Analysis of magnetic properties rocks and soils around the Danau Diatas, West Sumatra

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Abstract. The magnetic characteristics of the rocks have different magnetic properties of each kind. If this rock experiences weathering, then the rock material will be carried around the area such as the lake, through the wind, the water is then sedimentated. These sediments can also come from dust from volcanic eruptions (volcanic ash) where the magnetic properties that come from surrounding rocks are different from the magnetic properties derived from dust from volcanic eruptions. This study was used to determine the magnetic characteristics of rocks and soil around the Danau Diatas West Sumatra, which is one source of sediment. This the magnetic properties can be determined using rocks magnetism method that are commonly used to determine the magnetic properties of a material nature. Characteristics magnetic determined through test susceptibility magnetic using Bartington MS2B (Magnetic Suceptibility sensor B) dual frequency of 470 Hz and 4.7 kHz. Results this study shows values χ_{LF} (susceptibility low frequency), χ_{HF} (susceptibility high frequency) and χ_{FD} % (susceptibility frequency dependent). Value of susceptibility of rocks and soil obtained variations in the range of 23.77 x 10^{-8} m^3 / kg - 2791.6 x 10^{-8} m^3 / kg and 17.4 x 10^{-8} m^3 / kg - 2804.4 x 10^{-8} m^3 / kg. The value of magnetic suceptibility of rock and soil is included in the ferromagnetic mineral group and the types of minerals contained there in are ilmenite ($FeTiO_3$) and hematite (Fe_2O_3). The value of frequency-dependent magnetic susceptibility χ_{FD} (%) ranges from 0.4% to 13.5%. For the value of χ_{FD} (%) 0.4% - 1.1% means that there is no or contains less than 10% superparamagnetic grain, for the value of χ_{fd} (%) 3.3% means the mixture of superparamagnetic grain and coarser non-superparamagnetic grain, or superparamagnetic grain measuring < 0.005μm, and for the value of χ_{fd} (%) 13.5%, meaning that the whole or consists of more than 75% superparamagnetic grains.

1. Introduction

Volcanoes in Indonesia have a large number stretching from west to east from Sumatra, Java to the Banda Sea. All these mountains are in a Sunda Bow series. Indonesia is located at the confluence of Eurasian and Indo-Australian tectonic plates, both of which collide causing Indonesia to have 129 active volcanoes or about 13% of the active mountains in the world along Sumatra, Java to the Banda Sea [1]. Sumatra has at least 30 active volcanoes that can affect the environment. Volcanic activity of this mountain shows the presence of lava under the surface of the earth which is a source of rock and forms rock structures on the surface of the earth.

Rocks are part of the earth's crust, which has solid chemical compounds derived from magma consisting of 1 or more minerals which are formed naturally with different magnetic values. If this rock

experiences weathering, then the rock material will be carried around the area such as the lake, through the wind, the water is then sedimentated. Environmental conditions can be known from the presence of sedimentary magnetic minerals and their abundance, quantitatively the magnets in the sediment are relatively small, but magnetic minerals are always present in the sediments even though their abundance is small enough about 0.1% of the rock mass [2].

Magnetic minerals in rocks can be identified using several methods. One method that is often used is the method of rock magnetism. This method is based on measuring variations in magnetic field intensity on the earth's surface caused by variations in the distribution of magnetized objects under the earth's surface or called susceptibility. Magnetic susceptibility of a material is a quantitative measure of the material to be magnetized when subjected to magnetic fields [3]. Magnetic properties of rock-forming materials - rocks can be divided into:

a. Diamagnetic

Diamagnetic materials have small and negative material magnetic susceptibility values.

b. Paramagnetic

Paramagnetic material has a small magnetic susceptibility value (less than 10^{-6} m^3 / kg), but is positive.

c. Ferromagnetic

Ferromagnetic material has a very large magnetic susceptibility value

d. Ferrimagnetic

Ferrimagnetic material has a large magnetic susceptibility value, which is greater than 10^{-6} m^3 / kg

Measurement of magnetic suceptibility of samples in the open will provide information about the minerals contained in the sample [4]. The number of magnetic minerals in the rock will affect the size of the magnetic susceptibility obtained, the greater the number of minerals that are magnetic, the greater the value of magnetic susceptibility and vice versa. The contribution of magnetic minerals in a material is directly proportional to the susceptibility of the ingredients [5]. Each rock has different magnetic susceptibility values.

