Hydrogeochemistry of Thermal Water from Surface Manifestation at Gunung Ciremai and Its Surrounding, Cirebon, West Java – Indonesia

Niniek Rina Herdianita, Tri Julinawati and Indah Edria Amorita

Study Program of Geology
Faculty of Earth Science and Technology (FITB)
Bandung Institute of Technology (ITB).
Jl. Ganesa 10 Bandung 40125 – Indonesia.

herdianita@gc.itb.ac.id

Keywords: Ciremai, geothermal, Gunung Kromong, hydrogeochemistry, surface manifestation.

ABSTRACT

Gunung Ciremai has a parasite cone of Gunung Kromong. In this area, there are several surface geothermal manifestations having different physical and chemical characteristics, i.e. as hot springs, hot pool and *kaipohan*.

Results on water chemistry and stable isotope of $\delta^{18}O$ and δD indicate that the origin of thermal fluid in the research area is meteoric water. The water has been heated by volcano-magmatic activity of Gunung Ciremai. Within reservoir, the thermal fluid then boils at temperature of no more than 210°C. Hot water then flow laterally through the surface as chloride water appearing at Gunung Kromong and flank of Ciremai, whereas steam fraction continuously discharges and condensates into groundwater and surface water at high elevation. Consequently, sulfate and bicarbonate water are formed.

1. INTRODUCTION

Gunung Ciremai has a parasite cone located at north flank namely Gunung Kromong. It is located about 30 km southwest of Cirebon or about 100 km east of Bandung (Figure 1). There are several geothermal surface manifestations appearing in Gunung Ciremai, including Gunung Kromong and its surrounding. The type and characteristics of manifestation in Gunung Kromong are different, but have a similar origin of Ciremai geothermal field (Pertamina, 1985).

Sub surface hydrogeochemical pattern of thermal water can be well understood based on the geothermal surface manifestation, i.e. characteristics of hotspring and surface hydrothermal alteration (cf. Hochstein and Browne, 2000; and Browne, 1978). Knowing its pattern, the geothermal system including heatflow, reservoir, upflow and outflow can be known. Therefore, detail investigation and further development of geothermal energy can optimally be done.

This study investigated the Gunung Kromong geothermal system and its surrounding in West Java, and was done at the surface condition through rock alteration and discharge of hotspring, steaming ground, *kaipohan*, fumaroles and mud pool. Furthermore, the condition of geothermal system was understood. This study also answered the relationship between the Gunung Kromong geothermal system and the active volcano of Ciremai.

2. GEOLOGY AND SURFACE MANIFESTATION

Gunung Kromong is one of volcanic cone in the study area. It has morphology with steep slope and elevation of 400 to 450 m. Other cones occur at south of Gunung Kromong including Gunung Kuda, Gunung Jajar, and Gunung Goong. Alluvial plains cover areas within the volcanic cones and mainly are used as rice paddy and village.

Following van Bemmelen (1949), the physiographic of the study area is included to the area where is influenced by Quaternary volcano of Ciremai. The study area also lies at the boundary of Bogor Zone. It seems that sedimentary rocks of Bogor Zone are basement of Gunung Kromong and its active volcanoes.

Geology of Gunung Kromong and its surrounding is dominated by Quaternary volcanic rocks overlying Tertiary sedimentary rocks (Djuri, 1973). The basement is a part of Bogor Zone and consists of sandstone and shale of Cinambo Formation having age of Oligocene, limestone of Kromong Complex having age of Miocene, and Pliocene conglomerate and claystone of Kaliwangu Formation (Djuri, 1973). Andesitic intrusions occur at the study area and form volcanic cones (Djuri, 1973). Geological structures in the study area are local as a result of Ciremai activity. These structures are NE-SW and NW-SE normal faults, young and control the appearance of hotsprings in the study area (Djuri, 1973).

Five geothermal surface manifestations were identified in this study, i.e. Palimanan, Gunung Kuda, Cipanas, Kedondong and Liang Panas hotsprings. Location and some direct field measurements are given in Figure 1 and Table 1.

Surface manifestation of Palimanan is located about 3 km SW the Palimanan residential area or at a limestone quarry in westside road of the cement industry. The manifestation covers area of about 50 km^2 having several and discharges different characteristics of thermal features. The temperature of thermal waters ranges between 51 and 56°C and pH of about 6.4 (Table 1). Water from the hottest spring was taken as sample of KR-1.

Thermal water also discharges inside the cement industry site as Palimanan 2 (KR-6). The discharge is a hot pool having area of about 4 x 5 m, temperature of 60°C, pH of 6.5 and conductivity of +48.0 MeV (Table 1). There are significant smell of H_2S gas flows and white travertine deposit around the discharge area.

