PETROGRAPHY, GEOCHEMISTRY AND PETROGENESIS OF GREY GNEISSES OF PART OF OKE-ODE AREA, SOUTH-WESTERN NIGERIA

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Abstract
Oke-Ode area, northeast of Ilorin, is part of the Precambrian Basement Complex of southwestern Nigeria. There are no published data on the gneisses, which are well exposed, unlike the adjacent terrains. The area was mapped in order to determine the petrographic, geochemical and petrogenetic attributes of the grey gneisses. The acquired sets of field, mineralogical, and geochemical data indicated that the medium-to coarse-grained gneisses are of igneous origin, and have witnessed multiple tectono-thermal readjustments. Occurrence of xenoliths in the rocks points to magmatic origin. The range of anorthite molecular contents of the plagioclase (An26-34) suggests an andesine to oligoclase composition, indicating derivation from granodioritic to tonalitic progenitors. Petrographic studies showed that the rocks witnessed complex interplay between metamorphism, deformation, and migmatization, which culminated in grain-boundary migration under a relatively stable, low-strain, high-temperature conditions involving mechanical rotation, during grain-scale dynamic recrystallization. Geochemically, plots of Ni vs Zr/TiO_2 and K_2O/Al_2O_3 vs Na_2O_3/Al_2O_3 also constrained the the gneisses to the igneous field while the TiO2 - K2O - P_2O_5 ternary plot further indicated a continental tectonic setting prior to the widespread Pan African magmatism. The rocks are essentially peraluminous calc-alkaline rocks, which are moderately saturated with respect to silica. They are products of fractional crystallization of a basaltic magma in a continental setting but later reworked during the Pan African time. The grey gneises have similar geo-chemical characteristics with some gneisses from other parts of the Basement Complex of Nigeria, but at distinct variance with others.

Keywords: Grey gneisses, geochemistry, xenolith, tonalitic gneiss, peraluminous, precambrian

Introduction

The study area is situated about 50km NE of Ilorin and about 80km SE of Jebba, in part of the Precambrian Basement Complex of south-western Nigeria, east of the West African Craton (Fig. 1). Varieties of gneisses, some of which are migmatized, outcrop in various parts of Nigeria and have been described under different nomenclatures such as banded gneiss, early gneiss and grey gneisses. They are also sometimes referred to as granodioritic, tonalitic or granitic gneisses on the basis of origin and petrography (Adedoyin, 2015; Annor, 1986). Gneisses have been studied by several authors (Adedoyin, 2015; Okonkwo and Garnev, 2012a, 2012b; Kroner et al, 2001; Dada, 1989; Dada et al, 1995; Dada, 1999). King and de Swardt (1949) worked around the south-eastern quadrant of Sheet 224, which is outside the present mapped area while Oluyide et al (Oluyide et al, 1998) worked on the adjoining Ilorin Sheet to the west and both constrained the gneisses to the Precambrian. On the basis of field associations with meta-sediments, Oluyide et al (op. cit) are of the opinion that the migmatitic gneisses of Ilorin area (Sheet 50), to the west, are of sedimentary origin. But Rahaman (1988) opined, as we do, that field methods are often inadequate determining the origin. In Jebba area, north-wesk of the present study area, although the migmatitic gneisses were constrained to a sedimentary parentage (Okonkwo and Wincester, 1996), yet, about one-third of their samples point to igneous sources. However (Odigi, 2002) got a contrary source for the Bode Saadu orthogneisses, southwest of Jebba, which they constrained to be calc alkaline, magnesian, metaluminous and of Eburnean age. In Okene-Lokoja area, south-east of the present study area, (op.cit) deduced igneous origin for the gneisses. From the published data, it is clear that the chemistries of the rocks are variable from one locality to the other.

In this study, field, mineralogical, and geochemical evidences were used to determine the origin of the migmatitic gneisses. This paper presents results of the petrography, major-element and selected trace-element geochemistry for the petrogenesis of the grey gneisses of part of the Basement Complex of southwestern Nigeria for which there are no published data. Several authors (Ejimofor et al, 1996; Ephraim, 2012) have used major elements and selected trace kelements to study gneisses in other terrains. We are also of the opinion that the results of this work will provide initial information, which are hitherto lacking, on the studied grey gneisses and more so in understanding the interplay between the geotectonic and geodynamic processes involved during the evolution of the rocks.

