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Association of Applied Geochemists Student Support Initiative:

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

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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

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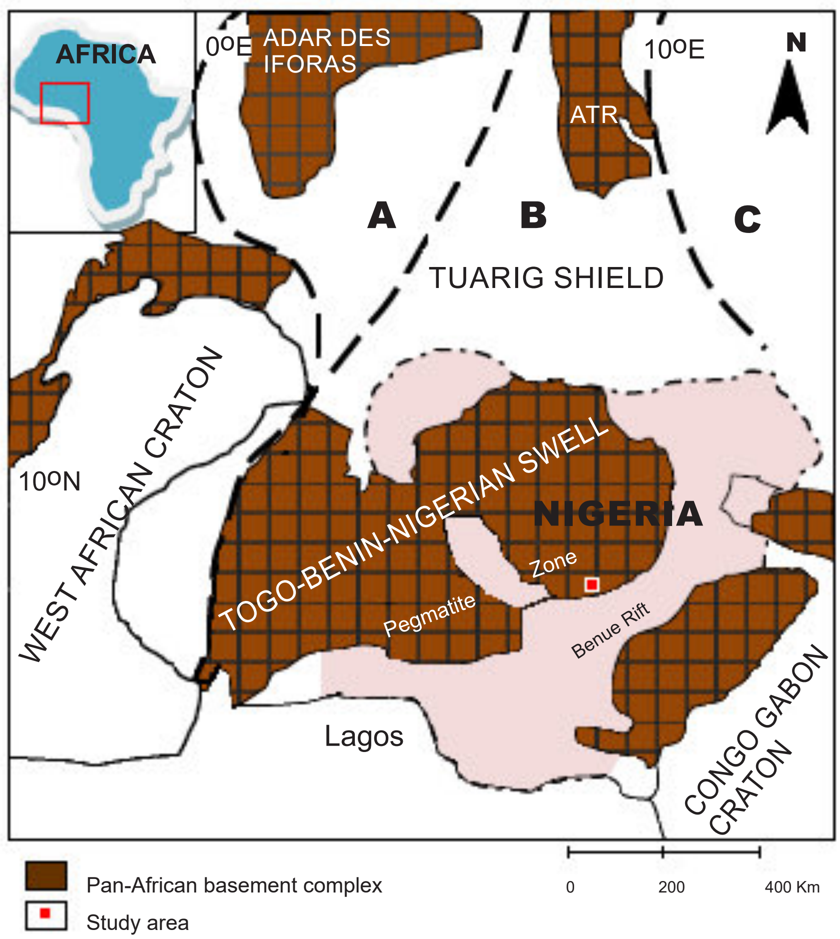

Figure 1. Location of the Precambrian basement complex of Nigeria in relation to the West African and Congo cratons and southern Tuareg Shield. (A) represents the western Tuareg Shield (Pharusian belt); (B) central Tuareg Shield (Hoggar-Air segment); (C) eastern Tuareg Shield (East-Saharan Craton). Modified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

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EXPLORE Publication Schedule

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- **Deadlines** for submission of articles or advertisements:
  March newsletter: January 15
  June newsletter: April 15
  September newsletter: July 15
  December newsletter: October 15
- **Manuscripts** should be double-spaced and submitted in digital format using Microsoft® WORD. Articles should be between 2000 and 3000 words. Do **not** embed figures or tables in the text file.
- **Figures and/or photos** (colour or black and white) should be submitted as separate high resolution (2000 dpi or higher) tiff, jpeg or PDF files.
- **Tables** should be submitted as separate digital files in Microsoft® EXCEL format.
- All scientific/technical articles will be reviewed. Contributions may be edited for clarity or brevity.
- Formats for headings, abbreviations, scientific notations, references and figures must follow the Guide to Authors for *Geochemistry: Exploration, Environment, Analysis* (GEEA) that are posted on the GEEA website at:
  https://www.geolsoc.org.uk/geea-authorinfo
- An **abstract** of about 250 words must also be submitted that summarizes the content of their article. This abstract will be published in the journal ELEMENTS on the 'AAG News' page.

Submissions should be sent to the Editor of **EXPLORE**:
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Notes from the Editor

Welcome to the third **EXPLORE** issue of 2021. This issue features an article describing the geochemistry of LCT pegmatites in part of northeastern Nasarawa state, northcentral Nigeria by A. Chukwu, S.C. Obiora, and T.C. Davies. This article reports research that received analytical support for the Ph.D. research of the first author under the Association of Applied Geochemists Student Support Initiative.

EXPLORE thanks all those who contributed to the writing and/or editing of this issue, listed in alphabetical order: Steve Amor, Dennis Arne, Al Arsenault, John Carranza, Tony Chukwu, Steve Cook, T. Davies, David Leng, S. Obiora, and Jessey Rice.

Beth McClenaghan
Editor

President's Report

The motion proposed by AAG Council to change the bylaw relating to eligibility criteria for members proposing to become Senior Members or Fellows has been passed by an over-whelming majority of Fellows (63 in favour; 1 against). The revised by-law is now:

2.11 SENIOR MEMBERS and SENIOR FELLOWS. Members in good standing with the AAG may elect to become a Senior Member or Senior Fellow once they are over the age of ***65****. Senior Members and Senior Fellows* ***may*** *not receive the full range of AAG publications, but in return will pay reduced dues, as determined by Council from time to time. The range of publications available to Senior Members and Senior Fellows will be determined by Council and will be summarized in the newsletter and on the website.*

The revised by-law removes the necessity of trying to establish whether a Senior Member or Fellow is actually retired and replaces it with a set age of 65 for eligibility. As some of you may have discovered recently, it's not that easy to retire during a mining and exploration resurgence!

The proposal to develop a continuing professional development program (CPD) for applied geochemists is progressing under the expert guidance of Professor David Cohen. Various platforms have been investigated and suitable options have been identified. The development of a curriculum and the identification of specific modules is currently under discussion. Much work remains to determine the structure of individual modules and how these will be commissioned. A CPD proposal is being developed in tandem with the identification of topics for a special volume in GEEA on the fundamentals of exploration geochemistry. Thomas Bissig and Ryan Noble will act as guest editors in bringing this endeavour to fruition with the GEEA editorial board. On another front, Lynda Bloom and Owen Lavin have completely re-written the AAG's "Writing Geochemical Reports" manual and now need input from the practitioners of various survey methods in summarizing the critical information to be provided. Taken together, these initiatives will provide some of the content for the CPD program in exploration geochemistry and capture some of the collective knowledge and wisdom held by Members and Fellows of the AAG.

2021, being not dissimilar to 2020, means the Annual General Meeting (AGM) this year will be another virtual meeting. It is scheduled for September 15-16, depending on which side of the international dateline you are locked down on. Al Arsenault, our AAG Business Manager, has recently sent out the notice to all Members and Fellows, and I hope that some of you will participate. Reports will be accepted "as read" unless issues for discussion are identified. This approach will hopefully leave time to discuss some of the initiatives that are underway and to provide an opportunity for Members and Fellows to provide input and ask questions. The rationale for running the AGM and Council meetings on a tight schedule is the late hour of the meetings for those living on the eastern side of North America. We have benefited from the participation of more members from Europe and Africa in recent meetings, although it means a very early start to the day for them. The AGM will be followed by a short Council meeting.

