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Analysis on the Relationship of Rare Earth Elements and Magnetic Minerals Inside Pumice in the Southern Tip of Lampung Province

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Abstract: In advanced clean energy technologies, rare earth elements (REEs) are an important component. The position of rare earth elements in the future is increasingly strategic so it is necessary to strive to be developed sustainably. At the southern tip of Lampung province, rare earth elements are not yet known. The aims of this study were to analyze the magnetic susceptibility value, composition and percentage of rare earth elements, and the relationship of rare earth elements with magnetic mineral concentrations in pumice at the southern tip of Lampung Province. The method used is rock magnetism with Bartington Magnetic Susceptibility Meter Type B and X-Ray Fluorescence. Pumice in the southern region of Lampung Province has diverse magnetic susceptibility values, pumice from Bandar Lampung City has the highest magnetic susceptibility value, while the lowest was in South Lampung Regency. This pumice has antiferromagnetic and ferrimagnetic properties, almost no superparamagnetic grains and also found a mixture of superparamagnetic and coarse grains. The composition of rare earth elements contained in pumice at the southern tip of Lampung Province obtained 3 rare earth elements, samples from Bandar Lampung City contained europium, cerium, and yttrium elements and samples from South Lampung Regency contained europium and yttrium elements. Rare earth elements and magnetic mineral concentration have a relationship, the obtained χ_{lf} values decrease with increasing percentage of rare earth elements.

Keywords: Magnetic Susceptibility, Pumice, Rare Earth Elements, Rock Magnetism, X-Ray Fluorescence.

1. Introduction

Rare earth elements (REE) are important components found in cutting-edge clean energy technology [1]. There are 17 rare earth elements, consisting of 15 lanthanides plus *scandium* and *yttrium* [2]. Rare earth elements can support the development of new materials that provide

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significant technological developments in materials science. In the future, the position of rare earth elements is increasingly strategic, so it is necessary to strive for sustainable development [3]. Some elements in the rare earth element group such as lanthanum, cerium, neodymium, and yttrium in high-tech devices are used as components, such as flat-screen televisions, computer monitors, LED (light-emitting-diode) lights, camera lenses, projectors, battery electrodes, microphones, wind turbines, lasers, hybrid cars, and high-powered magnets. [2].

In Indonesia, rare earth elements have not received much attention. Some elements of rare earth elements contained in rock-forming minerals [4], one of them is magnetic minerals. The concentration of magnetic minerals is affected by the rare earth elements that combine in these minerals. To establish the concentration of magnetic minerals and their relationship with rare earth elements, the Rock Magnetism Method is used. Which is one of the geophysical methods to define the magnetic characteristics of a material. In the Rock Magnetism Method, magnetic susceptibility is a magnetic parameter used to investigate the concentration of magnetic minerals in a material [5].

The Rock Magnetism Method has been widely used in studying the fingerprints of volcanic eruptions in Sumatra. Magnetic susceptibility analysis of pumice in the Pahae Julu area, North Sumatra [6], analyzing the magnetic properties of rocks and soils around Lake Diatas, West Sumatra [7], and magnetic susceptibility analysis of lava before and after the caldera in Maninjau, West Sumatra [8]. Those are the uses of the Rock Magnetism Method assisted by X-Ray Diffraction (XRD) and X-Ray Fluorescence XRF.

Analysis of geochemical and magnetic characteristics of placer gold deposits has been conducted in Central Kalimantan, Indonesia [9], 4 rare earth elements, namely Eu, Tb, Dy, and Sc, were found, there is a relationship between magnetic susceptibility and the concentration of main elements and rare earth elements, showing that the value is significantly correlated with the concentration of Fe and Sc. This suggests that magnetic susceptibility can be used as a proxy indicator to detect Sc and other rare earth elements.

In Lampung Province, precisely in West Lampung Regency, the elemental composition of pumice has been analyzed [10]. In this pumice, it was found that the elemental content in pumice included Al, Si, Fe, Ti, Mn, and K. Although the elemental composition in West Lampung Regency has been analyzed, it has not been discussed about the composition of rare earth elements found in pumice. Therefore, using the Rock Magnetism Method, it is necessary to analyze the composition of rare earth elements and their relationship with the concentration of magnetic minerals in pumice in several areas in the southern tip of Lampung Province, namely in South Lampung Regency and Bandar Lampung City.

