Magnetic Domain Distribution Analysis of Volcanic Material from the 2017 Eruptions of Mount Agung, Indonesia

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Abstract. Three types of volcanic materials of Mount Agung Bali Indonesia, i.e., volcanic ash, sand, and gravel have been tested magnetic susceptibility using a Bartington MS2B susceptibility meter. Of the three types of materials, volcanic ash has one order lower of the magnetic susceptibility of about 7.7×10⁻⁶ m³kg⁻¹ than that of sand and gravel which have magnetic susceptibility ranging from 14.1 to 26.8×10⁻⁶ m³kg⁻¹. Based on the χ_d Vs. χ_M analysis, it can be seen that magnetic minerals contained in the volcanic ash have dominated the stable single domains (SSD), while magnetic minerals in sand and gravel have dominated by multidomain (MD). The domain distribution of the magnetic mineral in various sizes of volcanic materials from Mount Agung of naturally approximates the exponential form.

Keywords: Magnetic susceptibility, volcanic material, mount agung

1. Introduction
In the past few decades, the Rock Magnetic method has been widely applied and is developing rapidly. Besides the applications for the study of paleomagnetism, environmental magnetism, biomagnetism, magnetoclimatology, in the last decade, the application of rock magnetism methods penetrated in agriculture known as agromagnetism and in the volcanic material to understand more deeply the volcano mechanism, known as vulcanomagnetism. The measurement of magnetic properties, especially magnetic susceptibility of volcanic materials such as basalt, diorite, although for different purposes such as magnetic anisotropy susceptibility (AMS) test for the benefit of paleomagnetism studies has been done, magnetic susceptibility test can also be used to predict the origin of magnetic minerals and processes that affect the time of deposition [1-2]. In an effort to deduce various geophysical and environmental phenomena, geophysical methods are often juxtaposed with a geochemical analysis [3-7]. The application of rock magnetism method is also applied to materials in geothermal environments such as hot springs [8-9].

Vulcanomagnetism is specifically studied with long-term goals, understanding the characteristics of the volcanic material that may tell the characteristics of volcanoes more closely related to temperature and energy of the eruption. Several studies concerning volcanic processes properties have long been initiated by researchers as discussed in the book on the use of paleomagnetic and magnetic magnetism to understand volcanic processes [10]. In this study, the method of rock magnetism and
chemical element analysis was used in the volcanic material to provide a detailed description of the magnetic properties of the volcanic material and their usefulness in understanding the characteristics and mechanisms of volcanoes.

2. Experimental Methods

Three types of samples namely volcanic ash, sand and gravel of Mount Agung on November 2019 eruption were taken around the location of the mountain peak on March 4, 2018, precisely in the village of Sebudi, Selat District, Karangasem Regency, Bali. There are three sampling points, the first point at the top, near the parking area, volcanic ash (P1) and gravel (P4) samples were taken. The second sampling point is 500 meters from the top parking area, with sand sample types and coded P2. The third point is 1 km from the top parking are taking two types of samples, namely sand and gravel which are coded P3 and P5 respectively. The samples taken in the field are then taken to the laboratory to prepare measurements of magnetic susceptibility by taking a small portion of sample samples and put them into a standard plastic holder for measuring magnetic susceptibility (plastic cylinders with a diameter of 2 cm and height of 2.2 cm). Each type of sample is prepared 10 holders, for example, volcanic ash samples are coded P1.1 to P1.10. Then the sample was measured by Bartington, MS2B with low and high frequencies and calculated mass-based susceptibility from low and high-frequency measurements and dependent frequency susceptibility. The calculation results are then mapped to see the domain of magnetic mineral distribution [11]. The method is also used in detail can be used to map magnetic top soil susceptibility and soil stability [12-13]. Some of the samples selected in this study were also tested for the content of elements with Panalytical X-Ray fluorescence (XRF). Furthermore, the correlation of element content with magnetic susceptibility values as described in the discussion.

3. Results and Discussion

The results of the magnetic susceptibility test using Magnetic Susceptibility Meter Bartington MS2B generated the volume of susceptibility value (κ), then analyzed and produced a mass-specific susceptibility (χ). The measurement was done with two frequencies namely low frequency and high frequency. From this measurement, we obtained the value of low-frequency magnetic susceptibility (χ₀) and high-frequency magnetic susceptibility value (χ₀₀). Based on the calculation the value of low-frequency magnetic susceptibility (χ₀) and high-frequency magnetic susceptibility values (χ₀₀, we obtain magnetic susceptibility frequency dependent (χ₀₀).

The overall measurement results of the magnetic susceptibility of volcanic material from Mount Agung eruption have a range of low-frequency magnetic susceptibility values (χ₀) with a range of (7.66–26.80) × 10⁻⁶ m³kg⁻¹ with a dependent magnetic susceptibility value(χ₀) between 0.8%–2.7%. The correlation of the low-frequency magnetic susceptibility value (χ₀) with high-frequency magnetic susceptibility value (χ₀₀) is shown in Figure 1. Based on the R-value, the measurement of low-frequency susceptibility with high frequency shows high consistency and stability.

At each sampling point also showed a high consistency in the measurement which can prove the distribution of magnetic susceptibility values in Figure 2 looks to collect for specific sampling points. The lowest susceptibility of volcanic ash compared to sand and gravel samples. However, the gravel sample has the widest susceptibility range, namely in the sand area, between 15–20 × 10⁻⁶ m³kg⁻¹ and 25–30 × 10⁻⁶ m³kg⁻¹. Based on the χ₀₀ value in each group susceptibility value, it can be seen that for sand and gravel, the magnetic minerals are dominated by multidomain (MD) grains, while volcanic ash is dominated by single domain (SD) to superparamagnetic (SP) grains [11].
Figure 1. The Correlation of low-frequency $\chi_{lf}$ magnetic susceptibility and high-frequency $\chi_{hf}$ magnetic susceptibility of samples from Sikka Nusa Tenggara Timur.

