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Evolution of Cisolok – Cisukarame Geothermal System, West Java – Indonesia, Based on Its Surface Manifestation

Niniek Rina Herdianita and Wulandari Mandradewi

Study Program of Geology, Faculty of Earth Science and Technology,
Institut Teknologi Bandung (ITB). Jl. Ganesa 10 Bandung 40125 - Indonesia

herdianita@gc.itb.ac.id

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ABSTRACT

The geothermal surface manifestations of spouting springs and surface alterations indicate that the Cisolok geothermal system has changed. The deep reservoir water has changed from Cl to HCO_3 waters due to subsurface water-rock interactions. Temperature of the reservoir has been cooling down, i.e. from above 220°C to 160-200°C. These changes also affect the characteristic and mineralogy of surface alteration deposits, i.e. from silica sinter to travertine deposits.

1. INTRODUCTION

The geothermal system of Cisolok and Cisukarame is considered a geothermal prospect area in West Java. The geothermal manifestation appears at 106°27'13.4" E and 6°56'0.5" S in the Cisolok River. It is about 70 km west of Sukabumi or about 170 km from Bandung (Figure 1). The geothermal manifestation of Cisukarame itself is located about 6 km north of Cisolok. At the present, the geothermal manifestation of Cisolok is used as public bathing place.

The geothermal system considered a geothermal prospect area as a result of its intense geothermal surface manifestations including hot spring and surface alteration. Thermal water discharging in the Cisolok River has a very high temperature that is at times above the boiling point. The thermal water also has neutral pH and very high discharge rate. Hydrothermal alteration occurs at the surface and the bank of the Cisolok River showing very high alteration intensity that is dominated by the occurrence of thick silica sinter and travertine.

The type and characteristic of this surface manifestation indicates that the geothermal system of Cisolok and Cisukarame has a shallow, high temperature reservoir. However, this geothermal resource has yet to be utilized for purposes beyond tourism. One reasons for this is the behavior of Cisolok and Cisukarame geothermal system is still largely unknown.

A geothermal system including reservoir conditions and subsurface flow patterns can be understood by studying surface geothermal manifestations such as hot springs, hot pools, steam vents and hydrothermal surface alteration (Hochstein and Browne, 2000, and Browne, 1978). Identification and correlation of an active and fossil geothermal system can aid in the understanding of the evolution of a geothermal system including changes in reservoir conditions and subsurface flow patterns.

2. GEOLOGY

Morphology of the study area can be divided into three parts including steep mountain, gentle mountain, and plain. The steep mountain forms at the northern and western parts of the study area. Its elevation is above 200 m with slopes between 40 and 70°. At the eastern part of the study area there is a zone of gentle mountain at elevations less than 150 m and slopes of less than 30°. The last morphology zone is plain and occurs in south coastal area.

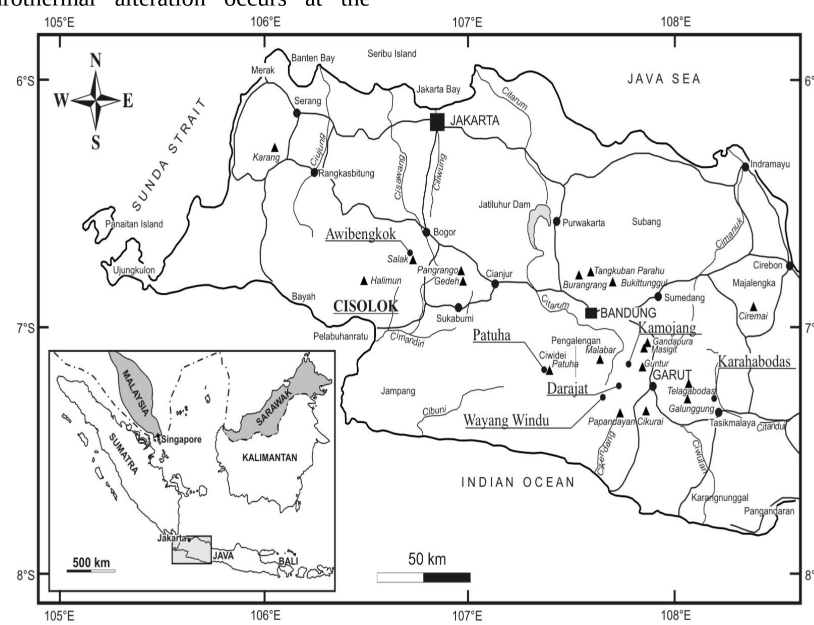

Figure 1: Map of West Java and Banten showing the location of the study area, Cisolok, Sukabumi.