2. Materials and Method

Sampling was conducted in South Lampung Regency and Bandar Lampung City and South Lampung Regency, both of which are located in the southernmost part of Lampung Province. Figure 1 shows the sampling locations.

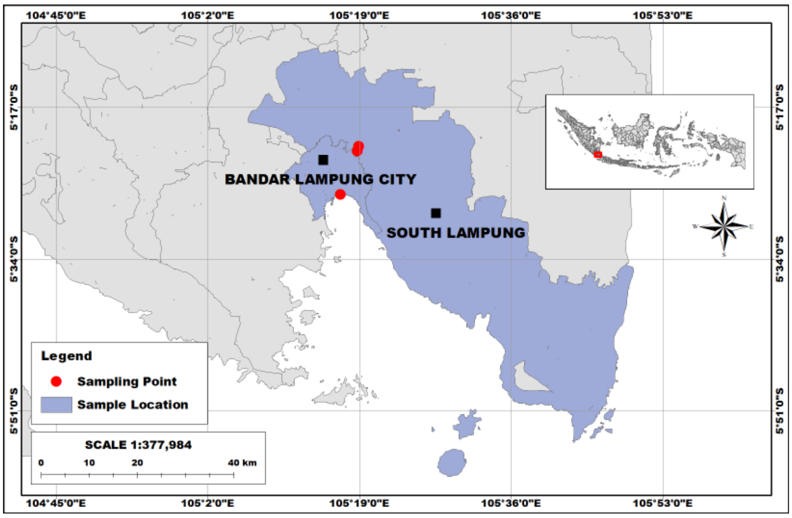

Figure 1. Sampling location

Figure 1 shows that samples were taken from 2 locations and 3 samples were obtained. Where from Bandar Lampung City, precisely at Bukit Kunit with coordinates S05.44607° E105.28208°, 1 sample was obtained. From South Lampung Regency, precisely at Institut Teknologi Sumatera, 2 samples were obtained, with coordinates S05.35653° E105.31581° and S05.36497° E105.31363°. After sampling, samples were prepared in the laboratory and pulverized and put into cylindrical holders with a size of 10 ml (each sample was put into 4 holders). Then, weigh the sample using a digital balance (Ohauss Balance). After all the samples were put into the holder, using the Bartington Magnetic Susceptibility Meter Sensor type B (MS2B), magnetic susceptibility measurements were taken [11]. With two different frequencies, magnetic susceptibility measurements were made. The low frequency of 0.46 kHz obtained low field susceptibility value data (χ_{lf}) and the high frequency of 4.6 kHz obtained high field susceptibility value (χ_{hf}). Frequency-dependent magnetic susceptibility can indicate the content of superparamagnetic minerals present in the sample [11]. From the measurement results with different frequencies, with equation (1), the frequency dependent susceptibility (χ_{fd}) (%) value is obtained.

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

Where, χ_{lf} is the mass unity susceptibility at low field and χ_{hf} is the high-field mass unity susceptibility [11].

The results obtained from the magnetic susceptibility measurements were analyzed. The magnetic susceptibility value that has been obtained can be used to determine the magnetic properties of the sample [12]. Then, from the frequency-dependent susceptibility value (χ_{fd}) (%), magnetic mineral grains can be determined [11].

Determination of elemental composition in the sample with X-Ray Fluorescence (XRF) [13] which is at the Instrumentation Laboratory, Department of Chemistry, FMIPA, UNP. XRF can be used to study the elements present in minerals as well as calculate element concentrations based on wavelength [14]. The XRF measurement results provide information on the content of elements and rare earth elements.

From the mangnetic susceptibility values and rare earth element content that have been obtained, analyzed to determine the relationship of rare earth element content with magnetic mineral concentrations, using linear equations:

$$y = ax + b \qquad (2)$$

Where, y is the independent variable, x is the dependent variable, a is the gradient / variable coefficient $x$where if the value of a is positive $(+)$ then the value of the element to χ_{lf} has a directly proportional relationship, the more percent of the element, the higher the value of the element χ_{lf}, and if the value of a is minus $(-)$ then the value of the element against χ_{lf} has an inversely proportional relationship. b is a constant, R2 is the level of confidence / determination, r is the correlation coefficient. A good linearization curve has a determination value of R2 > 0.9 (close to 1) [15].

3. Results and Discussion

Magnetic susceptibility values on pumice from the southern region of Lampung Province as found in Table 1.

