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Lithofacies Analysis and Paleaoenvironment of Deposition of Lokoja Formation, Southern Bida Basin, North Central, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The sedimentary facies and depositional environment of Lokoja Formation, Southern Bida Basin was evaluated through the study of some of its exposed sections and the samples obtained are subjected to pebbles morphometry and granulometric analasysis. The study area comprises of three (3) litho-facies which are the conglomerate, pebbly sandstone and siltstone/mudstone facies which displayed lithological characteristics, sedimentary structures and textural variation that indicate alluvial deposit which might have prograded through braided streams to nearshore marine conditions. From the pebbles morphometric analysis, the coefficient of flatness indicated that the pebbles are of fluvial origin as it consist of over 90% above fluvial limit. The elongation ratio indicated that the pebbles are of fluvial origin as over 90% has values between 0.6-0.9. Maximum Projection Sphericity Index (MPSI) of the pebbles analysed showed that about 95% were below 0.66 and this indicate beach origin. Oblate Prolate Index (OPI) which ranges from -0.1 – 19.0 show significance of fluvial deposit with minimal beach. From the granulometric analysis, the value of graphic mean ranges from -1.33 to 1.02 and this inferred that the grain size of the sandstone of the Lokoja Formation ranges from medium to very coarse grained. Sorting values ranging from 0.72 to 1.41, these values are indicative of moderate to poor sorting. The skewness values ranges from -1.01 to 0.36 which indicated that the sandstone is nearly symmetrical, strongly fine skewed and

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strongly coarse skewed. The values of kurtosis ranges from 1.0 to 4.08 which indicated mesokurtic to extremely leptokurtic. The plots of graphic mean and skewness against the standard deviation showed that the study area is dominantly of fluvial origin. Generally it can be conclude that the Lokoja Formation is dominantly of fluvial origin with little beach (marine) influence.

Keywords: Litho-facies; depositional environment; Lokoja formation; Southern Bida Basin.

1. INTRODUCTION

The Bida Basin, also known as the Mid-Niger or Nupe Basin, is located in west-central Nigeria. The Bida Basin is a NW-SE trending intracratonic structure extending from slightly south of Kontagora in Niger State in the north to the area slightly beyond Lokoja (Kogi State) in the south [1]. The formations deposited comprises the Bida Sandstone at the base, followed successively upward by the Sakpe, Enagi and Batati formations in the Northern/Central Bida Basin while the Lokoja, Patti and Agbaja formations constitute lateral equivalents in the Southern Bida Basin [2]. According to [3], Sedimentological analysis of basins involve three main aspects: provenance studies, the distribution of facies and paleoenvironment, and the changes in these through time during the basin evolution. Several works have been done on the evolution, stratigraphy and depositional environment of the basin [4-8]. However, this study aims to improve on the existing knowledge of the study area by carrying out detailed geological investigation in order to determine the paleoenvironment of deposition of the Lokoja Formation through systematic logging of exposed sections, and laboratory analysis of the sediments within the study area.