Regional geology of the study area is shown by Sujatmiko and Santosa (1992). Cikotok formation is the oldest exposed rock in the western part of the study area. It has an age of early Oligocene and consists of volcanic breccias, tuff and lava (Sujatmiko and Santosa, 1992). It is overlain by early Miocene Citarete and Cimapag formations. The Citarete formation consists of limestone and tuff units, and the Cimapag formation is dominated by breccias and conglomerate (Sujatmiko and Santosa, 1992). Andesite and dacite intruded in the southern part of the study area during the middle to late Miocene (Sujatmiko and Santosa, 1992). In the western part of the study area, igneous rocks occur as granodiorite to granite covered by dacitic lava and pyroclastic deposits.

Marine sediments and volcanic unit product of Citorek were deposited unconformably over the Cikotok, Citarete and Cimapag formations during the Plio-Pleistocene. Quaternary andesite and basaltic lavas produce the Gunung Halimum and volcanic breccias and agglomerates product of Tapos then overlaid the area (Sujatmiko and Santosa, 1992). River alluvial and coastal deposits are the youngest deposits.

Structural geology found in the study area is E-W and N-S faults (Sujatmiko and Santosa, 1992). These faults are old, formed during the Plio-Pleistocene and have been covered by Quaternary volcanic deposits.

3. SURFACE MANIFESTATIONS

Resistivity survey of Hochstein (1988) indicates that the study area is an outflow zone because of the low resistivity value along the Cisolok River. The study also indicates that the Cisolok and Cisukarame comprise one geothermal system. The difference in the resistivity values indicates that the Cisolok area consists of more permeable rocks compared to the Cisukarame area. This is likely due to the occurrence of limestone in the Citarete formation below Cisolok.

Geothermal manifestations of Cisolok occur at the surface as hot springs emerging in the Cisolok River with temperatures above the boiling point. This thermal water has a neutral pH. Along the river bank around the hot spring, there is hydrothermal surface alteration dominated by silica sinter and travertine. Another surface manifestation occurs in Cisukarame, about 6 km north of Cisolok (Sujatmiko and Santosa, 1992). Based on resistivity survey of Hochstein (1988), all these manifestations are a geothermal system having one similar reservoir and likely relate to volcanic activity of Gunung Halimun or Salak.

3.1 Hot Spring

There are at least six hot springs discharging continuously in Cisolok River (Figure 2). Hochstein (1994) named this manifestation as spouting springs that occur under artesian condition. Cisolok thermal water has temperature of between 90 and 100°C, pH of about 8 and very high flow rate. The discharging thermal water then mixes with stream water having temperature of about 28°C and results in a temperature of 34°C in the mixed water. One of six hot springs in Cisolok has collected in a pond. Water samples were taken at CSL-01, from the most northern hot spring in Cisolok River, and from the pond hot water (CSL-07).

