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Background and Progress of the Korean EGS Pilot Project

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ABSTRACT

The Korean government launched a geothermal power generation project in Pohang, southeastern part of Korea, adopting Enhanced Geothermal System (EGS) technology at the end of 2010. The EGS pilot plant project is the first attempt to realize geothermal power generation in Korea. It is a five-year term, government funded and industry matching project. The project consists of two phases: I) site preparation, drilling a 3 km deep well and confirming the temperature anomaly in two years, and II) extending the 3 km deep well down to 4.5 - 5 km, hydraulic stimulation and reservoir creation, drilling another well and completing doublet system, and finally installing a MW class binary power plant in another three years.

During the first phase, geophysical data were reassessed and stress measurement along an exploratory hole was made to figure out the stress distribution around the site. A micro-seismicity monitoring system with nine, borehole three-component accelerometers has been installed and is currently in operation. The first well spudded in September, 2012 and reached 2,241 m in December, and drilling has temporarily stopped. During the drilling, a seismic-while-drilling (SWD) survey was tried by deploying four radial surface geophone arrays to determine velocity structure which is critical in micro-seismic interpretation.

Drilling of the first well restarted in May, 2013 and reached 4,127 m in granite basement in October. Progress of the drilling has been delayed mostly due to lack of experience in deep drilling and engineering. First hydraulic stimulation for testing and creating geothermal reservoir is scheduled to be performed in 2014 which will be followed by detailed assessment of the reservoir, next well design, and so on.

1. INTRODUCTION: BACKGROUND OF THE PROJECT

Geothermal utilization in Korea has been direct use, especially with ground-source heat pump (GSHP) installations, because there are no high temperature resources associated with active volcano or tectonic activity. GSHP installation in Korea has increased rapidly since the middle 2000s and total installed capacity exceeded 600 MWt in 2013. This successful deployment led the general public as well as professionals in the energy sector to become aware of what the geothermal energy is, especially its nature of covering base load. Exploration and exploitation of low-temperature geothermal water through deep fractures have been tried by the Korea Institute of Geoscience and Mineral Resources (KIGAM) over some potential regions from the beginning of the 21st century. Information on recent stories of low-temperature power generation including enhanced geothermal system (EGS) in Europe, Australia and US have caused decision makers and industries in Korea be interested in geothermal power generation, and this interest resulted in the launching of the EGS pilot plant project at the end of 2010.

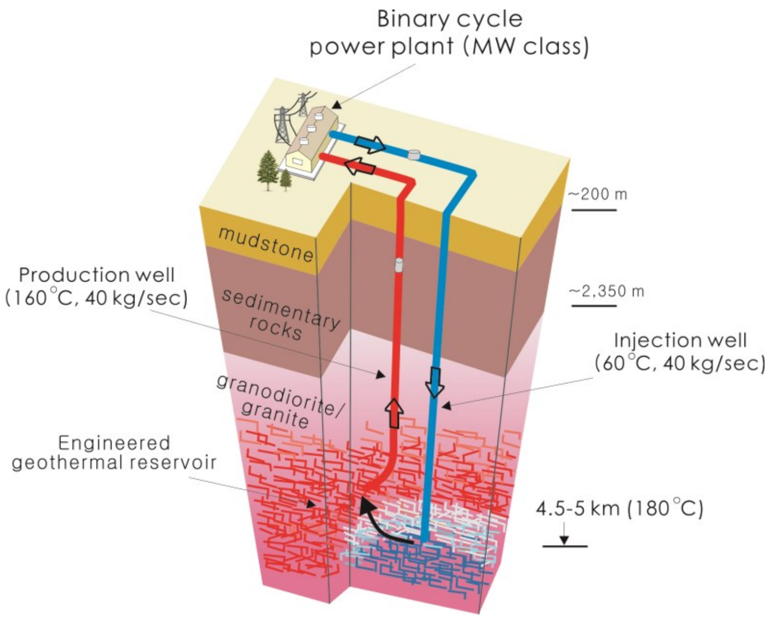

Figure 1. Conceptual model of the Korean EGS pilot plant project.

