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DEPOSITIONAL ENVIRONMENT OF THE TERTIARY KERRI – KERRI FORMATION IN THE GONGOLA SUB-BASIN, NORTHERN BENUE TROUGH: PEBBLES MORPHOMETRIC AND GRAIN SIZE ANALYSIS APPROACH

[1]*U. ABUBAKAR, [1]S. MUSA, [1]R. P. TABALE , [2]N. A. YELWA, [1]J. U. IKECHUKWU, [1]A. U. USMAN, [1]M. B. USMAN, [3]M. B. ABUBAKAR, [1]A. SULAIMAN, [1]A. OLASEHINDE, [1]A. YUSUF, [4]S. MUKKAFA and [1]A. M. BELLO

[1]Department of Geology, Gombe State University, Gombe Nigeria, P.M.B. 127, Gombe, Nigeria.
[2]Department of Geology, Usmanu Danfodiyo University, P.M.B. 2346, Sokoto, Nigeria.
[3]National Centre for Petroleum Research and Development, A.T.B.U Bauchi, Nigeria.
[4]Department of Environmental Management and Toxicology, Federal University, P.M.B. 7156, Duste, Nigeria

Corresponding Author: uabubakar2002@gmail.com

ABSTRACT

Pebbles have been reported in the Sandstones units of the Kerri - Kerri Formation, but their application as a tool for interpreting the depositional environment is limited. In this context, 510 quartz pebbles and 16 sandstone samples were collected for pebble morphometric and grain size analyses in order to assess the depositional environment of the formation. For the pebble morphometric study, the long (L), intermediate (I), and short (C) axes of each pebble were measured. For each pebble, four geometrical parameters related to depositional environmental studies were computed, these are: Maximum Projection Sphericity, Oblate Prolate Index, Coefficient of Flatness, and Disk - Road - Index. The standard sieving method was used to sieve the sandstone samples. Mean grain size (Mz), sorting (I), skewness (SKI), and kurtosis (KG) were determined as statistical parameters of the grain size. The mean value of the computed pebble shape parameters for the pebbles of the Kerri – Kerri Formation indicates that the pebbles were deposited in a fluvial environment. Based on the grain size analysis, the sediments were deposited by fluvial action with moderate to low energy of deposition setting closer to the source of the sediments. The bivariate plots show that all the pebbles and sandstone samples lie clearly within the river field, which suggests fluvial origin.

Keywords: Pebble Morphometry, Grain Size Analysis Depositional Environment, Kerri – Kerri Formation, Gongola Sub-basin, Northern Benue Trough

INTRODUCTION

In terms of age, the Kerri - Kerri formation is the youngest geologic unit in the Gongola Sub-Basin of the Northern Benue Trough (Nwajide, 2013). Adegoke et al. (1978) dated the formation Paleocene in age using palaeontological data. The formation is essentially flat-lying and unfolded (Adegoke et al. 1986 and Dike 1993). It overlies the basement complex in the western part of the Gongola sub–basin and progressively overstepped the Cretaceous sediments to the east (Adegoke et al. 1986). According to Adegoke et al. (1986), the Kerri - Kerri Formation's sediments are mostly made up of clayey grit, coarse-grained sandstone, siltstone, and clays. Only a few conglomerate bands and lenses may be found close to the western boundary. The sandstones can be found in certain places with channel-lag deposits, conglomeratic lenses, or more typically, graded bedding.

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Pebbles occurence have been documented in the Kerri-Kerri Formation at several locations within the Gongola sub-basin of the Northern Benue Trough (Carter et al. 1963; Adegoke et al. 1978, 1986; Dike, 1993; Nwajide, 2013). However, their application as a tool for interpreting depositional environment is scanty. Hence, using information from pebble morphometry and grain size, this study is aimed at characterizing the depositional environment of the Kerri-Kerri Formation.

Study Area

The study area (Fig. 1) lies between longitude 10º 00′ 00″ E and 11º 45′ 00″ E and latitude 10º 00′ 00″ N and 11º 15′ 00″ N. The central portion of the area is covered by the Kerri – Kerri Formation and bounded to the west by a basement complex and Cretaceous sediments to the east (Figure 1). This study concentrates on three different localities (Figure 1 and 2) having good outcrop exposure of the Kerri – Kerri Formation within the Gongola Sub-Basin of the Northern Benue trough. Localities 1 and 3 are found at the west close to the basement complex while Locality 2 is situated to the east close to the Cretaceous sequences (Figure 1 and 2). In the three localities, the formation is generally composed mainly of sandstones and interbeds of clays, dominated by reddish, very coarse and pebbly sandstones, transiting to medium to fine-grained sandstones.

Geological Settings

The Gongola sub-basin is an arm of northern Benue trough that trends in a north-south pattern. The anticlinal features of the Dumbulwa - Bage high constitute the northern boundary of the ssub-basin. It is flanked to the south by the "Zambuk ridge," a region of significant NE - SW trending sinistral strike-slip faulting (Zaborski, 1998 and Abubakar 2014). The Gongola Sub-basin's genesis and evolution are linked to the origin of the Benue Trough. Many experts relate the genesis and evolution of the Benue Trough with the break-up of Africa and South America (break-up of Gondwana continent) during the eEarly Cretaceous period (Benkhelil, 1989 and Abubakar, 2014). This was followed by the continents spreading apart, which led to the opening of the South Atlantic, and the expansion of the Mid-Atlantic ridge (Benkhelil, 1989; Nwajide, 2013 and Abubakar 2014).