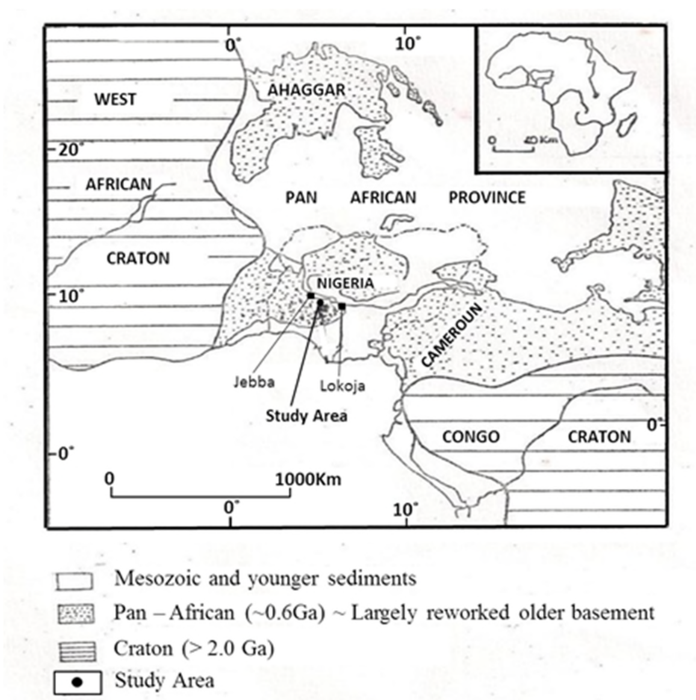

Fig. 1: Location of the study area within the Pan African mobile segment of West Africa. Inset is the position of Nigeria within the African continent (Boher et al, 1992).

Materials and Methods

Geological fieldwork was carried out on scale 1:25000 in the area which covered about 1100 Km2. Some of the selected samples were used in preparing thin-sections that were studied under a conventional petrographic microscope. Other samples were pulverized at the Obafemi Awolowo University, Ile-Ife, Nigeria, by standard jaw crushers to ≤40µ in preparation for geochemical analysis. Major, minor, trace and rare earth elements were determined through Inductively Coupled Plasma (ICP) methods which were carried out at the Activation Laboratories (ACTLABS) Ltd, Canada. The major oxide geochemical results of the gneiss samples were also subjected to correlation analysis to corroborate other petrographic and geochemical results.

Results and Discussion

Geology and Petrography

Migmatitic gneiss of varying compositions and structures form the country rocks (Fig. 2) which is overlain by members of the Quartzite-Schist Complex and intruded by late- to post- tectonic granitoids (Adedoyin, 2015). It is the oldest rock unit in the area, occurring as low-lying exposures which make sharp contacts with the intrusive units.