The EGS project aims to install a pilot geothermal power plant of a MW class in 5 years from 2010 to 2015 in Pohang, in the southeastern part of Korean Peninsula, which shows relatively higher heat flow. Figure 1 shows a conceptual model of the Korean EGS pilot plant project. The Pohang site is composed of Tertiary marine sediments of some 200 m thick, Cretaceous sedimentary formations down to 2,220 - 2,400 m depth, and Permian granodiorite basement with granite intrusion. Target depth for reservoir creation or enhancement is 4.5 - 5 km at which the subsurface temperature is expected to be 180 °C. Minimum target flow rate is 40 kg/sec for this doublet system assuming no natural permeability is met in that depth. The choice of a doublet is solely due to budget considerations and it will be extended to a triplet system through commercialization once the desired flow rate is accomplished.

2. EXPLORATION AND DEVELOPMENT HISTORY OF POHANG SITE

Pohang area is the only region in Korea covered with Tertiary sediments. The Pohang geothermal site belongs to the Tertiary Pohang Basin overlying Eocene volcanic rock (tuff), Cretaceous sedimentary (sandstone and mudstone) and volcanic (tuff and andesite) rocks, and Permian granodiorite basement. The Pohang Basin consists of Miocene marine sediments and bottommost clastic sediments layer. The marine sediments are of low thermal conductivity and hydraulic permeability preserving high geothermal gradient of 35-40 °C/km comparing to average value of 25.1 °C/km in Korea (Kim and Lee, 2007), which is quite uncommon in Korea. The basin also shows relatively high heat flow; up to 80 mW/m^2 or higher, and that is why geothermal exploration and exploitation activities have been concentrated on this area since 2003 by KIGAM.

The fact that the Pohang Basin is of Tertiary marine sediments had led Korean government to try to explore petroleum resources from middle of the 1960s until the early 1980s. There were many exploratory boreholes and the deepest one went down to 3 km in 1976. Although no evidence of economic hydrocarbon resources was found, people came to know that the subsurface temperature in this area is higher than other regions in Korea. Furthermore, there were found many permeable fracture zones during drilling, which was partly a driving moment of hot spring development in this area.

In 2003, KIGAM started a low-temperature geothermal project to develop geothermal water for district heating and agricultural application in Pohang. The target area was selected first by the geothermal anomaly shown from heat flow and geothermal gradient maps. Then, lineament distribution analysis using Landsat image and structural geological mapping was applied to find possible deep fractures that would work as geothermal water conduits.

We have applied various geophysical exploration methods such as gravity and magnetic surveys to interpretation of the regional geologic setting, magnetotelluric (MT) and controlled-source audio-frequency MT (CSAMT) surveys to mapping the resistivity structure and possible fracture zones, and self-potential survey to examining hydrologic condition associated with geothermal flow. Drilling of two pilot wells 165 m apart from each other, one a rotary well (BH-2) and the other a coring borehole (BH-1), started in August 2003 to confirm the existence of the geothermal reservoir. BH-2 went down to 1.5 km and BH-1 to 1.1 km. The drilling results showed a geothermal gradient of 40 °C/km in Tertiary sediments and existence of several permeable zones related with fracture systems in the lower part.

After finishing the pilot wells, pumping tests along with monitoring of self-potential over the area and draw-down at the adjacent well, and chemical analyses of pumped water have been performed to confirm that there exist several permeable zones associated with deep fractures. The pumping test produced geothermal water of 51 °C in temperature and of 560 m^3/day in flow rate, which is fairly good condition in Korea. A three-dimensional (3-D) imaging of subsurface structures using MT data has been made and it was identified that the fracture zone extended down to at least 2 km in depth.

Based on these results, another well (BH-4) has been drilled down to 2.383 km, to find basement at a depth of 2.265 km at the end of 2006. Several geophysical loggings were performed only down to less than 2 km due to instruments durability against high pressure and temperature. Drilling and geophysical logs indicated that there are several permeable zones, where considerable amounts of leakage of the drilling mud and abrupt change in temperature profile were observed.

