Mineralogy, Geochemistry and Economic Potentials of Pegmatites around Egbe-Ejiba-Isanlu, Isanlu Sheet 225 Southwestern, Nigeria

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ABSTRACT

This study focused on the geochemistry and economic potentials of the rare metal mineralization within the pegmatites of the Egbe-Ejiba-Isanlu areas using geological, geophysical, and geochemical techniques. From a total of 92 fresh rock samples collected, 40 were cut into thin sections for petrographic studies, 20 cut and polished for ore microscopic studies while 30 were analysed for elemental composition of major oxides and trace elements, using XRF and ICPMS techniques respectively. Petrographic study shows that the area is underlain by Biotite Gneiss, Migmatitic Gneiss, Augen Gneiss, Banded Iron Formation (BIF), Quartzite, Quartz-mica Schist, Porphyritic Granites, Coarse-grained Granite, Quartz Diorite and Pegmatite. Structural data shows a dominant NNE-SSW trending lineaments with minor complimentary NNW-SSE trends. The Total Magnetic Intensity and Reduce to Equator images from aeromagnetic anomaly data were used to enhance existing inferred geological boundaries of adjoining lithological units. The Total Magnetic Intensity map (TMI) depicts magnetic anomaly values that ranges between 52.5- 85.2. The map also shows prominent high magnetic anomaly (71.5nT- 84.0nT) in rocks of the eastern part of the area. The molecular plot of $Al_3O_2/CaO+Na_2O_3+K_2O$ versus SiO_2 reveals that the pegmatites have I-type characteristics. The K/Rb vs Cs discrimination diagram indicates that the pegmatites of the Egbe, Omi, Takete and Idofin areas are of the mineralized type. The geochemistry of some selected pegmatite samples shows enriched concentration values in ppm of 716.10, 19.68, 37.40, 92.00 and 481.70 for Rb, Cs, Ta, Sn and Nb respectively. These suggests that the pegmatites are rare metal type with enrichment trend of Rb>Nb>Sn>Ta>Cs, exhibiting strong negative Eu anomalies, which suggests that the pegmatites are of the LCT-type. Ore microscopic studies show that the pegmatites are associated with tantalite, pyrite, chalcopyrite, tourmaline, and galena ores of economic values as evidenced in the high level of artisanal mining activities in the areas.

Keywords: anomaly, enrichment, pegmatite, rare metal, artisanal mining

INTRODUCTION

The study area covers Isanlu, Idofin, Ijagbe and Takete Isaho, Ejiba and Igbaruku and lies between longitude 5°30ˈ00"E and 5°54ˈ00"E and Latitude 8°09ˈ00"N and 8°20ˈ00"N (Figure 1). The area is underlain by seven major lithological units including Migmatitic Gneiss, Augen Gneiss, Banded Iron Formation (BIF), Quartzite, Mica schist, Diorite, Coarse grain Granite and Pegmatite. The gneisses form the basement on which the metasediments were unconformably overlain, deformed and infolded, and were together intruded by the Pan African Older granite suites. The schist outcrops around Ejiba area, with strong foliation, medium grained textured and melanocratic coloured. Quartz diorite was mapped as boulders with most of it covering Odo-Ara area (Figure 2).

The Pan African pegmatites of Nigeria occur mostly as dyke-like intrusions which vary from few meters to several kilometres in length and few centimeters to meters in width, trending mostly NW-SE (Akintola et al., 2012). Pegmatites are known worldwide to host economically important mineral deposits such as Tantalum, Niobium, Tin and Tungsten (Akintola and Adekeye 2008). Nigeria is a tin producing country and over 350,000 tons of cassiterite concentrates have been won from pegmatites in Nigeria between 1912 and 1944 (Jacobson and Webb, 1946).

Pegmatites within the study area occur as intrusion within the major rock types such as the granites, the migmatitic gneiss and the schist. They often occur as dykes which are vertically dipping and most trend in the N-S direction. These pegmatites host most of the tantalites mined within the study area especially around Ejiba and Igbaruku areas thereby constituting the targets for rare-metal mineralization in the area. Though these areas lie within the Kabba-Isanlu pegmatite belt (Okunlola, 2005) which is well known for heavy artisanal mining activities, however, there is no available record of a systematic study of the rare metal mineralization potentials in the pegmatites of the area. This study, therefore, focuses on carrying out a scientific study of the distribution, mineralogy, geochemistry and economic viability of the rare metal mineralization in the area whose confirmation has become expedient to add to the geoscience database of the Nation.

REGIONAL GEOLOGY

The basement rocks are believed to be the results of at least four major orogenic cycles of deformation, metamorphism and remobilization corresponding to the Liberian (2,700 Ma), the Eburnean (2,000 Ma), the Kibaran (1,100 Ma), and the Pan-African cycles (600 Ma). The first

three cycles were characterized by intense deformation and isoclinal folding accompanied by regional metamorphism, followed by extensive migmatization. The Pan-African deformation was accompanied by a regional metamorphism, migmatization and extensive granitization and gneissification which produced syntectonic granites and homogeneous gneisses (Ajibade et. al, 1987; Abaa 1983). The Nigerian rare–metal pegmatites was formed over a time span of 562–534 Ma (Matheis and Caen Vachette, 1983) marking the end of Pan–African magmatic activity.

Since the pegmatites are related to the Nigerian major fault lineament systems, the albitization and rare–metal may have been due to late-stage fluids available at the waning stage of the Pan– African metamorphic cycle (Ekwueme and Matheis, 1995) or due to sodium rich hydrothermal solution from the mantle along ancient lineaments (Wright, 1970). However, Matheis and Caen Vachette (1983) concluded that the rare–metal pegmatites of southwestern Nigeria are products of partial melting and leaching process of the basement units rather than the truly pegmatitic phase of the proximal Older Granite. It was also suggested by Matheis and Emofurieta (1987) that the rare-metal pegmatite mineralization of the southwestern Nigerian was derived from reactivation of deep-seated tectonic lineaments combined with partial melting and external fluid supply.

The rare-metal pegmatites trend in a NE-SW direction extending from Ife to Jos and appears to crosscut the geological boundary between the eastern and western Nigerian terranes (Kinnaird, 1984; Woakes et al., 1987). Recently, (Okunlola, 2005) defined the metallogeny of the raremetal pegmatites of Nigeria, outlining it into seven broad fields; Ibadan-Osogbo, Ijero-Aramoko, Kabba-Isanlu, Kushaka-Birni Gwari, Lema-Share, Nasarawa-Keffi, and Oke-Ogun which have varied sizes, internal zoning, geochemistry, and mineralogy (Figure 1).