Table 1. Values of Magnetic Susceptibility on Pumice from Bandar Lampung City and South Lampung Regency

No.	Sample Name	Magnetic Susceptibility (χ) (x10 m-8 3 /kg)		χ_{fd} (%)
		χ_{lf}	χ_{hf}	
1.	SSU 19-12-1	289.5	288.6	0.31
2.	SSU 19-12-2	284.8	283.7	0.39
3.	SSU 19-12-3	284.1	283.7	0.14
4.	SSU 19-12-4	270.2	269.6	0.22
	χ_{Min}	270.2	269.6	0.14
	χ_{Max}	289.5	288.6	0.39
	$\chi_{Average}$	282.15	281.4	0.26
5.	SSU 19-13-1	4.8	4.7	2.08
6.	SSU 19-13-2	4.3	4.1	4.65
7.	SSU 19-13-3	4.2	4.2	0
8.	SSU 19-13-4	4.8	4.7	2.08
	χ_{Min}	4.2	4.1	0
	χ_{Max}	4.8	4.7	4.65
	$\chi_{Average}$	4.52	4.425	2.20
9.	SSU 19-14-1	18.9	18.4	2.65
10.	SSU 19-14-2	18.6	17.8	4.3
11.	SSU 19-14-3	17.9	16.9	5.59
12.	SSU 19-14-4	18.7	18.4	1.6
	χ_{Min}	17.9	16.9	1.6
	χ_{Max}	18.9	18.4	5.59
	$\chi_{Average}$	18.52	17.875	3.53

The magnetic susceptibility value of pumice in samples SSU 19-13 and SSU 19-14 from South Lampung Regency and sample SSU 19-12 from Bandar Lampung City (Table 1). In sample SSU 19-12 which has the χ_{lf} value (289,5 x 10-8 m3/kg) is found in sample SSU 19-12-1 and the sample that has the χ_{lf} the smallest (270,2 x 10-8 m3/kg) is in the sample SSU 19-12-4, the average being 282,15 x 10-8 m3/kg. The value of χ_{fd} (%) the largest (0,39 %) is found in the sample SSU 19-12-2 and χ_{fd} (%) the smallest (0,14 %) is found in the sample SSU 19-12-3, with an average of of 0,26 %.

In sampe SSU 19-13 the pumice that has the largest χ_{lf} value (4,8 x 10-8 m3/kg) is found in samples SSU 19-13-1 and SSU 19-13-4, the sample that has the χ_{lf} smallest (4,2 x 10-8 m3/kg) is found in sample SSU 19-13-3 the average being 4,52 x 10-8 m3/kg. The value of χ_{fd} (%) the largest (4,65 %) is found in sample SSU 19-13-2 and the smallest (0 %) is found in sample SSU 19-13-3 ang χ_{fd} (%) the smallest (0 %) is found in the sample SSU 19-13-3 with an average of 2,20 %.

In sample SSU 19-14, the pumice that has the greatest χ_{lf} value (18,9 x 10-8 m3/kg) is in sample SSU 19-14-1 and the sample that has a value of χ_{lf} smallest (17,9 x 10-8 m3/kg) is found in sample SSU 19-14-3 the average being 18,52 x 10-8 m3/kg. The value of χ_{fd} (%) the largest (5,59 %) was found in sample SSU 19-14-3 and the value of χ_{fd} (%) the smallest (1,6 %) is found in the sample SSU 19-14-4, with an average of 3,53 %.

Each sample from Bandar Lampung City and South Lampung Regency has a varied range of magnetic susceptibility values (Table 1). Each sample contains different magnetic minerals, as evidenced by the fact that each sample has varying degrees of magnetic susceptibility [16]. The existence of a range of high or low magnetic susceptibility values can be caused by differences in the total distribution of magnetic minerals found in the sample as well as environmental conditions in the sampling area and the addition of anthropogenic materials, such as non-magnetic elements [5]. High concentrations of magnetic minerals are show by high magnetic susceptibility values because of the way that minerals are transported by the wind or the water [17][18][19], while low concentrations of magnetic minerals are show by low magnetic susceptibility values caused by the process of weathering and deposition mixed with organic materials that are diamagnetic [7][17].
Measurement results of pumice magnetic susceptibility values from Bandar Lampung City and South Lampung Regency (Table 1), a plot of the relationship between χ_{lf} and χ_{fd} (%) values can be made, and has a considerable difference can be seen in Figure 2.

