GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL, 9, NO.2, 2011 253-263
 ISSN 1596-6798
www.globaljournalseries.com, Email: info@globaljournalseries.com

SOME GEOCHEMICAL CONSIDERATIONS IN THE PETROGENESIS OF MADAGALI GRANITOIDS, NORTHEASTERN NIGERIA

SAIDU BABA

(Received 30 November 2010; Revision Accepted 10 February 2011)

ABSTRACT

Major and trace element geochemical data on granitoids of Madagali area of northeastern Nigeria show a series that ranges from K-calc-alkaline, through granodiorite-monzogranite to granite. They are characterized as mildly peraluminous to metaluminous and I-type based on alumina saturation index (ASI). Trace element contents preclude the possibility of entire mantle origin and indicate significant crustal involvement in the evolution of the granitoids. The enrichment in LREE (La, Ce and, Nd), depletion in HREE (Ho, Er, Yb and Lu) and a pronounced negative Eu anomaly with $(La/Yb)_N$ suggest that the granitoids must have evolved by partial fractionation or partial melting of the pre-existing crust in which plagioclase feldspar was retained. Furthermore, the enrichments in some large-ion-lithophile elements (LILE) such as Rb, Ba, Th and K and depletion in some high field strength (HFS) elements such as Nb, P, and Ti as well as some transitional elements Cr and Ni are supportive of crustal involvement in their genesis.

KEY WORDS: Madagali, Nigeria, Granitoids, Geochemical considerations, Petrogenesis.

INTRODUCTION

The study area is the northeastern tip of the Nigerian Basement complex, separated from the southern part (Oban-Obudu Massif) by the Upper Benue Trough. It forms the western terminal of the Western Cameroon Domain (WCD) (Ferre et al. 1996, 2002; Ekwueme and Kroner, 1997, 1998); (Fig.1). The WCD is part of the remobilized Pan-African terrain formed in the Neoproterozoic (approx. 600Ma) by continental collision between the converging West African Craton, Congo Craton and East Saharan block. It consists of an amalgamation of Precambrian terrains (Caby, 1989; Castaing, et al. 1994; Black and Liegeois, 1993; Ferre et al. 1996, 2002) that show long and complex crustal evolution with strong imprints of Neoproterozoic events (Toteu et al. 2004), which include: Neoproterozoic medium-high grade schists and gneisses (Ngako, 1986; Ngel, 1986; Toteu, 1990) ; Pan-African pre-,syn-, and late tectonic calc-alkaline granitoids (Toteu, et al. 1987, 2001); and Post-tectonic alkaline granitoids (felsic and mafic dykes,e.g. the Burashika Group).

Madagali area is dominantly underlain by the Neoproterozoic medium to high-grade gneisses intruded by large volumes of Pan-African granitoids and many of these Pan-African granitoids in Nigeria have been variously discussed in terms of nomenclature, classification and origin (Baba et al, 1996). For example, Umeji (1991) described them as calc-alkaline monzogranites with charnockitic affinity in Jato-Aka area of southeastern Nigeria and concluded that they were formed from mantle-derived magmas. Onyeagocha (1986) concluded that the Pan-African granitoids in central Nigeria were derived by partial melting of the country rocks (schists and gneisses), while Ezepue and Odigi (1993) showed that the various components of the granites are not co-genetic and that they were derived from upper mantle and crustal materials. Ukaegbu and Beka (2007) deduced that the enderbite-charnockite association in the Pan-African Obudu plateau are peraluminous (S-type) formed at lower crust. Ferre et al (1998), using Sr initial ratios suggested that the source of the granitic magmas of the Pan-African rocks of eastern Nigeria is the lower crust characterized as ferro-potassic with trans-alkaline affinity. Dada (2008) in his broad multi disciplinary synthesis of Nigeria-Boborema province opined for a mixing model between juvenile Pan-African material and the Archean basement with a prominent involvement of the later in the genesis of the Pan-African granitoids.

In their study of the Pan-African granitoids of the extreme northeastern tip of the Nigeria, north of the Benue Trough, Islam and Baba (1992) described the rocks as alkaline and of mixed origin. Baba et al. (1996) described the Liga Hills granites as being products of anatexis of crustal materials. On the petrogenesis of the Pan-African granitoids from Gwoza area Baba, et al (2006) reasoned that they were calc-alkaline and I-type. Following the suggestion in Baba et al (2006), this paper presents some trace and rare earth elements data on the granitoids and discusses their significance in the petrogenesis of the rocks in addition to providing an updated geological map of the area.

Saidu Baba, Department of Geology, University of Maiduguri, P.M.B 1069, Maiduguri, Borno State

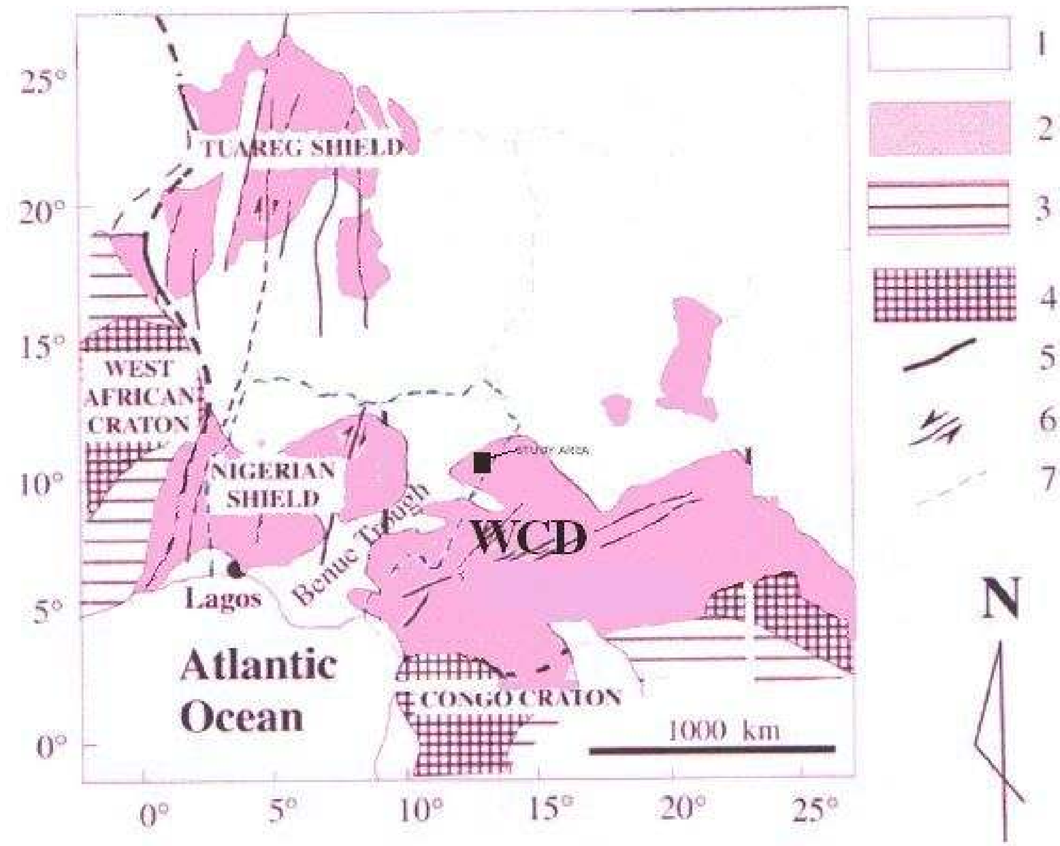


Fig. 1: Sketch diagram showing the location of the Study Area within the Pan African Belt

