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Characterising Geothermal System of the Tampomas Area, West Java, Indonesia by Water Chemistry and Stable Isotope Analyses

Yudi Rahayudin[1,2], Koki Kashiwaya[1], Yohei Tada[1], Katsuaki Koike[1], Irwan Iskandar[3], Andi Susmanto[2]

1. Graduate School of Engineering, Kyoto University, Japan
2. Ministry of Energy and Mineral Resources, Republic of Indonesia
3. Faculty of Mining and Petroleum Engineering, Institute of Technology Bandung, Indonesia

E-mail: yudi.rahayudin.28w@st.kyoto-u.ac.jp; yudi.rahayudin@esdm.go.id

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ABSTRACT

The Tampomas geothermal area is located at 42 km northeast of the Bandung basin, West Java, Indonesia and seated in the intra-volcanic basin by the Indonesian subduction system. This study aims to clarify the geothermal system and resource potential of the Tampomas geothermal area. Dominant directions of fractures, northeast and northwest, inferred from the lineament data are in agreement with the regional pattern of west Java structure. The fluid path from the geothermal reservoir to the surface may be formed in the high-density zone of fractures in the north-eastern part. The hot spring manifestations are situated in the transition domain between the geothermal water and groundwater, and their waters are mostly Cl-HCO_3 type originated from the mixing of Cl water with the groundwater or HCO_3 water in the flow process. The $\delta^{13}C$ (CO_2) stable isotope data suggest CO_2 origins are magmatic and marine bicarbonate, while the source of geothermal fluids is meteoric water indicated by the $\delta^{18}O$ and deuterium isotope data. Furthermore, the subsurface temperature in the Tampomas geothermal area is estimated in the range from 142 to 167 ºC by a silica geothermometer. Consequently, the study area is classified as medium enthalpy geothermal system.

1. INTRODUCTION

Tampomas geothermal area, located 42 km north-eastern of the Bandung basin, West Java Indonesia, is a volcanic mountain range that was formed as a result of the subduction activity between the Eurasian and Indian-Australian plates (Fig 1). Tampomas geothermal field is seated in the northern part of Bandung Basin, one of the highest geothermal potential areas in Indonesia. The geothermal potential in the northern Bandung basin is estimated to be lower than the southern basin, including Tampomas. This area is located in the mountain ranges of Java, with marine sedimentary rock as a basement. The geochemical analysis was applied to investigate the trace of sediment influence in geothermal water.

Many hot spring manifestations appear on the ground throughout the depression and faulting zones, generally at the eastern slopes of Mt. Tampomas, which indicates the occurrence of geothermal and magmatic subsurface processes. However, the geothermal system in the Tampomas area has not yet been clarified. This study aims to clarify the geothermal system and geothermal fluids features in the Tampomas geothermal area by detailed water and isotope investigations using geothermal water samples and a Hg map by a preceding exploration.

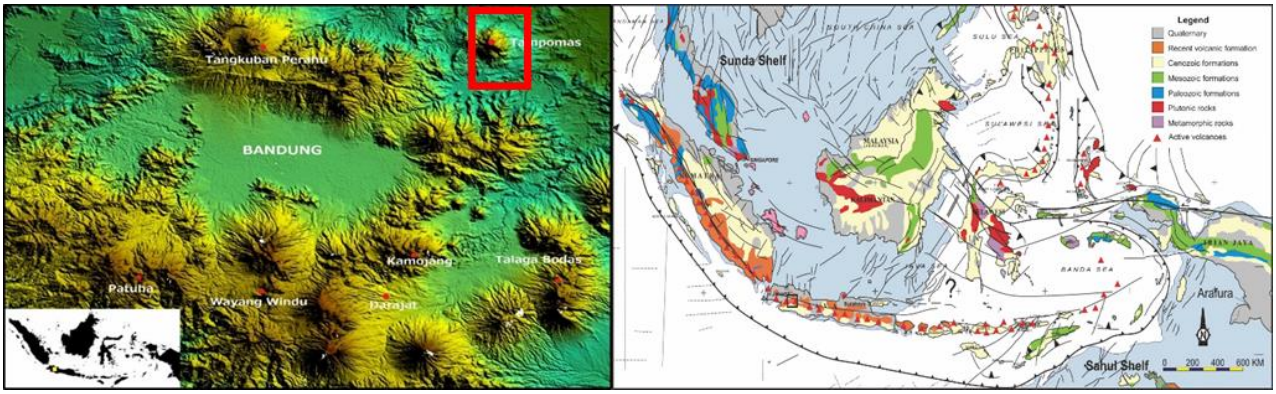

Figure. 1. Tampomas geothermal area located in the northeast of Bandung, Indonesia (left) and schematic geologic structures of the Indonesia arc showing the main tectonic structure (right). The subduction between Eurasian and Indian-Australian plates is a primary control factor of the Java volcanism (Darman and Sidi, 2000).