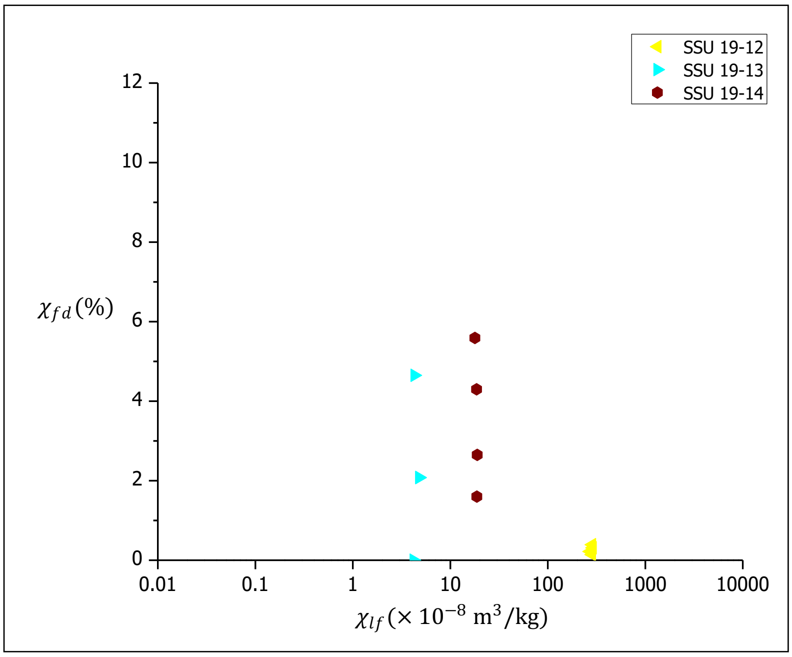

Figure 2. Plot of value relationship χ_{lf} with value χ_{fd} in samples

Value difference χ_{lf} with the value of χ_{fd} (%) in all samples is quite far (Figure 2). The yellow point (SSU 19-12) on the graph shows the magnetic susceptibility value of Bandar Lampung City. The tosca (SSU 19-13) and brown (SSU 19-14) dots on the graph show the susceptibility values of pumice from South Lampung Regency. Using Table 1's magnetic susceptibility value, grouping the sample's magnetic characteristics and grain type, so that the sample's magnetic mineral characteristics are as shown in Table 2.

Table 2. Magnetic Mineral Characteristics of Pumice from Bandar Lampung City SSU 19-12 and South Lampung Regency (SSU 19-13 and SSU 19-14)

No.	**Sample Name**	**Magnetic Susceptibility Value $(10^{-8}m^3/kg)$**	**Magnetic Properties**	**χ_{fd} (%)**	**Grain Type**
1	SSU 19-12	270.2 - 289.5	Antiferromagnetics	0.14 - 0.39	Almost no SP granules
2	SSU 19-13	4.2 - 4.8	Ferrimagnetics	0 - 4.65	Almost no SP granules
3	SSU 19-14	17.9 - 18.9	Ferrimagnetics	1.6 - 5.59	Mixture of SP and coarse grains, or SP grains < 0.05 µm

Based on Table 2, the magnetic mineral characteristics of each sample can be seen. The magnetic properties of pumice from Bandar Lampung City in sample SSU 19-12 are antiferromagnetic, with a range of values χ_{lf} which is 270,2 x 10-8 m3/kg – 289,5 x 10-8 m3/kg. And pumice from South Lampung Regency in sample SSU 19-13 is ferrimagnetic with a range of values χ_{lf} which is 4,2 x 10-8 m3/kg – 4,8 x 10-8 m3/kg and in sample SSU 19-14 is ferrimagnetic with a value range of χ_{lf} which is 17,9 x 10-8 m3/kg – 18,9 x 10-8 m3/kg.

The grain type in the pumice sample from Bandar Lampung City was found to have almost no superparamagnetic grains with a value range of 0,14 % - 0,39 %, the ratio in this sample is less than 1 %, this shows that the value is almost the same and there is not too much difference in the value of magnetic susceptibilias at high frequencies and low frequencies [20]. And in pumice samples from South Lampung Regency there are almost no superparamagnetic grains to superparamagnetic grains and rough grains (SP grains <0.05 μm) with a range of χ_{fd} (%), namely (0 % - 4.65 %) and (1.6 % - 5.59 %), higher χ_{fd} (%), the higher the superparamagnetic grain content [7]. Based on table 2, the value of χ_{fd} (%) means that superparamagnetic grains <10% in the sample.

