



Potential Use of Rock Magnetism Method to Uncover Magnetic Minerals from Rocks in Talamau Segment, West Pasaman, Indonesia

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Abstract. *The Talamau segment in West Pasaman Regency is a tectonically active area with a variety of lithologies such as crystalline limestone, volcanic breccia, alluvial deposits, ultramafic rocks, and ancient volcanic coarse alluvium. The tectonic and geological complexity of the region is reinforced by the occurrence of an earthquake with a magnitude of Mw 6.1 on February 25, 2022, which indicates high fault activity and the potential for changes in the physical and magnetic properties of rocks in the region. Identification of magnetic minerals in rocks is very important to understand the impact of tectonic activity on magnetic properties and subsurface mineral distribution, but understanding of the magnetic characteristics of lithologies in the Talamau Segment is still limited. In this regard, there are many mineral identification methods, such as XRF for chemical element composition analysis and XRD for identification of crystalline mineral phases in geological samples. However, in this study, the rock magnetism method was chosen as the main approach due to its effective ability to reveal the distribution and concentration of magnetic minerals in various lithologies. This study aims to analyze the potential of the rock magnetism method, especially through magnetic susceptibility measurements, in revealing the distribution and concentration of magnetic minerals in various lithologies in the Talamau Segment. The study was conducted through a systematic literature review (SLR) on 100 scientific articles (2010-2025) selected based on lithological suitability, magnetic mineral focus, and use of rock magnetism methods. The 12 most relevant articles were analyzed in depth to identify the magnetic characteristics of similar lithologies. Results show that the rock magnetism method is very effective for distinguishing magnetic characteristics between dominant lithologies; crystalline limestones generally have low susceptibility values, while volcanic breccias and ultramafic rocks have higher, indicating the content of ferromagnetic minerals such as magnetite. The advantages of this method include fast, simple, flexible (laboratory/in situ), cost-effective, and relevant measurements for geological applications. This study confirms that the rock magnetism method has great potential as an effective initial tool in geological research and exploration in tectonically active areas such as the Talamau Segment, and can be the basis for understanding the dynamics of geological changes due to tectonic events..*

Keywords: *Talamau segment, active tectonics, magnetic minerals, magnetic susceptibility, rock magnetism method*

Abstrak. Segmen Talamau di Kabupaten Pasaman Barat merupakan daerah aktif secara tektonik dengan beragam litologi seperti batugamping kristalin, breksi vulkanik, endapan aluvial, batuan ultramafik, dan aluvium kasar vulkanik purba. Kompleksitas tektonik dan geologis wilayah ini diperkuat oleh terjadinya gempa bumi dengan magnitudo Mw 6,1 pada tanggal 25 Februari 2022, yang menunjukkan aktivitas sesar yang tinggi dan potensi perubahan sifat fisik dan magnetik batuan di wilayah tersebut. Identifikasi mineral magnetik dalam batuan sangat penting untuk memahami dampak aktivitas tektonik terhadap sifat magnetik dan distribusi mineral bawah permukaan, namun pemahaman tentang karakteristik magnetik litologi di Segmen Talamau masih terbatas. Dalam hal ini, terdapat banyak metode identifikasi mineral, seperti XRF untuk analisis komposisi unsur kimia dan XRD untuk identifikasi fase mineral kristalin dalam sampel geologi. Namun, dalam penelitian ini, metode magnetisme batuan dipilih sebagai pendekatan utama karena kemampuannya yang efektif untuk mengungkap distribusi dan konsentrasi mineral magnetik dalam berbagai litologi. Studi ini bertujuan untuk menganalisis potensi metode magnetisme batuan, khususnya

