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The Determination of Volcanic Characteristics Based on Deuterium and Oxygen-18 Isotope Compositions: A Case Study at Dieng Plateau, Central Java

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Abstract - To find out volcanic characteristics, a geochemical approach can be used, one of which is through the measurement of deuterium and oxygen-18 isotopes from condensate and crater water samples. In this study, Dieng Plateau in Central Java was chosen, because it has a wide spread of fumarole fields and crater water. In addition, research in the Dieng Plateau is very useful in the management of geological-based tourism and geopark development in the future. Results of isotope analysis in Candradimuka Crater show the average number of isotope deuterium is $\delta D - 50^0/_{00}$ and isotope oxygen-18 is $\delta^{18}O -3^0/_{00}$ which produce the value of the mixing fraction of $f\,^{18}O = 47.11\%$. This figure is the highest isotope number compared to other craters on the Dieng Plateau. The high value of the isotope-18 mixing fraction is supported by a strong plume from three vents in Candradimuka. Meanwhile, the results of crater water isotope tests obtained the highest results in Sikidang Crater with the value of the deuterium isotope is $\delta D = -\ 10.30^0/_{00}$ and the isotope oxygen-18 is $\delta^{18}O = 6.57^0/_{00}$ which are in the metamorphic water area from the mixing of magmatic processes with surface meteoric water. Based on the deuterium isotope approach with oxygen-18 crater water and fumarole condensate supported by subsurface temperature data, most of the Dieng Plateau has magmatic-hydrothermal characteristics, except Candradimuka Crater which belongs to the magmatic group.

Keywords: isotope, deuterium, oxygen-18, mixing fraction, Dieng Plateau

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Introduction

Dieng Plateau is a Quaternary volcanic group which physiographically is part of the North Serayu Mountains. This plateau in the north is bordered by the northern Java alluvial plain. In the south, it is restricted by the Central Java depression. In the west and east it is bounded by the Quaternary Volcano Zone (Bemmelen, 1949). Dieng Plateau is a rubble consisting of several cones as high as 100-300 m, lined along 14 km with a width of 6 km. This volcanic lane (Figure 1) extends southwest and southeast, which is the continuation of the

Figure 1. Dieng Plateau lined along 14 km x 6 km, at 2,200 m above average sea level.

Sumbing-Sindoro Mountain range (Kusumadinata *et al*., 1979; Miller *et al*., 1981).

Since Junghuhn first recorded eruptions (Kusumadinata, 1979; Miller *et al*., 1981), Dieng has several times demonstrated its activities in the form of blasting material from inside. Until now, it has been recorded that in the last 200 years in the Dieng Plateau, at least seventeen times volcanic activities have taken place, some of which have caused casualties (Badan Geologi, 2011). At December 4th, 1944, there was an eruption in Sileri Crater with 114 people were killed and 38 were injured. At February 20th, 1979, a phreatic eruption in Sinila Crater occured, followed by the release of CO_2^- dominated gas from the Timbang Crater, caused 149 Dieng residents did (Kusumadinata *et al.*, 1979; Le Guern *et al.*, 1982; Badan Geologi, 2011).

Most of the eruptions were hydrothermal types that produced mud spread only around the crater and flowing through rivers located on the crater slopes (Zen and Muzil, 1980). The hydrothermal eruption was very possible as the effect of the dominant gas content in the Dieng Volcano. From the results of the investigation (Sulistiyo *et al*., 2002; Humaida *et al*., 2003a, Priatna, 2014), it was known that CO_2 gas was the main gas type in the west.

Priatna (2019) reported the subsurface temperature of Dieng and the ratio of $CO_2/S_{T.}$ These data combined with isotop data are very usefull to explain the Dieng characteristics.

The isotope ratio deuterium (δD) and oxygen-18 ($\delta^{18}O$) condensate from the Gendol Crater is entirely in the magmatic water area. This indicates that the water vapour in the Gendol Crater is almost entirely magmatic water (Priatna and Kadarsetia, 2007).

The purpose of the study is to understand the volcanic characteristics of the craters and fumaroles using analysis of the deuterium oxygen-18 isotope ratio in the fumarole field, crater water, and ponds in the Dieng Plateau. This study aims to provide chemical information on the characteristics of the volcanic activities as well as to evaluate the surrounding environment in relation to volcanic disaster mitigation. In order to achieve these objectives, a comprehensive study about the characteristics of the fumarole field, crater water, and ponds in the Dieng Plateau were undertaken.

The study was done in twelve locations around the Dieng Plateau, *i.e.* Lake Dringo, Candradimuka Crater, Sileri Crater, Lake Merdada, Sibanteng Crater, Sikidang Crater, Sikendang Crater, Lake Warna, Lake Pengilon, Pakuwaja Crater, Lake Cebong, and Lake Menjer (Figure 2).

