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Magmatism of Papandayan Volcano based on Deuterium and Oxygen-18 Isotopic Composition

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Abstract— *This study aims to find out the magma contribution using geochemical approach, one of which is through the measurement of deuterium and oxygen-18 Isotopic composition from condensate samples. In this study the Papandayan Volcano was chosen because it has a wide spread of fumarole fields. In 2017, fifteen years after 2002 eruption, the mixing fraction of oxygen-18 isotope generally decressed from high to medium and low such as Welirang 4.17%, Balagadama 41.15, Nangklak 34.21%, and Mas 61,15%. Mas Crater shows the highest number compared to all condensate samples in the Papandayan crater. To differentiate the classification of oxygen-18 mixing fraction which is analogous to the contribution of magma, the levels are arranged from very low to very high. Based on the deuterium isotope approach with Oxygen-18 fumarole gas, Papandayan has magmatic-hydrothermal characteristics and the magma contribution change to medium and very low mixing fraction of Oxygen-18 isotope. In addition, the study is very useful in the management of geological-based tourism and geopark development efforts in the future.*

Keywords— *Isotope, deuterium, oxygen-18, mixing ratio, Papandayan.*

I. INTRODUCTION

Papandayan is an A-type active volcano located in the southern part of Garut Regency, about 70 km southeast of Bandung, Indonesia. Its earliest recorded eruption, and most violent and devastating outburst occurred in 1772 and the latest eruptions occurred in the period of 11 November to 8 December 2002, and consisted of freatic, freatomagmatic and magmatic types of eruption [1]. Papandayan is dominated by young Quaterary andesitic rocks, showing cones, faults, dome and collapse structures. Extensive alteration of inner and outer volcanic flank with high tempearature fumaroles (80–150ºC), indicates that H_2S gases affect on fresh rocks. The gas geothermometry shows 250ºC or higher subsurface temperature, suggesting the low temperatur gas may take place below the older Tegal Alun-Alun volcanics [2].

Before the 2002 eruption, a small phreatic eruption occurred in 1998 discharging gas and mud that reached a height of 5 m above the crater. The distribution of the eruption products just confined around the horseshoe-shaped crater [3]. According to [1], it shows that the 2002 eruption that deformation during eruption tends to be local, e.g. just around the crater. Pressure source is difficult to be properly modeled from GPS results, due to limited GPS data available and differences in topography, geological structure and/or rheology related to each GPS station.

Meanwhile, [3] states that during the 2002 eruption the increase in seismicity, the fine-grained hydrothermal altered rocks, and the existence of some faults that pass through the summit region might have weaken the stability of the summit area. As the result, a landslide occurred on the north flank of Mount Nangklak where the landslide material blocked the upper course of Cibeureum Gede River. This landslide material had formed big mudflows that caused several houses of five villages were partly burried, some bridges were devastated and several hectares of cultivated land were damaged.

According to [4], the study based on hydrothermal system. It shows that changes in chemistry of Papandayan observed in 2003 were the consequence of the opening of new fractures where unaltered or less altered volcanic rocks were in contact with the ascending acid water. The high δ34S values (9-17‰) observed in the acid sulphate-chloride water before the November 2002 eruption suggest that dissolved sulphates were mainly formed by the disproportionation of magmatic SO_2. On the other hand, the low δ34S values (-0.3-7 ‰) observed in acid sulphate-chloride water sampled after the eruption suggest that the origin of dissolved sulphates for these waters is the surficial oxidation of hydrogen sulphide.

According to [5], it indicate mean SO_2 emission rates of 1.4 t d−1 from the fumarolic activity of Papandayan. Performed self-potential (SP), soil temperature, and gas concentrations in the soil (CO_2, SO_2, and H_2S) measurements in 2012, [6] proven than the information of the subsurface at a relatively shallow to intermediate depth was of particluar interest in mitigating a volcanic activities of Papandayan. Once again, [7] find that the main degassing zones in the crater, Kawah Emas, Manuk and Kawah Baru, are all connected by conduits to this common reservoir at a depth of 100 m. Because the location of this good conductor coincides with elevated ground temperature, main fumaroles, and with detectable SO_2 degassing, they interpret it as an acid hydrothermal plume. So they conclude that the assessment of the pH conditions is necessary for the interpretation of electrical resistivity structures and self-potential distribution on hydrothermal systems where acid conditions and acidity variations can be expected due to chemical reactions between volcanic gases and groundwater.

