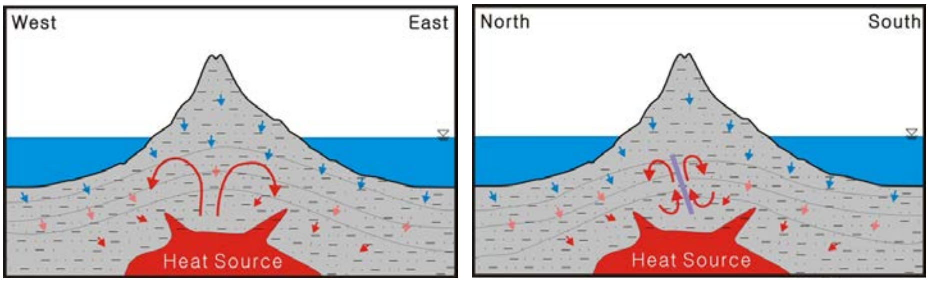


Fig. 3. A conceptual model of geothermal system in Ulleung Island.

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