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The Application of Geochemical Ternary Diagram to Analyze Characteristics of Geothermal Waters in Sumatera Island, Indonesia

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ABSTRACT

There are a lot of geothermal prospects reported in Sumatera Island, Indonesia. Most of those geothermal prospects are still in an exploration stage to understand their geothermal system with geological, geophysical, and geochemical surveys. Geochemical surveys are usually used to analyse the characteristic of water, gas, or soil manifestations, geothermometers, and type of systems. This study utilises water geochemistry to calculate geothermometers while considering the equilibrium of fluid, analyse characteristic of water manifestations, and its correlation to the Great Sumateran Fault. This study focused on the evaluation of water geochemistry with Cl-SO_4-HCO_3 ternary diagram, Na-K-Mg ternary diagram, and the ratio of another geoindicator to know its association in either deep or shallow levels, compare equilibrium temperature, and water geochemical characteristics between each geothermal prospect in Sumatera Island. The results of this study show that some of the geothermal waters in Sumatera geothermal prospects have fluids which do not directly come from a reservoir, and encounter dilution with meteoric water or mixing process, or come from steam heated from brine. Another geothermal water of the manifestations in Sumatera Island is characterised by a brine that comes from deep liquid geothermal water with not much mixing process or dilution with meteoric water. Other analysis from this study that uses geoindicator showed the association of some prospect with Great Sumateran Fault with some explanations about each water chemical characteristic.

