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Granulometric analysis of the sandstone facies from the Bima Sandstone in Girei and environs, Yola sub-basin, Upper Benue Trough, Northeastern Nigeria

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ABSTRACT

The granulometric analysis of Bima Sandstone in Girei and environs was carried out covering the area within latitudes 9°16’00” and 9°24’00”N and longitude 12°28’00” and 12°38’00”E. The aim of the study is to determine the grain size distribution of the Bima Sandstone, its transportation history, and its depositional environment. Fourteen rock samples were subjected to granulometric analysis. The result shows that the sandstone is fine, medium to coarse, and very coarse-grained; it is moderate and poorly sorted. The graphic mean size ranges from -0.06^{Φ} to 1.03^{Φ}, which suggests high to low flow regime of transportation; the inclusive graphic skewness shows positive skewness with few samples falling under negative skewness ranging from −0.1 to 2.0; the inclusive graphic standard deviation ranges from 1.0 to 1.4; and the inclusive graphic kurtosis ranges from 0.68 to 4. The probability plot of the representative rock samples shows that the Bima Sandstone was transported by saltation and suspension, while the bivariate scatter plot of Y2 against Y3 suggests that the Bima Sandstone is deposited in a continental setting.

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1. Introduction

The Bima Sandstone is the oldest sedimentary formation in the Upper Benue Trough; it unconformably overlies the Precambrian basement complex. The formation varies in thickness from 91.4 to 3,048 m and its relative age is inferred to range from Aptian to Albian (Carter et al., 1963). The variation in thickness may be due to irregular relief of the crystalline basement complex floor on which the sediment accumulated and partly to the differing degrees of accommodation space in the basin of deposition. The type locality is in Bima hills, 25 miles east of Gombe, where, although the complete thickness of the formation is not seen, over 0.4575 km, feldspartic grits with subsidiary sandstones and ironstones are exposed. Field studies showed that the complete section of the Bima Sandstone is in the Lamurde Anticline and this is now used as the standard section of the formation (Carter et al., 1963). In the Lamurde Anticline section, three divisions of the Bima Sandstone, not recognize elsewhere, can be distinguished and this are shown separately on the maps as the Lower, Middle, and Upper Bima Sandstones (Carter et al., 1963). The facies architecture of the Middle and Upper Bima Sandstone of Girei was presented and interpreted with varying paleoenvironments, ranging from proximal to deltaic environments (Braid, 1992). The choice of the study

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area was informed by excellent exposures of the Bima Sandstone in the opted location and the work is aimed at providing a regional understanding of the "grains size distribution, transport history, and depositional environment" of the earlier Cretaceous sediments of the Bima Sandstone in Girei and environs.

2. Geological Setting

The Bima Formation is the oldest lithological unit sitting at the base of the Cretaceous successions in the Northern Benue Trough (Figs. 2 and 3). The sediments originated from basement rocks juxtaposed to it. These are the older granites and gneisses and were deposited in a continental environment under widely varying conditions of alluvial–fluvial systems (Braide, 1992; Guiraud, 1990). The sedimentary structures include large-scale trough cross-bedding, planar cross-bedding, groove marks, and soft sediment deformation structures (Braide, 1992; Guiraud, 1990; Samaila et al., 2006). Carter et al. (1963) and Guiraud (1990) differentiated the formation into three members; the Lower Bima (B1), the Middle Bima (B2), and the Upper Bima (B3). These three lithological units were also identified in the seismic section of the Nigerian sector of the Chad Basin, the Lower Bima (B1). Recently, the Bima Sandstone was re-subdivided and reduced to two members, namely Lower and Upper members (Tukur et al., 2015). The Aptian–Albian Bima Sandstone have been described as consisting of fault-controlled conglomerates, sands, and gravels with poorly defined internal structures characterized by well-defined fining upward successions (Guiraud, 1990). The facies architecture of the Middle and Upper Bima Sandstone of Girei are presented and interpreted with varying paleoenvironments ranging from proximal to deltaic environment (Braid, 1992). The Albian Middle Bima (B2) unconformably overlies the Lower Bima member. It is composed of medium to very coarse-grained feldspathic sandstones with trough and tabular cross-beddings interbedded with clays (Offodile, 1976; Zaborski et al., 1997). It is considered to have been deposited in a deeply entrenched braided river system (Abubakar, 2006; Carter et al., 1963). The Upper Bima (B3) conformably overlies the Middle Bima (B2). It has a relatively homogeneous appearance consisting of planar cross-bedded medium to coarse-grained sandstone associated with soft sediment deformation structures (Samaila et al., 2006).