The size of magnetic grains greatly affects the properties of magnetic minerals [21]. The magnetic grain is the most important thing in the magnetic domain. Because both show the same magnetic susceptibility values from high and low frequency measurements [20].

The elemental composition looked at is the macro elemental composition or the composition of the main elements. The samples measured were 1 representative sample from and pumice from South Lampung Regency and Bandar Lampung City. Table 3 contains the results of the elemental composition analysis performed using XRF on sample SSU 19-12.

Table 3. XRF Measurement Results on Sample SSU 19-12 Bandar Lampung City

Basic		**Oxide**	
Component	**Concentration (%)**	**Component**	**Concentration (%)**
Al	8.565	Al_2O_3	10.419
Si	62.726	SiO_2	73.41
P	3.177	P_2O_5	3.235
Cl	0.022	Cl	0.01
K	14.439	K_2O	7.277
Ca	4.014	CaO	2.144
Ti	0.504	TiO_2	0.312
Mn	0.276	MnO	0.129
Fe	4.095	Fe_2O_3	2.108
Zn	0.04	ZnO	0.017
Rb	0.102	Rb_2O	0.038
Sr	0.062	SrO	0.025
Y	0.017	$Y2O_3$	0.007
Zr	0.103	ZrO_2	0.048
Ag	1.255	Ag_2O	0.568
Ba	0.495	BaO	0.206
Ce	0.037	CeO_2	0.015
Eu	0.045	Eu_2O_3	0.019

Table 3 shows that sample SSU 19-12 has a dominant oxide content, namely Al_2O_3 as much as 10,419%, SiO_2 as much as 73,41%, P_2O_5 as much as 3,235%, K_2O as much as 7,277%, CaO as much as 2,144%, TiO_2 as much as 0,683%, Ag_2O as much as 0,568%, and Fe_2O_3 as much as 4,749%. Data from the measurement of elemental composition using XRF on sample SSU 19-13 as shown in Table 4.

Table 4. XRF Measurement Results on Sample SSU 19-13 South Lampung Regency

Basic		Oxide	
Component	**Concentration (%)**	**Component**	**Concentration (%)**
Al	9.168	Al_2O_3	11.088
Si	59.805	SiO_2	70.526
P	3.468	P_2O_5	3.658
Cl	0.123	Cl	0.056
K	10.663	K_2O	5.607
Ca	4.188	CaO	2.386
Ti	1.037	TiO_2	0.683
Mn	0.369	MnO	0.181
Fe	8.817	Fe_2O_3	4.749
Zn	0.061	ZnO	0.027
Rb	0.114	Rb_2O	0.043
Sr	0.114	SrO	0.047
Y	0.039	$Y2O_3$	0.017
Zr	0.086	ZrO_2	0.041
Ag	1.059	Ag_2O	0.5
Ba	0.729	BaO	0.32
Eu	0.123	Eu_2O_3	0.054

In Table 4, it can be seen that sample SSU 19-13 has a dominant oxide content, namely Al_2O_3 as much as 11,088%, SiO_2 as much as 70,526%, P_2O_5 as much as 3,658%, K_2O as much as 5,607%, CaO as much as 2,386%, TiO_2 as much as 0,312%, Ag_2O as much as 0,5%, and Fe_2O_3 as much as 4,749%. From the oxide content of the SSU 19-12 and SSU 19-13 samples (Table 3 and Table 4), This type of rock is categorized as volcanic rock, and volcanic rock typically contains SiO_2 in concentrations between 48,29% and 58,34%, TiO_2 ranging from 0,49%-0,81%, Al_2O_3 ranging from 12,49%-17,18%,and P_2O_5 ranging from 0,20%-0,41% [22]. Figure 3 shows a comparison of the elemental content of pumice from South Lampung Regency and Bandar Lampung City.

