Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Geothermal Exploration for Combined Heat and Power Generation in Seokmo Island, Korea

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Keywords: Geothermal Exploration, Combined Heat and Power Generation, Magentotelluric, Binary Power Generation

ABSTRACT

Korea Institute of Geoscience and Mineral Resources (KIGAM) have launched a new geothermal development project in Seokmo Island, Korea in 2009, which is funded by ministry of knowledge economy. The purpose of the project is to develop deep geothermal water of over 95 °C within 3 km depth and to utilize the geothermal water for combined heat and power generation, which will be the first geothermal power plant in Korea.

Preliminary geological and geophysical surveys have been carried out for deep geothermal development in Seokmo Island, Korea. Basement rocks, mainly Precambrian schist and granite in Jurassic or Cretaceous periods can be found even on the surface or close to the surface. In this crystalline formation, the most possible scenario for the geothermal regime can be a deep circulation of sea water along with the fracture systems. Magnetotelluric surveys, geophysical well logs and drilling results support the scenario. Additional geophysical investigations, such as additional MT surveys to cover wider area and seismic reflection survey, borehole surveys, and well loggings for more than 20 existing boreholes, will be followed to get information of deeper parts.

1. INTRODUCTION

In Korea, we can hardly expect to find high-temperature geothermal energy resources for electric power generation, since there were any recent volcanic or tectonic activities. Instead, people have used hot spring water for bathing for more than a thousand years. There have been many hot springs for bathing, but the highest temperature so far is only 76 °C (Song et al., 2010). Most of the hot springs produce water of temperature below 40 °C mostly within 1 km depth. These low-temperature geothermal phenomena are closely related to granite distribution, especially of Jurassic and Cretaceous periods (Kim and Yum, 1999), and localized through deeply connected fracture system as geothermal water conduit.

Heat flow map and geothermal gradient map has been compiled (Kim and Song, 2005) and updated continuously (Kim et al., 2010). They show several anomalous regions, e.g. geothermal gradient higher than 55 °C/km at Tertiary sediment area in Southeastern part. In 2003, Korea Institute of Geoscience and Mineral Resources (KIGAM) granted research budget from the government for drilling at the Pohang, southeast of Korean Peninsula. After geological surveys and numerous geophysical surveys, a pilot well of 1.5 km depth can produce geothermal water of 51 °C and with flow rate of 560 m^3/day, which is fairly promising result in Korea. Based on those results, another production well has been drilled down to 2.383 km in 2006. Bottom-hole temperature exceeds 90 °C and several permeable zones are detected from drilling and geophysical logs. Well completion and reservoir characterization is planned in 2009.

In 2009, a new geothermal development project have launched by KIGAM in Seokmo Island, Korea in 2009, which is funded by ministry of knowledge economy. The purpose of the project is to develop deep geothermal water of over 95 °C within 3 km depth and to utilize the geothermal water for combined heat and power generation. Many wells have already drilled for the development of hot spring within the island, and some of them are succeeded to develop nearly 70 °C geothermal water within the depth of 1.2 km, most of which are artesian wells. Preliminary geological/geophysical surveys including magnetotelluric surveys and geophysical well logging from existing boreholes have been carried out to delineate the geothermal regime, deeply connected fracture systems, which is most possible reason that makes the geothermal anomalies in the island. In 2009, as a first year of the project, intensive geological, geophysical and hydro-geological surveys have performed to delineate fracture systems in depth and eventually to determine the target depth and location.

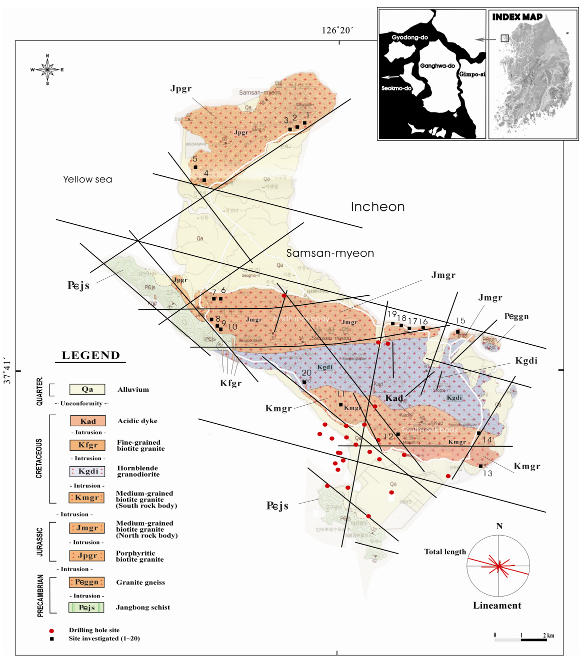

Figure 1: Geological map of Seokmo Island superimposed with lineaments (lines) and drilling wells (red dots)

2. GEOLOGY

Seokmo Island characterized by outcrops of basement rocks and consists mainly of Precambrian schist and granite gneiss, Jurassic granites with medium grains, and Cretaceous granites with fine to medium grains. Some parts of the island are covered by very thin (< 20 m) Quaternary sediments layer (Figure 1). One can divide the island into three parts according to geology; Jurassic granite is mainly distributed in the northern part, Cretaceous granite in the south, and Precambrian schist in the west and south of the island. Main target area, where most of drill-wells are located in Figure 1, is located in the boundary between the schist in the south and Cretaceous granite. Note that lineament directs mainly to N40~50°W in the figure.