(a) According to Benkhelil, (1986, 1983); the Bima III which is the upper Bima Sandstone is the most exposed part of the entire Bima Sandstone.

(b) The name Bima Sandstone was given to the oldest formation both in Chad Basin and Upper Benue Trough, the formation is directly overlying the Precambrian Basement complex Falconer, (1911).

(c) The origin of the Bima Sandstone was enhance by tectonic quiescence in a climatic setting that is humid during mid Cretaceous Haruna et al., (2012).

(d) The source rock from which the Bima Sandstone originated from is believed to the crystalline basement of Adamawa, Cameroon, Hawal Massifs and Mandara Mountain that actually surrounds the Benue trough Haruna et al., (2013).

(e) Opeloye, (2012) concluded that the Bima Sandstone is composed of four facies association that reflect depositional setting that range from alluvial fan, point bars, braided river and crevasse splay.

2.1. Location and methods

Grain size is an important element of texture; its distribution has long been used for determining the environment of deposition. Physical properties, particularly texture and sorting, are direct products of sedimentary processes (Boggs, 1995; Passega, 1977). Textural evaluation gives quantitative insight when comparative studies of characteristics are needed on deposited sedimentary rocks in a familiar depositional setting, e.g., along a beach or river. This analysis is commonly used in quantification of contemporary processes of transport and deposition (Nichols, 2009).

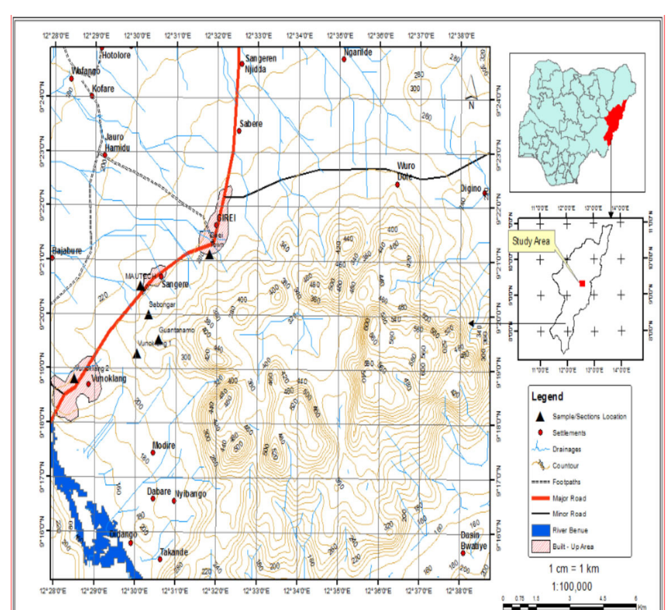

Figure 1. Topographic map showing the study area (Modified after USA survey agency, 2010).

The Bima Sandstone was studied in four locations within the area between latitudes 9o16’00” and 9o24’00”N and longitude 12o28’00” and 12o38’00”E in Girei and environs (Fig. 1). Detailed field studies were conducted on the exposed lithological section in the localities noting the rock types, lithology, and sedimentary textures of the formation. Fourteen representative samples of about 100–200 g were obtained from Girei, MAUTECH, Guantanamo, Sabon-Gari, and Vunoklang using a spot sampling method and rigid grid spacing. For the granulometric analysis, each of the samples was appropriately disaggregated using ceramic pestle and mortar. The weight of the bottom pan, selected empty sieves (4.00 mm, 2.00 mm, 0.50 mm, 0.250 mm, 0.125 mm, 0.063 mm, and pan) and 200 g of the various crushed samples was obtained by using “YP10 KN electronic weighing balance.” The required sieves were built up into a pile. The sieve with the smallest opening at the base with an empty container (pan) below it was used to collect the finest grain at the bottom; the topmost part of the piled sieves was covered with a lid, while the entire mesh and the basal pan were tied to the Ro-top mechanical sieve shaker. 200 g of each sample was poured into the upper sieve; the machine was turned on for 15 minutes. Sediments in each of the sieve and the pan at the base of the sieve shaker were reweighed and recorded. Data obtained from the sieve shaker were analyzed using GRADISTAT software. The results are presented in Table 2. The formula of Folk and Ward (1957) was used to calculate the mean, standard deviation, skewness, and kurtoses. The outcome of the analysis was interpreted based on verbal terms related to calculated values as presented in Table 2.

