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A Correlation Study between Volcanic Activities and Thermal Water Changes in Tangkuban Perahu Hydrothermal Prospect, Jawa Barat, Indonesia

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ABSTRACT

Tangkuban Perahu is one of the active volcanoes in Jawa Barat, Indonesia. The volcano and its surrounding thermal manifestation areas are classified as a Volcanic Hydrothermal System that implies strong association of the reservoir fluid with volcanic activities from the Tangkuban Perahu Volcano. In September 2012, based on observations of the Center for Volcanology and Geological Hazard Mitigation (PVMBG), there was increased activity at Tangkuban Perahu. The increased activity was observed with seismographs and gas contents of H_2S and SO_2. As a result, prior to exploitation of geothermal energy in this area, it was expected that the significant variation in thermal manifestations occurred due to a natural volcanic activity.

This paper will present the variation and the changes of hydrothermal waters at Tangkuban Perahu based on chemical changes in thermal manifestations. Hydrothermal water samples at Tangkuban Perahu were collected in 1987, 2002, 2008 and 2012.

The study shows that Kancah and Ciater thermal manifestation areas became sulfate water in 2012. Chloride content in Domas Crater has decreased > 90 mg/L and the sulfate increased > 1000 mg/L. Domas Crater water exhibit δD and $\delta^{18}O$ enrichments from a steam heating magmatic end member. This evolution is assumed because additional magmatic volatiles, such as H_2S, increased during the activity. In peripheral manifestations, such as in Batu Kapur, Batu Gede, Ciracas, Cimangu and Maribaya, HCO_3 increased.

All waters have highly variable and unreliable temperatures and none of the fluid is at equilibrium with host rock. The result of this study can also become a baseline for variation of thermal manifestation waters due to natural volcanic activities.

1. INTRODUCTION

Volcanic Hydrothermal Systems are mainly confined to stratovolcanoes or young calderas and exhibit characteristic surface manifestations that are spatially zoned with respect to their volcanic center, namely solfataras, fumaroles, hot acid lakes and acid hot springs discharging sulfate and sulfate-chloride waters (Goff and Janik, 2000). At lower elevations, minor thermal springs may discharge neutral pH, chloride, or sometimes bicarbonate–chloride waters such as the thermal spring at Tangkuban Perahu Volcano. Tangkuban Perahu Volcano is an active volcano where the magmatic activity affects thermal manifestations around the volcano.

Ellis and Mahon (1997) mention many active volcanoes containing high-temperature gases such as HCl, HF, and SO_2 and also low-temperature gases such as H_2S. Gas can come out from the rock that melts at shallow depths near the surface and then condense. On the other hand, Goff and Janik (2000) said the subduction-related magmatic water, e.g. Indonesia setting, may have a very uniform isotopic composition, with δD = -20 ± 10‰ and $\delta^{18}O$ = -10 ± 2‰. Under these conditions, it is assumed that increased volcanic activity will be followed by an increased temperature, decreased pH, increased isotope δD and/or $\delta^{18}O$ and increased contents of chloride and sulfate, especially at Domas Crater.

In Tangkuban Perahu Prospect, there are two geothermal CoW areas still in the advance exploration stage. Later, if geothermal energy is to be produced from this area, there are possible changes of the reservoir fluid's characteristic that may cause environmental problems or geological hazards. The changes of reservoir's characteristics because of geothermal energy exploitation are often observed from changes in the fluid of surface thermal manifestations. Therefore, assessment of fluid from surface manifestations, starting at the beginning of geothermal energy development, is very important. However, because the data from this area is not well defined, it is difficult to conduct a surface manifestation study in the area. Fortunately, reports from several well-studied geothermal prospects associated with active volcanoes are available, e.g. Mount St. Helens, Washington, USA (Shevenell and Goff, 1994), Poas Volcano, Costa Rica (Martinez et al., 2000), Arenal Volcano, Costa Rica (López et al., 2006) and Usu Volcano, Japan (Shibata et al., 2008). This makes the evaluation of chemical fluid changes from surface manifestations in this area possible for better interpretation.

