TECTONIC SETTING AND PROVENANCE ANALYSIS OF THE PROTOLITHS OF PRECAMBRIAN BASEMENT COMPLEX ROCKS AROUND KEFFI, NORTH-CENTRAL NIGERIA: IMPLICATIONS FOR PAN-AFRICAN TECTONICS

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ABSTRACT

Geochemical signatures of the Precambrian Basement Complex rocks around Keffi, North-central Nigeria reveal that they originated from sedimentary protoliths of shale, greywacke and arkose compositions, with minor contributions from calc-alkaline igneous sources. The progenitors of these protoliths were upper continental crust materials of acid to intermediate compositions. Twenty two (22) representative samples of the different lithologic units and subunits were analyzed and the major element oxides, the trace- and rare-earth element (REE) compositions were obtained using the Inductively Coupled Plasma (ICP) methods at the Activation Laboratories (ACT LABS) in Canada and graphs of the values were plotted using (grapher 4) software. The plots on the various discrimination diagrams reveal that the metamorphic rocks of the study area were deposited in a passive margin setting with inputs of continental island arc magmatism. The development of these tectonic settings cannot be separated from the development, existence and closure of the ancient sea at the eastern margin of the West-African craton. The provenance analyses reveal that the protoliths of these rocks have dominantly felsic igneous and subordinate quartzose sedimentary provenances.

Key words; precambrian, basement, keffi, protolith, geochemical, passive, margin, continental, island, arc.

INTRODUCTION

Keffi North-Central Nigeria, (see Figure1) is underlain by the Precambrian Basement Complex rocks consisting mainly of gneisses and migmatites, as well as a schistose belt, which include garnet mica schist, Hornblende schist, quartzo-feldspathic schist, staurolite mica schist and micaceous quartzite, together with garnetiferous biotite-muscovite granite and pegmatites (simple and complex types) (Ugwuonah and Obiora, 2011). Ugwuonah and Obiora, 2014a however have shown that the protoliths of these metamorphic rocks were largely sedimentary. Sedimentary rocks are an important source of information about previous orogenic conditions and may contain detritus that describes the evolution of orogenic settings (Johnsson, 1993). Sediment composition has been used to determine relationships between tectonic setting and provenance (Dickinson and Suczek, 1979; Johnsson, 1993). The composition of clastic sedimentary rocks is controlled by several factors, which include source rock, weathering, erosion, deposition, transport, burial, and diagenesis (Johnsson, 1993). The most important factors noted by Johnsson (1993) are source rock composition, chemical weathering, abrasion, sorting during transport, and diagenesis.

These factors are affected by three main interrelated components, namely, tectonic setting, climate and the nature of the depositional system. Each of these factors affects the characteristics of the others, producing different clastic compositions. As sediments are transported long distances from the source area, lithics become separated from relict quartz, and are chemically broken down. This results in quartz-rich sandstones that are characteristic of continental interiors and passive margin platform settings, and massive, mud-rich deltas characteristic of passive continental margin slope settings. In contrast, magmatic arc depositional systems tend to have short transport distances, which reduce physical sediment sorting, and chemical weathering, and results in sandstones that are less enriched in quartz, and more abundant in lithics.

As a result of these complex interactions, the chemical compositions of these sediments are difficult to match back to their source rock compositions (Johnsson, 1993). However, correlations between provenance, tectonic setting, and sandstone composition have been observed (Dickinson and Suczek, 1979; Dickinson et al., 1983). This suggests that, even though the interactions between these factors are complex, they typically behave in similar ways in any given setting. Furthermore, the influence of these factors upon sediment composition varies from one setting to another, thus producing similar and consistent compositional groups in each setting (Seiver, 1979).

Keffi in Northern Nigeria and its environs is situated at the southern margin of the North-Central Basement Complex of Nigeria. This area according to Ugwuonah and Obiora (2011) is underlain by typical basement rock units including migmatitic gneisses, porphyroblastic/augen gneisses, schists, older granites and pegmatites etc. The grades of the metamorphism were also identified to range between upper greenschist to upper amphibolites facies. The protoliths of these rocks have been constrained to be dominantly arkosic to greywacke sediments, Ugwuonah and obiora (2014a). But in tracing the progenitors of the protoliths of these basement metasediments and granitoid rocks and the prevailing tectonic settings, one will not fail to consider similar researches done on corresponding terrains east of the West-African craton.

