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Gas Origin and Fluid Circulation Regimes Interpreted from Gas Geochemistry in Geothermal Areas around the Bandung Basin, Indonesia

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ABSTRACT

Understanding origin and circulation regime of geothermal fluid in geothermal systems is essential to achieve sustainable utilization of geothermal energy. Gas samples were collected from fumaroles and hot springs in three geothermal areas (Patuha, Tangkuban Perahu, and Tampomas) around the Bandung Basin, west Java, Indonesia. The bulk gas concentrations, noble gas isotope ratios ($^3He/^4He$ and $^4He/^{20}Ne$) and carbon isotope ratios of CO_2 and CH_4 were analyzed to estimate origin of the gas components and circulation regimes of geothermal fluids.

Measured noble gas isotope ratios indicated that mantle-source He was dominant in almost all the samples. Mixing ratios of crustal-sourced He were relatively higher in the geothermal areas located in southern side of the basin (Patuha) compared to the areas in northern side (Tangkuban Perahu and Tampomas). Carbon isotope ratios of CO_2 and CH_4 also showed that the gases of the northerly areas are relatively nearer to MORB type compared to the gases from the southerly areas. These gas origins may indicate recharge of fluid that has longer residence time in the crust and/or a longer or slower circulation of geothermal fluid in the southerly fields, meanwhile gas from volcanic systems in the northern areas has less contribution of crustal gas sources.

1. INTRODUCTION

Geothermal energy is a kind of renewable energy and its utilization is expected to decrease CO_2 emissions and global warming. In conventional geothermal power generation, steam and/or hot water in a reservoir is withdrawn at production wells and electricity is generated by rotating a turbine connected to a generator. Steam production needs to be appropriately managed for long term use of a geothermal system, and thus information about the geothermal system is essential for the sustainable use of geothermal energy. Particularly, understanding the origin of geothermal fluids is important to interpret the circulation regime. This study aims to estimate origins of geothermal gases in geothermal areas distributed around the Bandung Basinin in Indonesia and from this, interpret circulation regimes of fluid in the geothermal areas.

2. STUDY SITE

Gas samples were collected in three geothermal areas, Patuha, Tangkuban Perahu, and Tampomas, around the Bandung Basin, west Java, Indonesia. Patuha is located in approximately 30 km south-west of Bandung. Fumaroles, hot springs, and cold gas discharges are known surface manifestations in this area (Layman and Soemarinda, 2003). Patuha geothermal power plant (55 MWe) is operated by PT Geo Dipa Energi. The samples were collected in Cibuni crater and Ciwidey crater, located respectively on the western and eastern side of Mt. Patuha. Many active discharges of hot water and fumarolic gas can be found in Cibuni crater and gas sample was collected from one of the fumaroles. Gas sample was taken from a bubbling pool in Ciwidey crater. Tangkuban Perahu is approximately 20 km north from Bandung. This geothermal area is associated with Mt. Tangkuban Perahu, and surface manifestations such as fumaroles, solfatara, and hot springs are reported (Nasution et al., 2004). The samples were collected from a fumarole in Domas crater and hot spring in Ciracas. Domas crater is located in eastern side of peak of Mt. Tangkuban Perahu and fumaroles and hot springs are found across in bare ground. Ciracas is in north-northwest from the Domas crater and discharge points of hot water and gas can be found in rice paddy field. Tampomas area is approximately 40 km northeast from Bandung. The samples were collected in two hot springs, Sekarwangi and Cileungsing. In Sekarwangi, hot water and gas discharges in a pool and the free gas was collected. In Cileungsing, free gas was collected from a hole at thefoot of a tree where hot water and gas discharges. Other discharge points were also found around the sampled point, where hot water discharge and strong bubbling on river bed were found.

