Research Journal of Environmental and Earth Sciences 3(2): 95-102, 2011
ISSN: 2041-0492

Received: October 27, 2010 Accepted: December 02, 2010 Published: March 05, 2011

Geochemical and Mineralogical Composition of Bima Sandstone Deposit, Yola Area, NE Nigeria

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Abstract: The aim of this study is to determine the geochemical and mineralogical composition of Bima Sandstone deposite of northeastern Nigeria. A total number of sixteen (16) sandstone samples were collected in Yola area inorder to classify the deposit of the Bima Sandstone exposed in this area on the basis of its chemical and mineralogical make-up. All the samples were selected randomly and subjected to both geochemical and petrographic studies. Relative concentration of the major oxide groups such as silica and alumina alkali oxides, iron oxide and magnesia has been used to classify the deposit. The results of the log of ratio of the major oxide groups indicate that Bima Sandstone of the study area can be classified as greywackes, arkoses and lithic arenites including sub-greywackes and protoquartzites. The abundant alkali values as shown by the relatively high log K_2O/Na_2O ratio in most of the samples indicated immature sandstones whereas low alkali values in samples F, H and M revealed mature sandstones. The enrichment of silica (quartz) over Al_2O_3 (log SiO_2/Al_2O_3<1.5) indicate that Bima Sandstone has undergone long period of transportation and have been subjected to intense weathering resulting in the destruction of other minerals especially plagioclase and potassium feldspars during transportation. Microscopic examination of about sixteen slides (16) of Bima Sandstone under both plane and cross polars revealed the following average mineralogical composition: quartz (65%) feldspars (14%), mica (9%), iron oxide (5%), calcite (3%) further confirms quartz/lithic arenites and greywackes as some of the predominant sedimentary rocks in the study area.

Keywords: Bima Sandstone, geochemical, Nigeria, Northeast, petrographic, Yola area

INTRODUCTION

Sedimentary rocks are classified generally based on texture, cement and groups. These groups can be subdivided into three such as detrital/clastic, biogenic and chemical sediments. These sediments belong to the clastic group, which could be clean having silica cement, matrix rich-greywacke and the arkosic type.

The Upper Benue is an extensive sedimentary basin, with an areal extent of about 203,000 km^2 and occupies the upper reaches of the Benue valley. Its main drainage network comprises numerous streams and rivers flowing into the River Benue from the north and south. The major system includes the Gongola, Kilunga and Pai to the north and the Faro and Taraba from the south of the River Benue. The ground slopes from the west, northeast and eastern areas into the centre of the valley, but regionally sloping towards the southwest, the direction of flow of the River Benue.

It is a pull-apart basin which was initiated during the early Cretaceous separation of African and the South American lithospheric plates (Wright, 1968; Burke and Dewey, 1973; Olade, 1975; Freeth, 1979; Fitton, 1980; Benkhelil, 1982a) They further attributed the origin of the Benue Basin to the Y-shaped triple junction rift model (RRR) which is believed to be responsible for the break-up of the Afro-Brazilian Plate.

The Benue Basin was subjected to several folding episodes notably in the Cenomanian, Santonian, Post Maastrichtian and possibly Paleocene. Geology and Stratigraphy of the Basin has been extensively discussed by various workers: (Carter *et al*., 1963; Offodile, 1976; Benkhelil, 1982b; Popoff *et al*., 1986, Ofoegbu, 1988; Abubakar *et al*., 2006).

The Upper Benue Basin is underlain by patches of the Basement Complex rocks, including a number of volcanic plugs, basaltic flows and sedimentary rocks of Cretaceous age. The geologic sequence comprises the Basement overlain by a thick sequence of shales of the Asu River Group, continental sandstone of the Bima Sandstones and shales, clays and limestones of various geological formations as indicated in Table 1. About nine (9) lithostratigraphic units have been identified and described by these workers as shown in Table 1.

