GEOCHEMICAL CONSTRAINTS ON THE ORIGIN OF PRECAMBRIAN BASEMENT COMPLEX ROCKS AROUND KEFFI, NORTH-CENTRAL NIGERIA.

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ABSTRACT

Geochemical characteristics 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. 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 salient differences in the meta-pelites (meta-shales) and the meta-greywackes as observed in this study is shown in their major element geochemistry. The meta-greywackes have higher silica content (72.7-75.1) than the meta-arkoses (70.9-74.2) and the meta-pelites (61.6-69.56), and has lower Al_2O_3 *(10.5-14.5),* Fe_2O_3 *(t) (3.72-5.02) and Mg (1.05-1.94) relative to the meta-pelites which have* Al_2O_3 *(15.1-16.9),* Fe_2O_3 *(t) (6.11-7.37) and Mg (2.57-3.37). The arkoses have* Al_2O_3 *values which are higher than the values in the greywackes but lower than those in the shales (ie. 11.57-15.6), with* Fe_2O_3*(t) (0.12-2.69) and Mg (0.01-0.65) values which are far lower than those of the greywackes and shales. The rare-earth-element concentrations in rocks of Keffi compare closely with those of the crustal and shale concentrations. The pegmatites in this study can be classified as mineralized as seen in samples 26, 27 and 28 ,which have K/Rb ratios of 95, 75 and 84 and Rb values (>1000, 455 and >1000 ppm), respectively. The ubiquitous LREE enrichment coupled with pronounced negative Eu-anomalies suggesting high fractionation in the schists and gneisses, and the similarities of the major element oxides, trace- and rare-earth-elements compositions of the rocks with crustal compositions suggest that their sedimentary progenitors were derived from a cratonic source.*

Key words; precambrian, basement, keffi, protolith, geochemical, garnet, staurolite.

1.0 INTRODUCTION

The Precambrian Basement Complex rocks around Keffi North-Central Nigeria, (see Fig. 1) consist mainly of the rocks belonging to the migmatitic gneiss complex namely: porphyroblastic/augen gneiss, migmatitic banded gneiss and banded hornblende gneiss, as well as the rocks of the Keffi Schist 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). Some of the rocks of the Precambrian Basement Complex, including the Schist belts had been designated ‘‘meta-sediments’’ in earlier geological maps produced by the then Geological Survey of Nigeria (see Malomo, 2000) because of their undoubted sedimentary, mineralogical and textural/structural attributes. It is now becoming clear that the rocks of the migmatite- gneiss complex (including the migmatitic gneisses and the porphyroblastic gneisses) could also be of sedimentary origin on account of their contents of index metamorphic minerals such as garnet (almandine), cordierite and sillimanite (McCurry, 1976; Onyeagocha, 1983; Rahaman, 1988; Ugwuonah and Obiora, 2011), and now on their trace- and rare-element compositions.

Whole-rock geochemistry is a useful parameter for ascertaining the nature of the protoliths of metamorphic rocks, even in the absence of index metamorphic minerals. This approach has also been used to confirm the meta-sedimentary origin of the Nigerian Precambrian Basement Complex rocks belonging to the migmatitic gneiss complex (Ekwueme and Onyeagocha, 1986; Ejimofor et al., 1996; Oyinloye, 1998; Obiora, 2006). In this paper, whole-rock geochemical data, including major elements oxides, trace- and rare-earth elements of the Precambrian Basement of Complex rocks around Keffi have been used to assess the origin of these relatively unstudied rocks and their progenitors.

1.1 Description of Field Occurrences and Petrographic Characteristics of the Precambrian Basement Complex Rocks around Keffi

Gneisses are the most dominant suite of rocks in the study area; they enclose the schists and stick-out prominently within the schist dominated areas (Figure 2). All elevated areas are conspicuously underlain by the gneisses, which are subdivided into porphyroblastic/augen gneiss unit and the migmatitic banded-gneiss unit.

