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MAJOR AND TRACE ELEMENT GEOCHEMISTRY OF PEGMATITES IN UMAI, OBAN MASSIF, SE, NIGERIA: CONSTRAINTS ON THEIR CHARACTERIZATION AND MINERALIZATION POTENTIAL

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ABSTRACT

Pegmatites are highly sort for due to their ability to host diverse minerals such as lithium, tantalum, niobium, and gemstones. This study focuses on the geochemistry of the pegmatites in Umai, Oban Massif, SE, Nigeria. The aim is to characterize the pegmatites and infer their mineralization potential. Fifteen (15) fresh samples of pegmatites were analyzed using inductively coupled plasma mass spectrometry (ICP-MS). Fractional indices such as Ba/Rb, K/Rb, Na/K, K/Cs, Nb/Ta, Ta/Cs, and discrimination plots such as Na_2O+ K_2O vs SiO_2, Rb vs Sr, K/Rb vs Rb, K/Rb vs Cs, Be vs K/Nb, Ta vs K/Cs were utilized in this study. From the geochemical classification diagram of Na_2O+ K_2O vs SiO_2, the pegmatites in Umai are mainly granodioritic in composition. The K/Rb ratio for the samples analyzed are below 100 indicating mineralization. The Nb/Ta ratio for the samples is <1 indicating tantalite mineralization. Also, from the Ta Vs K/Cs plot some data plot on the tantalum mineralization field indicating tantalum mineralization. For some of the samples with Nb/Ta >1, they indicate columbite mineralization. Beryllium concentration >20ppm was observed in some samples analyzed suggesting possible beryllium mineralization.

KEYWORDS: Pegmatites, geochemistry, Oban massif, mineralization

INTRODUCTION

Pegmatites are of increasing economic importance due to their role as major sources of rare metals such as lithium (Li), beryllium (Be), cesium (Cs), scandium (Sc), niobium (Nb), tin (Sn), tantalum (Ta), tungsten (W), thorium (Th), and uranium (U) (Karampelas et al., 2020). These rare metals are critical raw materials in the manufacturing of high-tech equipment. Additionally, pegmatites are significant hosts of various gemstones like topaz, tourmaline, aquamarine, fluorite, and morganite, which are extensively used in jewelry and ornamental stonework (Karampelas et al., 2020).

Moreover, pegmatites are valuable sources of industrial minerals, including lithium ores, ceramic feldspar, mica, and high-purity quartz (London, 2018). The economic significance of pegmatites extends beyond their rare metal and gemstone content. Their unique mineralogical compositions make them attractive for various industrial applications, from electronics to jewelry. Understanding the mineralization potential of pegmatites, especially in underexplored regions like the Umai area, Southeastern (SE), Nigeria (Okon et al., 2022) could enhance mineral resource assessments, inform mining strategies, and contribute to the sustainable exploitation of these resources (Dill, 2015).

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Pegmatites are very coarse-grained intrusive igneous rocks formed from the crystallization of residual melt (London, 2018). They often occur as irregular masses, lenses, sills, or dykes within various geological settings, with sizes ranging from a few meters to many kilometers (Sweetapple & Collins, 2002). Depending on their mineralogical composition, pegmatites are classified into various types, including granite, gabbro, and syenite pegmatites (Tyrrell, 1978). Pegmatites can be simple, containing few exotic minerals, or complex, hosting a wide array of minerals, some of which are rare and limited to specific localities (London, 2005). Globally, pegmatites have been classified based on various criteria, including economic significance and mineralogical characteristics (Dill, 2015).

Several studies have classified pegmatites based on various criteria. Cerny and Ercit (2015) classified pegmatites into three families—Lithium-Cesium-Tantalum (LCT) pegmatites, Niobium-Yttrium-Fluorine (NYF) pegmatites, and Mixed LCT-NYF pegmatites—using a combination of emplacement, depth, metamorphic grade, and minor element contents. Elbialy and Th (2022) discussed these classifications further. Dill (2015) further classified pegmatites according to their economic significance, mineralogical characteristics, and distribution, identifying types such as Sn-W-Ta-Nb pegmatites, Li-Cs-Rb pegmatites, and REE-U-Nb pegmatites, each associated with specific minerals and geographic locations. These classifications provide a framework for understanding the diversity and economic potential of pegmatite deposits worldwide (Cerny, 2002).

In Nigeria, pegmatite outcrops with mineralization potentials are primarily found in three basement complexes: the southeastern (Oban and Obudu), southwestern (Ekwueme and Matheis, 1995; Edem et al., 2015), and north-central complexes (Adetunji & Ocan, 2010). Pegmatites in the southwest and north-central regions have been studied due to their association with economic metals such as tin (Sn) and tantalum (Ta) (Mafimisebi, 2023). The central Nigerian pegmatites, first investigated by Jacobson and Webb (1947), were found to contain cassiterite and tantalum-bearing minerals similar to those in the Jurassic younger granites of the Jos plateau in north-central Nigeria. The Sn-Nb-Ta metallogenic province in Nigeria is believed to be confined to a distinct belt extending in a NE-SW direction for about 400 km (Adekoya, 1998).

In the southeastern region, the Oban Massif is a notable area where pegmatite outcrops with mineralization potential have been documented (Ekwueme and Okoro, 2019). Researchers like Ero and Ekwueme (2009) investigated pegmatites in the Oban Massif, specifically in locations such as Uyanga, Akwa Ibami, Iwuru I, Iwuru II, and Igbofia. They found that these pegmatites are highly albitized and mineralized, enriched in elements like Li, Be, Sn, Ba, Ta, Ni, Cs, and Zn. Using various fractionation indices and discrimination plots, Ero and Ekwueme (2009) demonstrated that the pegmatites considered in their study are mineralized. Oden et al. (2011) further examined the pegmatites in Igbofia, Akwa Ibami, and Iwuru, revealing that these pegmatites were richer in SiO_2, Al_2O_3, Na_2O+K_2O, Rb, Li, Cs, Be, Zn, Nb, and Ga compared to their host rocks (schists and granodiorites).

While significant research has been conducted on pegmatites in various parts of Nigeria, there is a noticeable knowledge gap regarding the mineralization potential of pegmatites in the Umai region, Oban Massif, southeastern Nigeria. Unlike other regions where pegmatites have been extensively studied for their economic metal content, the pegmatites occurring as intrusives in granodiorite mapped in Umai area (Figure 1), remain largely unexplored. There is a lack of detailed investigation to determine whether these pegmatites are mineralized or barren.

This study aims to bridge the knowledge gap by conducting a comprehensive investigation of the pegmatites in Umai area, Oban Massif, southeastern Nigeria. The primary objective is to characterize these pegmatites and constrain their mineralization potential. By analyzing mineralogical and geochemical data, this study seeks to determine whether the Umai pegmatites are mineralized and assess their potential economic significance. This research will contribute to the mineral inventory of Nigeria, providing valuable insights for resource assessment and sustainable development.

Geological Setting

The study area (Figures 1 and 2), part of the Precambrian basement complex of Oban massif is situated in Southeastern Nigeria and spans between latitude 5°30'0''N to 5°35'0''N and longitude 8°10'0''E to 8°10'0''E. The Umai area is located in Biase local government area of Cross River State.

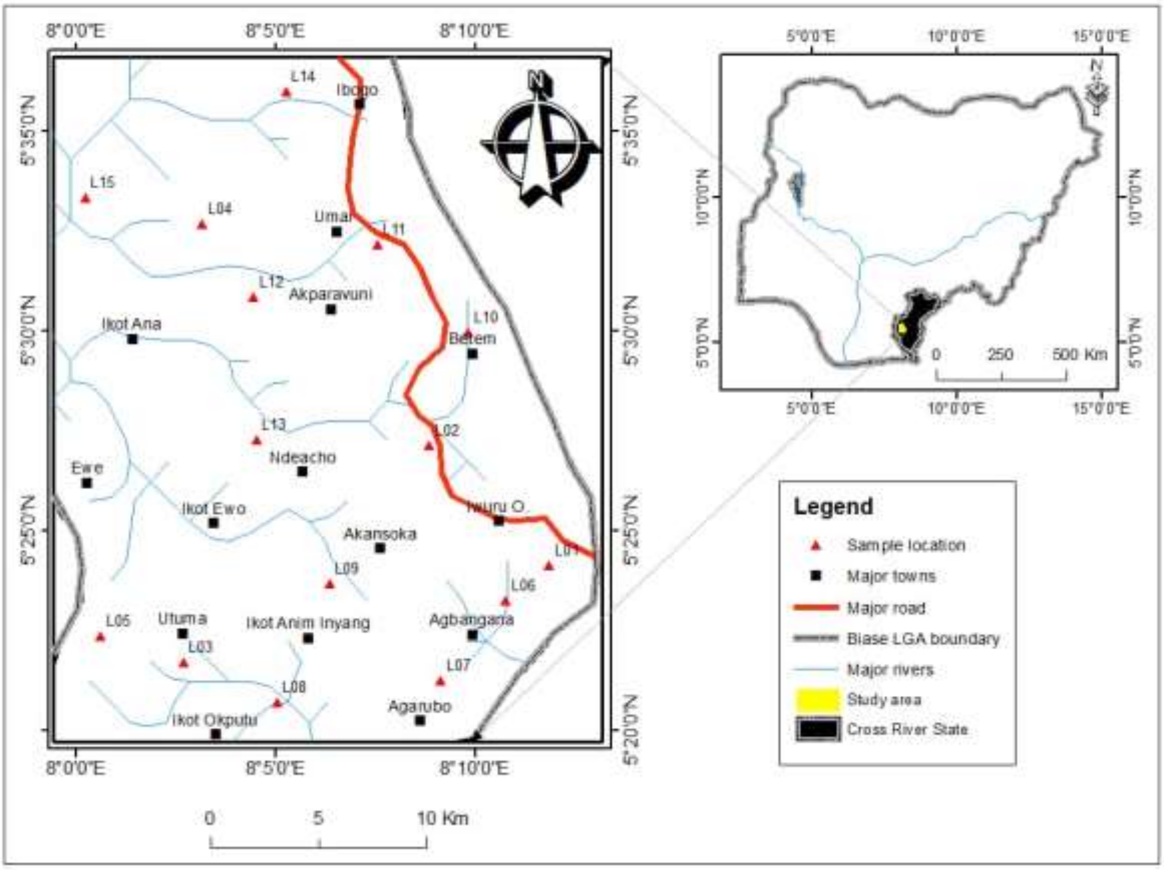

FIG.1. Sample location map of the Umai area, Oban massif, SE, Nigeria

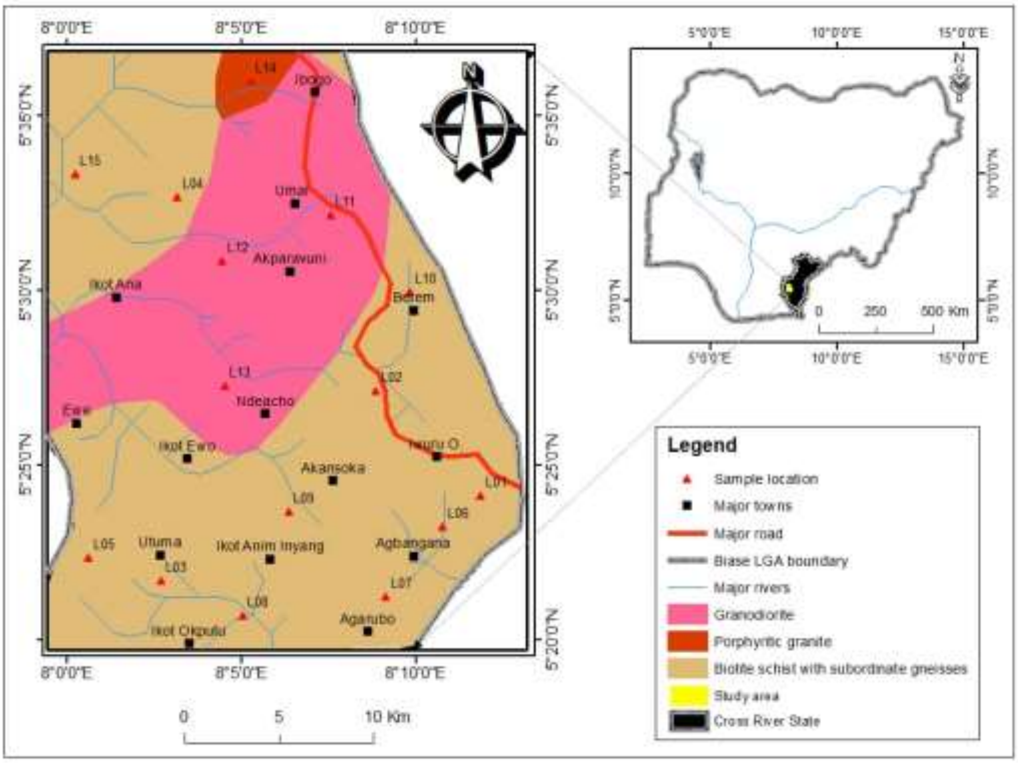

FIG. 2: Geologic map of the Umai area, Oban massif, SE, Nigeria

Generally, it has been established that the Nigerian basement complex (Figure 3) is a product of a minimum of four orogenic cycles that include major deformational episodes, metamorphism, and remobilization, conforming to the Liberian (2700 Ma), Eburnean (2000 Ma), Kibaran (1100 Ma), and Pan-African orogenies (Ajibade et al., 1988; Dada, 2006; McCurry, 1976; Rahaman, 1976). The Pan-African mobile belt, which is the most recent orogenic episode, developed during a collision involving the passive continental margin of the West African Craton and the active continental margin of the Tuareg Shield around 600 Ma ago. The Pan African event largely obliterated the imprints of earlier orogenies (Andongma et al., 2021; Dada, 2008; Obaje, 2009; Ohioma, 2020).

