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MINERALIZATION POTENTIALS OF PEGMATITES IN THE NASARAWA AREA OF CENTRAL NIGERIA

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ABSTRACT

Pegmatites in Nasarawa area of Central Nigeria lie within a fracture-controlled east-north-east trending rare metal pegmatite belt closely associated with late Pan African peraluminous granites in Nigeria. Trace elements of feldspars and muscovites of pegmatites in Nasarawa area of Central Nigeria were analyzed to determine the rare metals mineralization potentials of the pegmatites. The minerals show fractionation even within units of complex mineralized pegmatites as indicated by the wide ranges of K/Rb in Na-feldspars (albites), muscovites and K-feldspars and the wide range of K/Tl in the latter two minerals. Cs, Rb and Tl and the rare earth elements (REEs) Ce, La, Pr and Y are enriched in the K-bearing muscovites and K-feldspars; K-feldspars have the highest average values of Tl, Ce, La, Pr and Y while the muscovites have the highest average values of Sn, Nb, Ga, F and Zn. Average values of Ta, Sr, Ba, W and Zr are highest in the albites, which also have the lowest average Nb/Ta ratio. This is an indication that these elements are enriched along late Na-rich rare metal mineralizing fluids. The rare alkalis Rb and Cs and Tl are positively correlated with the rare lithophile elements (Ta, REEs, Pb, Bi and Y), in both the pegmatite K-feldspars and muscovites, strongly positively correlated with Sn in the muscovites but negatively correlated with Nb in the minerals. In the pegmatitic albites, Nb has very strong positive correlations with Ta (0.868) and Zr (0.847), which is indicative of the incorporations/substitution of these elements in the crystal lattice of the ore minerals. There is a general enrichment of the rare elements towards the middle and inner zones of the complex mineralized pegmatites. Fluorine, phosphorus and boron-rich fluids played significant roles in the magmatic complexation/fractionation and concentration of Sn-Ta-Li-Cs-Be in the albitized zones of the highly evolved pagmatites. K/Rb versus Cs in the K-feldspars classify the pegmatites into barren, Be-, Li-Be, and Li-Cs-Be-Ta types. Comparably low Nb/Ta ratios in the late albites and amblygonites indicate the paragenesis of these minerals with the tantalum ores in the middle/inner zones of the complex mineralized pegmatites. While the Be-, and Li-Be-types are highly prospective for gem tourmaline, beryl and

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columbite; the most evolved pegmatites in this area are good candidates for tantalite, amblygonite-montebrasite, and probably pollucite prospecting/mining.

***Key words*:** Rare metals, Pegmatites, Muscovites, Feldspars, Mineralization, Correlations.

RESUMEN

Pegmatitas en el área de Nasarawa, Nigeria central, se encuentran dentro de un cinturón de pegmatitas con metales de tierras raras controlado por fracturas, con tendencia Este-Noreste, y estrechamente asociado con granitos peralumínicos del Pan Africano tardío en Nigeria. Elementos trazas en feldespatos y muscovitas de las pegmatitas del área de Nasarawa, Nigeria central, fueron analizados para determinar el potencial de mineralización de metales de tierras raras en las pegmatitas. Los minerales muestran fraccionamiento aún dentro de unidades en las pegmatitas complejamente mineralizadas, como lo indica el amplio rango K/Rb en feldespatos sódicos (albitas), muscovitas y feldespatos potásicos y el amplio rango de K/TI en estos dos últimos minerales. Las muscovitas potásicas y los feldespatos potásicos están enriquecidos en Cs, Rb y TI y en los elementos de tierras raras (REEs) Ce, La, Pr e Y; los feldespatos potásicos poseen el mayor valor promedio de TI, Ce, La, Pr y Y e Y mientras que las muscovitas tienen los mayores valores promedios de Sn, Nb, Ga, la F y Zn. Los valores promedios de Ta, Sr, Ba, la W y Zr son más altos en las albitas, las cuales poseen también el promedio más bajo de Nb/Ta. Esto indica que estos elementos son enriquecidos por fluidos mineralizantes tardíos ricos en sodio y metales de tierras raras. Los elementos alcalinos raros Rb and Cs y TI se correlacionan positivamente con los elementos litofilos (Ta, REEs, Pb, Bi y Y), en los feldespatos potásicos y las muscovitas de las pegmatitas, y tiene una fuerte correlación positiva con Sn en la muscovita pero la correlación es negativa con Nb en los minerales. En las albíticas pegmatiticas, Nb tiene una correlación positiva muy fuerte con Ta (0.868) y Zr (0.847), lo que indica la incorporación o sustitución de estos elementos en la estructura cristalina de los minerales de mena. Hay un enriquecimiento general de los elementos de tierras raras hacia la mitad y las partes mas profundas del complejo pegmatítico mineralizado. Fluidos ricos en flúor, fósforo y boro jugaron un papel importante en la complejización y fraccionamiento magmatico y en la concentración de Sn- Ta-Li-Cs-Be en las zonas albitizadas de las pegmatitas altamente evolucionadas. K/Rb vs Cs en feldespatos potásicos clasifican las pegmatitas en tipos estériles, de Be, de Li-Be, y de Li-Cs-Be-Ta. Relaciones de Nb/Ta comparativamente bajas en las albitas y ambligonitas tardías indican la paragénesis de estos minerales con las menas de tantalio en las zonas medias e internas del complejo pegmatítico mineralizado. Mientras los tipos Be y Li-Be son altamente prospectivos para tourmalina, berilo y columbita como gemas; las pegmatitas más evolucionadas en esta área son buenas candidatas para la prospección minera de tantalita, ambligonita- montebrasita, y probablemente polucita.

***Palabras clave*:** Metales raros, Pegmatitas, Moscovitas, Feldospastos, Mineralización, Correlaciones.

Introduction

Nigeria possesses a very large pegmatite environment. The pegmatites are widely distributed with a marked concentration of mineralized pegmatites in a broad belt, which extends from Ago-Iwoye in the southwest to Bauchi in the northeast, an air distance of more than 400kilometers. Thousands of pegmatites occur in this belt, most of which have never been mapped or sampled in a systematic, scientific manner. Potassium feldspar, albitic plagioclase, quartz, and subordinate, if any muscovite and/or biotite constitute the major minerals while a wide spread spectrum of minerals including lepidolite, tourmaline (green, pink, black and blue), beryl, chrysoberyl, apatite, amblygonite, monazite, lithiophyllite-triphyllite, ghanite, cassiterite, wodginite, nigerite, columbo-tantalite, tapiolite, microlite, bismuthinite, bismuthite, scheelite, cholite, andalusite and sillimanite occur as accessory minerals in the pegmatites, Bowden and Kinnaird (1984).

The ages, mineralogy, and composition of these pegmatite units appear to be analogous to those of the pegmatites environment in Brazil, Canada and Australia. The pegmatitic belt and the orientation of the units within it appear to be related to rotational stresses created by the Benue Trough. From a more global perspective, this trend is probably the northern extension of the Brazilian pegmatite belt, which runs from Rio Grande del Sul to Rio Grande del Norte. The pegmatite field of this study area is part of late Pan African, (Jacobson and Webb, 1949; Wright, 1970), rare (specialty) metals granitic pegmatites. The primary mineralization of tantalum, niobium, tin, beryllium and lithium is hosted in quartz-feldspar-muscovite pegmatites (Kinnaird, 1984).

