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Characteristics of the Density and Magnetic Susceptibility of Pumice from the Maninjau Caldera-Forming Eruption, Indonesia

Karakteristik Densitas dan Suseptibilitas Magnetik Batu Apung dari Letusan Pembentuk Kaldera Maninjau, Indonesia

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Abtract- *Lake Maninjau is a volcanic caldera formed by a volcanic eruption located in West Sumatra. This volcanic eruption threw pyroclastic materials, one of which is pumice, as far as ± 75 km from the center of the eruption. This study aims to determine density and magnetic susceptibility characteristics of pumice from maninjau caldera-forming eruptions, indonesia. The method used is the rock-magnetic method. It is used to measure magnetic susceptibility based on the distribution of volcanic material. The samples were selected from 3 different locations around Mount Maninjau with distances varying between ±12-32 km. A Bartington Magnetic Susceptibility Metre Type B (MS2B) instrument was utilised to determine the susceptibility of rocks and X-ray fluorescence (XRF) to identify rock element levels. The results of the data analysis obtained have magnetic density and susceptibility values in the NGS (Ngarai Sianok) area, which ranged from 0.67-1.77×10*^{3} *kg/m*^{3} *and 4.4-826×10*$^{-8}$*m*^{3}*/kg, the LBS (Lubuk Basung) area which ranged of 0.74-1.34×10*^{3} *kg/m*^{3} *and 6.6-625.4×10*$^{-8}$*m*^{3}*/kg, and the PRM (Pariaman) area, which ranged from 0.68-3.63×10*^{3} *kg/m*^{3} *and 8-359×10*$^{-8}$*m*^{3}*/kg. The results showed that when sampling closer to Mount Maninjau, the pumice is characterized by dense, fresh, but very small pore size and dominated by slightly greyish white pumice with few white crystals on its surface. Therefore, the location of the pumice from Mount Maninjau has a significant influence on its characteristics, including density, magnetic susceptibility, and iron (Fe) and titanium (Ti) content.*

Keywords: Pumice, Density, Magnetic Susceptibility, Mount Maninjau, XRF

Abstrak*-Danau Maninjau merupakan kaldera vulkanik yang terbentuk akibat letusan gunung berapi yang terletak di Sumatera Barat. Letusan gunung berapi ini melontarkan material piroklastik, salah satunya batu apung, sejauh ± 75 km dari pusat letusan. Penelitian ini bertujuan untuk mengetahui karakteristik densitas dan suseptibilitas magnetik batu apung dari letusan pembentuk kaldera maninjau, indonesia. Metode yang digunakan adalah metode magnetik batuan. Metode ini digunakan untuk mengukur suseptibilitas magnetik berdasarkan sebaran material vulkanik. Sampel dipilih dari 3 lokasi yang berbeda di sekitar Gunung Maninjau dengan jarak yang bervariasi antara ±12-32 km. Instrumen Bartington Magnetic Susceptibility Meter Type B (MS2B) digunakan untuk menentukan suseptibilitas batuan dan X-ray Fluorescence (XRF) untuk mengidentifikasi kadar unsur batuan. Hasil analisis data yang diperoleh memiliki nilai densitas magnetik dan suseptibilitas di daerah NGS (Ngarai Sianok) yang berkisar antara 0,67-1,77×10*^{3}*kg/m*^{3} *dan 4,4-826×10*$^{-8}$*m*^{3}*/kg, daerah LBS (Lubuk Basung) yang berkisar antara 0,74-1,34×10*^{3}*kg/m*^{3} *dan 6,6-625,4×10*$^{-8}$*m*^{3}*/kg, dan daerah PRM (Pariaman) yang berkisar antara 0,68-3,63×10*^{3}*kg/m*^{3} *dan 8-359×10*$^{-8}$*m*^{3}*/kg. Hasil penelitian menunjukkan bahwa ketika pengambilan sampel lebih dekat dengan Gunung Maninjau, batu apung memiliki karakteristik padat, segar, tetapi ukuran pori-pori sangat kecil dan didominasi oleh batu apung berwarna putih keabu-abuan dengan sedikit kristal putih di permukaannya. Oleh karena itu, lokasi pengambilan batu apung dari Gunung Maninjau memberikan pengaruh yang signifikan terhadap karakteristiknya, termasuk densitas, kerentanan magnetik, dan kandungan besi (Fe) dan titanium (Ti).*

Kata Kunci: *Batu Apung, Densitas, Suseptibilitas Magnetik, Gunung Maninjau, XRF*

INTRODUCTION

The West Sumatra area is famous for its beauty, with various natural panoramas, especially at lake Maninjau. Lake Maninjau is a caldera formed from the violent eruption of Mount Maninjau with a volcanic explosivity index (VEI) of 7 that produced a volume of dense-rock equivalent (DRE) of (220-250 km^3) (Suhendro et al., 2022) . Mount Maninjau is located ±15 km from Bukittinggi City, West Sumatra (Akmal et al., 2021). Mount Maninjau has its own uniqueness, which is in the form of a volcanic basin found at an altitude of 1200-1400 metres above sea level and with a maximum depth of 157 metres from the surface of the lake (AlFajar et al., 2023; Alloway et al., 2004). Stable temperature all year long at 25°C (Milto & Bezman-Moseyko, 2021). Mount Maninjau is an important source of water for the local community and the caldera is unique geological feature.

