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Geochemical Classification, Petrogenetic Association of Magmatic Rocks in the Gboko Area and the Tectono-Magmatic Influence on the Evolution of the (Gboko Area) Lower Benue Trough of Nigeria

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Abstract

Magmatism in the Gboko area is found to be genetically related to the evolution of the lower sectorial part of the intracratonic sedimentary Benue Trough of Nigeria. Geochemical interpretations of major and trace data show that the rocks which are mainly volcanics with some hypabyssal and plutonic varieties are mainly basaltic (basalts, basaltic trachyandesites, trachydacites), phonolitic (phonolite, tepri-phonolites,), rhyolites and nepheline syenites are generally of calc-alkaline series. They are peraluminous to metaluminous with a few peralkaline. Major and trace elements tectonic discrimination plots reveal that the basaltic rocks are characteristic of Within Plate Basalts (WPB), Oceanic Arc Theoliites (OIT), and Ocean Island Alkalic (OIA) while the nepheline syenites are characteristic of Within Plate Granites (WPG). The plots also show that the tectonic setting is continental in a spreading centre and related to orogenesis.

The evolved rocks in the Gboko area of the Lower Benue Trough are products of interaction between magmatism and tectonism which resulted from progressive crustal thining related to a spreading centre that regulated contamination from the crust and/or asthenosphere.

Keywords: Tectonism, magmatism, Benue Trough, contamination, magmatic fractionation

1. Introduction

The Cretaceous intracratonic Benue Trough of Nigeria is about 800 km long and 130 – 150 km wide (Fig 1). It is genetically part of the central African rifts in West and Central Africa, collectively known as West and Central African Rift System (WCARS) or the Mid-African Rift System (MARS) (Fig.2).

The WCARS were formed during regional tectonics that separated South America from African continent during the Cretaceous. These basins were formed under different tectonic setting with or without magmatism. For the Benue Trough its formation is linked to the St. Helena hotspot (O'Connor and Duncan, 1990; O' Connor and Le Reox, 1992) with a wide plume head of 520 – 1000 km (O'Connor and Le Reox 1992; Wilson 1992) which may have served to weaken the lithosphere along the Benue Trough by conduction of heat and transport of volatiles from the underlying mantle plume head.

The evolution is also related to the effects of Equatorial Atlantic oceanic fractures zones transmitted along the Benue Trough through transcurrent movements along deep seated faults extending along the trough during the early stages of separation of Africa and South America as indicated by Wilson and Williams (1979); Benkhelil (1982) and Benkhelil and Guiraud (1980). Benkhelil (1982) and Benkhelil and Robineau (1983) linked these faults to the Romanche, Chain and Charcot Fractures. Benkhelil (1986; 1988) later indicated that only the Chain and Charcot Fracture Zones are associated with the strike-slip faults extending into the Benue Trough which were responsible for the formation of the trough and creation of sub-basins (Fig.3).The structural evolution of the Benue Trough and the Central African Shear Zone (CASZ) which are complementary ancient shear zones were reactivated during the Cretaceous, the later being the extension on the African plate of the Pernambuco fault in Brazil which is known as the Foumban shear zone in Cameroun (Fig.2). According to Guiraud and Maurin (1991;1992) shear movements originating along the transform faults of the equatorial Atlantic due to differential opening between the Central and South Atlantic oceans were transmitted into the African plate as sinistral and dextral strike-slip movement along the Benue Trough and the CASZ respectively.

According to Fitton (1980; 1983; 1987) the Benue Trough and the Cameroon Line are complementary features with the former as a rift valley containing relatively few volcanic rocks and the latter a line of volcanic with rift valley affinities but lacking rifting. According to Fitton (1987) the magmas originally destined for the Benue Trough rifted area reached the surface as the Cameroon line instead.

The tectonic evolution of the Gboko area started with strike-slip sinistral movements along NE – SW trending faults in the Early Cretaceous. Protrusion of acidic volcanics (Rhyolites) along a major NE-SW fault north of Gboko dated 113 Ma (Umeji and Caen-Vachette, 1983) was related to the onset of rifting in the area.

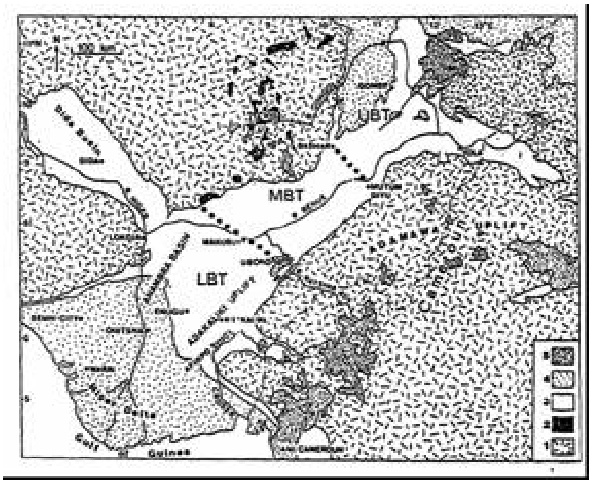

Fig 1: Outline geological map of the Benue Trough and adjacent areas (after Zaborski, 1998). LBT, Lower Benue Trough; MBT. Middle Benue Trough; UBT Upper Benue Trough. 1. Precambrian. 2. Jurassic Younger Granites? 3. Cretaceous. 4. Post-Cretaceous sediments. 5. Cenozoic Recent basalts including those of Cameroon Line.

Fig. 2: Extent and location of West African rift sub-system (WAS) solid line – Central African shear zone (CASZ) modified from Wycisk *et al.* (1990) and Genik (1993).

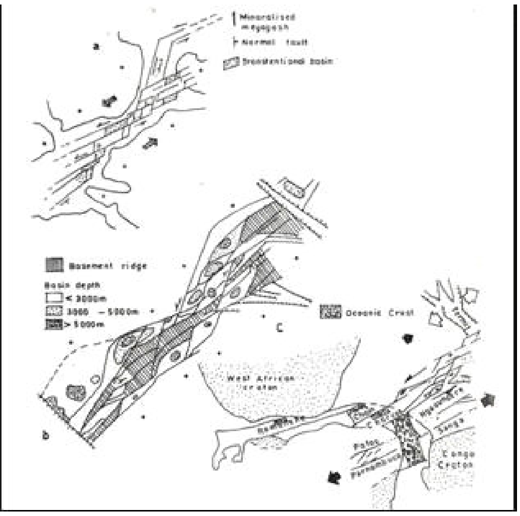

Fig. 3a) Proposed transtentional origin of sub-basin comprising the Benue Trough (after Benkhelil and Robineau, 1983). Note en-echelon arrangement of sub-basin, which corresponds to inverted Albian depocentres.

