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PROVENANCE AND PALEOENVIRONMENTAL STUDIES OF BIMA AND DUKUL FORMATIONS IN THE YOLA BASIN, NORTHERN BENUE TROUGH, NIGERIA.

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ABSTRACT

Sedimentological studies of some areas located within latitudes 11^{0}35$^'$E & 12^{0}00$^'$E, and longitudes 9^{0}14$^'$N & 9^{0}25$^'$N were undertaken to delineate the surface lithologies of the Yola sub-basin, in the Northern Benue Trough. Field observations of the surficial deposits at Mayolope, Taana, Kpasam and Bille revealed that they are Bima Formation while the ones in Abare are Dukul Formation. Paleoenvironmental studies based on the characteristics of lithofacies of these exposed sections and laboratory assessments of some selected samples showed that the Bima Formation was deposited in a continental setting while the Dukul Formation was deposited in a low-energy marine setting. Petrographic studies of framework components showed that the samples of the Bima Formation were predominated by quartz minerals, leading to their identifications as sandstones and classifications as quartzarenites while the samples of the Dukul Formation were limestones and were classified as bioclastic packstones. Heavy mineral compositions of the sandstones revealed their provenance; Zircon and Tourmaline with a combined amount of 60.1% suggested igneous and low-grade metamorphic rocks while rutile and staurolite with a total amount of 27.7% indicated contributions from high-grade metamorphic rocks.

Keywords: Benue Trough, Bima Formation, Dukul Formation, Paleoenvironment, Heavy Minerals.

INTRODUCTION

This study was carried out in the Yola Basin, an extension of Benue Tough in northern Nigeria. The Benue Trough is a north-east trending and elongated sedimentary basin within Nigeria. Based on tectonics, geographical and stratigraphic features, it has been subdivided into Northern, Central and Southern Benue Troughs (Nwajide, 2013) corresponding to what other authors refer to as Upper, Middle and Lower Benue Troughs. Reports showed that the trough has been investigated by several workers since the time of Falconer (1911). A consensus among the workers is that the trough underwent a series of tectonic and structural evolution since its inception in the Cretaceous when the African and South American plates separated from each other. Two sub-basins are structurally and stratigraphically distinguished at the Northern Benue Trough, they are the Gongola and Yola arms. On the origin of the Yola Basin, Braide (1992a), suggested a wrench fault tectonics considering the similarities of its stratigraphy to those of other pull-apart basins. On its stratigraphy, seven units have been delineated beginning from the oldest, Bima Formation, through Yolde Formation, Dukul Formation, Jessu Formation, Sekule Formation, Numanha Formation to the youngest, the Lamja Sandstone.

The oldest and the third in a series of the above formations were the objects of interest in this study. The pre-Aptian-Albian Bima Formation is a large-scale deposit which is composed mainly of sandstones. It's laterally extensive and has a maximum thickness of 1,700m. Some workers (Carter *et al.*, 1963; Brunet et al., 1988, Guiraud, 1990, andBraide, 1992a,) reported the studies of Bima sediments; the basal part of the Cretaceous deposits at different geographical areas in the northern Benue Trough. Braide, (1992a) reported three members of the sedimentary fills, with the two upper members recognized in the Yola sub-basin (Nwajide, 2013). More works by Etobro and Ejeh (2007), and Adamu *et al.*,(2020) elucidated the characteristics of the Bima Formation at different geographic positions of its expansive area. At Wuro-Dole and its environs, Etobro and Ejeh (2007) investigated the heavy mineral assemblages of the sandstones and inferred that their sources were felsic igneous and high-grade metamorphic rocks. However, interpretations of the geochemical contents of the Bima Group at Kaltungo section by Adamu *et al.*, (2020) suggested that the sources were derived from pre-existing Cretaceous sedimentary rocks.

Reports on the lower Turonian Dukul Formation exposed at different geographic areas within the Yola Basin revealed an interbedding of shales and limestones. Mode (1993) recognized interbeds of black shale with thin grey to black bioclastic limestones and dark marl at Bambam. Ojo and Akande (2000) in their work at Lakun, Kutari, Jessu and Dukul identified interbedding of shales and limestones. The latter was described as fossiliferous and nonfossiliferous, micritic, marly, massive, indurated or friable and sometimes phosphatic (Nwajide, 2013). In the present work, the surface lithologies at Mayolope, Abare, Taana, Kpasham and Bille, and environs were analysed in order to widen the scope of the studied areas within Yola Basin, determine the paleodespositional environments and provenance of the sediments.

Study Areas

The exposed sedimentary successions investigated within the studied areas are located at Mayolope (9° 4' 10"N and 11°41'30"E), Abare (9° 15' 15" N and 11°37'30"E), and (9° 15' 30" N and 11°36'50"E), Taana (9° 16' 45" N and 11°41'30"E), Kpasham (9° 16' 40" N and 11°46'00"E) and (9° 17' 30" N and 11°45'30"E), and Bille (9° 16' 05" N and 11°55'10"E) in the northeastern part of Nigeria, Yola Sub Basin, Northern Benue Trough (fig.1). The topography is flat with river channels that drain into the River Benue. The areas experience tropical climates of wet and dry seasons and are covered with Sudan savannah vegetation.