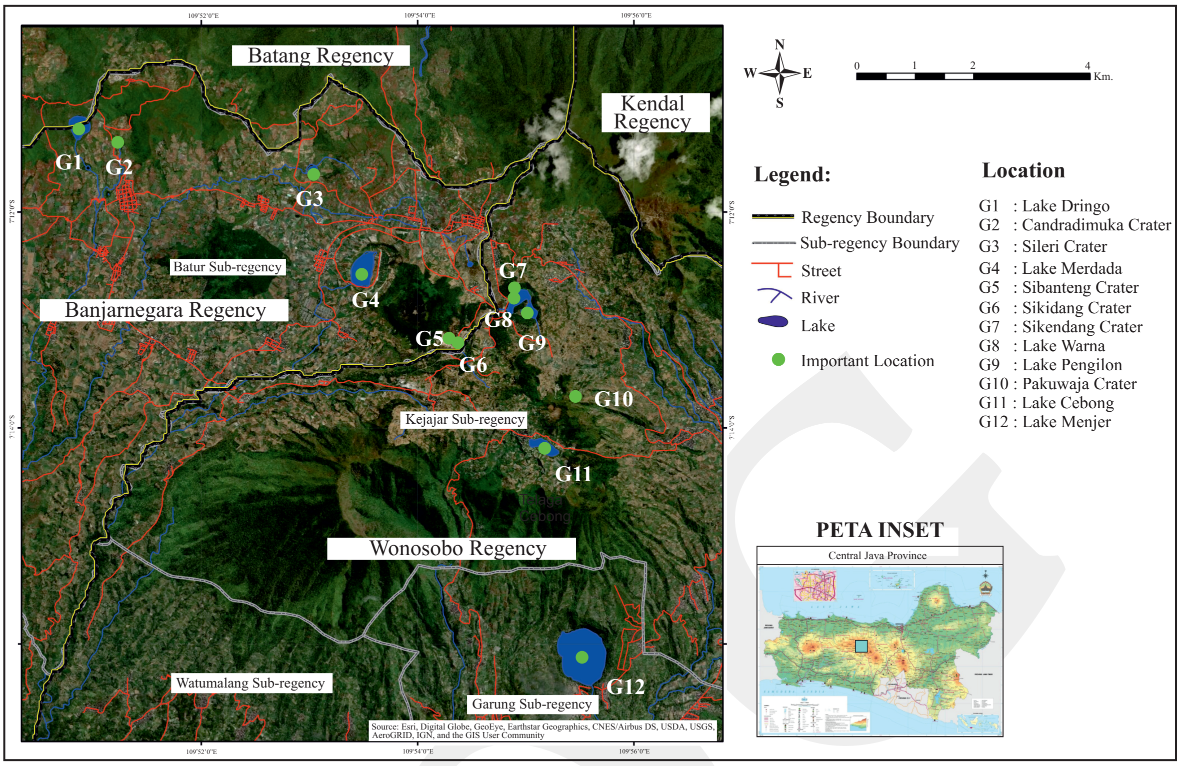

Figure 2. Location map of studied area, Dieng Plateau, Central Java.

Based on basic chemical and isotope data, Cioni *et al*. (1984) and Chiodini *et al*. (1996) (in Panichi and Volpi, 1999) it is suggested that fumarole vapour 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 numbers of $-30^0/_{00}$ up to $-20^0/_{00}$.

Based on the results of the plotting on the graph, there is an area of metamorphic water that has changed, or water that was resulted from the mixing magmatic activity with hydrothermal activity in the volcanic system. The metamorphic water group has a relatively high oxygen-18 isotope number in the magmatic water area, but has a higher deuterium isotope value than magmatic water, which is in the range of $\delta D = -15^0/_{00}$ to $-5^0/_{00}$.

According to Iskandar *et al*. (2018), a simple mass equilibrium equation used to estimate mixing fraction and fluid concentration is calculated using line equations and oxygen-18 isotope content.

Materials and Methods

To find out the isotopic compositions of deuterium and oxygen-18 on the Dieng Plateau, condensate samples were taken from the fumarole fields of Sikidang, Sibanteng, Pakuwaja, Sileri, and Candradimuka. While water sampels were taken from Sikidang, Sibanteng, Sileri Crater, and Candradimuka Craters, and water from Lakes Dringo, Merdada, Cebong, Warna, Pengilon, and Menjer. The sampling had been carried out from January 2017 to November 2019. Meanwhile, to determine the equation for the meteoric water line, cold water samples were taken from nine locations on the Dieng Plateau plus five secondary data from several locations in Java.

The condensate samples from the fumarole and crater water fields were analyzed at Laboratorium Pusat Aplikasi Isotop dan Radiasi (PAIR), Badan Tenaga Atom Nasional (BATAN), to prepare and to 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 Penyelidikan dan Pengembangan Teknologi Kebencanaan Geologi (BPPTKG) in Yogyakarta.

The D/H volcanic condensate gas and water samples analysis used the hydrogen method of water with a conventional zinc reduction technique, then followed by an isotope mass spectrometry. 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).

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

While to find out the isotope ratio, the equation from Craig (1961) was used, namely $\delta D = 8\ \delta^{18}O + 10$. This equation comes from the analysis of isotopes in river, lake, rain, and snow water throughout the world, in the range from -320 to +40 ($^0/_{00}$) for δD and -40 to +6 for $\delta^{18}O$, which included 130 samples of water.