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melalui pengukuran susceptibilitas magnetik, dalam mengungkap distribusi dan konsentrasi mineral magnetik pada berbagai litologi di Segmen Talamau. Studi ini dilakukan melalui tinjauan literatur sistematis (SLR) pada 100 artikel ilmiah (2010-2025) yang dipilih berdasarkan kesesuaian litologi, fokus mineral magnetik, dan penggunaan metode magnetisme batuan. Dua belas artikel yang paling relevan dianalisis secara mendalam untuk mengidentifikasi karakteristik magnetik dari litologi yang serupa. Hasil menunjukkan bahwa metode magnetisme batuan sangat efektif untuk membedakan karakteristik magnetik antara litologi dominan; batugamping kristalin umumnya memiliki nilai susceptibilitas rendah, sedangkan breksi vulkanik dan batuan ultramafik memiliki nilai yang lebih tinggi, menunjukkan kandungan mineral feromagnetik seperti magnetit. Keunggulan metode ini meliputi cepat, sederhana, fleksibel (laboratorium/di lapangan), hemat biaya, dan pengukuran yang relevan untuk aplikasi geologi. Studi ini menegaskan bahwa metode magnetisme batuan memiliki potensi besar sebagai alat awal yang efektif dalam penelitian dan eksplorasi geologi di daerah yang aktif secara tektonik seperti Segmen Talamau, dan dapat menjadi dasar untuk memahami dinamika perubahan geologi akibat peristiwa tektonik.

Kata kunci: Segmen Talamau, tektonik aktif, mineral magnetik, kerentanan magnetik, metode magnetisme batuan

1. INTRODUCTION

The Talamau segment, located in West Pasaman Regency, West Sumatra, is in a highly dynamic tectonic zone and is part of the Sumatra Fault System. The Pasaman region has a significant diversity of geological formations, and is traversed by the Central Sumatra Fault Zone which includes segments such as Barumun, Angkola, Sumpur, Sianok, Sumani, Suliti, and Siulak [1]. The oldest rock formation process in this area is estimated to have occurred in the Permian to Cretaceous interval, including intrusive and metamorphic rocks with varying degrees of alteration, ranging from diorite to granite [2].

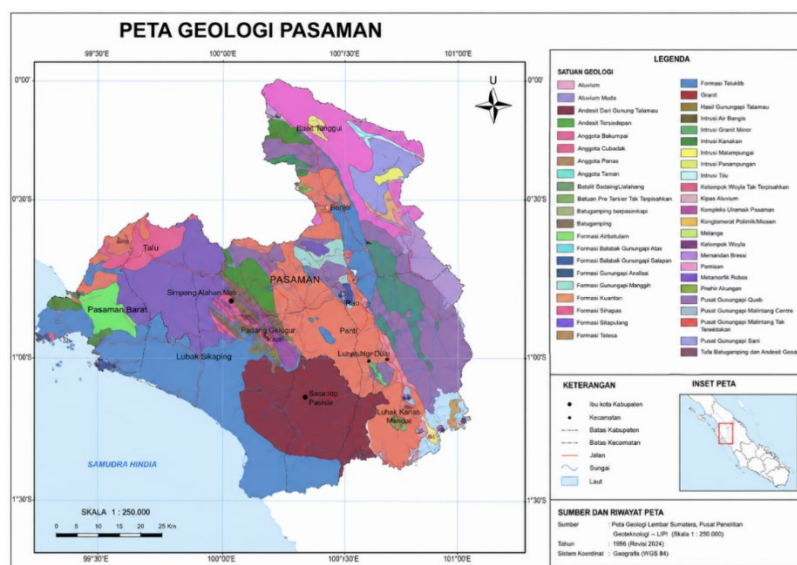


Figure 1: Geology of Pasaman including Lubuk Sikaping Sheet Geologic Map (this image was created with ArcMap 10.8 application).

Based on the Geological Map of Lubuk Sikaping Sheet [3], the rocks in the Talamau Segment are composed of sedimentary rocks, young volcanic rocks, and intrusive rocks that have been deformed by the tectonic activity of the Great Sumatra Fault. Dominant lithologies include crystalline limestone, volcanic breccia, alluvial deposits (river sediments), ultramafic rocks, and ancient volcanic coarse alluvium.

