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Rare Earth Elements of Sarawak: An Overview

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ABSTRACT

Rare earth elements (REEs) are indispensable to permanent magnets, electronics, catalysts and defence systems, but the geological occurrence of REEs does not by itself establish an economically recoverable resource. This review critically evaluates the evidence for REEs in Sarawak, with particular emphasis on the Riih area of Serian, West Sarawak. The strongest published Sarawak-specific evidence is a 2025 study of two laterite profiles developed over basaltic trachyandesite of the Serian Volcanics.

The parent rock contained approximately 209 mg kg^{-1} total REE, whereas intensely weathered material (chemical index of alteration, CIA, 99–100%) reached 1,715.98 mg kg^{-1}. Kaolinite dominance, the reported absence of discrete REE minerals in analysed laterite, and ion-exchangeable REY recoveries exceeding 75% in selected samples support an ion-adsorption interpretation. These results demonstrate a mineralised weathering system at the sampled locality; they do not yet establish lateral continuity, tonnage, a compliant mineral resource, or commercial viability. Elsewhere in Sarawak, granitoids, volcanic rocks and alluvial systems are geologically plausible source or host environments, but published deposit-scale evidence remains sparse, and claims for Bau or statewide HREE resources should be treated as exploration hypotheses.

The review integrates Sarawak geology, ion-adsorption processes, mineralogical and geochemical controls, exploration and analytical methods, economic considerations, environmental risks and Malaysia's evolving regulatory framework. It proposes a staged research programme centred on representative regolith mapping, size- and horizon-controlled sampling, sequential extraction, hydrometallurgical testing, hydrogeological baselines and transparent resource classification. Sarawak has credible REE prospectivity, but responsible development requires converting promising geochemistry into reproducible geological, metallurgical, environmental and socioeconomic evidence.

Keywords: Sarawak; Serian Volcanics; rare earth elements; ion-adsorption clay; laterite; tropical weathering; regolith geochemistry; critical minerals

INTRODUCTION

The rare earth elements comprise the lanthanides together with yttrium and, by common geochemical and policy usage, scandium. Their similar ionic radii and predominantly trivalent charge produce coherent behaviour in many geological systems, although redox-sensitive cerium and europium can depart from the group. The label "rare" is therefore misleading: several REEs are not unusually scarce in the crust, but economic concentrations are uncommon because the elements are dispersed among multiple minerals and are difficult to separate chemically (Balaram, 2019; Goodenough et al., 2018).

Supply risk arises from the concentration of mining, separation and magnet-manufacturing capacity, not simply from global crustal abundance. Nd, Pr, Dy and Tb are especially important to high-performance permanent magnets, while other REEs serve in catalysts, phosphors, polishing materials, ceramics and specialised alloys.

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Demand forecasts vary with technology, substitution, recycling and policy; consequently, static reserve rankings and large monetary valuations are poor substitutes for deposit-specific grade, tonnage, mineralogy, recovery and cost data (Golev et al., 2014; Zhou et al., 2017).

Sarawak has recently attracted attention because deeply weathered volcanic and granitoid terrains could host regolith-related REE enrichment. The scientific case, however, is uneven. Direct peer-reviewed evidence presently centres on the Serian Volcanics near Riih. The broader state contains plausible parent rocks and sedimentary traps, but prospectivity must not be described as a discovered resource.

This paper therefore uses an evidence hierarchy: (i) demonstrated Sarawak observations supported by published analyses; (ii) geological potential inferred from mapped lithology, weathering and regional analogues; and (iii) unverified claims that require primary data. This distinction is essential because a geochemical anomaly is not a mineral resource, total REE is not exchangeable REE, and laboratory extraction is not equivalent to field-scale recovery.

Geological setting of Sarawak

Sarawak occupies north-western Borneo and spans several tectonostratigraphic domains assembled through Mesozoic-Cenozoic subduction, accretion, magmatism and sedimentation. West Sarawak lies largely within the Kuching Zone, south of the Lupar Line, and includes Palaeozoic-Mesozoic sedimentary and metamorphic rocks, the Bau and Pedawan successions, volcanic units and granitoid intrusions.