There have been met various problems in the well BH-4, such as incomplete well casing, partial collapse in uncased depth interval, remaining mud cakes in permeable zones, etc. All of these problems have resulted from lack of experience in deep drilling of even water wells. Nevertheless, it is quite important experience in Korea in that this is the first systematic trial of deep geothermal development beyond hot spring exploration and made people learn valuable lessons (Lee and Song, 2008). Static temperature measurement along BH-4 was made in 2009 by deploying a distributed temperature sensing (DTS) technique to show 91 °C at the depth of 2 km which tells that we have an average geothermal gradient of 38 °C/km considering mean annual surface temperature of 15 °C.

Figure 2 shows the location map of MT survey lines, existing wells (BH-2, BH-4) drilled before EGS project started, EGS site (EXP-1) and micro-seismic monitoring holes.

3. MAJOR ISSUES IN THE BEGINNING OF THE EGS PROJECT

There were some scientific and technical issues in the beginning of the EGS project. Electricity generating capacity linearly increases with temperature difference between producing and injection geothermal fluid, flow rate and thermal efficiency. For thermal efficiency of a binary cycle power plant, due to the thermodynamic limit there is little room to enhance the currently accepted empirical relationship as used in Beardsmore et al. (2010). For temperature of subsurface which governs the producing fluid temperature, we assume to have 180 °C at the depth of 4.5 km, which requires an average 37 °C/km geothermal gradient considering mean annual surface temperature of 15 °C. We could see a geothermal gradient as high as 38 °C/km with long-term monitoring down to 2 km along the offset well BH-4 so that there is little uncertainty of the subsurface temperature considering that the final depth of drilling would be between 4.5 and 5 km.

Then most important issue was to create the subsurface reservoir enough to ensure a flow rate of 40 kg/sec. Because growth of the reservoir as a consequence of a hydraulic stimulation in crystalline rock is governed by the stress regime, accurate knowledge of the stress distribution of the site is quite important. Although there can be found a recent compilation of stress measurements over the southeastern part of Korea (Chang et al., 2010), the measurements were limited to shallow depths only (mostly less than 300 m) and no data are found in the vicinity of the Pohang site. Information on stress is necessary not only in terms of spatial distribution, but also in vertical profile, so new measurement along deep boreholes was required. Permeable fractures in target depth can reduce the risk of the insufficient flow rate, if any, but there is no detailed information on the deep fracture system either.

