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Rare Metals (Ta-Nb-Sn) Mineralization Potential of Pegmatites of Igangan Area, Southwestern Nigeria

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Abstract

The study was carried out to determine the rare metal mineralization potential of some pegmatites associated with metasediments in the Igangan 240 NW sheet. Geological mapping on a scale of 1:50,000 revealed the pegmatites intrude metasediments and geochemical analysis for major, trace and rare earth elements were carried out using ICP MS/AES. Petrographic studies reveal a mineral assemblage of quartz, microcline and tourmaline; SEM studies revealed garnet and tourmaline to be close to the spessartine end-member and schorl respectively with albite occurring as the dominant plagioclase feldspar in the pegmatites. Result of geochemical analysis revealed SiO_2 with an average of 73.91% in the whole rock pegmatite Al_2O_3 with an average of 13.93%, and average concentration of 0.57%, 4.3% and 4.77% for CaO, Na_2O and K_2O respectively. It also revealed average concentration of 29 ppm, 153 ppm, 30 ppm, 118 ppm and 129 ppm for W, Li, Ta, Nb and Sn in the mica respectively which is above the average values in the whole rock, felspars and tourmaline extracts. REE abundance in the whole rock pegmatites is low to moderate with ΣREE varying between 8 - 220 ppm, 2 - 23 ppm in feldspars and 3 - 32 ppm in mica signifying no form of REE enrichment. Geochemical analysis results and trace elemental plots such as K/Rb vs. Rb, Ta vs. Ga, Ta vs. Cs were used to assess rare metal mineralization and it revealed the pegmatites have low level of rare metal and rare earth element mineralization with average k/Rb values of 177 indicative of low fractionation levels in the pegmatites.

Keywords

Rare Metals, Mineralization, Rare Earth Elements, Pegmatites

1. Introduction

Pegmatites are economically important sources of ceramic materials and high technology metals such as Rb, Cs, Be and the high field strength elements [1]. Its genesis is a controversial topic based on the different ideas and schools of thought on its genesis. The entirety of pegmatite genesis is a continuum of increasing fractionation and increasing spatial order via segregation of internal mineral assemblages [2].

Granitic pegmatites are an important part of granitic intrusions in orogenic belts and are characterized by strong enrichment in incompatible elements such as Rb, Cs, Li, Be and Sn. They are also associated with Nb-Ta-Sn-W mineralisation and the petrogenesis of pegmatites can be studied from the feldspar, mica and tourmaline which are sensitive indicators of magmatic and post magmatic events responsible for pegmatite evolution [3].

Various studies have been carried out on pegmatites in Nigeria by [4] [5] [6]. In the southwestern part of Nigeria, pegmatites are hosted within varieties of rocks of metamorphic and igneous origin where they intrude the older lithologies discordantly [7] [8] [9] [10] but there is paucity of information on pegmatites in Igangan sheet 240 NW.

Recent studies in Nigeria by [11] and [12] revealed that Nigeria has a pegmatite belt which is beyond the confines of the 400 km NE-SW trending belt from Abeokuta, southwestern Nigeria to North Central Nigeria which previous authors thought they extend [13] [14]. [15] delineated the occurrence of new rare element pegmatites in Nigeria thereby revealing the possibility of more pegmatite bodies than previously thought. Geochronological studies have been carried out on Nigerian pegmatites with recent studies by [16] suggesting an age of 709 Ma for emplacement of pegmatites in Ede, southwestern Nigeria based on U-Pb zircon geochronology.

2. Regional Geological Setting

The study area falls within the basement complex of southwestern Nigeria, it lies within the Pan-African belt which resulted from the collision of the passive continental margin of the West-African Craton and the active margin of the Tuareg shield during the Pan African tectonic event (**Figure 1**, [17] [18] [19] [20]).

The Nigerian Precambrian basement complex bears the imprint of the Liberian (ca 2500 Ma), Eburnean (ca 2000 Ma) and Pan-African (ca 600 Ma) tectonic events; it is polycyclic and can be broadly grouped into the migmatite gneiss complex, the schists belts and the older granite suite (**Figure 2**, [21] [22] [23] [24] [25]).

The migmatite gneiss complex consists mainly of migmatites and gneisses of different origin as well as meta-igneous rocks of basic to ultrabasic composition; the schist belts consists of fine grained clastics, pelitic schists, phyllites, banded iron formations, marble and amphibolites with imprints of the Kibaran (ca. 1200 Ma) and Pan African tectonic events [26], while the older granites consist of

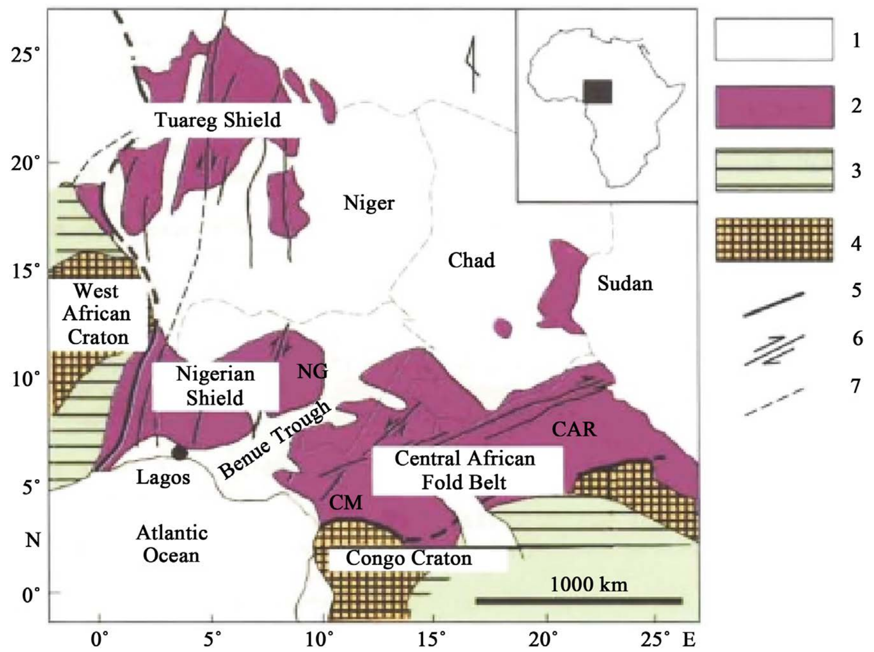


Figure 1. Sketch map showing Pan-African domains in West Central Africa. 1. Post-Pan African domains, 2. Pan African domains, 3. Pre-Mesozoic platform deposits, 4. Archean to Paleoproterozoic cratons, 5. Craton limits, 6. Major strike-slip faults, 7. State boundaries. CAR: Central African Republic, CM: Cameroun, NG: Nigeria (Modified after [27]).

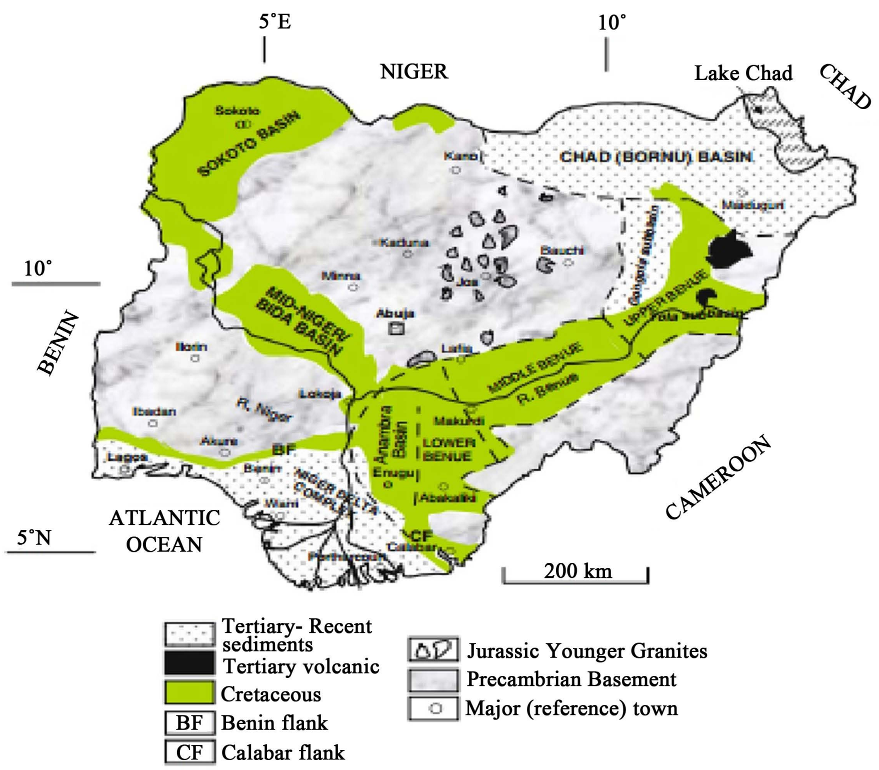


Figure 2. Geological sketch map of Nigeria showing the major geological components (Adapted from [28]).

orogenic (Pan-African) igneous rocks emplaced in the migmatite gneiss complex and the schists belts with varied lithology of granites, granodiorites, diorites, tonalities, syenites and pegmatites.