Carter et al. (1963); Zaborski et al. (1997), Zaborski, (1998); and Tukur et al. (2015), among others, have had an in depth study of the stratigraphy of the Cretaceous Gongola sub-basin (Figure 3). According to Zaborski et al. (1997), the basin comprises of a thick continental Lower Cretaceous sequence, known as the Bima Sandstone, which is overlain mostly by a marine upper Cretaceous successions, of the Yolde, Pindiga, and Gombe formations. A middle Turonian regression resulted in the deposition of sandy members within the middle portion of the Pindiga Formation, these include; the Gulani, Daban Fulani, and Dumbulwa members. The sea finally receded from the Gongola sub-basin during the Maastrichtian, when the Gombe Formation was deposited in a shallow sea towards the south. The end of the Maastrichtian folding resulted in the formation of a depression on the western border of the Upper Benue Trough (Benkhelil, 1989). The asymmetrical depression was filled by the Cenozoic Kerri-Kerri Formation, which is made up of flat-lying to moderately sloping basal conglomerate, grit, sandstone, siltstone, and clay that unconformably overstepped the Maastrichtian Gombe Formation (Adegoke et al. 1986 and Nwajide, 2013).

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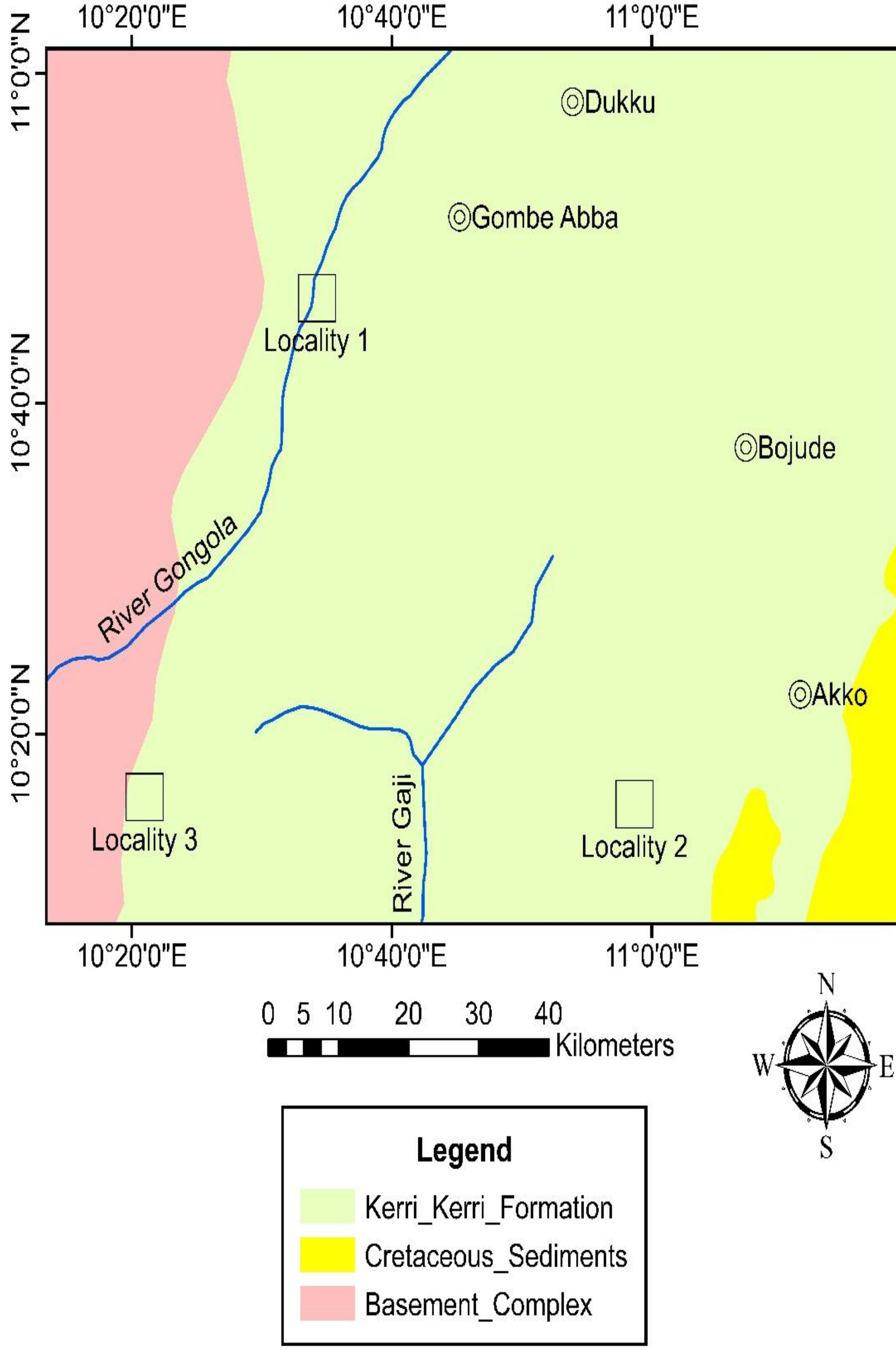

Figure 1. Geological map of the study area, showing the location of the three localities (Modified after Adegoke et al. 1986).

