Recharge Elevation of Hot Spring Study in the Mt. Muayat at the Kotamobagu Geothermal Field, North Sulawesi, Indonesia Using the Stable Isotope 18O and 2H

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RECHARGE ELEVATION OF HOT SPRING STUDY IN THE MT. MUAYAT AT THE KOTAMOBAGU GEOTHERMAL FIELD, NORTH SULAWESI, INDONESIA USING THE STABLE ISOTOPE ^{18}O AND ^{2}H

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ABSTRACT

Water samples of Mt. Muayat consisting of hot spring and river water were analyzed stable isotope. Rain water was also collected using a rainwater collector of open air type from five locations with elevations ranging from 556m to 1500m during March 2010 to June 2010. Six hot spring waters of Mt. Muayat have shift of less than 2‰. This implies that the origin of hot spring water is mainly meteoric water. The meteoric water has recharged to the ground of Mt. Muayat flowed through the shallow aquifer at low temperature to the west or south west. The pathway of water in the shallow aquifer may be through the high permeability in pumice tuff or can through the fault before discharged to the hot springs in the lower elevation in Liberia, Bongkudai, Bilalang and Wangga villages. The sources of hot spring recharge in the Kotamobagu was estimated by evaluating the isotope of local meteoric water and hot springs with neglected effect of evaporate located from 893m to 1227m above sea level of Mt. Muayat.

INTRODUCTION

Kotamobagu geothermal field is located in North Sulawesi Province, Indonesia, 200 km to the southwest of Manado city, capital of the province (Fig.1). The field has been proved to be one of the geothermal prospects in Indonesia (Hochstein and Sudarman, 2008). Pertamina Geothermal Energy Co. (PT. PGE) conducted reconnaissance and feasibility studies in Kotamobagu and concluded that the field has high potential for power generation, (PT.PGE, 2005).

The relationship between stable isotope (δ^{18}O and δ^{2}H) of rainwater, river water and elevation the isotope content of groundwater commonly used to determine the recharge zone. This relationship of the composition of stable isotope decreasing with increasing elevation (Dansgaard, 1964), is a way for delineating the zone of recharge by elevation.

In the geothermal area, the rain water from that elevation come to the surface, to infiltrate and percolate into the ground, flowing in the shallow aquifer, receipt of warming up by an underground heat source and discharges to the lower elevations or continuing to the depth reach the reservoir of geothermal fluid and flows up again to the surface as the cycles. Meteoric waters are entering the ground and are heated to a certain extend depending on the depth and the distance to the heat source. The isotope exchange kinetics between water and rock is very slow rate at normal temperature. There is no significant change of the δ^{2}H in the groundwater or aquifer when the water through the rock or still represent region of recharge from meteoric water. The enrichment δ^{18}O in geothermal water occurs due to interaction of the meteoric water and the rock at high temperatures where the composition δ^{18}O of rocks changing to poor and water become to richer (Panichi et al., 1978). Most of geothermal waters have oxygen isotope shift of less than 2‰. The oxygen isotopes shift in Tengchong, China: 1.8-3.5‰ of Ruidian geothermal field and 1.6-2.0‰ of Hot Sea geothermal field (Minzi et al, 1988); about 1‰ in New Zealand and Columbia (Panichi et al., 1978). The purpose of this study is to estimate the recharge elevation of hot spring waters using term of stable isotope (δ^{18}O, δ^{2}H).

GEOLOGY

Geological Setting

Geological map of Kotamobagu is shown in Fig.2. The area is covered by the Tertiary and the Quaternary rocks. The Tertiary sedimentary rocks consist of shale and sandstone with intercalation of limestone and chert, and are overlain by the Tertiary and Quaternary volcanic rocks. The Tertiary rocks are limestone and chert, and are overlain by the Tertiary and Quaternary volcanic rocks. The Tertiary volcanic rocks are the products of Old volcano and consist of breccia, tuff, andesitic lava, dacite and rhyolite to form Mt. Simut and Mt. Lemibut located to the north of Mt. Muayat. The Quaternary volcanic rocks consist of the Old and Young Ambang volcanic. Tuff-pumice and andesitic-breccia are the products of the Old Ambang Volcano. The Young Ambang volcanic rocks consist of andesitic lava and magma breccia are overlain Mt. Muayat, Mt. Banga, and Mt. Ambang asymmetrically.

