



Geotectonothermal Evolution of Granitoids of Northwest Obudu Plateau, Bamenda Massif, Southeastern Nigeria: Geochemistry Evidence

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Abstract Geochemical investigation of granitoids in Northwest Obudu, Southeastern Nigeria, was carried out in order to determine their petrogenetic significance to crustal evolution of African Continent. Results reveal that, granites, granodiorites, pegmatites and aplites constitute the main granitic rocks outcrops in the area. These are closely associated with migmatites gneisses, schists and granulites/charnockites which they intrude, Modal analysis shows that all the granitic rocks are enriched in quartz (16-31), plagioclase (An₃₂₋₄₈ 16-37), orthoclase (3-20), biotite (10-15), but relatively depleted in garnet (4-6 vol. %), hornblende, sphene and hematite. This is in accordance with their acid characteristics. Bulk rock geochemistry shows that all the granitic rocks are depleted in Fe₂O₃(total), CaO and MgO, with average values of 3.97wt.%, 2.58wt.%, and 1.03wt% respectively, but relatively enriched in SiO₂ (70.7 wt.%), Al₂O₃ (13.81wt.%) and alkalis (6.37wt.%) average values, which is consistent with their intermediate-acid character. The CIPW Norm shows enrichment of Q(s) and Ab and depletion of Ol and Mt corroborating their granitic character. Chemical discrimination diagrams show that the granites were late-stage magmatic protoliths, emplaced dominantly in within plate to syn-collision tectonic setting. They played significant role in the tectonothermal evolution of the Pan African Continent.

Keywords Geochemistry, Granitoids, Geotectonothermal evolution, Obudu Plateau, Protoliths, Pan-African Continent, Tectonic Setting.

Introduction

Obudu Northwest is the fourth quadrant of the area Obudu sheet 291. The area is located between Latitudes 6°45' - 7°00'N and Longitudes 9°00' - 9°15'E. The area is a part of the two giant spurs Oban Massif and Obudu plateau which projects into the Cretaceous Benue Trough of Southeastern Nigeria [1]. The granitoids of the area had received some, but less geological attention compared with its northern and south-western counterparts. This has been mainly due to the rugged topography, thick vegetation and wild-life occurrences of the area. Research has shown that adequate information does not exist in literature on the geochemistry of the granitoids of the area. The pioneer published geological works in the area [2-7]. The present study uses the petrography and whole rock geochemistry of the granitoids to unravel the petrology, petrogenetic and tectonic evolution of the Obudu Bamenda Massif in the Pan-African continent.

Location of Study Area

The area of study is Northwest Obudu Plateau Bamenda Massif, Southeastern Nigeria. It is geographically situated between latitudes 6°45'N - 7°00'N and longitudes 9°00'E - 9°16'E in topographic sheet 291 Obudu (Fig. 1). It covers an approximate surface area of 860.32 km², extending from Ushongo, Konshisha to Kwande and Vandeikya Local Government areas in southern Benue State, to parts of Obudu and Bekwara Local Government areas in northern Cross River State of Southeastern Nigeria. The area is bounded in the west and northeast by Benue Trough, in the south by Mamfe Embayment, which separates it from the Oban Massif, and on the east by the Bamenda Massif of western Cameroon from which it extends into Southeastern Nigeria [8].

Geological Setting

Nigeria land mass is underlain by about 50% Basement Complex Rocks and 50% Cretaceous to Tertiary sedimentary rocks [9]. The basement rocks crop out in three main areas of the country; the Northern,



Southeastern and Southwestern regions. The area of study extends from the Basement Complex area into the sedimentary environment. The granitoid rocks occurring in the study area include granites, granodiorite, pegmatites and aplites. They occur in association with the basement migmatites, gneisses, schists, metaquartzites, and granulites facies rocks, which they intrude [7]. The litho-structural features of the granitoids as revealed by the field geological sampling/mapping are presented in (Figs. 1 & 2). The figs show the various litho-outcrop units and their field relationship [8].

Granitic Rocks

Granitic rocks (Figs. 4) mapped in the Northwest Obudu area include granite, aplite pegmatites and subordinate occurrence of granodiorite. They are closely associated with the basement gneisses, migmatites and schists, which they intrude. Most the granites show porphyritic texture in places, with phynocrysts/laths of plagioclase feldspar set in the groundmass of quartz and biotite. They are often criss-cross by veins or dykes of aplites and pegmatites (Fig. 4), indicating second generation magmatic intrusion/igneous activity. The granodiorite consists of euhedral crystals of quartz and feldspar. The feldspars are often zoned indicating metastable equilibrium condition of emplacement [10].

