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Facie Analysis and Geochemical Characteristics of Bima Formation at Wuyo, Part of Gongola Sub-Basin, Upper Benue Trough, Northeastern Nigeria: Implications for Provenance, Paleoenvironment and Tectonic History

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Abstract— The studied section of the Bima Formation at the Wuyo village composed of finning upward cycles of mudstones and medium-coarse grained sandstones sediments with total thickness of about 61.9m. The section consists of ten fining upwards sequence with individual cycles characterized by an erosional base overlying lithologies of either sandstone or mudstone beds. The lithofacies similarities also suggest hydrodynamic condition leading to their deposition is similar throughout. The geochemical plot of Al_2O_3/SiO_2 versus Fe_2O_3 +MgO wt% for the discrimination of sample plotted in and around (PM), (ACM), (CIA), (OIA). From all the plots of the four samples, three of the points falls outside all the fields and majority around the continental island arc (CIA) field; the remaining point falls within the active continental margin (ACM). In the Bivariate plot of (K_2O/Na_2O) against SiO_2, all the four points plotted falls within the active continental margin (ACM), while in the plot of K_2O/Na_2O versus Fe_2O_3+ MgO wt%, all four points plotted falls outside all the fields but are generally around oceanic island arc (OIA).The geochemical analysis showed few of the points fell within the oceanic island arc (OIA), continental island arc (OIA) and active continental margin (ACM) fields, while majority fell outside all fields but are generally around the active continental margin (ACM) fields, suggesting that most of the samples of the Bima studied at the Wuyo village formed in active continental margin (ACM) settings. This is also supported by the dominance of litharenite in the formation which indicates high tectonic activities.

Keywords—Geochemical analysis, Bima, Geochemical plot, Wuyo, Litharenite.

I. INTRODUCTION

Bima Sandstone is the name given to the continental intercalaire in the Chad Basin and Upper Benue Trough of Nigeria. It is the oldest sedimentary deposit in these regions. The composition of Bima Sandstone mainly arkose to quartz arenite and its depositional structures have generated wide speculations as to the source and environment of deposition. The Early Cretaceous continental Bima Sandstone (which is the formation of concern) unconformably overlies the Pan African basement rocks. In most places it represents by far the greatest proportion of the lithostratigraphic succession in the Upper Benue Trough. The Formation is divided into three siliciclastic members: lower (B1); middle (B2) and upper (B3) members.

The geochemical characteristics of clastic sedimentary rocks are useful in determining the depositional setting and its associated provenance. The study of sedimentary provenance interfaces several of the mainstream geological disciplines and it includes the location and nature of sediment source areas, the pathways by which sediment is transferred from source to basin of deposition, and the factors that influence the composition of sedimentary rocks (e.g., relief, climate, tectonic setting). Information on transport history, palaeoenvironment of deposition and energy of transport medium can be deduced from mineralogical studies and the incorporation of this into data from inorganic geochemistry will ultimately result in a concise depiction of sediment provenance amongst other information.

The aim of this work is directed at carrying out comprehensive provenance studies of the Bima sandstone exposed at Wuyo village by means of a facie analysis and inorganic geochemical studies with a view to determining the provenance and tectonic history

STUDY AREA

The study area is located in Wuyo town in Borno State and the studied section falls between latitude $10^0$15' N and longitude 11^0 12' E (Figure 1). It is characterised by undulating terrain with few flat plains. The climate is semi-arid with three distinct seasons; a long hot dry season from April to May. Day time temperatures are in the range of 36^0 to 40^0C and night time temperatures fall to 10^0 to 17^0C. This is followed by a short rainy season from May to September with a daily minimum temperature of 20^0C and a maximum of 31^0C with relative humidity of 40 to 60% and annual rainfall from 860 to 900 mm. Finally, the cold (harmattan) season runs from October to March when temperatures fall to about 20^0C and a dry dusty wind blows from the Sahara desert.