Geological Structure

Faults in Kotamobagu have directions northwest to southeast, northeast to southwest and west to east as shown in Fig. 2. In this figure, the fault is indicated with solid line and the inferred fault with dashed line. A fault system with a direction of west to east which is crossing the sedimentary rocks controls the appearance of hot springs at Pusian and Bakan, located to the southwest and south of Kotamobagu. Another fault system with a direction of northwest to southeast controls the presence of hot springs at Lobong in the west of Kotamobagu (PT.PGE, 2005). Fumaroles on top of Mt. Muayat located in the east of Kotamobagu have a high temperature 102.7°C and are associated with faults running northeast to southwest (PT.PGE, 2005). This fault system also controls an appearance of hot spring at Liberia village as well as Bongkudai village.

SAMPLING LOCATION

Twenty one water samples were collected from hot spring and river water distributed in the area 10 km NS and 20 km EW of Kotamobagu, Fig.1. Elevation of sampling site ranges from 256m up to 752 m, Table 1. Hot spring samples at Liberia village in the eastern of Kotamobagu (LIBH-1, LIBH-2, and LIBH-3) were collected in the paddy field.

Natural discharges were collected of river floors at Bongkudai (BONH-6), Bilalang (BILH-13) and one sample on 2m beside of the river at Wangga village (WANH-14). The number of the sample ID corresponds to that in Fig.2.

Rainwater at three locations (R1, R2, and R3) in the southern and at the two locations (R4 and R5) in the northern of Mt. Muayat were collected, and these elevations are ranging from 556 m to 1500 m.

Rainfall data was obtained from Kotamobagu Station (RS1) and Modoinding Station (RS2). RS1 is located at the low elevation 189m of western Kotamobagu and RS2 at the high elevation, 1095m, in the north-eastern Kotamobagu on the slope of Mt. Muayat. Information on wind direction was collected from Meteorology and Geophysics of Board (BMG) in Manado city.

SAMPLING METHOD AND ANALYSIS METHODS

Samples of hot springs and river were collected in 250 ml polythene bottle after filtrating by 0.45μm membrane filter for isotope ($\delta^{18}O$, $\delta^{2}H$) analysis. Water temperature, Electric Conductivity (EC) and pH were measured on site by portable instruments.

Twelve rain water samples and fifteen river water were collected using rainwater collectors and stored in 50 mL polythene bottle after filtering through a 0.45μm membrane filter. The rainwater collectors of open type with a 2 L volume were mounted on the top of wooden stick and exposed to the open air at 75 cm high from the ground.

All water samples were equilibrated with CO_2 and H_2 for $^{18}O/^{16}O$ and D/H analyses, respectively. The isotope ratios were then measured using a DELTA Plus mass-spectrometer at Fukuoka University, Japan. The precision of the measurements is ±0.1 ‰ for the O isotope ratios and ±1‰ for the H isotope ratios.

RESULT AND DISCUSSION

Stable Isotope

Analyzed results of stable isotope of rainwater and river water are summarized in Table 1 and Table 2.

The isotope of rainwater in April have ranging from -6.1 ‰ to 6.2‰ for $\delta^{18}O$ and -35 ‰ to -36‰ for $\delta^{2}H$, in May from -8.9 ‰ to -9‰ for $\delta^{18}O$ and -59.8 ‰ to -60.4‰ for $\delta^{2}H$ and in June from -8.1 ‰ to -9.0‰ for $\delta^{18}O$ and -51.0 ‰ to -61.4‰ for $\delta^{2}H$. These are lighter than that of the δ-values ($\delta^{18}O$, $\delta^{2}H$) in March ranging from -2.2 ‰ to -3.2‰ for $\delta^{18}O$ and -1 ‰ to -9‰ for $\delta^{2}H$. In Fig. 3 and Fig. 4 shows the relationship between isotope value and season.

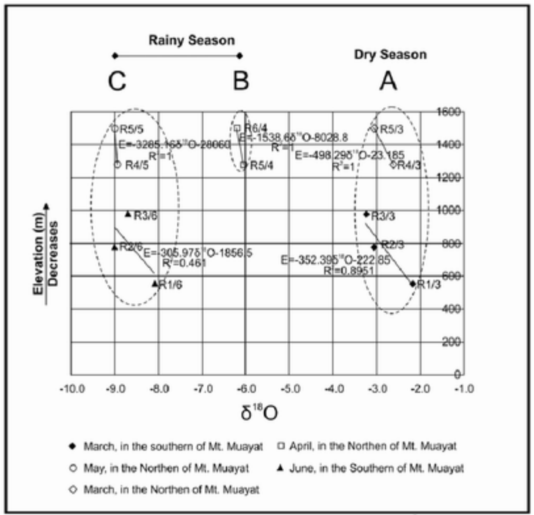

Fig. 3: Sample groupings based on $\delta^{2}O$ values, elevation and season. With increasing

elevation, the δ^2H-values of precipitation decrease (Dansgaard, 1964).