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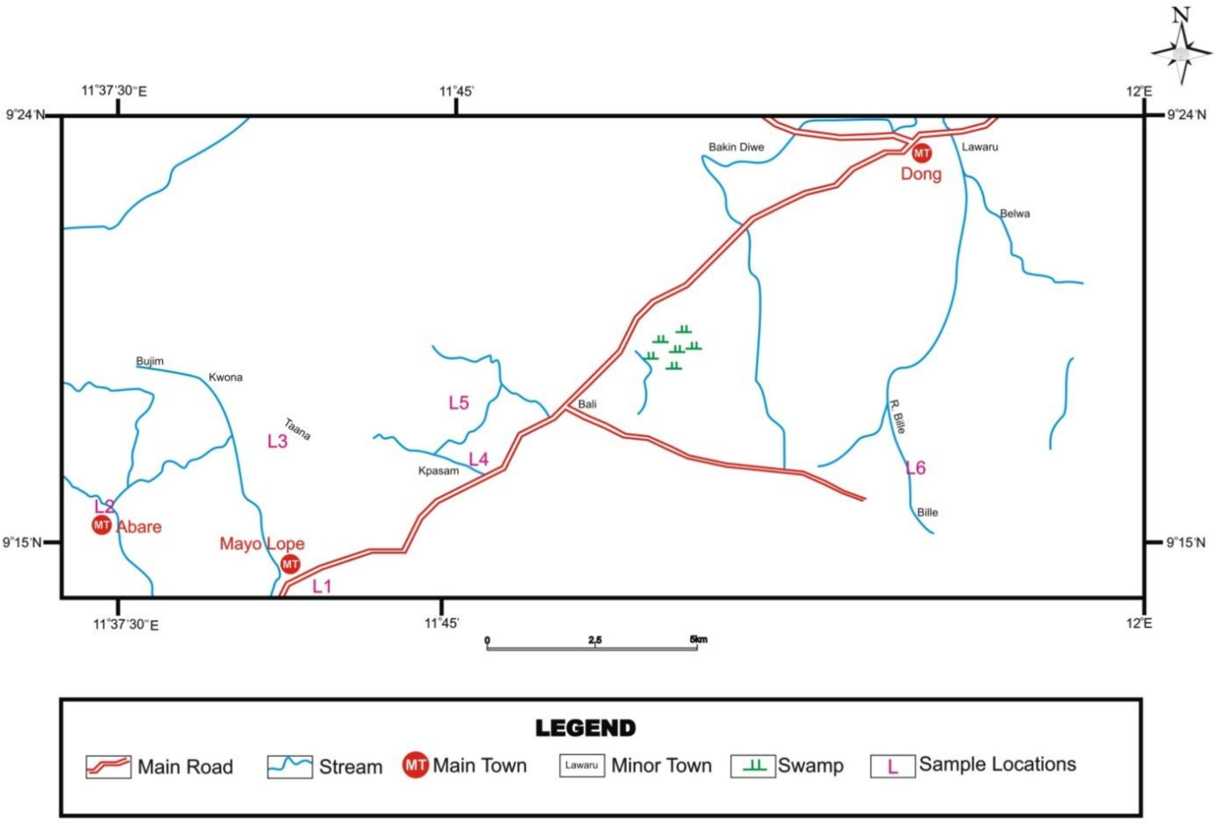

Figure 1: Topographic map, showing the locations of the study area and the sampling locations

METHODS

Geologic fieldwork was carried out at the study areas during which exposed sedimentary rocks along river channels were identified, observed and described. Graphic sedimentary logs were drawn to depict the lithostratigraphic sequences. Some samples were collected and taken to the laboratory for more studies to determine the actual grain sizes and mineral contents, and infer the paleoenvironment and provenance respectively.

Grain size distributions of eight samples of the sandstones were analysed using a dry sieving procedure. The samples were disaggregated before 100g of each sample was measured and poured into the sieves which were stacked together in a decreasing order of the largest to the smallest sieves with a plate beneath and placed on a mechanical shaker. The shaker was connected to an electrical source and switched to work for 15 minutes after which the weight of grains retained in each sieve was measured and the cumulative weight retained calculated. Graphical representations of the values were constructed to produce the grain-size cumulative curves. By picking the grain (Phi) sizes that corresponded to some specified percentile values on the cumulative curves, statistical parameters including the means, standard deviations and skewness were calculated using the graphical methods of Folk,(1974);

i. Graphic mean (M_z) = $(\phi_{16} + \phi_{50} + \phi_{84}) / 3$
ii. Inclusive graphic standard deviation $\sigma_1 = (\phi_{84} - \phi_{16})/4 + (\phi_{95} - \phi_5)/6.6$
iii. Inclusive graphic skewness:

$Sk_1 = [(\phi_{16} + \phi_{84} - 2\phi_{50})/2(\phi_{84} - \phi_{16})] + [(\phi_5 + \phi_{95} - 2\phi_{50})/2(\phi_{95} - \phi_5)]$

Petrographic analysis of the framework minerals of eight sandstone samples and components of four limestone samples were carried out from their thin sections. To begin with, the samples were smoothened, cut and reduced to a thickness of about 0.03mm using logtech machine and carborandum grits. The thin sections were mounted on thin glass slides using Canada Basalm and heated to about 90ºC. The glass slides were allowed to cool and washed with methylated spirit. Secondly, each thin section was mounted on a petrological microscope and viewed to observe, identify, describe and count the minerals. The percentage composition of each kind of mineral was calculated. Also, grain shapes, sizes, packing, matrix and types of cement were noted.

