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Geochemistry of Madagali Granitoids, North – Eastern Nigeria

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Abstract

Results of geochemical data of the granitoids of Madagali area of north – eastern Nigeria, show that the rocks are calc – alkaline, and essentially granitic in composition. The samples have AL/CNK ratios of >1.1, high value of Na_2O (> 3.2%) and presence of normative corundum are characteristics of sedimentary origin (S – type). The trace element contents are possibly suggestive of crustal involvement in genesis. The K – Rb diagram shows that the granites are crystallised within the range of crustal value. The enrichment in Light Rare Earth Element (La, Ce, and Nd), decreased in Heavy Rare Earth Element (Ho to Lu) with negative Eu anomaly suggest that the granitoids were evolved by partial melting of sedimentary rocks. Presence of contents of Large Ion Lithophile Elements such as Rb and Th with negative values of Nb and Sr is suggestive of fractional crystallisation process as well as the involvement of crustal materials in their origin.

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Granitoids, Calc – alkaline, Petrogenesis, Madagali, Nigeria

Introduction

The study area is situated in the north-eastern part of Nigeria within latitudes 13° 30' and 13° 45' and longitudes 10° 45' and 11° 00 N. The study area belongs to basement complex of Nigeria within the pan African mobile belt. Mandara Hills area is one of the least studied of the basement terrains of Nigeria. The outcrops in the area, has for long being described as undifferentiated basement complex for the lack of geological data covering the area (Carter etal.1963 and Okezie,1984). However, Babaetal., (1991) has been succeeded in differentiating the various rocks units in the northern part of the Hills and it was based on the study of aerial photographs, detailed field work and laboratory studies.

The rock units identified in basement complex are of several major and minor types. The major rocks are migmatite – gneiss schists and quartzite's, cataclasites, medium to coarse grained granites, coarse porphyritic granites, fine grained granite, mylonites, aplites and pegmatites. The minor ones are diorite, Ankara mite, amphibolite, hydrothermalrocks, rhyolites and pyroclastic. This study has shown that, the study area is under lain mainly by migmatite gneisses and granitoids with minor mylonites and intrusions of rhyolites, aplites, dolerite and granodiorites (fig.1). The outcropsare restricted to the eastern part of the study area while the western side is characterized by low plain land. The rocks are grouped into gneisses and migmatites complex (including amphibolite, quartzite), granitoids, mylonites and intrusive in order of decreasing age and according to major and minor types.

The study area is the north eastern tip of the Nigerian Basement Complex, separated from the southern part (Oban – Obdudo massif) by the upper Benue Tough, it forms the western terminal of the western Cameroon Domain(WCD) (Ferre etal.1996,2003, Ekwueme and kroner,1997,1998). The WCD is part of the remobilized Pan – African terrain formed in the Neoproterozoic (appro.600 ma) by continental collision between the converging West Africa 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, 1980, Ngel, 1986, Toteu, 1990),Pan – African pre – Syn – and late tectonic calc – alkaline granitoids (Toteuetal.1987, 2001), and post – tectonic alkaline granitoids (felsic and mafic dykes,eg. The Bushashika Group). Onyeagocha(1986) concluded that the Pan – African granitoids in central Nigeria were derived by partial melting of the country rocks(schists and gneisses),while Ezeplle 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),described that the ender bite – charnockite association in the Pan – African Obudu plateau are per aluminous(S – type)formed at lowest crust using Sr initial ratios suggested that the source of the granitic magmas of Pan – African rocks of eastern Nigeria is the lower crustal characterized as Ferro – potassic with trans – alkaline affinity. Islam and Baba (1992) in their study of the Pan – African granitoids of the extreme north-eastern tip of Nigeria, described the rocks as alkaline and of mixed origin. Also, Baba *et al.,* (1996) concluded that the Liga Hills granites as being products of anataxis of crustal material. In this study, we described the geochemical features and attempted to discusses their significance in the origin of the rocks, in addition to providing a geological of the study area. Although geochemistry of major and trace element can provide an important tool on the magma source of granite (e.g. Frost etal.2016).

Regional geology

The Nigerian basement complex which covers about 50% of the country has been described by various authors(Ekwueme,2003). The Nigerian Pan – African Basement Complex is part of the Neoproterozoic Trans – Saharan Orogenic belt. This Neoproterozoic (Pan – African) belt is belived to have formed by the amalgamation of allochthonous terranes between the west African Craton, Congo Craton and pharusian belt of the Tuareg Shield between 700 and 580 ma (Ajibade and wright 1989, Caby1989, Ferre and Caby 2007). The north – eastern part of the Nigeria as a whole is demarcated from south – eastern region by the Benue Trough and from the north – western by the younger Granite Complex of north – central Nigeria. The basement complex in the north – east disappeared beneath the thick deposits of the Chad Basin(Baba,1983). The basement complex of northern Nigeria grouped into four groups, includes the basement complex, such as paragneiss, basic and calcareous schist, marble, quartzites, orthogneiss and granite, younger metasediments, the older granites series and volcanic rocks (youngest rocks recognized in both north west and north – east Nigeria, post older granite) (MC curry 1976).

The rock units of the basement complex in the southeast Nigeria, grouped into, pre- Pan – African rocks (2.8 – 1.3 Ma) which comprise migmatite gneiss complex and ancient granites and Pan – African rocks (600+_ 150Ma), comprising of the older granite and metavolcano – sedimentary series(Ekwueme,1990). The rocks of the northeast terranes which best classified, the poly-metamorphic migmatite – gneiss complex, metasedimentary and metavolcanicrocks, Pan – African granitoids and undeformed acid and basic dykes. Furthermore, the Mandara Hills in northeast Nigeria as a part of basement complex in northeast Nigeria the rocks have been described and grouped into, the migmatite – gneisses, quartzites, schist, amphibolites and Older Granites (granites, pegmatites and mylonites) (Islam etal.1989). In addition, the Liga hills (parts of Mandara Hills) has mapped and identified granite gneisses and granites of various textures(Baba1990).

Geological setting and petrography

The Madagali area is the north-eastern peak of the Nigeria Basement Complex, separated from the southern part (Oban – Obudumassif) by the upper Benue Trough it forms the western terminal of the western Cameroon Domain(WCD) (Ferre etal.1996,2002, Ekwueme and Kroner,1997,1998), (Fig.2). The study area is under lain mainly by migmatite gneisses and granitoids with minor mylonites and intrusions of rhyolites, aplites, dolerite and granodiorites. The out crops are restricted to the eastern part of the study area while the western side is characterized by low plain land.

Madagali area is dominantly under lain 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). The migmatites are generally medium grained with leucosome(light)and melanosome (dark) bands observed in the field referred to as injection gneiss (Wimmenauer and Bryhni,2002). The contacts between these rocks and the surrounding granites are gradational, the foliation trends are generally N – S with dips which are near vertical (88 – 90°).