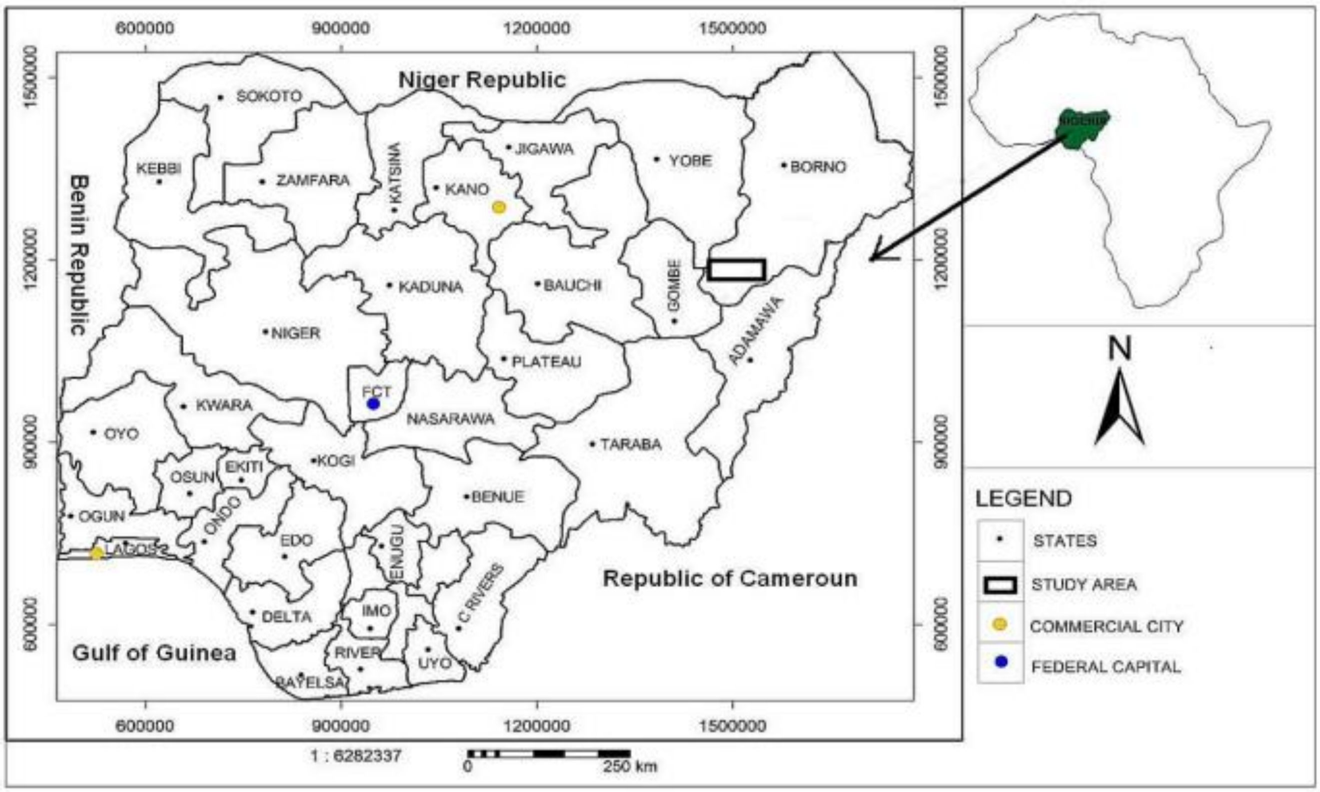

Figure 1: Location map of the study area

II. REGIONAL STRATIGRAPHIC SETTING

The regional geology and stratigraphy of the Benue Trough have been comprehensively discussed, reviewed and presented by [10,15,24,31,33,48,50]. In both arms of the Upper Benue Trough (Figure 2), the continental Albian Bima Sandstone lies unconformably on the Precambrian basement as the oldest known Cretaceous sediment in the region. The Yolde Formation which is Cenomanian to Turonian in age lies conformably on the Bima Sandstone. It is made up of a variable sequence of sandstones and shales that marks the transition from continental to marine sedimentation.

The sandstone occurrence is suggestive of a beach environment [31]. In the Gongola Arm, the laterally equivalent Gongila and Pindiga Formations lie conformably on the Yolde Formation. These Formations represent full marine incursion into the Upper Benue during the Turonian-Santonian times and are lithologically characterized by dark/black carbonaceous and pale colored limestones and shales with minor sandstones. In the Yola Arm, Dukul, Jessu, Sekule and Numanha are the Turonian-Santonian equivalents of the Gongila and Pindiga Formations. These successions are overlain by the Campanian to Maastrichtian Gombe Sandstone in the Gongola Basin and Lamja Sandstone (Lateral equivalent) in the Yola Basin [10]. The Tertiary Kerri-Kerri Formation caps the succession west of Gombe in the Gongola Basin. The Gombe Sandstone and the Kerri-Kerri Formation are lithologically composed of sandstones, siltstones and abundant coal intercalations.

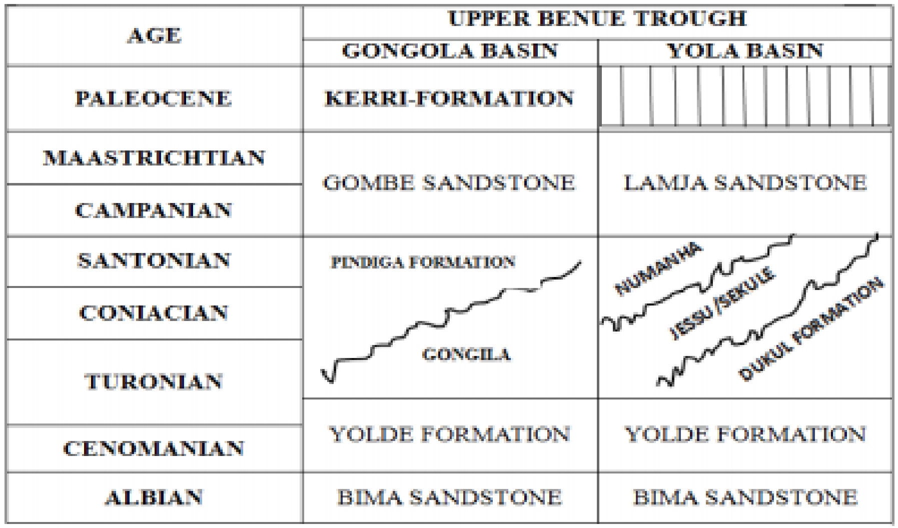

Figure 2. A Generalized Stratigraphic Correlation in the Gongola and Yola Basin [33]

III. METHODOLOGY

In the field, careful examination of exposures in a section was done to have an idea about the different types of structures and textures present. This tends to give an idea on how to view a bigger picture of a whole section. The thickness across exposure was measured, the name of the locality and coordinates were recorded in a field note book. The lithological characteristics of the rocks were observed and recorded i.e. colour, sorting, grain shape, structures, fossil content, degree of induration and mineral composition of the rock. Samples were collected and labelled accordingly.