The African continent is underlain by three large cratons: the Congo, Kalahari, and West African cratons, which are separated from each other by a series of mobile belts that were active during the late Proterozoic times. The Nigerian Basement Complex lies to the east of the West African Craton, bounded in the southeast by the Congo Craton, and in the north by the Tuareg Shield within a mobile belt affected by the Pan-African Orogeny (600 ± 150 Ma) (Petters, 1991). These rocks are primarily exposed in the north-central and southwestern parts of Nigeria and to a lesser extent in the southeastern and northeastern parts, particularly around the Obudu and Oban Massif areas (Ukaegbu and Ekwueme, 2006).

The Precambrian pegmatites of Nigeria occur mainly as dykes that vary in length from a few meters to several kilometers and in width from a few centimeters to several meters, within the basement complex rocks (gneisses, migmatites, schists, amphibolites, and granitoids) (Okunlola and Ocan, 2009; Obaje, 2009; Omang et al., 2022; Oluwakayode et al., 2021). These pegmatites evolved during the period of 600 to 530 Ma, indicating the later stages of Pan-African magmatism.

The geological setting of Umai area, particularly within the Oban Massif (Figure 4), is characterized by a variety of rock types (Okon et al., 2022). The predominant rock types in the Umai area are phyllites, schists, and gneisses, which are intruded by granites and granodiorites (Opara et al., 2014).

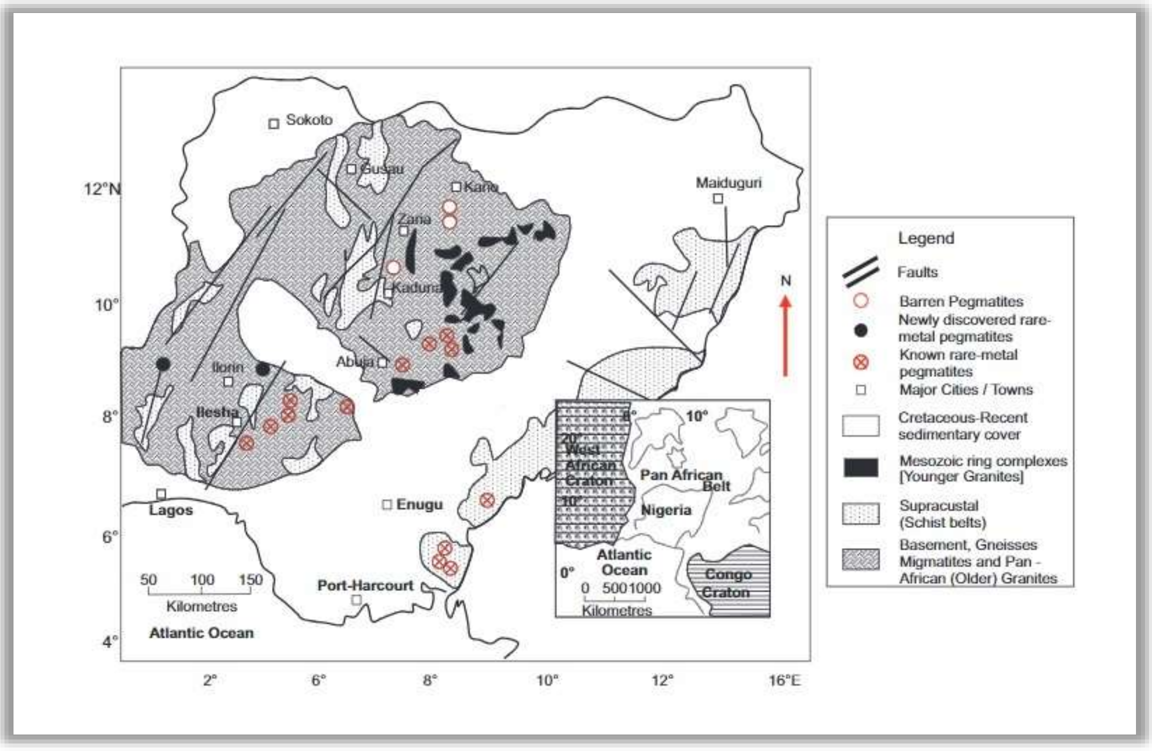

FIG.3. Geological Map of Nigeria Showing the Regional Fractures and Location of Areas of Rare-metal and Barren Pegmatites (after Garba, 2003)

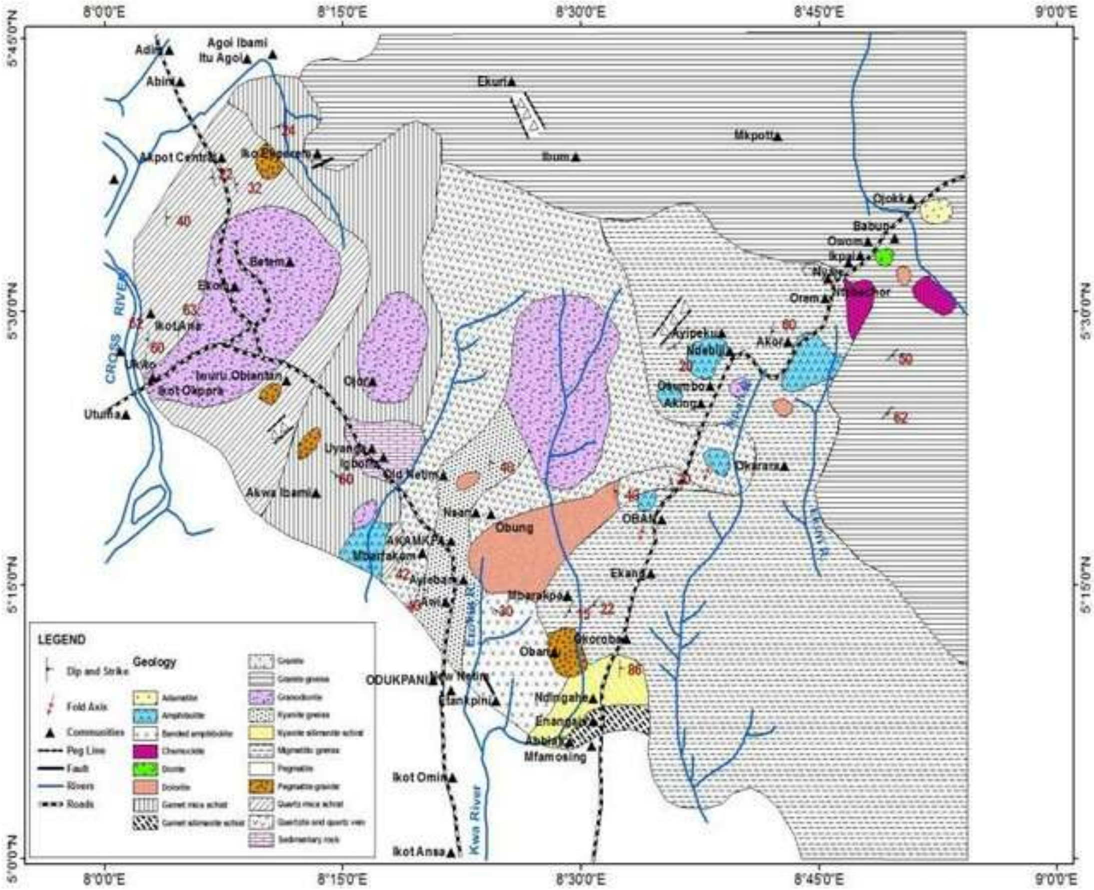

FIG. 4. The geologic map of the Oban Massif (after Ekwueme and Okoro, 2019)

MATERIALS AND METHOD

Materials

A base map at a 1:50,000 scale and a GPS device were used to locate and document sample points. Field observations were recorded in a notebook. A geologic hammer and sledgehammer were used to collect and break pegmatite outcrop samples. Samples were labeled with masking tape and marker pen and stored in sample bags to prevent contamination. In the laboratory, samples were crushed and ground into a fine powder using a mortar and pestle. A sieve was used to separate particles by size, and a weigh balance was employed to measure the mass of the pulverized samples for analysis.

Methods

Fifteen samples collected from Umai were processed in the geology laboratory at the University of Calabar. The samples were air-dried for two weeks to ensure complete dehydration. They were then crushed using a jaw crusher with a 10-mesh screen to achieve a particle size of less than 2 mm. The crushed samples were further pulverized in a porcelain mortar to achieve a fine powder of 200 mesh (less than 80 micrometers) to ensure uniformity for analysis. Each prepared sample, approximately 30 grams in weight, was sealed in a pharmaceutical bag and sent to Actlab for analysis using the inductively coupled plasma mass spectrometry (ICP-MS) technique.

RESULT AND DISCUSSION

Geochemistry of Pegmatite in Umai

The results of geochemical analysis of the Umai pegmatites, are shown in Tables 1 and 2. The show a wide spectrum of values, showcasing the diverse nature of these rocks. The silica content spans from 43.25% to 69.10%, with an average of 57.30wt%. This range suggests significant variability within the pegmatite samples, yet the average silica concentration positions them as intermediate felsic rocks, falling within the mid-range of silica content typical for such geological formations (Pagung et al., 2023). The K_2O/Na_2O ratios, which range from 5 to 51.75, show that potassium oxide (K_2O) consistently is more sodium oxide (Na_2O), indicating the prevalent presence of K-feldspars over albite within the pegmatite compositions. The alkaline index, calculated as $(Na_2O+K_2O)/SiO_2$, yields values less than one, suggesting that the pegmatites exhibit subalkaline properties (Monespérance et al., 2022). This indicates a lower proportion of alkali metals relative to silica, a feature often associated with certain rock types such as basalt and indicative of distinct geological environments

(El-Mezain et al., 2015) . Further analysis reveals that the aluminum oxide (Al_2O_3) content exceeds the combined content of calcium oxide (CaO), sodium oxide (Na_2O), and potassium oxide (K_2O), indicating peraluminous characteristics within the pegmatites. This implies an enrichment of aluminum (peraluminous) relative to other major elements, which can provide insights into the petrogenetic processes responsible for the formation of these rocks

Table 1: Major element composition of the pegmatites in Umai area, Oban massif, Southeastern Nigeria

Samples	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI	Total
UMAI 1	49.38	30.70	6.29	0.01	0.14	0.02	0.02	0.62	0.47	0.08	12.68	100.40
UMAI 2	43.27	26.40	11.20	0.05	1.27	0.03	0.17	3.08	1.33	0.23	11.60	98.62
UMAI 3	63.03	21.66	1.66	0.07	0.28	0.05	2.53	6.48	0.12	0.10	2.72	98.70
UMAI 4	51.16	30.43	0.17	0.11	0.09	0.05	0.54	10.23	0.01	0.01	5.71	98.52
UMAI 5	53.40	31.06	0.64	0.10	0.22	0.07	0.12	6.21	0.04	0.02	8.15	100.00
UMAI 6	72.90	22.50	0.18	0.19	0.10	0.10	0.60	3.00	0.15	0.16	2.50	102.38
UMAI 7	52.38	30.70	0.62	0.01	0.14	0.02	0.02	0.62	0.47	0.08	12.68	97.74
UMAI 8	53.27	26.40	0.38	0.05	1.27	0.03	0.17	3.08	1.33	0.23	11.60	97.81
UMAI 9	63.03	21.66	0.07	0.07	0.28	0.05	2.53	6.48	0.12	0.10	2.72	97.11
UMAI 10	51.16	30.43	0.10	0.11	0.09	0.05	0.54	10.23	0.01	0.01	5.71	98.44
UMAI 11	53.40	31.06	0.10	0.10	0.22	0.07	0.12	6.21	0.04	0.02	8.15	99.49
UMAI 12	57.20	28.50	0.30	0.19	0.10	0.02	0.20	5.00	0.20	0.09	7.70	99.50
UMAI 13	61.50	27.00	0.20	0.15	0.10	0.03	0.30	4.50	0.10	0.11	6.40	100.39
UMAI 14	65.30	25.50	0.10	0.09	0.10	0.05	0.40	4.00	0.21	0.18	5.10	101.03
UMAI 15	69.10	24.00	0.18	0.09	0.10	0.07	0.50	3.50	0.12	3.12	3.80	104.58
Mean	57.30	27.20	1.48	0.09	0.30	0.05	0.58	4.88	0.31	0.30	7.15	99.65

Table 2: Trace element composition of the pegmatites in Umai area, Oban massif, Southeastern Nigeria

Sample	Be	Sc	Cr	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Y	Zr	Mo	Nb
UmaiP 1	2	0.5	20	5	20	10	50	2	0.5	100	200	10	100	2	4
UmaiP 2	4	1	40	15	40	20	90	4	1	200	400	20	200	1.5	12
UmaiP 3	3	0.5	30	10	30	15	70	3	0.5	150	300	15	150	2	3
UmaiP 4	6	2	60	25	60	30	130	6	2	300	600	30	300	2	14
UmaiP 5	7	2.5	70	30	70	35	150	7	2.5	350	700	35	350	1.6	29
UmaiP 6	5	1.5	50	20	50	25	110	5	1.5	250	500	25	250	2	7
UmaiP 7	8	3	80	35	80	40	170	8	3	400	800	40	400	1.9	10
UmaiP 8	9	3.5	90	40	90	45	190	9	3.5	450	900	45	450	1.5	14
UmaiP 9	2	8.1	51	1	8	37	16	8	3	70	307	16	155	2	22
UmaiP 10	6	24.3	153	19	58	90	110	3	3	140	19	59	321	2	3
UmaiP 11	54	4.4	14	1	12	6	125	2	3	1320	47	1	58	2	11
UmaiP 12	17	0.7	1	1	3	7	86	2	3	650	52	5	4	2	9
UmaiP 13	15	2.5	1	1	4	3	77	2	3	570	45	13	40	2	2
UmaiP 14	9	2.1	15	5	11	14	22	4	2	110	89	15	221	2	17
UmaiP 15	12	1.7	25	17	9	11	30	3	2	187	56	19	35	2	24

Table 2: Trace element composition of the pegmatites in Umai area, Oban massif, Southeastern Nigeria (Contd.