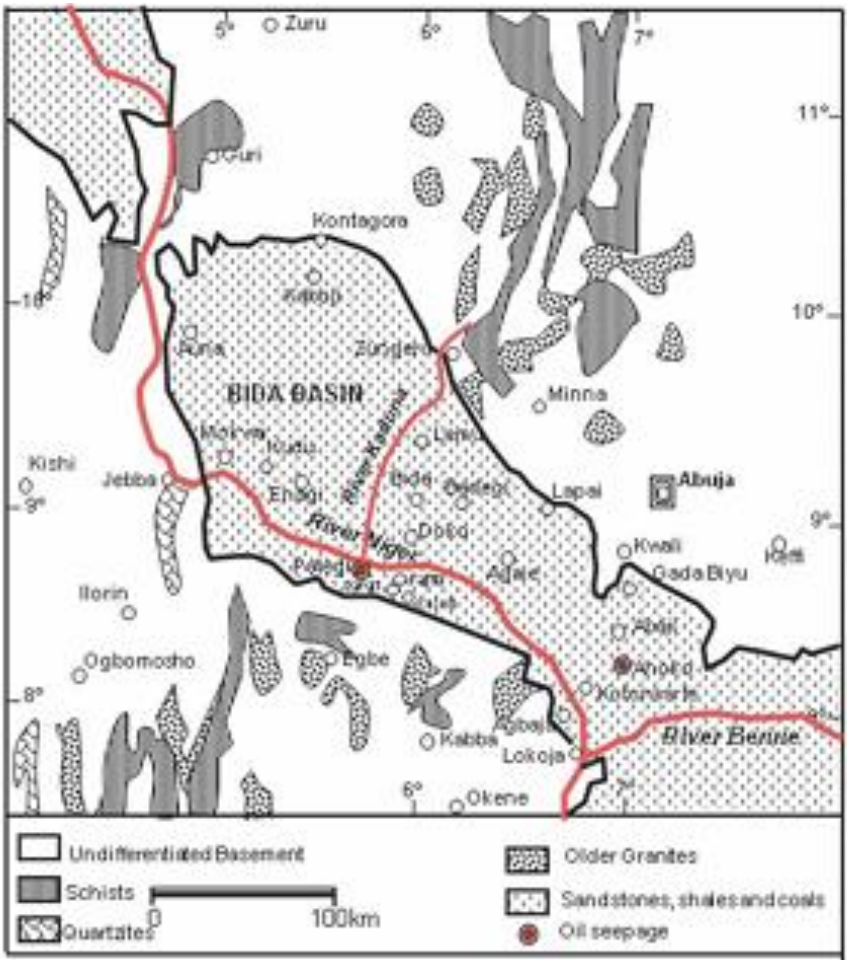

Fig. 1. Geological and Location Map of Bida Basin and Environs [4]

1.1 Geology of the Study Area

The area of study is located within and around Lokoja in Kogi State in the North-central part of Nigeria. The study area consists of both basement and sedimentary rock types. The basement area is underlain predominantly by migmatite, augen gneiss, biotite gneiss as well as minor occurrences of pegmatite and quartzo – feldspathic veins [9]. Petrographic and chemical analyses of the rock samples from this area show the migmatites to generally consist of quartz, feldspar (plagioclase, microcline and orthoclase), biotite and a few accessory minerals like epidote and zircon [10]. The basement complex is unconformably overlain by the Lokoja Formation. Specifically, this study focuses on the Lokoja Formation, Southern Bida Basin. The Lokoja Formation which unconformably overlies the basement complex consists of sandstones, which crop out around Lokoja area between Felele and KotonKarfi. Around this location, conglomerates, coarse falsebedded sandstones, fine to medium-grained sandstone, siltstone and claystone are known to occur [1]. It is close to confluence of the River Niger and Benue; the area is sandwiched between River Niger and Mount Patti respectively which had streamlined the settlement to a linear one and has a modifying effect on the climate. The climatic condition of the study is known as a local steppe climate. It has an annual rainfall between 1100 mm and 1300 mm. The rainy season lasts from April to October. The dry season which lasts from November to March, is very dusty and of cold as a result of the north easterly wind, which brings in the harmattan. The average temperature in Kogi state is 26-28 0^0C with about 747 mm of precipitation fall annually.

2. METHODOLOGY

Field mapping and laboratory analyses were employed in this study.

2.1 Field Mapping and Sample Collection

The field work was carried out in the month of June and it covers most part of Mount Patti and environs. The major formations encountered are the Lokoja Formation and Agbaja Ironstone since sections of Patti Formation are mostly covered by vegetation, rarely exposed along the strike of Mount Patti, but the study focused on the Lokoja Formation. Six (6) exposures were studied within latitude 7.8307^{0}N and Longitude 6.7166^{0}E and they include; opposite cemetery, Robinson Street at Kabawa, Ayoola Ajao Avenue at GRA, and Mount Patti and NE direction of the New Stadium in Lokoja town. The field work involved exposure description (logging of the exposed sections), measurement of bed thickness and sample collection. Bedding characteristics in terms of texture and lithology were studied in the field. Data, such as elevation, longitude and latitude of each location were obtained using the Global Positioning System (GPS). Images of outcrop and the structures on them were also taken using the camera. Sandstone and conglomerate samples were obtained from the study area for further laboratory analysis.