Caby et al (1981) suggested the existence of an upper Proterozoic island arc and marginal trough volcano-detritic assemblages in western Hogger when discussing the Precambrian of West-Africa. In consonance with Burke and Dewey (1970) and other researchers, Black et al. (1979) presented accumulated evidence to confirm that the Pan-African should be regarded as a modern Himalayan type belt which resulted from collision between the passive margin of the west-African craton and the active margin of a continent to the east, represented by the Tuareg shield to the north and the Benin-Nigerian shield to the south. The Benin-Nigerian shield is the southern prolongation of the Pan-African belt. To the west, it is trust unto the west-African craton or, in most cases, on the Volta basin, (Black 1980). This collision led to the closure of an ancient sea with an eastward dipping subduction. Here, the oceanic opening was either small or the oceanic crust and active margin of the Benin-Nigeria shield have been entirely subducted (Black 1980).

It is also notable from the analysis of the works of Black (1980) that there are many suture zones east of the west-African craton including major and minor ones. The occurrence of these suture zones, and ophiolite sequences in Morocco along the northern edge of the west-African craton (Leblanc, 1981) are evidences of various and varying degrees of subduction and tectonic processes. On the Benin-Nigerian shield alone, Black (1980) established six major shear zones – three on the southern Nigeria and three on the north-central Nigerian basement rocks.

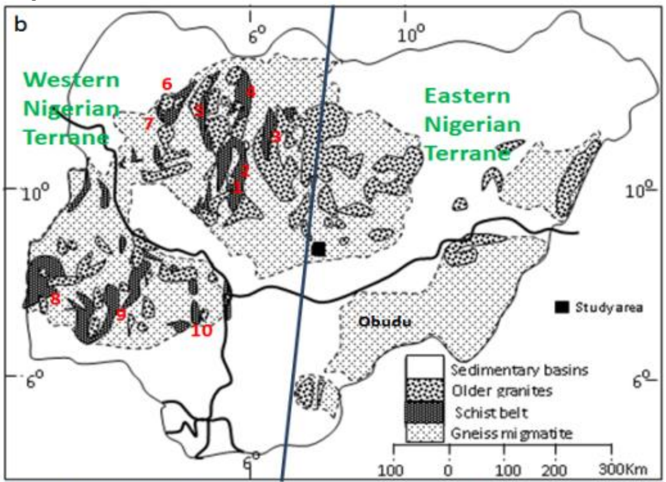
Although it is difficult to relate Pan-African granitoids to subduction zones, Black (1980), we can at least begin to ask relevant questions like; what are the provenances of the sedimentary protoliths of the north-central Nigerian basement? What tectonic settings existed in the Benin-Nigerian shield prior to and during the Pan-African orogeny and how do the answers to these questions fit into the larger picture of the tectonic history of west-Africa? In this paper, we have attempted to proffer the solutions to these questions using the best evidences available to us.

Geochemistry

Analytical Procedure

Different lithologic units and subunits were studied and a total of twenty (20) representative samples were analyzed for geochemistry using the latest equipments in Micro-spectrometry (Inductively Coupled Plasma Micro-spectrometer) in the Activation Laboratories in Canada. Sample numbers 1, 2, 3, 6, 7, 8 and 11 represent garnet-mica schists; 10 is staurolite-mica schist while 12 is hornblende schist. Samples 14 and 15 are representative of the migmatitic banded gneiss while 13 is banded hornblende gneiss. Samples 16, 20, 21, 23 and 24 represent the porphyroblastic/augen gneiss while sample 22 is garnetiferous biotite-muscovite granite; Sample 25 is micaceous quartzite; 26 is homogeneous simple pegmatite while samples 27 and 28 are homogeneous complex pegmatites. The sample numbering follows the outcrop numbering in Figure 2 and that of the geochemical tables. Sample numbers like 4, 5, 9, 17, 18 and 19 do not feature in the geochemical analysis. Though they represent real sample numbers that were all analyzed for petrography, only those analyzed for geochemical studies (representative samples of rock units) are presented here.

Major element oxides, the trace- and rare-earth element (REE) compositions were obtained from the geochemical analysis.



Parts of the Nigerian schist belts are named according to their localities as: 1. Zungeru-Birning Gwari, 2. Kushaka, 3. Karaukarau, 4. Wonaka, 5. Maru, 6. Anka, 7. Zuru, 8. Iseyin-Oyan River, 9. Ilesha and 10. Igarra.

Fig.1; Map of Nigeria showing

the study area.