In thin – section the minerals identified in order of their abundance are quartz, biotite, orthoclase, plagioclase, microcline in some sections and the accessory minerals include iron oxides, zircon, sphene, garnet, and hornblende. The average modal compositions of quartz (33%), orthoclase (20%), plagioclase (6%)and biotite (16%).Quartz occurs in two forms, the first consists of large grain which exhibit undulatory extinction with irregular margin while the second, consist of smaller grains with extinction and polygonal out lines. Biotites occurs in significant amount (24%), more than microcline (0.75%)in the rock, it appears as large but distorted and stretched out plates commonly wrapping round crystals of feldspar defining foliation in the rock (Fig.3 a, b and c). Orthoclase appears as subhedral to anhedral crystals, colourless to cloudy, non – pleochroic and has perfect cleavage parallel to (001). Plagioclase is anhedral to subheral and commonly grey in colour with albite – twins. Extinction angle of about 13° - 19° implies albite content of (An 18° - 24°). A few crystals have deformed lamellae, Myrmekitic textures are developed at plagioclase quartz border (Fig3c).

Zircon is a common accessory mineral and occurs in minute crystals of short prismatic habit, often as inclusion in biotite and surrounded by pleochoric haloes. Hornblende, garnet and sphene were identified but they occur as traces or in small proportion to otherminerals. Granitoids are the most dominated rocks types in the study area.

In hand specimen rocks samples are homogenous massive, equigranular, leucocratic (grey – pinkish) in colour. Texturated rocks are range from fine to coarse grained and are non – foliated.

Quartz and feldspars are abundant minerals, in thin section, minerals identified are quartz, orthoclase, biotite, plagioclase and microcline form the essential minerals while iron oxide, muscovite, hornblende, sphene and zircon are the accessory minerals (table1). Quartz is the predominant mineral which occurs as anhedral to subhedral grains and has low relief and weak birefringence (Fig.3d). Quartz content ranges from 33.68% (Average) in coarse grained to 40.51% in fine granites. Orthoclase is more abundant than plagioclase occurs as anhedral with low relief and has values vary from 16.49% in coarse grained to 23.22%(average) in fine grained granites. Biotite occurs as anhedral to subhedral from, pale brown to greenish brown and strongly pleochroic, with average values differ in fine granite 3.90% to16.41 in medium grained granite. Plagioclase is observed as anhedral to subhedral crystal with low relief and lamellae twining. Sericite is occasionally developed as alteration product of feldspar. Microcline grain are characterized by their cross – hatched twinning. Iron oxide is the most visible accessory mineral in its matrix and followed by muscovite grains. Hornblende is observed as minor in few sections, in anhedral form pale green in colour with strong pleochroic. Sphene was also identified by their appearance in anhedral form with low relief and exhibit symmetrical extinction. While zircons are commonly and is mainly pronounced in biotite. Mylonite is dark grey, fine grained highly foliated and splits easily along the cleavages. The rocks are composed essentially of quartz and alkali feldsparmegacrysts set in a smeared rock floor ground mass of quartz, feldspar and mica with accessory iron oxide, sphene and zircon. The rocks therefore range from protomylonite to ultramylonite. While the minor intrusions include granodiorite, rhyolite, aplite and dolerite dykes.

Geochemistry:

Analytical methods

Out of thirty (30) representative samples, twenty seven(27) were crushed, pulverized and shipped to Canada and were analysed at Activation Laboratories Ltd(ACTLABS),Ancaster, Ontario, Canada. While the remaining (3)samples were analysed in the Centre de Researches Petrographiques et Geochemique CRPG) Nancy Cedex, France.Intruments used in both Canada and France for major, trace and rare earth elements composition, using the lithogeochemistry analytical package developed by (ACTLABS and CRPG)which involves lithium metaborate/tetra borate fusion and subsequent analysis by Inductively – Coupled Plasma – Mass Spectrometry (ICP – MS) analytical technique.

Major elements

The result of major elements composition of the granitoids in the study area are presented in table(2). The SiO_2contents range from 71.44% in medium grained granite to 72.93% in fine granite. All the granitoids samples have SiO_2 values exceeding 64% characterizing the rocks as "felsic."

Which is consistent with their felsic colour index. Such result its agree with study of (Baba etal.2006).

To that extend when plotted on the Q-A-P Streckeisens diagram (1973) shows that are granitic(fig4).

In a plot proposed by O'Connor (1965), showing An-Ab-Or diagram (fig.5), the Madagali granitoids plot in granite field. The granitoids appears to be typically of calc-alkaline as also recorded in the Na_2O +k_2O VS. SiO_2% diagram, After Middle most (1997), except (sample20). The plotof K_2O VS. SiO_2(fig.6)of the Madagali granitoids appears as high – K-calcalkaline nature.

The content of Al_2O_3(14.05%) (Average) in the rocks appear moderate in all the samples while, the alumina values are slightly more than total(Al_2O_3>Na_2O+K_2O). The Alumina Saturation Index(ASI), A/CNK ratio in most of the samples is more than one. Ranging from 1.33 to maximum of 1.54 with an average of 1.39. The geochemical data are further plotted in the Al_2O_3/Na_2+K_2O or A/NK versus A/CNK diagram proposed by Moniar and Piccoli (1989) where the rocks plot within the peraluminous field (fig. 7) which is similar to their modal composition and major oxides, contents (Table2).

Trace and Rare Earth Elements

Some of the trace elements and rare earth elements(REE)concentrations of the Madagali granitoids are shown in table (3). The rocks are rich in Ba, Rb, Sn, and Zr which ranges from 71ppm to 1386ppm with average (846.82ppm), Rb 87ppm to 302 ppm with average (180.18ppm), Snfrom (<1 – 14ppm), while Zr from (43ppm – 537ppm)but Mineralization show poor concentration in the rocks of Madagali area compared to adjacent Ghumchi area which has known uranium mineralisation of 5ppm (Suh 1997).

Rare earth element(REE) content for granitoids in table (4) show that total REE of the samples studied ranges from 53ppm to 880.9ppm with an average of 252. 79ppm.The Madagali granitoids show generally trend, the patterns, dominated by moderate enrichment in LREE and near flat HREE (fig.8); (fig.9a, b) suggesting formation by partial melting. However, the majority of the units are characterized by a more or less pronounced negative Eu anomaly. The samples displayed LaN/YbN ratios ranging from 8.47 to 41 in coarse grained granites to 9.48 to 195.52 in medium granites with 14.63 to 25.54 in fine grained granites. While the LaN/SmN ratio on other hand, vary in the same order (Table 5) from 2.46 to 6.74,4.85 to 10,3.56 to 5.15. The higher values of LaN/YbN and LaN/SmN with prominent negative Eu anomalies are signature of fractional crystallization process. The multi – ionic plot for Madagali granitoids shows broadly similar patterns for all samples. The enrichment is observed in large ion lithophile elements(LILE) (Table 6), especially Th, Rb, K and Ta, while negative anomalies are recorded for Ba, U, Nb, Sr, P, Zr and Tl (Fig.10a, b, and c) for granitoids indicative of crustal involvement in the gneisses of Madagali granitoids(Toteu,1987).

