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# Analysis of Rare Earth Metal Potential of Parmonangan Area Using X-Ray Fluorescence

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**Abstract:** Rare Earth Elements (REEs) are strategic commodities essential for various high-technology applications, including renewable energy, electronics, and defense systems. However, their uneven global distribution and increasing demand have intensified the need for exploration in undercharacterized regions. This study investigates the REE potential of weathered granitic rocks in the Pamonangan Sub-district, North Sumatra. A total of 200 mesh rock samples from outcrop and subsurface locations were analyzed using X-Ray Fluorescence (XRF) to determine their elemental composition. The geochemical results show high concentrations of $SiO_2$ and $Al_2O_3$ relative to $Fe_2O_3$, suggesting significant weathering of the granitic parent rocks. The combination of elevated $SiO_2$ and low $P_2O_5$ contents indicates a predominance of silica-hosted REE phases over phosphate-hosted minerals. Mineralogical analysis confirms the presence of cassiterite, chlorite, monazite, and zircon as secondary REE carriers, particularly of Ce and La. These findings point to a previously unrecognized potential for REE mineralization in the region. This research provides a geochemical and mineralogical framework for future exploration and highlights the importance of weathered granitoids as prospective REE sources in Indonesia.

**Keywords:** Granite; REE; Weathering; XRF

## Introduction

Rare Earth Element (REE) is a strategic commodity that continues to increase in the world. REE commodities contribute to the improvement of modern technology as raw materials for energy sources, energy conversion, defense industry, electric vehicles and electronic industry Kementerian Energi dan Sumber Daya Mineral (2019), The use of rare earth metals triggers the development of new materials that provide high technological developments that are applied in the improvement of products such as computer memory, hybrid cars, to anti-radar paint so dubbed "technology metals"(Adam, 2016). Rare earth metals by term are not widely found, are found in small and limited quantities and in nature in the form of complex compounds formed naturally as a combination of a number of rare earth elements. REE minerals are more than 100 types and 14 of them are known to have high rare earth oxide content grouped in carbonate, phosphate oxide, silicate and fluoride minerals. The rare earth metals bastnaessite, monazite xenotime, and zircon are most commonly found in nature (Suprapto, 2009).

Rare Earth Metals are part of a group of trace elements, namely elements whose presence is no more than 0.1wt% in the earth's crust (Sutarto et al., 2021). The deposits formed by the concentration of REE elements as mining commodities in the formation process are influenced by chemical and physical factors, as well as the content of elements in the earth's crust. The process of forming deposits in the earth's crust layer from the medium of magmatic solution or residual magmatic

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fluid will transport elements contained in the earth's crust and concentrated based on environmental conditions both physically and chemically. Magma moving towards the earth's crust undergoes changes in composition due to differences in pressure, temperature and composition of the material in the environment which results in the formation of diverse minerals with variations in enrichment of elements that have economic value, one of which is rare earth metals (REE) (Suprapto, 2009).

Rare earth metals (REE) are found in carbonatite and alkaline igneous rocks that are weathered with elements transported with other elements in minerals that form placer deposits and tend to remain as residual deposits or alterites (Kementerian Energi dan Sumber Daya Mineral, 2019). Pegmative and weathered rocks in alluvial tin and quartz sand are REE formers (Vansla et al., 2023). Quartz sandstone lithology containing mica, clay flakes, quartz conglomerates and coal is a potential area for the formation of sandstone-type REE primary deposits. Granitoids are one of the sources of REE-rich rocks. REE deposits derived from weathering are found in acid igneous rocks (granite) undergoing complete weathering and concentrated in the form of clay layers in the weathered crust. The weathering process takes place on granitic rocks in the Parmonangan area of North Tapanuli, North Sumatra (Rasyid, 2011).

Geochemical methods using X-RayFluorescence to determine the composition and concentration of all elements or elements in the periodic system can be measured qualitatively, semiquantitatively and quantitatively in powders, solids and liquids and compounds quickly, do not damage the sample and are environmentally friendly (Ngadenin et al., 2020; Rasyid, 2011). The content and elements of rocks determine the formation and presence of rare earth metals. Research to analyze the potential of rare earth metals in the Parmongan area using X-Ray Fluoresence (XRF) is important as an investment and to be used sustainably.