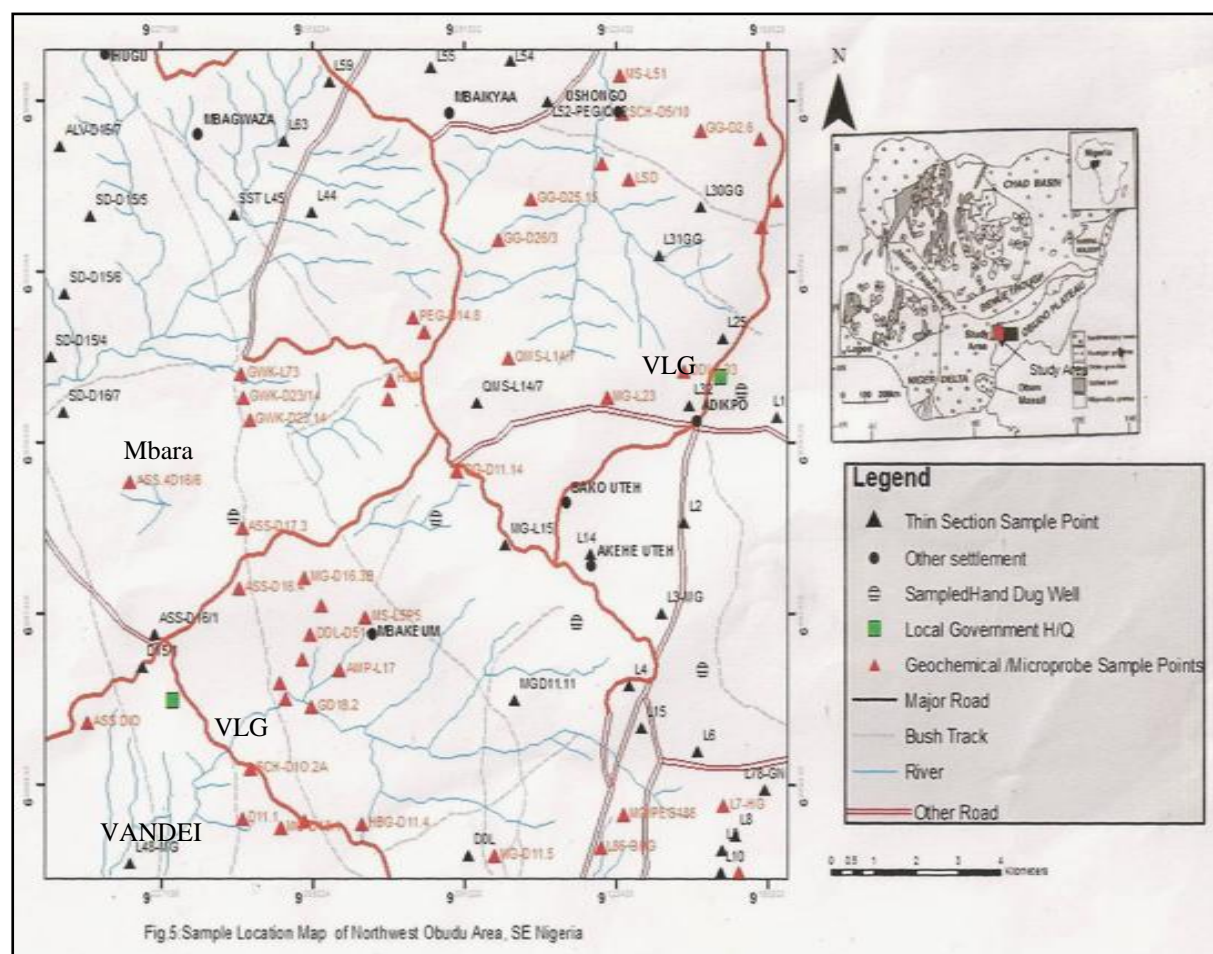


Figure 1: Sample location map of Northwest Obudu area, Southeastern Nigeria

The aplite has sugary, equigranular texture, consisting of quartz, feldspar and subordinate amount of muscovite. The pegmatite (Fig. 4) consists of megacrysts feldspar, quartz, muscovite, and radiating rods of tourmaline. Modal analyses (Table 2), shows that the granitic rocks consists in the average of quartz (33 – 40 vol. %), orthoclase (20-23 vol. %), plagioclase (14 - 40 vol.%), muscovite (2 -15 vol.%), with maximum enrichment occurring in the pegmatite, zircon < 2 vol.% in the granite, tourmaline (8 vol.%) in the pegmatite. The dolerite consisting of average modal composition; pyroxene (42 vol. %), plagioclase (40 vol. %), olivine (7 vol. %) and opaques (3-5 vol. %), intrude the granitoids around Vandeikya town (Table 1).