2.2 Processing and Analysis of the Samples

The laboratory study involved pebble morphometry and granulometric analysis. Pebbles of different sizes were described and measured with important indices recorded. The granulometric analyses of the sandstone sample were carried out using the sieve shaker and set of sieves.

2.2.1 Pebble morphometry

Three hundred (300) pebbles were picked randomly beneath and imbedded in the pebbly beds at the outcrops studied. Fifty (50) clasts samples each were taken from different exposures at the various locations. The clasts samples taken were fresh and unbroken ones. The samples were washed carefully and labelled according to the location it was obtained from (for example, A1 A2 e.t.c) and then pictures were taken. The short(S), intermediate (I) and long axis (L) of each clasts was measured using the vernier caliper and its values recorded. Some of the computed data includes: Flatness ratio, Elongation ratio, Maximum projection sphericity index (M.P.S.I.) and Oblate Prolate Index (OP-index). These parameters were calculated using the formula in Table 1 as given by different authors. Graphs of coefficient of flatness ratio against sphericity and sphericity against OP-index were plotted respectively.

Table 1. Computed and estimated morphometric properties used in the study

Morphometric Indices	Formula	Author
Flatness Ratio (F.R)	S/L	[11]
Elongation Ratio (E.R)	I/L	[12]
Maximum Projection Sphericity Index (M.P.S.I)	$(S^2/LI)^{1/3}$	[13]
Oblate – Problate (OP) Index	10[(L-I/L-S)-0.50]S/L	[14]
Roundness	Visual estimation	

Table 2. Formulas needed for determining the various granulometric parameters

	Formular Used	Source
Graphic Mean	$M = \frac{\varphi 16+\varphi 50+\varphi 84}{3}$	
Sorting	$D = \frac{\varphi 84-\varphi 16}{4} + \frac{\varphi 95-\varphi 5}{6.6}$	[17]
Skewenesses	$S = \frac{\varphi 84+\varphi 16-2(\varphi 50)}{2(\varphi 84-\varphi 16)} + \frac{\varphi 95+\varphi 5-2(\varphi 50)}{2(\varphi 95-\varphi 5)}$	
Kurtosis	$K = \frac{\varphi 95-\varphi 5}{244(\varphi 75-\varphi 25}$	

2.2.2 Granulometric analysis

A total of nine samples were subjected to grain size analysis, the standard grain size analysis test determines the relative proportions of different grain sizes as they are distributed among certain size ranges. Grain size distribution is one of the most important characteristics of sediment. This is true because grain size is a powerful tool for describing a site's geomorphic setting, interpreting the geomorphic significance of fluid dynamics in the natural environment and distinguishing local versus regional sediment transport mechanisms. Characterizing the physical properties of sediment grains is important in determining its suitability for various uses as well as studying sedimentary environments and geologic history.

The physical properties of sediments can be described by several parameters. Grain size is the most important of these and is the main ways in which sediment are classified [15].

2.2.3 Test procedure

A representative oven dry lump and conglomerated sample of soil weighing 120g was taken and crushed together using agate mortar and pestle. The mass of the sample accurately. $W_{t.}$ (g). Was determined. Similarly, care was taken to prepare a stack of sieves. Sieves having larger openings (i.e. lower numbers) are placed above the ones having smaller opening sizes (i.e. higher numbers). The very last sieve is 63micron and a pan is placed under it to collect the portion of the soil passing through the 63micron sieve. Afterwards, caution was taken to ensure the sieves are clean; many soil particles stocked in the openings were removed via the aid of brush. We poured the soil from step into the stack sieves from the top and place the cover, putting the stack in the sieve shaker and fixed the clamps, adjust the time on 10minutes and switch on the shaker from the source. Finally, we Stop the sieve shaker and measured the mass of the retained soil for each sieve.

The data derived from the grain size analysis were use to obtained cumulative weight % retained and Particle size distribution curves were plotted as cumulative % weight retained against phi (φ). From this curve, percentile phi (φ) values are then obtained in order to generate parameters such as sorting/standard deviation, graphic mean, graphic skewness and kurtosis using the formulas given in Table 2.