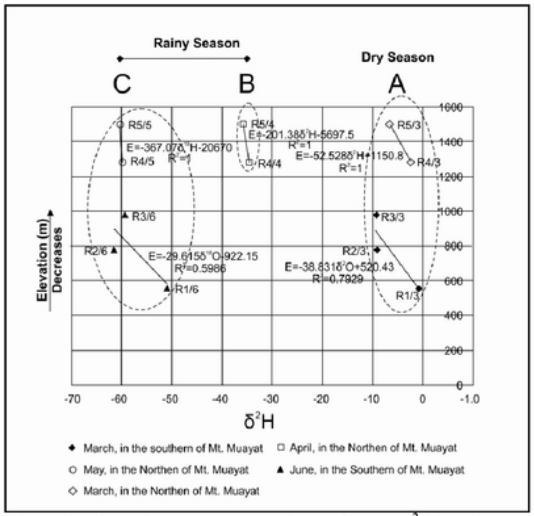

Fig. 4: Sample groupings based on δ^2H values, elevation and season. With increasing elevation, the δ^2H-values of precipitation decrease (Dansgaard, 1964).

The most effected one is evaporation speed, kinetics. Increasing elevation has decreasing of isotope values (Dansgaard, 1964 and Panichi et al., 1978).

The heavier rain was showed the δ^{18}O-values more negative in April (-6.1 ‰ to 6.2‰), May (-8.9 ‰ to -9‰), and June (-8.1 ‰ to -9.0‰) as rainy season compared to in March (-2.2 ‰ to -3.2‰) as dry season, Fig. 3 and Fig 4. In rainy season the δ^{18}O-value has more depleted and dry season as that inverse, (IAEA, 1981).

The relationship between isotope δ^2H‰ and δ^{18}O‰ of rainwater, river water and hot spring at Kotamobagu was summarized in Fig. 5.

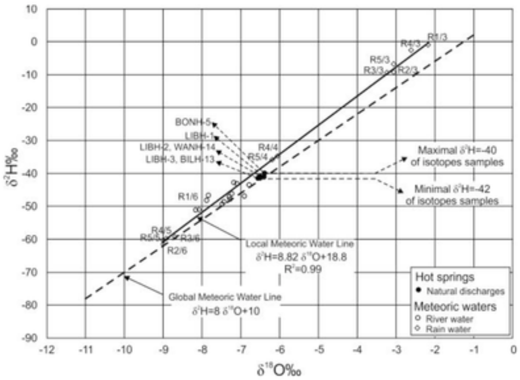

Figure 5: The relationship between isotope δ^2H‰ and δ^{18}O‰ of rainwater, river water and hot spring.

Kotamobagu area has a local characteristic of evaporation amount, degree of condensation of a vapor mass and precipitation as results of formation temperature through elevation by local topography. Formation temperature it means the formation of temperature in atmosphere at Kotamobagu area. The local characteristics of formation temperature in Kotamobagu have correlate with the composition of stable isotope in precipitation that influence to the local meteoric water. The formation temperature decreases, the δ-values of precipitation decreases, (Dansgaard, 1964).

The isotope values in twelve rain water samples collected from March to June 2010 and fifteen river water samples collected in April 2011 were plotted to determine the local meteoric water line as shown in Figure 5 using a linear interpolation with the least squares equation.

The isotope volume in June is close to the global meteoric water line due to evaporation speed, kinetic of rainy season as temperature respectively.

Hot spring samples data in Table 3 were plotted in the same figure to identify the origin of water and flow path of geothermal fluid using analysis of isotope values both of δ^2H and δ^{18}O.

Table 3: Stable isotope of hot spring water.

Sample ID	Location/ village	Elev. (m)	δ^2H (‰)	δ^{18}O (‰)
LIBH-1	Liberia	608	-41	-6.5
LIBH-2	Liberia	645	-41	-6.6
LIBH-3	Liberia	629	-42	-6.6
BONH-5	Bongkudai	476	-40	-6.5
BILH-13	Bilalang	291	-42	-6.6
WANH-14	Wangga	321	-41	-6.6

The recharge water line (RWL) was expressed by linear interpolating of isotope δ^{18}O for all locates of rainfall collectors (R1, R2, R3, R4, and R5) using least square method, (E=-672.32δ^{18}O -3512 in Fig.6) with neglected a small evaporation as long water travel to the ground.