The eruption of Maninjau volcano released 220-250 km^3 of various types of volcanic material, one of which is pumice (Anggraeni & Sulistyorini, 2021; Arrazi et al., 2023) . Pumice is volcanic rock that formed from lava rich in gases. Pumice is formed from fragments of sedimentary rock carried by magma (Jägerup et al., 2023). This magma contains gas bubbles and, during the cooling process, these bubbles results in small holes on the surface of the rock (Prasetyo et al., 2022) . Pumice has unique physical and chemical properties (Dearing et al., 1996; Dong et al., 2023) . It contains elements including the oxides SiO_2, K_2O, MgO, CaO, Al_2O_3, SO_3, Fe_2O_3, Na_2O, TiO_2, and Cl (Alduraibi, 2018; Carlut et al., 2024). Pumice also contains minerals such as tridymite, quartz, cristobalite, and feldspar. Due to its porosity and low density, pumice experiences upward lifting (buoyancy force), and can therefore float in water. This buoyant force is exerted by the fluid and counteracts the weight of objects in the water. This is in accordance with the Archimedes Principle, which states that objects floating in water experience buoyancy forces equal in magnitude to the weight of the fluid displaced by the object. The ability of pumice to float depends largely on its gas content, size, shape, mineral composition, and formation process. Over time and due to environmental influences, these properties can change, causing some pumice stones to sink. So, while pumice is known as a stone that can float, it doesn't mean that all pumice stones will always float.

Density and magnetic susceptibility are key properties that characterise pumice (Kanamaru et al., 2022).Density is a physical property that describes the bond density of the materials that make up the rock (Schon, 2011). Each rock has a different density due to the mass and volume of the rock. The value of rock density is closely related to the strength of rocks. The density and strength of a rock are positively correlated. Rock density is also influenced by the number of mineral types attached to the pores. When rocks have increased porosity, it reduces the density of the rock, and vice versa.

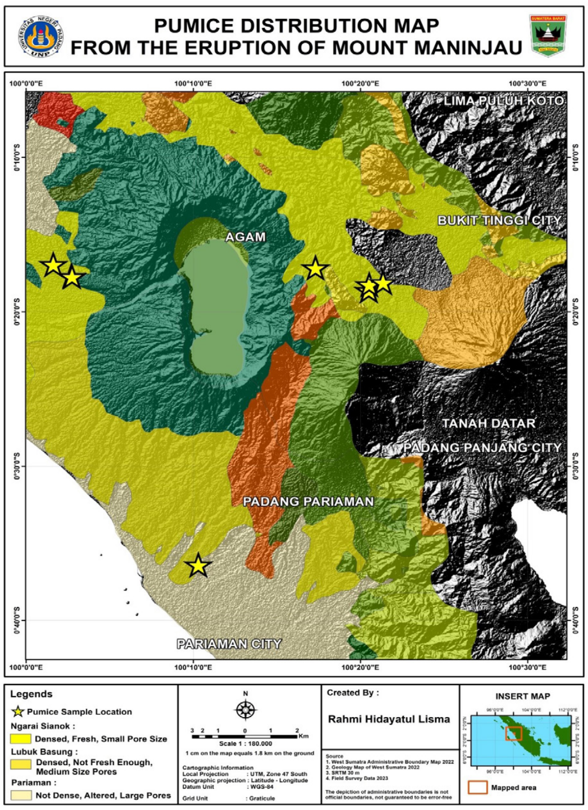
In addition to density, the value of magnetic susceptibility is also closely related to the properties and characteristics of pumice (Siregar et al., 2022). Changes in the physical properties of rocks can affect magnetic anomalsies, which can then be used to determine the subsurface structure of rocks (Dong et al., 2023) . The magnetic susceptibility of pumice varies greatly with different susceptibility averages, especially pumice on Mount Maninjau. This variation is due to differences in iron content in igneous rocks, which suggests a relationship between magnetic susceptibility and rock composition (Anggraeni & Sulistyorini, 2021). Pumice's magnetic susceptibility is influenced by its mineral composition, such as iron and titanium oxide (Elitok et al., 2010). This magnetic susceptibility can be studied using the rock magnetism method. A Bartington instrument is used to measure the magnetic susceptibility of rocks (Akmal et al., 2021; Hunt et al., 1995). The characteristics of pumice are strongly influenced by its environment of formation. Variations in location and distance from the volcanic source result in differences in the mineral composition, pore size and density of the pumice. This study seeks to address the following questions. At different locations, what are the characteristics of pumice from the eruption of Mount Maninjau? What are the things that can affect the characteristics of pumice? The purpose of this study is to analyse the physical properties of pumice based on magnetic susceptibility and density in three different locations around Mount Maninjau.

METHOD

Location and Samples

The research method used is the rock magnetic method (Fajri et al., 2019) using the following steps. First, identify outcrops around Mount Maninjau (Figure 1). The sampling process was carried out at 3 different locations, namely Ngarai Sianok, Lubuk Basung, and Pariaman, with the corresponding coordinates of 0.30^o 00' 00" S-100^o 21' 22" E; 0.28^o 16' 48" S-100^o 1' 39" E; 060^o 0' 0" S-100^o 10' 19" E (Figure 1). Samples were taken from outcrops that have not been exposed to significant weathering or erosion. The chosen location was not overgrown with vegetation suggesting that the outcrop was relatively undisturbed, with limited weathering or other environmental factors that can change its composition. Pumice sampling was carried out by the mechanical breaking method using a hammer and shovel to obtain fresh fragments from the outcrop.

