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Low-enthalpy geothermal exploration in Pohang area, Korea

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Abstract: KIGAM (Korea Institute of Geoscience and Mineral Resources) launched a new project to develop the low-enthalpy geothermal water in the area showing high geothermal anomaly, north of Pohang city, for large-scale space heating from KORP (Korea Research Council of Public Science & Technology) funding. Surface geologic and geophysical surveys including Landsat TM image analysis, gravity, magnetic, Magnetotelluric (MT) and controlled-source audio-frequency MT (CSAMT) and self-potential (SP) methods have been conducted and the possible fracture zone was found that would serve as deeply connected geothermal water conduit. By the end of 2003, two test wells of 1 km depth will be drilled and various kinds of borehole survey along with additional MT measurements and sample analysis will follow and then the detailed subsurface condition is to be characterized. Next step would be drilling the production well of 2 km depth and all further steps remain to be determined depending upon the results of the test well studies.

1. Introduction

In the year of 2003, we have launched a project to develop the geothermal water in the area showing high geothermal anomaly (Kim et al., 2003), north of Pohang city, for large-scale space heating from KORP funding. This includes detailed geological and geophysical surveys over the target area following geothermal data analysis and regional geologic structure interpretation. Real development starts with drilling of two test wells down to 1 km depth. After completing the hydrological and geophysical surveys using the test wells we are to decide whether to drill 2 km deep production well and where to drill, if positive.

In Korea, we can hardly expect to find geothermal energy resources for electric power generation 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-enthalpy 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. Statistics say that more than 400 geothermal wells have been developed, most of which are solely for hot spa, not for other direct utilization such as space heating, green house, aquaculture and so on. Although there has been some attempt to use the ground water in green house heating in early 90's, it is hard to find currently operating facilities. There were also some R&D works to locate low-enthalpy geothermal water resources for space heating, but they have not been followed up with subsequent development. So, this attempt is the first large field-scale low-enthalpy geothermal usage R&D case in Korea.

In this article, we briefly discuss the geology of the target area and the results of the geophysical survey including gravity, air-borne magnetic, MT, CSAMT and SP methods.

2. Geothermal Characteristics and Geology of Pohang Site

Figure 1 shows the geologic map (1:50,000) 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.

Figure 2 shows the distribution map (KTM Zone 3 coordinates) of the geothermal gradient of existing wells superimposed on the Landsat TM image with lineaments. We can identify the big fault, Yangsan fault, running NNE-SSW direction (226,000 – 223,000 in KTM). The highest geothermal gradients, higher than 55 °C/km, can be seen

in Pohang city. Although the high geothermal anomaly shows North-West trends, this is rather because of insufficient and irregular sampling locations than due to structural origin since there can be seen many lineaments running the same direction as Yangsan fault, which does not say any correlation with this trend. As mentioned in the previous section, 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. Therefore, we concentrated our survey on the southern part of Heunghae basin in which several lineaments cross each other.