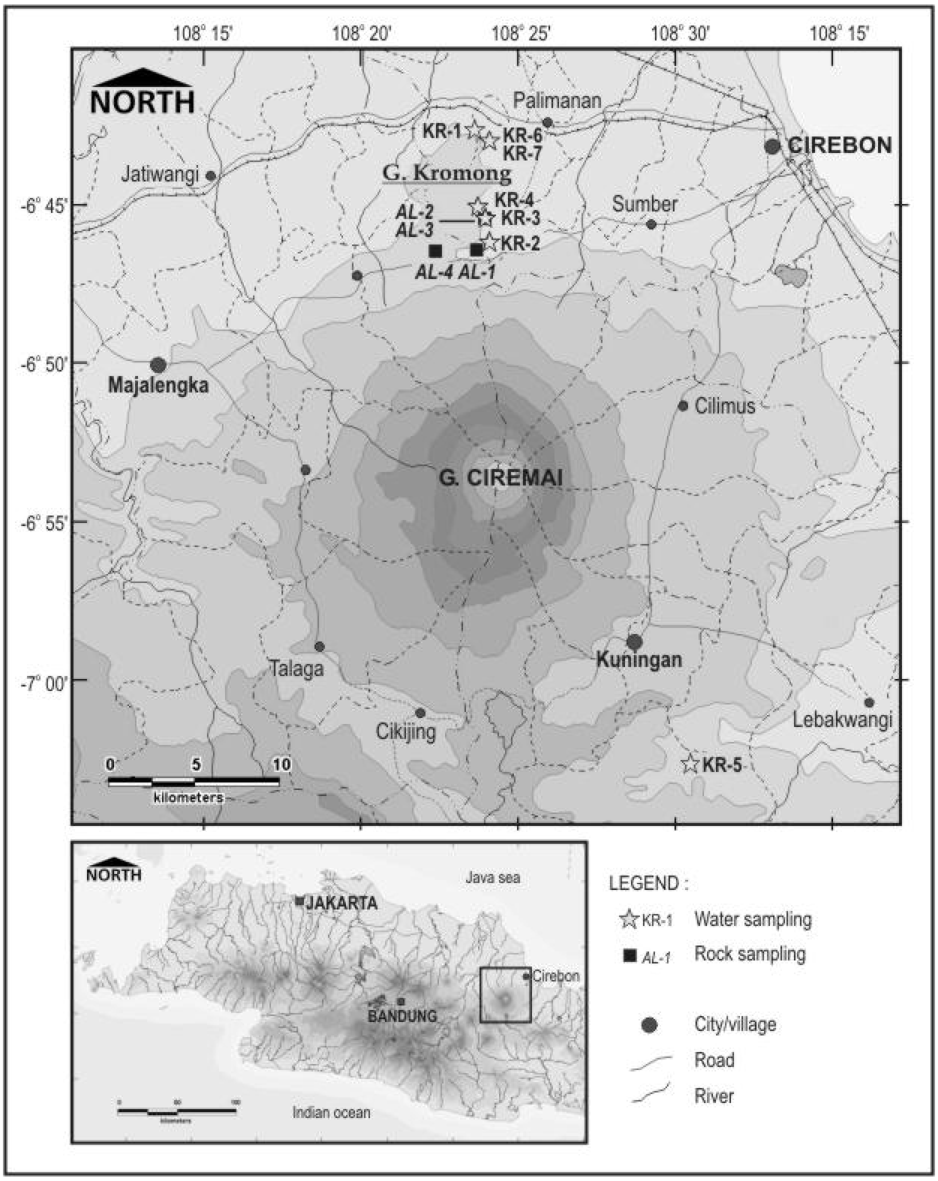

Figure 1. Location of geothermal surface manifestation in the study area, i.e. around Gunung Kromong and Gunung Ciremai, West Java.

Other hotsprings occur in Gunung Kuda (KR-2), Cipanas (KR-3), Kedondong (KR-4) and Liang Panas (KR-5). The temperatures of thermal waters are warm ranging from 36 to 38°C and pH of about 6, except water from Cipanas which has pH of 2.6. At Cipanas, *kaipohan* forms as about 15 x 20 m area with strong gases diffuse of sulphuric mixed with organic gases, dead vegetation and strong argillic alteration. The temperature of soil is 34.6°C.

3. CHEMICAL COMPOSITION

3.1. Thermal Water

Result of water chemical analyses is given at Table 2. It shows that the thermal waters have total dissolved solid (TDS) of 477 to 10330 mg/L and electronegativity of 680 to 14800 μS/cm (Table 2).

Based on SiO_2 content, thermal waters in the study area can be grouped into two clusters, i.e. thermal water having SiO_2 between 27 and 72 mg/L and more than 100 mg/L (Table 2). The first group is represented by KR-1, KR-3 and KR-5, whereas the second group is KR-2 and KR-4. The different of SiO_2 contents can be resulted from the difference of thermal fluid type, but also can be due to interaction of water with different type of rocks. The amount of Cl varies up to 3000 mg/L (Table 2). The higher the values of TDS and electronegativity, thermal water will have higher amount of Cl. The relationship is not shown between the amounts of Cl and SiO_2 or SO_4 as shown previous study (*e.g*. Salvania and Nicholson, 1990; Herdianita and Priadi, 2008).

Thermal waters at the study area commonly have ion balance of less than 5%, except waters from Cipanas (KR-3) and Palimanan 6 (KR-6, Table 2). The chemical analyses of KR-3 and KR-6 show the unbalance between the amounts of cation and anion due to either the type of thermal water and its undergone processes or unreliable analyses. The unbalanced thermal water of KR-3 seems to be resulted from the first reason, but that of Palimanan water of KR-6 is due to poorly analyses. Therefore the analyses of KR-6 is rejected during interpretation and represented by thermal water of KR-1.