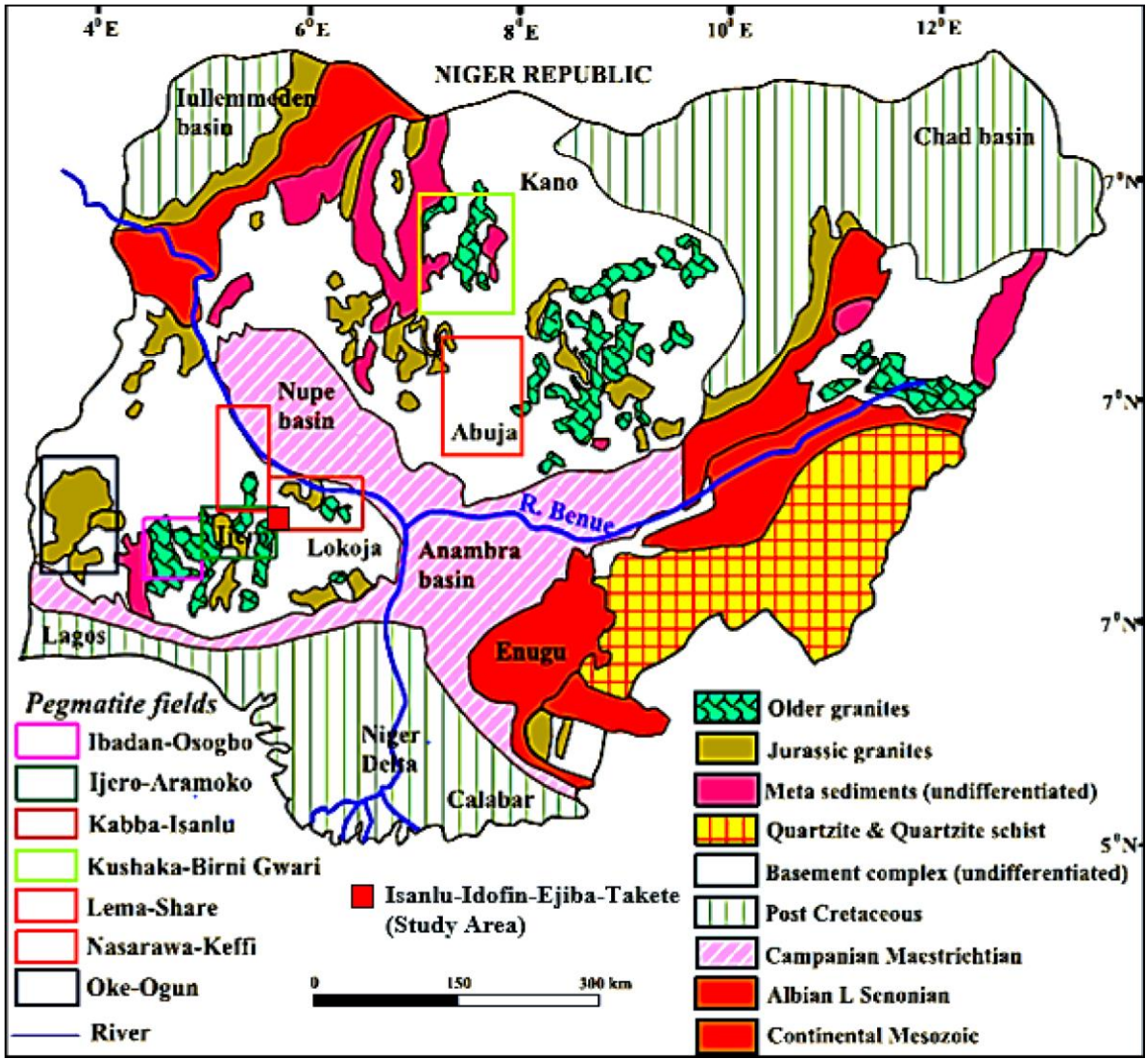


Figure 1- Simplified geological map of Nigeria with colored-edge boxes showing the metallogenic province of rare-metal pegmatites of Nigeria (modified after Okunlola, 2005)

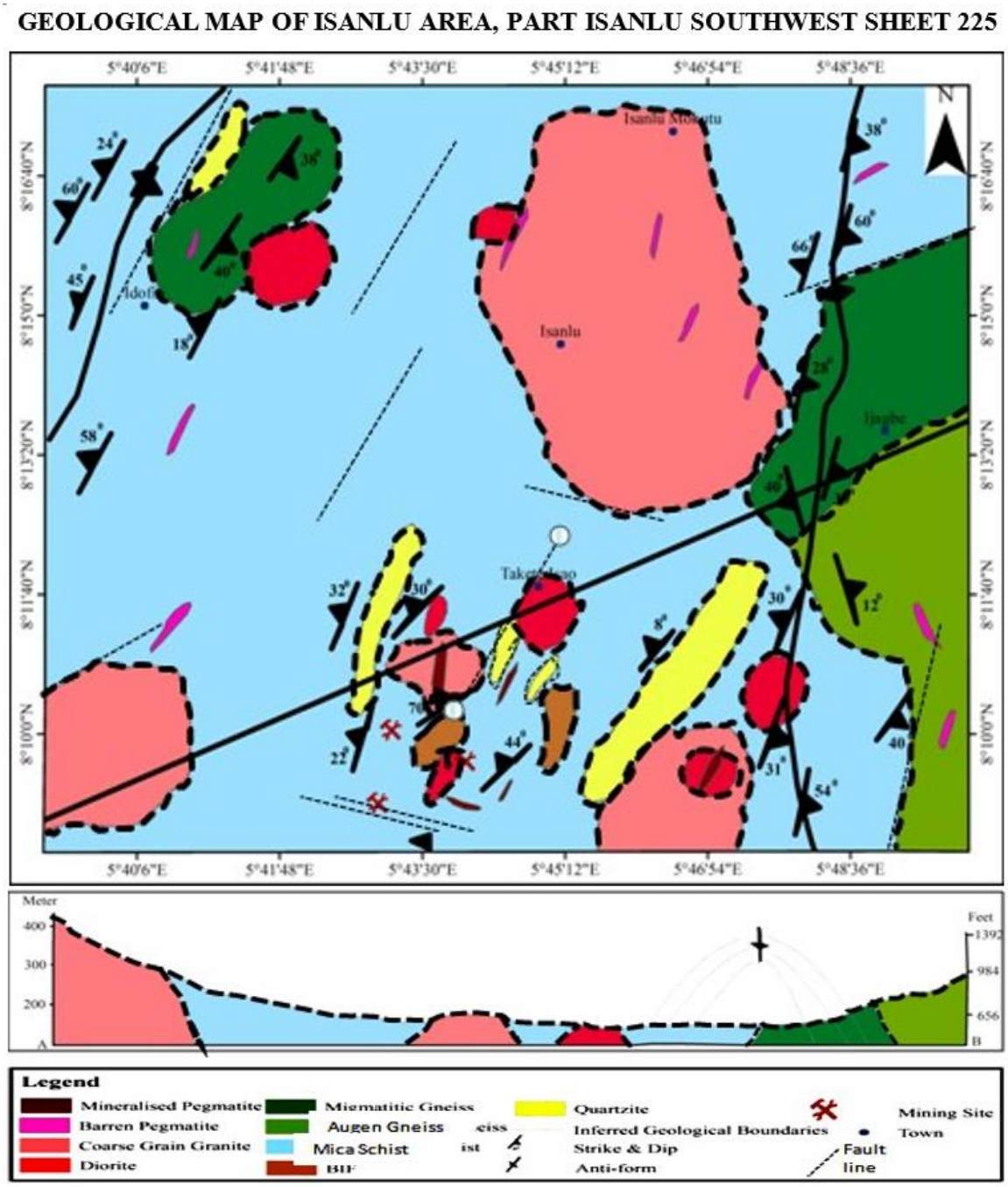


Figure 2: Geologic map of Isanlu area showing lithological distribution.

MATERIALS AND METHODS

This research work was carried out in five phases which includes desk study, geological field mapping, geophysical survey, laboratory work and data analysis in other to achieve the aim and objectives of this research work. The geological mapping was done using traverse method. Exposures of the different rock types occurring along river valleys, quarries, road-cuts, as well as

on the break of slope of some hills were mapped. Thin sections were prepared for twenty (20) samples at the geoscience laboratory of the Department of Geology and Mineral Sciences at the Kwara State University (KWASU), Malete Nigeria out of about twenty 52 samples collected from the field. The petrographic study to examine the 20 thin sections was carried out using the transmitted light petrological microscope in the same laboratory. About fifteen selected rock samples were pulverized in a tungsten carbide mill at the Geoscience laboratory, KWASU and shipped to MS laboratory in Canada to determine the elemental compositions which were analysed by Acid-Digestion Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), for major and trace elements including rare-earth elements (REE).

Aeromagnetic data was acquired from the Nigeria Geological Survey Agency (NGSA) in other to ascertain the lithological boundaries and to extract the regional lineament possibly hosting the economic minerals within the study area. Six polished rock samples were studied under the reflected light microscope, using the immersion oil at the Al-Hikmah University Ilorin, Kwara State with a view to ascertaining the ore minerals present within the pegmatites in the area. The plotting of structural data on lithological map (Figure 2) such as strike and dip values, trends of intrusions and joint directions was achieved with the aid of georose software while the mineral model analysis in petrographic studies was done using bar charts. The analysis and interpretation of the geochemical data obtained from the Canadian laboratory were achieved using Petrograph software.

LOCAL GEOLOGY

Migmatitic Gneiss

The two major type of migmatite found in the study area are nebulite and stromatite (lith-par-lith banding). Migmatitic gneiss dominated the NE and NW part of the study area, grading into the Schist at the NE part. Most of the migmatitic gneisses outcrop as low-lying exposures, covering an average area of about 150m by 100m in dimension. Most of the outcrops are hosting pegmatitic veins of up to 2 meters width in dimension. The migmatitic gneiss is a deep grey to black, fine to medium grained texture. The average dominant strike and dip direction is 08°/44°W. The major structures include fold, joint, fault, pinch and swell etc. The quartz has subhedral shape with high relief in thin section while plagioclase feldspar shows multiple twining and subhedral crystal

shape. Modal analysis as observed in thin section are Quartz (25%), Myrmekite (20%), Plagioclase (10%), Microcline (20) and Biotite (25%) (Figures 3 and 4).