3. METHODS

Gas samples were collected using bottles similar to the doubleport bottles in Fahlquist and Janik (1992). 50 mL of 4M NaOH solutions was poured into the washed and dried bottle and the bottle was evacuated using a rotary pump. At the sampling point, the bottle was connected to a tube from which sample gas discharged and the gas was collected by opening a valve on the bottle. In the bottle, N_2, O_2, H_2, He, Ne, Ar, and hydrocarbons are mainly partitioned to headspace gas and H_2O, CO_2, H_2S, NH_3 condenses or dissolves to the caustic solution. Two bottles were taken at one sampling point to determine gas composition with gas chromatography using He carrier and Ar carrier. The bottles were transferred to the laboratory and connected to a sample introduction line of a gas chromatograph system (GC-2014, Shimadzu Corporation). The line was evacuated by a rotary pump and the sample gas in the bottle was expanded to the line. Pressure in the line was measured with a pressure gage on the line and a part of the gas was taken in loops with known inner volumes. . The gas in the loops was introduced into a gas chromatograph equipped with thermal conductivity detector and flame ionization detector. Following H_2, O_2 and He measurement using Ar carrier gas, part of the gas sample was transferred from the bottle to a stainless-steel sample cylinder for noble gas and carbon isotope analyses. N_2, Ne, Ar, and hydrocarbons

were measured using He carrier gas. CO_2 was quantified using a titration method (Nicholson, 1993) with a sulfuric acid solution. Noble gas isotope ratios were determined using a noble gas isotope ratio mass spectrometry system. The sample cylinder was connected to the gas purification line of the system. Water and other reactive gases were removed. The purified gas was introduced to a noble gas isotope ratio mass spectrometer (VG5400, GV instruments) and isotope ratios ($^3He/^4He$ and $^4He/^{20}Ne$) were determined. Carbon isotope ratios of CH_4 ($\delta^{13}C–CH_4$) were measured using the gas in the sample cylinder. Because pressure in the cylinder was lower than atmospheric pressure, He gas was injected into the cylinder to elevate the pressure above atmospheric pressure. The sample gas was taken with a gas tight syringe and injected to an isotope ratio mass spectrometer equipped with a gas chromatograph (Delta V advantage and GC IsoLink II, Thermo Fischer Scientific: GC-IRMS). The carbon isotope ratios of CO_2 ($\delta^{13}C–CO_2$) were determined by analyzing CO_2 dissolved in the caustic solution. Part of the caustic solution was transferred to a vial and sealed, and the headspace was replaced with He gas. Heated phosphoric acid was added to the caustic solution in the vial and degassed CO_2 was injected into the GC-IRMS system using a gas tight syringe.