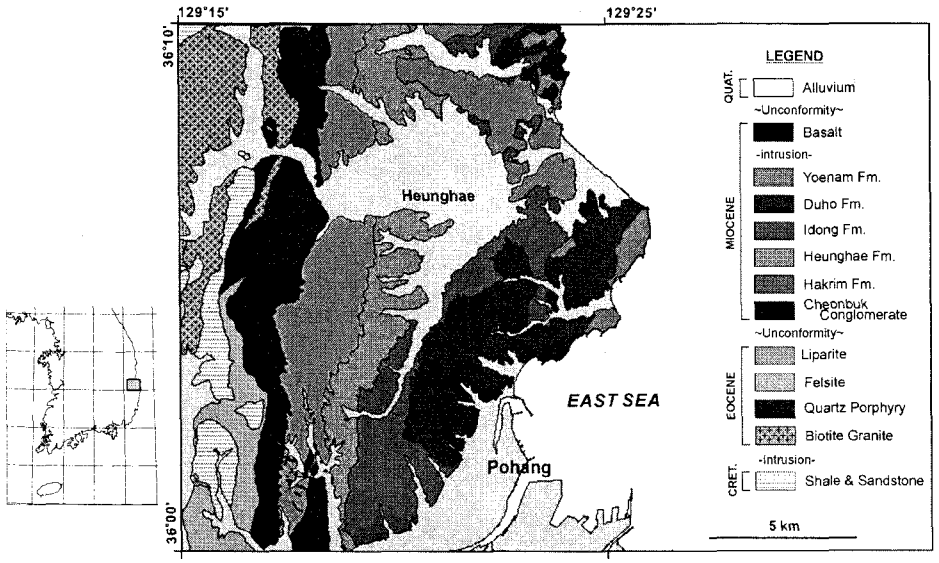

Fig. 1. Geologic map (1:50,000) of target area, Heunghae.

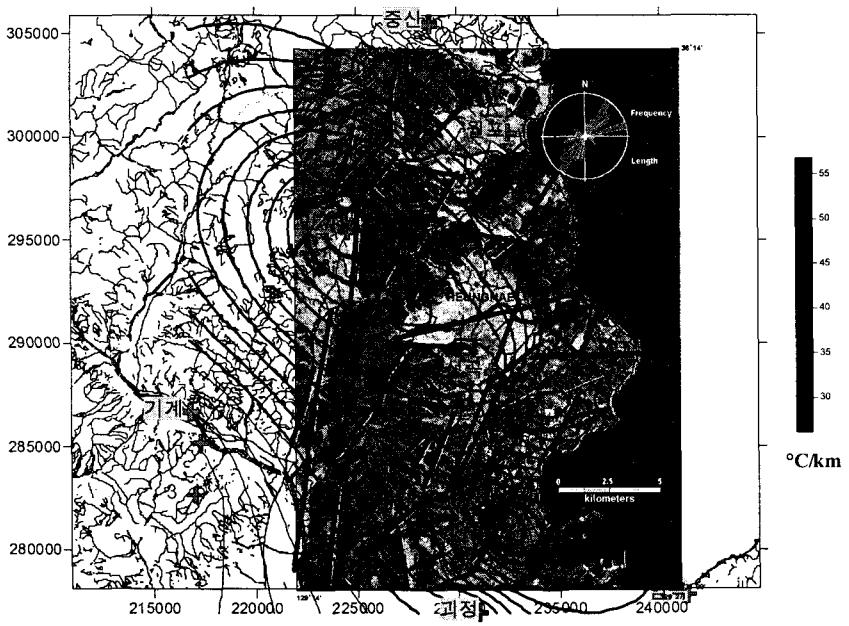

Fig. 2. Geothermal gradient map complied with existing well data superimposed on the Ladnsat TM image (R/G/B/: 4/3/2 band) along with interpreted lineament distribution. The coordinates are denoted in KTM Zone 3.

3. Regional Geophysical Survey

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).

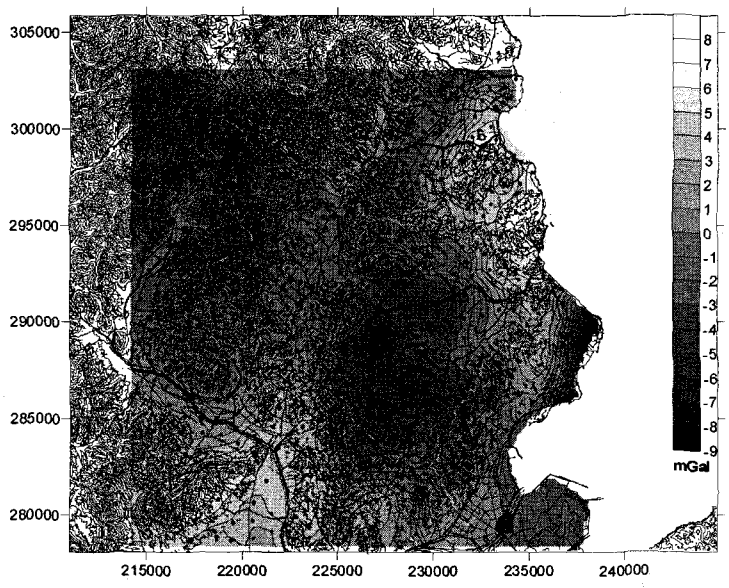

Fig. 3. Residual Bouguer anomaly map superimposed on topographic map. Total of 392 measuring stations is denoted by dot, which is roughly 1 km apart from each other.