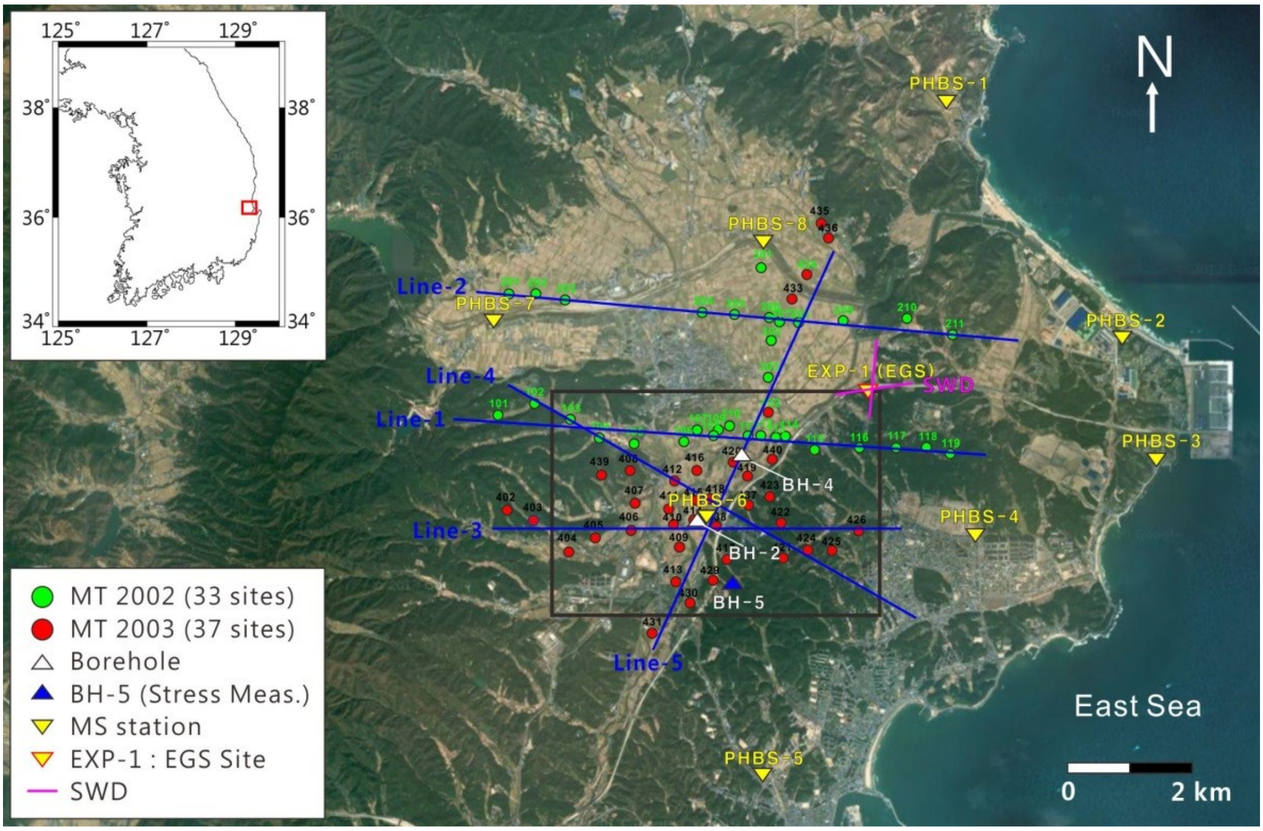

Figure 2. Location map of the Pohang site showing MT measurements, major wells, geophone lines for seismic-while-drilling (SWD), and nine MS monitoring stations (PHBS-1~8 and EXP-1). Boreholes BH-1 and BH-3 are in close vicinity of BH-2 and BH-4, respectively, so are omitted for the sake of simplicity. Note that EXP-1 is located at EGS drilling site.

Micro-seismic (MS) monitoring is practically the only way to observe the growth of the reservoir resulting from hydraulic stimulation, and installation and operation of MS monitoring system should start far before stimulation. Because the locating method of micro-earthquake events is exactly the same as in earthquake monitoring, accurate information of 3-D velocity structure is critical in accurate location of events. Unfortunately, neither surface nor borehole seismic survey has been performed in the region mainly due to the absence of petroleum exploration activity. 3-D seismic surveys may be necessary to provide accurate velocity structure and information on possible deep fractures. However, 3-D seismic survey is not an option because complicated land usage along with adjacent small villages would not allow use of big sources (explosives or vibroseis) for deep penetration, besides the budget problem. Therefore we have to devise other ways to define the velocity structure.

Besides limited budget, lack of experience in deep drilling and engineering was another serious concern. An EGS project should be well prepared, arranging every technical and scientific procedure in one Gantt chart in order to not only save time and money but also reduce possible technical risk. Furthermore, there is no service company related with deep drilling in Korea and timely procurement was also an important issue. So almost everything was the first trial and the project team had to help themselves from the very beginning of learning curve. An effective way of making progress was to keep close contact with international expert groups in EGS to consult and to get valuable and critical comments at each step and, at the same time, was to devise an efficient management scheme, which was partly successful so far.

4. PROGRESS OF THE PROJECT AND CURRENT STATUS

Selection of a drilling site may be the first thing to do once the project is approved. After reassessment of many existing geophysical results and logging data at offset wells, a boundary of the candidate region was defined. Major concerns were access to main roads, power lines and water supply. EXP-1 site in Figure 2 was finally selected and civil engineering work was performed. The site has direct connection to the main motorway and power line while water for drilling is from a groundwater well. Future demand of water for hydraulic stimulation is to be met by an agricultural reservoir nearby.