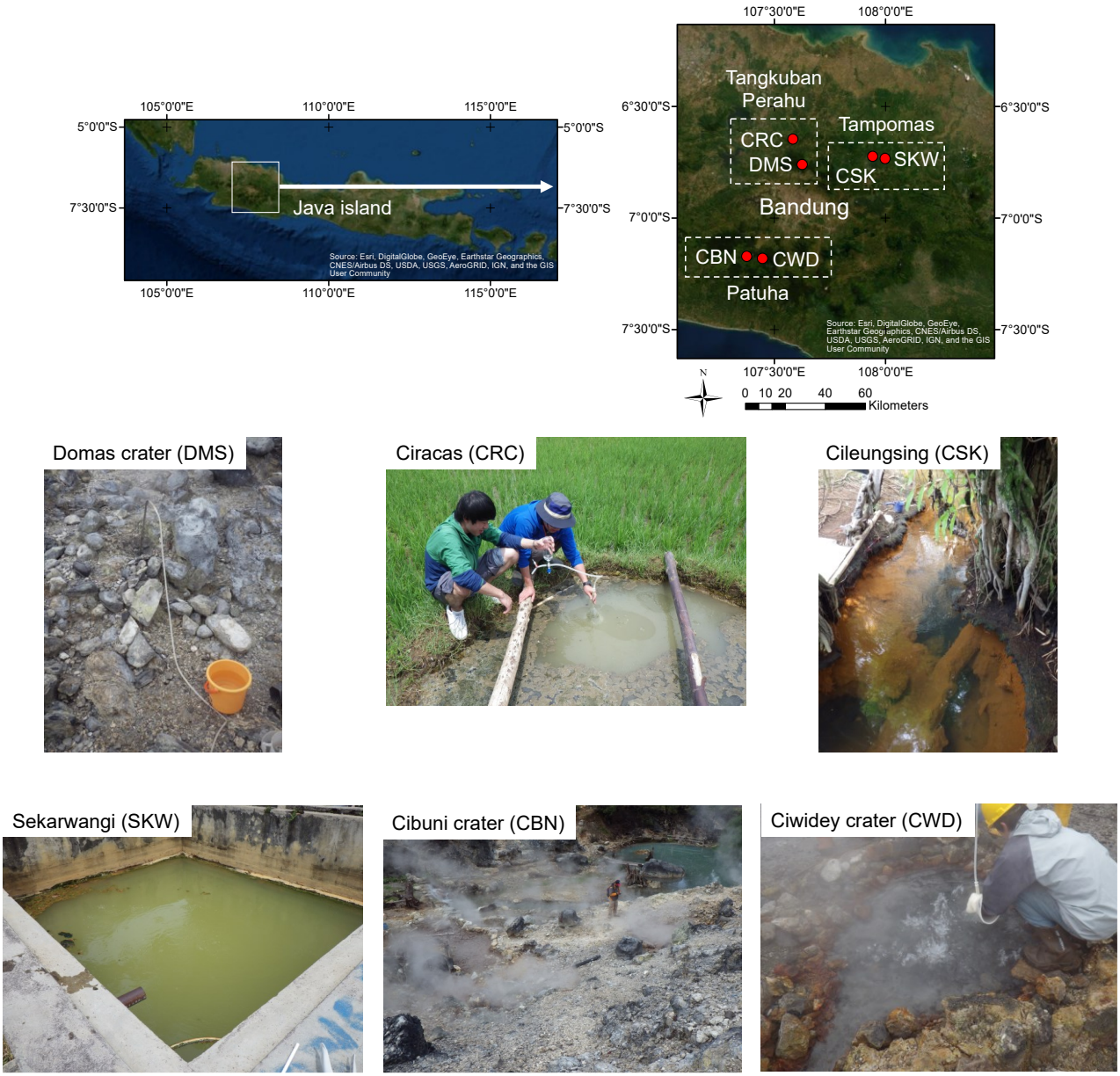

Figure 1: Gas sampling points in this study.

4. RESULTS AND DISCUSSIONS

Ternary diagrams of N_2–Ar–He and N_2–Ar–CO_2 are presented as Figure 2. In the both diagrams, the samples from Patuha and Tangkuban Perahu are distributed between the lines of N_2/Ar ratios corresponding to magmatic gas and air or atmospheric saturated water (ASW). CBN and DMS have N_2/Ar ratios between magmatic gas and air. These two points were both collected from active fumaroles in the craters and thus these compositions can be explained by mixing of air into magmatic gas. CRC and CWD are plotted between lines of air and ASW. These were collected as free gas in a hot spring or gas discharged in a bubbling hot spring. Their water surfaces are exposed to atmosphere. Therefore concentrations of major gas components were likely to be influenced by equilibrium with atmospheric air, although apparent signature of magmatic gas was recognized in He and C isotopes as will be discussed later. Considering the temperature dependency of gas solubilities, the N_2/Ar ratio of dissolved gas increases with temperature. This implies

that N_2/Ar of free gas decreases with an increase in temperature. The low N_2/Ar ratio of CSK may be caused by equilibration in temperatures that are higher than those of ASW.

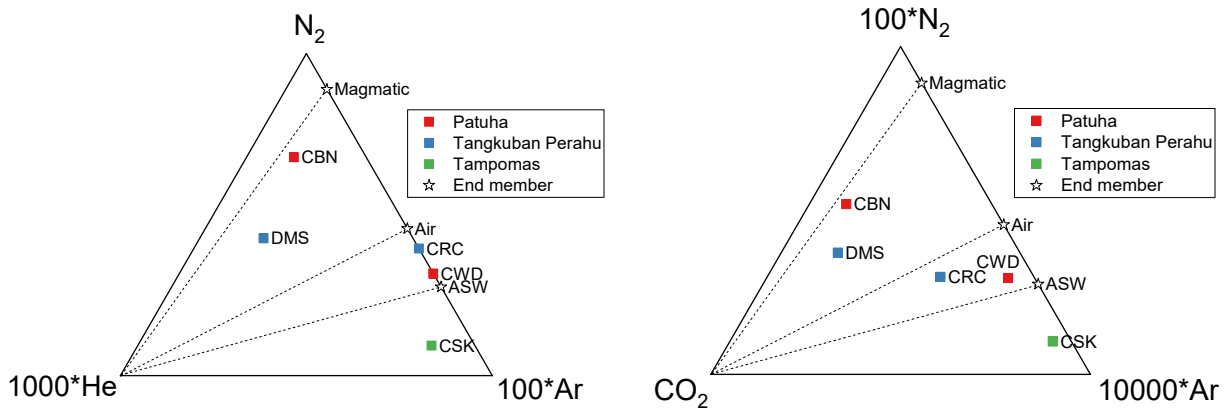

Figure 2: Ternary diagrams showing concentration ratios of N_2–Ar–He and N_2–Ar–CO_2 of the gas samples. ASW is abbreviation of atmosphere saturated water. He was not detected in CRC and CWD in the GC analysis. The end members show only N_2/Ar ratios and their He and CO_2 concentrations were not considered here.