1. INTRODUCTION

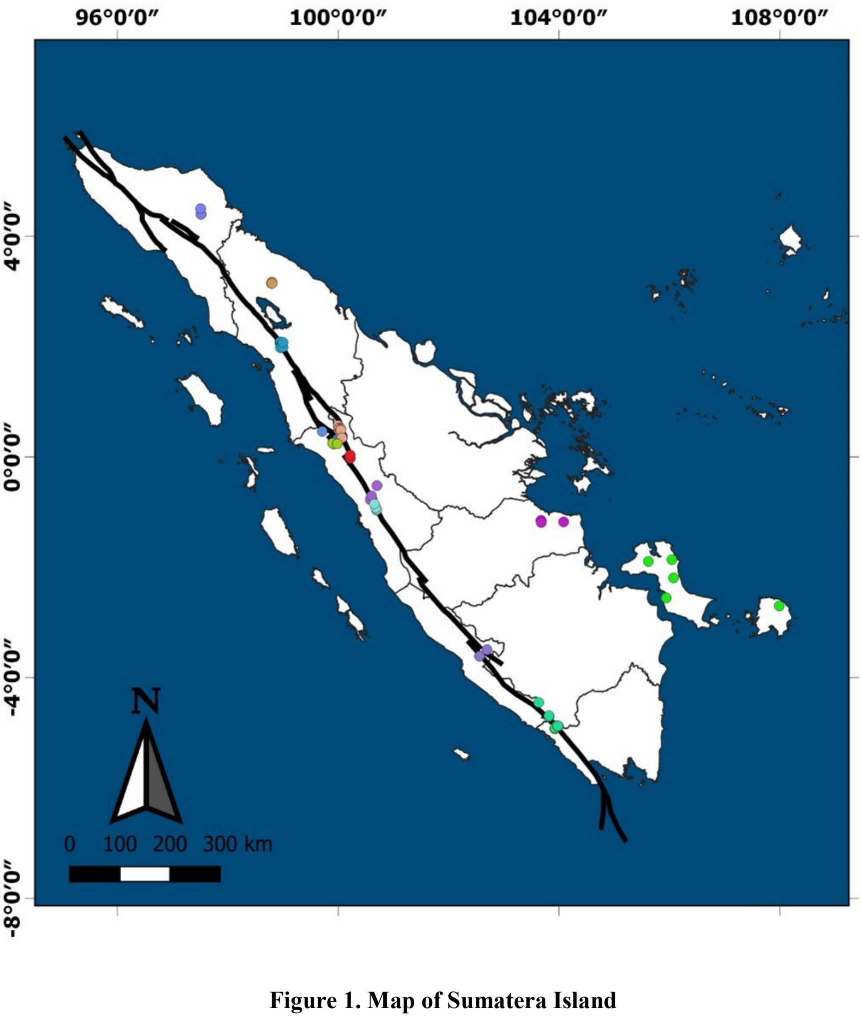

Figure 1. Map of Sumatera Island

Indonesia has a lot of geothermal resources, some of them located in Sumatera Island (Figure 1). Geothermal resources in Sumatera Island is indicated by the presence of thermal manifestation, consisting of steaming grounds, mud pools, fumaroles, and hot springs. Some of those thermal manifestation associated with the Great Sumatera Fault.

Geothermal exploration provides a great understanding of location, nature and origin of geothermal waters in a geothermal system and generally geochemical exploration will measure the earth's chemical properties in order to delineate geothermal fields, locate the aquifers, site wells and provide useful information to make decisions of commercial viability can be made on geothermal resources (Mwangi, 2013). Surface water classified into meteoric water, ocean water, evolved connate water, magmatic water, and juvenile water (Ellis and Mahon, 1977). Conservative considerations are used for tracing origin and flow or geothermal fluids, stable isotopes along B and Cl being most important. Chemical composition elements in rocks (e.g. SiO_2, Na, K, Ca, Mg, CO_2, H_2) are used to predict subsurface temperatures, potential production problems, and characterise water types.

This paper presents water geochemical data from 17 geothermal prospects in Sumatera Island, consists of thermal and cold waters. The sampling was carried out in varies year from 2003 until 2018, from Center for Mineral, Coal, and Geothermal Resources, Bandung, West Java, Indonesia.

2. GEOLOGICAL SETTING

Regionally, tectonic setting of Sumatra Island is affected by the converging movement between Eurasian Plate ad Indian-Australian Plate. However, this tectonic process is more complex locally. The Island is currently located in the southwest segment of the Eurasian plate. The movement direction of these plates causes the formation of dextral lateral faults (strike-slips). The most influential fault is The Great Sumatran Fault, referred to as the Semangko Fault, which extends along the island of Sumatra from the Sunda Strait to the Andaman Sea (Page et al., 1979).

The relationship between these structures controls the distribution of lithologies on the surface and shows complex tectonic activity. Pulunggono and Cameron (1984) and Barber et al. (2005), interpreted that the island of Sumatra was formed from collision and suturing processes of microcontinents at the end of Pre-Tertiary. In recent time, the Indian-Australian Oceanic Plate is subducted under the Eurasian Continental Plate at N20°E and with an average movement of six to seven centimeters per year.

Areas along the Sumatra Fault are areas prone to earthquakes and landslides, due to the high seismic and volcanic activity caused by the movement of faults in the system. Within this great fault, most areas with geothermal activity were found. These areas are Sipoholon Siriaria, Cubadak, Simisuh, Talu Tombang, Sumani, Bonjol, Gunung Talang, Kepahiang, Wai Selabung and Danau Ranau. The subduction process had also formed a non-volcanic forearc and volcano-plutonic back-arc along the island, parallel to the plate movement. The back-arc segment might also be related to the remaining fields, such as Lokop, Dolok Marawa, Geragai and Bangka Belitung.

3. METHODS

Geochemical methods were carried out to determine the characteristics of the fluid and the temperature of the geothermal reservoir. Data samples were collected in Bandung, Indonesia for Mineral, Coal, and Geothermal Resource. There are more than 100 samples from 17 geothermal prospects in Sumatera Island (Figure 2). Geochemical methods are used in this paper are from surface discharges which included thermal water and cold-water manifestations. Characteristics of several parameters are obtained from the type of manifestation, the concentration of chemical compounds in the thermal water contained in the water sample, as an indication of geothermal resources. The parameters used in this paper included the physical and chemical properties of manifestations and data from water chemical analysis results. Data samples were calculated using excel spreadsheets for geothermal water geochemistry by Powell and Cumming (2010), and samples that are used in this paper were selected based on their ion balance. Water samples from 17 geothermal prospects in Sumatera Island then plotted into the Na-K-Mg and Cl-SO_4-HCO_3 ternary diagram and calculated the ratio of another geoindicator to know its association in either deep or shallow levels, compare equilibrium temperature, and water geochemical characteristics between each geothermal prospect in Sumatera Island.

