EXPLORE
Newsletter for the
Association of Applied Geochemists
www.appliedgeochemists.org
NUMBER 192 SEPTEMBER 2021

Association of Applied Geochemists Student Support Initiative:

Geochemistry of LCT Pegmatites in part of Northeastern Nasarawa state, Northcentral Nigeria

A. Chukwu[1], S.C. Obiora[2] and T.C. Davies[3]
[1]Department of Geology, Ebonyi State University, Abakaliki, Nigeria
[2]Department of Geology, University of Nigeria, Nsukka, Enugu Nigeria
[3]Department of Geosciences, University of Lagos, Lagos, Nigeria
Corresponding author: achukwu1@gmail.com

https://doi.org/10.70499/SPQU4159

INTRODUCTION

Pegmatites around the globe are known to host significant rare metals, such as Be, Nb, Ta, Sn, Cs, and Li. These metals are presently in high demand due to their exceptional characteristics, such as high boiling and melting points, resistance to corrosion, ductility, alloys well, superconductivity, low coefficient of thermal expansion, and a high coefficient of capacitance (capacity to store and release an electrical charge) (Selway *et al.* 2005). They are very significant in the electronics industry for the manufacture of capacitors, which are found in cell phones, video cameras, and laptop computers. Hence, the need for continuing to explore for potential hosts of these rare metals globally cannot be overemphasized. The geology of Nigeria is of interest as it has considerable potential to host rare metal mineralization in its pegmatites.

The pegmatites are in the northeastern Nasarawa, where north-central basement complex is part of the unmetamorphosed rocks of acid and basic dykes of late- to post-tectonic Pan-African rocks (600 ± 150 Ma; Grant 1970; Matheis & Caen-Vachette 1983; Obiora & Ukaegbu 2009). The pegmatites are reported in a broad belt extending from the Ago – Iwoye area in the southwest to Jos, northcentral basement Nigeria (Fig. 1) (Jacobson & Webb 1946; Wright 1970; Matheis 1987; Kuster 1990). They are also reported in Zuru-Gusau, northwest (Garba 2003; Okunlola & King 2003) and the Obudu area of southeastern Nigeria (Ekwueme & Matheis 1995). Presently, rare metal recoveries of these pegmatites in the study area are partially known only around Wamba areas, but not known in other parts of the study area. Furthermore, artisanal mining of rare metals, dominantly cassiterite and surbordinate columbite-tantalite, has been ongoing for decades around Wamba (Kuster 1990). The pegmatites of the southwest and part of Wamba are dated from 580-530 Ma by the Rb/Sr method (Matheis 1987).

Most of the studies in the Nasarawa north-central basement were concentrated in the western part around the Keffi area. Onyeagocha (1984) and Obiora & Ukaegbu (2009) described the basement rocks around the boundary between the basement and sediments as migmatitic banded gneisses and granitic rocks of calc-alkaline and peraluminous compositions, but fail to account for the pegmatite mineralization

continued on page 5

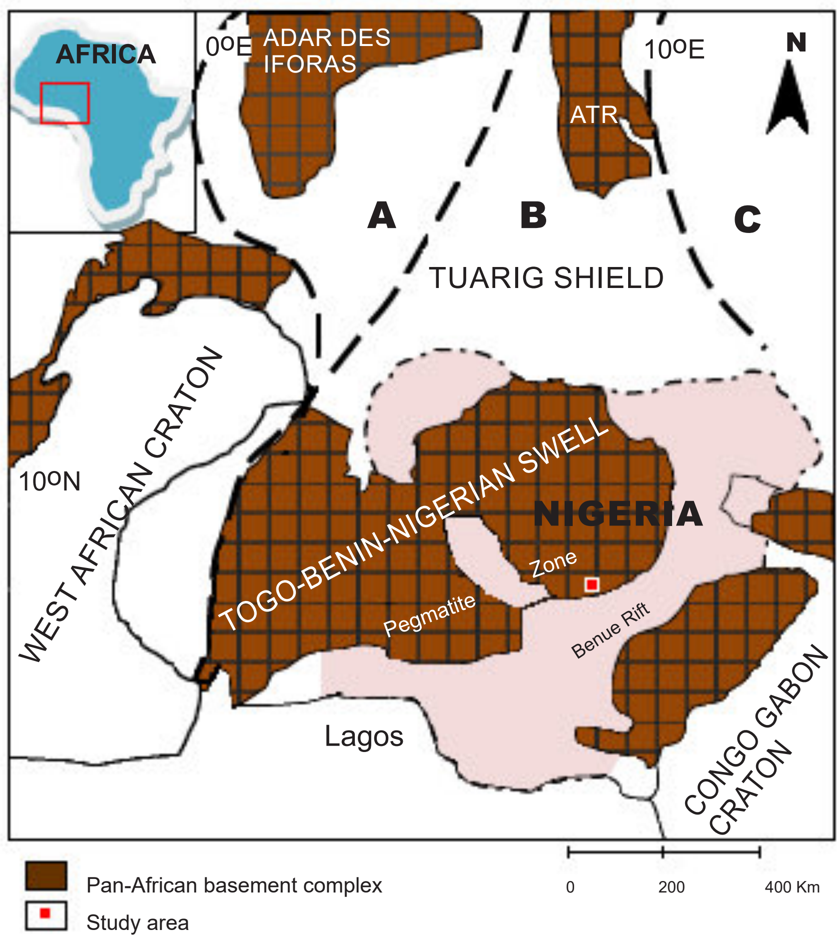

Figure 1. Location of the Precambrian basement complex of Nigeria in relation to the West African and Congo cratons and southern Tuareg Shield. (A) represents the western Tuareg Shield (Pharusian belt); (B) central Tuareg Shield (Hoggar-Air segment); (C) eastern Tuareg Shield (East-Saharan Craton). Modified after Obiora & Ukaegbu 2009.

Geochemistry of LCT Pegmatites… *continued from page 1*

potential. Other workers on pegmatites mostly around the Keffi area, NW of Akwanga include Adekeye & Akintola (2007, 2008) and Akintola & Adekeye (2008) who suggested that these pegmatites were structurally controlled and have a high potential for rare metals. Okunlola & King (2003) revealed the occurrence of Ta-Sn-Li-Be mineralization in vertical and lateral pegmatites around the Keffi area. Jacobson & Webb (1946), Kuster (1990), and Akintola & Adekeye (2008) thought that the rare metal pegmatites in part of Wamba, Nigeria, are genetically related to the Pan African granitoids, based on field observations and available data; however, earlier age differences from isotopic data from Matheis and Caen-Vachette (1983) proved otherwise that led Matheis (1987) to suggest that the pegmatites in southwest Nigeria resulted from reactivation of tectonic trends in addition to partial melting and external volatiles.

