Magnetic susceptibility of pre- and post caldera lavas from Maninjau, West Sumatra

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Abstract. Lake Maninjau was formed after a caldera forming eruption ~50,000 years ago. Even though this eruption is one of the biggest Quaternary eruptions on Sumatra, it is not studied in detail so far. Only few attempts to study the volcanic processes have been carried out, mainly focusing on stratigraphy, physical volcanological parameters and geochemical characterization of volcanic rocks around the lake but the magnetic susceptibility of the pre- and post caldera lava have not been studied. Identification of the magnetic susceptibility of rocks can be done by using Bartington Magnetic Susceptibility Meter type MS2B. This study aims to determine the concentration of magnetic minerals based on the value of magnetic susceptibility in rocks. The Magnetic susceptibility data can be used as initial characteristics to understand the volcanic processes in the past and explain the environmental changes processes. The magnetic susceptibility values obtained ranged from 967.8 x 10⁻⁸ m³/kg - 2187.0 x 10⁻⁸ m³/kg. This Range indicates that the sample is estimated to be dominated by ilmenite (FeTiO3). Further frequency dependent susceptibility (χₙθ%) defined as ratio of magnetic susceptibility measured with difference frequency ranges less than 1%. Our results show all the samples are virtually no superparamagnetic and generally dominated by multi-domain (MD) grains.

1. Introduction
The Maninjau Caldera was formed by a cataclysmic eruption ~50,000 years ago. The eruption produced at least 220-250 km³ of volcanic material spread up to 75 km from the eruption center[1]. Various attempts to study the volcanism process that occurred in the past had been carried out with various approaches such as stratigraphic and physical volcanical studies and geochemical analysis of volcanic rocks around the lake. Determination the age of andesite and tuff around the Maninjau caldera with geochemical analysis using the K-Ar method, based on rhyolitic age measurements ashflow, at the end of the Pleistocene to the Holocene (0.01-1.8 million years ago) there was a large eruption on Mountain Maninjau Purba, when the Lake Maninjau was began to form as a result of the caldera collapse[2]. Field observations and theprostratigraphical, sedimentological and geo-chronological approaches have been applied to better understand the caldera forming eruption[1]. Geochemical analysis of pyroclastic rocks from around the Lake Maninjau, with high K rhyolite’s content to calcaline-andesite indicate that magma originates from a zoned magma chamber[3]. Bathymetric survey of lakes Maninjau have been done too[4]. However, the magnetic susceptibility of
pre- and post caldera lava haven’t studied yet. Minerals found in nature generally have either weak magnetic properties (Diamagnetic), moderate (Paramagnetic) or strong magnetic properties (Ferromagnetic)[5], and all of them have different the magnetic susceptibility values. These characteristic can be very useful as initial data to understand the volcanic process that occured in the past to explain the enviromental changes process.

The Magnetic properties in rocks can be identified by using the rock magnetism method. The magnetic properties of rocks can be determined by knowing the characteristics of magnetic minerals such as their concentrations, types, magnetic domains, grain sizes and Currie’s temperature. Determine magnetic properties of a materials is considered very effective, inexpensive, sensitive, fast and not destructive[6]. Rock magetism has been widely used in various fields of research such as the study of magnetism in living environments, enviromagnetism[7], magnetoclimatology[8]. Case studies on magnetic properties in guano have been carried out in Cave[9, 10]. Further, magnetic susceptibility was used to Study iron sands[11]. Rock magnetism methods has also been carried out in studying the case studies of Paleomagnetic Rocks Environmental Magnetism (PREM), such as determining the magnetic properties of Lake El’gygytgyn, Russia[12]. Measurement of magnetic susceptibility, anisotropy and innate sedimentary rocks of Latvia[13], in the field of volcanomagnetism regarding the anisotropic pattern of magnetic susceptibility of igneous rocks of the North Sulawesi[14], Magnetic susceptibility of granite rocks from Zaria[15], Magnetic Properties of rocks and soils around the Lake Diatas[16]. This Research aims to determine magnetic mineral concentration of pre- and post calera lavas from Maninjau. There for we used the magnetic susceptibility meter to estimate the concentration of magnetic minerals in rock samples. The relative values of magnetic susceptibility can indicate the amount of magnetic minerals contained in the rock samples.

2. Method
XX samples were collected at 3 locations around the Lakes Maninjau at several place. Our sample set includes (1) pre- caldera lavas from sungai batang (S00.32751° E100.22455°) along the road around the lakes as well as, post caldera lavas from (2) and island in the south of lake Maninjau (S00.37957° E100.16950°) and (3) the tip of the Maninjau peninsula (S 00.35429° E100.18564°) Figure 1.