The purpose of the study is to understand the volcanic characteristics of volcanic activity in 4 locations around the Papandayan Volcano, i.e. Mas Crater, Nangklak Crater, Balagadama Crater, and Welirang Crater. The study aims to provide chemical information on the characteristics of volcanic activities as well as to evaluate the surrounding environment in relation to volcanic disaster mitigation efforts. In order to achieve these objectives, the comprehensive study about the characteristics of the fumarole field of Papandayan Volcano were undertaken.

Based on basic chemical and isotope data, [8] and [9] in [10] suggest that fumarole vapor is the result of the mixing process of the meteoric water component with magma fluid in the shallow part of the andesite type which is at $\delta^{18}O$ in the range of 3 to $6^0/_{00}$ and δD in the range of $-30^0/_{00}$ up to $-20^0/_{00}$.

According to [11], a simple mass equilibrium equation used to estimate mixing fraction and fluid concentration is calculated using line equations and oxygen-18 isotope content. To differentiate the classification of oxygen-18 mixing fraction which is analogous to the contribution of magma, the levels are arranged from very low (green colour, less than 20%), low (20-40%), medium (40-60%), high (60-90%), and very high (90-100%) marked by red colour [12].

II. Method

To find out the isotopic composition of deuterium and oxygen-18 in the Papandayan Volcano, gas samples were taken from the fumarole fields of Mas Crater, Nangklak Crater, Balagadama Crater, and Welirang Crater. The data was collected from 1995 to 2017. Meanwhile, to determine the equation for the meteoric water line, cold water samples were taken from several locations from four provinces on Java.

The condensate samples from the fumarole and crater water fields were analyzed at Pusat Aplikasi Isotop dan Radiasi (PAIR), Badan Tenaga Atom Nasional (BATAN) to prepare and analyze deuterium and oxygen-18 using the LGR Liquid-Water Stable Isotope Analyzer (Los Gatos Research) DLT-100. While measurements of cold water samples were carried out at the Chemistry Laboratory of Balai Penyelidikdan dan Penembangan Teknologi Kebencanaan Geologi (BPPTKG) in Jogjakarta.

To analyze D/H volcanic condensate gas and water samples used the hydrogen method of water with a conventional zinc reduction technique, followed by an isotope mass spectometry. The ratio of $^{18}O/^{16}O$ condensate and water samples was determined using the equilibrium technique of the CO_2-H_2O ratio, then continued with mass spectometry measurements. The analytical error of isotopic measurement is ± 1 and 0.1 ($^0/_{00}$) respectively. The analysis results for all D/H and $^{18}O/^{16}O$ hydrogen and oxygen isotope ratios are expressed in numbers δ, and are called per mil deviation from Vienna Standard Mean Ocean Water (V-SMOW).

$$\delta = [R\ sample / R\ standard - 1] \times 1000\ (^0/_{00})$$

While to find out the isotope ratio, the equation from [13] is already used largerly, namely $\delta D = 8\ \delta^{18}O + 10$. This equation comes from the analysis of isotopes in a river, lake, rain, and snow water throughout the world, covering a range from -320 to + 40 ($^0/_{00}$) for δD and -40 to + 6 for $\delta^{18}O$, which includes 130 samples of water.

Ocean water is chosen as a standard and it's called standard mean ocean water or SMOW [13]. The Oxygen-18 and Deuterium value of water in the nature will generally follow the correlation with the linear line of meteoric water with the following equation:

$$\delta D = 8\ \delta^{18}O + 10$$

δD : Deuterium isotope (^2H)
$\delta^{18}O$: Oxygen isotope (^{18}O)

