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# Petrological and geochemical study of the Precambrian basement complex rocks in Katchuan Irruan areas, southeast of Ogoja, Southeastern Nigeria

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https://doi.org/10.70499/FEII3952

## INTRODUCTION

Pan-African tectonics and crustal evolution have been the subjects of much discussion over the last thirty years or so (Rahman *et al*. 1988; Ekwueme 1987). The Nigerian Precambrian Basement Complex (Fig. 1) is made up of gneisses and migmatites, weakly migmatized to unmigmatized paraschists (also referred to as “Younger Metasediments” or “Schist belts”) and rocks of the Older Granite suite comprising of granite, granodiorite, charnockite (hypersthene granites), syenite, as well as minor gabbroic and dioritic rocks. Unmetamorphosed diabase and rhyolitic porphyry dykes, pegmatite dykes and numerous veins of quartzo- feldspathic composition are commonly found in the Basement Complex (Oyawoye 1964, 1970; Rahaman 1976, 1989; Makanjuola 1982; Ekwueme 1987, 1994; Olarewaju 1987; Obiora 2005, 2006).

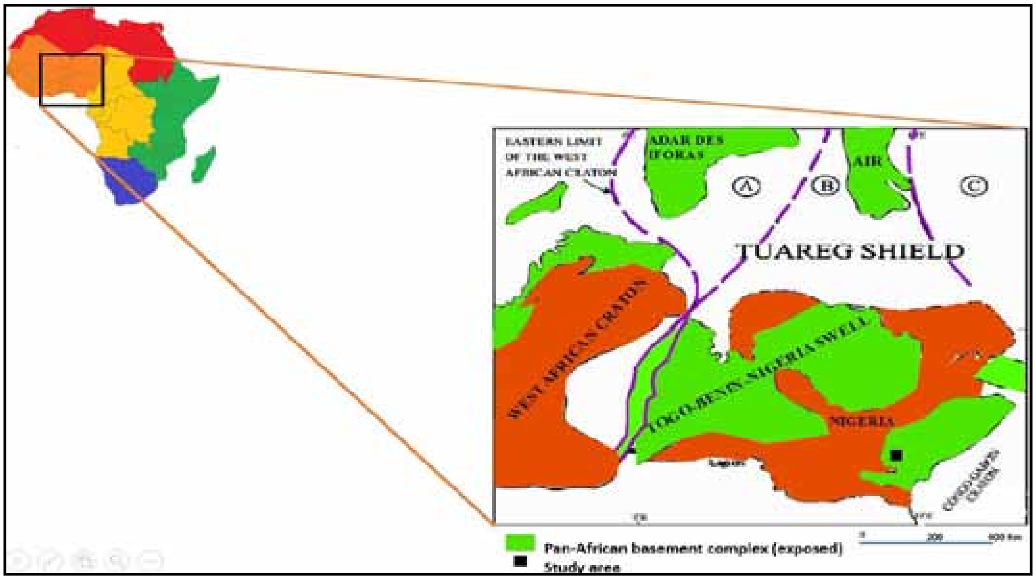

*Figure 1. The location of the Precambrian Basement Complex in Nigeria between the West African craton, the Congo-Gabon craton and the southern part of the Tuareg shield (after Ibe & Obiora 2019).* Ⓐ *Western part of the Tuareg shield called the Pharusian belt;* Ⓑ *central part (the Hoggar-Air segment);* Ⓒ *eastern part (the East-Saharan craton).*

The Precambrian Basement Complex rocks in the study area have previously received little attention. Much of the information on the geology of the area is contained in geological maps of Nigeria produced by the Nigerian Geological Survey Agency where it is shown to be underlain by “Undifferentiated Basement”, “Granulites terrain” and “Granitoids” (Nigerian Geological Survey Agency 1994, 2004, 2011). The present study was therefore undertaken to map and delineate the different varieties of rock within the Precambrian Basement Complex in the study area (Fig. 2), as well as to perform detailed petrographic and geochemical studies (major-, trace-, and rare-earth elements, [REE]) on the rocks for their proper classification and assessment of their petrogenesis, provenance and tectonic origin.

## REGIONAL GEOLOGY

The study area (Fig. 2) is located within the extension of the Bamenda highlands of Cameroun into southeastern Nigeria, otherwise referred to as the “Bamenda massif”. The Bamenda massif constitutes the southeastern Nigerian Precambrian Basement Complex. The Precambrian Basement Complex of Nigeria belongs to the Pan-African trans-Saharan belt which is located east of the West African craton and northwest of the Congo-Gabon craton (Fig. 1). Based on evidence from the eastern and northeastern margins of the West African craton, it has been observed by previous authors that the Pan-African trans-Saharan belt evolved by plate tectonic processes that involved the collision of the active margin of the Pharusian belt (Taureg shield) and the passive continental margin of the West-African craton, about 600 Ma (Fig. 1, Burke & Dewey 1972; Leblanc 1981; Black *et al*. 1979; Caby *et al*. 1981). Subduction and consequent collision at the eastern margin of the West African craton (McCurry & Wright 1977) produced extensive melting of the older rock suites resulting in the emplacement of the mainly calc-alkaline granitoids and basaltic intrusions.