Ocean water was chosen as a standard called *standard mean ocean water* or SMOW (Craig, 1961). The oxygen-18 and deuterium values of water in the nature will generally follow the correlation with the linear line of meteoric water with the following equation:

$$\delta D = 8\ \delta^{18}O + 10 \quad \text{......................................(1)}$$

δD : deuterium isotope (^2H)

$\delta^{18}O$: oxygen isotope (^{18}O)

To calculate the fumarole oxygen-18 isotope mixing fraction in the Dieng Plateau, the value of the Standard Magmatic Water condensate of Gendol Crater used is the average measurement of the oxygen-18 isotope of $6.7^0/_{00}$. The value of the Dieng condensate mixing fraction was compared with the value of Merapi Volcano oxygen-18 fraction (Priatna and Kadarsetia, 2007). The isotope data of Gendol Crater and Woro Crater are very useful to be used as comparative data with the Dieng Plateau by comparing two different volcanic character traits. Merapi Volcano has explosive eruptive properties, while Dieng activity is a typical phreatic eruption that has widespread hydrothermal activity. For the calculation of the Dieng Plateau condensate mixing fraction, the Standard Magmatic Water value of the Merend Gendol Crater used is $6.77^0/_{00}$, and the Standard Meteoric Water value was calculated through the meeting of meteoric water lines and sample line equations (Priatna, 2019). Furthermore, the calculation of the mixing fraction can use the equation:

$$f\delta^{18}O = \frac{(\delta^{18}O - SMeW)}{(SMaW - SMeW)} \times 100\% \quad \text{.........(2)}$$

With:

$f\delta^{18}O$: oxygen-18 isotope fraction sample

$\delta^{18}O$: sample isotope value

SMeW : Standard Meteoric Water (oxygen-18)

SMaW: Standard Magmatic Water (oxygen-18)

Results 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 potential of volcanic activity in the Dieng Plateau, deuterium and oxygen-18 isotopes were measured from samples of water and condensate in several locations of fumarole and crater water. The initial stage is to analyze the ratio of deuterium and oxygen-18 isotopes to rainwater, well water, and cold water which will be used to determine the equation of the meteoric water line. Then the condensate samples were measured from the fumarole field, model of the crater water, and sample of the lake water. The final stage was plotting the isotope ratio data in the isotopic composition graph of meteoric water.

In this study, Merapi Volcano deuterium and oxygen-18 isotope ratio data is used as comparative data. Graphical data is displayed together with isotope ratio data from several locations.

Determination of the Meteoric Water Line Equation

To obtain the equation of the meteoric water line at the studied site, meteoric water samples were taken from eight locations at the Dieng Plateau in 2017 (Table 1).

The deuterium isotope (δD) value of meteoric water in the Dieng Plateau is in the range of -67$^{0}/_{00}$ to -57.20$^{0}/_{00}$, and the range of the oxygen-18 isotope ($\delta^{18}O$) is from -10$^{0}/_{00}$ to -9.1$^{0}/_{00}$.

The eight data are plotted in the graph of $\delta^{18}O$ to δD (Figure 3) resulting in a meteoric water line equation (3):

$$\delta D = 7.8\ \delta^{18}O + 15 \quad \text{.................................(3)}$$

The Dieng Plateau meteoric water equation (δD) = 7.8 $\delta^{18}O$ + 15. The regression coefficient is only 0.2 different when compared with the world meteoric water equation (Craig, 1961) that is δD = 8 $\delta^{18}O$ + 10. The equation of line (3)

Table 1. Deuterium and Oxygen-18 Isotopes of Dieng Plateau Meteoric Water in 2017

No	Year	Location	($^{0}/_{00}$)	
			$\delta^{18}O$	δD
1	2017	Sikidang Cold Water	-9.36	-59.40
2	2017	Water Park Cold Water	-9.10	-57.20
3	2017	Dieng Obs Cold Water	-9.84	-61.10
4	2017	Kebun Dieng Cold Water	-9.71	-61.30
5	2017	Dieng Rainwater	-9.80	-61.10
6	2017	Dieng Park Rainwater	-10.00	-67.00
7	2017	Dieng Mosque Cold Water	-9.77	-62.60
8	2017	Prau Cold Water	-9.90	-62.10