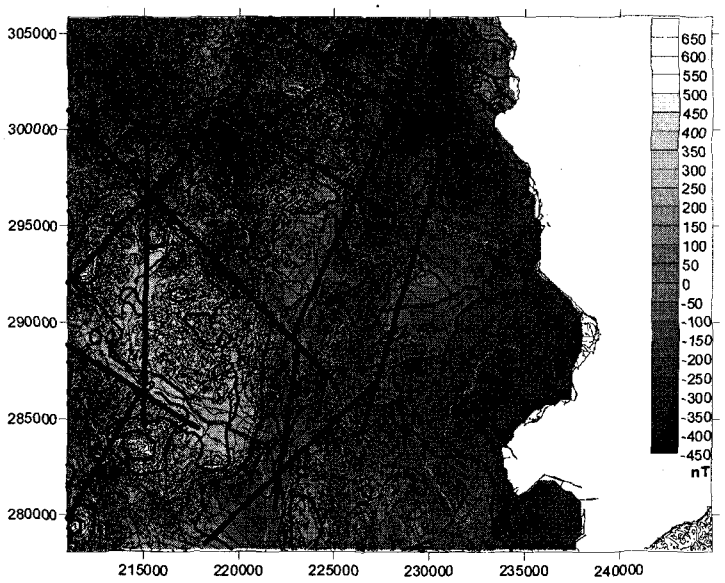

Fig. 4. Magnetic lineaments superimposed on residual air-borne magnetic map in terms of RTP data.

Spectral analysis of the reduction-to-the pole (RTP) map of the residual air-borne magnetic data (Figure 4) also shows that the thickness of the basin is approximately the same as that of gravity data. Furthermore, the magnetic lineaments show the similar trend as in Landsat TM image; big Yangsan fault and some parallel and conjugate ones. These results say that the detailed survey should be focused on the possible deeply extended fractures associated with lineaments and also that the thickness of the sedimentary basin is more or less 500 m.

3. Electric and Electromagnetic Survey

Figure 5 shows the location map of the MT and CSAMT survey stations over the target area on Heunghae basin. The five MTU-5 systems manufactured by Phoenix Geophysics Ltd. in Canada and owned by AIST and Hokkaido Univ., Japan were employed in this MT survey. The survey has been conducted as a part of ongoing collaboration works between researchers in Korea and Japan from the October until November, 2002. There were two remote reference (RR) sites running through the survey period; one was at Andong, about 60 km apart from the site and the other at Kyushu, some 520 km away. Since the site is located close to the big, noisy town, Pohang city and also encompassing Heunghae town, we could not suppress the noise using the RR data at Andong while RR processing with Kyushu data provided reasonable estimates of impedance data sets.

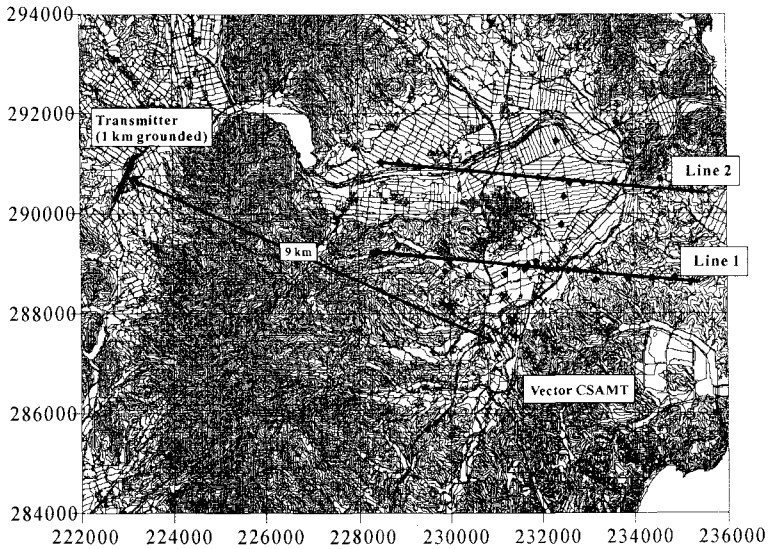

Fig. 5. Location map of the MT (diamond) and CSAMT (cross) survey stations and designated survey lines. Transmitter, 1 km long grounded wire, location is also shown.