3b) Model for the formation of Aptian to Albian sub-basin in the Benue Trough along a transcurrent fault system (after Benkhelil et. al., 1988) the axial basement high is assumed to be an original feature in this model.Gulf of Guinea area during the Albian (after Benkhelil 1988) Sinistral strike-slip movement along the Benue Trough is induced by a more rapid movement apart of Africa and South America to the southeast of the Benue Trough and is related to extensions in the Niger rifts.

The sinistral movement along NE-SW faults induced dextral movement along the complementary NW – SE faults and created the normal E – W and N – S faults. The movements along the faults resulted in block faulting, subsidence and formation of horst and graben structures.

Murat (1972) showed that major fault movements along NE – SW faults resulted in the formation of the rift-like Abakaliki Trough in the Albian. Benkhelil *et al.* (1989) identified a graben at Ambighir at the southeastern edge of the Gboko area and described the basin and syn-sedimentary structures as similar to those underlying the sediments in the Abakaliki area. The effect of the NE-SW sinistral strike-slip movements and formation of sub-basins continued from pre-Albian into the Early Cenomanian and was followed by thermotectonic sag from Late Cenomanian to Santonian.

The magmatic activity in the Gboko area (Fig. 4) and other parts of Lower Benue Trough have taken place in three phases; 1) The first phase was from Late Jurassic to Early Albian (Najime 2010; Najime *et al,* 2012) before the onset of sea floor spreading in the Equatorial Atlantic. The phase was characterized by protrusions of dyke-like bodies into zones of weakness along updoming areas with a N – S trend on the Afro-Brazilian plate. The Gboko Hills, Mount Ikyuen and the dyke-like swarms of rhyolites dated 113 ± 3 Ma (Umeji and Caen-Vachette, (1983) in the Gboko area are the oldest traces of magmatism in the Lower Benue Trough. The Wanakande syenite dated 104 ± 4 Ma (Wright, 1989), also belongs to this phase. The phase is related to the main extentional tectonic regime (141-106 Ma) of Baudin, (1991) and (Late Jurassic to Albian period 147 – 106 MA) of alkali transitional basalts and associated peralkaline rhyolites (bimodal Volcanism) and by tholeiitic transitional basalt of Maluski *et al.* (1995).

2) The second phase of magmatism in the Lower Benue Trough spanned the Middle-Albian to Early Santonian. According to Wright (1989) the products were abundant intrusives and minor occurrences of tuffs and lavas interbedded with the Albian sediments. The intrusives appear to be abundant in Albian sediments, less common in Turonian and absent in the post-Turonian sediments. Reyment and Tait (1983) also indicated that minor volcanic activities took place from Middle-Albian to Cenomanian and Late Cenomanian to Middle Turonian. Farrington (1952), Cratchley and Jones (1965) and Nwachukwu (1972) associated the volcanic activity with the postulated Cenomanian folding phase. Basaltic rocks within Albian sediments occur along the River Mu north of Gbemacha. Similar lavas occur between clastic alluvial fans and the shales and limestones of Albian age along the River Konshisha northwest of Buabunde in the Gboko area.

3). The third phase of volcanism in the Benue Trough is of Santonian age, a major folding phase in the Benue Trough. Burke *et al.* (1970), Burke *et al.* (1971), Günthert and Richards (1960), Murat, (1972), Freeth (1979) and Benkhelil (1987; 1989) have documented undersaturated magmatic rocks with alkaline characteristics in the Abakaliki area. The rocks are dated 81 – 83 Ma (Wright, 1989), in line with the Santonian age. Oyawoye (1972), Adighije (1979; 1981), Ajayi and Ajakaiye (1981), Ofoegbu (1986; 1988) and Ojoh (1990) reported the presence of intrusives and volcanic flows around Isiagu, Abakaliki, Lefin, the Egedde Hills, the Agilla area and some in the Gboko area (Najime 2010; Najime *et al,* 2012) (Fig.5) as earlier indicated by Cratchley and Jones (1965)

The aim of this paper is to characterize the magmatic rocks and to show the influence of tectonism and magmatism on the evolution of the Gboko area and the Lower Benue Trough in general.

1.1 Method of Study

A general geological mapping of the upper part of the Lower Benue Trough (Gboko Sheet 271) was undertaken on a scale of 1:50,000. Magmatic rocks in the area were mapped; sampled and ground into powder/pulverized using a Tungsten carbide spex mill at the Department of Geology, Ahmadu Bello University, Zaria, Nigeria. Fused beads prepared from ignited samples for the major and some trace elements and pressed powder pellets for some other trace elements on an X-ray Fluorescence Spectrophometer (XRF) were done at the analytical laboratories, Earth and Planetary Sciences McGill University Canada.

2. Result

The result of major elemental contents, trace elements and the CIPW norm calculations for the magmatic rock analysed (11 samples) is presented in Table 1. The major elements variation based on Harker variation diagram is plotted in figure 6 and trace elements partitions is presented (Fig.7).The major elements are used in the geochemical classification of the rocks based on (CIPW) norm and the total alkaline versus silica (TAS) diagram (Figs.8a-b). Other plots are the alkali, iron and magnesium (AFM) variation diagram (Fig 9), Si_2O-K_2O diagram (Fig. 10) and A/CNK-A/NK diagrams (Fig.11) showing rock suites based on major and minor oxides. The tectonic discrimination diagrams based on plots of major and trace elements are also presented (Figs. 12 to 14)