3. DISCUSSION

The result presented include information obtained from field mapping, pebble morphometry and granulometry analysis which aids in the description of its lithofacies and environment of deposition.

3.1 Description of Lithofacies

The Lokoja Formation consists of three lithofacies associations. These are conglomerate, sandstone and siltstone/ mudstone facies. The discussions below were based on field observations and literature reviews.

3.1.1 Conglomerate facies

The conglomerate facies comprise of matrix supported conglomerate and was recognised in exposed sections at Robinson Street and Hill adjacent cemetery in Kabawa. The conglomerate facies at Robinson Street (Fig. 2a) is overlain by latheritic overburden which is about 5.5m thick. It has visible laminations observed and is covered by roots of trees. At the sides of this succession (Fig. 2b), is the matrix supported conglomerate sub-facies where the cobble to boulder sized clasts of quartz, feldspar and metamorphic rock fragment are embedded within milky white sandy matrix. The conglomerate facies at Hill adjacent cemetery in Kabawa (Fig. 3a) consist of Clasts supported by paraconglomerate of quartz. Generally the conglomerate are poorly sorted and the clasts vary from angular to rounded while the sandy grains are very coarse, poorly sorted. The grains show abundance of quartz, feldspar and few rock fragments. Herringbone cross bedding is well displayed at the base of the exposure at Robinson Street (Fig. 3b). The lithologic log for both exposures are given in Fig. 4a and 4b.

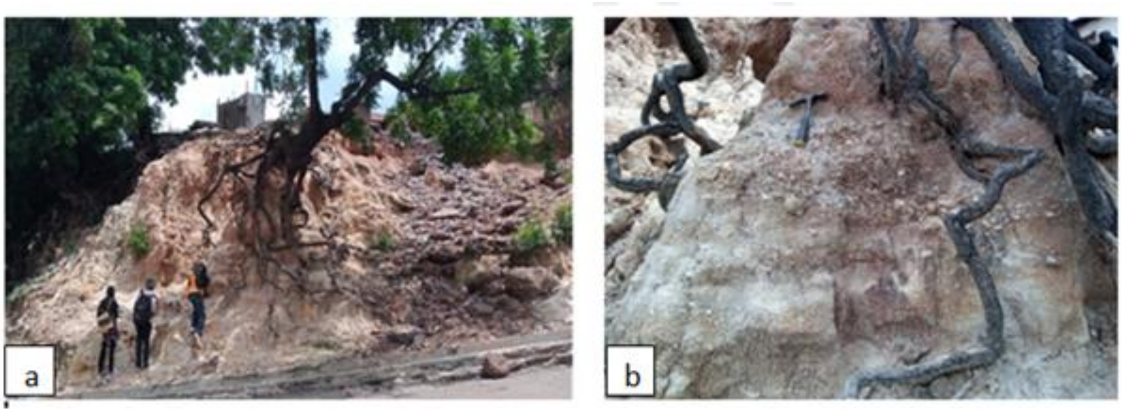

Fig. 2. (a) Matrix supported Conglomerate facies of Lokoja formation at Robinson Street (N 07º 48' 46.8" E 06 º 44' 40"). (b)) Clasts embedded in the pebbly sandstone Conglomerate facies at Robinson Street (N07º 48' 46.8" E 06 º 44' 40")

