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Lithium, Rare-Metal and Gemstone Potential of the Pegmatites in Arikpa, North-Central Nigeria

Nasir Hassan Bello and Ishak Yau Tanko
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Abstract: Lithium-Caesium-Tantalum (LCT) pegmatites of the Nigerian Basement Complex are increasingly targeted for their rare-metal potential, yet the geochemical and petrogenetic characteristics of many occurrences, including the Arikpa pegmatites of Nasarawa State, remain undocumented. This study presents major-oxide, trace-element, and rare-earth-element (REE) geochemistry of pegmatites and associated host rocks from Arikpa, North-Central Nigeria, obtained by X-ray fluorescence (XRF) analysis of eleven pegmatite samples and nine host-rock samples, integrated with petrogenetic and tectonic discrimination diagrams. SiO_2 contents range from 51–74 wt%, with systematic negative correlations of MgO, Fe_2O_3, CaO, TiO_2, and P_2O_5 against SiO_2, indicating progressive fractional crystallisation. A/NK–A/CNK and A/CNK–SiO_2 plots classify the pegmatites as predominantly metaluminous to peraluminous I-type granitic melts, while R_1–R_2 tectonic discrimination places the suite within late- to post-orogenic fields consistent with emplacement during the waning stages of the Pan-African orogeny. Trace-element data show strong enrichment of large-ion lithophile elements (K, Rb, Ba) with pronounced negative Nb-Ta-Ti anomalies, and K/Rb–Rb and Zn/Sn–K/Rb relationships indicate a genetically related pegmatite suite showing progressive Sn enrichment with increasing fractionation. Li_2O concentrations range from 0.18–0.50 wt%, averaging below 1 wt%, indicating that the Arikpa pegmatites are only moderately fractionated with respect to lithium and are not currently prospective as a standalone lithium resource, although they show moderate potential for Sn-Li-Rb multi-metal mineralization. Comparison with the Wamba, Nasarawa, Keffi, and Janjala pegmatite fields places Arikpa within the regional LCT pegmatite province of Central Nigeria.

***Keywords**: Pegmatite, Geochemistry, Petrogenesis, Lithium, Arikpa, North-Central Nigeria.*

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1.0 Introduction

Lithium-bearing pegmatites have become increasingly important exploration targets because of the growing demand for lithium in rechargeable batteries, electric vehicles, renewable-energy storage systems, and other advanced technologies. This growing demand has intensified exploration for hard-rock lithium resources, particularly in granitic pegmatite provinces where lithium may occur together with other economically important rare metals and gemstone mineralsIn Nigeria, increasing exploration activity has highlighted the potential of pegmatite-hosted lithium and associated rare-metal mineralization within the Precambrian Basement Complex, particularly in North-Central Nigeria, where numerous pegmatite fields are spatially and genetically associated with Pan-African granitoids. (Nex et al., 2020; Olade, 2024). Geological and

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geochemical investigations indicate that many of the rare-element pegmatites of Nigeria belong to, or show strong affinities with, the lithium-caesium-tantalum (LCT) family, which is internationally recognised for its association with lithium, caesium, tantalum, tin, niobium, beryllium and other rare-metal mineralization.(Olade, 2024). However, despite increasing exploration interest in Nigerian pegmatites, the geochemical characteristics, degree of magmatic fractionation, petrogenetic evolution, and rare-metal and gemstone potential of several occurrences remain poorly constrained. In particular, systematic geochemical information on the Arikpa pegmatites and their associated host rocks is limited, making it difficult to determine their relationship to the established LCT pegmatite province of North-Central Nigeria and to evaluate their potential for lithium, tin, tantalum, niobium, and gemstone mineralization. Importantly, LCT affinity alone does not establish economic lithium potential, as the abundance, mineralogical form, degree of magmatic fractionation, distribution of lithium-bearing minerals, and associated rare-metal enrichment vary considerably among pegmatite systems. Consequently, detailed geochemical evaluation is required to distinguish weakly fractionated pegmatites from highly evolved systems capable of hosting economically significant lithium and other rare-metal mineralization.

The pegmatites of North-Central Nigeria occur within a region characterised by widespread Pan-African granitoids and associated rare-element mineralization. Well-documented pegmatite fields around Wamba, Nasarawa, Keffi and Janjala demonstrate that the region hosts geochemically evolved pegmatitic systems with variable enrichment in Li, Rb, Cs, Sn, Nb and Ta. Comparison of the Arikpa occurrence with these established fields is therefore important for determining whether its geochemical characteristics reflect a similarly evolved LCT system or a less fractionated pegmatite suite.

The aim of this study is to characterise the geochemical composition and petrogenetic evolution of the Arikpa pegmatites and their associated host rocks and to evaluate their lithium and associated rare-metal potential. Specifically, the study investigates the major-oxide, trace-element and REE characteristics of the pegmatites; assesses their degree of magmatic fractionation; determines their geochemical classification and tectonic setting; and compares their characteristics with those of established pegmatite fields in North-Central Nigeria.The significance of this study lies in providing baseline geochemical information for a relatively poorly documented pegmatite occurrence in North-Central Nigeria. The results will contribute to understanding the evolution of Nigerian LCT pegmatite systems and provide a geochemical basis for evaluating the prospectivity of the Arikpa pegmatites for lithium and associated rare metals, including Sn, Nb and Ta, as well as potentially associated gemstone minerals. The study also provides comparative information that may assist future mineral exploration and resource evaluation within the regional pegmatite province.

2.0 Literature Review

2.1 Geochemical Framework of LCT Pegmatites

Granitic pegmatites are generally regarded as highly evolved, late- to post-magmatic products of felsic magmatism that crystallise from volatile-rich residual melts enriched in incompatible elements. Their formation may involve extensive fractional crystallisation, fluid–melt interaction, and the concentration of elements such as Li, Rb, Cs, Be, Sn, Nb and Ta in the residual melt. (London, 2008). Geochemical discrimination parameters such as Rb/Sr, K/Rb, Zn/Sn, and abundances of Ti, Sn, Nb, and Ta are widely used to assess the degree of fractionation in granitic pegmatite systems; decreasing K/Rb ratios and increasing Rb concentrations indicate progressive melt differentiation and enrichment of incompatible elements in residual melts (Černý, 1991; London, 2005), a trend characteristic of rare-element pegmatite systems.

In addition to rare metals, evolved pegmatites may host economically valuable gemstones and ornamental minerals, including beryl, tourmaline, garnet, quartz, feldspar, topaz, spodumene, petalite and lepidolite. The occurrence and quality of such minerals depend on the mineralogical and geochemical evolution of individual pegmatite bodies. Consequently, assessment of pegmatite potential should consider not only lithium and rare-metal enrichment but also the possible occurrence of gemstone-bearing zones.

2.2 Lithium and Rare-Metal Pegmatites of North-Central Nigeria

Nigeria hosts numerous pegmatite occurrences associated with the Pan-African Basement Complex, particularly within the North-Central region. These pegmatites display considerable variation in mineralogy and geochemical evolution, ranging from relatively simple quartz–feldspar–mica bodies to highly evolved rare-element pegmatites enriched in Li, Rb, Cs, Sn, Nb and Ta. Such variation reflects differences in the degree of fractional crystallisation and the physicochemical conditions of pegmatite formation.

Lithium mineralization in Nigerian pegmatites occurs primarily as spodumene, lepidolite, and petalite, with reported Li_2O contents reaching up to 2.5% in some localities of Makarfi and Pategi (Adekunle et al., 2023; Ejike et al., 2023). Detailed geochemical studies of the Wamba pegmatite field classify the pegmatites as members of the rare-metal class (Li-Cs-Ta), with associated Sn-Nb-Ta mineralization (Küster, 1990). Similarly, the Nasarawa, Keffi, and Janjala pegmatite fields have been classified as LCT-type, mineralised pegmatites consisting of quartz, feldspar, and accessory beryl, lepidolite, and tourmaline, with pervasive sericitic and muscovitic alteration associated with Nb-Ta-Sn mineralization (Adekeye & Akintola, 2007; Tanko, 2014; Tanko et al., 2020; Tanko & Dzigbodi-Adjimah, 2021a, 2021b). Despite these advances, geochemical data integrating major-oxide, trace-element, and REE systematics with tectonic discrimination are lacking for the Arikpa pegmatites, which this study addresses.