The Bima Sandstone rocks in the Upper Benue Basin have been sub-divided from base to top into three sandstone members. These include the Lower Aptian/Albian Lower Bima (B1), the Middle Albian Bima Sandstone (B2) and the late Albian/Cenomanian Upper Bima Sandstone (B3) (Carter *et al*., 1963).

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Table 1: Stratigraphic succession in the Upper Benue Basin

S.No.		Lau basin	Gombe/Zambuk Ridge	Chad basin
1	Pleistocene			Chad Formation
2	Paleocene			Keri-keri Formation
3	Maastrichtian	Lamja Sandstone	Gombe Sandstone	
4	Campanian	Numanha Shales	Gulani Sandstone	
5	Santonian	Sekule Formation		
6	Upper Turonian	Jessu Formation		
7	Lower Turonian	Dukul Formation		
8		Yolde Formation	Yolde Formation	
9	Cenomanian	Bima Sandstone	Bima Sandstone	
10	Precambrian	BasementComplex	BasementComplex	BasementComplex

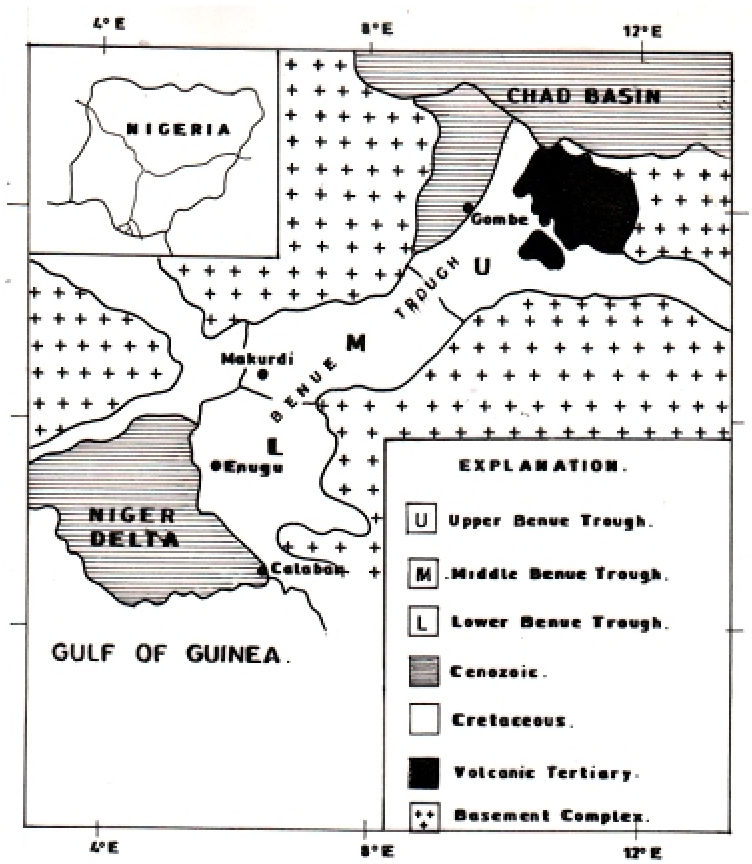

Fig 1a: Geographical location of the Benue Trough in nigeria (After Obaje *et al.* 1999)

The study area is underlain by the upper member of the Bima Sandstone (B3) which is a cretaceous sedimentary unit of the Yola Arm of the Upper Benue Trough. The Upper Bima Sandstone (B3) was marked by the deposition, during the cenomanian? Of fluvio-deltaic sandstones and arkoses, which commenced in the south and extended progressively northwards? Several episodes of transgressions and regressions (often linked with sedimentary disturbances) are registered in the Bima Sandstone. The surface geologic units of the study area are the fine-medium grained sandstone to the north and south and the coarse grained sandstone to the northeast (Obiefuna and Orazulike, 2010). The depth to the bedrock varies from 30 m to more than 45 m.

