GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL, 10, NO.1, 2012 47-58
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PETROLOGY AND RARE EARTH ELEMENTS (REE) DISTRIBUTION PATTERNS OF MAGMATIC ROCKS IN GBOKO AREA, LOWER BENUE TROUGH NIGERIA: IMPLICATION FOR TECTONIC EVOLUTION

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Received 18 March 2010; Revision Accepted 8 March 2011)

ABSTRACT

Volcanic rocks can be subdivided according to tectonic setting into oceanic, sub-oceanic, sub-continental and continental. The relationship between the magma chemistry and the tectonic settings determines the end products (rocks) by magmatic fractionation and/or progressive crustal contamination.

Attempts to explain the magmatic and tectonic evolution of the Gboko area is considered in terms of the magmatic end products and the REE distribution patterns. Volcanic and intermediate rocks such as basalts, trachyandesites, trachytes, dacites, rhyolites, nepheline syenites and quartz diorites occur within the area intermittently.

The distribution of the chondrite normalized values is used to determine the effect due to magmatic fractionation and the crustal contamination.

The REE distribution shows relative enrichment of the LREE compared to the chondrites and the HREE except for one of the rhyolites.

The distribution patterns show similar trend for basalts, trachyandesites, dacites and quartz diorites. The trends show slight Ce, Pr, Sm, Dy and Tm negative anomalies. In the quartz diorites there is comparatively more depletion of the LREE and a significant negative anomaly of Tm. Closely similar to the trends of basalts are those of trachyte and nepheline syenite. The trachtyes and nepheline syenites have similar negative Sm, Eu, Tb, Dy, and Tm anomalies and slight positive Gd and Er anomalies as well as higher relative depletion of HREE. The rhyolites display similar trends with significant negative Eu anomaly, except in one of the rhyolite where there is relative enrichment of the HREE and a significant negative Ce anomaly.

The trends of the basalts are comparable to theoleiitic basalts and their similarity with the other rocks indicates the same source magma. In theoleiitic provinces, basalts coexist with trachyandesites and rhyolites as residual products of differentiation of basic magmas as confirmed by the similar trends. The significant Ce and Eu negative anomalies in the rhyolites and quartz diorites indicate that mineral fractionation and crustal contamination has played a part.

KEYWORDS: Benue Trough, Magmatism, Rare earth elements (REE), Petrology, Tectonic Evolution

INTRODUCTION

The sedimentary Benue Trough, is subdivided into three sectors (Zaborski, 1998). The subdivisions consist of the Lower Benue Trough equivalent to the “Abakaliki Trough” of Murat (1972) and Whiteman (1982), and include the area south of a line through Makurdi and Gboko; the Middle Benue Trough is part of the “Benue Trough” of Murat (1972) and part of the “Lower Benue Trough” of Whiteman (1982). It lies between a line through Bashar and Mutum Biyu and the Makurdi/Gboko line and the Upper Benue Trough is the northern part of the “Benue Trough” of Murat’s (1972) and part of the “Upper Benue Trough” of Whiteman (1982). The subdivision places the Gboko area (Gboko Sheet 271) in the Lower Benue Trough with a portion transcending the Makurdi/Gboko line (Fig. 1).

Regional tectonics during the Cretaceous was responsible for the separation of the African and South American plates and the formation of the intracratonic Benue Trough. The Benue Trough developed along lines of lithospheric weakness (Maurin and Guiraud, 1983) under the influence of a mantle plume (St. Helena hot spot) around the present Niger Delta Trough. The event resulted into rifting, stretching and subsidence along the Benue Trough and other African crustal blocks.

Magmatic activity in the Lower Benue Trough is considered to have taken place in three phases; 1) the first phase is recognized to occur from Late Jurassic to Early Cretaceous 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 the updoming areas along a N – S trend on the Afro-Brazilian plate. In the Benue Trough the Gboko Hills, mount Ikyuen and the dyke-like swarms of rhyolites dated 113 ± 3 My are the oldest traces of magmatism in the Lower Benue Trough. The Wanakande syenite dated 104 ± 4 My also belong to this phase. 2) The Second phase of magmatism in the Lower Benue Trough spanned from Mid-Albian to Early Santonian. According to Wright, (1989) the magmatism during this period consisted of abundant intrusives and

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minor occurrences of tuffs and lavas interbedded with the Albian sediments. The intrusives appear to be abundant in Albian sediments and less common in Turonian and absent in the Post Turonian. Reyment and Tait (1983), however indicated that minor volcanic activity took place flrom Mid-Albian to Cenomanian and Late Cenomanian to Middle Turonian. Farrington, (1952); Cratchley and Jones (1965) and Nwachukwu (1972) associated the volcanic activity with the Cenomanian folding phase; 3) The third phase of volcanism in the Benue Trough is recognized to be of Santonian age with undersaturated rocks with alkaline characteristics in the Abakaliki area dated 81 – 83My Wright, (1989). Burke et al., (1970); Burke et al., (1971); Güthert and Richard (1960); Murat, (1972); Freeth (1979); Benkhelil (1987; 1989) have documented magmatic rocks in the Abakaliki area which they associated with the Santonian folding phase, though the exact nature of some rocks is disputed. Oyawoye, (1972); Adijhije, (1979; 1981) ;Ajayi and Ajakaiye, (1981) Ofoegbu, (1986; 1988); Ojoh, (1990) reported the presence of intrusives and flows around Isiagu, Abakaliki, Lefin, the Egedde Hills, Agilla areas and within Ngbo Formation belonging to this phase (Fig.2). Cratchley and Jones (1965) speculated that sizeable bodies could be present in southwest (SW) of Gboko. The magmatic rocks southwest of Gboko and their implication to the tectonic evolution of the area and the Lower Benue Trough in general is the subject of this paper.