2. TANGKUBAN PERAHU ACTIVITIES AND CHEMICHAL CHARACTERISTICS OF THERMAL SURFACE MANIFESTATION

Tangkuban Perahu, located in Jawa Barat, is one of the active volcanoes in Indonesia. Tangkuban Perahu is located between the two cities, Bandung (20 km to the south) and Subang (27 km to the north). This active volcano has a record of minor phreatic eruptions, seismicity increase and temperature increase of the gas.

Kusumadinata (1979) and Kadarstia et al. (1997) noted that phreatic eruptions occurred in 1929, 1961, 1969, 1971, 1983, 1986, 1992 and 1994, and increased seismicity in 2004 (Geology Agency, 2011). Although phreatic eruptions occurred several times, this volcano has not experiencing a magmatic eruption since 1600 (Van Bemmellen, 1949). The Center of Volcanology and Geological

Hazard Mitigation (PVMBG) noted that Tangkuban Perahu activity increased in September 2012. This was observed by data from seismographs, where the magnitude of microseismicity increased six times from the early years. The content of H_2S was 8-10 ppm and SO_2 increased by 2 ppm. Water temperature of Ratu Crater increased from 110°C to 220 °C. The increased activity of the volcano hypothetically changed Tangkuban Perahu's termal manifestations, i.e. Domas Crater, Kancah, Ciater, Batu Kapur, Batu Gede, Ciracas, Cimangu, and Maribaya.

Domas Crater is located at the west flank of Tangkuban Perahu's main vent, at elevation of 1604 m a.s.l. (Figure 1). The alteration zone in this area is more than 20,000 m^2. The solfataras and fumaroles in this area have temperatures of 70 – 100°C. Boiling springs emerge with the crater, having high temperatures of 85.5 – 91.1°C, low pH of 1.27 – 2.45 and low flow rates of 0.3 – 0.5 L/s. The main crater, west of Domas Crater, is Ratu Crater (1,800 m a.s.l.). The Ratu Crater has fumaroles with temperatures of 95 - 100°C. Ciater (999 m a.s.l.) hot springs in the north west of flank Tangkuban Perahu Volcano have temperatures of 44 – 46.9°C with low pH of 1.8 – 2.8 and high flow rates of 2 – 15 L/s. The water with the high flow rate passes through the pyroclastic and lava (Nasution et al., 2004). The warm springs of Kancah are located in the south of Tangkuban Perahu Volcano. These warm springs (1326 m a.s.l.) have temperatures between 31.1 – 34.5°C, flow rates 3.3 – 5.1 L/s and low pH 2.86 – 3.43.

At the northern part of Tangkuban Perahu (Figure 1) are three thermal areas, Batu Kapur, Batu Gede and Ciracas. Neutral warm springs of Batu Kapur are located at elevation of 370 m a.s.l. The warm springs have temperatures of 39.4 – 40.1°C, pH of 5.49 – 6.2 and flow rates of 2.2 – 3.9 L/s. Batu Gede is located at elevation of 432 m a.s.l., approximately 12 km northeast of Tangkuban Perahu. The warm springs in this area have temperatures of 42.1 – 45.5°C with slightly neutral pH of 5.66 – 6.43 and low flow rates of 0.2 – 1 L/s. The thermal discharges of Ciracas are located 5 km to the west of Batu Gede (485 m a.s.l.). They have pH 5.74 – 6.66, temperature 41.6 – 46°C, low flow rate 0.2 L/s. These manifestations, to some extent, are expected to have sedimentary influences in their chemical composition due to possible subsurface sedimentary layer occurrence in this area. This sedimentary formation is interpreted, by Nasution et al. (2004), to thicken toward the north of Tangkuban Perahu.