I trust you are all staying safe and gainfully occupied during these trying times.

Dennis Arne, *President*

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

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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

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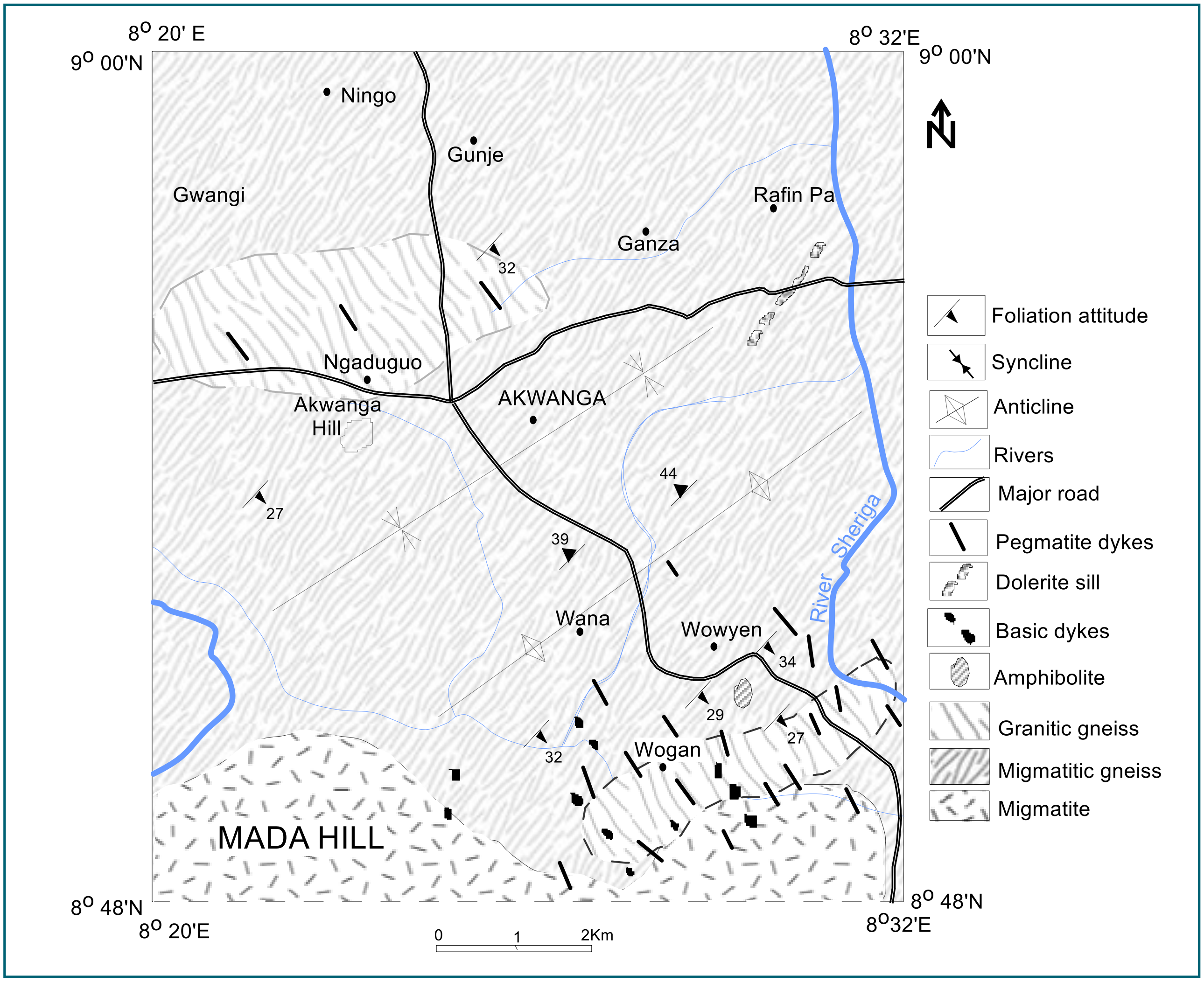

Figure 2. Geological map of the study area showing the locations of the pegmatites and the host rocks

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.

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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

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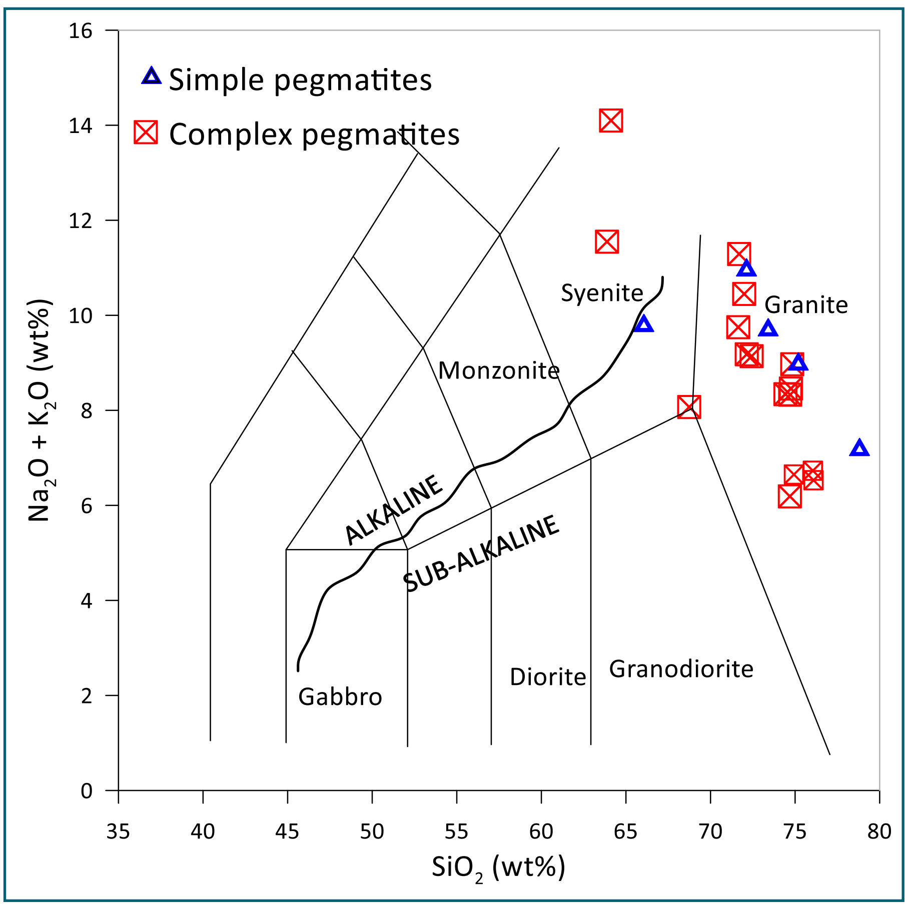

Figure 3. Nomenclature of the granitic pegmatites using alkaline-silica diagram.

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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).