2. GEOLOGIC SETTING

Based on the physiography zone of Java island (Bemmelen, 1949), Tampomas geothermal area belongs to the Bogor zone and accompanies the Quaternary volcanic activities such as Mt. Salak, Mt. Gede, and Mt. Tangkuban Perahu. During the Plio-Pleistocene, the northern part of West Java basin was folded and faulted along with this volcanic system and the Tambakan formation was deposited as well as the andesitic intrusion of Mt. Geulis. Moreover, a series of fault zones, a part of the Baribis faults lane, was developed in the northern part of Tampomas.

According to the geological map of Bandung and Arjawinangun (GRDC, 2003; 2011) (Fig. 2), the Tertiary sedimentary deposit is the oldest rock and underlies the volcanic rock complex. Subang (Upper Miocene), Kaliwangu (Lower Pliocene), and Citalang Formations (Middle Pliocene) are major sedimentary rocks whose structures have been directly affected by the faulting and folding. The sedimentary rocks generally strike NW-SE and dip southward. The oldest sediment is the Subang Formation (Miocene), dominated by claystone and in some areas laminated by limestone and glauconite sandstone.

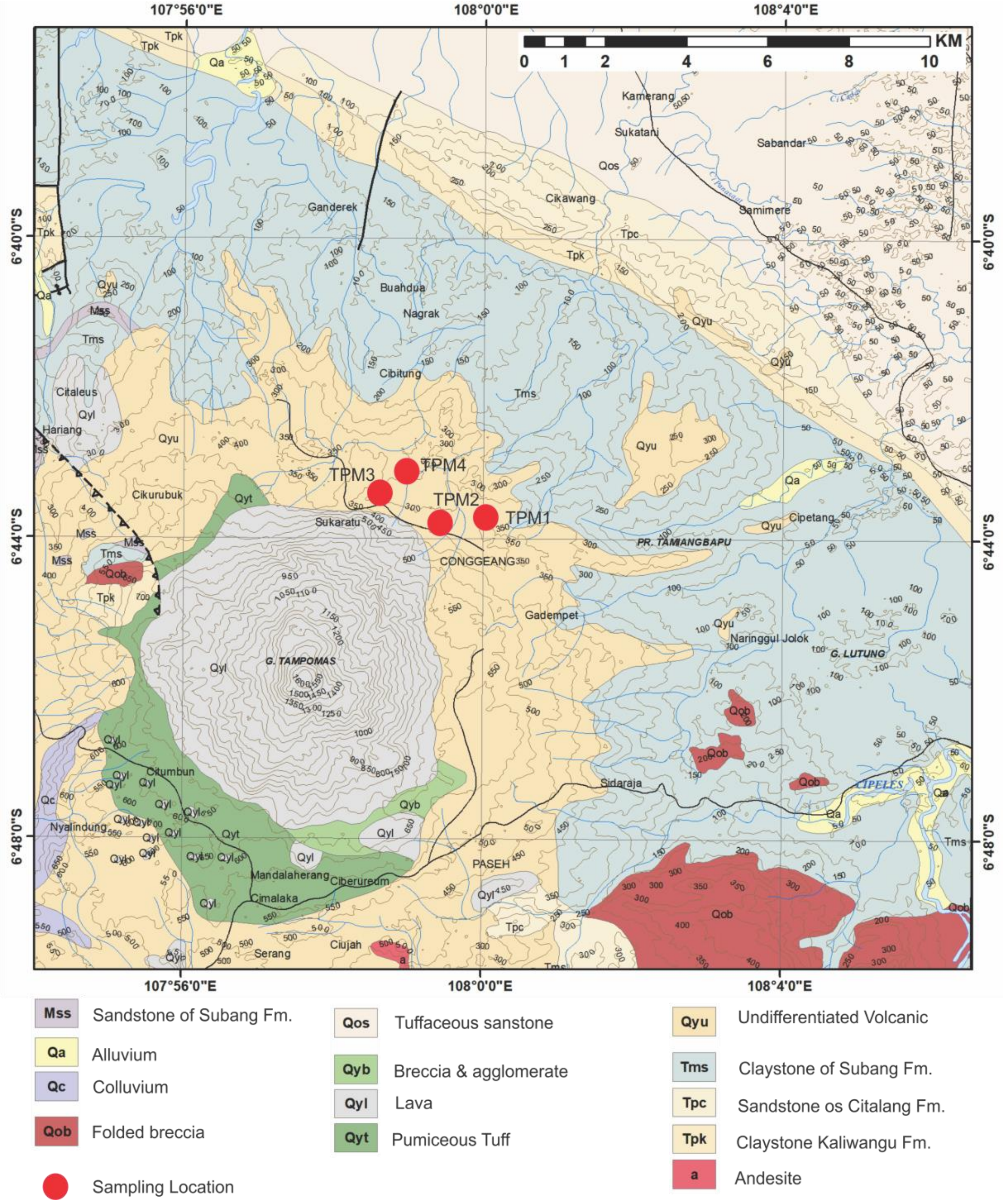

Figure 2. Sampling locations and geological map of the Tampomas geothermal area, dominated by sedimentary rocks of the Subang Formation (modified from GRDC, 2003; 2011)

3. SAMPLING AND METHODS

At first geologic structure of the Tampomas geothermal area was characterised from a fracture system using a lineament analysis with digital elevation model (DEM) data and computer-aided lineament extraction method, LINeament Detection and Analysis (LINDA: Masoud and Koike, 2017). Water samples were collected for major ion, stable isotope ($\delta^{18}O$, δD and $\delta^{13}C$). Samplings were