Stratigraphically, the Bima Sandstone consist of alternating layers of poorly to moderately consolidated fine to coarse grained sandstones, clay-shales, siltstone and mudstone with an average thickness of more than 250 m as seen from their outcrops in the field. This geologic formation which reaches several hundred meters in thickness is of significant hydrogeologic interest. From field observations, exposures of Bima Sandstone in the study area is light brown to reddish brown in colour, feldspathic and fine to coarse grained in texture. It is highly crystalline and cemented in places especially north of Jimeta and Yola around Girei area.

The present investigation was carried out in Yola area of Northeastern Nigeria which is underlain entirely by the

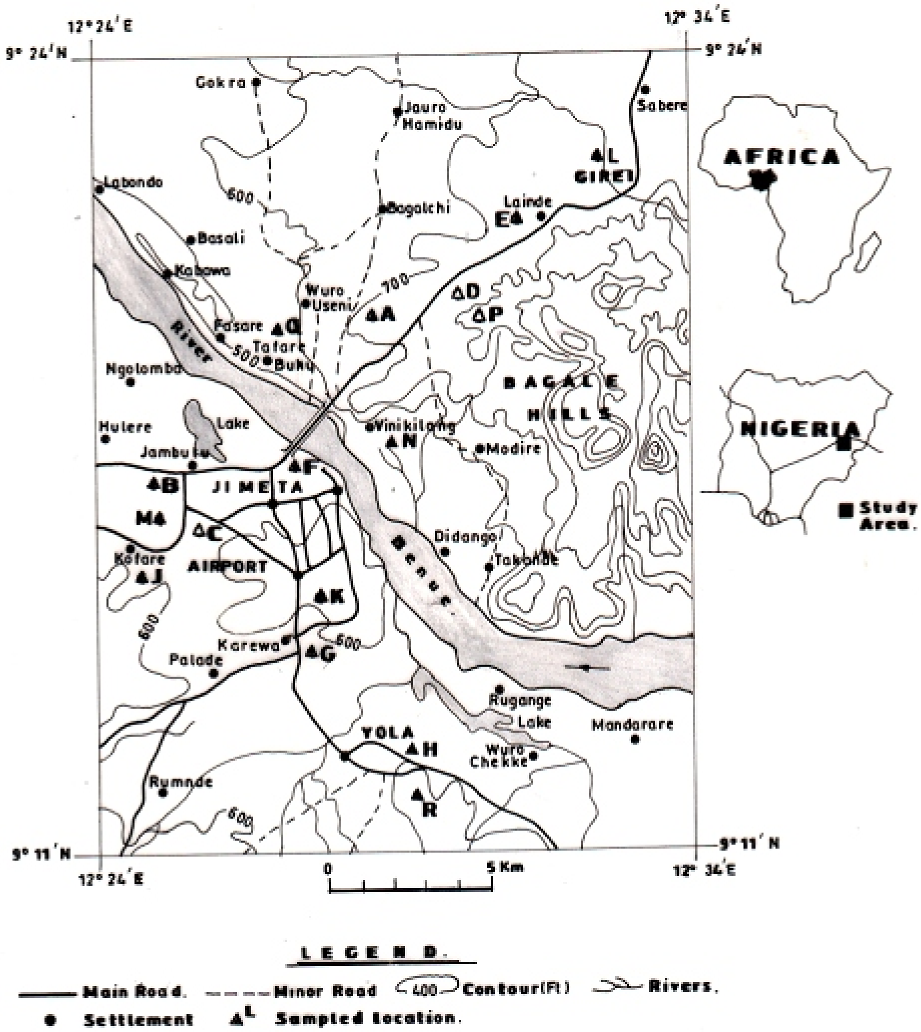

Fig 1b: Map of the study area showing access routes and sample locations

Bima Sandstone Formation. This study intends to classify the sandstone deposit of the Bima Formation (Oldest stratigraphic unit of the Upper Benue Basin) as exposed in this area on the basis of its chemical and mineralogical composition.

study area: The study area occur at an elevation varying from 152 to 455 m above mean sea level and falls within the Upper Benue Basin which acts as a catchment area of about 203,000 km^2. It is located within longitudes 12º 20′E and 12º34′E and latitudes 9º11'N and 9º24'N and lies about 50 km South of the Hawal Massifs. It is bounded to the east by the Republic of Cameroun and to the west by Ngurore town.