Modern geochronological and geochemical studies interpret the region as part of a long-lived Sundaland-Pacific margin rather than a single simple arc (Breitfeld et al., 2017; Hutchison, 2005; Wang et al., 2021).

The Serian Volcanics are central to current REE research. Wang et al. (2021) obtained Late Cretaceous ages of approximately 77-98 Ma for mafic rocks of the Kuching Zone and interpreted the Serian suite as arc-related magma influenced by recycled sediment.

At Riih, the parent rock sampled for the REE study was classified as basaltic trachyandesite (Taniou et al., 2025). Prolonged warm, humid weathering has transformed such rocks into highly leached lateritic profiles. This weathering architecture is not merely the presence of volcanic rock but is the immediate control on the observed secondary enrichment.

Granitoids at Jagoi and elsewhere in the Kuching Zone warrant geochemical screening because felsic rocks may contain accessory monazite, xenotime, allanite, apatite, titanite and zircon. Yet mapped granite does not demonstrate an REE deposit. Accessory minerals may resist weathering and retain REEs in a non-exchangeable residual fraction, or release REEs that are subsequently adsorbed by clays and Fe-Mn oxides.

The balance depends on primary mineralogy, fracture permeability, drainage, weathering intensity, pH, organic ligands, clay assemblage and erosion history. Likewise, the Bau district's well-established carbonate-hosted and hydrothermal mineral systems do not constitute evidence of a clay-hosted REE resource. Bau is best framed as a target for systematic testing, not as a confirmed REE occurrence.

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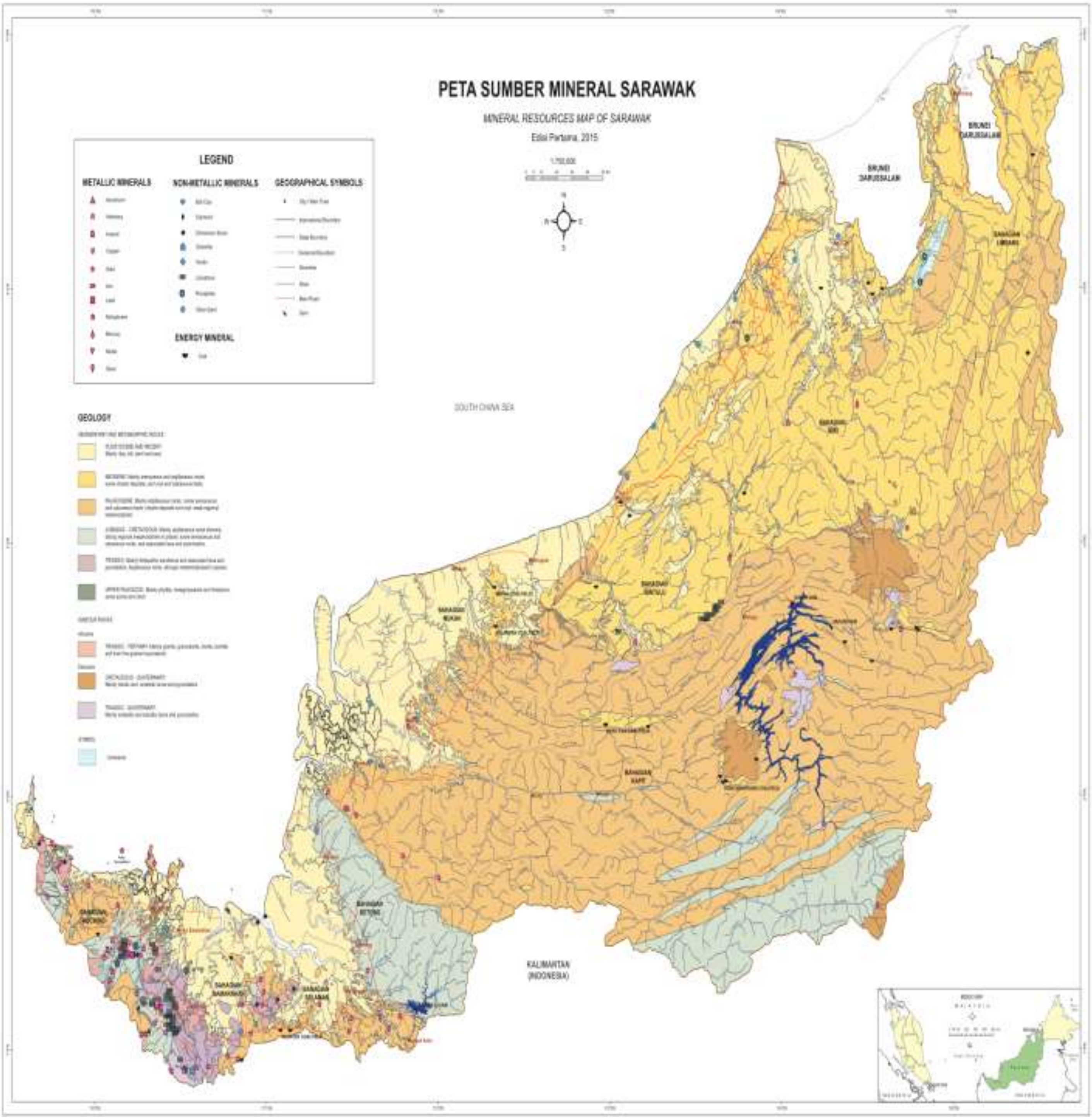