Results and Discussions

Field relationship, petrographic and geochemically study the rocks occurring in Madagali area(NE)which are central to the works, with the principal aim of providing further insight into the evolutionary and petrographic history of the basement complex of north east Nigeria. The field relationship demonstrates that the contact between the migmatitic gneiss and the surrounding granites are sharp, while the contacts between the various granite types are usually gradational.

The geochemical and mineralogical data of plutonic rocks can be used to identified such as the values of K_2O>N_2O and the occurrence of normative corundum with absence of normative diopside in all samples characterized the granitoids to be S – type granitoids (Sedimentary progenitor) (Chappell and White1974), per aluminous to strong per aluminous (Figs.7 and 11).A binary diagram Na_2O + K_2O% VS.SiO_2(After Middle Most1997) is used in classifying the granitic rocks, the granitoids appears to be typically of calc – alkaline in nature(fig.6).The Madagali granitoids have Al_2O_3/CaO+Na_2O+K_2O or A/CNK ratios (table 2),ranging from 1.33 in coarse grained granite to 1.54 in fine grained granite, indicating that they are S –type granites of predominantly per aluminous in composition(ASI >1).According to Chappell and White,(1974),A/CNK ratios of less than 1.1 are characteristics of I – type granites while S – type granite have ratio above (1.1).In addition,(Turpin etal.1990) pointed out that such per aluminous granites are generally considered to be generated by partial melting of the upper crustal rocks, especially during continent – continent collision events or at active plate margins. However, the studies granitoids appear to be similar to that of the Liga hill granites (part of Manadra hills)as being product of anataxis of crustal material(Baba *et al.*, 1996).

Table.1 The average estimated modal composition of granitoid of the study area

Samples Minerals	**CGG**	**MGG**	**FGG**	**GRDIO**
	n=14	n=17	n=4	n=2
Quartz	33.68	33.78	40.51	15.45
Orthoclase	16.49	20.70	23.22	21.37
Microcline	4.63	4.22	5.82	0.65
Plagioclase	10.76	6.90	6.91	29.67
Biotite	16.27	16.41	3.90	18.57
Hornblende	2.44	2.97	-	6.89
Sphene	1.94	1.11	0.22	0.99
Zircon	1.61	0.67	0.29	0.84
Iron Oxide	4.29	5.24	3.81	-
Muscovite	3.27	2.81	1.16	-
Sericite	1.04	2.92	7.74	5.55
Garnet	0.05	-	-	-
Ilmenite	-	0.35	4.09	-
Others	0.98	0.8	0.29	0.66
TOTAL	**98.01**	**99.01**	**97.96**	**100.64**

KEY
n= Total number of samples
CGG = Coarse Grained Granite; MGG = Medium Grained Granite; FGG = Fine Grained Granite;
GRDIO= Granodiorite

Table.2 Average percentage (wt) compositions of the oxides of major elements of the rocks at madagali area

Sample Elements	**CGG (n=7)**	**MGG (n=6)**	**FGG (n=4)**	**Grdio (n=2)**	**Rhy (n=2)**
SiO_2	71.91	71.44	72.93	66.67	69.68
Al_2O_3	13.64	14.69	13.81	15.35	13.75
TiO_2	0.44	0.40	0.19	0.54	0.14
$Fe_2O_{3\,(T)}$	2.78	2.16	1.62	3.45	2.96
MnO	0.05	0.03	0.02	0.06	0.12
MgO	0.46	0.68	0.23	2.03	0.2
CaO	1.53	1.78	0.85	2.94	0.94
Na_2O	3.16	3.84	3.21	4.21	3.36
K_2O	5.08	4.36	5.23	3.03	4.78
P_2O_5	0.12	0.12	0.05	0.16	0.03
LOI	0.55	0.49	0.81	1.05	3.12
TOTAL	**99.72**	**99.99**	**98.95**	**99.49**	**99.08**

KEY
CGG = Coarse Grained Granite, MGG= Medium Grained Granite, FGG = Fine Grained Granite,Grdio = Granodiorite; Rhy = Rhyolite

Table.3 Trace element composition of the madagali rocks (ppm), mandara hill, ne Nigeria

Sample	CGG (n=7)							MGG(n=6)						FGG(n=4)				Grdio (n=2)			Rhy (n=2)
Elements	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Sc	6	6	4	7	8	6	2	3	3	3	3	4	4	4	2	2	-	7	7	-	-
Bc	3	3	2	3	3	3	2	6	5	3	2	5	4	3	3	<1	2	3	3	4	4.27
V	23	17	12	20	25	22	<5	16	24	45	17	42	8	16	<5	<5	26.5	59	58	<i.d.	<i.d.
Ba	1021	1122	1076	928	1118	1384	347	629	653	1161	1386	652	394	877	388	71	1189	907	915	326	48..2
Sr	186	211	380	176	222	248	221	174	285	366	496	352	112	136	121	17	282	597	595	81.8	20.5
Y	31	34	6	40	45	34	17	8	11	6	6	13	15	19	5	21	20.2	13	15	52.4	111
Zr	463	481	152	499	537	393	58	230	344	470	106	287	106	187	43	156	271	166	172	559	771
Cr	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	40	<20	<20	<20	<20	11.6	50	50	<i.d.	7.4
Co	51	49	63	56	33	42	64	86	56	49	68	62	86	51	56	67	3.37	45	48	<i.d.	<i.d.
Ni	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	5.8	20	30	3.1	4.7
Cu	20	<10	10	<10	<10	20	<10	30	<10	10	<10	10	<10	<10	<10	<10	6.3	30	50	<i.d.	3.3
Zn	30	40	<30	40	50	80	<30	50	60	80	30	60	<30	30	<30	<30	63.9	40	60	162	216
Ga	20	22	19	22	22	23	18	25	31	31	18	27	20	18	18	17	20.5	21	22	29.8	39.6
Ge	2	2	1	2	2	2	1	1	1	1	<1	1	2	1	1	2	1.24	1	1	1.78	2.10
As	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<i.d.	<5	<5	2.15	<i.d.
Rb	200	188	143	166	164	170	113	302	195	202	120	168	234	227	176	133	162	87	93	147	187
Nb	27	27	9	30	31	24	7	19	15	9	5	11	16	15	3	3	12.2	9	11	174	152
Mo	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	0.43	<2	<2	1.83	0.95
Ag	1.9	2	0.5	2.3	2.3	1.1	<0.5	1	1.4	2	<0.2	1.1	<0.5	0.6	<0.5	0.5	-	0.5	0.6	-	-
In	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<i.d.	<0.2	<0.2	0.15	0.16
Sn	11	8	5	7	8	3	<1	8	8	14	4	11	6	3	2	4	2.21	7	6	6.49	8.90
Sb	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<i.d.	<0.5	<0.5	0.27	0.27
Cs	2.3	1.6	2.9	1.4	2	1.6	0.8	6.6	3.4	1.4	2	2.3	4.1	2.6	2.5	<0.5	2.66	2.4	2.6	0.32	0.32
Hf	11.8	12.9	4.4	13.2	13.5	10.3	2.1	6.6	9.7	11.7	2.8	8	3.9	5.8	1.6	5.2	7.40	4.2	4.5	15.9	22
Ta	1.8	2	1.4	2.2	2.2	1.5	1	2.7	1.4	0.8	0.9	1.4	2.6	1.5	0.7	0.6	1.12	1	1.1	14.1	11
W	365	348	437	393	207	288	477	594	388	308	477	384	591	352	402	474	0.29	265	277	3.43	2.18
Tl	0.3	0.4	0.4	0.3	0.3	0.6	0.4	0.6	0.7	0.5	0.3	0.4	0.7	0.8	0.7	0.4	-	0.2	0.3	-	-
Pb	10	16	17	12	11	47	51	20	25	17	16	14	20	26	53	17	18.5	12	19	13.3	20.3
Bi	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<i.d.	<0.4	<0.4	<i.d	<i.d
Th	11.4	8.2	9.5	32.3	10.8	17.9	15.4	49.6	57.1	85.9	7.7	38.4	17.5	23.8	8.1	8.3	16.1	8.5	8.4	22	27.6
U	2.8	2.1	1.1	2	2.2	2.5	1.3	3.8	4.8	4.4	0.9	4.6	5.1	3.2	2	0.7	1.42	3	3.1	4.32	5.10