This research provides the first comprehensive geochemical data for REE content in weathered granitoids of Parmonangan. The results serve as a baseline for future exploration, highlighting the area's potential as a new REE-bearing zone. By filling a key knowledge gap in the geochemical mapping of REEs in Sumatra, this study supports informed investment strategies and the sustainable development of critical mineral resources in Indonesia.

## Method

The research was carried out in the Parmonangan area, located in North Tapanuli Regency, focusing on identifying the potential for rare earth elements (REEs) within weathered granite formations. A total of four sampling points were selected, each representing distinct rock outcrops that exhibited varying degrees of weathering and mineralization (Fig. 1). These sampling locations were strategically chosen based on preliminary field observations, geological mapping, and accessibility to representative lithologies. The collected samples were then subjected to laboratory analysis, including geochemical characterization using X-ray fluorescence (XRF), to determine the composition and concentration of REE-bearing minerals. This sampling approach aimed to provide a spatially distributed geochemical profile of the area, contributing to a more comprehensive understanding of the REE distribution and its relation to local geology and weathering processes.


**Figure 1.** Sampling points

Rock samples were first ground to a fine powder with a particle size of 200 mesh to ensure homogeneity and enhance analytical accuracy. These prepared samples were then subjected to geochemical analysis using two types of X-Ray Fluorescence (XRF) instruments. The first was the XOS HD Mobile 1.2.6.IOP-M2 10WPS S7 4SS, which was used to determine the elemental composition of the samples (Vansla et al., 2023), while the second, the S6 Jaguar Bruker, was employed to identify the elemental content in their oxide forms (Figure 2). The XRF technique operates based on the principle of fluorescence, where the sample is irradiated with primary X-rays. In response, the atoms in the sample emit secondary (fluorescent) X-rays with energies that are characteristic of specific elements present in the material. These emitted X-rays act as a unique elemental "fingerprint," allowing for the qualitative and quantitative determination of a wide range of elements (Ana, 2022). The combined use of portable and benchtop XRF instruments enables a more comprehensive geochemical characterization, facilitating rapid, non-destructive, and accurate analysis suitable for both field and laboratory settings.

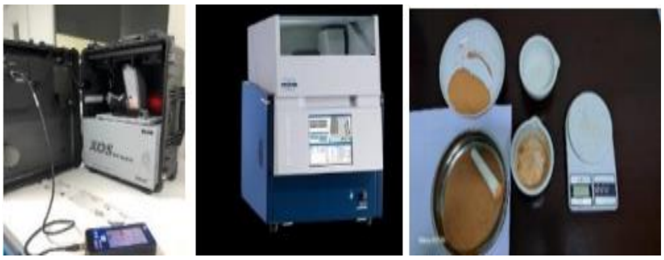


**Figure 2.** Geochemistry of rocks using XRF

## Result and Discussion

*Compound and Rock Element Concentrations*

X-Ray Fluorescence S6 Jaguar Bruker results were used to determine the element in oxide form. The dioxide compounds of the 4 samples identified the concentration of compounds and rock elements. The concentrations of the main compounds and rock elements of the 4 samples are presented in Tables 1 and 2.

**Table 1.** Concentration of Major Rock Compounds

| Major Compound | Concentration (%) | | | |
|---|---|---|---|---|
| | T3 | T4 | T5 | T6 |
| $Na_2O$ | - | - | - | 0.75 |
| $Al_2O_3$ | 25.31 | 18.12 | 2.52 | 8.36 |
| $SiO_2$ | 24.97 | 22.51 | 44 | 28.48 |
| $P_2O_5$ | - | - | - | 0.14 |
| $K_2O$ | 1.56 | 3.61 | 0.78 | 3.67 |
| $TiO_2$ | 0.81 | 0.72 | 0.11 | 0.35 |
| CaO | - | 0.14 | 0.84 | 2.21 |
| $Mn_2O_3$ | 0.66 | - | - | - |
| $Fe_2O_3$ | 4.66 | 9.12 | 1.10 | 5.00 |
| $ZrO_2$ | 0.21 | - | - | - |
| $Sb_2O_3$ | 0.16 | 0.18 | 0.26 | - |
| BaO | 0.17 | - | 0.15 | - |
| $Ta_2O_5$ | - | 0.11 | - | - |

