

Preliminary REE Characteristics of Selected Metamorphic and Metasedimentary Rocks from Bayat, Central Java

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Abstract

Bayat, Central Java, exposes metamorphic and metasedimentary rocks in the West and East Jiwo Hills, where REE characteristics remain insufficiently documented despite prior work on petrography, mineralogy, structure, and mineralization. This study presents a preliminary evaluation of REE variation in four samples from Gunung Gajah, Gunung Cakaran, Jokotuo, and Sekarbolo, based on megascopic descriptions and whole-rock REE concentrations from La to Lu, compared through total REE (Σ REE) and chondrite-normalized patterns. Σ REE values range from 88.18 to 163.46 ppm, highest in Sekarbolo and lowest in Gunung Gajah, with Gunung Cakaran and Jokotuo intermediate, and the chondrite-normalized patterns generally show LREE enrichment relative to HREE. These differences may reflect variations in siliciclastic input, mica- or clay-rich components, carbonate dilution, source-rock composition, and REE-bearing accessory-mineral abundance, though megascopic and whole-rock data alone cannot determine the specific mineral hosts. By documenting these inter-locality differences, this study contributes the first preliminary REE dataset for the Jiwo Hills metamorphic complex, establishing a geochemical baseline not previously available. The observed variation should nonetheless be regarded as a preliminary signal rather than definitive evidence of REE mineralization or economic potential, requiring further study through additional samples, major and trace element geochemistry, detailed petrography, XRD, SEM-EDS, and mineral chemistry.

Keywords: Bayat, Metamorphic Rocks, Metasedimentary Rocks, Rare Earth Elements, Chondrite-Normalized Pattern, Preliminary Geochemistry.

INTRODUCTION

Bayat, particularly the West and East Jiwo Hills, is an important area in Central Java where metamorphic and metasedimentary rocks are exposed, recording the pre-Tertiary basement, lithological variation, and low-grade metamorphism of southern Central Java. The area is geologically complex, comprising metamorphic basement rocks, sedimentary successions, carbonate units, intrusive rocks, and volcanic to volcanoclastic sequences that preserve an important record of metamorphism, deformation, sedimentation, and mineralization (Adha et al., 2018; Kurniasih et al., 2018; Mulyaningsih, 2016).

Metamorphic rocks in Bayat include phyllite, schist, quartzite, marble, graphite-bearing rocks, and other metasedimentary lithologies. Kurniasih et al. (2018) reported muscovite-chlorite schist, chlorite schist, and phyllite in the West Jiwo Hills, with protoliths interpreted as fine-grained sediments such as siltstone and claystone. Puspitasari et al. (2025) identified additional foliated and non-foliated types, including mica schist, calc-silicate schist, mica and chlorite phyllite, graphite phyllite, quartzite, marble, and serpentinite. Maulana et al. (2024) reported base-metal mineralization hosted by Cretaceous metamorphic rocks in Jiwo Hills, underscoring their relevance for mineralization studies.

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Rare earth elements (REE) are increasingly used in geological studies to identify sediment sources and rock-forming processes, and are regarded as strategic elements for their applications in modern technologies, renewable energy, high-performance magnets, and electronics (Balaram, 2019; Jyothi et al., 2020). In this study, however, REE are used primarily as geochemical indicators of preliminary variation among selected rocks from Bayat, rather than from an economic perspective.

REE data provide information on total abundance, LREE–HREE fractionation, and geochemical patterns reflecting source-rock or lithological control, and are commonly used in sedimentary and metasedimentary rocks to evaluate provenance when interpreted together with field and petrographic observations (McLennan, 1989). Even a limited dataset can therefore offer a useful preliminary basis for identifying geochemical differences among samples.

Although previous studies in Bayat have discussed petrography, structural geology, mineralogy, metamorphic facies, and mineralization, preliminary REE characteristics of metamorphic and metasedimentary rocks from different localities in the Jiwo Hills remain insufficiently documented, particularly how REE contents vary among representative samples from Gunung Gajah, Gunung Cakaran, Jokotuo, and Sekarbolo (see Figure 1). This gap is important because these localities represent different parts of the Jiwo Hills and may record different geochemical characteristics.

This study aims to evaluate the preliminary REE characteristics of four selected metamorphic and metasedimentary rock samples from Gunung Gajah, Gunung Cakaran, Jokotuo, and Sekarbolo, Bayat, based on megascopic observations and REE data (total abundance and distribution patterns). Rather than estimating economic potential, it is intended to identify inter-locality REE variations and establish a foundation for more comprehensive subsequent studies involving additional samples, petrography, whole-rock geochemistry, and mineralogical analysis.