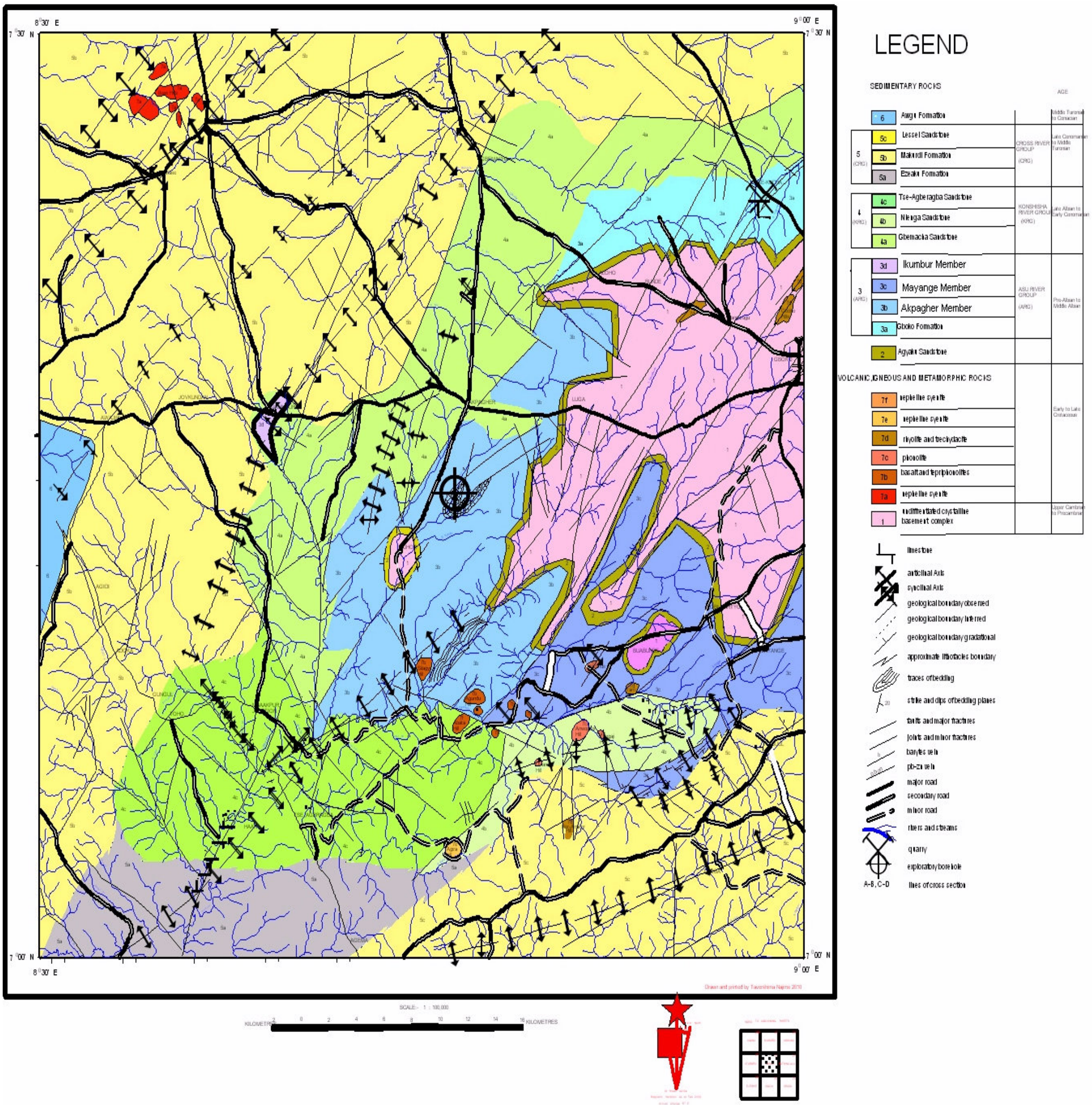

Fig. 4: Geological map of the Gboko Area (Sheet 271) showing the distribution of magmatic and sedimentary rocks and structural features.

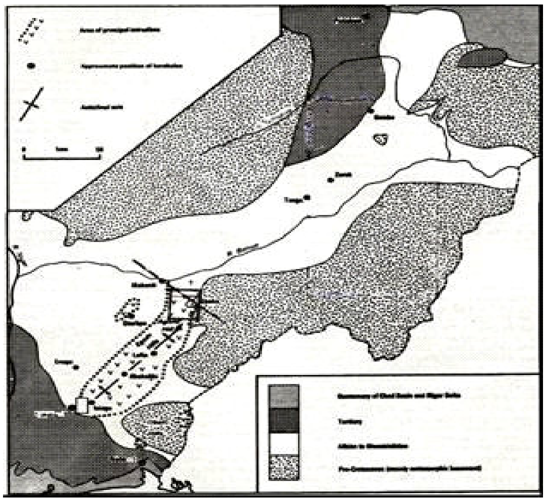

Fig. 5: Map of the Benue Trough with the studied area around Gboko indicated (inet square) showing the extent of the Cretaceoues magmatism in the Lower Benue Trough and the Gboko area. Adapted from Cratchley and Jones, (1965) with modifications from Burke *et al.* (1971); Nwachukwu (1972); Geological Survey of Nigeria 1: 250,000 Sheets 64 (Makurdi); 79 (Umuahia); 80 (Oban Hills); Geological map of Nigera 1: 2000,000 (1974) and the present work.

Table. 1: Major, trace elements content in the magmatic rocks of the Gboko area and their CIPW norm

Major Elements %

Samples	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12
SiO_2	78.72	51.59	45.53		55.40	50.81	49.42	56.14	47.59	67.25	49.57	48.19
TiO_2	0.0657	2.0231	3.9873		0.4030	1.1107	1.5466	0.5871	1.4468	0.3750	1.1644	1.4891
Al_2O_3	11.71	17.04	14.11		20.67	22.59	20.18	21.01	22.58	16.98	21.30	20.57
Fe_2O_3	1.0122	10.6440	13.0517		3.1266	4.6816	6.0910	3.4416	6.2923	2.9915	5.3101	6.0700
MnO	0.0048	0.1432	0.1698		0.1319	0.1480	0.1566	0.1712	0.1791	0.2119	0.1679	0.1631
MgO	0.15	5.21	6.07		0.20	0.94	2.04	0.28	1.87	0.03	1.19	1.64
CaO	0.06	2.04	9.70		0.65	2.67	4.90	0.75	4.44	0.05	3.55	4.92
Na_2O	0.0924	5.5760	3.1576		9.9110	9.2009	8.7542	10.0659	6.0795	7.2518	7.9879	8.5949
K_2O	6.40	0.32	1.16		5.64	3.99	2.97	4.97	4.11	3.62	4.58	3.55
P_2O_5	0.008	0.213	0.911		0.041	0.261	0.342	0.077	0.591	0.060	0.330	0.424
LOI	1.49	5.02	2.30		3.18	3.21	2.91	1.84	4.28	1.26	4.64	3.70
Total	99.71	99.84	99.52		99.35	99.61	99.31	99.25	99.45	100.08	99.79	99.31
TRACE ELEMENTS (ppm)												
Ba	464.6	1130.4	356.6		33.6	831.8	654.6	306.5	1369.3	238.1	906.2	996.5
Co	<d/l	48	43		<d/l	<d/l	11	<d/l	<d/l	<d/l	<d/l	<d/l
Cr	<d/l	338.7	288.7		24.7	26.9	54.8	33.8	23.3	27.6	20.4	21.2
Cu	<d/l	95	68		7	20	42	12	26	3	14	24
Ni	<d/l	147	118		<d/l	<d/l	16	<d/l	<d/l	<d/l	<d/l	<d/l
Sc	<d/l	20	18		<d/l	<d/l	<d/l	<d/l	<d/l	<d/l	<d/l	<d/l
V	10.1	195.5	261.7		34.6	79.5	122.3	34.8	112.2	13.5	104.3	118.1
Zn	36	108	96		62	49	56	58	53	72	61	56
Ga	47.0	25.8	22.5		30.4	23.2	21.2	24.5	21.6	29.7	24.9	19.8
Nb	211.2	15.0	57.6		88.9	88.6	79.3	138.7	127.1	175.6	96.7	104.2
Pb	10.4	9.6	<d/l		13.5	7.9	4.8	11.3	7.2	118.1	10.0	4.3
Rb	251.7	7.8	21.7		151.8	73.9	56.2	107.6	122.7	52.4	121.3	67.7
Sr	10.0	217.5	830.4		23.8	472.4	713.6	44.5	1314.2	20.4	853.1	965.9
Th	25.0	1.9	4.2		12.5	6.5	6.1	10.6	8.2	20.7	9.4	7.4
U	8.8	<d/l	1.8		6.8	3.1	2.0	6.9	5.6	7.6	4.2	2.4
Y	61.2	22.1	35.7		10.4	18.0	23.9	16.5	22.6	42.5	23.1	24.8
Zr	411.4	92.9	317.9		930.4	377.2	334.2	604.3	279.3	1249.2	362.2	284.3