3. Local Geological Setting

The lithologies in the study areas include porphyritic granites, schists, biotite granites, granite gneisses as well as charnockites and amphibolites. These rocks are intruded by dolerite, granitic dykes, pegmatites quartz veins and aplites of varying length and thickness.

In the study area, the northwestern and northeastern flank is predominantly granitic, the southeastern flank and south central flank is dominantly by granite gneisses and migmatites with the central flank of the study area being dominantly schistose in nature with intercalations of quartzite and dolerite dykes occurring in the northeastern flank of the study area as intrusions associated with quartzites while the charnokites and amphibolites occurs as pods mostly within the schists (**Figure 3**).

Pegmatites occur as intrusions of various dimensions, varying length and thicknesses some of which crosscut the host rocks, it has interlocking grains of quartz, feldspars and in some cases minor traces of biotite, muscovite, garnet, tourmaline and agate; it follows a NW/SE trend with massive deposits occurring in the central portion of the study area as intrusions within the mica schist (**Figure 4**).

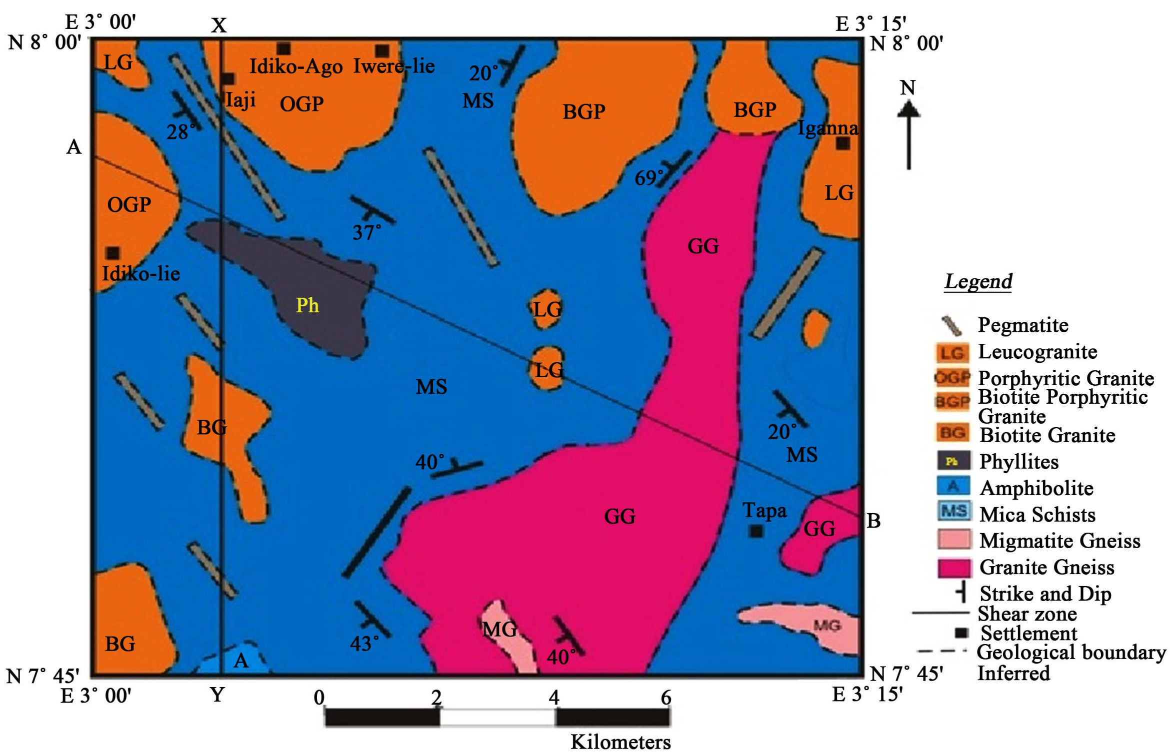


Figure 3. Geological map of the study area.

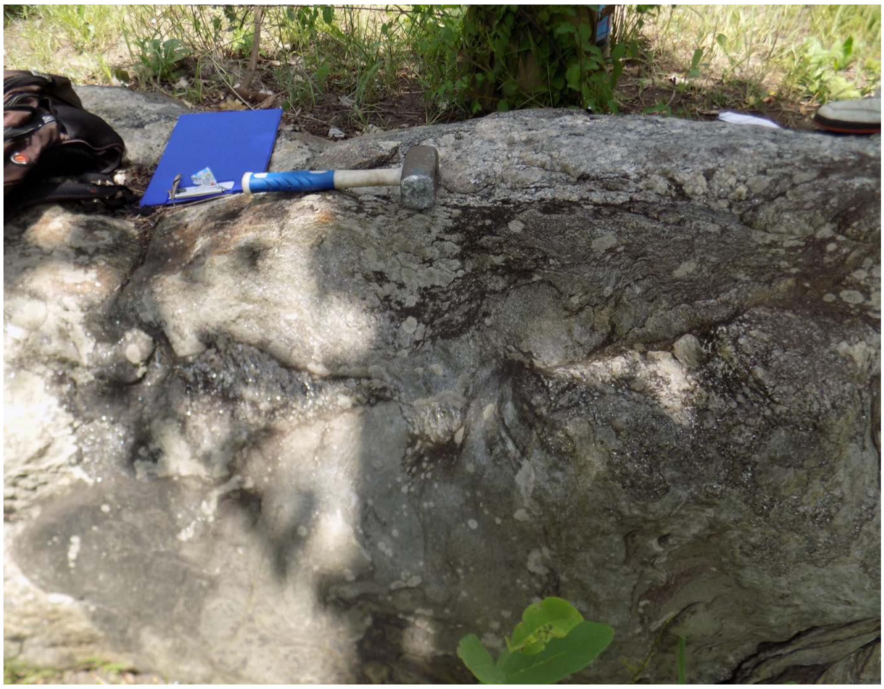


Figure 4. Schist pegmatite contact (hammer is about 30 cm in length).

Pegmatites are typically coarse grained but they show great variation in grain size, the contact between pegmatite and host rock are sharp in the granites, migmatites and granite gneisses while the contact in the schists was rarely observed due to the friable nature of the schists. Pegmatites associated with the porphyritic granites, migmatites and granite Gneisses are simple pegmatites dykes with central quartz bounded by feldspar, they are not extensive, they have similar mineralogy of quartz, microcline and occurrence of schorl in some areas while the pegmatites associated with the schist are mostly extensive and possess varying mineralogy with feldspars varying from orthoclase to albite, tourmaline, garnet, fluorite and tourmaline amongst others.

The polycyclic nature of the Nigerian basement complex is evident in the area with structural features such as faults and folds observed mainly in the migmatite gneiss and the NW/SE trend of the pegmatite as well as the NW/SE and NE/SW orientation of the joints with the NW/SE direction the main orientation of joints in the area. Some of the pegmatite bodies predate some of the structural features, this evident by structural deformation which manifest by brittle/ductile fault offsets by the structural episode.