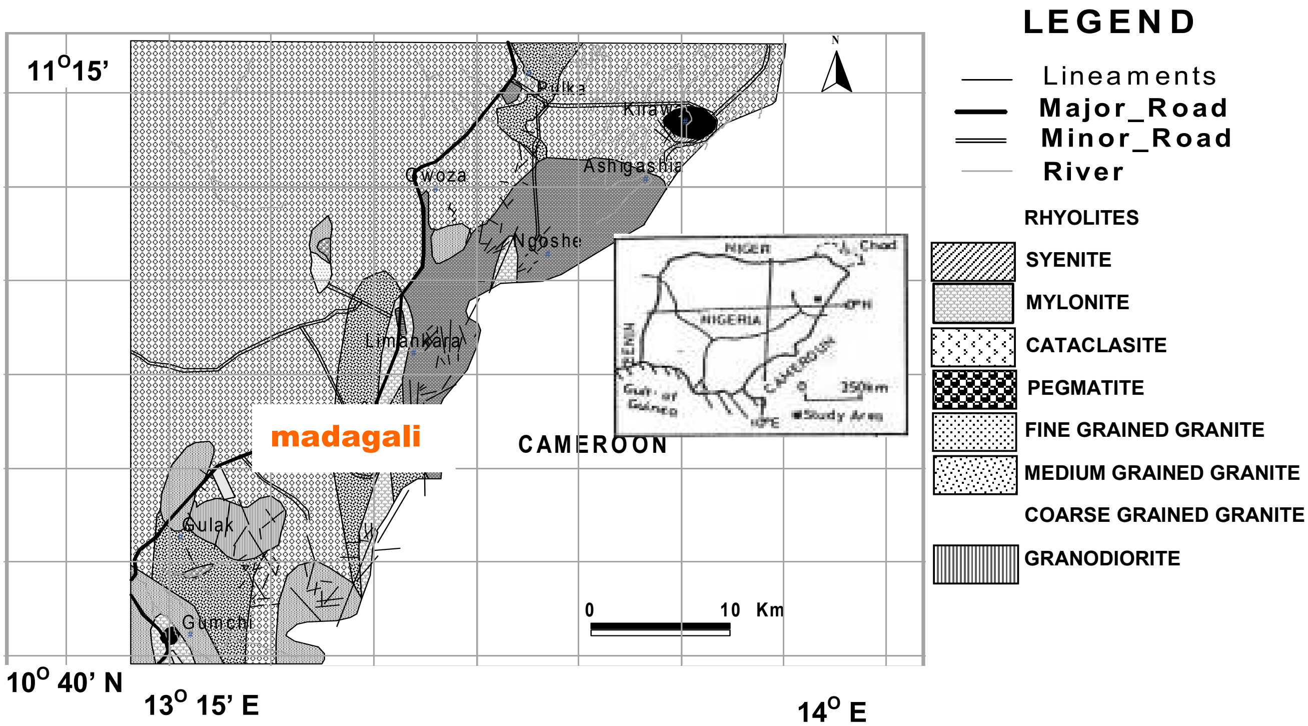
1-: Post Pan-African Cover; 2- Pan-African Belt; 3- Pre-Mesozoic Series; 4- Archean to Paleoproterozoic Crateos; 5 - Craton Limits; 6- Faults; 7- State boundaries.
WCD - Western Cameroun Domain (modified after Toteu et al. 2004)

FIELD RELATIONS AND PETROGRAPHY

Neoproterozoic migmatitic gneisses, minor schists (unmappable) and quartzites intruded by large volumes of Pan-African granitoids (Fig.2) underlie the study area. The migmatitic gneisses and their associated dismembered amphibolites that form the basement *sensu stricto* (Dada et al. 1995) are cross cut by felsic veins (Baba et al, 2006). N-S to NNE-SSW foliation trends with near vertical dips are predominant. The schists and the quartzites are relatively minor and exposed only at foothills and stream channels.

The granitoids form large bodies in form of batholiths concordant with the foliation trends in the gneisses and sometimes oval-shaped plutons making up the main Mandara range. The dominant hill-forming granitoids, which are the rocks of interest, are mineralogically uniform but variable in texture ranging from fine grained through medium to coarse and even porphyritic. Contacts between them are often sharp and sometimes lobate especially amongst the late-phase (post-tectonic) members, suggesting contemporaneous emplacement. They also carry xenoliths of gneisses and schists to suggest possible anatexis (Baba et al. 2006).

Minerals identified in thin-section include K-feldspar (mainly microcline), quartz, plagioclase and biotite with hornblende in some sections. Iron oxides (as opaque), sphene, zircon and apatite make up the accessories. The average modal compositions give quartz (32%), plagioclase (27%) K-feldspar (26%) and biotite (13%). Microcline occurs in anhedral to subhedral form characterized by crosshatch twining but often-developed perthitic texture, which obliterates the twining. Quartz occurs in two generations, the first generation made up of large anhedral, often cracked grains with sutured margins and undulose extinction while the second generation grains are smaller in size, subhedral to euhedral and often polygonal with triple junction. In some sections, the second-generation quartz fill-up the cracks in the first generation grains. Plagioclase crystals are subhedral prismatic, generally cloudy and in some sections, the lamellae are deformed and sometimes contain sericites. The undeformed and unaltered crystals give extinction angles of 7^0-10^0 (oligoclase). Biotite flakes are sometimes bent and show slight alteration to iron oxides along their cleavage planes, often containing pleochroic haloes resulting from the radioactive nature of the zircon inclusions. Iron oxides as opaques are the dominant accessory minerals occurring as anhedral to subhedral grains intimately associated with biotite and sphene. Sphene occurs in its characteristic rhombic form, zircons appear dominantly as inclusions in biotite while apatite occurs as discrete grains as well as inclusions in sphene. Using the modal Q-A-P Streckeisen diagram, Baba et al (2006) showed Madagali granitoids as quartz monzonite-granite.



GEOCHEMISTRY

Analytical Methods: 15 representative samples of the granitoids were separately crushed and pulverized to about 106 microns. Each sample was then homogenized and later quartered and sent for analysis in the Activation Laboratories, Ontario, Canada where major, trace and rare earth elements were determined by Inductively Coupled Plasma (ICP) Spectrometry. Analytical precision in general is better than ± 2% for major and ± 5% in trace elements.

Major Elements

Table 1 shows no significant variation amongst the major elements composition of the granitoids except in silica (SiO_2) which ranges from 62.00% in coarse porphyritic granites to 75.61% in the fine-grained granites. These analyses agree with those in Baba et al (2006) in that when plotted in the KCN and normative Ab-An-Or diagrams, they all plot in quartz monzonite-granite fields. However, the samples plot dominantly in the regions of granite- monzogranite-granodiorite field (Fig.3) when Q^{I}-Anor (CIPW-Norm values) diagram of Streickeisen and Le Maitre (1979) was used in this study, as given in Bowden et al (1984), In the SiO_2 vs. K_2O diagram of Rickwood (1989), all the samples except one (sample 7) plot in the field of high K calc-alkaline (HKCA) (Fig.4).

The average content of Al_2O_3 (13.86%) in the rocks is considered moderate and in all the samples however, the alumina values are only slightly greater than total alkalis plus lime ($Al_2O_3 > Na_2O + K_2O + CaO$). The molecular Al_2O_3/ ($CaO + Na_2O + K_2O$) or Alumina Saturation Index (ASI) A/CNK ratio in almost all the samples is approximately one,

ranging from a minimum of 0.96 to a maximum of 1.12 with an average of 1.01. Al/ (Na+K+2Ca) ratio also ranges from 0.78 to 1.02 with an average of 0.85. The poor aluminous nature is better illustrated when the molecular ratio A/CNK is plotted against Si_2O after Chappel and White (1974) where most of the samples clustered in the region of mildly peraluminous to metaluminous (Fig.5).