Sample ID	Ag	Cd	Sb	Cs	Ba	Bi	Br	Hf	Ta	Th	U	V	W
UmaiP 1	0.5	0.2	1.1	5	100	0.2	1	1.1	2	0.5	0.2	50	10
UmaiP 2	0.5	0.4	3.5	10	200	0.4	2	1.3	4	0.9	0.4	70	14
UmaiP 3	0.5	0.3	2	8	150	0.3	1.5	3.2	3	0.7	0.3	60	12
UmaiP 4	0.5	0.6	5	15	300	0.6	3	5.2	6	1.3	0.6	90	18
UmaiP 5	0.5	0.7	6	20	350	0.7	3.5	2.6	7	1.5	0.7	100	20
UmaiP 6	0.5	0.5	4	12	250	0.5	2.5	4.1	5	1.1	0.5	80	16
UmaiP 7	0.5	0.8	7	25	400	0.8	4	4.7	8	1.7	0.8	110	22
UmaiP 8	0.5	0.9	8	30	450	0.9	4.5	5.8	9	1.9	0.9	120	24
UmaiP 9	0.5	0.5	0.2	3.3	31	2	1	4.3	3	15.8	5.9	65	3
UmaiP 10	0.5	0.5	0.2	14.8	600	2	1	8.3	1	19	5.9	199	3
UmaiP 11	0.5	0.5	1.2	71.9	114	2	1	2.9	38	5.2	1.5	17	3
UmaiP 12	0.5	0.5	51.4	3500	52	2	1	0.5	155	0.5	0.5	5	3
UmaiP 13	0.5	0.5	9.5	682	128	8	1	1.2	51	2.9	4.8	6	3
UmaiP 14	0.5	0.6	4.8	14	112	4	1.2	2.1	32	3.8	3.6	57	2
UmaiP 15	0.5	0.5	30	20	132	2	1.4	3	52	6	2.9	48	2

The Aluminum Saturation Index (ASI), calculated as $Al_2O_3/(CaO+Na_2O+K_2O)$, consistently exceeds one, confirming the peraluminous nature of the Umai pegmatites. This reinforces the dominance of aluminum in relation to other major elements and solidifies the classification of these rocks within the peraluminous category(Castro, 2020). Comparatively, the mean SiO_2 content of the Umai Pegmatites is notably lower than that of several other localities, including Uyanga, Akwa-Ibami (I&II), Igbofia, and Iwuru (I&II), as reported by Ero and Ekwueme (2009). Additionally, the Na_2O content is slightly lower compared to that of these localities, albeit with a higher MgO content. However, the concentrations of other elements appear to be similar across these locations. The distribution of the major oxides and trace elements of Umai pegmatites is depicted in Figure 5,6 and 7.

The trace element analysis presented in Table 2 reveals elevated concentrations of Rb, Ba, Zr, Sr, Cs, Zn, and V, with average values of 949.80ppm, 224.60ppm, 202.27ppm, 334.33ppm, 295.40ppm, 95.07ppm, and 71.80ppm, respectively. Other trace elements exhibit concentrations below 50ppm.

Notably, the Ta concentration in the Umai pegmatites (25.07ppm) is significantly higher than that of several other localities, suggesting potential differences in mineralization patterns across these regions.

Comparing the elemental concentrations with data from the Upper Crust (Taylor and McLennan, 1981), it is observed that the Umai pegmatites exhibit lower average concentrations of Ba, Zr, Sr, Th, and U, but higher concentrations of V. This suggests that the magma source for the Umai pegmatites may not originate from the upper crust (Taylor and McLennan, 1981).

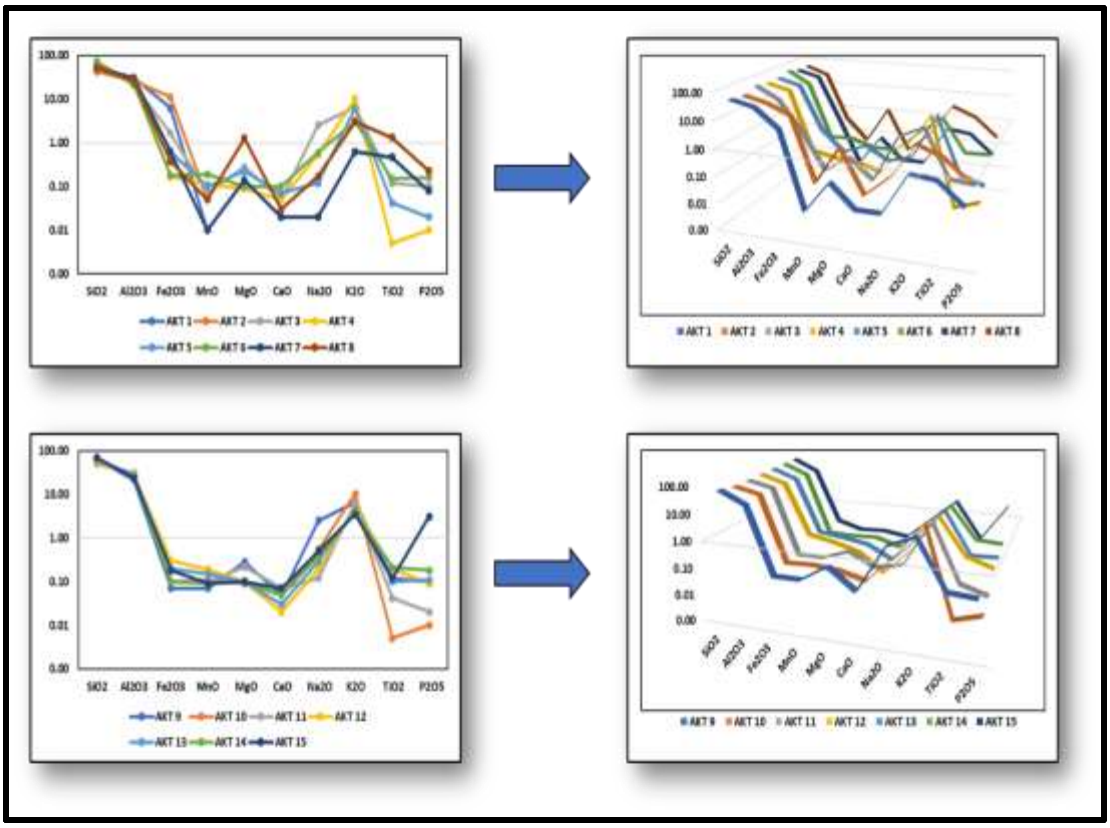

FIG.5. 2D and 3D distribution plot of major elements in Umai pegmatites, Oban massif, S.E. Nigeria

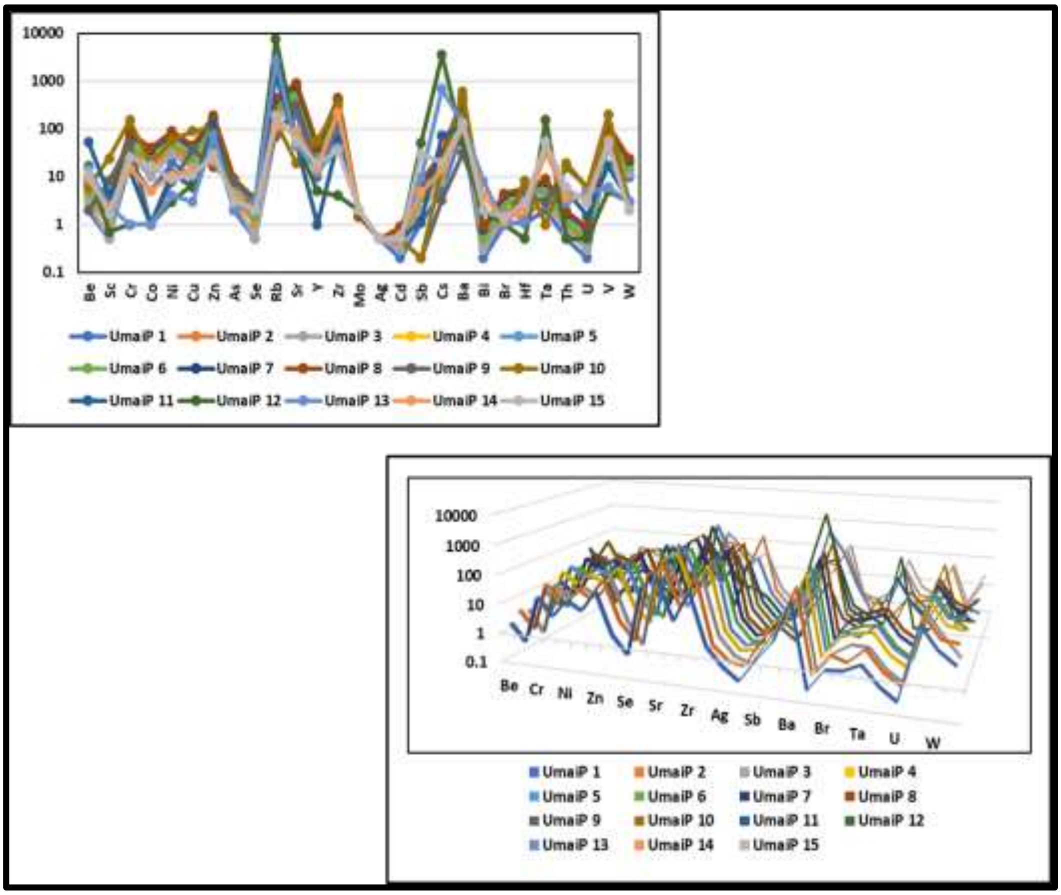

FIG.6. 2D and 3D distribution plot of trace elements in Umai pegmatites, Oban massif, S.E. Nigeria

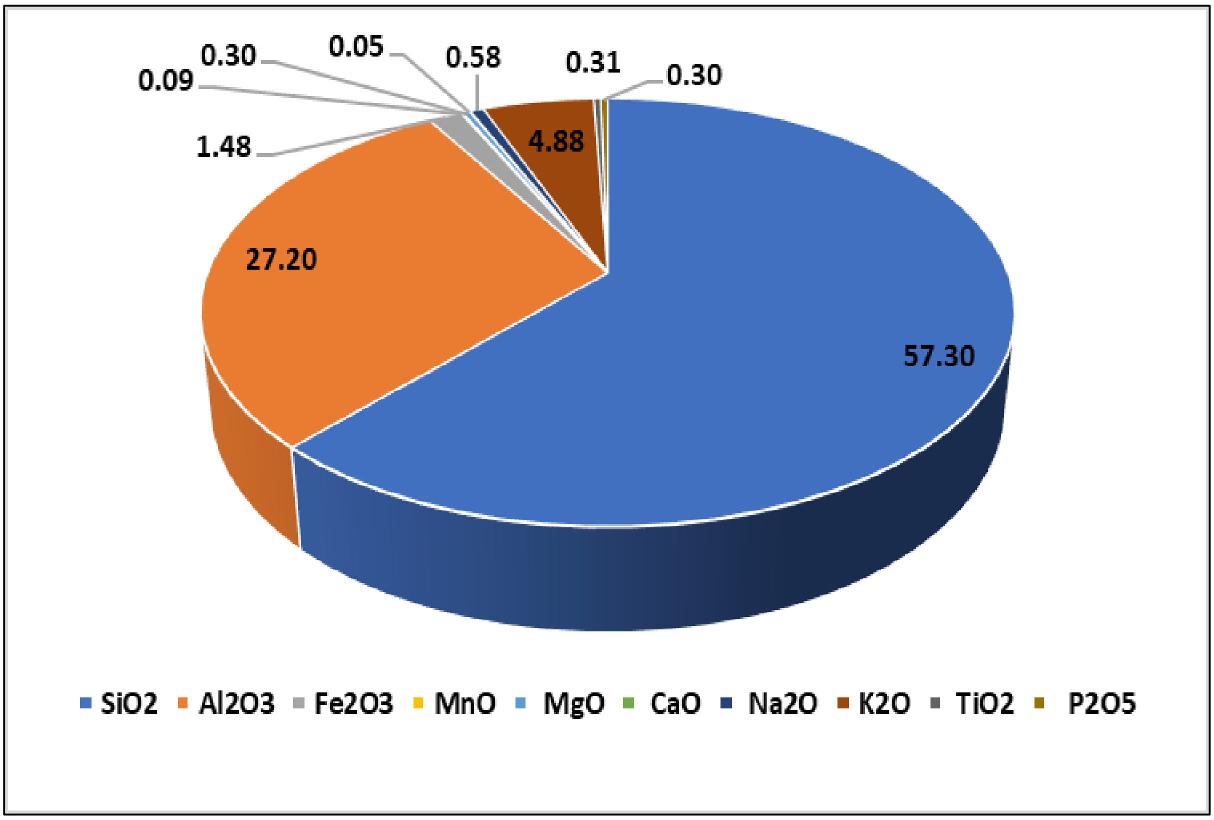

FIG.7. Pie chart showing the major element distribution in Umai pegmatites, Oban massif, S.E. Nigeria

The elevated concentration of Cs in the Umai pegmatites compared to the Upper Crust suggests potential pollucite mineralization, indicating the presence of unique geological processes or mineralization events within the Umai pegmatite deposits (Taylor and McLennan, 1981).