They lack any form of foliation and they show no form of regional zoning, this could be due to the lower volatile contents of parent melts and the emplacement of their parental granitic melts at relatively shallow depth. Although variations in mineraology and field features in the pegmatites are obvious, it was not possible to investigate the changes in the bulk chemistry of the host rocks related to pegmatite formation due to the lack of clear cut contact zones between the pegmatites and the schists in some areas and the level of weathering of the metasediments. Presently, no geochronological data is available for rocks in the study area but studies are ongoing to acquire absolute age for the granites and pegmatites.

4. Method of Study

Field work involved systematic geological mapping on the scale of 1:50,000 to delineate the geological units in an area extending from 3˚00' - 3˚15' and 7˚45' - 8˚00' with an area extent of about 829 km^2. It involved the direct observation of the rocks in the study area, their structures features as well as their basic mineralogy.

During the study, lithological relationship between the pegmatites and host rocks was established; pegmatites samples were collected, thin sections as well as polished sections of the pegmatites were carried out at the department of geology, Rhodes University, Republic of South Africa and geochemical analysis was carried at Bureau Veritas Mineral Commodities, Canada.

Samples for polished sections were cut into ~2 cm diameter x ~1 cm rock fragments and mounted in epoxy. They were then polished with 3 µm and then 1 µm diamond paste, carbon coated with a Q150T Turbo-Pumped Sputter Coater/Carbon and analysed with a Jeol JSM6610 SEM equipped with a Thermo Fisher Ultradry EDS detector. Polished sections were examined using back-scattered electron imagery in an attempt to detect phases with high back-scattered electron intensity. These were subsequently analysed by means of energy dispersive X-ray spectrometry in order to determine the chemical composition of the phases. Analysis was carried out at the University of Free State, South Africa.

5. Results and Discussion

5.1. Mineralogy and Petrography

Hand samples of pegmatites vary from samples with a graphic texture composed of orthoclase and quartz with low percentage of mica, to pegmatites with albite/othoclase bond to a central quartz and muscovite with rare biotite; the presence of muscovite over biotite in the pegmatites is an indication of the general peraluminous nature of the pegmatite.

Petrographic studies revealed a mineral assemblage of quartz, microcline and tourmaline with accessory minerals that are opaque. Quartz display a low positive relief under crossed nicols while microcline displayed cross hatched twinning; albite displayed a polysynthethic albite twinning with perthitic habit indicating the intergrowth of two feldspars.

Potassium feldspars consist mostly of orthoclase which shows varying degrees of perthitic intergrowth, sodium felspars which are mainly albite; feldspars probed by SEM are mainly albites with very few of the plagioclase probed having compositions tending towards oligoclase.

Quartz occurs in all the pegmatites as an intergrowth with feldspars in some outcrops and as well developed euhedral crystals in some locations; it is mainly colorless in the pegmatites and composed almost entirely of SiO_2 based on SEM analysis. Micas occurs as muscovites and rarely as biotite with the presence of muscovite over biotite in the pegmatites an indication of the general peraluminous nature of the pegmatites.

The predominant minor minerals are garnet and tourmaline. Garnet is very rare in the pegmatites and was only observed at the only pegmatite/schist contact while tourmaline is also rare but more common than garnet, it is black in color and presumed to be schorl.

Garnet is euhedral with inclusions of apatite (**Figure 5**, **Figure 6**, **Table 1**) and composition close to the spessartine end-member with a formula; $Mn_3^{2+}Al_2(SiO_4)_3$; garnet chemistry reveals the chemical evolution of the phase from which the garnets crystallized and the presence of a garnet end member

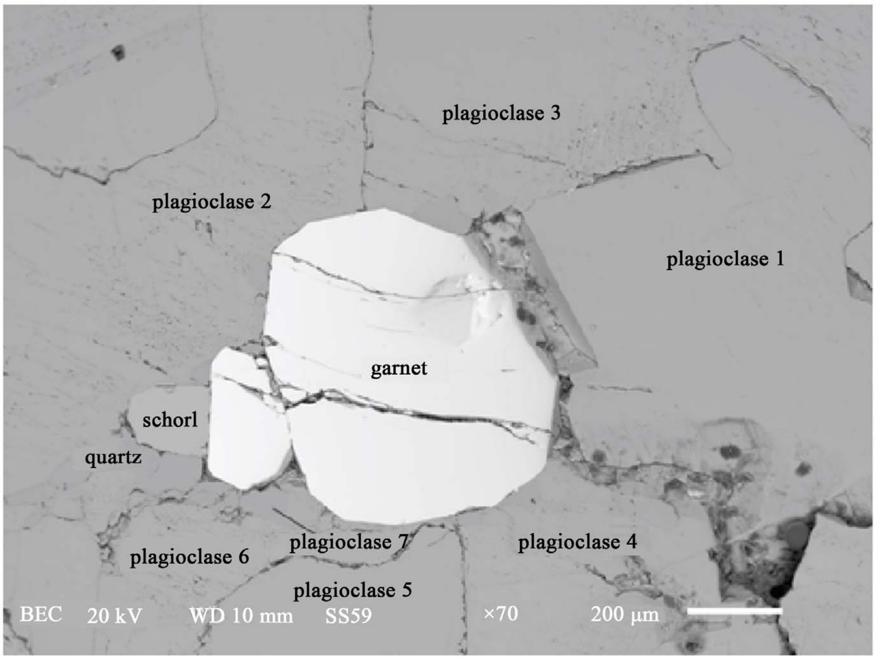


Figure 5. Backscatter electron image of quartz, schorl and plagioclase in pegmatite

Table 1. Composition of garnet probed by SEM.

F	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Ta_2O_5
1	-	1.34	17.16	32.40	-	-	0.53	-	29.95	18.63	-
2	-	0.43	17.24	31.99	-	-	1.09	-	24.41	24.84	-
3	-	0.54	17.28	32.23	-	-	1.08	-	24.10	24.77	-
4	-	0.59	17.54	32.34	-	-	1.14	-	23.66	24.75	-
5	-	0.61	17.36	32.41	-	--	1.07	-	23.97	24.58	-
6	-	0.66	17.31	32.39	-	-	1.15	-	23.32	25.16	-
7	-	0.56	17.30	32.07	-	-	1.11	-	24.15	24.82	-

can be used to draw inference on the possible petrogenesis of granitic magma and the approximate depth of formation and garnets from the study plots in the field of igneous (Figure 7).

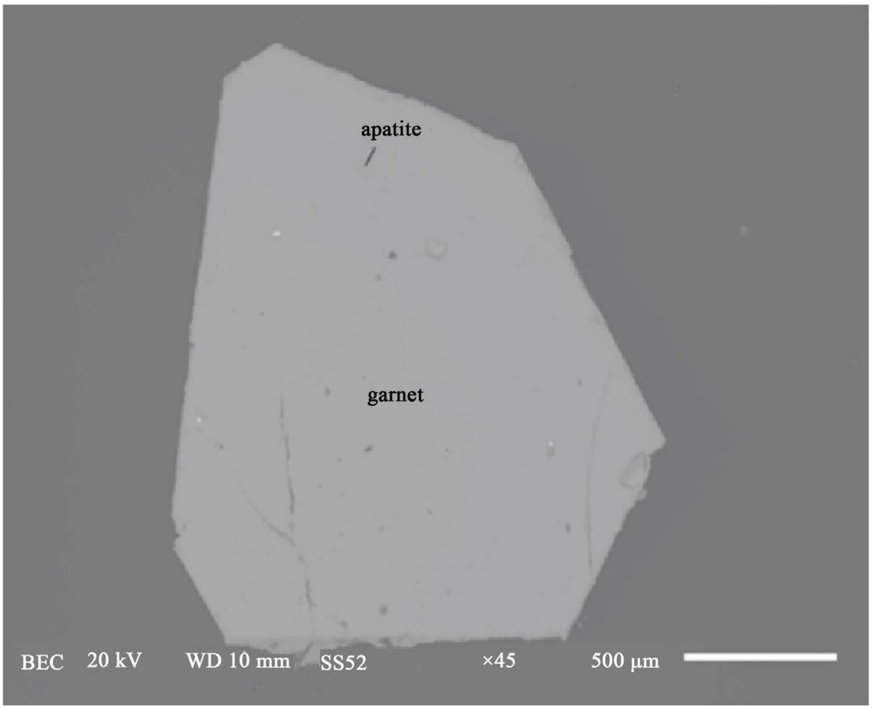


Figure 6. Garnet and plagioclase in pegmatite and backscatter electron image of garnet rain mount with inclusions of apatite.