Most of these investigators of pegmatites in Nigeria attributed their formation to the model of extended fractional crystallization of fertile parent granites (cf. Crouse & Černý 1972; Stilling *et al*. 2006) even when such granite bodies are unknown. However, recent work by Goodenough *et al*. (2014) and Melcher *et al*. (2015), which considered the age differences (more than 100 Ma difference) between the pegmatites in Sarkin Pawa north-central Nigeria and Pan African granitiods, concluded that they are not genetically related, suggesting a pegmatite conundrum. Apart from the generalized classification of the pegmatites in north-central basement as Wamba-Nasarawa field of the 'Older Tin-field' by Jacobson & Webb (1946), literature accounts of pegmatitic rocks in part of the northeastern Nasarawa area are rare. Secondly, data on whole-rock geochemistry of the pegmatites in Nigeria is very rare. This work used detailed field studies, mineralogical and bulk rock chemistry to characterize the pegmatites in the northeastern Nasarawa region.

REGIONAL GEOLOGICAL SETTING

The Nigerian basement complex is situated between the West African and Congo cratons and south of the Tuareg Shield (Fig. 1). The Pan-African trans-Saharan mobile belt evolved through plate collision of the active margin of the Pharusian belt (Taureg shield) and the passive plate of the continental margin of the West African craton approximately 600 Ma (Burke & Dewey 1972; Black *et al*. 1979). McCurry & Wright (1977) reported that the subduction and the collision at the eastern margin of the West African craton led to extensive melting of rocks and emplacement of calc-alkaline granitoids and basaltic intrusions.

Rocks of the Nigerian Basement Complex are believed to have undergone a series of orogenic cycles that are characterized by deformation, metamorphism, remobilization and reactivation. These correspond to the Liberian (2650 ± 150 Ma), Eburnean (2000 ± 50 Ma), Kibaran (1100 ± 200 Ma) and Pan-African (600 ± 150 Ma) cycles. The basement complex of Nigeria consists of migmatite-gneiss complex (biotite and biotite-hornblende gneisses, quartzites, quartz schist and small lenses of calc-silicate rocks), slightly migmatised to unmigmatised paraschists and metaigneous rocks (pelitic schists, quartzites, amphibolites, talcose rocks metaconglomerates, marbles, banded iron-formations, and calc-silicate rocks) and older granites (granodiorites, granites, and potassic syenites).

Migmatite-gneiss complex represents the oldest basement rocks of the Nigerian Basement complex and common in most parts of the Nigerian Basement complex. They exhibit a great variation in composition, which is a result of the different protoliths and pressure-temperature conditions under which they were formed (Obiora 2005; Obiora and Ukeagbu 2009). The components of the migmatite-gneiss include the leucosome, mesosome, and paleosome. The schist belt represents the younger meta-sediments with occasional metaigneous units. The schist trends mostly N-S and appears to have been restricted to the western half of the Nigerian Basement, although meta-sediments have been mapped around the Nigerian Oban massif (southeastern basement complex). The Pan-African granite suites intruded the migmatite-gneiss and the schist complex. Other rocks of the Pan-African granites include porphyritic/porphyroblastic muscovites-granites, aplites, tonalities, diorites, syenites, and charnokites (Obiora 2005), with calc-alkaline and peraluminous to metaluminous compositions. These granitic rocks are

continued on page 6

Geochemistry of LCT Pegmatites… *continued from page 5*

often slightly foliated, with gradational contacts, which may not be magmatic. Jones & Hockey (1964) identified three phases of the Pan-African granite suites based on field relationships, mineralogy, and textures: 1) early phase comprising gabbroic rock, dolerites, granodiorites, and quartz diorites; 2) main phase made up of coarse porphyritic hornblende granite, syenites, and coarse porphyritic biotite granite; 3) late phase made up of homogenous granite, pegmatite, and aplite dykes. However, Dada & Respaut (1989) using field and geochemical evidences believed that the dolerites and pegmatites were unmetamorphosed rocks of the Basement complex since they cross-cut the Pan-African rocks, representing the youngest rocks of the Basement complex. The Jurassic Younger granites of the Jos area intruded the basement complex. In contrast to the older granites, it has sharp contacts with the basement rocks, which shows that it is magmatic, occurring as ring dykes and is alkaline in nature. These Jurassic Younger granites serve as a major source of tin and other rare metal mineralization within the basement, especially around the Jos Plateau of Nigeria.

METHODOLOGY

The study was carried out by intensive field studies involving visitation of outcrops and collection of rock samples for further laboratory studies. Nineteen representative samples of large pegmatite bodies (more than 3 kg) were collected. The samples were selected from traverses across the ridges of the pegmatites according to field grouping in key locations. The samples were crushed to a minimal grain size of less than 5 mm to achieve homogeneity and powdered to 200 mesh using a tungsten mill at the Department of Geology, University of Nigeria, Nsukka. The samples were analyzed at Genalysis (Intertek) Laboratory Services Pty Ltd, Maddington, Australia. The major oxides were determined using X-Ray Fluorescence (XRF) spectrometry, whereas the trace elements and rare earth elements were determined by lithium metaborate fusion Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Loss on ignition (LOI) was determined by robotic thermos-gravimetric analyzer (TGA). Lower detection limits for the major oxides are: 0.01 wt. %, 20 ppm for B, 5 ppm for Li, 2 ppm for Sn, 0.5 ppm for Rb, 0.1 ppm for Cs, 10 ppm and 0.1 ppm for Nb and Ta, respectively.

LOCAL GEOLOGY AND PETROGRAPHY

The basement rocks of the northeastern Nasarawa area consist of largely migmatitic gneisses, granitic gneisses, and sparse amphibolites (Fig. 2). The grade of metamorphism ranges from greenschist to amphibolite facies across the region. These basement rocks are discordantly intruded by the pegmatites. The migmatitic gneiss shows coarse-grained, mesocratic and gneissose foliations with NNE-SSW directions. The foliation planes dip ranges from about 15° - 60° in SE direction. There are obvious banding (folia) and alignments of biotite and conspicuous alternation of leucocratic and melanocratic components within the gneisses. The locally developed leucosome is composed mainly of quartz, microcline, and plagioclase, whereas the melanosome is composed of mainly biotite and minor hornblende, with other minor constituents including cordierite and sillimanite. There is also evidence of undifferentiated older meta-sediment (paleosome) in the migmatitic gneisses. The migmatitic gneisses also possess quartzo-feldspathic veins ranging from 0.5 – 5 cm, mostly concordant with a few cross-cutting the foliation trends. Ptygmatic folds of the quartzo-feldspathic