The northern boundary is demarcated by Gokra town and the southern boundary by the Mandarara town (Fig. 1a, b).

The main Access Routes are tarred roads such as Yola-Maiduguri Road to the North and Yola-Fufore Road to the South as well as Yola- Numan Road to the West. These road networks enhanced accessibility by linking the urban and rural areas as well as agricultural and upland area.

MATERIALS AND METHODS

A total number of sixteen sandstone samples were collected randomly at different locations from exposed Bima Sandstone deposits. They were first disaggregated cautiously to preserve the grain shapes and sizes and subsequently subjected to mineralogical and chemical analyses.

The mineralogical analyses was carried out petrographically with the prepared thin sections and

Table 2: Relevant elemental composition of Bima sandstone deposit in the study

S.No.	Location	Sample no.	SiO_2	Al_2O_3	MgO	CaO	Na_2O	K_2O	Fe_2O_3	SiO_3	P_2O_5	Mn_2O	TiO_2	LOI
1	Bajabure	A	92.68	4.65	0.010	0.290	0.040	0.64	0.58	0.030	0.010	0.040	0.230	1.75
2	Jambutu	B	92.42	5.65	0.010	0.010	0.060	1.22	0.37	0.030	0.010	0.040	0.360	1.16
3	Jimeta	C	88.78	7.25	0.010	0.200	0.010	0.01	1.20	0.020	0.010	0.040	0.330	2.87
4	Sangirei	D	91.41	6.02	0.010	0.010	0.006	0.01	1.12	0.012	0.010	0.038	0.170	2.31
5	Lainde	E	90.75	6.29	0.010	0.010	0.070	1.45	0.50	0.014	0.010	0.059	0.470	1.38
6	Jimeta	F	94.93	4.97	0.000	0.010	0.029	0.01	0.59	0.017	0.010	0.072	0.240	1.59
7	Karewa	G	90.12	5.92	0.023	0.190	0.049	0.56	0.95	0.022	0.010	0.058	0.451	1.69
8	Yola	H	92.45	4.49	0.004	0.010	0.018	0.01	0.56	0.055	0.010	0.044	0.185	1.65
9	Kofare	J	84.76	6.50	0.040	0.670	0.050	1.17	1.54	0.080	0.010	0.115	0.549	2.21
10	FCE	K	92.08	4.45	0.016	0.010	0.075	1.76	0.47	0.046	0.010	0.048	0.187	1.36
11	Girei	L	92.84	5.01	0.010	0.010	0.005	0.01	0.43	0.027	0.006	0.040	0.349	1.81
12	Damilu	M	92.67	4.30	0.010	0.010	0.012	0.01	0.95	0.051	0.010	0.043	0.209	1.41
13	Vinikilang	N	91.99	5.91	0.005	0.010	0.016	1.31	0.63	0.049	0.010	0.040	0.124	1.76
14	Sabongeri	P	89.11	7.19	0.015	0.058	0.001	0.01	0.81	0.058	0.129	0.061	0.070	2.09
15	Tofare Buhu	Q	93.66	3.75	0.001	0.057	0.049	0.83	0.18	0.059	0.225	0.045	0.213	1.17
16	ABTI	R	80.61	5.90	0.010	0.010	0.060	1.49	6.04	0.015	0.010	0.450	0.250	2.57