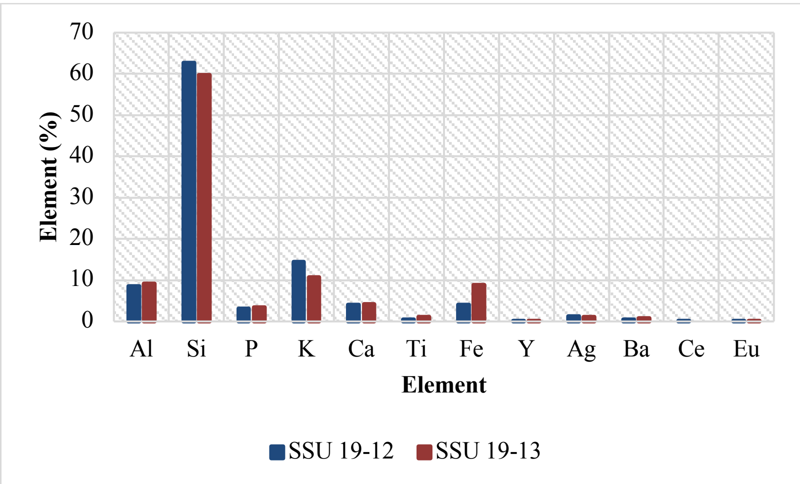

Figure 3. Histogram of element content in samples SSU 19-12 Bandar Lampung City and SSU 19-13 South Lampung Regency

In Figure 3 it can be seen that the most dominant element content in pumice from South Lampung Regency and Bandar Lampung City was found to be Al (8,565 %-9,168 %), Si (59,805

%-62,726 %), P (3,468 %-3,177 %), K (10,663 %-14,439 %), Ca (4,014 %-4,188 %), Ti (0,504 %-1,037 %), Ag (1,059 %-1,255 %), and Fe (4,095 %-8,817 %). Rock-forming elements in Bandar Lampung City and South Lampung Regency consist of Si, Ti,Cl, P, Ca, Mn, Fe, Al, K, Zn, Rb, Ag, Y, Sr, Eu, and Ba, the results obtained are the same as the composition of rock-forming elements in West Lampung Regency, including Si, Al, K, P, Fe, Ti, Ca, Y, Ag, and Eu [10].

Elements forming magnetic minerals were also found in samples SSU 19-12 Bandar Lampung City and SSU 19-13 South Lampung Regency, including Fe and Ti. The magnetic susceptibility value contained in a material depends on the elements Fe and Ti. The magnetic susceptibility value is directly proportional to Fe and Ti, the magnetic susceptibility value included increases with the level of Fe and Ti in a material, and a material's low levels of Fe and Ti result in a lower magnetic susceptibility value[23][24]. The rare earth element composition found in sample SSU 19-12 is Eu (0,045 %), Ce (0,037 %) and Y (0,017 %) and the rare earth element composition found in this sample is Eu (0,123%) and Y (0,039 %). To see the relationship between rare earth element content and magnetic mineral concentration in Figure 4.

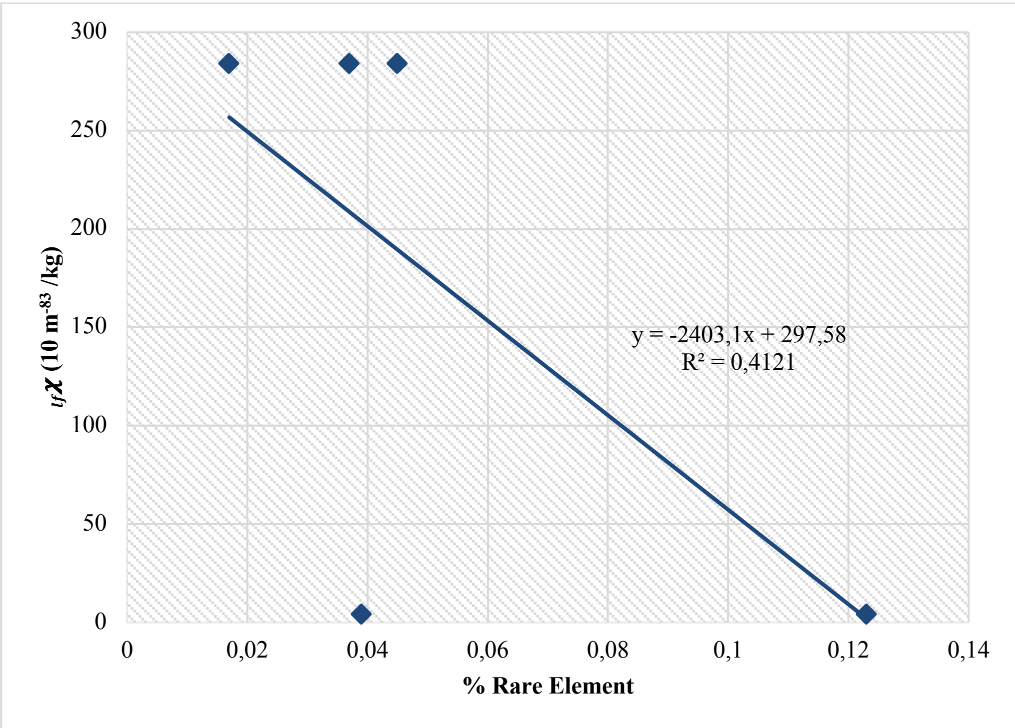

Figure 4. Plot of the relationship between rare earth element percentage and χ_{lf}