The sampling location of the vertical and lateral variations of the 52 ka eruption deposits of Mount Maninjau, namely the eastern, western, and southern parts (Figure 2). Based on observations, it was found that the eruption deposits forming Mount Maninjau consisted of a thick succession (up to 250 m) of ignimbrite without previous fall deposits (Plinian free eruptions). Although the ignimbrite of Maninjau is radially distributed in all directions (around Mount Maninjau), Ngarai Sianok (Site 3) (dc = ±15 km), it deposits the eastern part especially in the deep-etched valley. Here, pumice quartz varies from 0.2 to 9 cm. The western ignimbrite(dc = ±12 km) Lubuk Basung (Site 1) is massive, has grey pumice and abundant crystals, and is rich in lithic. Pumice and lithic stones observed are usually <20 cm in size and 10 cm in size, respectively. Conversely, at a massive outcrop of ignimbrite in the south (Site 2) (dc = ±32km), the pumice measures 4 to 9 cm and has oxidised intensively.



Note: A yellow asterisk indicates the location of pumice sampling.

Figure 1. Lake Maninjau pumice samples and locations

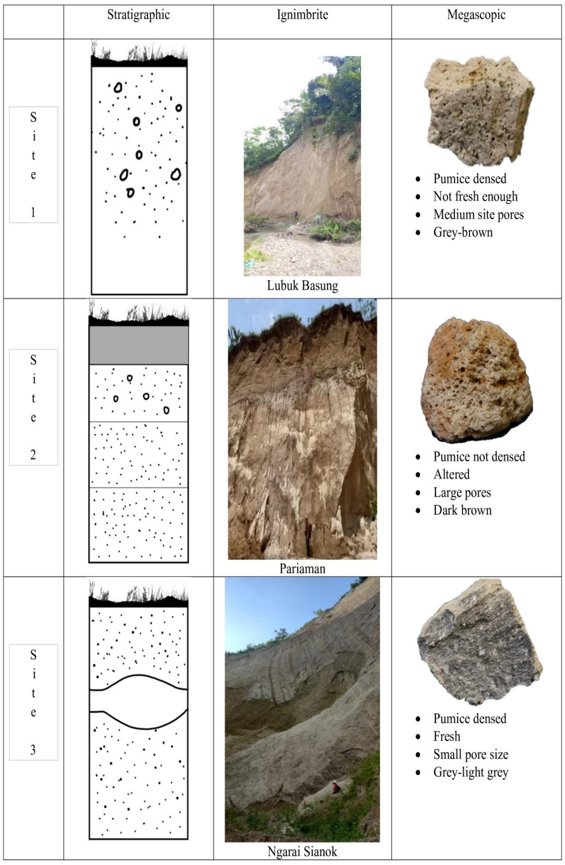


Figure 2. Outcrops of ignimbrite deposits and a detailed megascopic image of pumice from a). Lubuk Basung (Site 1), b). Pariaman (Site 2), and c). Ngarai Sianok (Site 3)

Samples covered up to 306 pumice boulders ranging in size from 4 to 30 mm. The sample data processing technique consists of several steps. The first step is to weigh the pumice stone using a digital balance. Digital balance sheets have high accuracy ranges from +/- 0.01 grams to +/- 0.001 grams, and the measurement results can be directly read on the screen.

Magnetic Measurements

This activity was carried out at the Geophysical Laboratory of Padang State University. The instrument used was a magnetic susceptibility metre on the dual frequency sensor (470–4700 Hz) (Bijaksana et al., 2019). This instrument can measure magnetic susceptibility from 1×10^{-6} to 999×10^{-3} (m^3/kg). The magnetic measurements utilize the relationship between magnetic susceptibility at low and high frequencies.

Measurements were made with two frequencies, namely 470 Hz for low-frequency susceptibility (χ_{lf}) and 4.7 kHz for high-frequency (χ_{hf}). Measurements were repeated three times in a low-field state and three times in a high-field state so that the average magnetic susceptibility value (χ average) was obtained. The ratio of measurements at both frequencies is recorded as the value of frequency-dependent susceptibility (χ_{fd}), obtained through the equation (Dearing et al., 1996):

$$\chi_{fd} = \frac{\chi_{lf} - \chi_{hf}}{\chi_{lf}} \times 100\,\% \qquad (1)$$

The results of the χ_{lf} and % χ_{fd} measurements were plotted so that the type of domain was obtained by matching it to the scategram scheme. Dearing, 1999 Data interpretation refers to the Dearing table, 1996.

Density Calculation

Density calculation was performed using Archimedes principal (Alduraibi, 2018; Kanu et al., 2014). This was done to assess the realtionship between the value of magnetic susceptibility and the density of pumice.

The next step is counting the density of pumice using the following equation:

$$\rho = \frac{m}{v} \qquad (2)$$

Information:

ρ = density (kg/m³)

m = pumice mass (kg)

v = pumice volume (m³)

Next, the pumice rocks were ground into fine grains and inserted into the holder. A total of 140 holders were obtained, namely 56 holders from each Ngarai Sianok and Lubuk Basung, and 28 holders from Pariaman.