Isotope δ^{18}O of rain samples from each rain-collector were calculated by average of isotope values vs. total rainfall each month (in mm) as below (IAEA, 1981 and Scholl et al., 1996):

$$\delta^{18}O_{sample}=\frac{\sum_{elev=1}^{n}(\delta^{18}O)_n(R)_n}{\sum_{elev=1}^{n}(R)_n}$$

Where $(\delta^{18}O)_n$ is the isotope value of precipitation for elevation interval n that collected from rainwater collectors (R1, R2, R3, R4, and R5), $(R)_n$ is the estimated recharge amount for the elevation interval n or total rainfall each month.

Elevation intervals were 220-300m. Total rainfall each month was computed by average of total rain a month for two rain-stations: St. Kotamobagu at low elevation 189 m and St. Modoinding at high elevation 1095 m.

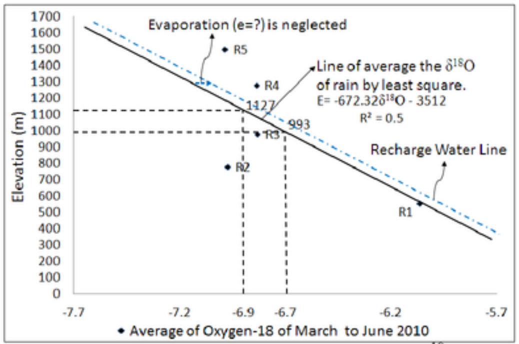

Figure 6: The relationship between $\delta^{18}O$ and elevation

The results of RWL are use to identify the recharge elevation of Mt. Muayat. The recharge elevation obtained by the minimal (-6.9‰) and the maximal (-6.7‰) of isotopes samples, where have shifting $\delta^{18}O$ in that history of water travel before discharges to hot springs, in Fig.5, to correspond with intersection between the elevation and the RWL (Fig. 6). The minimal (-6.7‰) and maximal (-6.9‰) of $\delta^{18}O$ value are results of intersections between local meteoric water line and minimal (-42‰) and maximal (-40‰) of ^{2}H of isotope samples, (Fig.5).

The recharge elevation of Mt. Muayat was obtained by evaluating the stable isotope ($\delta^{18}O$, $\delta^{2}H$) of local meteoric water and hot springs located from 993±100m to 1127±100m above sea level with neglected effect of evaporate. Computed ±100m because the altitude effects, (Yamanaka et al., 2007 and Blasch et al., 2007)

The RWL is shown relationship between the δ-values and elevation, where the stable isotope ^{18}O of precipitation decreases with increasing altitude, Fig.6. The stable isotopes of local meteoric water at Kotamobagu in March to June 2011 were obtained the $\delta^{18}O$-value decrease 0.15‰ per increasing 100m. A low correlation factor between isotope values and elevation ($\delta^{18}O$‰ vs. Elevation, R^2=0.5) in Fig. 6 may be caused of: (i) in March, 23 to 19 2011, increasing elevation from 980m to 1280m has contradicts with increasing isotope value from -3.2 to -2.6. This is maybe caused of the different sampling date and distance from the source/sea to the area of precipitation. R3 at 980m in southern Mt. Muayat are longer distance than R4 at 1280m and R5 at 1500m in northern Mt. Muayat when the wind direction south to north. (ii) Significant of decreasing isotope value from 556m to 780m compared to from 780m to 980m and the continuing to 1280m and 1500m. This is maybe caused of the different sampling date and/or source of precipitation.

Several conditions have contributed to influence the result of isotope sample in this study as below:

- Source of precipitation.
  - Amount of rainfall and formation temperature.

    Large amount of rainfall in April, May, and June may cause depletion the $\delta^{18}O$-values compared to that in March, Table 1 and Fig. 3. The lighter value of isotope in April May and June is because that the formation temperature in April, May and June is lower than March, Fig. 3 and Fig. 4.
  - Wind direction, topographic and distance from the source (sea).

    The wind blowing in March and June from the south to the north (33 km) takes the cloud of precipitate longer distance than in April and May when the wind direction from east to west (23 km), Fig. 1. The heavy isotope will be decreasing with an increase of the distance from the sea to the area of precipitation caused of altitude effect.
- Location of rainwater collector.

  The rainwater collectors of R1, R2, and R3 are located in the southern slope of Mt. Muayat and those of R4 and R5 are in the northern slope of Mt. Muayat. This means if the wind takes the cloud from south to north, the northern part area of Mt. Muayat have more depleted isotope values compared to the southern part as effect of distance and elevation.

Conceptual Model

On the Basis of lies hot springs load were made two cross sections such as A-A' and B-B' shown in the Fig.2. These cross sections (Fig. 7. and Fig. 8) showing the origin of water, pathway and discharges of geothermal fluid at Kotamobagu.