Before securing the drilling site, stress measurement was performed along the borehole BH-5, 3.8 km south of the EGS site (see Figure 2). Although the depth of the BH-5 is 1 km, we could measure the data only for the depth interval from 670 m to 810 m due to extremely weak formation for applying hydraulic pressure. Hydraulic fracturing tests over the three separate depth intervals along with images of the drilling induced tensile fractures and the borehole breakouts showed that the direction of maximum horizontal stress (σ_H) is rather constant to be N48°W and of strike-slip regime in general. However, because the covered depth range was too short and the formation is extremely weak, there is still some uncertainty in stress regime.

Micro-seismicity is critical in monitoring creation and growth of a geothermal reservoir as a result of hydraulic stimulation. We have completed construction of the MS monitoring system with nine, borehole three-component accelerometers. Eight observatories are located on two circles with radius of 3 and 5 km, respectively, centered on the EGS site as shown in Figure 2. Depths of burial of accelerometers are 120-130 m except the one at the site which was installed at 180 m depth. All nine observatories are connected to a high speed internet network so that we can process the data with a sampling frequency as high as 1,000 Hz in real time.

Drilling of the first well PX-1 began with the spudding on 19th of September 2012 with 17.5 inch bit through the preinstalled surface conductor of 20 inches diameter. Because there has been no deep drilling for oil and gas in Korea, the rig must be imported either by purchase or by lease basis. Considering the relative short term of drilling, the long time interval between the first and the second wells, and the cost for mobilization/demobilization in case of lease, a rig with API static hook load of 3,150 kN has been purchased. Besides relative delay of the rig import, progress of drilling was much slower than planned, mainly due to lack of experience including procurement problem of spare parts, necessary items and services. We reached 2,250 m (2,241 m GL) on 14th December 2012 and decided to stop drilling temporarily due to unexpected delay of progress.

While drilling PX-1, a surface shallow reflection seismic survey was performed to define the uppermost sediment layer in terms of depth variation and travel time. Because velocity structure is a fundamental input parameter for processing and interpretation of MS monitoring data, we adapted a seismic-while-drilling (SWD) survey scheme, a variation of reverse vertical seismic profiling (VSP) with drill bit vibration as seismic source, in order to get information on seismic velocities in the deeper region. For SWD, four radial surface geophone arrays were deployed to 500 m length each and geophones were at every 10 m in array as shown in Figure 2. Covered bit depth ranges were from 330 m to 1,700 m in 2012 (Yoon et al., 2015).

After careful check of rig and other equipment and assessment of performance in 2012, we re-entered the PX-1 well on 23rd of May 2013. After several days of drilling we met the top of the crystalline rock at the depth of 2,347 m GL. 9 5/8 inch drilling went down to 2,391 m GL and the well has been cased and cemented. Drilling continued with 8 1/2 inch bit until another temporary shut off at 3,547 m GL due to frequent drill string instability problem. Image of geologic sequence as a result of mud logging is superimposed on the well diagram in Figure 3, in which depth to the top of granodiorite was measured from gamma ray logging. Bit depth covered by SWD survey was from 2,782 m to 3,556 m in 2013.

Figure 3 shows the image of geologic sequence that resulted from mud logging superimposed on the final well specification and a merged drilling depth versus time plot for the first well PX-1. As we can see from the drilling depth versus time plot, there were unexpected delays during the drilling such as non-productive times due to delayed procurements and lack of experiences in drilling. Rate of penetration (ROP) was rather slower than planned, due to the absence of data from an offset well. Consequently, total days for drilling were 174 excluding two intermissions.