On February 25, 2022, the region experienced a Mw 6.1 earthquake triggered by fault activity in the Talamau segment [4]. The intensity of tectonic activity not only causes physical deformation in rocks, but also has the potential to change the magnetic properties of rocks through mechanisms such as differential pressure and frictional heating [5]. The magnetic properties of rocks are affected by the distribution and type of iron, which is the fourth most abundant element in the Earth's crust [6] [7]. Most iron-bearing minerals such as iron silicates, carbonates (e.g., siderite and ankerite), and some sulfides (e.g., pyrite), generally do not exhibit magnetic properties at ambient temperatures [8].

However, the presence of magnetic minerals, although usually only about 0.1% of the total rock mass, greatly affects its magnetic properties. The existence of various types of magnetic minerals that can be contained simultaneously in rocks makes the magnetic properties complex and varied. Magnetic minerals can be classified based on their magnetic properties into three types, namely diamagnetic, paramagnetic, and ferromagnetic [9]. The type of mineral that can be said to be a magnetic mineral is a ferromagnetic mineral, which is a mineral that can maintain magnetism permanently or temporarily [10]. Examples of these minerals include iron oxides (such as magnetite, maghemite, and hematite), oxyhydrates (such as goethite), as well as some iron sulfides (such as pyrotite and greigit). Although these minerals are present in very small amounts in the rocks, they still play a role in determining the magnetic characteristics of the rocks.

Although the Talamau Segment has high geological complexity and tectonic activity, in-depth understanding of the distribution and concentration of magnetic minerals in its various lithologies is still limited. The rock magnetism method is one of the geophysical methods widely used to identify magnetic minerals in rocks. This method has several advantages, including that it can be applied to various types of materials without limitation of certain properties, as well as the measurement process is safe, simple, fast, and does not damage the sample. Besides being flexible because it can be

used in the laboratory or in situ, this method can also complement other environmental analyses, thus increasing the accuracy and completeness of the data. In addition, this method is more cost-efficient than other methods [11].

The purpose of this study is to analyze the potential of the rock magnetism method, especially through magnetic susceptibility measurements, in revealing the distribution and concentration of magnetic minerals in various lithologies in the Talamau Segment. This study is expected to provide an initial basis for magnetic mineral mapping and further understanding of rock response to tectonic activity in the region.

2. RESEARCH METHOD

Literature Review Method

This study uses the systematic literature review (SLR) to analyze the potential use of the rock magnetism method in revealing magnetic minerals in the Talamau Segment. The literature analyzed includes scientific articles published between 2010 and 2025. With the main criteria being articles that examine various types of rocks with lithologies similar to the Talamau Segment through the application of rock magnetism methods, especially magnetic susceptibility analysis. The literature study process was carried out with the following steps

- a. Searching for scientific articles using Publish or Perish software by entering keywords used include a combination of: "rock magnetism", "magnetic minerals", "geology Sumatra", "geology Talamau", "Talamau segment", "magnetic susceptibility of crystalline limestone", "magnetic susceptibility of limestone", "magnetic susceptibility of volcanic breccia", "magnetic susceptibility of river sediments", "magnetic susceptibility of ultrabasic rocks", "magnetic susceptibility of coarse ancient volcanic alluvium", "magnetic properties and tectonics", and "magnetic properties".
- b. The search produced an output of 100 scientific articles.
- c. The articles were selected based on thematic suitability (focusing on the magnetism of magnetic rocks and minerals), lithological characteristics similar to the Talamau Segment, and research methods using magnetic susceptibility analysis.

- d. The selection resulted in 12 most relevant scientific articles.
- e. The selected literature was analyzed in depth to identify findings, methods, and their relevance to the application of rock magnetism methods in the Talamau Segment.

The results of the analysis are systematically organized to support the discussion of the potential use of the rock magnetism method in revealing magnetic minerals and magnetic properties in rocks in the Talamau segment.