TABLE 1: MAJOR ELEMENTS AND NORMATIVE MINERAL COMPOSITIONS OF MADAGALI GRANITOIDS (wt %)

Wt.%	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	AV
SiO_2	62.20	64.57	67.13	69.66	70.70	70.72	70.80	71.55	72.29	74.01	75.11	69.21	69.77	73.89	75.61	70.48
Al_2O_3	13.66	14.20	14.74	13.99	15.18	14.79	14.39	13.80	14.20	13.00	12.79	15.19	14.75	13.01	11.15	13.86
$Fe_2O_{3(T)}$	7.20	5.62	4.03	3.27	2.57	2.66	2.75	2.24	1.72	1.50	1.32	1.69	2.15	1.49	2.70	2.86
MnO	0.10	0.09	0.07	0.05	0.03	0.04	0.04	0.30	0.04	0.03	0.03	0.02	0.03	0.27	0.04	0.06
Mg O	5.49	3.23	1.00	1.40	0.99	1.33	0.56	1.08	0.21	0.18	0.12	0.57	1.13	0.17	0.10	1.17
Ca O	1.95	2.25	2.54	1.96	2.98	2.47	1.95	2.55	1.05	1.10	1.26	1.37	2.25	0.88	0.75	1.82
Na_2O	2.60	3.07	3.54	3.48	4.40	4.07	3.64	3.67	3.19	3.25	3.50	4.12	4.21	3.33	2.80	3.53
K_2O	4.09	4.31	4.53	4.12	2.04	3.11	4.14	2.75	5.25	4.81	4.68	5.20	3.30	5.00	5.09	4.16
P_2O_5	0.99	0.90	0.81	0.44	0.34	0.26	0.18	0.23	0.18	0.16	0.14	0.39	0.33	0.17	0.20	0.38
TiO_2	0.14	0.20	0.26	0.10	0.06	0.05	0.04	0.05	0.06	0.12	0.04	0.12	0.10	0.06	0.05	0.10
LOI	1.22	0.85	0.47	0.88	0.50	0.55	0.56	1.12	1.49	1.21	1.01	0.82	0.62	1.03	0.55	0.86
TOTAL	99.64	99.29	99.12	99.35	99.79	100.05	99.05	99.34	99.68	99.37	100	98.70	98.64	99.30	99.02	99.28
C I P W NORMS																
Q	16.14	28.49	40.84	29.79	28.68	28.44	28.20	29.75	31.3	32.88	33.58	21.74	27.83	33.32	38.06	29.94
Or	24.76	22.66	20.56	23.71	12.18	18.53	24.84	28.44	32.0	30.0	27.91	31.42	20.16	30.24	30.77	25.22
Ab	22.49	22.79	23.08	28.66	37.53	34.39	31.24	29.51	27.78	28.8	29.82	35.63	36.74	28.78	24.18	29.43
An	9.67	8.99	8.30	8.66	14.58	11.79	9.0	7.05	5.01	5.14	5.37	6.34	10.93	4.11	2.84	7.85
C	1.51	0.75	-	0.52	0.43	0.55	0.67	0.58	0.49	0.20	-	0.54	0.37	0.65	-	0.48
Di	-	0.09	0.18	0.13	-	-	-	-	-	0.21	0.61	-	-	-	0.44	0.11
K_2O/Na_2O	1.57	1.40	1.27	1.24	0.46	0.76	1.14	0.75	1.65	1.48	1.34	1.26	0.78	1.50	1.82	1.23
Na_2O/CaO	1.33	1.36	1.40	1.98	1.48	1.65	1.87	1.44	3.04	2.96	3.78	3.01	1.87	3.78	3.73	2.31
K_2O/CaO	2.10	1.92	1.78	2.10	1.26	2.12	1.08				3.71	4.52	1.47	5.68	6.77	2.97
Al/(Na+K+2Ca)	0.88	0.83	0.78	0.84	0.87	0.85	0.85	0.84	0.85	0.86	0.82	0.86	0.86	0.87	0.80	0.85
A/CNK	1.12	1.03	0.96	1.01	1.02	1.01	1.02	1.01	1.03	1.04	0.97	1.02	1.01	1.04	0.96	1.01
A/NK	1.57	1.43	1.37	1.36	1.60	1.46	1.37	1.52	1.20	1.23	1.18	1.22	1.40	1.19	1.10	1.34

1-3=coarse porphyritic granites, 4-7=coarse-grained granites, 8-12=medium grained granites, 13-15= fine-grained granites

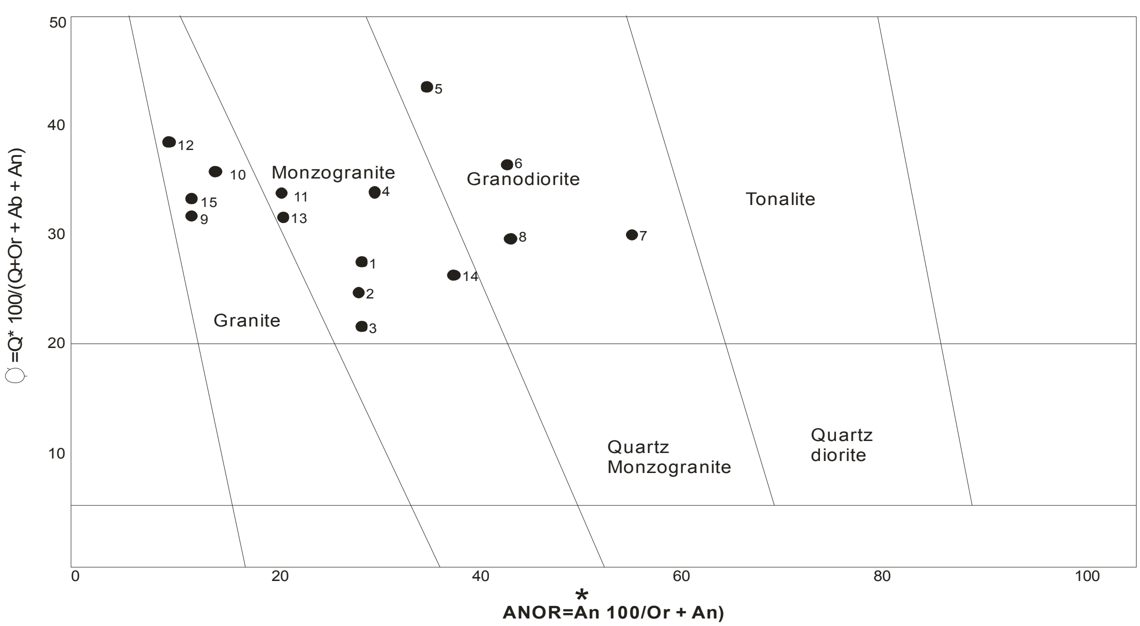


Fig. 3: Q'-Anor diagram for Madagali granitoids (CIPW norm values) following Streckeisen and Le Maitre (1979).