The Nasarawa area lies between latitudes 8º 18' N and 8º 30' N and longitudes 7º 35' E and 7º 50' E, west of the southern boundary of Afu complex- the southern most unit of the Younger Granites complexes (Figure 1). Mining of tantalite from both pegmatites and the eluvials started in the area some years ago. The mining continues for the major periods of the year except during the very dry months of February to early April when lack of water makes it difficult to mine and concentrate the minerals. Columbite and cassiterite are recovered as by-products of the tantalite mining, while other pegmatite minerals like quartz, feldspar, amblygonite-montebrasite, cookeite and mica are still being discarded in waste dumps.

Area description, methods and materials studied

Regional Geology

Central Nigeria is part of an Upper Proterozoic mobile belt extending from Algiers across the southern Sahara into Nigeria, Benin, and the Cameroun. This Pan-African belt continues into Northeast Brazil where analogous rare-metal mineralized pegmatites are also known (Schuiling, 1967). Bordered to the west by the West African Craton (stabilized around 2 Ga) the Pan-African belt itself is made up of gneiss-migmatites, metasediments, and metavolcanics that have been subjected to polycyclic metamorphism, and emplacement of igneous rocks. These rocks all constitute the Precambarian to Lower Paleozoic Basement Complex rocks. The gneiss-migmatites bears imprints of the Liberian (ca. 2500Ma), Eburnean (ca 2000Ma) and Pan African (ca. 600Ma) tectonic events (Oversby, 1975; Turner, 1983). Within the sequence are domains of metasediments and metavolcanics intruded by igneous rocks, which constitute the north/south trending schist belts.

The schist belt lithologies which consist of fine grained clastics, pelitic schists, phyllites, banded iron-formations, marble and amphibolites are considered to be Upper Proterozoic assemblages (Turner, 1983). They host most of the economic minerals in the Basement Complex. During the Pan-African episode, the Proterozoic gneiss-migmatite-schist complex were intruded by various granitoids resulting from oceanic closure, subduction, oblique collision between the West African craton and the Hoggar – Nigeria shields (Black, 1984) and crustal thickening. The Pan-African granitoids of Nigeria, which is collectively termed Older Granites, comprise gabbros, charnockites, diorites, granites, and syenites.

Geochronological data from previous works (Rb – Sr whole-rock and U-Pb zircon) of Pan-African granitoids intruding the reactivated Archean to Lower Proterozoic crust of central and south-western Nigeria show that intrusive magmatite activity in these areas lasted from at least 630 to 530 Ma (van Breemen *et al*., 1977; Rahaman *et al*., 1983; Dada *et al*., 1987; Matheis and Caen-Vachette, 1983; Umeji and Caen-Vachette, 1984; Akande and Reynolds, 1990). Results of the rock ages also show that pegmatities' emplacement in the southwestern Nigeria occurred mainly after the peak of the Pan-African orogenic event in this area.

The end of the Pan-African tectonic event is marked by a conjugate fracture system of the strike-slip faults (Ball, 1980). Fault directions have

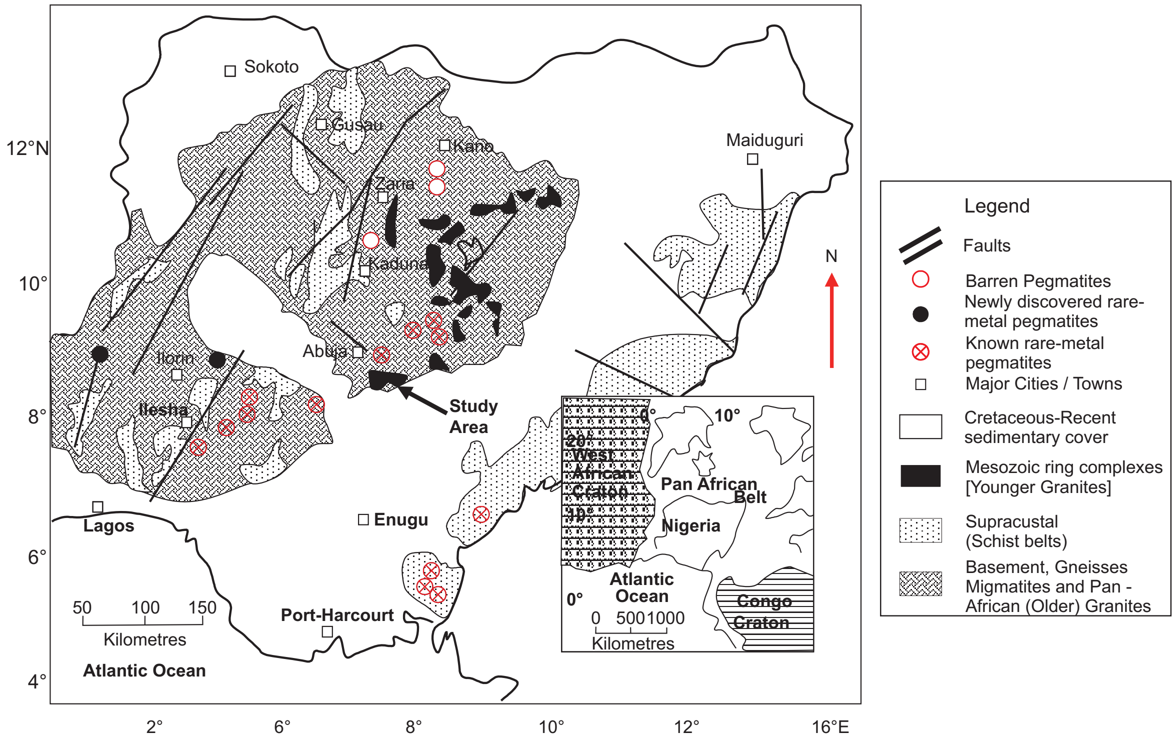

Figure 1: Geological Map of Nigeria Showing the Regional Fractures and Location of Areas of Rare-metal and Barren Pegmatites (after Garba, 2003)

consistent trend and sense of displacement; i.e. a NE-SW (NNE-SSW) trending system having a dextral sense of movement and a NW-SE trending system a sinistral sense (McCurry, 1971; Wright, 1976; Holt *et al*., 1978; Ball, 1980). Both sets crosscut all the main Pan-African structures, including older N-S trending shear zones (mylonites) and late orogenic granites (Ball, 1980; Ajibade and Wright, 1989; Kuster, 1990; Garba, 1992). Gold and pegmatities' rare mineralization are closely associated with the fractures in the Pan-African belt (Kuster, 1990; Ekueme and Matheis, 1995; Garba, 2002, 2003).

About 100km north-east of the area of study at Wamba, rare metal pegmatites have also been geochemically linked to peraluminous late Pan-African tectonic granitoids, the emplacement of which have largely been controlled by the regional fractures (Kuster, 1990). Chemical data on granites, and granitic and pegmatitic muscovites show that RB, Cs, Sn, Nb, and Ta are enriched during both magmatic and postmagmatic evolution, with the highest contents of these elements occurring in early muscovites of the albitized and mineralized pegmatities (Kuster, 1990).

Albite, K-feldspar, and quartz are the main pegmatitie-forming mineral; white mica is a typical but minor component. From a geochemical point of view, quartz is of no particular interest since it diadochially (substitutionally) hosts trace elements to a negligible extent. Feldspars and white micas are the most informative minerals because their element distributions reflect the trace elements contents in either early pegmatite forming fluids or in the later metasomatizing solutions (Moller and Morteani, 1987). Feldspars and white micas of pegmatites in the Nasarawa area were sampled and analysed for trace elements to determine the mineralization potentials of the pegmatites. Data from this area is also compared with published data on well-studied pegmatities for comparison of the potentials.