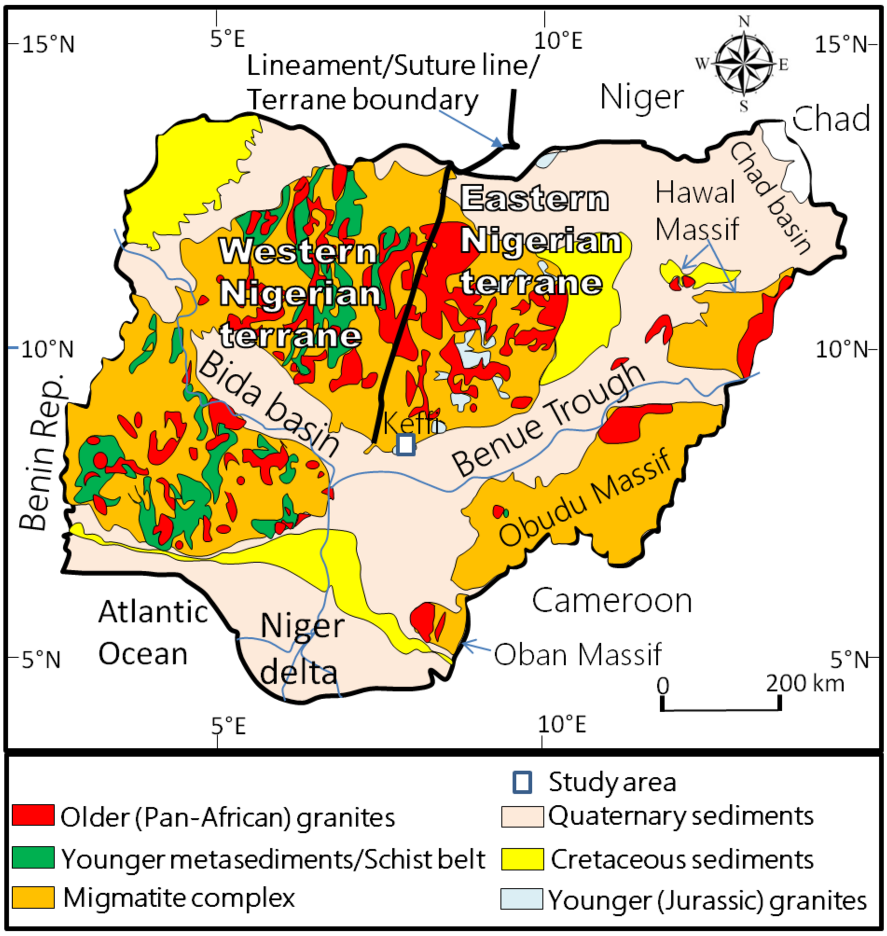


Figure1. Map of Nigeria showing the study area.

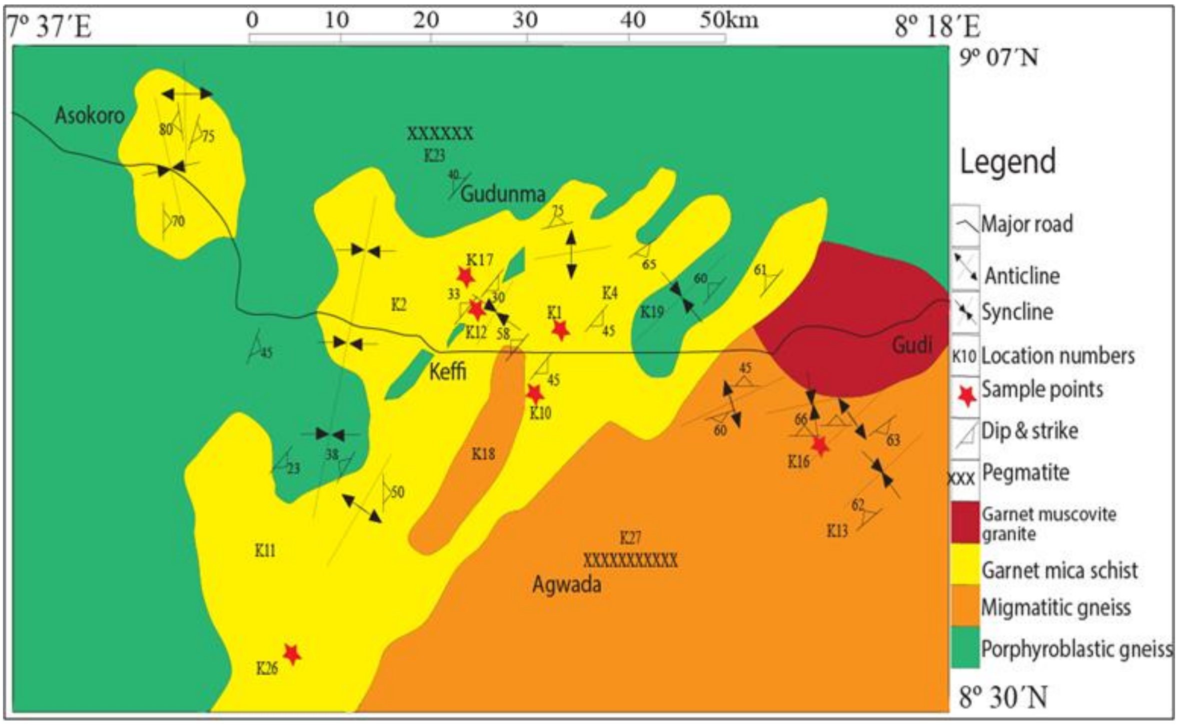
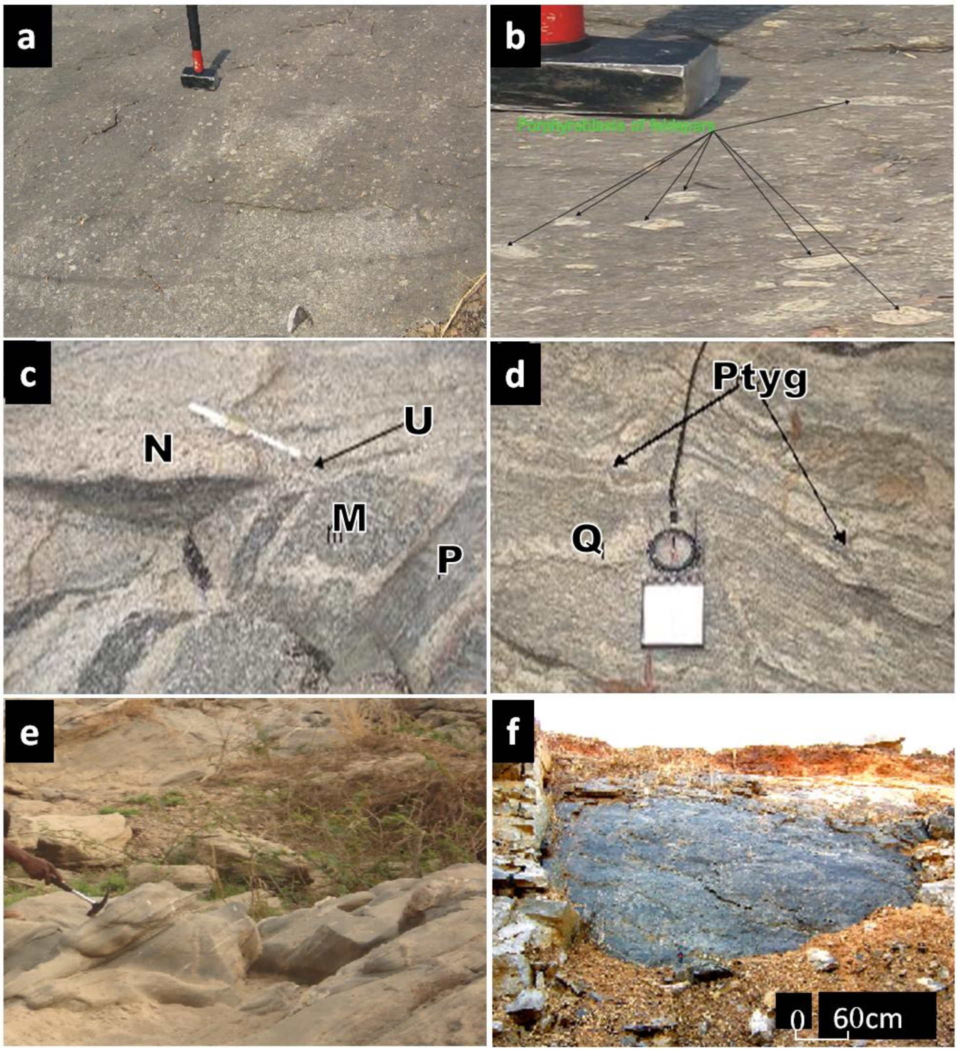