3. Result

The textural parameters of the analyzed Bima Sandstones and their interpretations are presented below.

3.1. Grain size and statistical parameters

Fourteen sandstone samples were sieved; as such, the statistical parameters of the various samples were determined and are presented in Table 3. Quantitative values of percentile from various samples obtained are presented in Table 1, while the grain size data for the individual weight percentage for the various samples of the Bima Sandstone obtained are presented in Table 2. These were obtained using the formula of Folk and Ward (1957).

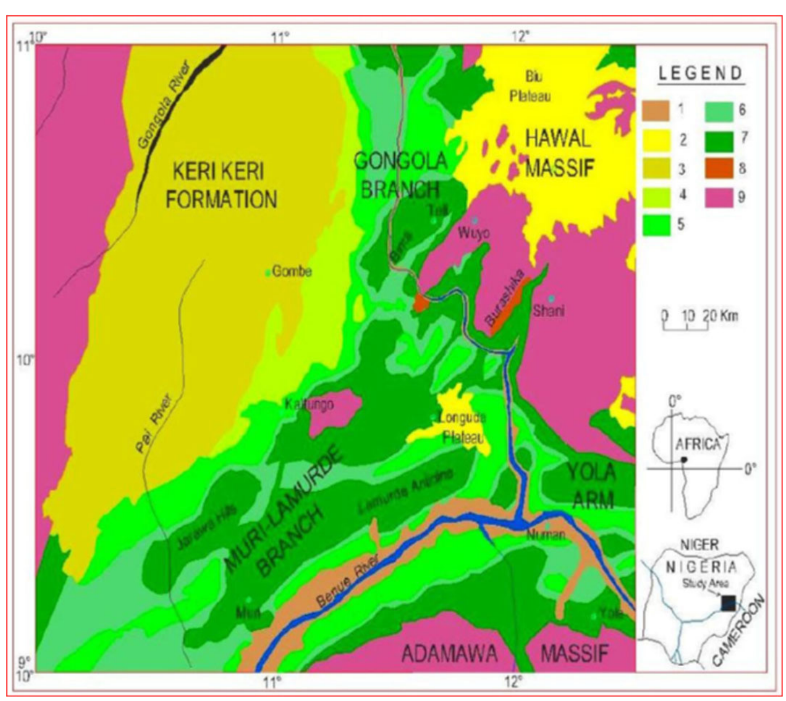

Figure 2. Geological map of the Upper Benue Trough. 1, quaternary alluvium; 2, tertiary to recent volcanism; 3, KerriKerri formation; 4, Gombe sandstone; 5, Pindiga formation; 6, Yolde formation; 7, Bima Sandstone; 8, Burashika group (Mesozoic volcanism); 9, granitoids Precambrian (Modified after Maurin et al., 1985).