3. 0 Materials and Methodology

3.1 Sampling and Analytical Methods

Rock samples comprising migmatite gneiss, granitic gneiss, biotite granite, rhyolite, and pegmatite were collected from the study area during geological field mapping for geochemical analysis. X-ray fluorescence (XRF) spectroscopy was employed to determine the major-oxide, trace-element, and rare-earth-element (REE) composition of the samples, and to quantify lithium content and other trace elements of economic relevance. Flame photometry (atomic emission spectroscopy) was additionally used to determine concentrations of alkali and alkaline-earth metal ions, including sodium, potassium, lithium, and calcium.

3.2 Data Analysis

Geochemical data were evaluated using major-oxide Harker variation diagrams, alumina-saturation (A/NK–A/CNK) and petrogenetic classification diagrams, trace-element ratio plots (K/Rb–Rb, Zn/Sn–K/Rb), a Ti–Sn–(Nb+Ta) ternary diagram, a MORB-normalised multi-element spider diagram, and the R_1–R_2 tectonic discrimination diagram (Batchelor & Bowden, 1985), to characterise the fractionation trend, source characteristics, and tectonic setting of the pegmatites, and to assess their lithium and rare-metal mineralization potential.

4.0 Results and Discussion

4.1 Major-Element Geochemistry

Major-oxide compositions of the migmatite gneiss, granitic gneiss, biotite granite, and rhyolite host rocks are presented in Table 1, and those of the pegmatites in Table 2. Across the host rocks and pegmatites, SiO_2 contents range from 47.83–74.06 wt%, TiO_2 from 0.009–2.21 wt%, Na_2O from 0.54–8.06 wt%, Al_2O_3 from 11.29–14.93 wt%, MnO from 0.004–0.069 wt%, P_2O_5 from below detection to 0.45 wt%, K_2O from 2.17–13.38 wt%, CaO from 0.32–12.97 wt%, and Fe_2O_3 from 0.50–14.25 wt%. MgO was below the analytical detection limit in all analysed samples, indicating very low concentrations of Mg-bearing components. This characteristic is compatible with the highly felsic composition of the pegmatites, although the absence of measurable MgO alone cannot be taken as definitive evidence of fractional crystallisation.Li_2O concentrations in the pegmatite suite range from 0.12–0.53 wt%, with a mean value of approximately 0.30 wt%, indicating generally low lithium enrichment across the sampled pegmatites.Fig.. Harker variation diagrams of SiO_2 against the major oxides (Fig. 1) show systematic compositional variations across the analysed rocks.

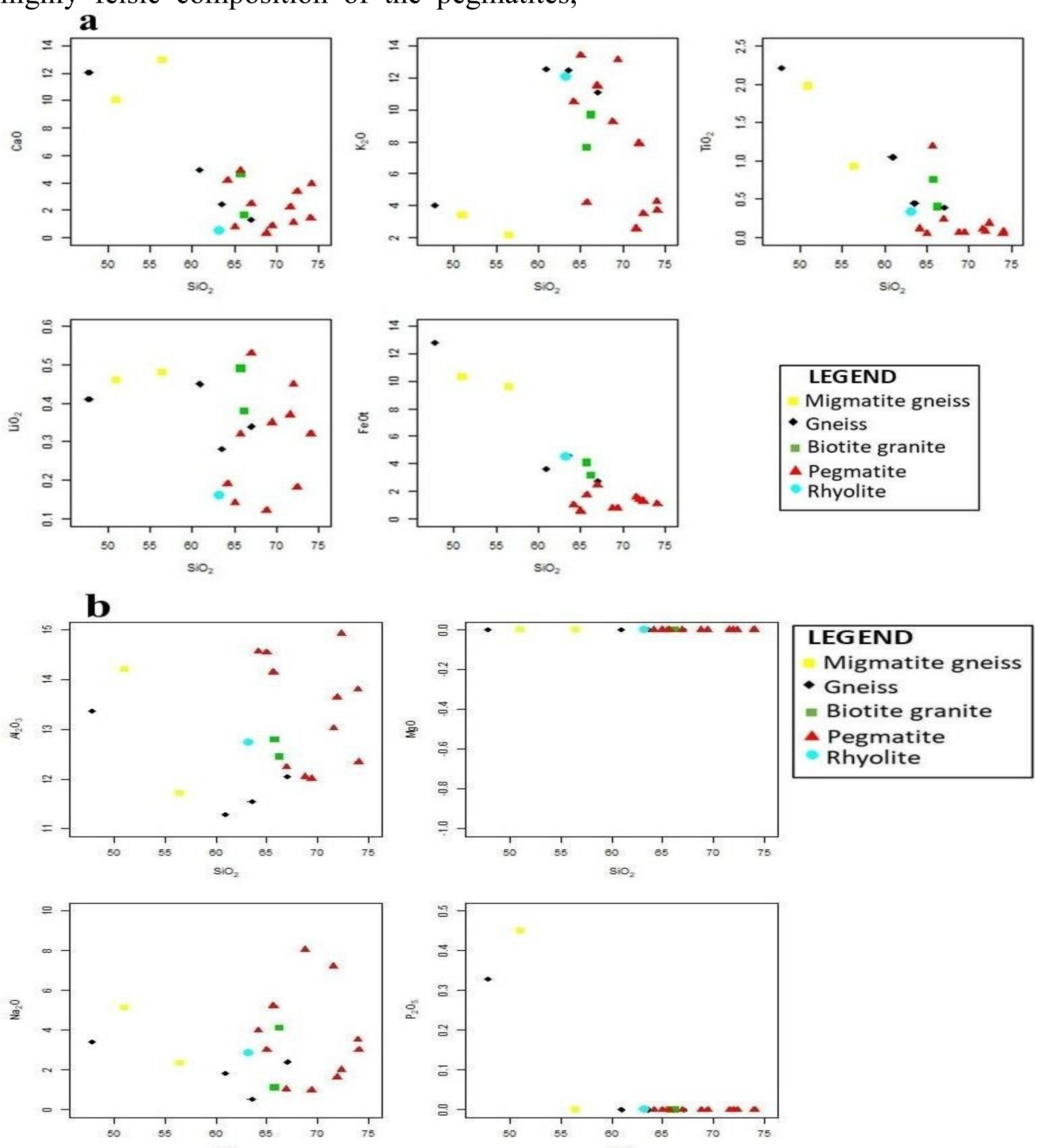

Fig. 1: Harker variation diagrams showing major-element oxides plotted against SiO_2. (a) K_2O, CaO, TiO_2, Li_2O and Fe_2O_3 versus SiO_2; (b) Na_2O, MgO, Al_2O_3 and P_2O_5 versus SiO_2 Fig.

Table 1: Major-Oxide Concentrations of Migmatite Gneiss, Granitic Gneiss, Biotite Granite, and Rhyolite from the Study Area (wt%)

Oxide (wt%)	NHR 6A	NHR 7B	NHR 8B	NHR 10	NHR 10B	NHR 11A	NHR 12	NHR 13A	NRY 14
SiO2	56.482	65.81	51.03	66.251	47.826	63.577	67.077	60.959	63.244
Al2O3	11.712	12.795	14.204	12.449	13.361	11.546	12.045	11.288	12.74
CaO	12.969	4.589	10.022	1.618	12.051	2.421	1.278	4.918	0.518
Fe2O3	10.64	4.5	11.48	3.484	14.245	5.07	3.021	4.003	4.994
K2O	2.165	7.606	3.412	9.656	3.993	12.449	11.075	12.562	12.062
MgO	ND	ND	ND	ND	ND	ND	ND	ND	ND
Na2O	2.353	1.115	5.127	4.125	3.412	0.537	2.41	1.82	2.852
P2O5	ND	ND	0.45	ND	0.329	ND	ND	ND	ND
TiO2	0.929	0.754	1.971	0.398	2.21	0.442	0.395	1.049	0.335
MnO	0.013	0.009	0.011	0.014	0.011	0.015	0.011	0.021	0.069
LiO2	0.480	0.490	0.460	0.380	0.410	0.280	0.340	0.450	0.160
Na2O+K2O	4.520	8.720	8.540	13.780	7.400	12.990	13.480	14.380	14.910
A/CNK (ASI)	0.390	0.690	0.470	0.620	0.420	0.620	0.660	0.440	0.680

Table 2: Major-Oxide Concentrations of Pegmatites from the Study Area (wt%)