The value of magnetic susceptibility was measured using the Bartington Magnetic Suceptibility Meter MS2 model connected to the MS2B sensor. The measurement of magnetic susceptibility consists of susceptibility low frequency (χ_{LF}), susceptibility high frequency (χ_{HF}), and susceptibility frequency dependent (χ_{FD}). The method and technique of measuring magnetic susceptibility is chosen because the method is easy, simple, and inexpensive, which is a non-destructive method with uncomplicated field equipment [6].

Rock magnetism can be carried out for environmental studies because magnetic minerals are found in all types of environments including rocks, sedimentary soils, dust, organic tissues and man-made materials. In the last few years studies on rock magnetism have increased. In Indonesia rock magnetism has been studied and developed since the 19th century [7]. Starting with the application of paleomagnetism which is used to track plate tectonics [8], after that it is applied to biomagnetism, namely the study of magnetism in living things; enviromagnetism; magnetoclimatology [9]; industry [10] and the study of rock magnetism that is currently developing is agromagnetism [11] and volcanomagnetism [7].

The purpose of this study was to examine the magnetic properties of rocks and soil around the Danau Diatas. Study of the magnetic properties of rocks and soil, including the concentration of magnetic minerals, to determine the magnetic characteristics of rocks and soil, as a reference to determine the source of sedimentary minerals in the Danau Diatas. The study of magnetic properties of rocks around the Danau Diatas is very important to do for environmental studies (environmental magnetism). Based on the description above, researchers are interested in conducting research on "Analysis of Magnetic Properties of Rocks and Soils Around the Danau Diatas, West Sumatra".

2. Method

2.1. Research Location and Design

The research was carried out around Danau Diatas, Solok Regency, West Sumatra (Figure 1a). Danau Diatas is located in a geographical position between 1°01'51"- 1°07'39" South Latitude, and between 100°43'01"-100°50'26" East Longitude, approximately south of Danau Dibawah (Figure 1b).

a)   b)
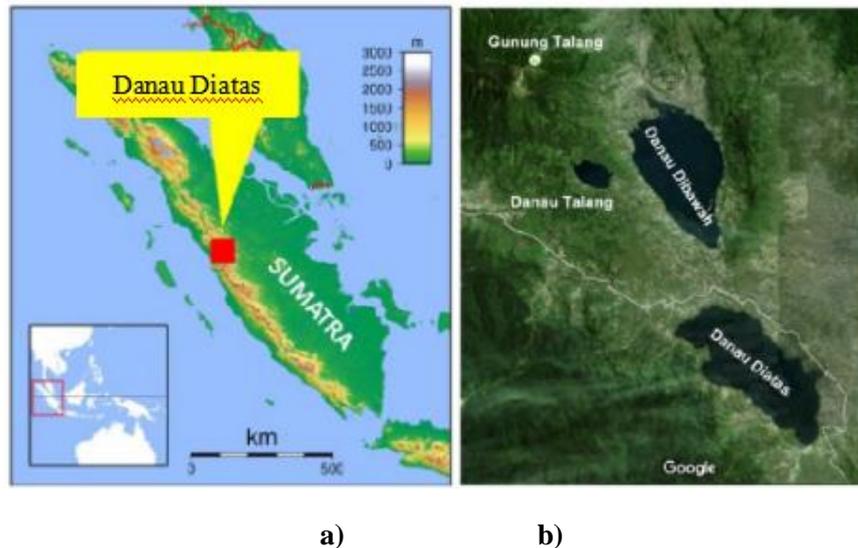
Figure 1. Map of Location of Research Areas Around the Danau Diatas. a) Map of Sumatra b) Map of Location Danau Diatas