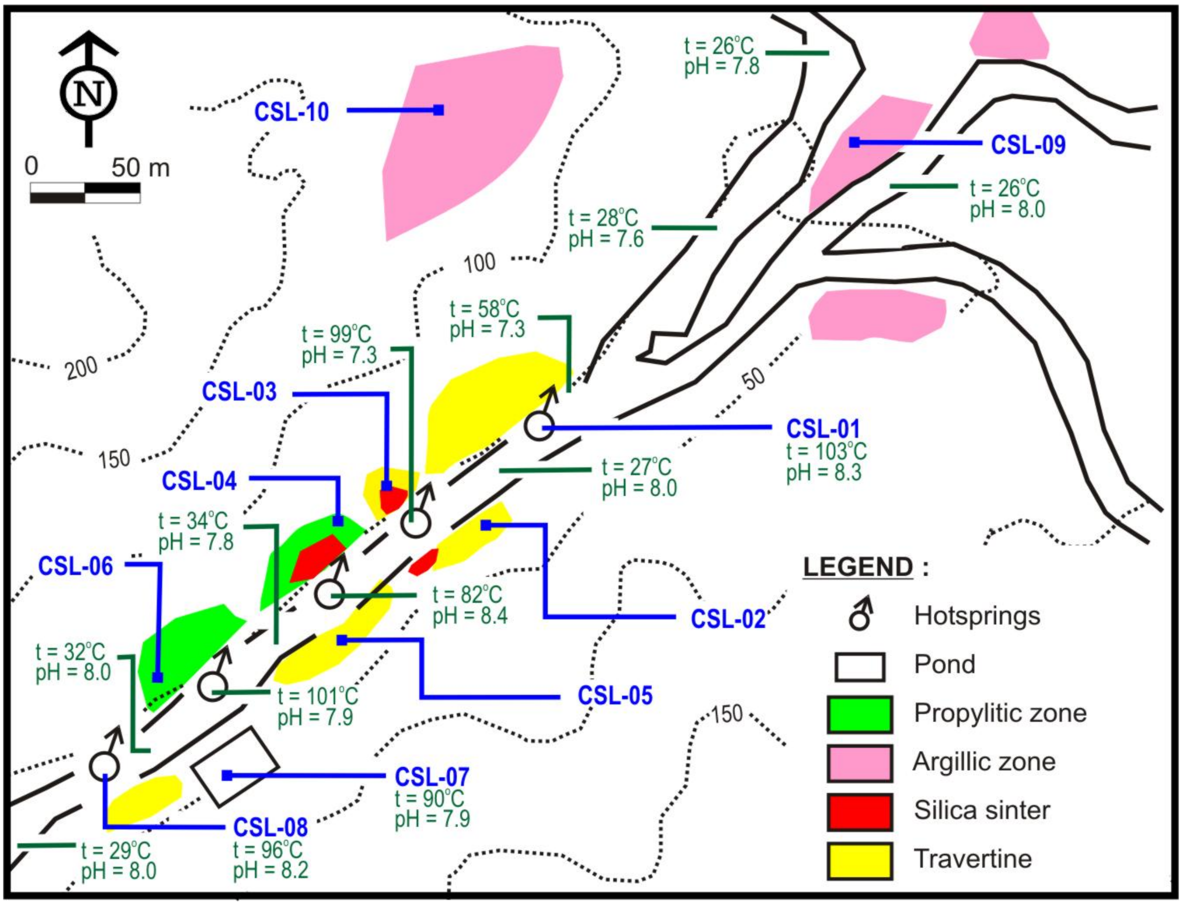

Figure 2: Geological traverse along the geothermal surface manifestation of Cisolok.

Total dissolved solid (TDS), electric conductivity (EC) and chemical composition of thermal water are given in Table 1. Figure 3 shows that the CSL-01 thermal water is HCO_3 type, whereas the CSL-07 water is Cl type. Compared to the CSL-01 water, the CSL-07 thermal water has a weakly basic pH, lower TDS and EC, and lower concentrations of alkalis and ferromagnesian. However, both CSL-01 and 07 waters have major cation of Na. In addition, because the CSL-07 thermal water contains more Cl than the CSL-01 water, the CSL-07 water has higher SiO_2 and more balance ratio of cation to anion. Table 1 and Figure 3 also show that the composition and type of the Cisolok thermal water given by Priadi and Herdianita (2005) slightly differ from this time. According to Priadi and Herdianita (2005), the Cisolok thermal water is SO_4 type having high SiO_2 concentration.

Table 1: Result of chemical analyses of Cisolok and Cisukarame hot springs. Data from Priadi and Herdianita (2005) is given for comparison.

Parameter	Unit	Sample Number			
		Priadi and Herdianita (2005)	CSL-01	CSL-07	CRM
Temperature	^oC	87	103	90	46
pH	-	6.9	8.3	7.9	7.7
pH $_{(lab, 25°C)}$	-	7.00	7.24	8.32	8.48
TDS	mg/L	-	3360	1510	118
EC	μS/cm	-	4800	2160	164
Ca^{2+}	mg/L	-	68.82	50.05	1.19
Mg^{2+}	mg/L	-	28.10	8.34	2.52
Cl^-	mg/L	284.00	369.86	369.86	6.73
F	mg/L	-	1.033	1.033	0.290
SO_4^{2-}	mg/L	609.02	268.04	187.45	12.52
Na^+	mg/L	-	1022.59	325.37	79.05
K^+	mg/L	-	77.33	24.92	0.52
Fe	mg/L	-	0.144	0.093	-
B	mg/L	-	0.000	0.072	0.003
NH_4	mg/L	-	0.475	0.673	-
SiO_2	mg/L	159.69	12.22	13.55	20.19
CO_3^{2-}	mg/L	-	28.64	6.51	16.38
HCO_3^-	mg/L	142.56	1416.36	201.20	154.64
As^{3+}	mg/L	0.4	0.0414	0.0476	0.0094
Li^+	mg/L	-	0.179	0.175	0.014
Anion	-	-	39.23	17.63	2.98
Cation	-	-	52.20	17.97	3.72
$\Delta_{Anion\text{-}Cation}$	%	-	14.19	0.96	10.94
Cl/Mg	-	-	20.39	68.71	4.14
Mg/Ca	-	-	0.30	0.12	1.54
Na/Mg	-	-	87.02	93.29	75.01
Ca/Mg	-	-	1.47	3.60	0.28
Na/K	-	-	22.42	22.14	257.78
HCO_3/SO_4	-	0.15	3.36	0.68	7.85

