Lesson Learned from low-temperature geothermal development in Pohang, Korea

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ABSTRACT

In the year 2003, Korea Institute of Geoscience and Mineral Resources (KIGAM) have launched a project to develop the deep-seated geothermal water for large-scale space heating in Pohang city, located south-eastern part of Korean Peninsula, with the funding from KORP (Korea Research Council of Public Science and Technology). Various geologic and geophysical surveys including Landsat TM image analysis, gravity and magnetic surveys, magnetotelluric (MT) and self-potential (SP) surveys have been performed to delineate possible fractures that would serve as deeply connected geothermal water conduit. Based on the surveys, two test boreholes have been drilled; one for coring, 1.1 km deep, and the other for production test, 1.5 km deep. Pumping test from the test borehole reserves geothermal water of 51 °C with the production rate of 560 tons/day. With the promising results, a production well have been located roughly 1 km north from the test site and drilled down to 2.385 km deep, starting with 16 inch diameter and ending with 6 and a half inches. Drilling logs and geophysical logging indicates there are several permeable fractures intersecting the borehole and the bottom temperature is over 90 °C. From the production well, above 70 °C of geothermal water is expected to be produced and is to be used, for the first time in Korea, in a cascade manner such as district heating for apartments or public buildings nearby, green houses, and aquacultures

Keywords: Low-temperature, Geothermal energy, Geothermal water, Space heating, Pohang

INTRODUCTION

In Korea, we can hardly expect to find volcanic-oriented high enthalpy geothermal energy for electric power generation within 2 km depth, since there cannot be seen any recent volcanic or tectonic activities. Instead, there have been many hot springs for bathing for more than a thousand years (Yum, 1999). 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.

There have been several efforts to develop and use geothermal water as energy source from early 90s. The first geothermal development project for district heating use have been carried out in 1991-1992 for Masan and Changwon area, which are located in southern part of Korean Peninsula. Intensive geological and geophysical surveys such as airborne gravity and magnetic surveys, radioactive, geochemistry and magnetotelluric surveys have been performed to delineate possible fractures which can carry deep geothermal water to near surface. And during 1993-1995, there have been a feasibility study to develop and utilize geothermal energy in Jeju Island, which is the only volcanic island in South Korea. The study locates most possible area to drill into in western part of the island. But both projects have failed to grant research budget for drilling. Finally, in the year 2003, the Pohang geothermal project has been launched, which is the first and the only geothermal development project that granted government funding for deep drilling so far.

Though Korea does not have high enthalpy geothermal energy, there are some anomalous regions that shows high geothermal gradient, where most of hot springs in Korea are located. Pohang is one of such regions that show high heat flow and geothermal gradient higher than 55 °C/km, while national average of geothermal gradient is about 25 °C/km. The Pohang project aimed to get 75 ^{o}C of geothermal water from 2 km depth.

In this article, we summarize our 6 years efforts in Pohang including the geological and various geophysical surveys to locate the test wells and development well as well as reservoir characterizations.

GEOTHERMAL CHARACTERISTICS AND GEOLOGY OF THE POHANG SITE

Figure 1 shows the geologic map of the target area. The area belongs to Tertiary Pohang Basin overlying Cretaceous sedimentary rocks, biotite-granite intrusion and Eocene volcanic such as tuff. Pohang Basin is consists of Miocene marine sediments and bottommost land sediments layer. Heunghae basin, main target of the geothermal exploration, is covered with Quaternary alluvium underlain by these thick Tertiary sediments, which is quite uncommon in Korea. Note that many lineaments run through NNE-SSW direction, which is the same direction as Yangsan fault (Song et al., 2006).

Figure 2 shows the 3-dimensional geological model of the area deduced from core and well logs for 4 wells shown in Figure 1. A thick quaternary semi-consolidate mudstone (S-MS) covers the area, thickness of which varies from more than 400 m at the south to about 200 m at the north. Beneath the S-MS, a cretaceous sedimentary layer of sandstone and mudstone with volcanic intrusions or eruptions are underlain with about 1,000 m thick. Then andesic volcanic breccia layer is followed, and finally Paleozoic granodiolite forms the basement. Age dating of the granodiolite results in 268±4 Ma, which is again unexpected results, because most geologist have believed that the granite in this area is formed in Jurassic or Cretaceous era.

