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Assessment of geothermal potential in an area of sulfate-rich hot springs, Bugok, southern Korea

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Abstract

Using a variety of chemical geothermometers we estimate the temperature of a deep geothermal reservoir in relation to thermal groundwater in the Bugok area, southern Korea, in order to assess the potential use of geothermal energy in South Korea. Thermal water at Bugok has been exploited down to about 400 m below the land surface and shows the highest outflow temperatures (up to 78 °C) in South Korea. Based on the hydrochemical data and occurrence, groundwater in Bugok can be classified into three groups: Na-SO_4 type thermal groundwater (CTGW) occurring in the central part (about 0.24 km^2) Ca-HCO_3 type cold groundwater (SCGW) occurring in shallow peripheral parts of CTGW; and the intermediate type groundwater (STGW). CTGW waters are typical of thermal water in the area, because they have the highest outflow temperatures and contain very high concentrations of Na, K and SiO_2 due to the sufficient reaction with silicate minerals in deep reservoir. Their enriched SO_4 was likely formed by gypsum dissolution.

The major ion composition of CTGW shows the general approach to a partial equilibrium state with rocks at depth. The application of various alkali ion geothermometers yields temperature estimates in the range of 88 to 198 °C for the thermal reservoir. Multiple mineral equilibrium calculation indicates asimilar but narrower temperature range between about 100 and 155 °C. These temperature estimates are not significantly higher than the measured outflow temperatures for CTGW. Considering the heat loss during the ascent of thermal waters, this fact may suggest that a thermal reservoir in the study area is likely located at relatively shallow depths (possibly close to the depth of preexisting wells). Therefore, we suggest a high potential for geothermal energy development around the Bugok area in southern Korea.

key word: Sulfate-rich hot spring. Bugok area, geothermometer, geothermal potential

1. Introduction

Hot springs in the Bugok area, in the southern part of Korea show very high outflow temperatures approaching 80 °C (i.e., highest in South Korea) and are characteristically rich in dissolved sulfate (Fig. 1). The Bugok area also has the highest geothermal gradient (80 °C/km) and heat flow (3.20 $\mu cal/cm^2 \cdot sec$ (HFU)) in South Korea. The genesis of hot springs in the Bugok area is still controversial (Yun et al., 1998; Koh et al., 2001). Therefore, the major purpose of this study is to estimate the potential temperature of a deep geothermal reservoir in relation to the formation of sulfate-rich hot springs in the Bugok area. For this purpose, various chemical geothermometers were applied to the observed hydrochemistry data. Finally, the potential of geothermal energy development in southern Korea is briefly discussed.

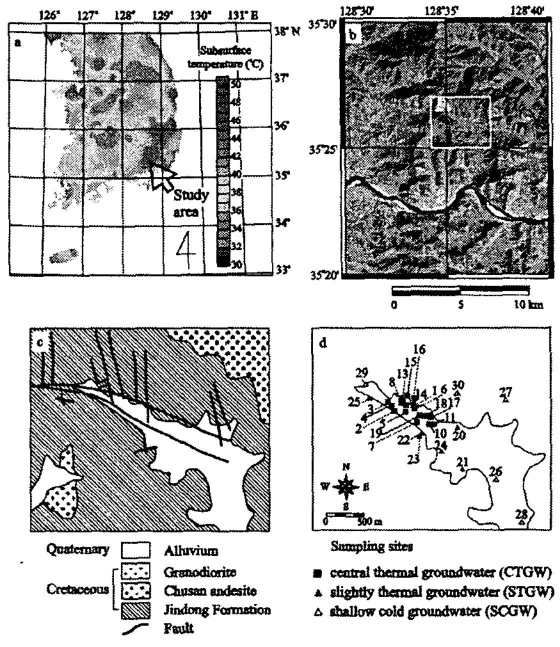

Fig. 1. (a) Distirbution of estimated subsurface temperatures (at a depth of 1km) in South Korea (after Lim et al., 1996), (b) the location and topographic map of the Bugok area, (c) the geology, and (d) sampling sites of the study area.

2. Sampling and analytical method

Water samples (N = 38) were collected twice between June 1994 and May 2000 (Fig. 1(d)). Chemical analysis was performed using ICP-AES (OPTIMA 3000XL) for cations, IC (DIONEX 120) for anions, Analytical data used in this study have the percent charge balance of < 5 %. Multivariate statistical analyses (hierarchical clustering and t-test) was performed on data in order to classify the samples based on hydrochemical characteristics, and to check the significance of the differences in chemistry between the designated water groups.

3. Result and Discussion

3.1. Hydrogeochemistry

Water samples from the Bugok area are classified into three groups based on the temperature and the chemical compositions (Fig. 2); central thermal groundwaters (CTGW, Na-SO_4 type) occurred in central part of the area, shallow cold groundwater (SCGW, Ca-HCO_3 type) located in peripheral area of thermal waters, and slightly thermal groundwaters (STGW, Na-SO_4-HCO_3 type) have an intermediate character between CTGW and SCGW by mixing of those two water types. The result of statistical classification well corresponds to the grouping on Piper diagram. High Na, K and SiO_2 concentration for CTGW is thought to be the result of geochemical reaction between circulated groundwater and silicate minerals, such as Na- and K-feldspar. For CTGW and STGW, the increases of both sulfate concentration and saturation index of gypsum with increasing outflow temperature indicate the larger degrees of the dissolution of gypsum and/or anhydrite toward more typical thermal groundwaters in the Bugok area.

