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**Geochemical Insights into Rare Earth Elements Distribution  
patterns in Granites of Nasarawa State, North-Central Nigeria**



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## Geochemical Insights into Rare Earth Elements Distribution patterns in Granites of Nasarawa State, North-Central Nigeria

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### Abstract

**Purpose:** To investigate the distribution of rare earth elements (REEs) in granites from selected locations within Nasarawa State, North-Central Nigeria, in order to evaluate their geochemical characteristics and assess their mineralization potential.

**Methodology:** Fourteen (14) granite samples were systematically collected and analyzed using Instrumental Neutron Activation Analysis (INAA) at the Centre for Energy Research and Training, Ahmadu Bello University, Zaria, Nigeria. Trace element concentrations and REE patterns were examined, and geochemical discrimination diagrams were employed to determine tectonic settings and source characteristics.

**Findings:** The trace element data show elevated concentrations of U (6.79 ppm), Co (64.81 ppm), Rb (266.89 ppm), Sb (2.04 ppm), Cs (43.83 ppm), and Ta (219.90 ppm) relative to Upper Continental Crust values, indicating moderate to extreme enrichment. REE patterns are dominated by light rare earth elements (LREE; average 58.44 ppm) over heavy rare earth elements (HREE; average 18.22 ppm). Geochemical discrimination diagrams indicate that the granites were emplaced in multiple tectonic settings, including syn-collisional, volcanic arc, and within-plate environments, and were primarily derived from the upper continental crust. Comparative analysis shows general depletion of most REEs, except for dysprosium (Dy), which exhibits elevated concentrations, suggesting potential Dy mineralization.

**Unique Contribution to Theory, Practice and Policy:** This study provides baseline geochemical data for REE distribution in granites of Nasarawa State and contributes to the understanding of crustal evolution and tectonic settings in the region. It highlights the potential for dysprosium mineralization, offering practical insights for targeted REE exploration and resource development. The findings can inform mineral exploration strategies, guide investment decisions, and support policy formulation aimed at sustainable exploitation of REE resources in Nigeria.

**Keywords:** REEs; Granites; Geochemistry; Dysprosium; Mineralization; Nasarawa; INAA; Tectonics

## 1.0 INTRODUCTION

In Africa and particularly in Nigeria, exploration for rare earth elements (REEs) remains limited despite the presence of geologically favourable granitoid terrains (Oyawoye, 1972; Dada, 2008; Kinnaird, 1985). Granitic rocks are well known to host trace and rare earth elements, and their geochemical characteristics provide important insights into tectonomagmatic processes, mineralization potential, and resource exploration strategies (Ibe and Obiora, 2019). Previous studies on Nigerian granitoids have reported variable REE concentrations, including localized enrichment of specific elements such as dysprosium (Dy), although comprehensive geochemical datasets remain sparse, particularly for North-Central Nigeria (Drobniak and Mastalerz, 2022).

Economically, REE mineralization occurs mainly in two categories: light rare earth elements (LREE) and heavy rare earth elements (HREE) deposits. Most LREE are typically associated with carbonatite deposits, whereas HREE are predominantly derived from ion-adsorption clay deposits, especially those of southern China. Although these deposits are relatively low in REE concentration, they are economically viable due to the ease of extraction. Other significant HREE sources include alkaline rock-hosted deposits where HREE and yttrium (Y) occur as primary or co-products. Generally, HREE deposits tend to be of lower grade compared to LREE deposits, although their higher unit value makes them economically attractive (Okunlola et al., 2022; Dostal, 2017).

In Nigeria, regional geochemical surveys conducted by the British Geological Survey in collaboration with the Nigerian Geological Survey Agency have identified anomalous concentrations of REEs in stream sediments, particularly within Southwestern Nigeria. These findings led to further investigations in areas such as Ikomu (Sheet 220), where granitoids were studied for REE occurrences, abundances, and mineralization prospects (Orris and Grauch, 2002). Additional studies have demonstrated that felsic rocks of the Precambrian Basement Complex in Southwestern Nigeria exhibit evidence of crustal assimilation, contributing significantly to LREE enrichment (Ukaegbu and Beka, 2008; Omotunde et al., 2020; Okunlola et al., 2022).

