FLUID GEOCHEMISTRY CHARACTERISTICS OF SIMBOLON AND PUSUK BUKIT GEOTHERMAL AREA IN TOBA CALDERA, NORTH SUMATRA PROVINCE, INDONESIA

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ABSTRACT

Lake Toba is administratively located in North Sumatra Province, Indonesia. Lake Toba is known as the largest volcanic lake on the earth formed by an explosive eruption about 74 ka. On the surrounding area of Lake Toba, hot springs are largely found. These hot springs are accompanied by alteration on the surrounding area. The most extensive hot springs are located on Pusuk Bukit and Simbolon area on the western part of the lake. Preliminary study of the geothermal system on Pusuk Bukit and Simbolon area revealed that these two areas are the hydrothermal system associated with Toba Caldera.

Geochemical analysis from hot springs provides information about the occurrence of two high temperature systems. The first system is in Pusuk Bukit which is associated with young volcanism. The up-flow in this area yields acid and sulfate-type hot springs. The gas chemistry shows that the source of the gas comes from meteoric origin. The second system namely Simbolon is associated with active heat source beneath Lake Toba (estimated as the remaining heat after the formation of Toba Caldera). Hot springs on Simbolon are mostly bicarbonate and sulfate water with near neutral acidity.

Fluids from Pusuk Bukit and Simbolon are the up-flow from each system. The fluids from both areas are immature fluid therefore solute geothermometer could not be applied. The fluids have high content of Na, K, and Mg. The geothermal fluid has also sustained water-rock interaction that is also supported by the occurrence of highly altered rocks largely found on the surrounding area. The stable isotope data of $\delta^{18}O$ and δD indicates boiling process for fluid in Simbolon. While fluid in Pusuk Bukit undergoes boiling and evaporation process. Based on geoindicator and stable isotope data, the geothermal fluid has meteoric origin.

1. INTRODUCTION

Indonesia is a country that is rich in geothermal resources. There are 299 geothermal prospect locations with total potential of 28.835 GWe (Geological Research and Development Centre, 2012). Based on the result of investigation, geothermal prospect locations are mostly concentrated in Sumatra Island with 90 locations. One of the geothermal potential areas is Lake Toba in North Sumatra Province (Figure 1).

Lake Toba is known as the largest caldera lake on the earth formed by an explosive eruption 74 ka (Chesner and Rose, 1991). The eruption ejected approximately 2,800 km^3 of magma (Rose and Chesner, 1990) in a single event and ranked as the largest volcanic eruption during Quaternary period. This eruption then generated the biggest caldera on the earth, measuring 100 x 30 km.

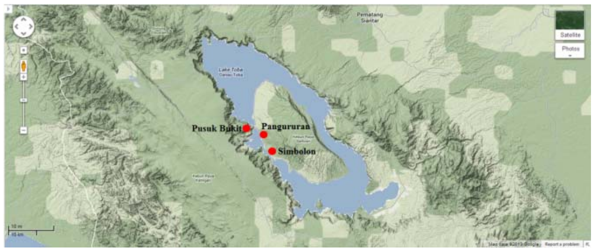

Figure 1: Lake Toba Research area (Google Maps, 2013).

On the surrounding area of Lake Toba, hot springs and altered rocks are largely found. The most extensive ones are located on Simbolon and Pusuk Bukit area on the south western part of Lake Toba. A total of seven (7) hot springs are found.

2. REGIONAL GEOLOGY

Lake Toba is a part of Toba Caldera Complex. Toba Caldera is known as the biggest volcanic caldera formed in Quaternary period. The effect of this eruption was felt almost on the entire part of South East Asia as temperature changes and environmental damages. The history of Toba Caldera formation and evolution was started at 1.3 Ma (Chesner, 2011) when the oldest volcanic rock unit formed before the caldera-forming eruption (Figure 2). The rock units in Toba Caldera Complex are as follows;

2.1 Pre-caldera Andesite

This is the oldest volcanic rock dated 1.3 Ma based on K-Ar dating (Yokoyama and Hehanussa, 1981). The rocks are pyroxene andesites and basaltic andesites. The outcrops can be found mostly on the northern part of Lake Toba, e.g. in Haranggaol to near Sipisupisu area. This rock unit is represented a large stratovolcano on the northern part of present caldera.