A high positive gravity anomaly which occurs in a narrow zone within the Dahomeyide orogen located at the southeastern margin of the West African Craton in Togo and Benin Republic is an evidence of evolution by plate tectonic

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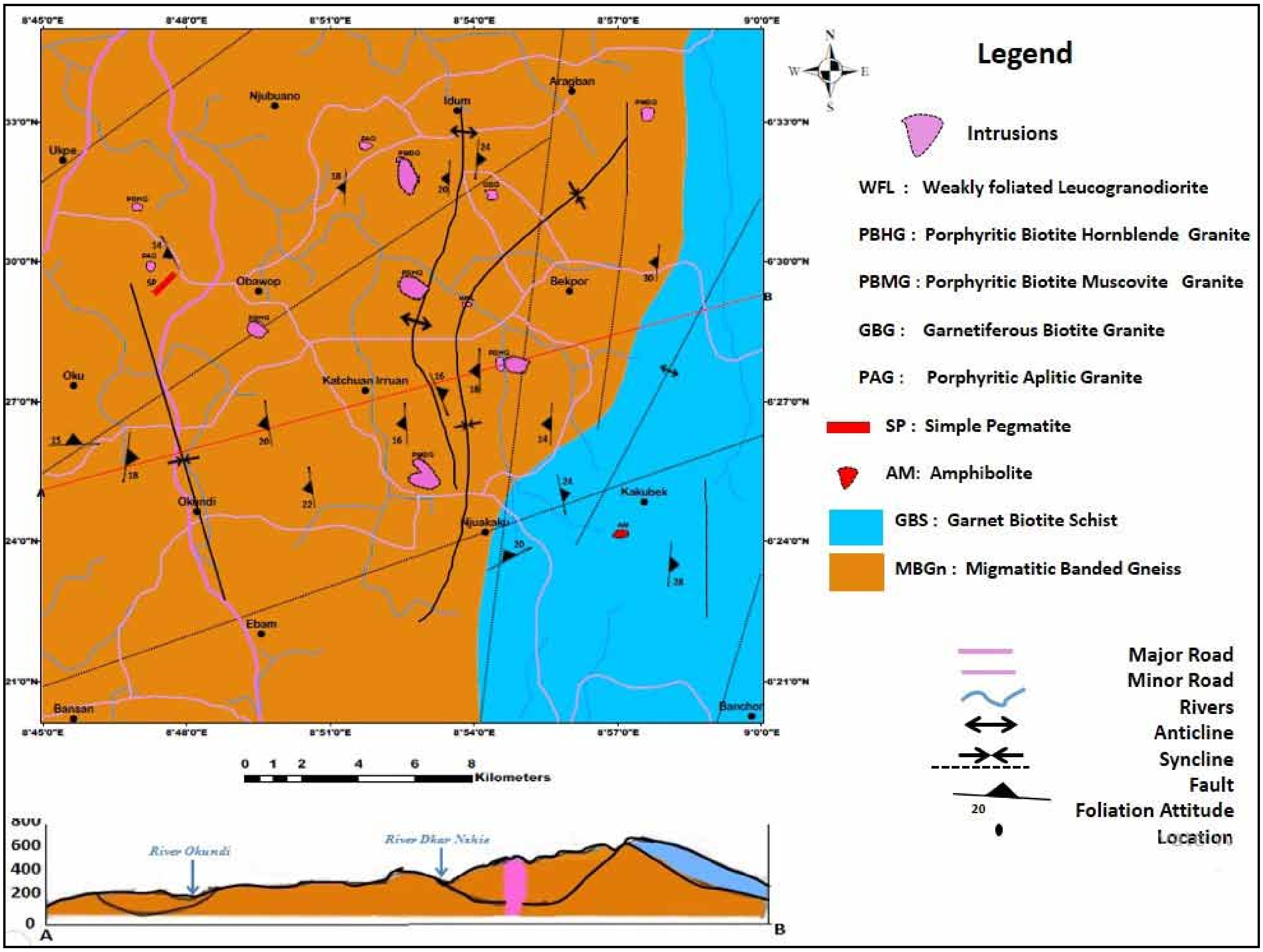

*Figure 2. Geological map of the study area.*

processes involving the collision of the Pharusian belt and the West African craton (Obiora 2012). The collision at this plate margin is thought to have led to the reactivation and remobilization of the internal region of the Pan-African belt. The Nigerian Precambrian Basement Complex lies within the remobilized part of the belt.

The Nigerian Precambrian Basement Complex rocks are also believed to be the results of at least four major orogenic cycles of deformation, metamorphism, reactivation and remobilization corresponding to the Liberian (2,650 ± 150 Ma), the Eburnean (2,000 ± 50 Ma), the Kibaran (1,100 ± 200 Ma), and the Pan-African cycles (600 ±150 Ma). Using the International Geologic Time Scale (2002), these ages can be referred to as, “Paleoarchean to Mesoproterozoic (3,600 to 1,600 Ma)” for Liberian and Eburnean, “Mesoproterozoic to Neoproterozoic (1,600 to 1,000 Ma)” for Kibaran and “Neoproterozoic to Early Paleozoic (1,000 to 545 Ma)” for Pan-African.