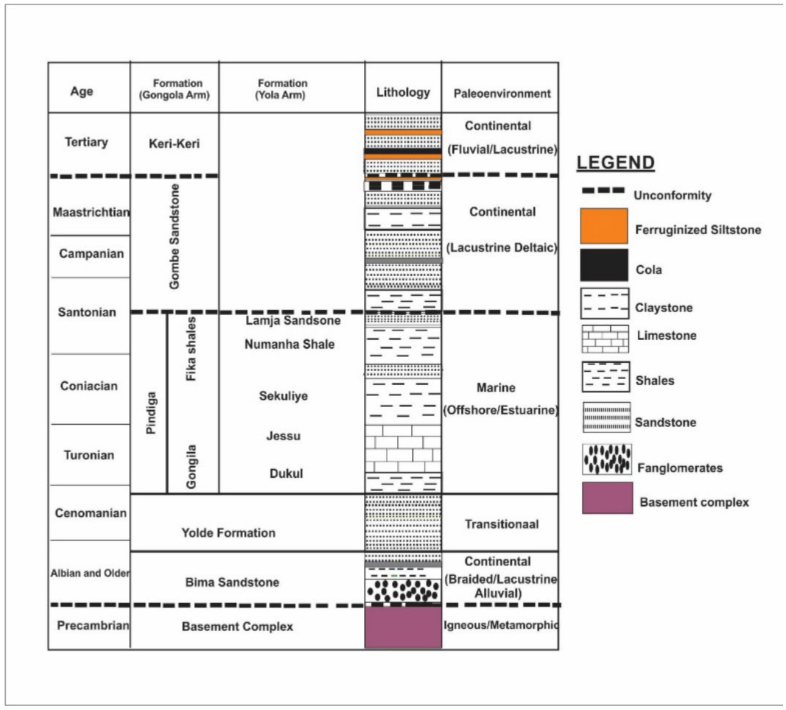

Figure 3. Stratigraphic succession of the Upper Benue Trough (Modified after Zaborski et al., 1997).

Table 1. Percentile value from cumulative curve plots of the samples analyzed.

Sample	ϕ5	ϕ16	ϕ25	ϕ50	ϕ75	ϕ84	ϕ95
G1	1.4	2.75	2.82	3.1	3.3	3.45	3.8
G2	2	2.15	2.25	2.6	3.1	3.3	4.3
GR1	1	2.08	2.15	2.4	2.7	3.0	3.5
GR2	2	2.1	2.2	2.4	2.7	3.0	3.5
GR3	2	2.1	2.2	2.4	2.6	2.8	3.3
M1	2	2.18	2.3	2.6	3.1	3.3	3.6
M2	2	2.15	2.22	2.5	2.9	3.1	3.5
M3	2.08	2.3	2.5	2.9	3.27	3.4	3.7
SG1	2	2.3	2.5	3.0	3.4	3.5	3.9
SG2	1	2.73	2.8	3.1	3.3	3.4	3.77
SG3	2.02	2.2	2.27	2.6	3.0	3.2	3.42
V1	1	2.8	2.82	2.85	3.3	3.45	3.8
V2	2.08	2.3	2.5	2.9	3.2	3.34	3.5
V3	1.15	1.3	1.9	2.3	2.7	3.0	3.6

3.2. Univariate grain size parameters

The granulometric analysis results of the 14 samples of the Bima Sandstone analyzed are presented in Table 1. The results obtained were interpreted based on Folk (1974).

The graphic mean size for the various samples (Table 3) ranges from −0.06Ø to 1.06Ø, which shows a medium to very coarse-grained sandstone. The standard deviation values range from 1.0 to 1.4, which indicates a moderate to poorly sorted sandstone. However, poorly sorted values predominates (Table 3), and this is interpreted based on Friedman's (1967) study. As for the values of skewness, various samples ranged from −0.1 to 0.2 from negatively skewed to positively skewed (Table 3); however, the positively skewed values predominate.

Table 2. Grain size data for individual weight percentage for various samples of the Bima Sandstone.

S/No	μm	ϕ	Cum w% G1	Cum w.% G2	Cum w.% GR1	Cum w.% GR2	Cum w.% GR3	Cum w.% M1	Cum w.% M2	Cum w.% M3	Cum w.% G2	Cum w.% SG1	Cum w.% SG2	Cum w.% V1	Cum w.% V2.2	Cum w.% V1
1	4.8 mm	−2.3	2.619	7.634	1.682	1.752	0.495	1.811	0.355	1.531	2.45	1.67	2.619	1.682	0.355	1.67
2	3.4 mm	−1.8	5.569	14.06	5.139	6.328	2.39	4.242	3.475	5.945	5.473	7.745	5.569	5.137	3.475	7.745
3	2.4 mm	−1.2	10.16	19.89	10.71	16.408	4.7	6.543	13.575	14.919	12.659	14.873	10.159	10.71	13.575	18.87
4	1.2 mm	−0.2	30.36	33.97	46.13	38.198	16.15	14.143	29.145	48.739	41.799	45.723	30.359	46.13	29.145	45.72
5	850 μm	0.2	46.19	42.57	61.35	51.318	34.92	23.593	46.245	63.449	62.999	63.893	46.189	61.35	46.245	63.89
6	425 μm	1.2	74.09	67.48	74.62	82.348	80.53	59.243	74.365	80.149	82.119	77.963	74.089	74.62	74.635	77.96
7	300 μm	1.7	81.60	79.49	78.676	88.767	86.885	73.313	84.895	87.712	87.146	90.703	81.601	78.676	84.895	90.70
8	212 μm	2.2	86.57	86.73	83.87	92.848	90.24	84.813	92.004	92.877	91.515	93.813	86.571	83.869	92.004	93.81
9	106 μm	3.2	94.15	92.96	90.06	96.057	94.775	93.127	95.516	95,407	93.473	95.373	94.151	90.068	95.516	95.37
10	75 μm	3.74	96.20	96.10	94.37	96.627	95.985	95.138	96.558	96.54	95.105	96.511	96.201	94.374	96.558	96.51
11	63 μm	3.9	97.69	98.03	97.43	96.805	96.963	97.144	97.492	97.309	97.144	97.459	97.691	97.083	97.144	97.45
12	Pan	5	1000	100.0	99.98	99.981	100.015	100.065	100.29	100.011	100.031	99.967	100.05	99.987	100.29	99.96