Heavy mineral suites of eleven samples were examined. The samples were pulverized and sieved with 0.112mm mesh screens. The samples that passed through the screens were collected and soaked in 30% hydrogen peroxide (H_2O_2) for about 24hours. The heavy mineral contents in the samples were separated from sand grains using bromoform ($CHBr_3$); a heavy mineral separation liquid. The obtained heavy minerals were washed and air-dried before mounting them on glass slides using Canada basalm. The slides were viewed with the aid of a microscope to identify and quantify the heavy minerals. Mineralogical maturity was determined using the ZTR index from the combined percentages of Zircon, Tourmaline and Rutile relative to the total heavy minerals present, and compared to a specific value following Hubert (1962), Bankole *et al.*, (2019) and Ijaleye *et al.*, (2021).

Field observations and laboratory results were interpreted in line with established procedures. Descriptions and interpretations of lithofacies were done after Akande *et al.*, (2005), Boggs Jr, (2006), Nichols, (2009), Ojo and Akande, (2012), and Adepoju *et al.*, *(*2019). The statistical parameters which include means, standard deviations and skewness were interpreted after Folk (1974)**,** Friedman, (1961), and Miola and Weiser, (1968). Mineral assemblages were interpreted following Pettijohn *et al*., (1973 and 1987), Folk, (1974), Dickinson and Suczek (1979), Morton (1985), Tucker, (1988), Mange and Maurer (1992), Bankole *et al*., (2019) and Ijaleye *et al*., (2021).

RESULTS AND DISCUSSION

Lithofacies

The exposed sedimentary rocks in the study areas were identified as Bima Formation and Dukul Formation. The Bima Formation is essentially sandstone (plate1), with a maximum surficial thickness of 4.3m recorded at Kpasham among the areas studied. The section at Mayolope is a1.2m thick bed**,** parallel stratified, poorly sorted, coarse sandstone (figure 2). At Taana, the section is 0.6m thick, massively bedded, poorly sorted, fine to medium sandstone with brown colour (figure 3). The sequence at Bille consists of 0.53m thick, massively bedded, poorly sorted, medium to coarse sandstone with whitish-grey colours at the base. It is overlain by 1.83m thick, parallel stratified, poorly sorted, medium to coarse sandstone with brown colour (figure 4). The successions of rocks at Kpasham consist of a 1.2m thick bed, parallel stratified, medium sandstone with whitish-brown colour at the base. It is overlain by 1.7m thick, massively bedded, poorly sorted, fine to medium sandstone characterized by white and purple colourations. This bed is succeeded by 0.4m thick, massively bedded, poorly sorted, pebbly to coarse sandstone with white colour and capped by 1m thick, massively bedded, medium sandstone with white colours (figure 5).

The Dukul Formation which was exposed at Abare consists of marlstone, mudstone, limestone and siltstone (plate2). The sections at Abare, location 2a, consist of 1.3m thick, massively bedded, whitish to grey-coloured, weakly consolidated marlstone extending from the base to the upper part. A dark-coloured, 0.16m thick, fossiliferous limestone with phosphatic particles succeeded the marlstone. On top of the limestone lies a 0.4m thick bed of calcareous mudstones that is capped by 0.1m thick, non-fossiliferous limestone with phosphatic particles (figure 6).