Surface geothermal manifestations of Cisukarame are located about 6 km north of the Cisolok manifestation. A hot pool occurs in the middle of a rice field in Cisukarame. The thermal water (CRM) has temperature of 46^{o}C and pH of about 7.7. Its flow rate is very low. The type and characteristic of the warm water of Cisukarame are similar to CSL-01, i.e. dominated by major anion of HCO_3 and major cation of Na. No surface alteration is found around the hot pool, except a mixture of colloidal silica and organic material found in the water surface of hot pool.

3.2 Surface Alteration

Surface hydrothermal alteration in Cisolok is present along approximately 400 m. Around the northernmost hot spring (CSL-01), there are white travertine deposits covering the surrounding rocks and alluvial materials (Figure 4). The deposit is friable and brittle and is a product of a young and active geothermal system. Atabey (2002) and Sant'Anna et al. (2004) classified this kind of deposit as micritic travertine containing impurities of aragonite, arsenic, antimony, sulphur, pyrite, goethite, hematite, and smectite.

Table 2. Mineralogy of surface alteration in the study area.

No.	Sample Number	Identification of mineral based on :		
		Petrography		XRD
		Mineralogy	Amount (%)	Mineralogy
1	CSL-01	Crystalline calcite	70	smectite
		Microcrystalline calcite	30	goethite
				calcite
				aragonite
2	CSL-02	Crystalline calcite	10	smectite
		Microcrystalline calcite	90	calcite
3	CSL-03	Crystalline calcite	70	smectite
		Microcrystalline calcite	30	calcite
				± quartz
4	CSL-04	-	-	smectite
				calcite
				± quartz
5	CSL-05	Crystalline calcite	80	smectite
		Microcrystalline calcite	20	calcite
				± quartz
6	CSL-07	Crystalline calcite	10-20	smectite
		Microcrystalline calcite	80-90	calcite
				± quartz
7	CSL-08	Crystalline calcite	60-100	smectite
		Microcrystalline calcite	<40	calcite
8	CSL-09	-	-	kaolinite
				hematite
				quartz
9	CSL-10	-	-	chlorite

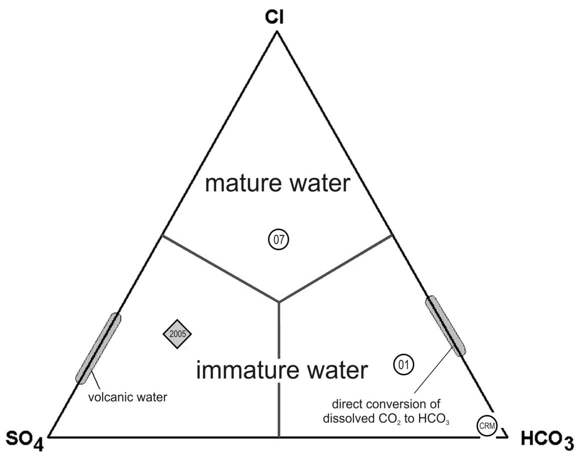

Figure 3: Relative concentration of Cl - SO_4 - HCO_3 (in mg/L) of hot springs in the study area. Point 01 is sample CSL-01, 07 is sample CSL-07, and CRM is sample from Cisukarame. Point 2005 is taken from Priadi and Herdianita (2005) as comparison.