## ANALYTICAL PROCEDURES

Fifty (50) fresh representative samples consisting of twenty four (24) migmatitic banded gneiss (MBGn), six (6) garnet biotite schist (GBS), two (2) amphibolite (Am) and two (2) garnetiferous biotite granite (GBG), four (4) porphyritic biotite muscovite granite (PBMG), three (3) porphyritic biotite hornblende granite (PBHG), three (3) weakly foliated leucogranodiorite (WFL), three (3) porphyritic aplitic granite ( PAG), and two (2) simple pegmatite (SP) were selected for geochemical analysis. The samples were crushed in a jaw crusher at the Inorganic Geochemistry Research Laboratory of the Department of Geology, University of Nigeria, Nsukka. The crushed samples were pulverized in a Vibrating Disc Mill. Final size reduction, mixing and homogenization to < 75 µm were done with a Mixer Mill. One hundred grams (100 g) of each sample were thereafter packaged and dispatched to Bureau Veritas Minerals Pty Ltd, Perth, Western Australia courtesy of the Association of Applied Geochemists (In-kind analytical support for major and trace element geochemistry using X-Ray Fluorescence (XRF) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS)).

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The samples were fused with sodium peroxide and subsequently the melt was dissolved in dilute hydrochloric acid for analysis. Due to high furnace temperatures, volatile components were lost. This fusion procedure is particularly efficient for determination of major element composition (including silica) in the samples and for breaking down refractory mineral species for total trace element contents. Boron was determined by Inductively Coupled Plasma-Optical Emission Spectrometry (ICP OES). The samples were cast using a 66:34 flux with 4% lithium nitrate added to form a glass bead. The major elements were determined by X-Ray fluorescence spectrometry (XRF) except for FeO, which was determined volumetrically.

### RESULTS

### Composition of the gneisses and schists

The gneisses have values of $SiO_2$ in the range of 57.1 to 73.84 wt.% with a mean value of 67.44%. They contain moderate $Al_2O_3$ (13.3-16.6 wt.%), low $TiO_2$ (0.1-1.15 wt.%), MgO (0.06-3.57 wt.%), MnO (0.03-0.14 wt.%) and high $K_2O$ (0.95-5.08 wt.%), $Na_2O$ (2.18-6.69 wt.%) and CaO (0.28-8.26 wt.%) compared to the other rocks. The Fe-number (Fe*) ranges from 3.96 to 13.4 and they are enriched in alumina (12.3-17.1). They are generally quartz, K-feldspar, albite, anorthite, hypersthene and corundum normative.

Trace element data on the rocks from the study area have been normalized to upper continental crust after McLennan & Taylor (1981) and plotted as spidergram (Fig. 3a). The rocks show an overall enrichment of the large ion lithophile elements (LILEs: K, Th, Ba and Rb) and the high-field strength elements (HFSE: REE, Zr, Hf, Y, Th) which usually occur in accessory minerals such as rutile and zircon. The chondrite-normalized REE pattern for the rocks show LREE enrichment relative to MREE and HREE (Fig. 3b). The rocks exhibit a negative Eu anomaly and show inclined MREE and flat HREE (Fig. 3b). Specifically, the Eu-anomalies, expressed as (Eu/Eu*) ranges from 0.03 to 1.4 in the gneisses and from 0.09 to 1.1 in the schist. The fractionation $La_N/Yb_N$ ratios range from 7 to 93 for the gneisses and 1.9 to 46.4 for the schist.

The schists (GMS) have moderate $Al_2O_3/(K_2O + Na_2O)$ values (2.31-3.85), low MgO (3.56-5.91 wt.%) and CaO (0.74 to 2.92 wt.%) contents with MgO exceeding CaO. Contents of $K_2O$ are generally greater than those of $Na_2O$. In the CIPW norm, Garnet Biotite Schist (GBS) is enriched in quartz. Further discrimination of the sedimentary protolith of the gneisses