3. GEOPHYSICAL SURVEYS

Geothermal regime in Seokmo Island was first reported by hot-spring developers. They happen to find geothermal anomaly there by drilling several hundred meters for developing hot water without detailed scientific investigations. From one well (BH-1 in Figure 2), great amount of geothermal water of approximately 70 °C overflows, while the other well (BH-2) failed to get geothermal water even at the depth of 1,200 m.

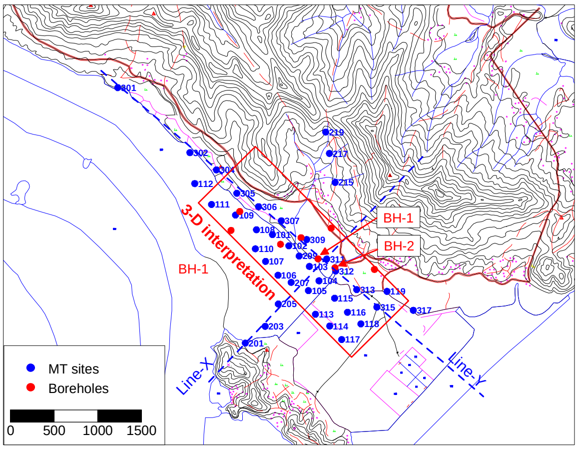

Figure 2: Target area and site map of magnetotelluric surveys

Figure 3 shows temperature logging for the boreholes BH-1 and BH-2 in comparison with geological section and natural gamma-ray log. Acid dyke shows high natural gamma-ray emission, while granite shows low. Temperature profile for BH-1 shows high temperature from the surface because of overflowing the geothermal water, while BH-2 shows a geothermal gradient of larger than 45 °C/km. When compared the fact that average geothermal gradient in Korea is 25 °C/km, this is an abnormal value. Most possible interpretation of this phenomenon can be a deep circulation of sea water along deeply extended fracture systems, which is most common feature in hot spring areas in Korea. Note in Figure 3 that BH-2 seems to meet a permeable zone at the depth of 830 m, where is a layer boundary between acid dyke and biotite granite, but it doesn't show enough inflow. To delineate the subsurface structures and fracture systems that acts as a conduit of deep circulation, a magnetotelluric (MT) survey and geophysical well logging for the two boreholes are carried out.

MT measurement sites are shown in Figure 2. A total of 39 measurements are made using Phoenix MTU-5A systems. It is not easy to access the mountain carrying heavy MT equipments, most of measurements have been made in rice fields, where topography is almost flat.

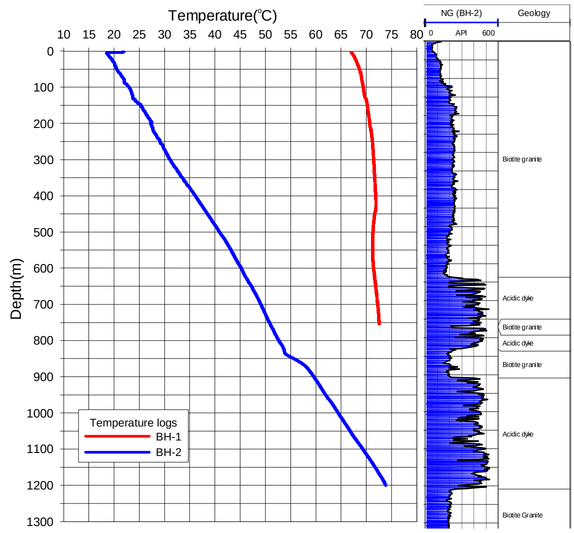

Figure 3: Temperature logs for the boreholes BH-1 and BH-2, and natural gamma-ray log with geologic column of BH-2

Figure 4 shows frequency diagram of estimated strike direction from measured MT impedance tensors. One can find from the figure that N30°E and N40~50°W is dominant over the survey region. In theory, the estimated direction has intrinsic rotational ambiguity of 90 degrees. Major strike direction of the basement rocks can be either N30°E or N60°W. This is consistent result with the major lineament direction shown in Figure 1.

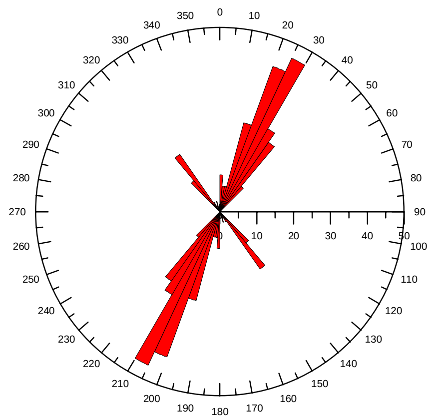

Figure 4: Rose diagram for strike directions estimated from MT impedance tensors

Considering major direction of lineament distribution described in Figure 1 and estimated strike direction shown in Figure 4, two-dimensional (2D) interpretations for the two survey lines (Line-X and Line-Y) are performed using a damped least square inversion scheme based on a finite element forward code (Uchida, 1993) as shown in Figure 5.