Samples collected from the field were taken to laboratory and subjected to several procedures. For the purpose of this work, X-ray fluorescence analysis (XRF) was employed.
Firstly, the samples were dried in an oven to expel the moisture content in the sample so as to enable easy pulverization. Before the start of crushing the pestle and mortar are cleaned with acetone and tissue paper to avoid contamination. For X-ray fluorescence method, the size and uniformity of a sample particle are very important in determination of the fluorescence accuracy usually (300-400 mesh).

The powdered samples were then placed on the glass plate. The samples were covered with tissue paper soaked with acetone, and pressed it down with fingers in such a way that the powdered sample swell slightly from the plate. The samples were mounted on the Goniometer sample holder. The target material affects the angle at which a peak appears in the fluorescence pattern and the quantity of fluorescence X-rays emitted from samples. The anode material for the X-ray tube was selected properly according to the properties of composition. Copper tube is generally used as standard with a cobalt tube to avoid an increase in the background level caused by fluorescence X-rays. All measurements and data analysis were under the control of a computer.

IV. RESULTS AND DISCUSSION

LITHOSTRATIGRAPHY OF THE STUDIED SECTION

The lithology of the Bima Formation usually ranges from medium to coarse grained feldspathic and calcareous sandstones. A total of about 61.9m of sediments were measured consisting of mudstones and medium-coarse grained sandstones. The section consists of ten fining upwards sequence with individual cycles characterized by an erosional base overlying lithologies of either sandstone or mudstone beds. The succession of the cycles from base to top is described as follows:

The first fining upwards cycle consist of about 4.7m of sediments. The cycle comprises of 3.5m grey, poorly sorted, medium grained, and trough crossbedded sandstone overlain by a 1.2m dark grey mudstone bed.

The second cycle consists of about 6.5m of sediments. Its base is defined by a 5m grey poorly sorted, very coarse grained trough crossbedded sandstone with sub-angular grains and erosional base associated with mudclasts. This is followed by a 1.5m grey poorly sorted, very coarse grained trough crossbedded with sub-angular grains.

The third cycle consists of about 9.3m of sediments. The sequence comprises of 5m grey poorly sorted, very coarse grained trough crossbedded sandstone with sub-angular grains and erosional contact associated with pebble logs and mudclasts at it base. This is succeeded by a bed of 2.5m grey poorly sorted, very coarse grained trough crossbedded sandstone with sub- angular grains. This unit is overlain by a 1.8m dark grey mudstone.

The fourth cycle consists of about 3m of sediments and made up of one bed of grey poorly sorted, very coarse grained trough crossbedded sandstone with erosional contact. The fifth cycle consists of about 5.7m of sediments. The succession comprises of a 2.5m grey poorly sorted, very coarse grained trough crossbedded sandstone with sub-angular grains and erosional contact at its base, and this is overlain by another bed of about 2m grey poorly sorted, very coarse grained, parallel laminated sandstone and capped by a 1.2m dark grey mudstone.

The sixth cycle is made up of three beds and it is about 6m thick. The first bed from the base is a 2m grey poorly sorted, very coarse grained trough crossbedded sandstone with sub-angular grains and erosional base associated with mudclasts. It is overlain by 2.5m grey poorly sorted, very coarse grained trough crossbedded sandstone with sub-angular grains and capped by a 1.5m dark grey mudstone.

The seventh cycle consists of about 6.5m of sediments. Its base is defined by a 5m grey poorly sorted, very coarse grained trough crossbedded sandstone with sub-angular grains and erosional base associated with mudclasts. This passes upwards to a 1.5m dark grey mudstone.

The eighth cycle consists of about 6.4m of sediments. The base is defined by a 5m grey poorly sorted, very coarse grained, trough crossbedded sandstone with sub-angular grains and erosional base associated with mudclasts. This is overlain by a 1.4m dark grey mudstone.

The ninth fining upwards cycle is composed of a 4m thick, grey poorly sorted, very coarse grained trough crossbedded sandstone with sub-angular grains and erosional base. The bed is further overlain by a 1.8m dark grey mudstone. This cycle is about 5.8m thick.

The tenth cycle consists of about 8m of sediments. The base is defined by a 6m grey poorly sorted, very coarse grained, trough crossbedded sandstone with sub-angular grains and erosional base associated with mudclasts. The bed is overlained by a 2m dark grey mudstone.