2.2 Haranggaol Dacite Tuff (HDT)

This rock unit is densely welded dacitic tuff and represents the beginning of caldera-forming eruption. Dating by fission track method gave 1.2 Ma of age (Nishimura et al., 1977) and interpreted as crater-lake type caldera eruption from the pre-caldera stratovolcano from which Pre-Caldera Andesite erupted. The HDT outcrops could be found in Haranggaol and on the rim between Haranggaol and Tigaras.

2.3 Oldest Toba Tuff (OTT)

Oldest Toba Tuff is the first three quartz-bearing Toba tuffs which have 840 ka in age by $^{40}Ar/^{39}Ar$ dating method (Diehl et al., 1987). The outcrops can be found on the southern part of Lake Toba with densely welded rhyolitic tuff in lithology. Based on the distribution of outcrops in Uluan Peninsula, the source of its eruption is estimated in the southern part of present Toba Caldera.

2.4 Middle Toba Tuff (MTT)

Middle Toba Tuff is found overlying Haranggaol Dacite Tuff. Distribution of Middle Toba Tuff outcrops on the northern part Lake Toba indicated that it has the same eruption source with Haranggaol Dacite Tuff. By $^{40}Ar/^{39}Ar$ dating method, the age of this rock unit is 501 ka (Chesner et al., 1991). The lithology of this rock unit is rhyolitic tuff.

2.5 Youngest Toba Tuff (YTT)

Youngest Toba Tuff is the latest quartz-bearing tuff with 74 ka in age (Chesner and Rose, 1991). The source of the eruption is approximately a linear vent system in southeastern part beneath Latung Strait. This eruption was the biggest which finally formed the present Toba Caldera. The eruption ejected about 2,800 m^3 magma and produced rhyolitic to rhyodacitic rocks. It covered all previous calderas and most of the stratovolcano on the north. The exposure of YTT is found in area between Prapat and Porsea.

2.6 Resurgent Dome

After the activity of Youngest Toba Tuff eruption, several activities have taken place in Toba Caldera. Lake Toba was filled with water almost immediately after the last eruption. The steep and unstable caldera walls surrounding Lake Toba became the main cause of landslides that resulted in sedimentation into the lake. Diatome-rich lake sediments cover all Samosir Island (excluding the eastern part). These lake sediments are known as Samosir Formation.

Samosir Island is believed as a resurgent dome that uplifted at least 1100 m to its present position. It is a westward tilted, 5-8° dipped to the west, diatomaceous lake sediment rich lava dome. This 60 x 20 km lava dome is indicated by ^{14}C dating method that it was still beneath lake level about 33 ka (Chesner et al., 2000). Another noticeable resurgent dome is Uluan Peninsula. Its surface dips 10-15° to the east. Both Samosir Island and Uluan Peninsula are considered to represent 2 half domes separated by a deep sector graben, namely the Latung Strait.

2.7 Lava Domes

After Young Toba Tuff eruption, there was an eruption from several lava domes. Post YTT eruption within the caldera was concentrated in two areas, the southwestern ring fracture and the northern part of Samosir fault. The composition of eruption material resembles YTT composition. This suggests that the remnant of YTT magma possibly erupted during the resurgence.