2.2.Sampling and Sample Preparation

a)   b)
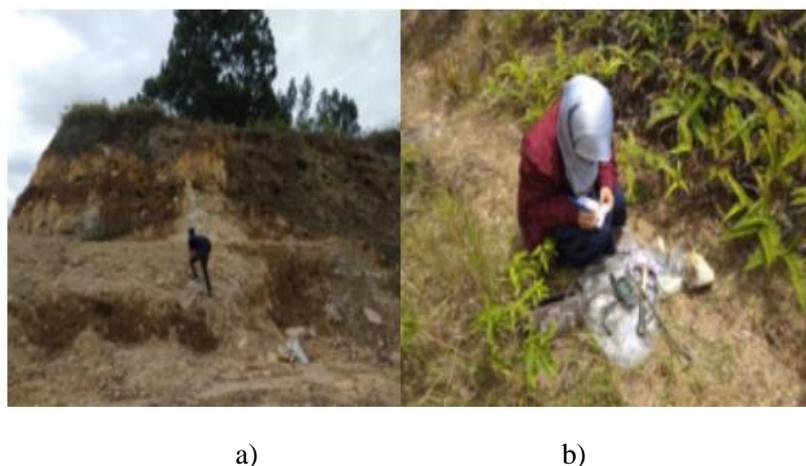
Figure 2. Sampling Process. a) Sampling Process b) The process of naming rock and soil samples

The sample in this study was taken in several locations, namely the first location was in Jorong Urak, Kecamatan Lembah Gumanti, the second location is in Batang Ari Jorong Batu Putiah Kecamatan Lembah Gumanti, the third location is in Jorong Taluak Dalam Kecamatan Lembah Gumanti, and the fourth location is in Simpang Tanjuang Nan IV Kecamatan Danau Kembar (Figure 2a). The geographical position of the sample (in the form of geographical coordinates) is determined using the GPS (*Global Positioning System*).

Figure 3. Sample Ready to Measure in Holder

In this study the type of sample used is rock and soil. All samples were 14 samples (Figure 3), namely: 9 rock samples and 5 soil samples. Each sample is distinguished from the sample naming system (Figure 2b), namely name of area, sequence of sampling locations (for rock samples: the order of the sampling location is given one number in the order of the location of the sample, while for the soil sample: the order of the sampling location is given two numbers in the order of the location of the sample), variation of sample type, Year - Month - Date. Sample naming examples: a) for rock samples: Diatas 01a 2018-07-21, b) for soil samples: Diatas 011a 2018-07-21. Each holder named sample, and then measured its mass using a digital balance, the measurement results entered in the Excel table.

For chunk shaped rock samples, it is crushed using a hammer, then mashed using mortar to become powder. Sample the powder is sieved in a filter to obtain finer powder samples. For soil sample, dried under the sun, then the soil is still clot smoothed using a mortar until powdered. Rock and soil samples that have been powdered are inserted into the holder until they are solid and full (Figure 3). Next, the mass holder is measured containing the sample using a digital balance, this measurement is intended to obtain a sample mass. The measurement results are included in the Excel table and the sample is ready to be measured (Figure 3).

2.3. Sample Measurement
Measurement of rock and soil samples, each sample was measured the value of magnetic susceptibility is 3 times the measurement, the results of the three measurements are averaged. This measurement is intended to produce *susceptibility frequency dependent* χ_{FD} (%), which is defined:

$$\chi_{FD} (\%) = (\chi_{LF} - \chi_{HF}) / \chi_{LFF} \text{ x } 100\% \tag{1}$$

Table 1. Interpretation of the value χ_{FD} (%) [12]

Value of χ_{fd} (%)	Information
< 2.0%	None or contains less than 10% superparamagnetic grain
2.0 - 10.0%	A coarser mixture of superparamagnetic and non-superparamagnetic grains, or superparamagnetic grain measuring <0.005μm
10.0 - 14.0%	Overall or consists of more than 75% superparamagnetic grain

3. Results and Discussion

The measurement results of the susceptibility of rock and soil magnetic minerals can be seen in Table 2. Based on the measurement results can be identified classification of magnetic material contained in the sample. From measuring 9 rock samples obtained the value of magnetic susceptibility varies in the range between 23.77 x 10 $^{-8}$ m ^{3} / Kg - 2791.6 x 10 $^{-8}$ m ^{3} / Kg. It can be said that there is a difference in the quantity of magnetic minerals in the rock. Magnetic susceptibility 23.77 x 10 $^{-8}$ m ^{3} / Kg, is the magnetic susceptibility value of slate rock. This can be said that the content of magnetic minerals at that point is lower or Ferrimagnetic samples. The low value of magnetic susceptibility at this point may be due to the weathering and precipitation process which results in mixed with diamagnetic organic materials [18] . If it is connected with Table 3 it can be interpreted that the magnetic minerals which become magnetic carriers in the sample are dominated by hematite mineral (Fe $_2$ O $_3$).

