https://dx.doi.org/10.4314/dujopas.v9i2a.6
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490

Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 9 No. 2a June 2023*

Sedimentological study of Bima Sandstone in Dumne and Environs, Yola Sub-basin, Upper Benue Trough, Northeastern Nigeria.

A. Amodu [a*]; Gambo I. Ndah [a]; Yunis B. Valdon [a]; Hifzullah A. Ahmed [a]

[a] Department of Geology,
Modibbo Adama University,
Yola, Adamawa State, Nigeria

Email adeniyiamodu@mau.edu.ng

Abstract

Field mapping was carried out on Bima sandstone from Dumne and its environs with the aim to understand the geology and determine the paleoenvironment of deposition. The integrated (outcrop study with granulometric and pebble morphometric) studies were used to achieve this aim. Based on outcrop studies, nine (9) lithofacies were identified from the proximal alluvial fan facies to the mid-fan braided river: massive, matrix-supported, gravel-dominated facies (Gmm); matrix-supported gravel (Gmg); clast-supported gravel stratified (Gh); gravel stratified trough cross-bedded sandstone (Gt); trough cross-bedded sandstone (St); planar cross-bedded sandstone (Sp); ripple cross-laminated sandstone (Sr); massive sandstone (Sm) and silt and mud (Fsm). The outcrop sampled materials were subjected to granulometric and morphometric analyses. The result of the granulometric shows that the Bima sandstones of the study area have an average graphic mean (Mz) of 0.82 (coarse grains), an inclusive graphic standard deviation (δi) of 1.33 (poorly sorted), a graphic kurtosis (K) of 1.11 (leptokurtic), and an inclusive graphic skewness (Ski) of 0.17 (positive skewed). The result of the pebble morphometrics shows that the grains have an average elongation ratio (ER) of 0.80, coefficient of flatness (FI) of 60.6%, oblate–prolate index (OPI) of 0.35, maximum projection sphericity index (MPSI) of 0.77 and roundness (ρ) of 0.43. The roundness versus elongation ratio plot indicates a fluvial to transitional environment. Several bivariate and ternary plots that include the granulometric and pebble morphometric data suggest a river environment for the Bima sandstone in the studied area.

Keywords: Field mapping, Bima sandstone, Lithofacies, Paleoenvironment, Outcrop

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 (Falconer, 1911; Carter, 1963). In detrital sedimentary rocks, the surface characteristics of the grains make up the particle morphology. These forms were acquired by the sedimentary grains during denudation processes such as weathering, erosion, and transportation (Benn, 2010; Dumitri et al., 2011). Data generated through morphometric analysis are used to give important insight on sediment source origin, transportation history, and sedimentation processes as well as in paleoenvironmental determination (Hurst et al., 2010; Okosun et al., 2009; Okoro et al., 2012; Zarma et al., 2015; Salihu et al., 2017).

In order to identify the depositional process and environment, sediments from various basins throughout the world have been studied using the integration of granulometry and pebble

**Author for Correspondence*

morphometric techniques. For the interpretation of ancient depositional settings and transport conditions, a full understanding of the nature and significance of sedimentary textures is essential (Boggs, 2014). Numerous scholars have studied the morphology and granulometry of the basin that makes up the study region (Opeloye, 2012; Zarma et al., 2015; Etobro et al., 2020; Finthan et al., 2022), but pebble morphometry has not been used to investigate the Bima sandstone that surrounds the study area. This is one of the driving forces behind the undertaking of this work.

To describe the geology and establish the paleoenvironment of the Bima sandstone, thorough field mapping and sampling were done in the study area. The study area (Dumne and its environs) is situated in Song Local Government Area of Adamawa State (Fig. 1). In order to better understand the lithostratigraphic unit and depositional environment, the study aim to combine outcrop data with statistical parameters from granulometry (Mean Mz; Standard Deviation δi; Skewness Ski; and Kurtosis K) and pebble morphometric indices (Elongation Ratio ER; Coefficient of Flatness CFI; Maximum Projection Sphericity Index MPSI and Oblate–Prolate Index OPI).