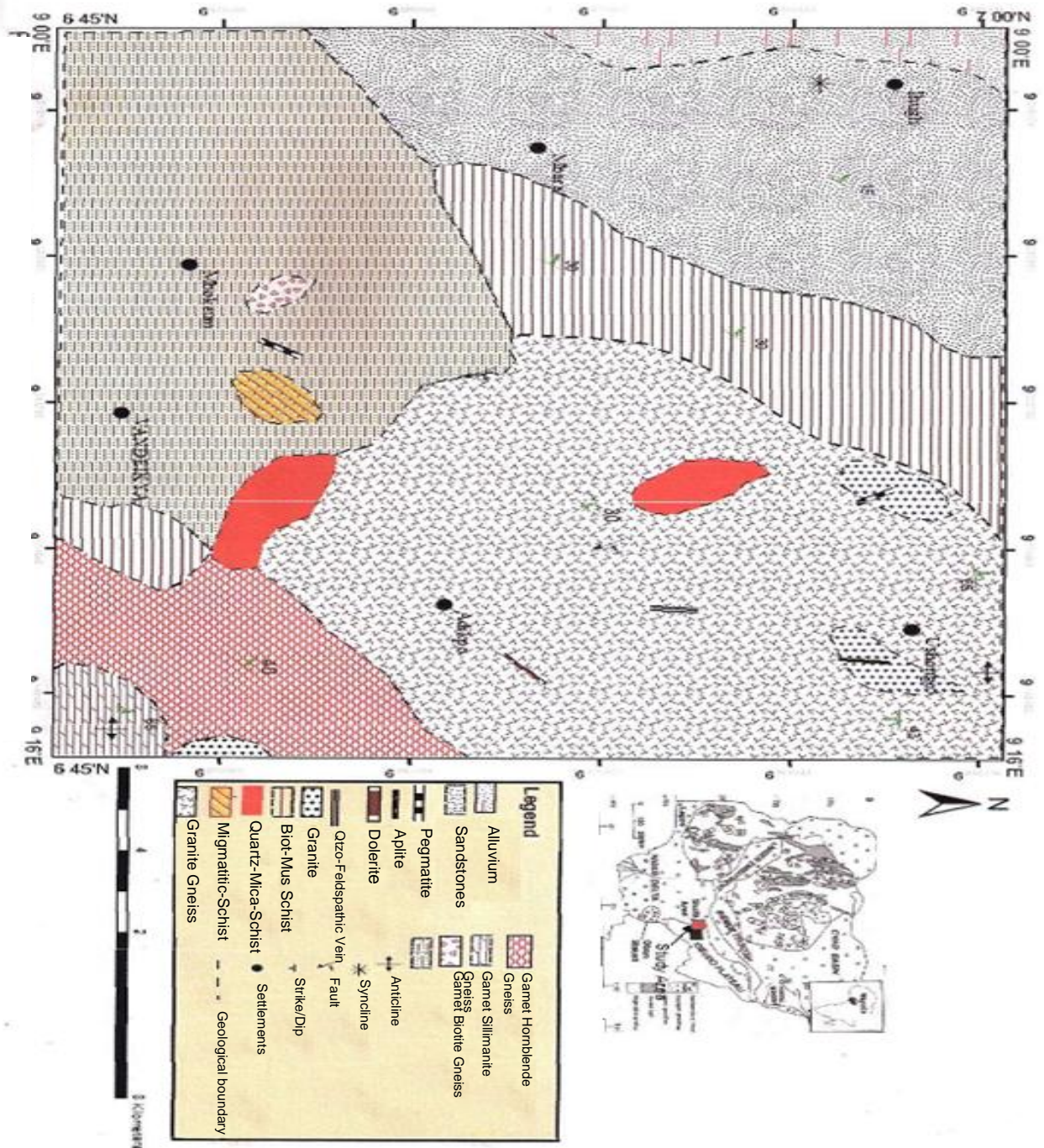


Figure 2: Geological map of Northwest Obudu Plateau, SE, Nigeria

Petrography

The thin section petrography was based on aerial coverage and available rock types. Thirty five thin sections of representative rock samples were prepared. The thin sections were made at the Geological Engineering Workshop/Laboratory of the University of Calabar, Calabar Nigeria. Fig. 1 is the sample location map of the study area showing the sample location points, while Fig. 3 is the geological map of the study area showing the distribution of the various lithological unites in the mapped area. Modal analyses of the rock samples were



carried out (Table 1). Photomicrographs of the thin sections of rocks specimens were taken with digital camera (Figs. 4 A-D).