Tabel 1. Location of water samplings and result on direct field measurements of temperature, pH and conductivity. Sample KR-7 is a cold water. Samples were taken at the end of April 2008.

No.	Location	Sample no.	Coordinate		t (°C)	t_{air} (°C)	pH	Conductivity (MeV)	Flowrate (approx. in L/minute)
			S	E					
1	Palimanan 1	KR-1	06º 42' 35.7"	108º 23' 35.7"	55.9	34.0	6.4	+54.1	0.17
2	Palimanan 2	KR-6	06º 42' 56.0"	108º 24' 03.0"	60.0	29.2	6.5	+48.0	-
3	*Palimanan 3*	*KR-7*	*06º 42' 56.7"*	*108º 24' 03.7"*	*30.4*	*27.9*	*8.0*	*-38.0*	*0.33*
4	Gunung Kuda	KR-2	06º 46' 08.1"	108º 24' 03.6"	36.2	28.9	6.2	+63.0	0.33
5	Cipanas	KR-3	06º 45' 23.4"	108º 23' 56.4"	36.7	29.0	2.6	+244.6	-
6	Kedondong	KR-4	06º 44' 59.6"	108 º23' 42.0"	37.3	28.0	6.1	+63.5	0.33
7	Liang Panas	KR-5	07º 02' 36.6"	108º 30' 28.1"	36.3	23.4	6.4	+52.7	0.50

Table 2. Results on chemical and stable isotope analyses of hotsprings in the study area, calculations of ion balances, ratios of several elements for the geochemical interpretation, and geothermometers.

Sample no.	KR-1	KR-2	KR-3	KR-4	KR-5	KR-6	*KR-7*
Location	Palimanan	G.Kuda	Cipanas	Kedondon g	L. Panas	Palimanan	*Palimanan*
$pH_{(lab,25°C)}$	6.77	8.36	2.82	7.31	6.69	8.62	*7.83*
TDS (mg/L)	10330	958	818	477	9150	10100	*322*
Electronegativity (uS/cm)	14790	1317	1169	681	12980	14800	*460*
Concentration (mg/L)							
Ca^{2+}	15.72	9.82	14.14	26.72	13.36	31.43	*21.22*
Mg^{2+}	165.43	30.49	20.58	36.77	89.1	442.64	*38.65*
F	1.49	0.01	0.07	0.01	0.01	0.01	*0.01*
Na^{+}	1873.4	146.05	8.54	61.4	2269	2939.5	*18.42*
K^{+}	138.6	6.2	2.86	4.51	113.6	113.6	*2.5*
Fe	0.01	0.75	21.3	0.57	1.74	0.01	*0.02*
Mn	0.05	0.05	1.23	0.05	0.05	0.05	*0.05*
B	0.182	0.01	0.01	0.003	0.075	0.003	*0.003*
NH_4	14.351	0.417	0.079	0.285	0.844	12.382	*0.005*
SiO_2	27.29	128.7	43.3	104.25	71.88	35.45	*9.74*
As^{3+}	0.006	0.001	0.0015	0.0158	0.0002	0.0002	*0.0022*
Li^{+}	0.09	0.051	0.035	0.63	0.009	0.033	*0.033*
Cl^{-}	2913.3	104.5	10.1	8	3616	2659	*9.1*
SO_4^{2-}	283.2	0.9	503.5	26.3	13.6	92.5	*167.7*
HCO_3^{-}	598.35	362.09	-	434.04	1029	664.55	*112.8*
$\Delta_{Anion-Cation}$	0.79	3.31	58.22	4.94	4.17	31.54	*4.6*
Ratio*							
Cl/Mg	27.28	5.31	0.76	0.34	62.88	9.31	*0.36*
Na/Ca	207.25	25.87	1.05	4.00	295.36	162.65	*1.51*
Stable Isotope (°/₀₀)							
$\delta^{18}O$	-0.09	-6.32	-7.9	-6.44	-4.85	-6.47	*-5.79*
δD	-32.2	-42.6	-44.9	-44.5	-31.5	-38.2	*-34.2*
Geothermometer (°C)**							
Quartz (conductive)	76	-	-	-	120	-	-
Quartz (adiabatic)	80	-	-	-	118	-	-
Chalcedony	44	-	-	-	91	-	-
Na-K (Fournier, 1979)	193	-	-	-	164	-	-
Na-K (Giggenbach, 1988)	209	-	-	-	183	-	-
K-Mg	96	-	-	-	99	-	-

* Atomic or molecular ratios

** Only for Cl water with $\Delta_{Anion-Cation}$ < 5%

3.2. Cold Water

As comparison, a sample of cold water was taken from spring inside the Palimanan industry site (KR-7). The water has temperature of 30.4°C, pH of 8.0 and conductivity of -38.0 MeV. The chemical analyses shows that the cold water has TDS and electronegativity value lower than that of thermal water, i.e. 322 mg/L and 460 µS/cm respectively (Table 2).

The cold water in the study area also contains 21 mg/L Ca, 18 mg/L Na and 2.5 mg/L K. Compare to other major anions, HCO_3 is dominant; it is present 113 mg/L in association with amount of total CO_2 of 1.8 mg/L (Table 2 and Figure 2). Therefore, the cold water in the study area is classified as HCO_3 – Ca facies.