In Line-X, a boundary at shallow part (< 500 m) can be seen as conductive south and resistive north. Basement is found from the surface in the northern part of Line-X, while shallow fracture systems with sea water intrusion can be expected in the southern part of Line-X. At deeper part, a conductive discontinuity can be found below the stations 207 and 209. The two boreholes are in the margin of this discontinuity.

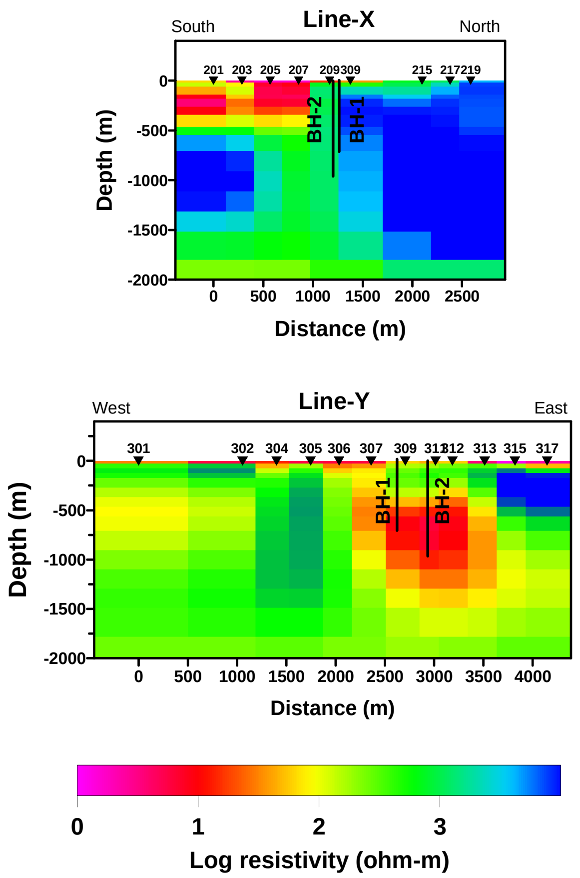

Figure 5: Resistivity image from TM mode inversion of MT data for survey lines, Line-X and Line-Y shown in Figure 2

In Line-Y, one can find very strong conductive anomaly at 500-1000 m depths and extended to deeper part. This can be a fracture system that carries geothermal water in BH-1. Geothermal water produced from BH-1 turned to be saline water with conductivity of 49,000 µS/cm; i.e. sea water. This is very strong anomaly and BH-2 is supposed to meet the fracture system in the resistivity image.

With these promising interpretations, additional drilling for BH-2 is decided and eventually it meet the fracture system at the depth of 1280m. More than 4,000 tons/day of geothermal water with temperature of 70 °C is overflowing from BH-2 as well (Figure 6).

Figure 6: Drilling rig (left) and overflowing geothermal water from BH-2 (right)

Chemical components of geothermal water from BH-1 and BH-2 are almost the same for various elements (Table 1). Geothermal water from the two boreholes shows similar temperature, the same chemical composition, and consequently the same origin. Note from Table 1 that the geothermal water contains large amount of sodium and chloride.

Table 1: Comparison of chemical composition of geothermal water from BH-1 and BH-2.

Geothermal Water (mg/L)	BH-1	BH-2
K	85.6	80.0
Na	4,815	4,441
CL	12,100	12,100
Mg	251	233
SiO2	54.4	48.6
SO4	970	970
Sr	76.39	72.30
Ca	3,489	3,240

DISCUSSIONS

Preliminary geological and geophysical surveys have been carried out for deep geothermal development in Seokmo Island, Korea. Basement rocks, mainly Precambrian schist and granite in Jurassic or Cretaceous periods can be found even on the surface or close to the surface. In this crystalline formation, the most possible scenario for the geothermal regime can be a deep circulation of sea water along with the fracture systems. Magnetotelluric surveys, geophysical well logs and drilling results support the scenario.

MT method can be a very useful tool for mapping subsurface fracture system as well as geo-electrical structures at depth. Unfortunately in this site, however, artificial electrical noise level is too high due to residences nearby, power lines as well as motors for pumping groundwater, so that MT data below 1 Hz cannot be obtained.

The purpose of the project is to develop deep geothermal water of over 95 °C within 3 km depth and to utilize the geothermal water for combined heat and power generation. In 2009, as a first year of the project, additional geophysical investigations will be followed to get information of deeper parts. This includes additional MT surveys to cover wider area and seismic reflection survey, borehole surveys, and well loggings for more than 20 existing boreholes.

ACKNOWLEDGEMENTS

This work was supported by Basic Research Project of Korea Institute of Geoscience and Mineral Resources (KIGAM) funded by the Ministry of Knowledge Economy.

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