X-Ray Fluoresence (XRF) Measurements

Of Fe and Ti elements by were carried out at the chemistry laboratory, Universitas Negeri Padang. From the whole sample, six sample holders were selected from each of the two different ignimbrites to be measured and analysed further, thus providing a more representative picture. Both holders selected have low-frequency magnetic susceptibility, which has the highest and lowest values.

RESULT AND DISCUSSION

The magnetic susceptibility and density of the rocks were measured based on three sampling locations around Mount Maninjau, namely 15 km to the east, 12 km to the west, and 32 km to the south.

Magnetic properties of pumice

The measurements of magnetic susceptibility and rock density at each location are reported in Table 1. Magnetic susceptibility is measured based on frequency. χ_{lf} is the value of susceptibility at low frequencies, χ_{hf} for high frequencies, and χ_{fd} for dependent frequencies. Based on the data, it was found that the value of magnetic susceptibility at low frequencies tends to be higher than magnetic susceptibility at high frequencies. This can be caused by several factors, such as magnetic mineral properties that are dominant in the material under study. The magnetic susceptibility of pumice is variable; and is influenced by the abundance of magnetic minerals contained in it (Putra et al., 2022). Some research suggests that certain magnetic minerals can cause magnetic susceptibility at low frequencies to be higher than at high frequencies (Alrahmadana et al., 2022; Fajri et al., 2020)

The magnetic properties of the NGS, LBS, and PRM pumice samples obtained are ferrimagnetic and antiferromagnetic. The magnetic properties of magnetic minerals are strongly influenced by the size of their magnetic grains (Sasmita et al., 2020). The more magnetic grains, the smaller the magnetic susceptibility value obtained. This happens because the size of the grain in volcanic material is inversely proportional to the value of magnetic susceptibility. The smaller the grain size, the greater the magnetic susceptibility value. The fine magnetic grain size of these volcanic samples indicates a lack of coarse magnetic minerals or a low intensity of the magnetization process (Putra et al., 2022).

The value of magnetic susceptibility at each frequency varies. However, studying the relationship between magnetic susceptibility values at two frequencies will produce a meaningful relationship and influence each other. First, the difference in magnetic susceptibility values at low frequencies and high frequencies for the three locations can be seen in Figure 3. The values of χ_{lf} and χ_{hf} have a directly proportional relationship, where the higher the value of χ_{lf} increases with higher values for χ_{hf} (Figure 3). It can be seen from the positive gradient value of 0.927 and the R value which shows the coefficient of determination in magnetic susceptibility measurements carried out close to 1, which is 0.9993 and a confidence level of 99.93%. The data shows a linear relationship with a significant degree of correlation. Linear correlation indicates that the increase in magnetic susceptibility value is mostly controlled by the contribution of the fine magnetic fraction. Measurements at higher frequencies do not allow superparamagnetic mineral grains to react with the alternating magnetic field used for changes faster than the relaxation time required for them (Prasetyo et al., 2022; Putra et al., 2022). The magnetic susceptibility values at high and low frequencies are identical, so there are no superparamagnetic grains.

Second, the relationship between magnetic susceptibility values at low frequencies and frequency-dependent values is examined and reported in Figure 4.

Table 1. Average density and magnetic susceptibility value of pumice

Coordinate	Sample Name	Magnetic Susceptibility (×10-8m3/kg)			Density (×103 kg/m3)	Magnetic Properties
		χlf	χhf	χfd		
060° 0' 0" S - 100° 10' 19" E	PRM 23-08R	85,4	83,9	2,7	0,46	Ferrimagnetic
	PRM 23-08D	42,8	43,3	3,1	0,69	Ferrimagnetic
	PRM 23-08P	119,8	118,0	1,2	0,20	Antiferromagnetic
	PRM 23-08SR	24,9	23,9	2,5	0,42	Ferrimagnetic
0.28° 16' 48" S -100° 1' 39" E	LBS 23-02	46,8	46	1,9	0,19	Antiferromagnetic
	LBS 23-03	443,6	437,9	0,6	0,28	Ferrimagnetic
	LBS 23-07	231	229	1,1	0,53	Ferrimagnetic
	LBS 23-02D	352,8	357,5	0,7	0,24	Ferrimagnetic
0.30° 00' 00" S -100° 21' 22" E	NGS 23-06	70,3	68,1	3,1	0,44	Antiferromagnetic
	NGS 23-07	519,7	496,2	1,9	0,53	Antiferromagnetic