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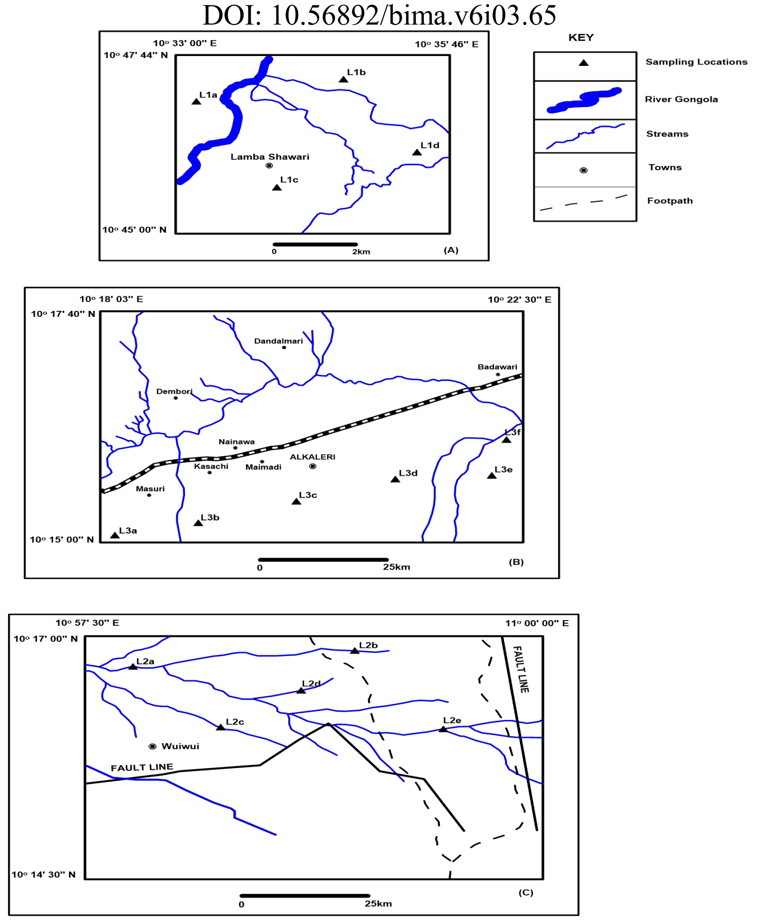

Figure 2: Maps of the three localities showing Sampling locations; (A) Locality 1 (B) Locality 2 (C) Locality 3.

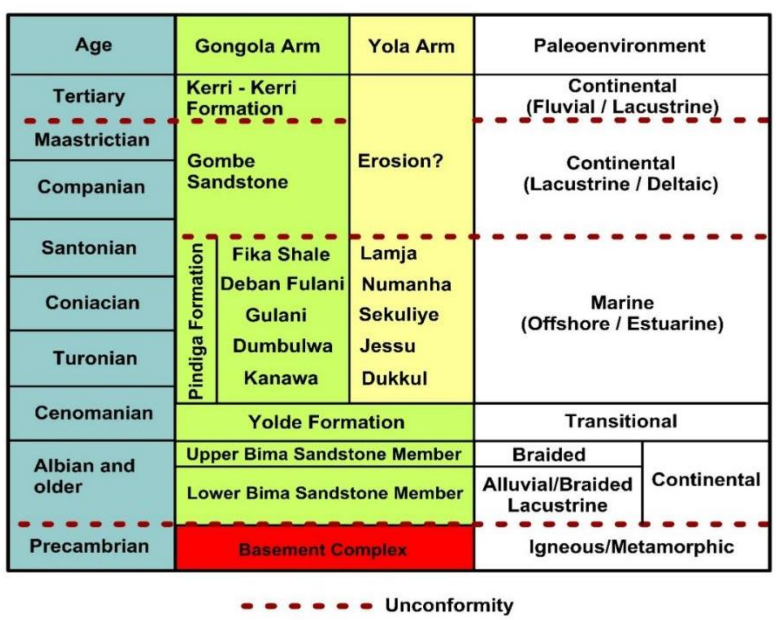

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Figure 3: Stratigraphic successions of Upper Benue Trough (Modified after Tukur et al. 2015)

MATERIALS AND METHODS

A total of 510 pebbles and 16 sandstone samples were collected (Table 1) from the three localities shown in Figures 1 and 2 for pebbles morphometric and grain size analysis respectively. The summary of the pebbles and sandstone samples collected from each locality is presented in Table 1 and the sampling location of each locality is shown in Figure 2. The pebble samples are composed of quartz minerals, and were collected by hand from highly weathered outcrops of the Kerri – Kerri Formation. The sandstone samples were selected based on textural variations and weathered samples were avoided as much as possible. The pebble morphometric and grain size analysis of the pebbles and sandstone samples was conducted at the Department of Geology, Gombe State University, Nigeria.

Table 1: Number of pebbles collected from each sampling location.

Locality	Sampling location	Number of Pebbles	Number of Sandstones	Total Number of Sandstones	Total Number of Pebbles
Locality 1	1a	20	1	4	80
	1b	20	1		
	1c	20	1		
	1d	20	1		
Locality 2	2a	30	1	5	150
	2b	30	1		
	2c	30	1		
	2d	30	1		
	2e	30	1		
Locality 3	3a	40	1	7	280
	3b	40	1		
	3c	40	1		
	3d	40	1		
	3e	40	1		
	3f	40	1		
	3g	40	1		

The length of the long (L), Intermediate (I) and short (C) axes of each pebble were measured by a Vernier caliper using the procedure outlined in Sneed and Folk (1958). Greatest care was taken not to measure broken or laminated pebbles as these would tend to give misleading results. From the axial lengths, axial ratios were calculated according to Zingg (1935). From these data, four shape parameters were calculated for each pebble namely; Maximum Projection sphericity ($\psi\rho$) after Sneed and Folk, 1958, Oblate Prolate Index (OPI) after Dobkins and Folks, 1970, Coefficient of flatness (F) after Stratten, 1974, and Disk – Road – Index (DRI) after Illenberger, 1990. The mean value of each parameter was then calculated for each sampling site using SPSS (V. 17) and 2013 Microsoft Excel software.

The sandstone samples (Table 1) were dried and sieved according to Folk and Ward (1957) and Lindholm (1987). The samples were air-dried before being disaggregated gently with a mortar and pestle. In a series of stacked sieves, 200g of each sample was placed in the highest sieve. The sieves were placed in the following sequence, with mesh sizes decreasing: 2.00mm (-1), 1.40mm (-0.5), 1.00mm (0), 0.71mm (0.5), 0.50mm (1), 0.25mm (2),

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0.15mm (2.7), 0.09mm (3.5), 0.06mm (4), and the pan, with the coarsest sieve at the top and finer ones below. After shaking the sieves for 10 minutes on an Endicott sieve shaker, the sands that remained on each sieve and the pan were removed and weighed. The graphical approach of Folk and Ward was used to compute grain size statistical characteristics such as mean grain size (Mz), sorting (I), skewness (SKI), and kurtosis (KG) (1957). The grain size parameters were computed and the data was graphically presented (cumulative frequency curves) using GraphPad Prism 6, SPSS (V. 17), and 2013 Microsoft EXCEL software.