Cross section A-A' in Fig. 7 shows the meteoric water has recharges to the ground of Mt. Muayat flows through the shallow aquifer at low temperature to the west. The pathway of water in the shallow aquifer may be through the high permeability in pumice tuff or can through the fault before discharges to the hot springs in the lower elevation at Bilalang and Wangga villages.

Cross section B-B' in Fig. 8 shows the meteoric water recharges to the ground of Mt. Muayat flows through the shallow aquifer at low temperature to the south-west. This continues to the hot springs discharges in the lower elevation at summit of Mt. Muayat, Liberia and Bongkudai villages.

CONCLUSIONS

1. The recharge elevation of Mt. Muayat was obtained by evaluating the stable isotope (δ^{18}O, δ^2H) of local meteoric water and hot springs located from 893m to 1227m above sea level.
2. The origin of hot spring water at the Kotamobagu geothermal field is meteoric water.
3. Conceptual model of a geothermal fluid at Kotamobagu was developed.

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Table 1: Isotope of rainwater analyzed.

Sample ID	Rainwater Collector	Sampling date	Elevation (m)	δ^2H	δ^{18}O	Total rainfall per month (mm)			Dominant wind direction
				(‰)		RS1	RS2	Average	
R1/3	R1	18/03/2010	556	-1	-2.2	39.5	93.2	66.4	South to North
R2/3	R2	23/03/2010	780	-9	-3.1				
R3/3	R3	23/03/2010	980	-9	-3.2				
R4/3	R4	19/03/2010	1280	-2	-2.6				
R5/3	R5	19/03/2010	1500	-7	-3.1				
R4/4	R4	06/04/2010	1280	-35	-6.1	178.0	293.4	235.7	East To West
R5/4	R5	06/04/2010	1500	-36	-6.2				
R4/5	R4	31/05/2010	1280	-60	-8.9	212.3	232.6	222.5	East To West
R5/5	R5	310/5/2010	1500	-60	-9.0				
R1/6	R1	08/06/2010	556	-51	-8.1	181.4	75.2	128.3	South to North
R2/6	R2	08/06/2010	780	-61	-9.0				
R3/6	R3	8/06/2010	980	-59	-8.7				

Table 2: Isotope analyzed of river water.

Sample ID	Sampling date	Elevation (m)	$\delta^{2}H$	$\delta^{18}O$
			(‰)	
7	22/04/2011	463	-43	-7.2
8	21/04/2011	576	-43	-7.1
9	21/04/2011	585	-43	-7.2
10	22/04/2011	833	-51	-8.2
11	22/04/2011	967	-48	-7.9
12	22/04/2011	1056	-48	-7.9
13	22/04/2011	1093	-47	-7.8
14	22/04/2011	573	-48	-7.3
15	21/04/2011	604	-47	-7.3
16	21/04/2011	634	-49	-7.5
17	21/04/2011	640	-48	-7.4
18	22/04/2011	483	-43	-6.8
19	21/04/2011	598	-47	-6.9
20	22/04/2011	403	-41	-6.5
21	22/04/2011	642	-46	-7.2