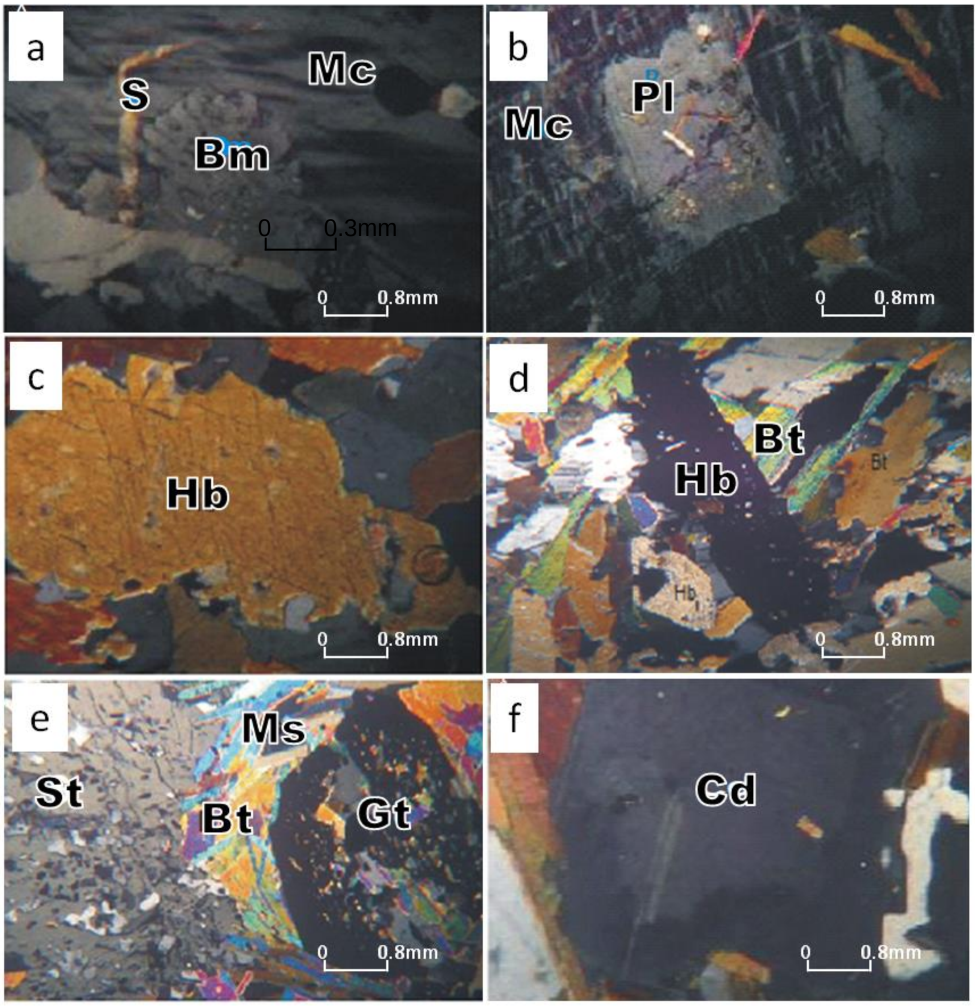
Figure 2. The Geological Map of the study area.