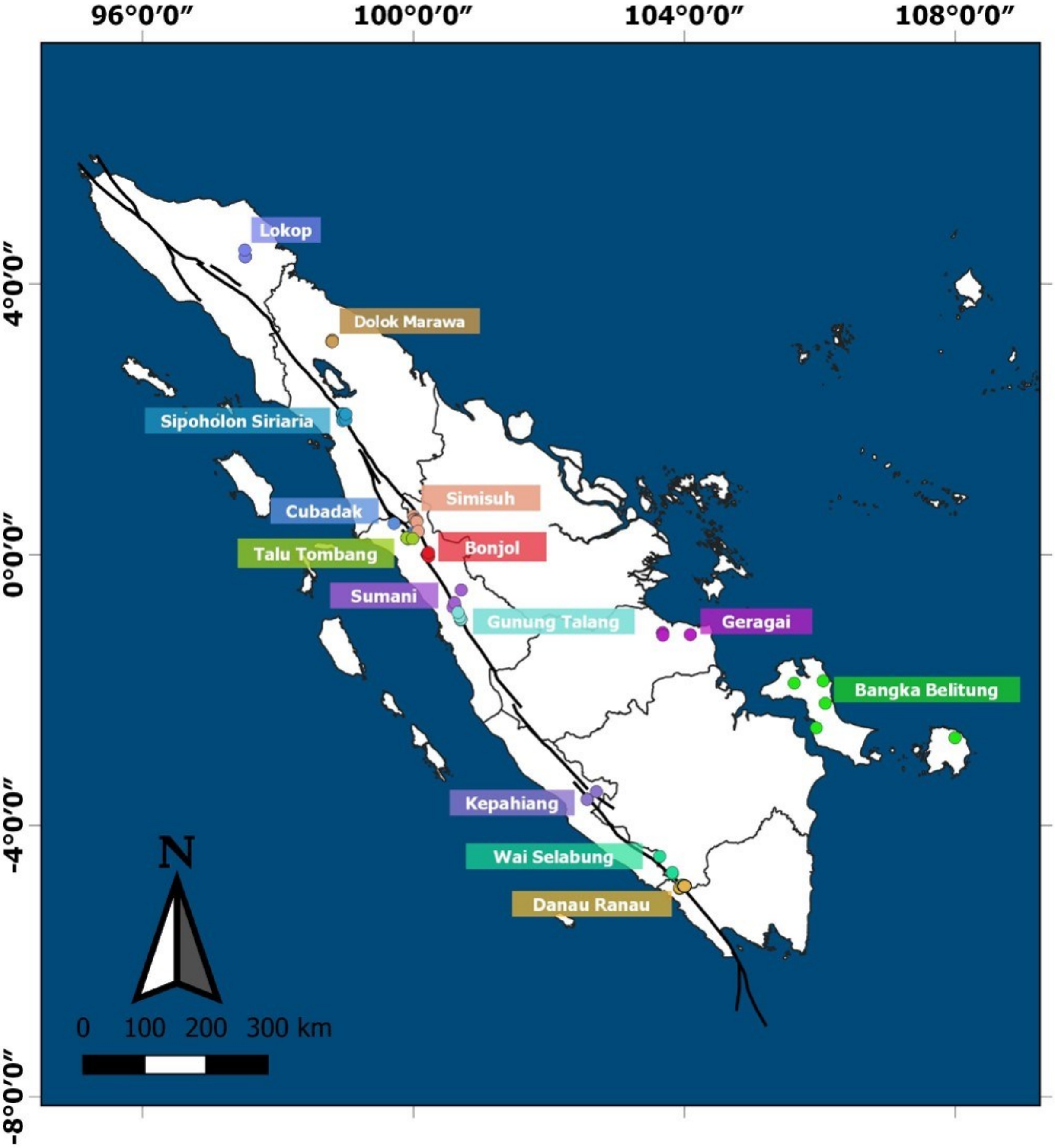

Figure 2. Map showing the location of samples of geothermal prospects in Sumatera Island