Figure 3: An Outcrop of Migmatitic Gneiss showing the palaesomes and leucosomes (N08° 09' 28'' and E005 47' 2.5'').



Figure 4: An outcrop of Migmatitic gneiss at Ikoro area (N08°09´00" and E005°30´12")

Augen Gneiss

The megacrists constituting the augen have an average size of about 40mm by 30mm and it is dominated by quartz and plagioclase feldspar within the groundmass of quartz, feldspar, amphibole and biotite. The gneissic texture of the rock is intruded by quartz veins trending in the northern direction. Other structures such as fold, fault were also mapped on the outcrop. Average strike and dip is 52°/18°E. The rock outcrops as low-lying exposures and as big boulders with an average size of 2m by 1m. Quartz and Plagioclase feldspar with multiple twining and euhedral crystal shape dominate the mineralogy of the rock. Micro-faults trending NW-SE were observed in the thin section. Modal analysis as observed in thin section are Quartz (30%), Plagioclase (35%), Microcline (25%), hornblende (5%), Biotite (3%) and Ore minerals (2%) (Figure 5).



Figure 5: Open fold in Augen Gneiss outcrop having an amplitude of 10cm and a wavelength of about 60cm (N08°13′6.6′′ and E004°51′52′′).

Banded Iron Formation

The iron-formation is exposed at the crustal zones of a series of discrete northeast-southwest trending ridges over a distance of about 600m near Takete village, some 10 km south of Isanlu-Makutu town.

Quartzite

The quartzite is composed of interlocking small granules of quartz with an overall sugary texture and a vitreous lustre. It is brittle, crystalline and scratches glass. The grains of quartz are wedged together by silica. The rock is well exposed along the road exposure at Takete village, having an average exposed height of about 2 meters above the surrounding country. The rock also outcrops at the extreme NW part of the study area. The mineralogical composition of the rock as observed in the photomicrograph includes quartz (95%) and subordinate muscovite (5%).

Mica Schist

Schist is dominant in the study area, occurring as background rock which host about 90% of the pegmatite around Takete area where the artisanal miners are currently working at subsistence level. The mica schist outcrops mostly as low-lying weathered exposures. The schistose outcrops are visible mainly in localized areas, where shearing has made the rock more indurated and competent, standing as high ridges with an average height of about 30 meters above the surrounding country. The rock exhibits a definite boundary with the coarse grain granite at Takete village. Its mineralogy includes quartz, feldspar, biotite, muscovite, beryl and tantalite with characteristic schistose banding that is intruded by pegmatite veins, most of which trends in the N-S directions. Additionally, the dominant strike and dip directions in the schist are 002°/32°W while brittle joints trend in the direction 064°. The quartz grains show anhedral shape with high relief in thin section. Modal analysis as observed in thin section includes Quartz (60%), Muscovite (15%), Biotite (15%), Amphibole (3%), Plagioclase (3%), Microcline (2%) and Ore mineral (2%).

Diorite

The dioritic rock outcrops as a low-lying dome-shaped exposures, having an average size of about 3m by 2m in area extent and up to 1m in height. Elsewhere, the rock is well exposed along the river channel around Takete where it outcrops as discrete relict boulders having an average size of 2m by 0.5m with abundant mafic minerals such as hornblende and biotite. The quartz is euhedral with high relief while plagioclase feldspar shows multiple twining with hornblende dominating the mafic minerals composition. Modal analysis as observed in thin sections includes Plagioclase (35%), Quartz (20%), Hornblende (15%), Orthoclase (15%), Biotite (10%) and Sphene (5%).

Coarse-Grained to Porphyritic Granite

The coarse-grained granite outcrops between Takete to Isanlu (Latitude N08°23’00” and Longitude E004°49’00”), outcropping as series of discontinuous dome-shaped hills of about 70m wide and trends in the direction N-S with an average height of about 10m above the mean sea level. The rock shows phaneritic texture, leucocratic coloured and are locally porphyritic in some places. The dominant constituent mineral from hand specimen observations are quartz, microcline, plagioclase, biotite, hornblende and orthoclase. Fault and joints constitute the dominant structures mapped on outcrops of this rock. Quartz is anhedral in shape with high relief under the thin section. Plagioclase feldspar shows multiple twining. The modal composition as observed in thin section includes Quartz (30%), Plagioclase (35%), Orthoclase (15%), Microcline (10%), Biotite (5%), hornblende (4%) and Zircon (1%).

Pegmatites

The rock is well exposed mostly as veins which massive intruded the Muscovite-Biotite Schist around Takete-Isaho axis (N08°10’52” and E005°46’25”). The emplacement of some of the pegmatites veins were observed to be syntectonic and have been caught up at the waning stage of the Pan African orogeny. These pegmatites are sometimes observed to have been folded within the Migmatitic Gneiss around Isanlu area. Most of the pegmatites are concordant with the foliation plane and trends in the N-S directions, with few discordant ones trending in the E-W directions. Some of the concordant pegmatite veins coalesce into dykes with widths ranging between 0.5m - 10m in size. Most of the pegmatites around Takete are mineralized and are hosting economic minerals such as beryl and tantalite which are currently being mined by artisanal miners.

The mineral composition includes quartz, sericite, oligooclase and microcline. The quartz has subhedral to euhedral shape while the oligooclase feldspar shows multiple twining and dominates the rock. Modal composition as observed in thin section include Quartz (25%), Oligoclase (40%), Microcline (25%) Muscovite (5%), and Sericite (5%) (Figure 6). Ore microscopic study shows that some of the pegmatites and the main schistose host rock around Isanlu area are mineralized with some economic minerals such as Tantalum, iron ore, galena, chalcopyrite, native antimony and garnet etc., and these, when properly explored and harnessed, can boost the economic potential, not only of the study area but of the Nation as a whole.

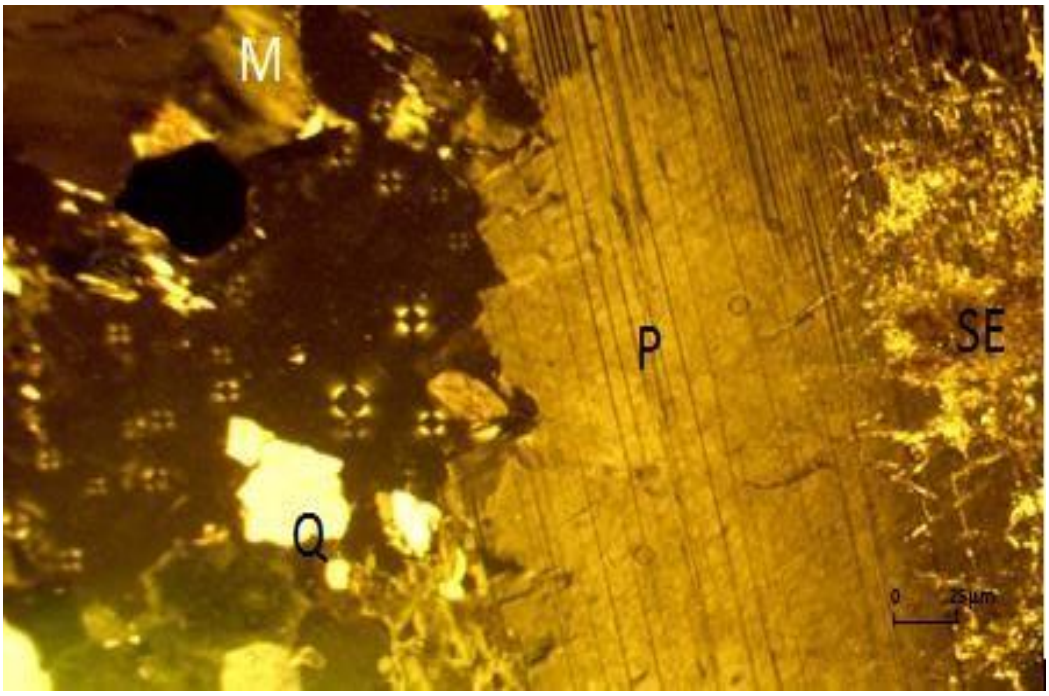


Figure 6: Photomicrograph of Pegmatite on cross polarized light (M=Microcline, P=Plagioclase, Q=Quartz, SE=Sericite)

STRUCTURAL GEOLOGY

Ductile structures which include folds, foliations, pinch and swell and Brittle structures such as fractures (joint and fault) were mapped on various scales on some outcrops in the field. Most of the foliated rocks mapped have strikes that dominantly trend in the NE-SW direction and dip mostly westerly with few easterly dips. This is consistent with the established NE-SW structural grains in the Nigeria Basement Complex. The dominant open joint direction in the area is NNE-SSW with fewer complimentary NNW-SSE trending joints (Figure 7). Most of the joints are healed with pegmatite and quartz vein and trends in the NNE-SSW direction (Figure 8). Subordinate healed joints trends along ENE-WSW, W-E and NW-SE directions.