Oxide (wt%)	NPG 1A	NPG 2	NPG 3	NPG 4	NPG 5	NPG 6B	NPG 7A	NPG 8A	NPG 9	NPG 11B	NPG 13
SiO2	71.582	68.779	65.69	66.973	64.155	74.064	72.402	69.418	65.003	71.928	73.99
Al2O3	13.016	12.046	14.144	12.235	14.565	12.341	14.926	12.006	14.544	13.641	13.802
CaO	2.21	0.324	4.879	2.479	4.153	3.889	3.324	0.814	0.745	1.083	1.409
Fe2O3	1.697	0.805	1.901	2.718	1.094	1.189	1.392	0.792	0.597	1.538	1.192
K2O	2.545	9.24	4.162	11.488	10.481	3.7	3.464	13.101	13.383	7.873	4.237
MgO	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Na2O	7.213	8.057	5.215	1.025	3.977	3.021	2.015	0.982	3.011	1.634	3.532
P2O5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TiO2	0.106	0.059	1.186	0.24	0.113	0.081	0.185	0.064	0.053	0.075	0.056
MnO	0.008	0.012	0.012	0.008	0.004	0.009	0.016	0.018	0.027	0.013	0.019
LiO2	0.37	0.12	0.32	0.53	0.19	0.32	0.18	0.35	0.14	0.45	0.32
Na2O+K2O	9.76	17.3	9.38	12.51	14.46	6.72	5.48	14.08	16.39	9.51	7.77
A/CNK (ASI)	0.70	0.51	0.64	0.66	0.57	0.77	1.14	0.69	0.7	1.04	1.07

The generally negative relationships of Fe_2O_3, CaO and TiO_2 with increasing SiO_2 are consistent with progressive removal of mafic and calcic mineral phases during magmatic differentiation. However, the interpretation of MgO and P_2O_5 trends is limited by their low concentrations and frequent values below detection limits. . Taken together, these compositional trends are consistent with progressive magmatic differentiation, although the Harker relationships alone do not establish a single parental source for all the analysed rocks.

4.2 Petrogenetic Classification

The A/NK versus A/CNK diagram (Fig. 2) indicates that the analysed rocks span metaluminous to peraluminous compositions, with some samples approaching the peraluminous field. These variations indicate differences in the relative proportions of alumina, alkalis and calcium among the analysed rocks. However, the A/NK–A/CNK relationship alone is insufficient to establish specific mantle or crustal source contributions. A/NK versus A/CNK plots (Fig. 2) show a compositional spread from metaluminous to peraluminous, and locally peralkaline fields (after Shand, 1943), implying heterogeneous magmatic sources involving mantle-derived melts with varying degrees of crustal assimilation.

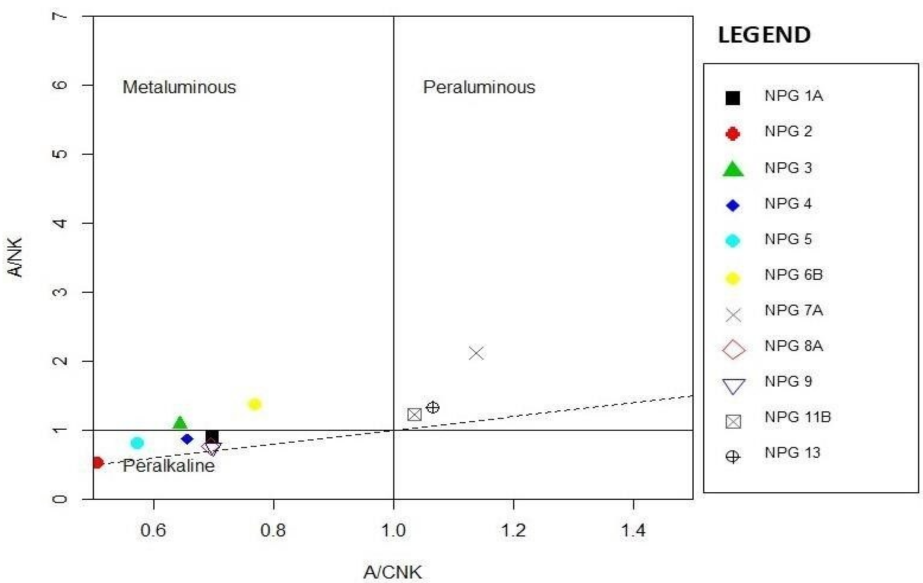

Fig. 2: A/NK versus A/CNK plot showing the distribution of the rocks as metaluminous, with a few samples trending toward the peraluminous field (after Shand, 1943).

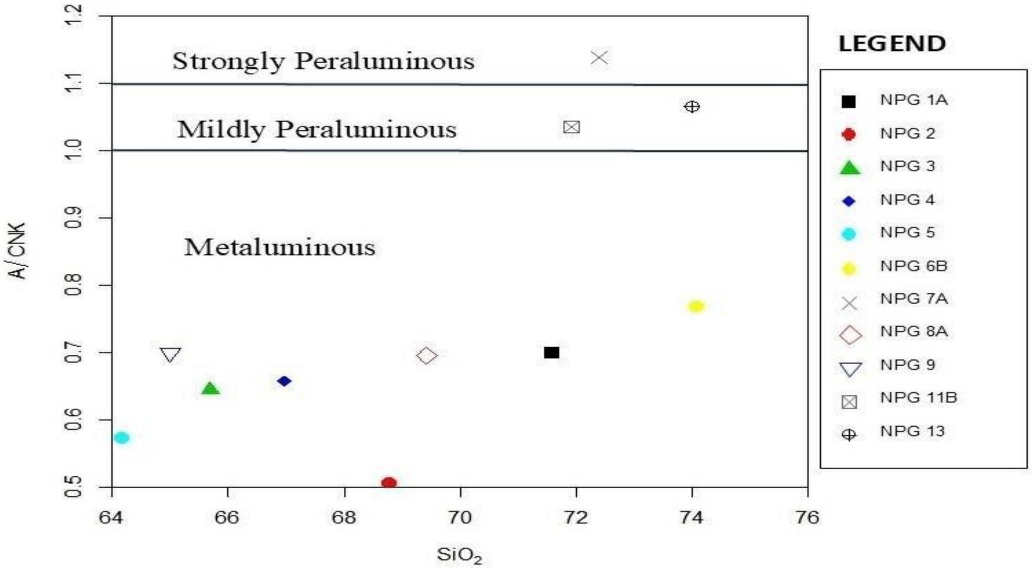

Fig. 3: A/CNK versus SiO2 plot showing source/origin of the pegmatites.

The pegmatite suite plots predominantly within the compositional field associated with I-type granitic rocks on the A/CNK versus SiO_2 diagram (Fig.5). This distribution suggests a predominantly igneous felsic affinity, although the I-type classification should be considered in conjunction with mineralogical, petrographic and additional geochemical evidence .rather than than sedimentary origin for the parent melt, a classification corroborated by the TiO_2 versus SiO_2 plot (Fig. 4, after Tarney, 1977).

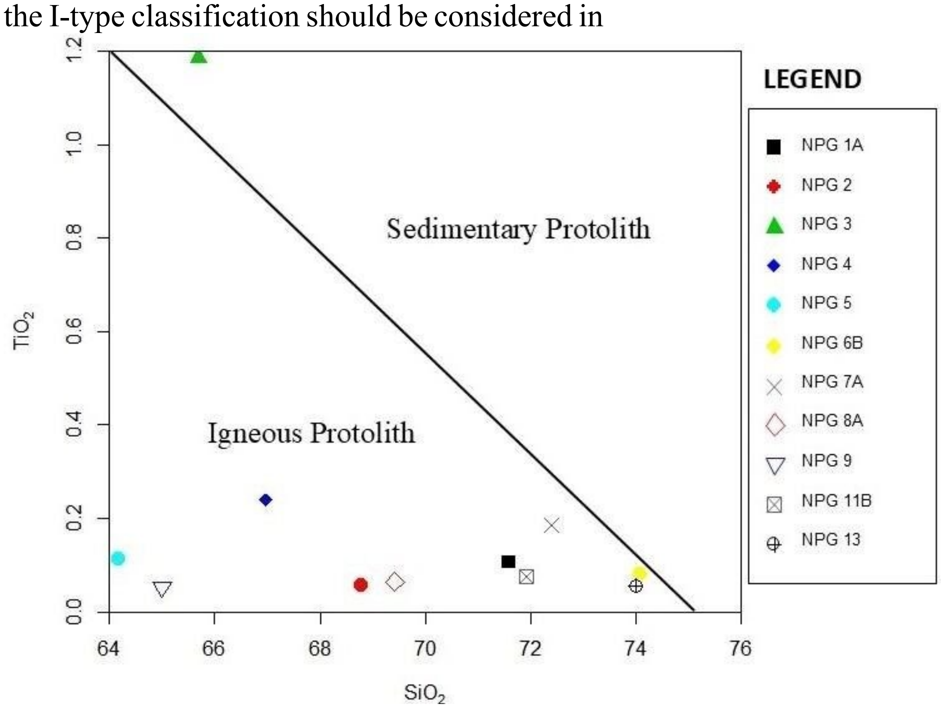

Fig. 4: TiO2 versus SiO2 plot (after Tarney, 1977) showing source/origin of the pegmatites.

