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Estimation of deep reservoir temperature of thermal groundwaters in Bugok and Magumsan areas, South Korea

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<요 약 문>

In this study, hydrochemical studies of thermal waters in the Bugok and Magumsan areas showing geothermal anomalies were carried, and the applicability of ion geothermometers and multiple mineral equilibrium approach was examined to estimate their potential deep reservoir temperatures. Typical thermal waters of the two areas are clearly grouped into two major types, according to water chemistry: Na-Cl type (group A) and Na-SO4 type (group D). Compared to group A, group B and C waters show some modifications in chemistry. Group E waters show the modified chemistry from group D. Geothermal waters from the two areas showed some different chemical characteristics. The thermal waters of group A and B in Magumsan area are typically neutral to alkaline (pH=6.7 to 8.1) and Cl-rich (up to 446.1 mg/L), while the waters of group D and E in Bugok area are alkaline (pH=7.6 to 10.0) and SO_4-rich (up to 188.0 mg/L). The group A (Na-Cl type) and group D (Na-SO_4 type) waters correspond to mature or partially immature water, whereas the other types are immature water. The genesis of geothermal waters are considered as follows: group A and B waters were formed by seawater infiltration into reservoir rocks along faults and fracture zones and possibly affected by fossil connate waters in lithologic units through which deep hot waters circulate; on the other hand, group D and E waters were formed by the oxidation of sulfide minerals (mainly pyrite) in surrounding sedimentary rocks and/or hydrothermal veins occurring along restricted fracture channels and were possibly affected by the input and subsequent oxidation of S-bearing gases (e.g. H2S) from deep thermal reservoir (probably, cooling pluton). The application of quartz, Na-K, K-Mg geothermometers to the chemistry of representative group A and D waters yielded a reasonable temperature estimate (99-147°C and 90-142°C) for deep geothermal reservoir. Aqueous liquid-rich fluid inclusions in fracture calcites obtained from drillcores in Bugok area have an average homogenization temperature of 128°C, which corresponds to the results from ion geothermometers. The multiple mineral equilibrium approach yielded a similar temperature estimate (105-135°C and 100-140°C). We consider that deep reservoir temperatures of thermal waters in the Magumsan and Bugok areas can be estimated by the chemistry of typical Na-Cl and Na-SO_4 type waters and possibly approach 105-135°C and 100-140°C.

Key words : thermal groundwaters, Bugok, Magumsan, reservoir temperature, geothermometers, mineral equilibrium.

1. Introduction

The investigations of thermal waters have been studied intensively in order to develop geothermal energy and geothermal water for commercial and medical purposes. These studies focused on the processes (e.g., dissolution and precipitation of minerals, ion exchange, mixing) occurring during the fluids generation at depth and /or during their rise to the surface. The important point of study of thermal water is to estimate reservoir temperature, because the chemical process of thermal water is changed when the reservoir temperature is changed. The assumption is that chemical equilibrium between groundwater and rock has to be attained in a deep reservoir and the chemical re-equilibrium has not occurred during ascent. Temperature of the deep reservoir can be estimated by applying chemical geothermometers to the chemical compositions of water outflowing to the surface. Bugok (up to 78°C) and Magumsan thermal areas (up to 54.8°C) in this study are famous for thermal waters, and potential area for the development of geothermal energy. The occurrence of group A and D thermal waters reflect complicated geological processes that may not be apparent from the surface geology. Thus, we aim to verify the deep reservoir condition and to estimate the deep reservoir temperature of group A and D using a coupled application of chemical geothermometers and multiple mineral equilibrium approach.

2. Results and Discussion

2.1. Geologic setting

The lithologic unit of study area in the Cretaceous Kyeongsang Basin, one of the tectonic provinces in South Korea, consists of the Cretaceous Jindong Formation, Haman Formation (mainly arkosic sandstone and massive dark impermeable calcareous shale) and intrusions or extrusions of Chusan andesite of the Cretaceous Yucheon Formation consisting of flows, sheets, dykes and intrusive bodies in occurrence and alluvium of Quaternary. Thermal waters occur along or near the NS-trending faults displaced by EW-trending ones and near intersect on between N10-20E- and N-40-50W-trending faults.

2.2. Hydrogeochemistry

Thermal waters are grouped into several chemical types: (group A: Na-Cl, group B: Na-Cl-HCO3, group C: $Ca-HCO^3$, group D and E: Na-SO4, group F: $Na-SO_4-HCO^3$, group G: $Ca-HCO_3$) (Fig. 1). Group A and B in Magumsan area and group D, E, and F in Bugok area are comparably enriched in Na, K, F, Cl, SO^4 and SiO_2, whereas group C in Magumsan area and group G in Bugok area are intermediate in major ion concentrations. The typical thermal waters of group A and B in Magumsan area are neutral to alkaline (pH=6.7 to 8.1) and Cl-rich (up to 446.1 mg/L). While,