The relationship between rare earth elements and magnetic mineral abundance can be determined using a simple linear regression equation, based on Figure 4, the equation is y = -2403.1x + 297.58, meaning that even though the value of rare earth elements = 0, there is still a value of χ_{lf} of 297.58 x 10-8m3/kg. It can be seen that the relationship between rare earth elements and magnetic mineral abundance is inversely proportional, it can be seen from the negative gradient value of -2403.1 and the coefficient of determination is 0.4121 with a confidence level of 41.21%.

4. Conclusion

The value of magnetic susceptibility in pumice from several regions in the southern tip of Lampung Province varies greatly. The highest susceptibility value is in the Bandar Lampung City area and the lowest is in South Lampung Regency, has antiferromagnetic and ferrimagnetic properties, and is found to have almost no superparamagnetic grains and also obtained a mixture of superparamagnetic and coarse grains. Pumice in the southern region of Lampung Province obtained 3 rare earth elements. Samples from South Lampung Regency contained elements of Eu and Y, and samples from Bandar Lampung City contained elements of Eu, Ce, and Y. Based on the analysis that has been done, the relationship between the amount of rare earth elements and the susceptibility value or concentration of magnetic minerals in pumice is obtained, the susceptibility value decreases as the percentage of rare earth elements increases.

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References

[1] N. Ngadenin, A. J. Karunianto, and F. D. Indrastomo, "Penentuan Daerah Prospek Logam Tanah Jarang di Pulau Singkep," *Eksplorium*, vol. 41, no. 1, pp. 15–24, 2020, doi: 10.17146/eksplorium.2020.41.1.5853.

[2] T. Dutta *et al.*, "Global Demand for Rare Earth Resources and Strategies for Green Mining," *Environ. Res.*, vol. 150, pp. 182–190, 2016, doi: 10.1016/j.envres.2016.05.052.

[3] S. J. Suprapto, "Tinjauan Tentang Unsur Tanah Jarang," *Bul. Sumber Daya Geol.*, vol. 4, no. 1, pp. 36–47, 2009.

[4] P. Möller, "Rare Earth Mineral Deposits and Their Industrial Importance," *Lanthanides, Tantalum and Niobium*, pp. 171–188, 1989.

[5] N. Y. Daryanti, S. Zulaikah, N. Mufti, and D. S. Haryati, "Suseptibilitas Magnetik dan Kelimpahan Mineral Magnetik pada Tanah Sawah di Lawang dan Soekarno-Hatta, Malang," *JPSE (Journal Phys. Sci. Eng.*, vol. 3, no. 2, pp. 48–54, 2018, doi: 10.17977/um024v3i22018p048.

[6] N. D. Siregar, H. Rifai, S. Syafriani, A. Fauzi, and F. Mufit, "Magnetic Susceptibility of Volcanic Rocks from Pahae Julu Region, North Sumatera Province," *J. Phys. Its Appl.*, vol. 4, no. 2, pp. 42–46, 2022, doi: 10.14710/jpa.v4i2.13597.

[7] R. N. Fajri, R. Putra, C. B. De Maisonneuve, A. Fauzi, Yohandri, and H. Rifai, "Analysis of magnetic properties rocks and soils around the Danau Diatas, West Sumatra," *J. Phys. Conf. Ser.*, vol. 1185, no. 1, 2019, doi: 10.1088/1742-6596/1185/1/012024.

[8] M. R. Fadila *et al.*, "Magnetic susceptibility of pre- and post caldera lavas from Maninjau, West Sumatra," *J. Phys. Conf. Ser.*, vol. 1481, no. 1, 2020, doi: 10.1088/1742-6596/1481/1/012017.

[9] G. Nahan, S. Bijaksana, P. B. Suryanata, and K. Ibrahim, "Geochemical and magnetic

characteristics of placer gold deposits from Central Kalimantan, Indonesia," *Rud. Geol. Naft. Zb.*, vol. 38, no. 2, pp. 99–107, 2023, doi: 10.17794/rgn.2023.2.7.