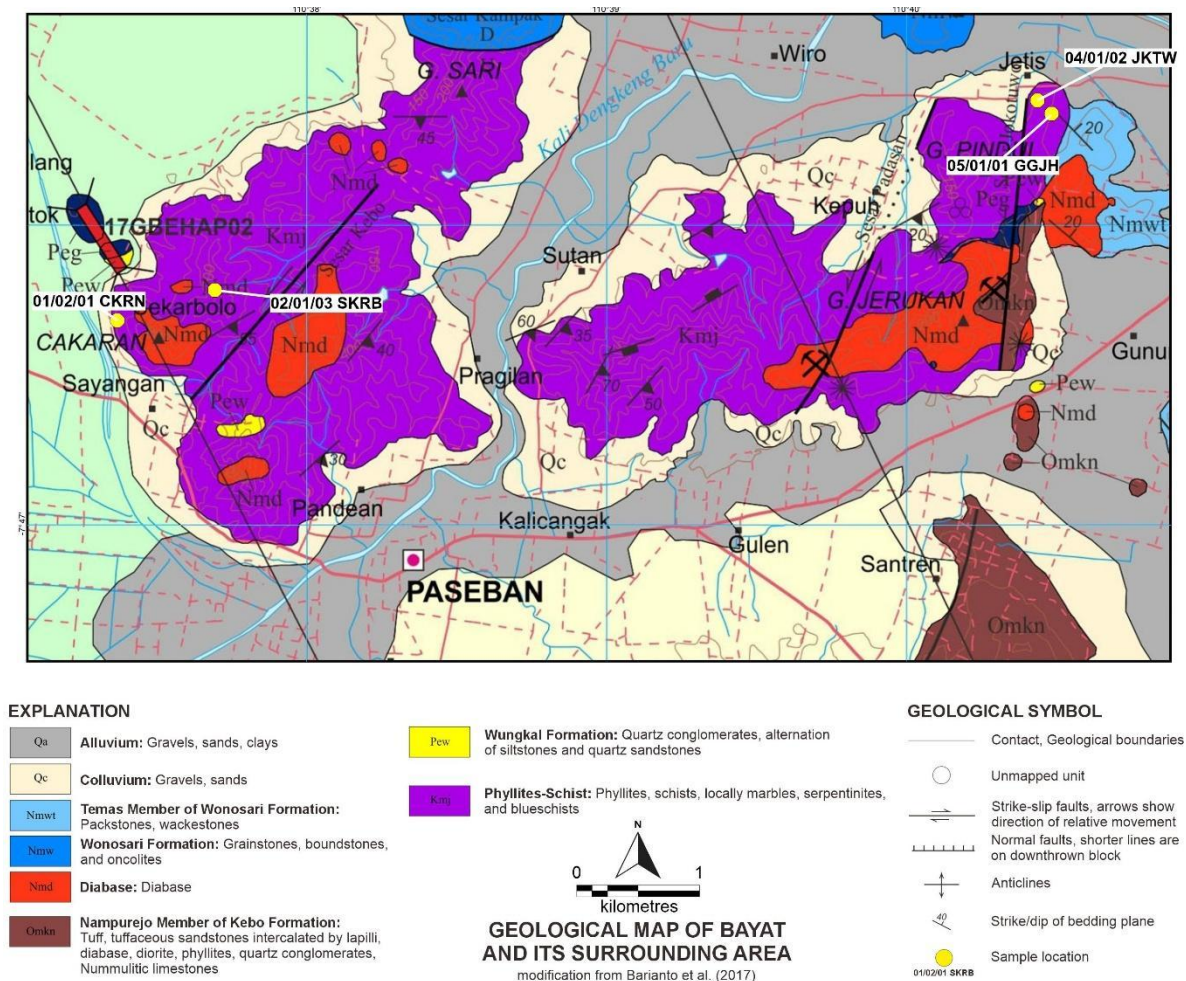


Figure 1. Location Map of Four Samples in the West and East Jiwo Areas

Note: Adapted from *Peta Geologi Lembar Wonosari, Jawa*, by D. H. Barianto, U. Margono, S. Husein, M. I. Novian, and A. K. Permana, 2017.