KEY

n = Total Number of Sample, CGG = Coarse Grained Granite (1-7), MGG = Medium Grained Granite (8-13), FGG = Fine Grained Granite (14-17). Grdio = Granodiorite (18-19), Rhy = Rhyolite (20 -21)

Table.4 Rare earth element (ree) concentration (ppm) of the rocks of madagali area, mandara hill, ne Nigeria

Sample	CGG (n=7)							MGG (n=6)						FGG (n=4)				Grdio(n=2)		Rhy (n=2)	
Elements	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
La	57.6	41.4	31.9	225	60.9	76.8	20.1	86.9	82.9	116	24.8	73.1	23.9	49.9	13	64.3	56.5	27.1	25.4	161	151
Ce	115	86.7	57.8	404	130	152	40.4	149	144	220	44.3	105	45.4	113	19.3	71.5	115	48.7	46.9	249	178
Pr	14.6	11.6	6.49	45.1	17.9	17.3	4.59	16	15.6	18.5	5.01	12.2	5.21	104	2.81	14.6	12.5	5.97	5.87	28.6	36.1
Nd	56.5	48.1	22.3	149	72.9	59.4	17.8	50.5	50.6	56.2	17.9	41.1	17.6	35.3	10.6	52.6	43.1	22.3	21.8	95.6	131
Sm	11	10.6	3.6	21	15.6	12.3	4.1	7.1	7.4	7.3	3.1	6.5	3.1	6.1	2.3	9.1	7.11	4.2	4.2	15.3	31.3
Eu	1.72	1.76	0.97	2.17	2.42	2.02	0.62	0.95	1.17	1.66	0.8	1.16	0.54	0.59	0.63	0.43	1.19	1.05	1.06	1.39	0.535
Gd	8.4	8.5	2.2	13.1	12	8.5	3.1	3.8	4	3.8	2.1	4.1	2.3	4.2	1.7	6.4	4.95	3.4	3.5	11.2	26.6
Tb	1.2	1.3	0.3	1.7	1.8	1.2	0.5	0.4	0.5	0.4	0.3	0.5	0.4	0.6	0.2	0.9	0.717	0.5	0.5	1.72	3.94
Dy	6.3	7	1.3	8.9	9.6	6.6	2.8	1.9	2.3	1.4	1.2	2.8	2.1	3.5	1.1	4.9	3.85	2.6	2.9	9.34	20.7
Ho	1.2	1.3	0.2	1.6	1.8	1.3	0.5	0.3	0.4	0.2	0.2	0.5	0.4	0.7	0.2	0.9	0.702	0.5	0.6	1.71	3.56
Er	3.1	3.6	0.6	4.5	4.8	3.4	1.6	0.9	1.2	0.6	0.6	1.4	1.4	2.1	0.5	2.3	1.96	1.3	1.5	4.70	8.93
Tm	0.45	0.51	0.09	0.62	0.69	0.47	0.25	0.13	0.16	0.09	0.09	0.2	0.24	0.34	0.09	0.31	0.297	0.18	0.23	0.700	1.23
Yb	2.8	3.2	0.6	3.7	4.2	2.9	1.6	0.8	0.9	0.4	0.6	1.2	1.7	2.3	0.5	1.7	2	1.2	1.4	4.57	7.52
Lu	0.4	0.44	0.09	0.51	0.55	0.41	0.24	0.1	0.13	0.06	0.09	0.16	0.27	0.34	0.07	0.21	0.322	0.16	0.19	0.683	1.12
∑REE	280.27	226.01	128.44	880.9	335.16	344.6	98.2	318.78	311.26	426.61	101.09	249.92	104.56	228.67	53	230.15	250.198	119.16	116.05	585.513	601.535

KEY

CGG = Coarse Grained Granite, MGG= Medium Grained Granite, FGG = Fine Grained Granite, Grdio = Granodiorite, Rhy = Rhyolite