Analytical procedures are as stated in Akintola and Adekeye (2006). The chemical data on the pegmatite mica and feldspars were subjected to bivariate correlations after a lognormal transformation of the data. Bivariate correlation coefficient of the elements, r, were interpreted to determine elemental geochemical associations and evolutionary trends in the pegmatites.

Local Geology

The geological setting of Nasarawa area is shown in Figure 2. From field evidence, the oldest rocks in the study area are micaceous pelitic schists. Variations in the schist composition for instance, the mica versus the quartz – feldspathic contents are observable in the field. This rock unit has undergone a polyphase metamorphism and ductile deformations evidenced by local variations in the strike and dips of the foliation. Like the other schist belt rocks in the country, the schists have a general strike of north-south, and in the area, dips at gentle angle (10º – 30º) to the east. The schists were intruded by Older Granites, which outcrop as hills especially to the northwest, and west of the area. These Older Granites have a range of granodiorite to granite compositions.

To the east of the area are rocks of the Afu complex of the Younger Granites. The Afu complex is made up of high-level anorogenic granites mainly biotic granites and minor quartz porphyry emplaced within Precambrian Paleozoic Basement gneisses and Older Granites but exposed beneath the Cretaceous-Recent sedimentary cover of the lower Benue Valley to the South. The geochemistry of the granites and the mica schists hosting the pegmatites in this area are discussed in Akintola and Adekeye (2006). Two groups of pegmatites are noticeable in the area with minor muscovite in the area: (1) simple, usually barren massive quartz – microcline pegmatites with minor muscovite and accessory tourmalines and (2) complex, albitized muscovite-quartz-microline pegmatites, bearing the rare-metals Ta, Nb, Sn, Li and Be mineralization.

The simple, barren quartz-feldspar (with minor mica) pegmatites occur at the north western and western parts of the area and are spatially closely associated with the main phase Older Granites. On an outcrop scale, the pegmatites grade into patches of aplite. The complex rare-metal pegmatites are found far away from the granite plutons usually hosted by schists (exterior pegmatites). Wall-rock alteration in the simple pegmatites is negligible, but more pronounced in the complex pegmatites especially at contacts with the hanging walls (Jacobson and Webb, 1946). Although tourmalinization is by far the most common type of contact alteration, it is generally accompanied by silicification, albitization, greisenization and sometimes formation of apatites/fluorapatites which give rise to graded contacts.

K-Feldspars

Table 1 shows the trace element contents of the microcline, microperthites (K-feldspars) taken from different pegmatites in the study area. For example, one sample of K-feldspar has the highest Cs (3489ppm), Tl (73ppm), Bi (21ppm), REEs Ce (69ppm), La (166ppm), Pr (29ppm) and very high Rb (9474ppm). It has the lowest total Fe and Mn (Fe_2O_3, 0.13%; MnO, 0.002%), and K/Tl (1558), Rb/Tl (130), K/Cs (33) and K/Rb (12) ratios. These characteristic indicate that the feldspar crystallized from a highly fractionated melt and although this particular sample has low concentration of the ore elements, Sn-Ta-Nb, an eluvial concentrate from the mine had earlier yielded high values of Ta (1749ppm) with high Ta/Nb ratio of 5.45, NIMAMOP (1998).

The average content of Ta in the K-feldspars is very low (2ppm). The K-feldspars have K/Rb range of 12-35 and a mean of 19. K/Rb has a very high negative correlation (-0.938) with Cs in the K-feldspars, Figure 3. In Figure 3, the Cs content is plotted versus the K/Rb ratio for K-feldspar together with the boundaries discriminating, according to Trueman

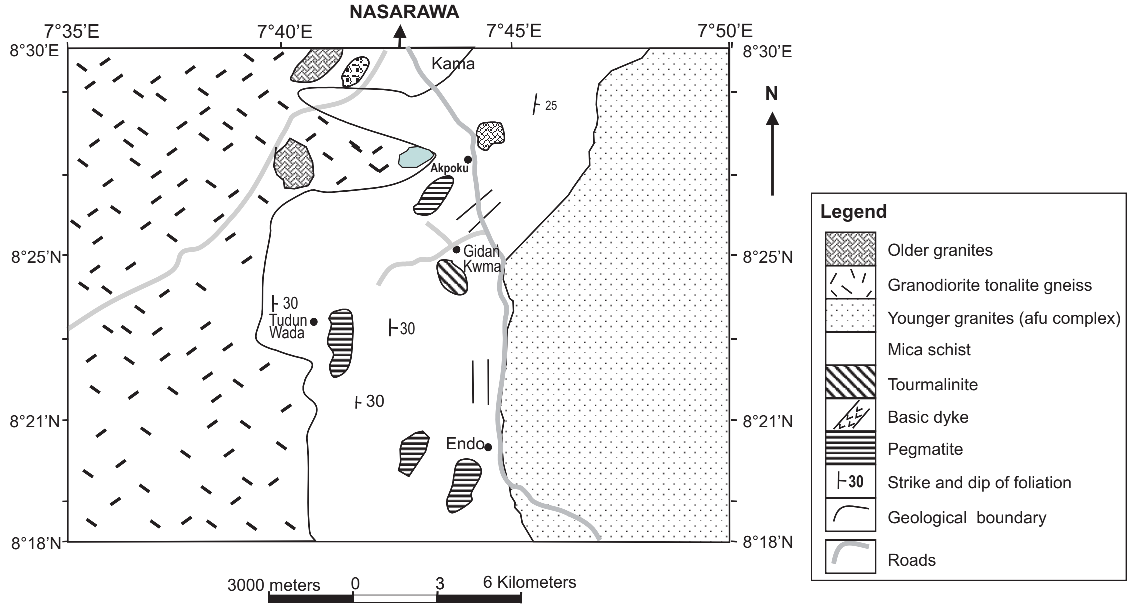

Figure 2: Geological Map of Nasarawa Area.

and Cerny (1982), between barren, Be-, Li-Be-, and Li-Cs-Be-Ta mineralized pegmatites. From the figure, the following pegmatites in the study area of which the K-feldspars were analyzed belong to the corresponding classes (Table 2).

It is important to note from this classification that some pegmatites from the same location have different degrees of evolution – some are more evolved belonging to the lithium-beryllium class and some belong to the beryllium class. The pegmatites in the beryllium and lithium-beryllium classes have high prospects for gem tourmaline and beryl mineralization, especially in the albitized zones of the pegmatites (Preinfalk *et al*., 2000). The Liberia and Onyelow Wazobia pegmatites mainly belong to the lithium-cesium-beryllium-tantalum class. It is also important to note here that a sample of the Liberia pegmatites plots in the lithium-beryllium class showing that the pegmatites must at least have evolved from the lithium-beryllium class to the lithium-cesium-beryllium-tantalum class. The Liberia pegmatite therefore has potentials for bearing ore mineral characteristics of both the lithium-beryllium and lithium-cesium-beryllium-tantalum classes in the different zones of the pegmatite. Active mining of Sn-Nb-Ta ores and analysis of mica and other mineral samples such as amblygonite and fluorapatite, confirm the enrichment of the pegmatite in the ores of Li-Be-B-Sn-Nb-Ta.

Na – Feldspars

The framework silicate samples (feldspars and feldspathoids) with low silica (SiO_2 < 55.95%) and Na/K greater than 1 (except cookeite) were grouped together for convenience as Na-feldspars (Table 2). The true Na-feldspars according to Deer *et al* (1966) have the following average contents of ore and lithophile elements: P_2O_5 (1.17%), F (bdl), Ga (27ppm), Nb (145ppm), Sn (221ppm), Ta (195ppm), Rb (175ppm) and Cs (31ppm).