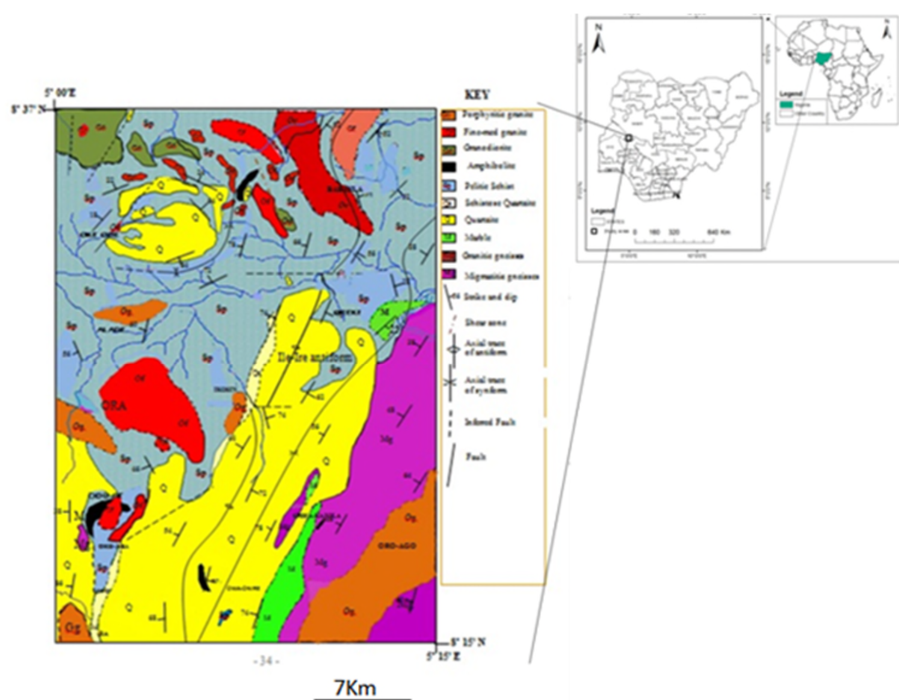

Fig. 2: Geological map of the study area, showing the areas of occurrences of gneiss (modified after Adedoyin, 2015).

To the right are locations of the study area in Nigeria, and the position of Nigeria in Africa.
Apparently, the intensity of migmatization was observed to increase towards the northeast in the area. In the west and central areas they appear to be light grey with high proportion of felsic

materials while in some cases, finely stripped banded variants of the gneisses (Fig. 3a) occur extensively, especially in the north-eastern part of the study area.

Several structural features such as stretching lineations defined by biotite and/or hornblende; shear zones; asymmetric to recumbent folds; and a host of felsic veins occur in the rock. In hand specimens, the rock is in shades of grey with medium to coarse-grained texture. In thin section (Fig. 3b), the mineralogy consists of quartz + biotite + microcline + plagioclase (An26 – 34) ±cordierite ± hornblende ± pyroxene ± muscovite ± myrmekite.

Fig. 3a: Field photographs of Gneisess. Left: Striped (stromatic) migmatitic gneiss, which developed probably in a major shear zone as a result of higher strain rate. north-eastern part. Length of pen is 14cm. Right: More light-coloured grey gneiss from the central areas.

Apatite, sphene ± garnet and opaque minerals are the accessories. Quartz and plagioclase are the most abundant mineral constituents. The albite twinning in some of the plagioclase crystals is preserved but some occur as distinct, stout crystals, which are often rimmed by myrmekite.

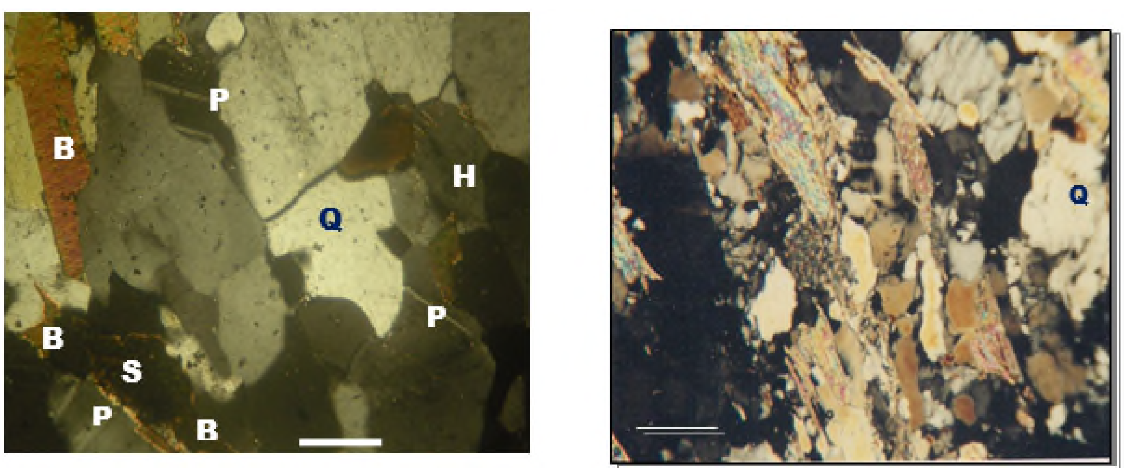

Fig. 3b: Photomicrographs of grey gneiss. Left: Quartz growing at the expense of plagioclase (central area) while biotite is being sericitized. Right: Photomicrograph of porphyroclastic gneiss with preferred alignment of biotite and muscovite. (H=hornblende,

B=biotite, S=sericite, P=plagioclase, Q=quartz, M=muscovite, Per= perthite).