Figure 6 shows an example of two-dimensional (2-D) inversion results along each MT survey line using the TM-mode impedance data processed with Kyushu RR observation. Although detailed image can be different from each inversion algorithm (of course, it was true in this case), we can identify deeply extended dipping conductors beneath the center parts of the both lines and it is much clearer at the south line (Line 1). We can also notify the conductive surface layers of 400 m – 600 m thick at the both image, which show the distribution of the Tertiary sediments and the thickness is the same as determined from gravity and magnetic data.

Location of the dipping conductor in the both images coincides with the lineament running NNE-SSW shown in Figure 2, while it is much clearer in south line. This implies the conductor may exist at south of the Line 1; at which another lineaments crosses the NNE-SSW lineament (Figure 2). Although it is not shown here, the induction arrows at the intermediate frequencies; 0.1 Hz to 0.3 Hz, also indicate the existence of conductor beneath the south of the Line 1.

To confirm this interpretation, we made CSAMT survey over the southern part of Heunghae basin along the possible lineament. We used GDP 16 receiver of 8 channels and GGT 30 transmitter manufactured by Zonge Engineering. The geology of the transmitter site is consists of granite, resistivity of which goes up to 1,000 ohm-m while that of the surface at the survey area is an order of several ohm-m (See Figures 1 and 5). Therefore, although the transmitter was 9 km apart from the survey area, we could not escape from the well-known source-overprint effect (Zonge and Hughes, 1991) stating that the high resistivity in the vicinity of the transmitter site makes the

penetration depth of the electromagnetic energy so deep that the far field assumption cannot be satisfied for lower frequencies. So we could not get the far field source below the 32 Hz; which corresponded only to less than 500 m depth and thus got the information on the conductive surface layer only.

Considering the other side of the survey area approaches the sea, ensuring the far field condition for CSAMT survey in this area seems quite difficult. This unusual situation renders us perform additional MT survey over the area in more detailed manner and in a 3-D way. Additional MT survey to make a 3-D image of the structure beneath the target area will be conducted in November, 2003.

Figure 7 shows the measured SP values over the small target area centered on the test well site. 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 7, we can identify negative anomaly zone centered on the drilling site and positive zone north of the center part, which may indicate the possible upflow but still not clear.

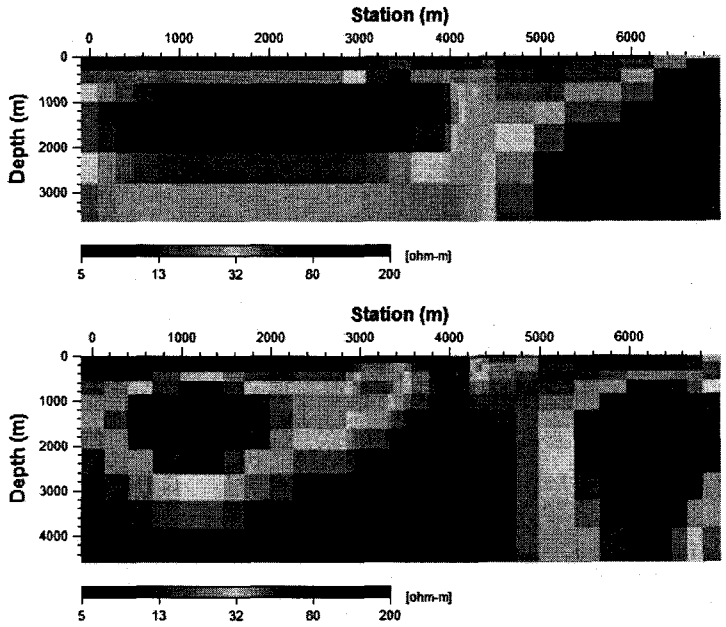

Fig. 6. An example of the resistivity distribution image as the results of the 2-D inversion of the TM-mode MT data. Upper: Line-2, lower: Line-1.