The porphyroblastic augen-gneiss (Figs. 3a and b) covers the northern and southwestern parts while the migmatitic banded-gneiss (Figs. 3c and d) underlies the central and the southeastern parts. The schists (Figs. 3e and f) occupy the central parts of the study area and are second most dominant rocks in the area.



Figures 3(a and b). Crystals of zoned feldspars in the Porphyroblastic gneiss, (c) Mixtures of paleosome(P), mesosome(M) and neosome(N) at an outcrop of the Migmatitic banded gneiss, (d) Quarzofeldspathic injections(Q) and ptygmatic folds(Ptyg) in migmatitic banded gneiss, (e) High angle dips on the staurolite mica schist, (f) Sharp contact between the hornblende schist and the host porphyroblastic gneiss.

They are notably found within the low-lying regions and valleys, especially along the river valleys with the entire outcrops lying in synformal troughs which run generally in the NNE-SSW trend conformable with the general trends of the Nigerian Schist belts as recorded by earlier workers. They are mostly fine - medium-grained while the gneisses are medium- to coarse-grained. The varieties of the schists are garnet-mica-schists, staurolite-mica-schist, Hornblende schist and quartzo-feldspathic schist. The metamorphic Basement Complex is characterized by N-S to NNE-SSW trending foliations, which are typical of the Pan-African orogenic event as suggested by McCurry (1971). The outcrops of the pegmatites encountered in the study area trend mainly in the E-W directions with some N-S trends. Occasionally, NE-SW trends are encountered. The predominant cross-cutting trend indicates that the pegmatites occur mainly as dykes as other pegmatites in the Nigerian pegmatite belts especially those in the Wamba area according to Matheis (1987) and Kuster (1990). Both the gneisses and schists contain typical pelitic assemblages, including chlorite, biotite, garnet, staurolite, cordierite and hornblende whereas plagioclase and microcline are more common in the gneisses (See Figs. 4a and b). Generally the mineral assemblages in the gneisses suggest that they were formed in the lower to upper amphibolite facies conditions of metamorphism with temperatures of 550-700 ºC and pressures of 3-10 Kb. Retrograde conditions are suggested by the presence of myrmekitic intergrowths, which are commonly associated with the breakdown of feldspars, as well as the presence of chlorite in the gneisses. On the other hand, the schists recorded middle to upper amphibolites facies representing temperature-pressure conditions of 600-700 ºC and 3-10 Kb (Ugwuonah and Obiora, 2011; Ugwuonah et al., 2017).



Figures 4(a). Bulbous myrmekite (Bm) and a ribbon of sericite (S) in a microcline porphyroblast in porphyroblastic gneiss. (b) Microcline porphyroblast (Mc) with a core of plagioclase (P) and muscovitic alteration product in porphyroblastic gneiss from location 17. Crossed polars (c) Basal sections of hornblende (Hb) and Muscovite (Ms) in Banded Hornblende Gneiss (Location 13). Crossed polars. (d) Exinction position of longitudinal section of hornblende and its Basal section (Hb), and Biototite (Bt). Crossed polars (e) Poikiloblastic porphyroblasts of Staurolite (St) and garnet (Gt) enclosed by an aggregate of muscovite (Ms) and biotite (Bt) crystals). (Location 6). (f) Zonning and twinning in cordierite (Cd) in garnetiferous cordierite-biotite-muscovite granite (location 22). Crossed polars (A) and Plane polars (B).

1.2 Geochemistry

1.2.1 Analytical Procedure

Twenty two (22) representative samples of the different lithologic units and subunits were analyzed. Samples numbered 1, 2, 3, 6, 7, 8 and 11 are representative of 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 are representative of the porphyroblastic/augen gneiss while sample 22 is garnetiferous granite; Sample 25 is micaceous quartzite; 26 is simple pegmatite while samples 27 and 28 are complex pegmatites of the homogeneous types. The sample numbering follows the outcrop numbering in Figure 2 and that of the geochemical tables (Tables 1, 4 and 5). 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.

The major element oxides, the trace- and rare-earth element (REE) compositions were analyzed using the Inductively Coupled Plasma (ICP) methods at the Activation Laboratories (ACT LABS) in Canada. Powdered samples of the rocks were sent to the ACTS LABS by Courier service.

2.0 **Results**

2.1 Major Elements Geochemistry

The major element oxide compositions of the rocks are presented in Table 1 (see support data). The samples of the porphyroblastic/augen gneiss and the migmatitic banded gneiss (14, 15, 16, 20, 24 and 25) have SiO_2 values that range from 67.11 to 74.21% with a mean of 71.12%. They show moderate Al_2O_3 (13.24-15.20%), low TiO_2 (0.176 - 0.935%), MgO (0.24 - 1.28%), MnO (0.011- 0.052%) and high K_2O (3.15 - 5.56%), Na_2O (2.6 - 4.21%) and CaO (0.9 - 3.59%).

These values with the mean values of the garnet-mica schists, the pegmatites (samples 26, 27, 28), the banded hornblende gneiss (sample 13), the hornblende schist (sample 12) and the Garnetiferous granite (sample 22) are presented in Table 2.