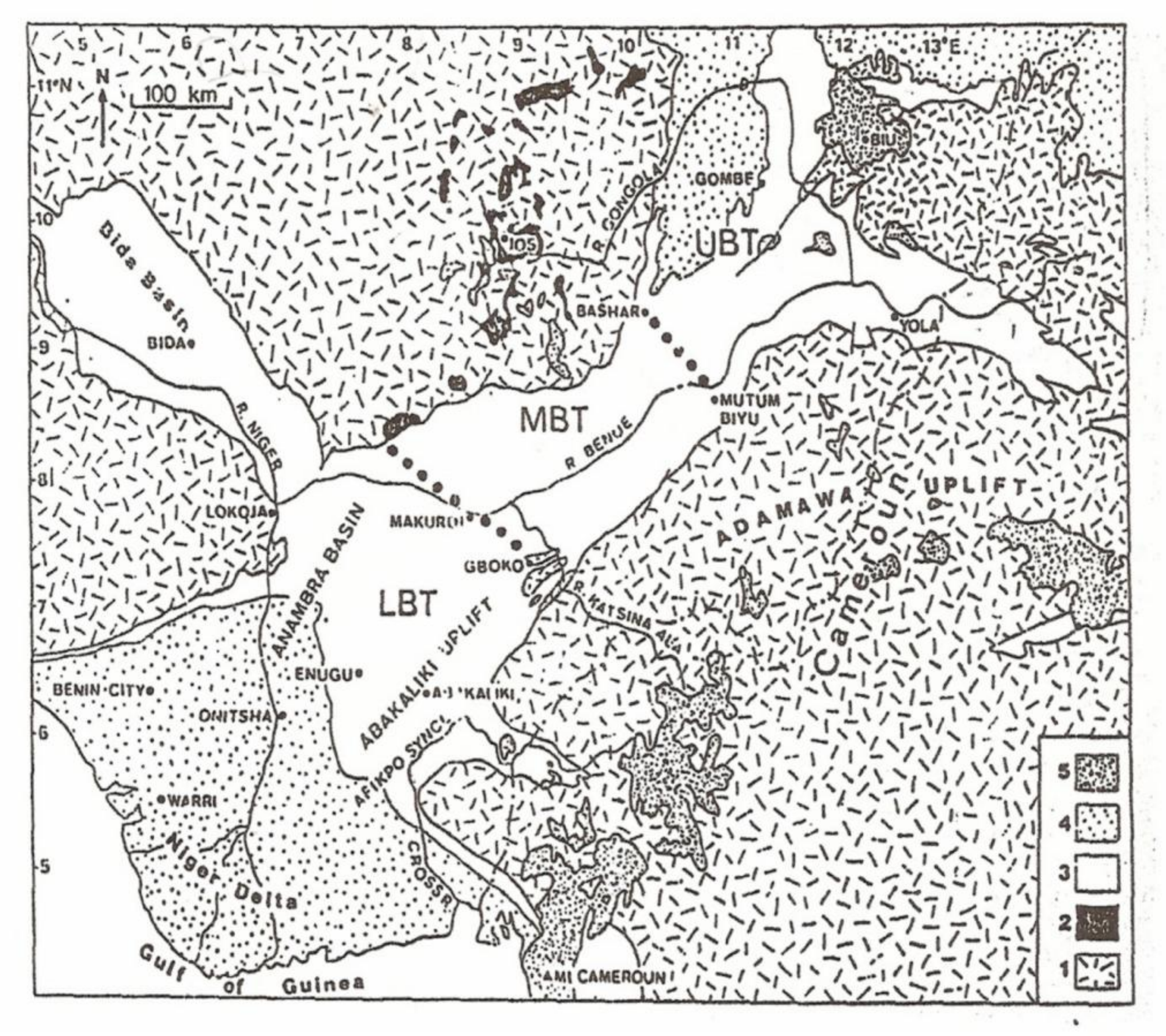


Fig 1: Outline geological map of the Benue Trough and adjacent areas (after Zaborski, 1998). LBT, Lower Benue Trough; MBT. Middle Benue Trough; UBT Upper Benue Trough. 1. Precambrian. 2. Jurassic “Younger Granites”. 3. Cretaceous. 4. Post-Cretaceous sediments. 5. Cenozoic Recent basalts including those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