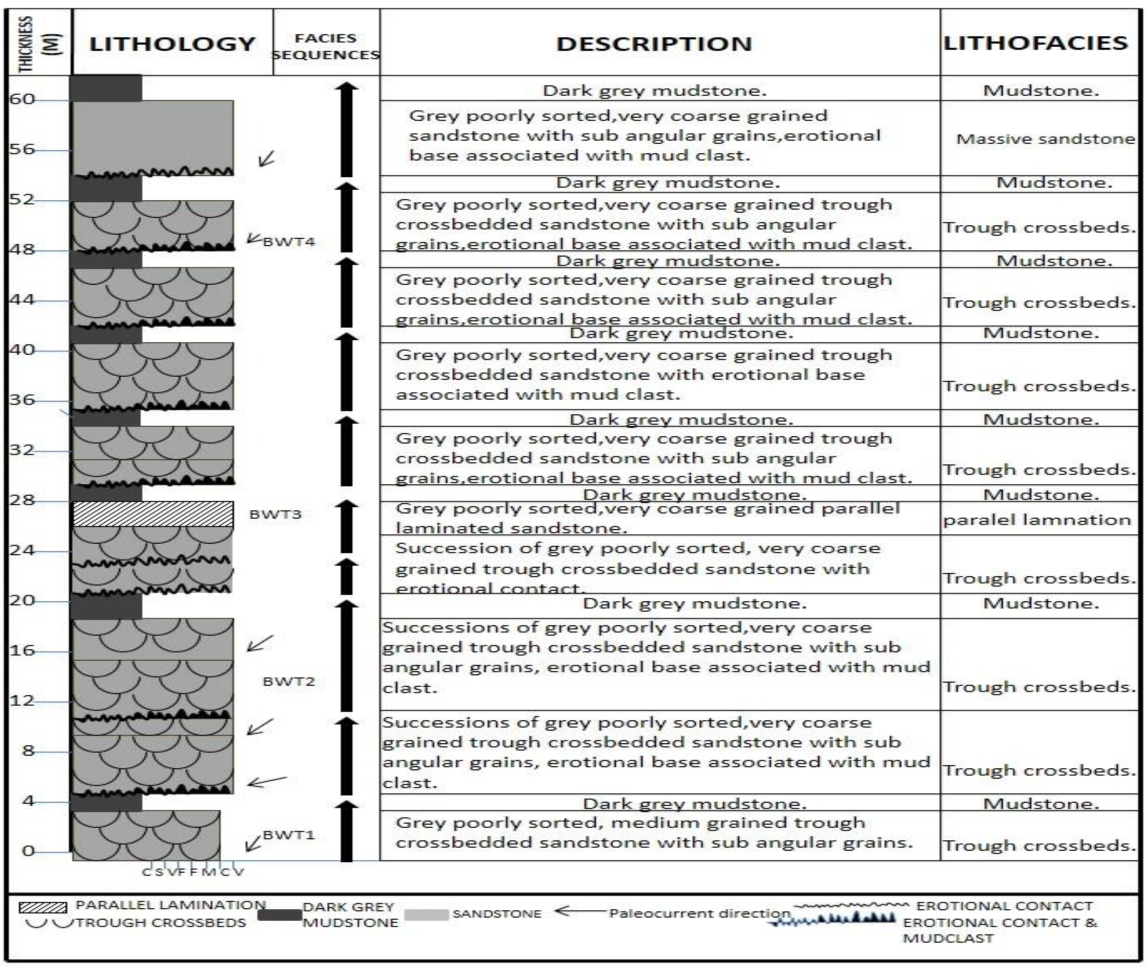

Figure 3: Studied section of Bima Formation at the Wuyo Village

GEOCHEMISTRY

Table 1 shows major elements concentrations of the four samples of the Bima sandstone analyzed for and which are used to classify the sandstones. The most discriminating parameters are; (SiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, K_2O, ZnO and Na_2O, LOI) using x-ray fluorescence (XRF). Table 2 shows the log ratios of Fe_2O_3/K_2O, and SiO_2/Al_2O_3 while Table 3 is the ratios of Al_2O_3/SiO_2, K_2O/Na_2O, $Al_2O_3/(CaO+Na_2O)$ and as well as the sum of Fe_2O_3+MGO. Others include, bivariate of $Al_2O_3/(CaO + Na_2O)$ versus Fe_2O_3 + MgO wt% for some representative samples plotted in and around the passive margin (PM), Active Continental Margin (ACM), Continental Island Arc (CIA), Oceani Island Arc (OIA) Using [7], bivariate plot of Al_2O_3/SiO_2 versus Fe_2O_3 + MgO wt.% for the discrimination of Plate Tectonic settings using [7] and bivariate plot of (K_2O/Na_2O) against SiO_2 showing the Tectonic discrimination diagram for some representative samples of Bima Sandstone after [42].

Table 1: Result of X-Ray Fluorescence analysis

SAMPLES	SIO_2	AL_2O_3	K_2O	CAO	FE_2O_3	NA_2O	MGO	MNO	ZNO	LOI
BWT 1	72.18	6.74	3.72	0.78	0.73	3.76	3.83	0	0.021	**1.18**
BWT 2	72.06	6.82	3.86	0.79	0.71	4.85	6.15	0.005	0.035	**0.017**
BWT 3	72.01	6.96	3.89	0.79	0.69	3.47	7.72	0	0.028	**0.07**
BWT 4	**72.06**	**6.77**	**3.83**	**0.78**	**0.71**	**3.33**	**6.19**	**0**	**0.024**	**0.02**

Table 2: Computed parameters for plottings

SAMPLES	$LOG(FE_20_3/K_20)$	$LOG(SI0_2/AL_20_3)$	$LOG(NA_20/K_20)$	K_20/NA_20	K_20	NA_20	SIO_2
BWT 1	-0.71	1.03	0.005	0.99	3.72	3.76	**72.18**
BWT 2	-0.74	1.02	0.099	0.796	3.86	4.85	**72.06**
BWT 3	-0.75	1.01	-0.05	1.12	3.89	3.47	**72.01**
BWT 4	**-0.73**	**1.03**	**-0.06**	**1.15**	**3.83**	**3.33**	**72.06**

Table 3: Computed parameters for plottings

SAMPLES	$AL_203/(CAO+NA_2O)$	FE_2O_3+MGO	AL_2O_3/SI_2O
BWT 1	1.48	4.56	**0.09**
BWT 2	1.21	6.86	**0.09**
BWT 3	1.63	8.41	**0.10**
BWT 4	**1.65**	**6.90**	**0.09**