Figure 1. Mineral Resources Map of Sarawak (Jabatan Mineral dan Geosains Malaysia [JMG], 2015). The map provides regional geological and mineral-occurrence context; it should not be interpreted as a map of demonstrated REE deposits.

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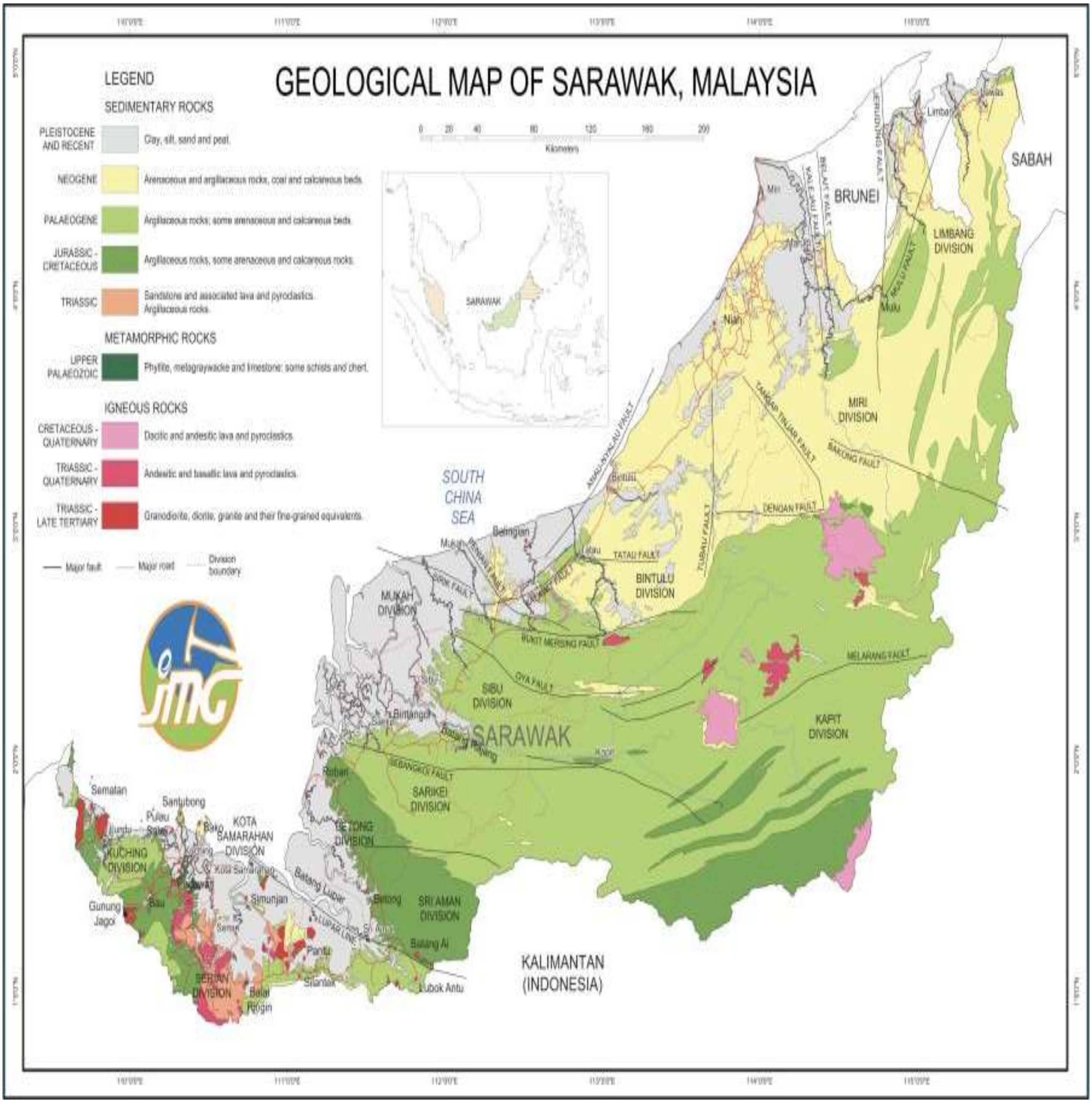