Biotite and hornblendke dominate the mafic contents occurring with distinct preferred orientations, perfect cleavages and strong pleochroism. Kinked or slightly bent biotite depicts high strain. Biotite is more abundant than muscovite, possessing ragged outlines due to sericitization, while muscovite occurs as tiny flakes. Microcline is often quartz-corroded, with subhedral crystals in the groundmass.

There are two generations of quartz: the first consists of large, fractured, anhedral crystals while the second consists of small subhedral quartz in the interstices between larger grains. The smaller crystals grew during metamorphism bk2ut have not been deformed. The larger anhedral quartz crystals are often fractured, signifying mechanical rotation during grain boundary migration but lack of fractures in the smaller varieties indicates a post-deformation evolution for such crystals that took place under a non-tectonic condition. Straight grain boundaries and triple-point junctions in quartz (observed in thin–section} signify stable, low-energy reactions, that depends on thermodynamic equilibrium between mineral grains. Etching of quartz crystals indicates deformation by grain-boundary migration under high temperature and low-strain rate during grain-scale dynamic recrystallization.

Geochemical characteristics

The geochemical concentrations are shown in Table 1. The silica content (~67%) and the Al2O3 (~ 14.73%) are moderate to high. The K2O content is higher than that of Na2O in all samples except for samples RG6 and RG8. The alkali contents of the migmatitic rocks are in the excess of 6%, averaging 7.2%. The relative consistency in the concentration of the alkalis may point to a fairly homogenous nature of the parent rock. The K2O/Na2O values range between <1 to 3.74 while the average K2O/Na2O for the gneisses is 2.8.

SiO2 has very strong negative correlations with all the major oxides (-0.88 to -0.42) except K2O (0.42). On the other hand, Fe2O3 and MnO show positively high correlation coefficients with all other oxides (0.30 to 93 and 0.13 to 0.34, respectively), except with K2O (-0.80). Other oxides with positive correlation coefficients are presented in Table 2 and discussed below.

Table I: Geochemical results of the grey gneisses

	KJ1	RG1	RG4	RG6	RG8	RG10	4L18A	XYZ	OGN	RG5	RG9	Z5
SiO_2	63.34	55.67	66.43	51.99	66.64	71.16	68.1	68.5	74.07	67.56	66.95	77.09
TiO_2	1.12	1.75	0.74	0.88	0.6	0.35	0.1	0.2	0.02	0.62	0.44	1.02
Al_2O_3	15.2	15.74	14.94	14.66	15.77	14.25	18.1	20.77	8.96	14.35	15.94	8.13
Fe_2O_3	7.55	10.72	5.57	11.33	4.1	2.51	0.2	0.16	2.4	4.84	3.67	6.39
MnO	0.08	0.14	0.07	0.2	0.05	0.04	TR	TR	ND	0.06	0.05	0.14
MgO	1.22	1.81	0.93	5.85	1.7	0.84	1.2	1.1	4	0.6	1.43	1.83
CaO	3.12	4.87	2.76	9.99	2.96	1.56	1.26	1.26	1.93	2.26	2.28	0.82
Na O	3.6	3.14	3.38	3.28	3.52	3.06	2.16	2.1	1.78	2.77	4.07	0.91
K_2O	3.59	4.21	4.19	0.88	3.35	5.06	8.07	4.59	5.96	5.65	4	2.57
P_2O_3	0.44	0.62	0.24	0.19	0.21	0.12	0.01	TR	TR	0.18	0.14	0.07