carried out close to the outlet or source of springs (Fig. 2). To prevent algal growth that could remove Mg, NH_3, and SO_4 from the samples as well as clogging in analytical tools, water samples were filtered using 0.45 μm syringe filter and then, acidified and stored in clean and sealed polyethylene bottles. The sampling of anion and cation followed the standard procedures of Clark (1995) and Arnorsson et al. (2006).

Water samples for the $\delta^{18}O$-H_2O and δD-H_2O analyses were collected directly from the geothermal manifestations to minimise the contact with atmospheric air and wells and then, kept away from direct sunlight to avoid evaporation that may cause changes in the stable isotope of the samples. The procedure of Fahlquist and Janik (1992) was used for the sampling and measurement of ^{13}C DIC. The results of isotope analyses are expressed in "delta notation" relative to PDB for carbon and the VSMOW standard for oxygen and deuterium.

4. RESULTS AND DISCUSSIONS

Lineaments that correspond with fractures induce deeper weathering than the surroundings and act as paths for water infiltration and groundwater flow (Magaia et al., 2017). Lineaments extracted trend dominantly NE and NW as shown in Figure 3. These directions are concordant with those of the major faults in western Java (Hariyanto, 2013) and a feature that the NE lineaments are longer than NW is also correspondent with the fault feature in the study area (MEMR, 2007). Fluid paths from the reservoir to the surface are thought to be formed in the high-density zones of lineaments situated in the north-eastern and northern sides of the peak of Mt. Tampomas.

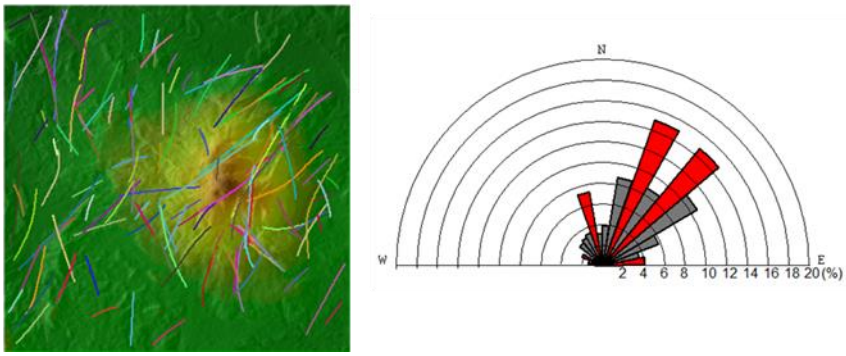

Figure. 3. Lineaments extracted from DEM (left) and a rose diagram of their directions (right).