3.2 Petrogenesis of the Pegmatites in Umai

The petrogenesis of the Umai pegmatites, as inferred from the various geochemical analyses conducted, provides valuable insights into their origin and formation processes. The use of discrimination plots and diagrams has proven instrumental in unraveling the geological history of these rocks within the study area. The Pearson's correlation matrix for the major oxides of the pegmatites in Umai given in Table 3, is significant at the 0.05 level (two-tailed). Correlation coefficient (r) close to 1 indicates a strong correlation, "r" around 0.7 to 0.9 indicates a moderate to strong correlation, "r" around 0.5 to 0.7 signifies a moderate correlation. "r" around 0.3 to 0.5 signifies weak to moderate correlation. "r" below 0.3 signifies weak correlation (Schober et al., 2018).

Pearson's correlation coefficient (r) gives insight into the evolutionary history of the melt that led to their formation. Notably, SiO_2 and Al_2O_3 (-0.71561), show a moderate to strong negative correlation. In petrology, negative correlation entails the crystallization of minerals. As mineral components crystallize, it is believed that the element will become depleted gradually in the melt relative to others. While positive correlation entails that the elements are still enriched in the melt. With continuous crystallization, these elements become completely depleted. This moderate to strong correlation indicates the crystallization of feldspar minerals. The weak correlation between SiO_2 and K_2O (-0.07555), shows crystallization of a potassium end-member (orthoclase). It could also reflect the crystallization of muscovite. The moderate correlation existing between SiO_2 and Fe_2O_3 (-0.55923), and the weak to moderate negative correlation between SiO_2 and MgO (-0.44588), reflects the crystallization of biotite.

Table 3: Pearson's Correlation Coefficient Matrix for Major oxides (wt.%) of Umai Pegmatites

	SiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5
SiO2	1									
Al2O3	-0.71561	1								
Fe2O3	-0.55923	0.050719	1							
MnO	0.482431	-0.15634	-0.43737	1						
MgO	-0.44588	-0.13786	0.560973	-0.37264	1					
CaO	0.576038	-0.31248	-0.36171	0.438116	-0.28128	1				
Na2O	0.406272	-0.71228	-0.16572	-0.03131	-0.09318	0.182862	1			
K2O	-0.07555	0.106772	-0.36643	0.368545	-0.23528	0.283584	0.340979	1		
TiO2	-0.46558	-0.04671	0.633766	-0.47296	0.926798	-0.46179	-0.27371	-0.50847	1	
P2O5	0.411831	-0.30072	-0.07761	-0.02505	-0.07373	0.254038	-0.03023	-0.18581	-0.05196	1

The Harker's plots for the oxides as observed in Figure 8, is a graphical representation of Pearson's correlation matrix. The coefficient of determination (R^2) analysis shed light on the crystallization sequence within the pegmatites, with a notable proportion of Al_2O_3 (51%) crystallizing from the melt along with other elements such as Fe_2O_3 (31%), MgO (19.88%), and K_2O (0.57%)(Irvine and Baragar, 1971). This reflects that the dominant mineral that crystallized is feldspar (specifically orthoclase), followed by biotite, and then muscovites. These mineral assemblages further support the classification of the Umai pegmatites as Granodioritic Pegmatites, consolidating the interpretations derived from the discrimination plots and diagrams

The AFM plot analysis revealed that a significant proportion of the samples clustered within the calc-alkaline magmatic field (Figure 9). This observation strongly suggests that the Umai pegmatites crystallized from a calc-alkaline magma source. This melt is more enriched in sodium (Na) and potassium (K) compared to the tholeiitic series composed mainly of iron (Fe) and magnesium (Mg). Calc-alkaline magmas are commonly associated with subduction zone settings, where the influx of fluids from the subducted slab influences magma composition and characteristics (Ernst, 2010).

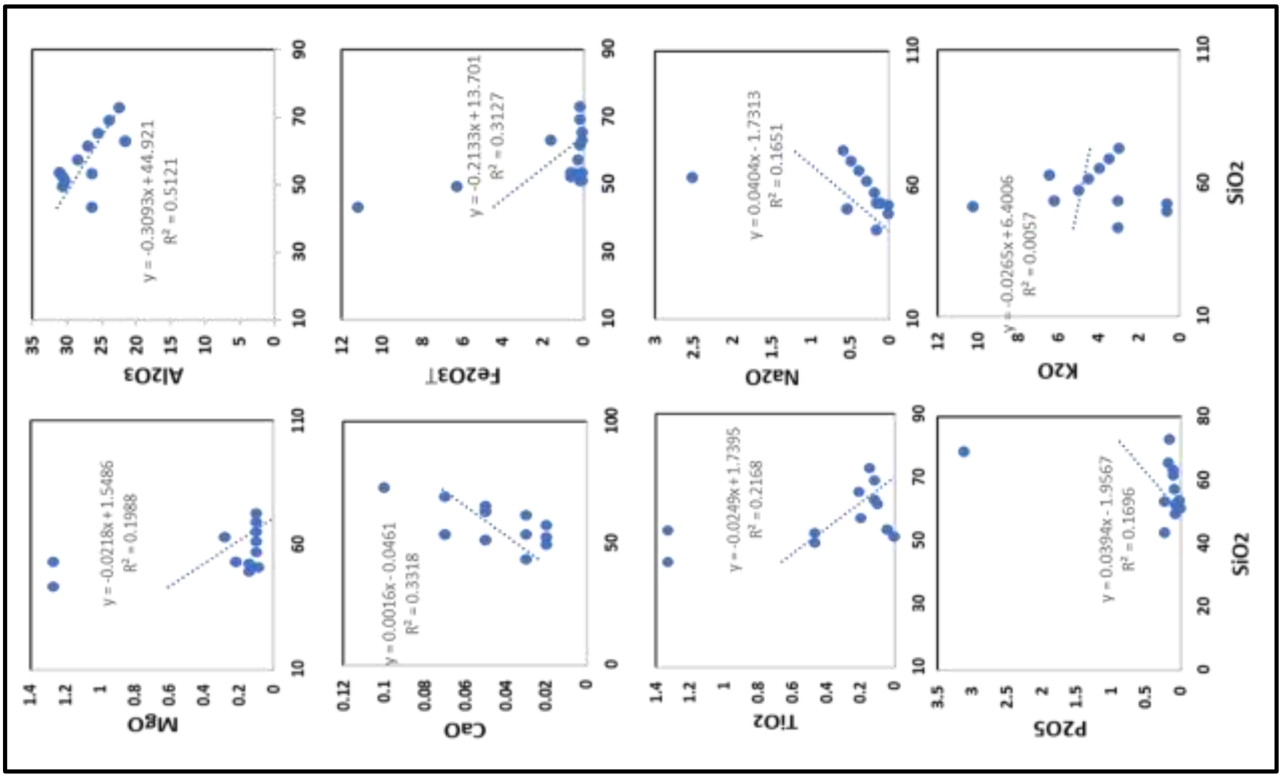

FIG.8. Harker's variation diagram of silica (SiO_2) versus major elements for the pegmatites of Umai area, Oban massif, SE, Nigeria

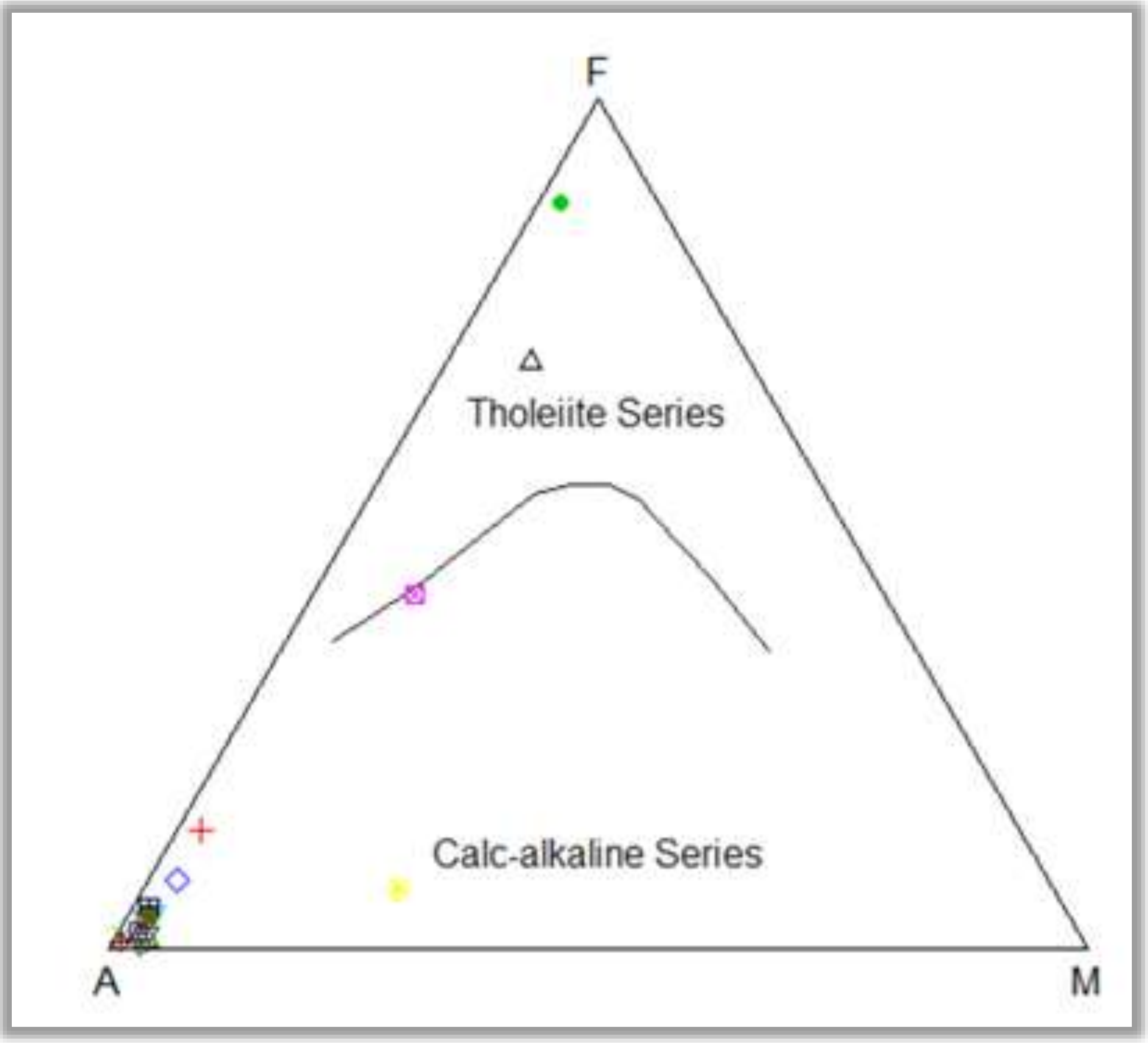

FIG.9. AFM diagram for pegmatites in the Umai area discriminating calc-alkaline magma field from tholeiitic magma field (fields after Irvine and Baragar 1971)

The molar Na_2O-Al_2O_3-K_2O plot is a powerful tool used in petrology to discriminate between different types of magmatic compositions, particularly peraluminous, metaluminous, and peralkaline compositions (Figure 10). This plot utilizes the molar ratios of major oxides, namely sodium oxide (Na_2O), aluminum oxide (Al_2O_3), and potassium oxide (K_2O), to characterize the chemical characteristics of igneous rocks and discern their petrogenetic origins. Peraluminous rocks are those with an "excess" of alumina (Benaouda et al., 2022). The aluminum oxide content (Al_2O_3) is greater than the combined concentration amount of sodium and potassium oxides (Na_2O + K_2O) present in the rock [Al_2O_3 > (Na_2O + K_2O)]. Granites, for example, fall into the peraluminous category. For metaluminous rocks, the concentration of aluminum oxide (Al_2O_3) is roughly equal to the total of sodium and potassium oxides (Na_2O + K_2O). It can be represented as Al_2O_3 ≈ (Na_2O + K_2O). Basalts and some types of andesite are often classified as metaluminous. In Peralkaline rocks, the combined concentration of sodium and potassium oxides (Na_2O + K_2O) is greater than that of aluminum oxide content (Al_2O_3). Syenites and some pegmatites can be classified as peralkaline. The molar plot of Na_2O-Al_2O_3-K_2O indicated the possible crystallization of the pegmatites from a metaluminous to peraluminous-rich melt. Metaluminous and peraluminous melts, characterized by their aluminum content, offer further insights into the composition of the parental melt from which the pegmatites derived. This suggests that the melt may have been enriched in aluminum (feldspar minerals).