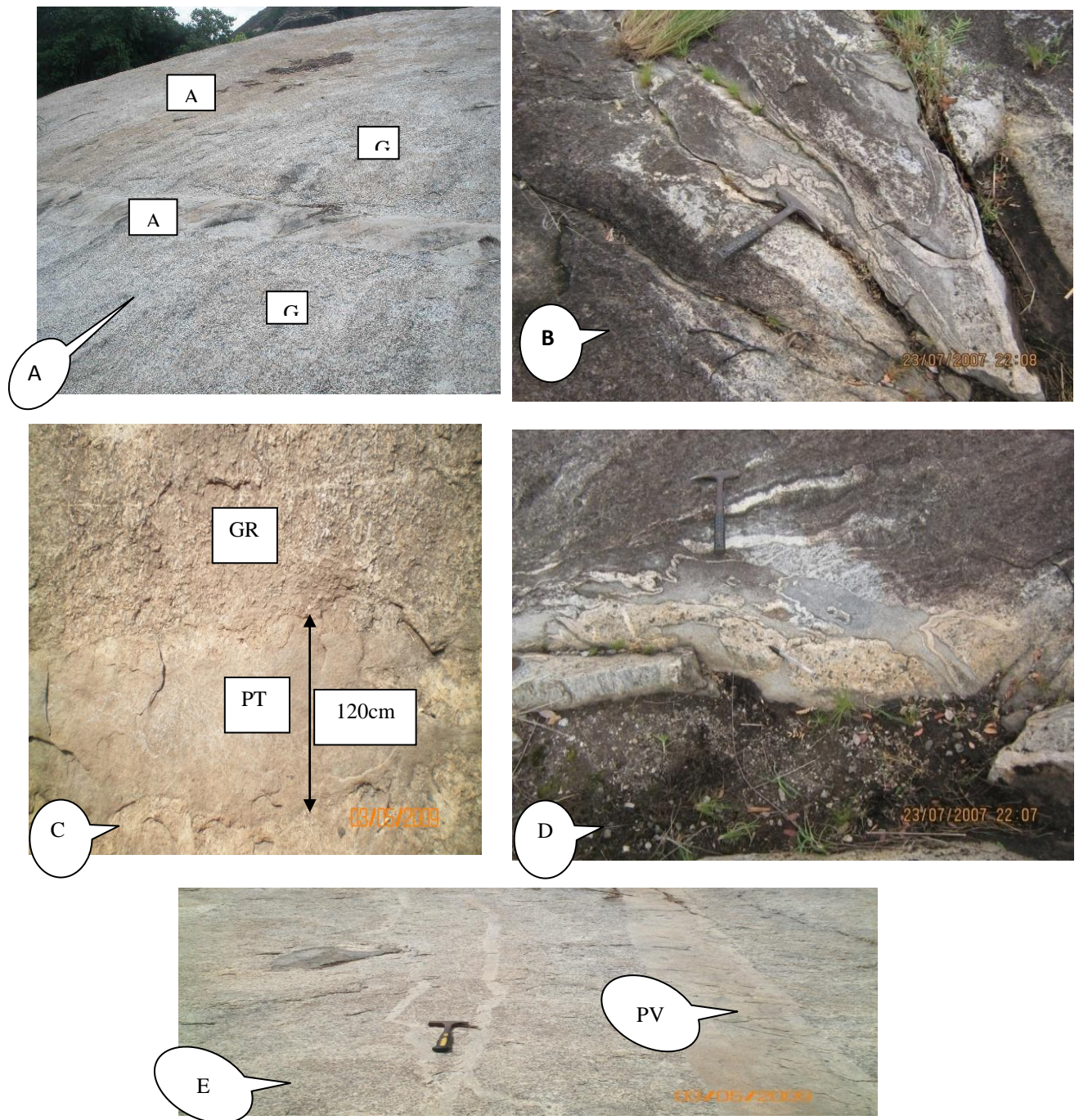


Figure 3: Field relations of granitoids of Obudu-Bamenda Massif, SE. Nigeria. (A) Aplite dykes AD1 & AD2 intrudes host Granite gneiss in NE-SW and NW-SE trends, Ushongo area. (B) Biotite granite, showing NW-SE plunging fold, Nende area. (C). Granitic rock (GR), showing pegmatite vein (PT), trending E-W direction and measuring ~ 120cm thickness, Vandeikya Area. (D). Garnet biotite gneiss, showing myrmakitic texture, Vandeikya area. (E) Granite gneiss (GG), showing pegmatite vein (PV), amphibolitic xenolith (Ax) and quartzo-feldspathic veins in Ushongo, Northwest Obudu.



Geochemistry

The geochemical studies involved whole rock geochemical analysis of thirty five representative granitoid rock samples by the inductively coupled plasma mass spectroscopy (ICP-MS) and the inductively coupled plasma emission spectroscopy (ICP-ES), at the ACME Analytical Laboratories Limited Vancouver, Canada. The analytical procedures were based on the methods after Skoog and West (1975). The digestion involved both Li-borate and Li-Tetraborate based followed by HCl dilution. The resolution was 100% for the major elements reported in oxide weight percent (wt. %), and 0.001 ppm for the trace and rare earth elements (REE). The cutting, crushing, pulverizing and weighing were done by special electronics handling (SEH). The norms (CIPW-NORM) were computed using the Min-Pet 2.0 soft-ware.

Results

Results of the whole rock geochemical analyses are presented in Tables 2 and 3. Table 2 shows the major element composition in oxide weight percent of the analyzed granitoids, including the CIPW Norm and the Niggli Norms. Table 3 shows the trace elements distribution in parts per million in the granitoids of Northwest Obudu area. Table 2 shows that all the granitoids are enriched in SiO₂, (63.52 – 78.59 wt. %, and 70.7 wt. % average), Al₂O₃ (10.69 –

17.7 wt. %, with average of 13.81 wt. %, and alkalis showing narrow variation range of 5.67 wt.% - 6.90 wt., and a mean value of 6.37 wt. %, with Na₂O > K₂O in all the analyzed samples, which is in line with their acid character. Conversely, all the granitoids are depleted in MnO,

