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REE Geochemistry and Protoliths of Gneisses of Northwest Obudu Plateau Southeastern Nigeria

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Abstract
Gneisses, which include migmatitic gneiss (MG), granite gneiss (GG), garnet biotite gneiss (GBG), hornblende gneiss (HG) and garnet sillimanite gneiss (GSG), underlie more than 70% of the area northwest Obudu Plateau in Southeastern Nigeria. These rocks are associated with schists, amphibolites and metagabbros and are intruded by granites, dolerites and pegmatites. The mineral assemblage consists of biotite – garnet - plagioclase (An_{32}), orthoclase – kyanite – sillimanite – hypersthene, indicating that the GBG and GSG had attained the uppermost amphibolite facies, and the MG and GG possibly the granulite facies metamorphism. The rare earth element (REE) distribution shows that the gneisses are enriched in the lighter rare earth elements (LREE) La, Ce, Pr and Nd, with concentration ranges from 8.6-112.9 ppm, 18.5-264.7 ppm, 2.39-33.99 and 9.9-137.8 ppm respectively, and relatively depleted in the heavy rare earth elements (HREE) Lu, Tm, Tb and Ho, with values of 0.07-0.37 ppm, 0.08-0.59 ppm, 0.34-1.58 ppm, and 0.29-1.07 ppm respectively, and they exhibit pronounced negative EU anomaly, indicating that the rocks are highly fractionated. Combined geochemical signatures, REE-chondrite normalized spidergrams and plots in the chemical discrimination diagrams including the Y versus Nb plot, show that the protoliths of the MG and GG gneisses were derived from partial melting and differentiation of granitic magma of hybrid origin which were emplaced in volcanic arc (VAG) to Syn-collision granite (Syn-COLG) tectonic setting. The GSG and GBG gneisses were derived from peliticprotoliths.

1. Introduction

Northwest Obudu is a part of the Obudu Plateau, a Precambrian basement spur in Nigeria. This together with the Hawal and Oban massifs constitutes the southeastern Nigerian basement Complex. The Gongola-Yola arm separates the Hawal massif from the Obudu Plateau which is in turn separated from the Oban massif by the Mamfe Embayment. These basement structures are bounded by the West African craton to the west and the Congo-Gabon craton to southeast (Fitton, 1980; Owona et al., 2012; Fig.1). The Obudu Plateau has been described as a vast westward projection of the Bamenda Massif of Western Cameroon into Southeastern Nigeria (Fitton, 1980; Toteu, 1987). Geological mapping and exploration of the northwestern Obudu basement areas had been few and inadequate compared with its Northern and Southwestern counterparts, and the sedimentary areas. Moreover, no rare earth element (REE) geochemistry of the Northwest Obudu area exists in literature. The early reconnaissance petrographic and major element geochemistry of the area was carried out byEjimofor et al., (1996). Other detailed geological works on adjacent blocks of Obudu Plateau include those of Ekwueme, (1993), Ukwang (2007) and Obioha and Ekwueme (2011, 2012). The present study is aimed at using the rare earth elements distribution, abundance and characteristics of the gneisses to unravel the petrogenesis of the area northwest of Obudu Plateau.

Location of Study Area

The area of study, Northwest Obudu Plateau is geographically situated between latitudes$6^0$45'N - $7^0$00'N and longitudes $9^0$00'E - $9^0$16'E in topographic sheet 291 Obudu (Fig. 2). It covers an approximately surface area of 860.32 km^2, extending from Ushongo, Konshisha to Kwande and Vandeikya local government areas of southern Benue State, to parts of Obudu and Bekwara Local Government Areas in northern Cross River State of Southeastern Nigeria (Fig. 2). The area is accessed by the Calabar – Adikpo – Katsina – Ala high way and the Obudu – Vandeikya – Ihugh – Gboko roads and other minor roads and tracts which were utilized during the mapping and samplecollection exercise. The area is drained by threemain rivers Aya, Dura and Konshisha rivers and their tributaries forming a fairly dendritic – trellis drainage pattern (Udo, 1970).

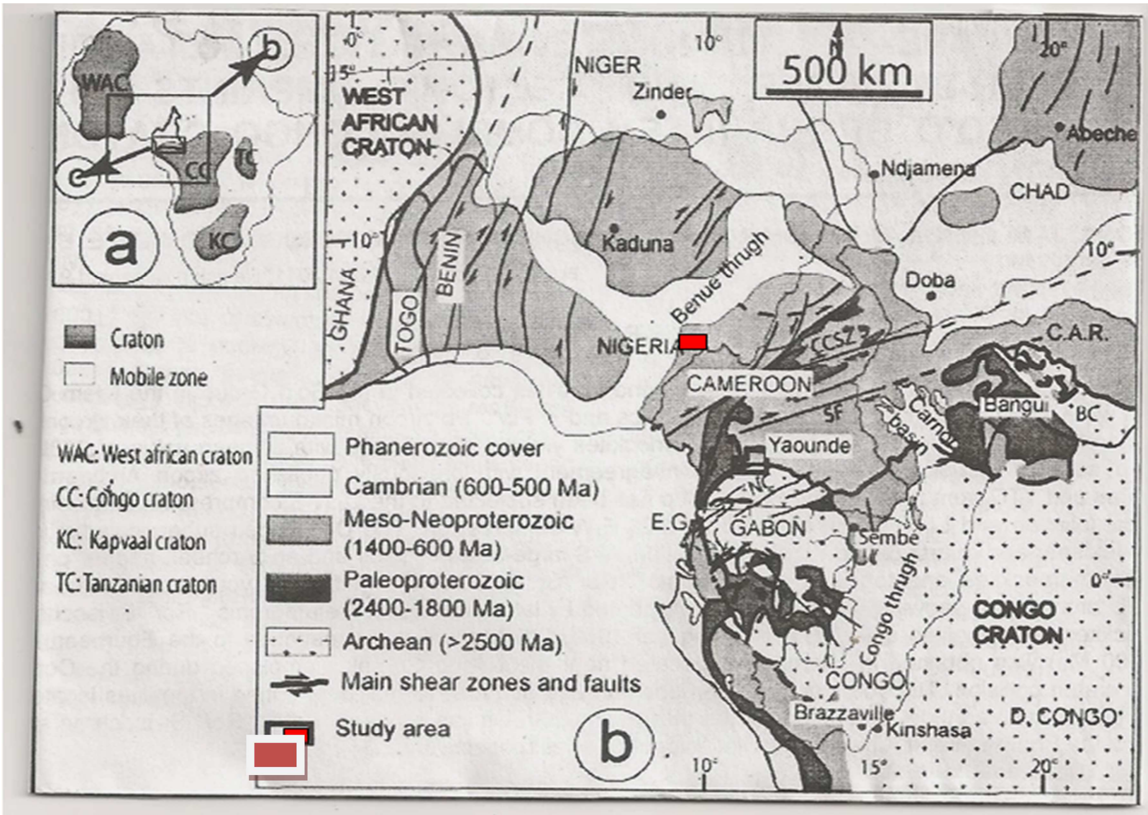

Fig. 1. Generalized geological map showing the Pan-African Belt of Nigeria and the location of the study area inObudu Plateau (Modified after Owona et al., 2012): Inset: (a) –Map of Africa showing (B), the Pan-African belt, the various cratons and mobile belts, (C) Obudu plateau exteuding from the Bamenda Massive of Cameroom into SE. Nigeria.