4. RESULTS AND DISCUSSION

4.1 Water Geochemistry

There are many types of water geochemistry in Sumatera Island and divided into clusters and have characteristics low to high-temperature geothermal systems. The composition of thermal fluids depends on many factors. The most important is the temperature-dependent reactions between host rock and hot fluid. Leaching also plays an important role when the amount of a particular component of the sample is too small to reach an equilibrium state (Al-Kohlani, 2010). Water geochemical analysis will determine characteristics, types, and environments of hot water, based on plotting the elemental content in a triangle diagram (Giggenbach, 1988). Geochemical characteristics of the geothermal water in Sumatera Island are listed (Table 1) and plotted in the geochemical water diagram (Figure 3 and Figure 4).

Giggenbach (1988), proposed Na-K-Mg ternary diagram also to estimate reservoir temperature. The reactions involving K-Na, equilibrate at high temperature and do not adjust rapidly to the physical environment at shallow depths will give high values of reservoir temperature. Reactions involving K/Mg, equilibrate at low temperature. Figure 3 shows that water samples from geothermal prospects in Sumatera mostly had characteristics of immature water. Some of the water samples have partial equilibrium, such as Cubadak, Sumani, Simisuh, Wai Selabung, Bonjol, Gunung Talang, and Bangka Belitung. The estimated reservoir temperature for geothermal prospects in Sumatera Island varies from 120˚C to 190˚C; Bonjol ranges around 180˚-190˚C; Way Selabung at about 175˚C; Simisuh at about 140˚-170˚C; Bangka Belitung at about 170˚C; Lokop at about 120˚C; Cubadak at about 170˚C.