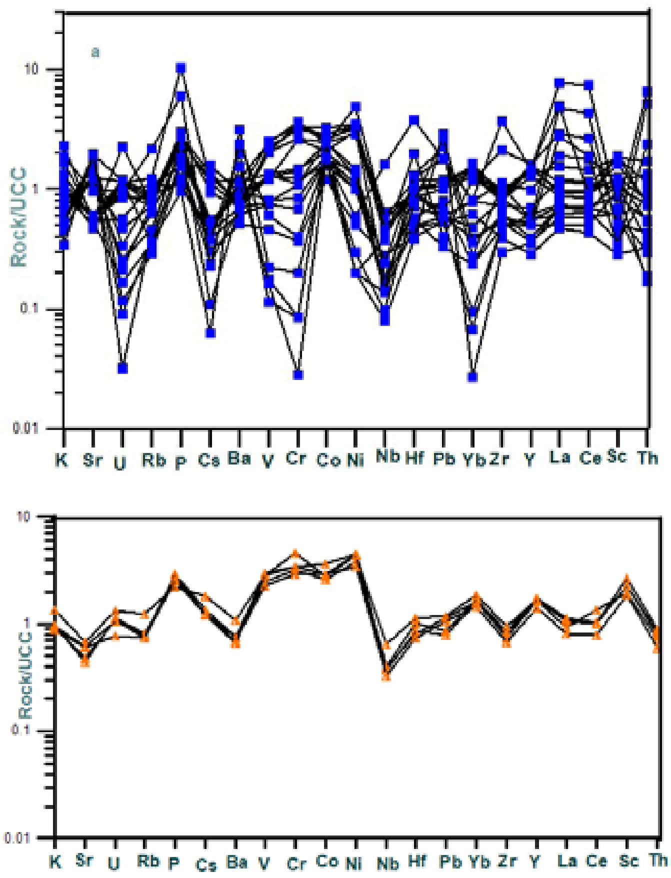

*Figure 3. UCC normalized spidergram for the Gneisses (blue) and Schists (brown).*

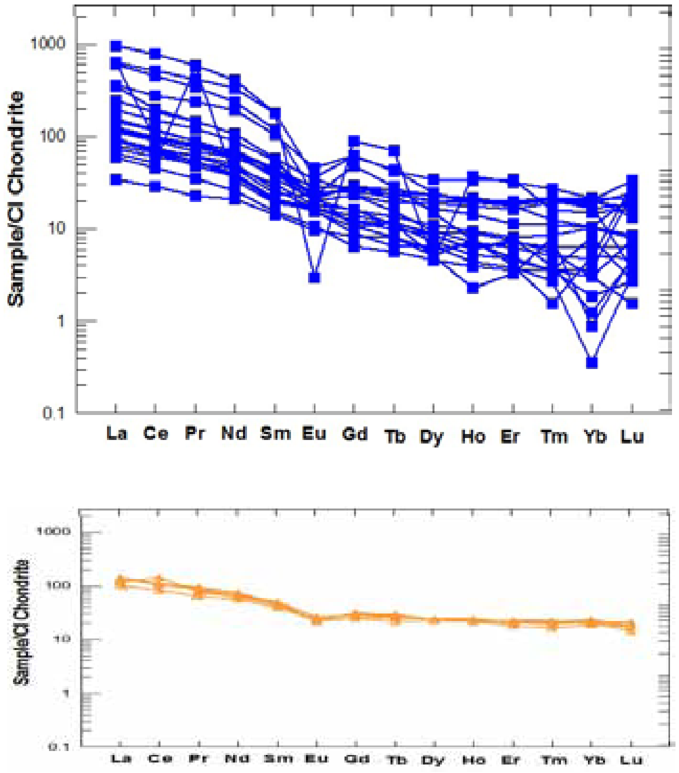

*Figure 3b. Chondrite-normalized REE diagrams for the Gneisses and Schists (Symbols same as Figure 3a) (Values from Sun & McDonough 1991).*

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and schists, the plot of log ($Fe_2O_3$(t)/K2O) vs log ($SiO_2/Al_2O_3$) after Herron (1988) (Fig. 4) was utilized. The gneisses plot in the Fe-shale, Fe-sand and greywacke and arkose regions whereas the schists plot in the shale and greywacke regions.

### Provenance of the gneisses and schists

In order to characterize the provenance of the protoliths of the metamorphic rocks in the eastern part of the southeastern metamorphic basement complex of Nigeria, the major-element-based diagram of Roser & Korsch (1988) (Fig. 5) is used because this bivariate plot uses parameters that are largely independent of grain-size effects (sandstone vs mudstone). The discriminant functions of the diagram use $Al_2O_3$, $TiO_2$, $Fe_2O_3T$, MgO, CaO, $Na_2O$, and $K_2O$ contents as variables. These functions discriminate among four sedimentary provenances: P1: mafic, ocean island arc; P2: intermediate, mature island arc; P3: felsic, active continental margin; and P4: recycled, granitic–gneissic or sedimentary source. The gneisses and schists plot on the P2 and P3 fields. P2 would indicate a provenance from a mature island arc, whereas P3 indicate a provenance from active continental margin.