Measured ^{3}He/^{4}He and ^{4}He/^{20}Ne ratios of the samples are presented in Figure 3, together with mixing lines of ASW and mantle source He or crustal He. All samples plot around the mixing lines between ASW and mantle He. Mixing ratios calculated from the ratios (right figure of Figure 3) shows that He in the samples are mainly sourced from mantle He and crustal He. Not only fumarolic gas but also free gas in the northern geothermal areas (DMS, CSK, SKW) have higher ^{3}He/^{4}He ratio than the fumarolic gas and bubbling gas in hotspring in the southern area (CBN and CWD) except for CRC. Meanwhile, ^{4}He/^{20}Ne is dependent on style of gas discharge (fumarole or hot spring) and gases from hot springs (CRC, CWD, CSK, SKW) have lower ^{4}He/^{20}Ne ratios than the fumarolic gases (DMS and CBN). These low ^{4}He/^{20}Ne ratios indicates that these samples were influenced by atmospheric air and it is consistent with the N_2/Ar ratios of the samples.

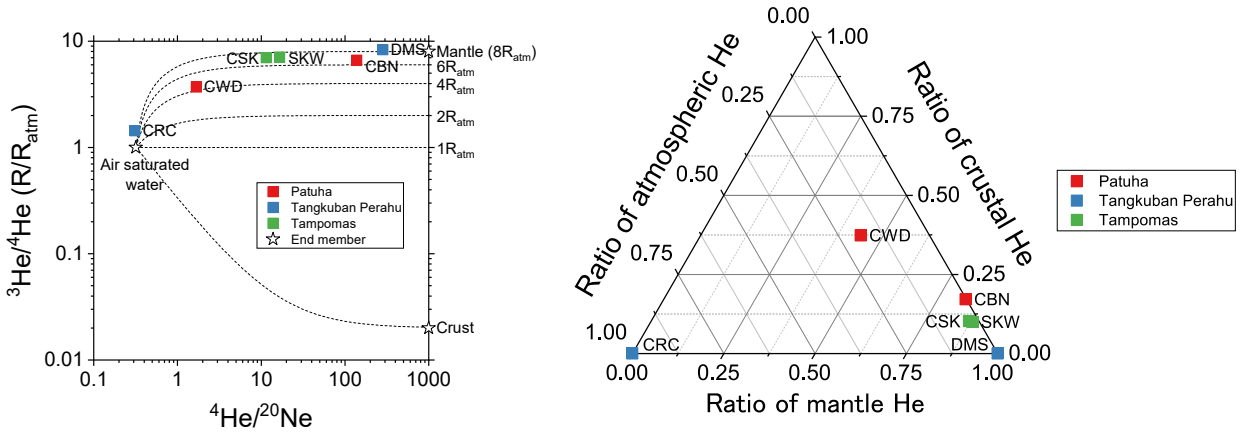

Figure 3: Measured noble gas isotope ratios of the gas samples (left) and mixing ratios of He estimated from the isotope ratios (right). In the right figure, He in DMS was regarded as all mantle He because the measured ^{3}He/^{4}He ratio was higher than the ratio of mantle He (8 R_{atm}). Similarly, He in CRC was regarded as all atmospheric origin because ^{4}He/^{20}Ne ratio of the CRC was lower than ASW.

Relationships of δ^{13}C–CO_2 and CO_2/^{3}He ratio (Figure 4) indicated that the gas collected in the northern geothermal areas (DMS, SKW, CSK) were nearer to MORB type than the gas collected in the southern area (CBN), although the gas samples from hot springs may be influenced by fractionation as indicated by Sano and Marty (1995). δ^{13}C-CH_4 also implied that CH_4 in gas samples from the northern areas show compositions similar to gases discharging from mid-oceanic ridges. The samples from the southern area were plotted in/around regions corresponding to thermogenic and sediment-covered ridge types (Figure 5).