LOI	0.4	0.9k	0.05	0.7	0.7	0.7	ND	ND	ND	0.6	0.8	0.7
TOTAL	99.66	99.58	99.76	99.97	99.61	99.65	100.9	99.71	100	99.49	99.77	99.67
ASI	1.47	1.28	1.44	1.03	1.6	1.47	1.57	2.61	0.92	1.34	1.54	1.89
Q	21.52	10.86	24.64	5.54	25.32	30.08	20.33	34.83	33.65	24.88	21.6	58.25
An	2.7	16.64	12.22	22.86	13.46	7.05	6.24	6.28	-	10.16	10.49	-
Sp	-	2.65	-	1.63	-	-	-	-	0.04	0.02	-	-
Hy	3.06	4.56	2.34	6.18	4.28	2.12	3.01	2.76	6.62	1.52	3.59	4.61
d'	-	-	-	18.32	-	-	-	-	7.42	-	-	-
Ab	30.72	26.91	28.85	27.92	30.12	26.15	18.45	18.02	13.04	23.69	34.76	-
Or	21.39	25.23	24.92	5.26	20.03	30.19	48.05	27.4	35.52	33.74	23.87	15.37
Ap	1.02	1.46	0.56	0.44	0.49	0.28	0.02	0.02	0.02	0.42	0.32	0.16
Ilm	0.17	0.29	0.15	0.43	0.11	0.09	0.09	0.09	-	0.13	0.11	0.3
C	0.76	-	0.39	-	1.49	1.2	3.57	10.19	-	-	1.13	2.54
Rut	1.04	0.53	0.67	-	0.55	0.3	0.05	0.15	-	0.55	0.38	0.87
Hm	7.61	10.86	5.61	11.42	4.15	2.54	0.2	0.16	1.75	4.89	3.71	6.46
Acm	-	-	-	-	-	-	-	-	1.93	-	-	-
Ni	3.8	2.6	3.2	4.1	3.2	4.1	15.3	1.6	17.3	4.4	4.2	28.2
Zr	406	77.9	386	155	65	102	93	162	148	39.2	78.3	25.9
Sr	457.3	292	364	552	394	408	346	396	442.9	385	327	172

Table 2: Correlation analysis result for the Grey Gneisses

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O
SiO_2	1									
TiO_2	-0.55228	1								
Al 2O3	-0.41613	-0.11834	1							
Fe_2O_3	-0.70867	0.871004	-0.25154	1						
MnO	-0.59727	0.782959	-0.28668	0.931941	1					
MgO	-0.41141	0.032093	-0.33945	0.453661	0.485882	1				
CaO	-0.87944	0.44111	0.060673	0.775323	0.744318	0.743742	1			
Na_2O	-0.59621	0.232745	0.438255	0.301797	0.127521	-0.07995	0.41361	1		
K_2O	0.422458	-0.54137	0.204454	-0.71427	-0.79728	-0.47626	-0.63232	-0.23737	1	
									-	
P_2O_5	-0.64614	0.88378	0.099684	0.74239	0.517902	-0.08513	0.410665	0.530231	0.30883	1

The mineralogy revealed a granodioritic or tonalitic progenitor, considering the anorthite molecular contents of the plagioclase. Occurrence of xenoliths in migmatitic gneisses also supports an igneous origin as adduced by earlier workers (e.g. Oluyide et al, 1998).

This view is also supported by earlier workers in adjacent areas (e.g. King and de Swardt, 1949). In south-eastern Nigeria, the grey gneisses are enriched in xenolithic inclusions and are thus considered to have evolved through the processes of stoping, during original magmatic emplacements (Ephraim, 2012). That the rocks are of igneous origink8 and later influenced during the Pan African tectonism shows that they are Pre- Pan African and can therefore be constrained to the earlier Kibaran (1100-950 Ma)? or Eburnean (2400-1800 Ma) orogeny.

The gneisses compare with those of central Nigeria (Odigi, 2012), which are of igneous origin. The elevated potassic contents of the rocks indicate an igneous composition, being similar to the some gneisses in Sierra Leone, which are derivatives of granitoids from mafic magmas (Rollinson, 2018) Migmatization in the Basement Complex, which occurred under upper amphibolites facies regional metamorphism (Onyeagocha and Ekwueme, 1990) contributed to the reworking of the original igneous progenitor. The remobilization through time is revealed in the tectono-thermal imprints and high potassic contents. The moderate silica content of the parent igneous rock, typical of intermediate to mafic rocks, is revealed in both the low quartz content and normative silica. Presence of pyroxene in the rocks is supported by the normative hypersthene, while the occurrences of sphene and apatite are also corroborated by their respective normative values.

The Ni vs Zr/TiO_2 and K_2O/Al_2O_3 vs Na2O3/ Al_2O_3 discriminant plots indicate that the rocks are compatible with those of igneous sources (Figs. 4 and 5).