CIPW (Volume % Norm)

	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12
Q	54.09	2.64	0		0	0	0	32.97	0	9.98	0	0
An	1.02	66.65	55.07		28.76	34.38	31.95	0	41.2	63.26	28.53	24.98
Or	40.55	3.46	8.67		35.85	26.46	20.27	20.91	28.73	22.81	31.02	24.55
Ne					27.71	31.61	31.2		19.54		29.86	34.43
C	3.06	3.21							0.81	0.74		
Di			16.46		2.03	2.39	10.95				5.18	10.83
Hy	0.93	18.62	1.51					0.62		1.94		
Ol			7.54		1.35	2.18	1.53		5.12		2.02	1.01
Ac					2.28			2.61				
K2SiO3								3.42				
Na2SiO3					1.48			22.52				
Rutile								11.7				
Il	0.08	2.51	4.96		0.44	1.24	1.78	3.23	1.68	0.41	1.33	1.72
Mt	0.25	3.05	3.73			1.21	1.61		1.68	0.75	1.39	1.61
He												
Ap	0.02	0.47	2.05		0.08	0.53	0.71	0.17	1.24	0.12	0.68	0.88
Sphene								1.85				

2.1 Major Elements Distribution and Trends

The silica content in the magmatic rock in the Gboko area show that the rhyolite and trachydacite are acidic rocks, phonolite and one of the nepheline syenite (A_8) is an intermediate rocks while the basaltic trachyandesite, tephriphonolites, nepheline syenites and the basalt are basic rocks. The normative quartz and hypersthene appears in the rhyolites, basalt, basaltic trachyandesite, trachydacite, nepheline syenite (A_8) indicating silica saturation to oversaturated rocks. Olivine and nepheline occur in the phonolite, tephriphonlites and the nepheline syenites (A_8, A_{11}) as unsaturated basic rocks. Titanium occurs in all the rocks in the mineral phases of magnetite and ilmenite but have low values in the rhyolite. Aluminium oxide (Al_2O_3) contents and saturation is relatively low in rhyolite, basaltic trachyandesite, trachydacite and the presence of corundum in the rhyolite, basaltic trachyandesite, nepheline syenite and trachydacite suggest alkali loss leading to formation of normative corundum.

The total iron content recalculated to (Fe_2O_3) has high values in the basalt and basaltic trachyandesite and account for the volume of ilmenite and magnetite, the manganese content in all the rocks is generally uniform, characteristic of basic and intermediate volcanic rocks but low in the rhyolite. Manganese is found in mineral phases of olivine, pyroxene, amphibole and feldspars in most of the rocks.

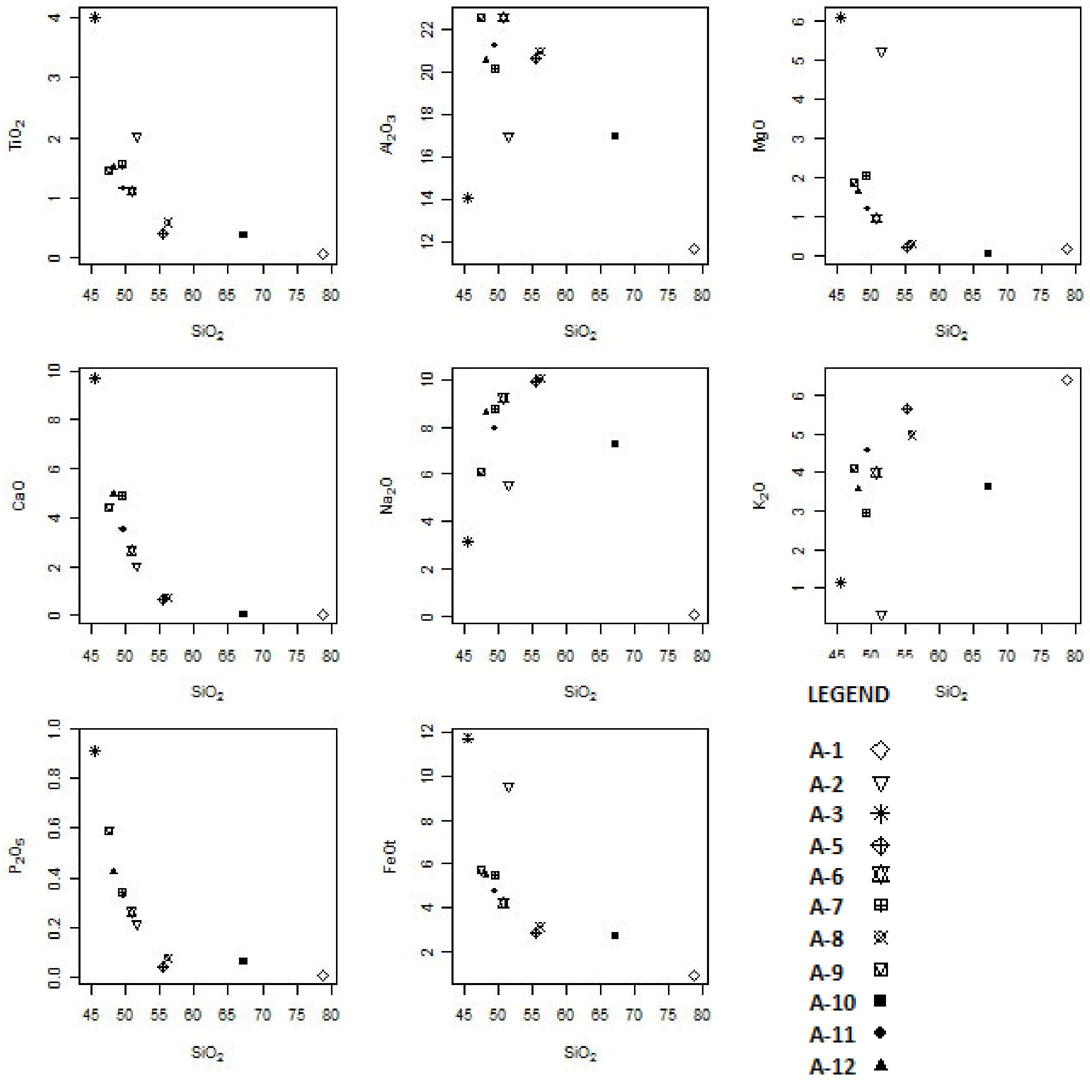

Fig. 6. Plots of major elements versus silica contents for magmatic rocks in the Gboko area adapting the Harker(1909) variation diagram.