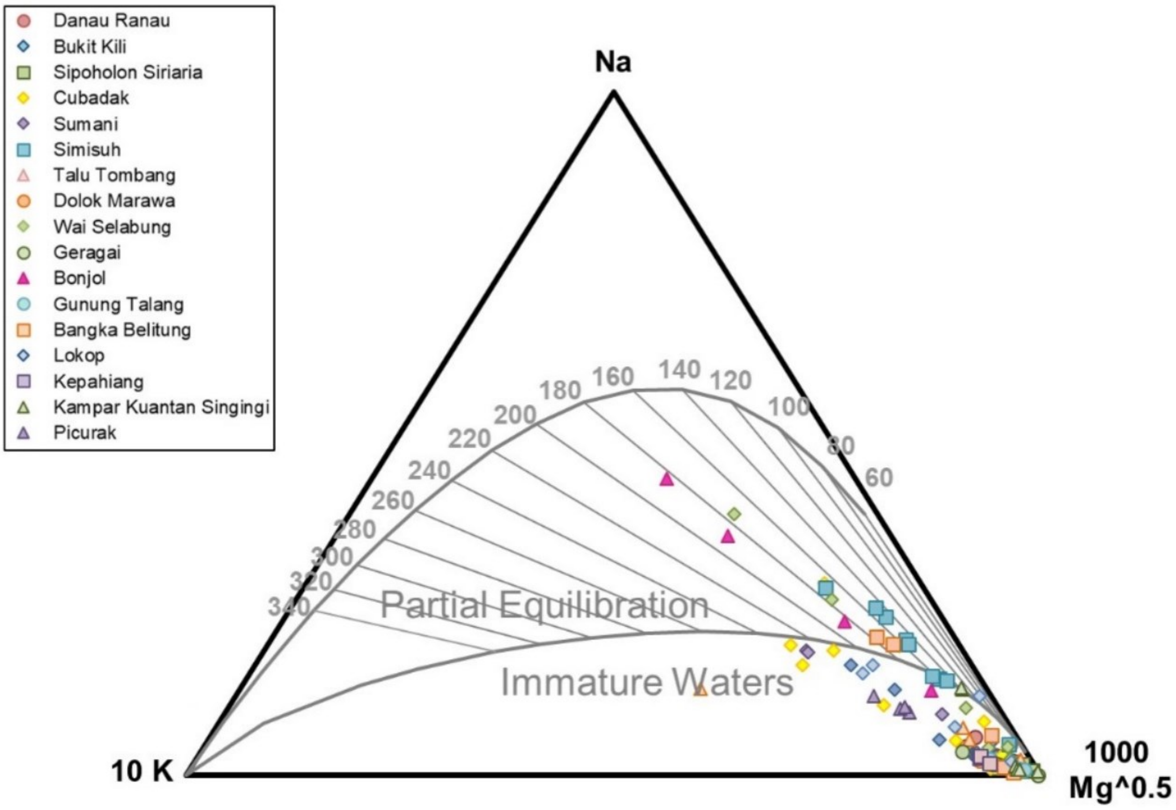

Figure 3. Na-K-Mg ternary diagram of geothermal water samples in Sumatera Island.

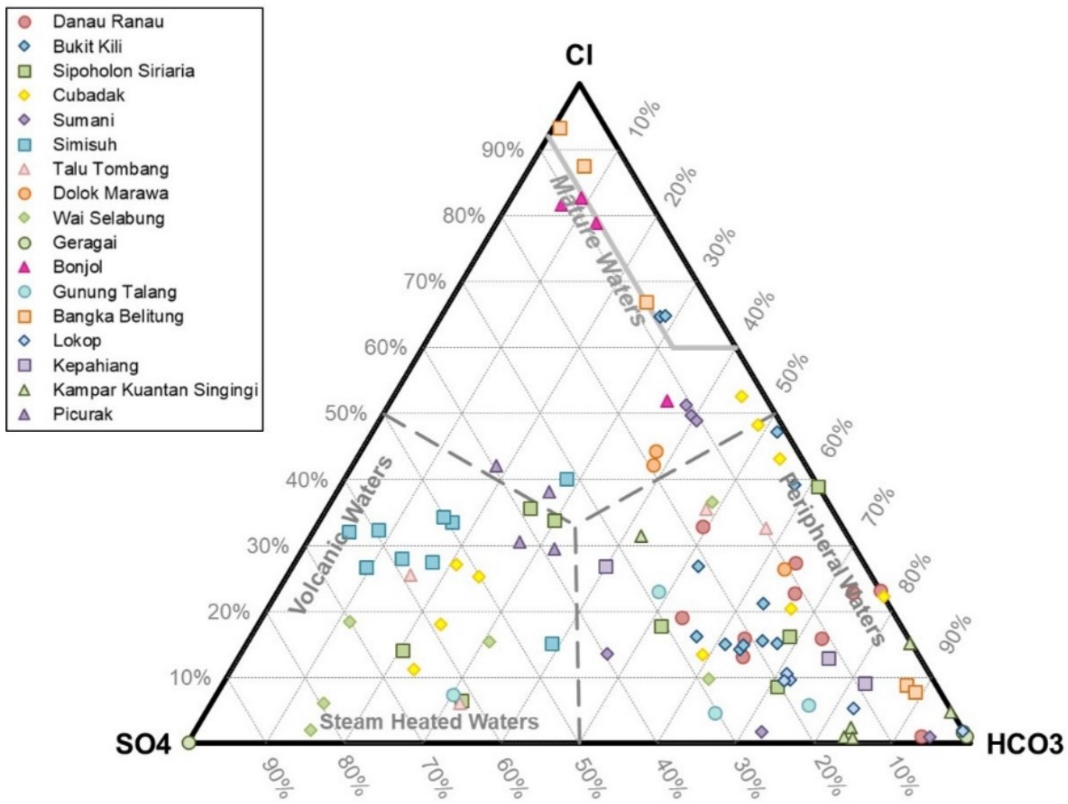

Figure 4. Cl-SO$_4$-HCO$_3$ ternary diagram of geothermal water samples in Sumatera Island