The concentrations of Hg in soils (MEMR, 2007) and 222Rn in soil gases (Iskandar et al., 2018), were measured to be relatively high along with the NE and E-W directions (Fig. 4), which supports important of the fractures of these directions as a fluid path. The high concentration of Hg (3,650 to 5,300 ppb) extends over 2.5 km^2 in the northern part of Mt. Tampomas. Hg is generally concentrated in the vapours in the topsoils of the geothermal system and absorbed by organic materials and clay minerals. High 222Rn concentrations generally occur in fault zones and thermal anomaly (Koike et al., 2014).

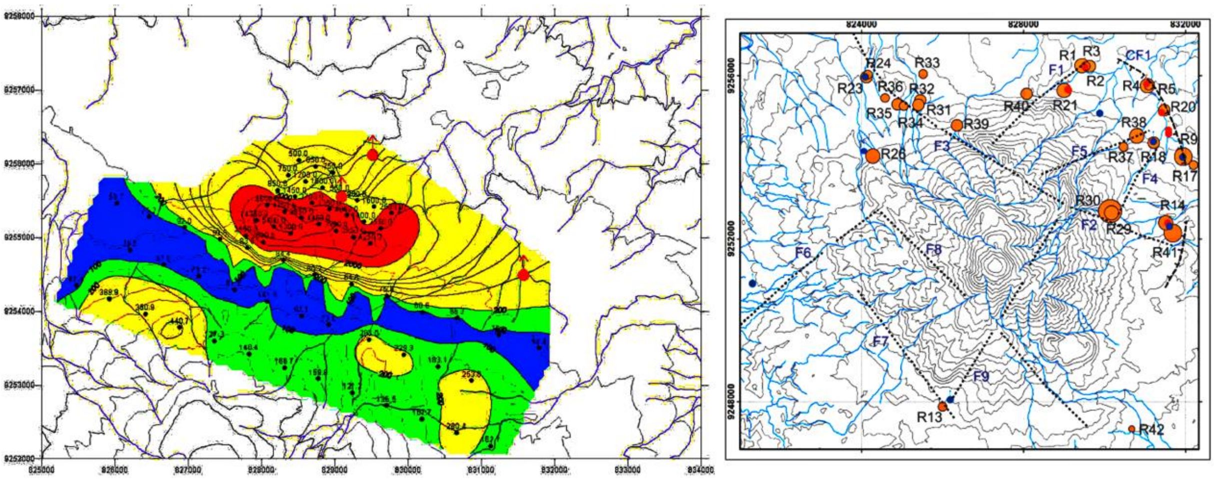

Figure. 4. Hg concentrations in soils showing high concentration zone in the north-eastern part of the study area (left; MEMR, 2007) and ^{222}Rn concentrations in soil gas (right: Iskandar et al., 2018)

Physical and chemical properties of water were influenced by the concentration of dissolved components, the residence time of the water in the evolution, the migration depth, and rock-water interactions (Chenaker et al., 2018). The water samples showed heterogeneous physicochemical features (Table 1) with a relatively neutral pH between 5.8 and 5.9. The major cation and anion are Na and HCO_3, respectively (Fig. 5). The most common water type in the deep part of the geothermal system is near-neutral pH with Cl as the dominant anion (Fournier, 1987; Nicholson, 1993). The solutes of geothermal water could be variable by water sources and the reaction between the water and host rocks when Cl water ascends from the reservoir to the surface. Cl, H_2SO_4, and HCO_3 are the three major and most frequently analysed anions of geothermal water (Giggenbach, 1997). Based on the ionic composition of HCO_3-Cl-SO_4 (Giggenbach, 1988), water geochemistry is plotted on the ternary diagram (Fig. 5). The result shows that the water chemistry is dominated by Cl-HCO_3 type that was developed by dilution of Cl water with the groundwater during the flowing process. Typically, major cation in the HCO_3 water is Na, as seen at TPM1, TPM2, and TPM3. The high Na, HCO_3, and Cl contents suggest an increase in the water residence time which could advance the water-rock interaction. High HCO_3 concentration in the geothermal manifestations is also due to the reaction of circulating meteoric waters with limestone, forming CO_2-rich waters, and also possibly from the mixture of magmatic water (Pasvanoğlu and Çelik, 2018).

Table 1. Chemical compositions of water samples.