From their mean values, the garnet-mica schist, migmatitic banded gneiss, garnetiferous biotite-muscovite granite and pegmatites of the study area, all show saturation with respect to silica (i.e. 69.37%, 71.12%, 74.15%, and 72.21%, respectively). Their K_2O-content increases from the garnet-mica schist to the pegmatites (i.e. 2.47%, 4.69%, 5.56% and 8.61%, respectively). The total iron oxide values show a reverse order (i.e. 5.36%, 2.96%, 1.43% and 0.63%, respectively). MgO also decreases in that order (i.e. 2.13%, 0.85%, 0.24% and 0.013%, respectively).

1.2 Trace- and Rare-Earth-Element Geochemistry

The trace-element compositions of the rocks are presented in Table 4 while rare-earth element (REE) compositions are presented in Table 5. Table 6 has been included for comparison of the trace-elements and REE contents of the rocks in this study with those of geological materials including; chondrite, crust, ultrabasic, basalt, granite, greywacke and shale.

Ba is high in almost all the rocks, with the gneisses containing the highest mean value (782.5 ppm). This is followed by concentration of Ba in the hornblende schist (sample 12). Be is extremely high (2097 ppm) in the complex pegmatites, but is almost absent in the rest of the samples. Cr, Co, Zn and Ni are present in considerable amounts in the hornblende schist with concentrations of 680, 38, 600 and 300, respectively, as well as in the banded hornblende gneiss (sample 13) with concentrations of 170, 42, 100 and 90, respectively. These are consistent with the basic nature of the samples (Carr and Turekian, 1961). Conversely, Cr, Co and Ni are generally low in the porphyroblastic/augen and migmatitic banded gneisses, garnetiferous biotite-muscovite granite and the pegmatites. (Snelling, 1958) ascribed a sedimentary origin to an amphibolite which contained 10 ppm Cr, 5 ppm Ni, and 20 ppm Co. These values are very low in comparison with basic rocks, and are consistent for the three elements.

3.0 Discussion

In comparison with the measured average chemical compositions of schists and paragneisses after Clarke (1924), Nanz (1953), Simonen (1953) and Zwart (1959) (see Table 3), the schists and gneisses of the study area show much higher values of silica and total alkalis, and much less values of alumina and total iron. This, points to a more quartzo-feldspathic protolith. This is made clear in the plot of log (Fe_2O_3(t)/K_2O) vs log (SiO_2/Al_2O_3) after Herron (1988) (Figure 5), where the migmatitic banded gneisses and porphyroblastic/augen gneisses with the exception of sample 20, some samples of the garnet-mica schist (1, 2, 6, and 8) and the hornblende schist (12) plot in the greywacke region. The banded hornblende gneiss (13) plots in the Fe-shale region. The other samples of garnet-mica schist (3, 7, and 11) and the staurolite-mica schist (10) plots in the shale region while samples 20 and 25 plot in the arkose region. It is shown in this diagram that the sedimentary protoliths of the rocks in the study area are dominantly greywacke followed by arkose and then shale.

The banded hornblende gneiss and the hornblende schist show much less saturation with respect to silica content (i.e. 52.65 and 56.81%), with much higher total iron oxide (10.73 and 12.34%), MgO (6.85 and 8.61%) and CaO (10.62 and 6.52%) relative to the garnet-mica schist, migmatitic banded gneiss, granite and pegmatites. Expectedly, these trends show that the rocks attained different levels of fractionation, with the banded hornblende gneiss and hornblende schist being more unfractionated while the pegmatites are the most fractionated.

In MgO-CaO-Al_2O_3 (ternary) diagram of Leyreloup et al. (1977) used for the determination of the protoliths of metamorphic rocks (Figure 6), 85% of the rocks plot in the sedimentary field. The garnet-mica schist (sample 8), the migmatitic banded gneiss (15) and the porpyroblastic/augen gneiss (16) plot almost on the magmatic/sedimentary boundary within the magmatic rocks field while the hornblende schist (12) and the banded hornblende gneiss (13) plot within the basalt field. This ternary diagram proves further that samples 12 and 13 have basic igneous affinity and are therefore meta-igneous. (Taylor, 1955) concluded from the Cr, Ni, Co and V content of greenschist bands in quartz-albite-biotite schists, that they were originally basic sills which intruded into greywacke sediments.

Potash-feldspathization was made possible in the hornblende schist due to its proximity and sharp contact with the porphyroblastic gneiss (Fig. 3f). This porphyroblastic gneiss host showed slightly higher K_2O content relative to the hornblende schist while the gneiss has slightly higher basic attributes (Fe_t, CaO and Mg) than all other gneisses. These clearly indicate elemental mobility during medium to high grade metamorphism. The meta-igneous rocks, namely: banded hornblende gneiss and hornblende schist, as well as the garnetiferous granite, respectively, plot as calc-alkaline gabbros, diorites, granites/mildly alkaline granites on the TAS diagram of Cox et al. (1979) (Fig. 7). These rocks also plot in the calc-alkaline field in an AFM diagram (Fig. 8). In the plot of (Fe_2O_3 (t) + MgO) (wt%) vs CaO (wt%), after Maniar and Picolli (1989) (Fig. 9a), the granitoid rocks of the study area are shown to have been emplaced in an orogenic environment. The rare-earth-element concentrations in the Precambrian Basement Complex rocks around Keffi compare closely with those of the crustal and shale concentrations. All the schists with the exception of the hornblende schist show good correlation with crustal concentrations.