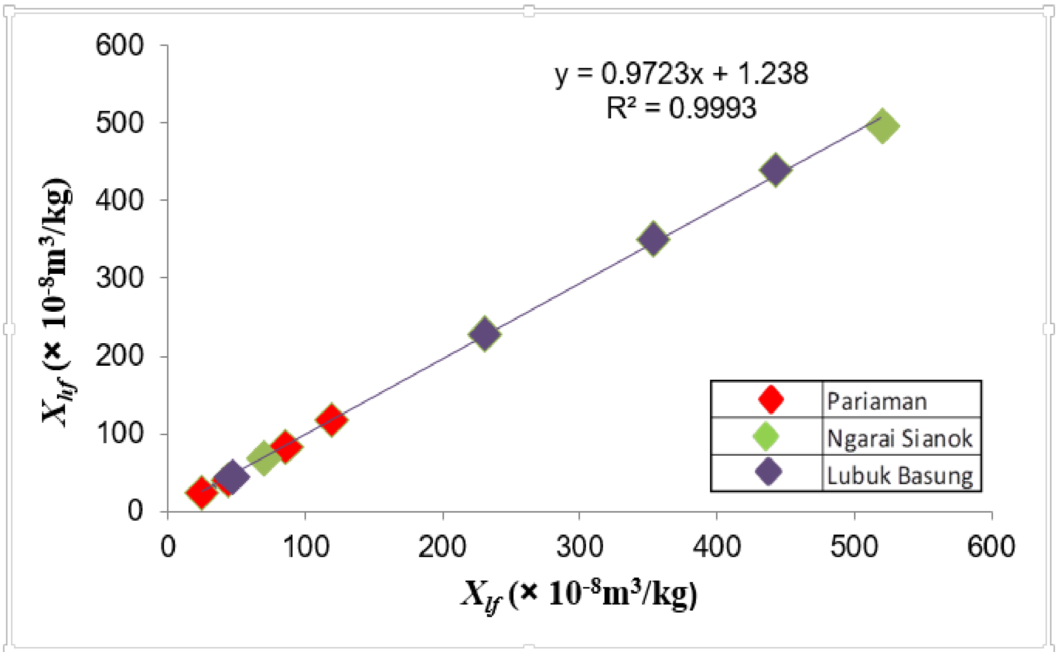


Figure 3. The Relationship Between Magnetic Susceptibility at Low and High Frequencies

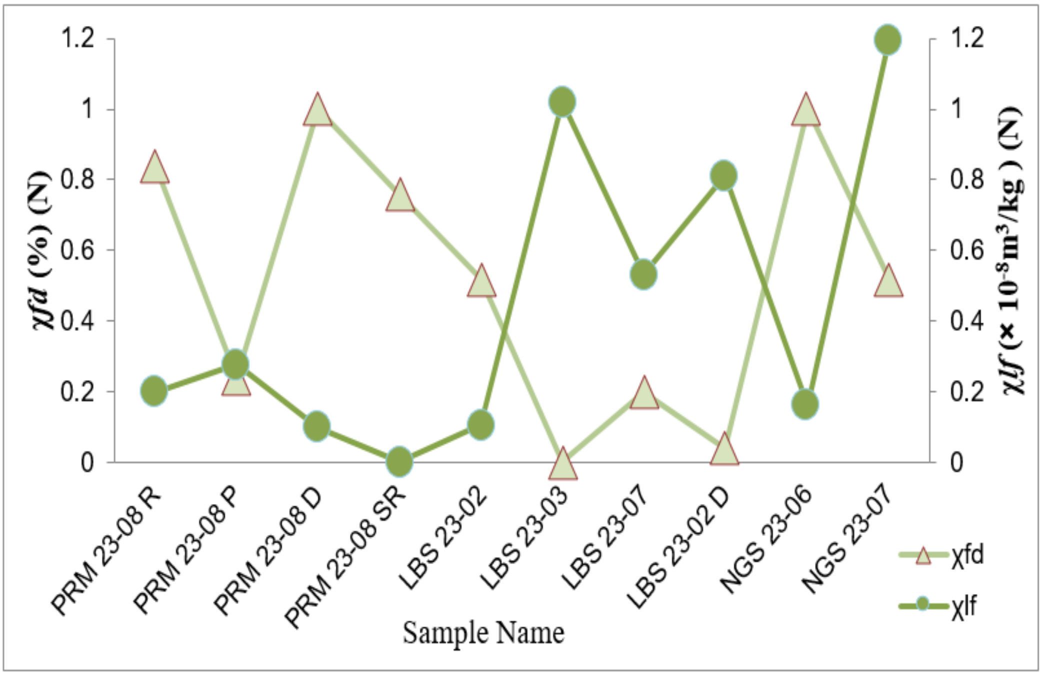


Figure 4. Comparison of magnetic susceptibility at low frequencies and dependents frequencies

The relationship between magnetic susceptibility at low frequencies and dependents frequencies. The relationship between χ_{fd} and χ_{lf} values at the PRM location is directly proportional, namely PRM 23-08 R, PRM 23-08 P, PRM 23-08 D, and PRM 23-08 SR where the χ_{fd} value ranges from 0-1% and χ_{lf} ranges from 0-0.5 ($\times 10^{-8} m^3$ / kg) (Figure 4). Additionally, values of χ_{fd} and χ_{lf} locations of LBS and NGS are inversely proportional, namely LBS 23-02, LBS 23-02, LBS 23-07, LBS 23-02 D, and at NGS 23-06, NGS 23-07, where the value of χ_{fd} ranges from 0-1% and χ_{lf} ranges from 0-1.2 ($\times 10^{-8} m^3$ / kg). The value of χ_{fd} (%) is an indicator of the presence of superparamagnetic mineral (SP) content. The greater the percentage of The magnetic properties of the mixture increase SP grain in a material. The range of χ_{fd} values is 0-2%, meaning that it has almost no superparamagnetic grains and is usually dominated by multidomain (MD) grain types, and χ_{fd} values of 2-10% Singledomain (SD) and superparamagnetic (SP) grain sizes.