Table 3. Grain size distribution and quantitative parameters for the samples of the Bima Sandstone analyzed.

Range	Location	Mean	Standard deviation	Skewness	Kurtosis
Minimum	Girei and environs	−0.06Ø	1.0	−0.1	0.68
Maximum		1.06Ø	1.4	0.2	4

Table 4. Discriminate function of each sandstone sample obtained from the study area.

Range	Location	Y1	Y2	Y3
Minimum	Girei and environs	2.7	86.2	−0.1
Maximum		21.6	24	−8.2

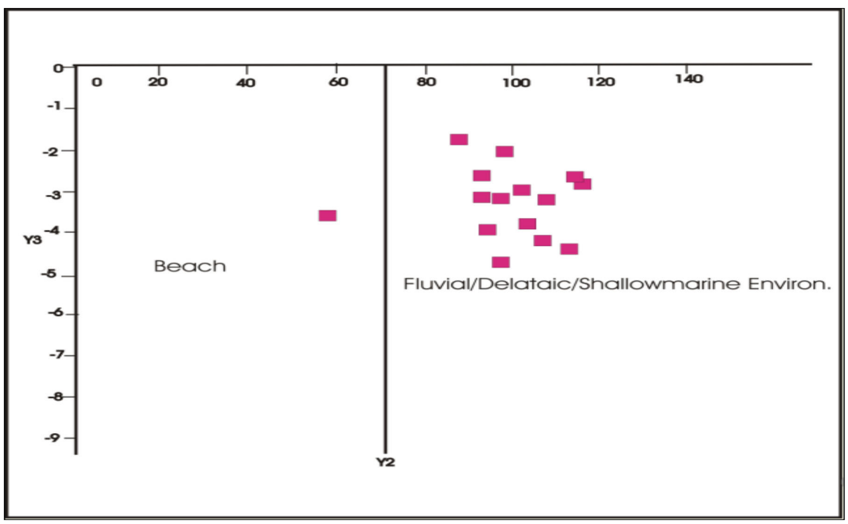

Figure 4. Bivariate plots of Y2 versus Y3 (Adopted after Sahu, 1964).

The values of inclusive graphic kurtosis range from 0.68 to 4 (very platykurtic to extremely leptokurtic) with an average of 1.3 (leptokurtic) (Table 3). Very little geologic information could be derived from kurtosis (Friedman, 1967; Pettijohn, 1987).

3.3. The relationship between bivariate grain size parameters

Plotting of the two discriminate functions (Y2 and Y3) as bivariate scatter plots was used from the values presented in Table 4 to improve the success rate and refinement of the discrimination of the depositional environment. The bivariate plots of Y2 and Y3 (Fig. 4) show that most of the Bima Sandstone samples might have been deposited in a fluvial environment.

3.4. Probability plots

The distinction between various sand populations is effectively important in environmental interpretation. The graphical representation of such sand population speaks volumes of the characteristics of either fluvial, beach, or wave zone. Visher (1969) characterizes the sand population graphs as follows: according to him, two sand populations graphs represent fluvial environment (Figs. 5 and 6); three sand populations characterize wave zone sandstone; and four sand populations characterize beach environment. From the analysis of the probability plot graphs, the Bima Sandstone shows two sand populations which are typical of fluvial environment (Figs. 5 and 6; Visher, 1969). These are reflected as follows:

1) Suspension population that is poorly sorted with a slope of 27o–45o (Figs. 5 and 6); as such, it reflects a distribution that ranges between 4% and 17%.
2) Saltation population that is well sorted with a slope of 60o–80o (Figs. 5 and 6), and it reflects 53%–77% of the sand population distribution.