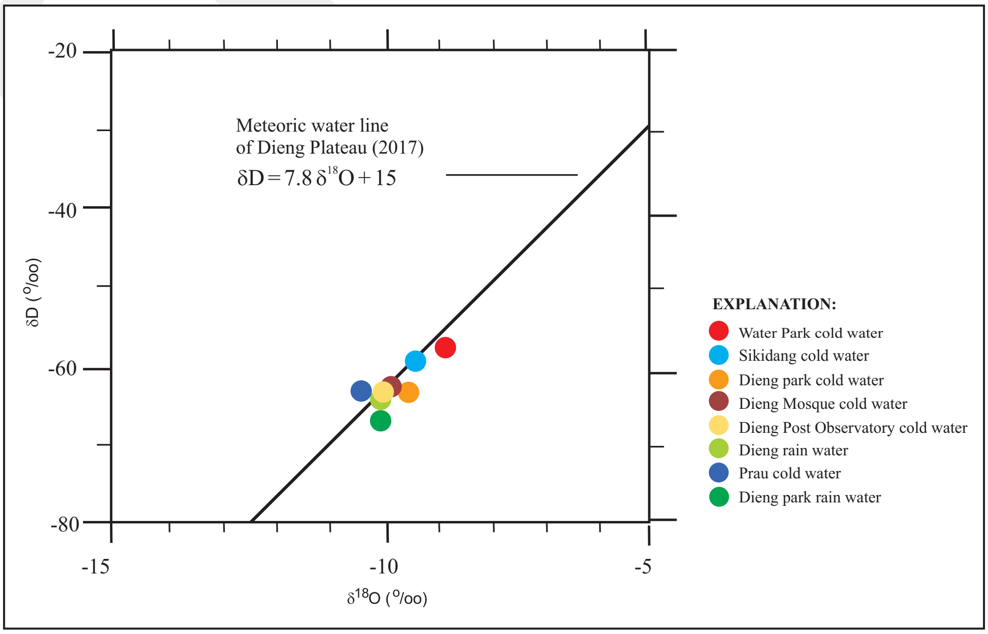

Figure 3. Plot of eight data of Dieng Plateau meteoric waterline 2017, on graph of $\delta^{18}O$ *versus* δD.

was used to determine Water Standard Meteoric (SMeW) in the calculation of the value of the oxygen-18 isotope mixing ratio of the sample. In this study, the value of Standard Magmatic Water (SMaW) was also calculated which indicates the average maximum magmatic value. In this calculation, the oxygen-18 isotope data of Gendol Crater of Merapi Volcano were used.

Deuterium and Oxygen-18 Isotopes in the Dieng Plateau Condensate

Six fumarole condensate samples of Sikidang, two samples of Sibanteng Crater, two samples of Pakuwaja Crater, one sample of Candradimuka Crater, and one sample of Sileri Crater give values of isotope-18 ($\delta^{18}O$) in the range of -11.65$^0/_{00}$ to -2.82$^0/_{00}$, and deuterium isotope δD in the range of -79.6$^0/_{00}$ to 49.1$^0/_{00}$ (Table 2).

In addition, the Dieng Plateau condensate isotope data also show the average Gendol Crater data (Priatna, 1996) namely $\delta^{18}O$= 6.77$^0/_{00}$ and δD= 28.78$^0/_{00}$ based on Dieng Plateau line equations. The Gendol Crater data can be used for the calculation of oxygen-18 isotope mixing fractions.

After being plotted on the oxygen-18 isotope correlation graph with the Dieng Plateau deuterium and the Gendol Crater (Figure 4), Equation 4 was obtained with a correlation value of 0.95:

$$\delta D = 2.9\ \delta^{18}O - 43 \qquad (4)$$

Of the twelve samples in the Dieng Plateau fumarole field, all are closer to the meteoric water line. The SK11 sample and SK12 sample, which are the closest sample pointing to the Sikidang Crater on the deuterium and oxygen-18 isotope graphs, have the highest oxygen-18 isotope values.

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

Oxygen-18 Condensate Isotope Mixing Fraction

Equation 3: $\delta D = 7.8\ \delta^{18}O + 15$ is the line equation of the Dieng Plateau meteoric water, while Equation 4: $\delta D = 2.9\ \delta^{18}O - 43$ is the line equation of the Dieng condensate and the

Table 2. Deuterium and Oxygen-18 Isotope Dieng Condensates

NO	Year	Condensate Sample	Code	($^0/_{00}$)	
				$\delta^{18}O$	δD
1.	10_2017	Sikidang 11	SK11	-5.10	-55.40
2.	07_2018	Sikidang 12	SK12	-4.20	-50.90
3.	10_2017	Sikidang 21	SK21	-10.10	-74.90
4.	07_2018	Sikidang 22	SK22	-9.96	-77.00
5.	10_2017	Sikidang 31	SK31	-11.50	-74.30
6.	07_2018	Sikidang 32	SK32	-11.07	-72.70
7.	10_2017	Sibanteng 11	SB11	-7.71	-66.80
8.	07_2018	Sibanteng 12	SB12	-4.35	-49.10
9.	10_2017	Pakuwaja 11	PW11	-8.73	-67.00
10.	07_2018	Pakuwaja 12	PW12	-6.81	-62.11
11.	11_2019	Sileri 01	SL01	-8.87	-77.60
12.	11_2019	Candradimuka 01	CD02	-3.10	-49.60
13	09_1996	Gendol Merapi	GM	6.77	-28.78