Maribaya warm springs are located at the south of Tangkuban Perahu (Figure 1). They have temperatures 45.1 – 46.6°C, slightly neutral pH 5.46 – 6.38 with flow rates 0.23 – 1.11 L/s. This area is located at high altitude of 1,100 m a.s.l. The Maribaya manifestations are confined to the Lembang Fault. The warm springs of Cimangu are located at the southwest Tangkuban Perahu Volcano, approximately 750 m a.s.l. The warm springs have temperatures 34.1 – 35.2°C, flow rates 2.3 – 2.85 L/s and neutral pH 6.05 – 7.01.

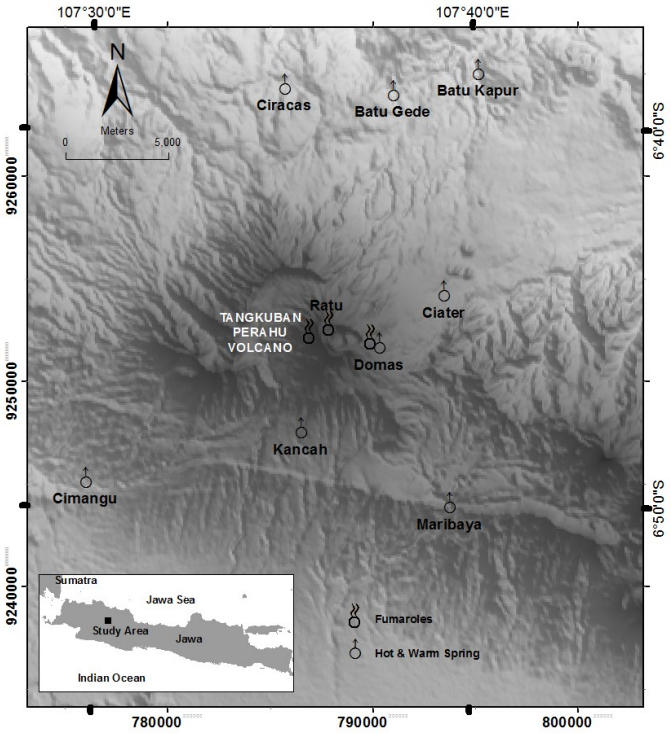


Figure 1: Map of Tangkuban Perahu geothermal prospect at Jawa Barat, Indonesia.

3. DISCUSSION

The detailed result of the chemical analyses of Tangkuban Perahu thermal waters have been presented in Boedihardi (1987), Nasution et al. (2004), PT. WSS and WestJEC report (2008), and Saputra (2014).

3.1. Isotopic Composition

The evidence of magmatic interaction with meteoric waters is presented in δD and/or $\delta^{18}O$ relation among thermal springs and meteoric water. Meteoric Water Line (MWL) at Tangkuban Perahu is $\delta D = 7.21\ \delta^{18}O + 6.37‰$ (Notosiswojo, 1989). Maribaya has δD -52‰ to -57‰ and $\delta^{18}O$ -3‰ to -9‰ in line with MWL, thus Maribaya is interpreted as originally from meteoric water. Influx

from magmatic inputs at Kancah and Ciater is undetected, even in 2011 (Figure 2). No isotope data was available for Kancah and Ciater until 2012, thus the evidence of magmatic influence on both manifestations cannot be derived. In 2011, isotope $\delta^{18}O$ at Batu Gede decreased -2‰ from MWL. This suggests the reaction of formation waters influx (Nicholson, 1993). Domas Crater increased 10‰ δD and 6‰$\delta^{18}O$ in 2012. That isotope plotting is near andesitic water which indicates magmatic influx to Domas Crater or steam heating near the surface.