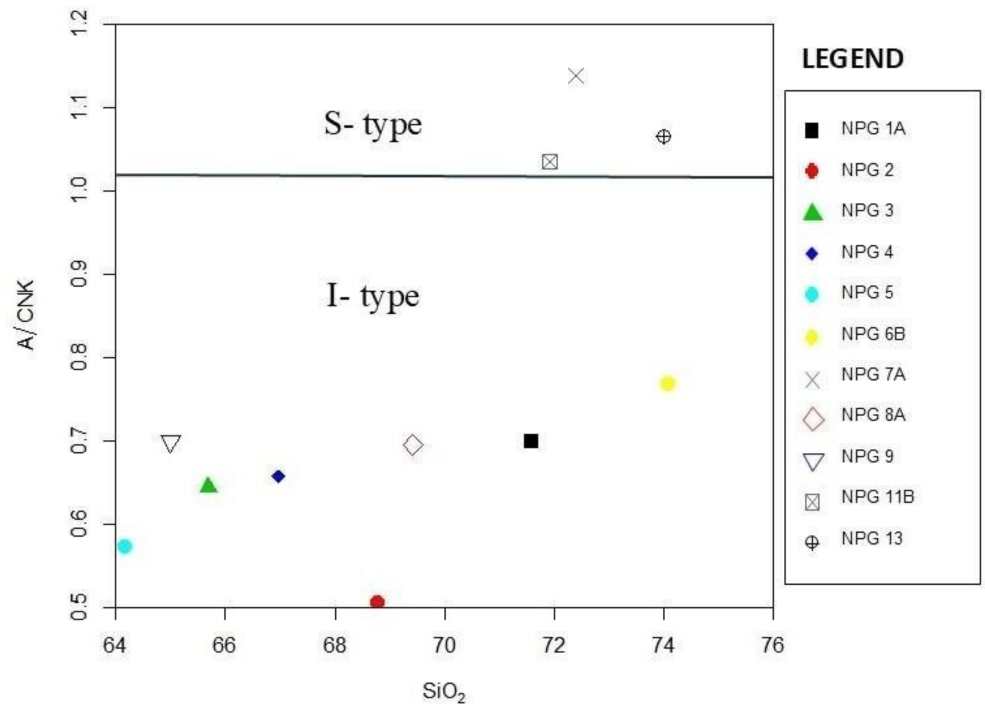

Fig. 5: A/CNK versus SiO2 discrimination diagram (after Chappell & White, 1974). Most of the pegmatites plot within the field of I-type granites

he Na_2O+K_2O versus SiO_2 (Figure 6) and K_2O versus SiO_2 (Figure 7) diagrams indicate predominantly alkaline to high-K calc-alkaline felsic compositions. These characteristics are compatible with evolved post-collisional to continental felsic magmatism, although the tectonic setting is more reliably constrained by dedicated tectonic discrimination diagrams and regional geological evidence (Cox et al., 1979;Peccerillo & Taylor, 1976)

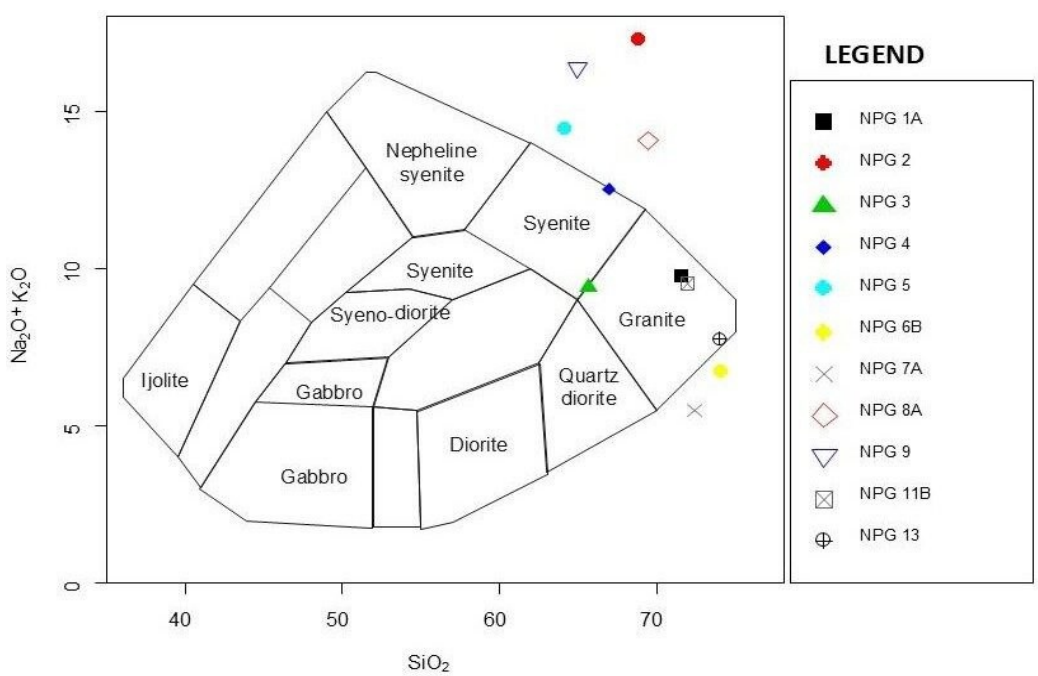

Fig. 6: Plot of Na2O+K2O vs SiO2 for the pegmatites (after Cox et al., 1979).

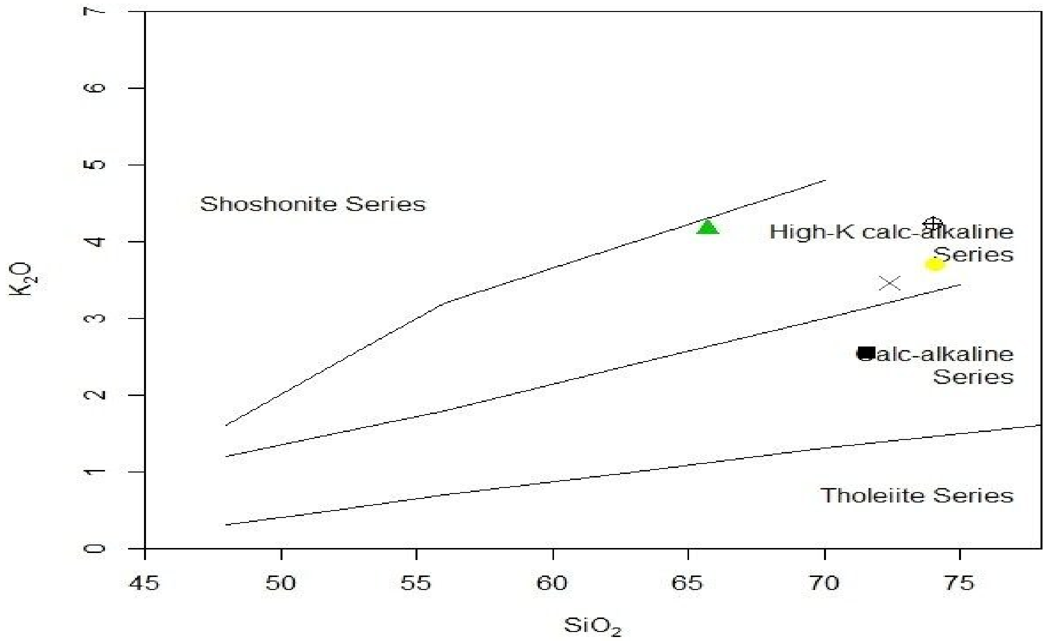

Fig. 7: K2O versus SiO2 diagram showing the distribution of the rocks within the fields of calc-alkaline and high-K calc-alkaline series (after Peccerillo & Taylor, 1976).

The CaO–Na_2O–K_2O ternary diagram (Figure 8) illustrates the relative proportions of the principal major cations, whereas the Q–A–P diagram (Fig. 9), based on the corresponding quartz, alkali-feldspar and plagioclase proportions, provides a mineralogical classification of the felsic rocks. The predominance of quartz and alkali-feldspar components is consistent with the highly felsic nature of the pegmatitic suite.

