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Hydrochemical Characterization for Identifying Hydrothermal Systems in the Bandung Volcanic Basin

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ABSTRACT

This study aims to clarify details of hydrothermal system in the Bandung volcanic basin (west Java, Indonesia), one of the richest geothermal resource areas in Indonesia, by hydrochemical methods. For this, hydrochemistry and stable isotope ratios of the water samples taken from the Bandung volcanic basin are analyzed and their differences between hydrothermal systems in the southern and northern parts of that area are revealed. Major ions, including several dissolved trace elements such as Li, B, F and As, were measured for the 19 samples collected from 10 hot springs, 1 crater, 4 springs, 3 wells and 1 surface water in the two regions. Hydrogen and oxygen isotope ratios were also used to identify the origin and hydrogeological process of the waters in each area. As the result, most hot springs in both the areas were found to be composed of immature waters in young hydrothermal systems while only 3 samples were classified as old hydrothermal waters. The southern part was characterized as the higher Li, B, F and As concentrations and the enrichment of oxygen 18 than those in the northern part. These differences suggest that the portion of deep thermal fluids of the hot springs in the southern part is higher than in the northern part. Another suggestion is advanced reaction between the rocks and hot waters in the southern part because of the higher reservoir temperature. Accordingly, the hydrochemical properties of the reservoir fluids is probably different between the two areas, which can serve bases to delineate the boundary of two areas, estimate water circulation patterns and assess geothermal resources by geothermometers using specific chemical elements.

1. INTRODUCTION

Bandung volcanic basin is one of the richest geothermal resource areas in Indonesia. This hydrochemical study needs to clarify different mechanism of hydrothermal system between its southern and northern parts. Recently, all geothermal power plants have been developed only at the southern basin ridge. Some preliminary investigations and early stage explorations have been also carried out at the northern volcanic ridge in order to develop new power generations. Hydrochemical information of the hydrothermal system in the two regions is important for the geothermal resource exploration and designing the power plant construction. To understand and distinguish the hydrothermal system of the two regions, hydrochemical and stable isotopes analyses were adopted in this study using 19 water samples taken from 10 hot springs, 1 crater, 4 springs, 3 wells and 1 surface water in the two regions.

2. LOCATION AND GEOLOGY

As the world's largest archipelago, Indonesia consist of many islands and contains many active volcanoes. Based on this condition Indonesia is rich in geothermal resources. One of the largely developed areas for geothermal power plants in Indonesia is located in Bandung volcanic basin, situated in West Java Province, Java Island, Indonesia under a tropical weather condition. Shallow parts of Bandung volcanic basin covered by Tertiary and Quaternary volcanic products and lacustrine deposits in the middle basin. Major geological structure such as faults and lineaments are distributed along N45ºE and N135ºE. Most of those faults control the locations of geothermal manifestations such as hot springs, springs and fumaroles. In the basin, volcanic ridges are separated into the southern and northern ridges. Morphological and geological conditions of the study area are summarized in Figures 1 and 2.

The samples were taken from hot springs, springs, craters and wells in the following geological formations:

1. Qv – lava of Mt. Patuha
2. Qyd – sandy tuff
3. Qyt – pumice tuff
4. Qvu – undifferentiated old volcanic products
5. Qgpk – volcanic rocks of Mts. Guntur, Pangkalan and Kendang
6. Qyu – undifferentiated young volcanic products