Magnetic susceptibility of 2791.6 x 10 $^{-8}$ m ^{3} / Kg, is a magnetic susceptibility value of diorite rock. this can be said that the magnetic mineral content at that point is quite high or the sample is ferromagnetic. This may be due to the content of elements from samples originating from the original rocks which have not undergone weathering. If it is connected with Table 3 it can be interpreted that the magnetic minerals which become magnetic carriers in the sample are dominated by ilmenite minerals (FeTiO3).

For the measurement of 5 soil samples obtained the value of magnetic susceptibility varies in the range between 17.4 x 10 $^{-8}$ m ^{3} / Kg - 2804.4 x 10 $^{-8}$ m ^{3} / Kg. Magnetic suceptibility with a value of 17.4 x 10 $^{-8}$ m ^{3} / Kg, it can be said that the magnetic mineral content in the soil is low or the amount of ferrimagnetic minerals contained in the sample is small. The low magnetic susceptibility value at that point may be due to the sampling location away from the magnetic source carrier (magnetic mineral). If it is connected to Table 3 it can be interpreted that the magnetic mineral which is the magnetic properties carrier in the sample is dominated by hematite (Fe $_2$ O $_3$).

Magnetic susceptibility 2804.4 x 10 $^{-8}$ m ^{3} / Kg, is a value of clay magnetic susceptibility. It can be said that the magnetic mineral content at that point is quite high or the sample is ferromagnetic . This may be caused by iron mineral content in high samples. If it is connected with Table 3 it can be interpreted that the magnetic minerals which become magnetic carriers in the sample are dominated by ilmenite minerals (FeTiO3). Theoretically the composition of ilmenite compounds (FeTiO3) consisted of 36.80% Fe, 31.57% Ti and 31.63% O or 52.66% TiO2 and 47.33% FeO. According to Madjid, A (2009), hematite and ilmenite are some minerals found in soil that belong to the group of oxide minerals, namely non-silica minerals.

Based on the relationship graph χ_{LF} (10^{-8} m^3 / kg) with χ_{FD} (%) for samples of rock and soil in figure 4 and the graph of χ_{HF} (10^{-8} m ^{3} / kg) with χ_{FD} (%) for rock and soil samples in figure 5 can It is seen that the value of χ_{FD} in soil samples is higher than that of rock samples. The value of χ_{FD} (%) obtained varies in the range between 0.4 - 13.5%. Magnetic susceptibility depends on the frequency of 13.5% is the value of soil χ_{FD} (%), based on Table 1 these values interpret that the sample contains more than 75% superparamagnetic grain. The higher the value of χ_{FD} (%), the higher the content of the superparamagnetic grain. Whereas χ_{FD} (%) with a value of 3.3%, and 4.6% is the value of χ_{FD} (%) soil, based on Table 1 these values interpret that the sample contains a mixture of superparamagnetic grains and coarser non-superparamagnetic grains, or a superparamagnetic grain measuring <0.005μm. For χ_{FD} (%) 0.8 % and 1.1 %, it is the χ_{FD} (%) value of soil based on Table 1 this value interprets that the sample contains less than 10% superparamagnetic grain.