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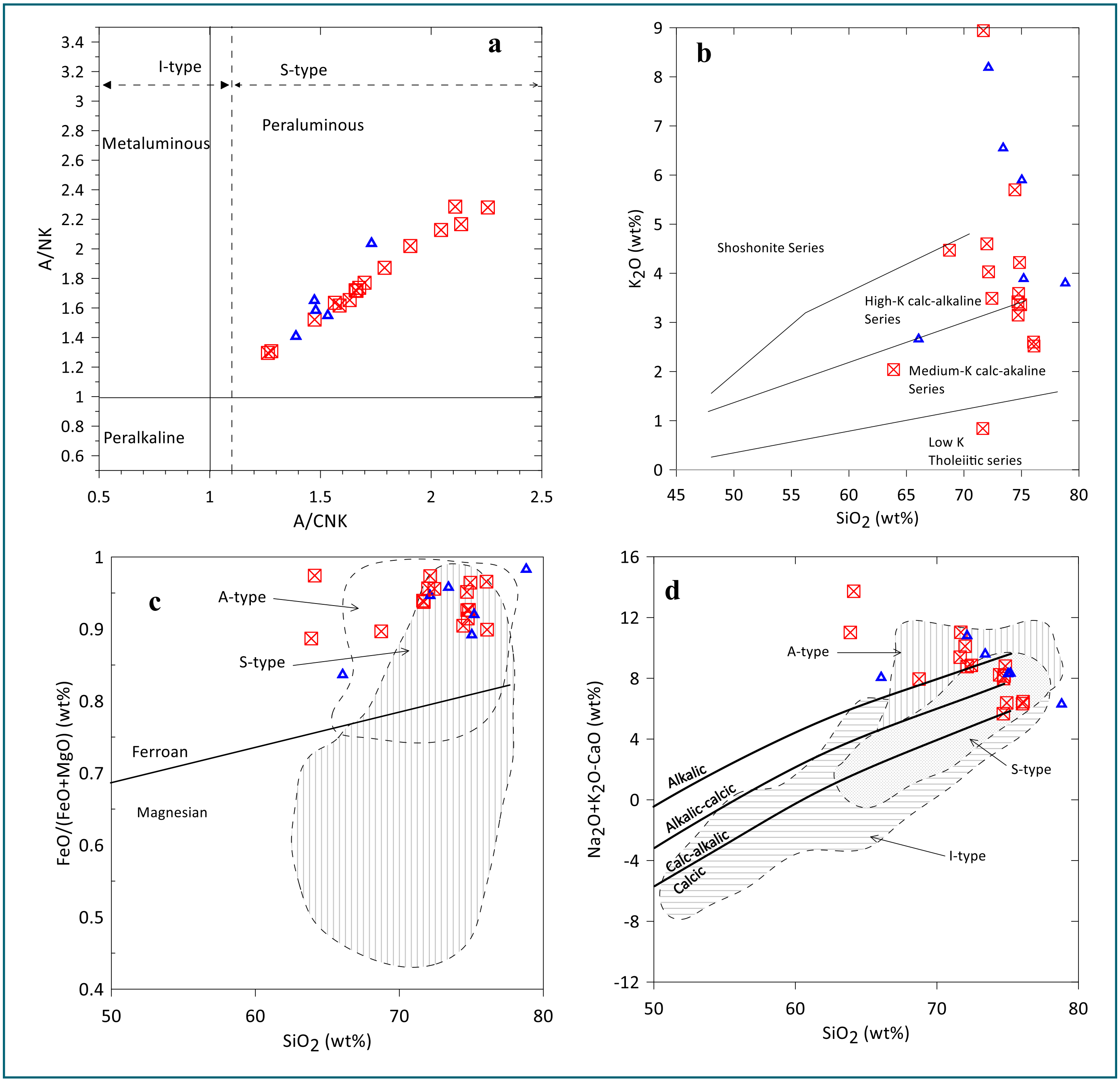

Figure 4. (a) Shand index plot for the pegmatites in Wogan area. A/NK = $Al_2O_3/(Na_2O+K_2O)$ and A/CNK = $Al_2O_3/(CaO+Na_2O+K_2O)$ after Maniar & Piccoli (1989). Binary plots for the granitic pegmatites in Wogan (b) K_2O versus SiO_2 of Peccerillo & Taylor (1976); (c) FeOt/(FeOt + MgO) versus SiO_2 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.

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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

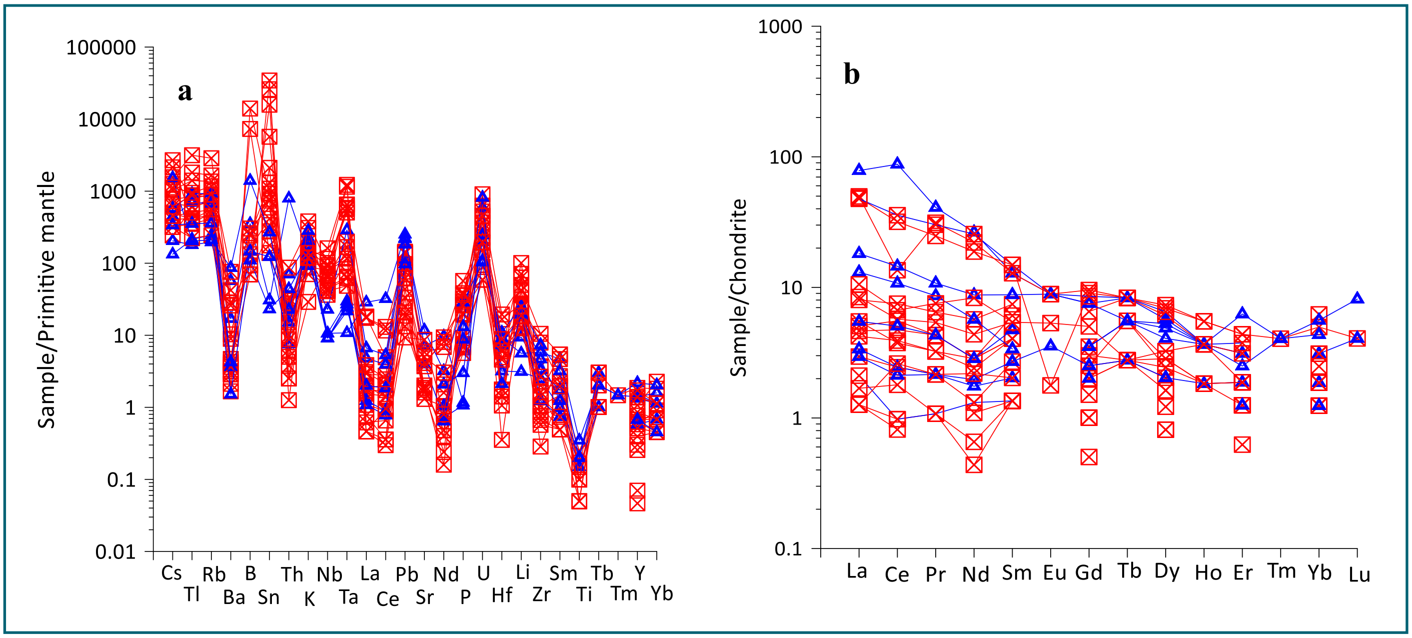
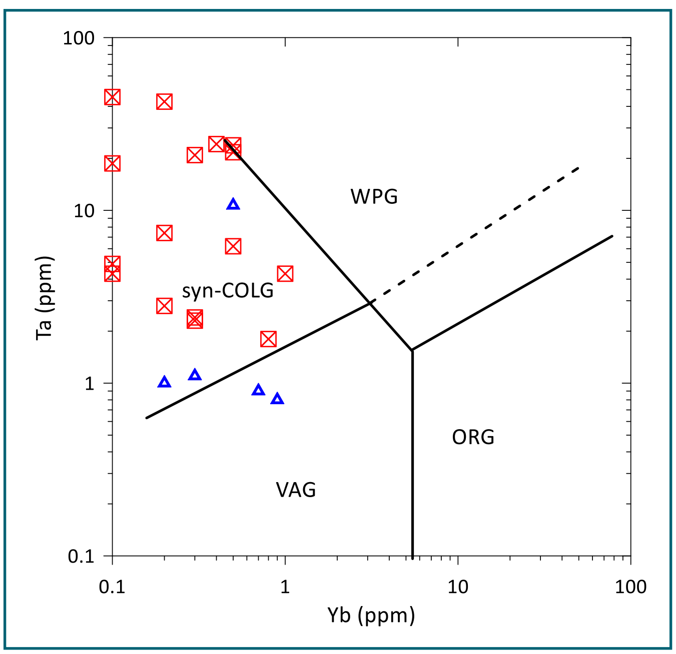