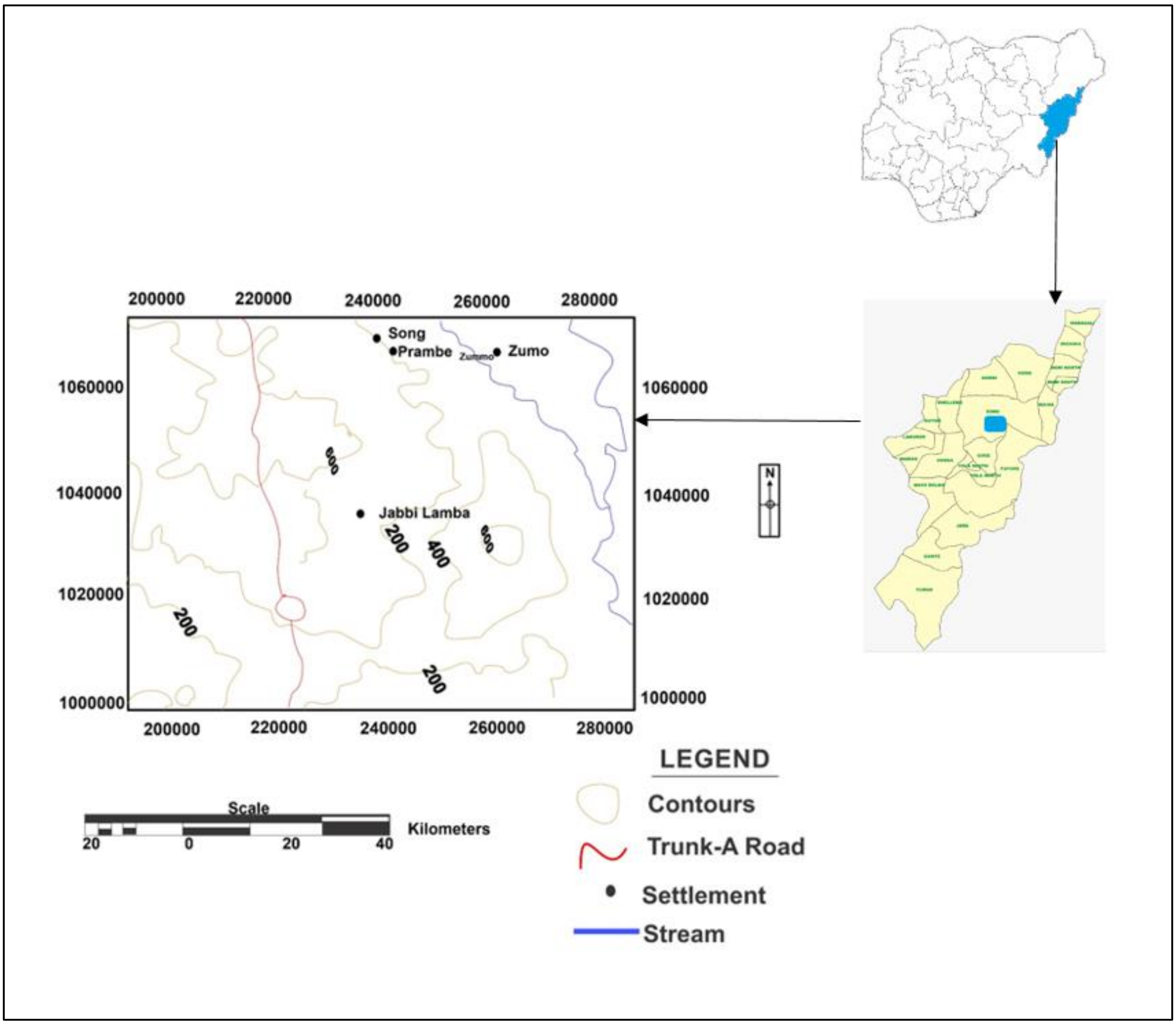

Figure 1: Location map of the study area (after U.S.A Survey Agency, 2010)

Geological Setting

The Bima Sandstone is the oldest, thickest, and widely most exposed Cretaceous sediments in the Upper Benue Trough (Carter et al., 1963; Guiraud, 1990). The Upper Benue Trough is subdivided into two sub-basins namely; the E-W trending Yola Arm and the N–S Gongola Arm and the Bima sandstone of the study area lies on the E-W trending Yola Arm. The stratigraphy of the Yola Arm is composed of Cretaceous sequences that overlies the Precambrian basement complex. This is unconformably overlain by Aptian-Albian continental Bima Sandstone (Carter et al., 1963; Guiraud, 1990). The non-marine Bima Sandstone is overlain by the Yolde Formation which is transitional in nature, the formation is composed of shale sandstone intercalation from the bottom and it pass into siltstone and carbonate rock, the Yolde Formation is overlain by the transgressive Dukul Formation which is purely marine deposit characterised by thick grey shales that pass up into thin silty bed of shale limestone intercalation, in an upward sequence, the formation is overlain by transitional Jessu Formation, marine Sekuliye, Numanha Formation and finally capped by the Lamja Formation (Fig. 2).

METHODOLOGY

Investigation techniques included both field work and laboratory analysis. The exposed outcrop areas, particularly roads and river channels, were mapped, logged, and described. Analyses of granulometry and pebble morphometry were performed on representative rock samples.

Granulometric Analysis

Samples obtained were subjected to Grain size analysis. A mortar and rubber-padded pestle was used to disaggregate the six (6) chosen representative samples after they had been air dried. Then, using the Ro-tap mechanical shaker, they were weighed and sieved for particle-size distribution in accordance with established standards. On an arithmetic graph, grain size distribution plots.

