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
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 occurred, 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 useful to explain the Dieng characteristics.

The isotope ratio deuterium ($\delta$D) 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).
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 6/00 and $\delta$D in the range numbers of -30/00 up to -20/00.

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= -15/00 to -5/00.

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 samples 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

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**Figure 2. Location map of studied area, Dieng Plateau, Central Java.**
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$_2$O ratio, then continued with mass spectrometry measurements. The analytical error of isotopic measurement is ± 1 and 0.1 ($^\circ/_{100}$), 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).

$$\delta = \frac{[R \text{ sample} / R \text{ standard} - 1] \times 1000}{^\circ/_{100}}$$

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 ($^\circ/_{100}$) for $\delta D$ 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:

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

$\delta D$ : deuterium isotope ($^2$H)

$\delta^{18}O$ : 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 $6.7^\circ/_{100}$. 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 $6.77^\circ/_{100}$ 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:

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

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).

| No | Year | Location             | δ18O (‰) | 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 |

The deuterium isotope (δD) value of meteoric water in the Dieng Plateau is in the range of -67‰ to -57.20‰ and the range of the oxygen-18 isotope (δ18O) is from -10‰ to -9.1‰.

The eight data are plotted in the graph of δ18O to δD (Figure 3) resulting in a meteoric water line equation (3):

\[
\delta D = 7.8 \delta ^{18}O + 15 \quad \ldots \ldots \ldots \ldots (3)
\]

The Dieng Plateau meteoric water equation (δD) = 7.8 δ18O + 15. The regression coefficient is only 0.2 different when compared with the world meteoric water equation (Craig, 1961) that is δD = 8 δ18O + 10. The equation of line (3)
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 $-11.65^{0}/_{oo}$ to $-2.82^{0}/_{oo}$, and deuterium isotope $\delta D$ in the range of $-79.6^{0}/_{oo}$ to $49.1^{0}/_{oo}$ (Table 2).

In addition, the Dieng Plateau condensate isotope data also show the average Gendol Crater data (Priatna, 1996) namely $\delta^{18}$O = $6.77^{0}/_{oo}$ and $\delta D = 28.78^{0}/_{oo}$ based on the 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:

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

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) = $6.7^{0}/_{oo}$.

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 | $\delta^{18}$O ($^{0}/_{oo}$) | $\delta D$ ($^{0}/_{oo}$) |
|----|------|-------------------|------|----------------------------|--------------------------|
| 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 |
The Determination of Volcanic Characteristics Based on Deuterium and Oxygen-18 Isotope Compositions: A Case Study at Dieng Plateau, Central Java (Priatna et al.)

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:

\[ 7.8 \delta^{18}O + 15 = 2.9 \delta^{18}O - 43 \]
\[ 7.8 \delta^{18}O - 2.9 \delta^{18}O = -43 - 15 \]
\[ 4.9 \delta^{18}O = -58 \]
\[ \delta^{18}O = -11.83^{\circ}/_{00} \text{ (SMeW)} \]

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

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

where:
- \( f\delta^{18}O \): mixing fraction of oxygen-18 isotope
- SMeW: Standard Meteoric Water (oxygen-18 isotope)
- SMaW: Standard Magmatic Water (oxygen-18 isotope)

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 \( \delta^{18}O = -3.1^{\circ}/_{00} \) and isotope \( \delta D = -49.60^{\circ}/_{00} \).

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...
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 Fraction of Crater Water**

Results of the analysis of fourteen isotope water samples in Sikidang Crater show the highest value of oxygen-18 isotope, that is $\delta^{18}O = 6.57\%$ (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:

$$\delta D = 3.2 \delta^{18}O - 32 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots(5)$$

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

| 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              | ◆       |

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

| No  | Sample | Code | $\delta^{18}O$ | SMeW | SMaW | $\delta^{18}O$ - SMeW | SMaW - SMeW | $\delta^{18}O$ |
|-----|--------|------|---------------|------|------|----------------------|--------------|---------------|
| 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 |

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

$$\delta D = 3.2 \delta ^{18}O - 32$$

Equation 3 and 5 generate:

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

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

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

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

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

| No | Sample          | Code | $f ^{18}O$ | 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       | SL01 | 15.84      | very low           |         |
| 12 | Candradimuka 01 | CD01 | 47.03      | medium             |         |

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

| No | Year   | Water Sample       | Code | $\delta ^{18}O$ | $\delta D$ |
|----|--------|--------------------|------|-----------------|------------|
| 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     |
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 $6.57 \text{‰}$ which is the highest content compared to other craters in the Dieng Plateau.

Then, the results were calculated in units of %.

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

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:

$$f \delta^{18}O = \frac{-3.27 - (-10.22)}{6.57 - (-10.22)} \times 100\% = 41.39\%$$

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.