Table 2. Results of Magnetic Susceptibility Measurement

No	Sample Name	Sample Type	Suceptibility (χ)		
			χ_{LF} ($\times 10^8 m^3$/kg)	χ_{HF} ($\times 10^{-8} m^3$/kg)	χ_{FD} (%)
1	Diatas 011 2018-07-21	Soil	802.4	776.2	3.3
2	Diatas 022 2018-07-21	Clay	779.8	771.1	1.1
3	Diatas 022A 2018-07-21	White Clay	2804.4	2781.9	0.8
4	Diatas 033 2018-07-21	Soil	58.4	50.6	13.5
5	Diatas 044 2018-07-2	Soil	18.2	17.4	4.6
6	Diatas 01A 2018-07-21	Andesite Rock	2332	2314.3	0.8
7	Diatas 01B 2018-07-21	Diorite Rock	2161.7	2144.9	0.8
8	Diatas 01C 2018-07-21	Diorite Rock	2791.6	2780.1	0.4
9	Diatas 02 2018-07-21	Slate Rock	23.9	23.77	0.6
10	Diatas 03A 2018-07-21	Andesite Rock	1828.5	1817	0.6
11	Diatas 03B 2018-07-21	Andesite Rock	1675.8	1668.5	0.4
12	Diatas 04A 2018-07-21	DioriteRock	1806.4	1795.5	0.6
13	Diatas 04B 2018-07-21	Andesite Rock	1887.4	1877.4	0.5
14	Diatas 04C 2018-07-21	Andesit Rock	1681.5	1675.3	0.4

Table 3. Magnetic properties of a number of rocks and magnetic minerals [13]

| Mineral	Chemical Formula	Density (10^3kg m^{-3})	Suceptibility	
			Volume k (10^{-6} SI)	Mass χ (10^{-8} m^3 kg^{-1})
Hematit	Fe_2O_3	5,26	500-400.000	10-760
Maghemit	$_\alpha Fe_2O_3$	4,9	2.000.000-2.500.000	40.000-50.000
Ilmenit	$FeTiO_3$	4,72	2.200-3.800.00	46-80.000
Magnetit	Fe_3O_4	5,18	1.000.000-5.700.000	20.000-110.000
Titanomagnetit	$Fe_{3-x}Ti_xO_4$	4,98	130.000-620.000	2.500-12.000
Titanomaghemit	$Fe_{(3-x)R}Ti_{xR}O_3$	4,99	2.800.000	57.000
Ulvospinel	Fe_2TiO_4	4,78	4.800	100
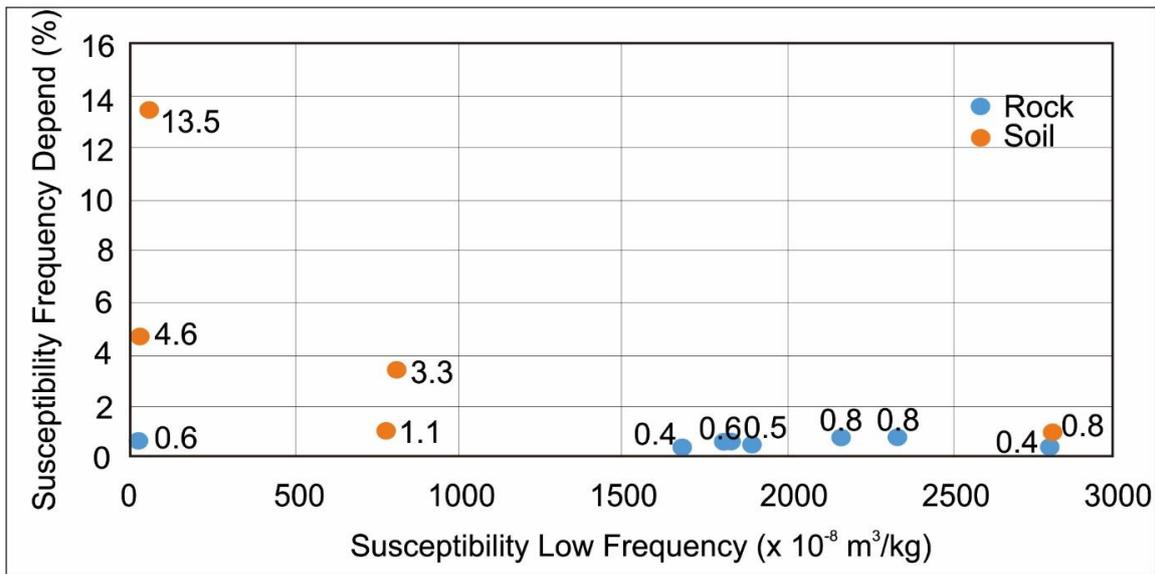
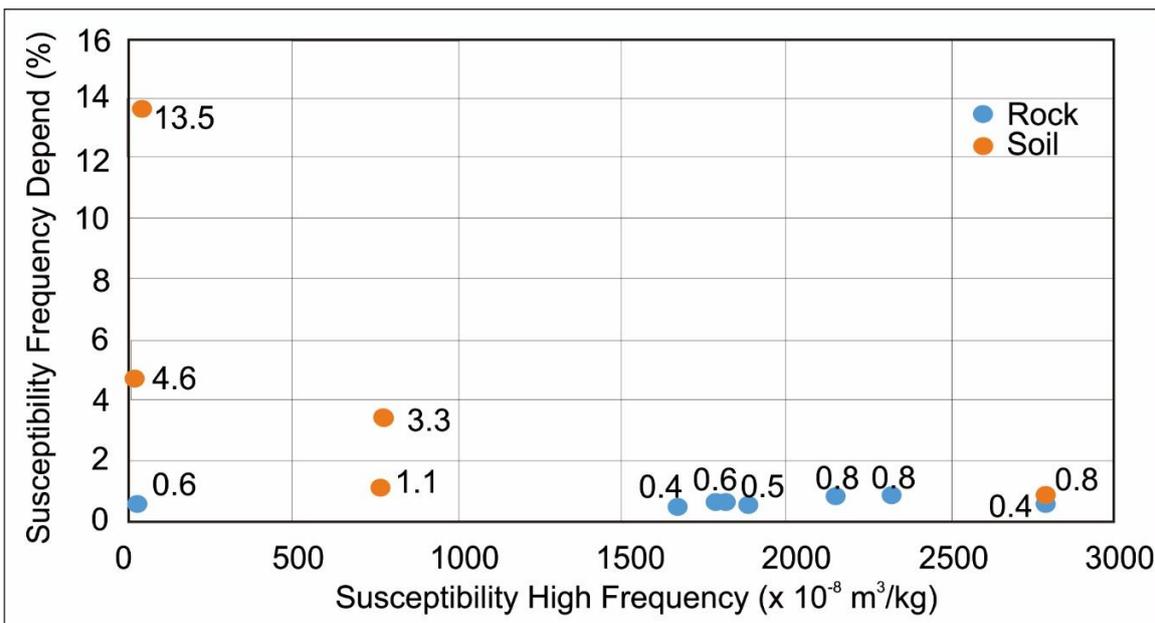**Figure 4.** Graph of relations χ_{LF} (10^{-8} m^3 / kg) with χ_{FD} (%) for rock and soil samples