SANDSTONE CLASSIFICATION GRAPH AND PLOTTINGS FOR GEOCHEMICAL ANALYSIS

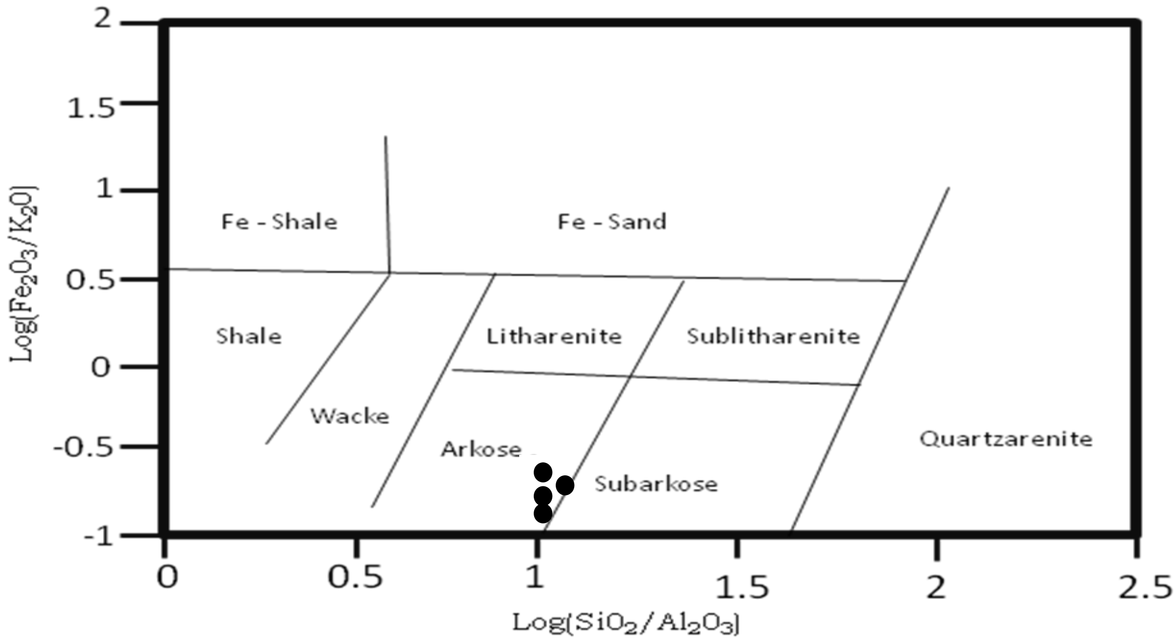

Figure 4: Sandclass classification of some representative samples of the Bima Sandstone based on the values of $Log(Fe_2O_3/K_2O)$ versus Log of (SiO_2/Al_2O_3)[39].

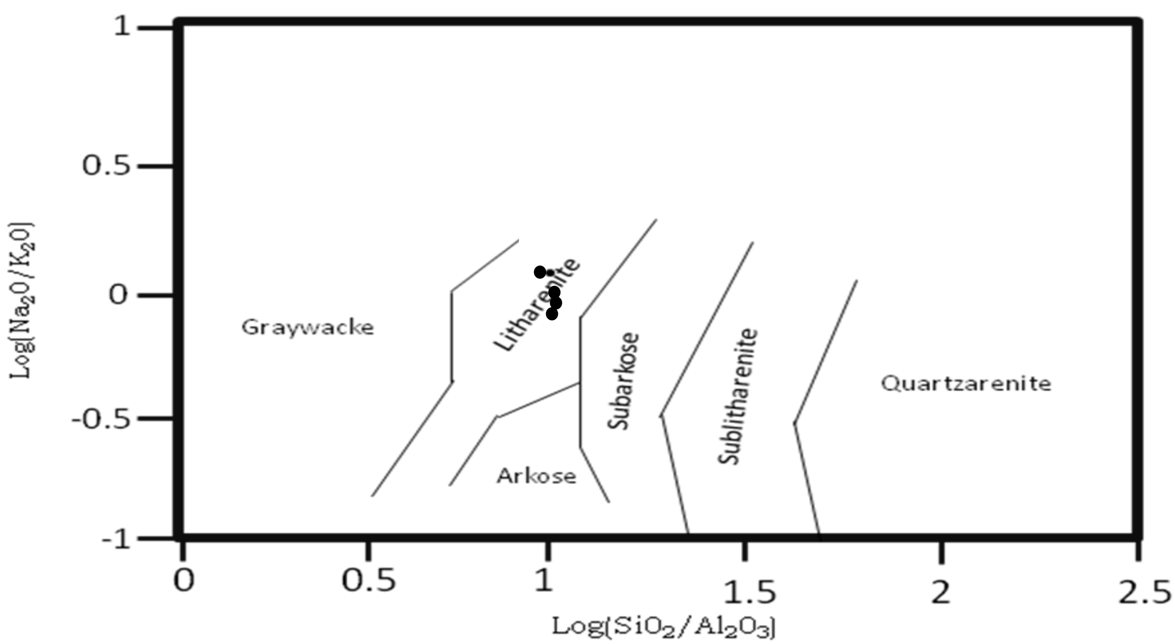

Figure 5 : Geochemical classification of some representative samples of the Bima Sandstone based on the values of $Log(SiO_2/K_2O)$[39].