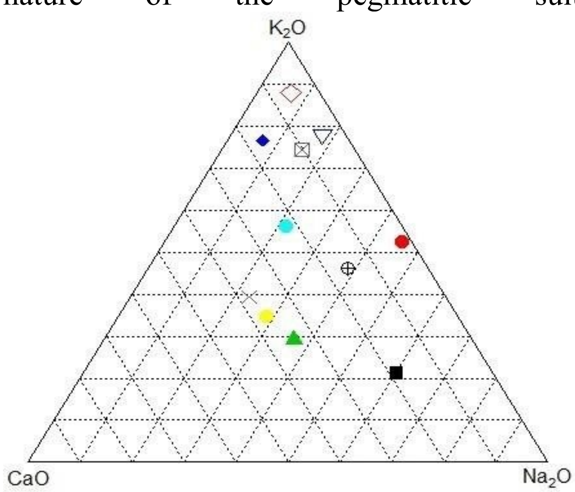

Fig. 8: CaO, Na2O and K2O ternary variation plot for the pegmatites in the study area.

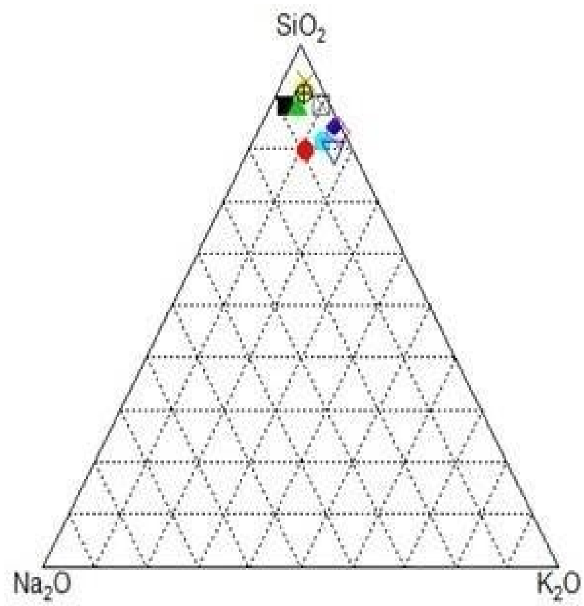

Fig. 9: Q-A-P ternary diagram for the pegmatites, showing that most samples plot towards the SiO2-rich (quartz) apex.

The Rb–Ba–Sr ternary diagram (Figure 10) illustrates the distribution of the associated felsic rocks and provides additional information on their relative enrichment and depletion in large-ion lithophile elements. The observed distribution is consistent with variable degrees of differentiation among the associated granitoid rocks. (El-Bouseily & El-Sokkary, 1975)

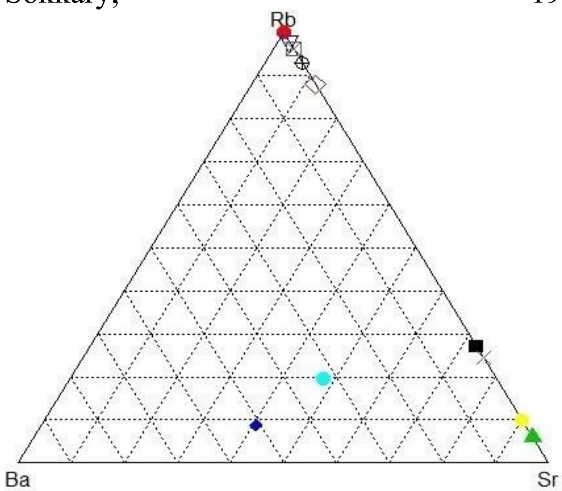

Fig. 10: Rb, Ba and Sr ternary diagram showing the distribution of the granites and the granodiorite in the study area (after El-Bouseily & El-Sokkary, 1975).

4.3 Trace and Rare-Earth Elements

Trace-element and REE data of the pegmatites are presented in Tables 3 and 4, with derived ratios in Table 5. There is a marked difference in trace-element and REE concentration and fractionation patterns among the pegmatite samples, with distinct enrichment of Ni, Zn, Y, Cu, Rb, and Cs, and, in many samples, Dy, Nb, Ta, Sn, Sr, La, Ce, Nd, and Ba. The high K/Ba, Rb/Sr, and K/Rb ratios attest to the granitic origin of the pegmatites, which show remarkable similarity in chemical composition despite their spatial separation. Chondrite-normalised REE patterns are characterised by enrichment in light rare-earth elements (LREE) relative to heavy rare-earth elements (HREE), with moderate fractionation and variable Eu anomalies, consistent with derivation from evolved granitic melts associated with calc-alkaline Pan-African magmatism.

The MORB-normalised multi-element spider diagram (Fig. 11) shows a coherent pattern across all samples, with strong enrichment in large-ion lithophile elements (LILEs) such as K, Rb, Ba, and Th, coupled with pronounced depletions in Nb, Ta, and Ti. The MORB-normalised multi-element patterns (Figure 11) show enrichment in several large-ion lithophile elements, including K, Rb and Ba, together with relative depletion of Nb, Ta and Ti. Such Nb–Ta–Ti depletions may reflect source modification by subduction-related processes, inheritance from previously modified crustal or mantle sources, and/or fractionation involving Ti-bearing accessory phases. The patterns therefore indicate a chemically evolved felsic system but do not, by themselves, uniquely establish a subduction-related mantle source.The relatively low concentrations of some HREEs may reflect residual mineral control during partial melting and/or subsequent magmatic fractionation; however, discrimination between crustal and mantle contributions requires isotopic or additional source-sensitive geochemical data. The parallel nature of the trace-element patterns indicates that the samples are petrogenetically related, consistent with magmas derived from an enriched mantle source modified by subduction-derived fluids and subsequently affected by fractional crystallisation of accessory mineral phases.

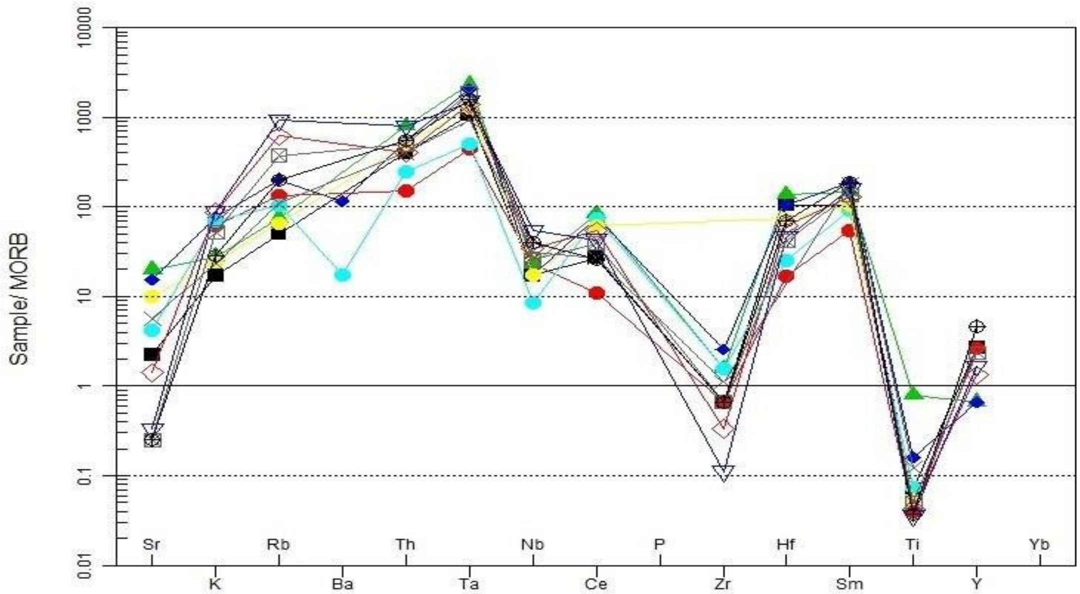

Fig. 11: Spider plot of trace-element concentrations normalized to the composition of average MORB (after Pearce, 1983).

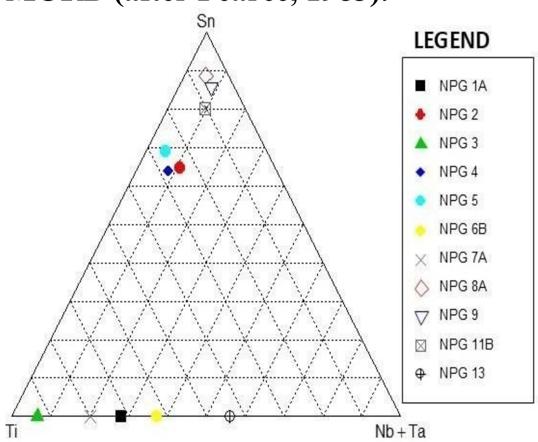

Fig. 12: Plot of Ti, Sn and Nb+Ta of pegmatites of the Arikpa area (adapted from Küster, 1990).