Table 3: Classification of Sandstone based on Chemical approach (After Blatt *et al.,* 1972; Hebron 1988; Pettijohn *et al.,* 1972; Potter 1978)

S.No.	Log of ratio of oxides	Types of sandstone
1	Log SiO_2/Al_2O_3>1.5	Arenites
2	Log SiO_2/Al_2O_3< and log K_2O/Na_2O<0	Greywacke
3	Log(SiO_2/Al_2O_3)<1.5, log(K_2O/Na_2O)>0 and Log (Fe_TO_3 + MgO)/Na_2O + K_2O)	Arkose
4	Log(SiO_2/Al_2O_3) <1.5 and either Log(K_2O/Na_2O)<0 or Log (Fe_TO_3 + MgO/K_2O) >0	Lithic Arenite (including subs-greywacke and protoquartzites

Table 4: Results of the log of ratio of the oxides of each analysed sample

No.	Location	Sample no.	Log SiO_2/Al_2O_3	Log K_2O/Na_2O	Log Fe_TO_3 + MgO/K_2O + Na_2O
1	Bajabure	A	1.30	1.20	-0.20
2	Jambutu	B	1.21	1.31	-0.36
3	Jimeta	C	1.09	0	0.34
4	Sangirei	D	1.18	0.22	0.33
5	Lainde	E	1.16	1.32	-0.24
6	Jimeta	F	1.28	-0.46	-0.21
7	Karewa	G	1.18	1.06	0.02
8	Yola	H	1.31	-0.26	-0.01
9	Kofare	J	1.12	1.37	0.21
10	FCE	K	1.32	1.37	-0.26
11	Girei	L	1.27	0.30	0.16
12	Damilu	M	1.33	-0.08	0.29
13	Vinikilang	N	1.19	1.91	-0.19
14	Sabongeri	P	1.09	1.00	0.36
15	Tofare Buhu	Q	0.57	1.23	-0.64
16	ABTI	R	1.14	1.40	0.79

viewed under both plane and cross polarized microscope in Department of Geology of the Federal University of Technology Yola Nigeria in March 2008. The proportion of the mineral composition of each sample was estimated in percentages.

X-ray fluorescence (XRF) analysis was later carried out on the sixteen selected samples for their major oxide composition in the Chemical Laboratory of the Ashaka Cement Plc Ashaka Gombe State Nigeria between March to April 2008.

RESULTS AND DISCUSSION

The results of the geochemical analyses are presented in Table 2. The concentration of three major oxide groups such as silica and alumina, alkali oxides and iron oxides plus magnesia were used to classify sandstones. The enrichment of SiO_2 over Al_2O_3 by mechanical and chemical process produces quartz arenites (Orthoquartzites). Silica (quartz) enrichment is a measure of sandstone maturity and is a reflection of the duration and intensity of weathering and destruction of other minerals during transportation. Abundance of alkalis (Na_2O and K_2O) characterizes immature sandstones such as Arkoses and greywackes whereas the ratio of Na_2O/K_2O determines both the provenance and diagenesis of the sandstone deposit (Akinmosin and Osinowo, 2008; Ibe and Akaolisa, 2010).

The values of the log SiO_2/Al_2O_3 in all the samples are less than 1.5 (Table 3 and 4) and while samples F, H, and M indicate log K_2O/Na_2O values that are less than 0 the remaining samples revealed log K_2O/Na_2O values that