LITERATURE REVIEW

Rare earth elements (REE) are widely used in sedimentary and metasedimentary studies because their distribution may preserve source-rock composition, sedimentary processes, and post-depositional modification. REE patterns in fine-grained siliciclastic sediments commonly reflect the average source composition after mixing during weathering, transport, and deposition (McLennan, 1989; Condie, 1991), supporting preliminary provenance interpretation when combined with field and petrographic observations.

In low-grade metasedimentary rocks, REE are generally less mobile than major elements, though redistribution may occur through fluid-rock interaction and REE-bearing accessory minerals. Patterns are therefore best interpreted as inherited protolith signatures rather than direct metamorphic indicators, applicable to Bayat, where phyllite, schist, quartzite, marble, and graphite-bearing rocks occur.

Chondrite-normalized REE patterns evaluate LREE enrichment relative to HREE, plus Eu and Ce anomalies. Rocks derived predominantly from evolved upper continental crust commonly show LREE-enriched patterns and negative Eu anomalies (Nance & Taylor, 1976; Taylor & McLennan, 1985; McLennan, 1989), so normalized patterns offer a useful preliminary comparison among localities even with a limited dataset.

Total REE content (Σ REE), the sum of concentrations from La to Lu, measures relative REE abundance. Variations can indicate siliciclastic input, carbonate dilution, clay- or mica-rich components, and accessory minerals such as monazite, xenotime, allanite, apatite, zircon, and titanite, though Σ REE alone does not prove mineralization or economic potential; the LREE/HREE ratio is likewise a descriptive fractionation measure without detailed mineralogy.

Eu and Ce anomalies add information but require caution. Negative Eu anomalies generally reflect evolved upper-crustal sources or feldspar fractionation, while neutral or positive anomalies may indicate different sources or processes; redox conditions can also matter, though interpretation is complicated by detrital input, post-depositional alteration, analytical effects, and mineralogical contamination (Bau & Dulski, 1996; Zhao et al., 2021). Eu/Eu* and Ce/Ce* are treated here as descriptive, not unambiguous, indicators.

Carbonate-rich rocks generally have lower absolute REE than siliciclastic rocks, though signatures can be affected by detrital impurities, phosphates, oxides, and post-depositional fluids (Zhao et al., 2021), relevant to Bayat, where marble, calc-silicate rocks, and calcareous schist occur in the Jiwo Hills (Puspitasari et al., 2025). Lower Σ REE in carbonate-bearing samples may thus reflect dilution rather than the absence of REE-bearing phases.

Based on these considerations, REE patterns and Σ REE provide preliminary information on geochemical variation among samples from Gunung Gajah, Gunung Cakaran, Jokotuo, and Sekarbolo, with interpretation limited to inter-locality variation. Conclusions on economic potential, mineralization type, or protolith evolution require additional samples, petrographic control, major- and trace-element data, and mineral identification.

RESEARCH METHODOLOGY

This study was conducted as a preliminary geochemical study of REE in metamorphic and metasedimentary rocks from Bayat, Central Java, focusing on four localities in the Jiwo Hills: Gunung Gajah, Gunung Cakaran, Jokotuo, and Sekarbolo. Each locality was represented by one sample, selected purposively based on locality representation, availability of REE data, and the presence of metamorphic or metasedimentary lithologies observed in the field, to provide an initial comparison of REE characteristics across the Bayat metamorphic complex.

Field and hand-specimen observations formed the main macroscopic basis for describing the samples, covering rock color, grain size, structure, foliation, visible mineral components, oxidation, quartz or carbonate veinlets, and carbonaceous or graphite-like material where present. Because this study does not include detailed petrographic or mineral chemical analysis, the mineralogical interpretation is limited to field-scale and hand-specimen characteristics.

REE data (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu) were obtained from PT. Geoservices Laboratory using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), with concentrations expressed in ppm. Total REE abundance was calculated as the sum of all analyzed elements from La to Lu, and the data were normalized to chondrite values following Boynton (1984) to evaluate LREE enrichment, HREE behavior, and possible Eu and Ce anomalies. Total REE values were used to compare relative abundance among the four samples, while normalized patterns evaluated the general REE distribution from LREE to HREE.

Because this study is based on only four samples and megascopic observations, interpretation is intentionally limited: the results are not intended to represent the overall REE potential or economic significance of REE in Bayat, but to provide preliminary information on inter-locality REE variation. Further work involving additional samples, petrographic analysis, whole-rock major and trace element data, XRD, SEM-EDS, and mineral identification is needed to clarify the geological controls of REE distribution.