Table.5 Rare earth element chondrite normalized values of madagali rock

	LaN	CeN	PrN	NdN	SmN	EuN	GdN	TbN	DyN	HoN	ErN	TmN	YbN	LuN	Eu/Eu*	LaN/ YbN	LaN/ SmN	CeN/ YbN	CeN/ SmN
1	185.81	142.33	119.67	94.17	56.41	23.67	32.43	25.32	19.57	16.71	14.76	13.89	13.4	12.42	0.55	13.87	3.29	10.62	2.52
2	133.55	107.3	95.08	80.17	54.36	23.95	32.82	27.43	21.74	18.11	17.14	15.74	15.31	13.66	0.57	8.72	2.46	7.01	1.97
3	102.9	71.53	53.2	37.17	18.46	13.2	8.49	6.33	4.04	2.79	2.86	2.78	2.87	2.8	1.05	35.84	5.57	24.92	3.87
4	725.81	500	369.67	248.33	107.69	29.52	50.58	35.86	27.64	22.28	21.43	19.14	17.7	15.84	0.4	41	6.74	28.24	4.64
5	196.45	160.89	146.72	121.5	80	32.93	46.33	37.97	29.81	25.07	22.86	21.3	20.1	17.08	0.54	9.78	2.46	8.01	2.01
6	247.74	188.12	141.8	99	63.08	27.48	32.82	25.32	20.5	18.11	16.19	14.51	13.88	12.73	0.6	17.85	3.93	13.56	2.98
7	64.84	50	37.62	29.67	21.03	8.44	11.97	10.55	8.7	6.96	7.62	7.72	7.66	7.45	0.53	8.47	3.08	6.53	2.38
8	280.32	184.41	131.15	84.17	36.41	12.93	14.67	8.44	5.9	4.18	4.29	4.01	3.83	3.11	0.56	73.23	7.7	48.18	5.06
9	267.42	178.22	127.87	84.33	37.95	15.92	15.44	10.55	7.14	5.57	5.71	4.94	4.31	4.04	0.66	62.1	7.05	41.39	4.7
10	374.19	272.28	151.64	93.67	37.44	22.59	14.67	8.44	4.35	2.79	2.86	2.78	1.91	1.86	0.96	195.52	10	142.26	7.27
11	80	54.83	41.07	29.83	15.9	10.88	8.11	6.33	3.73	2.79	2.86	2.78	2.87	2.8	0.96	27.87	5.03	19.1	3.45
12	235.81	129.95	100	68.5	33.33	15.78	15.83	10.55	8.7	6.96	6.67	6.17	5.74	4.97	0.69	41.07	7.07	22.63	3.9
13	77.1	56.19	42.7	29.33	15.9	7.35	8.88	8.44	6.52	5.57	6.67	7.41	8.13	8.39	0.62	9.48	4.85	6.91	3.53
14	160.97	139.85	852.46	58.83	31.28	8.03	16.22	12.66	10.87	9.75	10	10.49	11	10.56	0.36	14.63	5.15	12.71	4.47
15	41.94	23.89	23.03	17.67	11.79	8.57	6.56	4.22	3.42	2.79	2.38	2.78	2.39	2.17	0.97	17.53	3.56	9.98	2.03
16	207.74	88.49	119.67	87.67	46.67	5.85	24.71	18.99	15.22	12.53	10.95	9.57	8.13	6.52	0.17	25.54	4.45	10.88	1.9
17	182.26	142.33	102.46	71.83	36.46	16.19	19.11	16.46	11.96	9.75	9.33	9.26	9.57	9.94	0.61	19.05	5	14.87	3.9
18	87.42	60.27	48.93	37.17	21.54	14.29	13.13	10.55	8.07	6.96	6.19	5.56	5.74	4.97	0.85	15.23	4.06	10.5	2.8
19	81.94	58.04	48.11	36.33	21.54	14.42	13.51	10.55	9.01	8.36	7.14	7.1	6.7	5.9	0.85	12.23	3.8	8.67	2.69
20	519.35	308.17	234.43	159.33	78.46	18.91	43.24	36.29	29.01	23.82	22.38	21.6	21.87	21.21	0.32	23.75	6.62	14.09	3.93
21`	487.1	220.3	295.9	218.33	160.51	7.28	102.7	83.12	64.29	49.58	42.52	37.96	35.98	34.78	0.06	13.54	3.03	6.12	1.37

Rock type key

1-7=Coarse grained granite; 8-13= medium grained granite; 14-17= fine grained granite; 18-19= Granodiorite; 20-21= Rhyolite;

Table.6 Trace Element Compositions Normalised to Average Crust,(Weaver and Tarney 1984)

Sample	RbN	BaN	ThN	UN	KN	NbN	LaN	CeN	SrN	NdN	PN	HfN	ZrN	SmN	TiN	TbN	YN	TmN	YbN
1	3.28	1.44	2	2.15	2.68	2.08	2.06	2.02	0.37	2.46	0.84	2.51	2.2	2.68	0.94	5	2.21	1.88	1.83
2	3.08	1.59	1.44	1.62	2.85	2.08	1.48	1.52	0.42	2.09	0.68	2.74	2.29	2.59	0.81	5.42	2.43	2.12	2.09
3	2.34	1.52	1.67	0.85	2.08	0.69	1.14	1.01	0.76	0.97	0.21	0.94	0.72	0.88	0.32	1.25	0.43	0.38	0.39
4	2.72	1.31	5.67	1.54	2.41	2.31	8.04	7.09	0.35	6.48	0.68	2.81	2.38	5.12	0.86	7.08	2.86	2.58	2.42
5	2.69	1.58	1.89	1.69	2.18	2.38	2.17	2.28	0.44	3.17	1.05	2.87	2.56	3.8	1.12	7.5	3.21	2.88	2.75
6	2.79	1.96	3.14	1.92	2.43	1.85	2.74	2.67	0.49	2.58	0.84	2.19	1.87	3	0.91	5	2.43	1.96	1.9
7	1.85	0.49	2.7	1	2.32	0.54	0.72	0.71	0.44	0.77	NA	0.45	0.28	1	0.12	2.08	1.21	1.04	1.05
8	4.95	0.89	8.7	2.92	2.47	1.46	3.1	2.61	0.35	2.2	0.47	1.4	1.1	1.73	0.53	1.67	0.57	0.54	0.52
9	3.2	0.92	10.02	3.69	1.9	1.15	2.96	2.53	0.57	2.2	0.79	2.06	1.64	1.8	0.78	2.08	0.79	0.67	0.59
10	3.31	1.64	15.07	3.38	2.47	0.69	4.14	3.86	0.73	2.44	1.05	2.49	2.24	1.78	1.09	1.67	0.43	0.38	0.26
11	1.97	1.96	1.35	0.69	1.68	0.38	0.89	0.78	0.99	0.78	0.26	0.6	0.5	0.76	0.37	1.25	0.43	0.38	0.39
12	2.75	0.92	6.74	3.54	1.66	0.85	2.61	1.84	0.7	1.79	0.95	1.7	1.37	1.59	0.99	2.08	0.93	0.83	0.78
13	3.84	0.56	3.07	3.92	2.27	1.23	0.85	0.8	0.22	0.77	0.26	0.83	0.5	0.76	0.27	1.67	1.07	1	1.11
14	3.72	1.24	4.18	2.46	2.69	1.15	1.78	1.98	0.27	1.53	0.32	1.23	0.89	1.49	0.34	2.5	1.36	1.42	1.5
15	2.89	0.55	1.42	1.54	2.71	0.23	0.46	0.34	0.24	0.46	0.11	0.34	0.2	0.56	0.1	0.83	0.36	0.38	0.33
16	2.18	0.1	1.46	0.54	2.52	0.23	2.3	1.25	0.03	2.29	NA	1.11	0.74	2.22	0.23	3.75	1.5	1.29	1.11
17	2.66	1.68	2.82	1.09	2.04	0.94	2.02	2.02	0.56	1.87	0.63	1.57	1.29	1.73	0.62	3.25	1.44	1.25	1.31
18	1.43	1.28	1.49	2.31	1.43	0.69	0.97	0.85	1.19	0.97	0.84	0.89	0.79	1.02	0.89	2.08	0.93	0.75	0.78
19	1.52	1.29	1.47	2.38	1.45	0.85	0.91	0.82	1.18	0.95	0.84	0.96	0.82	1.02	0.9	2.08	1.07	0.96	0.92
20	2.41	0.46	3.86	3.32	2.43	13.38	5.75	4.37	0.16	4.16	0.36	3.38	2.66	3.73	0.27	7.17	0.37	2.92	2.99
21	3.07	0.07	4.84	3.92	2.12	11.69	5.39	3.12	0.04	5.7	NA	4.68	3.67	7.63	0.2	16.42	7.93	5.12	4.92