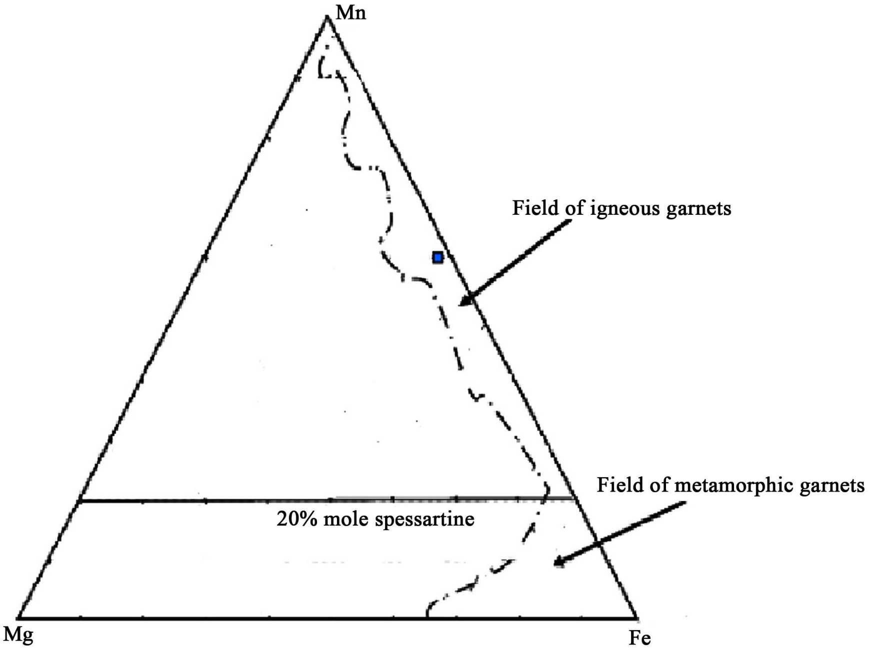


Figure 7. Composition of garnet. (a) Mn-Mg-Fe plot superimposed with the compositional field of igneous garnet [29].

SEM analysis revealed garnets have high concentration of SiO_2, MnO, Fe_2O_3 and Al_2O_3, and low concentration of Na_2O and CaO while P_2O_5, K_2O, Ta_2O_5, TiO_2 CaO concentrations were not obtained from the analysis (**Table 1**) while inclusions of apatite contains high concentration of P_2O_5 (39.9%), CaO (50.8%), MnO (4.48%) and F (3.45%); a composition indicative of flouroapatite.

5.2. Tourmaline

Analysis of tourmaline did not reveal the crystal structures of the tourmaline grains (**Figure 8**); tourmalines have high concentration of Al_2O_3, Fe_2O_3 and SiO_2 with average concentration of 36.2%, 14.9% and 40.6% respectively; low concentration of Na_2O and MgO with average concentration of 2.7% and 4.5% respectively while concentration of CaO, TiO_2, MnO and BaO are below 0.6%.

The tourmaline falls into the class of Fe rich quartz tourmaline rocks (hydrothermally altered granites), an indicating of boron metasomatism during the late stage crystallization of the pegmatites ([30], **Table 2** and **Figure 9**).

SEM analysis of feldspars reveal average concentration of 9.99%, 20.50%, 64.50%, 0.03%, 0.08%, 0.26% and 0.41% for Na_2O, MgO, Al_2O_3, SiO_2, P_2O_5, K_2O, CaO, Fe_2O_3 and ZnO respectively indicative of albite as the dominant plagioclase in the pegmatites (**Table 3**).

5.3. Geochemistry of Pegmatites

In terms of major elements the whole rock pegmatite samples have the highest concentration of silica and CaO with average of 73.91% and 0.57% respectively, the feldspar extracts have the highest concentration of Na_2O and P_2O_5 with a

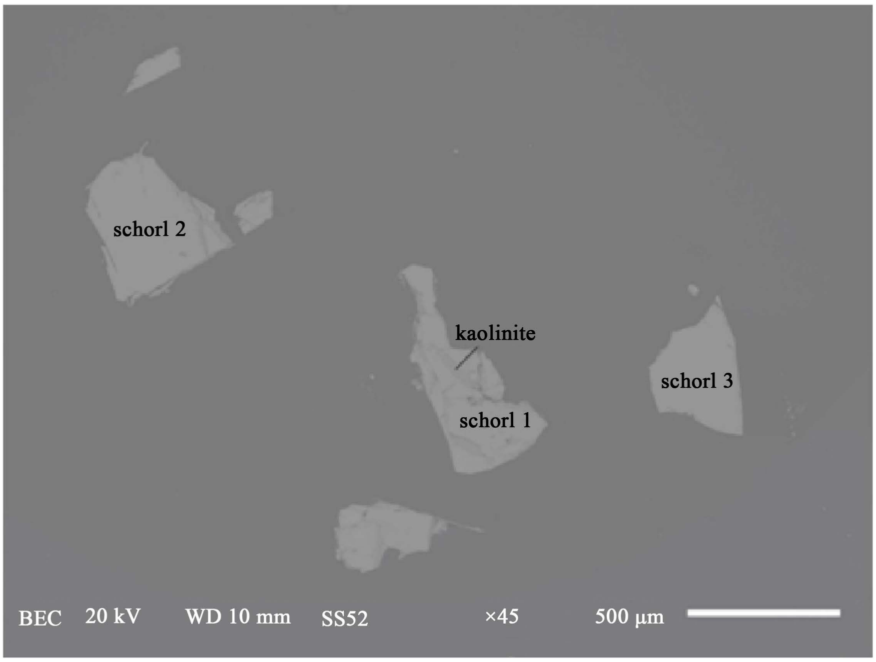


Figure 8. Backscatter electron image showing schorl associated with kaolinite.

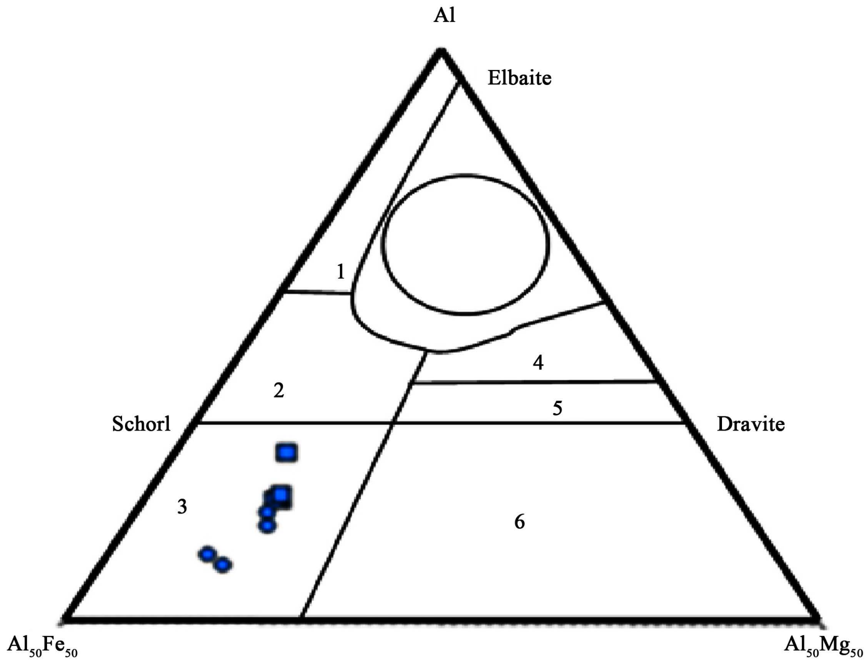


Figure 9. Composition of tourmaline from the study area. Al-Fe-Mg relations with fields of tourmaline (after [30]) from (1) Li-rich granitoid pegmatites and aplites, (2) Li-poor granitoids and their associated pegmatites and aplites, (3) Fe3+-rich quartztourmaline rocks (hydrothermally altered granites), (4) metapelites coexisting with Al-saturating phase, (5) metapelites not coexisting with Al-saturating phase, (6) Fe3+-rich quartz-tourmaline rocks, calc-silicate rocks, and metapelites.