3. RESULT AND DISCUSSION

To assess the potential use of the rock magnetism method in revealing the presence of magnetic minerals in the Talamau Segment, an analysis of magnetic parameters, especially the magnetic susceptibility of the dominant lithology in this area was carried out based on studies in other areas that studied similar lithologies.

a) Sifat Magnetik Batuan

1) Crystalline limestone

Crystalline limestone belongs to non-clastic carbonate sediments formed in the sea or coast without transportation process, through crystalline transformation of afanatic, clastic, or reef limestone. Chemically, limestone (CaCO_3) is mildly acidic and shows high reactivity to acids, especially hydrochloric acid (HCl) [12]. Crystalline limestone has very weak magnetic properties. The value of magnetic susceptibility (χ) in sedimentary rocks such as limestone is in the range of $1,17 \times 10^{-8} \text{ m}^3/\text{kg}^{-1}$, this value is much lower than igneous rocks such as andesite [13]. This occurs because the crystalline structure of calcite naturally reduces the concentration of magnetic minerals in crystalline limestone. As a result, the magnetic susceptibility value of crystalline limestone is at the minimum limit that can be detected by standard measuring instruments such as Bartington MS2B [14]. The dominant mineral in crystalline limestone is calcite (CaCO_3) which is diamagnetic in nature so these rocks tend to reject external magnetic fields and contribute to the low magnetic susceptibility values.

2) Volcanic breccia

Volcanic breccia is a clastic igneous rock composed of large fragments (angular clasts) from volcanic eruptions. The content of magnetic minerals in volcanic breccias varies greatly, depending on the magma source and post-eruption alteration process. The presence of minerals such as magnetite and pyroxene plays an important role in increasing the magnetic susceptibility value of volcanic breccia. Research in Upper Mamuju, West Sulawesi, found that volcanic breccias in the subsurface have magnetic susceptibility values ranging from 0.0006 to 0.00075 cgs, lower than lava (0.001 - 0.0015 cgs) but still higher than non-magnetic rocks such as sand [15]. Other studies have shown that volcanic breccias generally have striking magnetic susceptibility values compared to surrounding lithologies. One noted susceptibility contrasts reaching 251×10^{-4} SI, distinguishing it significantly from sandstone or basalt in the context of subsurface modeling [16]. The magnitude of the magnetic susceptibility value reflects the magnetic mineral content, where the higher the susceptibility value, the more magnetite there is.

3) Alluvial deposits (river sediments)

River sediments are loose materials carried and deposited by water flow, consisting of a mixture of mineral particles, organic matter, and weathered rock remains. The composition of the sediment is highly dependent on the source of the material, the speed of the water flow, and the environmental conditions around the river. In a geophysical context, river sediments hold important information about past geological and environmental processes, one of which is through the magnetic properties of rocks or magnetic susceptibility. The study of the sediments of the Lusi River in Central Java, which is related to the discovery of fossilized deer dated around 30,000 years old, aims to identify the similarity of mineral content between the fossils found in the riverbed and the surrounding sediments, in order to determine whether the fossils are buried in place or carried by the river flow [17]. The magnetic susceptibility measurement results obtained the lowest value of about $1,3 \times 10^{-8} \text{ m}^3/\text{kg}$ from the fossil sample and the highest value of about $37,8 \times 10^{-8}$ obtained from the sediment sample attached to the fossil. This value indicates that the magnetic mineral content is more in the sediment due to the long-term sedimentation process. X-Ray Diffractometer (XRD) results confirm that both fossil