To calculate the fumarole oxygen-18 isotope mixing fraction in the Papandayan Plateau, the value of the Standard Magmatic Water condensate of Gendol Crater is the average measurement of the oxygen-18 isotope of $6.7^0/_{00}$. Calculation of the value of the Papandayan condensate mixing fraction results is compared with the Mount-Merapi oxygen-18 fraction [12]. The isotope data of Gendol Crater and Woro Crater are very useful to be used as comparative data with the Papandayan, by comparing two different volcanic characteristics. Merapi Volcano has explosive eruptive properties while Papandayan is typical mixing phreatic and explosive eruptions. For the calculation of the Papandayan condensate mixing fraction, the Standard Magmatic Water value of the Merend Gendol Crater is $6.7^0/_{00}$ and the Standard Meteoric Water value calculated through the meeting of meteoric water lines and sample line equations. Furthermore, the calculation of the mixing fraction can use the equation:

$$f\ \delta^{18}O = \frac{(\delta^{18}O - SMeW)}{(SMaW - SMeW)} \times 100\%$$

With:
$f\ \delta^{18}O$: fraction of oxygen-18 isotope
$\delta^{18}O$: sample (oxygen-18 isotope)
SMeW : standard Meteoric Water (oxygen-18 isotope)
SMaW : standard Magmatic Water (oxygen-18 isotope)

III. Result and Discussion

The main results of this study are shown in tables and graphs as well as equations of straight lines of meteoric water. To find out the volcanic activity in the Papandayan Volcano, measurements of Deuterium and Oxygen-18 isotopes were measured from gas samples in several locations of fumarole. The initial stage is to analyze the ratio of Deuterium and Oxygen-18 isotopes to well water and cold water which will be used to determine the equation of the meteoric water line. Then measure the condensate samples from the fumarole field and the final stage plots the isotope ratio data in the isotopic composition graph of meteoric water.

In this study, Merapi Volcano's Deuterium and Oxygen-18 isotope ratio data were used as comparative data. Graphical data was displayed together with isotope ratios data from several locations. Examples of meteoric water and condensate from fumaroles were analyzed at the Chemical Laboratory of Kusatsu Shirane Post Observatory in Japan and Laboratory of Isotope and Radiation Application Centers of the National Nuclear Energy Agency.

3.1 Determination of the Meteoric Water Line Equation

To get the equation of the meteoric water line at the study site, meteoric water samples were taken from seven locations in the Java Island in 2017 (Table I).

TABLE I. Deuterium and Oxygen-18 isotopes of meteoric water in several location in Java [14]

No	Year	Location	($^{0}/_{00}$)	
			$\delta^{18}O$	δD
1	2017	Papandayan Observatory	-8.56	-54.20
2	2017	Pondok Saladah	-10.17	-66.10
3	2017	Sikidang Dieng	-9.36	-59.40
4	2017	Dieng Observatory	-9.84	-61.10
5	2017	Water Park Dieng	-9.10	-57.20
6	1996	Guntur Garut West Java	-8.20	-51.00
7	1996	Slamet Central Java	-0.90	2.00
8	1996	Baturaden Central Java	-5.50	-30.00
9	1996	Jrakah Merapi	-8.40	-52.00
10	1996	Lamongan East Java	-5.10	-30.00

The deuterium isotope value of meteoric water in Java Island is in the range of the deuterium isotope (δD) -66$^{0}/_{00}$ to 2$^{0}/_{00}$ and the oxygen-18 isotope range ($\delta^{18}O$) is at -10.17$^{0}/_{00}$ to -0.9$^{0}/_{00}$. The ten datas are plotted in the graph $\delta^{18}O$ to δD (Fig. 1) resulting in a meteoric water line (equation below)

$$\delta D = 7.2\ \delta^{18}O + 8.3$$

The Java meteoric water equation is $\delta D = 7.3\ \delta^{18}O + 8.3$, the regression coefficient is only 0.7 different when compared with the world meteoric water equation [13] that is $\delta D = 8\ \delta^{18}O + 10$. This equation of line (equation above) will be used to determine Standard Meteoric Water (SMeW) in the calculation of the value of the oxygen-18 isotope mixing ratio of the sample. In this study also calculated the value of Standard Magmatic Water (SMaW) which indicates the average maximum magmatic value using which in this calculation uses the oxygen-18 isotope data of Gendol Crater of Merapi Volcano.