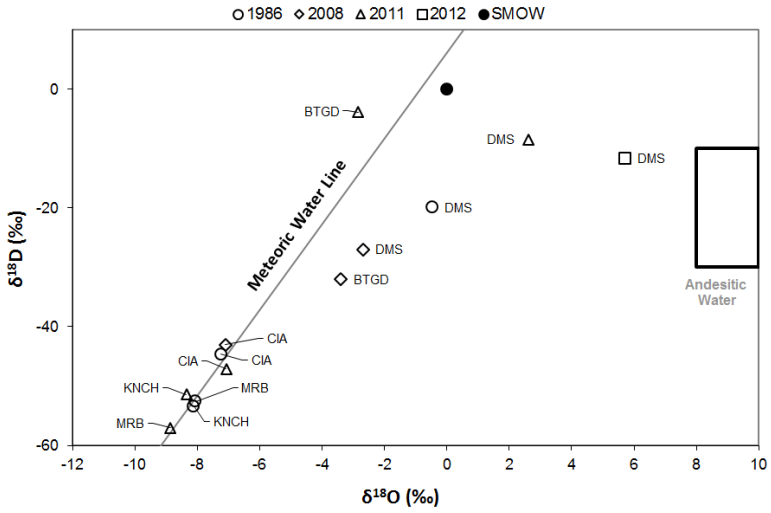


Figure 2: δD versus $\delta^{18}O$ for thermal water at Tangkuban Perahu Volcano. 1986 data is from Notosiswojo (1989), 2011 data from Susanna (2012) and 2012 data from Iqbal (2012). The abbreviations refer to the following: Domas Crater (DMS), Kancah (KNCH), Ciater (CIA), Batu Gede (BTGD), Batu Kapur (BTKP), Ciracas (CRC), Cimangu (CMG), and Maribaya (MRB).

3.2. Chemical Changes

From 1987 until 2012, temperatures of the thermal springs at Tangkuban Perahu were generally unchanged, except for the Domas Crater which decreased 8°C. On the other hand, the pH slightly decreased (0.5 - 1) at Domas Crater, Ciater, Batu Gede, Batu Kapur and Ciracas while it was unchanged at Kancah, Maribaya and slightly increased at Cimangu.

Figure 3 shows that Kancah and Ciater thermal manifestation areas became sulfate water in 2012. The chloride content of thermal manifestation at Ciater has increased to 600 mg/L and sulfate content to 200 mg/L whereas the chloride content at Kancah has decreased to 30 mg/L and sulfate content increased to 600 mg/L. Chloride of thermal water at Domas Crater has decreased from 90 mg/L to 1 – 5 mg/L. The sulfate content at Domas Crater has increased to 1,000 mg/L. On the contrary, peripheral manifestations which are mostly bicarbonate water such as manifestations at Batu Kapur, Batu Gede, Ciracas, Cimangu, and Maribaya have lower sulfate contents. At these areas chloride content has decreased, except at Batu Gede (increased more than 1,500 mg/L).

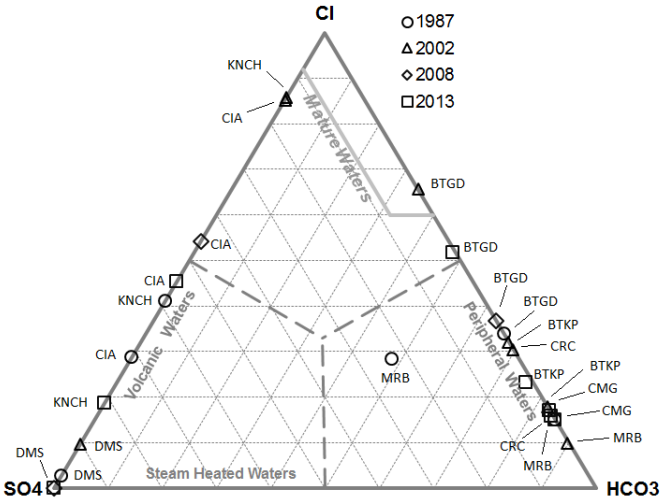


Figure 3: Ternary diagram of Cl-SO_4-HCO_3 for thermal water at Tangkuban Perahu.