3. 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. CSAMT survey conducted for the purpose of detailed imaging did not show any reliable result due to limited depth of investigation by geologically inevitable source overprint effect. SP distribution measured at the southern part of Heunghae basin showed negative anomaly zone centered on the test drilling site but any detailed interpretation is not available yet.

The two test well locations were selected considering MT interpretation results, lineaments distribution and geographical aspects (Figure 7). The two wells, one is coring and the other non-coring, and 165 m apart each other will be completed by the end of November, 2003. Subsequent borehole surveys and various sample analyses will be made to figure out the subsurface condition in detail also along with 3-D MT survey and interpretation. Next step would be locating, designing and drilling the production well of 2 km depth. We are expecting some 75 - 80 °C of

bottom temperature based on the existing well data nearby. 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 this first trial.

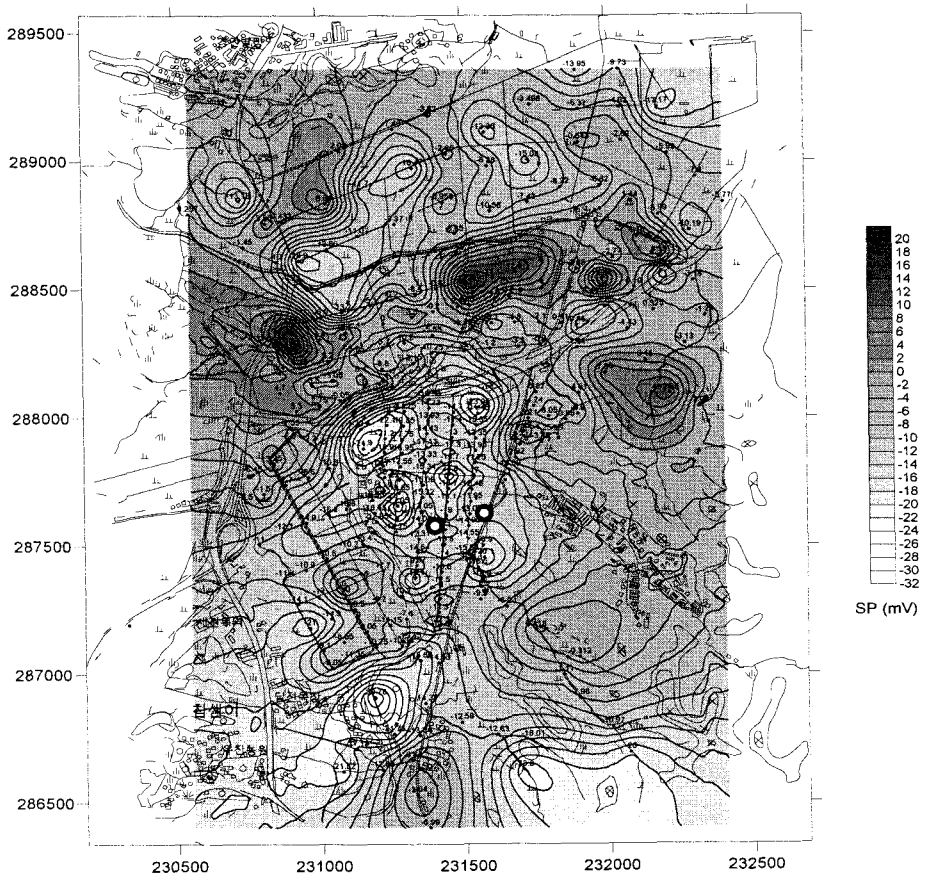

Fig. 7. Contour map of SP measurements superimposed on the survey station map (dots). The test well sites, 165 m apart each other, are denoted with open circles.

Acknowledgements

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