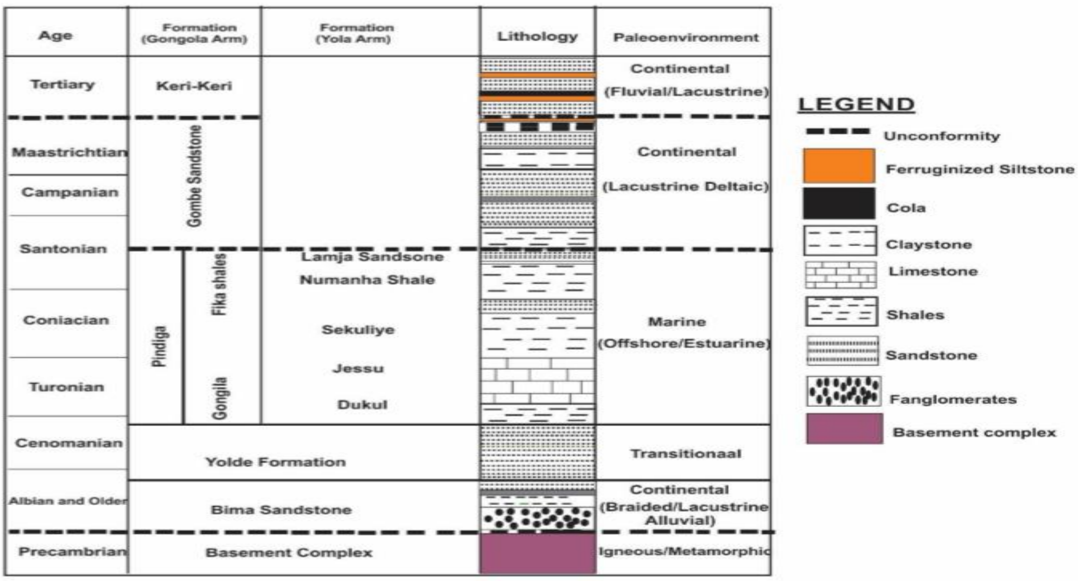

Figure 2: The Stratigraphic Succession of the Upper Benue Trough (adopted from Finthan and Mamman, 2020).

(cumulative frequency curves) were created. The needed univariate statistical characteristics for sieve analysis—mean size (Mz), sorting/standard deviation (σ), skewness (Ski), and kurtosis (Kg) were calculated from the graphs using the phi values of specific weight percentages (5%, 16%, 25%, 50%, 84%, and 95%). (Folk and Ward, 1957). The depositional environment of the study area was interpreted using the bivariate plots of Friedman (1967); Moiola and Weiser (1968); and Sahu (1964).

Pebble Morphometry

80 unbroken samples of pebbles were obtained, cleaned, and numbered for the morphometric study. The long (L), intermediate (l), and short (S) axes of pebbles were measured using a Vernier caliper in accordance with Ocheli et al. (2018). By comparing each pebble's appearance to those in Same's chart photographs, it was possible to establish how round each one was (Sames, 1966; Okoro et al., 2012). The pebble's roundness and the values of L, I, and S were utilized to determine and calculate the flatness ratio, flatness coefficient, oblate prolate index, maximum projection sphericity index and shape of the pebbles (Dobkins and Folks, 1970; Stratten, 1974). In order to identify the form classes of the pebbles obtained at various outcrop locations, the parameters ratios were also plotted on the Sphericity-Form Diagram of Sneed and Folk (1958) using the Tri-Plot program (Graham and Migley, 2000).

RESULTS AND DISCUSSION

The lithofacies description of the exposed outcrops as well as the outcomes of the laboratory (granulometric and morphometric) analyses were presented, and their interpretations are discussed below.

Lithostratigraphy Section

The lithostratigraphic section of the study area is depicted in figure 3. Nine (9) lithofacies were identified from the proximal alluvial fan facies to the mid-fan braided river: massive, matrix supported gravel dominated facies (Gmm); matrix supported gravel (Gmg); clast supported gravel stratified (Gh); gravel stratified trough cross-bedded sandstone (Gt); trough cross-bedded sandstone (St); planar cross-bedded sandstone (Sp); ripple cross laminated sandstone (Sr); massive sandstone (Sm) and silt and mud (Fsm).