4. Discussion

Grain size is an important element of texture; its distribution has long been used for determining the environment of deposition. Physical properties, particularly texture and sorting, are direct products of sedimentary processes (Boggs, 1995; Passega, 1977).

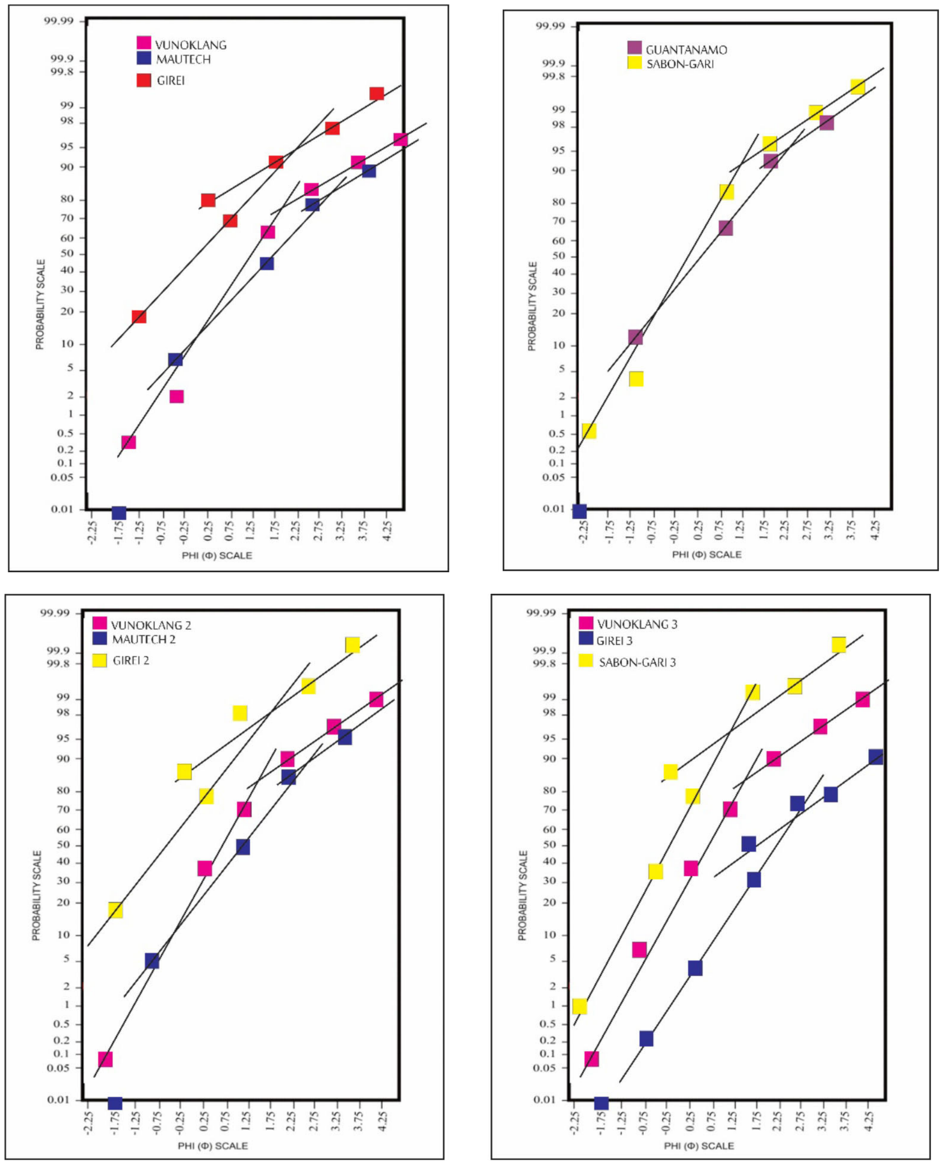

Figure 5. Probability plots of the Bima Sandstone from Vunoklang, MAUTECH, Sabon-Gari, Guantanamo, and Girei, showing the transport mode of sediments in the form of saltation and suspension.