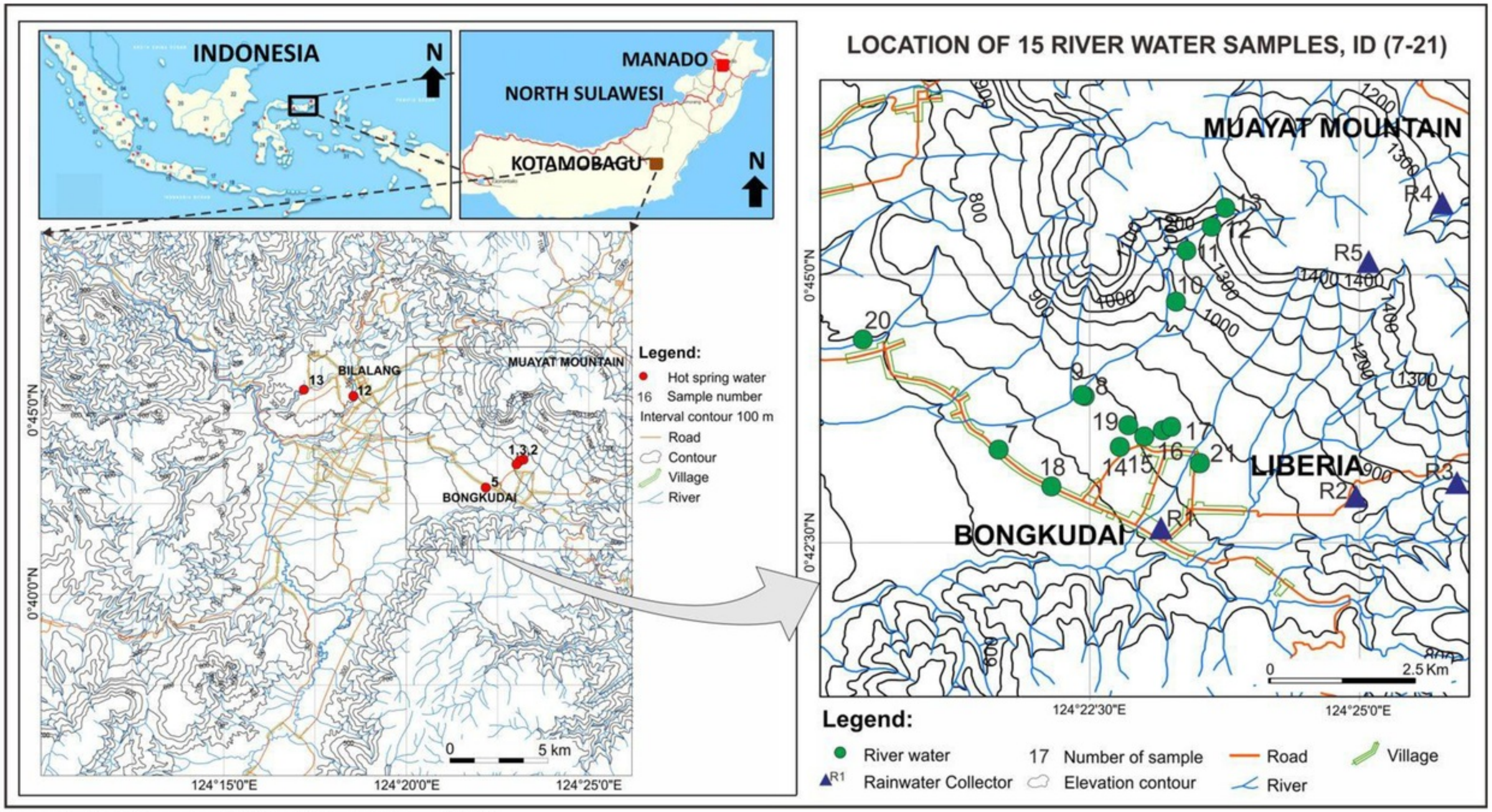

Figure 1: Location map of Kotamobagu geothermal field.