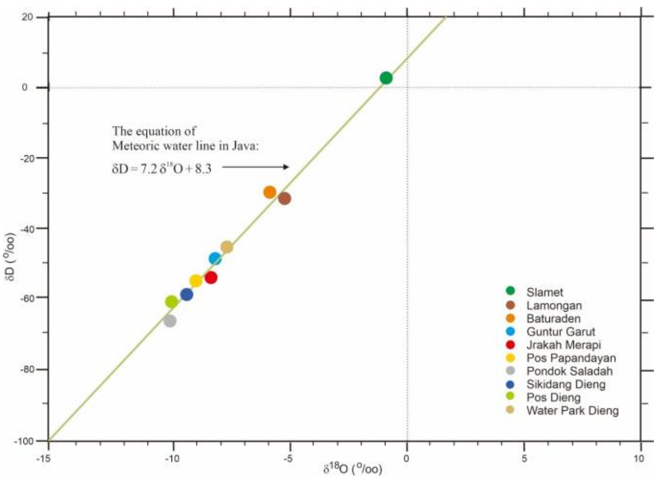

Fig. 1. Meteoric waterline from several locations in Java Island

3.2 Deuterium and Oxygen-18 isotopes in the Papandayan Condensate

Four samples of Papandayan Crater year 1995, and four samples year 1996, two samples of Mas and Nangklak Crater year 2009, and four samples year 2017 gave values of isotope-18 in the range of $\delta^{18}O$ -11.7$^{0}/_{00}$ to 4.5$^{0}/_{00}$, and deuterium isotope δD in the range from -88.3$^{0}/_{00}$ to -32$^{0}/_{0}$0 (Table II).

TABLE II. Deuterium and Oxygen-18 Isotopes of Papandayan Crater [15][16]

No	Year	Location	Code	($^{0}/_{00}$)	
				$\delta^{18}O$	δD
1	1995	Papandayan 1995	951	2.80	-35.0
2	1995	Papandayan 1995	952	3.50	-32.0
3	1995	Papandayan 1995	953	4.50	-32.0
4	1995	Papandayan 1995	954	1.30	-41.0
5	1996	Papandayan 1996	961	4.00	-36.0
6	1996	Papandayan 1996	961	3.10	-34.0
7	1996	Papandayan 1996	961	2.50	-35.0
8	1996	Papandayan 1996	961	3.20	-39.0
9	2009	Mas 2009	M09	3.40	-36.6
10	2009	Nangklak 2009	N09	1.90	-41.5
11	2017	Mas 2017	M17	-0.76	-35.6
12	2017	Nangklak 2017	N17	-5.95	-51.5
13	2017	Balagadama 2017	B17	-4.60	-45.7
14	2017	Welirang 2017	W17	-11.70	-88.3

In addition to the Papandayan condensate isotope data also shown the average Gendol Crater data [12] namely $\delta^{18}O$= 6.7$^{0}/_{00}$ and δD = 28.78$^{0}/_{00}$. Meteoric water line equations and the Merapi Gendol Crater data can be used for the calculation of Oxygen-18 isotope mixing fractions.

After plotted on the Oxygen-18 isotope correlation graph with Papandayan Deuterium and the Merapi Gendol Crater 1996 (Fig. 2, G96), equation below is obtained:

$$\delta D = 3\ \delta^{18}O - 44$$

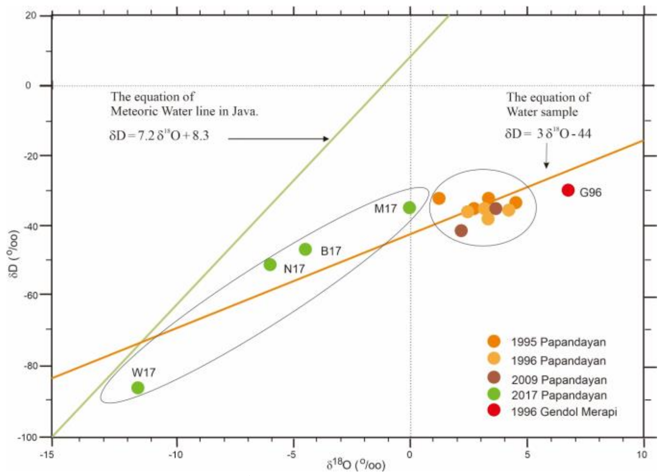

Fig. 2. Isotope δD-$\delta^{18}O$ of Papandayan and Merapi fumaroles

A total of 14 samples taken in 1995, 1996, 2009 and 2017 were divided into two large groups with oxygen-18 isotope values below zero and above zero. To study the relationship of the oxygen-18 isotope with the activity of Mount Papandayan, the point in 2002 was taken when the eruption occurred.