2. Geological Setting

Two mega-structural spurs constitute the Precambrian basement terrains in the northeastern and southeastern Nigeria, namely; the Hawal Massif (northeast), the Obudu Plateau which is separated from the Oban Massif by the Mamfe Embayment in the southeast. They were affected by the Pan-African thermotectonic events including high grade metamorphism, resulting in the occurrence of migmatites, gneisses, granites and granodiorites (Rahaman et al., 2005). These granulite facies gneisses and metapelites were intruded by Jurassic alkaline granites, dolerites, aplites and pegmatites of various dimensions and orientations (Bowden and Kinnaird, 1984; Benkhelil, 1986; Rahaman et al., 2005; Ephraim, 2009;Obioha and Ekwueme, 2011). Three main metamorphic rock suites, namely; migmatite - gneiss complex, granite gneisses and amphibolites occur in the area, into which the igneous rocks, mainlypegmatites, dolerites and basalts were emplaced. Ekwueme (2010) in a review of the Pan-African events of Southeastern Nigeria affirmed the occurrence of these gneisses, granitoids and metasedimentary schist belts in the Obudu area and gave their isotopic ages. Some of the interesting field features occurring in the study area are presented in Figs. 3 showing some aspects of the mega-structural features of the Northwest Obudu Plateau. The area is a polymetamorphic terrain, in which the gneisses had undergone the uppermost amphibolite to granulite facies metamorphism.

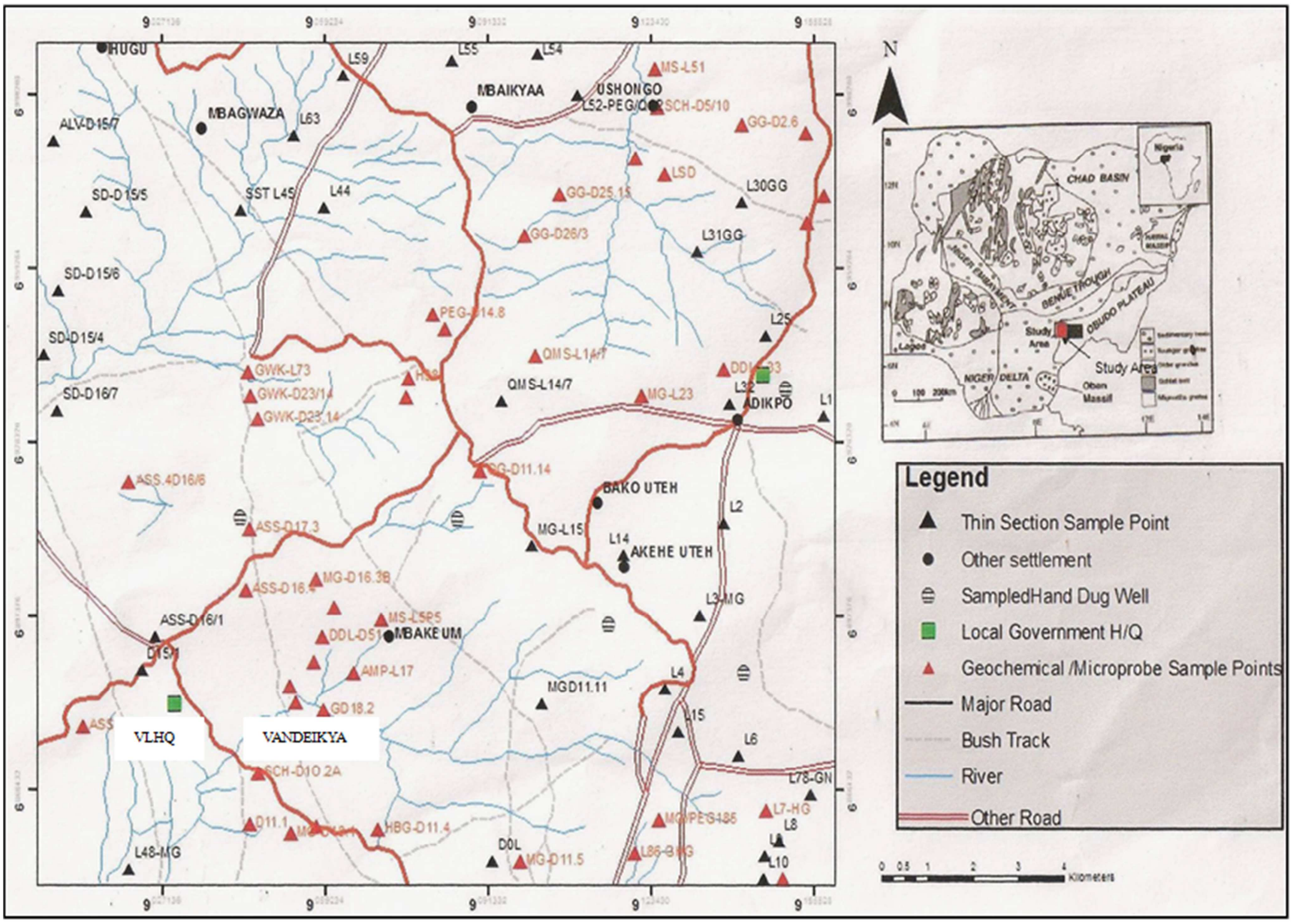

Fig. 2. Sample Location Map of Northwest Obudu Plateau, SE. Nigeria. Inset: Geological map of Nigeria showing the location of the study area in Obudu Plateau.

3. Sampling Technique and Petrography

The field mapping involved a detailed and systematic traversing and investigation of all the geological features and outcrops occurring in Northwest Obudu Plateau, using global positioning system (Magellan 300 GPS) to determine the locations, bearings and elevations of outcrops (Fig. 2). The streams/rivers channels, ridges, road cuts and quarries/mines occurring in the study area were carefully investigated. The foliations, strikes and dips and other structural features of the rocks were determined. Photographs of some field features were taken using digital cameras (Fig. 3). A digitizedgeological map of the study area showing the various litho-structuralunitsoutcropping in the area was produced (Fig. 4). Care was taken to ensure that about 50 representative samples of the gneisses were collected for laboratory analysis. Fifty thin sections of representative rock samples were prepared at the Geological Engineering Workshop / Laboratory of the University of Calabar, Nigeria. Error reduction was ensured by the use of conventional laboratory equipment and accurately grinding the slices to 0.03mm diameter for effective view and mineral identification. Modal analyses of the rock samples were carried out and the result tabulated (Table 1).

Five main types of gneisses occur in Northwest Obudu area, namely: migmatitic gneiss (MG), granite gneiss (GG), garnet biotite gneiss (GBG), and subordinate amount of garnet sillimanite gneiss (GSG) and hornblende gneiss (HB) (Obioha and Ekwueme, 2011). The dominant mineralogical assemblage in the analyzed gneiss samples consists of: quartz, plagioclase (An_{32}), biotite, garnet, orthoclase and hypersthene in the MG and GG gneisses; quartz, plagioclase (An_{32}), biotite, garnet, kyanite, sillimanite in the GSG; and quartz, plagioclase (An_{32}), biotite, garnet, orthoclase ± muscovite in the GBG (Tab1e 1). This assemblage indicates that all the gneisses had attained the upper amphibolite facies metamorphic grade. The occurrence of hypersthene in the modal assemblage of the MG and GG indicates that they have possibly attained the granulite faciesmetamorphism. Kyanite and sillimanite occur in the GSG, to an enrichment of 24 and 7 vol. % respectively, indicating formation from pelitic sources under medium to high pressure / temperature conditions. The presence of retrogradechlorite, variation in textural and structural orientations and the regional foliation in most of the rocks, all corroborate the fact that northwest Obudu area had experienced polyphase deformation and metamorphism.The coexistence of the index minerals garnet and hypersthene in the migmatitic and granite gneisses assemblages corroborates their possible attainment of the granulite facies metamorphism. The kyanite occurs as blades while the sillimanite occurs as a fibrous mass. The biotite shows pleochroism. The plagioclase is colourless, has low relief and twined on albite law. The hornblende is distinguished from pyroxene by its double cleavage directions, which are parallel to the rhombic prism at 56^o and 124^o as contrasted to that of pyroxene, which are about 87^o and 93^o, (Ekwueme, 1994; Rahaman, et al., 2007). Garnet occurs in all the samples as subhedral - euhedralporphyroblasts that range in size from medium (0.5mm) to coarse (2.0mm).