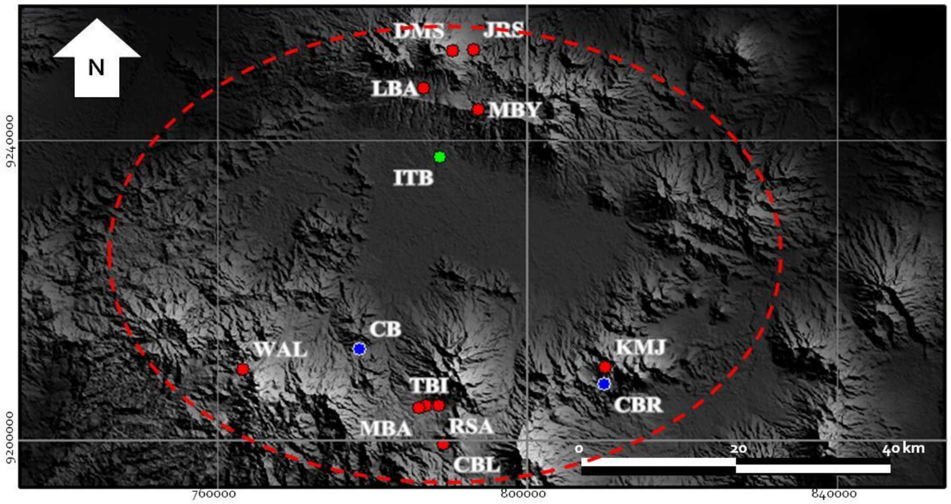

Figure 1: Morphology of Bandung volcanic basin based on digital elevation model and samples locations of hot springs (red), cold springs (blue) and groundwater (green).

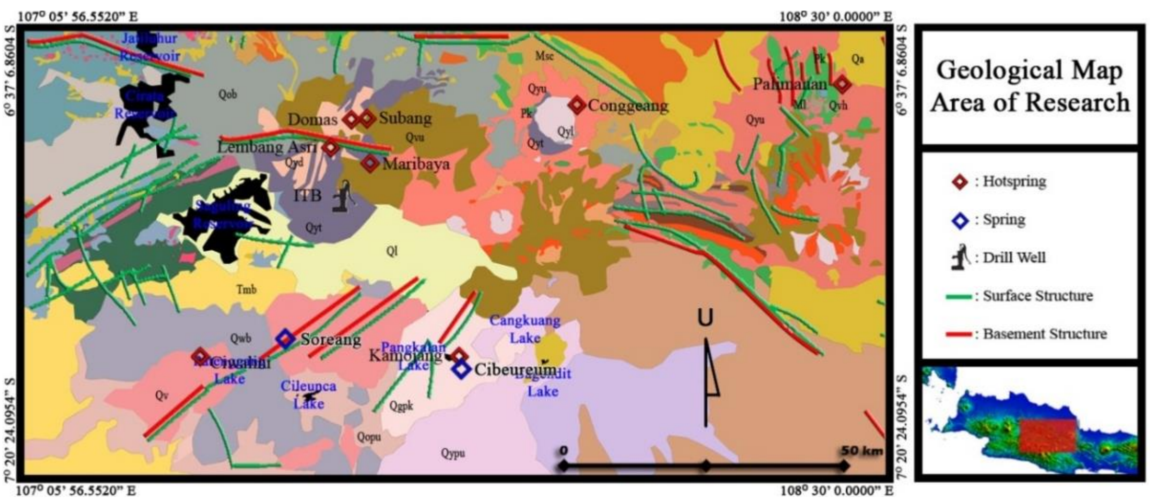

Figure 2: Geological map of Bandung volcanic basin, compiled from Koesmono (1996), Sudjatmiko (1972), Alzwar (1992), Silitonga (1973), Budhitrisna (1986) and Djuri (1973), and locations of water samples

3. METHODS AND ANALYSES

Hydrochemical composition of major ions of the water samples, i.e. Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, HCO_3^- and Cl^- were analyzed using Piper Diagram. As the result, all the water samples from the cold springs and groundwater were characterized as a $(Ca^{2+}+Mg^{2+})$-HCO_3^- rich type, while most hot spring samples were a mixing type of $(Ca^{2+}+Na^++K^+)$-$(HCO_3^-+SO_4^{2-}+Cl^-)$ (Fig. 3). Therefore, the hot waters in the study area is considered to have originated from mixing of shallow groundwater and deeper thermal water or fluids that are rich in Na, K, Cl and S.