The ore elements are finely disseminated in the albites. The aplitic footwall albite is probably secondary or at least late primary in crystallization. Most of the albite in the pegmatites is found in the albite-rich aplitic zone often occurring in the footwalls of pegmatites (Jahn and Tuttle, 1963; Jahn and Burnham, 1969).

The secondary albite has very low Nb/Ta ratio of 0.26, which is comparable to the low Nb/Ta ratio of

Table 1: Trace elements of the microline, microperthies (K-feldspars) of the pegmatites.

Sample	l3	l6	l7	l10a	luz	lu	ls	s2	k1	k3	w2a
P (ppm)	2400	2461	2662	2579	2130	4774	5398	6642	2854	2138	3024
F	0	0	0	0	0	0	326	0	0	0	0
Ba	44	35	34	67	10	30	53	36	69	91	39
Bi	20	10	17	15	17	15	10	13	12	10	21
Cd	13	7	9	5	6	bdl	bdl	Bdl	bdl	bdl	16
Ce	40	32	32	12	52	21	0	19	35	0	69
Co	16	33	18	28	20	28	31	25	23	31	18
Cr	10	13	9	14	2	15	35	11	6	1	6
Cs	1722	1487	1540	1226	1482	602	111	160	844	692	3489
Cu	7	7	14	9	0	13	13	8	4	19	16
Ga	18	15	17	15	17	16	44	19	18	14	17
La	95	73	74	58	84	27	2	16	38	31	166
Nb	8	5	9	7	9	22	39	8	4	8	8
Ni	20	0	31	28	0	0	0	0	0	0	27
Pb	70	57	81	79	69	46	0	35	125	140	93
Pr	19	15	16	13	18	8	0	6	9	8	29
Rb	8546	6536	9534	8303	8420	5537	2593	3069	5440	4089	9474
Sn	21	13	187	15	14	28	24	28	9	8	24
Sr	38	144	58	44	51	22	30	183	64	70	32
Ta	bdl	1	2	bdl	bdl	9	6	Bdl	bdl	bdl	bdl
Tl	49	38	57	49	49	30	12	16	39	30	73
W	155	241	137	187	176	203	195	154	143	204	160
V	10	0	0	14	18	0	0	0	0	0	20
Y	30	18	20	0	19	24	12	11	0	14	24
Zn	44	0	0	0	0	0	40	0	0	0	0
K/Ba	2521	2906	3492	1694	11058	3628	1696	2841	1571	1165	2916
K/Rb	13	16	12	14	13	20	35	33	20	26	12
K/Cs	64	68	77	93	75	181	811	639	128	153	33
K/Tl	2264	2676	2083	2316	2257	3628	7493	6393	2780	3534	1558
Rb/Tl	174	172	167	169	172	185	216	192	139	136	130

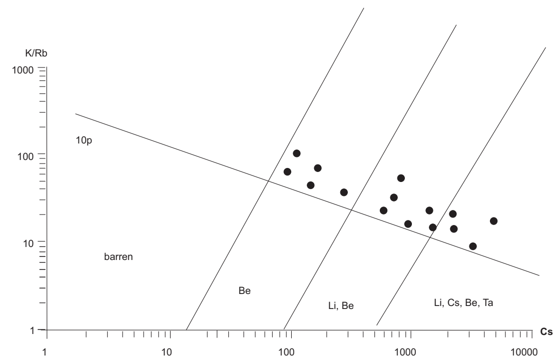

Figure 3. Classification of the Pegmatites Using the Plots of K/Rb Versus Cs of Their K-Feldspars.
Note: The lines discriminating between barren pegmatites and pegmatites with significant Be; Li-Be-, Li-Be-Ta-mineralization are given according to Trueman and Cerny (1982).

0.26 average in the amblygonites. Obviously, both the secondary albite/mica and the amblygonites are in paragenesis with the tantalum minerals. This observation is in agreement with the findings of Moller and Morteani (1987).

A sample with a very high (8.8%) L. O. I. was also identified (by XRD and ICP-OES) to be cookeite – a hydrated lithium aluminum silicate. It has Na/K ratio slightly less than 1. Cookeite crystallizes from late stage hydrothermal fluids evolved from residual albitic melts on stabilization of tourmaline (and the loss of other fluxing components such as P, B, Li, F and H_2O) from the pegmatite melts (Cerny, 1991b). Cookeite is known to occur with other low temperature minerals like adularia and zeolites in miarolitic cavities of the highly evolved complex rare metal pegmatites.

White Micas (Muscovites) in the Pegmatites

The average chemical composition of the muscovites is typical of rare element pegmatites with high, F, Cs, Rb and Li (Deer *et al*., 1966; Gordiyenko, 1971) (Table 3). The XRD diffractogram of selected samples of the micas show that the crystal structures of the muscovites are close to the ideal dioctahedral and R^{2+} - free composition typical of muscovites from the rare-element pegmatites class (Cerny and Burt, 1984). The muscovites have a wider range of Rb values (2659-10182ppm) and lower K/Rb ratios (8-31) than the K-feldspars' (2593-9534ppm) and (12-35) respectively (Table 4). A late generation mica Ð taken from an inner zone of Liberia pegmatite has very high Cs (2353ppm), Rb (9910ppm), Sn (647ppm) and Ta (103ppm) and correspondingly low K/Rb (8), Nb/Ta (0.66), and K/Tl (1600) ratios. These are comparable to average values of Cs (2294ppm), Rb (8978ppm), Sn (665ppm), and Ta (464ppm) and the correspondingly low average K/Rb (9), Nb/Ta (0.14), and K/Tl (1361) ratios in muscovites from highly mineralized pegmatites in the northern part of the area.

Nb/Ta ratios for the pegmatitic muscovites range from 0.13 to 8.07 with a mean of 2.965. The K/Rb ratios for the micas range from 8 and 31 with a mean of 16.20. Ta has a very high positive correlation with Cs (0.756) but a very high negative correlation with Nb (-0.856). Linnen (1998) and Morteani and Gaupp (1989) have observed that the different behaviour of Ta and Nb during crystallization is due to differences in solubility of Nb and Ta in Li-rich pegmatitic melts.

The Cs vs. K/Rb plots of pegmatite muscovites from the area (Figure 4) concentrate in the field typical of rare-element class pegmatites as defined by Cerny and Burt (1984). Only one sample which was collected about 100meters south of the Liberia pegmatite plots in the muscovite class. The K/Rb ratios of the muscovites range between 7.58 and 30.94. These low ratios of K/Rb as well as the high negative correlation of K/Rb and Cs (-0.830) are typical of muscovites of the rare-metals class of pegmatites (Preinfalk *et al.,* 2000) and have been used successfully as exploration tools for the pegmatites.