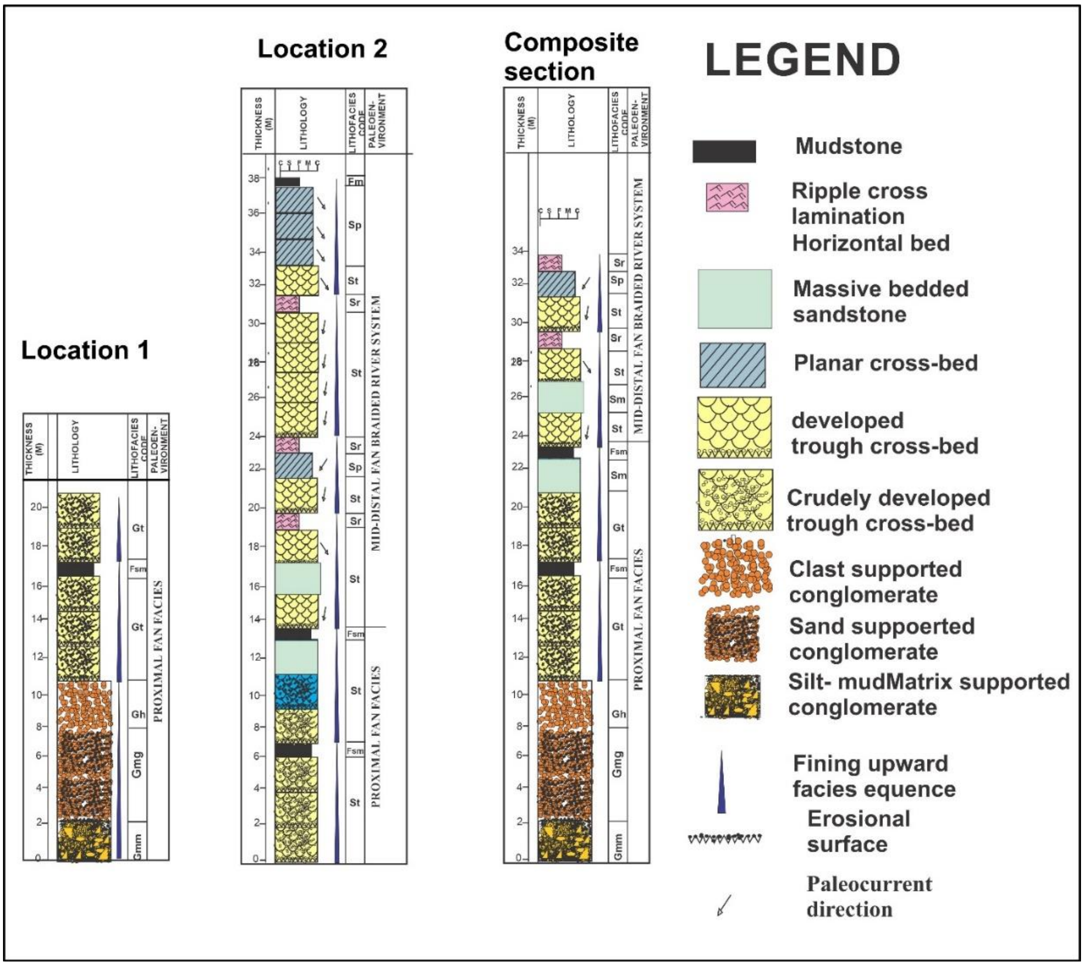

Figure 3: Lithostratigraphic section of the Study Area

Gravel dominated facies
Gmm Facies:

Very coarse-grained, angular quartz and feldspathic pebbles, cobbles, and boulders make up the facies Gmm (Fig. 3, Location 1). The length of the unstratified bed of the facies Gmm is around 2 m. The diameter of each angular quartz fragment varies between 0.5 and 1.7 cm. Additionally, it is evident that a crisp line separates each amalgamated unit from the others. The detrital sediments of the Gmm facies are estimated to be 10–20% abundant and the Gmm facies is frequently overlain by the matrix-supported gravel Gmg facies. The lithofacies Gmm from the study area corresponds to the work of Miall, (1977, 1978, 1996); Rust, (1978) and Finthan & Mamman, (2020)

Gmg Facies:
The lithofacies is characterized by poorly sorted rock materials, the clasts are floating in between mud matrix, the bedding geometry of the Gmg facies is internally unorganized without any type of erosional surfaces, though it showed sharp boundaries and lateral terminations, and the pebbles are not imbricated (Fig. 3, Location 1). The characteristics of the lithofacies show low-strength, viscous pseudo-plastic debris flows, which are opposite to the regular grading processes of deposition (Miall, 1977 and 1978; Opeloye, 2012; Finthan and Mamman, 2020).

Gh Facies:
Gravels with a rough bed supported by a clast (Fig. 3, Location 1). The rock is layered horizontally and is coarse, pebbly, clast-supported conglomerate with sporadic cobbles. Contrary to the former, which is matrix-supported, and the bedding contacts are weakly exhibited, the conspicuous clasts framework is in the form of grained to grained contact. The fact that this facies is well imbricated suggests that the amount of gravity-controlled deposition has decreased and may perhaps mark the start of streamflow influence. Furthermore, it also reflects longitudinal bedform, lag, and sieve deposit (Miall, 1978; Finthan and Mamman, 2020).

Gt Facies:
The sandy matrix, poorly sorted, coarse to very coarse grained, pebbly-cobbles sandstone constitutes the trough cross-bedded gravels facies. Conglomeratic gravels with a coarsely formed trough and a cross-bedded kind of stratification best describe these rocks. The average foreset angle of this dip is 20^0. The thickness of each individual bedding unit ranges from 0.7 to 1.5 meters (Fig. 3, Location 1 and 2). Collinson, (2002) regarded these facies as channel control debris flow deposit, while (Miall, 1978 and 2010) referred to this as minor channel fills.