Crustal abundances of elements are largely controlled by felsic rocks that dominate the upper continental crust, making granitic systems important targets for REE exploration. The geochemistry of granites varies widely depending on their origin, and granitoids typically reflect the characteristics of their source materials, forming the basis for their classification (White and Chappell, 1983; Frost et al., 2001).

Despite these advances, there is a paucity of detailed geochemical data on REE distributions in granitoids from Nasarawa State, North-Central Nigeria. This study therefore aims to investigate the geochemical characteristics and rare earth element (REE) abundances in granitoids from selected locations in the study area using Instrumental Neutron Activation Analysis (INAA), with a view to evaluating their mineralization potential and petrogenetic implications.

## 1.1 GEOLOGY OF THE STUDY AREA

The geology of the study area is a miniature of the general geology of Nigeria which comprises of the Basement Complex, the Younger Granites, and the Sedimentary Basins. Thus, the study area is underlain by the Basement Complex of Nigeria covering about 60% total area of the State while the remaining 40% is made up of Sedimentary rocks of the Middle Benue Trough. The Younger Granites intrudes the Basement Complex at Mada and Afu and therefore do not occupy any separate landmass of their own. Considering the Basement Complex, Migmaite-Gneisses alongside the Older Granites account for about 70% while rocks of schistose lithology and other metasedimentary series (quartzite, marble, ironstone) in the areas around Laminga, Nasarawa and Gadabuke make up the remaining 30% (Obaje *et al.*, 2006). This study was focused on the areas underlain by granitoids within the basement complex of the area (Figure 1).

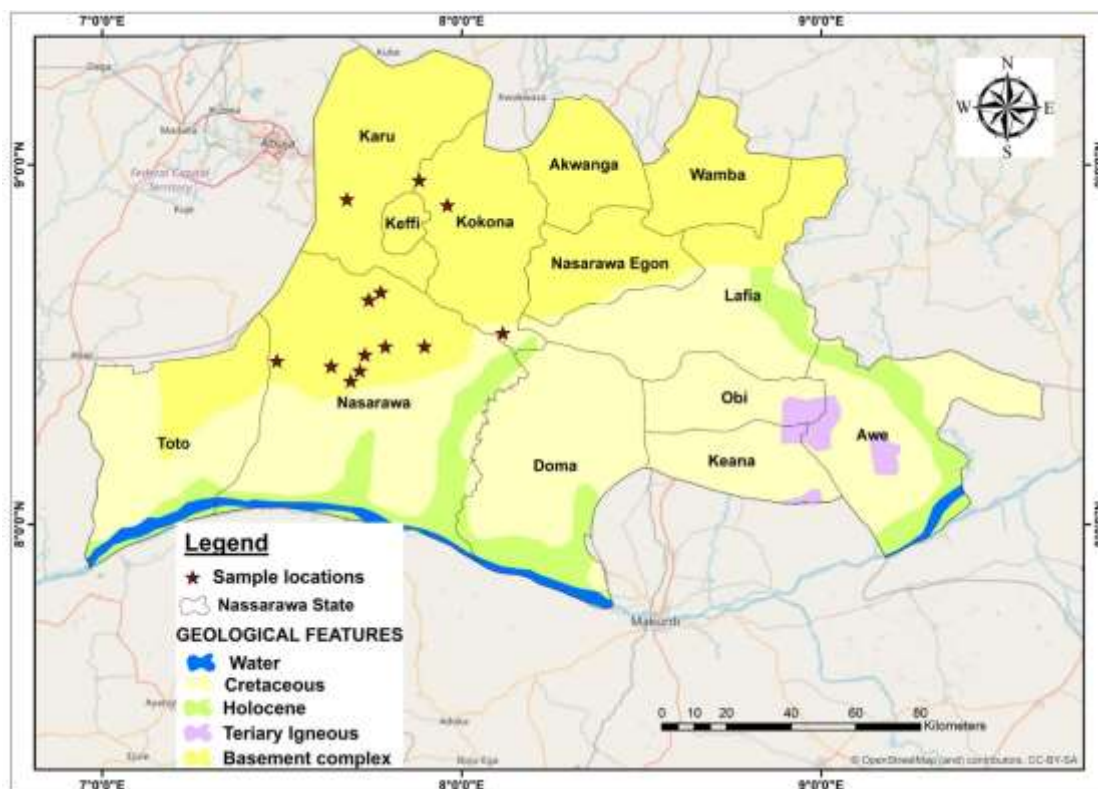
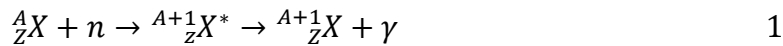