[10] N. F. Kurnia, H. Rifai, S. Syafriani, L. Dwiridal, and F. Mufit, "Identification of Elemental Content and Rock Types in West Lampung Regency," *EKSAKTA J. Sci. Data Anal.*, vol. 3, no. 2, pp. 65–69, 2022, doi: 10.20885/eksakta.vol3.iss2.art1.

[11] J. Dearing, *Environmental Magnetic Susceptibility Using the Bartington MS2 System*. British Library Cataloguing in Publication Data, 1999.

[12] C. P. Hunt, B. M. Moskowitz, and S. K. Banerjee, "Magnetic Properties of Rocks and Minerals: A Handbook of Physical Constants," *Rock Phys. Phase Relations*, vol. 3, p. 189−204, 1995, doi: 10.1029/RF003p0189.

[13] P. Brouwer, *Theory of XRF*. Netherlands: Netherlands: PANalytical BV, 2010.

[14] S. Zulaikah, "Prospek dan Manfaat Kajian Kemagnetan Batuan pada Perubahan Iklim dan Lingkungan," *J. Fis. Unnes*, vol. 5, no. 1, pp. 1–6, 2015.

[15] G. Borradaile, *Statistics of Earth Science Data*. Germany: Germany: Springer-Verlag Berlin Heidelberg, 2003.

[16] J. Jahidin, "Analisis Suseptibilitas Magnetik Pasir Besi Desa Laea Kabupaten Buton Utara Sulawesi Tenggara," *J. Apl. Fis.*, vol. 8, no. 1, pp. 20–24, 2012.

[17] R. A. Pratiwi, A. G. Prakoso, R. Darmasetiawan, E. Agustine, K. H. Kirana, and D. Fitriani, "Identifikasi Sifat Magnetik Tanah Di Daerah Tanah Longsor," *Pros. Semin. Nas. Fis.*, vol. V, pp. 7–10, 2016, doi: 10.21009/0305020402.

[18] S. Salomo, S. A. Purba, and R. Syech, "Vulkanik Erupsi Gunung Sinabung Kabupaten Karo Menggunakan Probe Pasco 2162," *J. Komun. Fis. Indones.*, vol. 15, no. 01, pp. 6–12, 2018.

[19] N. Sari, H. Rifai, and F. Mufit, "Penentuan Ukuran Bulir Dan Jenis Domain Magnetik Guano Dari Gua Rantai Dan Gua Solek Di Kecamatan Lareh Sago Halaban Kabupaten 50 Kota Dengan Metode Anhysteretic Remanent Magnetization (Arm)," *Pillar Phys.*, vol. 2, pp. 18–25, 2013.

[20] M. O. Kanu, O. C. Meludu, and S. A. Oniku, "A Preliminary Assessment of Soil Pollution in Some Parts of Jalingo Metropolis, Nigeria Using Magnetic Susceptibility Method," *Jordan J. Earth Environ. Sci.*, vol. 5, no. 2, pp. 53–61, 2013.

[21] S. B. Pranitha, S. Zulaikah, A. Hidayat, and R. Azzahro, "Uji Suseptibilitas Magnetik Tanah Gambut Kalimantan Tengah," *Semin. Nas. Jur. Fis. FMIPA UM*, 2015.

[22] J. Hutabarat, "Geokimia Batuan Volkanik Formasi Cikotok Di Segmen Utara Kubah Bayah, Banten," *Bull. Sci. Contrib.*, vol. 14, no. 2, pp. 195–204, 2016, doi: 10.24198/bsc%20geology.v14i2.10963.

[23] S. Putra, H. Rifai, R. Fadila, E. D. Ningsih, and R. Putra, "Distribution of Pyroclastic Deposits around Lake Maninjau Agam District, West Sumatera, Indonesia based on Magnetic Susceptibility," *Trends Sci.*, vol. 19, no. 7, 2022, doi: 10.48048/TIS.2022.3218.

[24] Y. S. Ulfa and A. Budiman, "Analisis Suseptibilitas Magnetik Tanah Pada Lahan Perkebunan Kopi di Kabupaten Solok," *J. Fis. Unand*, vol. 8, no. 3, pp. 219–226, 2019, doi: 10.25077/jfu.8.3.219-226.2019.