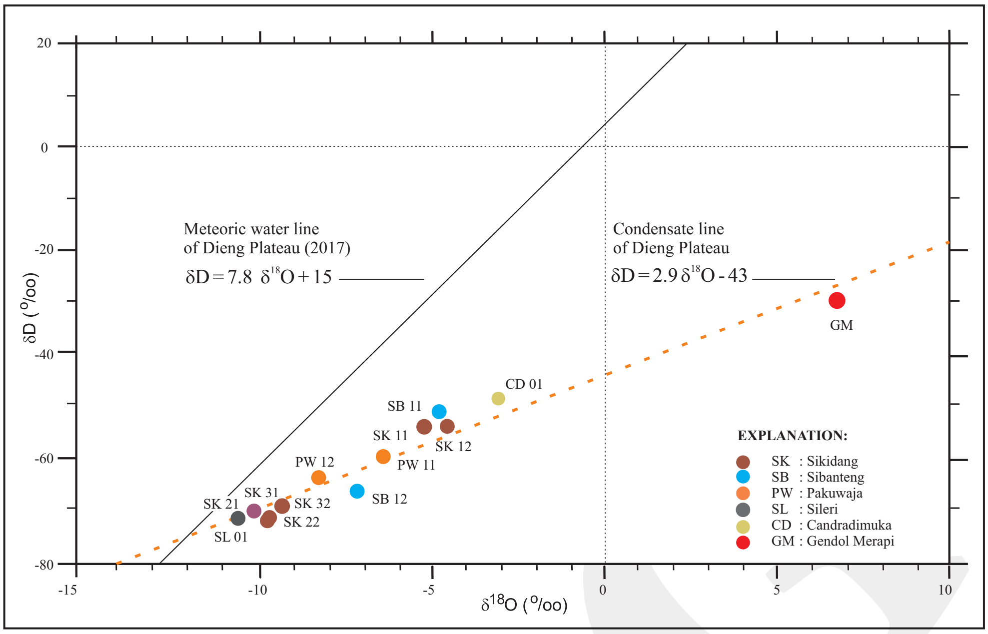

Figure 4. Graph showing isotope δD - δ^{18}O of Dieng and Merapi fumarole condensates.

Gendol Crater condensate samples. Both of these equations are used to find out the value of Standard Meteoric Water (SMeW), and are used as a baseline calculation of oxygen-18 isotope mixing fraction.

Line Equation 3 and line Equation 4 generate:

$$7.8\ \delta^{18}O + 15 = 2.9\ \delta^{18}O - 43$$

$$7.8\ \delta^{18}O - 2.9\ \delta^{18}O = -43 - 15$$

$$4.9\ \delta^{18}O = -58$$

$$\delta^{18}O = -11.83^{0}/_{00}\ \text{(SMeW)}$$

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

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

$f\delta^{18}O$: mixing fraction of oxygen-18 isotope

SMeW : Standard Meteoric Water (oxygen-18 isotope)

SMaW : Standard Magmatic Water (oxygen-18 isotope)

$$f\delta^{18}O = \frac{-3.1 - (-11.83)}{6{,}7 - (-11.83)} \times 100\%$$

$$= 47.11\%$$

The calculated value of 47.11% is the value of the oxygen-18 isotope mixing fraction of Candradimuka Crater which reflects the level of magmatism of the Candradimuka Crater. The sample of Candradimuka Crater (CD 01) produces isotope $\delta^{18}O = -3.10^{0}/_{00}$ and isotope $\delta D = -49.60^{0}/_{00}$.

The value of the Sikidang Crater isotope (SK11) has the highest mixing fraction value compared to other Sikidang samples which are located further from the Sikidang Crater (Table 3).

To find out the characteristics of the Sikidang Crater, condensate samples scattered around the Sikidang Crater were taken every 50 m towards the northeast. All condensate samples from the fumarole source in the Dieng Plateau have dominant meteoric water properties. The fraction of oxygen-18 isotope in the average are: Sikidang 17 %, Sibanteng 31.33%, Sileri 15.97%, Pakuwaja 21.91%, and Candradimuka 47.11%. The value of the mixing fraction in Candradimuka

Table 3. Mixing Fraction of Dieng Condensate Oxygen-18 Isotope

No	Sample	Code	$\delta^{18}O$	SMaW	SMeW	$\delta^{18}O$ - SMeW	SMaW-SMeW	$f\delta^{18}O$
1	Sikidang 11	SK11	-4.20	6.77	-11.83	7.63	18.50	41.02
2	Sikidang 12	SK12	-5.10	6.77	-11.83	6.73	18.50	36.32
3	Sikidang 21	SK21	-9.96	6.77	-11.83	1.87	18.50	10.09
4	Sikidang 22	SK22	-10.10	6.77	-11.83	1.73	18.50	9.34
5	Sikidang 31	SK31	-11.07	6.77	-11.83	0.76	18.50	4.10
6	Sikidang 32	SK32	-11.50	6.77	-11.83	0.33	18.50	1.78
7	Sibanteng 11	SB11	-7.70	6.77	-11.83	4.13	18.50	22.29
8	Sibanteng 12	SB12	-4.35	6.77	-11.83	7.48	18.50	40.37
9	Pakuwaja 11	PW11	-6.81	6.77	-11.83	5.02	18.50	27.09
10	Pakuwaja 12	PW12	-8.73	6.77	-11.83	3.10	18.50	16.73
11	Sileri 01	SL 01	-8.87	6.77	-11.83	2.96	18.50	15.97
12	Candradimuka 01	CD 01	-3.10	6.77	-11.83	8.73	18.50	47.11

Crater with the number of 47.11% shows the highest number compared to all condensate samples in the Dieng Plateau. Visually, the Candradimuka Crater emits steam with high pressure indicating that it still has magmatic properties compared to other craters on the Dieng Plateau.