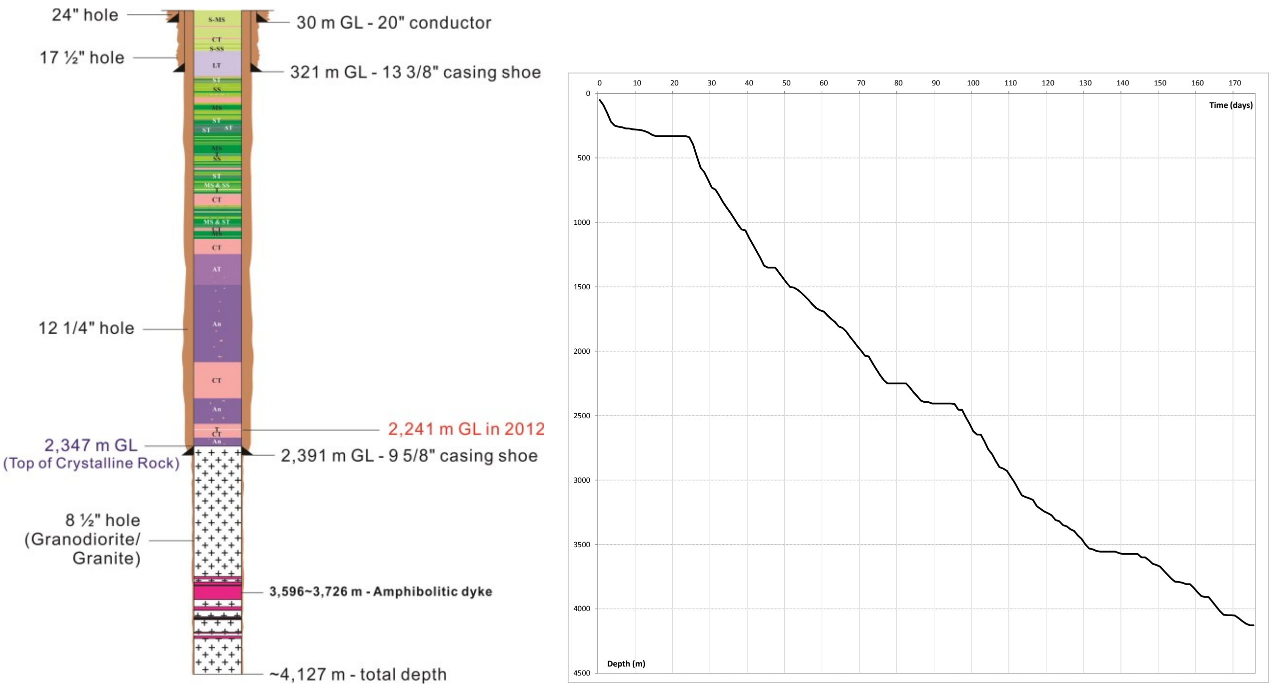

Figure 3. Geologic sequence as a result from mud logging superimposed with well specification (left) and merged drilling depth versus time plot (right).

5. DISCUSSION AND FUTURE PROSPECT

Overall progress of the project has been quite slow compared to the original time plan, due to extra budget demand for unexpectedly high cost of procurements and mostly due to lack of experience. First hydraulic stimulation for testing and creating the geothermal reservoir is scheduled to be performed during 2014 which will be followed by detailed assessment of the reservoir, next well design, and so on. Although we expect to enhance overall performance in that we have started from the beginning of the learning curve, there may be other unexpected factors causing further delay, for example higher cost of stimulation than planned, ambiguity in MS processing and thus improper feed-back to hydraulic stimulation parameters, and finally insufficient injectivity (in kg/sec/bar) as a result from the first hydraulic stimulation. Another important factor controlling the success of the project will be a proper design and drilling of the second well which is to deviate to meet reservoir geometry. Again due to complete lack of such an experience, collaboration with international expert groups will be of utmost importance.

The future of geothermal power generation in Korea definitely depends on the success of this EGS pilot project. There is still skepticism about the capability of geothermal power generation in Korea in that feasibility in terms of economy and technology is not validated yet. Although we succeeded in achieving notable flow rate with reasonable injectivity in this pilot project, active participation from industries is critical in scaling up and further commercialization, which has been affected by lack of legal framework for supporting geothermal power generation. There are on-going activities for including geothermal in the Renewable Portfolio Standard (RPS) system with higher Renewable Energy Certificates (REC) and also for implementing legal framework for geothermal energy. A technical roadmap of greenhouse gas reduction technology in Korea states that there can be 200 MWe of installed capacity in geothermal by 2030 in Korea (KETEP, 2011), which is one percent of the technical potential of EGS in Korea (Song et al., 2011). The outcome of the EGS pilot plant project, if successful, will surely be a milestone initializing the roadmap and we expect this pilot plant project to be scaled up to a level of 5-10 MWe by 2020.

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