Table 5: Summary of mineralogical composition of Bima Sandstone

S.No.	Location	Sample no.	Mineral under plane polars	Mineral under cross polars	Mineral (%)
1	Bajabure	A	-	Quartz	65
				Plagioclase	12
				Microcline	4
				Clay matrix	8
				Iron Oxide	8
				Calcite	3
2	Jambutu	B		Quartz	65
				Plagioclase	15
				Muscovite	7
				Clay matrix	6
				Iron Oxide	4
				Calcite	3
3	Jimeta	C		Quartz	66
				Plagioclase	14
				Biotite	6
				Clay matrix	4
				Iron Oxide	7
				Calcite	3
4	Sangirei	D	Muscovite	Quartz	67
				Plagioclase	13
				Muscovite	7
				Clay matrix	5
				Iron Oxide	4
				Calcite	4
5	Lainde	E	Muscovite	Quartz	66
				Plagioclase	12
				Muscovite	10
				Clay matrix	4
				Iron Oxide	5
				Calcite	3
6	Jimeta	F	-	Quartz	65
				Plagioclase	15
				Biotie	7
				Clay matrix	4
				Iron Oxide	5
				Calcite	4
7	Karewa	G		Quartz	65
				Plagioclase	14
				Muscovite	9
				Clay matrix	4
				Iron Oxide	6
				Calcite	2
8	Yola	H		Quartz	66
				Plagioclase	12
				Biotite	9
				Clay matrix	4
				Iron Oxide	6
				Calcite	3
9	Kofare	J	Muscovite	Quartz	67
				Plagioclase	13
				Muscovite	8
				Clay matrix	4
				Iron Oxide	6
				Calcite	2
10	FCE	K	Muscovite	Quartz	65
				Plagioclase	14
				Biotite	10
				Clay matrix	3
				Iron Oxide	4
				Calcite	4
11	Girei	L	-	Quartz	67
				Plagioclase	13
				Biotite	11
				Clay matrix	3
				Iron Oxide	4
				Calcite	2

Table5 : continued

12	Damilu	M		Quartz	65
				Plagioclase	15
				Muscovite	12
				Clay matrix	2
				Iron Oxide	5
				Calcite	1
13	Vinikilang	N		Quartz	67
				Plagioclase	14
				Biotite	7
				Clay matrix	3
				Iron Oxide	7
				Calcite	2
14	Sabongari	P	Muscovite	Quartz	64
				Plagioclase	15
				Muscovite	9
				Clay matrix	5
				Iron Oxide	4
				Calcite	3
15	Tafare Buhu	Q	Muscovite	Quartz	63
				Plagioclase	14
				Muscovite	12
				Clay matrix	3
				Iron Oxide	6
				Calcite	2
16	ABTI	R	-	Quartz	67
				Plagioclase	13
				Biotite	11
				Clay matrix	2
				Iron Oxide	6
				Calcite	1

are more than 0. Furthermore the log Fe_TO_3+ MgO/K_2O + Na_2O values are less than 0 in samples A, B, E, F, H, K, N and Q (-0.20 to -0.64) whereas the remaining samples indicate values that are generally more than 0 (0.02 to 0.79).

The abundant alkali values in most of the samples indicate immature sandstones whereas low alkali values in samples F, H and M revealed mature sandstones. The enrichment of silica (quartz) over Al_2O_3 (log SiO_2/Al_2O_3<1.5) is a reflection of the duration and intensity of weathering and destruction of other minerals during transportation. These indicate that Bima Sandstone has undergone long period of transportation and have been subjected to intense weathering resulting in the destruction of other minerals especially plagioclase and potassium feldspars during transportation.

The dataset as shown in Table 3 and 4 thus revealed a heterogeneous sedimentary formation that varies from immature to mature Arkose and lithic arenites including subgreywacke and protoquartzites.

Sixteen samples were selected and their slides prepared and observed under a polarizing microscope. Form the study of the rock samples under both plane polarized and cross polarized lights the following minerals were observed: quartz, orthoclase, biotite and muscovite. Quartz is generally anhedral in crystal form, has weak birefringence and shows grey to white first order interference. It has low relief, shows parallel as well as undulose extinction and is colourless under plane polarized light. Plagioclase feldspar is colourless under plane polarized light, sub-hederal in the norm and shows low relief and weak birefringence. It is also non-pleocroic and shows grey to white first order interference, parallel extinction and Carlsbad twinning.