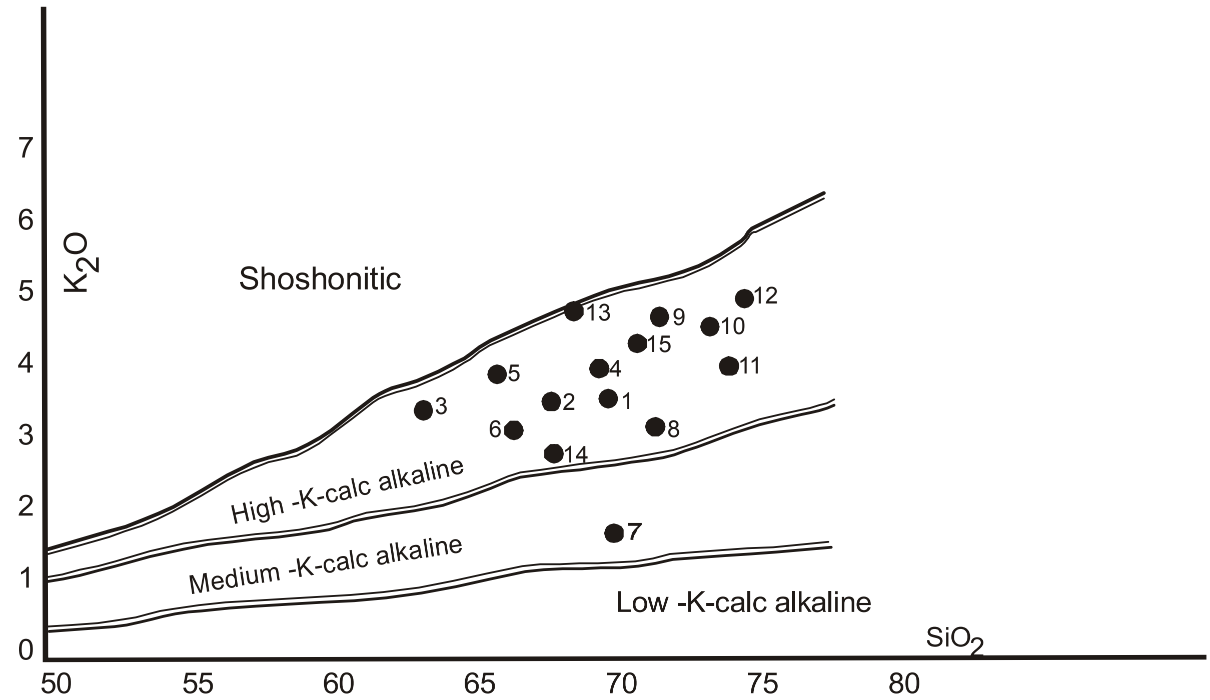


Fig 4 : SiO_2 vs K_2O diagram for Madagali granitoids (after Rickwood, 1989)

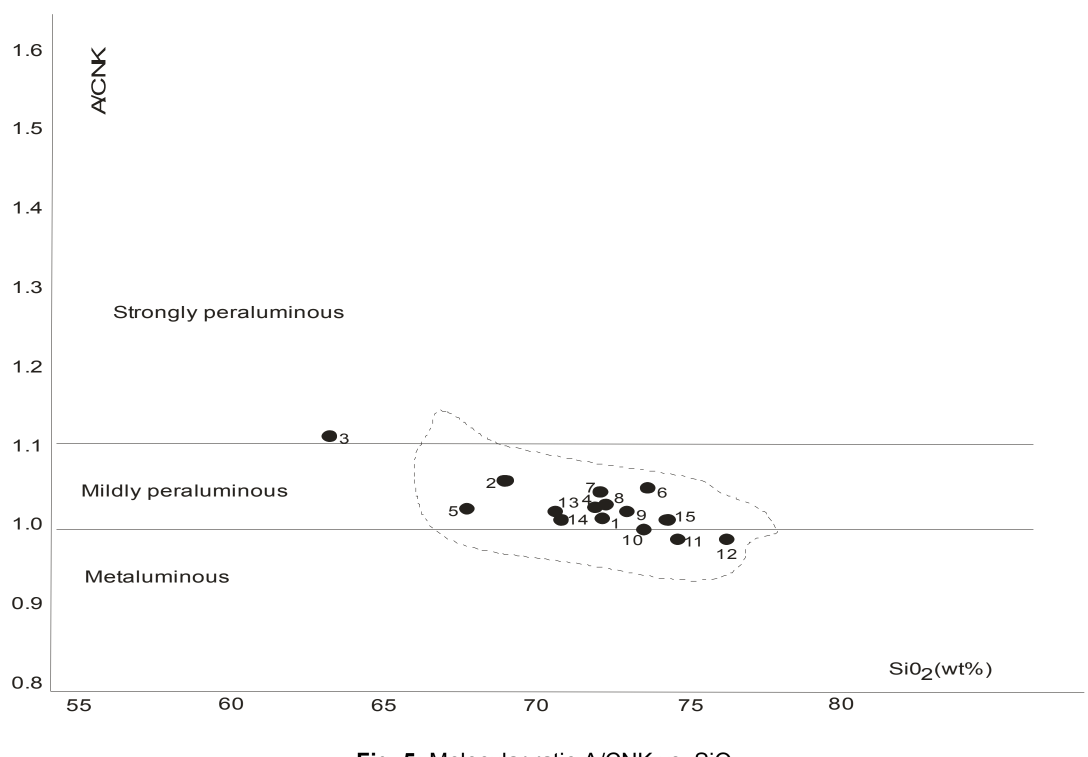


Fig. 5: Molecular ratio A/CNK vs. SiO_2

Trace and Rare Earth Elements

Table 2 shows the concentrations of some trace and rare earth elements (REE) in the studied granitoids. Some of the trace elements show considerable variations within the granitoids such as Ba, which ranges from 321ppm to 1153ppm (average 762ppm), Rb from 90ppm to 324ppm (average 181ppm),Sr from 80ppm to 615ppm (average 271ppm) and Th (7.7ppm-56.2ppm), while others show limited variations, e.g. Sn (2-6ppm) and uranium (1.4-5.8ppm).

The high field strength (HFS) elements such as Zr, Y and Nb contents in the Madagali granitoids are relatively high ranging from 106ppm-321ppm, 3ppm-48ppm,and 4ppm-33ppm with averages of 215ppm, 21ppm and 15ppm respectively.

The REE abundances in Table 2 show that the total REE of the samples studied ranges from 79.73ppm to 460ppm with an average of 264.22ppm. The distribution shows remarkable differentiation with general enrichment in the light rare earth elements (LREE) (La-Nd) and depletion in heavy rare earth elements (HREE) (Ho-Lu). This pattern becomes more elaborate when the chondrite-normalized values are plotted against the atomic numbers of the elements in the Masuda-Coryell diagram (Fig.6) showing clear enrichment in LREE with steep slope, depletion in HREE with near-flat pattern and pronounced negative europium anomaly. The pattern can be described as sub-parallel and overlapping suggesting similar evolutionary conditions. The $(La/Yb)_N$ ratio, in all samples except one (Sample 11) is greater than 10 ranging from 10.3 to 98.99 with an average of 39.99ppm

Figure 7 gives the multi-element distribution pattern (Spidergram) of the rocks. The samples are seen to be enriched in some large-ion lithophile elements (LILE) such as Rb, Th, and Ba, and depleted in some high field strength (HFS) elements such as Nb, Ta, Y, P, and Ti, as well as in some transitional elements Cr and Ni.