Figure 2. Geological Map of Sarawak, Malaysia (JMG, 2013; reproduced from the JMG MyGEMS Geologi Asas portal). Igneous units are differentiated in the legend as Cretaceous–Quaternary dacitic–andesitic volcanic rocks, Triassic–Quaternary andesitic–basaltic volcanic rocks, and Triassic–Late Tertiary granitoid and related intrusive rocks.

The geological map makes the regional contrast especially clear. Central and northern Sarawak are dominated at this scale by extensive Mesozoic-Cenozoic sedimentary successions, whereas West Sarawak contains a more closely interspersed assemblage of sedimentary, metamorphic, volcanic and intrusive units. The mapped igneous tracts around the Kuching, Bau, Lundu, Serian, Sri Aman and adjacent areas provide multiple parent-lithology targets for REE-oriented regolith screening. They include volcanic rocks comparable to the Serian parent material and granitoid bodies capable of hosting REE-bearing accessory minerals. Nevertheless, map-scale lithological abundance indicates geological opportunity only: each target must be tested for protolith fertility, preservation and thickness of weathering profiles, mineral residence, exchangeable REE fraction and spatial continuity before deposit potential can be assessed.

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Table 1. Evidence status of principal REE settings discussed for Sarawak

Setting	Current evidence	Interpretation and limitation
Riih, Serian Volcanics	Two published laterite profiles; bulk geochemistry, mineralogy and ion-exchange testing (Taniou et al., 2025).	Demonstrated local REE-enriched regolith with ion-adsorption characteristics; continuity, tonnage and economics remain untested.
Other Serian volcanic terrains	Regional mapping and petrogenetic evidence for volcanic rocks; limited public deposit-scale REE data.	High-priority exploration hypothesis requiring replicated profiles and spatial controls.
Jagoi and other West Sarawak granitoids	Mapped granitoids and regional geochronology; no verified resource in the literature reviewed.	Plausible primary source rocks and regolith targets; accessory-mineral residence may reduce exchangeability.
Bau district	Well-documented complex geology and historical gold mineralisation, but sparse REE-specific data.	REE potential is inferential; claims of HREE-rich clay horizons are not substantiated by accessible peer-reviewed datasets.
Alluvial/coastal heavy-mineral systems	General possibility of monazite/xenotime concentration; no Sarawak REE resource demonstrated here.	Requires mineralogical surveys, provenance work and radiological characterisation.