continued on page 8

Geochemistry of LCT Pegmatites... *continued from page 6*

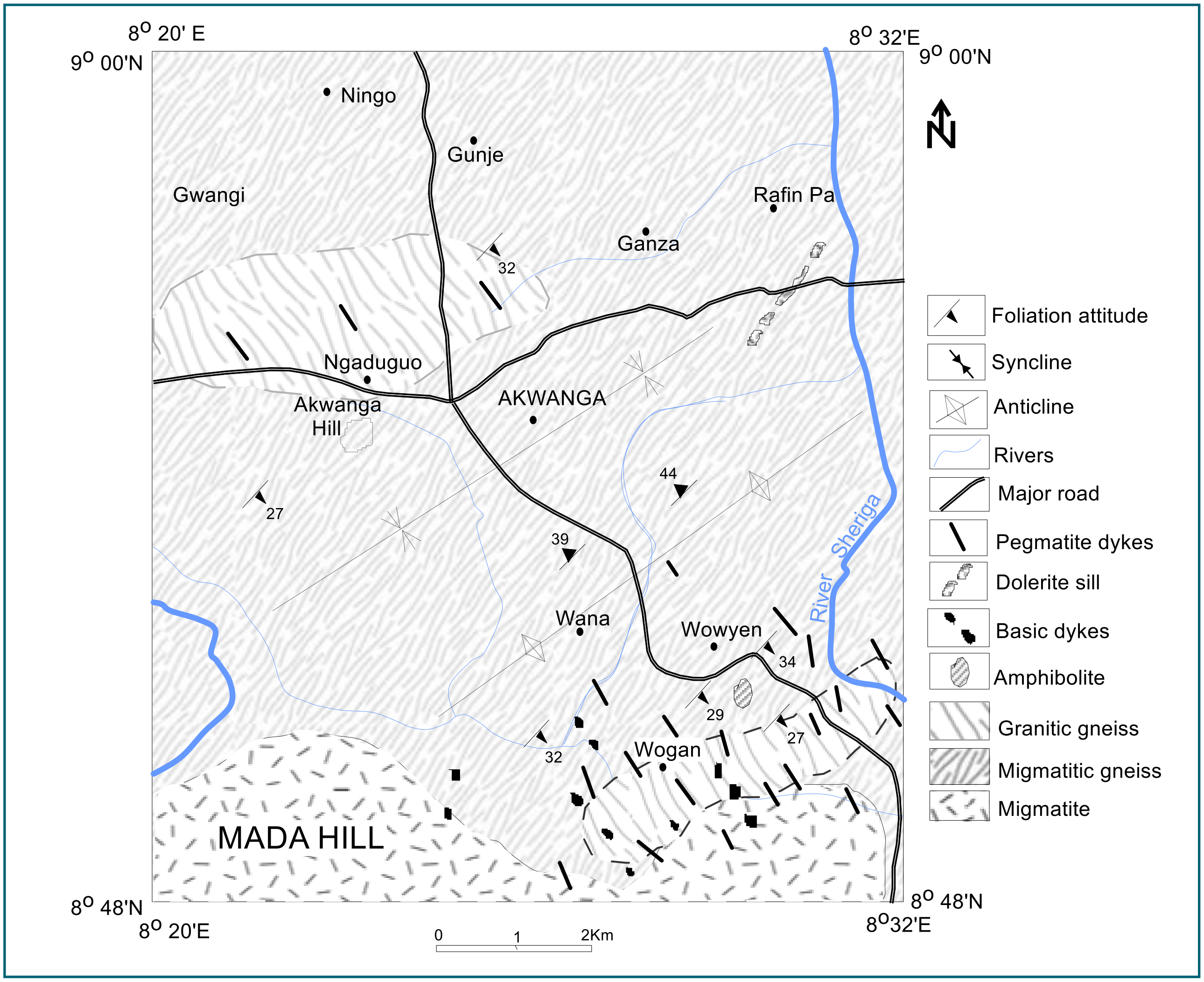

Figure 2. Geological map of the study area showing the locations of the pegmatites and the host rocks

veins and pinch and swell structures with lit per lit ejections are common especially around the Wowyen and Agbanju hills. Strike-slip faults, dextral and sinistral dislocation of veins and veinlets abound. The migmatite-gneisses are cross cut by basic dykes, basaltic and rhyolitic porphyries, and thin pegmatite dykes, although some occur as sills. Some of the biotite gneisses are porphyroblastic in compositions with phenocrysts of plagioclase forming augen structures. The plagioclase crystals occur as oligoclase in the leucosome and andesine-labradorites in the melanocratic components and are characterized mostly by albite polysynthetic twinning with few showing Carlsbad-albite combine twinning. Microcline is colourless, subhedral to euhedral with distinct cross-hatch twinning.

Granitic pegmatities are widely distributed within the granitic gneisses and migmatitic gneisses in the study area and less common in other rock types in the area. The pegmatites occur as discrete dykes down the base of Mada Hill and abound around the hills in Wamba areas, although some occur as lenses at the surface. Pegmatites occur as tabular bodies, numbering more than thirty-five in the study area. The major trend of the pegmatites is NNW-SSE, although some are also oriented NE-SW and rarely E-W. The thickness of the tabular and massive dykes ranges from 4 to 30 m; the length of the dykes ranges from 20 m to more than 700 m with discontinuity between the dykes. The pegmatites generally show sharp contacts with the host rocks and roof pendants of the granitic gneiss are observed close to the peripheral regions of the pegmatites, especially around the Wogan area. The pegmatites in the study area are grouped into simple and complex pegmatites, based on their field characteristics and mineralogy. The simple pegmatites (biotite-microcline-quartz pegmatites) occurred mostly towards the northern part of the map. The pegmatites show extremely coarse, euhedral grains of quartz, biotite, microcline, albite, muscovite, sparse garnet, and magnetite. The quartz is colourless whereas the feldspars are pinkish and blocky. The biotites are mostly primary and some are replaced by secondary muscovites. Biotite is brownish and pleochroic from pale brown to deep brown and exhibits parallel extinction. Albite is colourless with thin albite polysynthetic twinning. Microcline is colourless with its unique cross-hatch twinning. Small graphic to granophyric intergrowths occur as well as myrmekite that were observed petrographically.

continued on page 9

Geochemistry of LCT Pegmatites... *continued from page 8*

The complex pegmatites (albite-muscovite pegmatites) are dominant towards the southern and eastern parts of the mapped area (Fig. 2) around the Wogan-Wowyen-Wamba pegmatite field. There is no clear zoning in these pegmatites, although careful observations can trace large crystals up to 15 cm of quartz, muscovite-cleavelandite and locally black tourmalinized irregular core zones, whereas coarse to aplitic quartz-muscovite and minor biotite wall zones can be observed. These pegmatites have potential for Sn, Nb, and rare Ta mineralization in contrast to the earlier notion of Matheis (1987) who disputed the potential of columbite around the Nasarawa pegmatites. The pegmatites are categorized by colourless to smoky quartz, light - pinkish albite, and minor microcline, and large books of colourless to brownish muscovites. Black tourmaline patches also occur as accessory and garnet are sporadically distributed in the pegmatites. Miarolitic textures were observed in few locations of the pegmatites and graphic textures of quartz and albite are common than the simple pegmatites.

From the mineralogical studies, extremely coarse-grained and euhedral quartz, albite and muscovite are the major mineral constituents of the pegmatites. Biotite also occurs in less than 5 % of the mode. Quartz is characterized by colourless with undulating extinction in some of the samples. Albite shows albite twinning with anorthite composition of An_{7-13}. Graphic to granophyric, and myrmekitic textures (intergrowth of albite and quartz) are also common. Albitisation is the product of selective sodic metasomatic replacements in the pegmatites where some of the slides in modal analysis recorded almost 65 – 80 % albite (cleavelandites) in place of microcline and other K-feldspars, which occur as patchy replacements in most of the slides. Other accessory minerals are fractured almandine-garnet, black tourmalines (schorl), and tiny dark patchy minerals possibly cassiterite-columbite-tantalite, which are mostly associated with the albitisation. The muscovites are primary with no obvious deformation showing that the pegmatites are post-tectonic within the region.