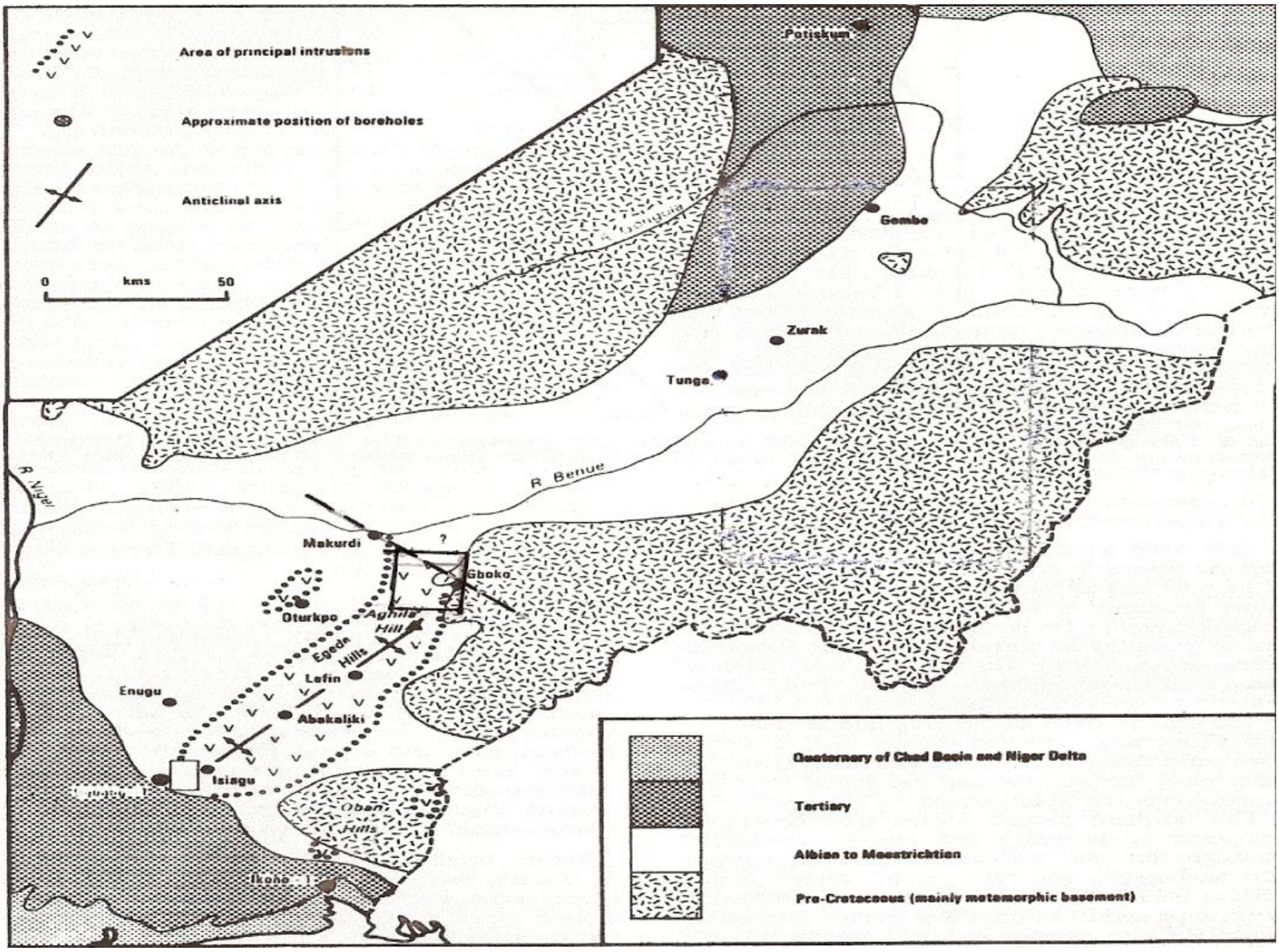


Fig.2. Benue Trough showing areas of Cretaceous magmatic rocks. After Cratchley and Jones (1965); Burke et al,. (1971); Nwachukwu (1972); GSN maps of sheet 64,79 and 80.
The rectangle is area of study Sheet (271) Line represent the Makurdi-Gboko line.

METHOD OF STUDY

General geological mapping of the Gboko Sheet (271) was undertaken on a scale of 1:50,000. A geological map on the scale of 1:100,000 was produced and digitized. The different volcanic rocks and minor intrusive rocks were sampled and the structural relationship between them was documented. The magmatic rocks were sampled and thin sections of the samples were studied under the petrological microscope Leitz Orthodox II Pol P.K at the Department of Geology, Ahmadu Bello University. The samples were also pulverized using a Tungsten carbide spex mill at the Department of Geology, Ahmadu Bello University. Geochemical analysis of the rocks using Parkin Elmer ELAN, DRC plus ICP-MS with fusion decomposition for the lanthanides was done at McGill University Canada.

DISTRIBUTION

Topographically high and low-lying magmatic rocks southwest of Gboko (Sheet 271) (Fig.3) include dyke –like rhyolites protruding into the basement rocks northwest of Gboko Town and form the Tam and Nor-Anakor Hills to the southwest. The basalts form the Agudu, Silagi and Anwogbor Hills and occur intrastratified with Albian to Cenomanian sediments. The trachyandesites form the Ikwe Hills. The dacites occur around Gbemacha area while the trachytes form the Uazande and Uviambe Hills. The Abata Hill is formed of nepheline syenite while the Agira Hill which is closely associated with NE – SW trending dykes are formed of diorites. NE – SW trending gabbro dykes are also common in the area.

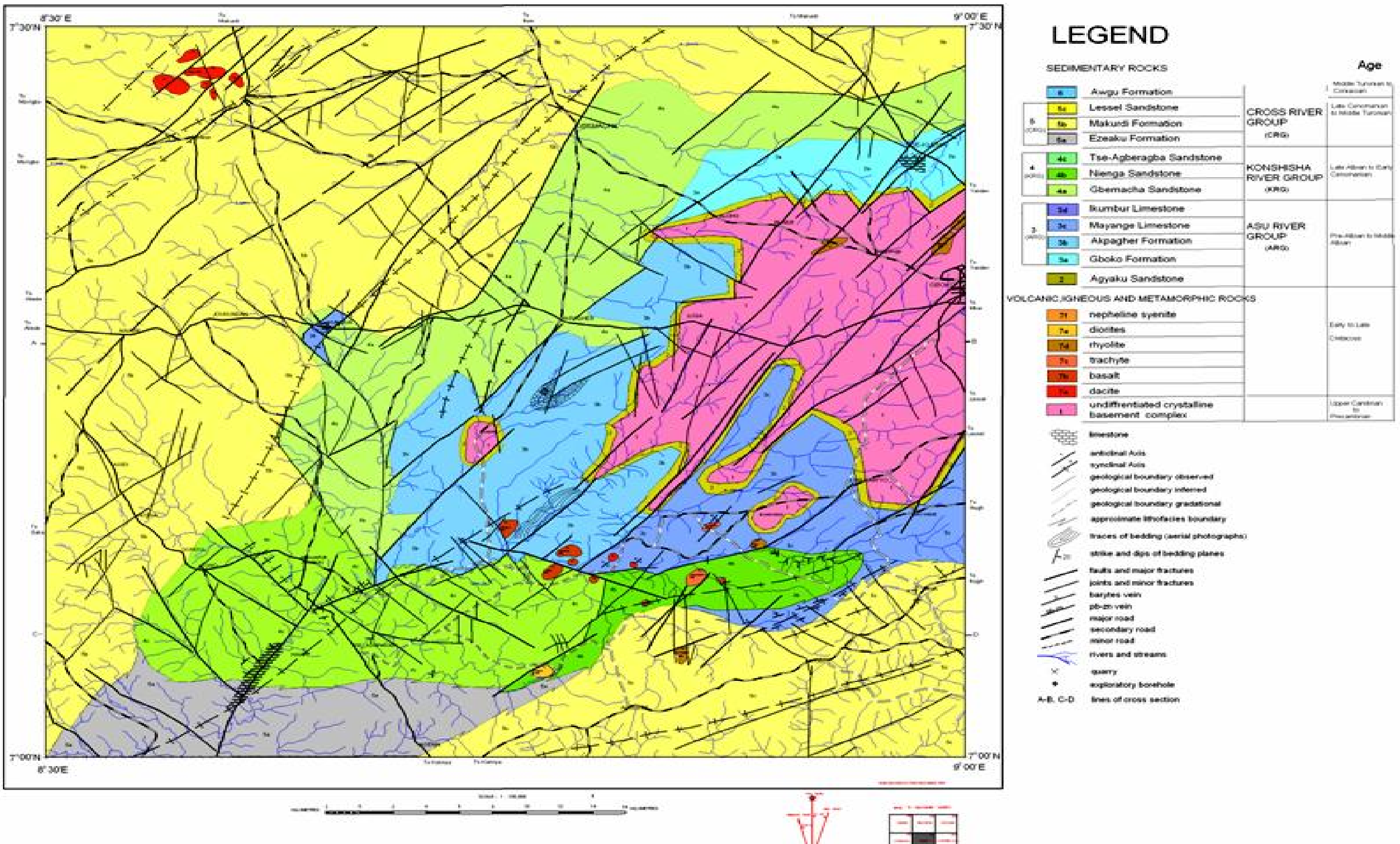


Fig. 3 Geological map of the Gboko area (Sheet 271)