**Table 2.** Element Concentration

| Elements | Concentration (%) | | | |
|---|---|---|---|---|
| | T3 | T4 | T5 | T6 |
| Na | - | - | - | 0.56 |
| Al | 13.40 | 9.59 | 1.34 | 4.43 |
| Si | 11.67 | 10.52 | 20.57 | 13.31 |
| K | 1.29 | 2.99 | 0.65 | 3.05 |
| Ca | - | 0.10 | 0.60 | 1.58 |
| Ti | 0.49 | 0.43 | 0.07 | 0.21 |
| Mn | 0.46 | - | - | - |
| Fe | 3.26 | 6.38 | 0.77 | 3.50 |
| Sr | - | - | - | 0.15 |
| Zr | 0.16 | - | - | - |
| Sb | 0.14 | 0.15 | 0.21 | - |
| Ba | 0.15 | - | 0.13 | 0.48 |
| Ta | - | 0.09 | - | |

The results of the analysis obtained geochemical minerals from the weathering of biotite granite in the form of $Na_2O$, $SiO_2$, $P_2O_5$, and $K_2O$ in the soil show a decrease in mineral content compared to the bedrock in the soil which has mobile properties. The composition of $SiO_2$ (22.51-44.00%) and $Al_2O_3$ (2.52-25.31%) which is greater than the composition of $Fe_2O$ (1.10-9.12) shows that the rock sample is a weathered granite igneous rock formed on the continent (Middelburg et al., 1988). The composition of $SiO_2$ (22.51-44.00%) which is higher than the low composition of $P_2O_5$ (0.14%) indicates the accumulation of rare earth-bearing Silica minireal so that the rare earth mineral-bearing Pospat mineral is slightly found. The composition of $Al_2O_3$ and $Fe_2O_3$ compoundsare elements left behind during weathering so the composition is high. The low composition of $Na_2O$, MgO, CaO and $K_2O$ in weathering rocks is due to the elements Ca, Na, Mg and K easily dissolve when weathering occurs (Hasnur et al., 2010).

The main mineral content in Table 1 contains general rock-forming elements with elemental minerals from carrier compounds listed in Table 2. The results show the presence of monazite and zircon elements as carriers of rare earth metals.

*Concentration of Rare Earth Metals Ce and Se*

The results of XRF analysis type XOS (HD Mobile 1.2.6.IOP-M2 10WPS S7 4SS) were used to obtain the composition of all elements. The concentration of La and Ce as REE elements in the Parmonangan area is potentially in the granite rock distribution area (Table 3). Rare earth elements have increased (depletion) due to weathering resulting in mobilization and fractionation. The content of La element is transported from carrier minerals that are reabsorbed into weathered minerals (Sanematsu et al., 2016).

