Magnetic characterization of soil to determine the source origin. Case study: soil around Bromo Volcano, Tengger Volcanic Complex

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The research on soil characteristics is very important in Indonesia. Indonesia is a well-known country for its volcanoes in the world. Many lush areas around the volcano are still active. One of the famous and still active volcanic complexes is the Tengger Volcanic Complex. The aim of this research is to analyze the magnetic characteristic of four volcanic soils around Bromo Volcano. The sample consists of soil from Gubug Glakah (GGK), Ngadirejo (NDJ), Nongko Jajar (NKJ), and Waringinanom (WAN) Village. Rock magnetism method combine with geochemical analysis are applied in this study. The results of this research are a significant difference in magnetic susceptibility value of WAN soil ($1.976.4 \times 10^{-8} \text{m}^3/\text{kg}$) with magnetic susceptibility value of three other soils (between $900-1200 \times 10^{-8} \text{m}^3/\text{kg}$). Meanwhile, X-Ray Fluorescence (XRF) analysis showed that FeO concentration on WAN soil was lower than other soils. This indicates that the concentration of magnetite minerals ($\text{Fe}_3\text{O}_4$) on WAN soil is higher than other soils. The difference of magnetite mineral concentrations in the soil may be due to difference sources. Based on these results, it is concluded that WAN soil may not come from a similar source. This study still needs further research.

1. Introduction

As an agricultural country, research on soil is very important in Indonesia. The fertile soil will have a good agricultural effect. One type of fertile soil is volcanic soil. Volcanic soil is produced from the weathering of volcanic products both from volcanic rocks and volcanic ash. One of the volcanic complexes that are still active in producing volcanic products is the Tengger Volcanic Complex in East Java [1,2].

Soil is one of the interesting objects to be studied. Research on soil has been done by using physics, chemistry and rock magnetism. One example of research on soil using rock magnetism methods such as Safiuddin et al. [3] examines laterite soil as an indicator of the process of pedogenesis. Furthermore, Bijaksana and Huliselan [4] examine the soil in landfills in Bandung. However, study about soil based on the distance from volcano with the rock magnetism method has been rarely carried out. The aim of

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this research is to analyze the magnetic characteristics of the four volcanic soils around Bromo Volcano, Tengger Volcanic Complex. Based on the magnetic characteristics obtained, the source origin can be determined.

2. Basic Theory and Method
Soil is the result of weathering rocks both physically, chemically and biologically. Soil contains nutrients, where the nutrient is composed of macro and micro elements [5]. In the study of magnetism of rock, the element that becomes the main character is iron (Fe). This element of iron despite its presence in nature is little but contributes very significantly.

The soil samples were taken from four sites around Tengger Caldera and Mount Bromo. All soil samples have relatively close proximity to the Tengger Volcanic Complex area. The soil samples taken were determined randomly with different distances to Bromo volcano. The nearest sample is taken at Ngadirejo (code sample NDJ) with a distance of 9 km from the Bromo volcano. Then, the sample was taken at Gubug Glakah Village (code sample CGK) with a distance of 14 km from the Bromo volcano. Furthermore, the soil samples were taken in Nongko Jajar Village (code sample NKJ) with distance of 15.3 km from Bromo volcano. The sample of soil in Waringinanom Village (code sample WAN) is the farthest soil sample from the Bromo volcano with a distance of 23.3 km. Figure 1 illustrates the position of each soil sample against Bromo volcano.

![Figure 1. Location of soil from Bromo volcano](image)

The method used is a combination of rock magnetism method with geochemical analysis. The measurements of rock magnetism method were carried out are magnetic susceptibility, anhysteretic remanent magnetization (ARM) and isothermal remanent magnetization (IRM). The methods have been explained in great detail in Santoso et al. [1]. All measurement carried out in the Laboratory of Characterization and Modeling of Physical Properties of Rocks, Basic Science Center A (BSCA), Institut Teknologi Bandung. Unless, geochemical analysis is carried out using X-Ray Fluorescence at the Central Laboratory of Minerals and Advanced Materials, State University of Malang.