Muscovite is pale yellow to colourless under plane polarized light, anhedral in crystal form and show moderate relief and moderate birefringence. It is very weakly pleochroic, shows purple to red interference colours and cleaves in one direction. Biotites is pale brown to dark brown in colour under polarized light, anhedral in crystal form, commonly pleocroic, and have a perfect cleavage in one direction. It shows moderate relief and moderate birefringence. Iron oxide is opaque under plane polarized light, anhederal in crystal form, of high relief and non-pleochroic.

Table 5 is a summary of the mineralogical composition and percentages. Petrographic studies show that silica in the form of quartz and iron oxides are the predominant cementing materials for the Bima Sandstone (Plate 1 and 2). Though the occurrence of clays in some samples could have originated from the weathering of the feldspars.

The grain-sizes range from 2.2 to 0.43 mm indicating a fine to coarse grained sandstone that is poorly to moderately sorted. The mineralogical composition of the Bima Sandstone consist essentially of 63-67% quartz, 12-15% plagioclase feldspar, 9% mica, 4% clay matrix, 5% iron oxide and 3% calcite and are thus classified as quartz/lithic arenites and greywackes as some of the predominant sedimentary rocks in the study area.

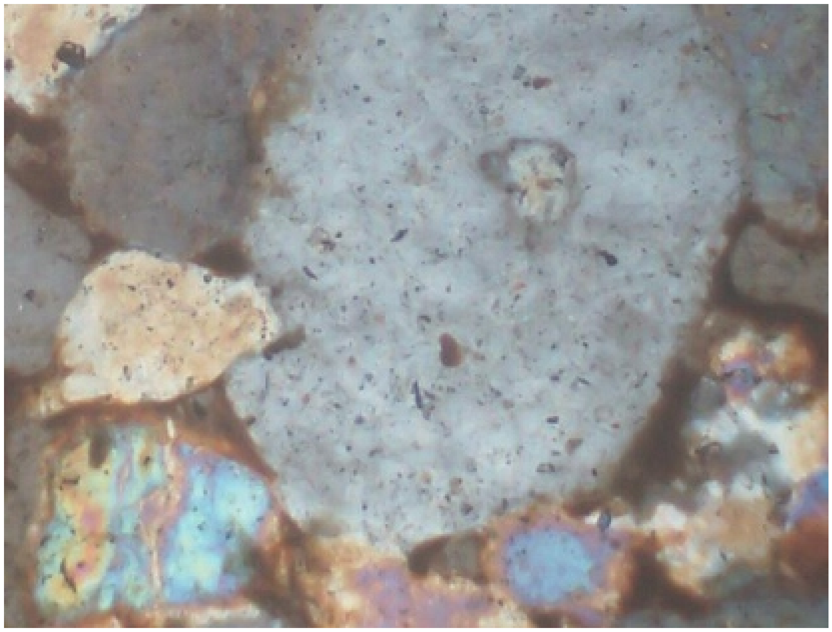

Plate 1: Photomicrograph of Bima Sandstone observed under a polarized microscope showing well developed crystals X30 Magnification