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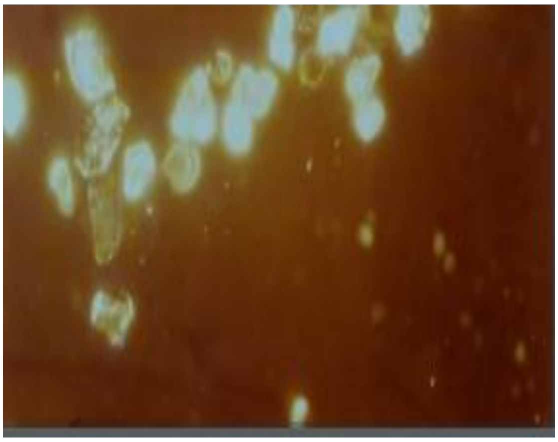
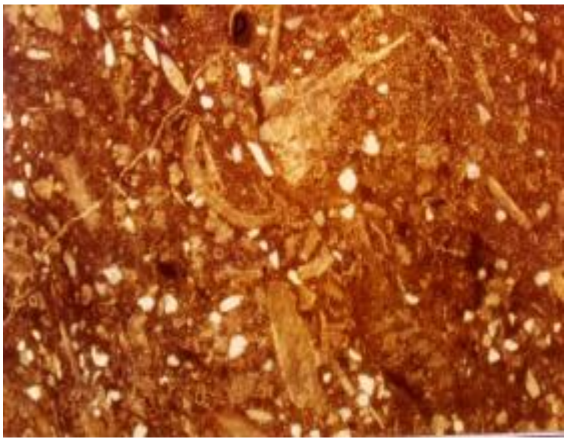
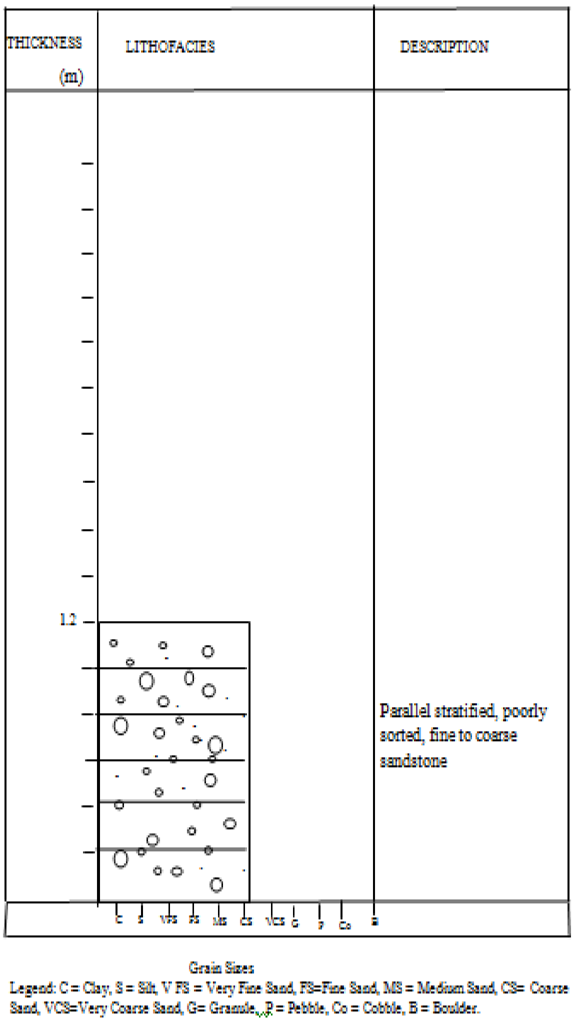
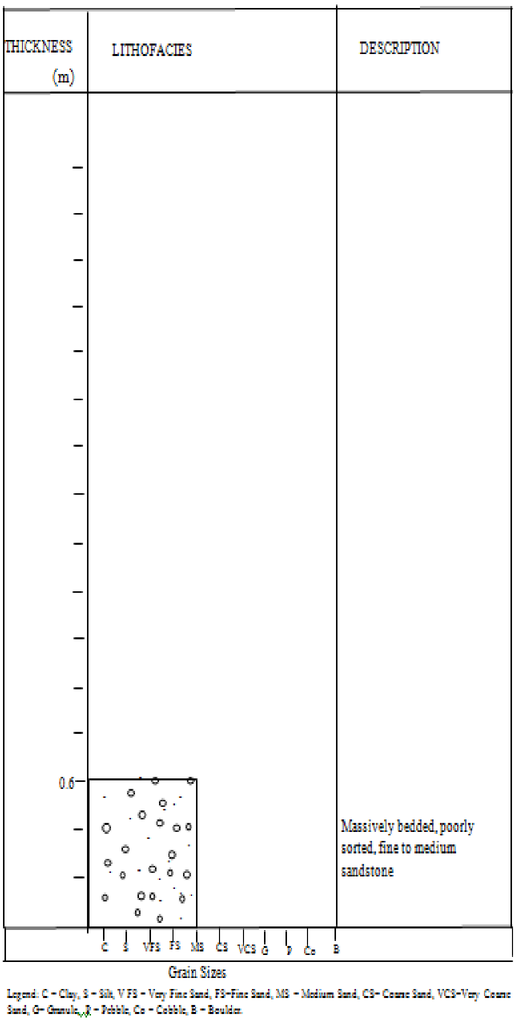
The sequences of exposed rocks at Abare, location 2b, consist of a 0.54m thick, brownish bed of calcareous mudstone that extends from the base to the middle of the section. The middle and the top of the section are intercalations of limestones and siltstones; an indurated, dark-brown coloured, 0.26m thick, ferruginous limestone at the middle of the section is succeeded by 0.1m thick, dark-grey coloured, siltstone that is overlaid by 0.1m thick, pink- coloured limestone and capped by 0.11m thick bed of grey-coloured siltstone (figure 7).


Plates 1 and 2 show the lithofacies of the Bima Formation at Bille and the Dukul Formations at Abare respectively.

Plates 3 and 4 show the heavy minerals in the sandstones of the Bima Formation and allochems in the limestones of the Dukul Formation respectively.