**Table 3.** REE Content of Parmonangan Region

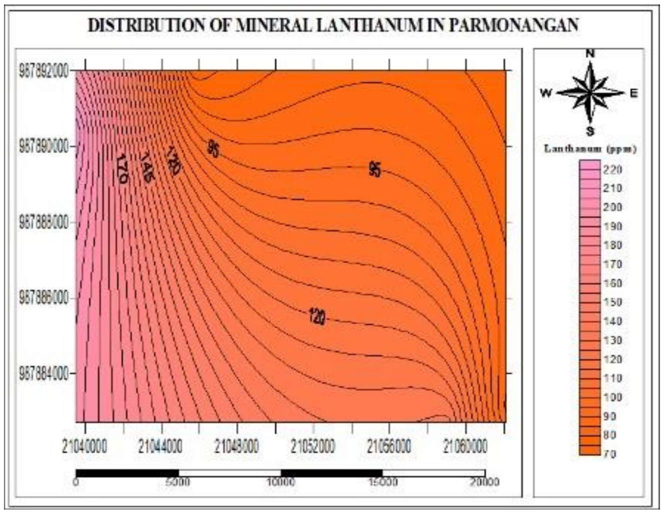
| Elements | | Sample Concentration (ppm) | | |
|---|---|---|---|---|
| | | | | T3 |
| Ce | Cerium | 35.3 | 35.7 | 35.1 |
| La | Lanthanum | 60.2 | 57.3 | 57.6 |
| | | | | T4 |
| Ce | Cerium | 38.4 | 32.1 | 36.8 |
| La | Lanthanum | 59.1 | 57.6 | 56.0 |
| | | | | T5 |
| Ce | Cerium | 117 | 92.7 | 58.6 |
| La | Lanthanum | 154 | 144 | 104 |
| | | | | T6 |
| Ce | Cerium | 64.8 | 64.0 | 65.3 |
| La | Lanthanum | 88.0 | 80.7 | 81.8 |

The rare earth metals Ce and La are in the carrier minerals of monazite and zircon. The REE content of Ce and La is quite significant with values of 32.1-117 ppm and 56.0-154 ppm. The high levels of La and Ce are thought to be related to the presence of monazite and zircon minerals. The presence of REEs found together with other elements in rocks is due to the subsumption of elements so that they are not found in single elements (Puspita et al., 2022). Cerium occurs in the weathering of granitoid crust in tropical climate zones (Chapela Lara et al., 2018; da Silva et al., 2018; Hidayati et al., 2023; Sababa et al., 2021). REE elements La and Ce are light rare metal elements that dominate with atomic numbers 57 and 58 with the use of La elements as camera lenses, studio lighting, projectors, battery catalysts, hybrid car batteries and for Ce elements useful for catalyst converters in cars, glass dyes, steel production, oil refineries (Sutarto et al., 2021; Vansla et al., 2023).

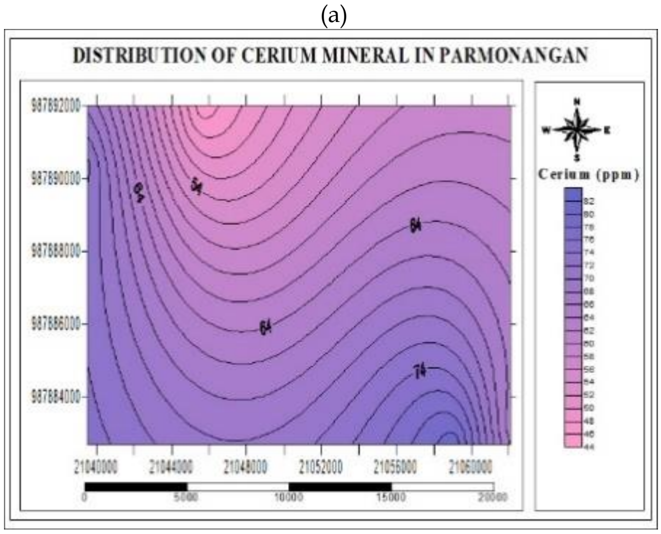
Recent studies in Indonesia have highlighted the potential of tropical weathered granite as a source of rare earth elements (REEs), particularly in regions such as Bangka-Belitung and West Kalimantan. Amin et al. (2017) reported that monazite and xenotime, which are rich in light REEs (LREEs) like Ce and La, are commonly found in weathered granitic terrains associated with tin deposits in Bangka Island. Wulandari et al. (2021) found significant concentrations of REEs in lateritic profiles overlying granitic bedrock in West Kalimantan, with Ce and La contents reaching up to 130 ppm and 110 ppm, respectively (Kisman et al., 2014). These values are within the typical range observed in tropical weathered granites globally and approach the lower economic threshold. According to Long et al. (2010) and the British Geological Survey (2011), the cut-off grade for economic viability of total rare earth oxides (TREO) in ion-adsorption or weathered granite-type deposits generally starts at ~100 ppm TREO, with more commercially viable grades exceeding 300–500 ppm TREO, especially when enriched in LREEs (Deng et al., 2022; Long et al., 2012). Although current REE concentrations in Indonesian weathered granites are still below this upper range, the presence of monazite and zircon as REE carriers indicates favorable geological conditions for secondary enrichment and potential co-extraction in tin or zircon mining operations. These findings underscore the strategic importance of further exploration and geochemical mapping in Indonesia's tropical granite regions, where weathering processes may play a crucial role in REE mobilization and enrichment.