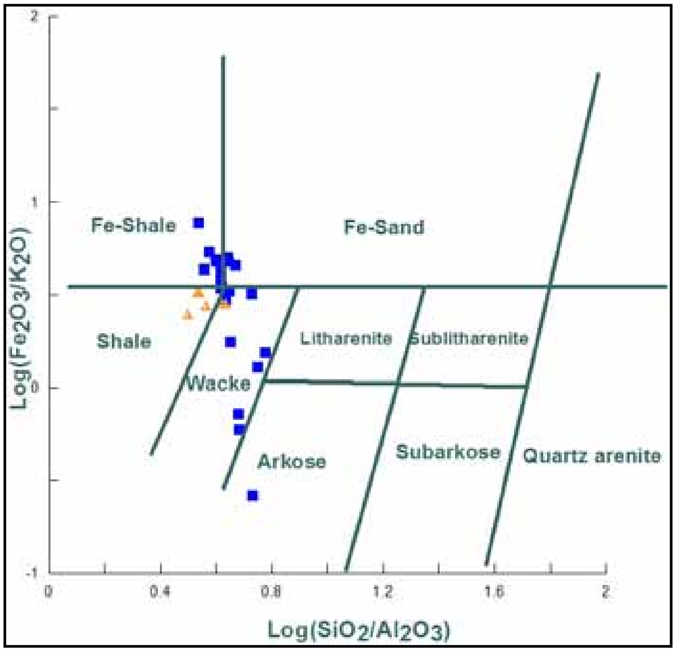

*Figure 4. Plots of gneisses and schists on the log ($SiO_2/Al_2O_3$) vs. Log ($Fe_2O_3$(t)/$K_2O$) diagram of Herron (1988), for the discrimination of sedimentary protoliths.*

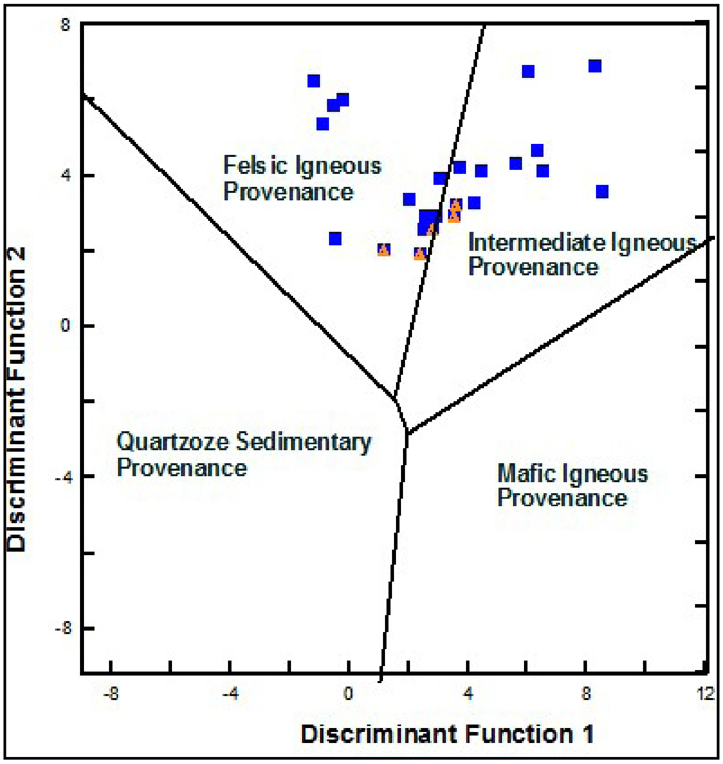

*Figure 5. Discriminant function diagram for the provenance signatures of sandstone-mudstone suites after Roser & Korsh (1988).*

*Discriminant function 1= $-1773TiO_2+0.607Al_2O_3+0.76Fe_2O_{3(total)}$ $-1.5MgO+0.616CaO+0.509Na_2O-1.224K_2O-9.09$*

*Discriminant function 2= $0.445TiO_2+0.07Al_2O_3-0.25Fe_2O_{3(total)}$ $-1.142MgO+0.438CaO+1.475Na_2O+1.426K_2O-6.9$*

*P1- Mafic, First-cycle basaltic and lesser andesitic detritus*

*P2- Intermediate, dominantly andesitic detritus*

*P3- Felsic-Acid, plutonic and volcanic detritus*

*P4- Recycled mature polycyclic quartzose detritus*

### Tectonic setting of gneisses and schists

Bathia & Crook (1986) assigned the sedimentary basins to four tectonic settings: oceanic-island arc, continental arc, active continental margins and passive continental margins. Most of the samples plot in the field of active continental margin and continental arc (Fig. 6). In the ternary plot of La–Th–Sc and Th-Sc-Zr/10, the gneisses and schists plot in the field of continental arcs and active continental margin (Fig. 6).