The 1995 and 1996 samples were in the oxygen-18 isotope value group above zero. This is related to the long increase in

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Papandayan activity prior to the 2002 eruption. After the 2002 eruption, it still had an impact until 2009 where the oxygen-18 isotope value was still above zero. Meanwhile, the results of isotope analysis in 2017 showed a shift in the four craters whose values were smaller than zero. Successively from the largest Mas Crater, Balagadama Crater, Nangklak Crater, and Welirang Crater.

The line equations of the Papandayan and the Gendol Crater Merapi Volcano and the magnitude of the oxygen-18 isotope blending fraction are then used to calculate the mixing fraction that determines the percentage of the oxygen isotope-18 in the Papandayan to the Gendol Crater which has magmatic properties, using the average value of Standard Magmatic Water (SMaW)= $6.7^0/_{00}$.

3.3 Oxygen-18 Isotope Mixing Fraction

Equation: $7.2\ \delta^{18}O + 8.3$ is the line equation of the Papandayan Volcano and Equation: $\delta D = 3\ \delta^{18}O - 44$ is the line equation of the Papandayan condensate and the Gendol Crater Merapi condensate. Both of these equations are used to find out the value of Standard Meteoric Water (SMeW), the value which is used as a baseline calculation of oxygen-18 isotope mixing fraction. The two equation above generate:

$$7.2\ \delta^{18}O + 8.3 = 3\ \delta^{18}O - 44$$
$$7.2\ \delta^{18}O - 3\ \delta^{18}O = -44 - 8.3$$
$$4.2\ \delta^{18}O = -52.3$$
$$\delta^{18}O = -12.5^0/_{00}$$

(Oxygen-18 isotope value of Standard Meteoric Water = SMeW)

Next the calculation example is displayed to find out the value of the isotope-18 mixing fraction of Mas Crater 2017 using the formula:

$$f\,\delta^{18}O = \frac{(\delta^{18}O - SMeW)}{(SMaW - SMeW)} \times 100\%$$

$f\,\delta^{18}O$: mixing fraction of Oxygen-18 isotop
SMeW : Standar Meteoric Water (Oxygen-18 isotope)
SMaW : Standard Magmatic Water (oxygen-18 isotope)

$$f\,\delta^{18}O = \frac{-0.76 - (-12.5)}{6{,}7 - (-12.5)} \times 100\%$$
$$= 61.15\%$$

The calculated value of 61.15% is the value of the oxygen-18 isotope mixing fraction of Mas Crater which reflects the level of magmatism of the Mas Crater. Sampling of Mas (M17) produces isotopes $\boldsymbol{\delta}^{18}O = -0.76^0/_{00}$ and isotopes $\delta D = -35.6^0/_{00}$.

By this calculation the value of the Papandayan Crater Isotope has the highest mixing fraction in 1996 whith 85.94% value compared to other Papandayan samples s which are located further from the Papandayan New Crater (Table III). And the lowest mixing fraction is the Welirang Crater 4.17%. This value compared with the oxygen-18 isotop in Merapi Volcano.

To find out the characteristics of the Papandayan Crater, a procedure is done by taking condensate samples scattered around the Papandayan Crater. Gas samples from the fumarole source in the Papandayan after 2002 eruption all have dominant meteoric water properties. The fractions of Oxygen-18 isotope are Welirang 4.17%, Balagadama 41.15%, Nangklak 34.21%, and Mas 61.15%. Mas Crater shows the highest number compared to all condensate samples in the Papandayan crater. Visually the Mas Crater emits steam with high pressure indicating that the Mas Crater still has magmatic properties compared to other craters of the Papandayan.

The volcanic characteristics in the Papandayan are different from the volcanic characteristics of Merapi Volcano. Merapi has magmatic characteristics with its typical explosive eruption while the Papandayan Plateau has two characters of eruption.

To differentiate the classification of oxygen-18 mixing fraction which is analogous to the contribution of magma, the levels are arranged from very low, low, medium, high, and very high [12].