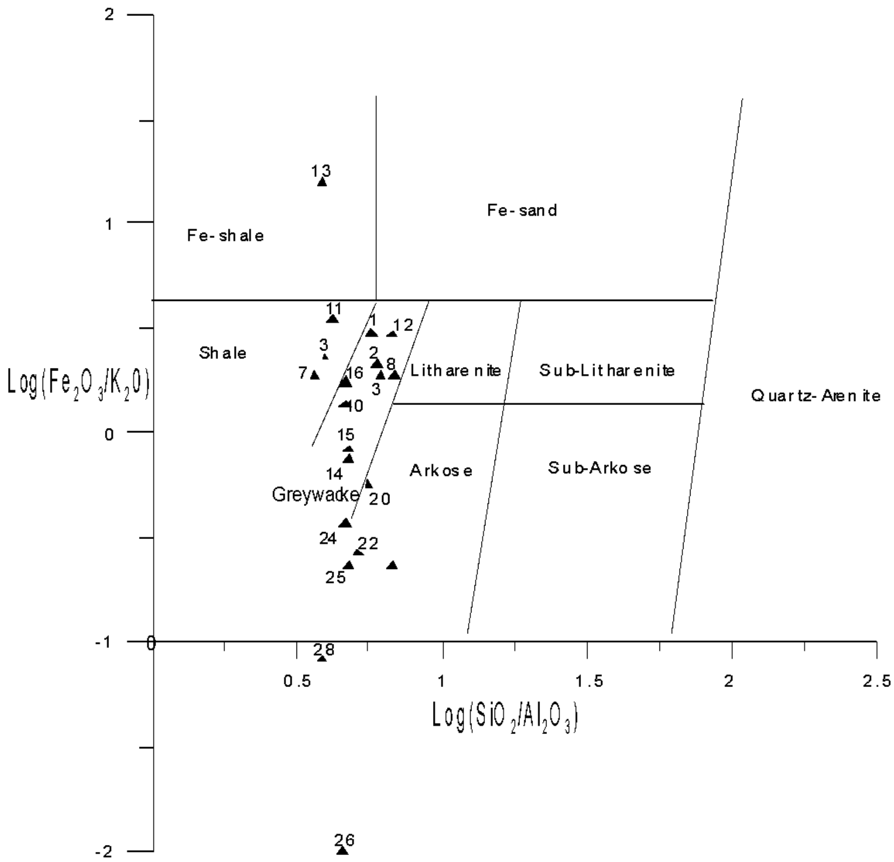


Figure 5. Plot of Log[Fe_2O_3(t)/K_2O] versus Log(SiO_2/Al_2O_3) (after Herron, 1988) for the determination of the composition of sedimentary protoliths of the Precambrian Basement Complex rocks around Keffi.

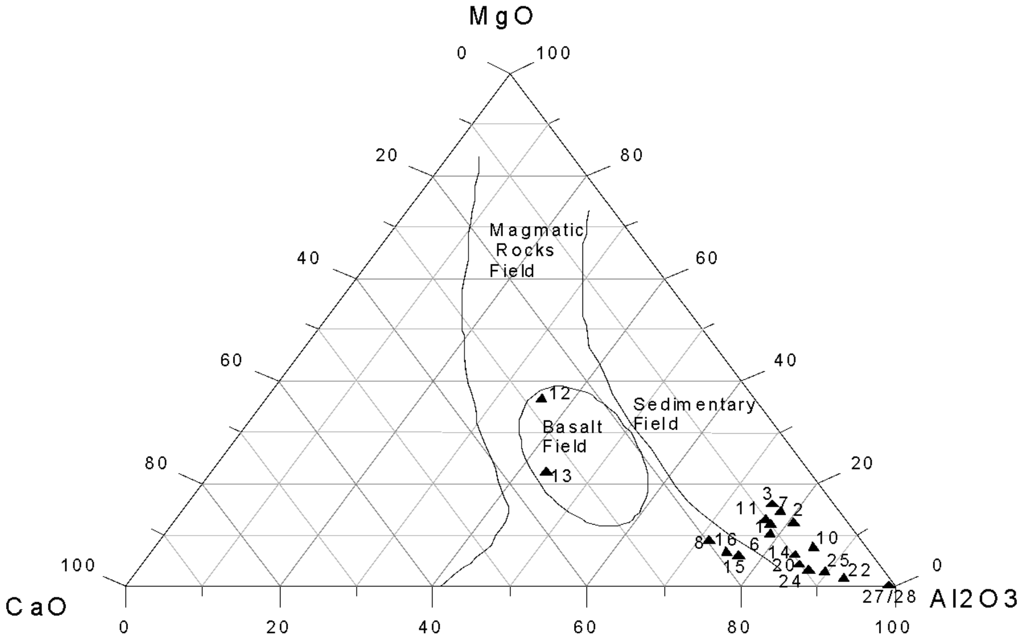


Figure 6. MgO-CaO-Al_2O_3 (ternary) diagram for discrimination of the protoliths of Precambrian Basement Complex rocks around Keffi (after Leyreloup et. al., 1977).