The graph of the relationship of low magnetic susceptibility and dependence has a linear relationship. The magnitude of the linear gradient and the coefficient of determination in the relationship between low and dependent magnetic susceptibility values have proven to be effective in classifying magnetic minerals based on their magnetic characteristics Figure 5.

Magnetic susceptibility at low frequencies is always inversely or negatively proportional to its dependent magnetic susceptibility value (Alduraibi, 2018). The greater the dependent frequency susceptibility value (χ_{fd}), the smaller the low-frequency magnetic susceptibility value (χ_{lf}). This is evident from the magnitude of the gradient value, which is -0.5758, and also from the R value, which shows the coefficient of determination in magnetic susceptibility measurements carried away from 1, which is 0.4181 with a confidence level of 41.81%. The sample is dominated by large magnetic minerals such as multi-domain (MD) pumice (Carlut et al., 2024).

Pumice density

The relationship between magnetic susceptibility and pumice density is also examined. Magnetic density and susceptibility are can be used to characterise pumice from different locations. The magnetic susceptibility used is at low frequencies. This is because only at low frequencies can the characteristics of pumice be distinguished. The relationship between magnetic susceptibility and density values can be seen in Figure 6.

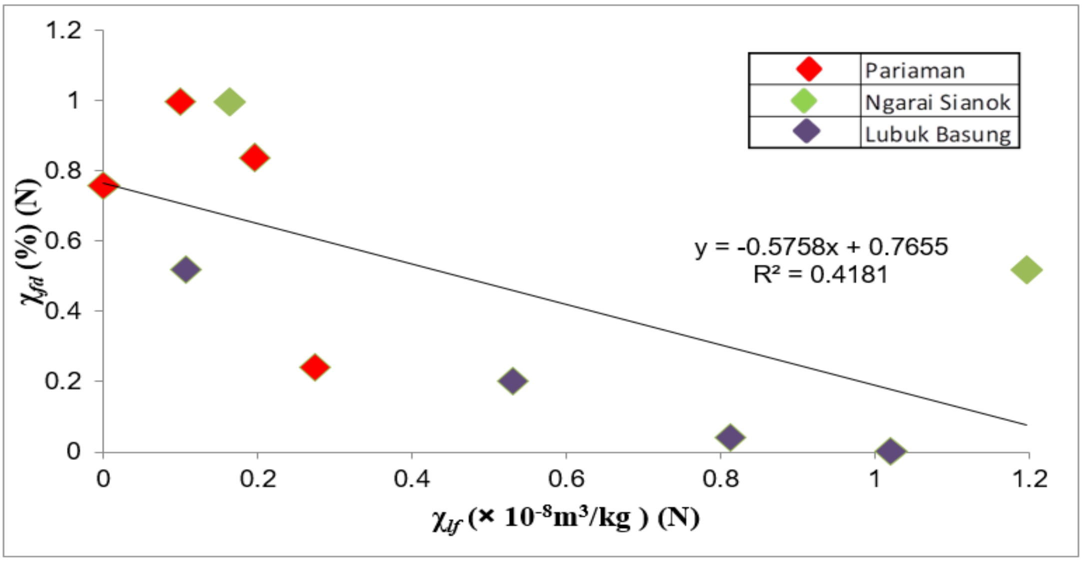


Figure 5. Large gradients and coefficients of determination of susceptibility at low and dependent frequencies