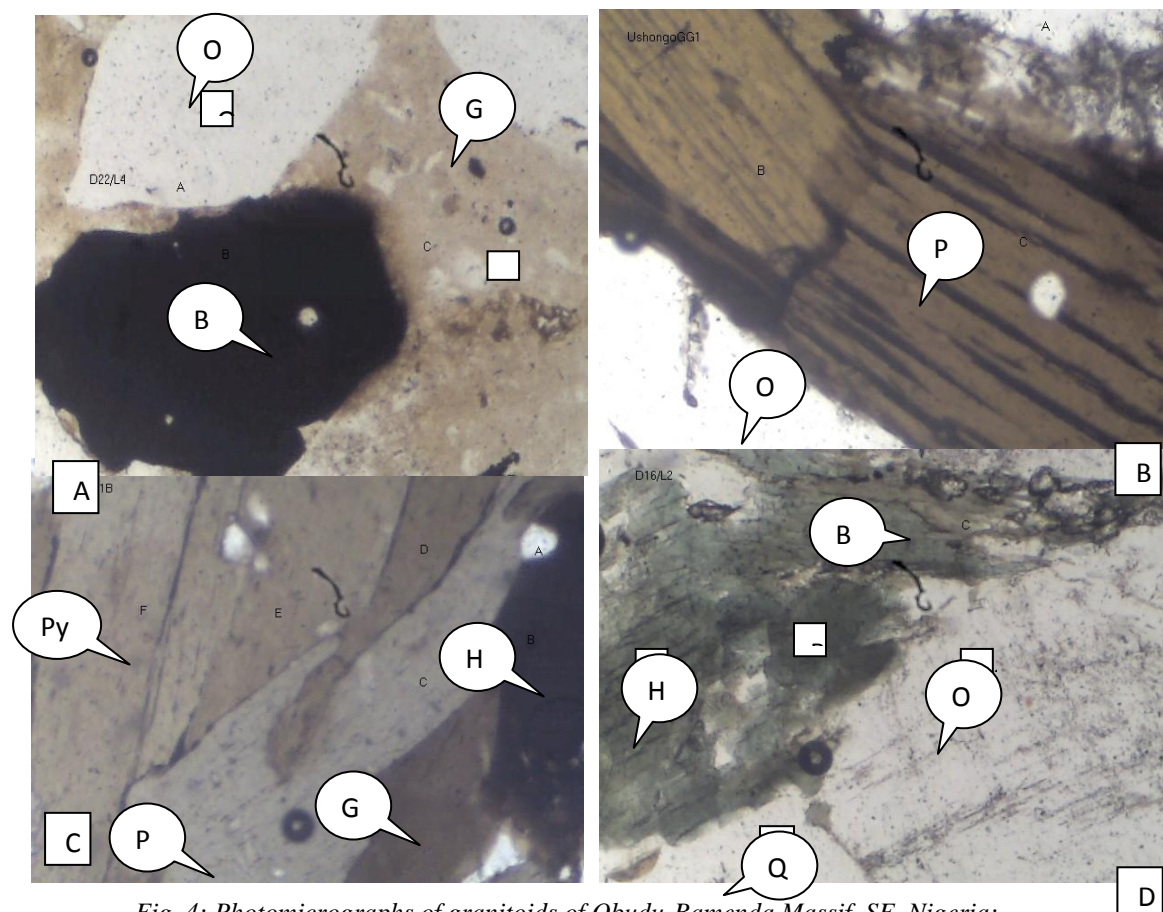


Fig. 4: Photomicrographs of granitoids of Obudu-Bamenda Massif, SE. Nigeria: (A) Gneiss, showing phynocrysts of biotite (B), garnet (G) and orthoclase (O) in textural equilibrium, Vandeikya area. (B) Granite gneiss, showing megacryst of plagioclase (P) and orthoclase (O), Mbaya Ushongo 2. (C) Metaperidotite, showing laths of pyroxene (Py), plagioclase (P), garnet (G) and biotite (B). (D) Granite-Ushongo, showing orthoclase (O), quartz (Q), biotite (B) and hornblende (H).



Table 1: Average modal composition (vol. %) of granitoids of Northwest Obudu Plateau, Bamenda Massif Southeastern Nigeria,

Minerals	Granite n = 6	Dolerite n = 5	Aplite n = 5	Pegmatite n = 5	Σ MG/N	Σ GG/N	Σ GSG/N
Quartz	38	-	40	33	28	20	20
Orthoclase	23	-	20	22	33	34	16
Plagioclase	25	40	25	14	14	15	3
Muscovite	2	-	3	15	10	11	15
Biotite	7	-	2	5	2	3	-
Hornblende	-	-	-	-	5	5	6
Orthopyroxene	-	8	-	-		3	9
Clinopyroxene	-	34	-	-			7
Olivine	-	8	-	-	2		24
Opagues	4	5	4	3	2	2	-
Zircon	1	-	-	-		2	-
Tourmaline	-	-	-	8	2	3	-
Other Accessories	-	5	6	-	2	2	-
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Mineralogical Assemblages:

Qtz-Olig- Biot- Gart- Ortho \pm Hyp; in the Migmatitic and Granite Gneisses

Σ MG/N = Average of the migmatitic gneiss

Σ GG/N = Average of the granite gneiss

Σ GSG/N = Average of the garnet sillimanite gneiss

TiO₂, MgO, P₂O₅, and Cr₂O₅, with mean values of 0.005 wt. %, 0.06 wt. %, 0.12 wt. %, 0.42 wt. %, 0.1.03 wt. % respectively. The concentration of Fe₂O₃ and CaO are variable across the analyzed samples. For example, the CaO shows minimum depletion of 1.07 wt. % in the pegmatite (D5.10B), to maximum enrichment of 3.63 wt. % in the granite at Ushongo (D10.4A, GNT.USH) (Table 2). The aluminum saturation index (ASI) > 1, with Al₂O₃ > {CaO + NaO + K₂O} in all the analyzed sample, indicating that all the granitoids are meta-aluminous (EKwueme, 1993). The CIPW Norms (Tables 2) shows that Q(S), Or, Ab, and An corroborating enrichment in quartz, plagioclase, and orthoclase. The Niggl Al, alk, Si are high, with positive (+ve) quarzal values indicating/corroborating high concentration of quartz and feldspar in the all the analyzed granitoids samples.