TABLE 2: SOME TRACE AND RARE EARTH ELEMENT (REE) COMPOSITIONS OF MADAGALI GRANITOIDS (ppm) AND SOME ELEMENTAL RATIOS

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**AV**
Rb	324	258	191	196	90	120	150	181	214	211	206	186	88	90	211	181
Y	16	32	47	21	11	16	21	22	21	19	12	3	9	21	48	21.27
Zr	232	271	309	218	241	257	272	210	147	128	106	262	113	138	321	215
Nb	23	26	29	16	6	9	12	13	12	12	12	4	5	15	33	15.13
Ba	587	863	1139	733	509	831	1153	920	687	581	321	1105	864	661	476	762
W	197	232	267	254	244	221	197	209	223	313	397	356	265	224	252	256.73
Hf	6.9	7.55	8.2	13	5.9	6.4	6.9	24.2	44	26.4	4.1	6.5	3.1	4.4	3.3	11.39
Ta	1.3	2.3	3.3	1.7	1.0	1.2	1.3	1.5	1.6	1.8	1.9	0.8	1.0	2.5	3	1.75
Th	29.8	25.5	21.1	24	28.5	21.7	14.8	16.2	21	24.8	28.7	56.2	7.7	17.3	24.1	24.09
U	1.4	1.8	2.1	2.7	2.9	2.3	1.7	2.2	3.4	4.01	4.5	3.1	2.3	5.8	4.0	2.95
Sr	223	275	326	267	526	413	300	210	119	112	108	380	615	106	80	270.67
K/Rb	105.7	138.6	196.8	174.4	188.1	215	229	126.1	203.6	189.2	1.5	232	311	461	200.2	190.7
K/Ba	68	41.5	33	46.7	33.3	31.1	29.8	24.9	61.1	68.7	121	39.1	31.7	62.8	106.2	45.3
Ba/Rb	1.81	3.35	5.96	3.74	5.66	6.93	7.69	5.08	3.21	2.75	1.56	5.94	9.82	7.34	2.26	4.21
Rb/Sr	1.45	0.94	0.59	0.73	0.17	0.29	0.50	0.86	1.80	1.88	1.91	0.49	0.14	0.85	2.64	0.67
Ba/Sr	2.63	3.13	3.49	2.75	0.97	2.01	3.84	4.38	5.77	5.19	2.97	2.91	1.41	6.24	5.98	2.82
Th/U	21.29	14.17	10.05	8.89	9.83	9.44	8.71	7.36	6.18	6.19	6.38	18.13	3.35	2.98	6.03	9.26
La	81.7	76.1	70.5	61	96.4	77.6	56.5	50.3	42	23	16.8	104	21.4	40.9	94.4	60.97
Ce	158	149	158	120.5	172	143	114	98	85.5	60.5	35.5	174	41.3	84.1	213	120.43
Pr	16.4	17.6	18.7	13.02	17.8	15.1	12.3	10.70	9.18	6.35	3.75	16.9	4.69	8.85	22.6	12.93
Nd	57.9	65.1	72.3	46.4	60.4	51.7	43.0	38	32.2	22.5	12.7	52.2	17.8	30.5	82.4	45.67
Sm	9	11.5	13.9	7.4	7.9	7.4	6.9	6.3	5.7	4.3	2.8	6.3	3.4	5.4	14.4	7.51
Eu	1.28	1.73	2.17	1.21	1.43	1.33	1.22	0.92	0.72	0.60	0.41	1.33	0.95	0.66	1.03	1.13
Gd	6.7	9.15	11.6	6.87	5.1	5.3	5.4	4.81	4.5	2.9	1.9	3.1	2.9	4.3	11.3	5.72
Tb	0.08	0.89	1.70	0.68	0.5	0.65	0.8	0.7	0.7	0.5	0.3	0.3	0.4	0.7	1.7	0.71
Dy	3.7	5.9	8.5	4.02	2.4	3.1	3.8	3.2	3.8	2.5	1.9	0.9	2.1	3.8	9	3.91
Ho	0.6	1.1	1.5	0.72	0.4	0.55	0.7	0.8	0.7	0.5	0.4	0.1	0.4	0.7	1.6	0.72
Er	1.6	3.0	43	2.03	1.0	1.55	2.1	1.9	2	1.6	1.2	0.4	1.1	2.2	4.9	2.06
Tm	0.22	0.42	0.62	0.30	0.13	0.22	0.3	0.41	0.32	0.3	0.21	<0.05	0.16	0.36	0.71	0.33
Yb	1.4	2.6	3.8	1.95	0.8	1.4	2.0	1.9	2.1	1.9	1.6	0.2	1	2.4	4.4	2.99
Lu	0.21	0.37	0.52	0.29	0.12	0.21	0.3	0.28	0.31	0.26	0.26	<0.04	0.14	0.35	0.65	0.31
∑REE	338.79	344.46	368.11	266.39	366.38	309.11	251.32	218.22	189.73	127.71	79.73	359.73	97.74	185.22	460.65	264.22
$(La/Yb)_N$	39.05	25.73	12.41	28.68	80.5	50.1	19.73	16.60	13.37	10.3	7.02	17.56	101.6	78.19	98.99	39.99

Legend as in Table 1.

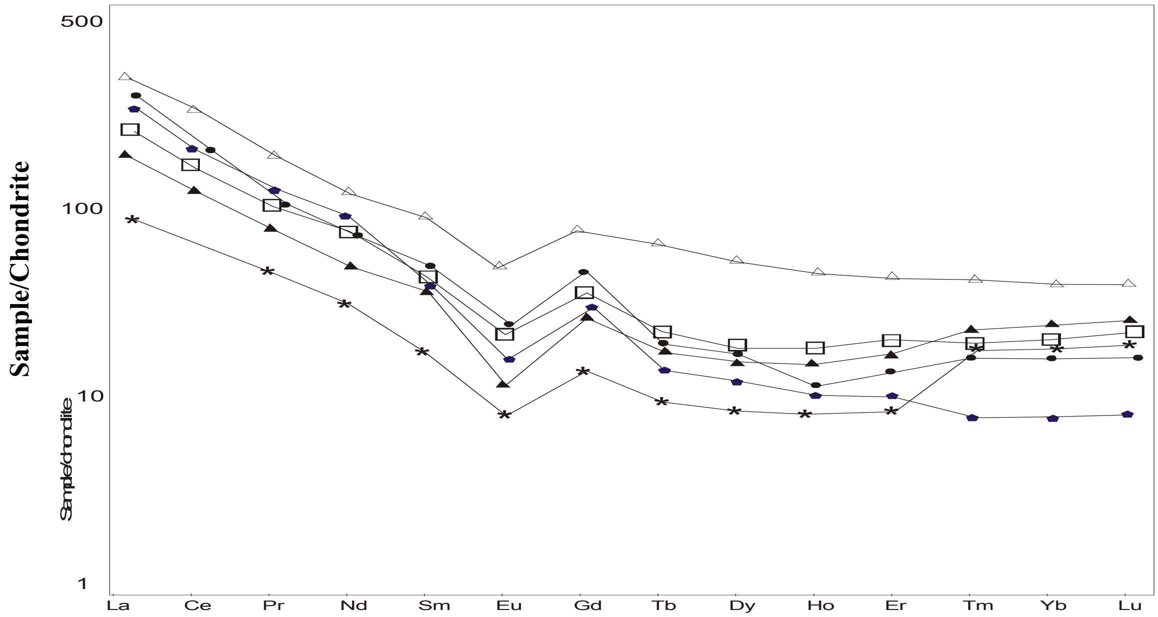


Fig.6: Chondrite normalized REE pattern for Madagali granitoids
(Normalizing values are from Nakamura, 1974)

KEY:

* Fine-grained granite
⬟ Medium-grained granite
● Coarse-porphyritic granite
△ Coarse-grained granite
▲ Coarse-grained granite
□ Granodiorite