3.3. Stable Isotope of δ^{18}O and δD

Amount of stable isotope δ^{18}O and δD of thermal waters can be used to interpret the origin of thermal water and its sub surface undergone process. The origin of thermal water can be meteoric and magmatic and the sub surface process includes boiling, heat conduction, mixing, evaporation, etc. Thermal waters discharging in the study area have variations of stable isotope δ^{18}O from -0.09 to -7.90‰ and stable isotope of δD between -31.5 and -44.9‰ (Table 2). The amount of stable isotope δ^{18}O and δD of local meteoric water (KR-7) is -5.79 and -34.2‰ respectively (Table 2).

4. HYDROTHERMAL ALTERATION

The occurrence of alteration mineral records the characteristic of thermal water having once interacted with surrounding rock. Knowing the alteration pattern and, then, compiling the data with active manifestation, such as hotspring and hot pool, evolution of a geothermal system can be understood.

At Palimanan manifestation, there is a thin deposit of travertine. The deposit is no more than 2 cm thick and, from its texture, it is actively formed. Other alterations occur at Gunung Kuda (AL-1), Cipanas (AL-2 and AL-3) and Gunung Jajar (AL-4). The alteration is dominated by the occurrence of argillic zone consisting of kaolinite, alunite and silica minerals, i.e. cristobalite and quartz.

5. THERMAL FLUIDS

5.1. Type of Water

Type of thermal waters is assessed by comparing the relative concentration of anion Cl, SO_4 and HCO_3 as shown in Figure 2. In the study area, only thermal waters from Palimanan (KR-1) and Liang Panas (KR-2) are Cl water discharging directly from a sub surface geothermal reservoir.

Thermal waters from Gunung Kuda (KR-2) and Kedondong (KR-4) are steam heated HCO_3 water and water from Cipanas (KR-3) is acid SO_4 waters. Unlike Cl water, HCO_3 and SO_4 waters do not derive from geothermal reservoir, but form near the surface due to condensation of steam into groundwater or surface water. This process is also indicated by the compositions of stable isotope of δ^{18}O and δD shown in Figure 3. Compared to the composition of meteoric water (KR-7), KR-4 has been depleted and KR-3 has been enriched, indicating steam heating and surface evaporation processes.

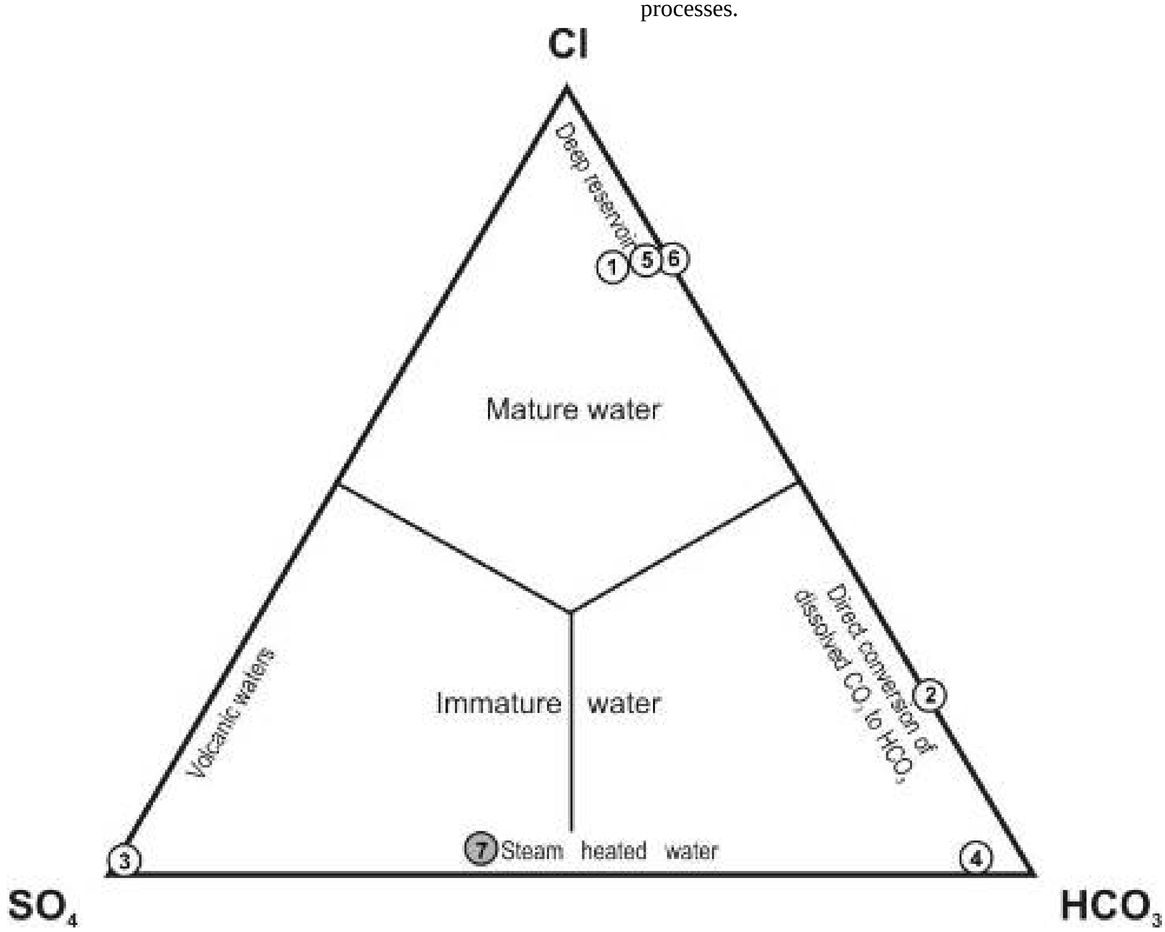

Figure 2. Relative concentration of Cl - SO_4 - HCO_3 (in mg/L) of hotsprings in the study area. Sample number and location follow Table 1. Sample KR-7 is cold water.