Figure 1: Geological map of Nasarawa State showing where granite samples were collected

## 1.2 Theoretical Framework

Neutron Activation Analysis (NAA) is a highly sensitive nuclear analytical technique used for the qualitative and quantitative determination of trace and rare earth elements in geological materials. The method is based on the principle that when stable nuclei of elements are irradiated with neutrons in a nuclear reactor, they capture neutrons and are transformed into radioactive isotopes. These newly formed radioisotopes subsequently decay and emit gamma rays with characteristic energies that are unique to each element (Ehmann & Vance, 1991; Glascock, 1992).

The fundamental nuclear reaction involved in NAA can be expressed as:



where  ${}^A_ZX$  represents the target nucleus,  $n$  is the neutron,  ${}^{A+1}_ZX^*$  is the excited compound nucleus formed after neutron capture, and  $\gamma$  represents the gamma radiation emitted during de-excitation. The emitted gamma rays possess characteristic energies that serve as fingerprints for identifying specific elements present in the sample (De Soete, Gijbels, & Hoste, 1972).

When geological samples are exposed to neutron flux within a nuclear reactor, neutron capture reactions occur in the constituent elements of the sample. The resulting radioactive isotopes decay according to their characteristic half-lives and emit gamma radiation. These gamma rays are detected and measured using high-resolution gamma-ray spectrometry, typically with a high-purity germanium (HPGe) detector. The intensity of the gamma radiation emitted is directly proportional to the concentration of the element in the sample (Ehmann & Vance, 1991).

The induced activity of a radionuclide formed during irradiation can be expressed using the activation equation:

$$A = N\sigma\phi(1 - e^{-\lambda t_d})e^{-\lambda t_c} \quad 2$$

where  $A$  represents the induced radioactivity of the radionuclide,  $N$  is the number of target atoms present in the sample,  $\sigma$  is the neutron capture cross-section,  $\phi$  is the neutron flux,  $\lambda$  is the decay constant of the radionuclide,  $t_i$  is the irradiation time, and  $t_d$  is the decay time before counting.

Because each element emits gamma rays with distinct energies, NAA allows simultaneous determination of multiple elements without chemical separation. This makes the technique particularly suitable for the analysis of trace elements and rare earth elements in geological samples at parts-per-million (ppm) or parts-per-billion (ppb) concentrations (Glascock, 1992).

Instrumental Neutron Activation Analysis (INAA), a variant of NAA used in this study, eliminates the need for post-irradiation chemical separation. Instead, irradiated samples are directly analyzed using gamma-ray spectrometry. This reduces contamination risks and enhances analytical precision. INAA has therefore become widely used in geochemical studies for determining rare earth element distributions and trace element signatures in igneous rocks such as granites (De Soete et al., 1972; Ehmann & Vance, 1991).

In geological investigations, NAA has proven particularly effective for characterizing geochemical signatures, identifying elemental enrichment patterns, and evaluating mineralization potential in granitoid rocks and other igneous formations.

## 2.0 METHODOLOGY

The established geology of the study area was adopted in this study which guided the location of targeted samples (granitoid). Compass traverse through the area existing roads, footpaths and bush clearing made the movement in the field easy, while global positioning system (GPS) help to determine the geo-location the exposed outcrops.

Each outcrops located was observed and described, the observed features were properly recorded on the field notebook. Fourteen (14) representative granite samples collected were crushed, pulverized and analysed for their trace and rare earth elements at the Nuclear Science and Technology Section Centre for Energy Research and Training, Ahmadu Bello University, Zaria, Nigeria. The method of analysis adopted was Instrumental Neutron Activation Analysis (INAA).