Table 2. Composition of tourmaline from SEM.

	F	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3	ZnO	BaO
1	-	2.50	4.84	**36.92**	**40.98**	-	-	0.11	0.06	0.53	**14.02**	0.02	0.05
2	-	2.44	4.65	**36.79**	**41.15**	-	-	0.16	0.21	0.49	**14.13**	-	-
3	-	2.70	4.77	**36.97**	**41.03**	-	-	0.13	-	0.50	**13.85**	-	0.06
4	-	2.38	3.79	**38.14**	**41.48**	-	-	0.56	0.20	0.96	**12.51**	-	-
5	-	2.53	4.70	**36.16**	**40.92**	-	-	0.29	0.24	0.48	**14.61**	-	0.07
6	-	2.73	4.99	**35.35**	**40.79**	-	-	0.30	0.43	0.50	**14.90**	-	0.15
7	-	2.72	3.67	**34.66**	**39.57**	-	-	0.52	0.81	0.36	**17.70**	-	-
8	-	3.26	4.52	**34.25**	**39.18**	-	-	0.68	0.60	-	**17.51**	-	-

verage concentration of 5.77% and 0.14% while the mica extracts have the highest concentration of Al_2O_3 (16.42%), Fe_2O_3 (2.11%), MnO (0.08%), MgO (0.42%) and K_2O (5.66%).

In terms of trace elements, for Nb, Sn and W average concentration in whole rocks exceeds that of the other extracts (whole rock > mica > feldspar > tourmaline). For Ta, elemental abundance is highest in micas and least in tourmaline (mica > feldspar > whole rock > tourmaline), Cs abundance is highest in the

Table 3. Composition of plagioclase from SEM.

F	Na_2O	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	Fe_2O_3	ZnO	Nb_2O_5	Ta_2O_5
1	9.61	19.49	69.7						1.21		
2	7.60	19.71	71.41						1.28		
3	7.30	19.65	71.26						1.8		
4	11.54	19.3	69.17								
5	9.83	19.31	68.67						2.19		
6	10.48	19.37	69.57		0.17				0.41		
7	9.95	19.07	69.94	0.07					0.98		
8	8.93	19.42	69.96						1.69		
9	11.45	19.2	69.2	0.07	0.08						
10	11.50	19.14	69.11	0.15	0.11						
11	10.07	21.29	65.28	0.03	3.34						
12	10.13	21.01	66.01		2.87						
13	9.74	21.83	64.56		3.87						
14	10.17	21.3	65.63		2.9						
15	9.88	21.47	64.8		3.85						
16	10.36	21.05	65.79		2.81						
17	9.93	21.6	64.57		3.89						
18	10.75	20.67	65.88		2.44			0.26			
19	9.76	21.83	64.69		3.72						
20	9.87	21.68	64.5	0.03	3.92						
21	10.11	21.27	65.18		3.44						
22	10.32	21	65.54		3.14						
23	10.47	20.98	65.66		2.89						
24	10.12	21.3	65.35		3.23						
Minimum	7.30	19.07	64.50	0.03	0.08			0.26	0.41		
maximum	11.54	21.83	71.41	0.15	3.92			0.26	2.19		
Mean	9.99	20.50	67.14	0.07	2.75			0.26	1.37		

feldspars and least in tourmaline (feldspars > whole rock > mica > tourmaline) and Li abundance is highest in micas and lowest in the whole rock samples (mica > tourmaline > feldspar > whole rock).

Generally the average REE content of the pegmatites is low; ∑REE ranges from 3 - 203 ppm, 2 - 26 ppm, 4 - 18 ppm and 25 - 33 ppm in whole rocks, mica, feldspar and tourmaline extracts respectively with an average of 31 ppm, 13 ppm, 7 ppm and 29 ppm in whole rocks, mica, feldspar and tourmaline extracts. Analytical results of the major oxide, trace and rare elemental composition of pegmatites and extracts is presented in **Tables 4-6**.

Table 4. Major oxide composition of pegmatites and extracts.

	Pegmatite whole rock (N = 22)		Feldspars (N = 12)		Micas (N = 14)	
	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)
SiO_2	69.06 - 81.12	73.91	66.38 - 73.42	70.79	59.7 - 76.79	71.72
TiO_2	0 - 0.36	0.07	0 - 0.01	0.00	0.05 - 0.13	0.10
Al_2O_3	10.35 - 20.19	13.93	12.71 - 21.27	16.42	11.05 - 25.58	15.33
Fe_2O_3	0.06 - 3.65	1.00	0.13 - 0.43	0.25	1.7 - 3.58	2.11
MnO	0 - 0.09	0.04	0 - 0.04	0.01	0.06 - 0.1	0.08
MgO	0.02 - 1.87	0.35	0.01 - 0.03	0.02	0.15 - 0.53	0.42
CaO	0.04 - 1.71	0.57	0.04 - 0.91	0.24	0.06 - 0.7	0.53
Na_2O	0.74 - 8.97	4.3	2.77 - 10.21	5.77	0.51 - 3.53	2.82
K_2O	0.69 - 7.87	4.77	0.66 - 11.33	5.30	4.72 - 8.87	5.66
P_2O_5	0 - 0.34	0.12	0.03 - 0.23	0.14	0.07 - 0.21	0.10

5.4. Major Element Variation

$CaO-Na_2O-K_2O$ diagram reveals a wide distribution of samples along the Na_2O-K_2O sideline, coupled with the very low Ca contents of the pegmatites. The samples show a significant departure from the Calc-alkaline trend of [31] as well as the Trondhjemitic trend of [32]. The plot shows that the samples are mainly potassium rich with a few exceptions showing high Na_2O and CaO composition due to the difference in feldspar type and composition (Figure 10).

5.5. Trace Elements and Mineralization Potential

Trace element data shows an enrichment of W, Li, Ta, Nb and Sn in the mica with an average of 29 ppm, 153 ppm, 30 ppm, 118 ppm and 128 ppm respectively which is above the average values in the whole rock, felspars and tourmaline extracts (Table 5). This prefential enrichment of some elements in the muscovite extracts can be explained by the ability of the muscovite to accommodate wide range of substitutions at various sites in its crystal structure [33] and [34].

K/Rb vs. Cs, Ta vs. Cs, Ta vs. Ga, Ta vs. Cs, Ta vs. K/Cs and Ta vs. Cs + Rb plots also reveals a low level of rare earth element mineralization (Figures 11(a)-(d)), based on the line of mineralization proposed by [35] and [36].

$Al_2O_3/Na_2O + K_2O$ vs. $Al_2O_3/CaO + Na_2O + K_2O$ (A/NK vs. A/CNK) shows pegmatites are strongly peraluminous (Figure 10(e)) and K/Rb values range from 24 - 575 with an average of 177 ppm (Table 7) with few samples having K/Rb ratios less than 100 ppm which is generally accepted as indicative of mineralization [37]. Plots of Cs vs. K/Rb and Ba vs. K/Rb show the pegmatites are non mineralized and belong to the muscovite class (Figure 11(f), Figure 11(g)) and they have Nb/Ta ratios of 1 - 19 (Table 7).

[38] inferred that rare metal pegmatites are typically the most distant pegmatites from their parent granites while [39] reported that classical pegmatite

Table 5. Trace elemental concentrations of pegmatites and extracts.