The volcanic characteristics on the Dieng Plateau are different from the volcanic characteristics of Merapi Volcano. Merapi has magmatic characteristics with its explosive eruption type, while the Dieng Plateau has the phreatic eruption type.

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 (Table 4).

Based on the value of the oxygen-18 isotope fraction analogy to the contribution of magma, the crater in the Dieng Plateau can be classified as shown in Table 5. Condensate samples from craters of Candradimuka, Sikidang, and Sibanteng have moderate magmatic properties, while other crater condensates have low and very low characteristics.

Oxygen-18 Isotope Mixing Faction of Crater Water

Results of the analysis of fourteen isotope crater water samples in Sikidang Crater show the highest value of oxygen-18 isotope, that is $\delta^{18}O = 6.57^{0}/_{00}$ (Table 6). Metamorphic water is water that has changed due to the mixing of magma activity with surface water and hydrothermal activity.

After being plotted on the graph of the deuterium isotope with oxygen-18, there obtained Equation 5:

$$\delta D = 3.2\,\delta^{18}O - 32 \quad \text{..................................(5)}$$

To find out the value of oxygen-18 isotope mixing fraction of crater water, isotope values of oxygen-18 sample to the distance between Standard Meteoric Water (SMeW) and Standard Metamorphic Water (SMiW) are used. The

Table 4. Classification of the O-18 Isotope Mixing Fraction (Analogy to the Contribution of Magma).

No	Isotope O-18 Mixing Fraction (%)	Contribution of Magma	Symbols
1	$01^{+} - 20$	very low	●
2	$20^{+} - 40$	low	●
3	$40^{+} - 60$	medium	●
4	$60^{+} - 90$	high	●
5	$90^{+} - 100$	very high	●

Table 5. Classification of the O-18 Isotope Mixing Fraction (Magma Contribution) Dieng Plateau Condensate

No	Sample	Code	$f\,\delta^{18}O$	Magma Contribution	Symbols
1	Sikidang 11	SK11	41.08	medium	●
2	Sikidang 12	SK12	36.22	low	●
3	Sikidang 21	SK21	9.95	very low	●
4	Sikidang 22	SK22	9.19	very low	●
5	Sikidang 31	SK31	3.95	very low	●
6	Sikidang 32	SK32	1.62	very low	●
7	Sibanteng 11	SB11	22.16	low	●
8	Sibanteng 12	SB12	40.27	medium	●
9	Pakuwaja 11	PW11	26.97	low	●
10	Pakuwaja 12	PW12	16.59	very low	●
11	Sileri 01	SL 01	15.84	very low	●
12	Candradimuka 01	CD 01	47.03	medium	●

Table 6. Compositions of Isotopes O-18 and Deuterium of Dieng Plateau Crater

NO	Year	Water Sample	Code	($^{0}/_{00}$)	
				$\delta^{18}O$	δD
1	10–2017	Sikidang Crater	SK11	6.57	-10.30
2	07–2018	Sikidang Crater	SK12	5.90	-9.10
3	10–2017	Sibanteng Crater	SB11	-3.11	-47.8
4	07–2018	Sibanteng Crater	SB12	-2.20	-42.25
5	10–2017	Sileri Crater	SL11	-6.02	-48.80
6	07–2018	Sileri Crater	SL12	-3.27	-45.60
7	10–2017	Candradimuka Crater	CD11	-5.18	-45.70
8	07–2018	Candradimuka Crater	CD12	-4.35	-42.10
9	01–2017	Dringo Lake	DR	-8.30	-55.00
10	01–2017	Menjer Lake	MJ	-8.60	-53.20
11	01–2017	Warna Lake	WN	-7.50	-51.70
12	01–2017	Pengilon Lake	PN	-10.20	-66.00
13	01–2017	Cebong Lake	CB	-9.10	-59.10
14	01–2017	Merdada Lake	MD	-8.70	-58.20

line equation from the crater and lake samples in the Dieng Plateau gives the line equation $\delta D = 3.2\,\delta^{18}O - 32$ (Figure 5).

To obtain the Standard Meteoric Water value (SMeW), two equations were used: the Dieng Plateau meteoric water equation and the crater and lake water sample equation. Metamorphic water was obtained from the highest oxygen isotope value in Sikidang Crater within the metamorphic water area.