Water samples were plotted into the Cl-SO_4-HCO_3 ternary diagram. This ternary plot illustrates the proportions of the major anions present in geothermal water in Sumatera Island (Giggenbach, 1991). This ternary also shows different types of geothermal water. The Cl-SO_4-HCO_3 ternary diagram shows that most of the samples have characteristics of bicarbonate water, several samples are sulphate water, and there are also chloride water samples from Bonjol, Bangka Belitung, and Lokop.

At pH 6-10 bicarbonate is the dominant species. Bicarbonate water might suggest an outflow of the geothermal fluids, this yields greater opportunity for rock-water reactions and therefore increased the production of HCO_3 (Nicholson, 1993). Generally, bicarbonate waters are used as a sign for outflow and a reference for the boundary of the system.

Sulphate (SO_4) concentration is usually low in deep geothermal fluids but increases with increasing oxidation of hydrogen sulphide. The high concentration of sulphate in surface waters are usually the results of steam condensation into near-surface waters.

Table 1 summarises the geochemical characteristics of geothermal prospects in Sumatera Island from the Na-K-Mg and Cl-SO_4-HCO_3 ternary diagram.

Table 1. Geochemical characteristics of water samples in Sumatera Island

No.	Geothermal Field	Ternary Diagram	
		Na-K-Mg	Cl-SO4-HCO3
1	Danau Ranau	Immature water	Bicarbonate water
2	Bukit Kili	Immature water	Chloride water Bicarbonate water: mostly samples
3	Sipoholon-Siriaria	Immature water	Bicarbonate water and sulphate water
4	Cubadak	Partial equilibrium and immature water	Bicarbonate water and steam heated water
5	Sumani	Partial equilibrium and immature water	Bicarbonate water
6	Simisuh	Mostly partial equilibrium	Mostly sulphate water
7	Talu-Tombang	Immature water	Bicarbonate water and sulphate water
8	Dolok Marawa	Immature water	Bicarbonate water
9	Wai Selabung	Partial equilibrium and immature water	Bicarbonate and sulphate water
10	Geragai	Immature water	Bicarbonate water
11	Bonjol	Partial equilibrium	Chloride water
12	Gunung Talang	Partial equilibrium	Bicarbonate water
13	Bangka Belitung	Partial equilibrium and immature water	Chloride water and bicarbonate water
14	Lokop	Immature water	Bicarbonate water
15	Kepahiang	Immature water	Bicarbonate water
16	Kampar-Kuantar Singingi	Immature water	Bicarbonate water
17	Pincurak	Immature water	Sulphate to Chloride water