FINDING AND DISCUSSION

Megascopic Characteristics of Selected Samples

Four representative samples were selected from Gunung Gajah, Gunung Cakaran, Jokotuo, and Sekarbolu to compare REE characteristics among different metamorphic and metasedimentary rocks in Bayat. Megascopic observations show that the samples span phyllitic, metasedimentary, graphitic, and chloritic-schistose lithologies (Table 1) rather than a single rock type — a distinction important for interpreting REE variation, since abundance and distribution may be influenced by siliciclastic content, mica- or clay-rich material, carbonate dilution, and carbonaceous or accessory-mineral components.

Table 1. Megascopic characteristics of selected metamorphic and metasedimentary samples from Bayat.

Locality	Sample Code	Megascopic Lithology	Main Characteristics
Gunung Gajah	05/01/01 GGJH	Quartz–biotite phyllite	Fine-grained, foliated, grey to dark grey rock; visible phyllitic fabric; quartz-rich with mica/biotite-bearing surfaces.
Gunung Cakaran	01/02/01 CKRN	Fine-grained metasedimentary rock	Fine-grained metasedimentary rock with weak to moderate foliation; dominated by siliciclastic components; locally shows weathered or oxidized surfaces.
Jokotuo	04/01/02 JKTW	Graphitic schist	Dark grey to blackish, foliated to schistose rock; contains carbonaceous or graphite-like material; locally associated with quartz and carbonate components.
Sekarbolu	02/01/03 SKRB	Chloritic schist	Greenish to greyish, fine- to medium-grained foliated rock; chloritic appearance; locally contains quartz-rich and Fe-Mg-bearing mineral components.

The selected samples show clear megascopic differences among the four localities (see Figure 2). The Gunung Gajah sample represents a quartz–biotite phyllite with well-developed foliation, suggesting a fine-grained pelitic to semipelitic metasedimentary origin. The Gunung Cakaran sample is interpreted as a fine-grained metasedimentary rock, characterized by siliciclastic components and weak to moderate foliation. In contrast, the Jokotuo sample shows a darker, graphitic to carbonaceous character, suggesting the presence of carbonaceous material and possible carbonate-bearing components in schistose fabric. The Sekarbolu sample is characterized by a greenish chloritic appearance and foliated texture, indicating the presence of Fe-Mg-bearing minerals such as chlorite or related low-grade metamorphic minerals.

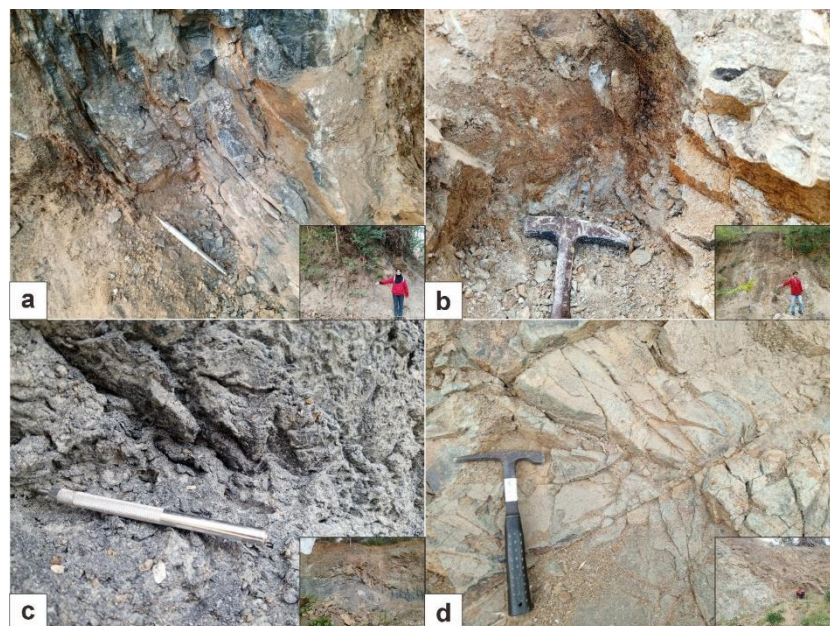


Figure 2. Megascopic characteristics of four selected metamorphic and metasedimentary rock samples from Bayat, Central Java. (a) Quartz-biotite phyllite from Gunung Gajah (05/01/01 GGJH); (b) fine-grained metasedimentary rock from Gunung Cakaran (01/02/01 CKRN); (c) graphitic schist rock from Jokotuo (04/01/02 JKTW); and (d) chloritic schist from Sekarbolo (02/01/03 SKRB).