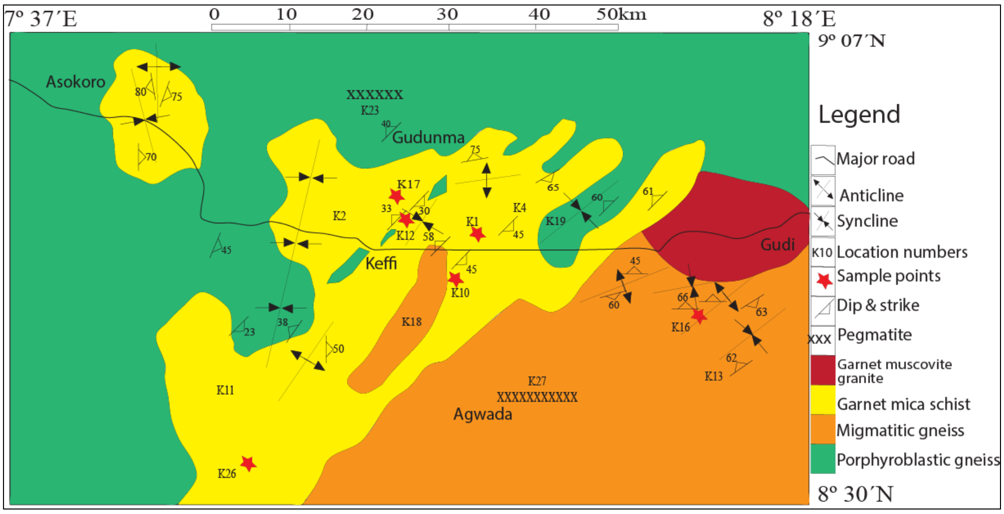


Fig. 2; The Geological Map of the study area.

Results

The major, trace and rare-earth element compositions, particularly the light lithophile elements (LILE) are highly variable owing to the compositional differences of the rocks and element mobility. The low loss on ignition (LOI) recorded in almost all the samples is related to the absence of calcite and mafic (OH)-bearing minerals such as epidote and chlorite – a pointer to the appreciable level of grade of metamorphism. However, some inconsistent patterns emerge in the provenance and tectonic setting discrimination plots even when immobile elements only are used. All samples show similar light rare earth element (LREE) enrichment patterns with (Ce/Yb)N varying from 1.03 to 111.5, (La/Sm)N from 1.41 to 4.04 and have flat heavy rare earth element (HREE) patterns for schists and decreasing heavy rare-earth element (HREE) patterns for the gneisses and granitoids. The variability in LILE reflects the mobility of these elements during deformation, and metamorphism, with especially K/Rb ratios ranging from 75 to 695. There are generally higher Th over U values, with Th/U ratios ranging from 0.067 to 7.94.

Discussion

On the plot of Th/Sc versus Zr/Sc diagram of McLennan et al. (1990) (fig. 3a), the rocks of Keffi and environs show a spread through mantle to the Upper-Continental Crust distributions. They also show a trend towards sediments recycling (reworking). In a similar way, the diagram of Th/u versus Th (after McLennan et al., (1993)) (fig. 3b), the rocks of Keffi and its environs show dominantly upper-crust composition, but with a weathering trend. In the plots of distribution of K (wt%) versus Rb (ppm) after Floyd and Leveridge (1987) (figs. 4a and 4b), these rocks show affinity for Upper-Continental Crust compositions constrained in the second diagram to be acid + intermediate compositions specifically arkosic sands and metagreywackes.

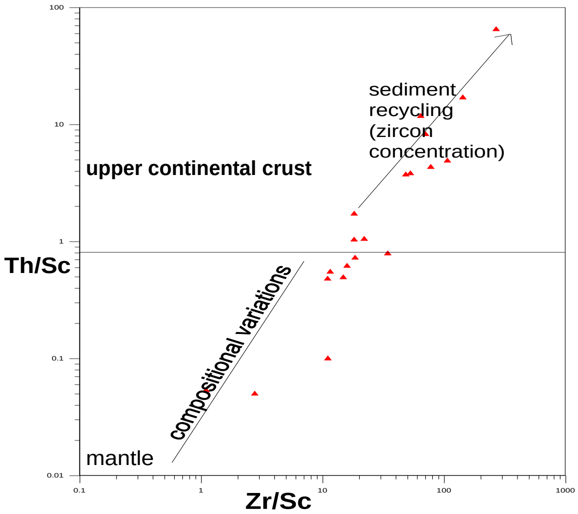


Fig. 3a Th/Sc versus Zr/Sc diagram of McLennan et al., (1990) showing a spread through mantle to upper continental crust and with a reworking trend.