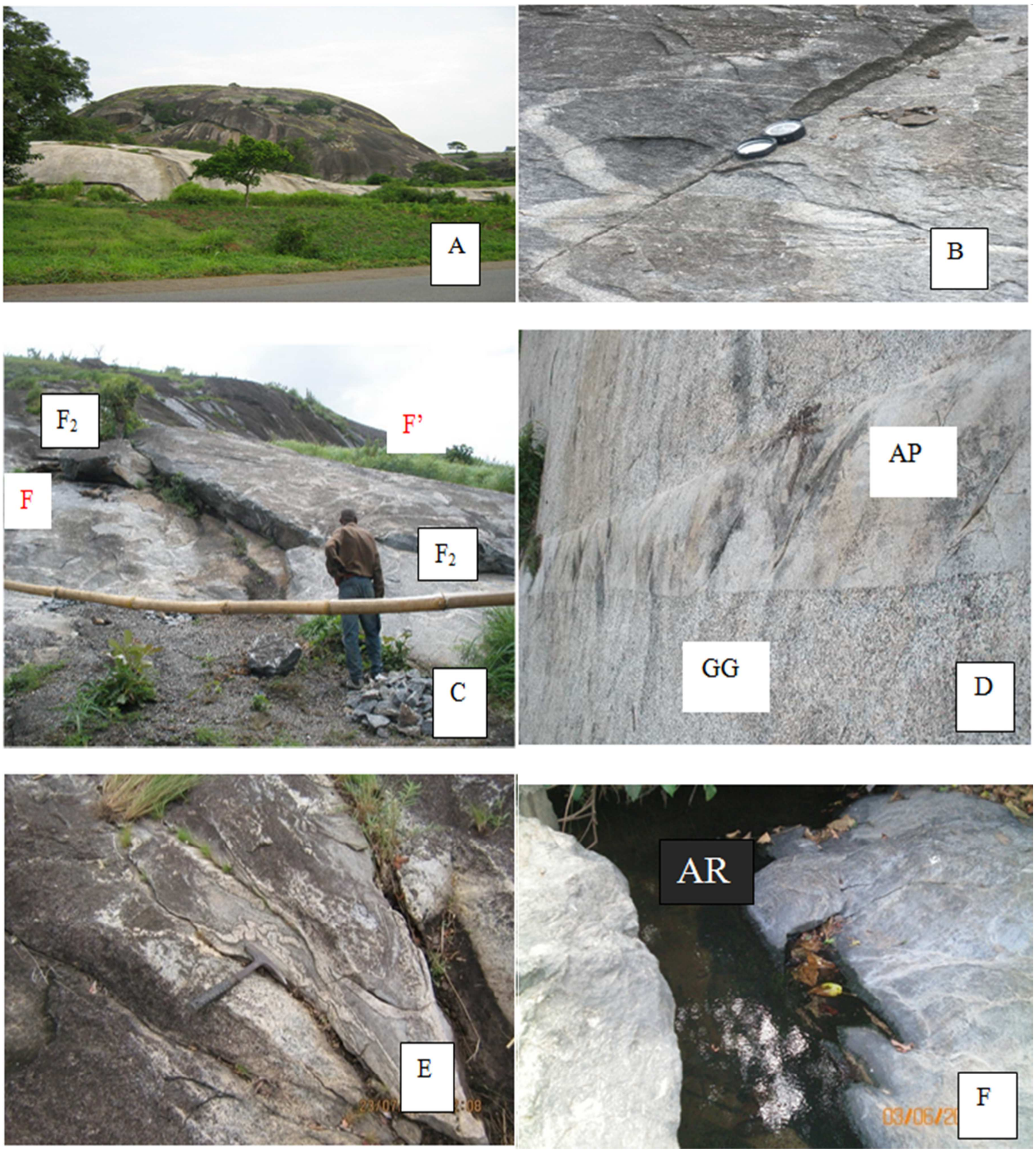

Fig. 3. *Field relations /structures of the gneisses of Northwest Obudu Plateau, SE. Nigeria:*

A =Granitoid Structure of the granite gneiss at Ushongo.
B = Hornblende gneiss, showing sinistral normal fault trending NE-SW.
C =Migmatitic gneiss at Mbakeum Quarry showing NE-SW (F-F') and NW-SE (F_1-F_1') trending faults.
D = Granite gneiss, showing aplitic dyke truncating NE-SW Foliation at Mbaya 2 Ushongo.
E = Garnet biotite gneiss at Nende, showing plunging folds, with axis trending NW-SE.
F = Porphyroblastic gneiss, complexly deformed and faulted, with angular fractures forming angular drainage pattern for Aya River (AR), in Vandeikya.

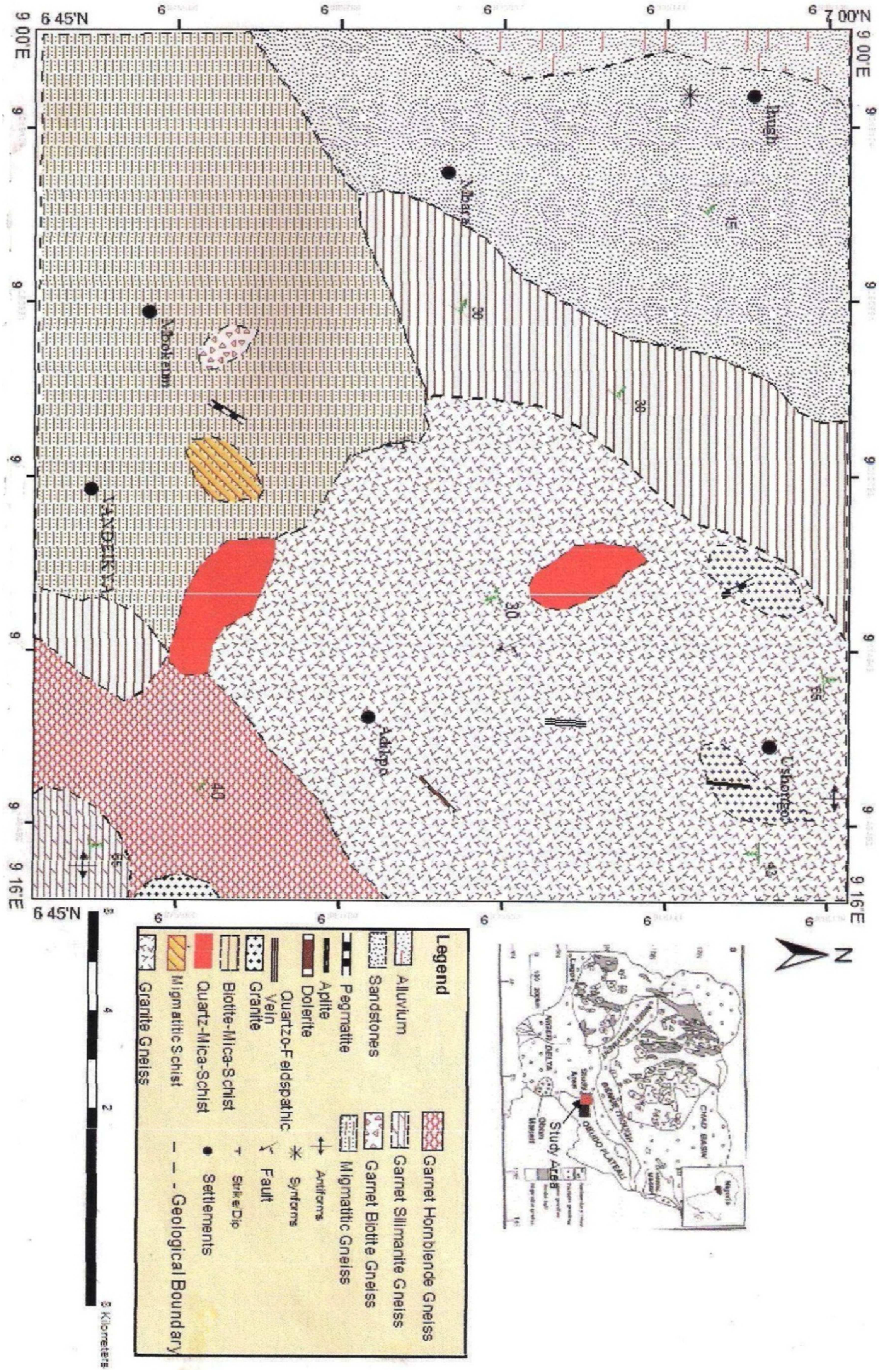

Fig. 4. *Geological map of Northwest Obudu Plateau, Southeastern Nigeria. Inset: Geological map of Nigeria showing the Basement and sedimentary areas.*