The unhealed joints measured from fractured rocks were mapped to be trending in the WNW-ESE direction. Asymmetrical folds occur within the migmatitic gneisses of Igbaruku area. Foliation planes measured on the augen gneiss and migmatite gneiss particularly in the southeastern sector of the study area were observed to be trending in the NW-SE direction where they defined the axes of a regional antiformal fold in conformity with the general structural trend in the Basement terrain. A conjugate fault system was mapped on the augen gneiss outcrop which shows that the rock has suffered from polyphase tectonic deformation (Figure 9).

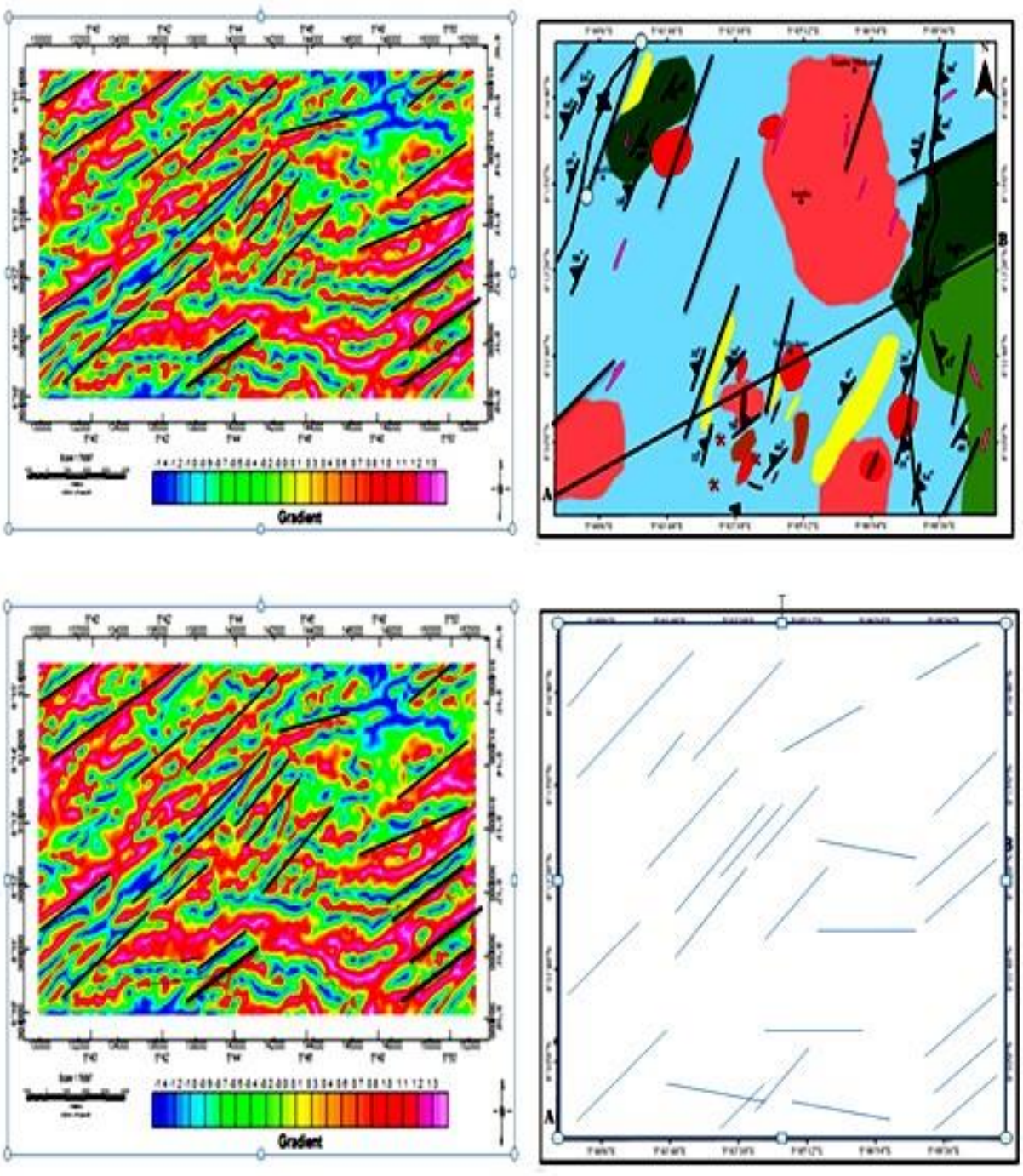


Figure 7: Lineament map of the study area derived from TDR map showing the dominant NE-SW trends

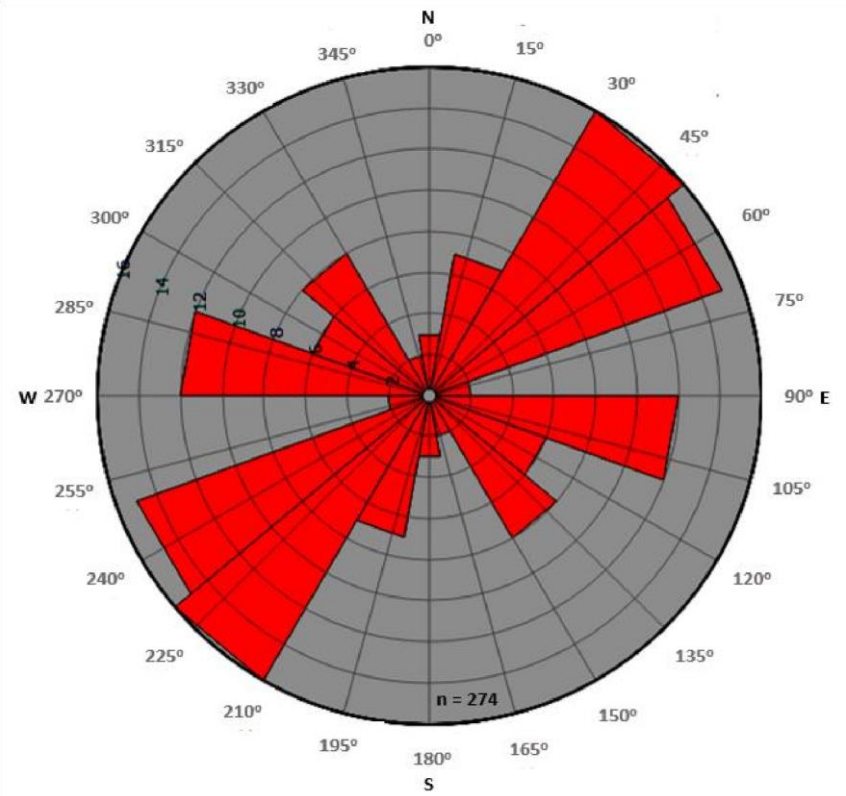


Figure 8: Rosette diagram of the trend of joints healed with pegmatite and quartz veins.



Figure 9: Conjugate faults on augen gneiss outcrop. (N08°13'6.6" and E005°51'52").

DISCUSSION

Isanlu-Egbe area is underlain by rocks of the Basement Complex of Nigeria including the Migmatitic Gneiss and Augen Gneiss that are overlain by the Banded Iron Formation, Quartzite and Schist which are together intruded by rocks of the Older Granite suites mainly Diorite and Coarse-grained Granite. This was subsequently followed by late-stage fractionation and crystallization of Pegmatitic and Aplitic dyke as well as Vein Quartz. This is consistent with the work of Rahaman (1989). Whole rock geochemical analysis of rock samples obtained from the study area were sent to MS Lab in Canada to determine the elemental composition of the selected samples. Oxides of major elements provide the bases for the classification of rock types, including proper naming of the rocks.