Table.7 Average of Some trace element ratios in the rocks of madagali area,north east nigeria

Sample /Ratio	Ba/Rb	Ba/Sr	Sr/Ba	Rb/Sr	Rb/Ba	Rb/Zr	Ce/Zr	Zr/Nb	Y/Nb	Th/U	K/Rb	K/Ba	Zr/Hf	C
Granitoids (n=17)	4.70	3.61	0.28	0.77	0.21	0.64	0.42	18.18	1.26	9.31	223.82	47.62	36.54	4

Fig.1 Geological Map of Madagali

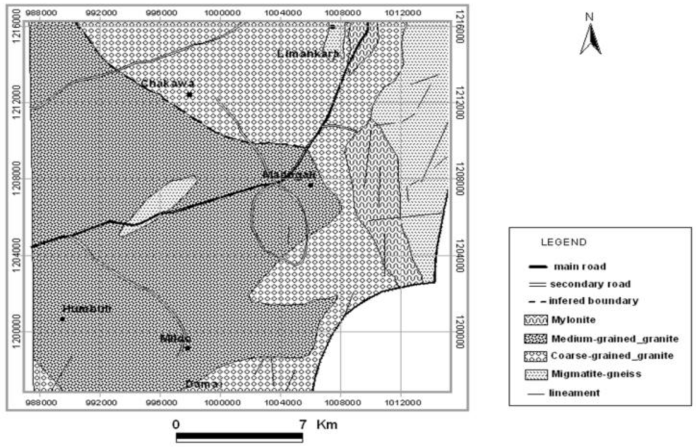


Fig.2 Geological map of Nigeria showing the StudyArea(Source: Kogbe, 1989)

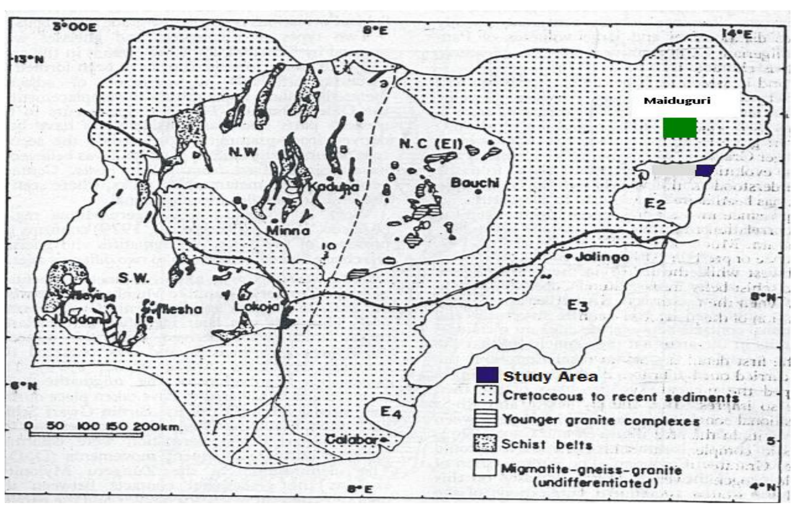


Fig.3 (a), (b) and (c) Gneiss showing grains of Garnet (Gr), Quartz (Q) and Feldspar, defining the foliation. (Magnification*10). (d) Coarse grained granite showing microcline (Mic), Plagioclase (OL) Polygonal quartz (Q). Magnification *10 Xpl