Table 1. *Average modal composition (vol. %) and mineralogical assemblage of gneisses of Northwest Obudu Plateau, Southeastern Nigeria.Key for rock types: MG.AYA = Migmatitic Gneiss from Ayanga. MG.MBK = Migmatitic Gneiss from Mbakeum quarry.GG.US = Granite Gneiss from Ushongo. GG.MBN = Granite Gneiss from Mbahan. GSG.ADKH = Garnet Sillimanite Gneiss from Andoaka Hill. GBG.VDK = Garnet Biotite Gneiss from Vandeikya, n = number of analysis.*

MINERAL	MG.AYAn = 5	MG.MBKn = 5	GG.USn= 5	GG.MBNn = 4	GSG.ADKHn = 4	GBG.VDKn = 4
Quartz	31	25	19	20	22	16
Plagioclase	33	32	33	36	18	38
Orthoclase	11	18	20	10	5	11
Biotite	14	10	12	10	16	17
Muscovite		2		3		2
Garnet	4	5	5	5	6	7
Hornblende			2	3	-	=
Kyanite					24	-
Sillimanite		2			7	-
Hypersthene	2	2	3	2	-	-
Chlorite				2	-	2
Opaque	2	3	5	7	2	6
Apatite	3	1	1	2	-	1
Total	100.0	100.0	100.0	100.0	100.0	100.0

Mineralogical Assemblages:
Quartz-Oligoclase- Biotite- Garnet– Orthoclase ± Hypersthene; in the Migmatitic and Granite Gneisses
Quartz-Oligoclase- Biotite- Garnet –Kyanite – Silimanitel– Orthoclase; in the Garnet Sillimanite Gneiss
Quartz-Oligoclase- Biotite- Garnet – Orthoclase; in the Garnet Biotite Gneiss

4. Analytical Technique

Fifteen representative gneiss samples were selected and analyzed for their major and rare earth element contents using two separate analytical methods: the G4A-G4B inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma emission spectrometry (ICP-ES), at the Acme Laboratories LTD, Vancouver Canada. The samples for the whole rock geochemical analysis were prepared by the conventional dressing techniques (Potts, 1987; Ekwueme, 1994). This involved cutting 1kg of specimen, crushing and sieving to 80 % passing 10 meshes, splitting 250g and pulverizing to 85 % passing 200 meshes. The weighing, mixing of pulps and digestion were done by special electronic handling (SEH). The samples were separately digested using Li-borate and Li-tetraborate, followed by fusion with nitric acid. The instrument resolution is 0.001 ppm, which corresponds to the lower detection limit for the trace and rare earth elements (REE), and 100 wt. % for the major element oxide.

5. Results

The result of the whole rock major element geochemistry of the gneisses of Northwest Obudu area had been given by Obioha and Ekwueme (2011), hence only a summary is given here. According to results presented in Table 2, all the gneisses are enriched in $Si0_2$ (63 – 72.9 wt %), Al_20_3 varies from 12.76 to 15.99 wt. %, and characteristically greater than the sum of the alkalies plus Ca0, with $K_20 > Na_20$, in the GBG and MG and vice versa in the MG and GG. This variation trend is in line with the mixed crustal metapelitic-metaigneous character of their protoliths. The alkalis increase with increasing $Si0_2$ content, and a corresponding decrease in the ferromagnesian components Mg0, Ca0 and $Fe_20_{3\ (total)}$, thus, corroborating the mixed metasedimentary / metaigneous nature of their protoliths. The Fe_20_3, Cr_20_5 and $Ti0_2$ contents are variable, being depleted in the MG and GG and relatively enriched in the GSG and GBG (Table 2). The CIPW Norm content shows enrichment in the Q(s), Or, and Ab with corresponding depletion in Ol, Mt and Ap, which is in line with their pelitic derivation (Table 2). The result of the Niggli Norm analysis (Table 2), corroborates both the Major elements and CIPW norms results. For example, the Niggli Al and Alkrange from 31- 47; and 14 – 32, +ve Qz values in all the samples (Table 2).

5.1. REE Abundance and Distribution

The results of the abundance and distribution of the rare earth elements (REE) in the gneisses of Northwest Obudu area are presented in Table 3. The results show that the gneisses are highly enriched in the lighter rare earth elements (LREE) Sm, Pr, Nd, La and Ce, in that order of increasing abundance, with values of 2.41 - 20.18 ppm, 2.39 – 33.99 ppm, 9.9 – 137.8 ppm, 8.6 - 112.9 ppm, 18.2 - 264.7ppm, respectively; and relatively depleted in the heavy rare earth elements (HREE) Lu, Tm, Tb, Ho, Yb and Er, with values ranging from 0.07 - 0.56 ppm, 0.08 - 0.59 ppm, 0.34 - 1.58 ppm, 0.29 - 1.07ppm, 0.52 – 3.89 ppm and 0.69 – 3.99 ppm respectively (Table 3). A pronounced negative Eu anomaly in all the analyzed samples, indicate that the gneisses are highly fractionated. For example, the La concentration varies from 8.6 ppm in the GBG at Vandeikya through 21.4 ppm in the MG at Ushongo, to 112.9 ppm in the GG at Mbahan, with an average value of 40.78 ppm, which is the same as the average abundance of 20 ppm in shale (Haskin et al, 1962). The GSG shows La value of 24.8 ppm, which is close to 25.0 ppm the average value in granite (Taylor, 1965), indicating that the pelitic source material must probably have been intruded and contaminated by a granitic magma. The Ce concentration is 54.2 ppm in the GSG, which is close to 60 ppm the average value in crustal material (Taylor, 1964). Gd varies from 5.05 ppm in the GSG, which is very close to 5.4 ppm for average crustal material (Taylor, 1965).

Table 2. *Whole rock major element geochemistry (wt. %), CIPW and Niggli Norms of gneisses of Northwest Obudu Plateau, Southeastern Nigeria. Key for rock types same as in Table 1.Fe as Fe_2O_3 total. Key for CIPW Norms: Q(s)=quartz, Or = orthoclase, Ab = albite, An = anorthite, C(A) =corundum, Di = diopside, Hy = hypersthene, Ol = olivine, Mt = magnetite, He = hematite, Il = ilmenite, Ap = apatite.; n - number of analyses; N – Number of rock types; GN = sum of the the total number of gneisses.*