The rare elements concentration was used for tectonic discrimination and classification as well as provides the bases for determining the rare metal mineralization potential of the various rock types. The major oxides compositions of the pegmatites in the study area include SiO_2 content which ranges from 70-77.75 wt%, and Al_2O_3 varying from 11.07-18.74 wt %. The CaO content ranges from 0.13-0.34 wt.%, Na_2O from 2.63-4.29 wt.% while K_2O content varied from 2.84-4.83 wt.% and TiO_2, from 0.2-4.72 wt.%, while Ta varies from 2.5-19.83 wt %. The high silica content in pegmatite suggest that they are corundum normative. The high concentration of tantalum (Ta) is also suggestive of the fact that most of the pegmatites in the area are highly mineralized in tantalite. This is evident in the measured geochemical data (Tables 1) which revealed that the mineralized pegmatites are highly enrich in Ta (53.2ppm), Rb (784ppm), Nb (90.7ppm) when compared to their crustal abundances of Ta (2.2ppm), Rb (112ppm), Nb (25ppm). The barren pegmatites shows a progressive enrichment in HREE and exhibit the lowest Eu anormalies. These barren pegmatites are characterized by low Rb, Cs, Ta and Nb but high Ba, Sr and K/Rb,

The general classification plot of the total Alkalies versus Silica diagram for plutonic rocks of the study area, modify after Cox-Bell-Pank (1979) display granitic composition with only the porphyritic diorite plotting at the granitic-quartz diorite boundary, which suggest granitic contamination of the dioritic source (Figure 10). Chemical classification of the granitic rocks using the molecular ratio of alumina to alkalis, $Al_2O_3/(Na_2O+K_2O)$ versus alumina to lime and alkalis, $Al_2O_3/(CaO+Na_2O+K_2O)$ discrimination diagram (modified after Shand, 1947) shows the granitoids plotting within the Peraluminous field. Only the quartz diorite and a granite sample exhibit Metaluminous characteristics (Figure 11). On the molecular $Al_2O_3/CaO+Na_2O+K_2O$

versus SiO_2 discrimination diagram of White and Chappell 1977, the plot shows most of the granitoids lying within the S-Type field (Figure 12).

Table 1: Major Element Oxides (%), Trace and Rare Earth Elements composition of some selected rock samples in the study area.

Oxide	QS63	BIF2	OGP4	OGc13	OGc58	P5	P8	P22	P34	P52	P54	OGd6	SCm37	OPg39	GG49
Al_2O_3	1.63	3.72	13.75	12.7	14.05	15	18.7	14	14.6	10.6	14.6	14.3	13.82	13.6	15.8
BaO	0.01	0.01	0.01	0.01	0.12	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.27	0.04	0.07
CaO	3.07	0.57	0.76	0.31	14.34	0.67	0.13	0.34	0.27	0.2	1.07	13.4	2.24	1.09	5.66
Cr_2O_3	0.01	0.01	0.01	0.01	0.01	0.7	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.22
Fe_2O_3	0.01	67.4	2	1.66	5.4	7.1	1.29	1.55	1.13	0.76	2.16	12.6	4.83	2.97	11.2
K_2O	0.08	0.5	4.77	4.83	2.23	1.21	3.04	3.77	2.84	4.88	4.72	0.45	6.69	5.59	3.22
MgO	0.03	0.89	0.08	0.02	1.78	0.03	0.03	0.09	0.15	0.03	0.33	5.92	0.7	0.45	2.83
MnO	0.01	2.11	0.03	0.02	0.09	5.2	1.2	0.04	0.05	0.1	0.07	0.27	0.08	0.04	0.17
Na_2O	0.02	0.84	3.97	2.63	3.82	4.29	4.29	0.01	3.71	2.78	3.64	0.65	2.5	2.73	3.26
P_2O_5	0.01	1.06	0.01	0.01	0.28	0.01	0.01	0.01	0.02	0.06	0.06	0.07	0.47	0.11	0.78
SiO_2	92.84	73.2	73.6	42.8	57.95	61	68.9	79.2	77.8	81	72.1	48.6	67.14	74.59	58.4
SrO	0.01	0.83	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.01	0.01	0.03
TiO_2	0.01	1.42	0.04	1.23	0.65	4.72	0.01	1.23	0.4	0.01	0.65	0.89	0.01	0.2	2.46
Ba	23.7	6.89	12.1	31.1	521.7	27.1	13.3	51.1	52.7	77.2	304	54.5	0.27	394.3	0.07
Cr	12	0.83	25	38	128.4	0.69	18	25	24	12	111	115	0.01	25	0.01
Cs	14	0.73	6.2	4.32	0.76	20	22	7.8	24.9	15.5	21.5	3.14	1.31	8.34	2.42
Ga	60	392	29.3	25.8	20	34	59	24	64.3	21.3	24.8	18.9	21.1	17.3	24.8
Gd	23.7	23	17.68	4.17	16.83	5.9	5.42	5.6	0.47	1.6	8.48	3	20.87	8.76	15.8
Hf	56.67	1.02	6.5	8.2	8.9	4	1.1	9.8	0.5	0.7	4.9	2	39.31	7.6	11.8
Nb	16	24.1	1.37	90.7	42.1	10.5	25.7	0.37	103	58.5	44.5	51.8	39	21.3	52.8
Rb	784	8.49	384	405.5	103.9	34	784	45.9	756	617	420	18.5	267.4	300.9	226
Sr	2.4	91.8	5.2	3.7	3.3	23	11.3	12	7.4	53.2	6.5	214	223	42.2	280
Sn	34.6	2.09	6	7	14	3.8	99	42.8	71	5	12	13	14	8	12
Ta	2.4	12.5	4.6	18.5	3.3	35	1.23	4.6	47.6	53.2	6.5	19.8	3.3	15.6	2.5
Th	45	91.8	53.3	35.62	54.68	2.42	2.34	53.3	1.2	45.7	31.1	2.7	54.68	25.65	44.7
U	4.9	3.7	22.81	14.88	9.23	3.12	12.4	22.8	0.58	15.3	20.6	1.27	9.23	6.23	5.07
V	9	8.9	10	8	72	10	9	10	10	10	12	282	72	23	154
W	1	3	1	8	7	1	6	1	6	1	0	282	5	1	3
Y	100.4	9	111.1	31	43	94.7	100	111	3.1	19	57	22.1	132	48..9	56
Zr	8.9	20	117	134	34.56	10	0.05	117	7	15	145	57	34	262	67
Ce	12	1.9	39.5	4	521.7	8	8	12	3.32	12	111	15.3	417.7	12	0.07
Dy	45	0.45	24.23	8.88	24.4	12.6	17.9	23.4	0.54	2.66	9.36	3.66	22.1	8.84	13.3
Er	4.6	0.83	12.25	4.65	14.23	12.4	16.3	4.6	0.25	1.64	5.37	2.37	12.68	4.58	6.49
Eu	0.6	0.67	0.06	0.04	2.07	0.08	0.03	0.08	0.08	0.18	0.73	0.93	4.08	0.08	3.75
Ho	78	2.3	4.96	1.8	5.12	5.6	4.23	7.5	0.1	0.54	1.97	0.85	4.39	1.87	2.48
La	76.9	9.51	15.8	1.8	63.1	5.9	3.3	34	1.8	6.8	55	6.7	138.7	54.4	116
Lu	34.56	4.95	1.37	0.6	1.92	10.5	11.1	12	0.09	0.33	0.83	0.4	2.15	0.64	0.89
Nd	23	23.4	29.5	3	63.7	12	4.7	23	1.8	5.2	44	9.9	127.9	48.1	109
Pr	26	31.6	6.14	0.58	15.82	34	1.12	13	0.44	1.51	12.3	2.12	35.47	13.16	29
Sm	6.7	12.8	13.8	6.7	16.8	9	3.28	2.65	15	1.5	8.68	2.6	0.54	8.83	20.4
Tb	3.9	4.3	3.79	1.18	3.64	1.98	4.5	3.79	0.1	0.37	1.51	0.58	3.84	1.47	2.47
Tm	1.63	0.63	1.76	0.72	2.23	5.38	0.9	1.76	0.07	0.33	0.38	0.92	2.23	0.73	0.98
Yb	100.4	13.1	10.44	4.64	4.63	63.9	64.3	10.4	0.5	2.45	5.74	2.69	3.64	4.56	45