Discussion

The granitoids rocks of various tectonic settings from Obudu Plateau and from other different parts of the world have been studied. For example, Ukaegbu and Ekwueme (2007) [11] studied the granitic and charnockitic rocks of southern Obudu Plateau Nigeria. The result showed that the granite of the present work shared similar geochemical characteristics with theirs, except that granites was relatively depleted in K₂O (av. = 2.18 wt. %), against 5.52 wt. % for that of the southern Obudu. Similarly, the Huldahalli charnockite, India [12], and the average chemical composition of some igneous [13], all show characteristics geochemical similarity with the properties of the aplites and pegmatites of the present study. The only slight difference being in the concentration of Fe₂O₃ which is higher (av. = 4.46 wt. %) in the granites from Vandeikya area (present study), and average of (0.78 wt. %,) reported by Nockolds (1954) [13] for some igneous rocks. The study reveals that the geochemical composition of the granitoids from Obudu Plateau Bamenda Massif is comparatively similar to values obtained from rocks of other tectonic settings from other parts of the world.

Petrogenetic study using various chemical discrimination diagrams (CDD) furnished further probe of the protoliths sources of the granitoids and their lithogeochemical affinities. In the Rb versus Y+Nb binary diagram (Fig. 5, [14]), the entire analyzed granitoids plot in the VAG field, indicating that they are of volcanic arc granite origin. In the SiO₂ versus Na₂O+K₂O binary diagram (Fig. 6), (after Irvine and Baragar, 1971), the granitic rocks all plot in the field of sub-alkaline rocks. In the ACNK versus ANK discriminant (Fig. 7) [15], the analyzed granitoids all plot in the peraluminous field, thus corroborating/ confirming their ASI affinity. In the CaO-K₂O-Na₂O ternary discriminant (Fig. 8) (after Condie, 1967), some of the granites plot in TNT field while some plot in the GD field, thus indicating that their protoliths ranged in composition from tonalite to granodiorite. However, the pegmatite plotted in the GNT field indicating that they are of late stage magmatic granite emplacement.



Conclusion

The granitoids of Northwest Obudu Plateau Bamenda Massif, has been systematically studied geochemically and petrogenetically. The investigation revealed that the rocks are of Pan-African (600 ± 150 Ma) age [16], occurring in the area includes granites, granodiorites, aplites, pegmatites. These granitoids intrude the host migmatites, gneisses and schists, and show occasional amphibolitic enclaves. Geochemically, all the analyzed granitoids are enriched in SiO_2 , Al_2O_3 , alkalis with $\text{Na}_2\text{O} > \text{K}_2\text{O}$, but relatively depleted in CaO , MgO , and TiO_2 , with variable Fe_2O_3 content. Petrogenetic probe shows that the granitoids are peraluminous, subalkaline rocks emplaced in volcanic arc tectonic setting.

Table 2: Average whole rock major elements, CIPW and Niggli norms (wt. %) distribution of the granitic rocks of Northwest Obudu Plateau, Bamenda Massif SE. Nigeria.

Oxide	D10.4A GNT.USH	D18.2B Aplite	D5.10B Pegmatite	GNT.1 GNT.VDK	Σ /N.GNT
SiO_2	63.52	74.0	78.59	66.68	70.7
Al_2O_3	17.7	12.04	10.69	14.81	13.81
TiO_2	0.65	0.19	0.17	0.65	0.42
Fe_2O_3	4.46	3.53	3.20	4.61	3.97
MgO	1.43	0.56	0.06	2.07	1.03
CaO	3.63	2.17	1.07	3.45	2.58
MnO	0.04	0.09	0.04	0.07	0.06
Na_2O	4.72	4.11	4.11	3.57	4.13
K_2O	2.18	2.49	1.56	2.71	2.24
P_2O_5	0.18	0.05	0.03	0.22	0.12
Cr_2O_5	0.007	0.002	0.002	0.009	0.005
LOI	1.30	0.60	0.30	1.0	0.80
Total	99.81	99.83	99.89	99.85	99.87
CIPW Norm of granitic rocks of Northwest Obudu area					
Q(S)	17.0	32.22	43.0	21.0	38.44
Or	12.8	15.1	9.45	16.13	13.35
Ab	39.8	35.0	34.6	30.4	35.11
An	17.0	7.0	3.62	15.3	11.96
C(A)	1.13		0.92	0.31	0.21
Di	10.1	2.6	6.14	11.94	
Hy		5.9			8.67
Ol	-	-	-	-	-
Mt	-	-	-	-	-
He	-	-	-	-	-
Il	1.2	0.31	0.3	1.22	0.76
Ap	0.93	0.93	1.86	1.86	0.93
Niggli Norm of granitic Rocks of Northwest Obudu Area					
Al	40	38	42	36	39
Fm	22	20	17	27	22
C	15	12	8	15	13
Alk	23	30	33	22	26
Si	243	393	514	272	339
K	0.23	0.29	0.21	0.33	0.26
Ti	1.86	0.65	0.8	1.98	1.43
P	0.23	0.13	0.08	0.5	0.29
Mg	0.30	0.23	0.05	0.46	0.34
Qz	+151	+173	+282	+84	+135
al+c	55	50	50	51	52
Al-c	25	26	34	21	26