RESULTS

The granitic pegmatites have moderate to very high SiO_2 contents (63.88 – 78.81 wt %). The cocentrations of TiO_2, MgO, CaO, MnO, and P_2O_5 are generally less than 1 wt.%. Na_2O concentrations predominate over K_2O consistent with albitization in the pegmatites across the study areas. Al_2O_3 concentrations are moderate to high (13 – 21 wt.%) across the pegmatite samples. The A/CNK of the pegmatites in the study area reflects strongly peraluminous (A/CNK = 1.45 – 2.14) compositions, with the complex pegmatites having the highest values. On the alkaline-silica variation diagram, the simple and rare metal pegmatites plot predominantly in the granite field, except two rock samples of the complex pegmatite and one sample of the simple pegmatite which plot in the syenite field (Fig. 3).

The Rb contents in the complex pegmatite (277 – 1719 ppm) and simple pegmatite (126.5 ppm – 559.8 ppm) are high. In contrast, the concentrations of Ba and Sr in the pegmatites are below average crustal abundances of Wedepohl (1995). The values of Sr in some samples of the pegmatites are mostly below detection limit of 20 ppm and not greater than 230 ppm. Tin, Nb, and Ta values in the pegmatites are higher in the complex pegmatite with values up to 4466 ppm Sn, 106 ppm Nb, and 45 ppm Ta compared to average fertile pegmatitic leucogranite of Superior Province (Černý & Meintzer 1988; Selway *et al.* 2005). Tin, Nb, and Ta contents in simple pegmatites range from 4 – 35 ppm, 7 – 15 ppm, and 0.8 – 10.7 ppm, respectively. The pegmatites are also depleted in REEs and base metals, e.g., Ag, Cr, Co, Ni, Cu, Mo, Pb, and Zn. Cs, Ga, and B values are enriched in complex pegmatites. The highest values of Cs, Ga, and B are up to 56.5, 59, and 4205 ppm, respectively. Lithium concentrations range from 5.0 ppm in the simple pegmatites up to 161 ppm in the complex pegmatites. These variations in elemental values show that the degree of fractionation is proportional to rare element

continued on page 10

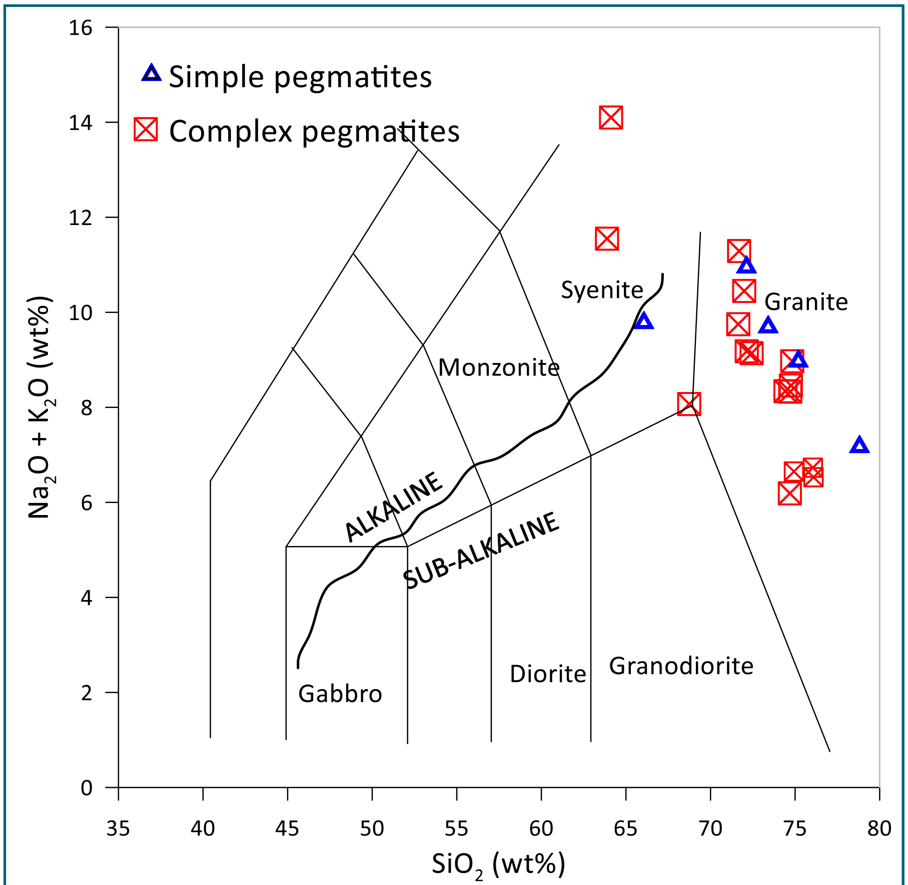

Figure 3. Nomenclature of the granitic pegmatites using alkaline-silica diagram.

Geochemistry of LCT Pegmatites... *continued from page 9*

abundances (Li, Be, B, F, P, Ga, Rb, Cs, Y, Nb, Sn, and Ta) in fertile granites (Černý & Meintzer 1988), whereas Ti, Sr, Ba, and Zr decreases with fractionation.

DISCUSSION

The strongly peraluminous nature of the pegmatites from the study area is clearly observed on the Shand index diagram (Fig. 4a), $Al_2O_3/(Na_2O+K_2O)$ versus $Al_2O_3/(CaO+Na_2O+K_2O)$ of Maniar & Piccoli (1989). The complex pegmatites are most evolved and show higher peraluminousity than the simple pegmatites. These pegmatites are spatially associated with S – type granites. Samples of the pegmatites plot predominantly in the high-K calc-alkaline and shoshonite series field of Peccerillo & Taylor (1976) (Fig. 4b). On the SiO_2 vs Fe* of Frost *et al*. (2001), the pegmatites fall in the ferroan field (Fig. 4c). The ferroan affinity of the rocks is consistent with the presence of magnetite both in the mode and norm of the pegmatites, in the absence of other Mg-rich ferromagnesian phases. In the MALI diagram of Frost *et al*. (2001), the pegmatites plot dominantly in the alkali and stretches into calcic-alkalic field (Fig. 4d).