Figure 5. (a) Primitive mantle-normalized multi-element diagrams for the granitic pegmatites. Normalizing factors from McDonough and Sun (1995). (b) Chondrite-normalized rare earth elements diagrams for the granitic pegmatites. Normalizing factors from McDonough and Sun (1995). Symbols are as in Figure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



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 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.

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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

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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.

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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.

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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.

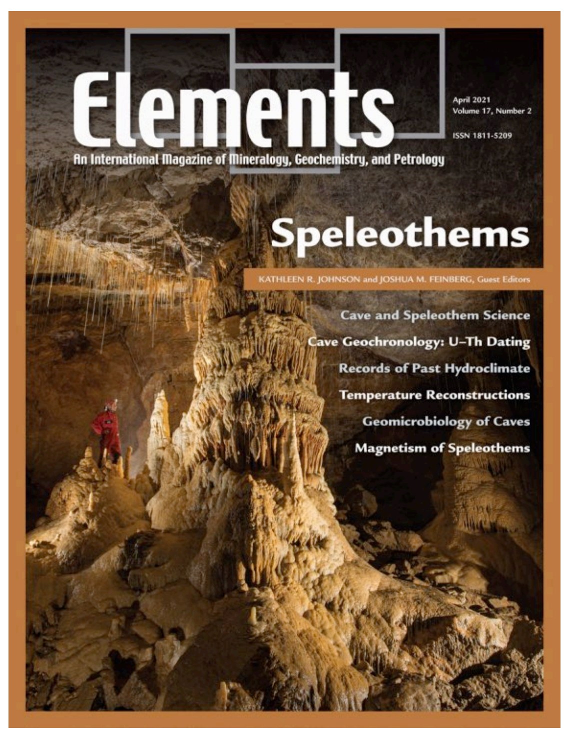
Wright, J.B. 1970. Controls of mineralization in the older and younger tin fields of Nigeria. *Economic Geol*ogy, **65,** 945 - 951.

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 S*ciences, **27,** 61-77.

Recently Published in Elements

April 2021, volume 17, no. 2, Speleothems

The articles in this issue introduce the various ways that speleothems are employed within the geoscience community to study natural Earth processes and our role in modifying them. There are three AAG news items in this issue. First, abstract of an article that appeared in issue 187 (June 2020) of the **EXPLORE** newsletter, namely "Exploring for laterally transported copper in gravels using radon detectors" by P.A. Winterburn, T. Bissig, and A.E. Brown. Second, abstract of an article that appeared in issue 188 (September 2020) of the **EXPLORE** newsletter, namely "Cesium Deposits" by D. Trueman, Bruce Downing, and T. Richards. Third, abstract of an article that appeared in issue 188 (September 2020) of the **EXPLORE** newsletter, namely "The Taron Cesium-Thallium Epithermal Geyserite Deposit, Salta Province, Argentina" by D. Trueman, B. Downing, T. Ledoux, and T. Richards.



Reminder: AAG members can access past issues of Elements at http://elementsmagazine.org/member-login/ using their e-mail address and member ID.

John Carranza

AAG Councillor Elections for the Term 2022-2023

Each year the Association of Applied Geochemists (AAG) needs motivated and energetic AAG Fellows to stand for election to the position of "Ordinary Councillor." Fortunately, each year some of our most outstanding Fellows are ready, willing, and able to meet this challenge. However, this year I'm sending this to **ALL MEMBERS**, to encourage those Members that have the experience and enthusiasm to be involved, to convert your membership status and look to make a bigger contribution to the AAG (see the website for details).

This note is the annual reminder to AAG Fellows (and Members that could become Fellows) that we need your participation on Council. It is our sincere hope that this email might entice more people to step forward for election to this important position. If you are not eligible to become a Fellow, but want to be more involved, please send me an email message as we are looking to get more of our junior members active in the AAG and other opportunities will be coming available.

Councillor Job Description

The AAG By-laws state that "the affairs of the Association shall be managed by its board of directors, to be known as its Council." The affairs managed by Council vary from reviewing and ranking proposals to host our biennial Symposium to approving application for new membership to developing marketing strategies for sustaining and growing our membership. These affairs are discussed and decisions made at Council teleconferences usually held 3-4 times per year. Each teleconference lasts about 1 hour. In addition, there is often a running email discussion about a selected issue or two between each teleconference. For a commitment of about 5 hours of your time per year, you can help influence the future of your Association. If you want to spend more than the minimum time required, there is plenty of opportunity to do so through committee assignments and voluntary efforts that greatly benefit the Association.

Qualifications and length of term

The only qualification for serving as Councillor is to be a Fellow in good standing with the Association. Please note the difference between being a *Member* of AAG and being a *Fellow* of the AAG. A Fellow is required to have more training and professional experience than a Member. Consult the AAG web site, Membership section, for further details. If you are not currently a Fellow and have an interest in serving on Council, please go through the relatively painless process of converting to Fellowship status in AAG.

Each Councillor serves a term of two years and can then stand for election to a second two-year term. The By-laws forbid serving more than two consecutive terms, although someone who has served two consecutive terms can stand for election again after sitting out for at least one year. Elections are usually held in October-November of the year for a term covering the following two years. Our next election will be in **October-November 2021** for the term of **2022-2023**.