	Pegmatite whole rock (N = 22)		Feldspars (N = 12)		Micas (N = 14)		Tourmaline (N = 2)	
	Range (ppm)	Average (ppm)	Range (ppm)	Average (ppm)	Range (ppm)	Average (ppm)	Range (ppm)	Average (ppm)
Mo	Bdl-1.69	0.68	Bdl-0.17	0.11	0.23 - 0.95	0.59	0.26 - 0.3	0.28
Cu	1.6 - 62.1	10.85	2 - 46.50	10.12	5 - 14.7	9.76	40.3 - 59.5	49.9
Pb	6.33 - 80.68	37.96	8.88 - 114.93	38.57	19.88 - 58.91	28.89	4.88 - 5.71	5.295
Zn	1.7 - 65	18.91	1.1 - 31	10.22	40.2 - 89.5	54.17	64.1 - 125	94.55
Ag	Bdl-133	48.35	Bdl-191	71.63	0.9 - 11.9	8.24	20 - 27	27
Ni	0.4 - 66.5	9.45	0.7 - 4.2	1.79	0.9 - 3.7	2.64	2.1 - 10.6	6.35
Co	Bdl-10.3	3.49	Bdl-1.1	0.61	Bdl-1.7	1.45	2 - 3.4	2.7
As	0.3 - 3.1	1.43	Bdl-1.4	0.76	Bdl-7.3	5.32	0.6 - 1	0.8
U	0.7 - 13.7	4.02	0.2 - 11.2	3.38	0.1 - 3.6	1.51	6.3 - 6.8	6.55
Th	0.1 - 23.7	4.1	Bdl-2.7	0.83	3 - 46	35.57	1.0 - 1.2	1.2
Sr	3 - 139	49.77	3 - 72	18.58	0.05 - 0.14	0.09	3 - 27	15
Cd	Bdl-0.18	0.08	Bdl-0.21	0.08	0.2 - 1.73	1.30	0.14 - 0.19	0.165
Sb	0.03 - 2.95	0.54	Bdl-1.64	0.40	0.06 - 0.55	0.41	6.59 - 20.28	13.435
Bi	0.04 - 36.28	2.05	0.09 - 26.46	2.75	2 - 20	15.21	2 - 13	7.5
Cr	Bdl-100	14.86	1 - 4	2.50	4 - 16	12.71	4 - 7	5.5
Ba	11 - 549	217.27	12 - 671	119.92	7 - 133	98.79	6 - 32	19
W	0.1 - 5.3	1.42	Bdl-1.3	0.54	16.3 - 55.6	28.61	0.2 - 0.3	0.25
Zr	0.6 - 132.2	30.85	Bdl-131	27.80	2 - 11.4	6.69	7.6 - 27.9	17.75
Sn	0.3 - 6.6	2.88	0.2 - 5.1	2.18	8.4 - 573.9	128.64	0.5 - 0.5	0.6
Be	1 - 18	5.36	Bdl-16	7.36	5 - 19	8.57	1 - 2	2
Sc	0.3 - 6.4	2.0	0.3 - 0.6	0.42	2.1 - 5.8	4.39	1 - 3.6	2.3
Y	0.7 - 15.2	4.64	Bdl-7	2.1	0.1 - 6.3	4.07	11.6 - 30.1	20.85
Hf	0.03 - 9.55	1.96	Bdl9.51	2.63	0.5 - 1.02	0.70	0.3 - 0.79	0.545
Li	2.3 - 216.3	42.22	7 - 295.9	57.53	69.6 - 437.1	152.76	15.6 - 374.1	194.85
Rb	12 - 1130	247.42	8 - >2000	716.67	304 - >2000	696.03	0.8 - 7.7	4.25
Ta	0.4 - 52.8	9.48	Bdl-44.1	14.93	21.8 - 45.70	30.61	0.2 - 12	6.1
Nb	1.2 - 170.01	32.24	0.31 - 106.63	28.91	59.17 - 314.85	118.61	1.85 - 7.91	4.88
Cs	0.7 - 127.1	32.81	2 - 113.30	44.68	14 - 53.70	23.71	1.4 - 1.9	1.65
Ga	9.41 - 35.53	20.03	11.95 - 37.72	22.65	27.68 - >100	45.67	10.22 - 10.45	10.335
Tl	Bdl-30	5.47	Bdl-4.15	1.24	1.51 - 12.65	3.94	-	-

zonation is typical of highly fractionated and mineralized pegmatites. The low level of rare earth mineralisation in this area is supported by lack of definate zonation patterns in the pegmatites and proximity to parent granitic bodies.

Table 6. Rare earth element composition of pegmatites and extracts.

	Pegmatite whole rock (N = 22)		Feldspars (N = 12)		Micas (N = 14)		Tourmaline (N = 2)	
	Range (ppm)	Average (ppm)	Range (ppm)	Average (ppm)	Range	Average (ppm)	Range (ppm)	Average (ppm)
La	0.4 - 46.6	6.04	0.20 - 4.90	2.19	2.5 - 4.1	3.3	0.20 - 4.6	1.12
Ce	0.68 - 90.99	12.28	0.90 - 10.50	4.85	6.31 - 6.56	6.4	0.19 - 4.14	1.76
Pr	0.2 - 9.8	1.67	Bdl-1.20	0.75	0.9 - 1	0.95	0.1 - 0.9	0.37
Nd	0.4 - 35.7	5.6	0.20 - 4.80	2.32	4.1 - 5	4.55	0.20 - 3.4	1.38
Sm	0.2 - 6.2	1.45	Bdl-1.20	0.81	1.4 - 2.7	2.05	0.10 - 1.2	0.49
Eu	0.1 - 0.9	0.14	Bdl-0.20	0.16	0.2 - 0.3	0.25	0.10 - 0.3	0.17
Gd	0.2 - 4.8	1.13	Bdl-1.10	0.63	1.4 - 3.8	2.6	0.10 - 1.1	0.49
Tb	-	-	-	-	0.2 - 0.8	0.5	-	-
Dy	0.2 - 3.1	0.92	Bdl-0.80	0.67	1.8 - 5.2	3.5	0.10 - 1.2	0.46
Ho	0.1 - 0.7	0.25	Bdl-0.20	0.12	0.3 - 0.9	0.6	-	-
Er	0.1 - 1.5	0.5	Bdl-0.40	0.33	1.1 - 2.2	1.65	-	-
Tm	-	-	-	-	0.2 - 0.4	0.3	-	-
Yb	0.1 - 3	0.74	Bdl-0.70	0.57	1.5 - 2.4	1.95	0.10 - 1.1	0.37
Lu	-	-	-	-	0.2 - 0.3	0.25	-	-

Bdl-below detection limit. -No data

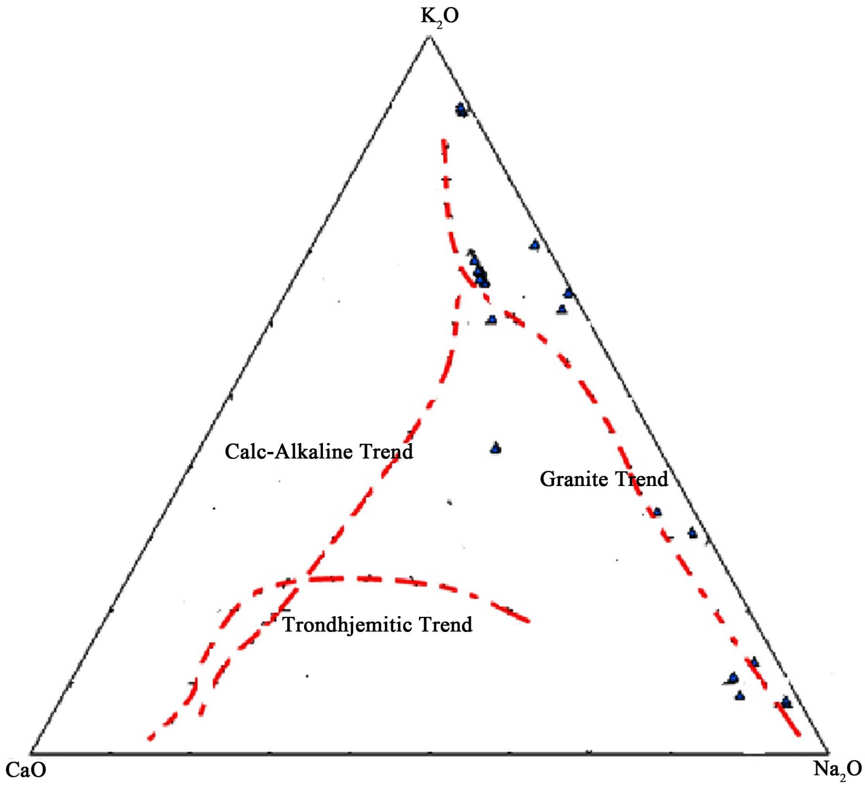


Figure 10. CaO-Na_2O-K_2O ternary variation diagram for whole rock pegmatites.

Table 7. Selected elemental ratios of whole rock pegmatites.