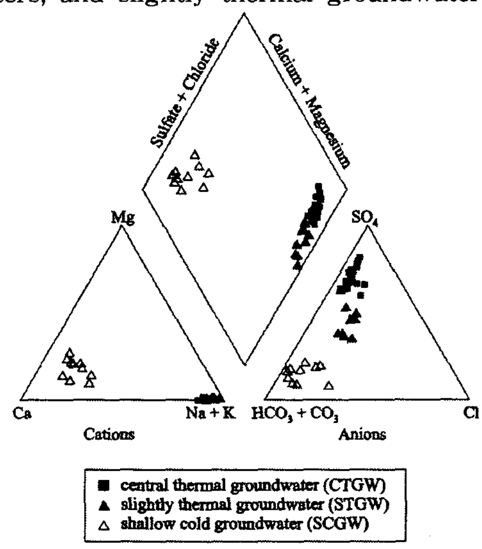

Fig. 2. Piper diagram showing the chemistry of three types of groundwater in the Bugok area, Korea.

3.2. *Alkali ion geothermometry*

The application of Na-K geothermometer to CTGW yields potential temperatures of a deep thermal reservoir in the range of 88 to 198 °C. The calculated temperatures from Na-K-Ca geothermometer fall in the range of 73 to 170 °C. This temperature range is similar with that from various Na-K geothermometers, implying a negligible effect of Ca ion. Plots of the chemistry of CTGW on the Giggenbach's Na-K-Mg diagram show that most of CTGW fall in the 'partially equilibrated' field (Fig. 3). Two trends of the samples are recognized. They have the constant Na/K ratios with variable Mg concentrations. However, the negligible effect of the mixing on the Na/K ratio suggests the applicability of Na-K geothermometers and the multiple mineral equilibrium geothermometer for our 'partially equilibrated' water (CTGW).

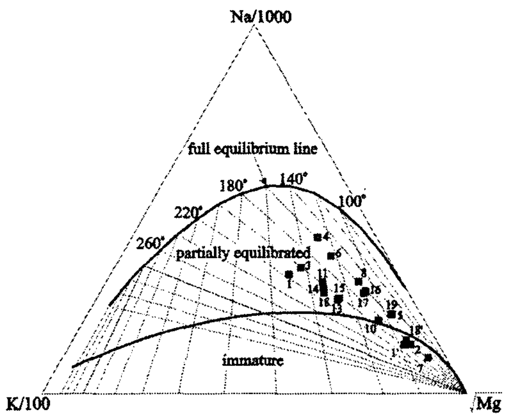

Fig. 3. Ternary Na-K-Mg diagram showing the chemistry of CTGW (central thermal groundwater) in the Bugok area, Korea (after Giggenbach, 1988).

3.3. *Multiple mineral equilibrium geothermometry*

The saturation indices of the water (BG 4) with respect to albite, calcite, quartz, chalcedony, kaolinite, montmorillonite and muscovite get closer to zero for the temperatures of about 120-150 °C. For the other samples of CTGW, the estimated temperatures fall in the range of 100-155 °C (Fig. 4). It is noteworthy that the trends of the temperatures estimated for a potential deep geothermal reservoir are far from the measured outflow temperatures. As an alternative approach to estimate the temperatures of geothermal water, we observed a few, aqueous liquid-rich fluid inclusions (N = 38), and had homogenization temperatures of 66 to 183 °C (average = 128 °C). It is probable that a potential deep geothermal reservoir related to the formation of sulfate-rich spa water in the Bugok area likely has temperatures around 100-155 °C.

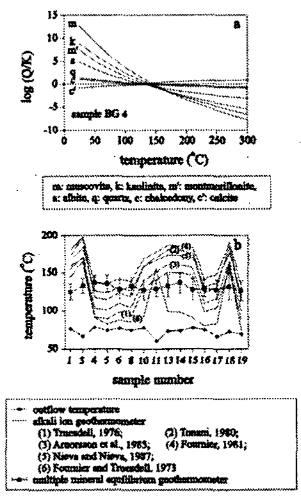

Fig. 4. (a) The changes of calculated saturation states (log Q/K) of various minerals as a function of temperature (sample BG 4). (b) The reservoir temperatures estimated by various geothermometers for each sample of central thermal groundwater (CTGW) in the Bugok area, compared with outflow temperature.

4. Conclusions

Sulfate-rich (up to 188 mg/L) thermal groundwaters with the highest outflow temperatures (up to 78 °C) in South Korea occur in the Bugok spa area, where the highest values of geothermal gradient (80 °C/km) and heat flow (3.20 HFU) were reported. By applying various chemical geothermometers to CTGW, the potential temperature of a deep geothermal reservoir is estimated to fall in the approximate range of 100-155 °C. This fact may suggest that the upflow velocity of spa waters is relatively fast (along faults?) and/or the heat source is located at relatively shallow depths. Considering the geothermal gradient (80 °C/km) and average annual temperature of the study area, the estimated reservoir temperatures suggest a reservoir depth of < 1.8 km below the land surface. In such a deep environment, water-rock interaction, mainly consisting of the dissolution of Na- and K-feldspars and sulfate minerals (gypsum and/or anhydrite) reached thermal and chemical equilibrium and resulted in the CTGW waters. This study will be helpful for re-evaluating the potential of geothermal energy use in South Korea.

5. References

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