Figures 2 and 3.Graphic logged section of the Bima Formation exposed at Mayolope and Taana respectively.

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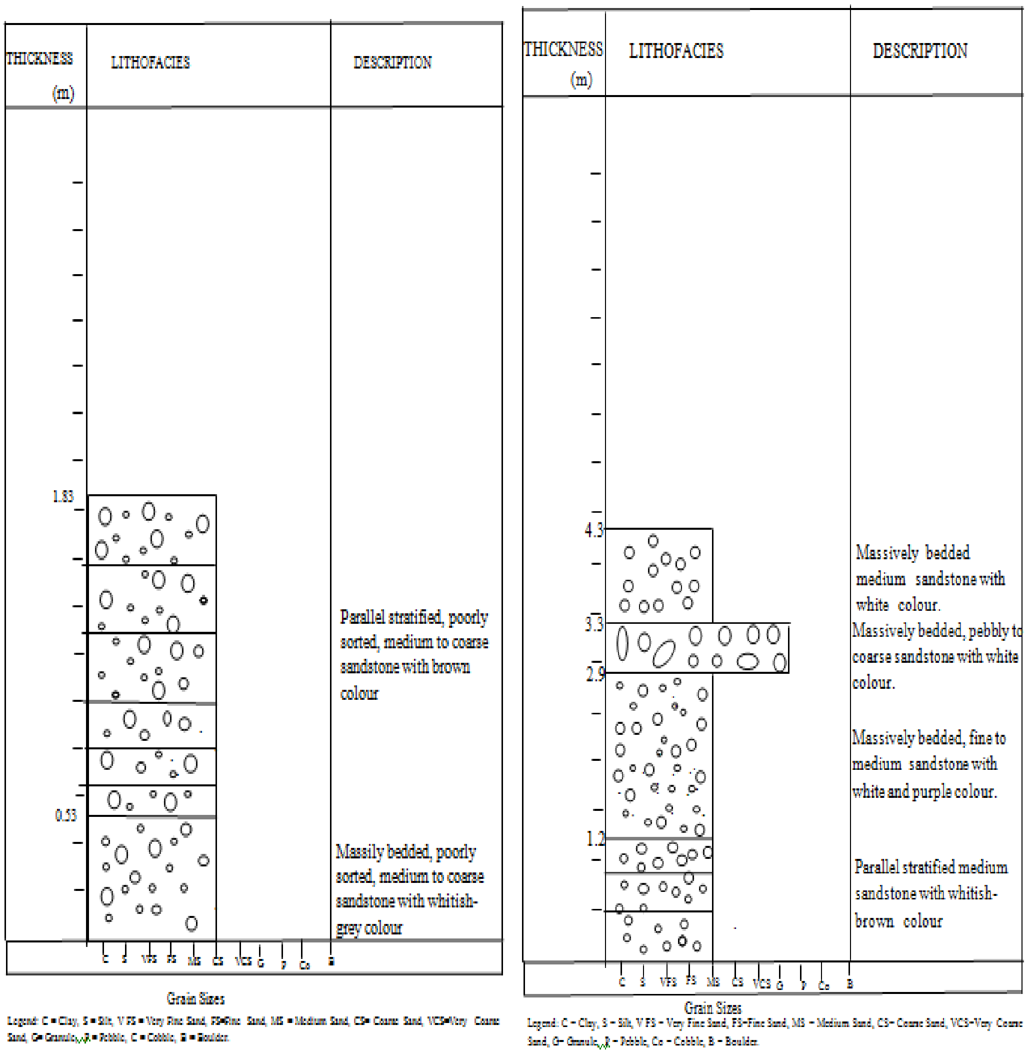
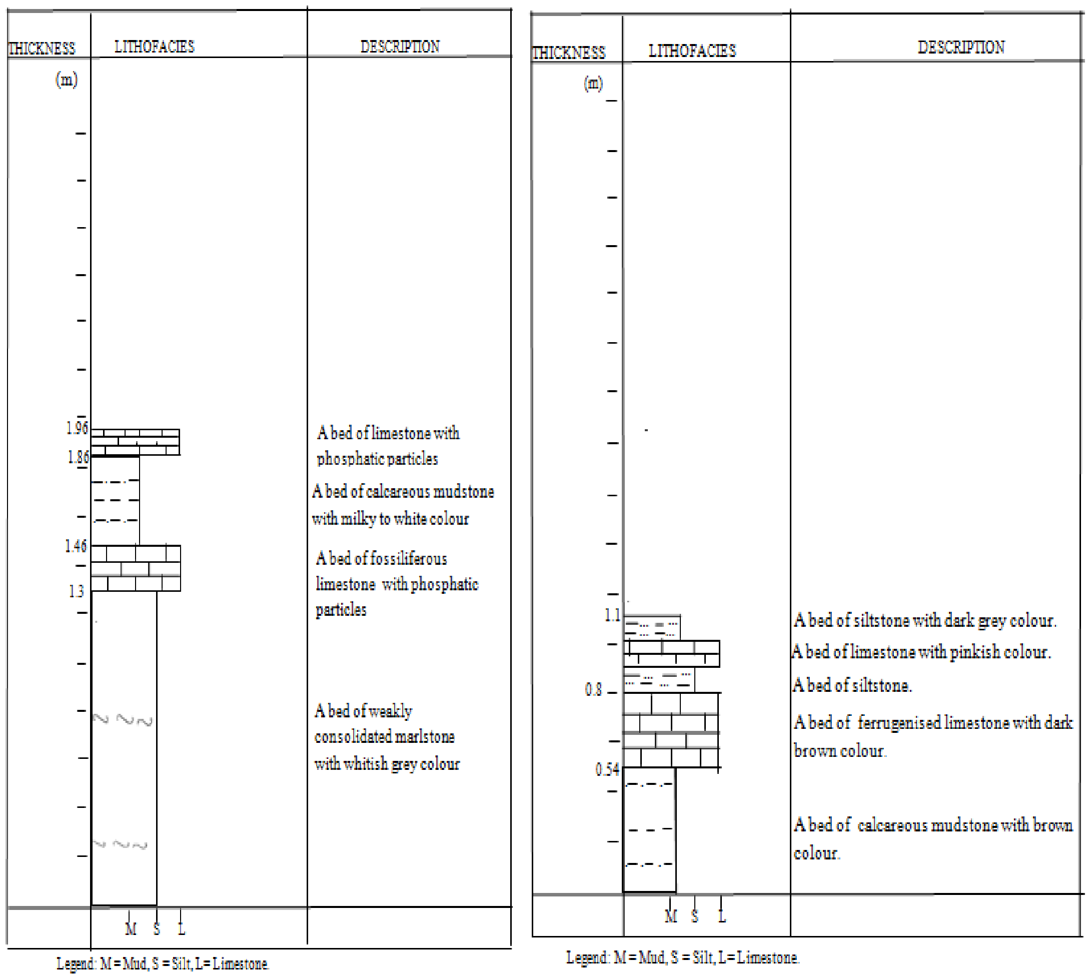