Fsm Facies:
Silt-mudstone facies (Fig. 3, Location 1 and 2). The Fsm facies is connected with sandy conglomerates of the Gmg and St lithofacies and frequently contains pebbles. The silt-mudstone facies is greyish to light brown, and it is vertically 70 cm thick and laterally 2 m wide. Most likely, these deposits are from a type of backswamp (Miall, 1977 and1978; Rust, 1978; Finthan and Mamman, 2020).

Sand Dominated Facies

St Facies:
Trough cross-bedded sandstone (Fig. 3, Location 2). This St facies is primarily very coarse to pebbly in texture, sporadically angular to sub-rounded, and its base units are frequently characterized by noticeable quartz conglomerate. sometimes, it lags deposits made of mudclasts. Individual coset thicknesses range about 1 m, while amalgamated coset thicknesses range from 1.4 m to 5.8 m. However, trough cross-bedded sandstone is frequently covered by either ripple cross lamination (Sr) or planar cross-bedded (Sp). This lithofacies was created by the 3-D migration of sinous crested and linguiod dunes (Miall, 1977, 1978, 1996, 2010; Tucker, 2003; Plint, 1983; Finthan and Mamman, 2020).

Sp Facies:
Sandstone with planar cross-bedding. There is little presence of iron concretion in certain areas and the facies is medium to very coarse grained, moderately to poor sorted, and brown to reddish in color. The facies Sp is frequently connected with the trough cross-bedded sandstone (St), and each cross-thickness bed's (or forset) varies from 1-2 cm. It frequently has ripple cross lamination (Sr)/mudstone as a top layer (Fm) and trough cross-bedded facies (St) as an underlayer. This lithofacies likely point to sand avalanches on foresets (Miall, 1978). As a result of the migration of a 2D dune with a transverse or linguiod bed form, the boundary surfaces of this lithofacies are flat and devoid of an erosional base; this distinctive feature maintained in the sandstone with planar cross-bedding (Sp) may have been caused by traction and intermittent suspension (Miall, 1977, 1978, 1996, 2010; Finthan and Mamman, 2020).

Sr Facies:
Cross laminated sandstone. The Sr facies is fine to medium grained, the individual cross laminae vary from 0.1 cm and 1cm. This ripple cross laminated sandstone (Sr) typically has trough cross bedded (St) or planar cross-bedded (Sp) as underlayer (Fig. 3, Location 2). This facies is assumed to have evolved due to ripples movement depending on flow velocity and rate sediment supply in the medium of deposition (Allen, 1984; Opeloye, 2012).

Sm Facies:
Massive sandstone facies (Fig. 3, Location 2). The Sm facies is medium, coarse, to pebbly grained. It appeared to be massive. The thicknesses vary from 1.5 m to 2.5 m, it displays normal grading and interpreted as gravity flow deposit (Miall, 1977, 1978 and 1996; Opeloye, 2012; Finthan and Mamman, 2020)

Granulometric Analysis
Table 1 displays the percentile values from the granulometric analysis for the six samples. Table 2 displays the findings from statistical analyses of the studied samples, which were then used to compare the outcomes of univariate and bivariate analyses. The results and explanation for the grain size summary are shown in Table 3. The mean of sandstones from samples 1 to 6 varies between 0.2 – 1.2 with an average grain size of 0.82. These suggest that the sandstones are medium to coarse grained, which indicates a depositional environment with intermediate to high energy (Folk and Ward, 1957). The sandstones are coarse grained on the average. The range of the sorting's standard deviation, which is measured, is 1.12 to 1.50, with an average of 1.33.

Table 1: Percentile values from the graphic plot

Samples	5φ	16 φ	25 φ	50 φ	75 φ	84 φ	95 φ
1	-1.4	-0.7	-0.45	0.2	0.8	1.15	3.0
2	-1.0	-0.5	-0.2	0.4	1.0	1.6	3.2
3	-0.9	-0.25	0.95	1.0	2.3	2.7	3.6
4	-1.2	-0.3	0.1	0.95	2.2	2.45	3.6
5	-1.6	-0.65	-0.2	0.65	1.9	2.4	3.4
6	-1.0	-0.15	0.25	1.1	2.0	2.6	3.4

Table 2: Result of Mean, Standard Deviation, Skewness and Kurtosis of Samples analyzed Using Graphic Method

Samples	Mean size	Sortings	Skewness	Kurtosis
1	0.2	1.12	0.28	1.39
2	0.5	1.16	0.24	1.43
3	1.15	1.42	0.15	0.84
4	1.08	1.46	0.15	0.94
5	0.78	1.5	0.11	0.98
6	1.2	1.34	0.08	1.06
Average	0.82	1.33	0.17	1.11

Table 3: Summary of Granulometric results and description (After Folk and Ward, 1957)