Furthermore, the Rb Vs Sr discrimination plot provides valuable information regarding the emplacement depth of the Umai pegmatites (Figure 11). The positioning of the pegmatites in

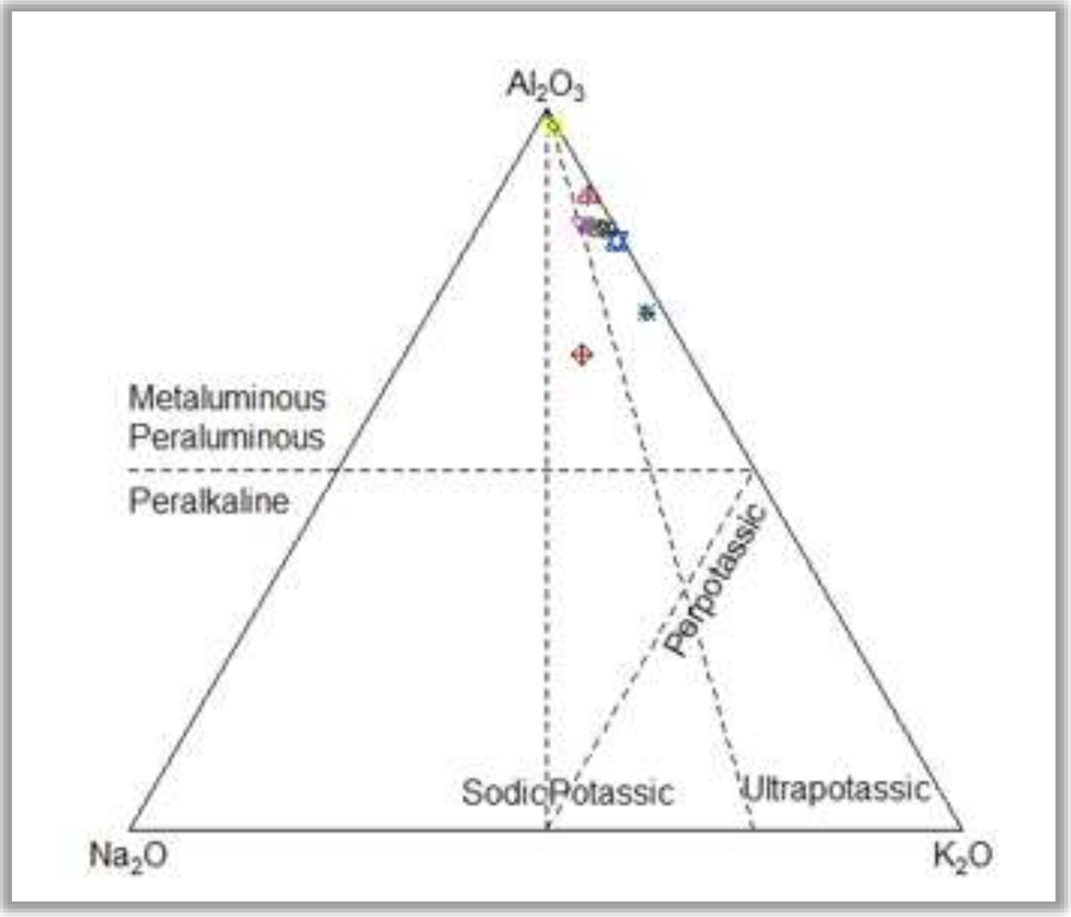

FIG.10. Molar Na_2O-Al_2O_3-K_2O plot discriminating metaluminous, peraluminous, and peralkaline compositions (Jayeola et al., 2023)

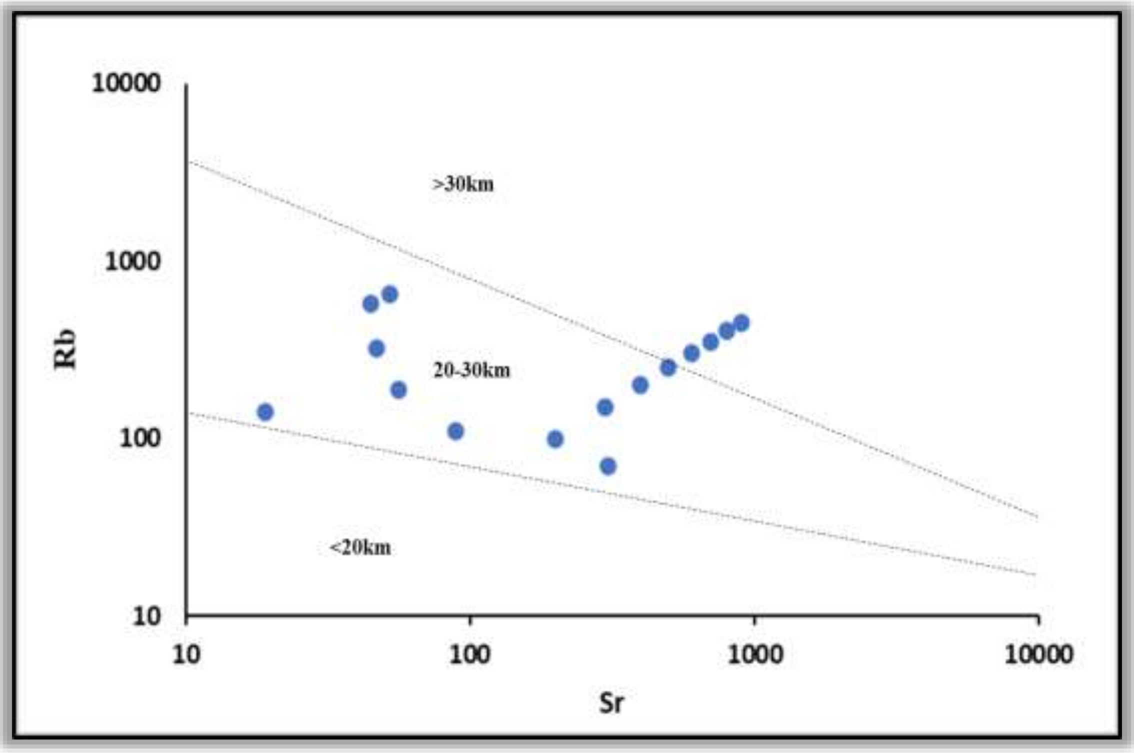

FIG.11. Rb Vs Sr depth classification of Umai pegmatites (Fields after Condie, 1981)

this plot suggests emplacement at depths ranging between 20-30 km within the Earth's crust. Such depths indicate significant geological processes and tectonic activity that likely played a role in the formation and subsequent exposure of the pegmatites. The geochemical classification diagram of Na_2O+ K_2O versus SiO_2, developed by Cox et al. (1979), is a fundamental tool in igneous petrology for classifying and characterizing igneous rocks based on their major element compositions (Bonin, et al., 2020). This diagram provides insights into the origin, and evolution of igneous rocks by plotting the molar sum of sodium oxide (Na_2O) and potassium oxide (K_2O) against silica (SiO_2) content. Na_2O+ K_2O vs. SiO_2 plot, based on established diagrams, indicated characteristics similar to granodioritic composition for the pegmatites (Figure 12). The TAS (Total Alkali-Silica) classification diagram, developed by Middlemost (1994), is a widely used tool for classifying igneous rocks based on their major element composition. It is commonly used for granitoid (igneous rocks with a high content of quartz and feldspar). Most of the data points plots in the granodiorite field, further affirming a granodioritic composition (Figure 13). This implies that the pegmatites originated from a parent granodioritic melt.

Mineralization Potential of the pegmatites in Umai

Indices of fractionation, such as Ba/Rb, K/Rb, Na/K, K/Cs, and K/Ba, are valuable tools in geochemical analysis, particularly in understanding the processes of mineralization within pegmatites(Wise and Brown, 2012). Pegmatites form from highly fractionated magmas that have undergone extensive crystal fractionation. This process involves the selective crystallization and settling of minerals from the melt, leading to the enrichment of certain elements in the residual melt that eventually solidifies into pegmatites. The more fractionated the pegmatites, the more the mineralization potential of the pegmatites. Lower values of

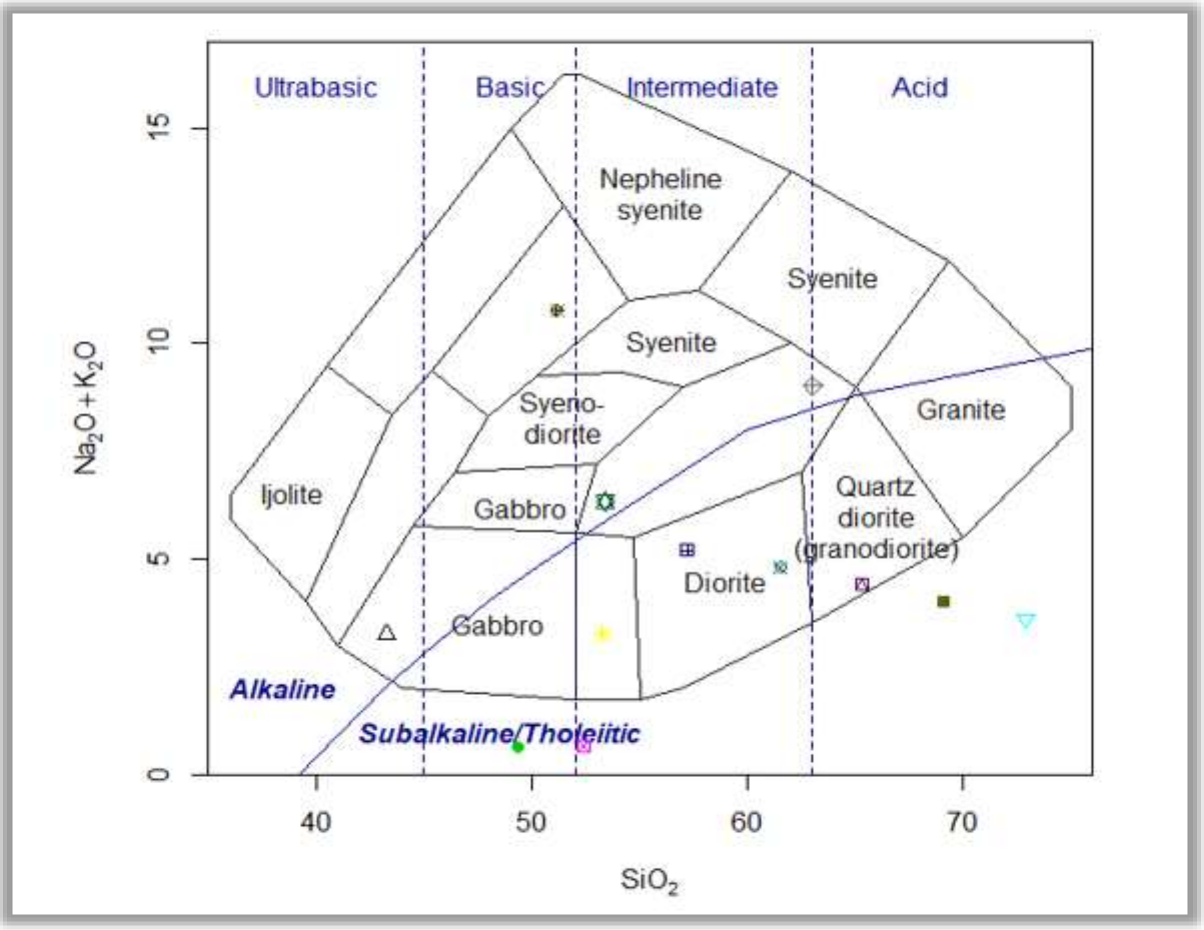

FIG. 12. Geochemical classification diagram (Cox et al., 1979) for pegmatite samples of Umai. The curved solid line (after Irvine and Baragar, 1971) subdivides the alkalic from subalkalic rocks