How to get on the ballot

If you are interested in placing your name into consideration for election to AAG Council, simply express your interest to the AAG Secretary (Dave Smith, email: dbsmith13@gmail.com) by **October 15, 2021** and include a short paragraph (no more than 250 words) summarizing your career experience. This summary should include the following:

- Your name
- Year that you became a Fellow of AAG
- Earth science degrees obtained, year of graduation of each, and institution of each
- Employment—list major employers and state years worked for each, e.g. 2010-2015, and describe the type of work
- Position(s) held as part of AAG or other past contributions to AAG
- 2-3 sentences about your professional experiences in applied geochemistry

All that is asked is that you bring energy and ideas to Council and are willing to share in making decisions that will carry the Association forward into a successful future. We look forward to hearing from you.

Denise Arne
President, Association of Applied Geochemists

International Applied Geochemistry Symposium Update

Due to the global pandemic that still affects many of us, and the restrictions that this implies, the Organizing Committee of the 29th International Applied Geochemistry Symposium, IAGS, has postponed the event until October 2022. IAGS2022 will take place in Santiago de Chile, Chile, on 16 – 22 October, 2022.

It is our expectation that by then we will be able to hold a face-to-face meeting. However, arrangements will also be made to have a hybrid event that allows for those who can travel to attend, but also allows for virtual participation of those who will not be able to travel.

Abstracts received to date will be considered in this new scenario. More information and new deadlines will be announced shortly.

Workshops and keynote lectures are being programmed to take place as online activities in October 2021. More information will be available shortly. We will soon be relaunching our conference website www.iags2021.cl. We invite you to follow us through our website and social media. Feel free to contact us at this email: iags2020@gmail.com

Report of B. De Vivo, AAG Regional Councillor for Southern Europe

Activities in Italy and within EuroGeoSurveys Geochemistry Expert Group (2018-2021)

The EuroGeoSurveys Geochemistry Expert Group (EGS-GEG) has at present 53 official EGS members, and including associate members, from outside organisations, more than 70 scientists participate in the activities of the group. The group closely cooperates with colleagues from the USGS (David Smith) and Geoscience Australia (Patrice de Caritat), where comparable continental scale geochemical mapping programmes are presently carried out.

The mission of the EGS-GEG is to provide high quality geochemical data of near-surface materials, to develop harmonised data bases for multi-purpose use, and to provide independent expert advice to the European Commission. To achieve this mission, systematic geochemical data for the whole of Europe are generated by harmonised methods of sampling of near-surface materials (soil, stream or floodplain sediment, water), sample preparation, chemical analysis, quality control, data processing and presentation. The systematic geochemical information is published in the form of geochemical atlases, which are freely available, and can be used for (a) state of the environment reports, (b) mineral exploration, (c) agriculture, (d) forestry, (e) animal husbandry, (f) medical geology, (g) determination of natural background values for environmental risk assessment, etc.

In Italy, the research Group lead by Prof. B. de Vivo, has accomplished a multidisciplinary Monitoring Project (Campania Transparent: 2015-2018) funded by Regional Government to map inorganic elements and Organic compounds (POPs), in soils, underground waters, air, vegetation and biological samples, with the participation of geochemists, engineers, hydrogeologists, soil sciences experts, and physicians, in order to get the state of the art of the environment related to health issues risks. The De Vivo research group has taken care of the soil and air matrices, producing Regional Geochemical Atlases (with about 1200 geochemical different type of maps) and tens of scientific publications on peer review journals. Below is the list of publications and Regional Geochemical Atlases (see particularly 4 large volumes, De Vivo *et al.*, 2021: 33-36 in the below list) published between 2018 to 2021:

2017

1 DUCCI, D., ALBANESE, S., BOCCIA, L., CELENTANO, E., CERVELLI, E., CORNIELLO, A., CRISPO, A., DE VIVO, B., IODICE, P., LANGELLA, C., LIMA, A., MANNO, M., PALLADINO, M., PINDOZZI, S., RIGILLO, M., ROMANO, N., SELLERINO, M., SENATORE, A., SPERANZA, G., FAGNANO, M., & FIORENTINO, N., 2017. Environmental characterization of a wide contaminated area (southern Italy) by means of Spatial Multi Criteria Decision Analysis (S-MCDA). *International Journal of Environmental Research and Public Health*. **74** (7), 693-715. Doi: 10.3390/ijerph14070693.

2 QU, C., ALBANESE, S., LIMA, A., DOHERTY, A.L., LI, J., QI, S. & DE VIVO, B., 2017. Residues of hexachlorobenzene and chlorinated cyclodiene pesticides in the soils of the Campanian Plain, southern Italy. *Environmental Pollution*, 231P2, 1497-1506. Doi: 10.1016/j.envpol.2017.08.100.

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2018

3 REZZA, C., ALBANESE, S., AYUSO, R., LIMA, A., SORVARI, J. & DE VIVO, B., 2018. Geochemical and Pb isotopic characterization of soil, groundwater, human hair, and corn samples from the Domizio Flegreo and Agro Aversano area (Campania region, Italy). Sp. Issue (Bech J. et al., Eds), *Journal Geochemical Exploration*. **184** (Part B), 318-332. Doi: 10.1016/j.gexplo.2017.01.007.

4 MINOLFI, G, ALBANESE, S., LIMA, A., BUCCIANTI, A., FORTELLI, A., & DE VIVO, B. 2018. A regional approach to the environmental risk assessment - Human health risk assessment case study in the Campania region. Sp. Issue (Bech J. et al., Eds). *Journal Geochemical Exploration*, **184** (Part B), 400-416. Doi: 10.1016/j.gexplo.2016.12.010.

5 ALBANESE, S., CICCHELLA, D., LIMA, A. & DE VIVO, B., 2018. Geochemical mapping of urban areas. In: *Environmental Geochemistry - Site Characterization, Data Analysis and Case Histories*, De Vivo B., Belkin H.E & Lima A, Eds, Elsevier, Chapter **8**, 133-151.

6 QU, C, DOHERTY, A. L., XING, X., SUN, W., ALBANESE, A., LIMA, A., QI, S. & DE VIVO, B., 2018. Polyurethane foam-based passive air samplers in monitoring persistent organic pollutants: Theory and application. In: *Environmental Geochemistry - Site Characterization, Data Analysis and Case Histories*, De Vivo B., Belkin H.E & Lima A, Eds, Elsevier, Chapter **20**, 521-542.

7 THIOMBANE, M., ZUZOLO, D., CAVALIERE, M., CICCHELLA, D., ALBANESE, S., LIMA, A. & DE VIVO, B., 2018. Soil geochemical follow-up in the Cilento World Heritage Park) (Campania, Italy) through exploratory compositional data analysis and C-A fractal model. *Journal Geochemical Exploration*,**189**, 85-99. Doi: 10.1016/j.gexplo.2017.06.010.

8 BUCCIANTI, A., LIMA, A., ALBANESE, S. & DE VIVO, B., 2018. Measuring the change under Compositional Data Analysis (CoDA): insight on geochemical system dynamics. *Journal Geochemical Exploration*,**189**, 100-108. Doi: 10.1016/j.gexplo.2015.10.006.

9 PETRIK, A., ALBANESE, S., LIMA, A. & DE VIVO, B., 2018. The spatial pattern of beryllium and its possible origin using compositional data analysis on a high-density topsoil data set from the Campania Region (Italy). *Applied Geochemistry*, **91**, 162-173.