REE deposit types and possible occurrence

Ion-adsorption regolith

Ion-adsorption deposits form when REEs are liberated from primary minerals during prolonged chemical weathering and retained as hydrated ions or surface complexes on clay minerals and other reactive phases. They are typically low-grade, bulk-tonnage deposits developed in weathered crusts. Their economic attraction lies in the proportion that can be displaced by electrolyte solutions, not in total REE alone (Sanematsu & Watanabe, 2016). The term should therefore be applied only after operational extraction tests demonstrate a substantial exchangeable fraction and mineralogical work excludes domination by refractory REE minerals.

Kaolinite is abundant in many profiles but does not alone prove adsorption. Halloysite, illite, smectitic phases, Fe-Mn oxyhydroxides and poorly crystalline materials may contribute; surface area, charge, pH and competing ions affect retention. Anions and organic complexes may mobilise REEs, whereas adsorption and coprecipitation immobilise them. Topography and groundwater flow redistribute dissolved loads, often creating an enriched lower or intermediate horizon rather than a simple surface maximum (Bao & Zhao, 2008; Sanematsu et al., 2013).

Primary hard-rock and residual-mineral occurrences

In primary rocks, REEs may occur in bastnäsite, monazite, xenotime and less commonly REE-bearing carbonates, but also as trace constituents of apatite, allanite, titanite and zircon. A bulk-rock anomaly can therefore reflect either a potentially recoverable phase or refractory accessory minerals. Petrography, automated mineralogy, electron-probe work and laser-ablation analysis are required before processing behaviour can be

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inferred. No carbonatite- or alkaline-intrusion-hosted REE deposit has been demonstrated in the Sarawak literature evaluated for this review.

Placer and heavy-mineral concentrations

Monazite and xenotime can survive erosion and accumulate with zircon, ilmenite and other dense minerals in fluvial or coastal placers. Such occurrences may carry Th and U and therefore require radiometric screening and mass-balance analysis. The draft paper's general discussion of heavy-mineral sands is geologically reasonable, but it should not be read as evidence that an economic Sarawak placer REE resource has been defined.

Geochemical and mineralogical controls during tropical weathering

Weathering initially removes mobile major elements such as Ca, Na, K and Mg and produces residual enrichment of Al, Fe and relatively immobile high-field-strength elements. The chemical index of alteration, CIA = 100 × $Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)$ on a molar basis, is a useful indicator of feldspar alteration, although protolith composition and secondary K addition must be considered. Values close to 100% in the Serian profiles indicate extreme chemical depletion (Taniou et al., 2025).

REE patterns should be interpreted using shale- or chondrite-normalised concentrations, LREE/HREE ratios and Ce and Eu anomalies. Ce may oxidise from Ce(III) to relatively immobile Ce(IV), creating positive residual anomalies or negative anomalies in leached material. Eu anomalies commonly inherit feldspar fractionation or change during feldspar destruction and redox processes. These signatures are process indicators, not direct measures of ore quality. Grain-size effects and detrital zircon or monazite can also produce apparent enrichment, making mineralogical control and duplicate preparation indispensable.

A robust mass-balance approach compares weathered horizons with a representative parent rock using an immobile-element framework. Concentration increases caused only by loss of other components must be separated from absolute REE addition. Sequential extraction can partition water-soluble, exchangeable, oxide-associated, organic/sulfide-associated and residual fractions, but the results are method-defined and sensitive to reagent concentration, pH, solid-to-liquid ratio and extraction time. Reporting those conditions is necessary for comparison across studies.