Correlation of the Trace Elements and Fractionation Trends

K/Tl, K/Rb, K/Cs, Al/Ga, Zr/Hf and Nb/Ta ratios give fractionation indices in the granite-pegmatites suites. Some of these ratios are compared with the average values of the trace elements in the pegmatitic minerals (Table 4). The table also shows that the rare earth elements (REEs) Ce, La, Pr, and Y are enriched in the

Table 2: Trace element content of the albitic pegmatite phases

							Phosphates		
			Albites			Cookeite	Fluorapatite		Amblygonites
Sample	**lb6a**	**lb8**	**sj3**	**rNa**	**lc19**	**kj2fsp**	**lb9**	**lb10**	**ch1**
P_2O_5 (%)	0.481	0.487	2.169	1.763	0.243	0.017	24.97	49.973	43.25
F(ppm)	1240	0	0	0	0	294	11637	13897	14203
As	0	0	7	8	6	1	0	0	0
Ba	19	51	37	26	102	56	31	33	61
Bi	14	11	11	16	12	12	38	1	8
Ce	14	12	22	14	0	0	443	0	7
Cd	7	bdl	bdl	bdl	bdl	bdl	27	bdl	bdl
Co	115	47	25	31	37	5	16	8	6
Cr	1	0	0	11	0	15	1	2	1
Cs	851	23	19	74	9	49	1	28	6
Cu	0	0	24	16	4	0	0	16	535
Ga	76	24	21	22	39	58	14	21	18
Hf	2	3	0	3	3	2	0	3	2
La	48	9	0	3	3	0	204	0	0
Mo	0	5	1	1	0	4	0	1	0
Nb	88	75	62	326	115	33	190	26	25
Nd	3	11	9	8	2	0	144	5	7
Ni	14	5	3	4	0	3	9	4	3
Pb	25	10	7	0	0	0	74	9	0
Pr	10	2	1	2	1	0	65	0	1
Rb	4829	69	347	252	31	444	46	290	62
Sc	0	0	9	0	4	0	0	0	5
Sm	1	3	2	2	1	1	66	1	1
Sn	565	659	14	174	35	54	28	231	67
Sr	263	52	1037	305	51	8	64	11	188
Ta	345	109	67	305	297	37	21	107	86
Th	0	0	0	0	0	3	2	1	4
Tl	23	bdl	bdl	bdl	bdl	5	bdl	bdl	bdl
U	0	3	0	10	0	1	216	0	7

Sample	lb6a	lb8	sj3	rNa	lc19	kj2fsp	lb9	lb10	ch1
V	5	1	4	15	6	5	16	4	8
W	502	346	201	247	298	64	46	89	124
Y	6	1	0	0	1	0	1391	1	0
Zn	229	63	26	187	12	39	62	26	119
Zr	17	12	17	68	18	5	17	54	7
H_2O	2.42	0.43	1.1	0.82	0.36	8.8	0.51	5.27	7.54
SUM	98.71	98.24	97.67	99.4	99.79	98.01	98.12	102.94	86.53
K	33457	1577	11540	3321	1079	9132	1494	3487	664
K/Rb	7	23	33	13	35	21	32	12	11
Mg(hx)				13		139		7	23
Li(hx)				225		685		16400	20750
Li(fusion)				227		2900		13366	17882
Na/K	1.17	43.74	5.81	19.80	72.80	<1	21.80	4.23	n.d
Nb/Ta	0.26	0.69	0.93	1.07	0.39	0.89	9.05	0.24	0.29

K-bearing minerals, K-feldspars and muscovites, with the highest concentrations of the element in the K-feldspars. Because of their similar geochemical migration patterns, K, Rb, Cs and Tl are concentrated, and have very high positive correlations in the K-feldspars and muscovites (Table 6). The muscovites however have higher fractionation indices compared with the K-feldspar as indicated by their low average K/Rb, K/Tl, and K/Cs ratios. The muscovites have high values of Sn (383ppm average), Nb (155ppm average), Ta (96ppm average), Ga (196ppm average), F (2128ppm average), and Zn (379ppm average) and have higher Rb/Tl ratio than the K-feldspars. The muscovites have the highest values of Ga (with a mean value of 161ppm) and lowest Al/Ga ratio of the minerals. This corroborates the observations of Cerny *et al* (1985) that tourmaline and muscovites are the main concentrators of Ga in pegmatites.

Ba, Sr, W, Zr and Ta are highest in the Na-feldspars with the lowest Nb/Ta ratios, which is an indication that these elements are enriched along with Ta in the late mineralizing fluids. The following groups of elements (Table 5) have high positive correlation indices in the Na-feldspars: Rb versus Cs (0.922), Cs versus Zn (0.866), Cs versus Co (0.802), Co versus W (0.974), Ga versus Co (0.890), Ga versus W (0.851), Nb versus Zr (0.941), Nb versus Bi (0.850), Ta versus Bi (0.769), Ta versus Ga (0.638), Ta versus Nb (0.629) and Ta versus W (0.538).The high positive correlations of these elements reflect their associations in the formation of rare metal ores from the Na-rich late fluids.

The pegmatitic K-feldspars have very high negative correlations of K/Tl and K/Rb with the rare lithophile elements such as Cs, Bi, Y, Rb, La, Pr, Pb (Table 7). Similarly, the muscovites have very high negative correlations of K/Tl and K/Rb with the rare lithophile elements as well as the ore elements Sn and Ta. Nb is negatively correlated with Rb, Cs, Tl, Ta, La, Pr and Sn but positively correlated with K and Ga in both the K-feldspars and muscovites (Table 7). Nb and Ga have positive correlations in both muscovites and K-feldspars (0.704 and 0.472) respectively. Obviously, the

Table 3. Trace elements in the pegmatite micas

Sample (ppm)	le7	le8	le14	le13	le18	l4	l10b	l8a	l9a	lz	lua	ls	7	Lc19	lc20	lc20a	s1	k	ka	lc23	lc28	w	w2	R	lc30	lc31	lc32	lc33
F	2933	3197	3215	3220	297	274	323	3131	2884	435	2465	2106	617	1004	390	393	329	667	461	2841	2254	2616	2965	4751	940	1088	881	374
Ba	15	60	31	27	24	12	30	35	20	3	12	35	37	69	35	19	13	28	15	42	25	100	74	33	16	23	44	18
Bi	17	21	20	16	21	25	16	19	12	19	13	14	12	15	28	34	14	21	17	18	20	11	18	15	13	12	13	17
Ce	12	29	5	20	26	13	0	11	0	0	0	0	9	32	39	37	18	26	14	1	29	0	27	0	22	0	2	3
Cs	171	874	290	300	260	874	100	1001	232	896	206	32	118	342	2120	2467	424	515	694	51	694	215	174	929	1499	63	116	346
Ga	167	163	163	153	167	168	158	164	162	174	155	203	200	166	156	164	159	141	176	174	197	154	145	162	97	147	161	138
La	0	57	15	20	23	54	44	45	10	36	9	0	0	47	98	108	17	14	36	0	40	32	0	49	71	0	2	15
Nb	181	116	178	165	182	131	119	113	185	144	178	218	256	187	75	55	146	151	160	211	143	193	200	127	64	223	190	135
Nd	9	17	4	14	10	6	0	7	2	0	2	0	1	9	12	7	7	13	2	1	7	0	11	0	9	4	5	7
Ni	7	27	17	18	21	23	24	24	21	23	13	8	9	18	27	31	18	21	16	11	20	10	6	17	11	16	18	24
Pb	18	47	23	21	30	46	45	45	19	44	17	6	4	25	47	64	18	26	22	7	33	10	9	33	27	9	18	19
Pr	3	15	6	8	8	14	12	12	6	11	6	1	3	11	19	22	6	6	9	2	11	7	3	11	13	2	4	5
Rb	4803	9410	5093	5578	583	913	915	8803	5289	887	4751	3133	2659	5638	7774	1018	4504	4941	5527	3471	7749	3284	2870	6803	4581	3645	4324	4248
Sn	217	471	275	336	357	525	533	597	274	681	239	61	266	397	681	649	295	364	394	87	437	139	118	902	539	147	271	219
Sr	15	50	41	18	19	24	27	25	17	24	16	11	13	18	25	32	16	18	19	11	23	15	12	21	15	17	17	16
Ta	44	58	45	50	63	53	59	71	71	71	41	27	46	72	502	425	75	85	115	31	51	62	64	120	183	39	31	140
Tl	22	43	24	27	26	40	39	39	25	40	21	17	15	31	52	64	24	29	28	16	35	18	17	36	33	18	21	25
W	71	51	65	71	237	39	33	28	38	77	25	84	65	40	86	89	34	36	48	56	52	40	49	91	56	114	32	61
Zn	421	1000	452	435	472	961	3	911	416	800	379	231	131	217	111	123	142	242	142	187	341	249	163	453	47	161	177	112
K/Rb	17	9	16	15	14	9	9	9	15	9	17	27	31	14	10	8	18	16	15	23	10	26	28	12	17	23	18	19
Mg(hx)	61	20	69	69	76	22	28	22	52	21	74	81	129	75	70	66	20	50	31	89	66	91	107	85	66	83	36	44
Nb/Ta	4.11	2	3.96	3.3	2.89	2.47	2.02	1.59	2.61	2.03	4.34	8.07	5.57	2.6	0.15	0.13	1.95	1.78	1.39	6.81	2.8	3.11	3.13	1.06	0.35	5.72	6.13	0.96
K/Rb(hx)	10.95	6.01	10.66	9.45	9.61	6.24	6.30	6.43	9.60	6.86	10.58	15.54	18.35	9.26	6.95	5.54	11.29	10	10.01	13.48	7.25	14.24	15.89	8.21	9.91	14.05	11.69	11.14
Mg/Li(hx)	1.3	0.34	1.35	1.17	0.84	0.26	0.17	0.19	1.24	0.24	1.57	16.2	32.25	2.21	5	7.33	10	1.61	15.5	11.13	11	4.55	4.46	8.5	22	5.72	2.25	11
Li-AAS(hx)	47	58	51	59	90	86	168	115	42	88	47	5	4	34	14	9	2	31	2	8	6	20	24	10	3	14.5	16	4
Li-AAS(fus.)	154	283	201	198	272	395	468	303	174	324	231	30	40	204	73	61	12	158	10	43	31	76	111	60	29	54	72	30
K-AAS(hx)	5805	4180	5918	4680	0		0	7225	4225		4815	5050	2845	4075	4310	3515	5305	4250	7455	5055	4930	4130	5165	4555	3815	5970	6080	4290
Rb-AAS(hx)	530	695	555	495	900	875	895	1124	440	4	455	325	155	440	620	635	470	425	745	375	680	290	325	555	385	425	520	385
-AAS(fus.)	2819	5299	3705	3604		6	8	6106	3436	0	3808	2512	2300	3934	4231	6886	3253	3083	4150	2783	4291	1444	2183	4435	3077	2207	3258	3580