The Ti–Sn–(Nb+Ta) ternary diagram (Fig. 12, after Küster, 1990) shows a fractionation trajectory dominated by Sn enrichment, suggesting a system evolving toward Sn-bearing LCT pegmatites rather than Nb-Ta-rich rare-metal types; the limited Nb+Ta enrichment indicates that the pegmatite field is evolved but not highly specialised toward Ta-Nb mineralization.

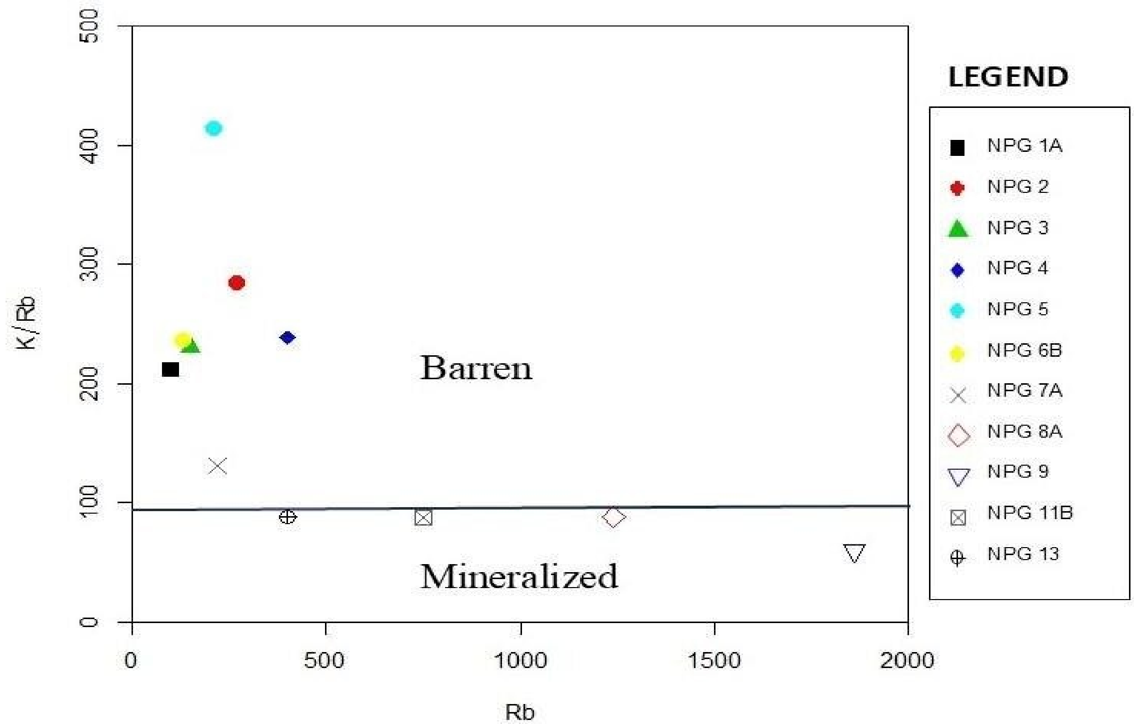

Fig. 13: K/Rb versus Rb plot of the pegmatites in the study area (after Černý et al., 1985).

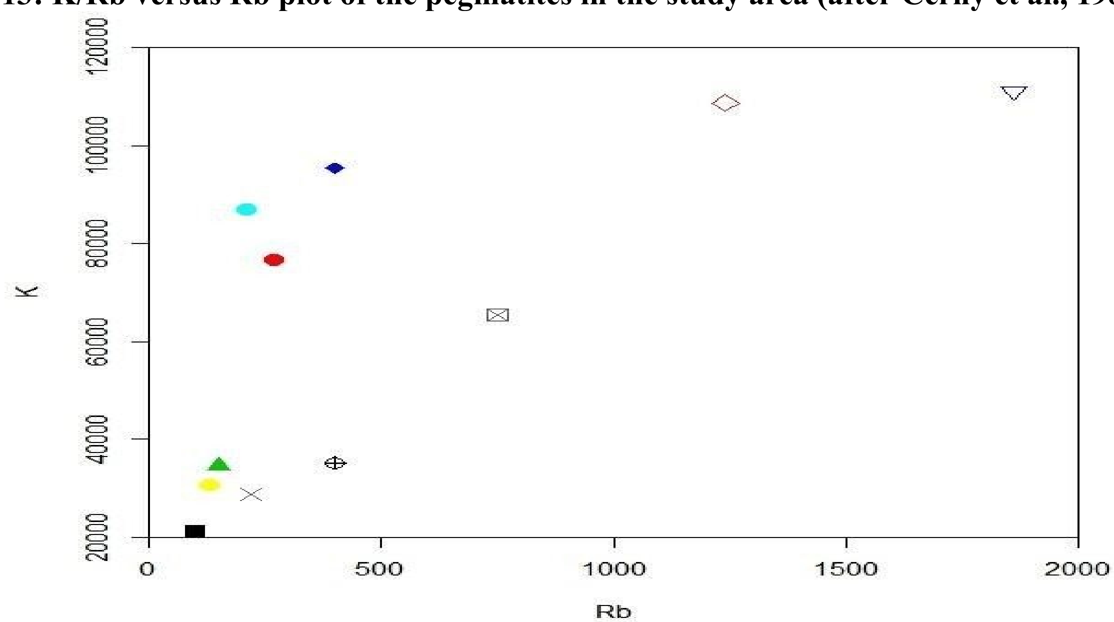

Fig. 14: Plot of K versus Rb showing the link amongst the pegmatites.

The K/Rb versus Rb plot (Fig. 13, after Černý et al., 1985) and K versus Rb plot (Fig. 14) show a continuity in concentration among samples NPG 1A, NPG 2, NPG 3, NPG 4, NPG 5, NPG 6B, NPG 7A, NPG 8A, NPG 9, NPG 11B, and NPG 13, indicating a genetic relationship and common source (igneous protolith) for the pegmatites of the study area. Variations in Rb concentration and K/Rb ratios reflect differing degrees of melt evolution, with lower K/Rb ratios corresponding to more evolved pegmatitic compositions.

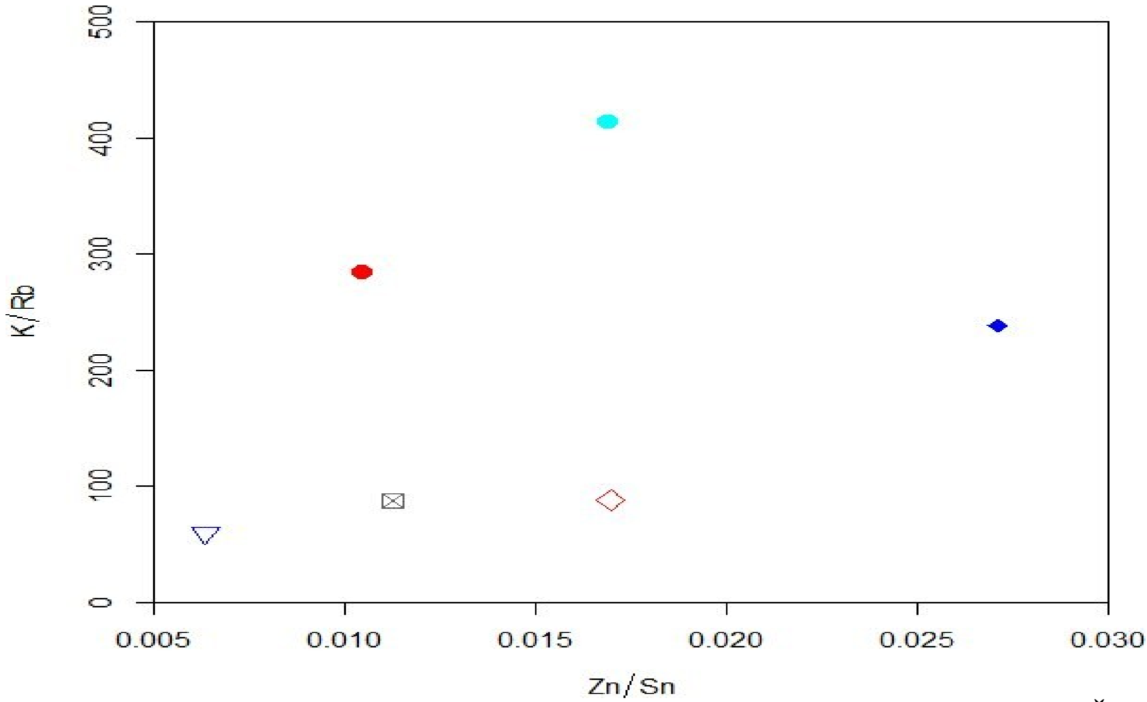

Fig. 15: Zn/Sn versus K/Rb variation plot of pegmatites in the study area (after Černý et al., 1985).