Samples	Mean Size	Sorting	Skewness	Kurtosis	Description
1	0.2	1.12	0.28	1.39	coarse sand, poorly sorted, positively skewed and leptokurtic
2	0.5	1.16	0.24	1.43	coarse sand, poorly sorted, positively skewed and leptokurtic
3	1.15	1.42	0.15	0.84	medium sand, poorly sorted, positively skewed and platykurtic
4	1.08	1.46	0.15	0.94	medium sand, poorly sorted, positively skewed and mesokurtic
5	0.78	1.5	0.11	0.98	coarse sand, poorly sorted, positively skewed and mesokurtic
6	1.2	1.34	0.08	1.06	medium sand, poorly sorted, symmetrical skewed and mesokurtic
Average	0.82	1.33	0.17	1.11	Coarse sand, poorly sorted, positively skewed and leptokurtic

These values point to a poor sorting (Folk and Ward, 1957; Ocheli et al., 2018). Poor sorting indicates fluvial-continental settings for the deposition of the sediments (Friedman, 1967; Fithan et al., 2022). The range of the kurtosis value is 0.84 to 1.43, with an average of 1.11. On the basis of this, it ranges from platykurtic to leptokurtic, and on the average the sandstones are leptokurtic. The skewness values range between 0.08 – 0.28 with an average value of 0.17. Blatt et al. (1991) described the skewness ranges as positively skewed to nearly symmetrical. The sandstones are positively skewed based on the average.

The various bivariate graphs, such as those showing skewness versus standard deviation (Fig. 4) and mean grains vs standard deviation (Fig. 5), indicated that all of the sampled sand was mostly from a river (fluvial) environment (Friedman, 1967; and Moiola and Weiser, 1968). Multivariate environmental discriminant functions (Y_3) of Sahu, (1964) was used: $Y_3 = 0.2852Mz - 8.7604\sigma^2 - 4.8932Ski + 0.0482$. If Y_3 is less than (<) -7.4190, the sample indicates fluvial deposit while if Y_3 is greater than (>) -7.4190, the sample indicates the shallow marine deposit. The results obtained from discriminant functions (Y_3) of Sahu (1964) are shown (Tab. 4). The samples are all deposits from fluvial settings

Morphology of pebbles

The coefficient of flatness index ranges from 36% – 85% with a mean value of 60.6% (Tab. 5). Coefficient of flatness index(CFI) was employed by Stratten (1974), Okoro (2012) and Ocheli et al. (2018) to distinguish between river and beach pebble. According to their findings, CFI with a mean value ≥ 45% denotes a fluvial process, whereas values <45% imply a beach setting. On the basis of this, the CFI for the analyzed samples with mean of 60.6% infers fluvial settings. The sample's maximum projection sphericity index(MPSI) has a mean value of 0.77 and ranges from 0.61 to 0.94. (Tab. 5). The MPSI from Dobkins and Folk (1970) was used, MPSI ≤ 0.65 infers beach while > 0.65 infer fluvial. Based on this, the mean MPSI value for the pebbles is 0.77, suggesting that they are product of fluvial process. The OPI ranges from -7.84 to 8.74 with a mean value of 0.35 (Tab. 5). OPI ≥ - 1.5 denotes a fluvial setting, while OPI < - 1.5 denotes a beach process (Dobkins and Folk, 1970). This makes the OPI for the study area with a mean value of 0.35 infer fluvial action.

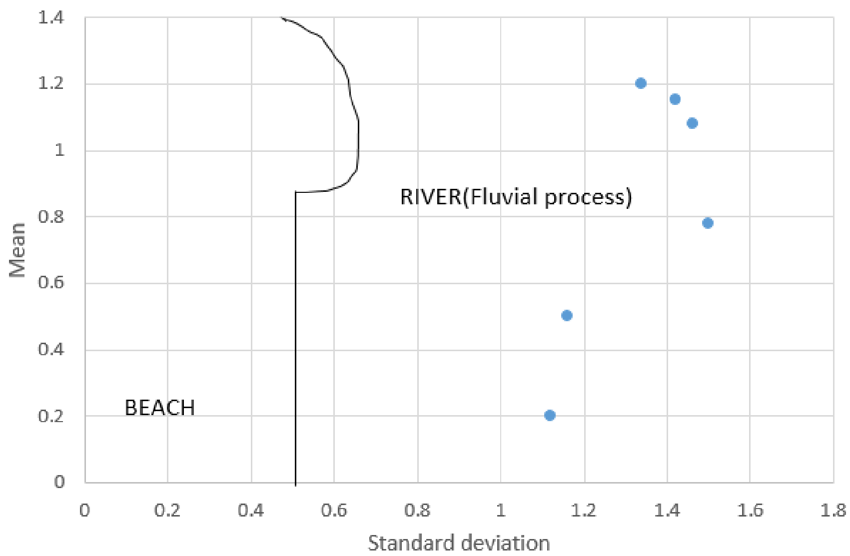

Figure 4: Bivariate plot of mean against standard deviation (After Moiola and Weiser, 1968)