![Figure 1. Maps and Sample Location](image-url)
The samples have been taken by using a geological hammer. Samples were bag and labeled according to their location. In total 6 samples were collected. The sampling process can be seen in Figure 2. All samples were transferred to the Physics Department laboratory (UNP), to measure the value of magnetic susceptibility. Magnetic susceptibility was measured by using Bartington MS2B Figure 3, therefore all samples were pulverized with a non-magnetic mortar and then put it into plastic holders before they were analyzed.

Bartington Magnetic Susceptibility was operated at magnetic fields of 80 A/m rms. The samples were measured in two difference frequency, at low frequency ($\chi_{lf}$) of 470 Hz, and High Frequency ($\chi_{hf}$) of 4700 Hz[6]. The relative difference in susceptibility values were measured at low frequencies and high frequencies is called frequency dependent susceptibility ($%\chi_{fd}$), and is obtained through the following equations:
The measurement results $\chi_{lf}$ and $\%\chi_{fd}$ are plotted using a scatter diagram[6] is shown in (Figure 4). Interpretation of data refers to Table 1.

### Table 1. Interpretation of frequency dependent susceptibility values [6].

| $\chi_{FD}$ | Percentage | Description |
|-------------|------------|-------------|
| Low $\chi_{FD}$ | < 2 % | virtually no (<10%) SP grains |
| Medium $\chi_{FD}$ | 2 – 10 % | admixture of SP and coarser non-SP grains, or SP grains <0.005 μm |
| High $\chi_{FD}$ | 10 – 14 % | virtually all (>75 %) SP grains |

### 3. Results and Discussion

The Magnetic susceptibility data in particular the low frequency ($\chi_{l}$), high frequency ($\chi_{h}$) and frequency dependent susceptibility ($\chi_{fd}$) of the pre- and post caldera lava from Maninjau Lakes can be seen in Tables 2. The magnetic susceptibility value at low frequency ($\chi_{l}$) range from $975.4 \times 10^{-8}$ m$^3$/kg to $187 \times 10^{-8}$ m$^3$/kg, while the results at high frequency ($\chi_{h}$) range from $967.8 \times 10^{-8}$ m$^3$/kg to $2184 \times 10^{-8}$ m$^3$/kg. The highest value was recorded in the pre-caldera lava SB ML 1 which was sampled close to Sungai Batang Maninjau. The lowest value was found in sample ML 5 which was taken at the tip of the west peninsula. The other samples SB ML2, ML PB, ML3 and ML4, have a relative close range from $1545.4 \times 10^{-8}$ m$^3$/kg to $1875.8 \times 10^{-8}$ m$^3$/kg. High magnetic susceptibility values indicate high mineral concentration, it means that samples contain lot of magnetic minerals. Whereareas low magnetic susceptibility values indicate low magnetic minerals concentration. In the geology maps, the Maninjau calderas geology are composed of pumice and andesite. The andesite rocks from the Maninjau caldera, all of which are pleistocene or 1.8 million years ago [18]. Based on geology maps and the classification of magnetic minerals are shown in Table 3 [17], the magnetic susceptibility data possibility to be indicated that ilmenite (FeTiO$_3$), is the dominant magnetic mineral phase in the pre and post-caldera lavas. As the comparison data, Rizki (2019), also was measured some rocks and soils round the Lake Diatas, Solok. The Results shows for many andesite rocks sample around the Lake Diatas has magnetic susceptibility values range from $1681.5 \times 10^{-8}$ m$^3$/kg to $2332.8$
\( x10^8 \text{ m}^3/\text{kg} \) and this values also interpreted to be indicated that Ilmenite is the dominant magnetic mineral phase.