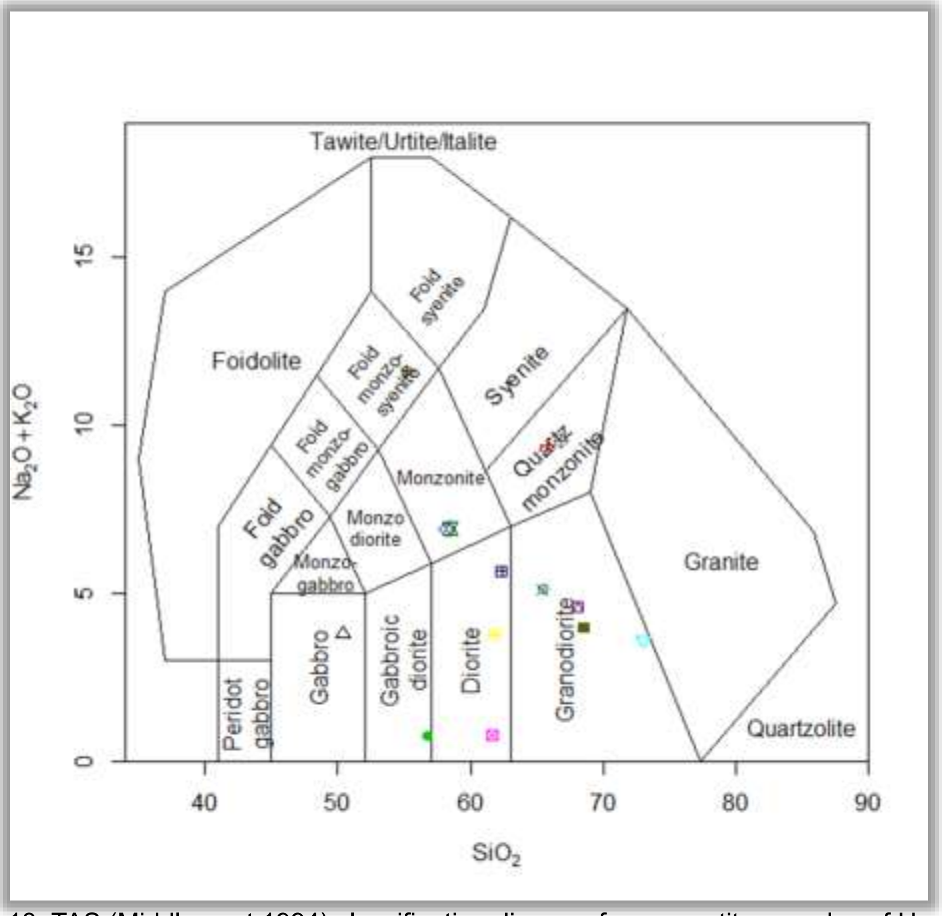

FIG.13. TAS (Middlemost 1994) classification diagram for pegmatite samples of Umai.

Ba/Rb, K/Rb, Na/K, K/Cs, and Ta/Cs indicates that the pegmatites are highly fractionated, and thus mineralized. While, higher values of Ba/Rb, K/Rb, Na/K, K/Cs, and K/Ba indicate that the pegmatites are not highly fractionated, and hence barren (Edem et al., 2015). Adetunji and Ocan (2010), also stated that the K/Rb ratio of pegmatite samples less than a hundred (<100) are mineralized, while those greater than hundred (>100) are barren. The indices of fractionation for the analyzed pegmatite samples are given in Table 4. The values of Ba/Rb, K/Rb, Na/K, K/Cs, Nb/Ta, and Ta/Cs are considerably low, and this implies that the pegmatites in Umai are highly fractionated and thus mineralized. The trend of increasing fractionation is from Umai 1 to Umai 15. Dostal and Gerel (2022), highlighted that Nb/Ta less than one (<1) are indicative of tantalite mineralization, while Van Lichtervelde et al. (2007), stated that Nb/Ta greater than one (>1) are indicative of columbite mineralization. From Table 4, Umai11, Umai12, Umai13, Umai14, and Umai15, are less than one (<1) indicative of tantalite mineralization. While Umai1, Umai2, Umai3, Umai4, Umai5, Umai6, Umai7, Umai8, Umai9 and Umai10 are greater one (>1) indicative of columbite mineralization. The degree of albitization, Na/K ratio, has been used to indicate fractionation and hence mineralization (Jacobson and Webb, 1946; Dekun, 1965). The average albitization index (0.1) is lower than that of Central Nigeria (Okunlola and Somorin, 2006) and that of Southwest Nigeria (Matheis, 1985) whose values are 0.86 and 0.52, respectively. These places currently are mining tin. Thus, can be used to predict the tin mineralization in the pegmatites of Umai. From this analysis, these pegmatites may be a possible host of tin mineralization.

Various discrimination plots have also been used to assess the mineralization potential of pegmatites. These plots help differentiate between potentially mineralized and barren pegmatites based on their geochemical composition (Okonkwo and Idakwo, 2020). Commonly used plots include:

LCT (Lithium-Cesium-Tantalum) vs. NYF (Niobium-Yttrium-Fluorine) Classification: This plot separates pegmatites enriched in lithium, cesium, and tantalum (LCT) from those enriched in niobium, yttrium, and fluorine (NYF). LCT pegmatites are often more prospective for lithium, cesium, and tantalum mineralization, while NYF pegmatites might be more promising for niobium and rare earth elements (REE). The Umai pegmatites are classified within the LCT (lithium-cesium-tantalum) family.

K/Rb vs. Various Elements: Plots like K/Rb vs. Ga (Gallium), K/Rb vs. Rb or K/Rb vs. Cs (Cesium) can help discriminate between barren and potentially mineralized pegmatites.

Ta vs. K/Cs: This discrimination plot helps to discriminate pegmatites that are tantalite mineralized from those that are not.

In this study, the discrimination plots employed are the K/Rb vs. Rb discrimination plot by Staurov *et al.,* (1969), the K/Rb vs. Cs plot by Cerny, (1982); Morteani et al., (2000), the Be vs. K/Nb plot by Beus, (1966), and the plot of Ta vs. K/Cs by Beus, (1966). The K/Rb vs. Rb discrimination plot discriminating barren and mineralized pegmatites as shown in Figure 14, reveals that the pegmatites in Umai are mineralized. The K/Rb vs. Cs plot discriminating between rare metal pegmatites from those of barren ones as seen in Figure 15, shows that the pegmatites in Umai belong to the rare metal pegmatite class, except samples like Umai 1, Umai 2, Umai 3, and Umai 9 samples which fall in the barren class. The Plot of Be vs. K/Nb by Beus (1966), reveals that all the samples do not have an affinity for beryllium mineralization except for Umai 11 (Figure 16). The Plot of Ta vs. K/Cs by Beus (1966) as seen in Figure 17, shows that only Umai 11, Umai 12, Umai 13, Umai 14, and Umai 15 have affinity for tantalite mineralization. This is consistent with the Nb/Ta ratios given in Table 4.

Spider plots of the rare earth elements normalized to that of chondrite by Taylor and McLennan (1985), as seen in Figure 18, show the enrichment of LREE over HREE

Table 4: Elemental ratios of major and trace elements in the analyzed pegmatites of Umai, Oban Massif, Southeastern Nigeria

Ratio	UMAI 1	UMAI 2	UMAI 3	UMAI 4	UMAI 5	UMAI 6	UMAI 7	UMAI 8	UMAI 9	UMAI 10	UMAI 11	UMAI 12	UMAI 13	UMAI 14	UMAI 15	Mean
Na/k	0.03	0.05	0.35	0.05	0.02	0.18	0.03	0.05	0.35	0.05	0.02	0.04	0.06	0.09	0.13	0.10
K/Rb	0.01	0.01	0.04	0.03	0.01	0.01	0.00	0.01	0.08	0.06	0.00	0.00	0.00	0.03	0.02	0.02
K/Cs	0.10	0.26	0.67	0.57	0.26	0.21	0.02	0.09	1.63	0.57	0.07	0.00	0.01	0.24	0.15	0.32
K_2O/Na_2O	31.00	18.12	2.56	18.94	51.75	5.00	31.00	18.12	2.56	18.94	51.75	25.00	15.00	10.00	7.00	20.45
Rb/Cs	20.00	20.00	18.75	20.00	17.50	20.83	16.00	15.00	21.21	9.46	18.36	2.19	3.77	7.86	9.35	14.68
Nb/Ta	2.00	3.00	1.00	2.33	4.14	1.40	1.25	1.56	7.33	3.00	0.29	0.06	0.04	0.53	0.46	1.89
Rb/Sr	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.23	7.37	28.09	147.12	57.11	1.24	3.34	16.57
Ta/Cs	0.40	0.40	0.38	0.40	0.35	0.42	0.32	0.30	0.91	0.07	0.53	0.04	0.07	2.29	2.60	0.63
Sr/Eu	285.71	142.86	3000.00	6000.00	875.00	625.00	727.27	562.50	767.50	10.56	33.57	173.33	450.00	171.15	51.85	925.09
Ba/Rb	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.44	4.29	0.09	0.01	0.05	1.02	0.71	0.97

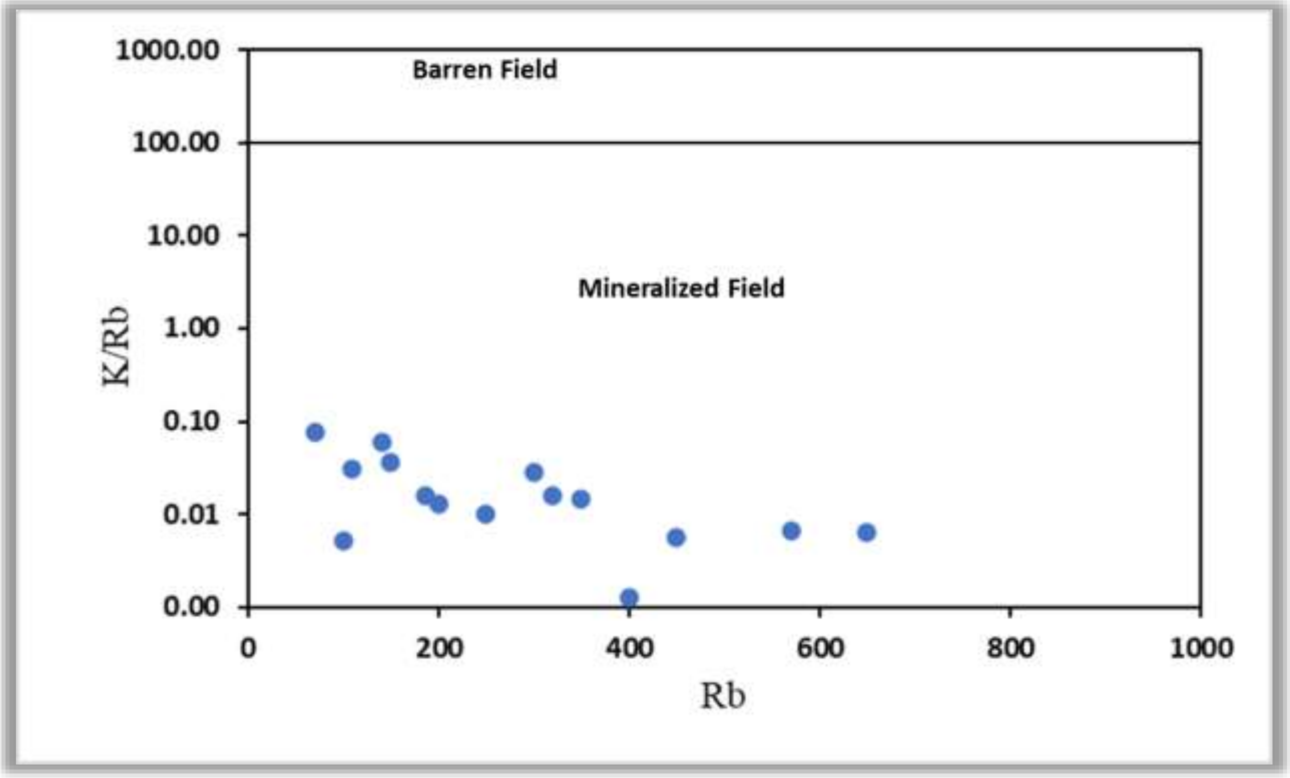

FIG. 14. K/Rb vs. Rb distribution pattern in the pegmatites of Umai, southeastern Nigeria showing barren and mineralized pegmatites (fields after Staurov *et al.,* 1969)