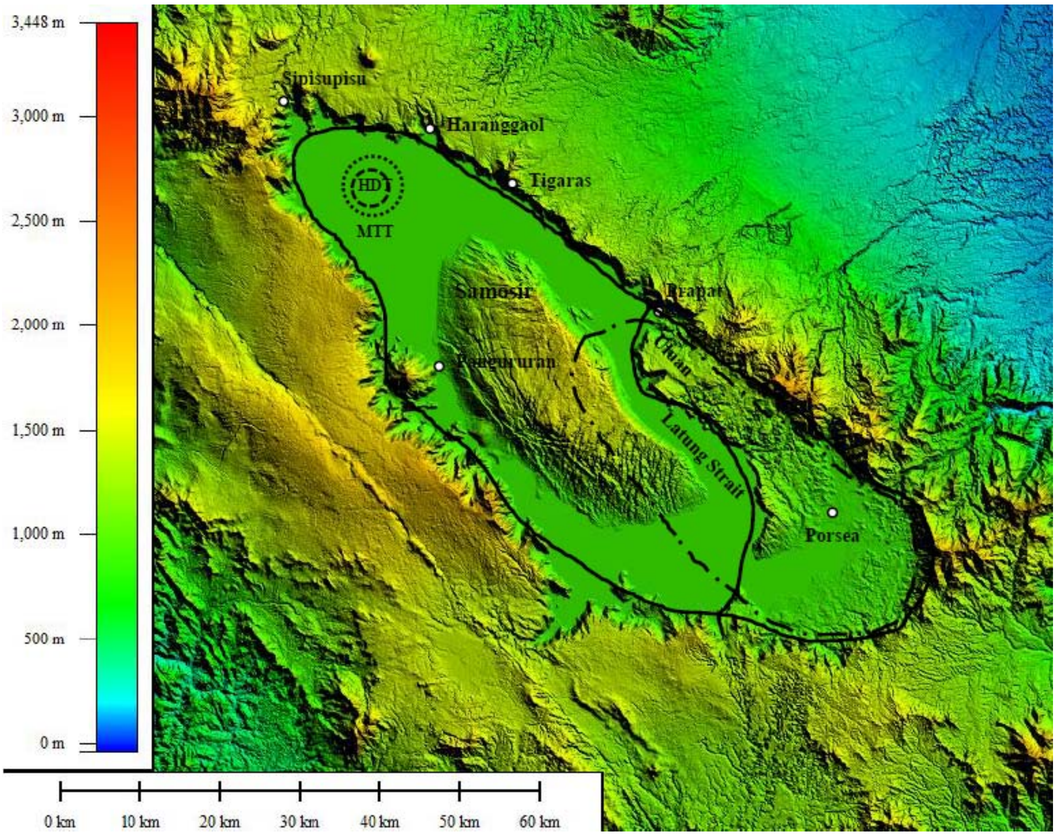

Figure 2: Distribution of pre-caldera volcanic rocks and caldera-fill rocks (modified from Chesner, 2011).