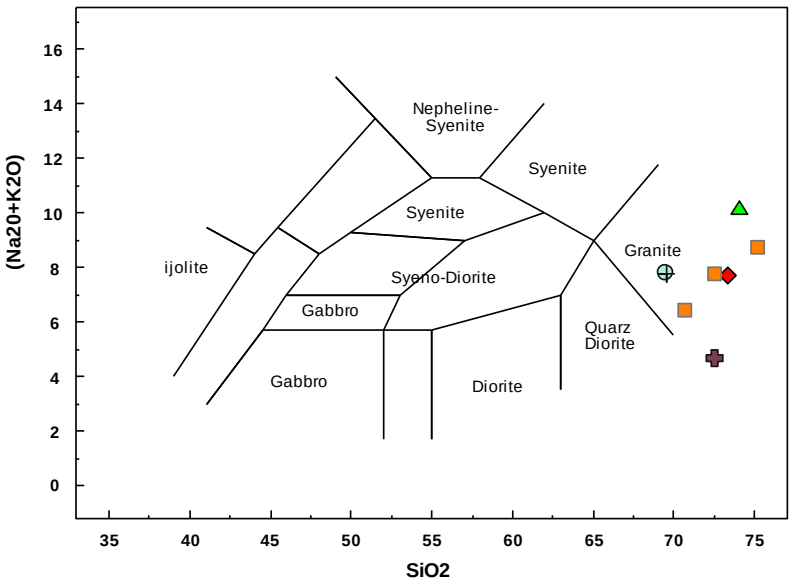


Figure 10: TAS Alkalies-Silica general classification diagram for plutonic rocks of (After Cox-Bell-Pank, 1979).

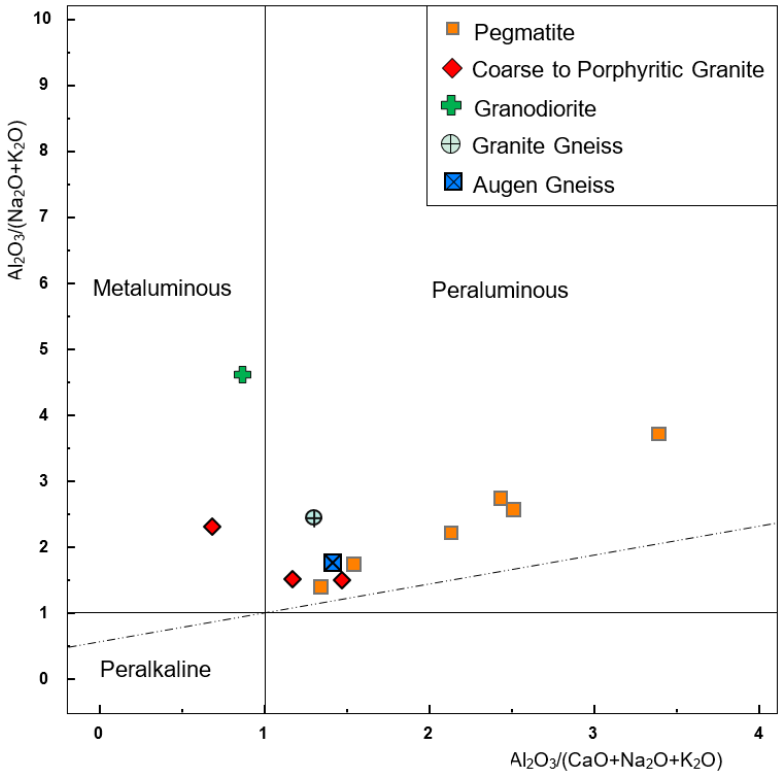


Figure 11: Chemical classification of the granitic rocks using the molecular ratio of alumina to alkalis [$Al_2O_3/(Na_2O+K_2O)$] versus alumina to lime and alkalis $Al_2O_3/(CaO+Na_2O+K_2O)$] discrimination diagram (after Shand, 1947).

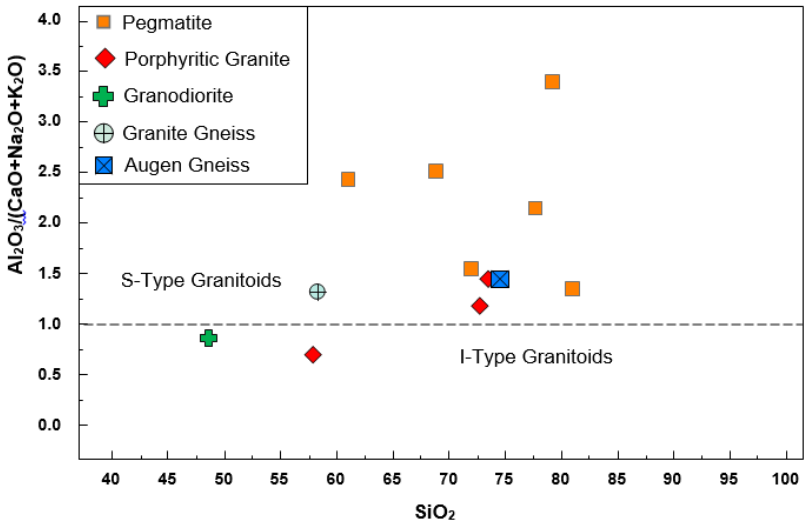


Figure 12: Molecular $Al_2O_3/CaO+Na_2O+K_2O$ versus SiO_2 diagram showing the classification of the rocks into the fields of I-type and S-type granitoids (after White and Chappell 1977).

The Yb+Ta versus Rb tectonic discrimination diagram of Pearce et al., (1984) for the rocks of the Egbe-Isanlu area revealed that the granitoids are of the within plate origin except for the quartz diorite and a sample of pegmatite which lies in the field of oceanic ridge granite (Figure 13). The K/Rb versus Cs discrimination diagram adapted from Morteani et al., (2000) (Figure 14) shows the degree of fractionation and mineralization pattern of the rocks in which the pegmatites around the southern and western part of Takete and Idofin areas are mineralized while those around Isanlu and northern part of Takete areas are the barren type. Similarly, the discrimination diagram of K/Rb versus the logarithm plot of Cs shows the mineralized pegmatites around Takete south, Takete west and Idofin west are the Beryl-type while those around Isanlu east and Takete north are barren (Figure 15).

Trace elements are known to serve as a guide to the processes and origin of igneous rocks as they may exhibit concentration range that is greater than major elements, suggesting mineralization enrichment. A high Rb/Cs ratio as shown in Figure 16 is suggestive of a more evolved pegmatites that are often associated with mineralized zones. The plot of Ta versus Nb discrimination diagram shows that the mineralized pegmatites in the area are enriched in tantalum (Figure 17). Figure 18 shows the plot of SiO_2 versus K_2O with higher silica content suggesting that the pegmatites and the surrounding host rocks were emplaced from a more evolved magma source. This plot can be used to assess the overall composition of the pegmatite. The REE distribution pattern in rocks of the study area shown on the Chondrite-normalized plot of Nakamura (1974), suggest a slight

enrichments in light rare earth elements (LREE) or near flat REE fractionation pattern with strong negative Eu anomalies (Figure 19). This shows that the mineralized pegmatites exhibit REE abundances that are close to the primitive chondritic values, suggesting minimal differentiation or a primitive source.

The observed strong negative Eu anomaly may be interpreted via a series of geochemical processes, mineral composition, and the genetic history of the pegmatite system. As minerals crystallize from melts, the behavior of Eu can be affected by the competition with other elements for similar sites in mineral structures (e.g., feldspars, phosphates). In magmatic systems, plagioclase (which can preferentially incorporates Eu^{2+}) and beryl, may show varying tendencies to incorporate Eu, thereby depleting the surrounding melt in Eu as it crystallizes. Alternatively, if the pegmatite is derived from a partially melted granitic source, the differentiation process can lead to an enrichment of Light REEs (LREEs), as observed in Figure 19, at the expense of Eu, thereby resulting in a negative anomaly in the REE pattern.

The strong negative europium anomaly in the REE plot for mineralized pegmatite of the study area is suggestive of complex geological processes involving crystallization and source rock characteristics. This anomaly reflects not only the geochemical behavior of europium in formation environments but also the evolutionary history of the pegmatite, providing valuable insights into its formation. Understanding this anomaly can aid in the exploration for REE resources, including lithium, as well as in reconstructing the tectonic history of the pegmatite's precursor. The dominant presence of plagioclase in the melt played a major role during fractionation with little or no role in the magmatic segregation.