and sediment samples are dominated by calcite (CaCO_3) and quartz (SiO_2) minerals, thus corroborating the notion that both formed in the same environment and underwent sedimentation processes. Meanwhile, measurements by Vibrating Sample Magnetometer (VSM) showed diamagnetic properties in all samples, with low saturation magnetization (M_s) (0,071–0,176 emu/g), very small remanent magnetization (M_r) (0,0001–0,009 emu/g), and coercivity (H_c) varying between 10,969 and 122,628 Oe. The M_r/M_s ratio $< 0,5$ indicates the multi-domain character of the magnetic grains. SEM-EDS analysis also confirmed that iron (Fe) is more abundant in the sediment, which is the main cause of its magnetic properties, while the fossil contains almost no Fe and therefore has very weak magnetism. From all these results, it is concluded that the fossils found at the bottom of the Lusi River have the same minerals and elements as the surrounding sediments, indicating that the fossils have been sedimented for a long time in the Lusi River. Another study of magnetic susceptibility in sediments of the lower Citarum River showed that low-frequency magnetic susceptibility values were in the range of 65,00 to $173,80 \times 10^{-8} \text{ m}^3/\text{kg}$, and high-frequency ranged from 64,90 to $165,70 \times 10^{-8} \text{ m}^3/\text{kg}$, with the difference between the two resulting in frequency-dependent magnetic susceptibility values in the range of 0,15 – 4,66% [18]. These values indicate variations in the content and type of magnetic minerals in the sediments.

4) Ultramafic Rocks

Ultramafic rocks are igneous rocks rich in mafic minerals, particularly olivine and pyroxene, with very low silica (SiO_2) content ($< 45\%$). They have high magnesium (Mg) and iron (Fe) contents, and few felsic minerals. Many ultramafic rocks form as part of the Earth's mantle and are often found in tectonic environments such as the mid oceanic ridge [19]. Some common types of ultramafic rocks include peridotite, dunite, clinopyroxenite, and serpentinite, which are the result of alteration of native ultramafic rocks. In the Meratus Mountains region, ultramafic rocks show high magnetic susceptibility values, indicated by strong positive magnetic anomalies. Susceptibility values are in the range of 0.0243 to 0.0255 SI, reflecting the character of basic igneous rocks containing olivine and serpentinite minerals, typical of ultramafic rocks [20]. Peridotite rock samples from Awang Bangkal Barat Village,

Banjar Regency, South Kalimantan, show that magnetic saturation occurs before the field reaches 300 mT, indicating the presence of magnetite (Fe_3O_4) as the main magnetic mineral. IRM saturation graphs and magnetic saturation curves also confirm the presence of the mineral [21].

5) Ancient volcanic coarse alluvium

The magnetic susceptibility of volcanic alluvium provides an important insight into the lithologic characteristics and geological processes in the surface to subsurface areas. In Tulungagung, the subsurface sequence consists of alluvium, mudstone, limestone and volcanic rocks such as breccia, andesite and tuff. The alluvium layer at the surface shows low magnetic susceptibility values, ranging from $0 - 18 \times 10^{-3}$ SI, with an average of about $0,9 \times 10^{-3}$ SI. In contrast, volcanic rocks such as andesite underneath have much higher values, reaching up to 160×10^{-3} SI, indicating the dominance of ferromagnetic minerals [22]. A similar phenomenon is also found in the Gedong Songo geothermal area, where volcanic alluvium as part of the surface sediments has a magnetic susceptibility value of about $7,0 \times 10^{-5}$ cgs emu [23]. This value is very low and reflects non-magnetic to weak properties, due to the process of hydrothermal alteration and volcanic sedimentation that took place over a long geological time. The low magnetic mineral content in this layer indicates that ferromagnetic minerals have been degraded or released by geothermal fluid activity.

b) Rock magnetism method

Rock magnetism methods utilize recordings of the Earth's magnetic field stored in rocks to identify and understand the presence of magnetic minerals. Although it was originally widely used in paleomagnetism to track the movement of tectonic plates [24]. However, along with the development of science, the rock magnetism method is also used to analyze the mineralogical composition of rocks, especially minerals that are magnetic. The identification of magnetic minerals in rocks is done by measuring several physical parameters of magnetism, such as magnetic susceptibility, magnetic remanence, susceptibility anisotropy, and hysteresis curves [25]. Among these parameters, magnetic susceptibility is the main indicator to identify the characteristics of magnetic minerals in samples, often analyzed using the Bartington Magnetic Susceptibility Meter.