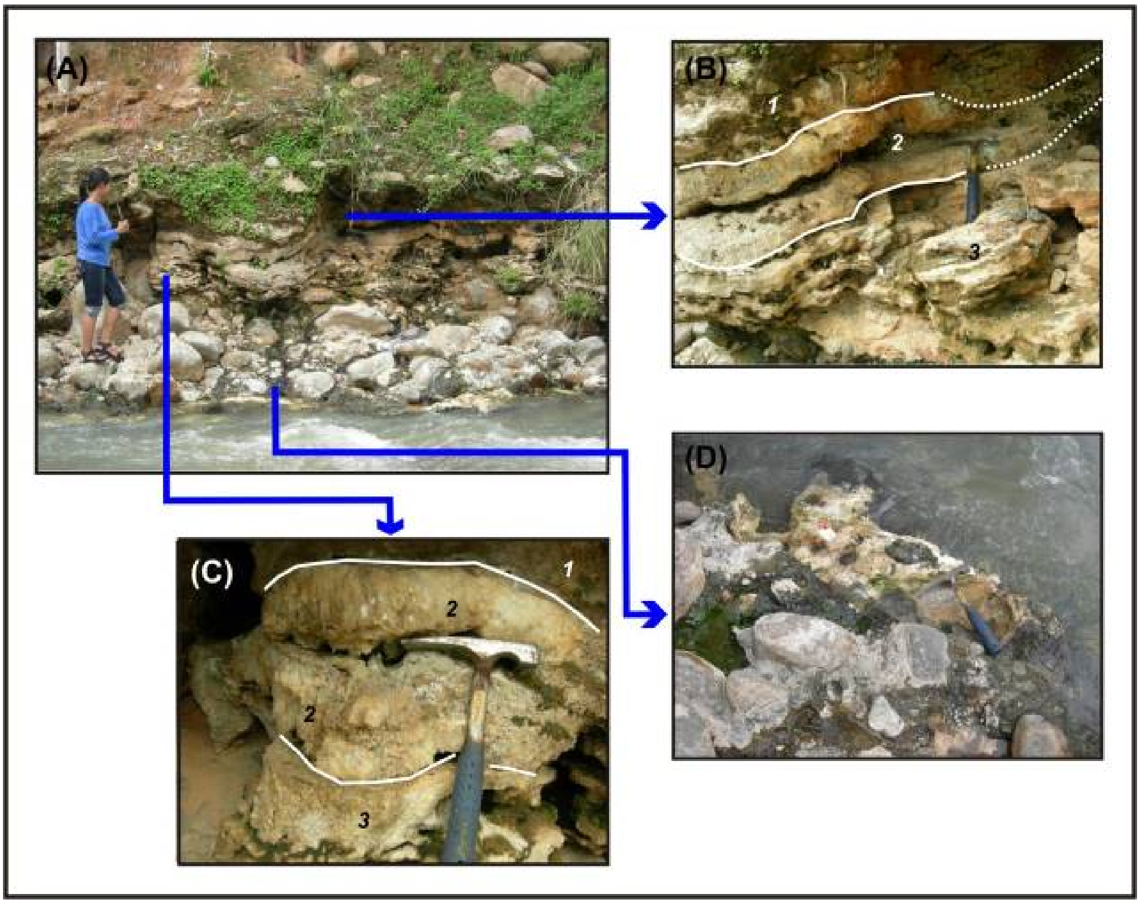

Figure 4: Alteration rocks around CSL-01.

Immediately west of the bank of CSL-01 until about 6 m to the headwater of Cisolok River, there are fossil travertine deposits. The deposits can be separated into several continuous layers. Each layer has different texture, i.e. crustiform, colloform, stromatholitic, comb, sucrose and dogteeth. Brecciation is always found at the lower part. According to the classification of Özkul et al. (2002), this travertine fossil belongs to the crystalline crust travertine and pebbly travertine lithofacies. Fossil travertine is still dominant at CSL-02 and 03. Locally, the travertine is associated with fossil silica sinter. Here, the sinter is massive and fractured, but not layered. The deposit can be classified into the lithoclast travertine lithofacies.

Propylitic alteration zone forms at CSL-04 and 06. The alteration changes igneous rock of dacitic and is marked by the presence of disseminated pyrite and quartz and calcite veins. Mostly, the veins show textures of crustiform and colloform. Amorphous silica sinter seems to cover the propylitic altered rocks and is found in the river bank.