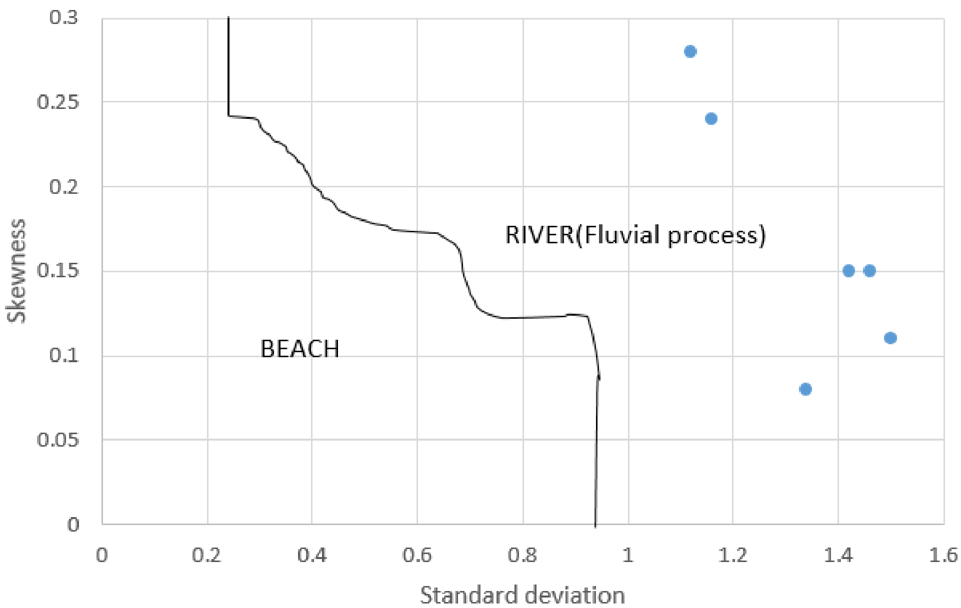

Figure 5: Bivariate plot of skewness against standard deviation (After Friedman, 1967)

Table 4: Multivariate discriminant results and their interpretation

Samples No	Y3: Sahu (1964)	Interpretation
1	-12.2351	Fluvial
2	-12.7509	Fluvial
3	-18.03	Fluvial
4	-19.0544	Fluvial
5	-19.9795	Fluvial
6	-15.7284	Fluvial

Table 5: Pebble form parameters, range values, mean values and their interpretations

Samples	Form Parameters	Range values	Mean values	Interpretation
Samples 1 - 7	CFI	36 to 85	60.6	Fluvial
	MPSI	0.61 to 0.94	0.77	Fluvial
	OPI	-7.84 to 8.74	0.35	Fluvial
	R	0.2 to 0.6	0.43	Fluvial

The range of the investigated pebbles' roundness is from 0.2 to 0.6, with a mean of 0.41. Sames, (1966) determined a limit of 0.45 for the roundness index in fluvial environments. Since the mean roundness is 0.41, a river depositional environment is also suggested.

In Figures 6 and 7, respectively, the bivariate plots of CFI against MPSI and roundness against ER are displayed. The bivariate plot of CFI versus MPSI shows that most of the plots are located in the fluvial region of the graph (Fig.6). The relationship between roundness and ER suggests a fluvial to transitional environment (Fig. 7).

Using the Tri-Plot program (Graham and Migley, 2000), each analyzed pebble was plotted on a Sneed and Folk (1958) diagram (Fig. 8), and the percentages of the form classes were calculated (Tab. 6). According to the analysis of the form indices, compact-bladed, compact-platy, compact-elongated, and compact make up 85% of the plots. Dobkins and Folk (1970) identified Sneed and Folk, (1958) shape classifications that are representative of specific environment. Fluvial environments are characterized by compact (C), compact-bladed (CB), compact-platy (CP), and compact-elongated (CE); transitional environments are characterized by platy (P), bladed (B), and elongated (E); and beach environments are characterized by very platy (VP), very bladed (VB), and very elongated (VE). This led to conclude that the investigated pebbles' form indices were shaped in a fluvial environment. The greater proportion of pebbles that show evidence of fluvial action supported the fluvial processes' dominance.

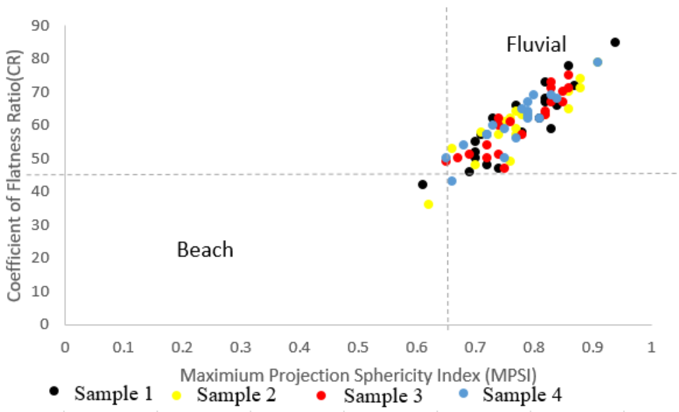

Figure 6: Coefficient of Flatness ratio against Maximum projection sphericity index (After Stratten, 1974)