Figure 5. Graph of relations χ_{HF} (10^{-8} m^3 / kg) with χ_{FD} (%) for rock and soil samples

Soil containing superparamagnetic grain makes the soil smooth. Smooth soil will more easily absorb water and experience faster saturation. For χ_{FD} (%) 0.4 % - 0.8 %, is the value of χ_{FD} (%) rock, based on Table 1 this value interprets that the sample contains less than 10% superparamagnetic grain. In the soil sample the value of χ_{FD} (%) gets smaller as the value χ_{LF} increases and χ_{HF}, while the rock samples χ_{FD} (%) value tends to increase with increasing value of χ_{LF} and χ_{HF}.

4. Conclusion

Based on the results of research conducted and discussion can be concluded that the use values of magnetic susceptibility of rocks and soil varies in the range between 23.77 x 10^{-8} m^3 / kg - 2791.6 x 10^{-8} m^3 / kg and 17.4 x 10^{-8} m^3 / kg - 2804.4 x 10^{-8} m^3 / Kg. The value of magnetic susceptibility of rock and soil around the Danau Diatas is included in the ferromagnetic and ferrimagnetic mineral groups. Mineral the magnetic carrier on the magnetic properties of samples are dominated by mineral ilmenite

($FeTiO_3$) and hematite (Fe_2O_3). For the value of magnetic susceptibility depending on frequency d $_{fd}$ (%) ranges between 0.4% to 13.5%. The value of magnetic susceptibility depends on the frequency in the range 0.4% - 1.1% , the value interprets that the sample contains less than 10% of superparamagnetic grains, the value of χ_{FD} (%) in the range of 3.3% and 4.6% of these values interpret that the sample contains a mixture of superparamagnetic grains and coarser non-superparamagnetic grains, or the superparamagnetic grain size <0.005μm, while the value of χ_{FD} (%) is 13.5%, the value interprets that the sample contains more than 75% superparamagnetic grain.

Acknowledgement

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