4.2 Ratio of Geoindicators

Table 2. Ratios of chemical indicators of geothermal water in Sumatera Island

Geothermal Field	Temp. (˚C)	pH	Ratio		
			Na/K	Cl/Mg	NH_4/B
Danau Ranau	37.3 - 63.7	6.9 - 7.5	5.00 - 32.13	0.85 - 9.72	0 - 0.28
Bukit Kili	36.7 - 61.1	6.8 - 7.6	4.58 - 15.62	2.72 - 90.55	0.03 - 1.23
Sipoholon-Siriaria	39.5 - 64.2	6.1 - 7.2	2.50 - 11.50	1.33 - 5.51	0.53 - 303.88
Cubadak	37.1 - 92.0	6.4 - 7.9	1.82 - 29.49	10.78 - 401.43	0 - 2.76
Sumani	34.9 - 71.6	6.4 - 7.1	3.79 - 28.87	0.19 - 118.83	0 - 2.88
Simisuh	41.2 - 91.4	7.4 - 8.9	23.83 - 35.56	14.40 - 773.33	0 - 0.27
Talu-Tombang	40.4 - 49.4	7.0 - 7.8	3.76 - 20.28	11.78 - 107.47	0.02 - 0.14
Dolok Marawa	37.4 - 63.2	6.6 - 7.6	3.27 - 3.64	6.07 - 8.21	0 - 0.03
Wai Selabung	44.4 - 92.5	7.8 - 9.5	10.05 - 26.36	1.41 - 1242.50	0 - 0.53
Geragai	32.55 - 61.5	2.3 - 7.5	2.63 - 4.78	0.04 - 0.87	0.31 - 42
Bonjol	27.4 - 87.9	6.5 - 7.5	18.34 - 19.69	33.76 - 6449.78	0.08 - 0.16
Gunung Talang	43.1 - 56.8	8.2 - 8.6	4.51 - 5.44	0.87 - 3.62	0.50 - 1.86
Bangka Belitung	37.3 - 61.8	4.9 - 6.9	1.20 - 24.88	3.23 - 289.52	0.80 - 1.88
Lokop	37.0 - 93.5	6.9 - 9.0	8.42 - 86.65	2.33 - 63.44	0.38 - 1.60
Kepahiang	36.0 - 43.3	5.5 - 6.4	3.46 - 5.01	2.06 - 4.69	0.33 - 1.27
Kampar-Kuantar Singingi	31.5 - 64.5	6.9 - 8.3	3.27 - 43.29	0.13 - 28.87	0.03 - 6.67
Pincurak	-	6.1 - 7.2	8.37 - 9.13	23.73 - 43.86	0.12 - 0.28

Table 2 shows that Cubadak, Talu-Tombang, Dolok Marawa, Bonjol, Bangka Belitung, and Pincurak has a ratio value of Na/K lower than ratio values of Cl/Mg. Low ratio of Na/K and a high ratio of Cl/Mg geoindicators can indicate upflow zones, high permeability, or high-temperature zones (Nicholson, 1993). Ratios of Na/K of samples from geothermal waters in Sumatera Island are relatively low, most of the ratios are less than 30, and Bangka Belitung has the lowest ratio of Na/K that ranges between 1.20-24.88. Ratios of Cl/Mg of samples from geothermal waters in Sumatera Island varies. Bonjol has the highest ratio of Cl/Mg that has range 33.76-6449.78; it can indicate that Bonjol has a high-temperature reservoir or high permeability.

Ratios of NH_4/B are relatively low to all samples from 17 geothermal prospects in Sumatera Island. Water from andesitic host rocks has higher boron levels than those associated with other volcanic rocks. The ratio of NH_4/B can indicate steam heating or sediment basement, and low ratios of NH_4/B in Table 2 indicate no steam heating near the surface.

5. CONCLUSIONS

One hundred samples from 17 geothermal prospects were used to know the characteristics of geothermal water in Sumatera Island. The characteristics of geothermal water in Sumatera Island based on the Na-K-Mg and Cl-SO_4-HCO_3 ternary diagram consisting of bicarbonate water, sulphate waters, and chloride water, but mostly are indicative of bicarbonate waters. Most of the geothermal waters are partial equilibrium water and immature water, caused by mixing with groundwater. The different of surrounding rock and various of water-rock interaction between geothermal waters and rock yields the differences between each geothermal prospect. The estimated reservoir temperature for geothermal prospects in Sumatera Island varies from 120˚C to 190˚C, with Bonjol being estimated to have the highest reservoir temperature at about 180˚-190˚C.

The ratio of geoindicators Na/K, Cl/Mg, and NH_4/B indicated that some geothermal prospects are associated with upflow, high-temperature zones, and no steam heating near the surface.

Geochemical studies provide an important role for geothermal resource assessments, especially for early exploration stages. Thus, careful geochemical studies are needed to help delineate of geothermal boundaries or to assist in making decisions to the next stage.

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