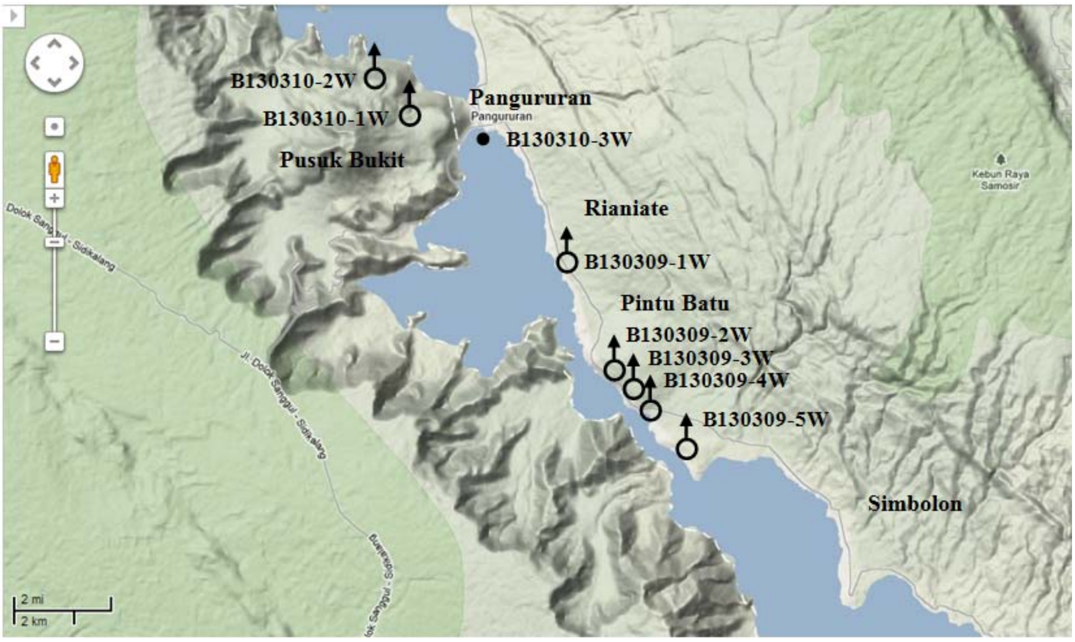

Figure 3: Location of hot springs in Simbolon and Pusuk Bukit geothermal fields (Google Maps, 2013).

3. FLUID GEOCHEMISTRY ANALYSIS

3.1 Samples

Geothermal manifestations such as fumaroles, hot springs, and altered rocks were mainly distributed at the western part of Lake Toba. There are two main sites of the hot springs; Pusuk Bukit and Simbolon fields.

Two hot spring water samples were collected from Pusuk Bukit and 5 samples from Simbolon area (Figure 3). Observation was done in each hot springs that consists of its location, hot springs appearance, and measurement of hot springs characteristics. The characteristics of each hot spring are shown on Table 1.

Table 1. Samples from Simbolon and Pusuk Bukit geothermal fields.

Sample Number	Location	Occurrence	Temperature (°C)	pH
B130309-1W	Rianite	Hot spring	69.6	6.79
B130309-2W	Pintu Batu	Hot spring	40.2	2.40
B130309-3W	Pintu Batu	Hot spring	49.4	2.28
B130309-4W	Simbolon	Hot spring	84.6	6.84
B130309-5W	Simbolon	Hot spring	40.8	2.37
B130310-1W	Pusuk Bukit	Hot spring	52.3	1.99
B130310-2W	Pusuk Bukit	Hot spring	96.3	2.09
B130310-3W	Pangururan	Lake water	27.3	6.88

3.2 Water and Gas Analysis

Hot spring water and gas samples were collected from each hot springs. In total, 8 water samples were taken; 7 samples from hot springs and 1 sample from lake water. As for the gas samples, 4 samples were taken in total. These samples were then analyzed for water chemistry, stable isotope, and gas chemistry in the laboratory.

3.3 Water Type

Water type is shown on Figure 4 based on the dominant anion (Giggenbach, 1988). Hot springs from Simbolon and Pusuk Bukit are grouped into 2 water types. The first type is Cl and HCO_3 type represented by hot springs from Rianiate. The water has near-neutral pH. The principle constituents are Cl in anions. The water suggests a mixing of deep neutral Cl and steam-heated bicarbonate water in origin. The hot spring is discharging at the northern end of Simbolon field.

The second type is steam-heated water; most of them are acid sulfate water from Pintu Batu and Simbolon in the Simbolon field, and from Pusuk Bukit field. The principal constituent of anion is SO_4 ranging from 635 to 2570 mg/l, and chloride ion which is less than a few mg/l. The pH of these samples is acid, about pH = 2. Such characteristics indicate typical steam-heated acid SO_4 water. Among the steam-heated water, B130309-4W from Simbolon is unique; where pH is neutral, and NH_4 is dominant in cation. Probably organic rich sediments could be underlain in these areas.

3.4 Geoindicator

Based on the content of Cl, Li, and B, Simbolon and Pusuk Bukit fields have different reservoir (Figure 5). The first reservoir is located in Simbolon area. Simbolon reservoir yields several surface hot springs including Rianiate hot spring, Pintu Batu warm spring, Pintu Batu hot spring, and Simbolon hot spring. This reservoir has small value of Li/B, Li/Cl and B/Cl. It indicates that water-rock interaction became the major process occurring within the system. Small ratio value also shows that the hot springs are the up-flow from reservoir. This is supported by the low value of Na/K and Na/Ca.

The second reservoir is Pusuk Bukit reservoir. The up-flow of this reservoir yields acid sulfate-type hot springs. The fluid from these hot springs shows relatively high value of Na/K and Na/Ca. The increasing value of Na/Ca indicates that the fluid is fed directly from reservoir as up-flow. The relatively high content of B in water samples give indication of interaction between geothermal fluid and organic rich sedimentary rocks at depth.