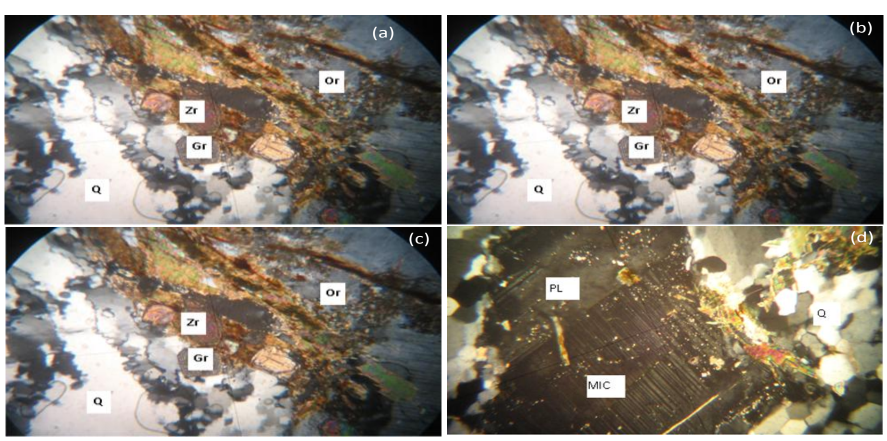


Fig.4 Q-A-P Streckeisen's diagram for Madagali granitoids

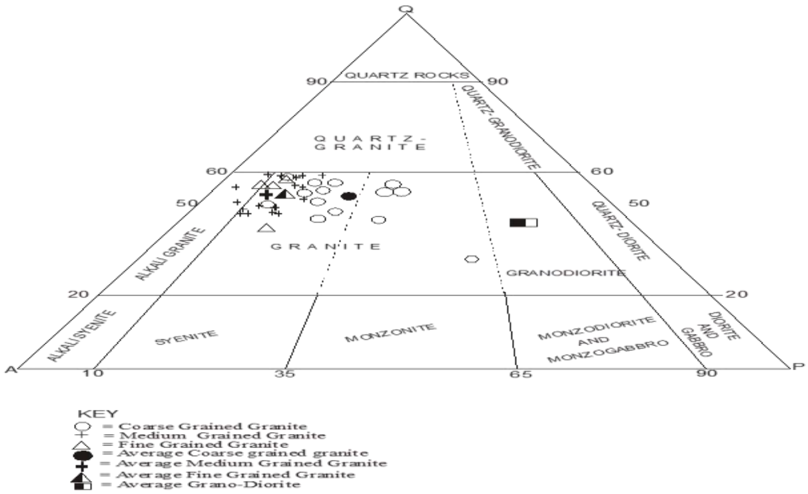


Fig.5 An-Ab-Or Diagram (O'Connor, 1965) showing plots of Madagali Granitoids

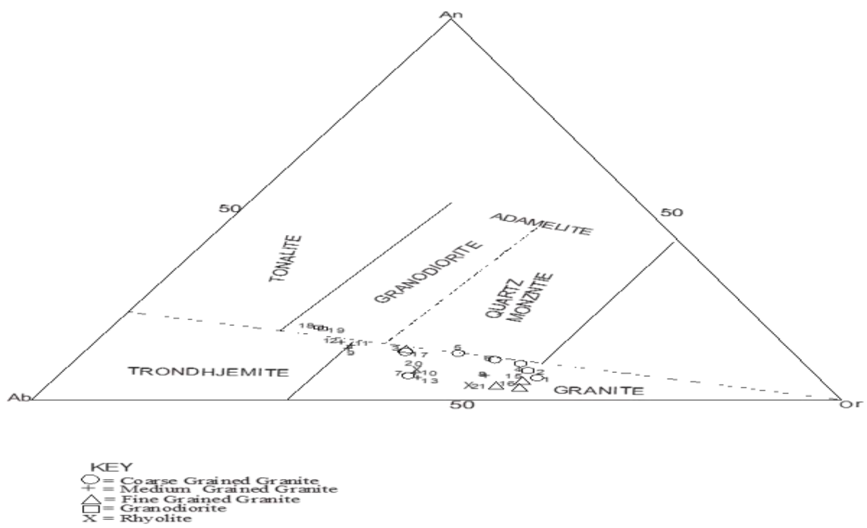


Fig.6 $K_2O\%$-$SiO_2\%$ Diagram for Madagali Granitoids (after Rickwood, 1997

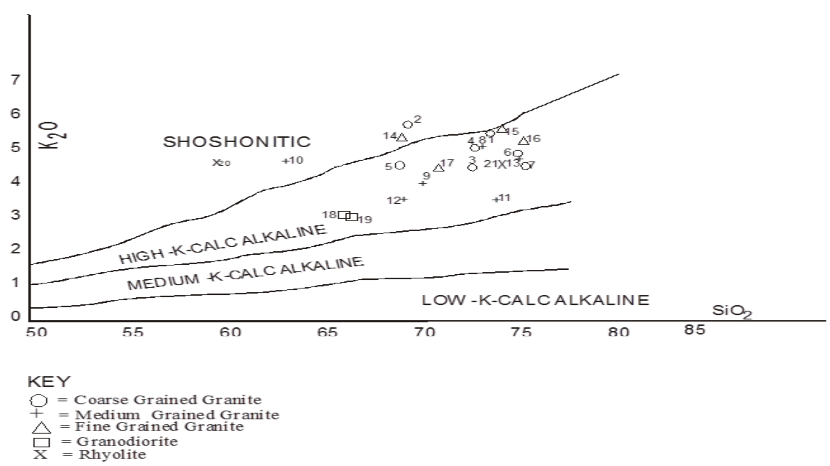


Fig.7 A/NK Vs A/CNK Diagram of Madagali Rocks (after Moniar and Piccoli, 1989)

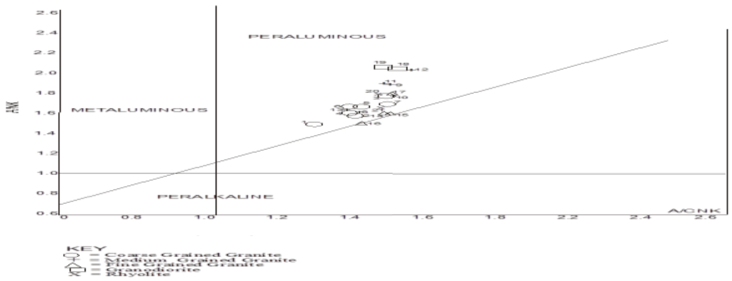


Fig.8 Chondrite-normalised REE pattern for Madagali Coarse Grained Granite (Normalising factors are those of Boynton, 1984)

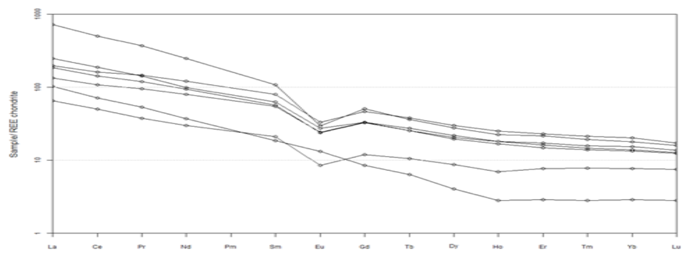


Fig.9 (a) Chondrite-normalised REE pattern for Madagali Medium Grained Granite (Normalising factors are those of Boynton, 1984). (b) Chondrite-normalised REE pattern for Madagali Fine Grained Granite (Normalising factors are those of Boynton, 1984)

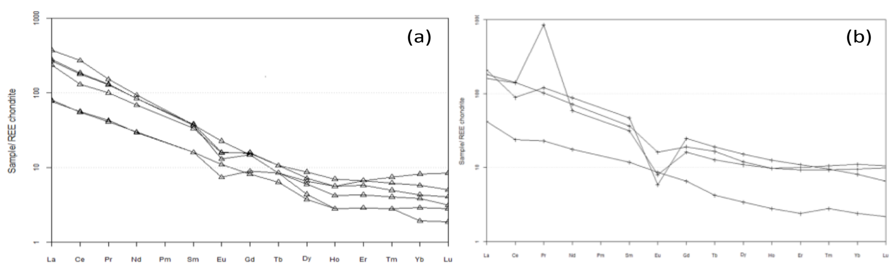


Fig.10 (a) Chondrite Normalised abundance of incompatible elements in Madagali Coarse grained Granites. (Normalizing values are from Weaver and Tarney, 1984). (b) Chondrite Normalised abundance of incompatible elements in Madagali Medium grained Granites. (Normalizing values are from Weaver and Tarney, 1984). (c) Chondrite Normalised abundance of incompatible elements in Madagali ine grained Granites

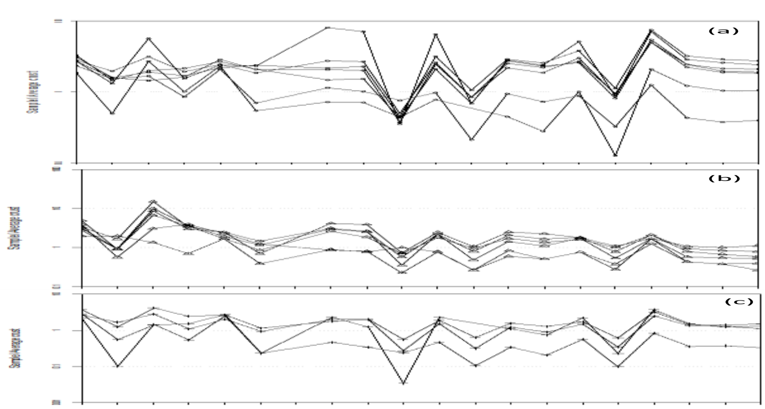


Fig.11 Molecular Ratio A/CNK Vs SiO_2 Plots for Madagali Granitoids (after Chappell and White, 1974)