### 3.0 RESULTS AND DISCUSSIONS

#### 3.1 Geochemistry and Tectonic Setting of the Granitoid

The granitoid mapped in the area are mainly granites. The trace elements geochemistry of the granites are presented in Table 1, with U, Co, Rb, Sb, Cs, Ta showing elevated concentrations. U ranged from 0.0 - 15.5 ppm (avg. 6.79ppm), with highest concentration recorded in sample NAS 5 (15.5 ppm). Co ranged from 40 - 89.20 ppm (avg. 64.81 ppm), with sample NAS 14 accounting for the highest concentration (89.20 ppm). Rb ranged from 37.10 – 980 ppm (avg. 266.89 ppm), recorded the highest value of 980 ppm in sample NAS 3. Sb ranged from 0.0 – 13.40 ppm (avg. 2.04 ppm) with highest concentration recorded in sample NAS 3 (13.40 ppm). In the case of Cs, it ranged from 1.96 – 230 ppm (avg. 43.83 ppm) while Ta ranged from 0.84 – 2551 ppm (avg. 219.90 ppm) with both recorded their highest values in sample NAS 3 respectively.

Trace elements such as U, Co, Rb and Sb all revealed moderate enrichments while Cs and Ta showed significant and extreme enrichments respectively when compared with the Upper Continental Crustal values (2.70, 17.30, 84.00, 0.40, 4.90, and 0.90 ppm respectively) by Rudnick and Gao (2003).

The geotectonic discrimination plots using trace elements after Pearce *et al.* (1984) revealed that the granites from the study area plotted around the boundaries of Syn-collision granite (Syn-COLG) – Volcanic arc granite (VAG) – within plate granite setting (Figure 2a and 2b). This is an indication that different processes may have influenced their emplacement as widely known that Nigerian Basement complex is Polycyclic in nature.

The rare earth elements (REEs) concentration in the granites is presented in Tables 1 and 2. The sum of the LREE, HREE, total REE and fractionation ratio revealed  $\Sigma$ LREE ranged from 2.98 – 152.7; avg. 58.44 ppm,  $\Sigma$ HREE ranged 0.0 – 80.67; avg. 18.12 ppm, while  $\Sigma$ REE ranged from 2.98 – 233.37; avg. 76.55 ppm. This implies fractional crystallization with the crystallizing magma sourced from the upper continental crust (Omotunde *et al.*, 2020). Variation plots of La and Yb relative to La/Yb ratio in the granites (Figure 3a and 3b) also indicated enrichment of LREE and depletion of HREE.

Similarly, normalized REE plot using chondrite values (Boynnton, 1984) (Figure 3c) though, not clear enough due to no reportage of some of the REE components in the sample but revealed continental sourced materials (Wedepohl, 1995). The slight enrichment in the Dy (Middle REE) may indicate the presence of ferromagnesian minerals rich granites.

Table 1: Geochemical Composition of Granitoids in the Study Area (Trace and Rare Earth Elements in ppm)