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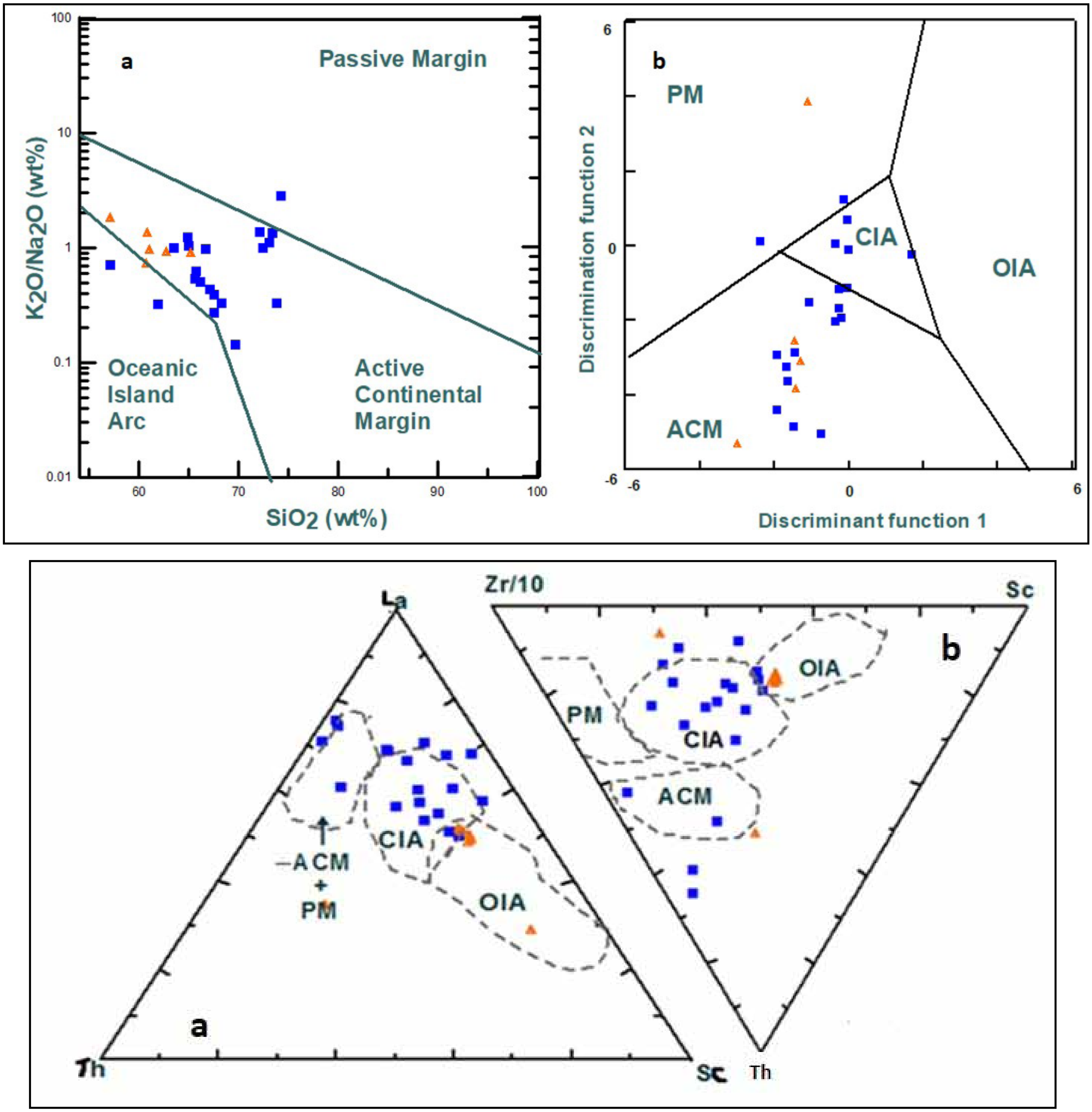

*Figure 6. (a) Plot for the tectonic setting of the gneisses and schists in a: Discriminant function diagram (modified after Bathia 1988) for the gneisses and schists. ACM= Active Continental margin, CIA= Continental Island arc, OIA= Oceanic Island arc, and PM= Passive margin.*

### Composition of granitic rocks

The granitic rocks are generally hypersthene and corundum-normative. They have variable $SiO_2$ (60.86 to 77.18 wt.%), $Al_2O_3$ (13.6 to 17.5 wt.%), Fe*(1.14 to 12.49 wt.%) and alkalis ($Na_2O+K_2O$) (4.54 to 9.95 wt.%) contents. Trace element data on the granitoids from the study area have been normalized to chondrites after Thompson (1982) and plotted as a spidergram (Fig. 7a). The rocks show an overall enrichment of the large ion lithophile elements (LILE: K, Th,

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Ba and Rb). HFS elements typically occur in accessory minerals such as rutile and zircon. The samples are relatively enriched in Zr, Hf and Nb indicating the presence of accessory minerals in the rocks.

The granitic rocks also show strong positive anomalies in Th, K, La, Ce, Nd, Sm, Tb and negative anomalies in Ba, Nb, Ta, Sr, Zr and Ti. They also show high concentrations of W and Co which resulted from the vibratory tungsten carbide (WC) disc mill used in preparing the samples but there was no Ca, Ta and Sc contamination, as expected. The granitic rocks exhibit similar REE patterns, relative to chondrite, exhibiting LREE enrichment relative to MREE and HREE, with distinct negative Eu-anomalies (Eu/Eu*= 0.23- 0.71), inclined MREE and flat HREE (Fig. 7b). The fractionated, $La_N/Yb_N$ values in the granitic rocks range from 3.04-228.4.

### Tectonic setting of the granitic rocks

In the FeO*/MgO vs $SiO_2$ diagram of Chappell & White (1974), the granitic rocks plotted within the I and S type fields correlating positively with the shoshonites and syn-collisional granites in the plateau area of the Himalayan. S-type granites originate by partial melting or ultrametamorphism of metasedimentary protoliths (containing Al, Na and K oxides and are said to be peraluminous) observable in the deeply eroded cores of fold-thrust mountain belts formed as a result of continent-continent collisions and are thus syn-orogenic granites. The granitic rocks in the study area plot within the post-collisional (Post-COLG) field on the Rb vs Y+Nb tectonic discrimination diagram after Pearce *et al.* (1984) (Fig. 8).