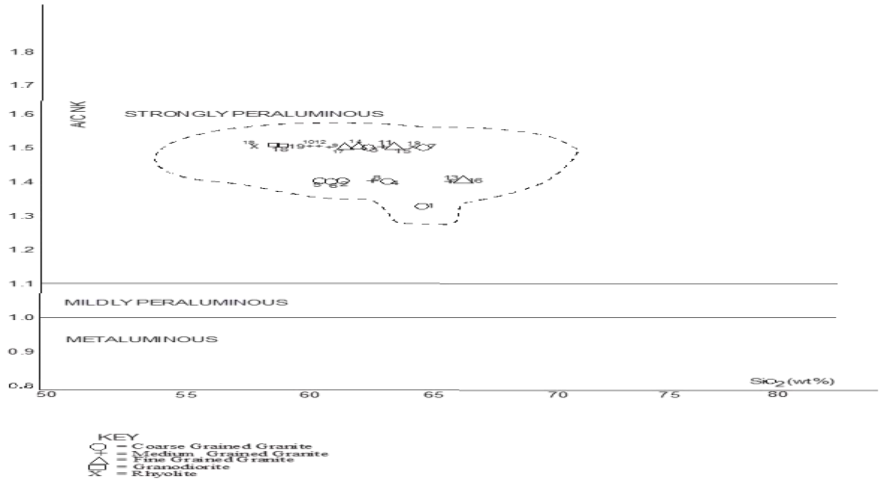
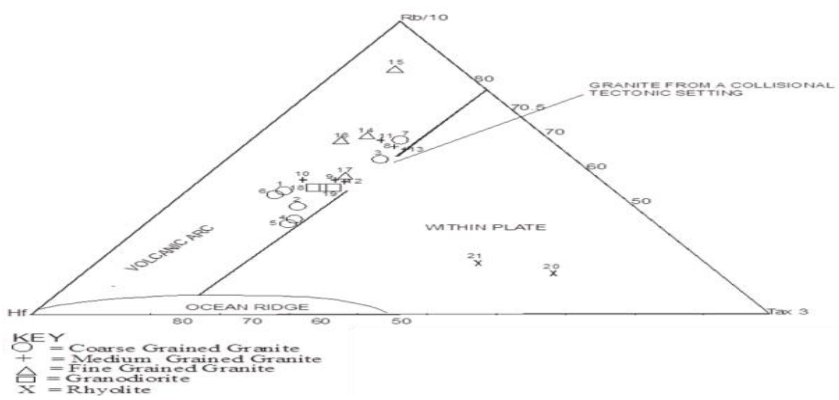


Fig.12 Hf-Rb/10-Tax3 Discrimination Diagram for Madagali Graitoids (after Harris et al, 1986) showing the field for volcanic Arc graites, withi plate granites and ocean ridge granites, granites from a collisional tectonic stting plot across the field boundary between volcanic arc and withi Plate Granites



The contents for granitoids are characterized by significant enrichment of LREE, and depletion in HREE with near flat pattern for most samples. However, the majority of the units are characterized by a more or less pronounced negative Eu anomaly, indicating the significant influence of plagioclase fractionation in the generation of granitoids. Further, the crystallization of plagioclase causes Eu depletion in the residual liquids in basic rocks. However, granitic rocks which show impoverishment in Eu anomaly have been interpreted to be possibly resulting from differentiation of rocks of more basic source (Onyeagocha 1986). In addition, all patterns of the Madagali granites are characterized by negative Eu anomaly which strongly supports the idea that the studied granites were derived by partial melting or anataxis of sedimentary rocks.

Indeed the positive Eu anomaly criterion is not recorded in any of the Madagali granitoids and therefore, metasomatism or granitisation is not likely in the granitic rocks of this work. Notably the REE patterns of Madagali granites have similar patterns to those of Akwanga granites in north central Nigeria which have evolved by anataxis of the surrounding gneisses (Onyeagocha1986). Similar approach has been shown by (McCarthy and Kabe1978) who indicated that such Eu depleted distributions may be expected of granites that have evolved from metasedimentary rock by partial melting or anataxis. Further, granite exhibit raft of amphibolite and gneisses which may possible be suggestive of anataxis (Baba etal.;2006). The granitoids displayed LaN/YbN ratios ranging from 8.47 to 41 in coarse grained granites to 9.48 to 195.52 in medium grained granites with 14.63 to 25.54 in fine grained granites. While the LaN/SmN ratios on other hand, vary in the same order (table5) from2.46 to 6.74,4.85 to 10,3.56 to 5.15, are signature of fractional crystallization. From the chondrite – normalized abundances of incompatible elements diagram (fig. 10a,b and c) the granitoids present high contents of large Ion Lithophile Element(LILE)such as Rb,K and Th with negative anomaly of Nb, Sr, P and Ba,this is suggestive of fractional crystallization process with the involvement of crustal participation in the generation of these rocks(Toteu1987,1990).The Madagali granitoids display lower values of Ni and Cr(19.16ppm and 20.68ppm on average).Such lower values, cannot be said to be derived from mantle source(Green1980).Further, the trace element in granites shows similar approach to the pattern of the fayalite - bearing quartz monzonite of Bauchi area, in Toro Charnockitic Complex(TCC),which is characterized by higher LILE with negative Cr,Ni and Nb anomalies(Dada etal.1995).It is noteworthy that negative Nb are characteristics of continental crust and may possibly be an indicator of crustal involvement in magma processes(Hugh1998).Also, the depletion of Ba/Nb and strong enrichment of Th and Ta in granitoids suggest significant amount of rework of the crust in the formation of the granites in this works. The elemental ratio of the granitoids (Table7) were compared with average crustal ratio values and displayed low values in K/Rb=223.82 and Ba/Rb=4.70 and high K/Ba=47.62 and Rb/Sr=0.77, where average crust show K/Rb=285, Ba/Rb=7.8, K/Ba=36 and Rb/Sr=o.123 respectively. Therefore, they reflection crustal source formation (Garba1992). A triangular diagram of Hf – Rb/10 – Ta x3 is used to further shows that all the granites fall in the volcanic- arc and within plate granite field (fig.12), then they are considered as collisional granites. Furthermore, the granitoids are indicated as predominantly volcanic arc and syn – collisional orogenic rocks. However, the plots of Madagali granites in the volcanic – arc may possibly be reasoned to the dilution effect of plagioclase accumulation which may shift granites from the within plate and Oceanic ridge fluids into volcanic – granites regions, (Pearce etal.1984). Ingeneral, the Madagali granitoids are calc – alkaline in nature, distinctively per aluminous in composition, therefore they were possibly generated from sedimentary rocks.

In conclusion from the geochemistry and petrographic studies of the Madagali area of north easternNigeria, it is clear that, the area is predominantly under lain by gneisses, granites of variable texture and mylonites. Granitoidscrop out in a large part of the study area, micrographic and myrmekitic textures have been observed widely in granites, as features which supports the idea of magmatic evolution of the rocks. The granites are calc – alkaline in nature and distinctive stronglyper aluminous in composition, in the all samples, signifiesa derivation from sedimentary origin (S – type). Chondrite – normalized REE patterns and amulti – ionic trace element plot of Madagali granitoids suggest were develop by partial melting typically of crustal materials of sedimentary rock in general.

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