Evaluation of the geothermal potential in the Mageumsan-Bugok area: Application of groundwater geochemistry

Seong-Sook Park[1)], Seong-Taek Yun[1)], Chil-Sup So[1)] and Yong-Kwon Koh[2)]

The exploitation and development of geothermal energy is drawing special attention in many countries. The geothermal potential in South Korea has been discussed by many researchers (e.g., Jang, 1970; Lim, 1995; Han, 1996), mainly focussing on the evaluation of geothermal gradients. Jang (1970) estimated the mean value of heat flow in Korean peninsular to be about 60 mW/m^2 by using the Box Probe method. According to Lim (1995) and Han (1996), the regional geothermal anomaly zone at depths (down to 2 km) occurs in the southern part covering Pohang to Bugok. However, there is no detailed and reasonable estimation on the potential of the use of geothermal energy in South Korea. For this purpose, careful examination of the groundwater chemistry would be helpful to estimate the temperatures in deep thermal reservoirs. This study has been undertaken to demonstrate the applicability of hydrogeochemical data to the geothermal exploration. We have tested the utility of the alkali ion and silica geothermometers for water samples collected within the Mageumsan and Bugok areas.

Both the Mageumsan and Bugok geothermal area are situated within the Cretaceous Gyeongsang Sedimentary Basin in which occur the non-marine sedimentary rocks of the Jindong Formation, andesitic volcanic rocks, and granitic plutons. The Jindong Formation is composed of shale, arkosic sandstone and chert with intercalations of tuffaceous and calcareous shale. Thermal springs in the two areas are located along faults cutting the volcano-sedimentary strata, and show high outflowing temperatures (up to 55℃ in the Mageumsan area, and up to 78℃ in the Bugok area). However, the outflowing temperatures are varied significantly within each area.

1. Hydrogeochemistry of thermal waters

The pH, Eh (mV), EC (μS/cm) and TDS (mg/l) values of thermal waters are 7.5 to 8.1, 84 to 374, 274 to 1514 and 180 to 613 respectively from the Mageumsan area, and 7.8 to 9.0, 163 to 362, 329 to 558 and 229 to 313 respectively from the Bugok area. The typical thermal waters in the Mageumsan area are characteristically enriched in Na, K and Cl, forming the Na-Cl water type, whereas the Bugok area's thermal waters are dominated by Na, K and SO_4 and belongs to the Na-SO_4 type. However, peripheral waters in each area show the simple Ca-HCO_3 type. Therefore, it is likely that groundwater systems in each area are very complex.

Careful examination of the inter-ionic relationships shows that the geothermal waters in the Mageumsan area which is located near the Southern Sea is affected strongly by seawater mixing. Theoretical evaluation of water chemistry by using the computer code PHREEQC also shows that alkali-ion (Na and K) concentrations in the Mageumsan area's thermal waters is generally similar to the seawater and are also affected by dissolution of feldspars. The calculations also show that nearly all of the thermal waters in the two areas are nearly saturated or supersaturated with respect to quartz, chalcedony and calcite.

2. Application of geothermometry: evaluation of the deep reservoir temperature

1) Silica geothermometers

The silica (quartz, chalcedony, amorphoud silica, etc.) geothermometers have been used for the estimation of deep reservoir temperatures. The quartz geothermometer can be successfully applied for the groundwaters with high subsurface temperatures (>150℃). In some granite terrains, however, the solubility of aqueous silica is controlled by quartz at temperatures above 90℃ and by chalcedony at lower temperatures (Foulliac, 1977). It should be noted that the silica geothermometers may give erroneous results when applied indiscriminately [see Rybach et. al. (1981) for this problem].

By applying the quartz geothermometers (Founier, 1991) to the thermal waters in the Mageumsan and Bugok areas, we have obtained appropriate reservoir temperatures between about 90 and 130℃ (88-127℃ for the Mageumsan area, and 109-128℃ for the Bugok area). The chalcedony geothermometer (Founier, 1991) yielded the temperatures of 57-100℃, which are lower than those by quartz geothermometers. The amorphous silica geothermometer yielded significantly lower temperature estimates than surface outflowing temperatures, as has been noted by Grasby et al. (2000). This suggests that the solubility of dissolved silica Si is controlled by quartz or chalcedony. Like this, the α-cristobalite and β-cristobalite geothermometers gave the lower values (<80℃) than surface temperature. If considered that chemical equilibria within the studied geothermal system is possibly attained after surface water mixing (as indicated by alkali ion thermometers), however, the silica geothermometers would give the temperature of last equilibrium under lowered temperatures. Thus, the silica geothermometers indicate that thermal reservoirs at depth has the minimum temperatures of 120-130℃.

2) Alkali ion geothermometers

The Na-K geothermometer gives an excellent temperature estimate if the waters are known to come from high-temperature environments (>180-200℃). The main advantage of the Na-K geothermometer is that it is less affected by dilution and steam separation. The calculation of the saturation index indicated that thermal waters from the Mageumsan and Bugok area are nearly undersaturated with respect to albite and anorthite. The application of the Na-K geothermometers yields the temperatures falling in the range between 74 and 194℃. The wide range results from the inconsistency of the empirical equations suggested by many researchers (Truesdell, 1976; Fournier, 1979, 1981; Tonani, 1980; Arnorrson et al., 1983; Nieva and Nieva, 1987; Giggenbach, 1988): the equation of Truesdell (1976) yields lower temperatures (74-137℃), whereas that of Giggenbach (1988) yields too high temperatures (141-194℃). Except these data sets calculated from the two equations, the estimates have the narrow range (mostly between 110 and 140℃), which corresponds well to the results from the silica geothermometers (120-130℃).

The Na-K-Ca geothermometer (β = 1/3; Fournier and Truesdell, 1973) also yields the reasonable temperature estimate between 108 and 153℃ (mostly 120-130℃). This correspondence is likely due to the low concentrations of Ca (<10 mg/l) in analyzed waters. Similarly, the

Mg-corrected Na-K-Ca geothermometer (Fournier and Potter, 1979; Duchi et al., 1994) yields the temperatures mostly falling in the range 110-153℃.

In summary, both the silica geothermometers and the alkali-ion geothermometers yield the temperatures between 110 and 140℃ for the deep geothermal reservoir in the Mageumsan and Bugok area. This temperature estimate can be used for the evaluation of the geothermal potential in southern Korea.

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1) Dept. of Earth & Evvironm. Sci., Korea Univ. Seoul

2) Korea Atomic Energy Research Institute