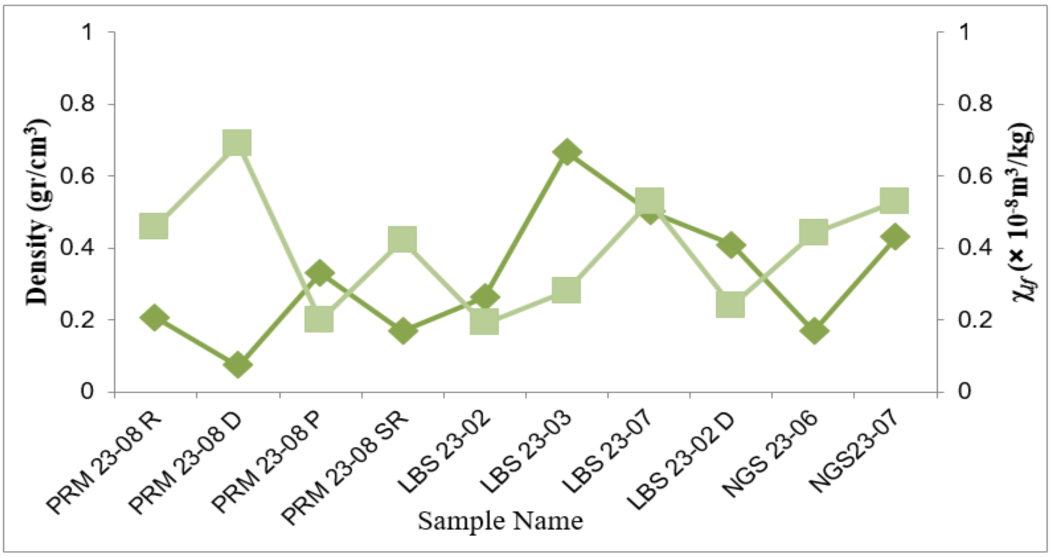


Figure 6. Relationship of low magnetic susceptibility value with density

The relationship between magnetic susceptibility at low frequencies is inversely proportional to the density of pumice in PRM. Second, in the LBS and NGS regions, the magnetic susceptibility value has a linear relationship with pumice density. This can be caused by various factors, one of which is the presence or absence of superparamagnetic grains in the material (Arrazi et al., 2023). The presence or absence of superparamagnetic grains in the material can cause differences between the two values (Silvia et al., 2022; Siregar et al., 2022). Based on the data, there are almost no superparamagnetic grains at the NGS and PRM locations, and only superparamagnetic grains at the LBS locations. In addition, the relationship between magnetic susceptibility and pumice density can be seen from the magnitude of the gradient value and the coefficient of determination (Figure 7).

Magnetic susceptibility at low frequencies is inversely or negatively proportional to the density of pumice. This is evident from the magnitude of the gradient value, which is -0.3243, and also from the R value, which shows the coefficient of determination in magnetic susceptibility measurements carried out away from 1, which is 0.1256. A significant increase in the value of magnetic susceptibility in pumice indicates a high concentration of ferrimagnetic minerals.

X-Ray Fluoresence (XRF) Measurements

The results of the second study were the results of measuring magnetic susceptibility values at low frequencies with the content of Ti and Fe elements in Mount Maninjau pumice. The value of magnetic susceptibility contained in a material also depends on the elements Ti and Fe. The sample measured for the second result in this study was as many as six holder samples from two holder samples from each location, representing the entire sample. Both holders selected have low-frequency magnetic susceptibility, with the highest and lowest values. The results of measuring magnetic susceptibility values at low frequencies against the content of Ti and Fe elements can be seen in Table 2.

The highest Fe element composition of 34.487% was found at the PRM location with a magnetic susceptibility value of 359×10^{-8}m^3/kg and the lowest 5.12% at the NGS location with the magnetic susceptibility of 4.4×10^{-8}m^3/kg, while the highest Ti element composition was 3.012% at the PRM location and 0.494% at the NGS location with the same magnetic susceptibility of 4.4×10^{-8}m^3/kg. The relationship between magnetic susceptibility at low frequencies and the content of Ti and Fe elements can be seen in Figure 8.

Elements Fe and Ti, have strong correlation with magnetic susceptibility. For the Fe element, an R value of 0.0391 is obtained, and in the Ti element, an R value of 0.1734 is obtained. Mount Maninjau pumice contains magnetic minerals such as iron oxide, titanium, iron sulphide, and iron hydroxide. The content of Fe and Ti elements in pumice affects the properties of rocks and the content of elements in them, such as resistance and ability to absorb water and attraction between mineral particles in rocks (Suhendro et al., 2022; Tiwow & Rampe, 2022). High levels of Ti and Fe elements cause their magnetic susceptibility values to be higher (Alduraibi, 2018; Wijaya et al., 2019; Wiwik Dyah Hastuti, 2017), and vice versa. Low magnetic susceptibility is caused by damage processes such as the weathering of rocks, environmental factors, or the presence of certain minerals that can affect the magnetic properties of a material that naturally mixes with diamagnetic materials. Meanwhile, the high magnetic susceptibility value causes the is a lot of magnetic mineral content in samples undergoing the mineral transport process.