Magnetic susceptibility (χ) is defined as a measure of a material's response to an external magnetic field [26]. When a material is subjected to an external magnetic field, it will respond by generating magnetization [27]. If this magnetization (M) is parallel and in the same direction as the external magnetic field (H), the constant of equality is called magnetic susceptibility per unit mass (χ). The value χ is a key parameter in rock magnetism methods; the higher the magnetic susceptibility value of a rock, the more magnetic minerals it contains. The level of magnetic susceptibility varies depending on the content of magnetic iron oxide compounds present in the mineral [28].

c) Implication of Rock Magnetic Properties on Tectonic Activity of the Talamau Segment

Based on the study of magnetic properties, especially magnetic susceptibility, which has been analyzed on various dominant lithologies in the Talamau Segment and similar areas, it can be concluded that the variation in magnetic susceptibility values reflects the composition of magnetic minerals and local tectonic and geological conditions. Rocks such as crystalline limestone, which are diamagnetic with very low magnetic susceptibility values, show limitations to directly detect strong magnetic anomalies. However, the presence of active faults and fractures in the Talamau Segment often induces fracturing and mineral alteration, which can locally affect the magnetic values of the rocks. This provides an opportunity to map fault structures through magnetic methods even though the bedrock itself has weak magnetic properties [29].

Meanwhile, volcanic breccia rocks containing magnetic minerals such as magnetite and pyroxene have higher magnetic susceptibility values and significant variations according to the degree of alteration and tectonic activity. This value makes volcanic breccia a lithology that is prone to giving prominent magnetic anomaly signatures, making it useful for detecting and mapping faults and faults in the subsurface. Studies in Upper Mamuju demonstrate the effectiveness of using the magnetic susceptibility of volcanic breccias in subsurface mapping. Furthermore, alluvial deposits hold information on tectonic activity through their magnetic mineral content that can be measured by magnetic susceptibility methods. Variations in iron

content in sediments and fossils in riverine areas such as the Lusi River provide insights into sedimentation processes and local tectonic influences [17][18]. These data reinforce that the magnetic properties of sediments in the Talamau Segment also contribute to mapping regional tectonic history and dynamics. Ultramafic rocks with high magnetic susceptibility, such as those found in mountainous regions, mark areas with abundant ferromagnetic minerals and are indicators of more active tectonic activity such as intrusion and crustal deformation [20][21]. Whereas ancient volcanic alluvium with low magnetic susceptibility due to hydrothermal alteration indicates complex tectonic and geothermal processes closely related to active faulting [22][23].

d) Potential Rock Magnetism Methods

Thus, variations in rock magnetic properties in the Talamau Segment not only reflect lithologic heterogeneity, but also provide a tool to observe dynamics and changes resulting from local tectonic activity. Rock magnetic analysis, particularly magnetic susceptibility measurements, is an effective method in detecting and mapping subsurface structures such as faults and fractures, as well as providing insights into the complex geological processes taking place. This is in line with study results showing that low magnetic anomalies often correlate with active fault zones [29]. As well as findings that confirm that magnetic minerals in igneous rocks can be a marker of tectonic evolution because they are strongly influenced by the formation and recrystallization processes resulting from tectonic activity [30]. Therefore, the rock magnetism method has great potential in the study of structural mapping and understanding of tectonic activity in the Talamau Segment.

4. CONCLUSION

Based on the results of a literature review of various relevant studies, it can be concluded that the rock magnetism method, especially through magnetic susceptibility measurements, has enormous potential and is effective for identifying and distinguishing magnetic mineral characteristics in various rock types in the Talamau Segment, West Pasaman Regency. Each of the main lithologies in the region-crystalline limestone, volcanic breccia, alluvial deposits, ultramafic rocks, and ancient volcanic coarse alluvium-shows a different magnetic response, depending on the content and type of

magnetic minerals they contain. The use of this method is considered simple, fast, flexible (can be done in the laboratory or in situ), and cost-efficient. The potential of this method is not only limited to mineral identification, but can also enrich geological analysis, especially in examining the influence of tectonic activity on the distribution and properties of magnetic minerals in the subsurface of the Talamau Segment.

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