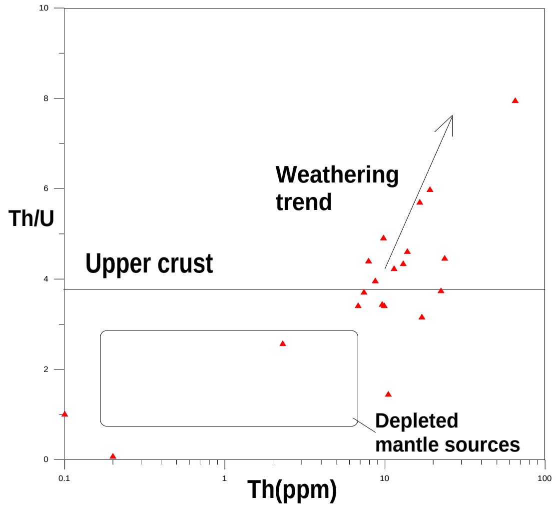
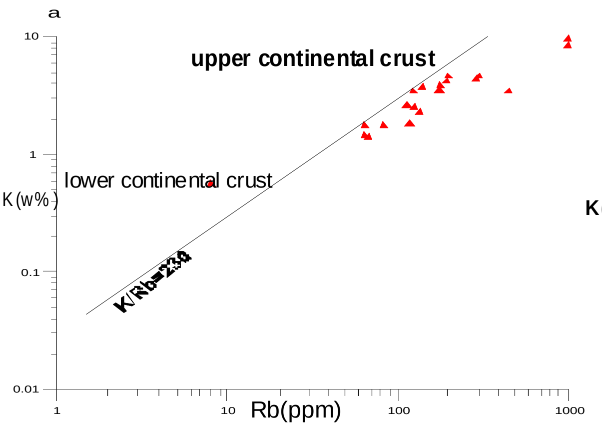
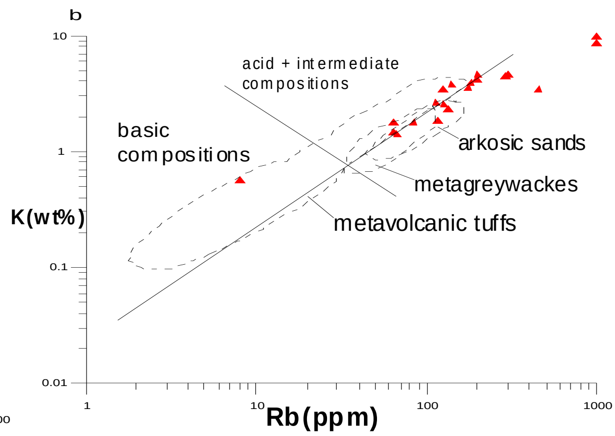


Fig. 3b Th/u versus Th diagram (after McLennan et al., 1993) for the rocks of Keffi and its environs showing dominantly upper-crust composition, but with a weathering trend.

This result tallies with the findings of Ugwuonah and Obiora (2014a). The Chondrite-normalized Rare-Earth Element patterns (figs. 5a and b) for the rocks of the study area also show that these rocks have Continental Crust affinity with high LREE and slightly lower HREE which are on average more than 10 times chondrite values.





Figs. 4a and 4b; Plots of distribution of K (wt %) and Rb (ppm) in the rocks of Keffi and environs (after Floyd and Leveridge, 1987) (a) showing affinity with Upper-Continental Crust compositions. (b) Showing affinity with acid + intermediate compositions specifically arkosic sands and metagreywackes.