Current evidence from Serian and elsewhere in Sarawak

Riih, Serian: demonstrated local evidence

Taniou et al. (2025) provide the most complete peer-reviewed Sarawak-specific dataset currently identified. Two laterite profiles developed over basaltic trachyandesite were characterised by bulk geochemistry, mineralogy and ion-exchange analysis. The parent volcanic rock contained about 209 mg kg^{-1} total REE. Intensely weathered horizons reached a reported maximum of 1,715.98 mg kg^{-1}, an approximately eightfold concentration relative to that parent value. The profiles had CIA values of 99–100%, and total REE generally decreased upward. Kaolinite dominated the clay assemblage; discrete REE minerals were not detected in the analysed laterite samples. Selected high-TREE, low-Ce-anomaly material yielded more than 75% extractable REY in the authors 'ion-exchange test.

These observations jointly support a local ion-adsorption-type system. Nevertheless, three qualifications are essential. First, the study concerns two profiles and cannot establish deposit geometry across the Serian district. Second, "not detected" is method- and detection-limit-dependent and does not prove that every REE atom is surface adsorbed. Third, a high laboratory exchangeable fraction does not supply density, thickness, hydrological behaviour, impurity loading, reagent consumption, product recovery, capital cost or environmental performance. The appropriate conclusion is promising occurrence-level evidence, not a resource or reserve.

Serian conference evidence and evolution of the dataset

An earlier GEOSEA abstract reported trachyandesitic to andesitic parent rocks with 322 mg kg^{-1} REE and weathered crust values up to 1,433 mg kg^{-1} (mean 613 mg kg^{-1}), based on LA-ICP-MS and XRF (Taniou et al.,

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2022). Differences from the 2025 article likely reflect sampling and dataset evolution. Where claims overlap, the peer-reviewed 2025 paper should be preferred; the conference abstract is useful for documenting the research trajectory but should not be combined with the later values as though all measurements belong to one homogeneous dataset.

Other Sarawak areas: potential rather than proof

No comparably detailed peer-reviewed evidence was located for Bau, Jagoi–Gading, central Sarawak or the northern divisions. Regional geological maps can guide target selection, and nearby West Kalimantan may offer geological analogues, but cross-border analogues do not establish Sarawak resources. Public claims should be evaluated against accessible coordinates, sampling protocols, laboratory accreditation, quality-control results and resource-classification standards. Until those data are available, statewide tonnage or monetary estimates should not be used as scientific results.

Table 2. Quantitative results and their defensible interpretation for Riih, Serian

Observation	Reported result	What it supports	What it does not establish
Parent lithology	Basaltic trachyandesite; ~209 mg kg^{-1} total REE	REE-bearing volcanic source material.	A mineable primary deposit.
Maximum laterite concentration	1,715.98 mg kg^{-1} total REE	Strong secondary enrichment at sampled points.	Average grade, tonnage or continuity.
Weathering intensity	CIA 99–100%	Extreme chemical weathering.	Unique causation; CIA is not an ore criterion.
Mineralogy	Kaolinite dominant; no discrete REE mineral detected in analysed laterite	Compatibility with adsorbed/poorly crystalline residence.	Universal absence of refractory REE phases.
Ion-exchange test	>75% extracted REY in selected material	Large operationally exchangeable fraction under test conditions.	Field recovery, reagent demand or environmental safety.

Exploration and analytical framework

Exploration should proceed by decision gates so that inexpensive regional evidence is acquired before disruptive testing. A credible programme integrates geology, regolith architecture, hydrogeology, mineralogy, geochemistry, metallurgy and social baselines from the outset.

1. Desktop and regional targeting. Compile modern lithological, structural, topographic, rainfall, land-use and drainage datasets; rank parent rocks by whole-rock REE fertility and weathering preservation.

2. Regolith mapping. Describe saprolite, mottled, ferruginous and soil horizons; record thickness, slope position, drainage and parent-rock contact. Avoid mixing horizons or particle-size fractions.