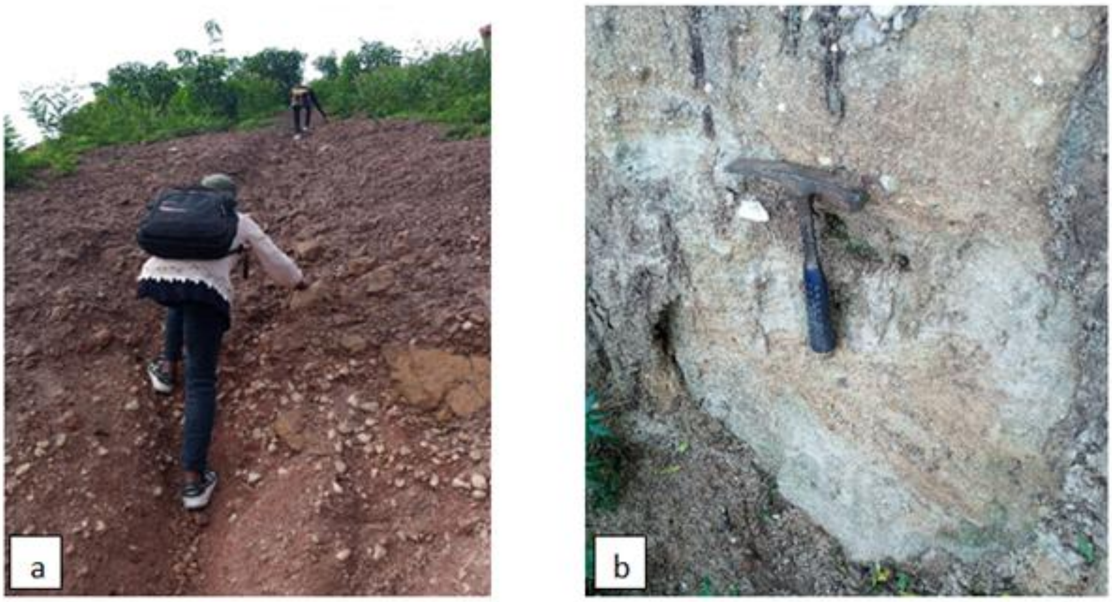

Fig. 3. (a) Clasts supported fabric (paraconglomerate) exposed around in the Conglomerate facies in the hill at Kabawa (N 07 º 49' 14.0" E 006 º 44' 40"). (b) Herringbone Cross bedding in the conglomerate facies at Robinson Street (N 07º 48' 46.8" E 06 º 44' 40")

Fig. 4. (a) Lithologic section of the Lokoja Formation exposed around Kabawa. (b) Lithologic section of the Lokoja Formation exposed at Robinson Street, Kabawa

3.1.2 Sandstone facies

The sandstone facies which consist of three sub-facies occurs in certain locations. They are: cross stratified pebbly sandstone sub-facies, bioturbated pebbly sandstone sub-facie and massive sandstone sub-facies.

The bioturbated pebbly sandstone sub-facies occur at the middle (bed 3) of the exposure at Ayoola Ajao Avenue in GRA (Fig. 5a). TFhis sub-facies, about 0.7m thick is strongly bioturbated, poorly sorted, coarsed- grain size, mesokurtic and nearly symmetrical and is recognised towards the top of the exposure at. In this sub-facies, the pebble to cobble sized clasts of quartz, feldspar and metamorphic rocks fragments are embedded within brownish sandy matrix. Generally the clasts vary from angular through sub-rounded to rounded. The grains show abundance of quartz, few feldspar, and rock fragments.

The cross stratified pebbly sandstone sub-facies (Fig. 5b) of the exposure behind the new stadium, is about 0.53m thick, poorly sorted, medium grained size, leptokurtic and nearly symmetrical grains is recognised at the base (bed 1). Moderately sorted, coarse grain size, very leptokurtic and strongly fine skewed grains are recognized at the middle (bed 4) where it attain average thickness of 0.41m. The prominent sedimentary structure is trough cross bedding. In this sub-facies, the cobble sized clasts of quartz, feldspar and metamorphic rocks fragments are embedded within pinkish to purplish white sandy matrix. Generally the clasts vary from angular to sub-rounded. The grains show abundance of quartz, feldspar and few rock fragments.

Massive pebbly to coarse grained sandstone sub-facie with an average thicknesss of 6m was identified in the exposure at opposite cemetery Kabawa (Fig. 6a). It lacks any internal sedimentary structure, poorly sorted, and contains coarse sand size quartz grains and feldspars with a few scattered pebbles in sandy matrix. The sandstone is brownish in colour. The lithologic logs for the three (3) sub-facies are given in Fig. 6b, 7a and 7b.