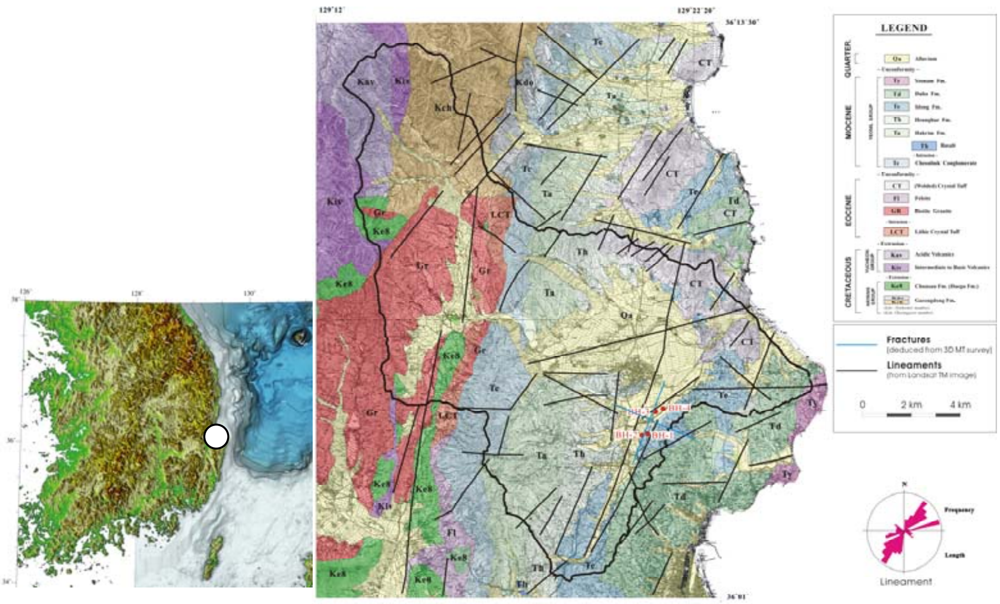

Figure 1. Geologic map with lineament distribution deduced from Landsat TM image analysis of target area (Lee et al., 2007).

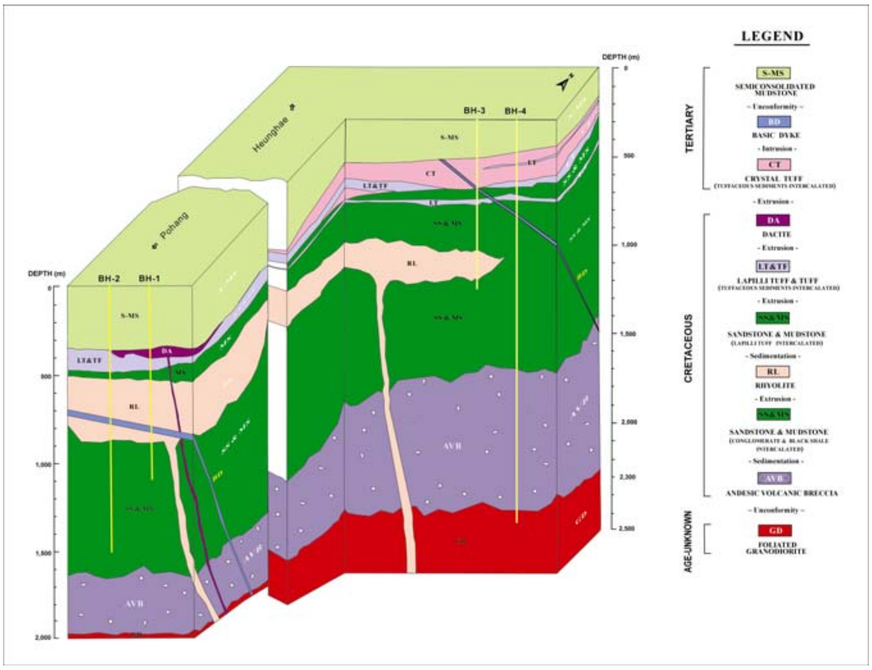

Figure 2. 3-D view of geological model of Heanhae basin deduced from core and well logs for 4 wells drilled in this project. Locations of the 4 boreholes are shown in Fig. 1 (Song et al., 2006).