Table 4: Average contents of trace elements (range given in brackets) in the K-feldspars, Na-feldspars and micas of the pegmatites

	K-fedlspar$^{(n=11)}$	**Muscovite$^{(n=29)}$**	**Albites$^{n=4}$(true albites)**
Ba	46ppm(10-91)	31ppm (3-100)	54ppm (26-102)
Cs	1214ppm (111-3489)	664ppm (32-2467)	31ppm (9-74)
Ga	19ppm (14-44)	161ppm (97-203)	27ppm (21-39)
La	60ppm (2-166)	33ppm (1-109)	Bdl
Nb	12ppm (4-39)	155ppm (55-256)	145ppm (62-326)
Pb	73ppm (10-140)	27ppm (4-64)	Bdl
Pr	13ppm (1-29)	9ppm (1-22)	Bdl
Rb	6504ppm (2593-9534)	5930ppm (2659-10182)	175ppm (31-347)
Sn	34ppm (8-187)	383ppm (61-902)	221ppm (14-659)
Sr	67ppm (22-183)	22ppm (11-64)	361ppm (51-1037)
F	Bdl	2128ppm (329-4751)	Bdl
Ni	9ppm (0-31)	18ppm (6-31)	Bdl
Ta	2ppm (0-9)	96ppm (27-502)	195ppm (67-305)
Ce	28ppm (0-69)	15ppm (0-47)	12ppm (0-22)
Zn	3.64	379ppm (47-1023)	72ppm (12-187)
Tl	40ppm (12-73)	30ppm (15-64)	Bdl
W	178ppm (137-241)	62ppm (25-237)	273ppm (201-346)
Y	16ppm (0-30)	15ppm (0-39)	0.5ppm (0-1)
K/Tl	3362 (1558-7493)	3096 (1206-5485)	-
Rb/Tl	168 (130-216)	198 (139-235)	-
K/Rb	19 (12-35)	16 (8-31)	26 (13-35)
K/Cs	211 (33-811)	121	140
K/Ba	3226 (1165-11058)	2575	81
Al/Ga	5359	1197	3680
Nb/Ta	7.04	2.89 (0.15-8.07)	0.77

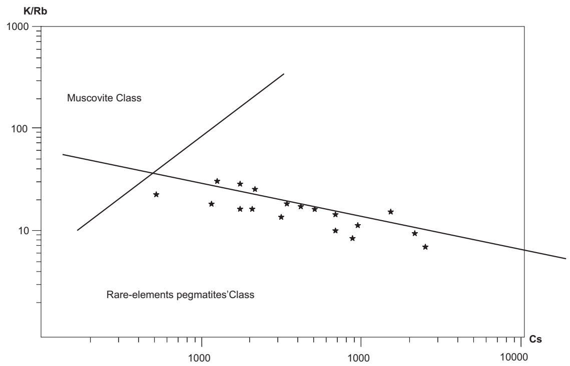

Figure 4: Plots of K/Rb Versus Cs for The Pegmatites' Muscovites.

Note: The dash line represents the boundry between the muscovite and rare-metal classes (after Cerny and Burt, 1984). The solid lines represent the best fit lines for the LCT type pegmatites.

Nb-dominant minerals crystallize earlier than Ta and the positive correlations of Nb, K and Ga indicate that Nb enters the silicate structure more easily than Ta. This agrees with the observations of Cerny and Burt (1989) that Nb/Ta ratios in silicates are rather high. Linnen (1998) has also observed that the different behaviour of Ta and Nb during crystallization is due to differences in solubility of Nb and Ta in Li-rich pegmatitic melts. Such behaviour has also been observed in the Bruno and Xuxa pegmatites of the Aracuai pegmatite District of Brazil (Preinfalk *et al*., 2000).

In the muscovites (Table 7), Ta has a very high positive correlation (0.756) with Cs but lower correlations with Rb in both muscovites and the albites (0.428 and 0.213 respectively). Ta and K/Rb however have better correlations in the muscovites and albites (-0.441 and -0.592 respectively) when compared with Ta and Rb. The reason for this relationship between the elements may be explained by the fact that ideal positions for TaO_4^{3-} and TaO^{3-} are lacking in the silicates. Therefore, Ta partitioning into mica will be small and TaO_4^{3-} which grow epitaxially at the mica faces account for much of the Ta contents in the micas (Moller and Morteani, 1987).

Mg/Li has a high negative (-0.856) correlation with Zinc; the high positive correlations of Zn, Li and F ($\geq$0.759) in the micas are traceable to the fact that the three elements occupy the octahedral layer in the mica crystal structure. Li has negative correlation with Ta (-0.244), which shows that Li content of the early pegmatite micas are higher than the later ones; obviously increased concentration of Li through fractionation in the late fluids crystallized to form discrete Li-minerals such as amblygonite-montebrasite rather than enter mica phyllosilicate structure. This is in agreement with the observation of Cerny *et al* (1985) that the buildup of Li concentration in a pegmatite melt that precedes the precipitation of Li minerals *sensu stricto* leads to increased contents of Li in early rock-forming mineral phases.

Sn average value is highest in the muscovites; it also has much higher positive correlations with Cs (0.902), Rb (0.829), Tl (0.868), La (0.799) compared with the very low correlations it has with these elements in the feldspars, which reflects the enrichment of tin with greisenization.