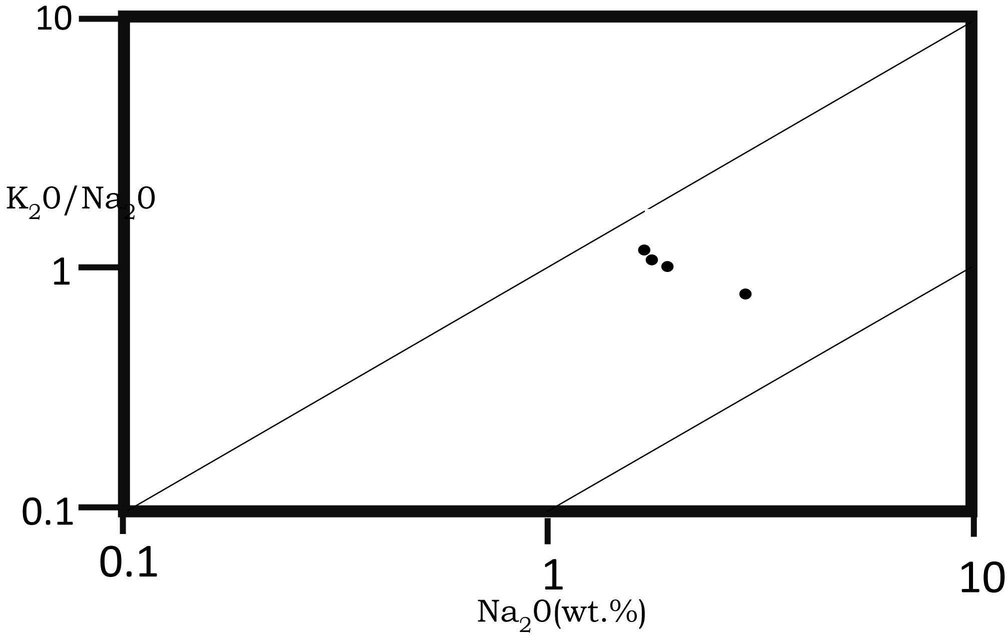

Figure 6 : Bivariate plot of (K_2O/NaO) against Na_2O(wt%) Showing the quartz- richness of some representative sample of Bima Sandstone [13].

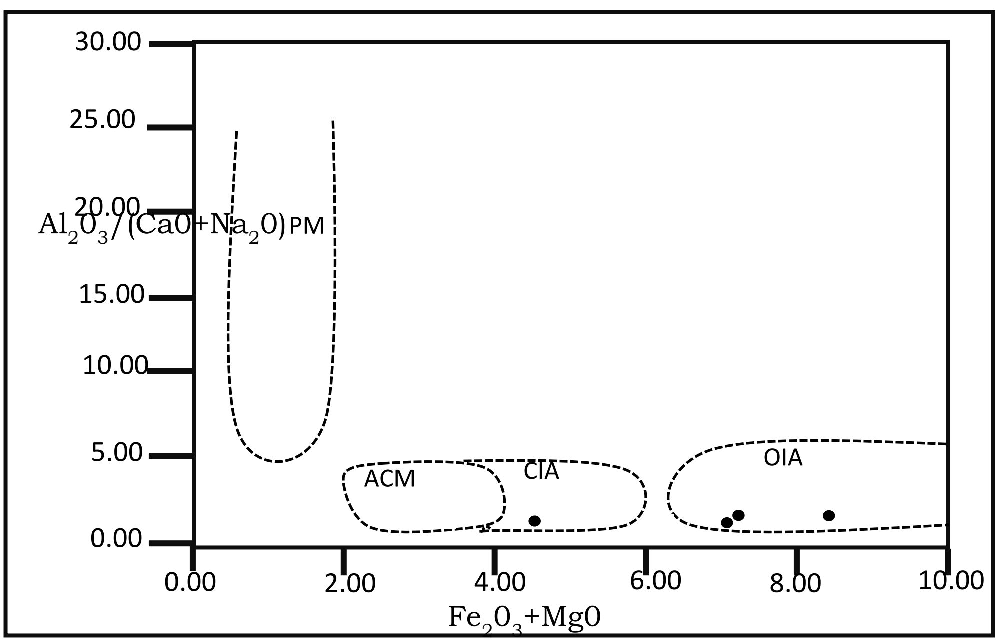

Figure 7 : Bivariate of Al_2O_3/(CaO + Na_2O) versus Fe_2O_3 + MgO wt% for some representative samples of Bima Sandstone plotted in and around the passive margin (PM), Active Continental Margin (ACM), Continental Island Arc (CIA), Oceani Island Arc (OIA)[7].