continued on page 11

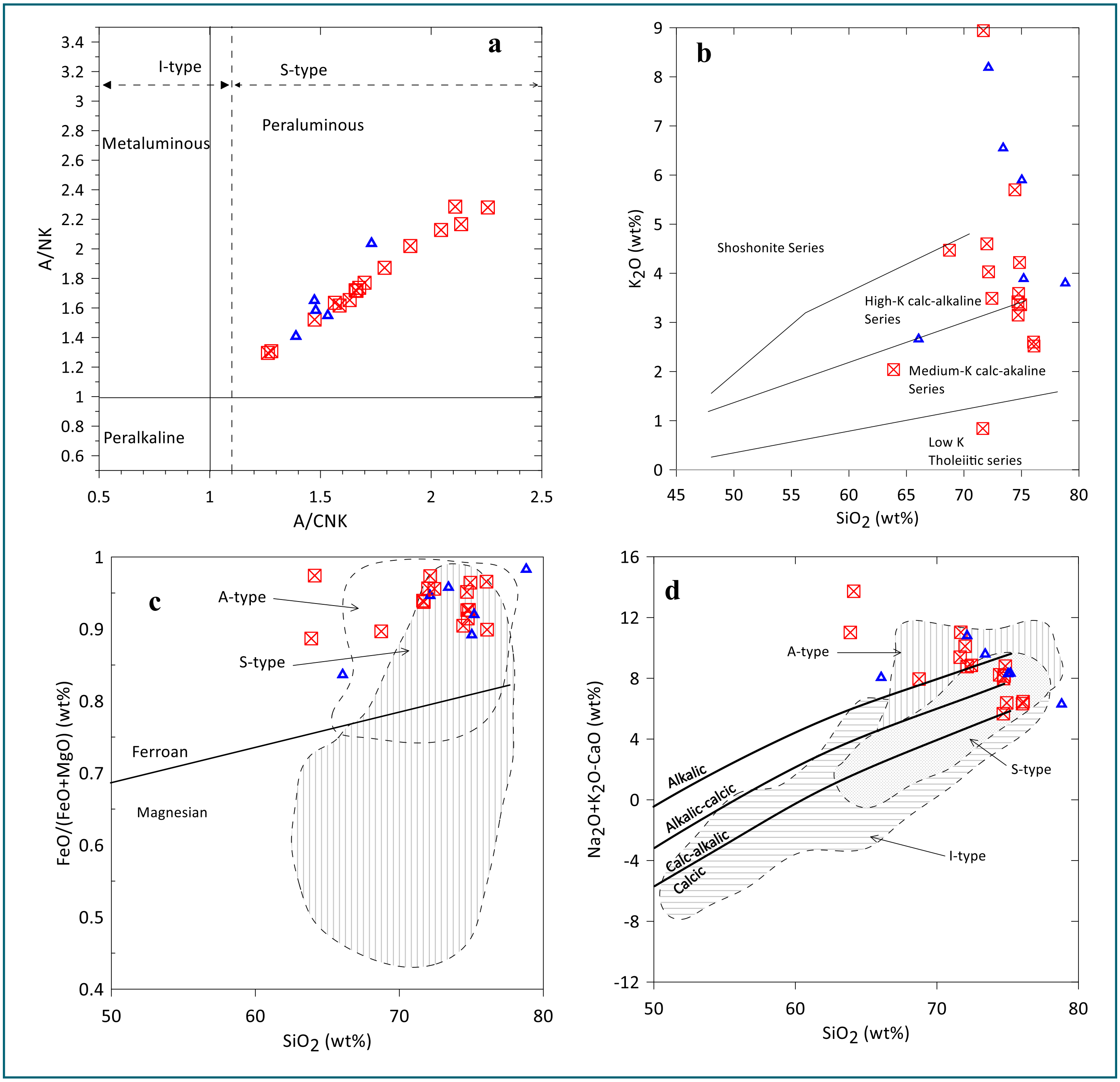

Figure 4. (a) Shand index plot for the pegmatites in Wogan area. A/NK = $Al_2O_3/(Na_2O+K_2O)$ and A/CNK = $Al_2O_3/(CaO+Na_2O+K_2O)$ after Maniar & Piccoli (1989). Binary plots for the granitic pegmatites in Wogan (b) K_2O versus SiO_2 of Peccerillo & Taylor (1976); (c) FeOt/(FeOt + MgO) versus SiO_2 after Frost et al. (2001); (d) modified alkali-Lime Index (MALI) versus SiO_2 of Frost et al. (2001). Symbols are as in Figure 3.

Geochemistry of LCT Pegmatites... *continued from page 10*

These geochemical properties are similar to the findings of Chukwu & Obiora (2021) and Goodenough *et al*. (2014) in pegmatites around the north-central basement complex of Nigeria. The peraluminous characteristic of the pegmatites in the study area are consistent with the observations of other rare metal and barren pegmatites in other parts of Nigeria, such as the southwestern Nigerian Oke-Asa and Igbeti pegmatites (Okunlola & Oyedokun 2009); north-central Nigerian Sarkin Pawa-Minna pegmatites (Goodenough *et al*. 2014) and Angwan Doka pegmatites (Akoh *et al*. 2015), and southeastern Nigeria's Oban and Bamenda massif pegmatites (Ibe & Obiora 2019).

The pegmatites in this study area show variable trace element and REEs patterns and are strongly fractionated, especially in the complex pegmatites. They are enriched in Cs, Tl, Rb, B, Sn, K, Nb, Ta, Pb, U, and Li, but show typically depletions in Ba, Th, and Ti, as well as, REEs (Fig. 5a). These pegmatites generally show low concentrations of REE (Fig. 5b) with some of the values below detection limit. Though the pegmatites have minor higher LREE relative to the HREE [$(La/Yb)_n$ = 1.23 – 25.3] with the simple pegmatites showing higher values, LREE and HREE concentrations are generally very low (Fig. 5b), because the REEs in pegmatites are easily partitioned into the accessory phases (Christiansen *et al*. 1993). Furthermore, the Eu concentrations in these pegmatites are very low, with most less than detection limit (< 0.1 ppm), except few samples of the simple pegmatites. Concentrations of Ho, Tm, and Lu in the pegmatites are also below detection limits of 0.1 ppm and the pegmatites are mildly depleted in Nd and Er. The different patterns of the REE in these samples probably reflect the crystallization of accessory phases, as well as garnet. The Eu anomalies in the pegmatites can be explained by restite feldspar, fractional crystallization of feldspars, and melt-fluid interaction (including albitisation) in the last stage of magma solidification (Abdelfadil *et al*. 2016; Chukwu & Obiora 2014, 2018). Considering the diagram of Pearce *et al.* (1984) (Fig. 6) the pegmatites fall in the field of syn-COLG which further supports that S-type granite originating from collision setting.