Using K/Rb, K/Tl and Cs, it is therefore possible to recognize different generations of feldspars and micas within a complex-zoned mineralized pegmatite (Table 8). E.g. early and late, which have significant differences in the range, and mean contents of the rare elements. Generally, the rare alkali (Rb and Cs) and Tl concentrations in the muscovites and K-feldspars give a good reflection of the concentration of the rare elements in the pegmatites.

The Liberia (lb) Pegmatite Deposit

In this section, the trace element contents of the K-feldspars and muscovites of pegmatites in the Nasarawa area are compared with those of well-studied pegmatites both within and outside Nigeria.

The Liberia pegmatite in the study area is the most exposed of the studied pegmatites, because some blasting and drilling had been carried out on it. Twelve (12) muscovite samples of the pegmatite were analyzed. Extensive fractionation within the pegmatite is indicated by the wide range of K/Rb

Table 5. Correlation matrix of some trace elements that have significant Bivariate Correlations in the Na-Feldspars (n=5)

	Ba	Cs	Ga	Nb	Rb	Sn	Ta	W	Zn	Zr	K/Rb	Nb/Ta
Ba	1.000											
Cs	-0.868	1.000										
Ga	-0.237	0.669	1.000									
Nb	-0.183	0.122	-0.168	1.000								
Rb	-0.900	0.922	0.565	-0.087	1.000							
Sn	-0.427	0.613	0.371	0.132	0.325	1.000						
Ta	-0.149	0.486	0.638	0.629	0.213	0.555	1.000					
W	-0.265	0.677	0.851	-0.166	0.465	0.483	0.538	1.000				
Zn	-0.891	0.866	0.274	0.402	0.718	0.740	0.393	0.467	1.000			
Zr	-0.351	0.160	-0.275	0.941	0.069	0.152	0.451	-0.355	0.427	1.000		
K/Rb	0.834	-0.973	-0.608	-0.301	-0.476	-0.818	-0.592	-0.685	-0.928	-0.290	1.000	
Nb/Ta	-0.016	-0.461	-0.961	-0.315	-0.131	-0.354	-0.541	-0.836	-0.045	-0.396	0.396	1.000

Table 6. Correlation matrix of trace elements that have significant Bivariate correlations in the K-Feldspars (n=11)

	Cs	**Ga**	**La**	**Nb**	**Pb**	**Pr**	**Rb**	**Sn**	**Tl**	**W**	**K/Tl**	**Rb/Tl**	**K/Rb**	**K/Cs**
Cs	1.000													
Ga	-0.667	1.000												
La	0.947	-0.801	1.000											
Nb	-0.566	0.704	-0.694	1.000										
Pb	0.738	-0.852	0.792	-0.783	1.000									
Pr	0.923	-0.812	0.997	-0.685	0.777	1.000								
Rb	0.943	-0.585	0.903	-0.454	0.610	0.888	1.000							
Sn	0.26	0.147	0.033	0.292	-0.216	0.057	0.236	1.000						
Tl	0.980	-0.662	0.940	-0.564	0.761	0.921	0.967	0.114	1.000					
W	-0.133	-0.033	-0.219	0.245	-0.247	-0.236	-0.254	-0.463	-0.275	1000				
K/Tl	-0.989	0.636	-0.934	0.561	-0.741	-0.911	-0.963	-0.081	-0.997	0.238	1.000			
Rb/Tl	-0.650	0.593	-0.628	0.637	-0.867	-0.602	-0.432	0.301	-0.648	0.215	0.650	1.000		
K/Rb	-0.938	0.532	-0.885	0.428	-0.561	-0.868	-0.996	-0.243	-0.954	0.236	0.955	0.397	1.000	
K/Cs	-0.999	0.651	-0.939	0.563	-0.723	-0.913	-0.933	-0.003	-0.971	0.104	0.983	0.646	0.931	1.000

Table 7. Correlation matrix of trace elements that have significant Bivariate correlations in the Pegmatites' Muscovites

	F	Cs	Ga	La	Nb	Rb	Sn	Ta	Tl	Zn	Li(x)	Li(fus)	Rb(x)	Rb(fus)	K/Rb	Nb/Ta	K/Tl	Rb/Tl	Mg/Li
F	1.000																		
Cs	-0.116	1.000																	
Ga	-0.155	-0.329	1.000																
La	-0.002	0.913	-0.327	1.000															
Nb	0.217	-0.875	0.472	-0.753	1.000														
Rb	0.180	0.821	0.012	0.771	-0.696	1.000													
Sn	-0.036	0.902	-0.185	0.799	-0.700	0.829	1.000												
Ta	-0.507	0.756	-0.394	0.675	-0.796	0.428	0.595	1.000											
Tl	-0.048	0.922	-0.156	0.851	-0.858	0.939	0.868	0.682	1.000										
Zn	0.759	0.160	0.348	0.193	0.075	0.559	0.281	-0.375	0.287	1.000									
Li(x)	0.666	0.127	0.044	0.183	0.056	0.452	0.232	-0.244	0.250	0.814	1.000								
Li(fus)	0.630	0.167	0.005	0.214	0.005	0.455	0.275	-0.194	0.284	0.773	0.980	1.000							
Rb(x)	0.279	0.583	0.072	0.558	-0.431	0.859	0.619	0.182	0.709	0.608	0.518	0.445	1.000						
Rb(fus)	0.116	0.696	0.129	0.623	-0.568	0.919	0.762	0.333	0.833	0.518	0.408	0.431	0.839	1.000					
K/Rb	-0.164	-0.830	0.006	-0.772	0.708	-0.998	-0.840	-0.441	-0.943	-0.534	-0.441	-0.446	-0.858	-0.921	1.000				

(8.0-17), K/Cs (66-406), K/Tl (1600-3764), and Nb/Ta (1.59-4.11) ratios in the micas (Table 9). Rb and Cs contents and K/Rb, K/Cs as well as Nb/Ta ratios in the micas show that there are at least two generations of primary muscovites in the pegmatite, the early and the late.

Table 8. Some trace elements distribution in the different muscovite generations in the Liberia Pegmatite Deposit

Element	Early generation	Late generation
Rb(%): Range	0.48-0.58	0.88-0.99
Mean	0.52	0.92
Cs(ppm):Range	171-300	874-2353
Mean	243	1168
Tl(ppm):Range	21-27	39-47
Mean	24.16	41.33
Ta(ppm):Range	41-71	53-103
Mean	52.33	69.16
Nb(ppm):Range	165-185	68-144
Mean	178	115
Sn(ppm):Range	217-357	471-681
Mean	283	575.67
K/Rb:Range	13.8-17	8.0-9.3
Mean	15.58	8.77
K/Cs:Range	242-406	66-81
Mean	301	74.6
K/Tl:Range	3007-3764	1600-2058
Mean	3375	1941
Nb/Ta:Range	2.61-4.11	1.59-2.47
Mean	3.54	2.02
Number of Samples	6	6

The Rb, Cs and Tl contents show enrichment in late muscovites by factors of 1.77, 4.81 and 1.71 respectively with a corresponding enrichment in the ore elements Sn and Ta by factors of 2.03 and 1.32 respectively but a noticeable depletion of Nb by a factor of 1.55 in the late muscovite. Thus, the enrichment of Ta and Sn in the late muscovites is accompanied by decrease in the K/Rb, K/Cs, K/Tl and Nb/Ta ratios. While there is also enrichment in Zn in the late muscovite, they are depleted in MgO and TiO_2. Similar enrichments of the rare elements have been observed in the late primary muscovites of well-studied pegmatites like Tanco, Noumas, Tip-top and Harding. Such late generation primary muscovites are found in the middle and central zones of the pegmatites where they occur in paragenesis with ores of the rare elements.