PETROLOGY

RHYOLITES

The rhyolites are fine-grained, massive and pinkish in colour. They contain large euhedral to subhedral crystals of sanidine with high degree of alteration to clay minerals in some crystals. Minor amounts of quartz and mafic minerals are present. The mafic minerals altered to iron oxides form myrmekitic textures or graphic intergrowths with quartz. Veins of feldspars with or without quartz rims are common. The relationship suggests alteration of alkali feldspars and the release of quartz. Magnetite is present as an accessory mineral. The rhyolites forming the Nor-Anakor Hill contain clots and bands of hematite within the matrix giving the rock a flow or banding texture. Minor amounts of aegirine-augite are present.

TRACHYANDESITES

The trachyandesites contains about 70% of prismatic to rectangular crystals of andesine with aligned and radiating textures. A few grains of orthoclase with mymerkitic textures are also present. About 15% of the rock by volume is made-up of prismatic to non-prismatic crystals of aegerine and aegerine-augite. The pyroxenes are grown within the feldspars and are randomly distributed in the interstices of the irregular shaped crystal of ilmenite and the interlocking feldspars. The ilmenite and accessory prismatic crystals of olivine and hornblende make up the remaining 15% of the rock by volume.

BASALTS AND LAVAS

The basalts contain about 35 – 60% of augite scattered in the rock as short to long prismatic crystals or as basal sections. In some of the rocks, aegirine in form of laths or basal sections are present. In-between the pyroxenes, sanidine and volcanic glass form the matrix of about 20 – 24% of the rock by volume. In others, hornblende forms a large proportion of the rock (5 – 20%) as large to medium prismatic crystals. Some of the hornblende crystals have grown at the expense of the pyroxenes. Magnetite, ilmente and hematite as alteration products of hornblende are scattered within the pyroxenes and feldspars. Olivine and sphene occur in accessory amounts. The basalt have tholeiitic affinities in terms of classification.

The basaltic lavas consist of a cryptocrystalline matrix of augite, hematite and feldspar crystals with a few scattered prismatic crystals of augite and hornblende. The pyroxene forms about 40% of the rocks with some of the crystals outgrown by hornblende. The hematite occurs as crystals, intergrowths and/or corona around the hornblende indicating corrosion of the hornblende and formation of hematite and secondary minerals.. Hornblende forms about 40% of the rock while hematite and feldspars have a total content of about 15%.

DACITES

The rock contains about 60% by volume of large prismatic crystals of aegirine-augite and a few crystals of augite evenly distributed in the rocks. Some of aegirine-augite crystals have altered to secondary minerals while others have hornblende formed at their expense. Large and prismatic crystals of sanidine, plagioclase and volcanic glass showing spherulitic textures, altogether make up about 20% of the rock by volume. Prismatic crystals of hornblende, with some partly altered to magnetite make up the remaining 10% of the rock by volume.

TRACHYTES

The trachytes are made of about 55% spicules of sanidine interlocked with spicules of aegirine-augite and augite in sub-parallel alignment in preferred directions giving rise to trachytic texture. The pyroxenes make up about 40% of the rock by volume. Phenocrysts of orthoclase and sanidine are scattered in the rock and in the groundmass feldspars and pyroxenes make up 5% of the rock by volume.

NEPHELINE SYENITE

The rock consists of large phenocrysts of nepheline and a few crystals of augite scattered in a groundmass of augite, nepheline, volcanic glass and altered minerals.

QUARTZ-DIORITES

The rock has a close resemblance to granite and consists of medium-sized crystals of ferroaugite interlocked with laths of plagioclase feldspar. The andesine display albite and carlsbad twinning and the plagioclases are variously altered to secondary minerals. The pyroxenes have inclusions of magnetite and a few crystals of aegirine show alteration to augite. A few crystals of quartz occur as accessory minerals.

GABBROS

The gabbros contain large to medium prismatic crystals of augite, aegirine-augite, sanidine and magnetite in various proportions which grade to the matrix. In the olivine gabbros a few cryptophenocryst of olivine are scattered in the matrix while in the hornblende gabbros, some of the hornblende crystals scattered in the matrix form at the expense of the pyroxenes. Some of the hornblende crystals have altered to hematite.

REE DISTRIBUTION AND PATTERNS

The values of lanthanides or rare earth elements (REE) for the volcanic and minor intrusive bodies showing absolute contents of the lanthanides are presented in Table 1. The plots of chondrite normalized values for the different rocks showing distribution patterns are presented in Figure 4.

The analysis of the different distribution patterns are outlined below and presented in Figures 5 – 10.

1 The REE distribution pattern of all the magmatic rocks analyzed, show that the LREE are enriched relative to the HREE. The LREE are also enriched relative to the chondrite values (Nakamura, 1974) except for one of the rhyolite (Fig. 4).

2. Plots of chondrite normalized values of rhyolites show significant Eu anomalies with relative enrichment of LREE. In one of them there is in addition a negative Ce anomaly also, with enrichment of the LREE and HREE. The pattern of the former is similar to trends of basalts in the area while the trend of the latter is similar to the trends of igneous rocks of the upper crust but with higher depletion of HREE. (Fig. 5)

3. The patterns of basalts are similar to the continental tholeiitic basalts (Herrmann, 1968). The trends show relative enrichment of LREE and depletion of HREE compared to oceanic tholeiitic basalts. The slight Ce, Sm and Dy negative anomalies are characteristic of basalts (Fig. 6).