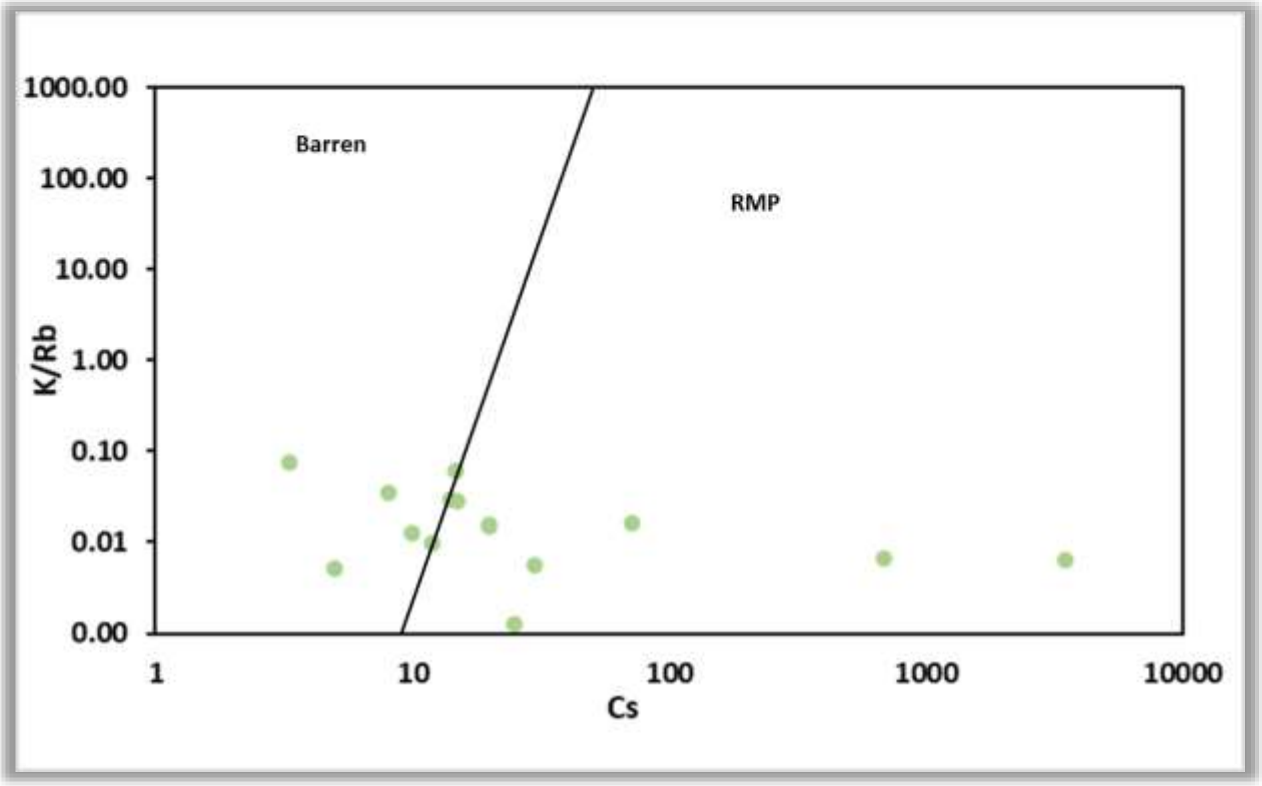

FIG. 15. K/Rb vs. Cs plot of pegmatites from Umai, southeastern Nigeria. The discrimination line separates the fields of rare metal pegmatites from those of barren ones (fields after Cerny, 1982; Morteani and Horn, 2000).

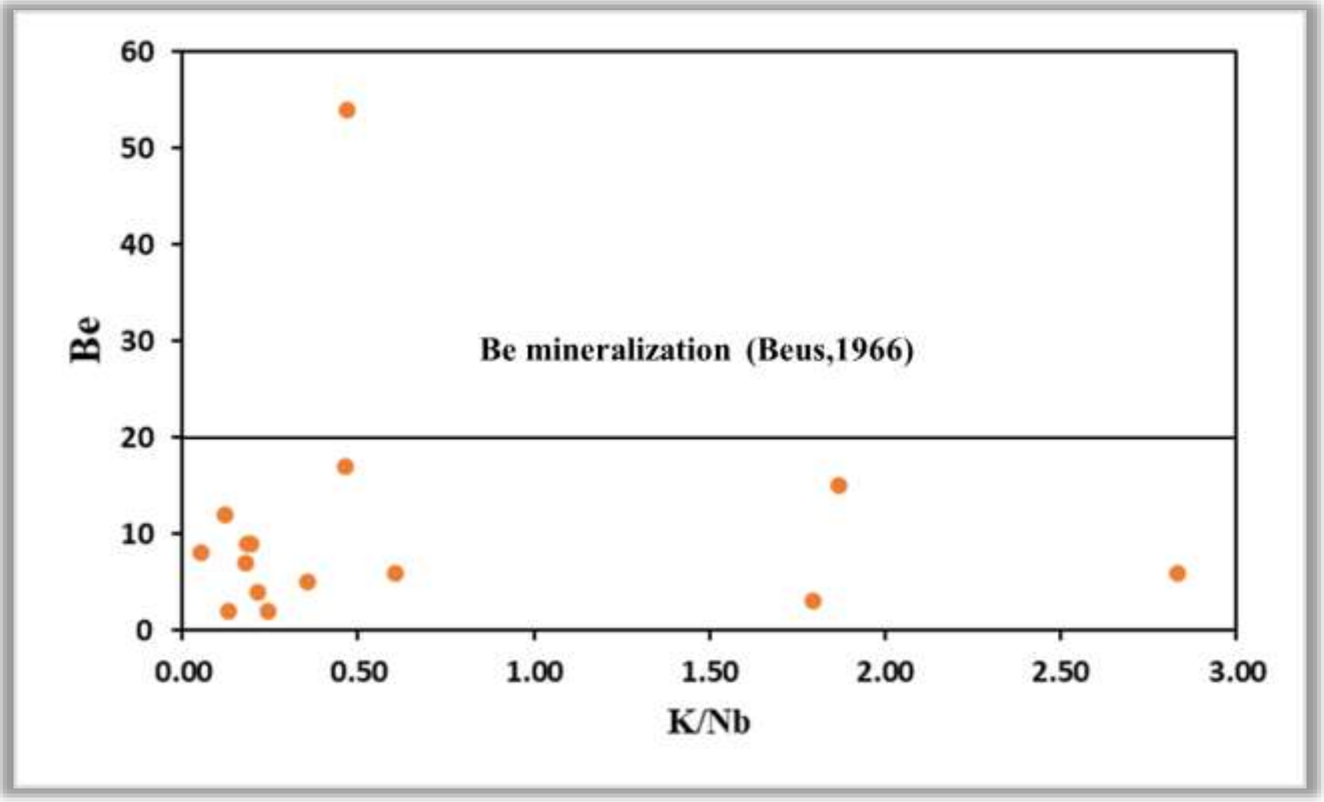

FIG. 16. Plot of Be vs. K/Nb to determine the Beryllium potential of the Umai pegmatites (field after Beus, 1966).

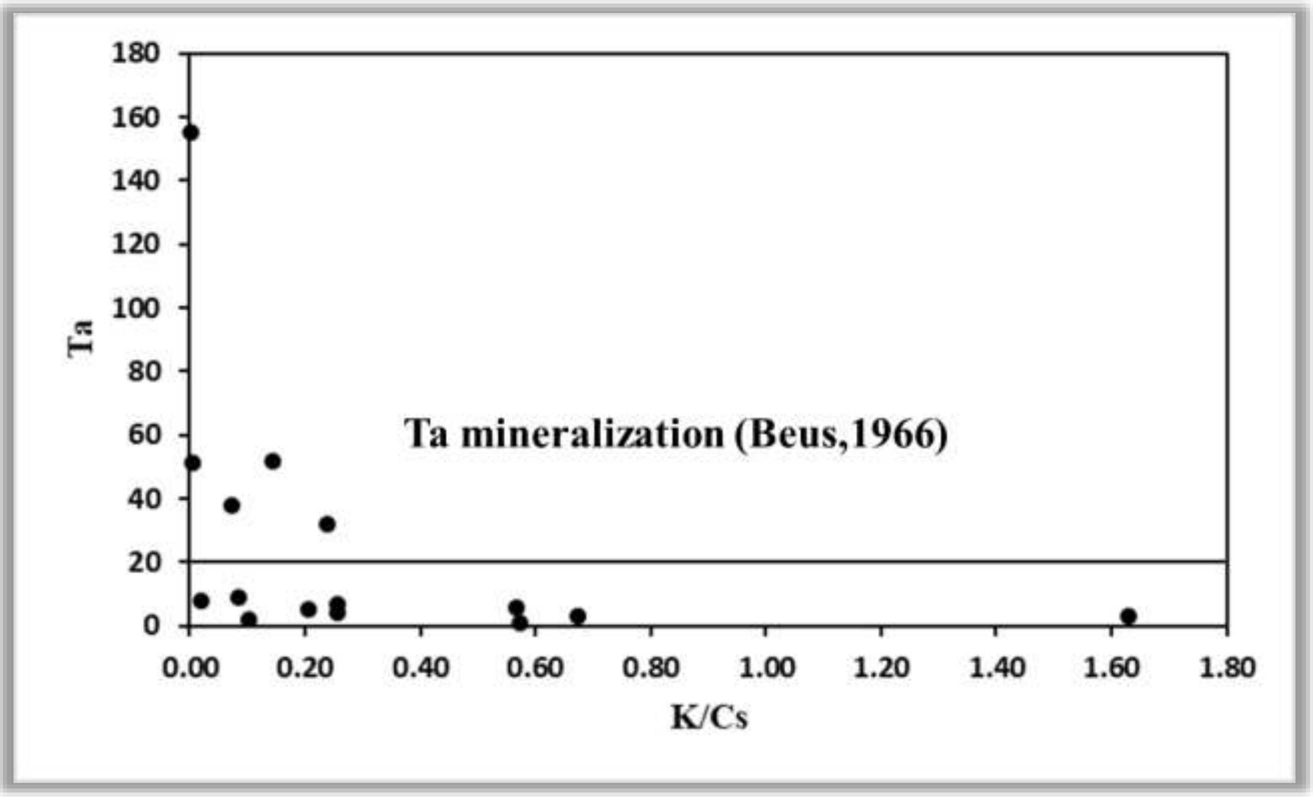

FIG. 17. Plot of Ta vs. K/Cs to determine the Tantalum potential of the Umai pegmatites (field after Beus, 1966).

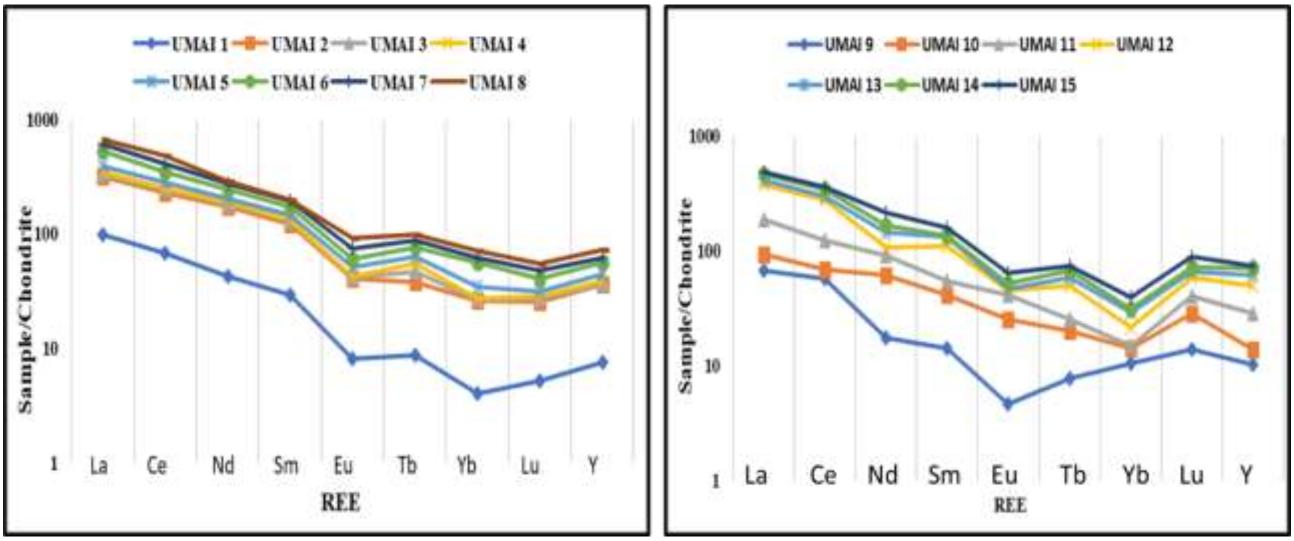

FIG. 18. Rare-earth elements chondrite-normalized plots for samples of Umai pegmatites (Normalizing data from Taylor and McLennan, 1985)

CONCLUSION

The geochemical analysis conducted on the Umai pegmatites presents a comprehensive understanding of their composition and mineralization potential. The pegmatites exhibit a wide range of silica content, spanning from 43.25% to 69.10%, indicating their intermediate felsic nature. This variation suggests significant heterogeneity within the samples, but the average silica concentration positions them within the mid-range typical for such geological formations. Examining the K_2O/Na_2O ratios reveals a consistent dominance of potassium oxide (K_2O) over sodium oxide (Na_2O), indicating the prevalence of K-feldspars over albite in the pegmatite compositions. This mineralogical characteristic shed light on the geological processes associated with the formation of these rocks. The alkaline index, calculated as $(Na_2O+K_2O)/SiO_2$, suggests subalkaline characteristics of the pegmatites, indicating a lower proportion of alkali metals relative to silica. Further analysis indicates peraluminous characteristics within the pegmatites, with aluminum oxide (Al_2O_3) content exceeding the combined content of calcium oxide (CaO), sodium oxide (Na_2O), and potassium oxide (K_2O). Comparative analysis with other localities reveals differences in silica and sodium oxide content, with elevated concentrations of trace elements such as Rb, Ba, Zr, Sr, Cs, Zn, and V in Umai pegmatites. Notably, tantalum concentrations are significantly higher in samples like Umai 11, 12, 13, 14 and 15 compared to others, which shows potential for columbite mineralization. The Pearson's correlation matrix and Harker's plots provide insights into the crystallization sequence of minerals within the pegmatites. Minerals mainly crystallized in these pegmatites are orthoclase, muscovite, and biotite. The AFM diagram suggests a calc-alkaline magma source for the pegmatites, while classification diagrams further affirm a granodioritic composition. Indices of fractionation indicate highly mineralized pegmatites in Umai, with tantalite mineralization potential suggested by Nb/Ta ratios. Various discrimination plots confirm the mineralization potential of the pegmatites, with some samples indicating tantalite mineralization while others are barren. Spider plots of rare earth elements show enrichment of light rare earth elements (LREE) over heavy rare earth elements (HREE), further supporting the mineralization potential of the Umai pegmatites.