10 ZUZOLO, D., CICCHELLA, D., ALBANESE, S., LIMA, A., ZUO, R. & DE VIVO, B., 2018. Exploring uni-element geochemical data under a compositional perspective. *Applied Geochemistry*, **91**, 174-184.

11 QU, C., ALBANESE, S., LIMA, A., WANG, M., SACCHI, M., MOLISSO, F. & DE VIVO, B., 2018. Polycyclic aromatic hydrocarbons in the sediments of the Gulfs of Naples and Salerno, southern Italy: status, sources and ecological risk. *Ecotoxicology & Environmental Safety*, **161**, 156-163. Doi: 10.1016/j.ecoenv.2018.05.077.

12 PETRIK, A., THIOMBANE, M., ALBANESE, S., LIMA, A. & DE VIVO, B., 2018. Source patterns of Zn, Pb, Cr and Ni potentially toxic elements (PTEs) through a compositional discrimination analysis: A case study on the Campanian topsoil data. *Geoderma*, **331**, 87-99. Doi: 10.1016/j.geoderma.2018.06.019.

13 ZUZOLO, D., CICCHELLA, D., DOHERTY, A. L., ALBANESE, S., LIMA, A. & DE VIVO, B., 2018. The distribution of precious metals (Au, Ag, Pt, and Pd) in the soils of the Campania Region (Italy). *Journal Geochemical Exploration*, **19**, 33-44. Doi: 10.1016/j.gexplo.2018.03.009.

14 PETRIK, A., ALBANESE, S., LIMA, A., JORDAN, G., ROLANDI, R., REZZA, C. & DE VIVO, B., 2018. Spatial pattern recognition of arsenic in topsoil using high-density regional data. *Geochemistry: Exploration, Environment, Analysis*, **18**, 319-330. Doi: 10.1144/geochem2017-060.

15 REZZA, C., PETRIK, A., ALBANESE, S., LIMA, A., MINOLFI, G. & DE VIVO, B., 2018. *Molybdenum, Sn and W patterns in topsoils of the Campania Region, Italy*. Thematic Issue (De Vivo et al., Eds) Geochemistry: Exploration, Environment, Analysis (GEEA), 18, 331-342. Doi: 10.1144/geochem2017-061.

16 QU C., SUN Y., ALBANESE S., LIMA A., SUN W., DI BONITO M., QI S. & DE VIVO B., 2018. Organochlorine pesticides in sediments from Gulfs of Naples and Salerno, Southern Italy. *Journal Geochemical Exploration*, **195**, 87-96. Doi: 10.1016/j.gexplo.2017.12.010.

17 MINOLFI, G., ALBANESE, S., LIMA, A., TARVAINEN, T., REZZA, C. & DE VIVO, B., 2018. Human health risk assessment in Avellino-Salerno metropolitan areas, Campania Region, Italy. *Journal Geochemical Exploration*, **195**, 97-110. Doi: 10.1016/j.gexplo.2017.09.011.

18 THIOMBANE, M., MARTÍN-FERNÁNDEZ, J-A., ALBANESE, S., LIMA, A., DOHERTY, A. & DE VIVO, B., 2018. Exploratory analysis of multi-element geochemical patterns in soil from the Sarno River Basin (Campania region, southern Italy) through Compositional Data Analysis (CODA). *Journal Geochemical Exploration*, **195**,110-120. Doi: 10.1016/j.gexplo.2017.03.010.

19 PETRIK, A., ALBANESE, S., LIMA, A., JORDAN, G., ROLANDI, R. & DE VIVO, B., 2018. Spatial pattern analysis of Ni and its concentrations in topsoils in the Campania region (Italy). *Journal Geochemical Exploration*, **195,** 130-142. Doi: 10.1016/j.gexplo.2017.09.009.

20 PETRIK, A., THIOMBANE, M., LIMA, A., ALBANESE, S., BUSCHER, T. J. & DE VIVO, B., 2018. Soil Contamination Compositional Index: a new approach to quantify contamination demonstrated by assessing compositional source patterns of potentially toxic elements in the Campania Region (Italy). *Applied Geochemistry*, **96**, 264-276. Doi: 10.1016/j.apgeochem.2018.07.014.

21 THIOMBANE, M., PETRIK, A., DI BONITO, M., ALBANESE, S., ZUZOLO, D., CICCHELLA, D., LIMA, A., QU, C., QI, S. & DE VIVO, B., 2018. Status, sources and contamination levels of organochlorine pesticides residues in urban and agricultural areas: A preliminary review in central-southern Italian soils. *Environmental Science and Pollution Research*, **25**, 26361-26382. Doi: 10.1007/s11356-018-2688-5.

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Report of B. De Vivo, AAG Regional Councillor for Southern Europe... continued from page 18

22 CICCHELLA, D., ZUZOLO, D., ALBANESE, S., DINELLI, E., LIMA, A., VALERA, P. & DE VIVO, B., 2018. Geochemical atlas of agricultural and grazing land soil of Italy (The GEMAS project in Italy). *ARACNE Editrice* s.r.l. Roma. ISBN 978-88-255-1640-1, 356 pag.

23 MINOLFI, G., REZZA, C., ZULUAGA, M.C., ALBANESE, S., LIMA, A., WANG, M., MOLISSO, F., SACCHI, M. & DE VIVO, B., 2018. Atlante geochimico–ambientale dei sedimenti marini dei Golfi di Napoli (inclusa la Baia di Bagnoli) e Salerno. ARACNE Editrice, Roma. ISBN 978-88-255-1739-2, 326 p.

24 DE VIVO, B., NI, P. & CICCHELLA, D. (Guest Editors), 2018. Regional exploration and environmental geochemistry in Italy and China. *Journal of Geochemical Exploration*, **195**, 1-2. ISNN: 0375-674.

2019

25 THIOMBANE, M., DI BONITO, M., ALBANESE, S., ZUZOLO, D., LIMA, A & DE VIVO, B. 2019. Geogenic versus anthropogenic behaviour and geochemical footprint of Al, Na, K and P in the Campania region (Southern Italy) soils through compositional data analysis and enrichment factor. *Geoderma*, **335**, 12-26. Doi: 0.1016/j.geoderma.2018.08.008.

26 QU, C., ALBANESE, S., LIMA, A., HOPE, D., POND, P., FORTELLI, A., ROMANO, N., CERINO, P., PIZZOLANTE, A. & DE VIVO, B., 2019. The occurrence of OCPs, PCBs, and PAHs in the soil, air, and bulk deposition of the Naples metropolitan area, southern Italy: Implications for sources and environmental processes. *Environment International*, **124**, 89-97. Doi: 10.1016/j.envint.2018.12.031.

27 THIOMBANE, M., ALBANESE, S., DI BONITO, M., LIMA, A., ROLANDI ,R., QI, S. & DE VIVO, B., 2019. Sources, patterns and characterisation of Polycyclic Aromatic hydrocarbons (PAHs) in urban and rural areas of Southern Italy. *Environmental Geochemistry and Health*, **41**, 507-528. Doi: 10.1007/s10653-018-0147-3.