Figure 5. Graph showing isotope $\deltaD-\delta^{18}O$ crater water and lake water of Dieng Plateau.
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$_2$/ST | Subsurface temperature (°C) | 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 bubble of gas extending to the southeast. The bubble gas that comes out along this line indicates the activity of gas is charge to the surface of “Te-laga 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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REFERENCES

Badan Geologi, 2011. Data Dasar Gunung Api Indonesia (2nd Edition). Bandung: Badan Geologi, Kementrian Energi dan Sumber Daya Mineral. DOI: 10.24198/jkk.vol1n1.6

Bemmelen, R.W. Van, 1949. The Geology of Indonesia. Martinus Nijhoff, Vol. IA, The Hague.
The Determination of Volcanic Characteristics Based on Deuterium and Oxygen-18 Isotope Compositions: A Case Study at Dieng Plateau, Central Java (Priatna et al.)

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

Cioni, R., Corazza, E., and Marini, L., 1984. The gas/steam ratio as indicator or heat transfer at the solfatara fumaroles, Phlegrean Fields (Italy). *Bulletin of Volcanology*, 47, p.295-302. DOI: 10.1007/bf01961560

Craig, H., 1961. Isotopic Variations in Meteoric Waters. *Science*, 133 (3465), p.1702-1703. DOI: 10.1126/science.133.3465.1702

Humaida, H., Sulistiyo, Y., and Hartiyatun, S., 2003. Fenomena Pemugaran Dieng Ditinjau dari Geokimia Gas. Balai Penyelidikan dan Pengembangan Teknologi Kebencanaan Geologi, Yogyakarta.

Iskandar, I., Dermawan, F.A., Sianipar, J.Y., Suryantini, and Notosihwoyo, S., 2018. Characteristic and Mixing Mechanisms of Thermal Fluid at the Tampomas Volcano, West Java, Using Hydrogeochemistry, Stable Isotope and 222Rn Analyses. *Geosciences*, 8 (103). DOI: 10.3390/geosciences8040103.

Kusumadinata, K., Hadian R., Hamidi, S., and Reksowirogo, L.D., 1979. *Data Dasar Gunungapi Indonesia*. Bandung: Direktorat Vulkanologi, Departemen Pertambangan dan Energi RI.

Le Guern, F., Tazieff, H., and Pierret, R.F., 1982. An example of health hazard: People killed by gas during a phreatic eruption: Dieng plateau (Java, Indonesia), February 20th 1979. *Bulletin of Volcanology*, XXXIV, p.153-156. DOI: 10.1007/bf02600430

Miller, C.D., Sukhyar, R., Santoso, and Hamidi, S., 1981. Eruptive History of the Dieng Mountain Region, Central Java, and potential hazards from future eruptions. *U.S. Geological Survey Open-File Report*, p.83-68. DOI: 10.3133/ofr8368

Panichi, C. and Volpi, G., 1999. Hydrogen, oxygen, and carbon isotope ratios of solfatara fumaroles (Phlegrean Fields, Italy): further insight into source processes. *Journal of Volcanology and Geothermal Research*, 91 (2), p.321-328. DOI: 10.1016/S0377-0273(99)00041-4.

Priatna, 2019. Karakteristik Vulkanik berdasarkan Korelasi Gas CO$_2$ dengan Gas Sulfur serta Isotop Deuterium dengan Oksigen-18 di Dataran Tinggi Dieng, Jawa Tengah (Dengan Referensi Kawah Sikidang). Program Pascasarjana, Fakultas Teknik Geologi, Universitas Padjadjaran, Bandung. DOI: 10.14203/risetgeotam2011.v21.51

Priatna, 2014. *Karakteristik Gas Vulkanik dan Implementasinya dalam Manajemen Mitigasi Bencana Gunung Api di Kawasan Wisata Dataran Tinggi Dieng, Jawa Tengah*. Program Magister Teknik Geologi, Fakultas Teknik Geologi, Universitas Padjadjaran, Bandung. DOI: 10.5614/bull.geol.2018.2.1.5

Priatna and Kadarsetia, E., 2007. Characteristics of volcanic gas correlated to the eruption activity; Case study in the Merapi Volcano, periods of 1990-1994. *Jurnal Geologi Indonesia* 2 (4), p.325-246. DOI: 10.17014/ijog.vol2no4.20074

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.

Sulistiyo, Y., Humaida, H., Sartini, E., and Suryono, 2002. Sebaran Gas CO$_2$ di Pegunungan Dieng. Balai Penyelidikan dan Pengembangan Teknologi Kebencanaan Geologi, Yogyakarta.

Zen, M.T. and Muzil, A., 1980. Hydrothermal Eruption at Sinila Crater, Dieng Volcanic Complex (Central Java). *Bulletin Departemen Teknik Geologi. ITB, Bandung.*