Oxide	**MG.AYA N = 5**	**MG.MBK N = 5**	**GG.US n= 5**	**GG.MBN n = 4**	**GSG.ADKH N = 3**	**GBG.VDK N = 4**	**ΣGN/N**
SiO_2	72.29	72.80	66.13	63.12	64.69	65.43	67.41
Al_2O_3	13.28	14.50	15.99	14.15	15.70	12.76	14.4
TiO_2	0.42	0.12	0.61	1.18	0.60	1.01	0.66
Fe_2O_3	4.34	2.03	4.46	9.21	5.99	9.03	5.84
MgO	0.66	0.26	0.83	2.22	2.17	3.39	1.59
CaO	2.77	0.89	2.28	2.36	4.09	1.53	2.41
MnO	0.07	0.03	0.05	0.11	0.08	0.17	0.085
Na_2O	4.4	3.48	4.24	2.35	3.75	1.80	3.27
K_2O	1.07	5.08	3.74	3.69	1.84	2.75	3.03
P_2O_5	0.09	0.10	0.17	0.46	0.15	0.13	0.19
Cr_2O_5	0.002	0.004	0.002	0.006	0.009	0.022	0.008
LOI	0.50	0.60	0.07	0.9	0.80	1.30	0.8
Total	99.89	99.92	99.74	99.75	99.86	99.79	99.68
C I P WN O R M of Gneisses of Northwest Obudu Area							
Q(S)	36	30	19.4	27.2	22.6	36.28	29
Or	6	30.02	22.24	21.1	11.2	17.0	18
Ab	37	29.4	36	21	32	15.2	28
An	8	3.6	13	9	20.1	8	11
C(A)	2	1.6	0.31	3.1	0.1	4.0	2
Di					2.7		
Hy	1	0.7	2.1	5.6	2.7	4.2	2.72
Ol						2.94	
Mt	1	0.5					
He	3	1.7	4.5	9.3	6.0	9.0	6.0
Il	1	0.3	0.15	0.3	0.2	0.5	0.2
Ap	5	1.0	1.0	2.8	1.0	1.0	
Niggli Norm of Gneisses of Northwest Obudu Area							
Al	39	47	40	34	35	31	37
Fm	21	11	20	37	30	49	30
C	15	5	13	10	16	6	11
Alk	25	37	27	18	19	14	22
Si	357	395	275	252	242	263	289
Ti	0.9	0.66	2.03	3.64	1.82		2.09
P	0.3	0.33	0.25	0.73	0.23		0.26
K	0.13	0.49	0.37	0.51	0.25	0.50	0.38
Mg	0.23	0.21	0.27	0.36	0.41	0.42	0.34
Qz	+157	+248	+208	+172	+176	+156	+101
al+c	54	52	53	44	51	3.18	48
al-c	24	42	27	24	19	0.25	26

Table 3. *Rare earth elements (REE) abundance(in ppm) and distribution in analysed gneiss samples of Northwest Obudu Plateau, Southeastern Nigeria. Key to colums: MG.AYA - Migmatitic Gneiss from Ayanga. MG.MBK - Migmatitic Gneiss from Mbakeum quarry. GG.USH - Granite Gneiss from Ushongo.GG.MBN - Granite Gneiss from Mbahan. GBG.VDK - Garnet Biotite Gneiss from Vandeikya. GSG.ADH - Garnet Sillimanite Gneiss from Andoaka Hill.ΣREE = TREE = Σ(La – LU) - Summation of total abundance of the rare earth elements (REE). ΣLREE = Σ(La – EU) - Summation of the light rare earth elements (LREE) , fromLanthanum to Europium. ΣHREE = Σ(Gd – Lu) - Summationof the heavy rare earth elements (HREE) , from Gadolinium to Lutetium. ΣLREE/ΣHREE = Ratio of the total light rare earth elements (LREE) to the heavy rare earth elements (HREE). ΣFX/N - Average elemental abundance of individual element*

REE	MG.AYA n = 5	MG.MBK n = 5	GG.US n= 6	GG.MBN n = 4	GSG.ADKH n = 3	GBG.VDK n = 4	ΣFX	ΣFX/N
La	21.4	18.6	58.4	112.9	8.6	24.8	244.7	40.783
Ce	44.5	36.6	108.5	264.7	18.2	54.2	526.7	87.783
Pr	5.66	4.17	11.9	33.99	2.39	6.57	64.68	10.78
Nd	21.9	15.5	42.6	137.8	9.9	26.7	254.4	42.4
Sm	4.36	2.93	6.53	20.18	2.41	5.35	41.76	6.96
Eu	0.93	0.42	1.31	1.19	0.73	0.93	5.51	0.918
Gd	4.35	2.32	3.69	12.39	2.27	5.05	30.07	5.012
Tb	0.74	0.36	0.49	1.58	0.34	0.49	4	0.667
Dy	4.52	1.71	2.02	7.14	1.74	5.91	23.04	3.84
Ho	0.92	0.29	0.35	1.07	0.29	1.25	4.17	0.695
Er	2.8	0.81	0.89	3.12	0.69	3.99	12.3	2.05
Tm	0.4	0.11	0.13	0.4	0.08	0.59	1.71	0.285
Yb	2.43	0.7	0.74	2.57	0.52	3.89	10.85	1.808
Lu	0.35	0.09	0.11	0.37	0.07	0.56	1.55	0.258
ΣREE	115.26	84.61	237.66	599.40	48.323	139.35	1225.44	204.24
ΣLREE	98.75	78.22	229.24	570.76	42.23	118.55	1137.75	189.62
ΣHREE	16.51	6.39	8.42	28.64	6.00	21.73	87.69	14.39
ΣLREE/ΣHREE	5.981	12.24	27.32	19.929	7.038	5.413	12.97	13.18

Similarly, Dy concentration is 5.91 ppm, in the GSG which is close to the value of 5.0 ppm for average shale (Taylor, 1965). This distribution in the multi-elements concentration shows that the GSG is possibly a product of metamorphism of pelitic rock which was contaminated by intruding magma of basaltic composition.

The tectonic settings of the gneisses were determined using the relation between multi-element discriminatsR1[4Si – 11(Na + K) -2(Fe + Ti)] versus R2[6Ca + 2(Mg + Al)] (Fig. 5), after Batchelor and Bowden (1985) and the Y versus Nb tectonic discriminant (Fig. 6), after Pearce et al., (1984). In Fig. 5 the migmatitic and granite gneisses plot clustering around [field 6] the syn-collision granite. Similarly, in Fig. 6 all the samples plotted in the volcanic- syncollision granite (VAG+Syn-COLG), except one sample of the migmatitic gneisses which plots in within plate granite (WPG) field (Fig. 6). These results are corroborative and support the view that the protoliths of gneisses of Northwest Obudu plateau were emplaced mainly in the volcanic arc to syn-collision granite tectonic setting with little effect from within plate granite tectonic setting.

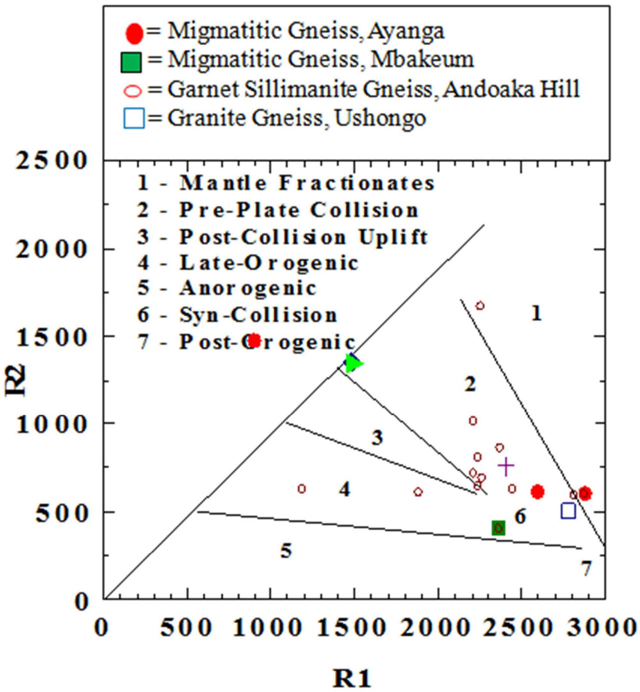

Fig. 5. *R1 vs R2 log-log multi-element binary discriminant for granitic rocks of Northwest Obudu Plateau (Fields after Batchelor and Bowden, 1985).*