In Table 8, a comparison is made of the Rb, Cs, Ta and Ga contents of muscovites of selected pegmatites in the study area, Wamba (100km north-east of the area), and some well studied pegmatites from other parts of the world. The micas have high Rb (0.8978%) and Cs (2294ppm) which are comparable to those of the higly mineralized Tanco pegmatite of Manitoba, Canada as shown in Table 9.

Pegmatites in the area have a wide range of mineralization potential from low Ta – pegmatites through medium Ta-pegmatites to high Ta-pegmatite. From Table 9, it is evident that the Rb and Cs contents of the micas reflect Ta mineralization in pegmatites. Extremely low K/Rb (8.86 or less), and K/Cs (34 or less) characterize such highly mineralized pegmatites like Tanco and Liberia. The high Ta-mineralization potentials of the complex pegmatites in this area is corroborated by the high average Ta_2O_5 content (406ppm) and Ta/Nb ratio (3) of eighteen concentrate samples taken from different mines in the area (Okunlola, 1998).

Muscovites of the mineralized pegmatites from Wamba area have low Ta-potential with correspondingly low Cs (116ppm), Rb (0.3150%) and high K/Rb (25) and K/Cs (800) Nb/Ta (4.50) ratios. The Wamba pegmatites vary from barren, muscovite class to complex albitized, and Sn-mineralized pegmatites (Kuster, 1990). On the whole, it appears the pegmatities in Nasarawa, the study area, are more fractionated and therefore have higher Ta-mineralization potential than those of Wamba and the other

Table 9. Geochemical characteristics of some well-studied pegmatites compared with Nasarawa Pegmatites

	K(%)	Rb(%)	Cs(ppm)	Ta(ppm)	Ga(ppm)	K/Rb	K/Cs	No of Samples
Liberia	8.0831	0.6972	556	57	163	12.6	198	11
Loc 20/20a	7.7997	0.8978	2294	464	160	8.86	30	2
K/Ka	8.2231	0.5234	605	100	159	15.75	119	2
W/W2	8.3145	0.3077	196	63	150	27.12	374	2
Tip Top, South Dakota (Low Ta)	8.52	0.355	222	56.0	175	24	384	13
Tanco, Manitoba (High Ta)	8.33	2.450	2420	240.9	433	3.4	34	19
Noumas, Namaqualand	8.21	0.357	566	74.2	92	23	145	2
Harding, New Mexico (Low Ta)	9.47	0.631	1917	64.0	123	15.0	49	21
Wamba, Central Nigeria	n.d	0.3150	116	53	n.d	25	800	51

studied pegmatites in Nigeria (Matheis and Kuster, 2001, personal communication).

Discussion and conclusion

The very low Ta contents in the K-feldspars may be attributed to the fact that TaO_3^- cannot enter the fully polymerized $(AlSi)O_4$ network of the K-feldspar (Moller and Morteani, 1987). Thus, the rare alkalis Rb and Cs are better indicators of the rare metals mineralization potentials in the pegmatites' K-feldspars than the ore elements Ta. The higher contents of the rare earth elements (REEs) Ce, La, Pr, and Y in the K-feldspar when compared with those of the other major pegmatite minerals shows that the REEs in the fluids from which the pegmatites crystallized were partitioned more into the K-feldspar than the other rock-forming minerals. This corroborates the observations of Simmons and Heinrich (1980) that REE-bearing minerals occur in K-feldspar-rich parts of pegmatites. The high negative correlation of K/Rb versus Cs is characteristic of K-feldspars of rare metal pegmatites and has been used along with K/Rb versus Cs in the micas as reliable prospection aids for rare metal pegmatites (Preinfalk *et al*., 2000).

High positive correlations between Cs, Rb and the REEs: Ce, La, and Pr are notable in the K-feldspars, compared with the muscovites. This may be due to selective complexing of the REEs in the residual melt by the framework silicate feldspar. The same process of selective complexing by P and F must have enriched the fluorapatite with high concentrations of the REEs. The low average Nb/Ta ratio for the muscovites (2.965) is still lower than the (4±0.7) upper limit diagnostic of Ta-pegmatites (Cerny, 1989). Higher Nb/Ta ratios (9.5±1.5) and high Nb-concentrations (≥200ppm) are diagnostic of the less specialized Nb-rich columbite pegmatites. Beus (1966) determined that ≥20ppm Ta concentrations are characteristic of columbo-tantalite pegmatites and Gordiyenko (1971) also determined that 65-75ppm Ta concentrations are characteristic of the Ta-enriched pegmatite (Figure 5). Simultaneous enrichment of Rb, Cs along with Ta in the LCT granite pegmatite suites makes the alkalis reliable indicators of rare-metals mineralization in pegmatites. Thus K/Rb versus Cs, and Ta versus Cs plots of primary muscovites have been reliably used to determine the mineralization potentials of pegmatites.

Matheis (1979) has earlier shown that mineralized pegmatites in Ijero and Egbe area of southwestern Nigeria are strongly depleted in Ba, Sr, and Zr but are enriched in Rb, Li, Y, Be, Sn, Nb, and Ta. Kuster (1990) has also observed similar geochemical evolution in late Pan African tectonic granites and mineralized pegmatites in Wamba area. The relative enrichment of Ba, Sr, W, Zr and Ta in the Na-feldspars indicate that pegmatites in Nasarawa area crystallize from a more fluid and rare metals-enriched melt than those of Ijero and Egbe, as well as Wamba areas. These results agree with observations of Cerny *et al.* (1985) who noted that these elements are enriched in late hydrothermal stages of pegmatite formation.

High activity of P during the primary pegmatite crystallization in this area resulted in the formation of the amblygonite subtype (Burt and London, 1982; London and Burt, 1982b; Cerny, 1991b) of the complex pegmatites. The exhaustion of Li and F by the phosphates from pegmatitic melt may account for the Li-, and F-poor micas with the highest Ta contents which probably crystallized after the crystallization of the amblygonites in the area.

Tl, Rb, Cs and the REEs La, Ce, Pr fractionation in K-feldspars and white mica demonstrates congruent/similar trends. K/Rb, K/Tl and K/Cs ratios are lower in the white mica than the K-feldspars. Ta and Cs have the highest positive correlation (0.756) in the micas, therefore low K/Rb (16), K/Tl (3096) and K/Cs (121) as found in the Nasarawa area indicate high rare metal Ta-Nb-Sn-Li-Be mineralization potentials as observed in the Nasarawa pegmatites.

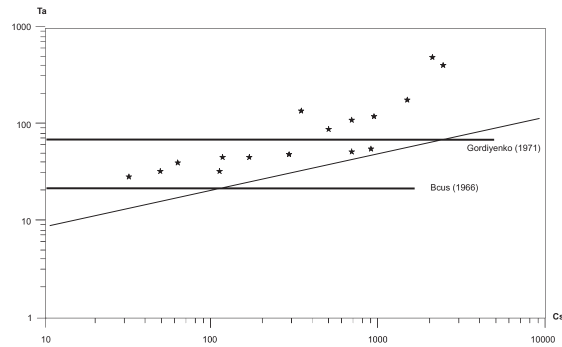

Figure 5. Plot of Ta Versus Cs For The Muscovites of Nasarawa Pegmatites.
Note: The limits of 20ppm Ta according to Beus (1966), and of 65-75ppm set by Gordiyenko (1971) for a Ta mineralization are also given.

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