S/NO	A/CNK	A/NK	K_20/Na_20	Ba/Rb	Rb/Sr	Rb/Cs	K/Rb	Nb/Ta
1	1.22	1.23	1.8	1.5	12.0	58.5	233.0	19.4
2	1.42	1.46	0.2	0.7	0.6	43.9	327.1	8.0
3	1.20	1.22	2.6	0.2	20.2	33.1	179.7	6.4
4	1.24	1.34	0.1	0.9	0.6	0.5	574.5	3.1
5	1.15	1.18	1.7	0.7	7.7	25.5	211.3	12.5
6	1.36	1.45	0.1	0.4	3.2	0.6	161.3	1.3
7	1.18	1.24	0.6	5.9	1.3	21.6	362.4	10.4
8	1.56	1.59	0.1	0.2	26.3	35.8	72.7	3.2
9	1.24	1.38	2.7	1.4	3.2	12.8	173.5	3.9
10	1.61	1.64	0.1	0.3	25.8	35.1	74.1	2.4
11	1.13	1.26	3.2	1.2	3.5	14.1	176.8	4.8
12	1.17	1.30	3.0	1.3	3.5	13.7	177.2	4.5
13	1.67	1.70	0.5	0.0	141.2	29.5	23.8	2.5
14	2.31	2.33	10.1	0.0	117.6	15.7	32.7	0.9
15	1.20	1.33	2.9	1.3	3.5	13.2	174.2	5.0
16	2.46	2.50	9.7	0.0	125.0	16.1	30.2	0.7
17	1.41	1.60	2.2	1.6	2.8	10.9	160.6	3.9
18	2.18	2.21	10.3	0.0	133.3	15.8	31.5	0.5
19	1.43	1.79	1.2	5.5	0.7	45.2	296.1	11.5
20	1.64	1.67	0.1	0.2	26.6	34.7	77.0	2.8
21	1.21	1.34	3.0	1.3	3.4	13.4	180.1	3.9
22	1.27	1.43	2.9	1.2	3.5	13.8	162.4	2.6
mean	1.47	1.55	2.68	1.18	30.26	22.89	176.92	5.19

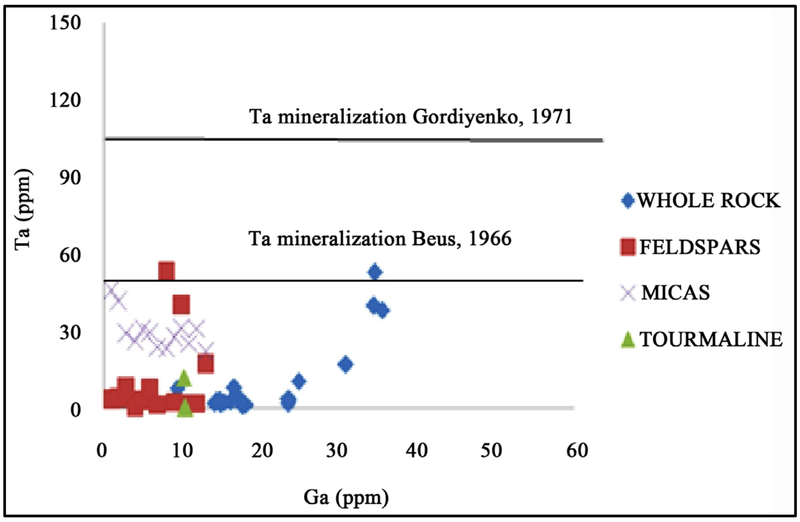
The rare-earth elements abundance of bulk rock and mineral extracts (muscovite and feldspar) of pegmatites from the study area are presented in **Table 5**.

Generally, the REE pattern of the bulk pegmatite samples and the mineral extracts display different REE patterns (**Figure 12**), REE abundance in whole rock pegmatites is low to moderately high with ΣREE varying between 7.67 - 220.37 ppm, a weak negative Eu anomy (Eu/Eu* = 0.15 - 1.53), a slightly discernable negative Ce anomaly and relative enrichment of HREE (La_N/Yb_N = 0.96 - 25.82).

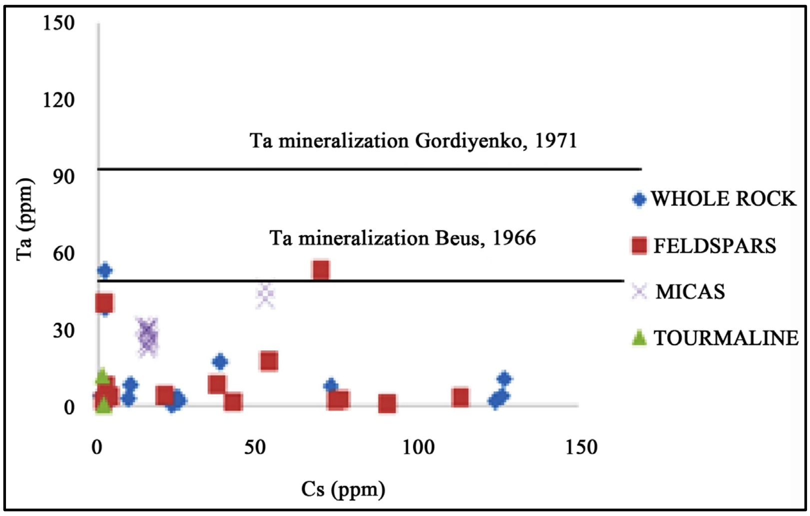
Based on the normalization plots; the pegmatites did not undergo considerable fractionation and metasomatism as well as the study of [42] that advanced the views that weak negative Ce signature and a strong negative Eu signature denotes considerable fractionation and metasomatism.

6. Conclusion

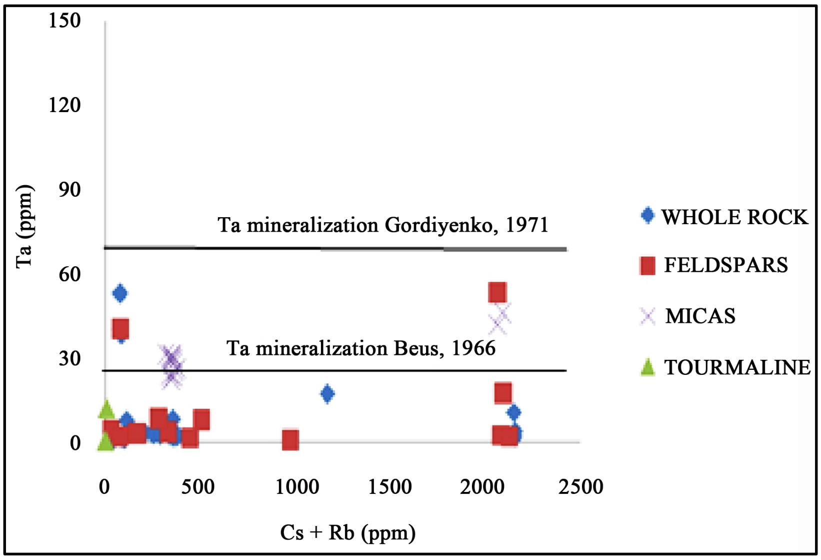
The study area which is majorly underlain by schist and potassic porphyritic


150
120
90
60
30
0
Ta (ppm)
Ta mineralization Gordiyenko, 1971
Ta mineralization Beus, 1966
0 10 20 30 40 50 60
Ga (ppm)
WHOLE ROCK
FELDSPARS
MICAS
TOURMALINE