Location of CSL-05 is located at east bank of the Cisolok River where the pebbly travertine lithofacies associated with silica sinter is found. Textures of the surface deposit include comb, crustiform and colloform. Calcite is mostly microcrystalline, but some are bladed and sugary calcites. Simmons and Christenson (1994) revealed that textures of comb, crustiform, colloform and sugary calcites are commonly found in calcite deposit, but bladed calcite is only found at condition indicating sub surface boiling.

At CSL-07, thermal water collects in a pond. At the bottom and wall of the pond, there are white travertine deposits. The raft travertine lithofacies (Özkul et al., 2002 classification) forms at pipe connections and at water surface mixing with organic materials. There is no doubt that this deposit is a result of an active geothermal system.

Quartz becomes dominant and calcite is absent in argillic alteration zones of CSL-09 and 10. Other hydrothermal minerals present with quartz are chlorite, smectite and kaolinite. The occurrence of clay minerals indicates that the alteration is not a surface product, but rather near surface alteration.

4. EVOLUTION OF GEOTHERMAL SYSTEM

Relative concentration of Cl, Li and B as shown in Figure 5 indicates that thermal waters in the study area contain more Cl relatively to Li and B. This indicates that the Cisolok (CSL-01 and 07) and Cisukarame (CRM) thermal waters are affected by volcano-magmatic activity. This is also supported by high content of F (Table 1) indicating the influence of volcanic gasses such as HCl, HF and H_2S at sub surface. A similar ratio of B/Cl indicates that the Cisolok and Cisukarame thermal waters have a similar reservoir.

Calculation of Na-K geothermometer indicates that the reservoir of Cisolok and Cisukarame thermal waters has a temperature between 190 and 200°C (Table 1, Figure 6). However, the reservoir temperature can be 170°C as shown by Na-K-Ca geothermometer or as low as 160°C as reported by Priadi and Herdianita (2005).

Figure 5 shows that thermal waters emerging in Cisolok have low ratios of B/Cl, Li/Cl and Li/B. This indicates that the Cisolok thermal waters flow laterally from the reservoir. This is unlike the Cisukarame thermal water that has a higher ratio of Li/Cl than the Cisolok water, indicating it flows directly from the reservoir below as upflow zone. This evidence is supported by ratios of some solutes as mentioned in Nicholson (1993). The lateral and upflow conditions of the Cisolok – Cisukarame geothermal system is also agree with the resistivity study by Hochstein (1988) described before. In addition, both the Cisolok and Cisukarame thermal waters are not influenced by dilution of groundwater and seawater as indicated by high value of Na/K and Cl/Mg ratios, also by low TDS and Cl/SO_4 ratio.

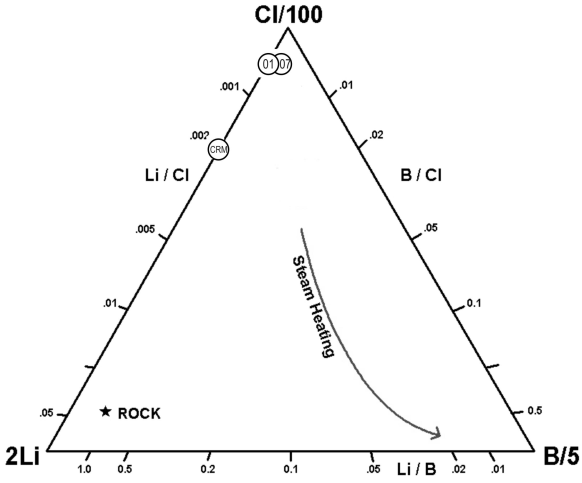

Figure 5: Relative concentration of Cl – Li – B, in mg/L, of hot springs in the study area. Point 01 is sample CSL-01, 07 is sample CSL-07, and CRM is sample from Cisukarame.

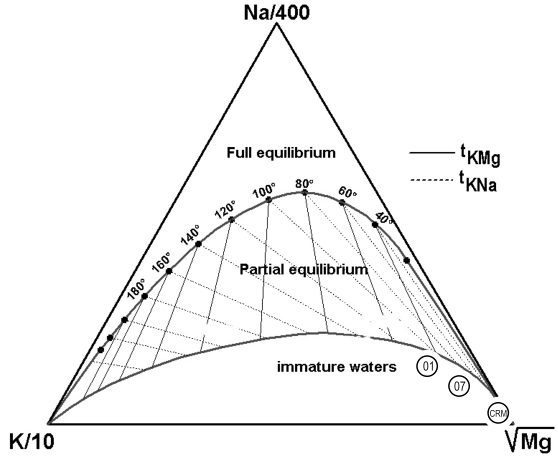

Figure 6: Relative concentration of Na – K – Mg of hot springs in the study area. The figure shows contour of sub surface temperatures calculated by K-Na (t_{KNa}) and K-Mg (t_{KMg}, Giggenbach, 1988) geothermometers. Point 01 is sample CSL-01, 07 is sample CSL-07, and CRM is sample from Cisukarame