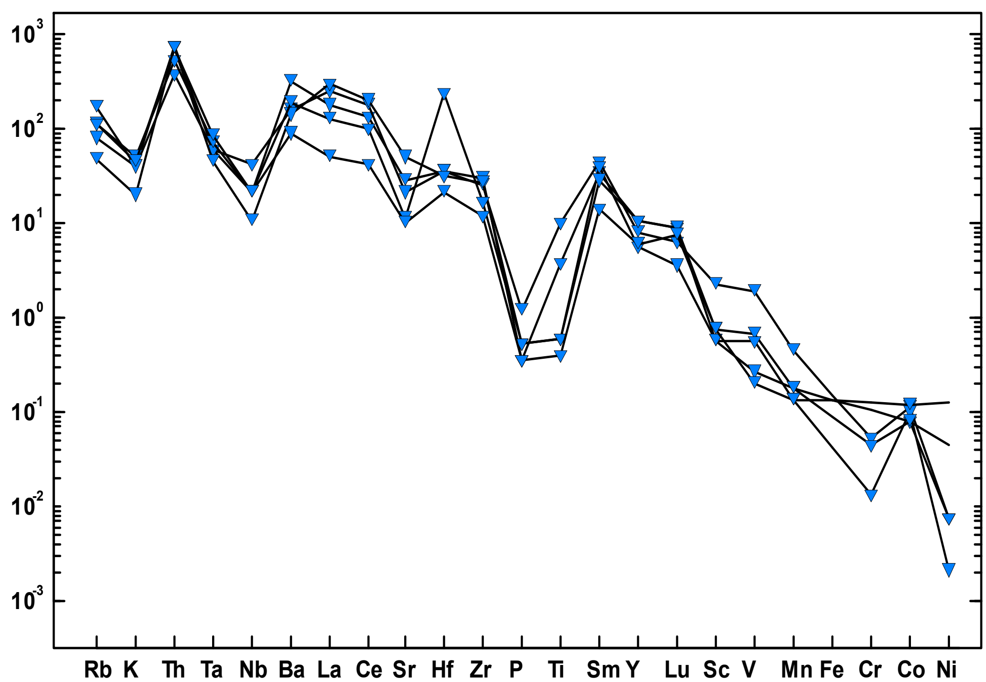


Fig. 7: Chondrite normalized abundance pattern of incompatible elements in Madagali granitoids (Normalizing values are from Wood et al. 1979)

DISCUSSION

The Madagali granitoids form large, elongated bodies trending concordantly with the foliation trends in the metamorphic rocks. In the field, the granites show no evidence of having been formed by in-situ recrystallization or metasomatism of the pre-existing or host gneisses. Besides, there are no significant replacement textures or structures in thin section except the strained and two-generation quartz grains. This implies that a more complex process involving both metasomatism and recrystallization may have taken place.

The mineral assemblages in the rocks do not contain any typical minerals (sillimanite or kyanite) that usually indicate S-type and neither are they particularly corundum-normative (Table 1) as to indicate some sedimentary origin. Though 12 of the 15 samples are weakly corundum-normative, the values are too low to suggest S-type progenitor. The rocks also did not evolve through massive direct fractional crystallization or some form of fractionation from single parent magma because the area lacks mafic rocks in the field.

Chemical classification based on major elements and normative mineral compositions indicate that Madagali granitoids are of granodiorite-monzogranite-granite series. Baba et al. (2006) used An-Ab-Or diagram of O'Connor (1965) to classify the granitoids of the same region as being dominantly granites with some quartz monzonitic varieties. When plotted in the K_2O vs. SiO_2 diagram of Rickwood (1989) the samples fall dominantly in the high K-calc-alkaline (HKCA) region (Fig.4). The K_2O/Na_2O ratio is on the average 1.23. This value, though greater than unity and is similar to that of the anatectic granites of northern Cameroun (1.31), is not particularly high and does not fit very well with those of the classical S-type granites (Toteu, 1990).

The A/CNK ratios, which range from 0.96 to 1.12 with an average of 1.01, indicate poor aluminous nature of the rocks. This range is slightly less than the values for the established peraluminous Elat granites (EG) and Shahmon gneissic granite (SGG) in southern Israel (1.03-1.16) (Eyal et al, 2004) and much less than the values for the strongly peraluminous granites of European Alps and Himalayas (1.16-1.66) reported in Sylvester (1998). These features along with the Al/(Na+K+2Ca) suggest that the rocks are aluminium-poor or metaluminous and according to Chappell and White (1974), such are characteristics of I-type granites. This nature is further highlighted in the A/CNK vs. SiO_2 diagram (Fig.5) where most of the samples plot in the mildly peraluminous field but with considerable number falling in the metaluminous region. These chemical features appear similar to those of the granitic gneisses of Jebba area, which are also HKCA and plot in the region between metaluminous and peraluminous granites (Okonkwo and Winchester, 1996). Madagali granitoids can therefore be characterized as mildly peraluminous to metaluminous, HKCA, I- type and monzonitic rocks.

The generally high Ba values in the rocks would also suggest a calc-alkaline source or parent but more specifically, Tarney and Windley (1977) have considered such Ba contents as evidence of partial melting of lower continental crust. James et al. (1976) however, consider the petrogenesis of such granitic rocks to be related with magmas from sub-crustal mantle sources.

Rb enrichment (181ppm) may suggest that Madagali granitoids are products of highly fractionated melts (Whitney et al. 1976). Some of these elements have earlier been used in Baba et al. (2006) to show that the granitic rocks of Gwoza area, which is part of the present study, have been emplaced in a crust that was greater than 30 km thick.

The average values of Zr, Y and Nb are comparable with the average values in Jebba granite gneiss of southwestern Nigeria calculated from Okonkwo and Winchester (2004) as Zr (283ppm), Y (56ppm) and Nb (14ppm) which have also been characterized as HKCA and dominantly I-type. In general, some transition elements like Ti, Zr and Nb usually are compatible in behavior and their concentrations in granitic liquids are generally inversely proportional to the degree of partial melting if there are no phases such as rutile or ilmenite (Jahn et al.1979). The various diagrams (Figs.3-7) reveal that no linear trends exist in the rocks, which strongly suggests against evolution by any single process of differentiation or crystallization of a single mafic magma. Furthermore, there is no systematic variation in the relationship of K_2O to Ba/Rb, all the rocks have similar K/Rb ratios (Table 2) and there are consistent relative high contents of Ba and Zr.

The average Th value of 24.09ppm and Th/U ratio of 9.27 are considered high and suggestive of crustal involvement in the evolution of the rocks (Fourcade and Allegre, 1981) and are characteristic of most differentiated granites (Umeji, 1991). It would appear that there is a comparative relatively lower Rb, Rb/Sr and K/Ba but higher Ba/Rb ratios in the finer grained granites, suggesting that the derivation of the rocks is from a source zone or region depleted in alkalis but enriched in Sr, and probably there was not much fractionation (Tarney, 1976).

The behavior of the REE is significant in the study of genetic problems of granites as they are quite resistant to metamorphic and metasomatic processes (Koljonen and Rosenberg, 1974). Therefore, the REE patterns, even in slightly altered rocks, can faithfully represent the original composition of the unaltered parent and a fair degree of confidence can be placed in the significance of the peaks and troughs and the slope of REE patterns. The total REE abundances ($\sum$REE) in the studied granitoids is on the average 264.22 ppm which falls within the normal values for acid to intermediate rocks (230-350 ppm) (Haskin and Schmitt, 1967) and very similar to the average value for upper crust granitic rocks of 290 ppm (Wedepohl, 1978). The average values of La (61ppm), Ce (120ppm) and Nd (46ppm) compare fairly with the values of 69ppm, 154ppm and 58ppm in Jebba granite gneiss, which are shown to be product of lower crustal melting (Okonkwo and Winchester, 1996). Furthermore, a common source for all the granitoids is indicated by the distribution of the immobile trace elements (REE) and their general similar configuration (Fig.6). The origin of the granitic rocks involving partial melting of the crust is also plausible since it is compatible with high Zr contents (Bowden et al. 1984). The abundance and predominance of coarse-grained to near porphyritic granites with monzonitic compositions also suggests partial melting of pre-existing continental crust. Again, the similar nature of the K/Rb ratios (almost all identical) is an indication that the granites did not form from the surrounding gneisses solely by partial melting and that if a melted phase of the gneisses had been involved, there would have been a greater variation in the K/Rb ratios (Compton, 1928).