Name	pH	Li (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	SiO2 (mg/L)	B (mg/L)	Cl (mg/L)	F (mg/L)	SO4 (mg/L)	HCO3 (mg/L)	NH4 (mg/L)
TPM1	5.8	16.9	6029.0	159.8	211.8	162.2	122.0	69.2	10850.0	0.00	6.1	1247.9	37.9
TPM2	5.9	0.9	290.7	17.1	55.4	32.2	147.8	5.6	487.0	0.01	0.0	598.0	2.1
TPM3	5.9	0.5	136.7	13.8	83.5	57.8	60.9	2.2	115.5	0.10	0.0	1037.3	1.6
TPM4	5.8	1.7	209.4	22.2	69.3	36.2	179.3	4.9	158.6	0.00	7.0	190.9	1.2

TPM1 is in the area with Cl water type that generally occurs in deep fluids of high-temperature system. At TPM1 site, the high Cl is not possibly caused by geothermal activity but may be the product of connate water trapped during the claystone sedimentation, and the Na concentration has been affected by a hydrolysis reaction or chemical weathering process of feldspar in the Tertiary Subang Formation (Rahayudin et al., 2018). Leaching of marine sediments can cause high Boron concentration (69.2 mg/L) in this location.

Furthermore, the $\delta^{13}C$ (CO2), stable isotopes value, ranging from -5.04 to -5.80 ‰, indicate the magmatic CO^2 and marine bicarbonate origins. Because the water isotopes in the study area are close to the meteoric water line (Rahayudin et al., 2018), meteoric water is a source of the geothermal fluids. Some data showed the negative shifting of $\delta^{18}O$ by seasonal water cycle (Belgaman et al., 2017; Suwarman et al., 2013) or likely produced by an isotope exchange between water and CO_2.

Subsurface reservoir temperature is estimated using a water geothermometer. Because of the conditions of geothermal water with high Ca and Mg, low surface water temperature, and the small spring discharge, a silica geothermometer was applied, and the temperature ranging 142 to 162 ºC was estimated. Consequently, the study area is classified as medium temperature/enthalpy geothermal system.

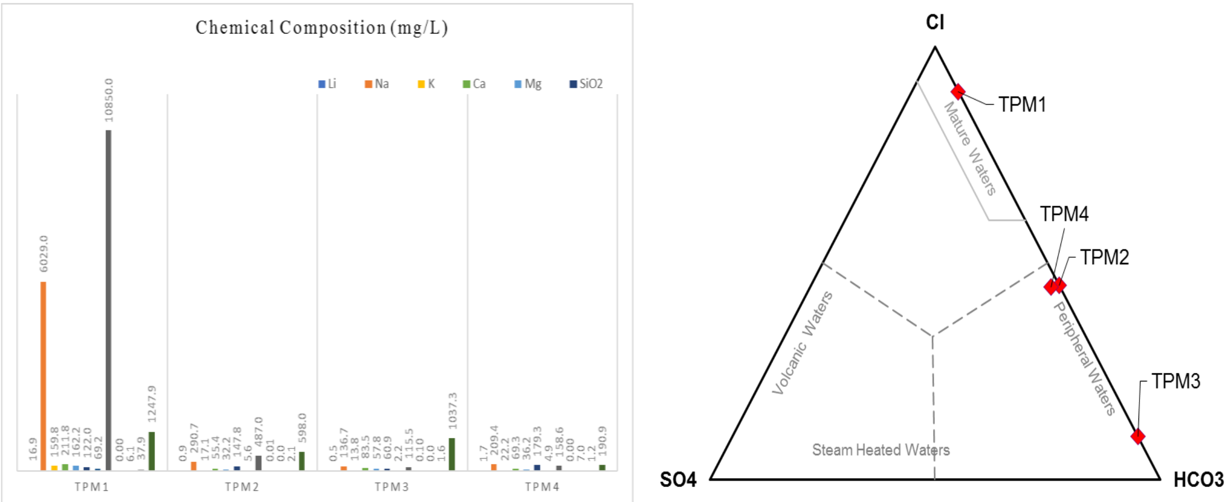

Figure. 5. Chemical compositions of water samples (left) and HCO3-SO4-Cl diagram showing the ionic composition of water manifestation, dominated by Cl-HCO_3 type (right).

4. CONCLUSION

The Hg and 222Rn concentrations were relatively high along with the NE and E-W directions agreeable with the zones of high lineament density. Geothermal fluid paths from the reservoir to the surface may be formed in these zones. In general, the geothermal waters in the Tampomas geothermal area are Cl-HCO_3 type, originated from the mixing of Cl water with the groundwater during the flow process. Water isotope data revealed that the meteoric water was a source of geothermal fluids, with partly influence of magmatic and marine bicarbonate as indicated by the carbon isotope data.

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