TABLE III. The mixing fraction of Papandayan oxygen-18 isotope.

No	Crater	Code	Oxygen-18 isotop ($^0/_{00}$)					$f\,\delta^{18}O$ (%)
			$\delta^{18}O$	*Amas*	*Ames*	$\delta^{18}O$ - *Ames*	*Amas-Ames*	
1	Papandayan 1995	951	2.80	6.7	-12.5	15.3	19.2	79.69
2	Papandayan 1995	952	3.50	6.7	-12.5	16.0	19.2	83.33
3	Papandayan 1995	953	4.50	6.7	-12.5	17.0	19.2	88.54
4	Papandayan 1995	954	1.30	6.7	-12.5	13.8	19.2	71,88
5	Papandayan 1996	961	4.00	6.7	-12.5	16.5	19.2	85.94
6	Papandayan 1996	961	3.10	6.7	-12.5	15.6	19.2	81.25
7	Papandayan 1996	961	2.50	6.7	-12.5	15.0	19.2	78.13
8	Papandayan 1996	961	3.20	6.7	-12.5	15.7	19.2	81.77
9	Mas 2009	M09	3.40	6.7	-12.5	15.9	19.2	82,81
10	Nangklak 2009	N09	1.90	6.7	-12.5	14.4	19.2	75.00
11	Mas 2017	M17	-0.76	6.7	-12.5	11.7	19.2	61.15
12	Nangklak 2017	N17	-5.95	6.7	-12.5	6.5	19.2	34.11
13	Balagadama 2017	B17	-4.60	6.7	-12.5	7.9	19.2	41.15
14	Welirang 2017	W17	-11.70	6.7	-12.5	0.8	19.2	4.17

TABLE IV. Classification of the O-18 isotope mixing fraction Papandayan Volcano

No	Sample	Code	$f\delta^{18}O$	Magma Contribution	Symbols
1	Papandayan 1995	951	79.69	high	●
2	Papandayan 1995	952	83.33	high	●
3	Papandayan 1995	953	88.54	high	●
4	Papandayan 1995	954	71.88	high	●
5	Papandayan 1996	961	85.94	high	●
6	Papandayan 1996	961	81.25	high	●
7	Papandayan 1996	961	78.13	high	●
8	Papandayan 1996	961	81.77	high	●
9	Mas 2009	M09	82.81	high	●
10	Nangklak 2009	N09	75.00	high	●
11	Mas 2017	M17	61.15	high	●
12	Nangklak 2017	N17	34.11	low	●
13	Balagadama 2017	B17	41.15	medium	●
14	Welirang 2017	W17	4.17	Very low	●

IV. CONCLUSION

Before the eruption in 2002 the oxygen-18 isotope showed numbers above 60% with a high classification, even 7 years after the eruption the oxygen-18 isotope still showed numbers above 75.00-82.81% classified as high magma content. However, in 2017 there was a drastic decline in Welirang, Balagadama, and Nangklak Craters, except for Mas Crater which still showed a relatively high figure with 61.15%.

The results of the calculation of the oxygen-18 isotope mixing fraction in the Papandayan showed the highest value by the Mas Crater with 61.15%. The results of the research on the ratio of condensate isotopes and crater water can find out the volcanic characteristics in the Papandayan. It can be explained through this study that the volcanic characteristics in the Papandayan based on the isotope data of Deuterium and Oxygen-18 are characterized by magmatic-hydrothermal volcanic system.

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REFERENCES

[1] Abidin, H. Z., H. Andreas, M. Gamal, Ony K. Suganda, Irwan Meilano, M. Hendrasto, M. A. Kusuma, D. Darmawan, M. A. Purbawinata, A. D. Wirakusumah & F. Kimata. 2003. Ground Deformation during Papandayan Volcano 2002 Eruption as Detected by GPS Surveys. In: PROC. ITB Eng. Science Vol. 35 B, No. 1, 2003.

[2] Nasution, A., Widarto, D.S., Hutasoit, L., Yuliani, D., and Hadisoemarto, S. 2008. Geothermal Geophysical Study of Mt. Papandayan, Garut District, West Java Indonesia. In: Proceedings of the 8th Asian Geothermal Symposium, December 9-10, 2008.