Key: D10.4A = Granite. D18.2B = Aplite. D5.10B = Pegmatite. GNT.US = Granite Ushongo Area. Σ /N.GNT = Grand mean of the granitic rocks.



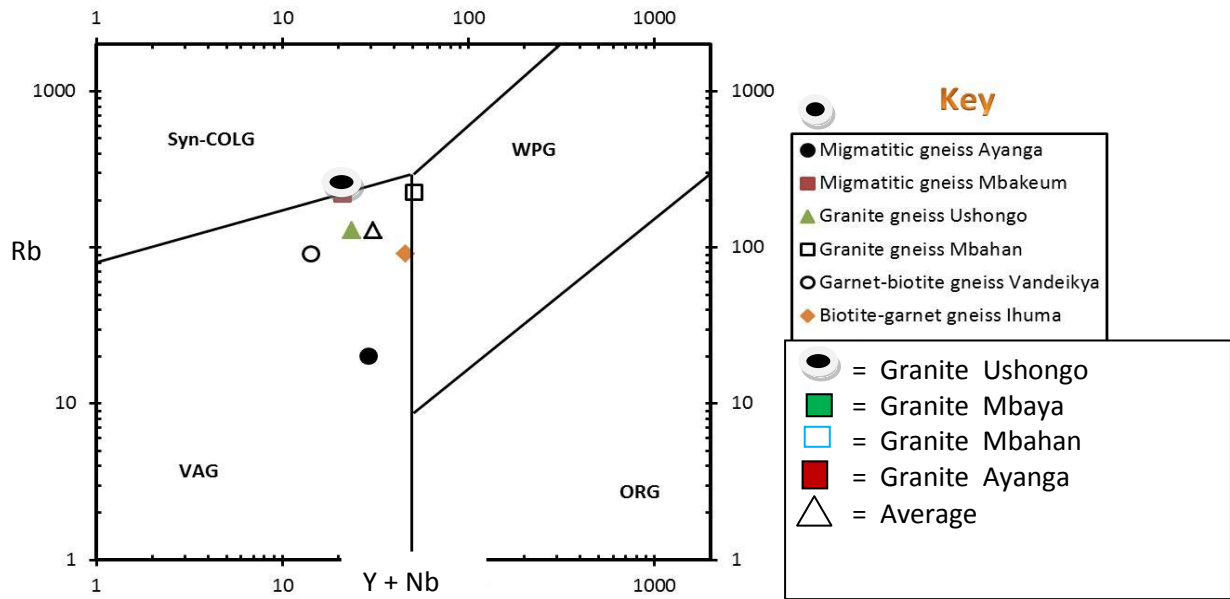


Figure 5: Rb versus Y + Nb discrimination diagram for granitoids of NW Obudu area [14]. Syn-COLG = syn collision granite. WPG = within plate granite. VAG = volcanic arc granite. ORG = Orogenic granite.

