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GEOCHEMISTRY OF GEOTHERMAL WATERS AND DEEP GROUND WATERS IN KOREA

Byoung Woo Yum

Korea Institute of Geology, Mining & Materials, 30, Kajung-dong, Yusong-gu, Taejon, Republic of Korea

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ABSTRACT

Most thermal waters in Korea are between 25 and 30°C, dilute (200-400 mg/l TDS), and richer in sodium, bicarbonate, silicate, and fluoride than the shallow ground waters. Generally, the thermal waters are associated with Cretaceous or Jurassic granite. Heat for these thermal waters is obtained during deep circulation in the fractured granites and is not related to volcanic or tectonic activity. Isotopic data indicate that the geothermal waters originate as local meteoric water. None of the thermal waters show any oxygen shift. Temperature-chloride relations show no evidence for mixing.

1. INTRODUCTION

High-enthalpy geothermal resources apparently do not occur in the southern Korean peninsula. However, the widely dispersed low-enthalpy waters have been extensively used for many centuries. Bathing in natural thermal waters is very popular in Korea. Thermal waters have also been used for medical therapy.

Yum (1994) divided the geothermal waters of Korea into “Old-Geothermal Area” and “New Geothermal Area”. Lim and Kim (1997) showed that the mean of heat flow in Korea is about 67mW/m^2, slightly higher than the world average (60mW/m^2), and that the areas of high heat flow are closely related to outcrops of Cretaceous and Jurassic granites. Granites also provide significant quantities of cold water for industrial uses and drinking water. Yum (1999) reviewed geothermal water uses in Korea and their histories. Geochemical characteristics of geothermal waters were also studied (Yum, 1993; Yum, 1995, Lee *et al*., 1997). Based on stable isotope data, Lee *et al*. (1997) suggested that the geothermal waters of Korea are of meteoric origin.

2. GEOLOGIC AND THERMAL CONSIDERATIONS

The Korean peninsula, which extends southward from northeast Asia, has a close affinity with the Asian continent in terms of the geologic and tectonic setting. The Korean peninsula is part of a tectonically stable craton. It does not have active volcanism like the Japanese archipelago (Kim, 1987). Most hot springs and thermal wells in Korea are associated with Jurassic or Cretaceous granite and represent low-enthalpy geothermal resources.

Aquifer characteristics of the geothermal waters have been investigated by in-situ pumping tests. Pumping yields are limited because most wells recover waters from faults, fracture zones, or joints in granite. Continuous temperature profiles have been completed on 416 boreholes (1982 to present). Pumping tests and chemical analyses have been completed at most of these sites. Only bottom-hole temperatures are shown in this report because they are less influenced by fluid inflow or outflow. Bottom-hole temperatures are plotted against well depth and show that most thermal waters are about 30°C and most wells are between 600 and 700 meters deep. Data from boreholes in the “Old Geothermal Area” plot above the “normal” temperature-depth line, indicating that thermal fluid flows upward in this area. Yum (1993) obtained a similar diagram based on 193 boreholes and calculated a mean thermal gradient of 28.3°C/km. The concentration of points between 600 and 700 meters deep (Figure 1) is a function of this being the depth at which waters above 25°C are usually encountered. The main purpose of these boreholes is to obtain title to the water under the “Spa Law”. In Korea, geothermal waters are defined and legally restricted to ground water that has a temperature of more than 25°C. As a result most boreholes are drilled just deep enough to obtain 25°C water.

3. GEOCHEMICAL CHARACTERISTICS

Water samples are divided into four groups based on their temperatures: A. very high temperature waters (>50°C; 34 sites); B. high temperature waters (30 to 50°C; 77 sites); C. moderate temperature waters (25 to 30°C; 233 sites); D. low temperature waters (<25°C; 26 sites). Although chemical data for the thermal waters of Korea show a wide range of compositions, most (about 2/3) are sodium-bicarbonate type (Figure 2). These waters are low in total dissolved solids (200-400mg/l), high in pH (8.5-9.5), Na (20-40mg/l), bicarbonate (40-120mg/l), and F (5-10mg/l), and low in K (trace-1mg/l), and Mg (trace-3mg/l). Ground waters in these areas tend to be Ca-Cl (-SO_4) types at shallow depths and Na-HCO_3 (-Cl) at greater depths. Lee *et al*. (1997) noted similar trends and stated that K and Mg depletions in deep environments were caused by formation of clay minerals.

Chloride concentrations in the thermal waters are relatively restricted in range (<50mg/l) and are independent of temperature (Figure 3). Chloride in these geothermal waters probably originates from fluid inclusions in the granites. Chemical speciation and mineral saturation models show that the deep ground waters and thermal waters are in equilibrium with the rock-forming minerals of the granites. Shallow ground waters are in equilibrium with minerals of the weathering environment.

4. ISOTOPIC RESULTS

Stable isotope data for 10 thermal areas are shown on Figure 4. All of the thermal waters are of meteoric origin and show no oxygen shift. Differences in stable isotope compositions are a function of differences in local precipitation. Donglae has the least depleted isotopic composition and is located at the lowest latitude. Hwasoon, Deoksan, Yusong, and Onyang are located on a plain far from any mountain ranges at slightly higher latitudes in the middle of the Korean peninsula. Thermal waters from these areas are more depleted than the waters at Donglae but less depleted than waters recharged in mountainous regions. Sockcho, Baekam, Suanbo, Deokgoo, and Pocheon are located in mountainous regions and have the most isotopically depleted waters.

5. DISCUSSION AND CONCLUSIONS

Geothermal water use in Korea has greatly increased in recent years due to expansion of the leisure industry. This has triggered activities related to the exploration and exploitation of geothermal waters. Over 100 new geothermal wells have been drilled as part of the development of the leisure industry. Most of these new geothermal localities are being actively developed.