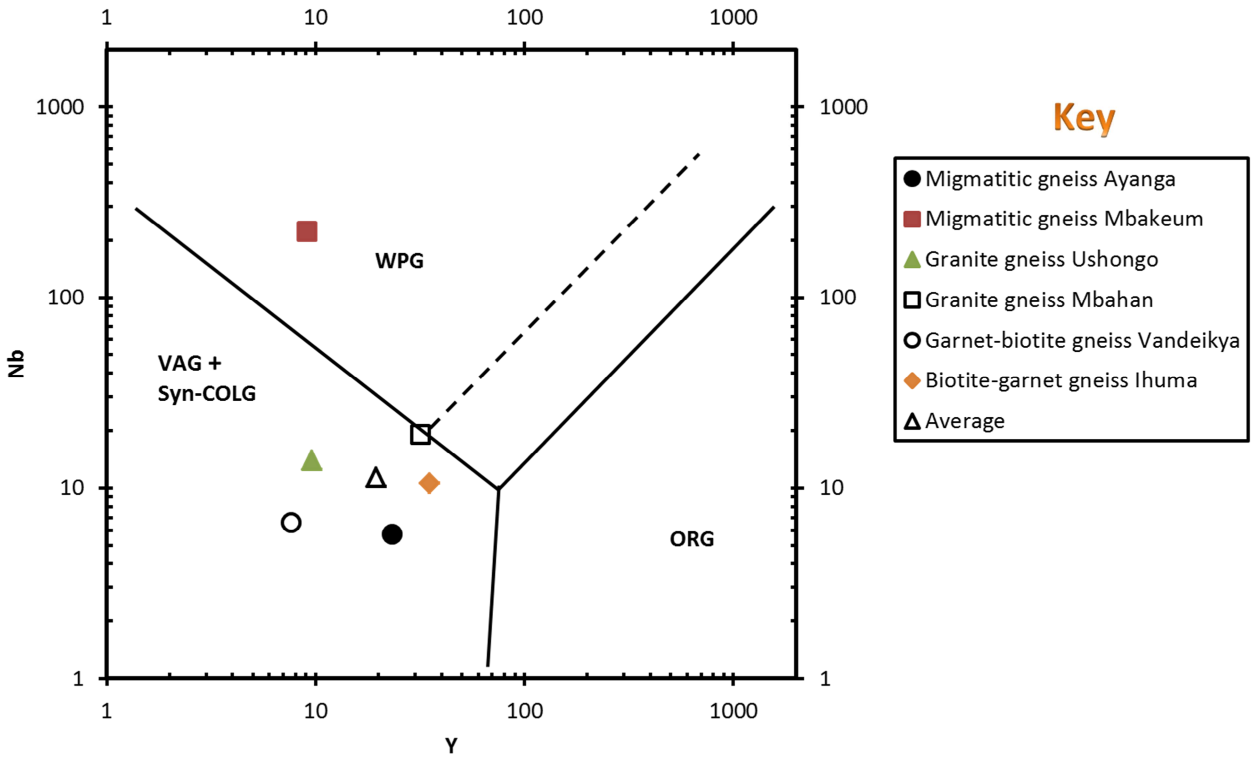

Fig. 6. *Nb vs Y diagram for discrimination of tectonic setting of gneisses of northwest Obudu Plateau (After Pearce et al., 1984). Syn-COLG = syn collision granite. WPG = withinplate granite. VAG = volcanic arc granite. ORG = Orogenic granite, --- = overlap between WPG and ORG .*

The total rare earth elements abundance {TREE = Σ(La + Ce + . . . + Lu)} varies from 48.32ppm in the garnet biotite gneiss (GBG) at Vandeikya, to 84.61 ppm in the migmatitic gneiss (MG) at Mbakeum, through 139.35 ppm in the garnet sillimanite gneiss (GSG) at Andoaka Hill, to a maximum total enrichment of 599.40 ppm in the granite gneiss (GG) at Mbahan (Table 3). The total light rare earth elements (TLREE = Σ(La + Ce + . . . + Eu} vary from42.23 ppm in the GBG at Vandeikya, to 78.22 ppm in the MG at Mbakeum,through 117.62 ppm in the GSG at AndoakaHillto a maximum total enrichment of 570.76 ppm in the GG at Mbahan (Table 3). Similarly, the total heavy rare earth elements (ΣHREE) abundance shows maximum depletion of 6.0 and 6.39 ppm in the GBG and MG respectively.The ΣLREE/ΣHREE ratio varies from 5.413 in the GBG, through 5.981 in the MG at Ayanga, to maximum of 27.32 in the GG from Ushongo.

Some selected elemental ratios of gneisses of Northwest Obudu Plateau (Table 4), show values which are in conformity with those of similar rock types from other tectonic settings from other parts of the world.For example, the K/Rb ratio varies from 134.5 in the GG at Mbahan, 163.4 in the GBG at Vandeikya to 191.3 in the MG at Mbakeum, which are all less than the average crustal abundance (232) given by Taylor (1965); that of the standard granite (205) by Wedepohl (1978); that of the average rhyolite (512) reported by Ekwueme (1993a) (Table 4).The K/Rb ratio rises to 239.6, 247.1 and 436.3 in the GBG, GSG and MG at Mbakeum respectively. This high variability indicates heterogeneity in the abundance of feldspar and biotite which host sites for entry of Rb. Similar correlation shows that the K/Ba ratio varies very narrowly 30.83 in the MG to 31.56 in the GG to 40.5 and 40.94 in the GBG and GSG respectively, corroborating their crustal derivation.

The REE – Chondrite normalized spidergrams of the gneisses of Northwest Obudu Plateau are presented (Figs 7 and 8). The characteristic patterns and abundance enable more reliable correlation and interpretation of the petrogenetic significance / history of the rocks of the study area. The spidergrams all showa general negative zigmodal slope from La - Lu, indicating depletion trend from the light rare earth elements (LREE)Ce, Pr, Nd to the heavy rare earth elements (HREE) Lu, Yb, Tm, Er, Ho, Dy with a pronounced negative europium (Eu) anomaly. However, there are variations observed in characteristic patterns among the various lithological groups. For example, in the sample plot of the REE – Chondrite normalized spidergrams of thegneisses (Fig. 7), all the samples show negative Eu anomaly magnitude increases from thegarnet sillimanitegneiss (GSG), through the migmatitic gneiss (MG) to a maximum peak atLa_N~500 in the granitegneiss (GG) at Mbakeum. In the aerial plot of the REE – Chondrite normalized spidergram (Fig. 8) for the gneisses, three genetic levels occur looped around by common hatch lines, indicating that though the gneisses are highly differentiated and fractionated, they are genetically associated and related to a common protolith source.

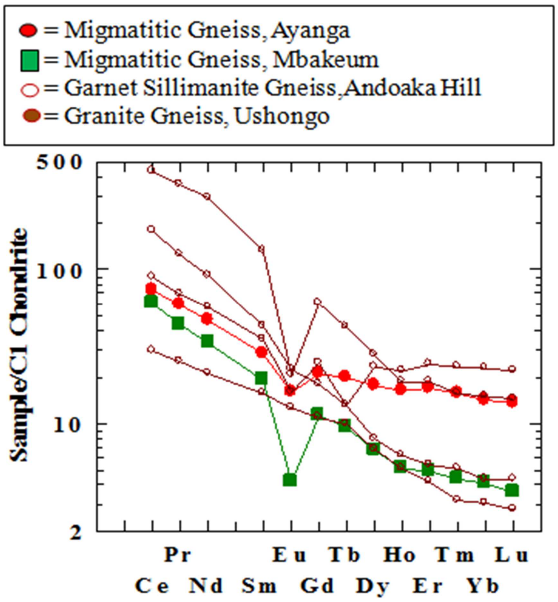

Fig. 7. REE versus Chondrite normalized Sampleplot of Gneisses of Northwest Obudu Plateau, SE. Nigeria.

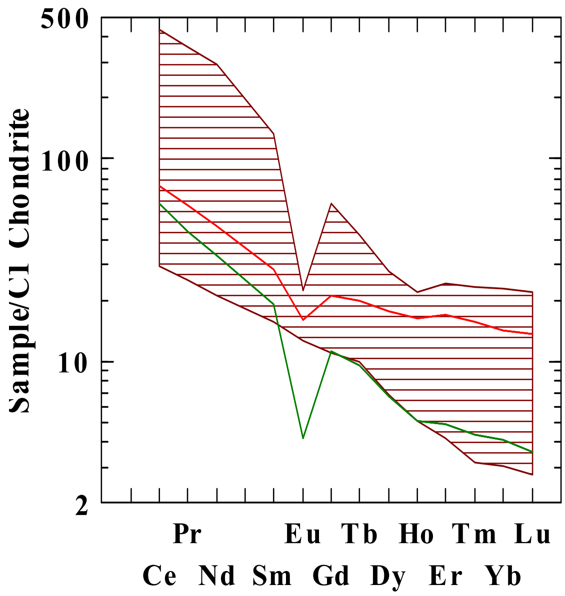

Fig. 8. REE versus Chondrite normalized area plot of Gneisses of Northwest Obudu Plateau, Southeastern Nigeria.