Piper Diagram cannot separate the hydrochemical types of hot water from the southern and northern parts. A part of major ion analysis, some trace elements dissolved in hydrothermal waters, Li, B, F, As and Hg were analyzed. Because most geothermal fluids have high Li, B, F, As and Hg contents, these elements can be used as an indicator of presence of deeper thermal fluids that were mixed with the shallow groundwater. The composition of Cl, Li and B in the fluids can classify the water samples of hot springs in the southern part into the water of young hydrothermal system and the samples in the northern part into the water of old hydrothermal system (Figure 4).

In addition to the analyses, the Li, B, F and As concentrations were compared between the southern and northern parts. Figure 5 shows the concentrations of dissolved trace elements in the hot water samples, which clarifies that the Li, B, F and As concentration of the water samples in the southern part are higher than those in northern part. Therefore, the mechanism and portion of the mixing of thermal fluids and waters may be different between the two regions: mixing ratio of the deep thermal fluids in the hot spring waters is estimated to be higher in the southern part than the northern part.

To deepen the hydrochemical characterization, stable isotope ratios of the water samples from the two regions, δH^2 and δO^{18}, were measured. Figure 6 shows the δO^{18} and δH^2 plots overlaid with the local Bandung meteoric water line that is after previous researches by Notosiswoyo (1989) for the northern part and by Hendrasto (2005) for the southern part. Obviously, the hot spring waters in the southern part are heavier inδO^{18} than those in the northern part.

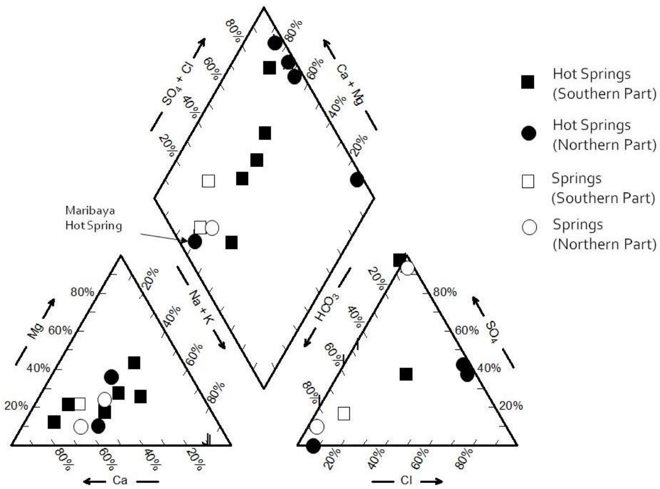

Figure 3: Piper diagram of samples collected in Bandung volcanic basin showing that the hot spring waters are a chloride-sulfate type by mixing of shallow and deep waters.

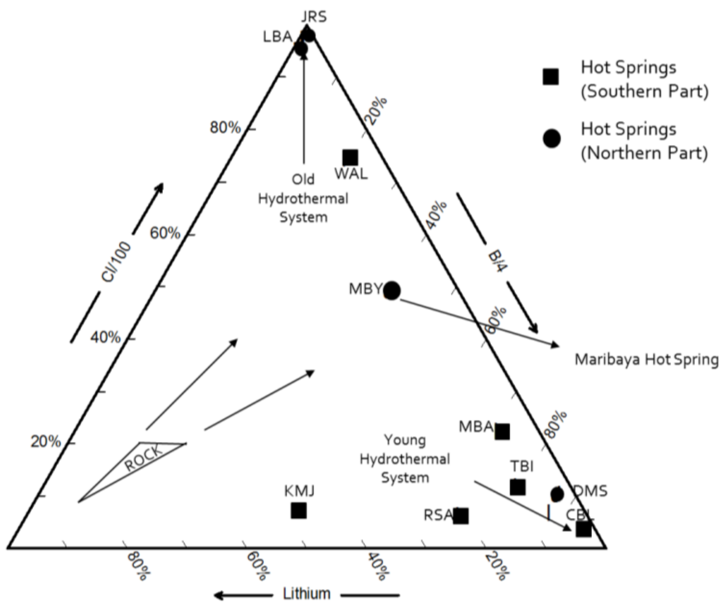

Figure 4: Cl-Li-B diagram of samples collected in Bandung volcanic basin suggesting that the hot spring waters in the southern part are originated from young hydrothermal system.