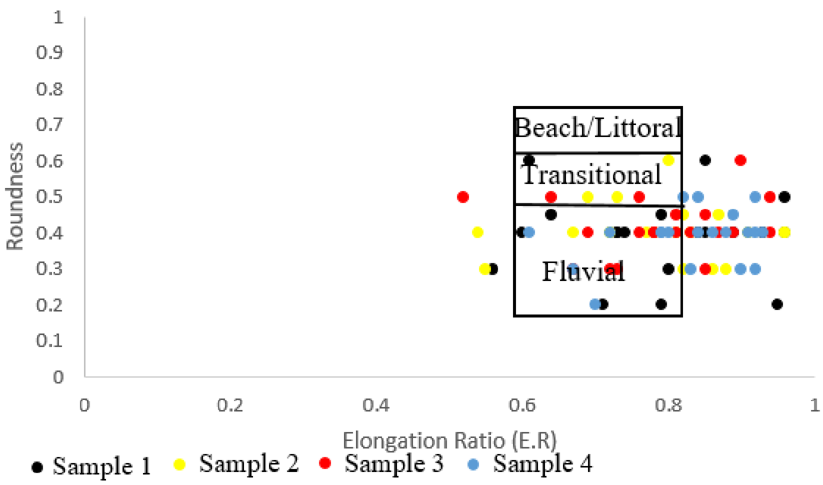

Figure 7: Roundness against Elongation ratio (ER) of the pebbles (After Sames, 1966)

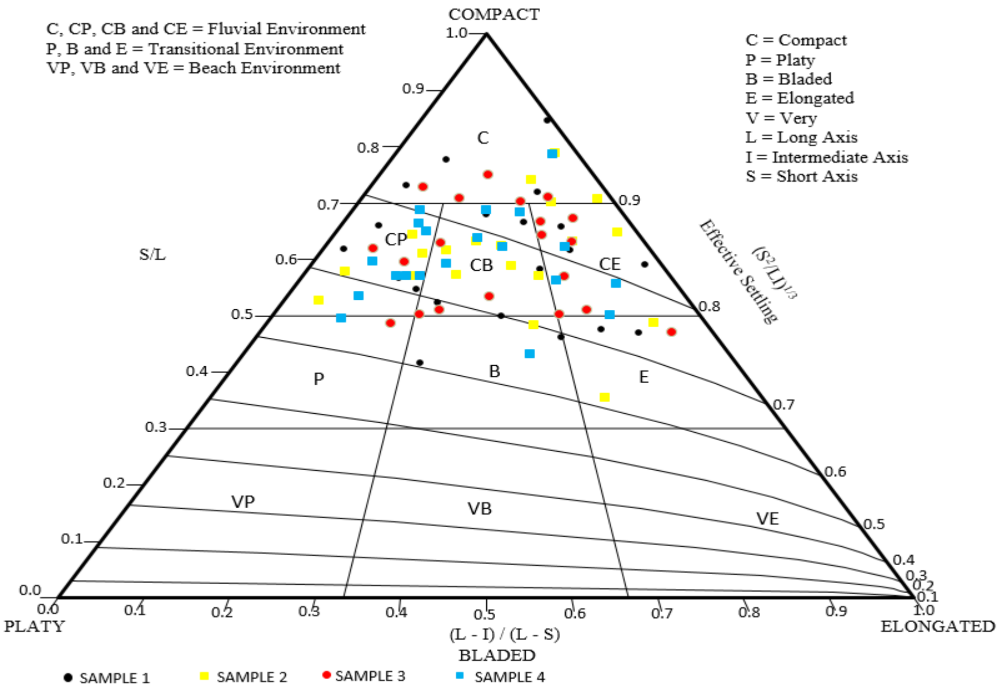

Figure 8: Ternary diagram showing the pebble ratios in the Study Area (After Sneed and Folks, 1958)

Table 6: Percentages of the pebble form classes

Sneed and Folk classes	Count	Percentage
Compact	14	17.50
Compact-Platy	19	23.75
Compact-Bladed	19	23.75
Compact-Elongate	16	20
Platy	2	2.50
Bladed	5	6.25
Elongate	5	6.25
Very-Platy	0	0
Very-Bladed	0	0
Very-Elongate	0	0

CONCLUSION

Geological mapping of the study area shows nine (9) lithofacies which were described and interpreted as the proximal alluvial fan facies to the mid-fan braided river. This study's use of granulometric and pebble morphometric parameters has shown to be a good indicator for differentiating the paleodepositional environments of Bima sandstone. The Bima sandstone in Dumne was primarily deposited in a fluvial setting, though a departure from a fluvial setting is seen, tending towards a transitional environment. This is shown by the various combinations of grain size parameters and those of pebble morphometry integrated with different bivariate plots. The granulometric analysis shows that the grains range in size from medium to coarse and that indicates a moderate to high energy environment of deposition.

ACKNOWLEDGMENT

The authors are grateful to the Department of Geology, Modibbo Adama University Yola, for allowing us access to the laboratory and Dr. B. Finthan for his contribution.

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