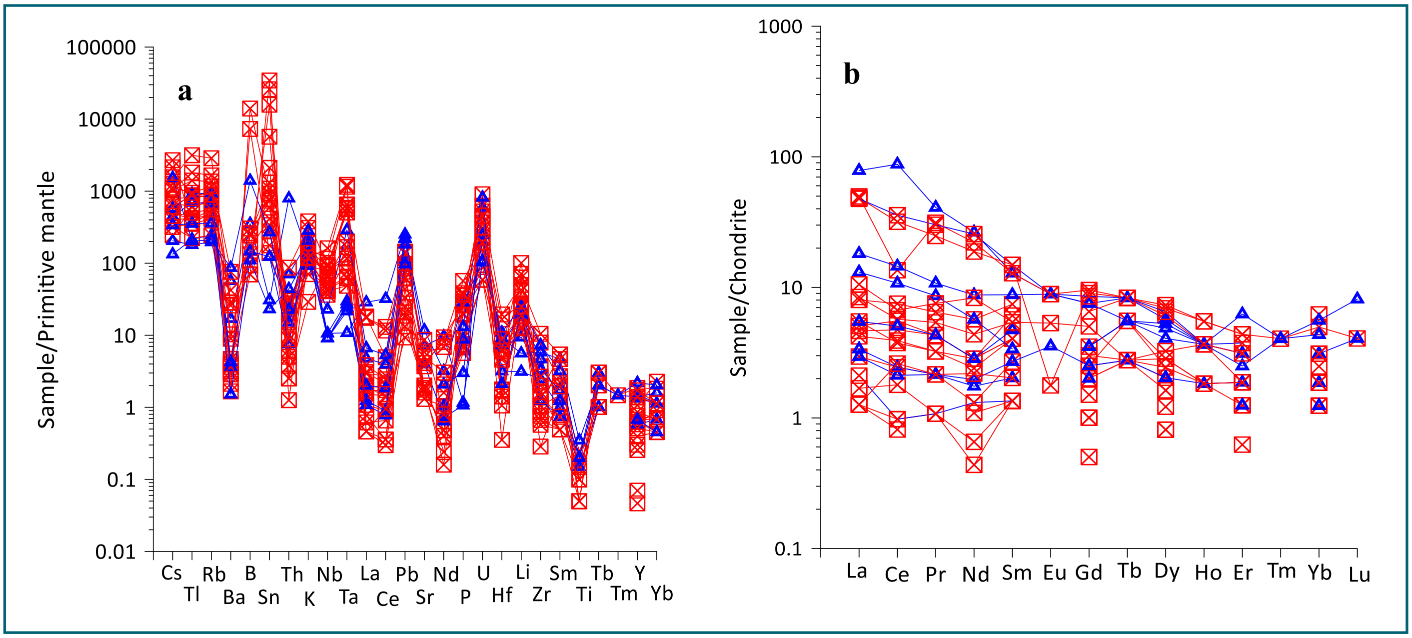

Figure 5. (a) Primitive mantle-normalized multi-element diagrams for the granitic pegmatites. Normalizing factors from McDonough and Sun (1995). (b) Chondrite-normalized rare earth elements diagrams for the granitic pegmatites. Normalizing factors from McDonough and Sun (1995). Symbols are as in Figure 3.

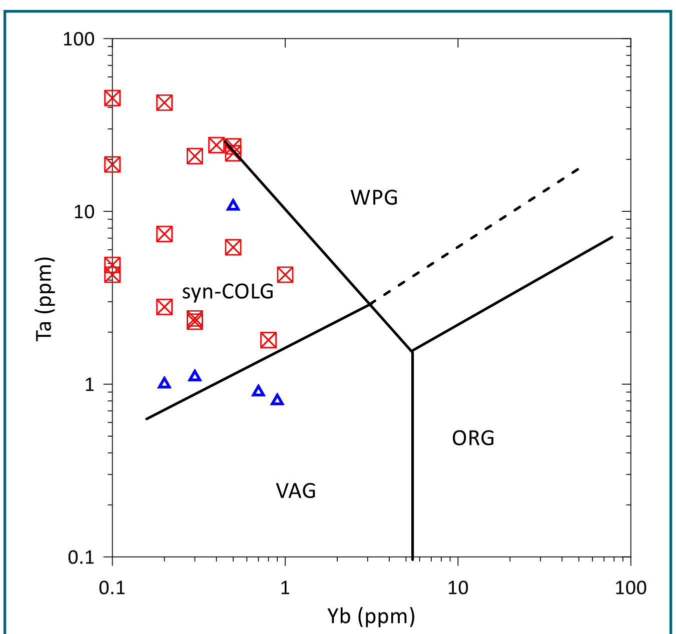

Figure 6. Ta versus Yb diagram of Pearce et al. (1984). VAG: volcanic arc granites; syn-COLG: syn-collisional granites; WPG: within-plate granite; ORG: oceanic ridge granites. Symbols are as in Figure 3.

continued on page 12

Geochemistry of LCT Pegmatites… *continued from page 11*

POTENTIAL MINERALIZATION OF THE PEGMATITES

The elemental enrichments (Cs, Rb, Nb, Ta, B, and Li) in the spidergrams (Fig. 5a) are in accordance with the field observations that show that the complex pegmatites contain Sn-Nb-Ta oxides and B-bearing minerals (e.g., tourmaline) compared to the simple pegmatites. The presence of muscovite in the complex pegmatites may explain the enrichment in Li, Rb, and Cs. These elemental enrichments and depletions are consistent with recognized data (Černý *et al*. 2012) as evidence for rare-metal pegmatites of the LCT (Li-Cs-Ta) family. Rare metal pegmatites in high-grade metamorphic terranes with similar whole-rock geochemical patterns are also known from other areas of collision and post-collisional magmatism, such as the Lewisian Gneiss Complex of northwest Scotland (Shaw *et al*. 2016) and Altai mountains of China (Zhu *et al.* 2006). In Nigerian Pan-African orogenic belts, there is a scarcity of whole-rock geochemical data on rare metal pegmatites, but the few data available (Okunlola & Oyedokun 2009; Goodenough *et al.* 2014) also show similar geochemical signatures as this present study.

Degree of geochemical fractionation in pegmatites can lead to elemental concentrations for further exploration for rare metals. Strongly peraluminous values (A/CNK > 1.2) are used to evaluate the degree of fractionation in fertile granite (Selway *et al.* 2005). A/CNK of the complex pegmatites that are extremely peraluminous (1.5 – 2.1) indicate that the pegmatites are highly fractionated and have abundant Al-rich minerals, such as garnet and muscovite. Rare element contents in fertile granites/pegmatites increase with increasing fractionation of Li, Be, B, F, P, Ga, Rb, Cs, Y, Nb, Sn, and Ta and decrease in Ti, Sr, Ba and Zr (Černý & Meintzer 1988). Certain trace-element ratios are good indicators of fractionation in fertile granites/pegmatites, such as K/Rb, K/Cs, Mg/Li, Al/Ga, and Nb/Ta. These ratios are expected to be significantly lower than average upper continental crust of Taylor & McLennan (1985) (see also Wedepohl 1995), and are comparable to bulk trace element ratios of Černý (1989) in fertile granite/pegmatites (cf. Selway *et al*. 2005). The average ratios of K/Rb, K/Cs, Mg/Li, Al/Ga, and Nb/Ta in the complex pegmatites are 64.5, 2872, 24.8, 2015, and 8.76 respectively while their average ratios in the simple pegmatites are 196, 4190, 20.5, 4009, and 5.81, respectively. This shows that the complex pegmatites are strongly fractionated and have strong potential for rare metals relative to the simple pegmatites (Table 1). High ratios of Na/K (2.55 average) in the complex pegmatites also indicate considerable albitisation in the pegmatites. These ratios are also within the range obtained in muscovites for rare metal pegmatites in other parts of the Nigerian Basement Complex (Černý 1989; Okunlola & King 2003; Okunlola & Oyedokun 2009; Akintola *et al*. 2012; Chukwu & Obiora 2021).