GEOPHYSICAL SURVEYS

We performed gravity survey and analyzed the air-borne magnetic data compiled by KIGAM. The purpose of the survey was to get the idea of the thickness of the sediments those work as the cap rock of the geothermal reservoir and to identify the regional structures, if any. Covered area with gravity survey using LaCoste-Romberg G-type gravimeter was 20 km by 20 km and total number of measuring stations was 392, each of which was roughly 1 km spaced. Figure 3 shows the residual Bouguer anomaly map with the measuring stations as dots. As we can see in the figure, the thick Tertiary sediments appear as central low anomaly. The spectral analysis of the data says that the thickness of this sedimentary basin is about 500 m. A three dimensional (3-D) inversion of gravity data incorporating topography also shows the shape of this basin and the thickness is 500 m in central part (Lee et al., 2003). The red rectangle shows the target area and is on the eastern margin of thick sedimentary basin.

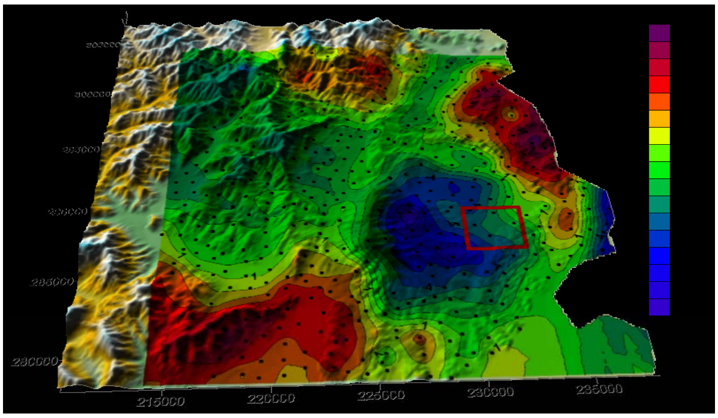

Figure 3. Residual Bouguer anomaly map superimposed on topographic map. Total of 392 measuring stations is denoted by dots, which are roughly 1 km spacing (Song et al., 2006).

As mentioned in INTRODUCTION, geothermal water in Korea is closely related with deeply extended fractures, which means that the geothermal anomaly should be analyzed in terms of the lineaments distribution. Thus, main target of geophysical surveys are deeply connected fracture zones and we concentrated our survey on the southern part of Heunghae basin in which several lineaments cross each other.

Figure 4 shows the results of self-potential surveys superimposed two major fractures from integrated interpretation of various geophysical data. SP distribution can be a direct indicator of the upflow of geothermal water although it is somewhat qualitative. But the monitoring of SP is quite useful during the pumping test since the spatial distribution of the potential variation shows the fracture orientation, if any. In this regard, we measured SP over the target area and corrected time variation using fixed reference point located eastern part of the area. In Figure 4, we can identify that the two fractures divide the region into 4-sectors and southern half shows dominant positive anomaly, while northern half shows negative anomaly. Note that the negative anomalies in the northern part appear along the fractures.

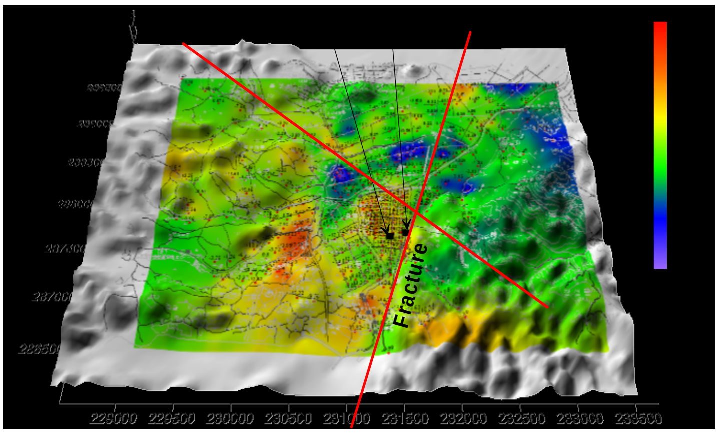

Figure 4. Measured SP anomaly superimposed on the survey sites (red dots) (Song et al., 2006).