The Zn/Sn versus K/Rb variation plot (Fig. 15, after Černý et al., 1985) indicates progressive Sn enrichment with increasing fractionation, consistent with the development of evolved pegmatitic members with rare-metal enrichment potential.

The Rb versus Sr plot (Fig. 17, after Černý et al., 2005) further constrains the fractionation trend of the pegmatite suite.

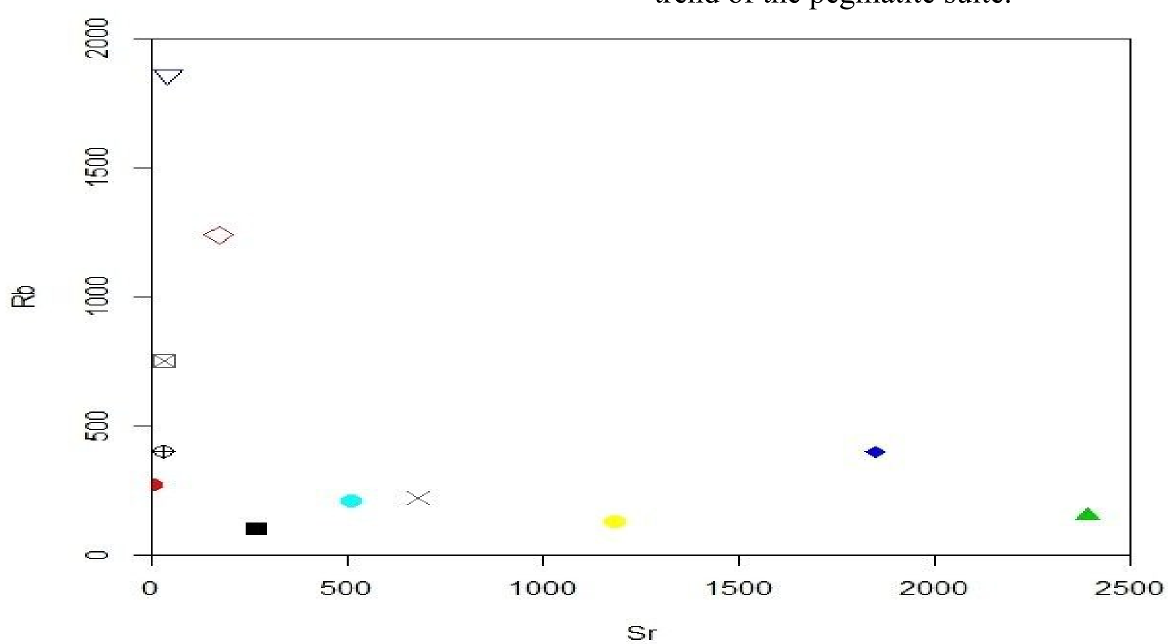

Fig. 17: Rb versus Sr plot of the pegmatites in the study area (after Černý et al., 2005).

Table 3: Trace-Element Concentrations of Pegmatites in the Study Area (ppm)

Element (ppm)	NPG 1A	NPG 2	NPG 3	NPG 4	NPG 5	NPG 6B	NPG 7A	NPG 8A	NPG 9	NPG 11B	NPG 13
S	780	110	1070	ND	470	160	1610	920	1410	880	610
K	21120	76710	34550	95370	87010	30710	28760	108760	111100	65360	35170
Sc	510	80	710	290	170	800	720	410	180	320	260
V	ND	20	80	120	60	ND	ND	ND	30	30	20
Cr	640	160	720	420	330	920	820	420	560	520	630
Ni	ND	ND	ND	ND	ND	ND	ND	10	ND	ND	ND
Cu	280	90	550	400	180	350	400	320	380	320	220
Rb	100	270	150	400	210	130	220	1240	1860	750	400
Sr	270	0	2390	1850	510	1180	680	170	40	30	30
Y	80	80	20	20	ND	ND	ND	40	50	70	140
Zr	60	60	140	230	140	ND	100	30	10	60	60
Sn	ND	960	ND	3320	1780	ND	ND	5900	4730	3560	ND
Cs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ba	ND	ND	ND	2320	350	ND	ND	ND	ND	ND	ND
Ta	190	80	420	370	90	230	170	250	270	340	280
Li	4800	4900	4600	3800	4100	3400	4500	3700	3200	1800	4500

ND = not detected, EL = Element

Table 4: Rare-Earth Element (REE) Concentrations of Pegmatites in the Study Area (ppm)

REE (ppm)	NPG 1A	NPG 2	NPG 3	NPG 4	NPG 5	NPG 6B	NPG 7A	NPG 8A	NPG 9	NPG 11B	NPG 13
La	ND	ND	240	ND	ND	ND	ND	ND	ND	ND	ND
Ce	270	110	840	770	740	620	270	540	430	390	260
Pr	180	ND	ND	120	90	140	150	ND	140	ND	ND
Nd	310	170	340	ND	50	380	640	600	680	370	380
Sm	340	180	480	620	300	340	600	430	520	450	610
Eu	170	100	410	160	170	160	320	0	230	140	0
Gd	330	120	620	760	160	320	360	440	300	360	440
Tb	ND	ND	ND	ND	ND	ND	ND	ND	ND	10	ND
Dy	1060	480	1440	2080	750	1140	1080	620	560	1340	850
Er	140	80	290	180	120	190	250	30	130	220	ND
Y	80	80	20	20	ND	ND	ND	40	50	70	140

ND = not detected.

Table 5: Selected Geochemical Ratios of the Pegmatites in the Study Area

Ratio	NPG 1A	NPG 2	NPG 3	NPG 4	NPG 5	NPG 6B	NPG 7A	NPG 8A	NPG 9	NPG 11B	NPG 13
K/Rb	211.2	284.11	230.33	238.43	414.33	236.23	130.73	87.71	59.73	87.15	87.92
Ba/Rb	ND	ND	ND	5.8	1.67	ND	ND	ND	ND	ND	ND
K2O/ Al2O3	0.2	0.77	0.29	0.94	0.72	0.3	0.23	1.09	0.92	0.58	0.31
Rb/Sr	0.37	ND	0.06	0.22	0.41	0.11	0.32	7.29	46.5	25	13.33
Zn/Sn	ND	0.01	ND	0.03	0.02	ND	ND	0.02	0.01	0.01	ND

Ratio	NPG 1A	NPG 2	NPG 3	NPG 4	NPG 5	NPG 6B	NPG 7A	NPG 8A	NPG 9	NPG 11B	NPG 13
Y/Nb	1.33	1	0.25	0.33	ND	ND	ND	0.33	0.26	0.78	1