In basic igneous rocks magnesium is relative concentrated in the early crystals forming high temperature olivine and pyroxene. The contents of magnesium are high in the basalts, phonolite, tephri-phonolites and nepheline syenite (A_9, A_{11}). In the presence of high water and oxygen fugacity normative hypersthene is formed instead of olivine as seen in the basaltic trachyandesite.

The contents of calcium is primarily in the rock forming minerals of plagioclase as is found in all rocks under study except in a nepheline syenite (A_8) and diopside, a calcium pyroxene occur in the basalt, phonolite, tephri-phonolites and nepheline syenite (A_{11}). Sodium which is an essential component in the feldspars, feldspathoids and the clinopyroxenes account for the formation of acmite, sodium silicate (Na_2SiO_3) in the nepheline syenite (A_5). Potassium another important component of feldspars (orthoclase) is found in all the rocks and potassium silicate in the nepheline syenite (A9). The phosphorus activity in magmas that emplaced the rocks in the Gboko area is manifested by the presence of apatite as accessory minerals in all the rocks. The phosphorus enrichment activity and formation of apatite is a measure of water content increase in a melt moved toward the middle and late stages of crystallization.

The plot of major elementts against silica (Fig. 6) show high values of TiO_2, MgO, FeO with relative low silica values is associated with the basalt and basaltic trachyandesites. High to medium values of Al_2O, Na_2O and K_2O and relatively low values of silica is associated with phonolites, tephri-phonolites and the nepheline syenites. The rhyolites and trachyandesites are associated high values of silica and low values of TiO_2, MgO, CaO, P_2O_5 and FeO

2.2 Trace Elements Distribution

The distribution of trace elements in the rocks of the Gboko area is summarized in the spider diagram (Fig. 7) and analysed based on trends of compatible elements closely matched with the large-ion lithophile (LIL) and the incompatible elements also closely matched with the high field strength elements (HFSE).

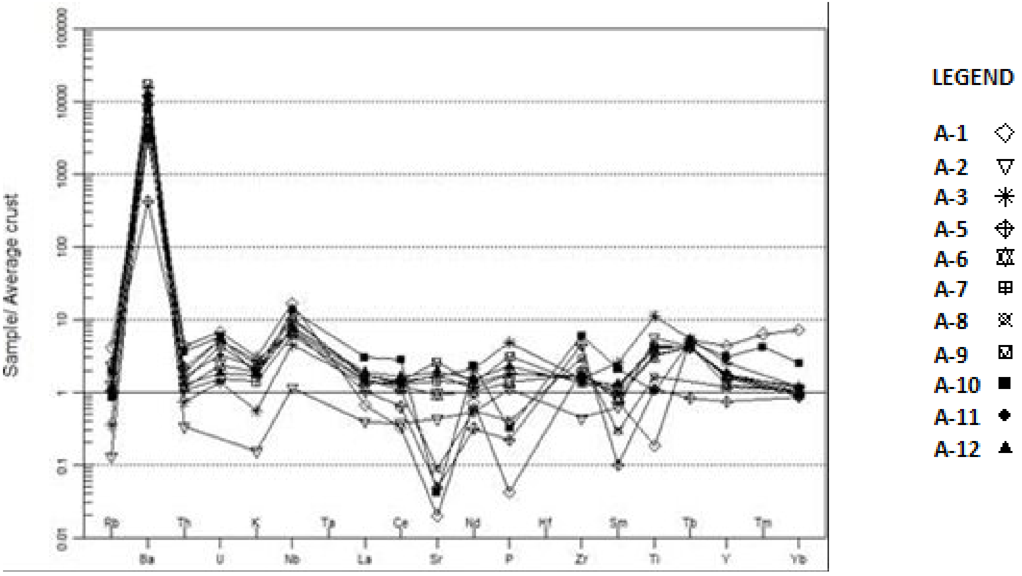

Fig. 7 Spider diagram of trace and rare earth elements of magmatic rocks in the Gboko area normalized to the average crust of Weaver and Tarney (1984)

2.2.1 Compatible Elements

The chromium contents record high values in the basaltic trachyandesite and basalts, characteristic of calc-alkaline basalts and relatively lower values in the other rocks and below the detection limit of 10 ppm.

The nickel contents above the detection limit of 3 ppm are recorded in the basaltic trachyandesite, basalt and tepri-phonolite (A_7) and less than the detection limit in the other rocks. The copper content are high <60 ppm in the basaltic trachyandesite and basalt, <10 ppm in tephri-phonolites, nephelitic syenites and >10 in phonolite, trachydacite and less than the detection limit of 2 ppm in the rhyolite. The cobalt contents above the detection limit of 10 ppm occur in the basaltic trachyandesite, basalt and tephri-phonolite (A_7) and less than the detection limit in the other rocks. The low chromium, cobalt and nickel contents show increase in contamination or differentiation.

The high values of barium >1000 ppm are found in the basaltic trachyandesite and one of the nepheline syenite (A_9), >500 ppm are found in the nepheline syenite (A_{11}) tephri-phonolites, >100 ppm are found in the rhyolites, basalt, nepheline syenite and <100 ppm in the phonolite. Barium concentration increases with contamination and differentiation similar to gallium. The contents of strontium < 50 ppm are in the rhyolite, phonolite, nepheline syenites (A8), trachydacite while contents > 800 ppm are in the basalt, nepheline syenite (A11) and tephriphonolite (A12). The high values of vanadium >50 ppm are recorded in the basaltic trachyandesite, basalt, tephri-phonolites, while values <50 ppm are recorded in the rhyolites, phonolite, nepheline syenite (A_8) and trachydacite. The high values zinc >90 ppm are recorded in the basaltic trachyandesite and basalt while a low value <40 ppm is recorded in the rhyolite.

2.2.2 Incompatible Elements

The uranium (U) contents indicate slight enrichment compared to the average crust values in all the rocks. Uranium values < 2 ppm are recorded in the basaltic trachyandesite and basalt, 2 to 3 ppm in tephriphonolites and > 4 ppm in nepheline syenite, trachdacite and rhyolite. The Th/U ratios indicate a value of 2.84 in rhyolites, 2.09 – 3.08 in tephri-phonolites, 2.72 in trachydacite, 1.54 – 2.2 in the nepheline syenites, 1.83 in phonolites, 2.3 in the basalt and 0.0 in basaltic trachyandesites. The lead (Pb) values range between <1 ppm (detection limit) in the basalt to 118.1 in the trachydacite and the contents between the two limits show no specific trend of enrichment or depletion. Scandium contents above the detection limit of 7 ppm are recorded only in the basaltic trachyandesite and basalt and less than the detection limit in the other rocks. Gallium (Ga) in the rocks range between 19.8 to 47 ppm with a high gallium value is recorded in the rhyolite. Gallium contents are usually present in magnetite and feldspars. The niobium (Nb) contents range between 15.8 to 211.2 ppm with high contents recorded in the rhyolite, nepheline syenites (A8, A9), trachydacite and one of the tephriphonilte (A12) followed by relatively higher values in phonolite, basalt, tephriphonolites (A6, A7), nepheline syenite (A11) and lower contents in the basaltic trachyandesite. The Rubidium (Rb) contents have a range of 7.8 to 251.7 ppm with a mean of 94.10. The yttrium (Y) contents ranges between 10.4 to 61.2 ppm. The zirconium (Zr) contents have a range of 92.9 to 1249.20 ppm with a mean of 478.7 and a standard deviation of 333.90. The average crust normalized values range between 0.1 – 10 indicating slight depletion or enrichment of zirconium in the rocks relative to the average crust values.