Greatly increased pumping in both the Old and New Geothermal Areas during the 1990's resulted in severe drawdown of the local ground water table. Recent studies, therefore, have concentrated on the re-evaluation and re-assessment of the geothermal aquifers and their recharge characteristics.

Most geothermal waters in Korea are closely related to outcrops of granites, and most are low in enthalpy and TDS, high in pH, sodium, fluoride, and bicarbonate, but low in potassium and magnesium.

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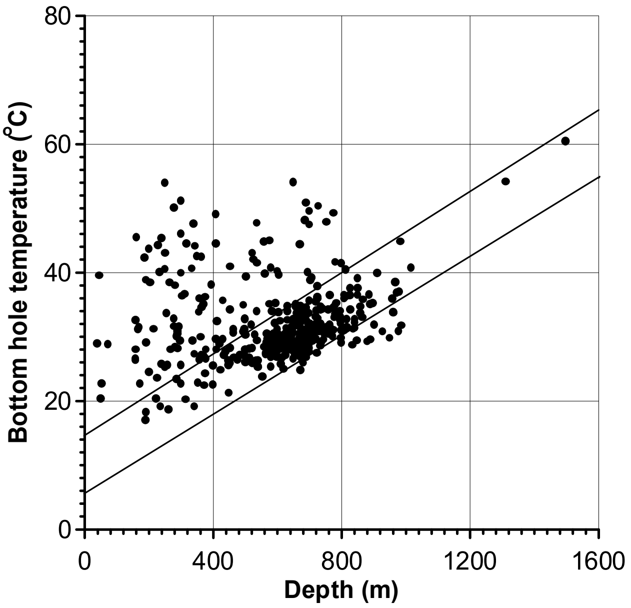

Figure 1. Plot of bottom hole temperatures versus borehole depths. Most boreholes are 600 to 700 meters deep. Solid lines define the zone of "normal" thermal gradient.

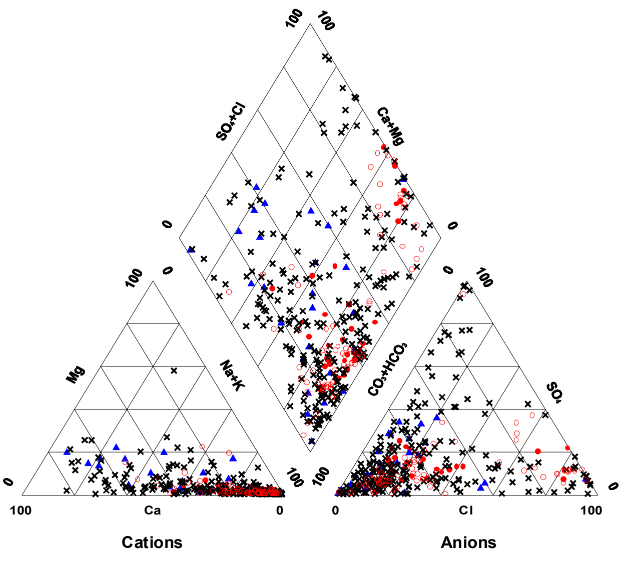

Figure 2. Trilinear diagram (after Piper, 1944) for geothermal waters and deep ground waters of Korea. Waters are grouped by temperature: above 50°C (●); 30 to 50°C (❍); 25 to 30°C (✖); and, below 25°C (▲).

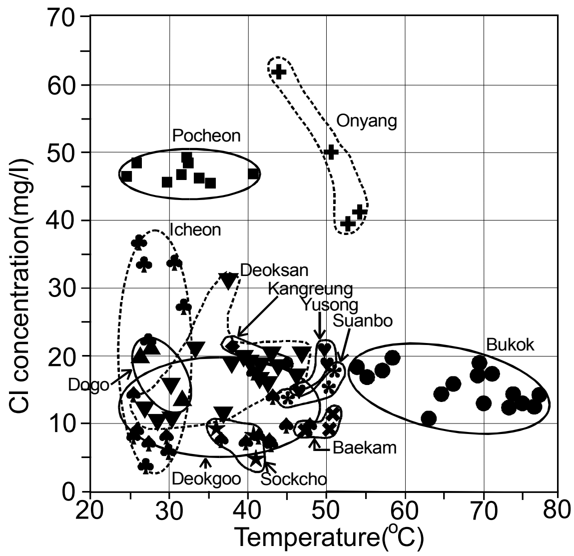

Figure 3. Plot of chloride concentrations versus temperature for geothermal waters in "Old Geothermal Areas".

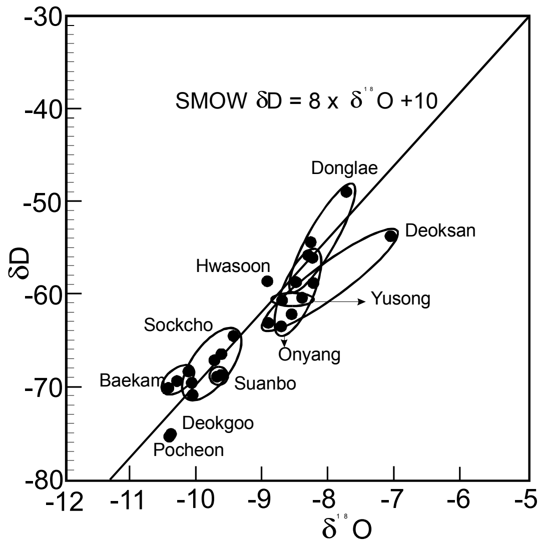

Figure 4. Plot of δD and $\delta^{18}O$ values for selected thermal areas. The meteoric water line of Craig (1961) is shown for reference.