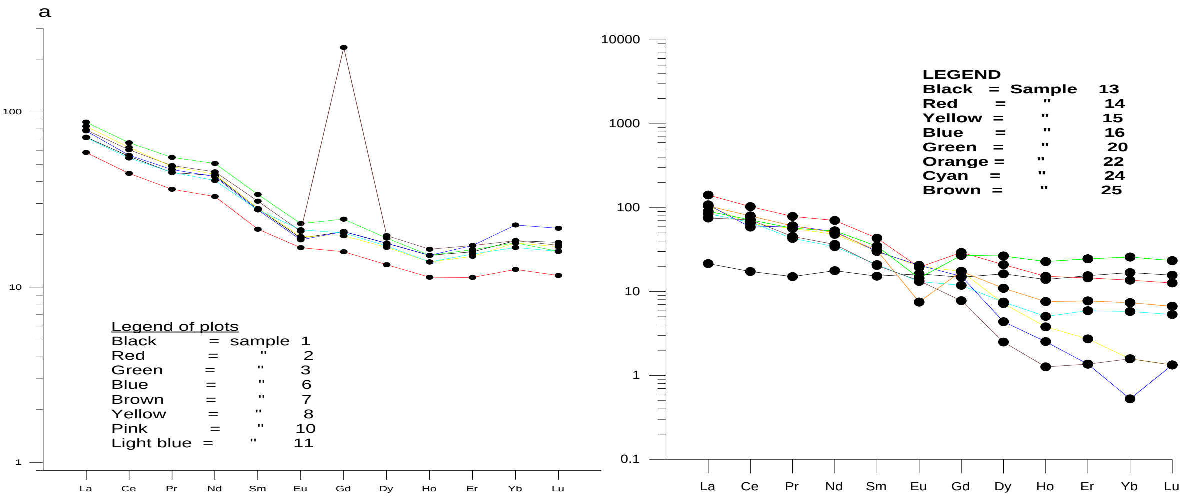


Fig. 5a; Chondrite-normalised rare-earth-element patterns for the schists (1-12) Fig. 5b; Chondrite-normalized rare-earth-element patterns for the Hornblend schist (12), banded hornblende gneiss (13), Migmatitic banded gneiss (14 & 15), Porphyroblastic/augen gneiss (16-20), Garnetiferous-granite (22) and Porphyroblastic/augen gneiss (20, 24 and 25) from Keffi and its environs.

In the analysis of tectonic settings, the K_2O/Na_2O (log scale) versus SiO_2 (wt %) tectonic setting discrimination diagram (after Roser and Korsch (1986)) (fig. 6a), shows a dominant distribution in the Passive Margin setting with subordinate Active Continental Margin distribution and only one Oceanic Island Arc distribution. But this discrimination diagram has no provision for classification of Continental Island Arc. However, using TiO_2 (wt %) versus $Fe_2O_3 + MgO$ (wt %), after Bhatia (1983) (fig. 6b), the rocks cluster around Passive Margin and Continental Island Arc. In the La-Th-Sc ternary tectonic setting discrimination diagram of Bhatia and Crook (1986) (fig. 7a), the rocks of Keffi and environs once more show concentration within passive Margin and Continental Island Arc settings with one distribution and two deviated distributions around oceanic island Arc setting. In the plot of La/Y versus Sc/Cr tectonic setting discrimination diagram of Bhatia and Crook (1986) (fig. 7b), the distribution is centered on Continental Island Arc and around Passive Margin, one distribution and two deviations around Oceanic Island Arc.

Sleep (1971) first proposed that passive continental margins form by thermal contraction following rifting and continental break-up. According to his model, the lithosphere is heated during rifting which causes thermal expansion and uplift over a broad region accompanied simultaneously by erosion. Cooling restores the uplifted lithosphere to its pre-rift level, but sub-aerial erosion thins it. The net result is that the lithosphere subsides below its initial level, thereby forming a marginal depression for continental-derived sediments to infill. Walcott (1972) showed that although thermal contraction and erosion may indeed combine to produce a marginal depression, sediments act as a load on the surface of the lithosphere and causes additional subsidence. He demonstrated that if sediments prograded into a 5 km deep basin, the lithosphere (which includes the crust) would bend or flex by as much as 8 km, depending on the weight of the sediment and, importantly, the flexural rigidity of the underlying lithosphere.