2020

28 GUAGLIARDI, I., ZUZOLO, D., ALBANESE, S., LIMA, A., CERINO, P., PIZZOLANTE, A., THIOMBANE, M., DE VIVO, B. & CICCHELLA, D., 2020. Uranium, Thorium and Potassium insights on Campania Region (Italy) soils: sources patterns based on compositional data analysis and fractal model. *Journal of Geochemical Exploration*, **212**, 106508. Doi: 10.1016/j.gexplo.2020.106508.

29 CICCHELLA, D., ZUZOLO, D., ALBANESE, S., FEDELE, L., DI TOTA, I., GUAGLIARDI, I., THIOMBANE, M., DE VIVO, B. & LIMA, A., 2020. Urban soil contamination in Salerno (Italy): concentrations and patterns of major, minor, trace and ultra-trace elements in soils. *Journal of Geochemical Exploration*, **213,** 106519**.** Doi: 10.1016/j.gexplo.2020.106519.

30 ZUZOLO, D., CICCHELLA, D., LIMA, A., GUAGLIARDI, I., CERINO, P., PIZZOLANTE, A., THIOMBANE, M., DE VIVO, B. & ALBANESE, S., 2020. Potentially Toxic Element in soils of Campania region (Southern Italy): combining raw and compositional data. *Journal of Geochemical Exploration*, **213**, 106524. Doi: 10.1016/j.gexplo.2020.106524.

31 ZUZOLO, D., CICCHELLA, D., DEMETRIADES, A., BIRKE, A., ALBANESE, S., DINELLI, E., LIMA, A., VALERA, P. & DE VIVO, B., 2020. Arsenic: Geochemical distribution and age-related health risk in Italy. *Environmental Research*, **182**, 109076 Doi: 10.1016/j.envres.2019.109076.

2021

32 QU, C., DE VIVO, B., ALBANESE, S., FORTELLI, A., SCAFETTA, N., LI, J., HOPE, D., CERINO, P., PIZZOLANTE, A., QI, S. & LIMA, A., 2021. Highly spatial-resolved measurements of passive-sampler derived air concentrations of persistent organic pollutants in the Campania region, Italy: Implications for sources and human exposure. *Environmental Pollution*, **286**, 117248. Doi: 0.1016/j.envpol.2021.117248

33 DE VIVO, B., CICCHELLA, D., LIMA, A., FORTELLI, A., GUARINO, A., ZUZOLO, D., ESPOSITO, M., CERINO, P., PIZZOLANTE, S. & ALBANESE, S., 2021a. Monitoragggio geochimico-ambientale dei suoli della Regione Campania. Il Piano Campania Trasparente. Volume 1. Elementi Potenzialmente Tossici e loro Biodisponibilità. Elementi Maggiori e in Traccia. Distribuzione in suoli superficiali e profondi. *ARACNE Editrice*, Roma. ISBN: 978-88-255-4036-9, 592 p. http://www.aracneeditrice.it/index.php/pubblicazione.html?item=9788825540369

34 DE VIVO, B., CICCHELLA, D., LIMA, A., QU, C., FORTELLI, A., GUARINO, A., ZUZOLO, D., ESPOSITO, M, CERINO, P., PIZZOLANTE, A, & ALBANESE, S., 2021b. Monitoraggio geochimico-ambientale dei suoli della Regione Campania. Il Piano Campania Trasparente. Volume 2. Composti Organici Persistenti: Idrocarburi Policiclici Aromatici, Policlorobifenili, Pesticidi. Distribuzione nei suoli superficiali. *ARACNE Editrice*, Roma. ISBN: 978-88-255-4107-6, 320 p. http://www.aracneeditrice.it/index.php/pubblicazione.html?item=9788825541076

35 DE VIVO, B., CICCHELLA, D., LIMA, A., QU, C., FORTELLI, A., GUARINO, A., ZUZOLO, D., ESPOSITO, M, CERINO, P., PIZZOLANTE, A., & ALBANESE, S., 2021c. Monitoraggio geochimico-ambientale della matrice aria della Regione Campania. Il Piano Campania Trasparente. Volume 3. Composti Organici Persistenti in PUF (Filtri Passivi di Poliuretano) e W&D (Deposimetri Passivi di Umido/Secco). Idrocarburi policiclici aromatici (IPA) Policlorobifenili (PCB), Pesticidi (OCP) e Eteri di Polibromobifenili (PBDE). Distribuzione nella matrice aria. *ARACNE Editrice*, Roma. ISBN 978-88-255-4107-6 650 p.

36 DE VIVO, B., ALBANESE, S., CICCHELLA, D., LIMA, A., QU, C., FORTELLI, A., GUARINO, A., ZUZOLO, D., CERINO, P., ESPOSITO, M., & PIZZOLANTE, A., 2021d. Monitoraggio di suoli e aria della regione Campania, a scala regionale e locale. Il progetto Campania Trasparente: Inquinamento ambientale, tra emozioni e realtà scientifica. *ARACNE Editrice*, Roma. ISBN 978-88-255-4036-9

CALENDAR OF EVENTS

International, national, and regional meetings of interest to colleagues working in exploration, environmental and other areas of applied geochemistry. These events also appear on the AAG web page at: www.appliedgeochemists.org.

The status of the meetings was confirmed on August 13th 2021, but further changes are likely, and users of the listing are strongly advised to carry out their own research as to the validity of an announcement.

Please let us know of your events by sending details to:
Steve Amor, Email: steve.amor2007@gmail.com
or
Tom Meuzelaar, AAG Webmaster, tom@lifecyclegeo.com

2021

Virtual Meetings

2-4 NOVEMBER 13th Fennoscandian Exploration and Mining. Website: femconference.fi

16-17 NOVEMBER Drill, Deal, or Drop: Exploration Decision-Making Website: tinyurl.com/v2768nz8

31 JANUARY - 3 FEBRUARY Mineral Exploration Roundup 2022. Website: roundup.amebc.ca

7-10 MARCH Prospectors and Developers Association of Canada Annual Convention. Website: www.pdac.ca/convention/programming

19-21 JULY William Smith Virtual Meeting 2021: Geological Mapping - of our world and others. Website: www.geolsoc.org.uk/wsmith21

24-29 JULY 15th International Conference on Mercury as a Global Pollutant. Website: tinyurl.com/2ch7e6fa

In-Person or Hybrid Meetings (status as of August 13th 2021)

9-17 OCTOBER 28th Colloquium of African Geology. Fez Morocco. Website: tinyurl.com/9bxy6a3t

10-13 OCTOBER GSA Annual Meeting. Portland OR USA. Website: community.geosociety.org/gsa2021

1-3 NOVEMBER GAC-MAC Joint Annual Meeting. London ON Canada. Website: gacmac2021.ca

25-28 NOVEMBER Conference of the Arabian Journal of Geosciences Istanbul Turkey. Website: www.cajg.org

1-5 DECEMBER 12th International Symposium on Selenium in Biology and Medicine. Honolulu HI USA. Website: se2021.jabsom.hawaii.edu

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CALENDAR OF EVENTS... *continued from page 20*