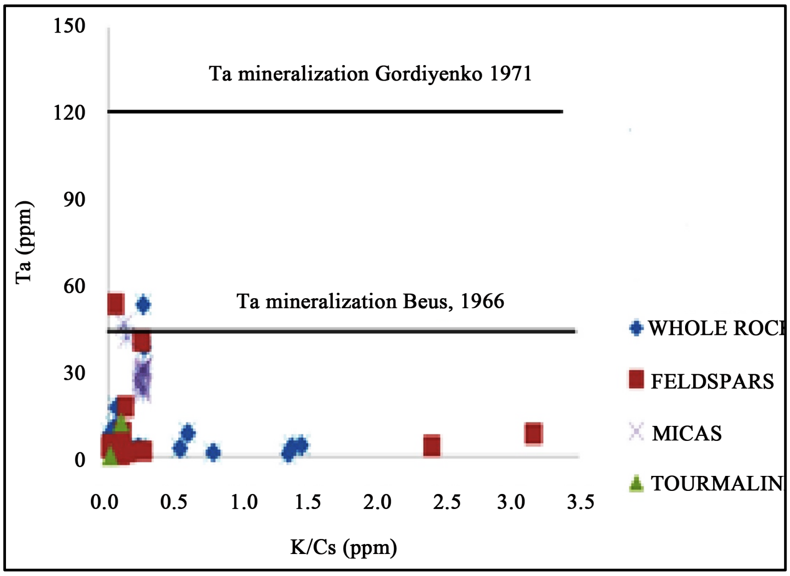
(a)


150
120
90
60
30
0
Ta (ppm)
Ta mineralization Gordiyenko, 1971
Ta mineralization Beus, 1966
0 50 100 150
Cs (ppm)
WHOLE ROCK
FELDSPARS
MICAS
TOURMALINE

(b)

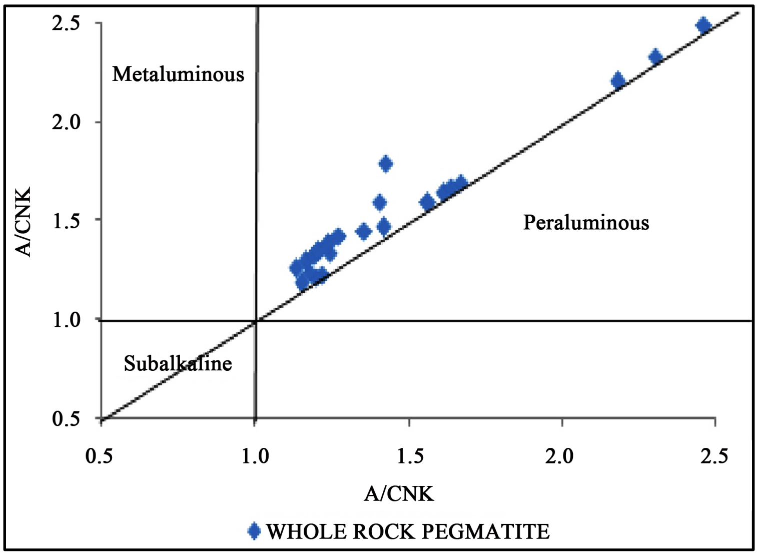

150
120
90
60
30
0
Ta (ppm)
Ta mineralization Gordiyenko, 1971
Ta mineralization Beus, 1966
0 500 1000 1500 2000 2500
Cs + Rb (ppm)
WHOLE ROCK
FELDSPARS
MICAS
TOURMALINE

(c)



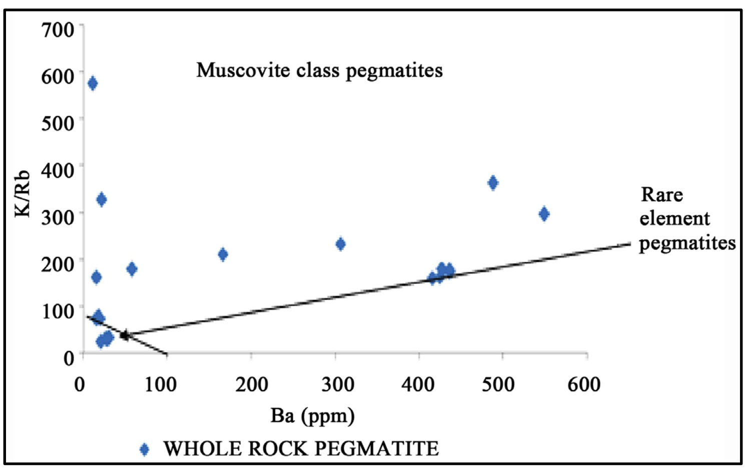
150
120
90
60
30
0
Ta (ppm)
Ta mineralization Gordiyenko 1971
Ta mineralization Beus, 1966
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
K/Cs (ppm)
WHOLE ROCK
FELDSPARS
MICAS
TOURMALIN

(d)



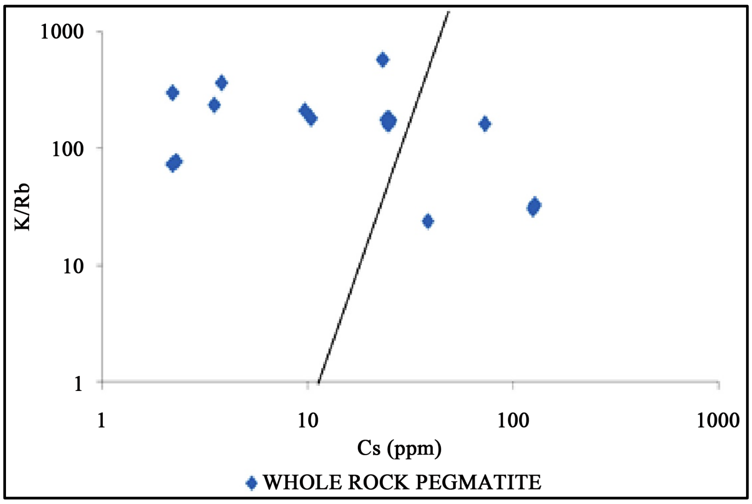
2.5
2.0
1.5
1.0
0.5
A/CNK
Metaluminous
Peraluminous
Subalkaline
0.5
1.0
1.5
2.0
2.5
A/CNK
WHOLE ROCK PEGMATITE

(e)



700
600
500
400
300
200
100
0
K/Rb
Muscovite class pegmatites
Rare element pegmatites
0
100
200
300
400
500
600
Ba (ppm)
WHOLE ROCK PEGMATITE

(f)



(g)

Figure 11. (a)-(g). (a) Ta vs Ga plot for pegmatitess and extracts from the study area; (b) Ta vs Cs plot; (c) Ta vs Cs + Rb; (d) Ta vs K/Cs; (e) molar A/NK vs. A/CNK (after [40]); (f) and (g) mineralization potentials and characterization of the pegmatites (discrimination lines after [41]).

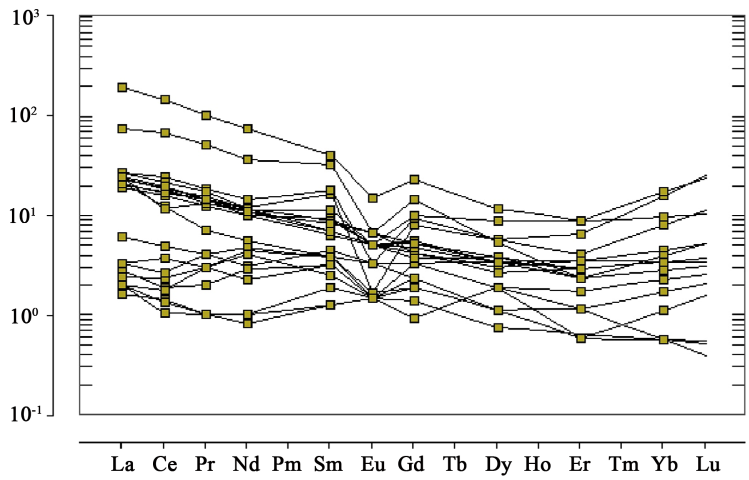


Figure 12. Condrite normalization plot for pegmatites and extracts. (condrite values after[43])

granites has been intruded by low lying NW-SE trending pegmatites. Results of geochemical analysis as well as trace elemental plots revealed low to medium enrichment in rare metals and REEs though there is potential for gem winning based on previous winnings of gems from the study area, unfortunately, there is no clear cut geochemical method to ascertain the presence or absence of gemstones in pegmatites from surface samples.

Further Studies

Understanding the genesis of pegmatites still remains a controversial topic. Further studies can be carried out using oxygen and hydrogen isotopes in conjunction with fluid inclusion studies (in progress) to obtain more information on the petrogenesis of these pegmatites and the mineralogy can further be studied to understand further the mineral species and delineate minerals which might be used to understand the genesis of the pegmatite and delineate the gem bearing zones.

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