3.5 Water Maturity

Water maturity for samples from Simbolon and Pusuk Bukit fields is shown on Figure 6. All samples are plotted in the immature water region. This suggests that all samples are not suitable for the evaluation by Na/K geothermometer. This is concordant with the occurrence of the hot springs; all of the hot springs except B130309-1W are steam-heated water. Although the B130309-1W is plotted in a region of immature waters, this suggests mixing of a deep water with 200°C and meteoric water.

3.6 Interpretation of Water Chemistry

Most of geothermal fluids from Simbolon and Pusuk Bukit geothermal fields are steam-heated water composed of acid SO_4 and neutral HCO_3-SO_4 types and only one sample (B130309-1W) is a Cl-HCO_3 type. Steam-heated waters contain are less amount of B. On the other hand, sample B130309-1W of Cl-HCO_3 type has relatively high content of B. This indicates that a part of the fluid undergoes reaction process with organic rich sedimentary rock at depth. This interaction with organic rich sedimentary rock is also supported by the high value of ammonium (NH_4) in steam-heated water of B130309-4W at Simbolon, the site shows a strong steaming activity in the Simbolon area. Once boiling occurs, NH_4 together with other gases go into the shallow zone and absorbed in to ground water. This NH_4 probably originated from organic rich sedimentary rock. In the research area, sedimentary rock is found as Kluet Formation that consists of metaquartzose arenites, metawackes, slates and phyllites (Aldiss et al., 1983).

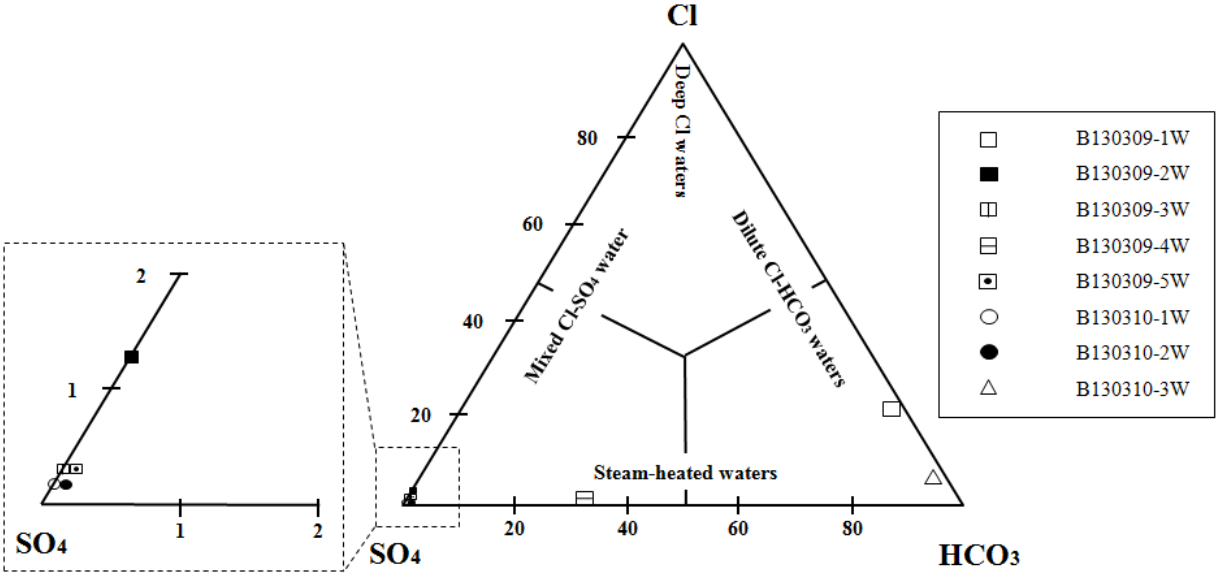

Figure 4: Chemical types for water from hot springs on Simbolon and Pusuk Bukit.