Table 1. Selected trace elements ratios in the Wogan pegmatites compared with fertile granites

	Complex pegmatite		**Simple pegmatite**		**UCC mean**	**Fertile Granites**
	Range	Mean	Range	Mean		
K/Rb	40.4-107.6	64.5	149.4-331.6	196.0	252.0	42-270
K/Cs	299.7-6869	2871	687.9-7336	4191	7630	1600-15400
Mg/Li	5.97-51.4	24.8	11.7-25.6	20.5	--	1.7-50
Al/Ga	1596-2160	2015	3686-4584	4010	--	1180-3100
Nb/Ta	1.36-15.4	8.76	1.40-8.75	5.81	11.4	--

*Fertile peg. ratios data from Černý (1989)
*UCC represents average upper continental crust after Taylor and McLennan (1985)

CONCLUSIONS

This research shows that the pegmatites in the migmatitic to gneissic basement complex in areas of northeastern Nasarawa are predominantly complex rare-metal pegmatites. The complex pegmatites are highly peraluminous, relatively low K/Rb and Al/Ga ratios, highly enriched in Sn and B, and relatively enriched in Rb, Li, Cs, B, Be, Nb, and Ta compared to the simple pegmatites. The rare-metal pegmatites are dominated by albitic feldspar, muscovite, and quartz. Almandine garnets, tourmaline (schorl), and Sn-Nb-Ta minerals also occur as accessories. The mineralogy and whole rock chemistry of the pegmatites suggest a highly peraluminous source probably a metapelitic to associated metasedimentary protolith that was enriched in incompatible

continued on page 13

Geochemistry of LCT Pegmatites… *continued from page 12*

LILE and HFSE. Complex pegmatites are highly fractionated compared to the simple pegmatites; these similarities in the chemical characteristics show that the complex pegmatites and the simple pegmatites are generated contemporaneously, the differences in composition arose from magmatic fractionation, possibly related to spatially associated S-type granites.

ACKNOWLEDGEMENTS

This research article was prepared for the EXPLORE newsletter to fulfill the requirement for receiving analytical support for the Ph.D. research of the first author under the Association of Applied Geochemists Student Support Initiative. The senior author is very grateful to the Association of Applied Geochemists (AAG) for sponsoring the whole rock geochemical analyses (in kind analytical support) as part of his PhD research. The support from management of Genalysis (Intertek) Laboratory Services, Australia, is highly appreciated for their detailed laboratory analyses. Finally, the senior author appreciates the efforts of the third author, Professor T.C. Davies for his help which led to the sponsorship of the work and supervisor Professor S.C Obiora for his encouragement and supervision. We are grateful to the EXPLORE Editor, Beth McClenaghan, and Professor David Lentz for their constructive reviews.

REFERENCES

Abdelfadil, K.M., Asimow, P.D., Azer, M.K. & Gahlan, H.A. 2016. Genesis and petrology of Late Neoproterozoic pegmatites and aplites associated with the Taba metamorphic complex in southern Sinai, Egypt. *Geologica Acta,* **14(3),** 219-233.

Adekeye, J.I.D. & Akintola, O.F. 2007. Geochemical features of rare metal pegmatites in Nassarawa area, central Nigeria. *Journal of Mining Geol*ogy, **43(1)** 15-21.

Akintola, O.F. & Adekeye, J.I.D. 2008. Mineralization potentials of pegmatites in the Nasarawa area of central Nigeria. *Earth Science Research,* **12(2),** 213-234.

Akintola, A.I., Ikhane, P.R., Okunlola, O.A., Akintola, G.O. & Oyebolu, O.O. 2012. Compositional features of Precambrian pegmatites of Ago-Iwoye area, southwestern, Nigeria. *Journal of Ecology and Natural Environ*ment, **4(3),** 71-87.

Akoh, J.U., Ogunleye, P.O. & Aliyu, A.I. 2015. Geochemical evolution of micas and Sn-, Nb-, Ta- mineralization associated with the rare metal pegmatite in Angwan Doka, central Nigeria. *Journal of African Earth Sci*ences, **97,** 167–174.

Burke, K.C. & Dewey, J.F. 1972. Orogeny in Africa. In: Dessauvagie, T.F.J., Whiteman, A.J. (eds), Africa Geology. *University of Ibadan Press, Ibadan*, pp 583–608.

Black, R., Caby, R., Moussine-Pouchkine, A., Bertrand, J.M., Fabre, J. & Lesquer, A. 1979. Evidence for the Late Precambrian plate tectonics in West Africa. *Nature,* **278,** 223–227.

Černý, P. 1989. Contrasting geochemistry of two pegmatite fields in Manitoba: products of juvenile Aphebian crust and polycyclic Archean evolution. *Precambrian Research*, **45,** 215-234.

Černý, P., London, D. & Novak, M. 2012. Granitic pegmatites as reflections of their sources. *Elements,* **8,** 257–261.

Černý, P. & Meintzer, R.E. 1988. Fertile granites in the Archean and Proterozoic fields of rare element pegmatites: Crustal environment, geochemistry and petrogenetic relationships. *In:* Recent Advances in the Geology of Granite-related Mineral Deposits. *Canadian Institute of Mining and Metallurgy, Special Publication,* **39,** 170-206.

Chukwu, A. & Obiora, S.C. 2014. Whole-rock geochemistry of basic and intermediate intrusive rocks in the Ishiagu area: further evidence of anorogenic setting of the Lower Benue rift, southeastern Nigeria. *Turkish Journal of Earth Sciences*, **23,** 427-443.

Chukwu, A. & Obiora, S.C. 2018. Geochemical constraints on the petrogenesis of the pyroclastic rocks in Abakaliki basin (Lower Benue Rift), Southeastern Nigeria. *Journal of African Earth Sciences*, **141,** 207-220.

Chukwu, A. & Obiora, S.C. 2021. Petrogenetic characterization of pegmatites and their host rocks in southern Akwanga, North-Central Basement Complex, Nigeria. *Journal of Earth System Science,* **130**:18, 1-23. https://doi.org/10.1007/s12040-020-01498-7.

continued on page 14

Geochemistry of LCT Pegmatites… *continued from page 13*

Christiansen, E.H., Stuckless, J.S., Funkhouser-Marolf, M.J. & Howell, K.H. 1993. Petrogenesis of rare metal granites from depleted sources: an example from the Cenozoic of western Utah. *In:* Recent Advances in the Geology of Granite-related Mineral Deposits. *Canadian Institute of Mining and Metallurgy, Special Publication,* **39,** 307-321.

Crouse, R.A. & Černý, P. 1972. The Tanco pegmatite at Birnic Lake, Manitoba; I, Geology and paragenesis. *The Canadian Mineralogist*, **11**, 591-608.