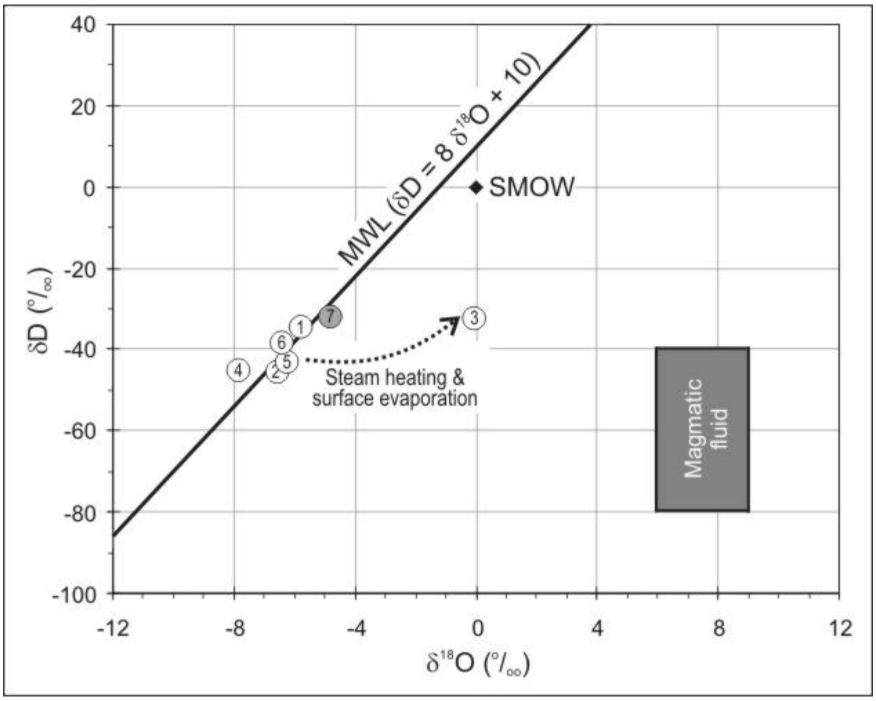

Figure 3. Graphic of the composition of δ^{18}O and δD stable isotopes of hotsprings in the study area. The meteoric water line (MWL) is an average of stable isotope composition of meteoric waters (rain water, groundwater, and surface water) and follows the equation of Brownlow (1996). SMOW (Standard Mean Ocean Water) is stable isotope composition of seawater, i.e. δD=0.00 and δ^{18}O=0.00. The magmatic fluid composition follows the stable isotope composition given by White (1974), i.e. +6 to +9‰ δ^{18}O and -40 to -80‰ δD.

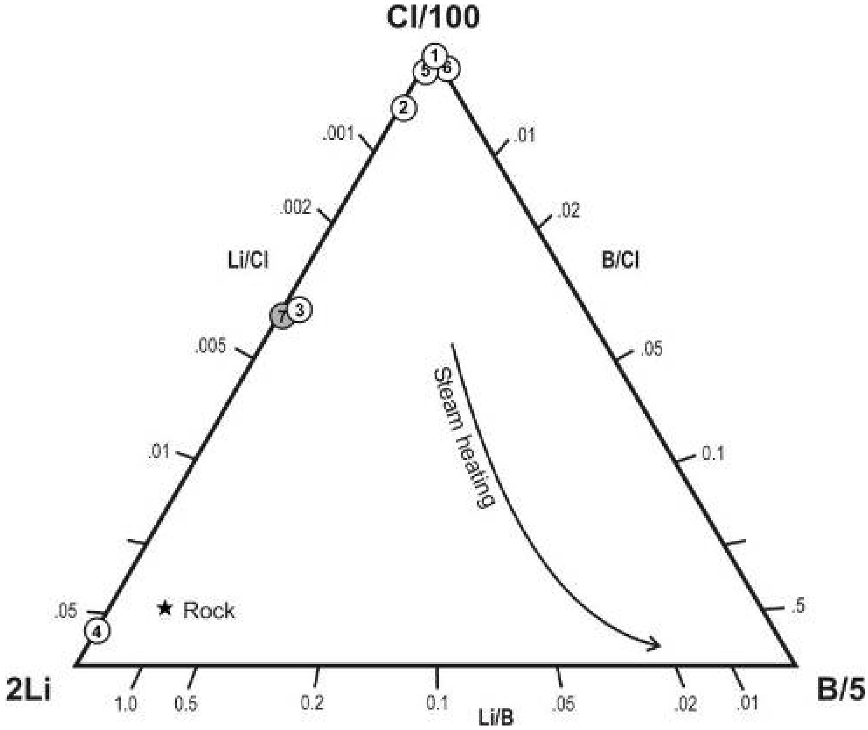

Figure 4. Relative concentration of Cl - Li - B, in mg/L, of hotsprings in the study area. Sample number and location follow Table 1. Sample KR-7 is cold water.