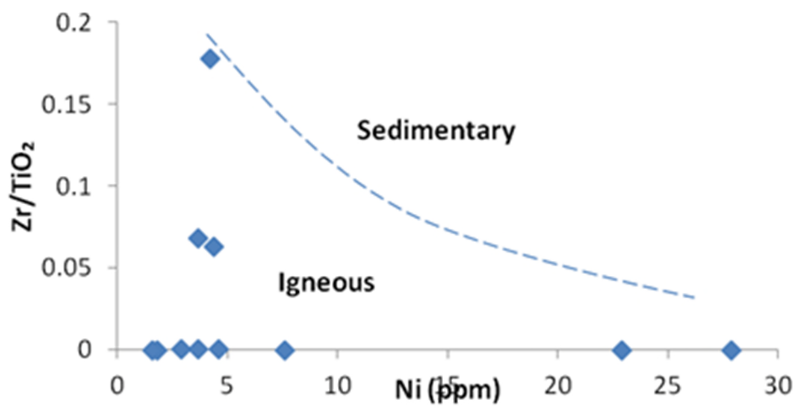

Fig.4 Discrimination plot for the origin of the grey gneisses (Winchester and Max, 1988)

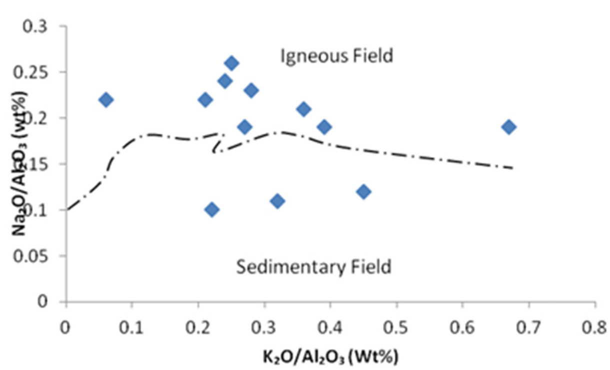

Fig. 5: K_2O/Al_2OvsNa_2O/Al_2O_3 segregation diagram (Garrels and Mackenzie, 1971).

The parent tonalitic rock, typified by high Sr content (~380ppm), is of basaltic origin because tonalite would only evolve from a basaltic magma (Garrels and Mackenzie, 1971, Arth, 1971) while the TiO2 -K2O - P_2O_5 ternary diagram (Fig. 6) indicates a relationship with continental environment. The parent magma was moderately homogeneous and closely resembles those of central Nigeria, which are of non-oceanic origin. Lower $Al_2O_3/CaO+Na_2O+K_2O$ than Al_2O_3/Na_2O+K_2O suggests essentially peraluminous (Fig. 7) rocks, which can also be deduced from the ASI while most of the samples show signatures of high calc-alkaline and calcic-alkalic series (Figs. 8 and 9). Figure 8 shows that the molecular proportion of alumina is greater than those of the oxides of sodium and potassium while, in figure 9, at any point where the weight percentage of calcium oxide and those of potassium and sodium oxides are equal, the weight percent of SiO_2 would range essentially between 51 and 56.

Negative correlation between SiO2 and most of the major oxides could implies that the silica was either sourced from a different environment, of different geochemical affinity. High correlation coefficients of Fe2O3 and MnO reflect similarities in the chemistry of the d-block elements.

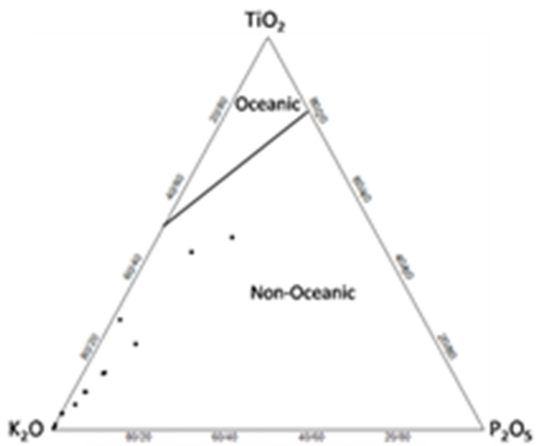

Fig.6: TiO_2 - K_2O - P_2O_5 or the diagram for the gneisses (Pearce, 1975), which depicts a non-oceanic environment.