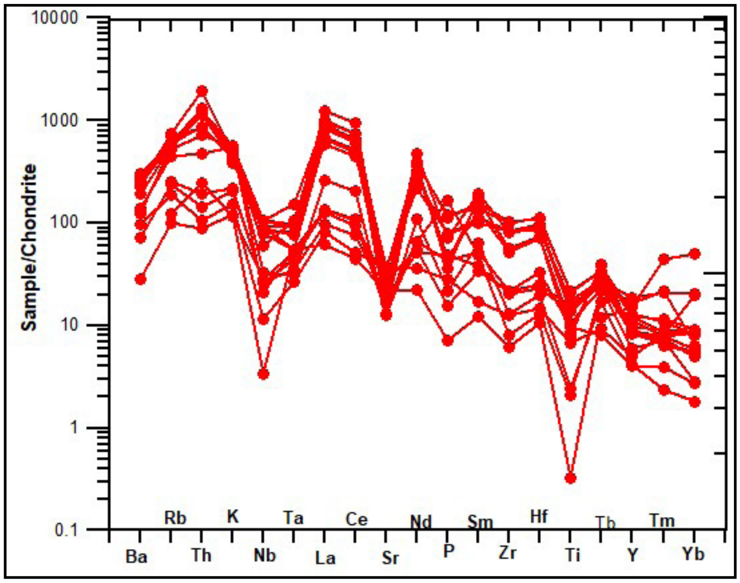

*Figure 7a. Chondrite-normalized Spidergram for granitic rocks (values from Thompson 1982).*

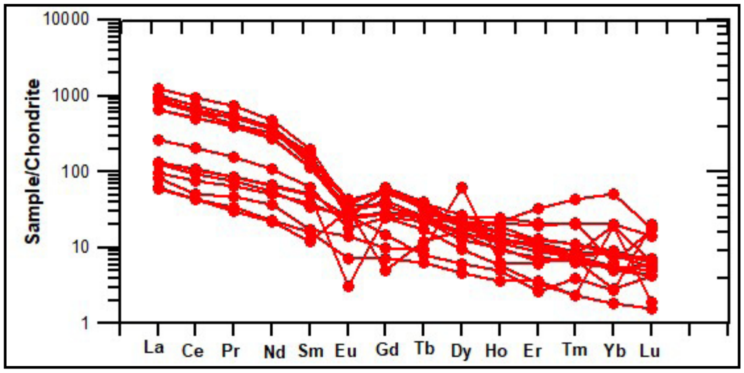

*Figure 7b. Chondrite-normalized REE diagram for the granitic rocks (values from Sun & McDonough 1991).*

### DISCUSSION

The metasedimentary (shale-greywacke-arkose) origin of the gneisses and schists is confirmed in the plots of log $Fe2O_3$ (t)/$K_2O$ vs log $SiO_2$ /$Al_2O_3$. This diagram shows that the protoliths of the gneisses are predominantly Fe-shale, Fe-sand, greywacke and arkose while those of the schists are shales. Most of the inferences about the tectonic setting of the shales, greywackes, arkose and sandstones of the metamorphic complex point to a continental arc derivation with a tendency to active continental margins (Fig. 6).

Active continental margins include sedimentary basins of the Andean type, thick continental margins and the strike-slip types. These basins are developed on or adjacent to a thick continental crust composed of rocks of older fold belts and the sediments are dominantly derived from granite-gneisses and siliceous volcanics of the uplifted basement. Based on evidence from the eastern and northeastern margins of the West African craton, it has been observed by previous authors that the Pan-African trans-Saharan belt evolved by plate tectonic processes which involved the collision of the active margin of the Pharusian belt (Taureg shield) and the passive continental margin of the West-African craton, about 600 ± 10 Ma (Burke & Dewey 1972; Leblanc 1981; Black *et al*. 1979; Caby *et al*. 1987; Obiora 2006, 2012). Evidence of this collision includes the presence of basic to ultrabasic rocks believed to be remnants of paleo-oceanic crust that are characteristic rocks of an ophiolitic complex arc. In this context, the sources for the sediments may have derived from the obducted continental arc of the Tuareg shield. Crustal melting occurred towards the end of the collision between the active continental margin of the Tuareg shield and the subducted oceanic crust which is believed to have reactivated the internal region of the Pan African belt forming the Pan African granites.