*Potential of Rare Earth Metals*

The potential of rare earth metals (REEs) in the Parmonangan region is evidenced by the accumulation of secondary carrier minerals such as monazite and zircon within acidic granitic rocks. These minerals, which are commonly associated with light rare earth elements (LREEs), are formed and concentrated through intense tropical weathering processes that affect the primary granitic bedrock. The geochemical analysis of rock samples using X-Ray Fluorescence (XRF) revealed significant concentrations of cerium (Ce) and lanthanum (La), indicating mobilization and subsequent enrichment of REEs during weathering. These elemental distributions were further visualized and spatially interpreted using Surfer 8 software (Figure 3), allowing for the identification of localized REE-rich zones. The mapping results highlight the Parmonangan area in North Tapanuli district as a geochemically favorable environment for REE accumulation. This underscores its potential as a prospective site for further REE exploration, particularly through sustainable extraction strategies targeting weathered granite-hosted deposits. Additionally, the presence of REE-bearing minerals as secondary products within a tropical regolith system enhances the economic feasibility of co-mining REEs alongside other industrial minerals such as zircon or tin.




(a)




(b)

**Figure 3.** Distribution of REE elements Ce and La. a) Distribution of lanthanum element, b) Distribution of cerium element

## Conclusion

Geochemical analysis using XRF obtained that the rock has a composition of $SiO_2$ (22.51–44.00%) and $Al_2O_3$

(2.52–25.31%), which is greater than the composition of $Fe_2O_3$ (1.10–9.12%), indicating that the rock sample is a weathered granitic igneous rock. The high $SiO_2$ (22.51–44.00%) and low $P_2O_5$ (0.14%) contents suggest the accumulation of rare earth-bearing silica minerals, with only minor presence of phosphate minerals typically associated with REE. The relatively high composition of $Al_2O_3$ and $Fe_2O_3$ reflects residual enrichment during weathering, while the low contents of $Na_2O$, MgO, CaO, and $K_2O$ result from their mobility and leaching during the weathering process. REE content in the form of Ce and La was detected in concentrations ranging from 42.2–84.8 ppm and 69.9–142 ppm, respectively. These rare earth elements show enrichment due to weathering, leading to their mobilization and fractionation. These findings contribute significantly to the strategic development of rare earth element (REE) exploration in Indonesia, particularly in tropical granite terrains. The identification of weathered granitic rocks enriched in light REEs such as La and Ce provides critical geochemical evidence that supports targeted exploration programs. From an economic perspective, although the REE concentrations in Parmonangan are currently below standalone commercial thresholds, the co-occurrence of monazite and zircon suggests potential for by-product recovery in existing or planned mining operations, such as tin or zircon extraction. Furthermore, this geochemical baseline offers valuable guidance for refining exploration strategies—prioritizing weathered granitic zones with similar geochemical signatures and leveraging low-impact, sustainable technologies for REE extraction. In the broader context of critical mineral security and green energy transition, the results highlight the importance of advancing domestic REE resource development to reduce dependency on imports and to strengthen Indonesia's position in the global REE supply chain.

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Rita Juliani, Rahmatsyah, Togi Tampubolon, Erni Halawa, Silvia Dona Sari, Ismayana, Rama Yana Purba**:** writing-original draft preparation, result, discussion, methodology, analysis, conclusion; Silvia Dona Sari: proofreading, review, and editing.

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**Conflicts of Interest**
The authors declare that there is no conflict of interest regarding the publication of this paper.

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