These megascopic characteristics thus provide the first-order geological basis for comparing REE characteristics among the four localities.

A. Total REE Variation

Total rare earth element abundance (Σ REE) was calculated by summing the concentrations of La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu. The Σ REE values of the four selected samples range from 88.18 to 163.46 ppm, indicating moderate variation among the selected rocks (see Table 2), with the highest in Sekarbolo (02/01/03 SKRB) and the lowest in Gunung Gajah (05/01/01 GGJH).

Table 2. Total REE contents of selected metamorphic and metasedimentary rock samples from Bayat.

Locality	Sample Code	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Σ REE
Gunung Gajah	05/01/01															
	GGJH	14	34	4.54	16	5.03	0.57	2.42	0.62	3.95	0.89	3.19	0.42	2.3	0.45	88.18
Gunung Cakaran	01/02/01															
	CKRN	26	63	7.55	28.1	5.88	1.63	5.87	1.11	4.86	1.22	3.22	0.87	3.79	0.61	153.91
Jokotuo	04/01/02															
	JKTW	26	48	5.62	20.8	5.62	1.87	5.56	0.58	3.7	0.63	1.22	0.4	1.38	0.26	121.74
Sekarbolo	02/01/03															
	SKRB	30	66	7.21	32.5	4.77	1.18	5.93	1.04	5.86	1.2	3.23	0.74	3.23	0.57	163.46

Sekarbolo records the highest Σ REE (163.46 ppm), slightly above Gunung Cakaran (153.91 ppm); both may represent relatively REE-enriched metasedimentary rocks (see Table 3). Their elevated values may relate to a higher proportion of siliciclastic material, mica- or clay-rich

components, chloritic minerals, and/or REE-bearing accessory minerals, though the specific REE-hosting phases cannot yet be determined without detailed petrographic or mineral chemical analysis.

The Jokotuo sample shows a moderate to relatively high Σ REE (121.74 ppm), consistent with its darker graphitic to carbonaceous, schistose character. Its REE content may reflect a mixture of graphitic metasedimentary components, siliciclastic impurities, possible accessory minerals, and carbonate dilution where carbonate is present, factors that warrant cautious interpretation given their combined influence on bulk-rock geochemistry.

The Gunung Gajah sample has the lowest Σ REE (88.18 ppm), still indicating measurable REE in this phyllitic rock. The lower value may reflect differences in source material, lower abundance of REE-bearing accessory minerals, or stronger dilution by quartz-rich components. Overall, the Σ REE variation among the four samples is moderate rather than extreme, showing differences in REE abundance without yet providing sufficient evidence for defining enrichment zones or economic potential.

Table 3. Total REE contents and preliminary interpretation of selected metamorphic and metasedimentary rock samples.

Locality	Sample Code	Σ REE (ppm)	Preliminary Interpretation
Gunung Gajah	05/01/01 GGJH	88.18	Relatively low to moderate Σ REE compared with the other selected samples.
Gunung Cakaran	01/02/01 CKRN	153.91	Relatively high Σ REE, possibly related to siliciclastic and mica-rich components or accessory minerals.
Jokotuo	04/01/02 JKTW	121.74	Moderate to relatively high Σ REE, possibly influenced by graphitic-metasedimentary components and non-carbonate impurities.
Sekarbolo	02/01/03 SKRB	163.46	Highest Σ REE among the selected samples, possibly related to siliciclastic, chloritic, or accessory mineral contributions.

These preliminary results indicate that Σ REE can serve as a simple comparative parameter for recognizing REE variation among localities, though it alone cannot determine the geological control of REE distribution. Further interpretation requires chondrite-normalized patterns, LREE/HREE ratios, Eu and Ce anomalies, and additional mineralogical data to identify whether REE are controlled by protolith composition, siliciclastic input, carbonate dilution, graphitic material, or accessory minerals.