The REE distribution patterns of Madagali granitoids, which show enrichment in LREE, and depletion in HREE with pronounced negative Eu anomaly obviously depicts an origin through partial melting. Feldspars essentially control europium anomalies, as Eu is compatible in plagioclase in contrast to the trivalent REE, which are incompatible. Thus, the removal of feldspars by fractional crystallization or the partial melting of a rock in which feldspars are retained in the source will give rise to a negative anomaly in the melt (Rollinson, 1998). The negative Eu anomaly in the Madagali granitoids is similar to the pattern in the Akwanga granites, which was shown to have been derived by partial melting of the surrounding gneisses (Onyeagocha, 1986). The patterns are also similar to those of the granitoid plutons of Fourcade and Allegre (1981) and post-kinematic Prosperous Lake granites (Drury, 1979). The $(La/Yb)_N$ ratio is in all samples except one (Sample 11) greater than 10 ranging from 10.3 to 98.99 with an average of 39.99 ppm majority of which are less than 40 thereby precluding the rocks from being entirely of mantle origin. The normalized multi-element/incompatible element diagram (Spidergram) of the granitoids shows enrichment in the more mobile LREE (Rb, Th,and Ba) and depletion in the less mobile high field strength (HFS) elements (Nb, Ti, and P) and some transitional group (Cr and Ni). This pattern is similar to that in the Fayalite-bearing quartz monzonite of Bauchi and in Toro Charnockitic Complex (TCC), which are also characterized by high LILE, and negative Cr and Ni anomalies as explained in Dada et al. (1995). The enrichment in the more mobile elements (LILE) in these rocks is an indication of crustal contamination. Furthermore, depletion in Nb, Sr, P, Cr and Ni are also suggestive of the evolution of these rocks in the crustal environment (Toteu et al. 1987, Toteu, 1990).These depletions in Sr, Nb, and P compliment the low modal contents of plagioclase, ilmenite, and sphene respectively (Cox et al, 1979).

The nature and form of distribution of the chemical elements in these rocks therefore exclude a model involving partial melting in their petrogenesis. The magma must have been initiated by partial melting of an upper mantle or lower crust source during the Pan-African thermo-tectonic event and with partial crystallization produced the coarse porphyritic biotite granites. The residual phase of this mantle or lower crust-derived magma would have ascended to higher levels and caused partial melting of the upper crustal rocks to generate more magma, which intruded and crystallized more granites. Possible further differentiation from the remaining residual magma at higher levels but along different independent paths probably produced coarse, medium and fine grained granites with similar chemical compositions. The relatively low to averagely normal K/Rb ratios in all the rocks just probably suggest crustal contamination since it tends to cause a sizeable decrease in the K/Rb ratios.

CONCLUSION

The composite plutons forming the prominent N-S trending Mandara Mountains in northeastern Nigeria commonly display sharp contact relationship with the surrounding metamorphic rocks and between them. The existence of partially digested gneissic and schistose xenoliths and the presence of cognate bodies and sharp as well as lobate contacts in the Madagali granitoids attest to the involvement of older crustal materials in their derivation.

The pattern and abundance of trace elements including REE and the overall trend of the elements in the Spidergram favor a mixed source for Madagali granitoids with the incorporation of older crustal components by partial melting.

ACKNOWLEDGEMENTS

This work is essentially part of the author's unpublished Ph.D thesis. I remain perpetually indebted to Professor S. S. Dada for effective supervision of the work generally. I am very grateful to Professor S. I. Abaa for reading, criticizing and improving the quality of this article. I also thank Mr. Kawu I. Kure for drafting the figures.

REFERENCES

Abaa, S. I., 1985. Some geochemical characteristics of alkaline rocks of the Mada Younger Granite complex, Nigeria. Journal of African Earth Sciences, 3 (1/2): pp115-121.

Baba, S., 2008. The Geology of Madagali Area, Northeastern Nigeria. Ph.D thesis (Unpublished). Federal University of Technology, Yola. 183p.

Baba, S., Emofurieta, W.O., and El-Nafaty. J. M., 1996. Petrochemistry of Liga Hill granites, Gwoza area, N.E Nigeria. Borno Journal of Geology, 1, 1, 35-58.

Baba, S., Abaa, S. I., and Dada, S.S., 2006. Preliminary Petrogenetic study of some rocks from Gwoza area, N.E Nigeria. Global Journal of Geological Sciences, 4,2, 147-155.

Black, R., and Liegeois, J.P., 1993. Cratons, Mobile belts, alkaline rocks and continental lithospheric mantle: the Pan-African testimony. Journal of the Geological Society of London. 150: 89-98.

Bowden, P., and Bachelor, P.A., Chappell, B. W., Didier, J., and Lameyre, J., 1984. Petrology, geochemistry and source criteria for the classification of granitic rocks: a discussion. Physics of the Earth and Planetary Interiors, Elsevier Science Publishers. 35: 1-11.

Bowden, P., Kinnaird, J.R and Abaa, S. I., 1984. Geology and Mineralization of the Nigerian anorogenic ring complexes. Geol. Jb. (Hannover) B, 56, pp1-65.

Caby, R., 1989. Precambrian terrains of Benin-Nigeria and Northeast Brazil and the late Proterozoic South Atlantic fit. Geological Society of America, Special paper 230: 145-158.

Castaing, C., Feybesse, J. L., Thiblemont, D., Triboulet, C., and Chevremont, P., 1994. Palaeogeographical reconstruction of the Pan-African/Braziliano orogen: Closure of an ocean domain or intracontinental convergence between major blocks? Precambrian Research, 67: 327-344.

Chappell, B. W., And White, J. R.,1974. Two Contrasting Granite Types. Pacific Geology. 8: 173-174.

Compton, P., 1928. Rare Earth Evidence for the Origin Of The Nuk Gniesses,Buksefjorden Region,Southwest Greenland. Contrib. Mineral. Petrol, 66, Pp283-293.

Cox, K. G., Bell, J.D., and Pankhurst, R. J., 1979. The Interpretation Of Igneous Rocks. George Allen And Unwin Ltd. London. 450p.

Dada, S.S., 2008. Proterozoic Evolution of the Nigeria-Boborema Province. In: Pankhurst, R.J., Trouw, R.A.J., De Brito Neves, B.B., And De Wit, M.J. (Eds). West Gondwana: Pre-Cenozoic Correlations Across The South Atlantic Region. Geological Society Of London, Special Publication, 294:121-136.

Dada, S. S., Briqueu, L., Harms, U., Lancelot, J.R., and Matheis, G., 1995. Charnockitic And Monzonitic Pan-African Series From North-Central Nigeria: Trace Element And Nd, Sr, Pb Isotope Constraints On Their Petrogenesis. Chemical Geology. 124: 233-252.

Drury, S. A., 1979. Rare Earth And Other Trace Element Data Bearing On The Origin Of Archean Granitic Rocks From Yellow-Knife, Northwest Territories. Canadian Journal Of Earth Sciences. 16, 4: 809-815.

Ekwueme, B. N., And Kroner, A., 1997. Zircon Evaporation Ages And Chemical Composition Of Migmatitic Schist In The Obudu Plateau: Evidence Of Paleoproterozoic (Ca. 1789ma) Component In The Basement Complex Of Southeastern Nigeria. Journal of Mining and Geology. 33: 81-88.