Table 4. Selected elemental ratios of gneisses of Northwest Obudu Plateau, Southeastern Nigeria.

REE	MG.AYA	MG.MBK	GG.USH	GG.MBN	GBG.VDK	GSG.ADH	Σ/NG
*K %	0.888	4.24	3.105	3.064	1.528	2.283	2.518
Ba	288	400	984	522	377	558	521.50
Rb	20.4	221.6	129.4	227.5	91.8	91.40	130.40
Sr	215.7	103.6	347.6	147.6	253	129.40	199.60
Ni	20	20	26	20	32	75	32.167
Zr	208.1	74.4	291.9	621.1	162.8	208.6	261.159
Th	3.1	11.9	13.0	78.1	0.6	6.9	18.933
U	0.2	15.6	1.8	5.2	0.4	1.9	4.183
Pb	1.0	4.8	8.0	3.6	2.7	6.4	4.417
Hf	6.0	3.2	7.9	18.1	4.7	5.9	7.633
K/Rb	436.3	191.4	239.6	134.5	163.4	247.3	235.4
K/Ba	30.833	106.0	31.555	58.697	40.531	40.94	48.284
Rb/Sr	0.095	2.14	0.372	1.54	0.363	0.706	0.6533
U/Pb	0.2	3.25	0.225	1.444	0.1482	0.2969	0.9470
Lu/Hf	0.05833	0.0281	0.0139	0.0204	0.0149	0.0949	0.0338
Sm/Nd	0.1991	0.189	0.1533	0.1464	0.2434	0.2004	0.1642

*K conversion factor is 1% = 10000 ppm.

Key: MG.AYA = Migmatitic Gneiss from Ayanga. MG.MBK = Migmatitic Gneiss from Mbakeum quarry. GG.USH = Granite Gneiss from Ushongo. GG.MBN = Granite Gneiss from Mbahan. GBG.VDK = Garnet Biotite Gneiss from Vandeikya. GSG.ADH = Garnet Sillimanite Gneiss from Andoaka Hill.

Various chemical discrimination diagrams were plotted to constrain the magmatic evolution of the protoliths of gneisses of Northwest Obudu area. In the $Si0_2$ versus Na_20+K_20 diagram (Fig. 9), after Cox et al., (1979) the MG and GG all plot around the rhyolite field while the GBG and GSG both plot within the dacite-granodiorite field, thus corroborating the result of the elemental distribution. In the $Ti0_2$ versus Zr binary diagram (Fig. 10) after Cox et al., (1979), The MG and GG plot in a trend showing rhyolite-granodiorite-daciteprogenitors.

5.2. Discussion

Various workers have studied the trace and REE elements composition of the basement rocks of Nigeria and those from other tectonic settings (Butler et al., 1962; Grant, 1971; Ekwueme, 1993; Obioha and Ekwueme, 2011; Oden et al., 2011) and many others. Butler et al., (1962) showed that as granites approach the ternary minimum in the system $Si0_2$-$NaAlSi0_4$ – $KAlSi0_4$, the major elements composition will tend toward uniformity and it is the trace elements concentration that will provide the basis to distinguish stages of differentiation. Field and petrographic studies have shown that the gneisses of Northwest Obudu Plateau are medium to coarse grained, highly foliated, N – S to NE – SW (0 – 35°) direction, dipping mainly in the NW with minor dip in the SW directions. Comparison of the trace elements composition of the gneisses with those of similar rocks from other tectonic settings (Table 5) shows that the gneisses conform in abundance and distribution with similar rocks from other tectonic settings. For example, all the analyzed samples are characteristically enriched in the LREE and depleted in the HREE, including the sample of whole rock REE of Zhoutan garnet mica Schist by Grongren HU et al., (2009), which has a TLREE of 172.1ppm and THREE of 19.64 ppm, yielding a TLREE/THREE ratio of 8.76 which is consistent with the general trend. This probably may be an indication of high abundance of the yttrium earth minerals, which concentrates the HREE relative to the LREE (Taylor, 1665) in the Zhoutan Group. Conversely, the depletion maxima is recorded in the garnet biotite gneiss (GBG) of the present study, which shows TREE abundance of 48.23 ppm, TLREE (42.23 ppm), THREE (6.0 ppm), giving a TLREE/THRE ratio of 7.04 (Table 5). The most enriched rock is the granite gneiss from Northeast Obudu, Bamenda Massif Southeastern Nigeria by Ephraim (2007), with TREE of 532.1 ppm, TLREE (504.5 ppm) and THREE (27.53 ppm), thus giving a TLREE/THREE ratio of 18.33 (Table 5).

Table 5. *Comparison of average REE Abundance (ppm) of gneisses of Northwest Obudu Plateau, Southeastern Nigeria, with values of similar rocks from other tectonic settings*

REE	1	2	3	4	5	6	7	8	9	10	11
La	20.0	85.65	8.6	24.8	50.6	80.4	39.0	49.35	39.4	20	30
Ce	40.6	186.6	18.2	54.2	106	192	74.6	99.45	81.36	50	60
Pr	4.91	22.95	2.39	6.57	-	-	8.1	10.55	9.299	6.0	8.2
Nd	18.7	30.2	9.9	26.7	44.6	90.4	30.2	40.1	34.55	24	28
Sm	3.65	13.34	2.41	5.35	8.51	16.9	5.35	7.45	6.556	6	6.0
Eu	0.68	1.25	0.73	0.93	1.84	3.1	1.43	1.595	1.318	1	1.2
Gd	3.34	8.025	2.27	5.05	6.98	14.8	4.95	6.025	5.52	6	5.4
Tb	0.55	1.035	0.34	0.49	-	-	0.87	0.998	0.883	1	0.9
Dy	3.12	4.58	1.74	5.91	4.79	10.2	4.98	5.25	5.217	5	3.0
Ho	0.61	0.71	0.29	1.25	-	-	1.04	1.093	1.049	1	1.2
Er	1.81	2.005	0.69	3.99	2.66	5.33	3.23	3.425	2.951	2	2.8
Tm	0.26	0.265	0.08	0.59	-	-	0.53	0.535	0.48	0.2	0.48
Yb	1.57	1.655	0.52	3.89	2.24	4.11	3.28	3.275	3.081	3	3.0
Lu	0.22	0.22	0.07	0.56	0.36	0.65	0.48	0.493	0.46	0.5	0.5
TREE	99.94	358.5	48.23	140.3	532.1	100.2	178.0	229.6	191.8	125	150.6
LREE	88.49	340.0	42.23	118.6	504.5	96.60	158.7	208.5	172.1	107	133.4
HREE	11.45	18.50	6.00	21.73	27.53	3.61	19.36	21.09	19.64	18.7	17.2
LREE/HREE	7.728	18.38	7.04	5.456	18.33	26.78	8.207	9.885	8.763	5.72	7.756

Key: Average REE Abundance of:
1. Migmatitic gneiss (MG) from Northwest Obudu Plateau, SE. Nigeria (Present study)
2. Granite gneiss (GG) from Northwest Obudu Plateau, SE. Nigeria (Present study)
3. Garnet biotite gneiss (GBG) from Northwest Obudu Plateau, SE. Nigeria (Present study)
4. Garnet sillimanite gneiss (GSG) from NW. Obudu Plateau, SE. Nigeria (Present study)
5. Granite gneiss from NE Obudu Plateau, Bamenda Massif, SE. Nigeria (Ephraim, 2005).
6. Granite Worldwide Locations (Taylor, 1964).
7.Hornblende biotite gneiss from Southwest Obudu Plateau, SE. Nigeria (Ukwang, 2007).
8.Garnet biotite gneiss from Southwest Obudu Plateau, SE. Nigeria (Ukwang, 2007).
9.Wholerock REE from Zhontan garnet mica Schist (Grongren HU et al., 2009).
10.Shale from Worldwide locations (Taylor and MacLennan, 1965).
11.Crustal abundance (Taylor, 1965).