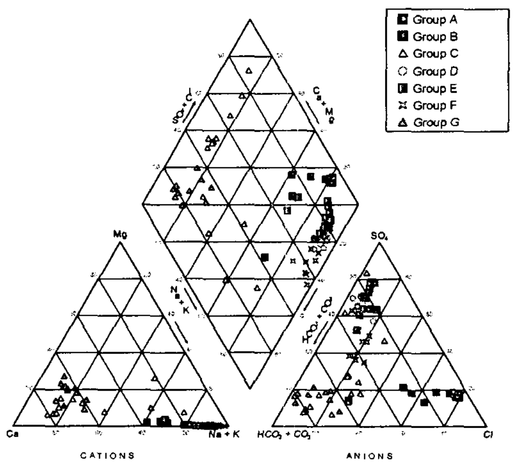

Fig. 1. Piper's diagram

the typical waters of group D and E in Bugok area are alkaline (pH=7.6 to 10.0) and SO_4^-rich (up to 188.0 mg/L). It is very important to know the origin of SO4 that is enriched in group D and E. The sulfate rich (group D and E) waters are likely to arise from (1) oxidation of sulfide minerals (mainly pyrite) in surrounding sedimentary rocks and /or from magmatic hydrothermal pyrites occurring in restricted fracture channels; (2) an input of S-bearing gases (e.g. H_2S) from below and subsequent oxidation of reduced-S species derived from deep thermal reservoir (probably, still cooling magma chambers) to sulfate. Group E reflects their influence from oxidation of sulfide minerals (mainly pyrite), because they are enriched in Na, K and have comparatively low pH. The chloride type (group A and B) waters owe their nature either (1) to slight seawater infiltration (<2wt. %) into the reservoir rocks along faults and fracture zone, or (2) to the presence of fossil connate waters in the lithologies through which the deep hot waters circulate.

2.3. Reservoir temperature estimates

2.3.1. Chemical geothermometers

Group A and D (BG 4, 5, 6, 8) fall into the 'partially equilibrated or mature' field, whereas the other waters are plotted in the 'immature' field (Fig. 2). It suggests that they are most representative of equilibration in the reservoir. A quartz geothermometer usually yielded slightly higher temperatures (113 to 129°C and 105 to 128°C) than a chalcedony geothermometer (85 to 102°C and 75 to 100°C) (Fournier, 1981). The application of Na-K geothermometer to the thermal waters in Magumsan and Bugok areas yielded temperature estimates of 110 to 194°C and of 88 to 227°C. However, due to high Ca content of some thermal the waters, Na/K geothermometers yielded too high temperatures (mostly above 200°C). The calculated Na-K-Ca temperature is generally lower (90 to 153°C and 73 to 170°C) than those from Na-K geothermometer. K-Mg geothermometer gives temperatures of 99 to 113°C and 74 to 128°C, which are similar to quartz geothermometer (Giggenbach, 1988). One end member Mg-poor group E was formed by mixing with pyrite-related waters during their upflowing. The others group F and G is Mg-rich and dominated by secondary mineral dissolution, mixing with cold groundwater and ion exchange near surface. We consider that the temperatures between 99-147°C and 90-142°C are reasonable estimates of deep thermal reservoir for thermal waters in Magumsan and Bugok area in Kyeongsang Basin.

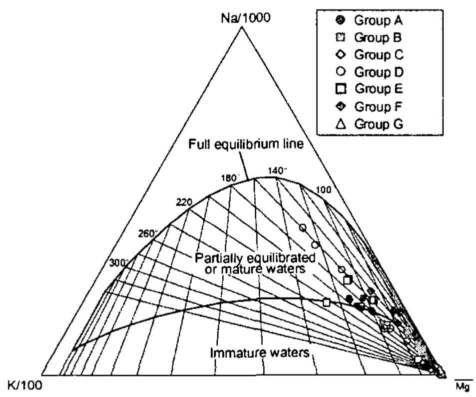

Fig. 2. Diagrams of Giggenbach (1988) showing the graphical estimates of water-rock equilibrium temperature.

2.3.2. Multiple mineral equilibrium approach

Better estimation of reservoir temperature can be achieved by simultaneous consideration of the equilibrium state between the specific water and many hydrothermal minerals as a function of temperature (Pang and Reed, 1998). Fig. 3 shows the SIs with respect to hydrothermal minerals versus temperature for the representative group A (M2) and group D (BG 4) to estimate the deep reservoir temperatures. SIs of the water with respect to quartz, albite, kaolinite, anorthite, muscovite, montmorillonite and paragonite approach to zero around the temperatures of 105-135°C (M2) and 100-140°C (BG4). This temperature range is assumed to indicate the equilibrium temperature within deep thermal reservoir.

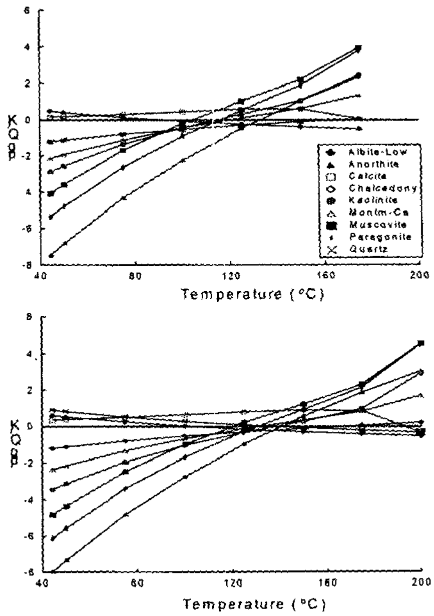

Fig. 3. Diagrams showing the change of calculated saturation indices of various minerals as a function of temperature.

3. Summary

Typical, group A (Na-Cl type) and group D (Na-SO4 type) waters occur in the Magumsan area and Bugok area, respectively, and correspond to mature or partially immature waters which were chemically least altered by mixing of cold bicarbonate-rich, groundwater and/or surface water and secondary reactions. The other type waters (group B, C, and E) show the hydrochemical characteristics of immature waters. Therefore, the use of ion geothermometers to estimate deep reservoir temperature can be applicable restrictedly to the group A and D waters. We consider that as suggested by the chemistry of group A and D, deep thermal reservoirs in the studied geothermal area potentially have the temperatures ranging from 105-135°C and 100-140°C.

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