The line equation of Dieng Plateau meteoric water is:

$$\delta D = 7.8\,\delta^{18}O + 15$$

The line equation of Dieng Plateau crater and lake water is:

$$\delta D = 3.2\,\delta^{18}O - 32 \quad \text{..................................(5)}$$

Equation 3 and 5 generate:

$$7.8\,\delta^{18}O + 15 = 3.2\,\delta^{18}O - 32$$

$$7.8\,\delta^{18}O - 3.2\,\delta^{18}O = -32 - 15$$

$$4.6\,\delta^{18}O = -47$$

$$\delta^{18}O = -10.22\,^{0}/_{00}\ \text{(SMeW)}$$

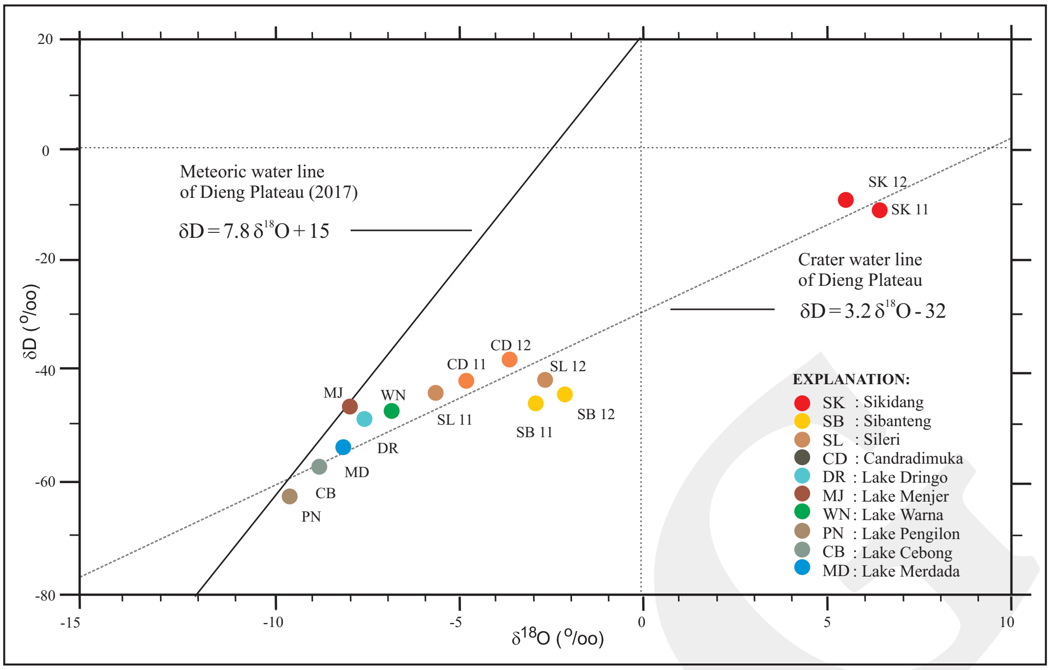

Figure 5. Graph showing isotope δD-$\delta^{18}O$ crater water and lake water of Dieng Plateau.

The isotope value of the Standard Meteoric Water (SMeW) used as the standard is the result of the calculation of the line equation of meteoric water in the Dieng Plateau and the line equation of Dieng Plateau sample. While the Standard Metamorphic Water (SMiW) specifically in this study is oxygen-18 isotope data from Sikidang Crater in the metamorphic water area having a value of $6.57^{0}/_{00}$ which is the highest content compared to other craters in the Dieng Plateau.

Then, the results were calculated in units of %.

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

With:

$f\delta^{18}O$: oxygen-18 isotope fraction

$\delta^{18}O$: oxygen-18 isotope

SMeW: Standard Meteoric Water (oxygen-18)

SMiW: Standard Metamorphic Water (oxygen-18)

Example of 11 Sileri Crater water sample calculation:

$$f\delta^{18}O = \frac{-3.27 - (-10{,}22)}{(6.57 - (-10{,}22)} \times 100\%$$

$$f\delta^{18}O = \frac{6.95}{16.79} \times 100\% = 41.39\%$$

Based on this calculation, it can be seen that the oxygen-18 mixing fraction of Sileri Crater water content is 41.39%. This fraction value is a comparison of the oxygen-18 isotope of Sikidang Crater water used as a metamorphic water baseline.

The content of oxygen-18 isotope fraction in Sikidang Crater situated in the area of metamorphic water is the result of fluid mixture and meteoric water. Sikidang Crater water has an isotope value of oxygen-18 in the magmatic area, but has a higher deuterium isotope value. The crater water that has an oxygen-18 isotope mixing fraction value apart from Sikidang Crater is Sibanteng Crater.

Meanwhile, the oxygen-18 isotope mixing fraction of other craters like Sileri has a value with a fairly short range of 25.01 to 41.39% (Table 7).

The continuing mud and gas flows in Sikidang Crater indicate that there is a gas hole in Sikidang Crater leading to the surface. When it reaches the crater, it is directly in contact with surface water. The constant gas pressure makes Sikidang Crater continues to emit mudflat and gurgling mud with a strong enough pressure of grey and white smoke.