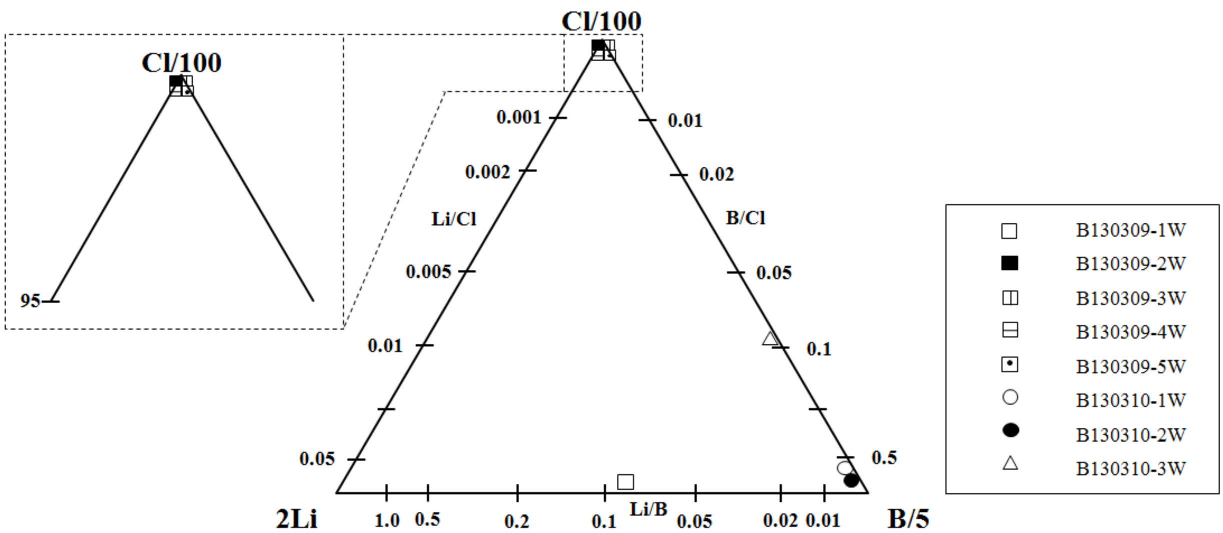

Figure 5: Cl-Li-B diagram for water from hot springs on Simbolon and Pusuk Bukit.

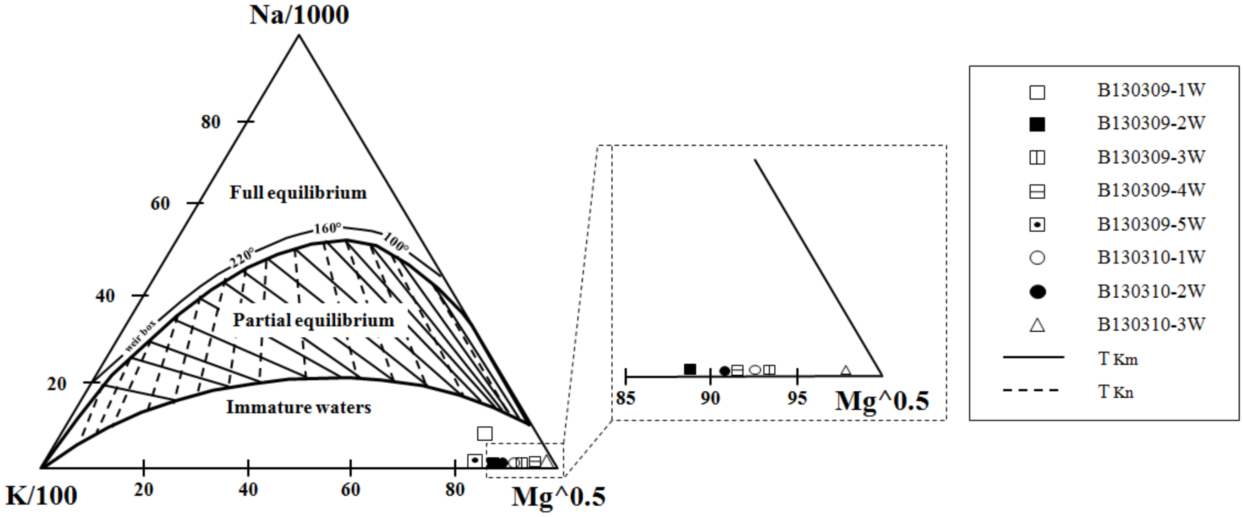

Figure 6: Na-K-Mg diagram for hot springs from Simbolon and Pusuk Bukit geothermal fields.