RESULTS

Pebble Morphometric Data analysis

Pebble morphometric data for the locations in Figure 2a, 2b, and 2c were summarized and presented in Table 2 (complete data are in supplementary materials). Overall mean values of Maximum Projection sphericity (ψρ), Oblate Prolate Index (OPI), Coefficient of flatness (S), and Disk – Road – Index (DRI) were calculated (Table 2). The long (L) axis of the studied pebbles was used to measure their sizes as suggested by Friedman (1958) and Tucker (2006). The long axis of the studied pebbles ranges from 2.18 to 4.71 with an average value of 3.34 (Table 2). Therefore, according to Tucker (2006) the pebbles may be taken as fine in size.

Each pebble sample acquired was plotted on a Sneed and Folk (1958) form triangle diagram using the "TRI - PLOT" application (Graham and Midgley, 2000) to establish the shape (Form) name of the pebbles (Figure 4). Figure 5 depicts the determined average percentages of the form classes. The nomenclature used in this work for pebble shapes is based on Sneed and Folk (1958). The result shows that the dominant form class of the studied pebbles is the compact form. Although the form is completely absent in pebbles from locality 1. Bladed, compact – bladed, and compact – elongated forms are the second, third and fourth dominant form classes (Figure 4 and 5). Bladed and compact – elongated are common in pebbles from locality 1 and 2 while Compact – bladed forms are found in all three localities (Figure 4 and 5).

Table 2. Mean values of the pebbles shape indices

Locality	Locations	L	I	S	I/L	S/I	S/L	DRI	ψρ	OPI	F
1	L1a	3.07	1.98	1.34	0.64	0.71	0.44	0.64	0.67	3.16	44.01
	L1b	3.44	1.87	1.37	0.54	0.75	0.40	0.76	0.67	6.66	40.27
	L1c	3.24	1.88	1.46	0.58	0.78	0.45	0.77	0.70	6.21	44.95
	L1d	3.20	1.81	1.19	0.57	0.69	0.38	0.70	0.64	5.45	38.24
	Mean	3.23	1.88	1.34	0.58	0.73	0.42	0.72	0.67	5.37	41.87
2	L2a	2.22	1.51	1.10	0.69	0.74	0.51	0.63	0.71	2.61	50.52
	L2b	2.18	1.46	0.97	0.68	0.67	0.45	0.58	0.67	1.81	45.38
	L2c	2.47	1.70	1.18	1.00	0.73	0.48	0.11	0.69	2.10	48.40
	L2d	2.29	1.45	1.05	0.65	0.72	0.47	0.66	0.69	3.73	46.61
	L2e	2.35	1.60	1.12	0.69	0.70	0.48	0.59	0.69	2.01	48.11
	Mean	2.30	1.54	1.08	0.74	0.71	0.48	0.51	0.69	2.45	47.81
3	L3a	3.61	3.25	2.68	0.90	0.83	0.75	0.44	0.85	-0.96	74.54
	L3b	3.99	3.54	2.63	0.89	0.76	0.67	0.33	0.80	-2.75	67.42
	L3c	3.91	3.40	2.68	0.87	0.81	0.70	0.46	0.83	-0.78	70.45
	L3d	4.71	4.09	3.22	0.87	0.79	0.69	0.45	0.81	-0.94	68.92
	L3e	4.20	3.68	2.92	0.88	0.81	0.71	0.46	0.83	-0.88	70.96
	L3f	4.35	3.88	3.12	0.89	0.81	0.72	0.42	0.83	-1.33	72.25
	L3g	4.20	3.68	2.92	0.88	0.81	0.71	0.46	0.83	-0.88	70.96
	Mean	4.14	3.64	2.88	0.88	0.80	0.71	0.43	0.83	-1.22	70.78

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Overall Mean	3.34	2.55	1.93	0.76	0.76	0.56	0.53	0.74	1.58	56.37

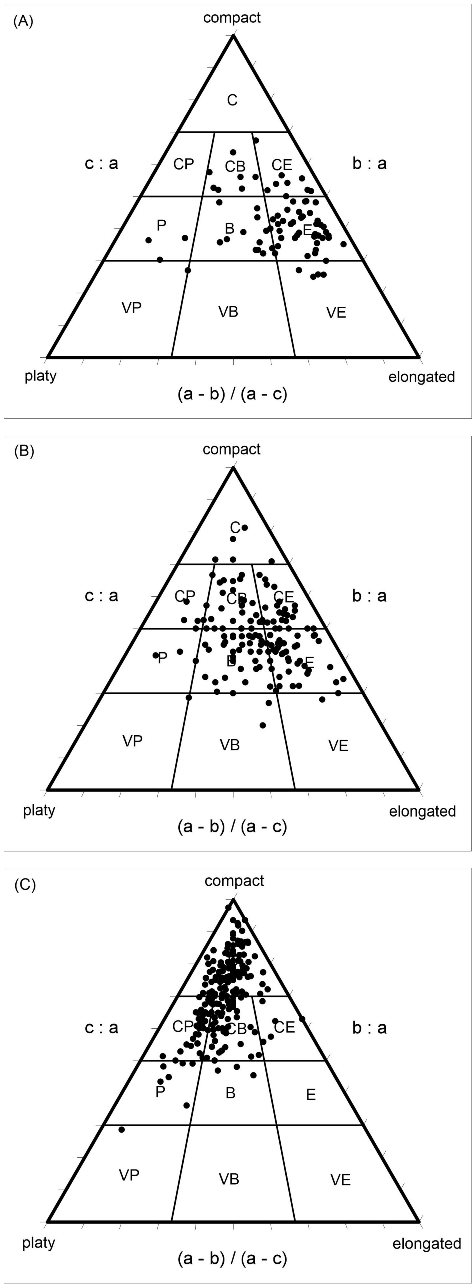

Figure 4: Plot of pebble shape on Sneed and Folk (1958) form triangular diagram, (a) Locality 1; (b) locality 2; (c) locality 3. C = Compact, CP = Compact - Platy, CB = Compact - Bladed, CE = Compact - Elongate, P = Platy, B = Bladed, E = Elongate, VP = Very Platy, VB = Very Bladed, VE = Very Elongate.