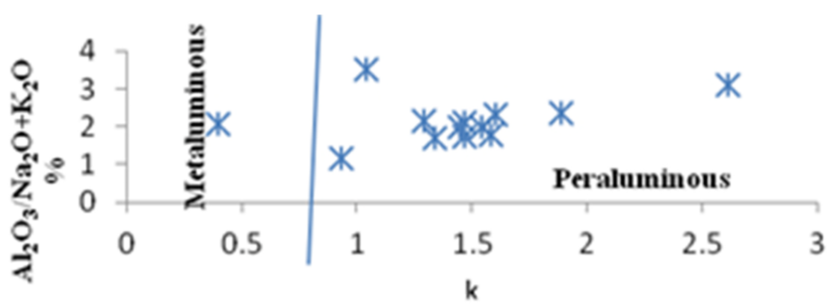

Fig.7: Al2O3/Na2O+K2O versus Al2O3/CaO+Na2O+K2O diagram (Manniar and Piccolli, 1989) indicating a peraluminous nature.

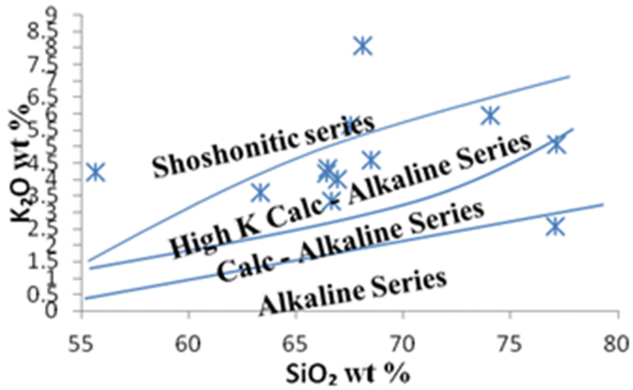

Fig.8: K_2O versus SiO_2 diagram after (Peccerillo and Taylor, 1976) constraining the gneiss into the high calc alkaline field.

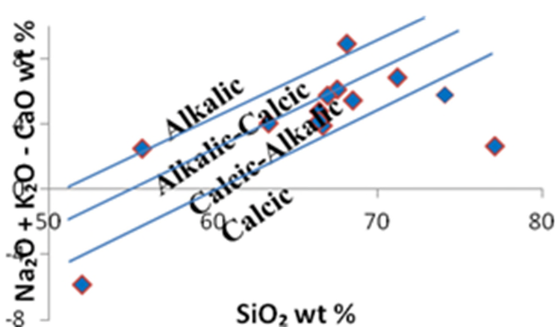

Fig. 9: Na2O+K20-CaO versus SiO2 diagram of the grey gneiss after Frost et al, 2001, indicating the calcic-alkalic nature the rock.

The relationship between Al2O3 and Na2O reflects the presence of plagioclase while the positive coefficient between other pairs of oxides indicates the mafic nature of the original magma, strengthening our claim for basic progenitors

Most of the samples indicate an igneous source while a few suggest sedimentary source. Partial melting of the under-plated Archaean protoliths, triggered by upper-mantle convection-induced processes during the continent-continent collision in the Neo-proterozoic time (Dada, 1997) likely contributed to the notable variations in the chemistry of the Early Gneisses, even at short distances, due to the 'mingling' between igneous and sedimentary materials. Therefore, progenitor of a gneiss terrain is dependent on the level of interactions between the pre-existing igneous and sedimentary materials. The results of this research thus support the opinion that some of the gneisses in the Nigerian Basement Complex are of igneous origin (Rahamn, 1988) as opposed to an entirely sedimentary origin.

Conclusions

The gneisses are metamorphic equivalents of essentially peraluminuos, high K calc-alkaline granodioritic or tonalitic rocks, which evolved from a fairly homogenous basaltic magma in a continental setting. The multiple thermo-tectonic deformations, which led to the obliteration of the original igneous features, were ultimately effected under a relatively stable, grain-scale dynamic process during the widespread Pan-African (600±150 Ma) plutonism..

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