The findings of this study are enumerated below;

a. The geochemical result reveals that the pegmatites of Umai are intermediate felsic rocks (granodioritic pegmatite).

b. The pegmatites of Umai are peraluminous and subalkaline

c. The pegmatites are highly fractionated and mineralized.

d. This study also revealed that the pegmatites of Umai are tantalite and columbite-bearing.

e. The pegmatite sample (Umai 11), reveals beryllium mineralization. Hence, the Umai pegmatites host beryllium-bearing minerals like emerald.

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REFERENCES

Adekoya, J. A., 1998. The geology and geochemistry of the Maru Banded Iron-Formation, northwestern Nigeria. Journal of African Earth Sciences, 27(2), 241–257. https://doi.org/10.1016/S0899-5362(98)00059-1

Adetunji, A., and Ocan, O. O., 2010. Characterization and Mineralization Potentials of Granitic Pegmatites of Komu area, Southwestern Nigeria. Resource Geology, 60(1), 87–97. https://doi.org/10.1111/j.1751-3928.2010.00116.x

Andongma, W. T., Gajere, J. N., Amuda, A. K., Digne Edmond, R. R., Faisal, M., and Yusuf, Y. D., 2021. Mapping of hydrothermal alterations related to gold mineralization within parts of the Malumfashi Schist Belt, North-Western Nigeria. The Egyptian Journal of Remote Sensing and Space Science, 24(3), 401–417. https://doi.org/10.1016/j.ejrs.2020.11.001

Beus, A. A., 1966. Geochemistry of Beryllium: And Genetic Types of Beryllium Deposits. WH Freeman.

Bonin, B., Janoušek, V., and Moyen, J.-F., 2020. Chemical variation, modal composition and classification of granitoids. Geological Society, London, Special Publications, 491(1), 9–51. https://doi.org/10.1144/SP491-2019-138

Castro, A., 2020. The dual origin of I-type granites: The contribution from experiments. Geological Society, London, Special Publications, 491(1), 101–145. https://doi.org/10.1144/SP491-2018-110

Cerny, P., 2002. Mineralogy of Beryllium in Granitic Pegmatites. Reviews in Mineralogy and Geochemistry, 50(1), 405–444. https://doi.org/10.2138/rmg.2002.50.10

Černý, P., and Ercit, T. S., 2005. The classification of granitic pegmatites revisited. The Canadian Mineralogist, 43(6).

Condie, K. C., 1981. Archean greenstone belts. Elsevier.

Cox, J. C., Ross, S. A., and Rubinstein, M., 1979. Option pricing: A simplified approach. Journal of financial Economics, 7(3), 229-263.

Dada, S. S., 2008. Proterozoic evolution of the Nigeria–Boborema province. Geological Society, London, Special Publications, 294(1), 121–136. https://doi.org/10.1144/SP294.7

Dill, H. G., 2015. Pegmatitic Rocks and Economic Geology. In H. G. Dill, The Hagendorf-Pleystein Province: The Center of Pegmatites in an Ensialic Orogen Vol. 15, pp. 1–54. Springer International Publishing. https://doi.org/10.1007/978-3-319-18806-5_1

Dostal, J., and Gerel, O., 2022. Occurrences of niobium and tantalum mineralization in mongolia. Minerals, 12(12), 1529.

Edem, G. O., Ekwueme, B. N., and Ephraim, B. E., 2015. Geochemical signatures and mineralization potentials of precambrian pegmatites of southern Obudu, Bamenda Massif, southeastern Nigeria. International Journal of Geophysics and Geochemistry, 2(3), 53-67.

Elbialy, M. Y., and Th, M. S., 2022. Origin and Economic Profits of Pegmatites: A Case Study from Egypt PREPARED BY. https://doi.org/10.13140/RG.2.2.33300.17289

Ekwueme, B. N., and Matheis, G., 1995. Geochemistry and economic value of pegmatites in the Pre-cambrian basement of Southeast Nigeria, pp. 375-392. IBH Publishing Co., New Delhi, India.

Ekwueme, B. N. and Okoro, A. U. 2019. Geology of the Oban Massif: Explanation of 1:250,000 sheet 80(Oban). Nigeria Geological Survey Bulletin 55, 180p

Ero, K. A., and Ekwueme, B. N., 2009. Mineralization of pegmatites in parts of the Oban Massif, Southeastern Nigeria: A preliminary analysis. Chinese Journal of Geochemistry, 28(2), 146–153. https://doi.org/10.1007/s11631-009-0146-2

Ernst, W. G., 2010. Subduction-zone metamorphism, calc-alkaline magmatism, and convergent-margin crustal evolution. Gondwana Research, 18(1), 8-16.

Garba, I., 2003. Geochemical characteristics of mesothermal gold mineralisation in the Pan-African (600±150 Ma) basement of Nigeria. Applied Earth Science, 112(3), 319-325.

Irvine, T. N., and Baragar, W. R. A., 1971. A Guide to the Chemical Classification of the Common Volcanic Rocks. Canadian Journal of Earth Sciences, 8(5), 523–548. https://doi.org/10.1139/e71-055

Jacobson, R., and Webb, J. S., 1947. The occurrence of nigerite, a new tin mineral in quartz-sillimanite-rocks from Nigeria. Mineralogical Magazine and Journal of the Mineralogical Society, 28(197), 118–128. https://doi.org/10.1180/minmag.1947.028.197.08

Jayeola, A. O., Ayodele, O. S., and Olususi, J. I., 2023. Petrology and Petrochemistry of Basement Rocks in Ila Orangun Area, Southwestern Nigeria. British Journal of Earth Sciences Research, 11(5), 48-88.

Karampelas, S., Kiefert, L., Bersani, D., and Vandenabeele, P., 2020. Gems and Gemmology: An Introduction for Archaeologists, Art-Historians and Conservators. Springer International Publishing. https://doi.org/10.1007/978-3-030-35449-7

London, D., 2005. Granitic pegmatites: An assessment of current concepts and directions for the future. Lithos, 80(1–4), 281–303. https://doi.org/10.1016/j.lithos.2004.02.009

London, D., 2018. Ore-forming processes within granitic pegmatites. Ore Geology Reviews, 101, 349–383. https://doi.org/10.1016/j.oregeorev.2018.04.020

Mafimisebi, P., 2023. Geochemistry, classification characteristics and mineralization potential of Pegmatites from Oke Ode, Kwara-State, Northeastern, Nigeria: Implications for provenance and weathering history. https://doi.org/10.31223/X5S09Z

Morteani, G., Preinfalk, C., and Horn, A. H., 2000. Classification and mineralization potential of the pegmatites of the Eastern Brazilian Pegmatite Province. Mineralium Deposita, 35, 638-655.

McCurry, P., 1976. The geology of the precambrian to lower palaeozoic rocks of northern nigeria. A review.

Monespérance, M. G. M., Sebastien, O., Moussa, N. N., Cyrille, S., Christian, B. A., and Guilliano,

F., 2022. Petrology and feldspar chemistry of the Penja–Manjo pegmatites in the Pan-African orogenic belt of Cameroon: economic implication. Arabian Journal of Geosciences, 15(7), 570.

Middlemost, E. A., 1994. Naming materials in the magma/igneous rock system. Earth-science reviews, 37(3-4), 215-224.

Obaje, N. G., 2009. The Basement Complex. In N. G. Obaje, Geology and Mineral Resources of Nigeria (Vol. 120, pp. 13–30). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-92685-6_2

Oden, M. I., Igonor, E. E., and Ekwere, S. J., 2011. A comparative study of ree geochemistry in precambrian pegmatites and associated host rocks from western Oban Massif, Se–Nigeria. Global Journal of Pure and Applied Sciences, 17(2), 197-208.

Ohioma, O. J., 2020. Detection of Sulphide Deposit Using Uranium/Potassium Ratio Map. Ghana Journal of Geography, 12(1), 145–158. https://doi.org/10.4314/gjg.v12i1.8

Okonkwo, S. I., and Idakwo, S. O., 2020. Petrographic and mineralisation Potentials of Precambrian Pegmatities and associated rock units of Olode area, Southwestern Nigeria. Journal of Geological Research, 2(4). https://doi.org/10.30564/jgr.v2i4.2312

Opara, K. D., Obioha, Y. E., Onyekuru, S. O., Okereke, C., and Ibeneme, S. I., 2014. Petrology and Geochemistry of Basement Complex Rocks in Okom-Ita Area, Oban Massif, Southeastern Nigeria. International Journal of Geosciences, 05(04), 394–407. https://doi.org/10.4236/ijg.2014.54038

Omang B.O, Asinya E.A, Udinmwen E, Oyetade O.P: Structural framework and deformation episodes in the Igarra schist belt southwestern Nigeria; Global Journal of Geological Sciences vol 20(1) ,1-17 2022 DOI: 10.4314/gjgs.v20i1.1

Oluwakayode A.O, Omang B.O, Adesola B.M, Olubusola I.S: Evaluation of Gold Mineralization Potential Using Electrical Resistivity Method Along River Chanchaga, Minna, North Central Nigeria, International Journal of Earth Sciences Knowledge and Applications, 2021 3 (3) 289-300

Okon E.E, Kudamnya E.A, Oyeyemi K D, Omang B.O, Ojo O, Metwaly M: Field Observations and Geophysical Research Applied to the Detection of Manganese (Mn) Deposits in the Eastern Part of Oban Massif, South-Eastern Nigeria: An Integrated Approach. Minerals 2022, 12, 1250. https://doi.org/10.3390/min12101250

Okunlola, O. A., and Ocan, O. O., 2009. Rare metal (Ta-Sn-Li-Be) distribution in Precambrian pegmatites of Keffi area, Central Nigeria. Nature and Science, 7(7), 90-99.

Okunlola and Okunola, O. A., and Somorin, E. B., 2006. Compositional features of Precambrian pegmatites of Itakpe area, central Nigeria. Global Journal of Geological Sciences, 4(2).

Pagung, R., Rosière, C. A., and e Silva, R. C. F., 2023. The Serra da Serpentina Group: a back-arc basin related to the Paleoproterozoic Minas-Bahia orogeny?. Journal of South American Earth Sciences, 128, 104427.

Petters, S. W. (Ed.)., 1991. Chapter 6 Late Proterozoic-Early Plaeozoic Pan-African Mobile Belts. In Regional Geology of Africa (Vol. 40, pp. 254–420). Springer-Verlag. https://doi.org/10.1007/BFb0020583

Rahaman, M. A., 1976. Review of the basement geology of south-western Nigeria.

Schober, P., Boer, C., and Schwarte, L. A., 2018. Correlation Coefficients: Appropriate Use and Interpretation. Anesthesia and Analgesia, 126(5), 1763–1768. https://doi.org/10.1213/ANE.0000000000002864

Stavrov, D., Stolyaro. Is, and Iovcheva, e., 1969. Geochemistry and origin of Verkh-Iset granitoid massif in central Ural. Geochemistry International Ussr, 6(6), 1138.

Sweetapple, M. T., and Collins, P. L. F., 2002. Genetic Framework for the Classification and Distribution of Archean Rare Metal Pegmatites in the North Pilbara Craton, Western Australia. Economic Geology, 97(4), 873–895. https://doi.org/10.2113/gsecongeo.97.4.873

Taylor, S. R., and McLennan, S. M., 1981. The composition and evolution of the continental crust: rare earth element evidence from sedimentary rocks. Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences, 301(1461), 381-399.

Tyrrell, G. W., 1978. Classification of Igneous Rocks. In G. W. Tyrrell, The Principles of PETROLOGY (pp. 101–131). Springer Netherlands. https://doi.org/10.1007/978-94-011-6026-1_6

Taylor, S. R., and McLennan, S. M., 1985. The continental crust: its composition and evolution.

Ukaegbu, V. U., and Ekwueme, B. N., 2006. Petrogenesis and geotectonic setting of the Pan-African basement rocks in Bamenda Massif, Obudu Plateau, southeastern Nigeria: Evidence from trace element geochemistry. Chinese Journal of Geochemistry, 25(2), 122–131. https://doi.org/10.1007/BF02872171

Van Lichtervelde, M., Salvi, S., Beziat, D., and Linnen, R. L., 2007. Textural features and chemical evolution in tantalum oxides: magmatic versus hydrothermal origins for Ta mineralization in the Tanco Lower pegmatite, Manitoba, Canada. Economic Geology, 102(2), 257-276.

Wise, M., and Brown, C. D., 2012. Mineral chemistry, petrology and geochemistry of the Sebago granite-pegmatite system, southern Maine, USA. Journal of GEOsciences, 3–26. https://doi.org/10.3190/jgeosci.061