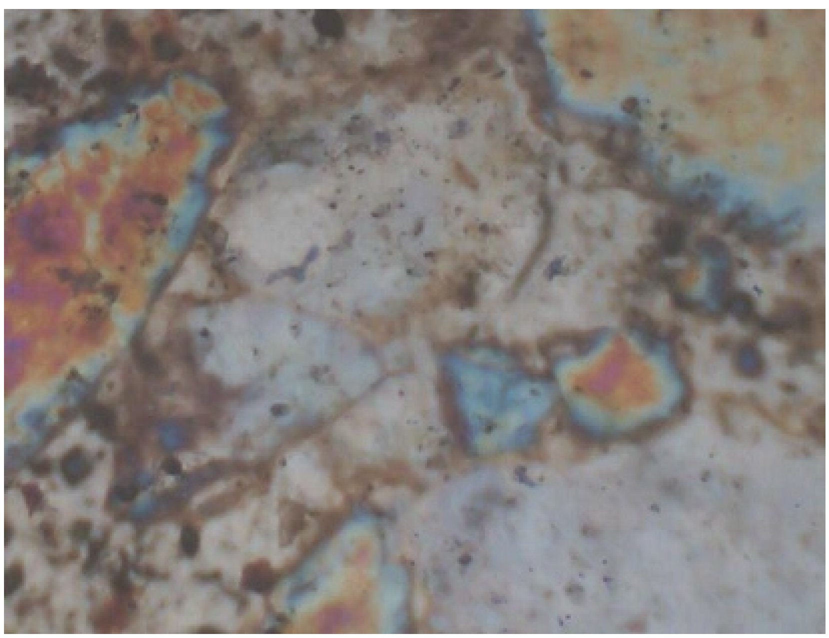

Plate 2: Photomicrograph of Bima Sandstone observed under a polarized microscope showing fine grained matrix X30 Magnification

In thin section, the quartz is sub-angular to sub-rounded and rimed by reddish brown colouration indicating iron-oxide. The feldspars are largely plagioclase which has been altered to clay matrix. It is thus both texturally and mineralogically immature and hence competent. The predominance of quartz grains could be due to diagenetic effect of compaction and pressure solution at greater depths. Hence the quartz grains responded by shifting into more dense packing arrangements during the middle to later stages of diagenesis lending to reduction in porosity of the sandstone. The sandstone is thus highly indurated and has reduced porosity probably due increased siliceous cementation especially adjacent to lineaments.

CONCLUSION

Sedimentary rocks are classified generally based on texture, cement and groups. These groups can be subdivided into three such as detrital/clastic, biogenic and chemical sediments. These sediments belong to the clastic group, which could be clean having silica cement, matrix rich-greywacke and the arkosic type.

A total number of sixteen (16) sandstone samples were collected in Yola area inorder to classify the deposit of the Bima Sandstone exposed in this area on the basis of its chemical and mineralogical make-up. All the samples were selected randomly and subjected to both geochemical and petrographic studies. Relative concentration of the major oxide groups such as silica and alumina alkali oxides, iron oxide and magnesia has been used to classify the deposit.

The results of the log of ratio of the major oxide groups indicate that Bima Sandstone of the study area can be classified as greywackes, arkoses and lithic arenites including sub-greywackes and protoquartzites. The abundant alkali values as shown by the relatively high log K_2O/Na_2O ratio in most of the samples indicated immature sandstones whereas low alkali values in samples such as F, H and M revealed mature sandstones.

The enrichment of silica (quartz) over Al_2O_3 (log $SiO_2/Al_2O_3<1.5$) indicate that Bima Sandstone has undergone long period of transportation and have been subjected to intense weathering resulting in the destruction of other minerals especially plagioclase and potassium feldspars during transportation.

The grain-sizes range from 2.2 to 0.43 mm indicating a fine to coarse grained sandstone that is poorly to moderately sorted. The mineralogical composition of the Bima Sandstone consist essentially of 63-67% quartz, 12-15% plagioclase feldspar, 9% mica, 4% clay matrix, 5% iron oxide and 3% calcite and are thus classified as quartz/lithic arenites and greywackes as some of the predominant sedimentary rocks in the study area.

ACKNOWLEDGMENT

The work described in this report is partly based on data generated for a doctorate degree dissertation by the first author Gabriel Obiefuna under the supervision of Prof. D.M. Orazulike. The authors will like to thank the Adamawa State Water Board Yola for their assistance during field work and to the Federal University of Technology Yola for giving the first author study fellowship to pursue a doctorate degree programme at the A.T.B.U Bauchi.

Finally I will like to thank my beloved wife Mrs. Obiageli R Obiefuna for typing the manuscript and Ibrahim Ahmed for drafting the figures.

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