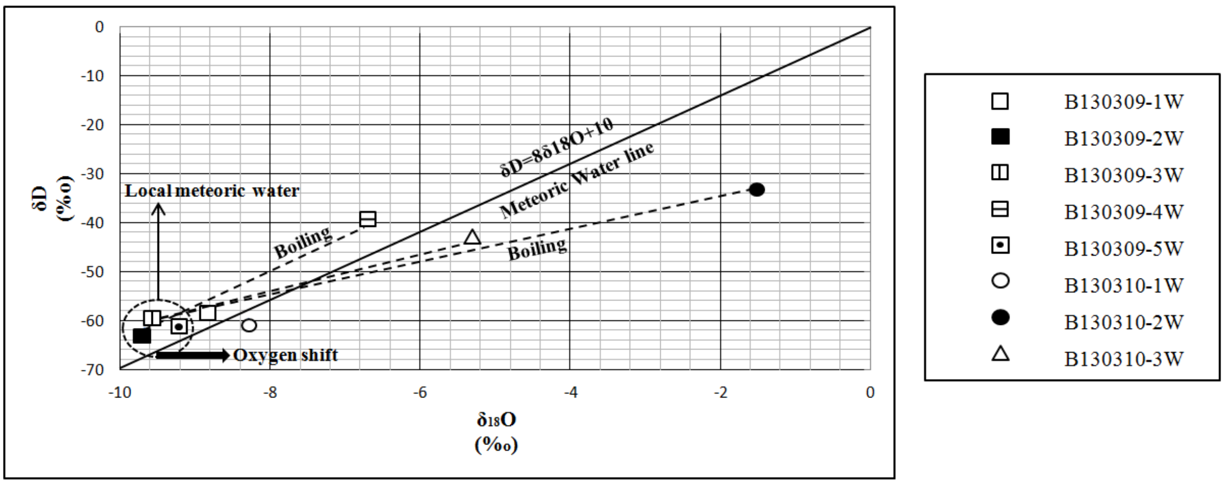

Figure 7: Stable isotope data of water from hot springs on Simbolon and Pusuk Bukit geothermal fields.

4. SOURCE OF FLUID

Result of stable isotope analysis is shown in Figure 7. Except B130309-4W and B130310-2W, most of the hot springs from Simbolon and Pusuk Bukit fields are plotted at about -60‰ for δD and -7.2‰ for δ^{18}O. These hot spring waters from B130309-2W, B130309-3W, B130309-4W, B130309-5W, B130310-1W, and B130310-2W are steam-heated water. These hot springs possibly originated from the local surface water at this level. These fluids are undergoing boiling process, following the trend line. The fluids from B130309-4W and B130310-2W suggest that they are residue from boiled water from Pintu Batu and Pusuk Bukit fields. Toba Lake water is probably enriched by evaporation under ambient temperature.

5. CONCLUSION

Lake Toba in North Sumatra Province, Indonesia is acknowledged as the largest volcanic lake on the earth. This lake was formed by the most striking volcanic eruption 74 ka. Lake Toba is a part of Toba Caldera on which several geothermal hot springs are found on the western part of the lake.

The hot springs are distributed in 2 areas, namely Simbolon and Pusuk Bukit fields. In total, 7 hot springs are found. From these hot springs, water samples were obtained in order to analyze their chemical content.

Based on geochemistry analysis, the hot springs in Simbolon and Pusuk Bukit geothermal fields show Cl-HCO_3 and steam-heated water type. The geothermal fluid on both areas has meteoric origin. Interaction between geothermal fluid and organic rich sedimentary rock is expected to occur at depth as evidenced by the high value of NH_4 and B in some samples.

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