Figure 5 shows the location map of the magnetotelluric (MT) survey stations over the target area on Heunghae basin. MT surveys have been carried out as a joint project between KIGAM and Advanced Industrial Science and Technology (AIST), Japan. We locate very far remote reference (about 480 km apart) at Kyushu island, Japan, because Korea suffers extremely strong EM noises due to the old formations that show high resistivity and power lines covering almost entire country. Using the far remote reference, we could get high quality MT data for 70 sites as shown in Figure 5. A 3D interpretation including the sea-water on the east of the site has been performed using the 44 measurement surrounded by a green rectangle in Figure 5, which is the first trial to include the sea effect in 3D inversion (Lee et al., 2007). The 3D inversion shows very clear image of electrical structures beneath the area and is consistent with the drilling results (Figure 6). One can see very clear deeply extended conductive structures from the inverted images, which are interpreted as two fractures intersecting at the position of the test well (BH-2). Note that the conductive top layer is as thick as 400 m in the southern part, while 200 m in the northern part, which is again consistent with the 3D geological model shown in Figure 2.

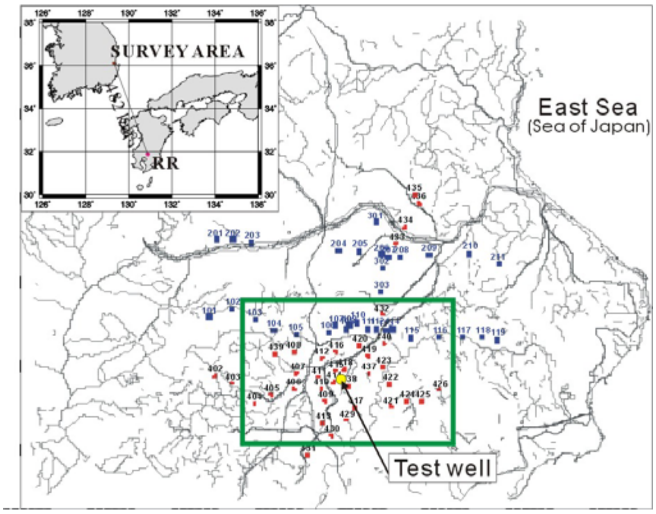

Figure 5. Location map of the MT survey stations and a remote reference site. Rectangle surrounds the 3D inversion region.