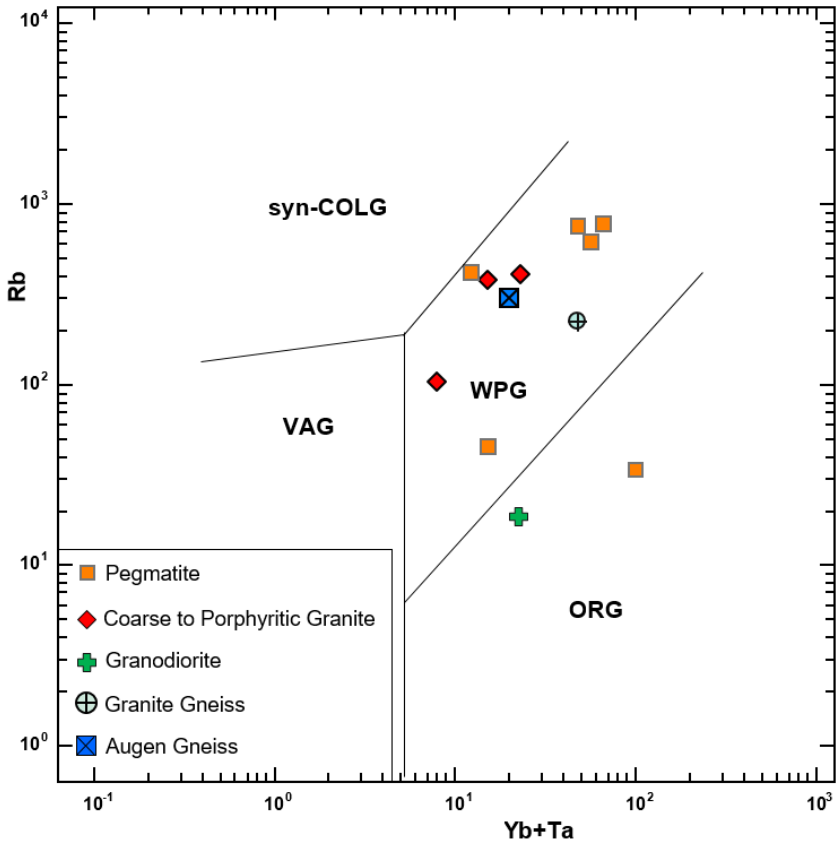


Figure 13: Tectonic discrimination diagram of Rb versus Yb+Ta for the granitoids of Isanlu area (After Pearce et al, 1984)

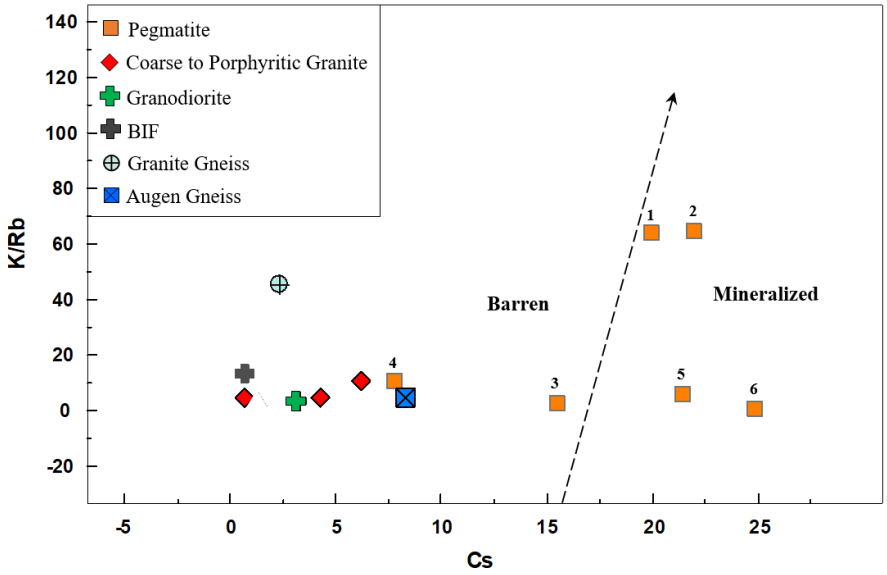


Figure 14: K/Rb versus Cs discrimination diagram showing the degree of fractionation and mineralization of the pegmatites (adapted from Morteani et al., 2000)

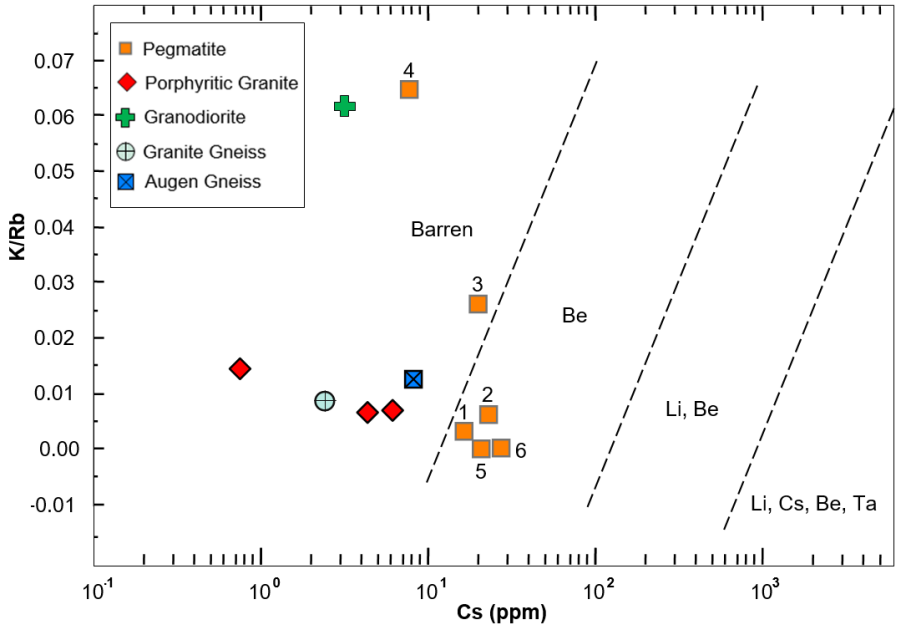


Figure 15: K/Rb versus Cs discrimination diagram showing the degree of fractionation and mineralization of the pegmatites (1 & 2=Takete south, 3=Isanlu east, 4=Takete north, 5=Takete west and 6=Idofin west) (after Morteani et al., 2000)

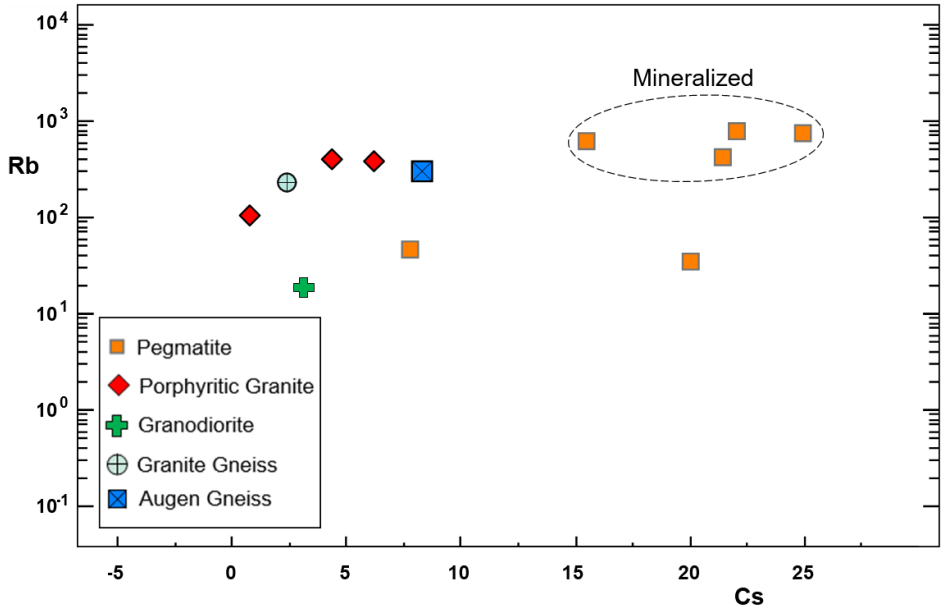


Figure 16: Rb versus Cs plot showing a high ratio for the mineralized pegmatites in the study area.