3. Orientation surveys. Test spacing, sample mass, grain-size preparation and horizon selection across known Serian profiles before regional deployment.

4. Geochemistry and quality assurance. Use accredited digestion and ICP-MS/ICP-OES methods, certified reference materials, blanks, field duplicates and pulp duplicates. Report detection limits, censored values and analytical uncertainty.

5. Mineralogy and residence. Combine XRD with SEM-EDS, automated mineralogy and, where necessary, electron-probe or LA-ICP-MS analysis. Clay separation and surface-area measurements improve interpretation.

6. Operational extraction and metallurgy. Measure exchangeable fractions using a fully specified neutral-salt method, followed by sequential extraction and column tests. Track Al, Fe, Th, U and other impurities, water balance and reagent consumption.

7. Resource definition. Only after continuity is demonstrated should drilling, density measurements, three-dimensional modelling and estimation under an accepted reporting code be attempted. Exploration results must remain distinct from Mineral Resources and Ore Reserves.

Table 3. Minimum analytical package for an ion-adsorption REE programme

Question	**Preferred evidence**	**Critical quality control**
How much REE is present?	Four-acid or fusion digestion with ICP-MS; full REE suite plus Y, Sc, Th and U.	CRMs matched to regolith, blanks, duplicates, detection limits and mass-balance checks.
Where is it in the profile?	Horizon-controlled channels or drilling; density and moisture measurements.	Coordinates, elevations, recovery, interval lengths and documented sample preparation.
What hosts the REE?	XRD clay mineralogy, SEM-EDS/automated mineralogy, selective microanalysis.	Representative subsampling and explicit mineral detection limits.
What fraction is exchangeable?	Standardised neutral-salt extraction and sequential extraction.	Reagent molarity, pH, time, temperature, liquid/solid ratio and replicate tests.
Can it be recovered responsibly?	Column/pilot tests, water balance, impurity and effluent characterisation.	Closed mass balance, kinetic data, hydrogeological monitoring and rehabilitation trials.

Economic and strategic significance

Sarawak's strategic opportunity lies not in geology alone but in whether an environmentally and socially acceptable chain can convert an exchangeable mixed-REE feed into separated products. Revenue depends on the distribution of individual oxides, not total REE. Nd-Pr, Dy and Tb may contribute disproportionate value, while abundant Ce and La can add volume but lower unit value. Payability is further reduced by mining dilution, moisture, recovery losses, impurity removal, separation costs, royalties, rehabilitation and long-term water treatment.

Ion-adsorption deposits may avoid crushing and grinding of hard rock, but low grades require movement or treatment of large volumes of regolith and solution. Economic studies must therefore integrate thickness and continuity, bulk density, exchangeable grade, strip ratio, permeability, solution recovery, reagent recycling, impurity penalties and land-use constraints. A local separation or magnet industry could capture more value than raw-material export, yet it requires scale, reliable feed, intellectual property, energy, chemicals, skills and waste infrastructure. Policy aspirations should not be presented as project economics.

For Sarawak, the near-term strategic value of the Serian work is that it validates a new exploration model: intensely weathered intermediate volcanic rocks can generate exchangeable REY enrichment, broadening

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attention beyond the granitic parent rocks commonly discussed in Malaysian ion-adsorption literature. The responsible next step is comparative science across parent lithologies, not premature production forecasts.

Environmental, social and regulatory considerations

Ion-adsorption mining is sometimes described as inherently benign because physical comminution may be limited and REEs can be exchanged by salt solutions. That description is incomplete. Historical heap and in-situ leaching in southern China has been associated with vegetation loss, erosion, slope instability, ammonia-nitrogen contamination, acidic drainage, sediment transport and incomplete recovery of leach solutions. Ammonium sulfate can mobilise REEs efficiently but may introduce nitrogen pollution and co-leach aluminium; magnesium or other reagents shift rather than eliminate environmental burdens (Liu et al., 2019; Moldoveanu & Papangelakis, 2012).