Instead of spouting springs, the surface geothermal manifestation at Cisolok also consists of several surface alterations. The geothermal manifestation of Cisolok can be sketched as a cross section as shown in Figure 7. By comparison the characteristics of hot spring and surface alteration, the evolution of the Cisolok geothermal system can be known.

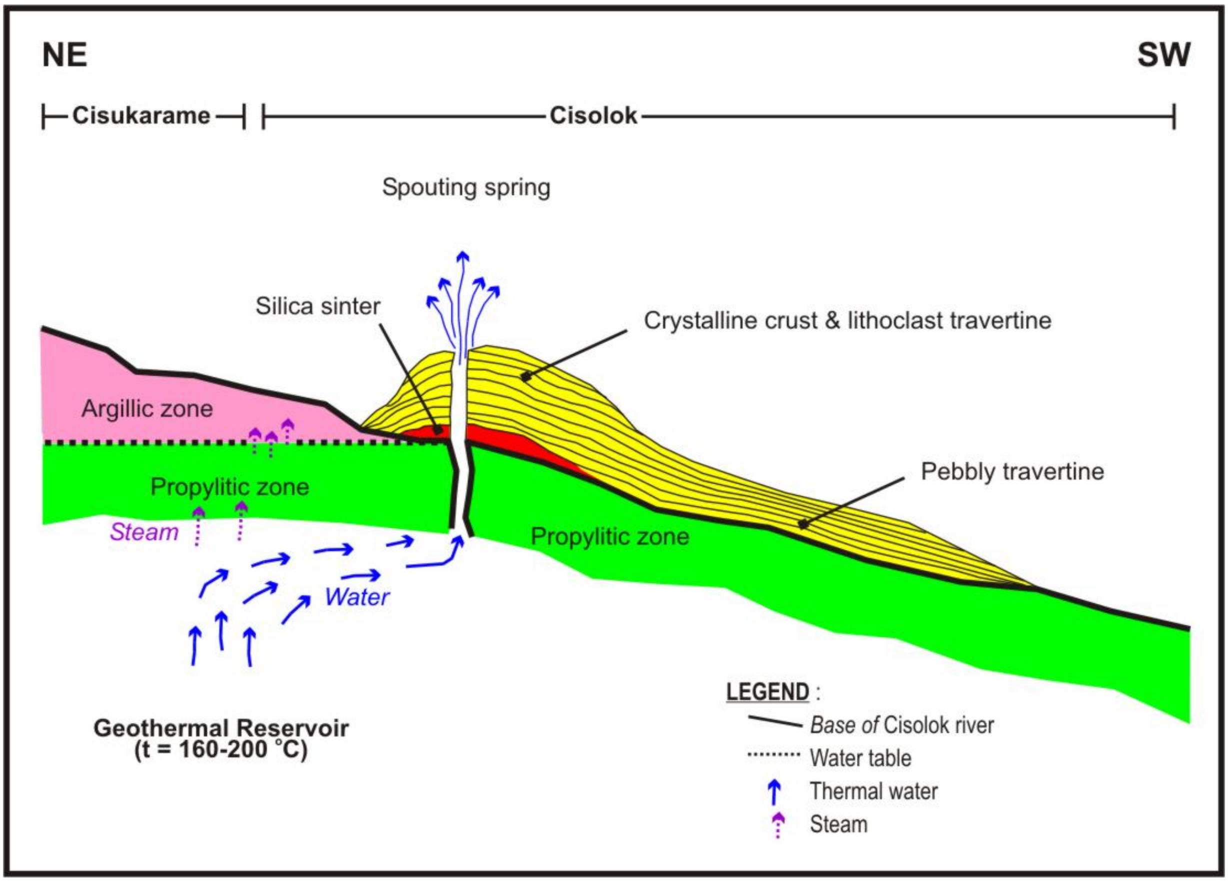

Figure 7: Sketch of NE – SW cross section along Cisolok River showing surface and near surface geothermal manifestation and its relationship to the sub surface geothermal reservoir condition. Not scaled.