Based on subsurface temperature and CO_2/ST values, Pakuwaja, Candradimuka, and Sileri Craters have higher volcanic activity properties compared to Sikidang and Sibanteng Craters. While based on the value of oxygen-18 isotope fraction of Sileri Crater, they have the lowest isotope mixing fraction value (Table 8), because the Sileri Crater is influenced by the volume of water in the crater. This is also supported by low data in Sikidang Crater. The gas positions of Sibanteng Crater and Candradimuka Crater are not affected by meteoric water, and they have higher oxygen isotope mixing fraction values. Similarly, water samples in the Candradimuka Crater located in a three-crater basin are more dominated by rainwater and surface water. The measurements of isotope ratios were then conducted in several lakes with the aim to determine the volcanic activity in each lake and also the dominance of surface and rain water.

Samples were taken at Dringo, Menjer, Warna, Pengilon, Cebong, and Merdada Lakes. Nearly all of the lake water samples in the Dieng Plateau in the deuterium isotope area to oxygen-18 are located close to the mete-

Table 7. Oxygen-18 Isotope Fraction of Dieng Plateau Crater Water

No	Crater Water	Code	$\delta^{18}O$	SMiW	SMeW	$\delta^{18}O$ - SMeW	SMiW- SMeW	f $\delta^{18}O$
1	Sikidang 11	SK11	6.57	6.57	-10.22	16.79	16.79	100.00
2	Sikidang 12	SK12	5.90	6.57	-10.22	16.12	16.79	96.01
3	Sibanteng 11	SB11	-3.11	6.57	-10.22	7.11	16.79	42.35
4	Sibanteng 12	SB12	-2.20	6.57	-10.22	8.02	16.79	47.77
5	Sileri 11	SL11	-3.27	6.57	-10.22	6.95	16.79	41.39
6	Sileri 12	SL12	-6.02	6.57	-10.22	4.20	16.79	25.01
7	Candradimuka 11	CD11	-5.18	6.57	-10.22	5.04	16.79	30.02
8	Candradimuka 12	CD12	-4.35	6.57	-10.22	5.87	16.79	34.96
9	Warna Lake	WN	-7.50	6.57	-10.22	2.72	16.79	16.20
10	Pengilon Lake	PN	-9.20	6.57	-10.22	1.02	16.79	6.08
11	Merdada Lake	MD	-8.70	6.57	-10.22	1.52	16.79	9.05
12	Dringo Lake	DR	-8.30	6.57	-10.22	1.92	16.79	11.44
13	Cebong Lake	CB	-9.10	6.57	-10.22	1.12	16.79	6.67
14	Menjer Lake	MJ	-8.60	6.57	-10.22	1.62	16.79	9.65

Tabel 8. Comparison of Crater Based on the Calculation of Gas Data and Oxygen-18 Isotope Fraction (Priatna, 2019)

No	Crater	CO_2/S_T	Subsurface temperature (^0C)	Isotope fraction of ^{18}O
1	Sikidang	1.35	306	17.11%
2	Sibanteng	2.17	352	31.33%
3	Sileri	6.68	337	15.97%
4	Candradimuka	9.44	543	47.11%
5	Pakuwaja	15.00	389	21.91%

oric water line. In other words, almost all of the ponds do not show any volcanic activity, and have a lot of meteoric water content. Of the six lakes, the water that has oxygen-18 isotope ratio and its position tends to go right of the meteoric water line turns out to be the one originating in the Warna Lake. That is because at a distance of about 30 m, there is Sikendang Crater activity on the edge of the Warna Lake, and also, in the middle of the crater which is aligned with the Sikendang Crater, there is a buble of gas extending to the southeast. The buble gas that comes out along this line indicates the activity of gas is charge to the surface of "Telaga Warna" Crater Lake. Lake Warna can also associate to the phenomenon of sulfur grains that sometimes appear on the surface and sometimes there is also a smell of sulfur. It is suspected that there is a portion of gas flow activity that penetrates towards Warna Lake.

Conclusion

The results of the calculation of the oxygen-18 isotope mixing fraction in the Dieng Plateau show the highest value by the Candradimuka condensate with 47.11%. With the value of the mixing fraction, it can be concluded that the magmatic characteristics of the Dieng Plateau are included in the classification of moderate magma contribution to the phreatic eruption type.

Meanwhile, crater water samples are shown by Sikidang Crater which is in the metamorphic water area with the same isotope value as magmatic water, but has a higher deuterium isotope. It is considered that there is a reaction in Sikidang Crater between meteoric water and hydrothermal activity in a small crater. The high value of oxygen isotopes is caused by evaporation which causes mud water in Sikidang Crater to become heavy water. Sibanteng and Sileri Crater water samples show the rates above 40% of metamorphic water resulting frequent occurrence of phreatic eruptions in these craters.

The results of this research on the ratio of condensate isotopes and crater water can find out the volcanic characteristics in the Dieng Plateau. It can be explained through this study that the volcanic characteristics in the Dieng Plateau based on the isotope data of deuterium and oxygen-18 are characterized by phreatic eruption with the magmatic-hydrothermal volcanic system.

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