Sarawak's high rainfall, dense river network, deeply weathered slopes and biodiversity increase the consequences of poor hydraulic control. Baseline work should cover seasonal surface water and groundwater, permeability and preferential flow, acid-base behaviour, suspended sediment, aquatic ecology, soil fertility and downstream water use. Trials require lined or demonstrably contained systems, solution inventories, leak detection, storm capacity, progressive rehabilitation and post-closure monitoring. Removing exchangeable base cations and adding salts may alter soil chemistry even where REE recovery is high.

Radiological risk depends on mineralogy. Ion-adsorbed REEs can be relatively low in Th and U, whereas monazite-bearing concentrates may trigger additional controls. Total and leachable Th/U, gamma surveys and mineral-specific characterisation should therefore precede any "non-radioactive" designation. Malaysia's framework involves federal environmental legislation, mineral and land powers exercised by states, technical oversight by JMG and radiation controls administered by the national atomic-energy regulator. The national NR-REE mining SOP provides a policy baseline, but project approval still requires site-specific legal review, environmental assessment and alignment with Sarawak's land, forestry, water and community requirements (NRES, 2025). Regulation should be described as necessary governance—not proof that impacts will be controlled automatically.

Meaningful engagement with Indigenous peoples and local communities must begin during target selection, before project designs harden. Land tenure, customary use, drinking-water sources, cultural sites, livelihoods and distribution of benefits need transparent documentation. Public disclosure of baseline data, monitoring results, incidents and closure liabilities is central to social legitimacy.

Research gaps and future directions

- Spatial representativeness: expand beyond two Riih profiles using stratified transects across lithology, landform and drainage position.
- Parent-rock controls: compare volcanic, granitoid and mixed colluvial profiles with immobile-element mass balance and accessory-mineral studies.
- Exchangeability standards: establish an interlaboratory Malaysian protocol and report both total and operationally exchangeable grades.
- HREE distribution: publish element-by-element grades and recoveries, not only TREE/TREY, to test claims of strategic HREE enrichment.
- Hydrometallurgy: perform kinetic column tests, reagent-recycle studies, impurity deportment and residue characterisation under realistic rainfall and permeability conditions.
- Hydrogeology and ecology: develop multi-season baselines before any injection or leaching trial and quantify catchment-scale cumulative impacts.

- Resource governance: release non-confidential sampling metadata and distinguish exploration targets, exploration results, resources and reserves using recognised terminology.
- Regional comparison: test geological analogues in West Kalimantan and Peninsular Malaysia without transferring grades or economic conclusions across jurisdictions.
- Value-chain analysis: model separated-oxide and magnet pathways using realistic feed volumes, energy, chemical and waste requirements.
- Community-centred research: co-design monitoring, benefit-sharing and closure criteria with affected communities and independent experts.

CONCLUSION

Sarawak possesses credible geological prospectivity for regolith-hosted REEs, but the demonstrated evidence is presently concentrated at Riih in Serian. The 2025 Serian study documents intense lateritisation of basaltic trachyandesite, local enrichment from approximately 209 to as much as 1,715.98 mg kg^{-1} total REE, kaolinite-rich material and a high ion-exchangeable REY fraction in selected samples. These results justify systematic follow-up and demonstrate that volcanic parent rocks can form ion-adsorption-style occurrences in West Sarawak.

They do not yet justify statewide resource claims, mineability, reserve terminology or assumptions of low environmental impact. Bau, granitoid terrains and placer systems remain valid exploration concepts, but their status must be explicitly described as potential until supported by reproducible deposit-scale data. The key scientific task is to connect total and exchangeable grade with three-dimensional continuity, mineral residence, hydrometallurgical performance and environmental behaviour. If Sarawak adopts transparent evidence standards, staged exploration and precautionary water and land governance, its REE research can contribute meaningfully to Malaysia's critical-minerals strategy without allowing strategic enthusiasm to outrun geological proof.

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