Elements (ppm)	NAS 1	NAS 2	NAS 3	NAS 4	NAS 5	NAS 6	NAS 7	NAS 8	NAS 9	NAS 10	NAS 11	NAS 12	NAS 13	NAS 14	Average
V	0.00	123.0	0.00	32.9	0.00	0.00	0.00	17.6	87.2	31.6	111.0	0.00	0.00	11.3	29.61
U	7.68	0.00	14.0	2.05	15.5	10.4	13.8	2.53	6.16	3.97	3.75	9.86	1.97	3.43	6.79
Sc	0.00	22.0	0.00	10.3	0.00	0.76	0.00	13.9	12.1	7.66	2.97	0.56	1.00	14.4	6.12
Co	86.10	52.0	62.6	44.6	57.1	75.3	56.1	42.0	71.8	57.3	58.1	54.2	101	89.2	64.81
Zn	66.00	240.0	0.00	104.0	58.7	66.2	64.8	118.0	110.0	79.7	78.0	160.0	47.3	96.9	92.11
Rb	435.0	120.0	980.0	159.0	534	501	40.9	108.0	254.0	99.5	115.0	259.0	37.1	93.9	266.89
Sb	5.31	0.00	13.4	0.00	0.00	8.03	0.00	0.00	1.84	0.00	0.00	0.00	0.00	0.00	2.04
Cs	129.0	7.98	230.0	3.32	44	112.0	13.2	2.14	54.7	4.58	2.85	2.12	1.96	5.74	43.83
Ba	0.00	1836	0.00	397	0.00	0.00	0.00	2313	521.0	409	1131	161.0	1343	498.0	614.93
Hf	1.62	8.77	3.35	7.23	2.45	7.38	1.88	19.7	9.49	4.30	5.54	11.4	0.94	6.52	6.47
Ta	169.0	2.88	2551	0.84	58.2	53.7	224	2.01	2.74	1.57	1.48	7.36	1.56	2.23	219.90
Th	28.90	10.6	0.00	29.3	1.62	8.4	50.3	6.04	20.3	25.9	10.8	33.3	25.1	14.7	18.95
La	4.96	37.1	3.04	42.5	1.62	2.99	1.63	33.0	36.2	44.5	36.7	58.4	5.66	51.2	25.68
Nd	0.00	43.3	0.00	25.2	0.00	0.00	0.00	36.5	53.0	45.7	39.1	76.2	0.00	43.6	25.90
Sm	0.84	8.49	1.69	9.81	1.64	0.79	1.35	2.34	7.61	10.2	6.44	17.6	1.39	7.95	5.58
Eu	0.00	2.53	3.65	0.94	0.37	0.33	0.00	3.95	1.09	0.80	1.70	0.50	0.57	1.55	1.28
Tb	0.00	1.81	0.00	2.03	0.00	0.00	0.00	0.74	0.62	1.12	0.00	1.96	0.00	0.59	0.63
Dy	0.00	17.1	0.00	34.8	0.00	0.00	0.00	22.8	15.3	27.3	2.93	65.2	3.52	19.2	14.87
Yb	0.00	2.48	0.00	3.47	0.00	0.00	0.00	3.26	3.00	3.44	0.00	11.3	0.63	3.41	2.21
Lu	0.00	0.23	0.00	0.72	0.00	0.00	0.00	0.59	0.67	0.60	0.00	2.21	0.00	0.58	0.40
ΣREE	5.80	113.04	8.38	119.70	3.63	4.11	2.98	103.18	117.49	133.66	86.87	233.37	11.77	128.08	76.56
ΣLREE	5.80	91.42	8.38	78.45	3.63	4.11	2.98	75.79	97.90	101.20	83.94	152.70	7.62	104.30	58.44
ΣHREE	0.00	21.62	0.00	41.02	0.00	0.00	0.00	27.39	19.59	32.46	2.93	80.67	4.15	23.78	18.12
LREE/HREE	0.00	4.23	0.00	1.91	0.00	0.00	0.00	2.77	5.00	3.12	28.65	1.89	1.84	4.39	3.84
La/Yb	0.00	14.96	0.00	12.25	0.00	0.00	0.00	10.12	12.07	12.94	0.00	5.17	8.98	15.01	-

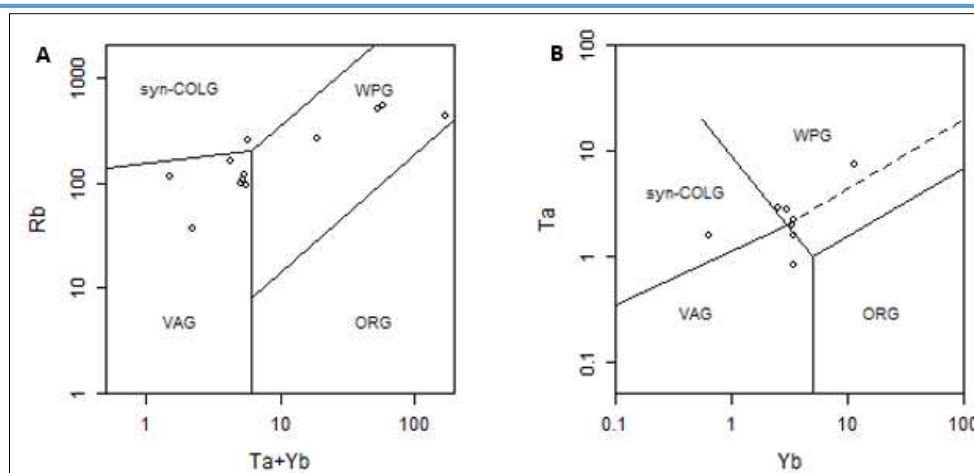


Figure 2: Geotectonic discriminate plots (A) Ta+Yb versus Rb (B) Yb versus Ta (after Pearce *et al.*, 1984)