Granulometric analysis provides quantitative information when a comparison of the characteristics is required from sediments deposited within a known environment, such as a beach or along a river. It is, therefore, most commonly used in the analysis and quantification of present-day processes of transport and deposition (Nichols, 2009). The grain size parameters of the studied Bima Sandstones and their interpretations are presented in Table 3. From the grain size and statistical parameters of the 14 sandstone samples that were subjected to granulometric analysis, the transport history of the sedimentary rocks was deduced; as such, the univariate grain size parameters from the graphic mean size for the various samples which indicates coarse to very medium grained sandstone could be a result of the fluctuation in the hydraulic condition. The inclusive graphic standard deviation (sorting) shows that the sandstone is moderate to poorly sorted (Table 3), and these characteristics may be due to an agitated condition of the brief marine processes that lead to the removal of clay material; this is supported by Friedman (1967). Furthermore, values for the skewness of various samples show negatively skewed to positively skewed; this may be due to the fact that most of the silts and clay sediments were removed by various degrees of river tributaries. From the inclusive graphic kurtosis for the various samples that show very platykurtic to extremely leptokurtic, very little geologic information could be derived (Friedman, 1967; Pettijohn, 1987).

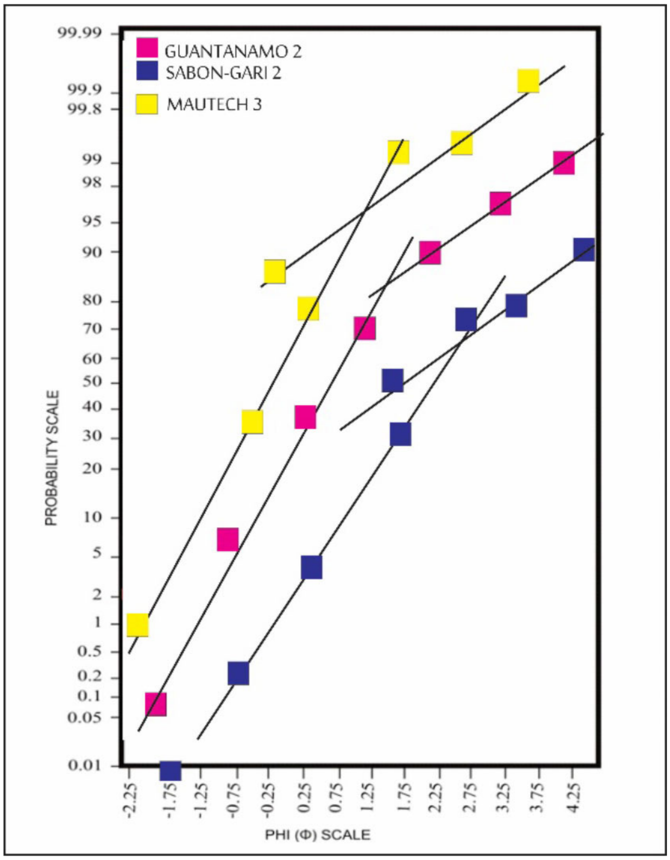

Figure 6. Probability plots of the Bima Sandstone from Vunoklang, MAUTECH, Sabon-Gari, Guantanamo, and Girei, showing transport mode of sediments in the form of saltation and suspension.

However, the fluctuation in values of the kurtosis may suggest change in energy of depositional medium. Various cumulative curve plots of the samples show that the sandstone is typical of a continental setting (Figs. 5 and 6); the cumulative curve of the sandstone also shows segregation which reflects admixtures of different transportation histories of the sediments at different levels of the flow regime. Interpretation is based on Folk and Ward (1957). Plotting of discriminate functions (Y2 and Y3) as bivariate scatter plots was used to improve the success rate and refinement of the discrimination of the depositional environment. The bivariate plots of Y2 and Y3 (Fig. 4) show that the Bima Sandstone is deposited in a fluvial environment. The model of the probability plot that show the transport mode of sediments in the form of saltation and suspension was adopted from Friedman (1979).

5. Conclusion

The determination of the depositional paleoenvironment of sediments from grain size analysis to cross-plotting values obtained from inclusive graphic Y2 against Y3s shows that the Bima Sandstone was deposited in an environment dominated by continental processes, which is typical of a fluvial environment. Generally, the Bima Sandstone is texturally medium to coarse-grained. The bivariate plot of the grain size parameters suggests substantial fluvial transportation history with two sand populations; the Bima Sandstone shows a transportation history dominated by saltation and suspension, respectively, and the grain sizes varied from fine, medium, coarse to very coarse-grained.

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