4. The dacites, trachyandesites, diorites and gabbros show similar trends to the basalts and similar slight Ce, Pr, Sm and Dy negative anomalies. This shows that the trends of gabbros, dacites, trachyandesites and diorites are similar to those of basalts. The dacites show a relatively higher depletion of the LREE compared to the other rocks and the trachytes show a prominent Sm, Eu and Tm negative anomalies with a positive Er anomaly (Fig. 7)

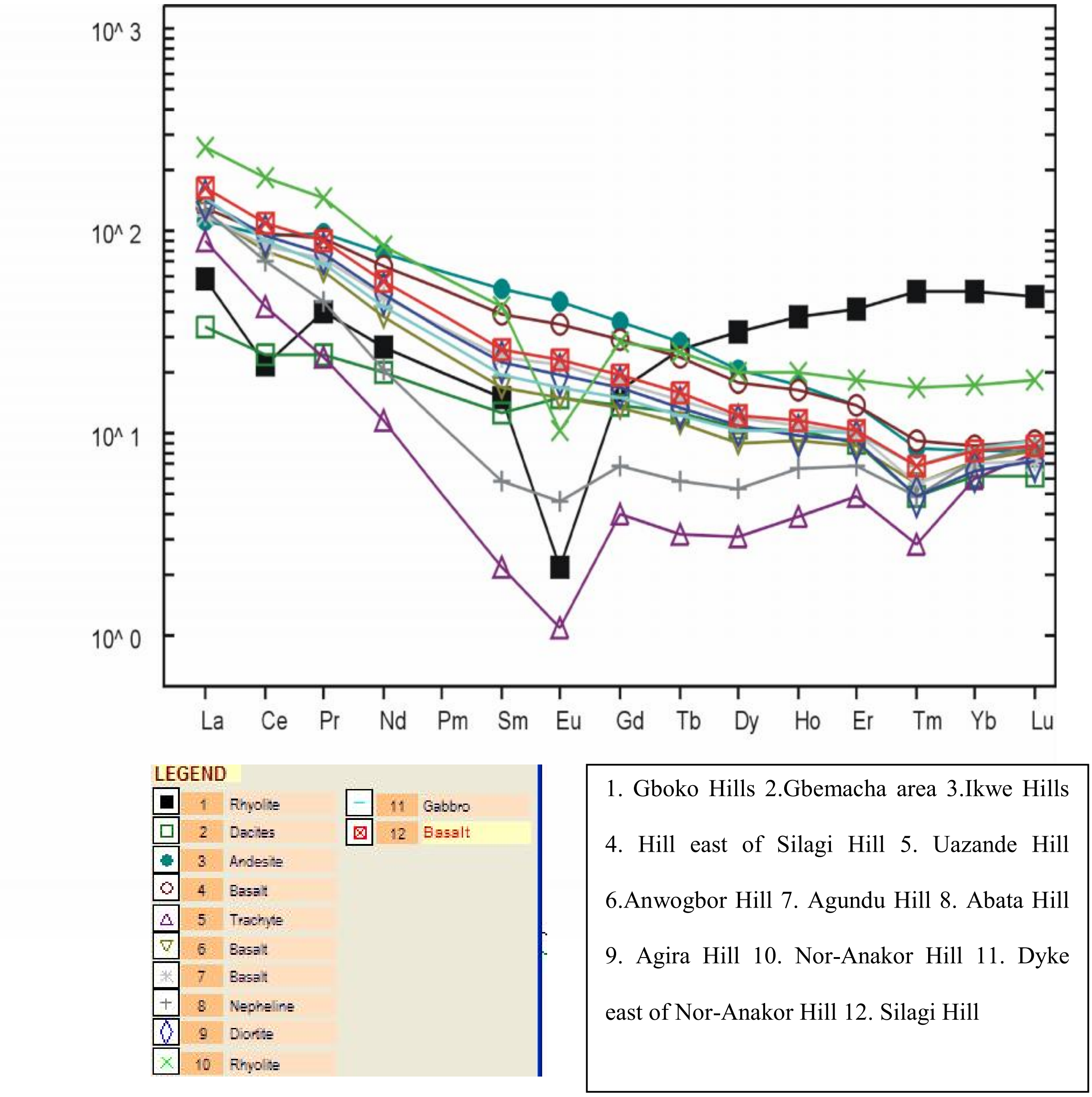
5. The distribution pattern of trachyte shows a different trend from gabbro, dacites, trachyandesites and diorites and, it displays a prominent Sm, Eu, Tm negative anomalies (Fig. 8).

6. The plots of the nepheline syenite, diorite and gabbros represent trends of intrusive rocks. The trends have similar negative anomalies of Sm, Eu, Tb, Dy and Ti. The Sm and Eu anomalies in the nepheline syenite is more prominent (Fig. 9)

7. The trends of nepheline syenite and trachytes are similar to the trends obtained for trachtyes and nepheline leucite for the Eifel area of Germany (Fig. 10) (Herrmann, 1968).

Table 1: Result of analyses of the magmatic rocks in the study area showing contents of REE

	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
A-1 RHYOLITE	18.91	18.66	4.436	16.58	3.020	0.167	4.498	1.229	10.808	2.624	9.226	1.520	11.100	1.624
A-2 DACITES	11.00	21.31	2.729	12.41	2.582	1.155	3.736	0.588	3.652	0.714	2.015	0.147	1.343	0.210
A-3 TRACHY-ANDESITE	37.10	81.36	10.834	48.67	10.329	3.394	9.802	1.328	7.061	1.223	3.077	0.253	1.792	0.274
A-4 BASALT	43.12	84.69	10.294	42.37	7.950	2.657	8.076	1.109	6.067	1.130	3.055	0.272	1.925	0.314
A-5TRACHYTE	29.27	36.06	2.682	7.31	0.440	0.084	1.089	0.147	1.068	0.272	1.110	0.084	1.320	0.272
A-6 BASALT	40.78	69.31	7.047	23.44	3.418	1.160	3.692	0.527	3.101	0.633	1.962	0.169	1.625	0.274
A-7 BASALT	39.29	73.23	8.150	30.00	4.857	1.688	4.940	0.688	4.044	0.771	2.251	0.167	1.563	0.250
A-8 NEPHELINE SYENITE	42.07	60.57	5.007	13.04	1.183	0.359	1.902	0.275	1.796	0.465	1.563	0.148	1.606	0.296
A-9 DIORITE	47.17	82.21	8.635	30.36	4.493	1.491	4.597	0.621	3.686	0.683	2.050	0.145	1.449	0.248
A-10 RHYOLITE	84.72	159.52	16.162	52.61	8.562	0.796	7.704	1.193	6.888	1.382	4.103	0.502	3.831	0.628
A-11 GABBRO	48.50	76.04	7.672	26.65	3.961	1.306	4.147	0.581	3.546	0.726	2.281	0.207	1.866	0.311
A-12BASALT	53.15	93.43	9.930	35.19	5.300	1.760	5.342	0.754	4.253	0.817	2.346	0.209	1.781	0.293



1. Gboko Hills 2.Gbemacha area 3.Ikwe Hills 4. Hill east of Silagi Hill 5. Uazande Hill 6.Anwogbor Hill 7. Agundu Hill 8. Abata Hill 9. Agira Hill 10. Nor-Anakor Hill 11. Dyke east of Nor-Anakor Hill 12. Silagi Hill

Fig. 4: REE distribution patterns of some magmatic rocks in the Gboko area.