5.2. Origin of Water

Compositions of stable isotope of δ^{18}O and δD of KR-1, KR-2 and KR-5 waters in the study area are similar to that of meteoric water (Figure 3). This indicates that the thermal waters are meteoric origin. Small shifting of δ^{18}O content between meteoric and thermal waters as shown in Figure 3 indicates that the thermal fluids have reached equilibrium with surrounding rocks.

Relative concentration of Cl, Li and B in Figure 4 shows that the thermal waters in the study area, especially KR-1, KR-2 and KR-5, have relatively high Cl compared to the amounts of Li and B. This indicates that the thermal waters are influenced by volcano-magmatic activity. An increase in molecular ratio of Li/Cl waters from KR-3 and KR-4 compared to the ratio of KR-1, KR-2 and KR-5 (Figure 4) indicates a more intensive process of water-rock interaction. However, the low content of B (Table 2) indicates that the rock is igneous, not sedimentary rock.

5.3. Flow of Water

Thermal waters from Palimanan (KR-1) and Liang Panas (KR-5) are Cl water directly discharging from reservoir. As reservoir water, the KR-1 and KR-5 waters also have Na/K ratio of more than 15 and high ratio of Na/Ca (Table 2). These all chemical trends are revealed by Nicholson (1993).

Cipanas water (KR-3) is indirect flow and forms near the surface, as indicated by low ratios of Na/K, Cl/Mg and Na/Ca (Nicholson, 1993, Table 2). In area like Cipanas, generally reaction between thermal water, groundwater and surrounding rock occurs near the surface. Conduction cooling, then, influences the area. Similarly are thermal waters from Gunung Kuda (KR-2) and Kedondong (KR-4), eventhough the waters are transition between direct and indirect flow from reservoir. The different Li/B ratio, shown in Figure 4, indicates that the water-rock interaction in Kedondong have been occurring longer than in Gunung Kuda.

6. RESERVOIR AND ITS TEMPERATURE

Figure 4 shows only one variation in B/Cl ratio of thermal waters in the study area, i.e. less than 0.003. This indicates that the reservoir of thermal waters in the study area is similar. Calculation of Na-K solute geothermometer using equations of Fournier (1979) and Giggenbach (1988) in Cl waters from Palimanan (KR-1) shows that the sub surface reservoir temperature ranges from 190 and 210°C, but slightly cooling to 160 and 180°C at Liang Panas (KR-5, Table 2 and Figure 5). However, reservoir water in the study area mixes with groundwater and reaches equilibrium near the surface at 100 to 120°C as indicated by geothermometers silica and K-Mg (Table 2 and Figure 5).

The reservoir temperature of about 200°C is also confirmed by the occurrence of travertine at Palimanan. The presence of silica residue, kaolinite and alunite in Gunung Kuda, Cipanas and Gunung Jajar indicates that mixing between reservoir fluid and groundwater occurs at temperature from 100 to 120°C.

7. HYDROGEOCHEMICAL OF THERMAL WATER

Geothermal surface manifestations of Ciremai occur at Gunung Kromong in northern part and at Liang Panas in southern flank of the volcano. Gunung Kromong is a parasite cone of Ciremai; it caused the hydrogeology of thermal fluid in Gunung Kromong is more complicated than that in the southern flank (Figure 6).

As meteoric water recharges to sub surface of Ciremai, the water is heated by volcanic-magmatic activity of Ciremai. Neither magmatic fluid nor connate water mixes with the heated meteoric water. Due to decrease in density of thermal fluid, the hot water discharges to the surface. The deep fluid discharges laterally as hot spring in Palimanan (Gunung Kromong, KR-1) and the outflow is due to either geological structure or lithology contact between limestone and andesite or both. At the southern part of Ciremai, the deep Cl-rich fluid discharges at Liang Panas (KR-5). Here emerging the groundwater level, rather than structure and lithology controls, seems to be a caused of the outflow in Liang Panas.