The moderate to high fractionations with pronounced negative Eu anomalies shown in the REE pattern for the granitic rocks is a typical behavior of crustal-generated granites and suggest either the fractionation of plagioclase or its retention in the source in the case of partial melting (Frost *et al*. 2001). The similarity of the REE patterns of the granitic rocks suggests that they are co-genetic. The light REE enrichment relative to the heavy REE enrichment in the rocks in this

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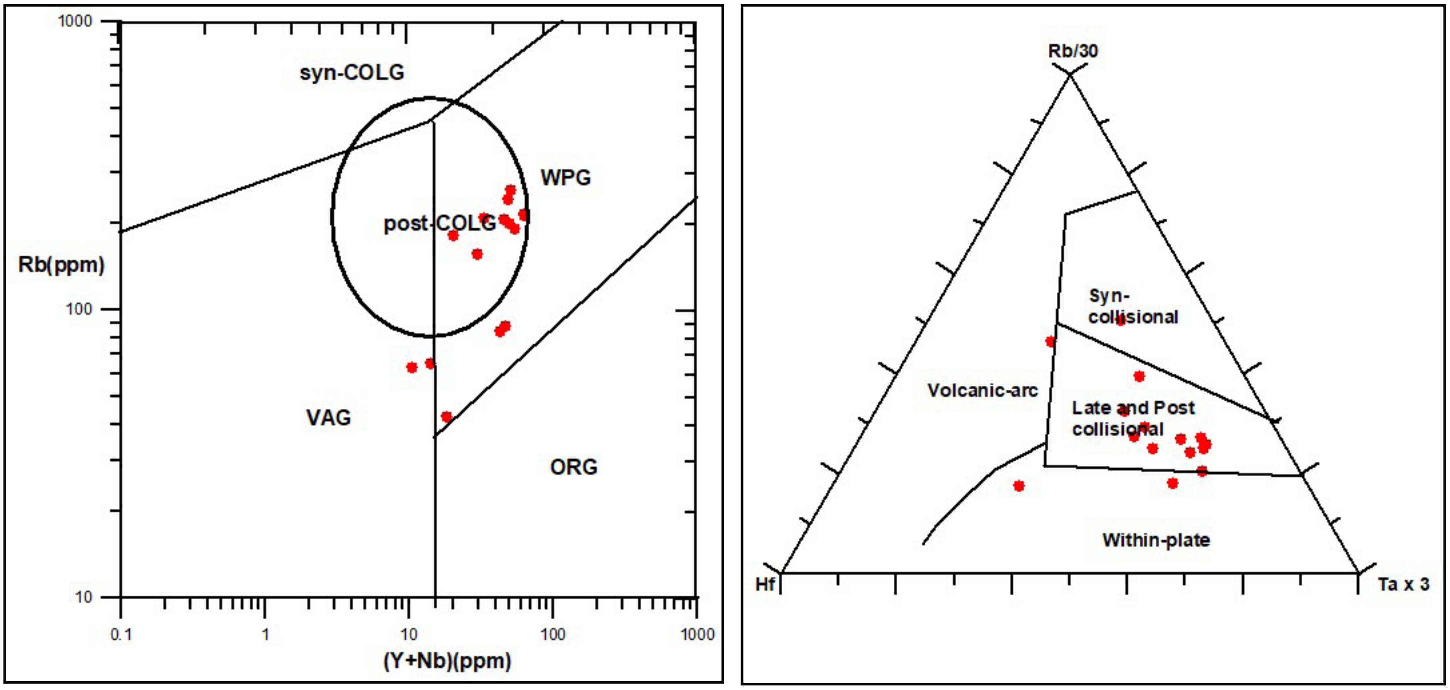

*Figure 8.A) Post orogenic character of the granitoids shown on the Rb versus Y + Nb of Pearce et al. (1984). Syn- COLG= syn-Collision Granites; post-COLG= post-Collision Granites; WPG= Within Plate Granites; VAG= Volcanic Arc Granites; ORG= Ocean Ridge Granites; B) Plots of the rocks in the fields of Syn-collisional to Late/post-collisional granitoids on the Rb/30 Hf (Ta x 3) diagram of Harris et al. (1986).*

study is considered as an indicator of varying degrees of partial melting. The granitic rocks in this study are quite similar to those of the Pan-African (older) granitic rocks which were emplaced towards the end of the Pan African orogeny (600 Ma), during the collision of the West African craton and the Tuareg shield.

## CONCLUSIONS

Geochemical criteria applied to the metamorphic rocks show that Fe shales, greywackes, Fe sand and arkose are the protoliths of the gneisses whereas the schists are mainly composed of shales. These sedimentary rocks were originally derived from felsic to intermediate igneous provenance. Trace element data indicate a source with an average upper crustal composition for the metamorphic complex. Independent of the rock type the tectonic setting is related with continental arc or active continental margins. The overall geochemical feature of the granitoids indicate that they were most likely derived from partial melting of crustal materials in an orogenic (post-collisional) tectonic setting. They are therefore related to the Pan-African granites, otherwise known as the Older Granites which were emplaced during the Pan African orogenic event.

## ACKNOWLEDGEMENTS

This research article was prepared for the EXPLORE newsletter as a requirement for receiving analytical support in 2016 for the M.Sc. research of the senior author under the Association of Applied Geochemists Student Support Initiative (https://www.appliedgeochemists.org/students/student-support-initiative). The authors wish to thank Bureau Veritas Minerals Pty Ltd., Perth, Western Australia and the Association of Applied Geochemists for their in-kind analytical support of this research. The contributions and corrections from the reviewers, Matthew Leybourne, David Corrigan, and the **EXPLORE** editor, Beth McClenaghan, are greatly acknowledged.

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