Chondrite-normalized REE Pattern and Preliminary Interpretation

The chondrite-normalized REE patterns of the four selected samples, normalized after [Boynton \(1984\)](#), generally show a decreasing trend from La to Lu, indicating enrichment of light rare earth elements (LREE) relative to heavy rare earth elements (HREE) (see Figure 3). This LREE-enriched pattern is commonly observed in sedimentary and metasedimentary rocks influenced by upper-crustal or siliciclastic source materials, though the degree of enrichment and curve shape vary among samples, suggesting that each locality records different lithological and geochemical characteristics.

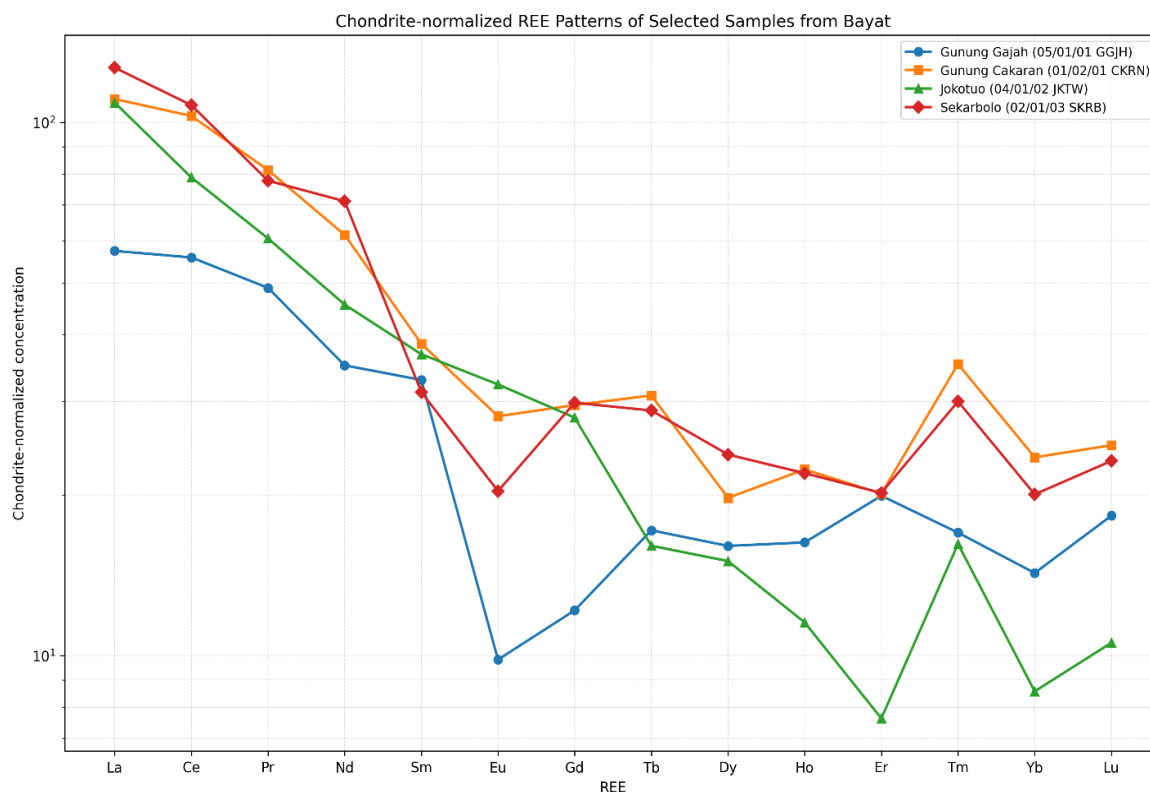


Figure 3. Chondrite-normalized REE patterns of four selected metamorphic and metasedimentary rock samples from Bayat (after [Boynton, 1984](#)).

The Gunung Cakaran sample shows a relatively enriched LREE pattern consistent with its fine-grained metasedimentary or phyllitic character, likely reflecting siliciclastic and aluminosilicate components, including clay- or mica-rich material that retains REE during sedimentation and low-grade metamorphism. The Sekarbolo sample also shows high REE abundance, but its pattern warrants careful interpretation given its chloritic and Fe-Mg-bearing composition, suggesting that REE distribution here is controlled not only by siliciclastic material but also by accessory minerals or specific mineralogical components. In sedimentary systems generally, clay-rich and fine-grained detrital fractions can influence REE distribution through mineral inheritance, adsorption, dissolution, and authigenic reactions ([McLennan, 1989](#); [Abbott et al., 2019](#)), and accessory minerals such as monazite, xenotime, allanite, apatite, zircon, and titanite may exert disproportionate control on whole-rock REE even at low modal abundance ([Balaram, 2019](#)). The elevated Σ REE of the Sekarbolo and Gunung Cakaran samples therefore cannot be attributed solely to their apparent chloritic, micaceous, or siliciclastic character, but likely reflects a combination of detrital source composition, fine-grained mineral fractions, and accessory mineral abundance.