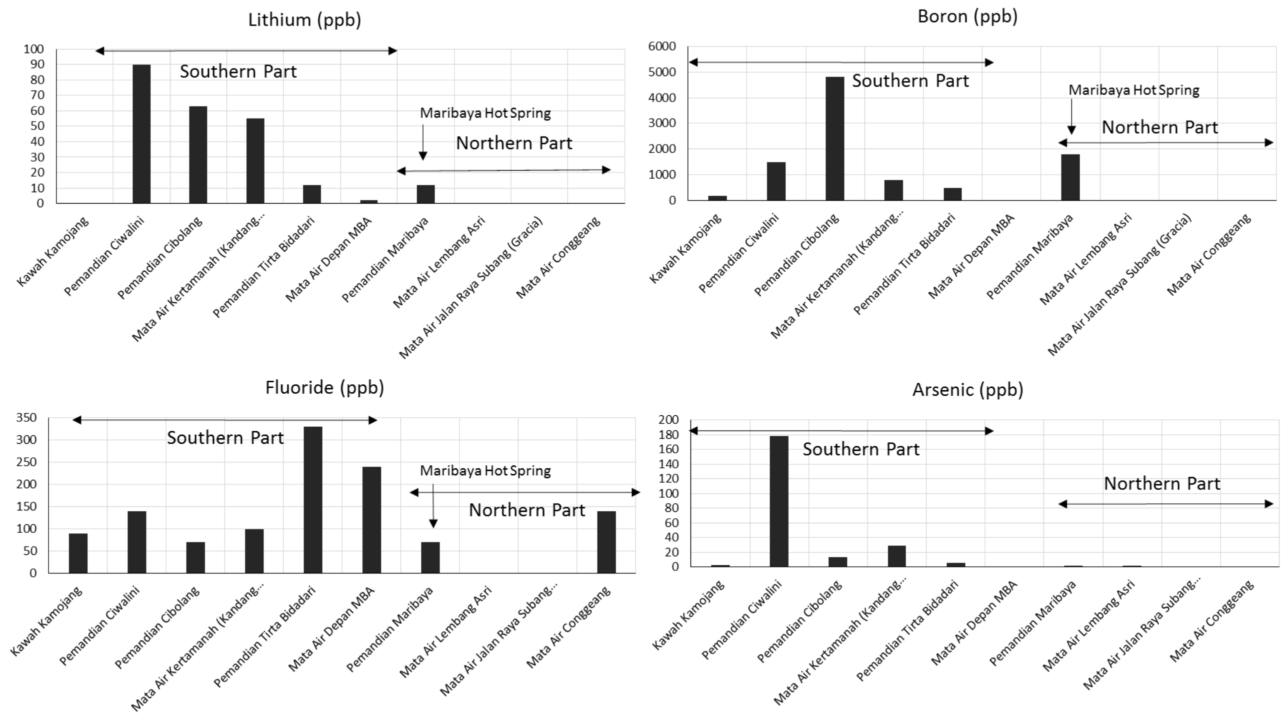

Figure 5: Concentrations of dissolved trace elements in hot spring water samples from Bandung volcanic basin showing that their concentrations in the southern part are higher than those in the northern part.