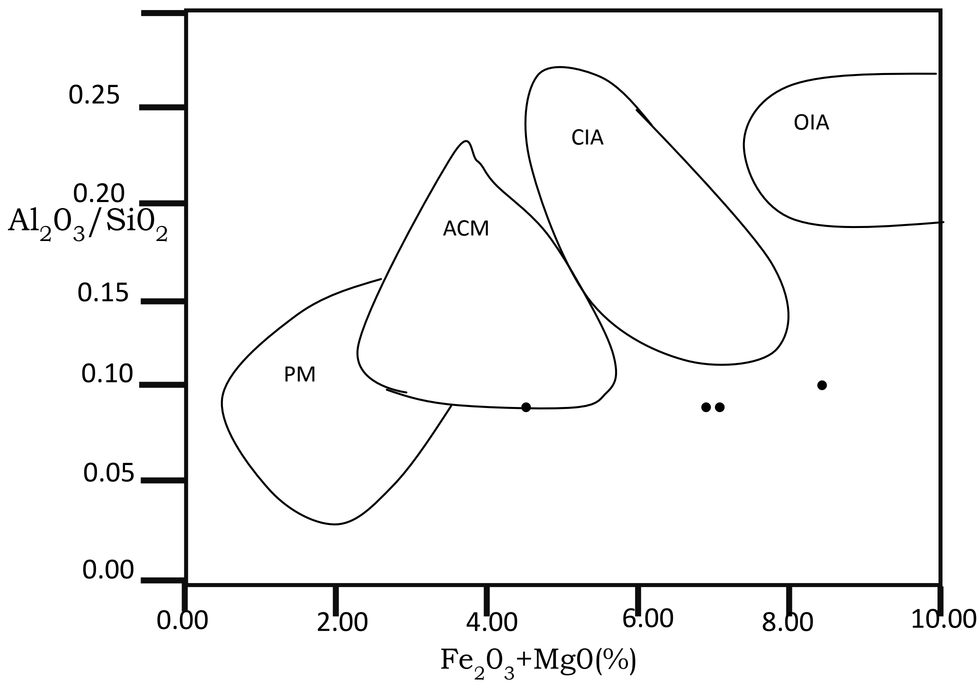

Figure 8 : Bivariate plot of Al_2O_3/SiO_2 versus Fe_2O_3 + MgO wt.% for the discrimination of Plate Tectonic settings of the Bima Sandstone [7].

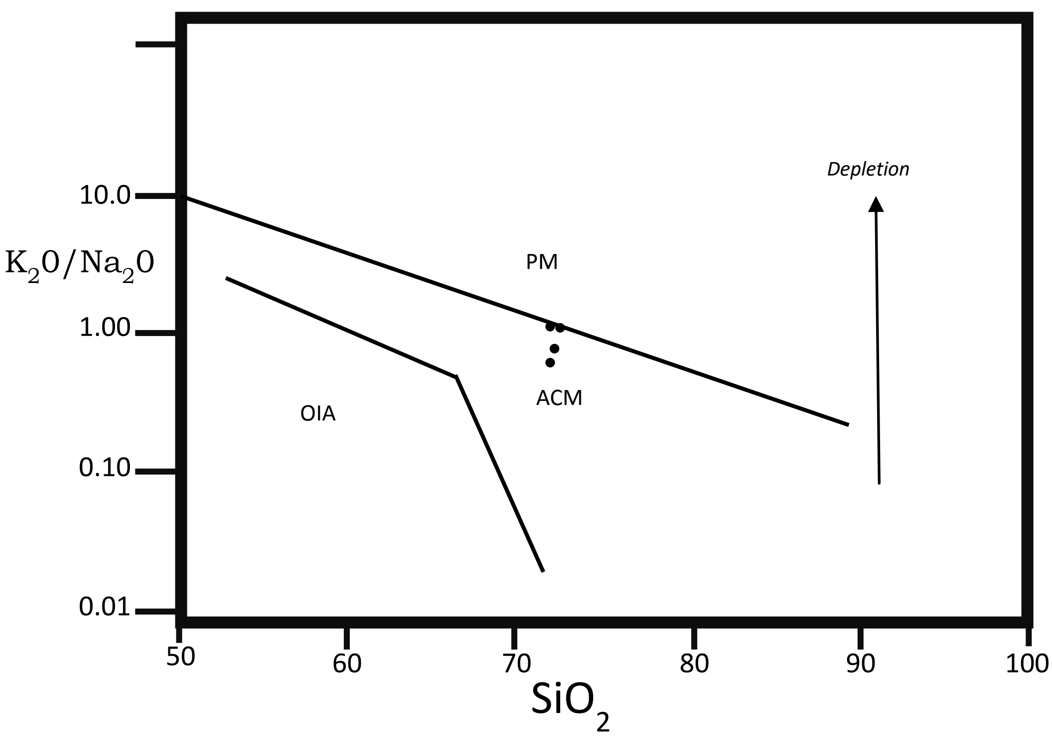

Figure 9: Bivariate plot of (K_2O/Na_2O) against SiO_2 showing the Tectonic discrimination diagram for some representative samples of Bima Sandstone after [42].