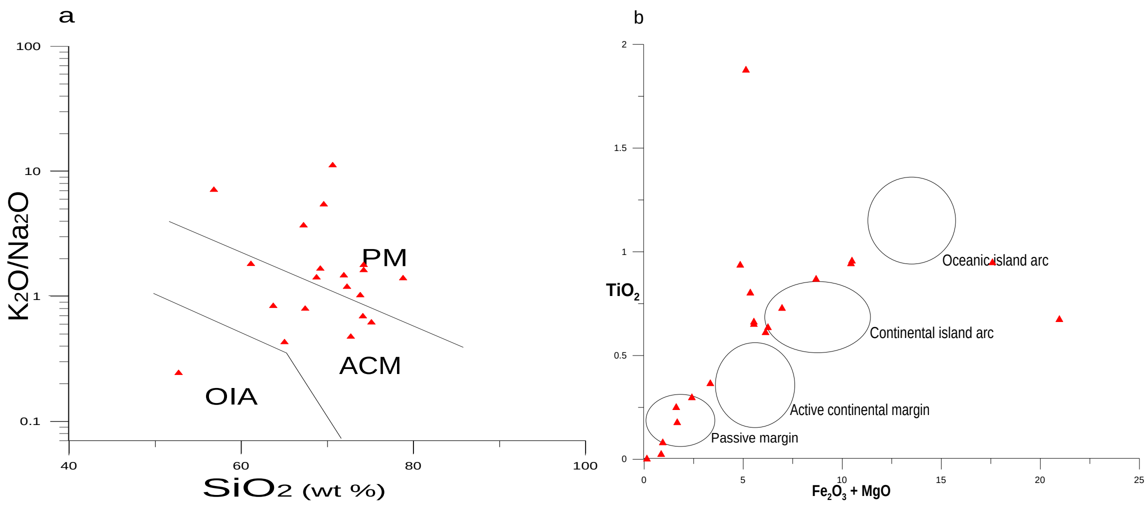


Fig. 6(a) K_2O/Na_2O (log-scale) versus SiO_2 tectonic setting discrimination diagram of the rocks of Keffi and environs (after Roser and Korsch 1986) showing dominantly Passive Margin with subordinate Active Continental Margin and occasional Oceanic Island Arc settings. (b) TiO_2 (wt%) versus Fe_2O_3 + MgO (wt%) tectonic setting discrimination diagram (after Bhatia, 1983) showing the rocks clustering around Continental Island Arc and Passive Margin settings with occasional Oceanic Island Arc.

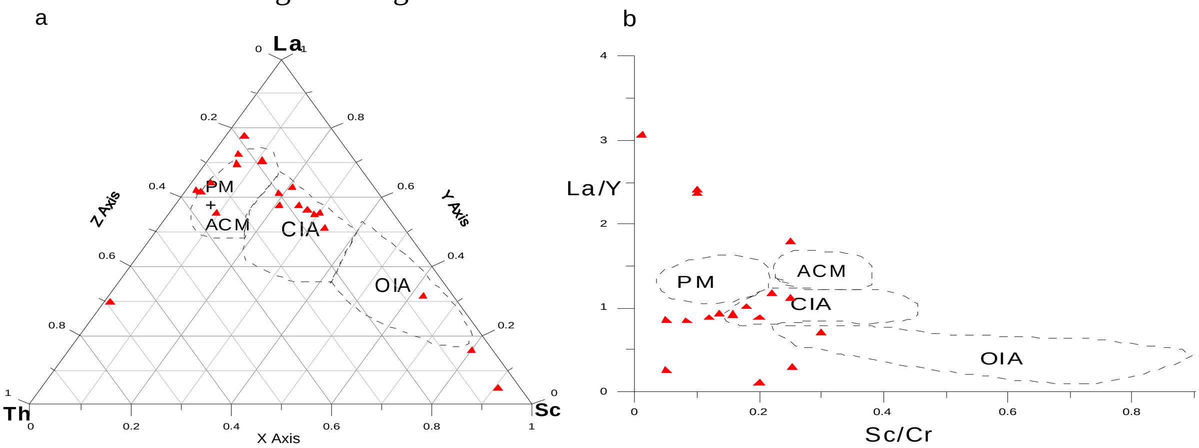


Fig. 7 (a) La-Th-Sc ternary tectonic setting discrimination diagram of Bhatia and Crook (1986) showing the distribution of the rocks of Keffi and environs within Continental Island Arc and Passive Margin tectonic settings with occasional representation of Oceanic Island Arc setting. (b) La/Y versus Sc/Cr tectonic setting discrimination diagram of Bhatia and Crook (1986) for the rocks of Keffi and environs showing the dominant distribution of the rocks within the Continental Island Arc setting.

Passive margins are characterised by large thicknesses of sediments (up to ~ 12 km) (Sleep, 1971). Even in our present day Niger-Delta basin, the deepest parts of the lowest rock unit (Akata formation), is estimated to be ≥ 12km. There is evidence from backstripping of biostratigraphic data that foreland basins are underlain by stretched crust (e.g. the western deep Gulf of Mexico basin which overlies the western Gulf Coast margin (Feng et al., 1994), the Papuan basin which overlies the Northwest Australia margin (Haddad and Watts, 1999), and the west Taiwan basin which overlies the South China Sea margin (Lin and Watts, 2002).

The Wilson Cycle theory implies that passive margins ultimately become the sites of orogeny. Although the mechanism by which this transition takes place are unclear e.g. Erickson, (1993), Begg, et al. (2007) showed that an ancient sea separated the West-African craton from the West-African mobile zone comprising of the Tuareg block to the north and the Benin-Nigerian block to the south. They further supposed that the sea closed up with an eastward dipping subduction during the Pan-African orogeny.