Ekwueme, B. N., And Kroner. A., 1998. Single Zircon Evaporation Ages From The Oban Massif, Southeastern Nigeria. Journal Of African Earth Sciences. 26: 195-205.

Eyal, M., Litvnovsky, B. A., Katzir, Y., and Zanvilevich, A.N., 2004. The Pan-African High K Calc Alkaline Peraluminous Elat Granite From Southern Israel: Geology, Geochemistry And Petrogenesis. Journal Of African Earth Sciences. 40: 11-136.

Ezepue, M. C., and Odigi, M. I., 1993. Petrology And Geochemistry Of Monzonite, Granodiorite And Granites From Precambrian Terrain Between Kabba And Lokoja, Sw Nigeria. Journal of Mining And Geology. 23, 1: 27-38.

Ferre, E. C., Dereris, J., Bouchez, J. L., Lar, A. U., and Pencat, J.J., 1996. The Pan-African Reactivation Of Eburnean and Archean Provinces In Nigeria: Structural And Isotopic Data. Journal of Geological Society of London. 153: 715-728.

Ferre, E. C., Gleize, G., and Caby, R., 2002. Obliquely Convergent Tectonics and Granite Emplacement In The Trans-Saharan Belt Of Eastern Nigeria: A Synthesis. Precambrian Research. 114: 199-219.

Ferre, E.C., Caby, R., Pencat, J.J., Capdevila, R., And Monie, P. 1998. Pan-African, Post-Collisional, Ferro-Potassic And Quartz-Monzonite Plutons Of Eastern Nigeria. Lithos, 45: 255-279.

Fourcade, S. And Allegre, C. J. 1981. Trace Element Behavior In Granite Gneiss: A Case Study. The Calc-Alkaline Plutonic Association From The Querigut Complex (Pyrenee,France). Contr. Miner. Petrol. 76, 117-195.

Haskin, L.A., And Schmitt, R. A. 1967. Rare Earth Distribution. In: Abelson, P.H. (Ed.). Researches In Geochemistry, 2. John Wiley And Sons, Inc. New York. 235-258.

Islam, M.R., And Baba, S. 1992. Some Geochemical Studies Of The Older Granite Suite From Northern Part Of Mandara Hills,. Nigeria. Discovery And Innovation, 4, 4, 53-60.

Jahn, B., Sun, S.S And Nesbitt, R.W. 1979.Ree Distribution And Petrogenesis Of The Spanish Peaks Igneous Complex, Colorado. Contib. Mineral. Petrol., 70. Pp281-298.

James, D.E., Brooks, C And Cuyubamba, A. 1976. Andean Cenozoic Volcanism: Magma Genesis In The Light Of Strontium Isotopic Composition And Trace Element Geochemistry. Bulletin Of Geological Society Of America, 87, Pp592-600.

Koljonen, T., And Rosenberg, R. J.1974. Rare Earth Elements In Granitic Rocks. Lithos. 7: 249-0261.

Mortimer, G.G., Corper, J.A., And Oliver, R.L. 1988.The Geochemical Evolution Of Proterozoic Granitoids Near Port Lincoln In The Gawler Orogenic Domain Of South Australia. Precambrian Research. 40/41: 387-406.

Nakamura,N. 1974. Determination Of Ree, Ba, Fe, Mg, Na And K In Carbonaceous And Ordinary Chondrites. Geochemica Et Cosmochimica Acta. 38, 757-775.

Ngako, V.1986. Evolution Mettamorphique Et Structurale De La Bordure Sud-Ouest De La

Serie De Poli (Segment Camerouneis De La Chaine Panafricaine). Memoires Et Documents De Centtre Armorricain De Tude Structurale Des Socles, No.5

Ngel, U. O, 1986. Paleogeographie D Un Segment De Iorogenese Pan-Africain: La Ceinture Volcano-Dimentaire De Poli (Nord Cameroun), Comptes Rendu De I Academie Des Sciences De Paris, 303: 1737-1742.

O'connor, J.T. 1965. A Classification Of Quartz-Rich Igneous Rocks Based On Feldspar Ratio. United States Geological Surveys, 79-84.

Okonkwo, C.T., And Winchester, J.A. 1996. Geochemistry And Geotectonic Setting Of Precambrian Amphibolites And Granitic Gneisses In The Jebba Area, Southwestern Nigeria. Journal Of Mining And Geology, 32: 11-18.

Onyeagocha, A.C.1986. Geochemistry of Basement Granitic Rocks from Northcentral Nigeria. Journal Of African Earth Sciences, 5,6, 651-657.

Rollinson, H., 1998. Using Geochemical Data: Evaluation, Presentation And Interpretation. Longman Group Ltd. 352p.

Rickwood, P.C., 1989. Boundary Lines Within Petrologic Diagrams, Which Use Oxides For Major And Minor Elements. Lithos. 22: 247-263.

Streckeisen, A. L., and Le Maitre, R. W., 1979. A Chemical Approximation To The Modal Qapf Classification Of Igneous Rocks. Neues Jahrb. Mineral Absh. 136: 169-206.

Sylvester, J.P., 1998. Post-Collisional Strongly Peraluminous Granites. Elsevier Science Publishers, Lithos. 45: 29-44.

Tarney, J., 1976. Geochemistry Of Archean High-Grade Gneisses, With Implication As To The Origin And Evolution Of The Precambrian Crust. In: B.F Windley (Ed.). The Early History of the Earth. Wiley, London, 405-424.

Tarney, J and Windley, B.F., 1977. Chemistry, Thermal Gradients and Evolution Of The Continental Crust. Journal Of Geological Society Of London, 134, Pp153-172.

Toteu, S.F., 1990. Geochemical Characterization of the Main Petrographic And Structural Units Of Northern Cameroun: Implication For Pan-African Evolution. Journal of African Earth Sciences. 10: 615-624.

Toteu, S.F., Michard, A., Betrand, J. M., and Rocci, G., 1987. U-Pb Dating of Precambrian Rocks From Northern Cameroun, Orogenic Evolution And Chronology Of The Pan-African Belt Of Central Africa. Precambrian Research, 37: 71-87.

Toteu, S.F., Van Schmus, R. W., Panaye, J., and Michard, A., 2001. New U-Pb and Sm-Nd Data From North Central Cameroun And Its Bearing On The Pre-Pan-African History Of Central Africa. Precambrian Research, 108: 45-73.

Toteu, S. F., Penaye, J and Djomani, P. 2004. Geodynamic Evolution of the Pan-African Belt in Central Africa With Special Reference To Camaroon. Nrc Research Press, Canada. Pp73-85.

Ukaegbu, V. U., And Beka, F. T. I., 2007. Petrochemistry And Geotectonic Significance Of Enderbite-Charnockite Association In The Pan-African Obudu Plateau, Southeastern Nigeria. Journal Of Mining And Geology, 43: 1-15.

Umeji, A.C., 1991. Petrology And Geochemistry Of Monzogranites From Jato-Aka And Their Significance To Plutonism In The Pan-African Belt Of Nigeria. Journal Of Mining And Geology, 27: 115-127.

Wedepohl, K. H., 1978. Handbook Of Geochemistry. 11-2 and 11-5. In Wedepohl, K. H. (Ed). Germany.

Whitney, A.J.R., Jones, L.M., And Walter, R. L. 1978. Stone Mountain Granite, Lithonia District, Georgia. Geological Society Of America Bulletin. 87:1067-1077.

Wood, D. A., Tarney, J., Vare, J., Saunders, A.D., Bougault , Y., Joran, J. L., Treuil, M. And Cann, J. R. 1979. Geochemistry Of Basalts Drilled In The North Atlantic By Ipod Leg 49: Implication For Mantle Heterogeneity, Earth And Planetary Science Letters. 42, 77-97.