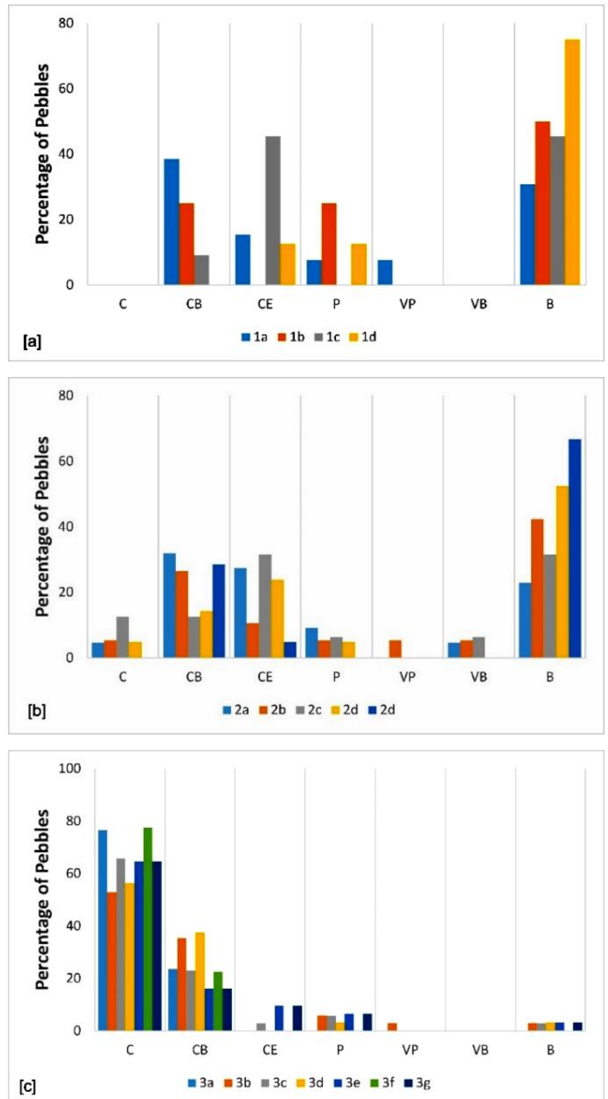

Figure 5: Percentage of pebbles in the Compact, Compact-Bladed, Compact-Elongate, Platy, Very Platy, Very Bladed, and the Bladed form class categories. (a) Locality 1; (b) Locality 2; (c) Locality 3.

Grain Size Analysis

The results obtained from the grain size analysis of the sandstone samples are presented in the form of cumulative frequency

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curves (Figure 6). Phi values were acquired from the cumulative frequency curves and they were used for the computation of the grain size parameters. The calculated values of the different grain size parameters were presented in Table 3. The average mean grain size values of locality 1, 2 and 3 were 0.42ɸ (coarse grain), 2.93ɸ (fine grain), and 2.12ɸ (fine grain) respectively. Generally, the mean grain size values of all the analyzed samples show a range from very coarse grain to very fine grain with an average mean grain size value of 1.95ɸ which indicate medium grain (Table 3). The sorting ranges from 1.18ɸ to 0.82ɸ, 1.44ɸ – 0.62ɸ, 1.49ɸ – 0.55ɸ for samples from locality 1, 2, and three respectively. The sorting values indicate that the samples vary from moderately well-sorted to poorly sorted (Table 3). Average sorting value of 1.05ɸ (poorly sorted) was recorded for all the analyzed samples. In locality 1, the average skewness value was 0.16 (fine skewed). Average Skewness values of -0.39 (strongly coarse skewed) and -0.11 (fine skewed) were recorded for locality 1 and 2 respectively (Table 3). In view of the above, the skewness can be said to be strongly coarse skewed to strongly fine skewed (Table 3). The kurtosis values in the locality 1, 2, and 3 samples vary from 1.53ɸ to 0.83ɸ (very leptokurtic to platykurtic), 2.87ɸ to 0.84ɸ (very leptokurtic to platykurtic) and 2.36ɸ to 0.78ɸ (very leptokurtic to platykurtic), respectively. An average kurtosis value of 1.42ɸ was recorded for all the studied samples (Table 3).