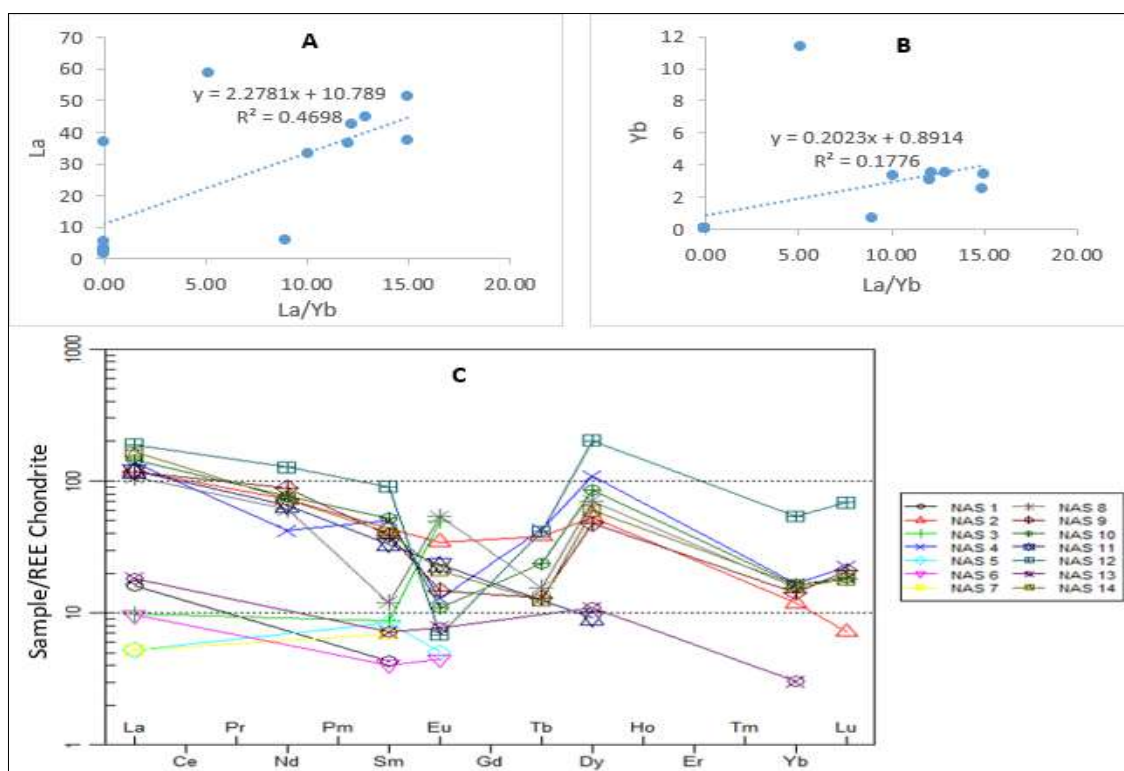


Figure 3: (A) Variation plot of La relative to La/Yb ratio (B) Variation plot of Yb relative to La/Yb ratio (C) Spider plot normalised by REE Chondrite for the granitoids in the study area (after Boynton, 1984)

### 3.2 REE Mineralization Potential

The concentration of the REEs within the granites from the study area were compared with those from areas of already proven or suspected mineralization in order to assess their mineralization potential (Table 2). In the study area, REEs were observed to be far lower in concentration when compared with those from granites of Komu area (Ajilore, 2018), granites of Dingnan, Southern China (Ishihara *et al.*, 2008), Pan-African granites from Obudu Plateau

(Ukaegbu and Beka, 2008) and Masamba granitic rocks in the Sulawesi, Indonesia (Maulana *et al.*, 2012). However, Dysprosium (Dy) was observed to have an increased concentration (avg. 14.87 ppm) compared with others listed earlier, indicating its possible enrichment or mineralization in granites of the study area. Dysprosium (Dy) is the element number 66 in the periodic table of chemical elements. It belongs to the lanthanides, and a middle rare earth element that has a bright and silvery lustre. Dysprosium's main use is in alloys for neodymium-based magnets. This is because it is resistant to demagnetisation at high temperatures. This property is important for magnets used in motors or generators. These magnets are used in hard drives, wind turbines and electrical vehicles, so demand for dysprosium is growing rapidly (<https://study.com>, 2025).