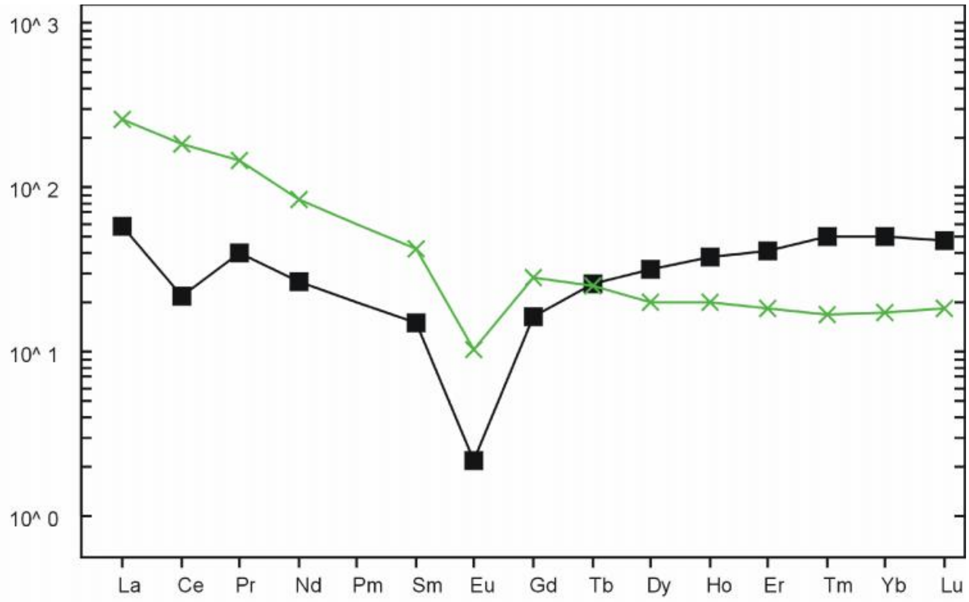


Fig. 5: Distribution pattern of rhyolites in the Gboko area

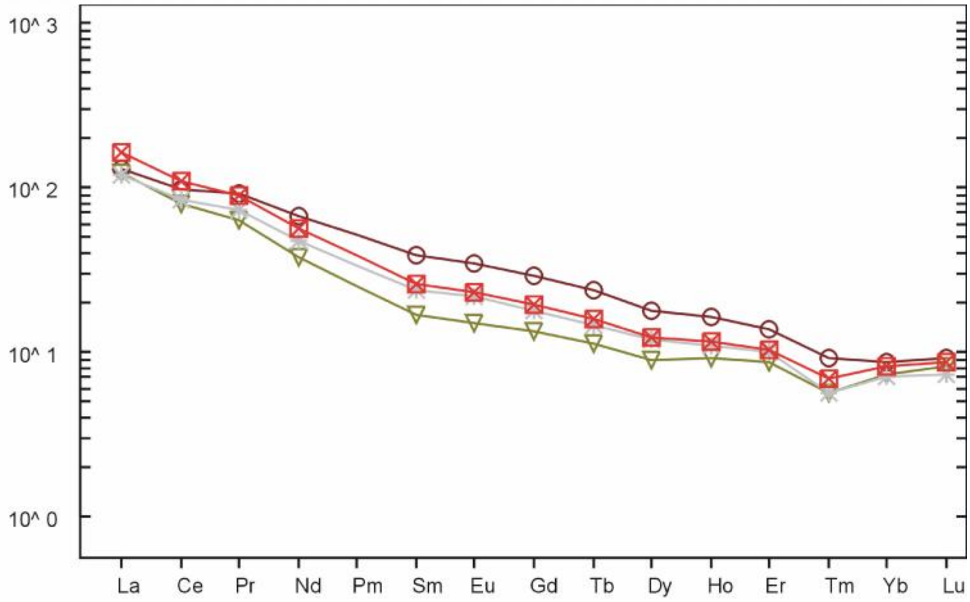


Fig. 6: The patterns of basalts showing similarity to the continental tholeiitic basalts (Herrmann, 1968).

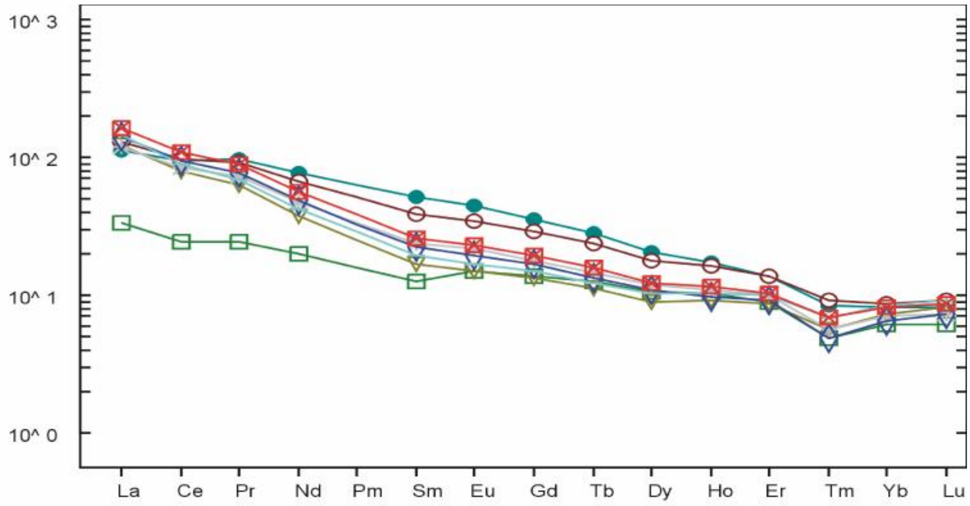


Fig 7: The distribution patterns of dacites, trachyandesites, diorites and gabbro showing similar trends to the basalts.