Dada, S.S. & Respaut, J.P. 1989. The quartz fayalite monzonite (bauchite) of Bauchi, new evidence of a syntectonic Pan-African magmatism in northern Nigeria. *Comptes Rendus Academie Science de Paris,* **309,** 887–892.

Ekwueme, B.N. & Matheis, G. 1995. Geochemistry and economic value of pegmatites in the Precambrian basement of southeast Nigeria. *In:* Magmatism in Relation to diverse Tectonic Settings, Eds. Srivastava, R.K. & Chandra, R.), New Delhi, Oxford & IBH Publishing Co., 375 - 392.

Frost, B.R., Barnes, C.G., Collins, W.J., Arculus, R.J., Ellis, D.J. & Frost, C.D. 2001. A geochemical classification for granitic rocks. *Journal of Petrology,* **42,** 2033–2048.

Garba, I. 2003. Geochemical discrimination of newly discovered rare-metal bearing and barren pegmatites in the Pan-African (600 ± 150) basement of northern Nigeria. *Applied Earth Science*, *Transactions of the Institution of Mining and Metallurgy, Section B,* **112,** 287-292.

Goodenough, K.M., Lusty, P.A.J., Roberts, N.M.W., Key, R.M. & Garba, A. 2014. Post-collisional Pan-African granitoids and rare metal pegmatites in western Nigeria: Age, petrogenesis, and the ‘pegmatite conundrum’. *Lithos,* **200-201**, 22-34.

Grant, N.K. 1970. Geochronology of Precambrian basement rocks from Ibadan, southwestern Nigeria. *Earth Planetary Science Letters,* **10,** 29-38.

Ibe, C.U & Obiora, S.C. 2019. Geochemical characterization of granitoids in Katchuan Irruan area: further evidence for peraluminous and shoshonitic compositions and post-collisional setting of granitic rocks in the Precambrian Basement Complex of Nigeria. *Acta Geochimica, **38**, 734-752.*

Jacobson, R. & Webb, J.S. 1946. The pegmatites of Central Nigeria. *Geological Survey of Nigeria Bulletin* **17**, 61 p.

Jones, H.A. & Hockey, R.D. 1964. The geology of part of southwestern Nigeria. *Geological Survey of Nigeria Bulletin* **31**, 87p.

Kuster, D. 1990. Rare-metal pegmatites of Wamba, central Nigeria – their formation in relationship to late Pan – African granites. *Mineralium Deposita,* **25,** 25-33.

Maniar, P.D. & Piccoli, P.M. 1989. Tectonic discrimination of granitoids. *Geological. Society of American Bulletin*, **101,** 635-643.

Matheis, G. 1987. Nigerian rare-metal pegmatites and their lithological framework. *Geological Journal*, **22** 271–291.

Matheis, G. & Caen-Vachette, M. 1983. Rb–Sr isotopic study of rare-metal bearing and barren pegmatites in the Pan-African reactivation zone of Nigeria. *Journal of African Earth Sciences,* **1,** 35–40.

McCurry, P. & Wright, J.B. 1977. On place and time in orogenic granite plutonism. *Journal of Geological Society of America*, **82(6),** 1713–1716.

McDonough, W.F. & Sun, S.-S. 1995. The composition of the Earth. *Chemical Geology,* **120,** 223-253.

Melcher, F., Graupner, T., Gabler, H.-E., Sitnikova, M., Henjes-Kunst, F., Oberthur, T., Gerdes, A. & Dewaele, S. 2015. Tantalum-(niobium-tin) mineralization in African pegmatites and rare metal granites: Constraints from Ta-Nb oxide mineralogy, geochemistry and U-Pb geochemistry. *Ore Geology Reviews,* **64,** 667-719.

Obiora, S.C. 2005. Field Descriptions of hard rocks with examples from the Nigerian Basement Complex (1st Edition). Snap Press (Nig.) Ltd. Enugu.

Obiora, S.C. 2012. Chemical characterization and tectonic evolution of hornblende-biotite granitoids from the Precambrian Basement complex around Ityowanye and Katsina-Ala, southeastern Nigeria. *Journal of Mining and Geology,* **48(1),** 13-29.

continued on page 15

Geochemistry of LCT Pegmatites… *continued from page 14*

Obiora, S.C. & Ukaegbu, V.U. 2009. Petrology and geochemical characteristics of Precambrian granitic basement complex rocks in the southernmost part of North-Central Nigeria. *Chinese Journal of Geochemistry*, **28,** 377–385.

Okunlola, O.A. & King, P. 2003. Process test work for the recovery of Ta_20_5 concentrates from rare meal bearing pegmatites of Nasarawa area, central Nigeria. *Global Journal of Geol*ogy, **1(1),** 10-15.

Okunlola, O.A. & Oyedokun, M.O. 2009. Compositional trends and rare metal Ta–Nb mineralization potential of pegmatite and associated lithologies of Igbeti Area, south–western Nigeria. *RMZ–Materials and Geoenvironment,* **56(1),** 38–53.

Onyeagocha, A.C. 1984. Petrology and Geologic history of Akwanga area in Northern Nigeria. *Journal of African Earth Sciences,* **2,** 41-50.

Pearce, J.A., Harris N.B.W. & Tindle A.G. 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks; Journal of Petrology, **25,** 956–983.

Peccerillo, A. & Taylor, S.R. 1976. Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, Northern Turkey. *Contribution to Mineralogy and Petrology,* **73,** 69-87.

Selway, J.B., Breaks, F.W. & Tindle, A.G. 2005. A review of rare-element (Li-Cs-Ta) pegmatite exploration techniques for the Superior Province, Canada, and large worldwide tantalum deposits. *Exploration and Mining Geology*, **14(1-4),** 1–30.

Shaw, R.A., Goodenough, K.M., Roberts, N.M.W., Horstwood, M.S.A., Chenery, S.R. & Gunn, A.G. 2016. Petrogenesis of rare-metal pegmatites in high-grade metamorphic terranes: A case study from the Lewisian Gneiss Complex of north-west Scotland. *Precambrian Research*, **281,** 338-362.

Stilling, A., Černý, P. & Vanstone, P.J. 2006. The Tanco pegmatite at Bernic Lake, Manitoba, XVI. Zonal and bulk compositions and their petrogenetic significance. *The Canadian Mineralogist*, **44,** 599-623.

Taylor, S.R. & McLennan, S.M. 1985. The continental crust; its composition and evolution; an examination of the geochemical record preserved in sedimentary rocks. Blackwell Scientific Publications.

Wedepohl, K.H. 1995. The composition of the continental crust. *Geochimica et Cosmochimica Acta,* **59,** 1217-1232.

Wright, J.B. 1970. Controls of mineralization in the older and younger tin fields of Nigeria. *Economic Geol*ogy, **65,** 945 - 951.

Zhu, Y.-F., Zeng, Y. & Gu, L. 2006. Geochemistry of the rare metal-bearing pegmatite no. 3 vein and related granites in the Keketuohai region, Altay Mountains, northwest China. *Journal of Asian Earth Sc*iences, **27,** 61-77.