The hornblende schist shows twice the concentration of the light rare-earth-elements (LREE) and half the concentration of the heavy rare-earth-element (HREE), compared to the crustal concentrations, suggesting that the hornblende schist is more fractionated and therefore of a more basic protolith. The REE data are normalized to the chondrite composition of Nakamura (1974) with additions from Haskin et al. (1968) and used to plot REE patterns (Figs. 9b, 10a and 10b).

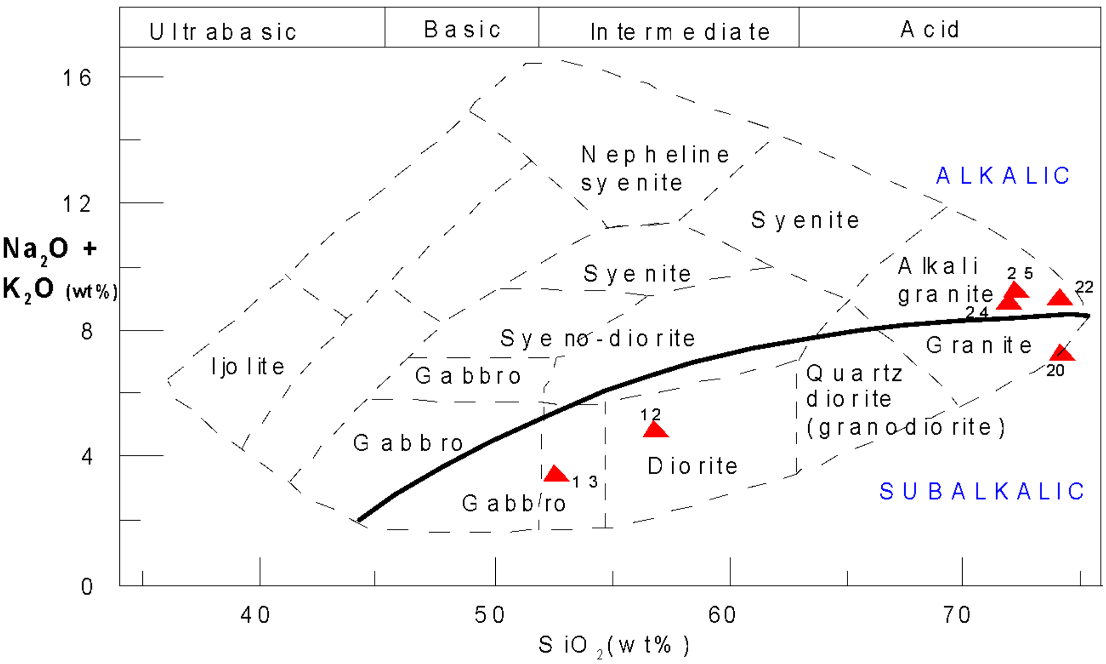


Figure 7. Total alkalis vs Silica diagram for the gneisses and granitic rocks in the study area.

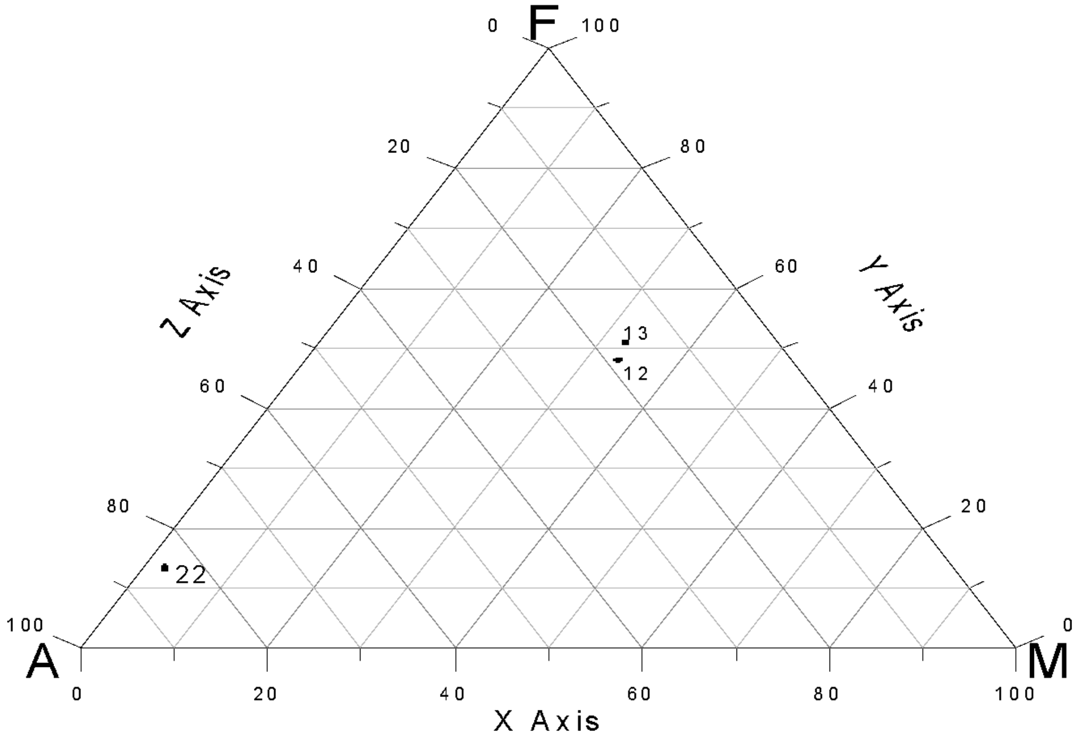


Figure 8. AFM diagram of the meta-igneous rocks and granite around Keffi, showing their calc- alkaline affinities.