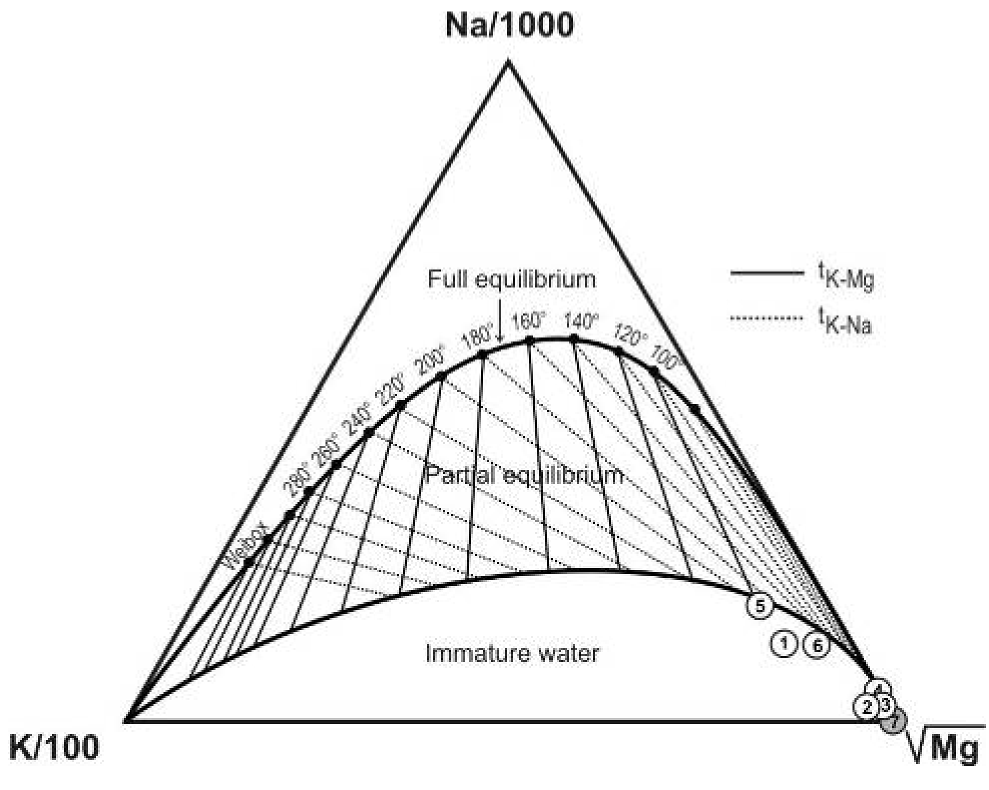

Figure 5. Relative concentrations of Na - K - Mg of hotsprings in the study area. The figure shows contour of sub surface temperatures calculated by K-Na (t_{KNa}) and K-Mg (t_{KMg}, Giggenbach, 1988) geothermometers. Sample number and location follow Table 1. Sample KR-7 is cold water.

The deep fluid also flows upward and fills reservoir. Furthermore in the reservoir the deep fluid boils at equilibrium temperatures of 190 - 210°C, but in the southern part of Ciremai, the reservoir equilibrates at slightly lower temperature than in the northern part, i.e. at 160 to 180°C. Boiling causes the thermal fluid to separate into liquid and vapor phases.

The vapor phase or steam is more mobile than the liquid phase. It can reach the peak of Ciremai and discharges as fumaroles and steaming ground. Pertamina (1985) reported the occurrence of geothermal surface manifestation near the crater of Ciremai. The manifestation is dominated by steaming ground having temperatures of about 90°C with very intensive sulfur deposit and CO_2-rich fumaroles having temperatures of 210°C (Pertamina, 1985).

At the southern flank of Gunung Kromong, i.e. area between Gunung Kromong and Ciremai, surface manifestations in Gunung Kuda, Kedondong and Cipanas indicate that steam has condensed into groundwater and surface water to form steam condensated SO_4 and HCO_3 waters. The condensation is likely to occur at temperature about 100°C. Not only condensation, steam also discharges directly through permeable zone at Cipanas as *kaipohan*. Here steam has also mixed with organic gas likely from claystone unit of Kaliwangu Formation.

8. CONCLUSION

Gunung Kromong is a parasite cone appearing at the northern part of Ciremai and it is a part of Ciremai geothermal system. However, the surface manifestations of Gunung Kromong indicate that the hydrogeochemical pattern of thermal fluid is not as simple as outflow of Ciremai.

Geological condition of Gunung Kromong is dominated by andesite and breccias overlying the younger sedimentary rocks of limestone and claystone. Sub surface interaction between thermal fluid and sedimentary rock cause the manifestation of Gunung Kromong to become complicated.

Five surface manifestations are identified in this study, i.e. hot pools at Palimanan, Gunung Kuda and Kedondong, warm pool at Cipanas and Liang Panas, and *kaipohan* at Cipanas. Generally, the thermal fluids have temperatures from 36 to 60°C and near neutral pH, except water from Cipanas that has very low pH.

Study of hydrogeochemical indicates that the thermal fluids are meteoric origin having been heated by volcano-magmatic activity of Ciremai. The fluids fill the reservoir and boil at temperature of no more than 210°C. The liquid and vapor phases resulted from boiling cause different type of surface manifestations at Gunung Kromong and surrounding.