4.4 Tectonic Setting

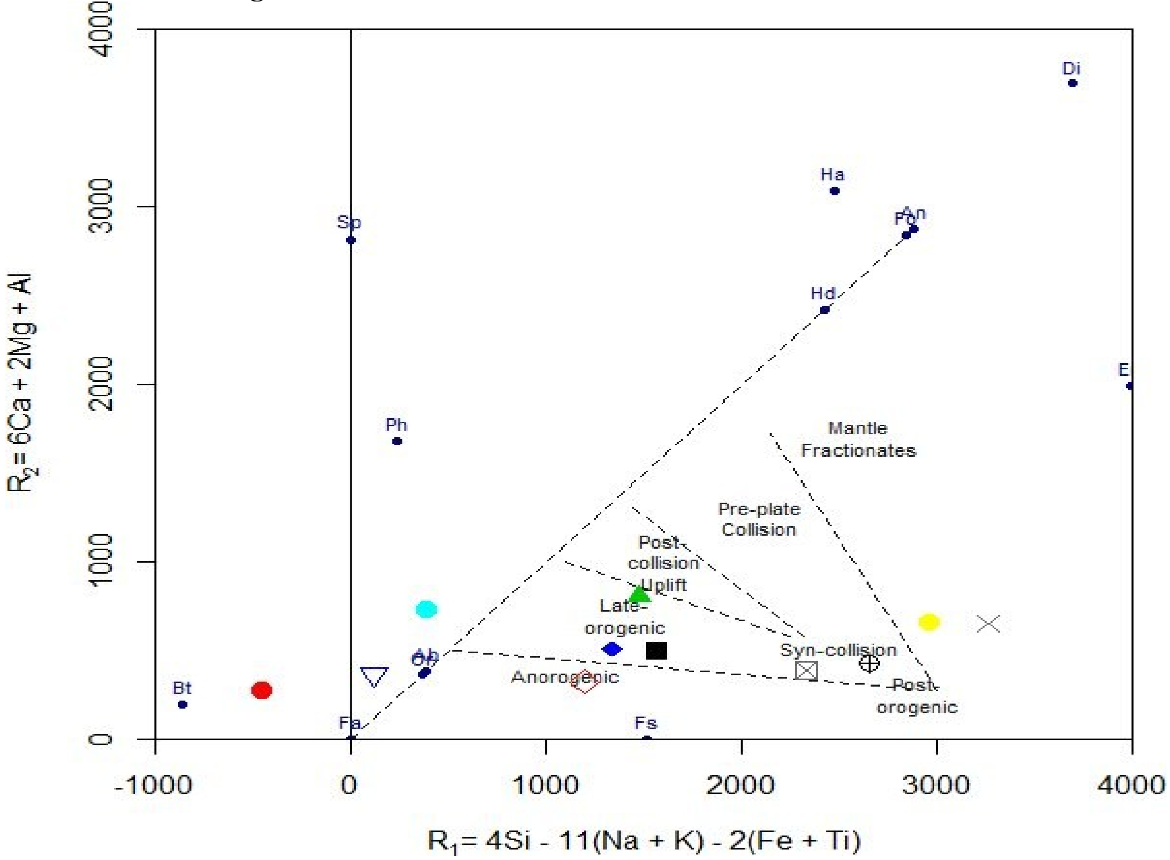

Fig. 16: Tectonic discrimination diagram (after Batchelor & Bowden, 1985), showing the distribution of the pegmatite suites within pre-plate collision, syn-collision, and post-orogenic fields.

The R_1–R_2 tectonic discrimination diagram (Fig. 16, after Batchelor & Bowden, 1985) places most pegmatites within late-orogenic to post-orogenic fields, implying emplacement during the waning stages of Pan-African deformation, when the crust transitioned from compressional to extensional regimes. Such settings favour crustal melting, volatile-rich magmatism, and the generation of pegmatitic melts.

4.5 Lithium and Rare-Metal Mineralization Potential

Concentrations of Li_2O in the Arikpa pegmatites range from 0.18–0.50 wt%, with an average below 1 wt%. In accordance with established pegmatite evolutionary models, extreme fractionation of Li_2O and other lithophile elements is a common geochemical indicator of mineralised granitic pegmatites (Černý, 1982a, 1982b, 1991; London, 2005), and most studies of North-Central Nigerian pegmatite fields consider Li_2O concentrations above 1 wt%, together with strong fractionation of Rb and Cs, as indicators of well-mineralised pegmatites, as documented in the Wamba (Küster, 1990), Nasarawa (Adekeye & Akintola, 2007), and Keffi pegmatites (Tanko, 2014; Tanko et al., 2020; Tanko & Dzigbodi-Adjimah, 2021a, 2021b). On this basis, the Arikpa pegmatites are only weakly to moderately fractionated with respect to lithium and are not currently prospective as a standalone lithium ore body.

Comparison with the Wamba, Nasarawa, Keffi, and Janjala pegmatite fields (Table 6) shows that, like these established LCT occurrences, the Arikpa pegmatites are classified as LCT-type, mineralised pegmatites consisting of quartz, K-feldspar, and plagioclase, with accessory beryl and aquamarine, and pervasive sericitic and muscovitic alteration, indicating moderate potential for Sn-Li-Rb mineralization rather than dedicated lithium ore.

Table 6: Comparison of the Mineralization Potential of Wamba, Nasarawa, Keffi, Janjala, and Arikpa Pegmatites

Field	Classification	Mineral Assemblage / Alteration	Mineralization Potential
Wamba (Küster, 1990)	**Rare-metal class (Li-Cs-Ta)**	**Garnet, tourmaline, beryl**	**Sn-Nb-Ta mineralization**
Nasarawa (Adekeye & Akintola, 2007)	LCT (Černý, 1991)	Quartz, microcline, microperthite, minor plagioclase; garnet, tourmaline, magnetite; pervasive albitization, perthite	Nb-Ta-Sn-Li-Be ores in complex (mineralised) pegmatites
Keffi (Tanko, 2014)	LCT-type	Quartz, microcline, plagioclase; garnet, tourmaline, sericite; sericitisation and tourmalinisation	Complex (mineralised) pegmatites
Janjala (Tanko et al., 2020)	LCT-type	Quartz, K-feldspar, plagioclase; beryl, lepidolite, levelandite, tourmaline, sphene; sericitisation, muscovitisation, tourmalinisation	Potential for Nb, Ta, Sn mineralization
Arikpa (present study)	LCT-type	Quartz, K-feldspar, plagioclase; beryl and aquamarine; pervasive sericitisation and muscovitisation	Moderate potential for Sn, Li, Rb mineralization

4.6 Discussion

Integration of the major-oxide, trace-element, REE, and tectonic discrimination data indicates that the Arikpa pegmatites were derived from a highly evolved granitic melt within the Nigerian Basement Complex. Major-oxide trends support fractional crystallisation as the dominant magmatic process, with the pegmatite suite plotting predominantly within the I-type, metaluminous to peraluminous, high-K calc-alkaline field. The R_1–R_2 diagram places the suite in late- to post-orogenic settings consistent with emplacement during the waning stages of the Pan-African orogeny, favouring volatile-rich, pegmatite-generating magmatism. Trace-element systematics, particularly the LILE enrichment and Nb-Ta-Ti depletion pattern, together with decreasing K/Rb ratios and increasing Sn enrichment with fractionation, are consistent with an evolved, genetically related pegmatite suite showing rare-metal (Sn-Rb) enrichment tendencies. However, in the absence of isotopic constraints, the precise relative contribution of mantle and crustal sources to the parental magma remains interpretative.

The Li_2O data (0.18–0.50 wt%, average below 1 wt%) place the Arikpa pegmatites below the threshold typically associated with economically mineralised lithium pegmatites elsewhere in Central Nigeria. This does not preclude localised lithium enrichment within more strongly fractionated pockets, but on current evidence the pegmatites should be regarded as moderately mineralised with respect to Sn-Li-Rb rather than as a primary lithium resource.

5.0 Conclusion

Geochemical and petrogenetic evaluation of the Arikpa pegmatites indicates a genetically related, I-type, metaluminous to peraluminous, high-K calc-alkaline pegmatite suite emplaced during the late- to post-orogenic stage of the Pan-African orogeny. Major-oxide trends and trace-element systematics point to derivation from a highly evolved granitic melt through progressive fractional crystallisation, with LILE enrichment and Nb-Ta-Ti depletion indicative of a subduction-modified, crustally reworked source. Li_2O concentrations (0.18–0.50 wt%) are below the 1 wt% threshold generally associated with well-mineralised lithium pegmatites in Central Nigeria, indicating that the Arikpa pegmatites are not currently prospective for lithium as a standalone commodity, but show moderate potential for combined Sn-Li-Rb mineralization, consistent with regional LCT pegmatite occurrences at Wamba, Nasarawa, Keffi, and Janjala.

Based on the findings of this study, the following are recommended:

i. Systematic trenching and drilling programmes should be conducted to evaluate subsurface pegmatite geometry and to estimate the resource potential for Sn, Li, and Rb at depth.
ii. Fluid-inclusion and stable-isotope studies should be carried out to further constrain the source, fluid evolution, and thermochemical conditions of the pegmatites.
iii. Detailed mineral-chemistry analysis of muscovite and associated accessory phases should be undertaken, as trace-element chemistry of pegmatitic micas has been shown elsewhere to provide an accurate signature of an area's rare-metal economic potential.
iv. Given the comparatively low bulk Li_2O content, exploration should prioritise identification of more strongly fractionated pegmatite pockets, where lithium and associated rare metals are most likely to be locally concentrated.

6.0 References

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Declarations

Consent for Publication

Not applicable.

Availability of Data

The data used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing Interests

The authors declare that they have no competing interests and no conflict of interest regarding the publication of this manuscript.

Ethical Consideration

Not applicable.

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Authors' Contributions

The first author conceived the work. Both authors were jointly involved in the fieldwork and in the development of the manuscript.