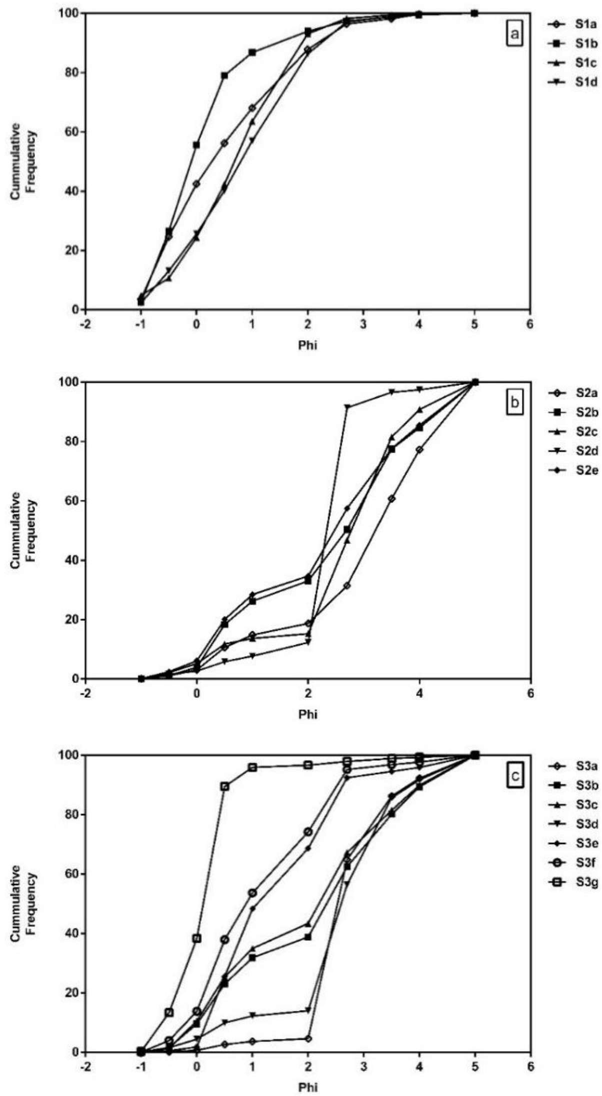

Figure 6: Cumulative frequency curves of the sandstone samples for (a) Locality 1; (b) Locality 2; and (c) Locality 3.

DISCUSSION

Depositional Environments based on Pebble Morphometric Data

The calculated pebble shape parameters provide useful information about the depositional environment which produced them or last acted upon them (Russell, 1980; Dadd and Foley, 2016). The use of pebbles shape parameters in Palaeo-environmental studies of both ancient and modern pebbles

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was provided by many authors with varying degrees of success. In this regard, the interpretation of the deposition environment deduced from each of the above parameters was compared with previous studies done on pebbles (e.g., Dobkins and Folk, 1970Stratten, 1974; Nwajide and Hoque, 1982; Howard, 1992; Okon, 2015; Dadd and Foley, 2016; Nton and Adamolekun, 2016; Usman et al. 2017).

According to Stratten (1974), the sphericity of a pebble is considered to be the most distinctive test to distinguish between fluviatile and beach environments. The ψρ values obtained for the pebbles can be interpreted when compared with those obtained by Dobkins and Folk (1970). Dobkins and Folk (1970), and Stratten (1975) reported that if a ψρ of a pebble is > 0.65 then, one can be 75% sure that it is from river (Fluvial). While, values < 65 are considered to be from beach. The ψρ values for the pepples of the Kerri – Kerri Formation for the three localities range from 0.64 to 0.85 with an average value of 0.74 (Table 3). It was observed that pebbles from locality 3 have higher ψρ values (range: 0.8 – 0.85) (Table 3). Thus, the ψρ of the studied pebbles strongly indicates shaping in a fluvial environment.

Dobkins and Folk (1970), and Russell (1980) suggested that OPI values > - 1.5 indicate river (fluvial) origin while < -1.5 indicate beach origin. The OPI values of the studied pebbles ranges from -2.75 to 6.66, with an average value of 1.58 (Table 3). An average value of 5.45 was recorded for OPI values of pebbles from locality 1 which is higher than those from locality 2 (mean: 2.45) and locality 3 (-1.22) (Table 3). In this regard, 1.58 average OPI value of the pebbles samples under study suggest influence of fluvial action.

Stratten (1974) established that fluvial pebbles were characterized by F values > 45 while beach pebbles have < 45. The computed values of F for all the pebbles from the three localities ranges from 38.24 to 74.54 with an average value of 56.37 (Table 3). It was noted that F values of pebbles from locality 3 (mean: 70.78) are greater than the F values of those from both locality 1 (mean: 47.81) and locality 2 (41.87) (Table 2). It is observed that pebbles from locality 1 have F values < 45 (Table 3) while that of locality 2 and 3 were > 45 (Table 2). Therefore, pebbles from locality 1 indicate shaping in the beach environment while pebbles from localities 2 and 3 indicate shaping in the fluvial environment. Whereas the overall average F value of all the pebbles samples is > 45 thus indicating shaping in a fluvial environment.

Table 3: Calculated grain size parameters for the different sampling locations

Locality	Sample I.D	Mean Size (Mz)	Sorting (σ_I)	Skewness (SK_I)	Kurtosis (KG)
Locality 1	S1a	0.42	1.18	0.30	0.83
	S1b	-0.02	0.82	0.35	1.53
	S1c	0.58	0.91	0.04	0.91
	S1d	0.70	0.97	-0.05	0.92
Locality 2	S2a	3.27	1.28	-0.40	1.54
	S2b	2.77	1.44	-0.39	0.86
	S2c	3.13	1.00	-0.42	2.40
	S2d	2.83	0.62	-0.41	2.87
	S2e	2.63	1.41	-0.33	0.84
Locality 3	S3a	3.30	0.55	0.02	2.36

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S3b	2.37	1.47	-0.20	0.86
S3c	2.27	1.49	-0.15	0.78
S3d	3.10	0.93	-0.34	2.34
S3e	1.83	0.93	0.24	1.09
S3f	1.50	1.03	-0.09	0.97
S3g	0.50	0.70	-0.28	1.64

Calculated values of DRI after Illenberger (1990) ranges from 0.11 to 0.77 with an average value of 0.53 (Table 3). In order of decreasing DRI mean values, Pebbles from locality 1 (mean: 0.72) have the highest DRI values followed by locality 2 (mean: 0.51) and then locality 3 (mean: 0.43) (Table 3). The average DRI values of the pebbles under study falls within the compact – bladed shape field. This is pointing to a fluvial environment (Illenberger, 1991 and Sneed and Folk, 1957).