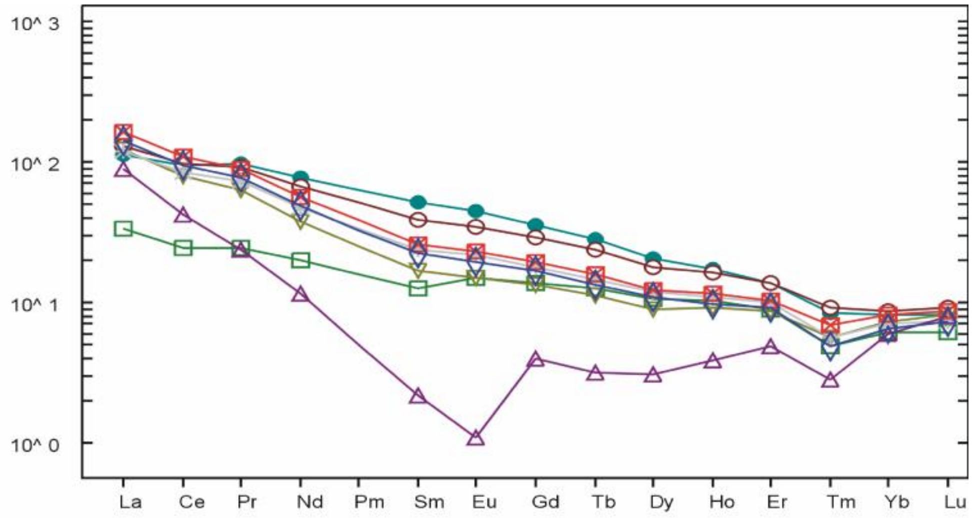


Fig. 8 The distribution pattern of trachyte showing a different trend from gabbro, dacites, trachyandesites, and diorites.

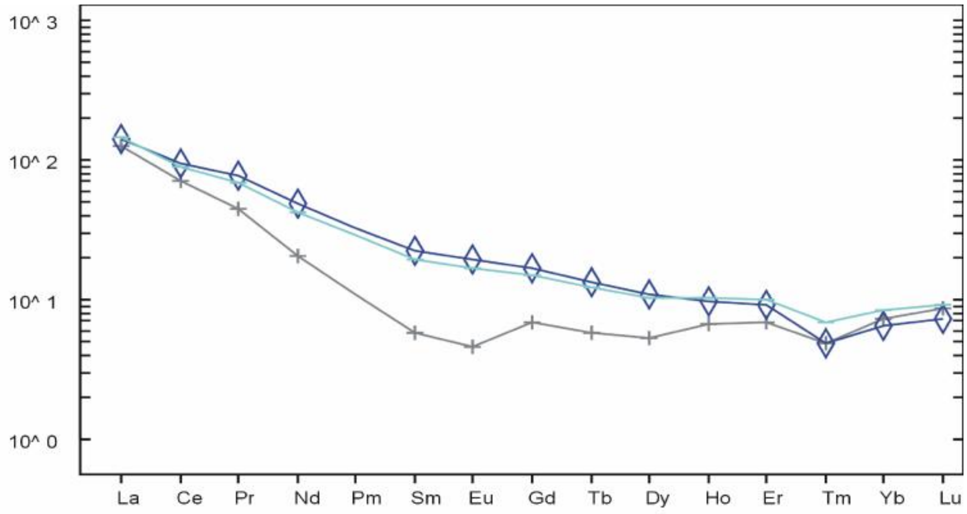


Fig 9: The distribution patterns of nepheline syenite, diorite and gabbro(Intrusive rocks).

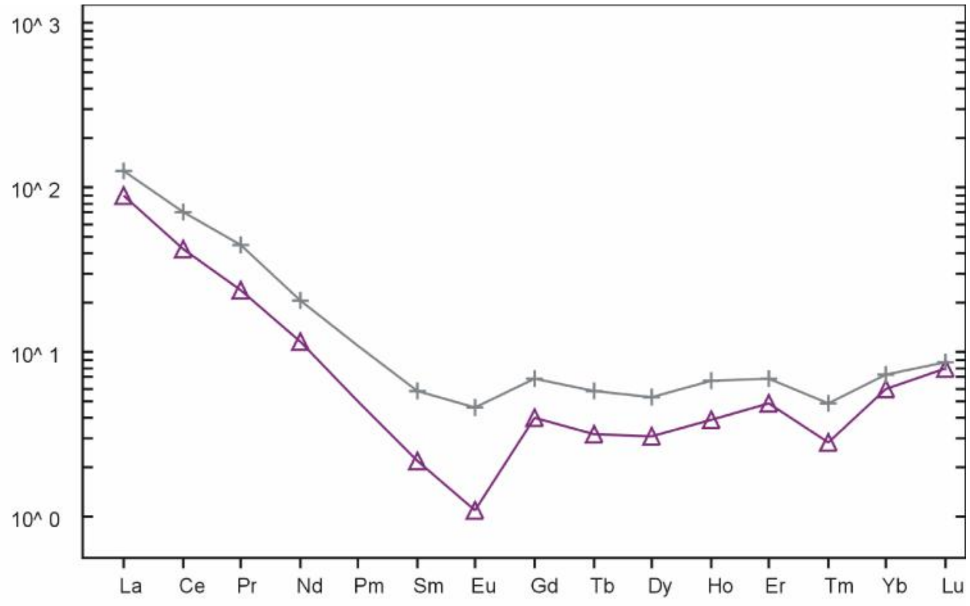


Fig. 10: The distribution patterns of nepheline syenite and trachytes.

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. These developments culminated in the separation of Africa and South America and its effects on the African plate was the development of a closely linked rift system in West and Central Africa (Fairhead, 1988; 1988b; Fairhead and Green, 1989; Fairhead and Binks, 1991; Binks and Fairhead, 1992; Genik, 1993). The rifts are collectively termed the West and Central Africa Rift System (WCAR) or the Mid – African Rift System (MARS) (Popoff, 1988).