Saputra (2014) stated that the effect of rainfall on chemical contents of thermal waters at Central Tangkuban Perahu, such as Domas Crater, Kancah and Ciater, will be smaller than the effect of increased volcanic activity. On the contrary, effect of rainfall

will be greater at North and South of Tangkuban Perahu, i.e. Batu Gede, Batu Kapur, Ciracas, Maribaya and Cimangu. Therefore, the chemical changes at Domas Crater, Ciater, and Kancah are expected due to a magmatic influx.

Chloride content increased at Ciater while it decreased at Domas Crater and Kancah, probably due to the HCl gas condense at the lower altitude (1,000 - 1100 m a.s.l.). Meanwhile, the sulfate content at Domas Crater increased three to four times more than increased sulfate at Kancah and Ciater, possibly as a result of the H_2S gas condense at the higher altitude (1,700 - 800 m a.s.l.). Increase of chloride content at Batu Gede is probably due to influx from formation waters with high chloride content such as marine sedimentary formation. This marine sediment has been noted by Nasution et al. (2004).

The relative anion concentrations of discharge waters from all manifestation are Mg > Na > K (Figure 4). Therefore, all thermal manifestations are immature waters. This indicates that all waters have unreliable temperatures and none of the fluid is at equilibrium with host rock.

The result of this study demonstrate that fluid of thermal surface manifestations in Tangkuban Perahu geothermal prospect change naturally with time, although the geothermal system has not been under exploitation. The data from this study is important as documents for baseline monitoring data, should the prospect be exploited in the future.

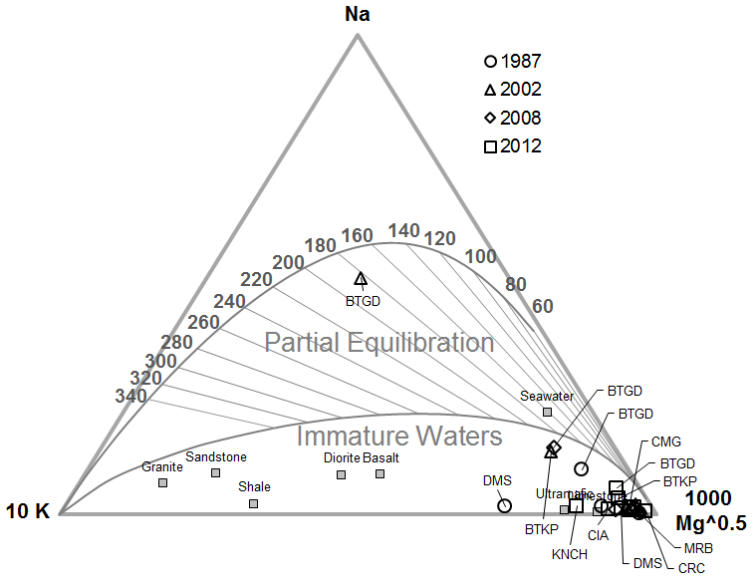


Figure 4: Ternary diagram of Na-K-Mg.

4. CONCLUSION

Evolution of thermal waters at Tangkuban Perahu from 1987 to 2012, indicates a decrease in temperature, especially at Domas Crater. Furthermore, pH slightly decreased at Domas Crater, Ciater, Batu Gede, Batu Kapur and Ciracas while at Kancah, Maribaya it was unchanged and at Cimangu it slightly increased.

The rainfall effect will be smaller than the effect of volcanic activity at Central Tangkuban Perahu, thus the evolution of thermal water at Central Tangkuban Perahu is expected due to magmatic influx. Kancah and Ciater thermal manifestation areas became sulfate water in 2012 because of additional magmatic volatiles such as HCl gas condense at altitude 1,000 - 1100 m a.s.l. (lower altitude) and H_2S gas condense at the altitude 1,700 - 800 m a.s.l. (higher altitude).

The result of this study shows that although exploitation of geothermal energy has not yet been carried out in Tangkuban Perahu geothermal prospect, the surface manifestations have already experienced chemical changes due to natural factors such as volcanic activity.

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