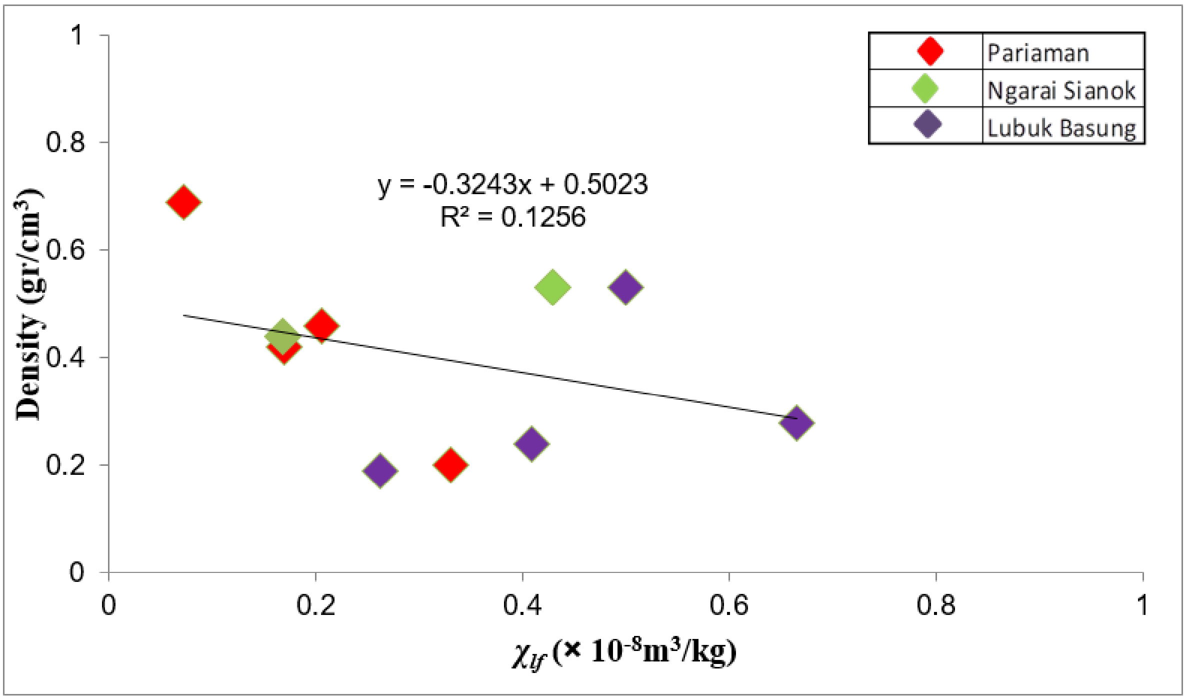


Figure 7. Large gradients and coefficients of determination of magnetic frequency susceptibility relationships with density

Table 2. Low Frequency Magnetic Susceptibility Value and Element Composition

Sample Name	χlf	Element Composition	
	(10-8m3/kg)	Fe (%)	Ti(%)
NGS 23-06-29	4.4	5.12	0.494
NGS 23-07-40	826.3	12.742	1.559
LBS 23-02-1	6.5	7.029	0.614
LBS 23-03-24	625.4	20.579	1.837
PRM 23-08-27 P	8	25.07	1.82
PRM 23-08-6 R	359	34.487	3.012

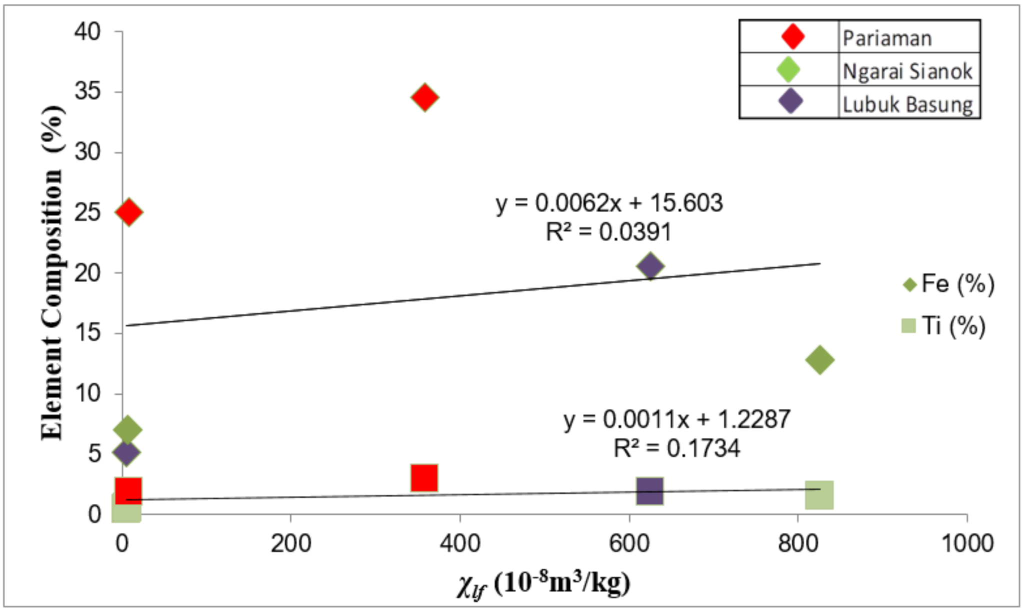


Figure 8. Graph of magnetic frequency susceptibility relationships with the percentage of Fe and Ti elements

CONCLUSION

The conclusion of this study is that the characteristics of Mount Maninjau pumice depend on magnetic susceptibility, density, Fe and Ti element content in pumice, and the proximity of the sampling location to the crater. The farther away the sampling location is from the crater, such as NGS and LBS, the higher the magnetic susceptibility and density and the lower the Fe and Ti content in the rock. This causes pumice to have porous, not fresh, characteristics in the dominance of reddish-brown pumice with numerous white crystals on its surface. Meanwhile, the closer the sampling location is to the crater, such as PRM, the lower the magnetic susceptibility and density and the higher the content of Ti and Fe elements in pumice. This pumice has a dense, fresh, non-porous characteristic, dominated by slightly greyish white pumice with few white crystals on its surface. Thus, to find a good pumice stone, it must be taken from a location around 10-15 km Mount Maninjau crater.

The data obtained show that pumice density does not correlate significantly with magnetic susceptibility or sampling distance from the eruption source. This variability in density indicates differences in the rate of gas release and magma cooling. These results suggest that despite originating from a single eruptive event and the same magma kitchen, pumice freezing processes can vary significantly before, during and after caldera formation.

In future work, this study can be improved with additional samples and collection sites. The current study also only focuses on pumice characteristics in terms of magnetic susceptibility, density, and Fe and Ti element content in pumice. Though there are many other elements that can be studied and there are other pyroclastic materials that would be of benefit to this work. This research contributes to our understanding of pumice characteristics around Mount Maninjau and other volcanoes. The results of this study, can serve as a guideline for other researchers to expand on this work, using additional rock types and sample locations.

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