All the gneisses and the granite except the banded hornblende gneiss (sample 13), have values slightly greater than or equal to crustal values of the LREE and slightly less than or equal to crustal values of the HREE. The REE compositions of the banded hornblende gneiss compare well only with those of ultrabasic compositions. This also suggests that the banded hornblende gneiss has ultrabasic protolith but may have undergone little fractionation to the basic composition as shown by the MgO-CaO-Al_2O_3 ternary diagram.

The pegmatites (samples 26 and 28) show absolutely low concentrations in both the LREE and HREE relative to crustal values while sample 27, shows conformity with crustal abundances of the REE. In terms of Cr, Co and Ni, the hornblende schist (sample12) shows basic to ultrabasic chemistry while the banded hornblende gneiss has basic chemistry (Taylor, 1955).

The chondrite-normalized REE patterns of all the schists, gneisses, granite and the pegmatite (27) (Figs. 10, 11 and 12) are characterized by enrichment in the light rare-earth-elements relative to the heavy rare-earth-elements, with over 70 times chondrite value for La and over 50 times chondrite value for Ce. This indicates a high level of fractionation, hence high fractionation indices. They also show negative (Eu) anomaly which is more pronounced in the gneisses and granite relative to the schists (compare Fig. 10 with Figs. 11 & 12). The negative Eu-anomaly indicates plagioclase fractionation with the highest fractionation in the gneisses and the granite. This is also supported by the quantitative measure of Eu-anomaly which is least in the gneisses and granite ie. Eu/Eu*, (Table 5). They all show flat HREE trends, with the values for the schists between 10 and 20 times chondrite and those for the gneisses between 0 and 25. It is not surprising that sample 7 which is garnet-mica schist, has a high concentration of Gadolinium (Gd) because, garnet and apatite with their smaller lattice sites show preferential enrichment in the smaller rare-earth elements (HREE).

Figure 9a. 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) Chondrite-normalised rare-earth-element patterns for the schists (1-11)

Fig.10a. Chondrite-normalized rare-earth-element patterns for the Hornblende schist (12), banded hornblende gneiss (13), Migmatitic banded gneiss (14 & 15) and Porphyroblastic/augen gneiss (16-20). (b) Chondrite-normalized rare-earth-element patterns for Garnetiferous-granite (22) and Porphyroblastic/augen gneiss (20, 24 and 25) from Keffi and its environs.

The banded hornblende gneiss (sample 13) shows an almost flat-lying REE pattern with slight LREE enrichment and flat HREE trend which is essentially 15 times chondrite. The hornblende schist (sample 12) shows the highest LREE enrichment of all the samples analyzed. Its HREE content is the lowest of all the schists, with a sloping trend. The fractionation trend of this rock has certainly been affected by that of the various tiny veins of cross cutting quartzo-feldspartic materials and by the metasomatic effect of the surrounding host gneiss. High fractionation factor $(La/Yb)_n$ (1.28 to 66.30) and pronounced negative Eu-anomalies suggest derivation from partial melting of hornblende-rich crustal sources.

In terms of rare-metals enrichment, the barren varieties of pegmatites from all the investigated localities in Nigeria are found to have K/Rb ratios above 100 and Rb values below 500 ppm while the mineralized ones have K/Rb <100 and Rb values >500 ppm (Stavrov et al., 1969)**.** Based on this, the pegmatites in this study can be classified as mineralized as seen in samples 26, 27 and 28 ,which have K/Rb ratios of 95, 75 and 84 and Rb values (>1000, 455 and >1000 ppm), respectively. They are mineralized with Sn (>1000 ppm in sample 27) and Be (=2097 ppm in sample 28)

The similarity in the major element oxides, trace- and rare-earth-elements compositions of most of the rocks in this study with crustal compositions is strong indication that they are crustally-derived. The ubiquitous LREE enrichment, suggesting high fractionation in the schists and gneisses, coupled with pronounced negative Eu-anomalies suggests that their sedimentary progenitors were derived from a cratonic source (Taylor and McLennan, 1985; Das et al., 2008).

4.0 Summary and Conclusion

The Precambrian Basement Complex rocks around Keffi, north-central Nigeria are essentially of sedimentary with minor calc-alkaline igneous sources. The sedimentary protoliths are dominantly greywacke followed by arkose and then shale. All the gneisses (migmatitic banded and porphyroblastic/augen) gneisses, some samples of the garnet-mica schist (1, 2, 6, and 8) have greywacke protoliths. Other samples of garnet-mica schist (3, 7, and 11) and the staurolite-mica schist (10) have shale protolith while some porphyroblastic/augen gneisses (20 and 25) have arkose protoliths. The hornblende schist (12) and banded hornblende gneiss (13) are most probably of calc-alkaline igneous protoliths of basic to ultrabasic compositions.

Orogeny and subsequent volcanic-arc activities were very important regimes in the paleo-environmental tectonics of the study area.

The major element oxides, trace- and rare-earth-elements compositions of the rocks suggest that their sedimentary progenitors were derived from a cratonic/crustal source, possibly in our case, the Older Granite suite.

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