Figure 2. Distribution of $\chi_{lf}$ and $\chi_{hf}$ of volcanic material from Agung Mount, Bali. P1 is volcanic ash, P2 and P3 are sand, while P4 and P5 are gravel.
The XRF measurement results from each selected representative sample show the contents of each element as shown in Table 1. The dominant elements measured are Fe, Si, Ca and Al. The sample content of the volcanic ash is the biggest among the others, but the Fe content is the lowest compared to the other two types of samples. Sand has a relatively similar content of Si, Al, Ca and Fe in two different picking places. The magnetic susceptibility, in this case, has a good correlation with Fe% content. The higher Fe, the higher the value of magnetic susceptibility. From these data, it can be concluded that magnetic minerals from the three types of samples are sourced from the same place [3]. This characteristic illustrates mount Agung which can be compared with other mountain materials in Indonesia and other countries. At one time, it might be possible to find a relationship between the characteristics of magnetic minerals and the characteristics of volcanoes such as shields or cones or the type of mountain volcano.

In Table 2, the susceptibility value and the content of Wt (%) elements from XRF data are shown from the four dominant elements and their correlation of five representative samples. Based on the data in Table 2, it can be seen that there is a positive correlation between an iron element content of Fe with a magnetic susceptibility, namely R = 0.98. Besides having a positive correlation with Fe, a magnetic susceptibility also has a positive relationship with Ca. Al and Si, on the other hand, show that the relationship is inversely proportional to Fe. This discovery can support previous findings on volcanic material in other places such as alkaline volcanic material such as in Isparta area SW Turkey [4]. This condition does not apply to other natural samples which in general susceptibility is not positively correlated with Fe because natural elements of Fe are not always associated with other elements forming ferromagnetic minerals, but can also form paramagnetic. Therefore, the presence of enough Fe even in natural samples can form paramagnetic with susceptibility that tends to be small [9], [11].

**Table 1.** XRF test results of Mount Agung Volcanic eruption material

| Unsur | P1.1 (%) | P2.9 (%) | P3.3 (%) | P4.9 (%) | P5.7 (%) |
|-------|----------|----------|----------|----------|----------|
| Al    | 10      | 9.1      | 9.3      | 7.7      | 10       |
| Si    | 34.7    | 30       | 30.4     | 24.4     | 32       |
| S     | 3.2     | 1.2      | 0.78     | -        | -        |
| P     | -       | -        | -        | 0.43     | -        |
| K     | 2.43    | 2.21     | 2.2      | 1.88     | 2.7      |
| Ca    | 13.8    | 16       | 15.9     | 13.9     | 17.7     |
| Ti    | 1.89    | 2.32     | 2.26     | 2.8      | 2.02     |
| V     | 0.13    | 0.16     | 0.15     | 0.23     | 0.12     |
| Cr    | 0.064   | 0.073    | 0.065    | 0.074    | 0.074    |
| Mn    | 0.31    | 0.51     | 0.53     | 0.61     | 0.58     |
| Fe    | 28.4    | 34       | 34.3     | 41.1     | 33       |
| Cu    | 0.15    | 0.16     | 0.15     | 0.13     | 0.2      |
| Zn    | 0.02    | 0.02     | 0.03     | 0.02     | 0.01     |
| Sr    | 0.54    | 0.72     | 0.74     | 0.7      | 0.69     |
| Mo    | 3.5     | 2.8      | 2.6      | 5.46     | -        |
| Eu    | 0.4     | 0.3      | 0.3      | 0.4      | 0.4      |
| Re    | 0.2     | 0.32     | 0.2      | 0.3      | 0.34     |
| Na    | 2.1     | 3.1      | 3.1      | 2.9      | 2.9      |
| Mg    | 0.3     | 0.48     | 0.4      | 0.56     | 0.66     |
Table 2. Magnetic susceptibility and element content dominance of 5 samples representative.

| Sample ID | Al  | Si  | Ca  | Fe  | $\chi_l (10^{-6} \text{ m}^3/\text{kg})$ |
|-----------|-----|-----|-----|-----|---------------------------------------|
| P1.1      | 10  | 34.7| 13.8| 28.4| 7.75                                  |
| P2.9      | 9.1 | 30  | 16  | 34  | 15.15                                 |
| P3.3      | 9.3 | 30.4| 15.9| 34.3| 18.72                                 |
| P4.9      | 7.7 | 24.4| 13.9| 41.1| 26.41                                 |
| P5.7      | 10  | 32  | 17.7| 33  | 15.31                                 |

4. Conclusion

From the results of the study, it can be concluded that the volcanic ash has the lowest susceptibility and the size of the magnetic mineral grain tends to be smaller than that of the two other measured materials, sand and gravel. Based on the $\chi_l$ Vs. $\chi_fd$ plot, the domain of magnetic minerals from the mount Agung volcanic ash, varies from MD to SD, while sand and gravel range in MD size. The content of the Fe element is positively correlated with magnetic susceptibility, while Al and Si are inversely proportional to magnetic susceptibility. Further studies are needed regarding the magnetic mineral morphology of the three materials to understand more about the mechanism of the mount Agung.

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