5-10 DECEMBER	American Exploration and Mining Association Annual Meeting. Sparks NV USA. Website: www.miningamerica.org/2021-annual-meeting

2022

17-22 JANUARY	Winter Conference on Plasma Spectrochemistry. Tucson AZ USA. Website:icpinformation.org/winter-conference
27- FEBRUARY – 4 MARCH	Ocean Sciences Meeting. Honolulu HI US. Website: www.aslo.org/osm2022
22-23 MARCH	International Mining Geology Conference 2022. Brisbane QLD Australia. Website: tinyurl.com/sk4uc
28-31 MARCH	15th Biennial Meeting of the Society for Geology Applied to Mineral Deposits. Rotorua New Zealand. Website:tinyurl.com/ykkf5wx8
27-29 APRIL	International Conference on Geographical Information Systems Theory, Applications and Management. Prague Czech Republic. Website: www.gistam.org
2-5 MAY	Geological Society of Nevada 2022 Symposium. Sparks NV USA. Website: www.gsnsymposium.org
22-27 MAY	Geochemistry of Mineral Deposits (Gordon Research Conference). Castelldefels Spain. Website: tinyurl.com/yxtyprqc
31 MAY-2 JUNE	10th World Conference on Sampling and Blending. Kristiansand Norway. Website: wcsb10.com
6-9 JUNE	12th International Conference on Environmental Catalysis. Awaji Japan. Website: catsj.jp/event/6373
27-29 JUNE	Australasian Environmental Isotope Conference. Ballina NSW Australia. Website: www.conferences.com.au/2022aeic
7 JULY	Target 2022: Innovating now for our future. Perth WA Australia. Website: www.aig.org.au/events/target-2022
10-15 JULY	Goldschmidt 2022. Chicago IL USA. Website: tinyurl.com/ybb4pct8
11-14 JULY	9th Annual International Conference on Geology & Earth Science. Athens Greece. Website: www.atiner.gr/geology
18-22 JULY	23rd General Meeting of the International Mineralogical Association. Lyon France. Website: www.ima2022.fr/
19-21 JULY	6th International Archean Symposium. Perth WA Australia. Website: 6ias.org
31 JULY- 5 AUGUST	World Congress of Soil Science 2022. Glasgow UK. Website: www.soils.org.uk/wcss2022
6-12 AUGUST	Geoanalysis 2022. Freiberg Germany. Website: geoanalysis2021.de/en
14-18 AUGUST	6th IAGOD Quadrennial Symposium. Dublin Ireland. Website: www.iagod.org/node/116
22-26 AUGUST	International Sedimentological Congress. Beijing China. Website: isc2022.scievent.com

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The AAG-SGS Student Presentation Prize

The Association of Applied Geochemists, through the support of SGS Mineral Services, awards a prize for the

Best oral presentation by a student at the biannual International Applied Geochemistry Symposium (IAGS)

The intent of this prize is to encourage the presentation of high quality research by students at an International Applied Geochemistry Symposium (IAGS) and provide further incentive to publish the results of the research in the Association's journal, *Geochemistry: Exploration, Environment, Analysis* (GEEA). The winner is determined based on feedback from a group of judges that includes Fellows and Members of the Association. Criteria for judging the presentations include excellence and originality in research design, research execution, interpretation, and the oral presentation itself. Honours, Masters, and Doctoral students are all eligible. The format of the presentation may vary between IAGS.

The Rules

1. The paper must be presented by the student at an IAGS as an oral paper, in the format specified by the IAGS organizing committee.
2. The conference presentation and paper must be largely based on research performed as a student. The student's supervisor or Head of Department may be asked to verify this condition.
3. The decision of the AAG Symposium Co-ordinator (in consultation with a representative from SGS) is final and no correspondence will be entered into.
4. Entry in the competition is automatic for students (but students may elect to "opt out").
5. The detailed criteria and process for assessing the best paper will be determined by the AAG Symposium Co-ordinator in consultation with the AAG Council and the LOC.
6. A paper substantially derived from the material presented at the IAGS and submitted for publication in the Association's journal *Geochemistry: Exploration, Environment, Analysis* within the timeframe specified by the AAG (normally 12 months) will be eligible for the increased value of the prize.

The Prize

1. $700 CAD from SGS Minerals Services (normally presented to the winner at the end of the relevant IAGS) with a further $300 CAD from AAG if a paper related to the oral presentation is submitted to GEEA within the nominated time frame after the IAGS;
2. A 2-year membership of the Association, including subscription to GEEA and EXPLORE; and
3. A certificate of recognition.

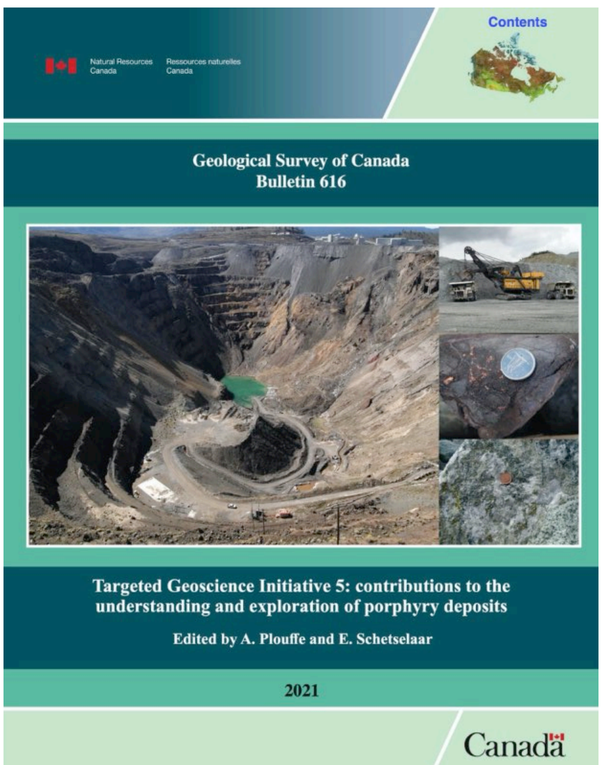
David Cohen
Chair of Student Prize Committee
University of New South Wales
Email: d.cohen@unsw.edu.au

CALENDAR OF EVENTS... *continued from page 21*

23-26 AUGUST	International Symposium on Environmental Geochemistry. Moscow Russia. Website: www.iagc-society.org/ISEG.html
11-15 SEPTEMBER	IWA World Water Congress & Exhibition. Copenhagen Denmark. Website: worldwatercongress.org
12-16 SEPTEMBER	10th International Conference of the International Association of Geomorphologists. Coimbra Portugal. Website: www.icg2022.eu
13-15 SEPTEMBER	14th International Symposium on Nuclear and Environmental Radiochemical Analysis. York UK. Website: tinyurl.com/y989mvvz
16-22 OCTOBER	29th International Applied Geochemistry Symposium (IAGS). Viña del Mar Chile. Website: iags2021.cl

2023

29 JANUARY-3 FEBRUARY	Winter Conference on Plasma Spectrochemistry. Ljubljana Slovenia. Website: ewcps2021.si



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