In Keffi area, Ugwuonah and obiora (2011) used geothermometric and geobarometric signatures on the metasedimentary basement rocks to constrain these rocks to have been exhumed from a depth of about 27km – assuming a geothermal gradient of 25^0C. In the FeO(t) + MgO (wt %) versus CaO (wt %) of Maniar and Piccoli (1986) (fig. 8a), almost all the samples plotted in the Orogenic granitoid region of Island and Continental Arcs collision. Using Rb/30 – Hf – Ta*3 ternary diagram of Haris et al. (1986) (fig. 8b), the granitoid rocks of Keffi and environs show varied distributions. They plotted in both volcanic arc, syn-collisional, late and post collisional and within plate settings. These distribution patterns are very significant in this study because (even though I must agree that element mobility due to metamorphism may have been important in the overall geochemical signatures of the rocks under study), it goes to say that these rocks may have been emplaced at different sessions of the Wilson cycle. This discovery is also supported by the dating works of earlier researchers on the igneous intrusives (Older granites) of the Basement Complex of Nigeria. Some of their results include the following rocks and their ages; Badiko gneissic granite – 2.5Ga, Okene gneissic granodiorite – 2.1Ga (Annor, 1995), Ile-Ife gneissic granite – 1.85Ga (Rahaman, 1988), Badiko syntectonic diorite – 623Ma (U-Pb), Ikerre massive charnockite – 620Ma (U-Pb) (Tubosun et al. 1984), Akure gneissic charnockite – 634Ma, Akure porphyritic granite – 621Ma, Idanre gneissic charnockite – 580Ma, Idanre porphyritic granite – 587Ma (Dada et al. 1989). These results and many more show at a glance that the intrusive activities in the Precambrian Basement Complex domains of Nigeria were both relatively episodic and continuous.

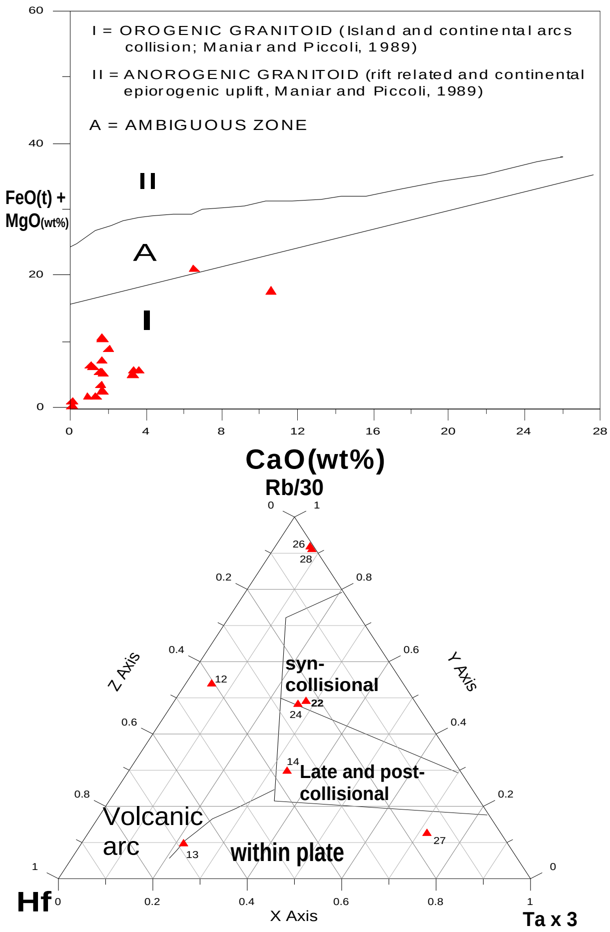


Fig. 8 (a) Plot of Fe_2O_3 (t) + MgO (wt%) vs CaO (wt%) for the tectonic setting of meta-igneous, gneisses and granitic rocks of the study area (after Maniar and Piccoli, 1989). (b) Rb/30-Hf-Ta×3 (ternary) diagram of Harris et al. (1986) for the granitoid rocks in Keffi and its environs.