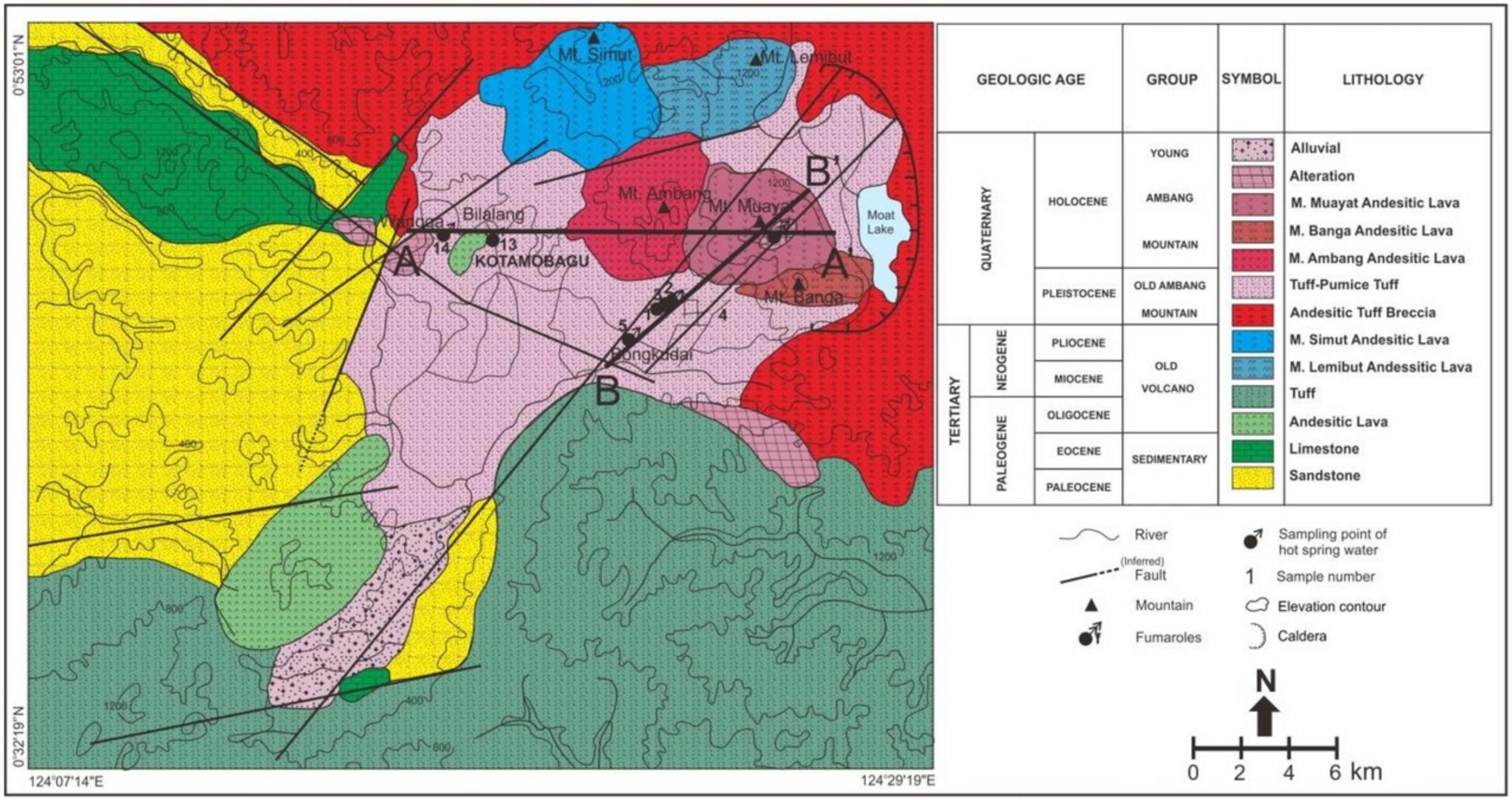

Figure 2: Geological Map of Kotamobagu. Figure is a Modified from Geological Map of Kotamobagu by Pertamina Geothermal Energy Co. (2005).