Figures 4 and 5.Graphic logged section of Bima Formation exposed at Bille and Kpasham respectively



Figures 6 and 7. Graphic logged section of Dukul Formation exposed at Abare, locations 2a and 2b respectively.

Grain Size Distribution

The results of the grain size analysis of eight samples are presented in Table 1. The mean grain sizes for samples from Mayolope ML_l, ML_m and ML_u (lower, middle and upper parts of the bed), and Bille (BL1 and BL2) are 0.83ф,0.77ф and 0.83ф respectively, and they suggest coarse sands. The mean grain sizes of samples from Kpasham (KL2, KL3 and KL4) are 2.07ф, 0.47ф and 1.33ф suggesting fine, coarse and medium sands respectively, (after Folk,1974 and Wentworth,1922). The standard deviation values of all the samples range from 1.34 to 1.95ф, showing that the sediments are poorly sorted. The measure of symmetry of the distribution was given by skewness. It was inferred that samples ML_l, $ML_m$and ML_u with skewness value of-0.005ф are near symmetrical. BL1,BL2 and KL4 with values -0.22ф, -0.21ф and -0.26ф respectively are coarse skewed while sample KL2 with -0.38ф is strongly coarse skewed and sample KL3 with value 0.19ф is fine skewed, (after Folk,1974).

Scientia Africana, Vol. 23 (No. 2), April, 2024. Pp147-160
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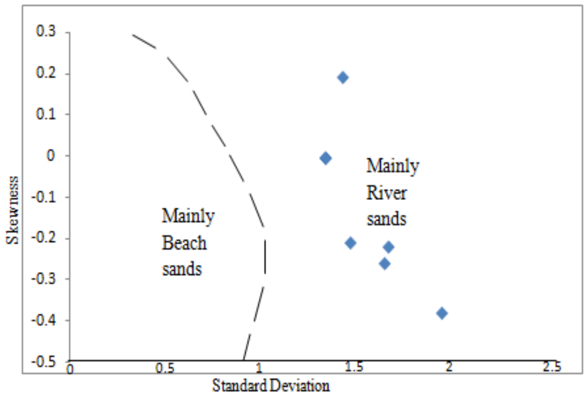
Table1. Results of grain size analysis of Bima sandstones

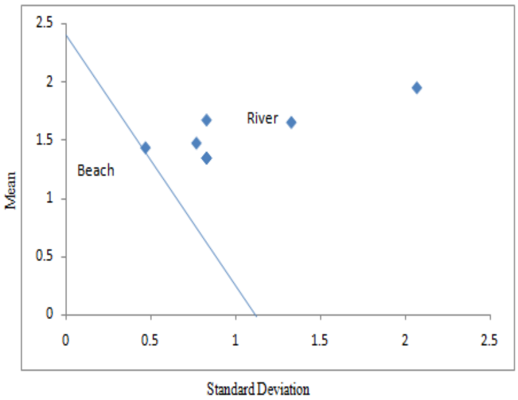
Sample Numbers	**Graphic Mean**	**Standard Deviations**	**Skewness**	**Interpretations**
KL2	2.07	1.95	-0.38	Strongly coarse skewed, poorly sorted, fine sand
KL3	0.47	1.43	0.19	Fine skewed, poorly sorted, coarse sand
KL4	1.33	1.65	-0.26	Coarse skewed, poorly sorted, medium sand
BL2	0.77	1.47	-0.21	Coarse skewed, poorly sorted, coarse sand
BL1	0.83	1.67	-0.22	Coarse skewed, poorly sorted, coarse sand
ML_u	0.83	1.34	-0.005	Near symmetrical, poorly sorted, coarse sand
ML_m	0.83	1.34	-0.005	Near symmetrical, poorly sorted, coarse sand
ML_l	0.83	1.34	-0.005	Near symmetrical, poorly sorted, coarse sand