[3] Hadisantono, R.D. 2006. Devastating landslides related to the 2002 Papandayan eruption. In: Jurnal Geologi Indonesia, Vol. 1 No. 2 Juni 2006: 83-88.

[4] Mazot, A. Bernard, A., and Sutawidjaja, I.S. 2007. Hydrothermal system of the Papandayan Volcano, West Java, Indonesia and its geochemistry evolution of thermal water after the November 2002 eruption. In: Jurnal Geologi Indonesia, Vol. 2 No. 1 Maret 2007: 15-29.

[5] Bani, P., Surono, M. Hendrasto, H. Gunawan, and S. Primulyana. 2013. Sulfur dioxide emissions from Papandayan and Bromo, two Indonesian volcanoes. In: Nat. Hazards Earth Syst. Sci., 13, 2399–2407, 2013.

[6] Byrdinaa, S., Revil, A., Gunawan, H., Saing, U.B., and Grandis, H. 2017. Hydrothermal System of the Papandayan Volcano from Temperature, Self-Potential (SP) and Geochemical Measurements. In: 1st International Geo-Electromagnetic Workshop (Geo-EM 2017). AIP Conf. Proc. 1861, 030033-1–030033-4; doi: 10.1063/1.4990920.

[7] Byrdinaa, S., Grandis, H., Sumintadireja, P., Caudrond, C., Syahbana, D.K., Naffrechoux, E., Gunawan, H., Suantika, G., and Vandemeulebroucka, J. 2018. Structure of the acid hydrothermal system of Papandayan volcano, Indonesia, investigated by geophysical methods. In: Journal of Volcanology and Geothermal Research 358 (2018) 77-86. https://doi.org/10.1016/j.jvolgeores.2018.06.008.

[8] Cioni, R., Corazza, E., Marini, L., 1984. The gas/steam ratio as indicator or heat transfer at the Solfatara fumaroles, Phlegrean Fields (Italy). In: Bull. Vulcanol. 47, 295–302.

[9] Chiodini, G., Cioni, R., Magro, G., Marini, L., Panichi, C., Raco, B., Russo, M., Taddeucci, G., 1996. Chemical and isotopic variation of Bocca Grande fumarole (Solfatara Volcano, Phlegrean Fields). In: Acta Vulcanologica 8 (2), 129–138.

[10] Panichi, Costanzo., Volpi, Gianni. 1999. “Hydrogen, oxygen and carbon isotope ratios of Solfatara fumaroles (Phlegrean Fields, Italy): further insight into source processes”. In: Journal of Volcanology and Geothermal Research, Volume 91, Issue 2, p. 321-328. DOI: 10.1016/S0377-0273(99)00041-4.

[11] Iskandar, I., Dermawan, F.A., Sianipar, J.Y., Suryantini; Notosiswoyo, S. “Characteristic and Mixing Mechanisms of Thermal Fluid at the Tampomas Volcano, West Java, Using Hydrogeochemistry, Stable Isotope and 222Rn Analyses”. In: Geosciences 2018, 8, 103. DOI: 10.3390/geosciences8040103.

[12] Priatna, Sulaksana, N., Hutabarat, J., Haryanto, I., 2020 “Determination of Volcanic Characteristics Based on Deuterium and Oxygen-18 Isotop Composition: A case Study at Dieng Plateau, Central Java”, Geological Agency, Indonesian Journal on Geoscience Vol. 7 August 2020 page 201-213.

[13] Craig, Harmon., 1961. “Isotopic Variations in Meteoric Waters”. In: Science, Vol 133, Issue 3465, p. 1702-1703.

[14] Priatna. 1996. The Characteristics of volcanic gases to predict volcano activity in the word. Final Report of Course on Volcanology and Volcanic Sabo Engineering, JICA, Japan.
[15] Primulyana, S. 2010. *Karakteristik Air Panas dan Fumarola di Gunung Papandayan, Jawa Barat serta Kaitannya dengan Aktivitas Vulkanik, Master Tesis, Institut Teknologi Bandung, Indonesia*. Unpublished.
[16] Cahyono, H.2017. *Laporan Penyelidikan Geokimia dan Isotop Stabil Air Gunung Papandayan, Jawa Barat*. PVMBG, Geological Agency, KESDM.