Bivariate plots

Following Dobkins and Folk (1970) and Stratten (1975), a bivariate plot of Maximum Projection Sphericity (ψρ) vs. Oblate Prolate Index (OPI) and Maximum Projection Sphericity (ψρ) vs. Luttig's (1962) coefficient of flatness (S) was drawn to interpret the depositional environment of the Kerri - Kerri Formation (Figure 7a and b). In both cases, the plots show that the majority of the pebbles were found in a river setting.

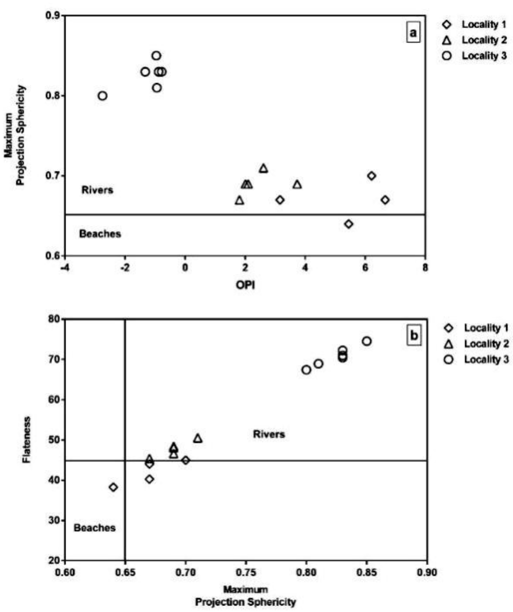

Figure 7: Bivariate Plots of (a) Maximum Projection sphericity (*ψρ*) vs. Oblate Prolate Index (OPI) and (b) Maximum Projection sphericity (*ψρ*) vs. Luttig's (1962) coefficient of flatness (*S*).

Depositional Environments based on grain size parameters

Bivariate plots were plotted for grain size parameters of the sandstone samples of the Kerri – Kerri Formation with aim of interpreting their depositional environment. When Comparing the bivariate plots of Skewness vs. Sorting (Fig. 8 a, c), and Mean grain size vs. Sorting (Fig. 8b) with similar works of Friedman (1961), and Miola and Wieser (1967), all samples plotted are indicative of fluvial environment. The dominance of coarse to very fine-grained particles, and moderately well to poorly sorted sandstones grains of the Kerri – Kerri

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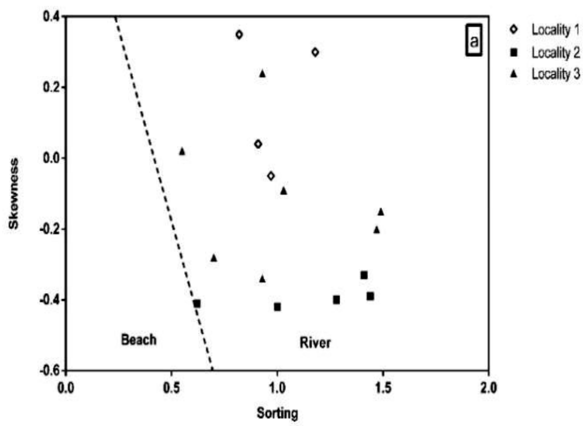
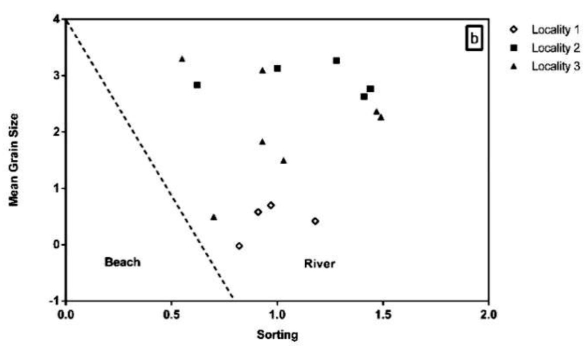
Formation probably points to a moderate to low energy depositional media, and sediments deposition closer to their sources. And that may be linked to those of a fluvial setting (Folk and Ward, 1957). The coarse to very fine grain nature of the sediment also indicates that the Kerri – Kerri Formation had to fine upward in sequences, which is a character of fluvial deposits. The skewness values recorded indicate deposition by fluvial action and also shows that much silt and clay is not removed by the fluvial currents, but is trapped between larger grains (Tucker, 2001).





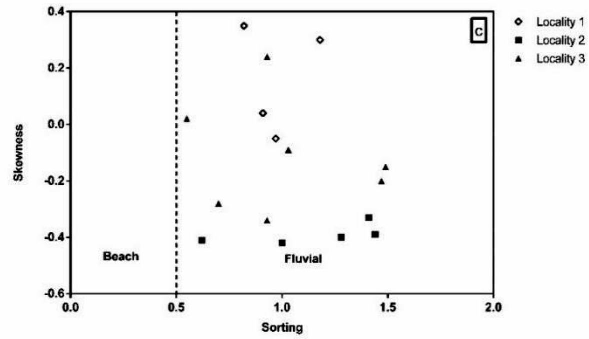


Figure 8: (a) Bivariate Plots of skewness vs. sorting after Friedman (1961) (b) Bivariate Plots of mean grain size vs. sorting after Friedman (1961) (c) Bivariate Plots of skewness vs. sorting after Miola and Wieser (1967).

CONCLUSIONS

Based on the result obtained from the pebble morphometric analysis of pebbles of the Kerri – Kerri Formation, the following conclusions were made:

1. The calculated mean values of the pebbles shape parameters i.e. maximum projection sphericity, oblate – prolate index, and disk – road – index (DRI) provide evidence of shaping in a fluvial environment.
2. The mean values of Coefficient of flatness suggest a fluvial processes for pebbles from locality 2 and 3. While those from locality 1 indicate beach action.
3. The dominant shape form classes indicate that the pebbles possesses a shape characteristics of a fluvial environment.