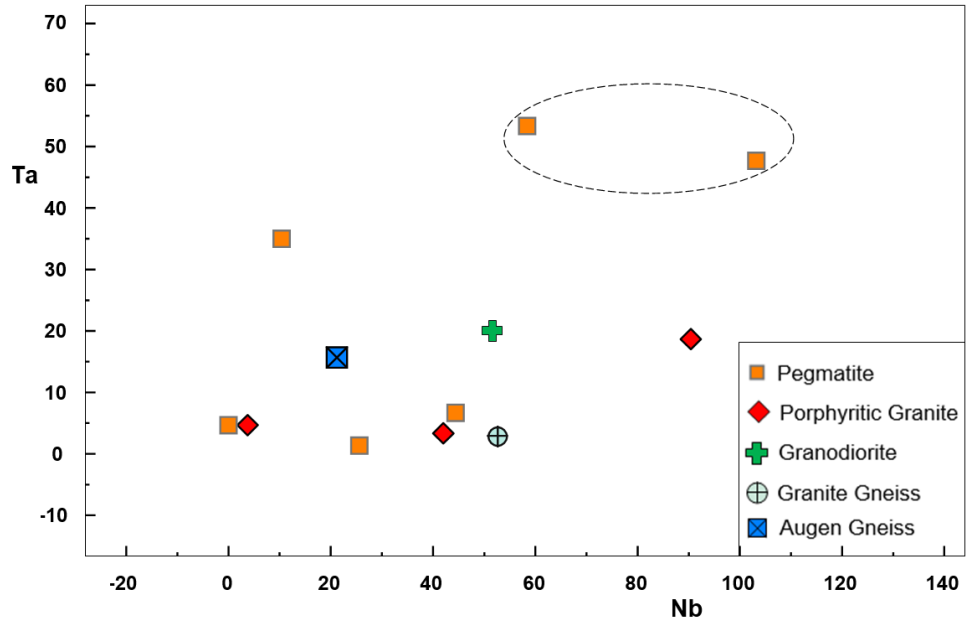


Figure 17: Plot of Ta versus Nb discrimination diagram showing tantalite bearing pegmatites in Isanlu area (in broken lines).

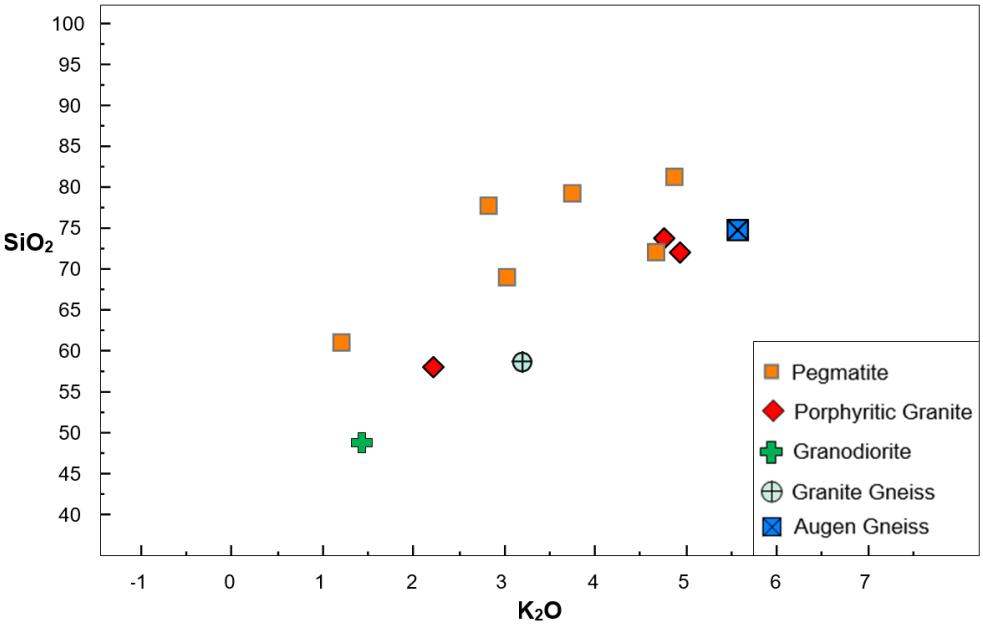


Figure 18: SiO_2 versus K_2O with higher silica content indicating a more evolved magma source.

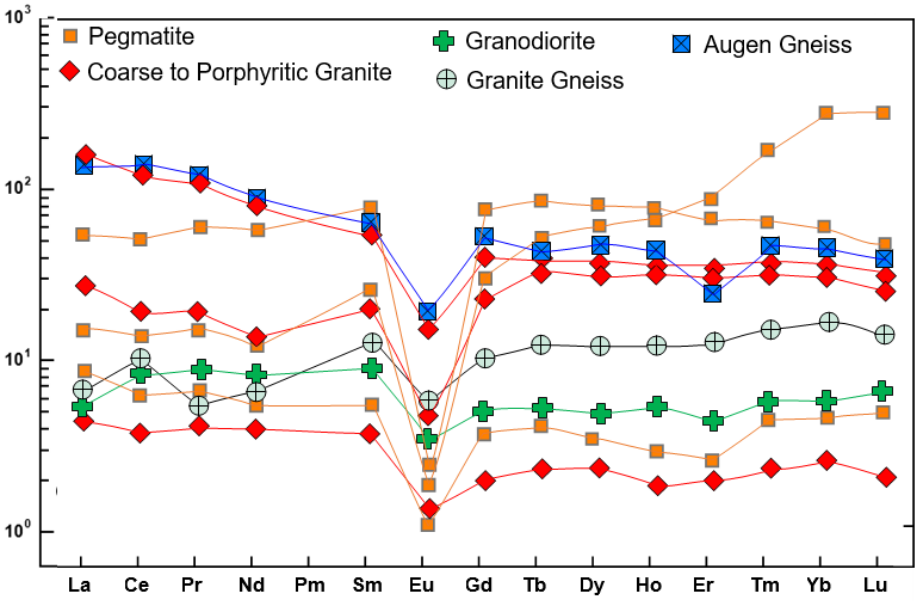


Figure 19: Chondrite-normalized plot of the rare-earth elements (REE) for rocks of the study area (After Nakamura, 1974)

CONCLUSION

The study area is underlain by various lithologic units including Migmatitic Gneiss, Augen Gneiss, Banded Iron Formation (BIF), Quartzite, Muscovite Biotite Schist, Diorite, Coarse-grained Granites, Pegmatites and Vein Quartz. Most of the foliated rocks in the study area are dominantly striking NE-SW direction and dipping Westerly with few easterly dips. This is consistent with the known structural grains in rocks of the Basement Complex of Nigeria. The dominant open joints directions are NNE-SSW with fewer subordinate discordant joints. Foliations, lineation, pinch and swell, joints, folds and faults are the common structures mapped within the study area.

The total magnetic Intensity map (TMI) derived from the aeromagnetic anomaly data depicts values that ranging between 52.5 - 85.2. The map also shows prominent high magnetic anomaly (71.5nT- 84.0nT) in both elongated and circular shapes distributed around the south-eastern and north-eastern part of the study area. The trend of dominant veins and joints directions obtained from the Tilt Vertical Derivatives (TDR) map also displayed NE-SW trends with few WNW-ESE trends which is consistent with the structural trends obtained from the field data. The general geochemical classification plots for the granitoids of the study area shows rocks of granitic composition which are largely Peraluminous except for diorite that lies around the granite-quartz diorite boundary and are Metaluminous in composition.

The tectonic discrimination plot shows the rocks lying in the within plate filed except for porphyritic diorite showing basaltic affinity and lies in the field of oceanic ridge granite. The results of geochemical classification of the igneous and metasedimentary rocks of the area also put the granitoids as having sedimentary precursor except for diorite and pegmatites which shows igneous affinity with contributions from sedimentary source during their prolonged fractionation. The REE fractionation pattern revealed on the chondrite-normalized plot that the rocks show slight or no enrichments in light rare earth elements (LREE) with pronounced negative Eu anomalies for granitoids of the study area, including the mineralized pegmatites.

This suggests the dominance of plagioclase in the melt which played a major role during fractionation with little or no influence from subordinate hornblende present in the fractionating melt. The rare-metal pegmatites found in the northern and southern part of Takete and western part of Idofin areas are mineralized and are chemically enriched in Eu, Rb, Cs and Ta, while the barren pegmatites in the eastern areas of Takete and Isanlu show a progressive enrichment in HREE and exhibit the lowest Eu anomaly and characterized by low Eu, Rb, Cs, Ta and Nb but high Ba, Sr and K/Rb ratio.

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