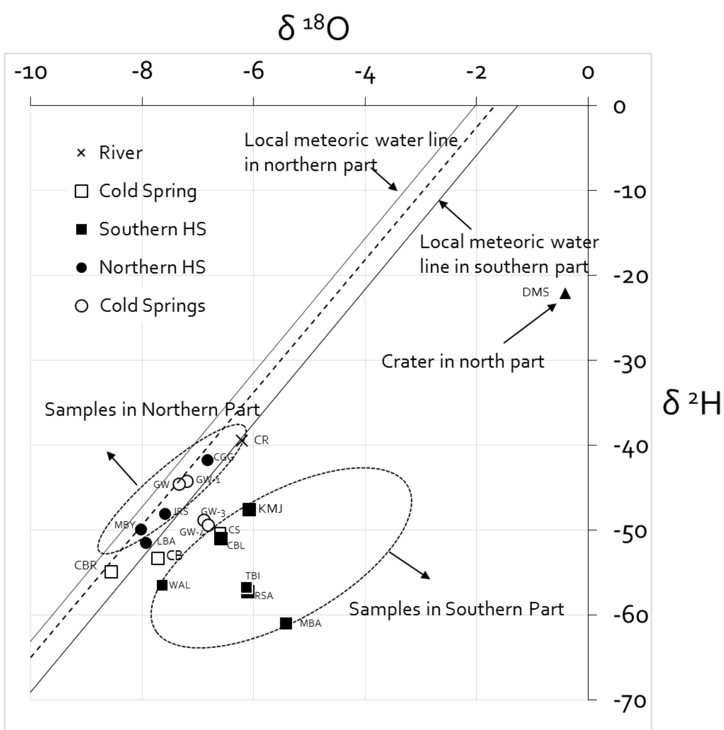

Figure 6: Stable isotope δO^{18} and H^2 plots of waters samples from Bandung volcanic basin showing that the water samples from the southern part are shifted to the right, larger ratio of O^{18}. The waters are significantly different from the water samples in the northern part whose plots are concentrated near the meteoric water line.

4. DISCUSSION

Based on the above hydrochemical characterization, the hot spring waters are probably originated from mixing of the deeper thermal water or fluids with the shallow groundwater. The presence of Cl^- and SO_4^{2-} anions in the hot spring waters also suggest this mixing. The dissolved trace elements of the hot water samples were richer in the southern part than the northern part. The trace elements such as Li, B, F and As are usually dissolved in hydrothermal fluids, which can be used as an indicator of geothermal resource assessment. The different concentrations of these elements between the southern and northern parts signify a difference in mixing ratio of the deep thermal fluids. As for the study area, the mixing ratio in the southern part is higher than the northern part, which means large ascent flows from deep parts in the southern part. This difference may have been controlled by higher rock permeability in deep parts of the southern part than that of the northern part.

Higher O^{18} in water samples can be caused by reaction of waters or fluids with rocks at high temperatures. This reaction in the southern part with higher δO^{18} values is regard to be more intensive than the northern part by two possible processes, 1) higher temperatures in the southern part than the northern part due to the presence of shallow heat sources such as young intrusive rocks and 2) ascent of deep thermal fluids. The first process is verified by a north-south geological cross-section of Bandung volcanic basin after Dam (1992) showing a presence of a relatively young intrusion in Miocene to Pliocene surrounded by the older volcanic products in the southern part (Figure 7). This late intrusion potentially is a shallow heat source. Many fractures may have been formed by such intrusion in this region with increasing initial rock permeability by the fracturing. As a conclusion, mixing mechanism of the deep hot thermal fluids with the shallow groundwater in the southern and northern parts of Bandung volcanic basin are schematically summarized in Figure 8.