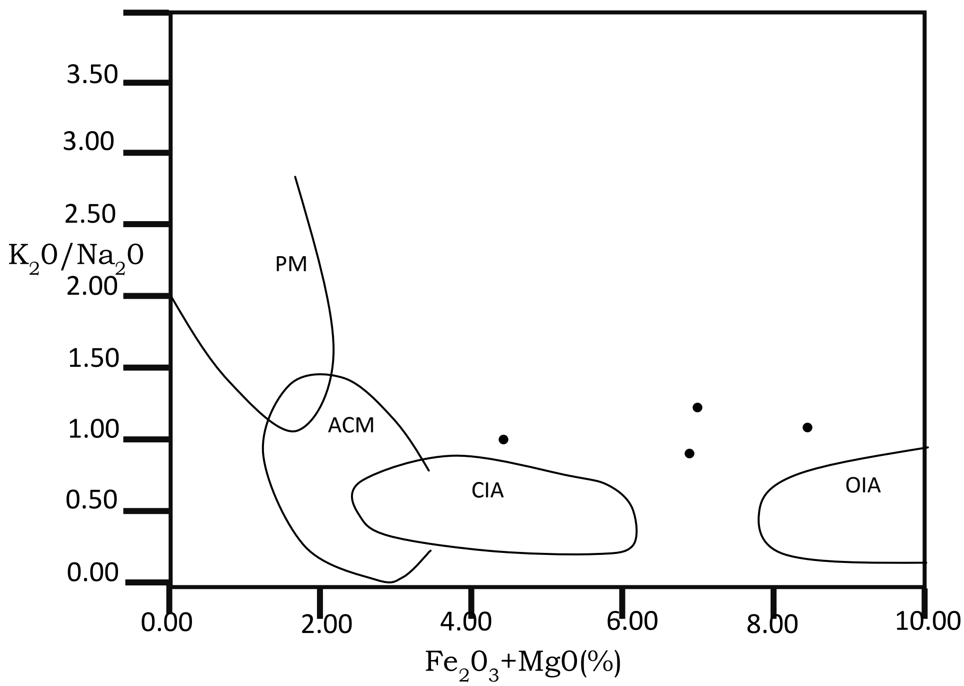

Figure 10: Bivariate plot of K_2O/Na_2O versus Fe_2O_3 + MgO wt. % for some representative samples of the Bima Sandstone [7]

DISCUSSION
FACIES ANALYSIS (SEQUENCE)

The section of Bima exposed at the Wuyo village is composed of succession of poorly sorted, medium to coarse grained sandstones with sub-angular grains usually associated with erosional base and mudclasts, these are fining to mudstone beds.

Considering the fact that there is no marine indicators, and coupled with the poorly sorting of the grains, it may be possible to suggest that the cycles are of fluvial environment. This is further supported by the unidirectional pattern of the current system.

Furthermore, due to the presence of higher percentage of sand than clay or mud in the section, the fluvial setting can be said to be formed by a braided river system. This is due to the lateral nature of the stream movement and the unstable nature of the flood plains.

Based on these facts, the environment can be suggested to be a fluvial environment and formed by braided river deposits. This is true for all the cycles as the similarities of the cycles shows that they are formed under the same hydrologic conditions.

GEOCHEMISTRY:
SANDSTONE CLASSIFICATION AND TECTONIC SETTINGS

The major element data (Table 1) was used in the classification of sandstones. Geochemical classification schemes (Figure 4 and 5) was used in classifying the Bima Sandstone into litharenite and arkose [39].

[7] Techniques a series of plots based on the Geochemistry of sandstones to differentiate four main tectonic settings which includes, the passive margin (PM), Active Continental Margin (ACM), Continental Island Arc (CIA), and Oceanic Island Arc (OIA).

In the geochemical model for the geochemical classification of sandstones, representative samples of the Bima base on the values of Log (Fe_20_3/K20) versus log Log ($Si0_2/Al_20_3$), were all plotted and fell into arkosic sandstone field. While the geochemical model of Pettijohn et al (1972), based on the values of log Na_2O/K_2O versus Log ($Si0_2/Al_20_3$) indicated litharenite and [13] indicated that the sandstones are generally quartz rich.

The variation in the geochemical characteristic of the sandstone sample may have been as a result of the tectonics activities that affected the Bima during its formation. During tectonic processes metasomatic activities are common and this may lead to remobilization of the minerals and elemental composition of the sandstones, thereby bringing about variations in the geochemical classification of the sandstones in [39] and [13] models.

The bivariate plot of ($Al_2O_3/(CaO+Na_2O)$) versus Fe_2O_2+MgOwt% of the four representative samples of the Bima plotted in and around the passive margin (PM), active continental margin (ACM), continental island arc (CIA), oceanic island arc (OIA) [7] . Three samples out of four samples plotted falls within Oceanic Island Arc (OIA) while the remaining sample falls within the continental island arc (CIA) field. The plot of Al_2O_3/SiO_2 versus Fe_2O_3 + MgO wt% for the discrimination of sample plotted in and around (PM), (ACM), (CIA), (OIA). From all the plots of the four samples, three of the points falls outside all the fields and majority around the continental island arc (CIA) field; the remaining point falls within the active continental margin (ACM). In the Bivariate plot of (K_2O/Na_2O) against SiO_2, all the four points plotted falls within the active continental margin (ACM) (Roser and korsch, 1986), while in the plot of K_2O/Na_2O versus Fe_2O_3+ MgO wt%, all four points plotted falls outside all the fields but are generally around oceanic island arc (OIA).

Base on the plots, few of the points fell within the oceanic island arc (OIA), continental island arc (OIA) and active continental margin (ACM) fields, while majority fell outside all fields but are generally around the active continental margin (ACM) fields (Figures 4 to 10). This suggests that the Bima formed on an active continental margin (ACM) settings. Supporting this is the dominance of litharenite in the formation which indicates high tectonic activity [7].

V. CONCLUSION AND FUTURE SCOPE

The section of the Bima Formation at the Wuyo village composed of finning upward cycles of mudstones and medium to coarse grained sandstones sediments with total thickness of about 61.9m. It consists of ten fining upwards sequence with individual cycles characterized by an erosional base overlying lithologies of either sandstone or mudstone beds. The lithofacies similarities may also suggest hydrodynamic condition leading to their deposition is similar throughout. The geochemical analysis showed that the Bima studied at the Wuyo village formed on an active continental margin (ACM) setting and the sandstone is classified as litharenite.

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