2.2.3 Elemental Ratios

The K/Rb ratio gives values of 0.05 in trachydacites, 0.044 – 0.045 in tephri-phonolites, 0.044 in basalt, 0.027 – 0.038 in nepheline syenites, 0.034 in basaltic trachyandesites and 0.021 in rhyolites. The trend show more contamination in the nepheline syenites, basaltic trachyandesite and rhyolite than in the trachydacite, tephriphonolites and basalt.

The Rb/Sr ratio is 25.17 for rhyolites, 6.37 for phonolites, 2.57 for trachydacite, 0.07 – 2.56 for tephriphonolite, 0.026 – 0.035 for basaltic trachyandesites and the basalt. The low ratios indicate formation of the mafic minerals while the high ratios indicate increase in the formation of the feldspars.

The Zr/Y ratios gives values of 89.5 for the phonolite, 12.4 – 36.6 for nepheline syenites 29.4 for the trachydacite, 11.5 – 18.7 for the tephri-phonolites, 8.9 for the basalt, 6.7 for the rhyolites and 4.2 for the basaltic trachyandesite. Plutonic rocks tend to have less zirconium and as an incompatible element the Zr/Y ratios indicate less contamination of the magmatic rocks.

2.3 Petrographic Classification

To classify the rocks based on chemical plots of total alkali versus silica (TAS) diagram of Middlemost (1994) for volcanic rocks was adapted (Fig. 8a) and Cox *et al.,* (1979) for the intrusive rocks (Fig.8b).

The plot (Fig. 8a and 8b) compared with the petrology of the same rocks of Najime *et al.,* (2012) shows that the rhyolites (A_1 and A_{10}) of Najime *et al.,* (2012) with silica content 78.72 and 67.25% and normative quartz plot as rhyolite and trachydacite respectively. The dacite and trachyandesite in Najime *et al.,* (2012) plotted as basaltic trachyandesite and basalt (A_2 A_3) respectively. The basaltic trachyandsite has normative corundum and hypersthene while the basalt has normative diopside, hypersthene and olivine. The silica contents of 51.59 and 45.53 with normative quartz indicate basic rocks. The trachyte (A_5) in Najime *et, al.* (2012) with pyroxenes (acmite and diopside) and olivine plotted as phonolite. The basalts (A_6, A_7 and A_{12}) of Najime *et al.,* (2012) with feldspars, diopside olivine and nepheline plotted as tephri-phonolites. Their silica contents between 49.19 to 50.81% indicate basic rock types. The coarse grained rocks of nepheline syenite, diorite and gabbro (A_8, A_9 and A_{11}) of Najime *et al.,* (2012) all plotted on the TAS diagram after Cox *et al.,* (1979) chemical plutonic equivalence of nepheline syenites. The silica contents (56.14) in one of the nepheline syenite with normative quartz indicate an intermediate rock. The other two with feldspars, hypersthenes, acmite, diopside, olivine, and nepheline and a silica content of 47.59 to 49.57 with no quartz indicate basic rocks.

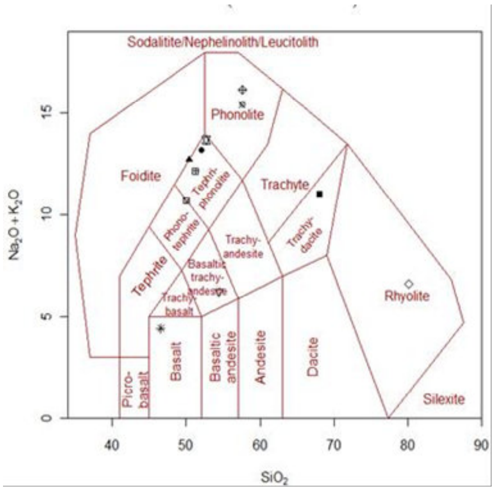

Fig. 8a Chemical classification of magmatic rocks (Volcanic) in the Gboko area adapting the total alkali versus silica (TAS) of Middlemost(1984)

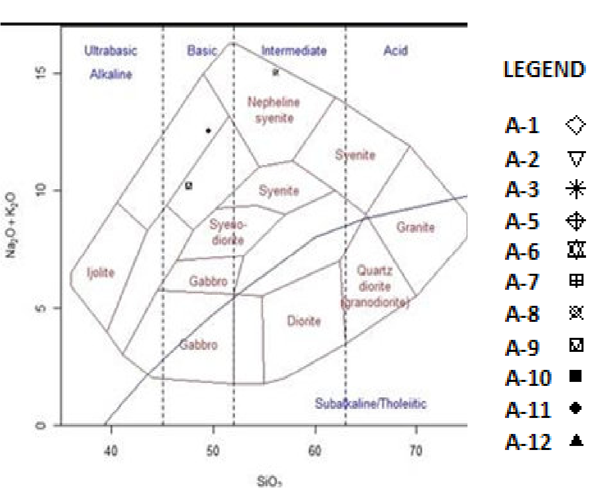

Fig.8b Chemical classification of magmatic rocks (Plutonic) in the Gboko area adapting the total alkali versus silica (TAS) of Cox et, al., (1979)

2.3.1 Petrotectonic Association and Tectonic Discrimination

The plots of the rocks on the $Na_2O + K_2O$, Fe + FeO, and MgO, (AFM) diagram of Irvine and Baragar (1971)(Fig. 9) show that all the rocks plot as calc-alkaline series, characteristic of highly evolved rock developed on thick crust. The degree of evolution as shown on the SiO_2-K_2O diagram of Peccerillo and Taylor (1976) (Fig. 10) indicate that the basalt, trachydacite and rhyolite? plot in the high-k calc-alkaline series field while all the other rocks plot in the shoshonite series field. The A/CNK – A/NK plot of Shand (1943) (Fig. 11 classify the basalt, tephri-phonolites and phonolite-tephrite plot as metaluminous while the trachyandesite and basaltic-trachyandesite are peraluminous and the nepheline syenite and phonolite are peralkaline.