The grain size analysis indicate deposition by fluvial action with moderate to low energy of depositional. Deposited closer to the source of the sediments.

The bivariate plot of Maximum Projection sphericity (ψρ) vs. Oblate Prolate Index (OPI); Maximum Projection sphericity (ψρ) vs. Luttig's (1962) coefficient of flatness (S); Skewness vs. Sorting; and Means grain size vs. Sorting were all in favour of a fluvial environment.

REFERENCES

Abubakar, M.B., 2014. Petroleum potentials of the Nigerian Benue Trough and Anambra Basin: a regional Synthesis. Natural Resources, 5 (1), 25 – 58.

Adegoke, O.S. Agumanu, A.E. Benkhelil, M.J. and Ajayi P.O. (1986). New stratigraphic, sedimentologic and structural data on the Kerri-Kerri Formation, Bauchi and Borno States, Nigeria. Journal of African Earth Sciences, 5, 249–277.

Adegoke, O. S. Jan Du Chene, R.E. Agumanu, A.E. and Ajayi, P. O. (1978). Palaenology and age of the Kerri-Kerri Formation, Nigeria. Rev. Espan. Micropaleontologia, 2, 267–283.

Barrett, P.J. (1980). The shape of rock particles, a critical review. Sedimentology, 27, 291–303.

Benkhelil, J. (1989). The evolution of the Cretaceous Benue trough, Nigeria: Journal of African Earth Sciences, 8, 251–282.

Carter, J.D. Barber, W. and Tait, E.A. (1963). Geology of parts of Adamawa, Bauchi and Bornu provinces in Northeastern Nigeria. Bulletin, geological Survey of Nigeria, 30, 1 – 108.

Dadd, K. and Foley, K. (2016). A shape and compositional analysis of ice-rafted debris in cores from IODP Expedition 323 in the Bering Sea. Deep Sea Research Part II Tropical Studies in Oceanography, 125, 191 – 201.

Dike, E.F.C. (1993). Stratigraphy and Structure of the Kerri – Kerri Basin, Northeastern Nigeria. Journal of Mining and Geology, 29, 77 – 93.

Dobkins, J.E. Jr. and Folk, R.L. (1970). Shape development on Tahiti-nui. Journal of Sedimentary Petrology, 40, 1167 – 1203.

Friedman, G.M. (1958). Determination of sieve-size distribution from thin section date for sedimentary petrological studies. Journal Geology, 66, 394 – 416.

Graham, D.J. and Midgley, N.G. (2000). Graphical representation of Particle shape using Triangular diagrams: and Excel spreadsheet method. Earth Surface Processes Landforms, 25, 1473 – 1477.

Hart, B.S. (1991). A study of pebble shape from gravelly shoreface deposits. Sedimentary Geology, 73, 185 – 189.

Howard, J.L. (1992). An evaluation of shape indices as palaeoenvironmental indicators using quartzite and metavolcanic clasts in Upper Cretaceous to Palaeogene beach, river and submarine fan conglomerates. Sedimentology, 39471 – 39486.

Illenberger, W.K. (1990). Pebble dynamics on a sandy beach, Algoa Bay, South Africa (abstract). 13th International Sedimentology Congress Nottingham, 238 – 239.

Nton, M. E. and Adamolekun, O. J. (2016). Sedimentological and geochemical characteristics of outcrop sediments of Southern Bida Basin, Central Nigeria: implications for provenance, paleoenvironment and tectonic history. Ife Journal of Science, 18, 345 – 369.

Nwajide, C.S. (2013). Geology of Nigeria's Sedimentary Basins. CSS Bookshops Ltd, Lagos, Nigeria, p. 565.

Nwajide, C.S. and Hoque, M. (1982). Pebble morphometry as an aid in environmental diagnosis: an example from the Benue Trough. Journal of Mining and Geology, 19, 114 – 120.

Russell, T. (1980). Use of clast shape in determining the sedimentary history of the Late Devonian Keepit Conglomerate, Australia. Sedimentary Geology, 25, 277 – 290.

Okon, E.E. (2015). Sedimentologic Characteristics and Provenance Studies of Awi Formation, Calabar Flank, South-Eastern Nigeria. Journal of Mining and Geology, 51, 121 – 138.

Sneed, E.D. and Folk, R.L. (1958). Pebbles in

DOI: 10.56892/bima.v6i03.65

the lower Colorado River, Texas, a study in particle morphogenesis. Journal of Geology, 66, 114 – 150.

Stratten, T. (1975). Notes on the application of shape parameters to differentiate between beach and river deposits in South Africa. Trans. Geol. Soc. S. Afr., 77(1), 59 – 64.

Tucker, M.E. (2006). Sedimentary Petrology: An Introduction to the Origin of Sedimentary Rocks. Blackwell Science, United Kingdom, 262p.

Tukur, A. Samaila, N.K. Grimes, S.T. Kariya, I.I. Chaanda, M.S. (2015). Two-member subdivision of the Bima Sandstone, Upper Benue Trough Nigeria: Based on sedimentological data. Journal of African Earth Sciences, 104, 140 – 158.

Usman, M.B., Mamman, Y.D., Abubakar, U., Sulaiman, A., Hamidu, H. (2017). Depositional environment of Gombe Formation in the Gongola Sub – Basin of the Northern Benue Trough: Using grain size parameters. Global Journal of Geological Sciences, 15, 25 – 39.

Zaborski, P.M. (1998). A review of the Cretaceous System in Nigeria. Africa Geoscience Review, 5, 385 – 483.

Zaborski, P.M. Ugodulunwa, F. Idornigie, A. Nnbo, P. Ibe, K. (1997). Stratigraphy and structure of the Cretaceous Gongola Basin, North Eastern Nigeria. Bulletin Centres Researches Exploration Production Elf, 21, 153-185.