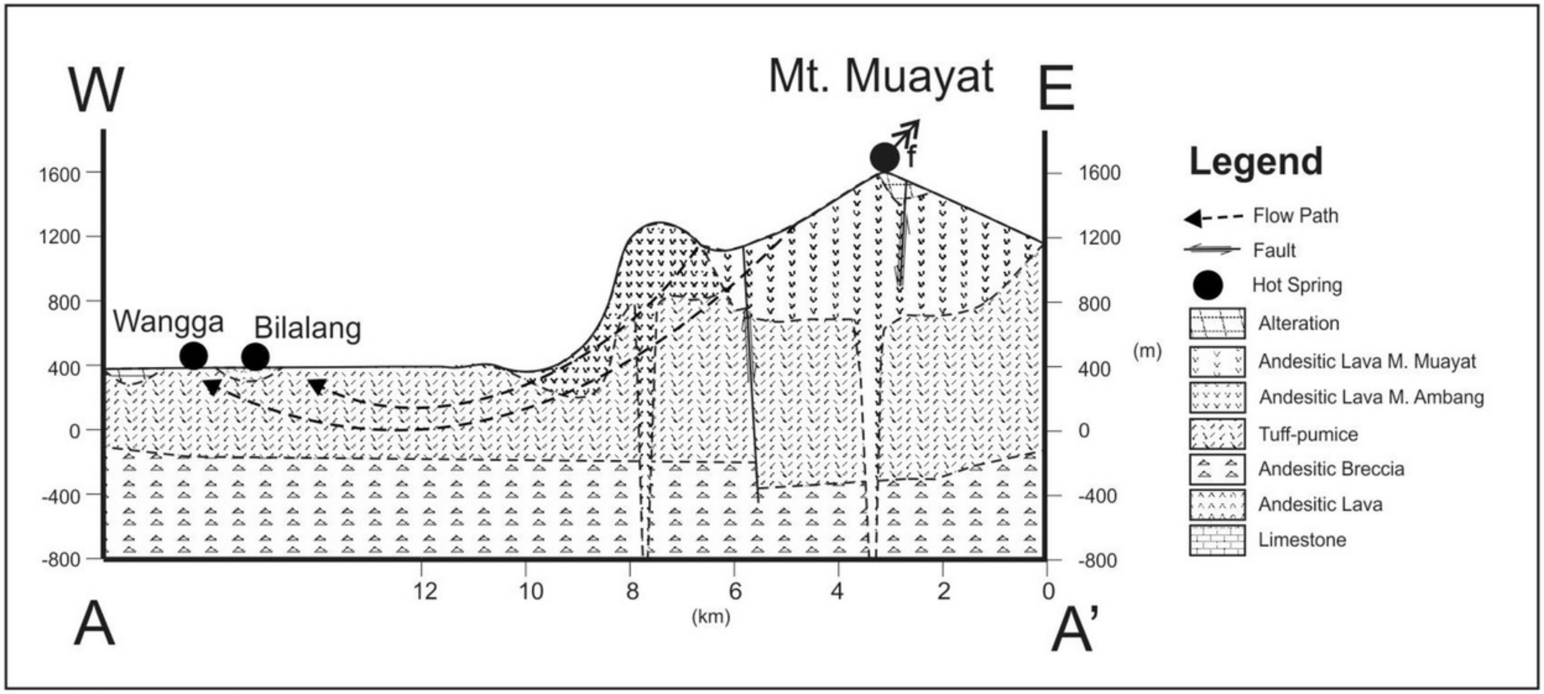

Figure 7: Conceptual model in cross section A-A'.

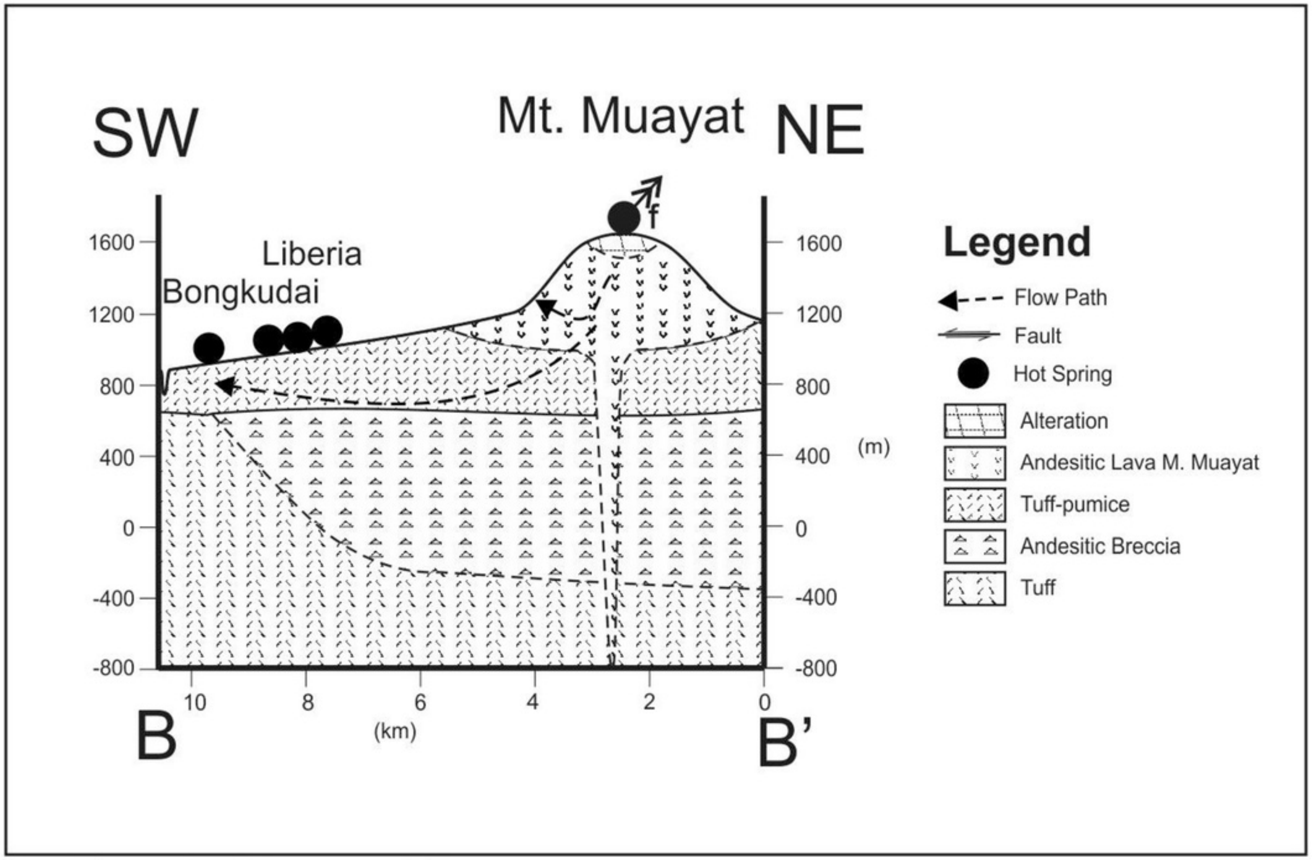

Figure 8: Conceptual model in cross section B-B'.

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