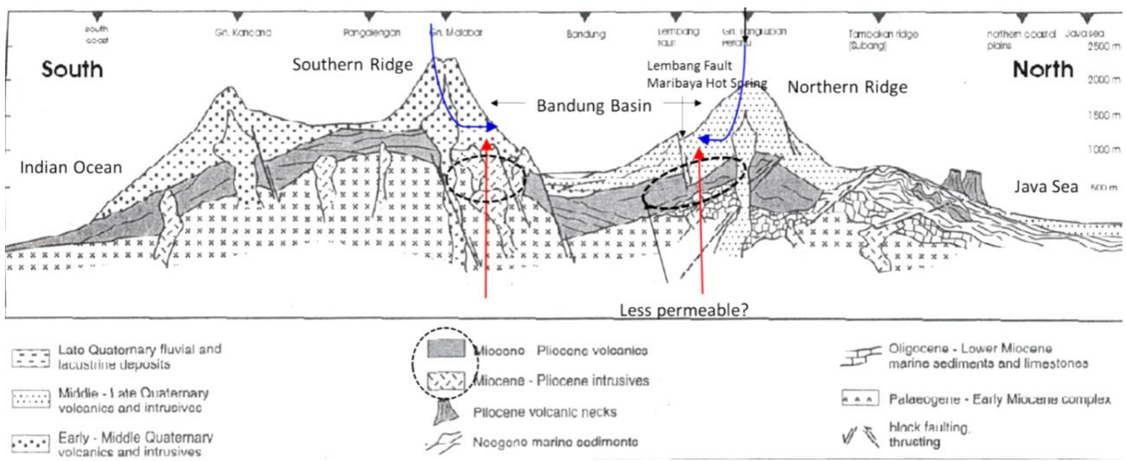

Figure 7: North-south-north geological cross-section of Bandung volcanic basin after Dam (1992) showing a presence of younger intrusions in the southern part of Bandung volcanic basin which may act as a heat source and have formed fracture zones with increasing rock permeability.

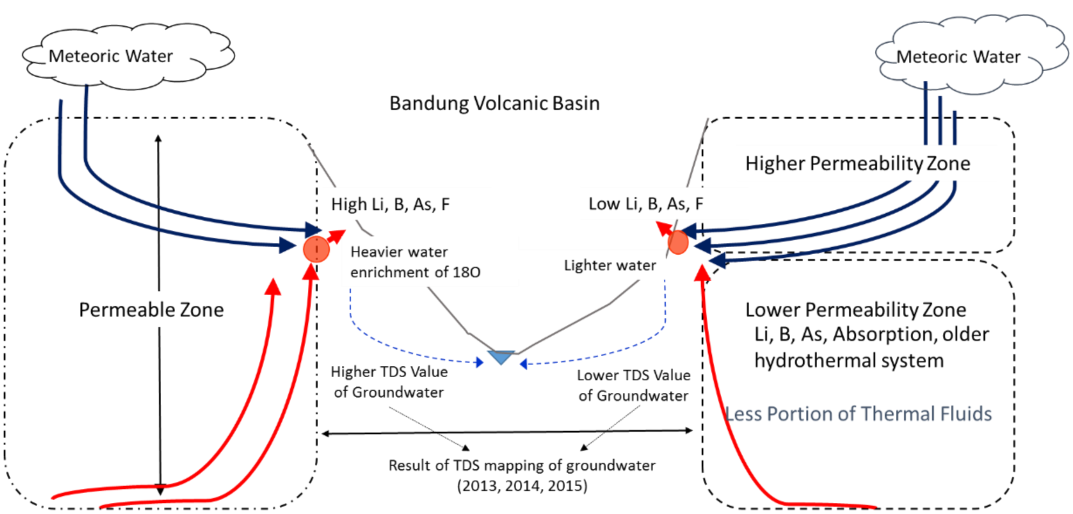

Figure 8: Schematic model for different mixing location of deep thermal fluids and shallow groundwater in the southern and northern parts of Bandung volcanic basin. Mixing ration of the deep thermal fluids in the hot springs in the southern part is higher than that of the northern part due to higher permeability by the fracturing.

5. CONCLUSIONS

Main results of the hydrochemical characterization of hot spring waters in the southern and northern parts of Bandung volcanic basin can be summarized as follows.

- The hot spring waters were probably originated from mixing of the ascending deep thermal fluids with the shallow groundwater, which signified by presence of chloride and sulfate anion in hot spring waters.
- The concentrations of trace elements (Li, B, F and As) dissolved in the hydrothermal waters are higher in the southern part than the northern part. This also signifies a higher mixing ratio of the deep thermal fluids in the southern part which may have been caused by higher rock permeability with fracturing.
- Two processes can be considered to explain the enrichment of O^{18} in the hot spring waters in the southern part, 1) presence of shallow heat source by relatively young intrusion in the southern part which induces strong chemical reactions between rocks and waters and 2) higher rock permeability in deep parts which induces much ascent flows.

Consequently, hydrochemical characterization combined with stable isotope analyses is effective to clarify the mixing mechanism of shallow groundwater with deep thermal fluids and its local difference in Bandung volcanic basin.

ACKNOWLEDGMENT

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