The very high enrichment trend possibly indicates high abundance of cerium earths which favours the concentration of LREE relative the HREE (Taylor, 1665). Comparison however shows, that the total REE abundance notwithstanding, the ratio of the LREE/HREE (18.33) in the granite gneiss of both Northeast Obudu (Ephraim, 2005; Table 5, No. 5) and that of the present study (18.38; Table 5, No. 2) is very similar. It is concluded therefore that both northeast and northwest Obudu gneisses are genetically related. Similarly, the ratio LREE/HREE (7.728) in the MG (Table 5 No. 1) and (7.04) in the GBG (Table 5 No. 3), are very close to the crustal abundance (7.756) (Taylor, 1965; Table 5, No. 11). Interpretation of the elemental abundance shows that the large ion lithophile element Rb vary from 129.4 ppm in the granite gneiss Ushongo, through 91.8 ppm in the garnet biotite gneiss at Vandeikya to 91.4 in the garnet sillimanite gneiss at Andoaka Hill. These values are very close the concentration of 120 ppm for average granodiorite (Taylor, 1965), 90.0 ppm for average crustal rock reported by Taylor and McLennan (1985). Thus corroborating a crustal source for the protoliths of both the GBG and GSG and that continental materials of granodioritic and greywacke composition affected the crustal evolution of Northwest Obudu Plateau, in Southeastern Nigeria during the Pan –

African tectonothermal events. The trend of distribution also shows that the gneisses of Northwest Obudu plateau are highly differentiated and fractionated, and generally conform to the characteristics of similar rocks from other tectonic settings.

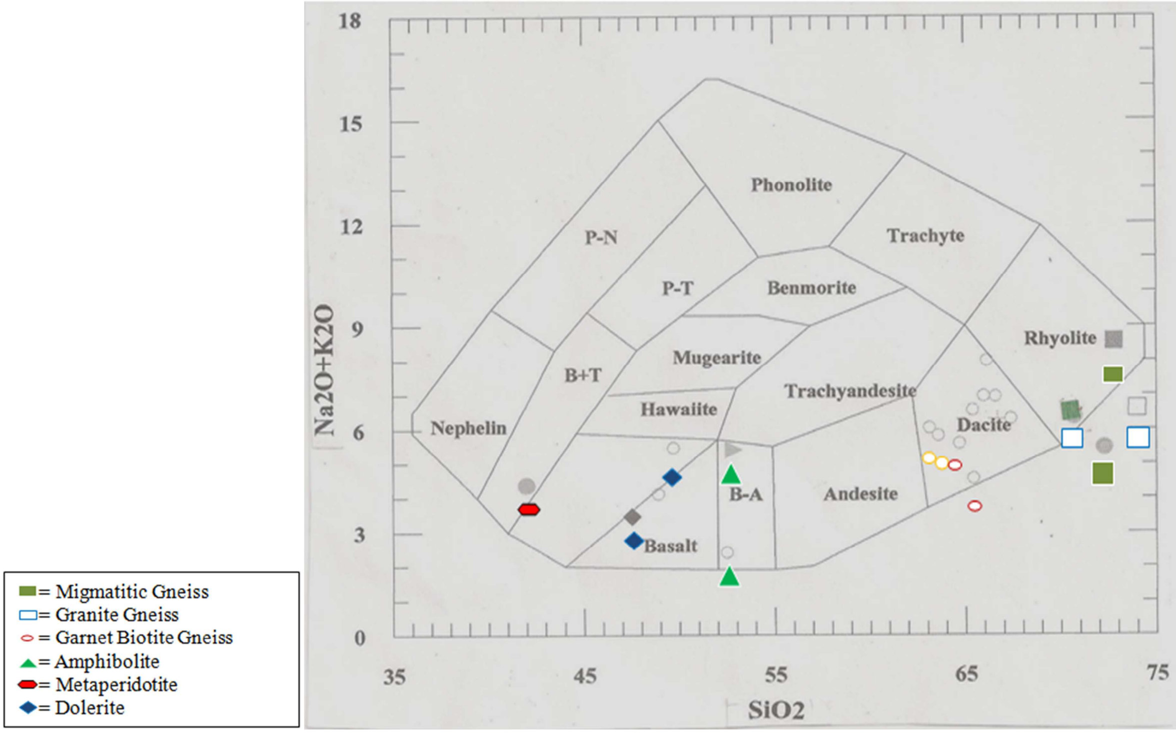

Fig. 9. *SiO_2 vs Na_2O + K_2O discriminant for the compositional classification of magma types of rocks of NW ObuduPlateau (after Cox et al., 1979).*

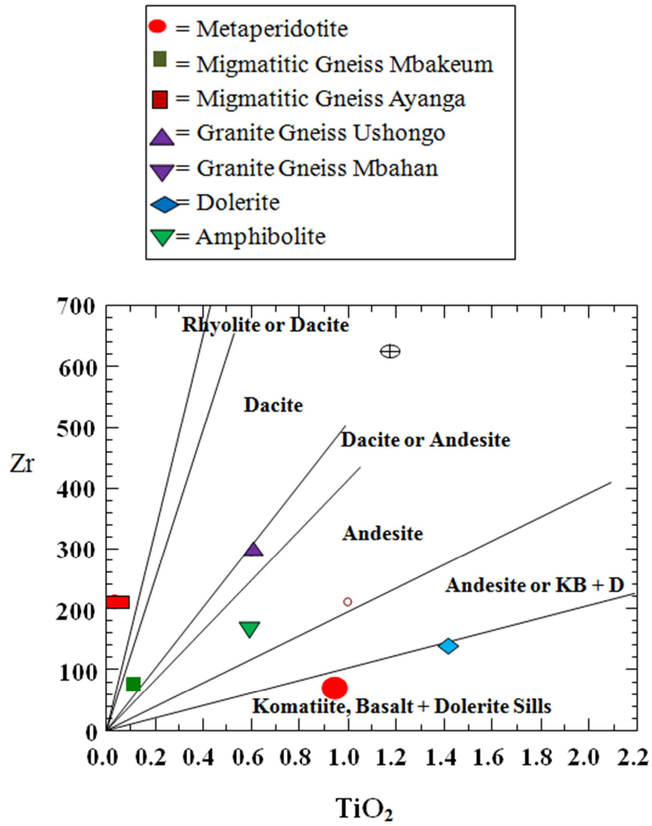

Fig. 10. *TiO_2VsZr binary diagram for compositional classification of magma types of rocks of NW Obudu Plateau (Fields specified after Winchester and Floyd, 1977)*

6. Conclusion

Precambrian, ortho- and para-gneisses constitute more than 70 % of the basement rocks of Northwest Obudu Plateau, Southeastern Nigeria. They are closely associated with schist, amphibolite, metaperidotite and intruded by granite, aplite and pegmatite in places. The gneisses have been differentiated into five petrological types (Obioha and Ekwueme, 2011). They are peraluminous, sub-alkaline, dacite – granodiorite / rhyolitic in composition, and of dual protoliths; metaigneous –metasedimentary, emplaced in a within plate granite – syn-collision granite tectonic setting. The REE characteristics and abundance show that the gneisses are highly enriched in LREE and depleted in the HREE, with pronounced negative Eu anomaly, indicating high differentiation and fractionation. Analysis using chemical discrimination diagrams shows that the protoliths of the MG and GG gneisses were derived from partial melting and differentiation of granitic magma of hybrid origin. The GSG and the GBG gneisses were derived from crustal sources of pelitic origin.

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