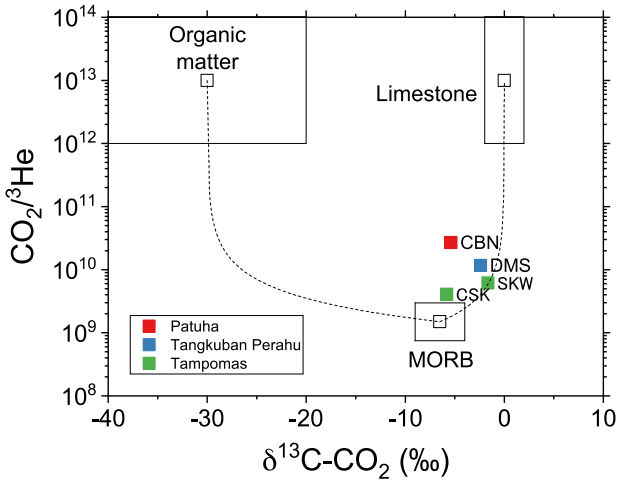

Figure 4: Relationships of $\delta^{13}C$–CO_2 and $CO_2/^3He$ ratios of the gas samples. The ranges of the endmembers were referred from Sano and Marty (1995).

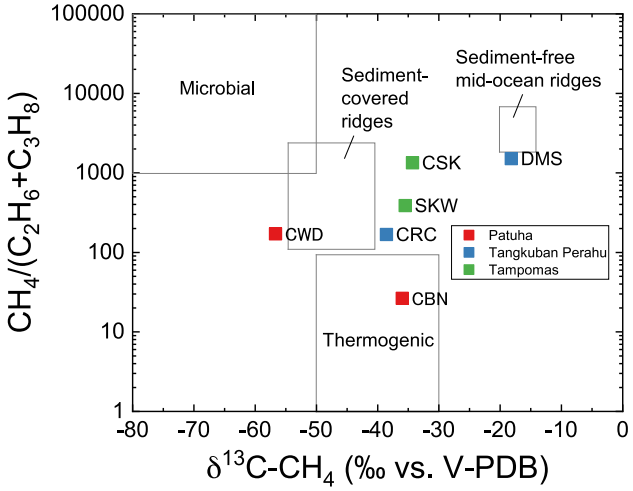

Figure 5: Relationships of $\delta^{13}C$–CH_4 and $CH_4/(C_2H_6+C_3H_8)$ ratio of the gas samples. The ranges of microbial, thermogenic gases and ridge gas compositions were drawn from Agusto et al. (2013) based on McCollom and Seewald (2007) and references in McCollom and Seewald (2007).

The results indicate that origin and formation processes of the gas components are different between the northern and southern geothermal areas. The fraction of deep (mantle) source gas was higher in the gases in the northern geothermal areas. Gas supplied from magmatic source is from relatively focused discharge points at the manifestations and thus the influence of gases formed in the crust is limited in the northern areas, although influence of air was recognized in the free gas samples. Meanwhile, the fraction of gas supplied from relatively shallow (crustal) sources is greater in the samples collected in the southern geothermal areas. Agusto *et al.* (2013) interpreted that locally low $^3He/^4He$ ratio in fumarolic gas was caused by permeation of fluid depleted in ^3He. The results in this study may also reflect circulation regimes of geothermal fluids in the areas. In particular, the results of the southern geothermal area imply recharge with fluid that has a longer residence time in the crust and/or longer circulation of the geothermal fluids themselves in the crust.

5. CONCLUSIONS

Gas samples were collected in fumaroles and hot springs in the geothermal areas around the Bandung Basin and their origins were estimated based on their bulk gas concentrations and isotope compositions. Fraction of deep source gas was higher in the northern geothermal areas and the difference of gas origin reflects difference of circulation regimes of geothermal fluid between the northern and the southern geothermal areas. The gases in the northern manifestations are directly supplied from magmatic source and fraction of crustal source gas is lower. Meanwhile, the results of the southern geothermal area presumably indicate recharge of fluid that has longer residence times in the crust and/or longer circulation of the geothermal fluids in the crust.

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