To discriminate tectonic setting of the basaltic rocks (45-54 wt % SiO_2), the Zr/Y-Zr variation diagram Pearce and Norry, (1979) (Fig. 12) shows that the basaltic trachyandesite and basalt in the Gboko area are within plate basalt (WPB). To further discriminate variation in their settings the MnO-TiO-P_2O_5 diagram after Mullen, (1983) (Fig. 13) shows that the tectonic discrimination diagram for basaltic trachyandesite and basalt (45-54 wt % SiO_2) in the Gboko area have characteristics of ocean island tholeiite field (OIT) and ocean island alkali basalt (OIA) respectively. In the MgO-$FeO_{(tot)}$-Al_2O_3 diagram after Pearce *et al.,* (1977) (Fig.14) the basaltic trachyandesites (A2) (51-56 wt % SiO_2) plotted in the orogenic field, the basalt in the continental field and all the associated rocks in the spreading centre island tectonic setting.

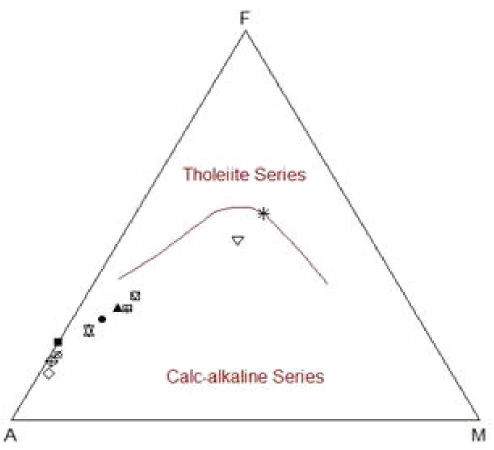

Fig. 9: An AFM diagram after Kuno (1968) and Irvine and Baragar (1971) showing trend of magmatic rocks in the Gboko area in the calc-alkaline field

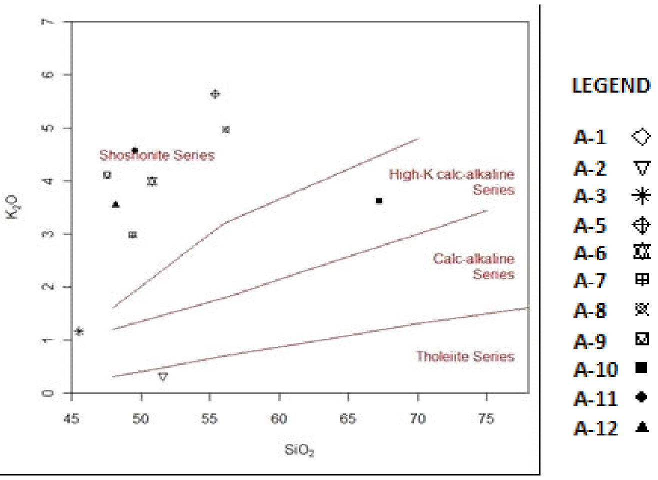

Fig. 10: The SiO_2-K_2O diagram of after Peccerillo and Taylor (1976) showing the classification of subalkaline magmatic rocks in the Gboko area on the basis potassium enrichment.

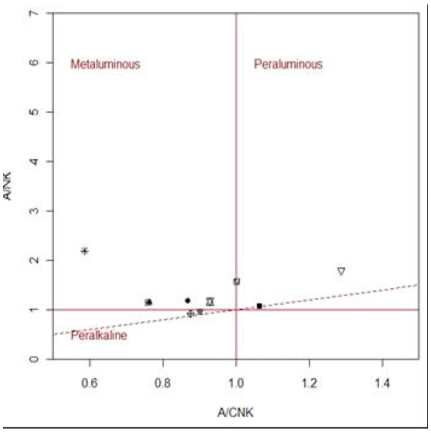

Fig. 11 An A/NK and A/CNK diagram after Shand (1951) showing subdivision of magmatic rocks in the Gboko area based on alumina saturation into peralkaline, peraluninious and metaluminious

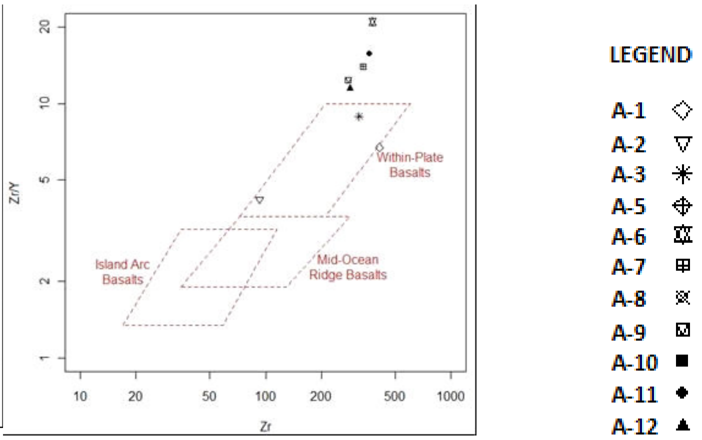

Fig. 12 The Zr/Y-Zr variation diagram for basalt discrimination diagram for basalt and basaltic andesites (45-54 wt % SiO_2) after Pearce, (1983) showing the tectonic setting of the basaltic trachyandesite and basalt in the Gboko area as ocean island tholeiite (OIT) ocean island alkali basalt (OIA).

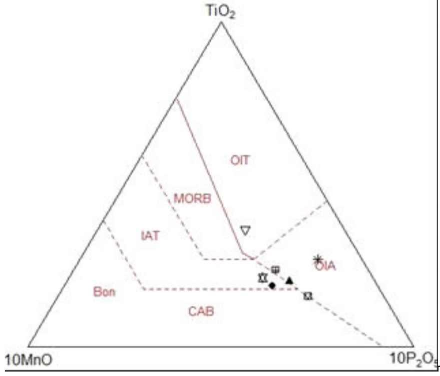

Fig. 13 The MnO-TiO-P_2O_5 after Mullen, (1983) showing the tectonic discrimination diagram for basalt and basaltic andesites (45-54 wt % SiO_2) in the Gboko area. In this category the basaltic trachyandesite plot in the ocean island tholeiite field (OIT) and the basalt in the ocean island alkali basalt (OIA).