Table 2. Results of Magnetic Susceptibility Measurements

| No | Sample list | Susceptibility (low frequency) \( x10^8 \text{ m}^3/\text{kg} \) | Susceptibility (high frequency) \( x10^8 \text{ m}^3/\text{kg} \) | FDS (%) |
|----|-------------|-------------------------------------------------|-------------------------------------------------|--------|
| 1  | SB ML 1     | \( \chi^1 \): 2188.3 \( \chi^2 \): 2185.9 \( \chi^3 \): 2186.7 \( \chi \text{ Averages} \): 2187.0 | \( \chi^1 \): 2184.6 \( \chi^2 \): 2178.2 \( \chi^3 \): 2189.1 \( \chi \text{ Averages} \): 2184.0 | 0.14   |
| 2  | SB ML 2     | \( \chi^1 \): 1877.7 \( \chi^2 \): 1874.9 \( \chi^3 \): 1875.8 | \( \chi^1 \): 1862.9 \( \chi^2 \): 1866.2 \( \chi^3 \): 1868.4 \( \chi \text{ Averages} \): 1865.8 | 0.53   |
| 3  | ML PB       | \( \chi^1 \): 1885.8 \( \chi^2 \): 1887.5 \( \chi^3 \): 1888.8 \( \chi \text{ Averages} \): 1887.4 | \( \chi^1 \): 1889.7 \( \chi^2 \): 1889.7 \( \chi^3 \): 1885.7 \( \chi \text{ Averages} \): 1888.4 | -0.05  |
| 4  | ML 3        | \( \chi^1 \): 1544.5 \( \chi^2 \): 1544.8 \( \chi^3 \): 1547 \( \chi \text{ Averages} \): 1545.4 | \( \chi^1 \): 1536 \( \chi^2 \): 1534 \( \chi^3 \): 1535.1 \( \chi \text{ Averages} \): 1535.1 | -0.24  |
| 5  | ML 4        | \( \chi^1 \): 976.6 \( \chi^2 \): 975.6 \( \chi^3 \): 974.1 \( \chi \text{ Averages} \): 975.4 | \( \chi^1 \): 968.3 \( \chi^2 \): 966.8 \( \chi^3 \): 968.3 \( \chi \text{ Averages} \): 967.8 | 0.78   |

Table 3. Range Values of Magnetic Susceptibility in Mineral [17]

| Magnetic Minerals | Magnetic Susceptibility | Volume \((x10^6 \text{ SI})\) | Mass \((x10^8 \text{ m}^3/\text{kg})\) |
|-------------------|-------------------------|-----------------------------|----------------------------------|
| **Magnetite** \((\text{Fe}_3\text{O}_4)\) | Ferrimagnetic            | 1.000.000 - 5.700.000       | 20.000 - 110.000                 |
| **Hematite** \((\alpha\text{Fe}_2\text{O}_3)\) | Antiferromagnetic        | 500 - 40.000                | 0 - 760                          |
| **Maghemite** \((\gamma\text{Fe}_2\text{O}_3)\) | Ferrimagnetic            | 2.000.000 - 2.500.000       | 40.000 - 50.000                  |
| **Ilmenite** \((\text{FeTiO}_3)\) | Antiferromagnetic        | 2.200 - 3.800.000           | 46 - 80.000                     |
| **Pyrite** \((\text{FeS}_2)\) | Ferrimagnetic            | 35 - 5.000                  | 1 - 100                          |
| **Pyrohotite** \((\text{Fe}_9\text{S}_8)\) | Ferrimagnetic            | 3.200.000                   | 69.000                           |
| **Geothite** \((\alpha\text{FeOOH})\) | Antiferromagnetic        | 1.100 - 12.000              | 26 - 280                         |
| **Non Magnetic Minerals** | | | |
| **Kuarsa** \((\text{SiO}_2)\) | Diamagnetic              | 13 - 17                     | 0.5 - 0.6                        |
| **Kalsit** \((\text{CaCO}_3)\) | Diamagnetic              | 7.5 - 39                    | 0.3 - 1.4                        |
| **Halite** \((\text{NaCl})\) | Diamagnetic              | 10 - 16                     | 0.48 - 0.75                      |
| **Galena** \((\text{PbS})\) | Diamagnetic              | 33                          | 0.44                             |

No Significant different can be observed between low and high frequecnes measurements (Figure 5), resulting in a relatively small ratio that is expressed as frequency dependent susceptibility. Based on equation 1, the ratio obtained in all samples are less than 1%. Based on the SP classification (see Table 1), this ratio shows that the minerals was measured virtually no superparamagnetic grains[6]. In generally this ratio is interpreted to be dominated by multi-domain grains. This result is in accordance with the concept which states that multi-domain (MD) magnetic grains because the results show the same value or not too much difference in magnetic susceptibility values at low and high frequencies (Kanu, et. al., 2013). The state of magnetic grains in samples is shown in (Figure 6).
4. Conclusion
The Pre and post caldera lavas that taken as samples have high concentration of magnetic mineral. Overall, the magnetic susceptibility values at $\chi_{lf}$ and $\chi_{hf}$ range from $967.8 \times 10^{-8}$ m$^3$/kg to $2187.8 \times 10^{-8}$ m$^3$/kg that samples estimated indicates ilmenite is the dominant magnetic minerals phases. Frequency Dependent Susceptibility values range less than 1%. That’s ratio shows all the samples are virtually no superparamagnetic and generally is dominated by multi-domain (MD) grains. This Results can be used as initial characteristic as background knowledge to study about paleovolcanology and explain the enviromental changes processes.

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