Based on the alteration pattern occurring in Cisolok, the reservoir seems to have temperature above 220°C as indicated by the occurrence of propylitic alteration, silica sinter and travertine deposits. The chemical compositions of thermal waters and study of Hochstein (1988) indicates that the deep thermal water will flow laterally to Cisolok, but the steam will discharge directly up to Cisukarame. Steam produced from sub surface boiling can then condense into groundwater and surface water and cause oxidation of CO_2 to H_2CO_3 and H_2S to H_2SO_4. These processes are also known as steam heating where argillic alteration can occur. The argillic zone is dominated by kaolinite and smectite in association with chlorite and quartz, indicating that the alteration occurs in an acid condition with temperatures below 120°C. A change in mineralogy of silica sinter from opal-A to opal-CT, perhaps into microcrystalline quartz, according to Herdianita et al. (2000), indicates that the activity of Cisolok geothermal system has been occurring more than 10,000 years.

Interaction between thermal water and surrounding rocks, including limestone, causes the deep Cl water to change into HCO_3 water. At the surface, the thermal water does not form silica sinter anymore, but travertine deposit. The travertine deposit will first cement the basement and alluvial materials to form pebbly travertine. Furthermore, the travertine will form crystalline crust and lithoclast above the pebbly travertine. Because the basement is dipping to SW, the travertine deposit seems to have only 1 slope, i.e. dipping to SW. Point, where the hot spring emerges, is about CSL-01 to 03 now.

After that, dropping of water table is likely to occur. Therefore, the hot spring activity shifts to SW. This can cause the CSL-01 hot spring to shifts to the oxidation zone and to be HCO_3 water. Fluctuation of the water table seems to occur. This causes a change in the chemical composition and type of Cisolok thermal waters, i.e. from HCO_3 water to Cl water as in CSL-07, in fact, to SO_4 water as reported by Priadi and Herdianita (2005).

The Cisolok geothermal system has a high potential to be utilized indirectly even though the reservoir temperature is not too high. Natural heat loss calculated by equation of Hochstein (1994) indicates that Cisolok has potency of more than 280 kW. However, to utilize this system, several comments should be point out:

1. The reservoir and upflow zone of the system are located below Cisukarame. Cisolok shows very spectacular manifestations, but this is only an outflow zone.

2. Location of reservoir, thickness of argillic zone and characteristic and pattern of propylitic alteration below the surface are several problems still at hand.

3. This geothermal system may potentially form scaling of calcite. However, the travertine can only form due to subsurface interaction of thermal water and limestone. The occurrence of limestone unit in the subsurface can be used to predict the occurrence of scaling.

5. CONCLUSION

Morphology of the study area can be divided into three zones including steep mountain at northern and western study area, gentle mountain at eastern part of the study area, and coastal plain at south. The Cisolok River is the main river flowing to Teluk Pelabuhanratu.

Geology of the study area is dominated by Quaternary rocks of andesite and basaltic lavas and pyroclastic deposits of Gunung Halimum and Tapos. There is a limestone unit of Citarete formation in the subsurface. Structural geology is dominated by E-W and N-S Plio-Pleistocene faults.

The study area of Cisolok and Cisukarame is located in Sukabumi, West Java. It is a prospective geothermal resource area as indicated by the occurrence of geothermal surface manifestations including spouting springs and intense alteration zones. The Cisolok and Cisukarame thermal waters have temperatures between 90 and 100°C, pH of about 8, and flow rates of about 10 L/min. The type of the Cisolok thermal water is HCO_3 water in association with Cl water. The geochemistry of Cisolok water indicates that the water is flows laterally in a deep geothermal reservoir having temperatures of 160 to 200°C. In contrast, the Cisukarame thermal water has temperature of less than 50°C and pH of 7.7. This water is an upflow of HCO_3 water resulted by condensation of steam into groundwater and surface water.

Surface alteration in the Cisolok river is along ± 400 m. The alteration is dominated by the occurrence of surface deposits of travertine and silica sinter. Propylitic and argillic zones occur locally. Characteristics of travertine and silica sinter deposit indicate that the alteration has formed more than 10,000 years due to interaction of HCO_3 water discharging from the reservoir of above 220°C.

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