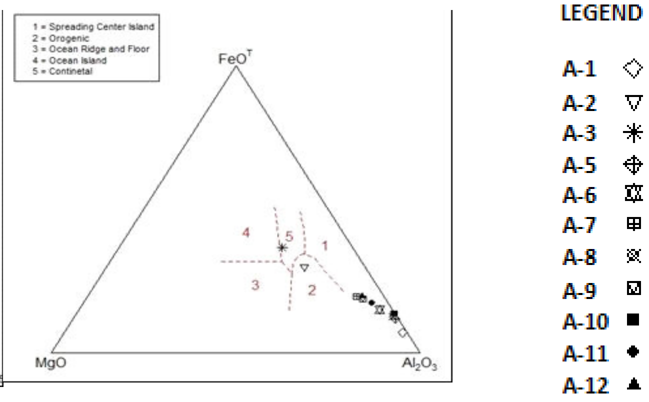

Fig. 14 The MgO-$FeO_{(tot)}$-Al_2O_3 after Pearce et. al., (1977) showing the tectonic discrimination plots for magmatic rocks (51-56 wt % SiO_2) in the Gboko area. In this category the basaltic trachyandesites plot in the orogenic field and phonolite in the spreading centre island

3. Discussion

Regions of uplifted Precambrian basement within the Afro-Brazilian plate from the Jurassic to Cretaceous are associated with domes whose formation was followed by development of triple rift system within the continents. Magmatism is identified as a forerunner in the break-up of rifted areas along the domed areas. In the Niger Delta area the St. Helena hot spot (O'Conner and Le Roex, 1992) initiated a mantle plume activity which gave rise to updoming along the Benue Trough; this was followed by crustal stretching and thining from Jurassic to Early Cretaceous. The period is coincident with the Pre-Albian to Early Cretaceous magmatism which was also necessary for thining and stretching of the crust. Rifting and tectonic displacement in the Benue Trough along major NE – SW trending faults related to the Charcot and Romanche ridges of the mid-Atlantic resulted in the formation of the rift-like Abakiliki Trough and the major faults outcropping in the Gboko area. Syn-rift magmatism was contemporaneous with rifting and sedimentation up to Cenomanian The Early Cretaceous rifting along the Lower Benue Trough was followed by thermo-tectonic subsidence which lasted till the Santonian. Magmatic activity during the sag-phase was minimal. In Santonian changes in direction of the relative movement of the African and South American plates (Fairhead and Binks, 1991) and north-south compression between the African and European plates (Guiraud *et al.*, 1987; Ziegler, 1990) caused a change in the movement vector between the African plate and Eurasian/Tethysian plates (Zonenshian *et al.,* (1990). In the Lower Benue Trough, the effect was marked by reactivation and reversal movements along NE – SW strike-slip faults and the formation of the Abakaliki anticlinorium, Anambra basin and Afikpo syncline. Magmatism within the same period utilized the reactivated faults for extrusion/intrusion of magma. The Abakaliki anticlinorium N 50^0 E faults are well expressed but the relationship with the basement rocks and older series are not visible but in the Gboko areas, the relationship between the older series and the uplifted basement has been documented (Benkhelil *et al.*, 1989; Najime 2010; Najime *et al.,* 2012). Similarly the relationship between the magmatic rocks and axial faults are well preserved. Most of the high-level magmatic extrusions are concentrated along a NE-SW trend southwest of Gboko. The trend is continuous with the trends of magmatism recorded in the Workum Hills and the Abakaliki area. Benkhelil *et al.,* (1989) observed that the axial part of the Abakaliki area was the site of syn-sedimentary magmatic activity during the Albian. The magmatic rocks occur as flows and extrusions which bear similarity in mode of emplacement with the magmatic bodies encountered in the Gboko area.

The geochemical classification of rocks in the study area indicate a bimodal sub-alkaline basaltic magmatism with basalt, basaltic trachyandesites and associated rhyolites, trachydacites, tephriphonolite and alkaline granitic rocks (nepheline syenites). The rock suite is calc-alkaline characteristic of thick continental crust with peralkaline phonolite and nepheline syenite (A8), the basalt, tephriphonolites and the other nepheline syenites are peraluminious while the trachydacite and basaltic trachyandesite are metaluminious. The degree of thickness, by measure of potassium contents (Fig. 9) indicate a shallow depth for the basaltic trachyandesite, followed by the basalt, phonolite and rhyolite with high-K and those in the shoshonite field portraying increasing thicker crust. The basalt and basaltic trachyandesite are characterized as within plate basalts WPB while the Rb/Y+Nb and Nb/Y ratios 0.69-1.0 and 4.2-8.4 respectively for the nepheline syenites indicate they are within plate granite (WPG) The tectonic discrimination of the rocks as ocean island tholeiite (OIT) and ocean island alkali basalt (OIA) for the basaltic trachyandesite and basalt respectively and the tephriphonolites as island arc tholeiite (IAT) are all indication of tectonic influence on the magmatic process.

4. Conclusion

The Gboko area presents a unique picture of structural trends and magmatism within the basement rocks which underlies the Lower Benue Trough and later effects of structural movement affecting the sedimentary trough areas and the attendant syn- and post-magmatism in the Lower Benue Trough.

Magmatic intrusions along NE – SW and NW – SE trends and alignment of extrusive/intrusive bodies along this bodies and their timing indicate that rifting and faults reactivation influenced the timing and sites of emplacement while the St. Helena mantle plume was the precursor to doming, stretching, thining and rifting along the Benue Trough. The alkaline magmatism in the area display characteristics similar to those found in mobile regions while those with sub-alkaline affinities are characteristic of continental margins. Another trend is the low contents of Sr, and Ba indicating plagioclase fractionation in rhyolite, phonolite, trachydacite, nepheline syeniteas (A8). The low contents of P and Ti in these rocks especially the rhyolite indicates assimilation and fractional crystallization (AFC) of ascending basaltic magma in unattenuated continental crust. The basalt and basaltic trachyandesite show high contents of Ni, Co, Cr (incompatible elements) indicating olivine fractionation and low U, Th, K, and Nb as well as less P indicative of thin or attenuated crust crustal. This explains why the basalt have characteristics of Ocean Island Alkali (OIA) and the basaltic trachyandesite that of an Ocean Arc Tholeiites (OIT). The basaltic trachyandesites have low values of Nb Ce, Zr and Sm characteristic of subduction zones and also plot as orogenic basalt. The basalt on the other hand plot as a continental basalt The tepriphonolites and nepheline syenites (A9 and A11) trace elements pattern similar to basalts but low values of Ni, Co and Cr and peraluminious indicating crustal assimilation and anatexis of sedimentary rocks. The general similar patterns of the intrusive and extrusive rocks in the Gbok area indicate evolution from a single source basaltic magma within a sub continental area. It is difficult to assign time ranges to the magmatic rocks in the area on the basis of geochemistry but interpretation of chemical changes resulting from crustal influence, crustal thining and AFC on the basaltic magmas could aid in discriminating pre attenuated crust magmatic rocks, attenuated crust with or without sedimentary rocks and those with orogenic characteristics. Rhyolites, trachydacites and basalts are naturally associated in tholeiitic or andesitic provinces. In the Gboko area the basaltic or andesitic magmas evolved to tracydacites, trachyandesites and rhyolites characteristic of continental arcs and at the same time into tepriphonolites and phonolites characteristic of oceanic arcs. The tectonic influence especially the tectonic setting in the Gboko area and indeed the Benue trough is generally regarded as major player on magmatic processes (differentiation and sialic material contamination) responsible for the generation of rock products characteristic of continental and oceanic settings.

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