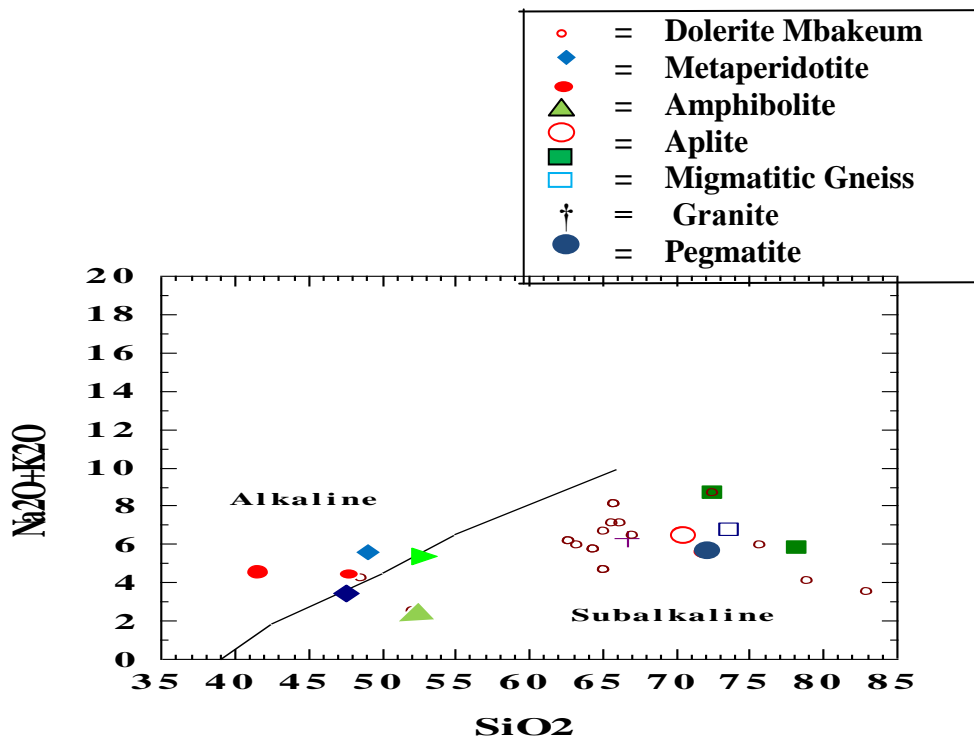


Figure 6: SiO₂ vs Na₂O+K₂O binary discriminant for rocks of NW Obudu (Fields after Irvine and Baragar, 1971) [17].

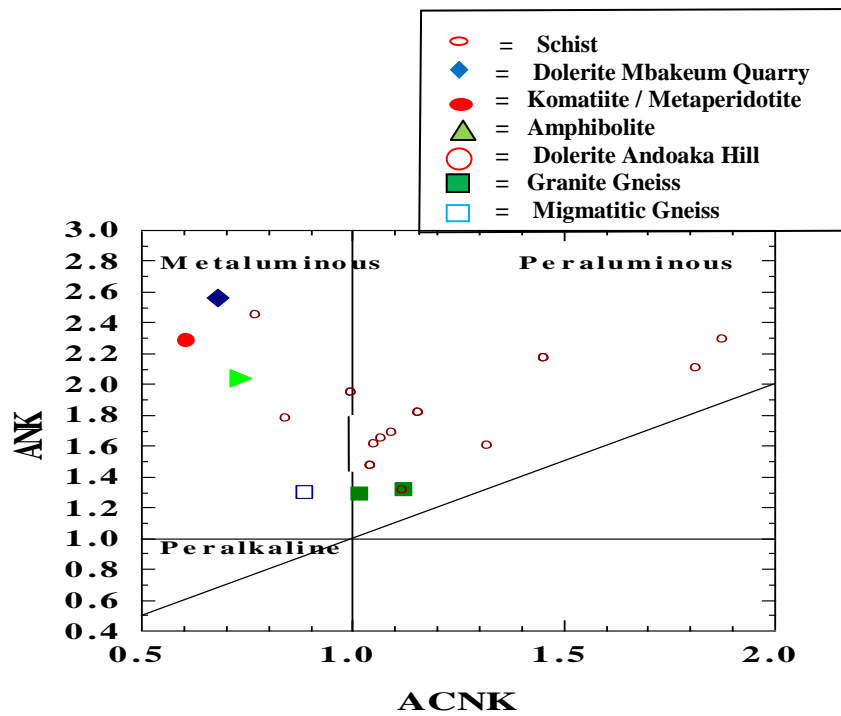


Figure 7: ACNK vs ANK binary discriminant for rocks of Northwest Obudu Plateau (after Pearce et al. 1977) [15].

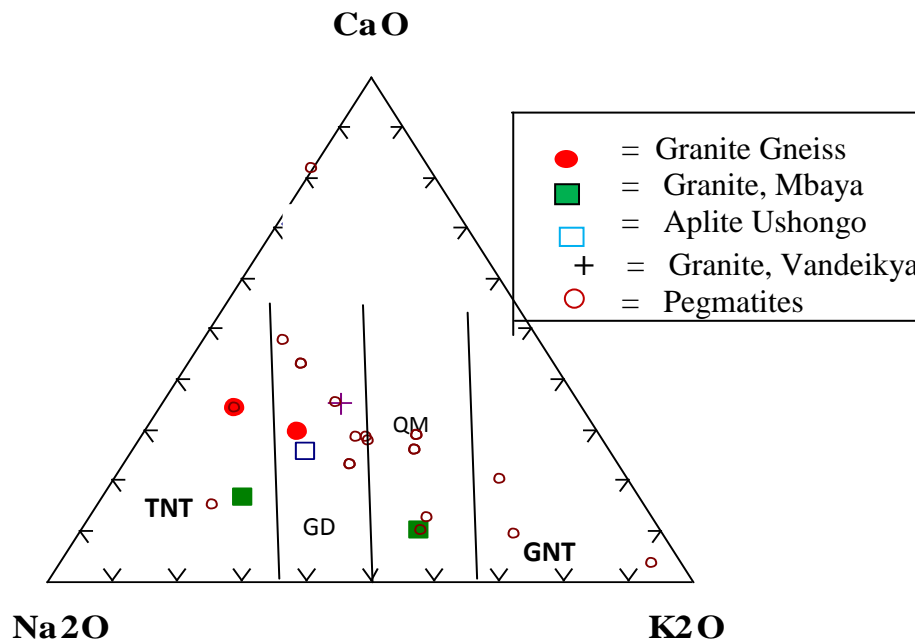


Figure 8: CaO – K₂O – Na₂O Ternary diagram for discrimination of granites and gneisses of Northwest Obudu area (after Condie, 1967) [18]. Key: TNT = field of tonalite, GD = field of granodiorite, QM = Field of Quartz monzonite, GNT = Field of Granite.

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