3. Result and Discussion
Table 1 is average of magnetic susceptibility value and the distance of samples from Bromo volcano. The magnetic susceptibility of soil decreases by increasing the distance from source. Soil samples derived from weathering of volcanic ash. Soil closed to the source contains a lot of heavy mineral magnetic from Fe₃O₄, as compared to soil far from the source. This is assumed that heavy volcanic ash falls near the source during the eruption. Magnetic susceptibility value decreases based on distance.
source only applies for NDJ, GGK and NKJ soil samples. Meanwhile, on the WAN samples occurs weirdness. The farthest sample distance with the source shows the higher magnetic susceptibility. Therefore it needs to be identified further.

Table 1. Average of magnetic susceptibility values and distance samples to Bromo volcano

| Code | $\chi_{LF}$ average ($\times 10^{-8}$ m$^3$/kg) | Distance from Bromo volcano (km) |
|------|-----------------------------------------------|---------------------------------|
| NDJ  | 1180,1                                        | 9                               |
| GGK  | 1090,2                                        | 14                              |
| NKJ  | 920,1                                         | 15,3                            |
| WAN  | 1976,4                                        | 23,3                            |

Based on IRM measurements, all soil samples are saturated before 300 mT indicating that the magnetic mineral type of the soil sample is magnetite. Based on the ARM measurements, all soil samples have a median destructive field (MDF) of 12 - 14 mT corresponding to a grain size of 6 - 10 μm [6] which represented the pseudo single domain (PSD).

Table 2a and 2b are the result of geochemical analysis from XRF measurement. All soil samples containing Fe and FeO concentration are almost similar, except for WAN soil. WAN soil has the lowest Fe and FeO concentration. Nevertheless, as seen in Table 1, WAN soil has the highest magnetic susceptibility value. It is caused by Fe$_3$O$_4$ concentration higher than other soil.

Table 2a. The element concentration (in weight %) of the soil sample

| Sample Code | Fe (%), Al (%), Si (%), Ti (%), Ca (%), Ni (%) | Others (%) |
|-------------|-----------------------------------------------|------------|
| NDJ         | 61,84, 8,7, 13,8, 2,6, 8,25, 0,26              | 4,55       |
| GGK         | 62,65, 11, 17,7, 2,73, 2,81, 0,24              | 2,87       |
| NKJ         | 61,78, 7,6, 14,9, 2,5, 6,18, 0,38              | 6,66       |
| WAN         | 50,51, 10, 21,8, 2,44, 10,6, 0,18              | 4,47       |

Table 2b. Mineral oxide concentration (in weight %) of the soil samples

| Sample Code | FeO (%), SiO$_2$ (%), Al$_2$O$_3$ (%), TiO$_2$ (%), CaO (%), NiO (%), Others (%) |
|-------------|-----------------------------------------------|---------------------------------|
| NDJ         | 52,19, 21, 12, 2,83, 7,69, 0,19, 4,1          |
| GGK         | 50,88, 26,3, 15, 2,91, 2,56, 0,16, 2,19       |
| NKJ         | 52,21, 22,8, 10, 2,75, 5,75, 0,26, 6,23       |
| WAN         | 39,26, 31,9, 14, 2,47, 9,21, 0,11, 3,05       |

To investigate the difference of Fe$_3$O$_4$, figure 2 is plotted, showing magnetic susceptibility versus Fe and FeO concentration of the soil samples. Soil samples were divided into two groups: group 1 (GGK, NDJ, and NKJ) and group 2 (WAN). This is because groups 1 and 2 come from different sources, i.e. the Tengger and Middle Quaternary Volcanic, respectively [7]. Different sources cause differences of Fe$_3$O$_4$ concentration in soil.
Figure 2. Plot of magnetic susceptibility versus Fe and FeO concentration of the soil samples

4. Conclusion
Magnetic characteristic of four volcanic soils around Bromo Volcano has been studied. The magnetic susceptibility of the soil decreases by increasing the distance of the source, only in the same source. Plots of magnetic susceptibility values with Fe and FeO concentration were able to identify source differences in soil samples. These results will be used as a preliminary study for agricultural soil research in Lampung.

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