Table 2: Comparison of the REE Concentrations in the Study Area with other Granitoid

Elements	1		2		3		4		5		6	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
La	1.62-58.40	25.68	0.98-81.9	45.6	33.4-101	63.08	588-663		40-285		7.6-75.1	
Ce	N/A	N/A	2.90-132.0	80.65	73.2-196	128.24	1229-1797		71.2-595		16.6-157	
Pr	N/A	N/A	0.3-13.4	9.05	8.11-20	13.7	92-118		8.67-64.5		2.11-17.2	
Nd	0.0-76.20	25.9	1.3-50.5	32.7	30.4-71.3	50.6	427-752		30.6-204		8.9-53	
Sm	0.78-17.60	5.58	0.4-10.8	6.43	6.49-13.6	10.47	75-169		5.59-33.1		2.3-7.18	
Eu	0.0-3.95	1.28	0.08-1.94	1.23	0.22-1.65	0.59	5.0-9.0		0.087-3.2		0.10-0.92	
Gd	N/A	N/A	0.2-12.5	5.27	5.71-15	10.08	57-131		4.0-20.7		2.41-5.98	
Tb	0.0-2.03	0.63	<0.1-2.6	1.03	0.89-2.62	1.71	N/A		0.47-5.21		0.50-0.86	
Dy	0.0-65.20	14.87	0.4-17.5	5.49	4.48-15.2	9.54	40-62		1.9-35.1		2.23-5.88	
Ho	N/A	N/A	<0.1-3.5	1.23	0.76-2.95	1.8	8.0-10.0		0.25-6.88		0.39-1.31	
Er	N/A	N/A	0.2-3.5	3.09	1.49-7.98	4.95	23-26		0.62-22.8		1.22-4.21	
Tm	N/A	N/A	<0.05-1.45	0.53	0.28-1.19	0.76	N/A		0.09-4.33		N/A	
Yb	0.0-11.30	2.21	0.3-9.6	3.2	1.72-7.45	4.7	15-17		0.58-28.6		N/A	
Lu	0.0-2.21	0.4	<0.01-1.39	0.59	0.24-1.05	0.66	0-2		0.09-4.12		0.03-0.21	
ΣLREE	2.98-152.70	58.44	6.0-282.0	176	154-402	267	N/A		N/A		38-310	
ΣHREE	0.0-80.67	18.12	1.0-58.0	19.92	16-53	34	N/A		N/A		9.0-17.0	
ΣREE	2.98-233.37	76.55	7.0-291.0	196	168-358	301	N/A		N/A		47-320	

1: Granites of the present research; 2: Granites of Komu area (Ajilore, 2018); 3: Granites of Dingnan, Sothern China (Ishihara *et al.*, 2008); 4: Precambrian alkali granite, Arabian Shield (Drysdall *et al.*, 1984); 5: Pan-African granites from Obudu Plateau (Ukaegbu and Beka, 2008); 6: Masamba granitic rocks in South Sulawesi, Indonesia (Maulana *et al.*, 2012)

#### 4. CONCLUSION

Granitic rocks from the study area in North-Central Nigeria were investigated based on the geological framework of Obaje *et al.* (2006), which guided systematic sampling. Trace element geochemistry indicates moderate enrichment of U, Co, Rb, and Sb, significant enrichment of Cs, and extreme enrichment of Ta relative to standard values, confirming the area's association with Li–Cs–Ta mineralization.

REE geochemistry reveals enrichment of light rare earth elements (LREE) over heavy rare earth elements (HREE), while tectonic discrimination plots indicate emplacement across syn-

collisional, volcanic arc, and within-plate settings, reflecting complex, multi-stage magmatic processes. Comparative analysis shows general depletion of REEs, except for dysprosium (Dy), which exhibits localized enrichment and suggests potential for targeted mineralization.

These findings provide a practical basis for focused exploration of Dy and associated rare metals in Nasarawa State. They also underscore the need for strategic policy support for REE development in Nigeria. The observed LREE dominance and selective Dy enrichment further contribute to existing models of REE fractionation and enhance understanding of REE distribution in Pan-African granitic systems, particularly in relation to their growing importance in clean energy technologies.

### Recommendations

1. Advanced analytical techniques such as ICP-MS and electron microprobe are recommended to better characterize REE-bearing minerals and their host phases.
2. Further isotopic studies (e.g., Sm–Nd, Rb–Sr) are necessary to constrain the origin and evolution of the granites. In addition, targeted exploration for Li–Cs–Ta mineralization, particularly lithium-bearing pegmatites, should be intensified.
3. Preliminary resource estimation and economic feasibility studies are required to evaluate the viability of Dy and associated critical elements, while environmental impact assessments should be conducted to ensure sustainable exploration and development.

### Funding Sources

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