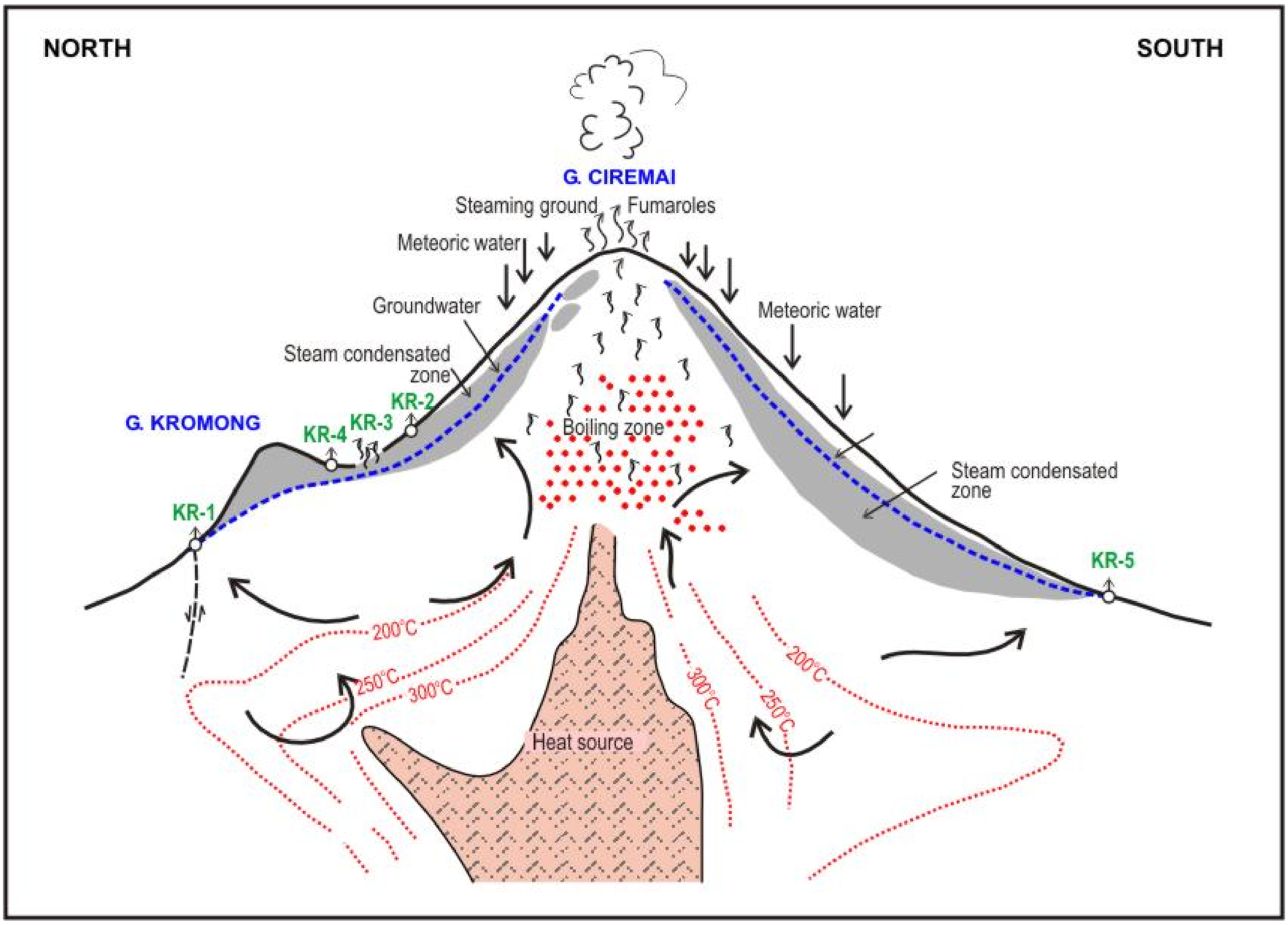

Figure 6. General model of geothermal system of Gunung Kromong area and surrounding, sketched as N-S cross section across Gunung Ciremai. Number and type of thermal waters follow Table 1 and Figure 2 (KR-1=Palimanan, KR-2=Gunung Kuda, KR-3=*kaipohan* at Cipanas, KR-4=Kedondong and KR-5=Liang Panas). Unscaled.

REFERENCES

van Bemmelen, R.W., The Geology of Indonesia. Vol.1A. The Hague, Government Printing Office, 732p (1949).

Brownlow, A.H., Geochemistry. 2nd Edition, Prentice-Hall, Inc., New Jersey, USA, 580p (1996).

Browne, P.R.L., Hydrothermal Alteration in Active Geothermal Fields. Annual Reviews in Earth Planet Science, v.6, 229-250 (1978).

Djuri, Peta Geologi Lembar Arjawinangun, Jawa. Geological Research and Development Centre (GRDC), Indonesia, - (1973).

Fournier, R.O., A Revised Equation for the Na/K Geothermometer. Geothermal Resources Council Transactions, 3, 221-224 (1979).

Giggenbach, W.F., Geothermal Solute Equilibria. Derivation of Na-Mg-Ca Geoindicator. Geochimica et Cosmochimica Acta, 52, 2749-2765 (1988).

Herdianita, N.R. and Priadi, B., Arsenic and Mercury Concentrations at Several Geothermal System in West Java, Indonesia. ITB Journal of Science, 40A, 1, 1-14 (2008).

Hochstein, M.P. and Browne, P.R.L., Surface Manifestation of Geothermal Systems with Volcanic Heat Sources. In Encyclopedia of Volcanoes, H. Sigurdsson, B.F. Houghton, S.R. McNutt, H. Rymer and J. Stix (eds.), Academic Press, 835-855 (2000).

Nicholson, K., Geothermal Fluids. Chemistry and Exploration Techniques. Springer-Verlag Berlin Heidelberg, 263p (1993).

Pertamina, Laporan Sementara Survei Pendahuluan Sisa Daerah Jawa. Unpublished report, Geothermal Division, Pertamina, Indonesia, - (1985).

Salvania, N.V. and Nicholson, K., Chemometrics Applied to the Fluid Chemistry of Geothermal Fields in the Taupo Volcanic Zone, New Zealand. Proceeding 12th NZ Geothermal Workshop, Auckland University, 157-163 (1990).

White, D.E., Diverse Origins of Hydrothermal Ore Fluids. Economic Geology, 69, 954-973 (1974).