Paleoenvironment of deposition

Previous work in the Yola Basin showed that the Bima sandstones were deposited in a continental environment (Braide, 1992a). In the present study, the paleodepositional environment was inferred from the characteristics of facies and granulometric analysis. The planar stratified coarse sandstone facies suggest deposition of sediments by traction transport at relatively low flow velocity while the planar stratified medium to coarse sandstone facies can indicate deposition of sediment by traction transport in rivers at high flow velocity, after Bogg Jr,(2006) and Nichols,(2009).The massively bedded sandstone facies can indicate an absence of transportation by traction and probably a result of rapid deposition from a concentrated mix of sediments and water such as debris flow. Alternatively, it could be a liquidized flow deposit; a thick and poorly sorted sand bed which formed by liquefaction. The process is associated with destruction of original stratification of sediments soon after deposition to form massive bedding. Otherwise, it could be an illusion of an apparent structureless bed that may require more techniques such as X-ray and staining methods to check for the presence of not visible internal structures (Pettijohn *et al.*, 1987 and Bogg Jr,2006). Evidence for continental environment was made clearer by the derivatives from the grain size statistical parameters after Friedman, (1961) and Moiola and Weiser, (1968) which showed that the sediments were river sands, hence, deposits of continental settings (figures 8 and 9).

Fine-grained lithofacies and limestones like those seen in the Dukul Formation are often associated with marine settings, as siltstones, mudstones and marlstones are linked to quiet and low-energy environments. However, additional studies like biostratigraphy can help to ascertain the specific paleoenvironment. By their interpretations of fossil contents of the Dukul Formation, Mode (1993), Mamman and Obaje,(2006), and Mamman et al, (2007) concluded that the formation was deposited in an anoxic, low-energy, open marine setting.





Figures 8 and 9. Grain-size bivariate graph of skewness versus standard deviation (after Friedman, 1961) and grain-size bivariate graph of mean versus standard deviations (after Moiola and Weiser, 1968) respectively, showing that the samples of Bima Formation plotted in the field of the river.

Petrography

Microscopic study of the framework minerals of Bima sediments revealed that quartz is the dominant mineral. It constitutes about 95 to 100% of the identified minerals in the rock samples. They occur as polycrystalline quartz in the samples from Taana (TN), Kpasham (KL2) and Mayolope (ML_m). The grains are closely packed; having contact with each other and showing grain-support fabrics. Two types of grain-to-grain contacts observed are sutured and long. The sutured contacts are more than the long contacts. The close-packing of the grains suggests that the sediments were compacted due to overburden. In the other samples from Kpasham (KL1, KL3 and KL4) and Bille (BL1 and BL2), the quartz minerals occur as monocrystalline quartz. The sediments have loosely packed fabrics and the grains are bound to the matrix. The shapes of quartz in all the samples vary from subangular to subrounded and their sizes range from fine to coarse grains. The shapes suggest a short period of transportation of sediments from their source while the variation in sizes indicates poor sorting. Other components of framework minerals such as feldspars mica, and rock fragments are not noticeable. Their absence suggests a high degree of disintegration and chemical weathering of the source rocks. Modal compositions of quartz, feldspars and rock fragments are useful in classifying sand stones (Pettijohn, 1972) and determining the tectonic fields of the source rocks (Dickinson and Suczek, 1979). Accordingly, the samples TN, KL2 and ML_m which contain almost 100% quartz grains in the absence of matrix are classified as quartzarenite while samples KL1, KL3, KL4, BL1 and BL2 with a very high proportion of quartz in a matrix are classified as quartzwacke. By plotting the percentage compositions of quartz in the QFL ternary chart, all the samples fell within the tectonic field of the craton interior (figure 10).

Microscopic observations of the Dukul Formation by thin-section analysis of limestone samples from Abare revealed the presence of allochems including bioclasts, lithoclasts and some peloids in a matrix-supported fabric (plate 3). By comparing the ratio of carbonate mud to biogenic fragments (after Dunham,1962), the limestones under present investigations are inferred from a large proportion of shell fragments to be bioclastic packstones.