In the provenance analysis using the major element discriminant function diagrams of Roser and Korsch (1988) the rocks of the study area show distribution on the felsic igneous, intermediate igneous and quartzose sedimentary provenance fields in (fig 9a). It is important to note that all the porphyroblastic gneisses and the granite plot in the felsic igneous field, while the migmatitic gneisses plot almost on the felsic igneous and quartzose sedimentary provenance boundary, sample 15 lie within the quartzose sedimentary field while 14 lie outside but high on the quartzose sedimentary field. The schists dominantly plot in the quartzose sedimentary field with sample 1, 10 and 11 ploting in the intermediate field. But, in (fig 9b), all gneisses plot in the felsic igneous field while the schists cluster around the felsic igneous and quartzose sedimentary boundary. Only sample 11 persists near the intermediate igneous field.

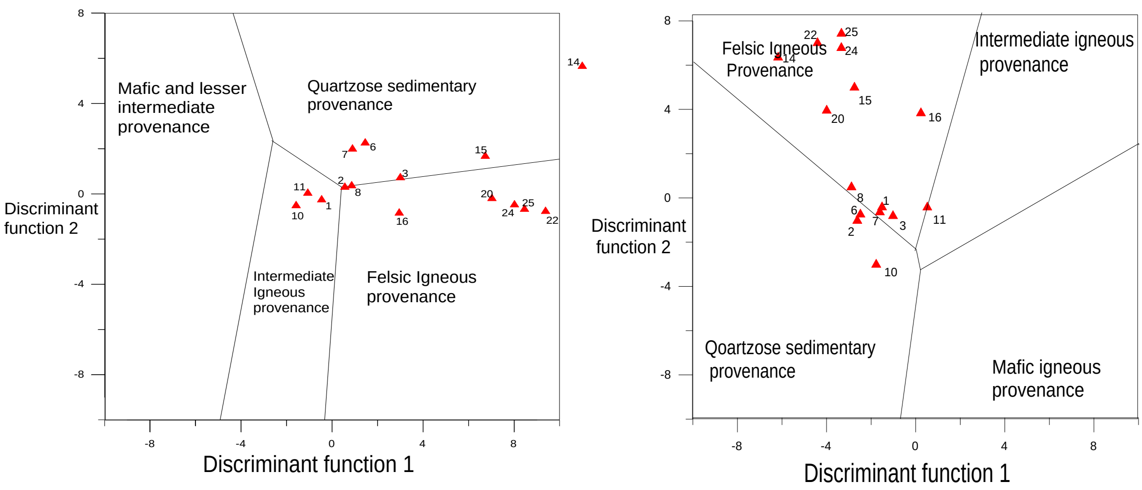


Fig 9(a) Plots of the rocks of the study area on the discriminant function diagram for the provenance signatures of pelites (sandstone-mudstone suits) using major elements (after Roser and Korsch, 1988). (b) Plots of the rocks of the study area on the discriminant function diagram for the provenance signatures of pelites (sandstone-mudstone suits) using major elements (after Roser and Korsch, 1988).

Summary and Conclusion

The Basement Complex rocks of keffi and its environs are dominantly of crustal origin with minor contributions of Oceanic Island Basalt compositions and there was sediment recycling (reworking) which is a further evidence for subduction and arc magmatism prior to the final phase of regional metamorphism.

The migmatitic gneisses and the porphyroblastic/augen gneisses are meta-sediments of arkosic to greywackic composition which were deposited in a passive margin setting that probably sloped westwards during the development of the ancient sea at the eastern margin of the West African craton. Regional/burial metamorphism must have been very important in the passive margin due to the thickness of sedimentary pile prior to the Pan-African orogeny, leading to the development of the migmatite-gneiss complex. The closure of the sea by an east-west compressive force was a gradual process creating first of all a line of back-arc spreading centers – an extensional fracturing of a belt in the passive margin area “the Mega Fractures”. This fractured belt started receiving sediments from the immediate vicinity. This infilling of the fractures took place simultaneously with the emplacement of some Continental arc magmatism leading to processes like the emplacement of the older granite suit of rocks, sediments recycling (reworking) and the sodic to potash feldspathization of some migmatitic gneisses to form most of the porphyroblastic gneisses. Most of these potasic and sodic porhyroblastic gneisses are found to have gradational contact with Pan-Afrcan igneous intrusives (Ugwuonah and Obiora 2014a). The compressive forces continued, leading to the metamorphism of the sediment fill of the fractures to form the schist belts, while the early continental arc intrusives were partially metamorphosed into the granitic gneisses or gneissic granites. The late Pan-African continental arc intrusives were however unmetamorphosed giving rise to the porphyritic granites and the leocogranites of the older granite suit. The protoliths of the rocks of this study have dominantly Felsic igneous and subordinate Quartzose sedimentary provenances.

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