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. Syn-rift magmatism was contemporaneous with rifting and sedimentation up to Cenomanian. This magmatic phase is coincident with the first rifting phase for the evolution of the Lower Benue Trough of Murat, (1972) and the third tectonic phase of Genik, (1993) for the evolution of the WCARS.

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 relative 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). Similarly the relationship between the magmatic rocks and axial faults are well preserved.

The petrology of rocks in the study area consists of rocks of the tholeiitic and alkaline series. The series indicate magmatism of a mid-place type (Olade, 1979) from a primary magma that was formed by partial or complete melting of silicate materials in the Upper mantle. According to Wilson (1992) the St. Helena plume did not generate large quantities of magma, and may have become cooled by entrainment of upper mantle material before its impact at the base of the plate. Rhyolites, dacites and basalts are naturally associated in tholeiitic or andesitic provinces. Dacites and trachyandesites are generally products of basaltic or andesitic magmas, while rhyolites are products of differentiation and sialic material contamination. The nepheline syenites indicate local contamination by soda-carbonate rich deuteric/hydrothermal fluids (Gunthert and Richards, 1960) or carbonate rocks. The occurrences of diorites within the area indicate differentiation and contamination of basic magmas. The gabbroic dykes represent the basaltic magmas that solidified within crustal rocks.

Petrographic evidence based on (Freeth, 1978, 1979b), Okezie (1965), Burke *et al,* (1971) had documented the presence of andesites in the Lower Benue Trough as a proof for sea floor spreading and subduction. This was vehemently opposed (Olade, 1975, 1976, Wright 1989). Previous records of andesitic rocks in Archean terrains indicate association of basalts, andesites, dacite and rhyolite or basalts. Andesites and dacites cycles in the Bulawayo Group and in Proterozoic basins with flat and gentle dipping strata, affected by mild warping during faulting and dyke invasion gave rise to continental tholeiitic basalts together with andesites, rhyolites and pyroclastics without the modern type sub-duction (Anhaeusser 1973). The evidence of a thin continental crust (Artsybashev and Kogbe, 1974; Adighije 1979) with faulted blocks subsiding (Fig. 11) into the upheaving mantle in the Lower Benue Trough may have allowed evolution of tholeiitic and andesitic rocks. This may explain the presence of trachyandesites, basalts dacites and rhyolites association in the Gboko area.

The REE patterns for all rocks in the Gboko area are characteristically skewed to the right. The patterns are similar to the patterns of basalts except for one of the rhyolites. The trends are generally similar to REE patterns for modern island arc oceanic tholeiites and Archean greenstone belts volcanics though the latter are characteristically flatter (Schilling 1971; White *et al.,* 1971; Jakes and White 1972; Jahn *et al.,* 1974).

The REE patterns for the rock shows relative enrichment of the LREE indicative of higher fractionation in which sialic material played a part. The negative Eu anomaly in the rhyolites, trachytes and nepheline syenite indicate mineral fractionation and crystal contamination within the basement rocks and/or sediment.

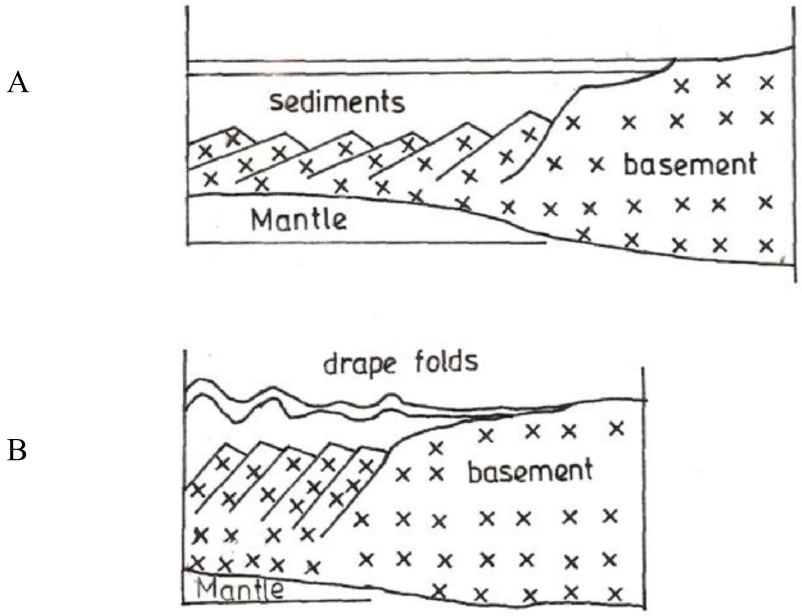


Fig. 11 A) Mantle up-heaving crustal stretching and block subsidence in early Cretaceous, B) Fault reactivation, reversal and compression in the Santonian. (modified from Wright, 1989)

CONCLUSIONS

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.

a) 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.

b) 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.

c). The REE distribution shows that the pre-rift rhyolite dyke-like bodies have patterns similar to crustal rocks. This clearly distinguishes it from the rhyolitic rocks emplaced within the sediments whose pattern is similar to the patterns of basalts.

d). The patterns of the latter rhyolites, basalts, trachyandesites, dacites, trachytes nepheline syenite, diorites and gabbro all show right-handed skewness. The trends indicate enrichment of LREE and relative depletion of HREE when compared to the flat trends for oceanic tholeiitic basalts. This indicates greater fractionation and contamination with crustal materials. Their similar patterns indicate evolution from a single source basaltic magma within a sub continental area.

e) The trachytes and nepheline syenites patterns show significant Sm and Eu negative anomaly and similar Tm anomaly with diorites. These anomalies are themselves indicative of the extent of crustal contamination of the magma made possible for their formation,

f) Discrimination between the Albian to Cenomanin magmatic rocks and Santonian types are quite subtle, for example magmatic rocks intra-stratified and intrusive into Albian to Cenomanian sediments indicate ages of host rocks while those intrusive or extrusive into Albian to Coniacian sediments and often with metamorphic aureoles in the surrounding sediments relate to the Santonian age.

ACKNOWLEDGEMENTS

The authors are grateful to Prof I. Garba and Prof. P.M. Zaborski for their contributions. We are also grateful to Prof R. F. Martins for the arrangements to analyze the samples at McGill University in Canada. We are also grateful to Christian Okedeh for his assistance during field work and Godwin Amedu for typing the manuscript. The work is supported by the Ahmadu Bello University Research Grant and the AAPG Grain-in-Aid.

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