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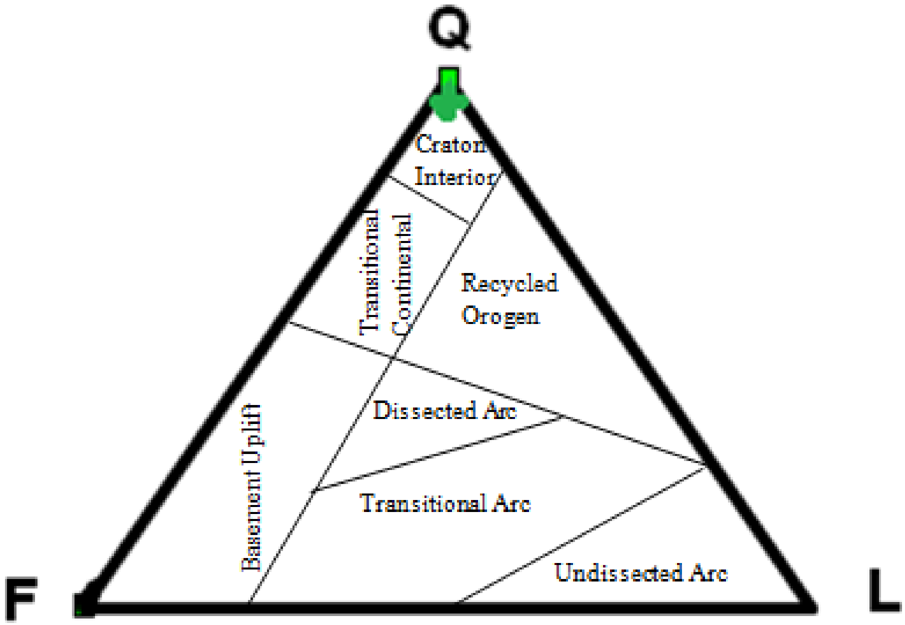

Figure 10.QFL Chart showing the tectonic field of the Yola arm, Northern Benue Trough (after Dickinson and Suczek, 1979). All the samples fall within the field of craton interior.

Q-total Quartz, F-Feldspar and L-lithic rock fragments.

Heavy Minerals

The results of heavy minerals identified in the samples are presented in Table 2. Non-opaque minerals are Zircon, Tourmaline, Staurolite, Apatite, Sphene and Rutile (plate 4). Zircon and Tourmaline are more common than others and are present in all the samples. Sphene and Apatite are rare; each occurs in small numbers and three samples. All samples but one has Rutile. The numbers of Zircon vary from 5 to 15 with a total of 70 counted in all the samples, representing about 38.7% of the non-opaque heavy minerals. The numbers of Tourmaline vary from 3 to 12 with a total of 46 counted in the samples and representing about 21.4% of the non-opaque heavy minerals. The proportions of other non-opaque heavy minerals are Rutile (16.7%), Staurolite (11%), Sphene (5.5%) and Apatite (2.8%).

Heavy minerals have been interpreted and applied to determine sources of sediments, mineralogical maturity and sediments stability (Pettijohn *et al.*, 1973, Morton, 1985, Mange and Maurer, 1992, Bankole *et al.*, 2019, and Ijaleye *et al.*, 2021)**.**The ones encountered in the present study were interpreted likewise and it was inferred from the presence of Zircon and Tourmaline with a combined percentage composition of 60.1% that the sediments were derived from igneous or low-grade metamorphic rocks, and that Rutile and Staurolite with a total composition of 27.7% suggest contributions from high-grade metamorphic rocks. Assessment of sediment stability from heavy mineral stability index shows that the ultra-stable mineral group represented by Zircon (39.6%),Tourmaline (26%) and Rutile (15.8%) with a combined percentage composition of 81.4% dominates the mineral suites followed by the stable mineral group represented by Staurolite (10.2%), hence, the sediments are generally considered to be ultra-stable. The calculated ZTR index ranges from 56.7 to 100% with values less than 75% indicating immature to sub-mature sediments and greater than 75% showing mineralogically matured sediments, Table 2.

Table 2shows the proportion of heavy minerals in the samples.

Samples	Zir con	Tourmaline	Staurolite	Apatite	Sphene	Rutile	Total non-opaque	Z+T+R	ZTR % index
BL2	5	5	5	2	-	3	20	13	65
BL1	7	3	2	-	-	3	15	13	86.7
KL2	5	3	-	-	-	5	13	13	100
KL3	7	3	4	-	2	2	18	12	66.7
KL4	11	9	-	2	-	-	22	20	90.9
TN	12	8	-	-	-	5	25	25	100
KL1	8	3	7	-	5	7	30	17	56.7
ML	15	12	-	1	3	3	34	30	88.2
Total	70	46	18	5	10	28	177	145	81.9
Percentage abundance of individual minerals	39	26	10.2	2.8	5.7	15.8			

CONCLUSION

Studies of the Bima and Dukul Formations were successfully undertaken indifferent localities withinYola Basin, northern Benue Trough, in the north-eastern part of Nigeria. The results revealed that the Bima sandstones were derived from the older basement complex rocks and deposited in a continental depositional setting while the Dukul Formation was deposited in a marine setting. The present results correspond to earlier reports on the formations in distant geographic locations, therefore showing the extent of lateral continuity of the formations in the Yola Basin.

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