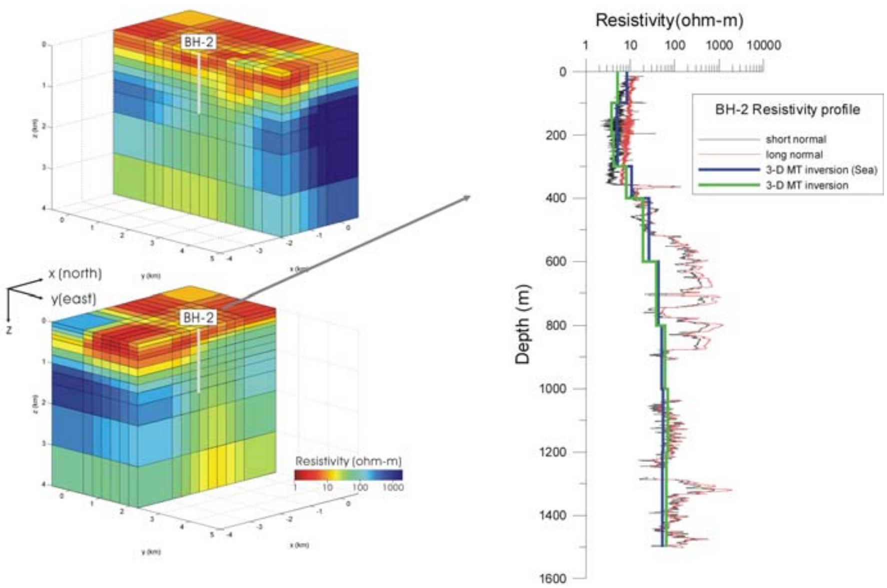

Figure 6. Resistivity models from 3D inversions considering the sea as a constraint and a comparison of the resistivity profiles between the resistivity log and the resistivity model by the 3-D inversion at the location of BH-2. The location of test borehole (BH-2) is overlain on the figure (Song et al., 2006).

DRILLING AND RESERVOIR CHARACTERIZATIONS

Based on the geological/geophysical survey, two test boreholes have been drilled in 2003, one for coring down to

1.1 km and the other for development of geothermal water down to 1.5 km. The wells are vertical rather than directional because Korea doesn't have directional drilling rig. The drilling technology in Korea is very primitive one. There have not been any demands for deep drilling because Korea doesn't have any oil fields or geothermal fields so far. Drilling for hot spring water usually reaches several hundred meters but no more than 1 km. During drilling, the engineers suffer difficulties to drill into because there are so many fractured zones at various depths. This means that our geological/geophysical surveys are very successful. Various well logging including caliper, gamma-ray, resistivity, and temperature logs have been performed and found geothermal gradient of the area is as high as 40 ^{o}C/km. Pumping test from the BH-2 confirms there are permeable zones and the borehole can produce geothermal water of 51 ^{o}C with flow rate of 560 m^3/day.

Figure 7. Drilling rig for test well BH-2 (left) and geothermal water developed from BH-2.

With the promising results, a production well (BH-4) is started to be drilled on September 2005 and reached down to 2. 385 km depth on November, 2006. Again the well is vertical starting with 16 inch diameter and ending with 6 and half inches. Considering the fact that it takes only 3 months with directional drilling for many geothermal fields to drill down to 4 or 5 km depth, one can feel that 14 months for 2.383 km is too long. It, however, is the first time to drill down to over 2 km with Korean drilling technology.
Drilling logs and well logging results shows that there are lots of fractured zones at various depths and bottom temperature will be over 90 ^{o}C. The well is cased down to 1 km depth to protect cold shallow water coming into the well, and screens are installed between 1 ~ 1.5 km based on the well log results. Below 1.5 km, it remains as open hole by now waiting for well logging and reservoir characterization.

SUMMARY AND FUTURE WORKS

For the geothermal development project started in 2003, we have conducted many geophysical surveys over the north of Pohang City that shows the highest geothermal gradient anomaly and strong tectonic deformation in Korea.
Analyses of gravity and magnetic data revealed that the Tertiary sediments cover the area with thickness of 500 m. There also exist lineaments mainly running NNE-SSW and crossing conjugates at the southern part of Heunghae basin in Landsat TM image. The results of MT survey to confirm this structure showed the possible fracture deeply extended in the area.
The two test well locations were selected considering MT interpretation results, lineaments distribution and geographical aspects. Various well logging including caliper, gamma-ray, resistivity, and temperature logs have been performed and found geothermal gradient of the area is as high as 40 ^{o}C/km. Pumping test from the BH-2 confirms there are permeable zones and the borehole can produce geothermal water of 51 ^{o}C with flow rate of 560 m^3/day. From the result, a production well have been drilled down to 2.385 km depth at the 1 km north of the test well, which is on-line with the interpreted fracture direction. The well is completed casing down to 1.5 km but still open hole below it.
We are expecting higher than 90 ºC of bottom temperature for BH-4. Next step will be well completion and reservoir characterization for the production well. All further steps such as circulation system design including injection well design, if necessary, pipe-lines to residential area, and expanding this works to the other areas, remain to be determined depending upon the results of the reservoir characterization.

ACKNOWLEDGEMENTS

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