The Jokotuo sample displays a distinct REE pattern, consistent with its darker graphitic to carbonaceous, schistose character and possible carbonate-bearing components; if carbonate minerals are present, both the absolute REE concentration and normalized pattern may be affected by dilution, though carbonate REE signatures are highly sensitive to contamination by clay, phosphate, oxide, and other non-carbonate phases even in small amounts ([Zhao et al., 2021](#)). A dark colour or carbonaceous appearance should not, however, be read as a direct indicator of REE enrichment: an elevated loss on ignition (LOI) value, where available, is not a reliable proxy for graphite content or REE abundance, since LOI can reflect combustion of organic matter, carbonate decomposition, or loss of structural water from clay minerals ([Heiri et al., 2001](#)). The Jokotuo REE

pattern is therefore best interpreted as a preliminary signal of mixed lithological control rather than direct evidence of REE enrichment.

The Gunung Gajah sample has the lowest Σ REE among the four samples, but its normalized pattern still provides useful information on REE fractionation: LREE enrichment with relatively flat HREE would indicate a preserved sedimentary or metasedimentary source signature despite lower overall abundance. This lower content may reflect differences in protolith composition, a lower abundance of REE-bearing accessory minerals, or dilution by quartz-rich components — a lower Σ REE value therefore does not imply reduced geological significance, just as the higher values in other samples should not be read as evidence of a mineralized system without further confirmation. Eu anomaly is another important feature of the normalized patterns. A negative Eu anomaly may indicate an upper-crustal or felsic sedimentary source, feldspar-related fractionation, or inherited protolith characteristics (McLennan, 1989); any such anomaly observed in the Gunung Gajah, Gunung Cakaran, or Sekarbolu samples should be read cautiously as a geochemical feature rather than a definitive indicator of source or process. A neutral or weakly positive anomaly in the Jokotuo sample may instead reflect carbonate influence or local geochemical variation.

Overall, the chondrite-normalized patterns indicate that the selected metamorphic and metasedimentary rocks from Bayat generally preserve LREE-enriched characteristics with variable total REE abundance and anomaly features. Differences among Gunung Gajah, Gunung Cakaran, Jokotuo, and Sekarbolu suggest that REE distribution may be controlled by lithological variation, siliciclastic input, carbonate dilution, carbonaceous material, and accessory mineral contributions, though whole-rock REE data alone cannot determine the specific mineral hosts, textural occurrence, or geological processes responsible. Detailed petrography is needed to establish mineral–texture relationships, XRD to identify major crystalline phases, and SEM-EDS and mineral chemistry to locate REE-bearing accessory minerals at the grain scale; additional sampling is also required to confirm whether observed values represent consistent locality-scale patterns.

CONCLUSION AND FURTHER RESEARCH

The four selected samples from Gunung Gajah, Gunung Cakaran, Jokotuo, and Sekarbolu show measurable variation in REE content. Σ REE values indicate that the investigated metamorphic and metasedimentary rocks do not present a uniform REE abundance, implying that lithological composition, source material, and the contribution of REE-bearing mineral phases vary among the four localities. The Sekarbolu and Gunung Cakaran samples show relatively higher total REE contents than the Jokotuo and Gunung Gajah samples, while the normalized patterns generally indicate LREE enrichment relative to HREE, differences that may reflect variations in siliciclastic input, mica- or clay-rich components, carbonate dilution, and accessory mineral abundance. However, because the present study is based on only four samples and megascopic observations, these parameters should be interpreted cautiously, and the available data cannot conclusively distinguish between the effects of protolith composition, metamorphism, fluid–rock interaction, carbonate dilution, and specific REE-bearing minerals.

Further research should include a larger, more spatially representative sample set supported by whole-rock major and trace element analyses, detailed petrography, XRD, SEM-EDS, and mineral chemistry, to identify the mineral hosts of REE, clarify the controls on REE distribution, and determine whether the observed variations represent consistent locality-scale patterns. The present results should therefore be regarded as a preliminary geochemical framework, not as definitive evidence of REE mineralization or economic potential in Bayat.

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