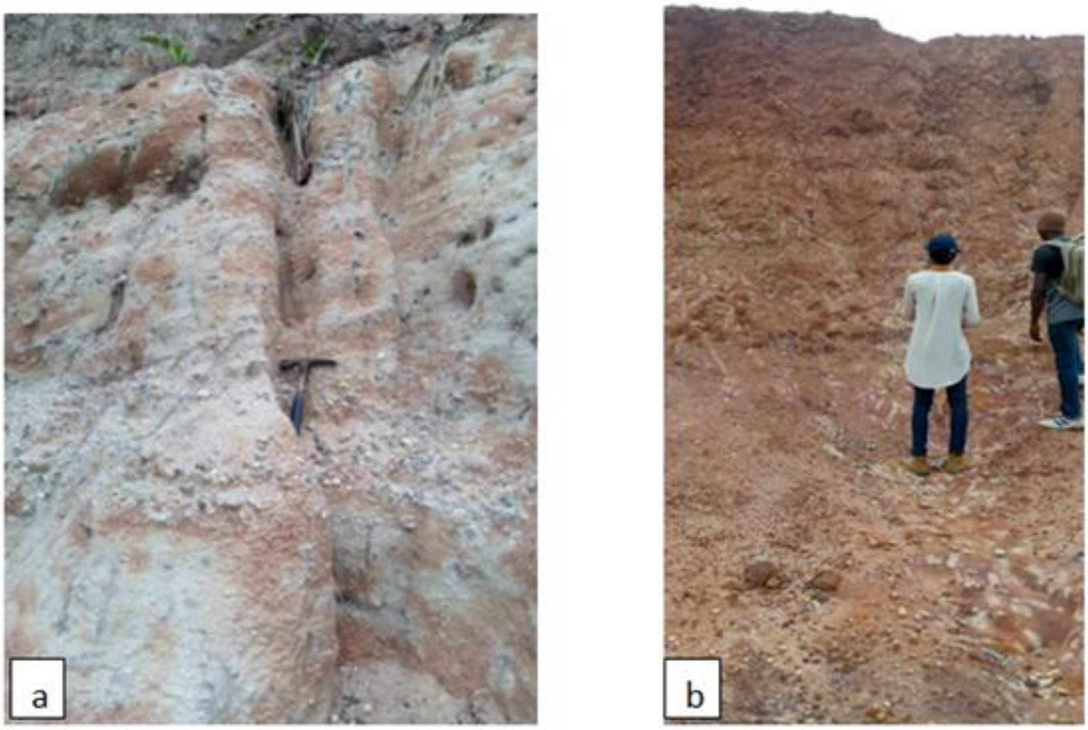

Fig. 5. (a) Biorturbated pebbly sandstone sub- facies in Ayoola Ajao Avenue, GRA (N 07 º 48' 15.2" E 006 º 43' 27.8"); (b) Trough crossbedding ion cross stratified pebbly sandstone sub-facies behind New stadium (N 07 º 48' 59.8" E 006 º 42' 29.7")

Fig. 6. (a) Clasts embedded in massive, pebbly to coarse grained sandstone sub-facies at Opposite Cemetery, Kabawa (N 07 º 49' 13" E 006 º 44' 42.6"). (b) Lithologic section of the Lokoja Formation exposed at Ayoola Ajao Avenue, GRA

3.1.3 Siltstone/ mudstone facies

The siltstone/ mudstone facies was recognised at some measured sections towards the top of the Mount Patti. In a particular section, a weathered clay stone overlies ironstone. This siltstone/mudstone facies have visible grains which are coarse. At another section, siltstone/ mudstone facies with convolute and parallel lamination was recognised. At the right hand side of the exposure, the bottom and the top section has woody-like structure (Fig. 8a). At another section, a bioturbated weathered feature was recognised on this facies. At another section, a wavy structure was recognised (Fig. 8b).

Generally, the three (3) facies associations and certain peculiar sedimentary features recognised in this Lokoja Formation are indicative of an alluvial deposit which might have prograded through braided streams to nearshore marine conditions and this has also been recorded by several researchers such as; [17],[18],[8], etc.

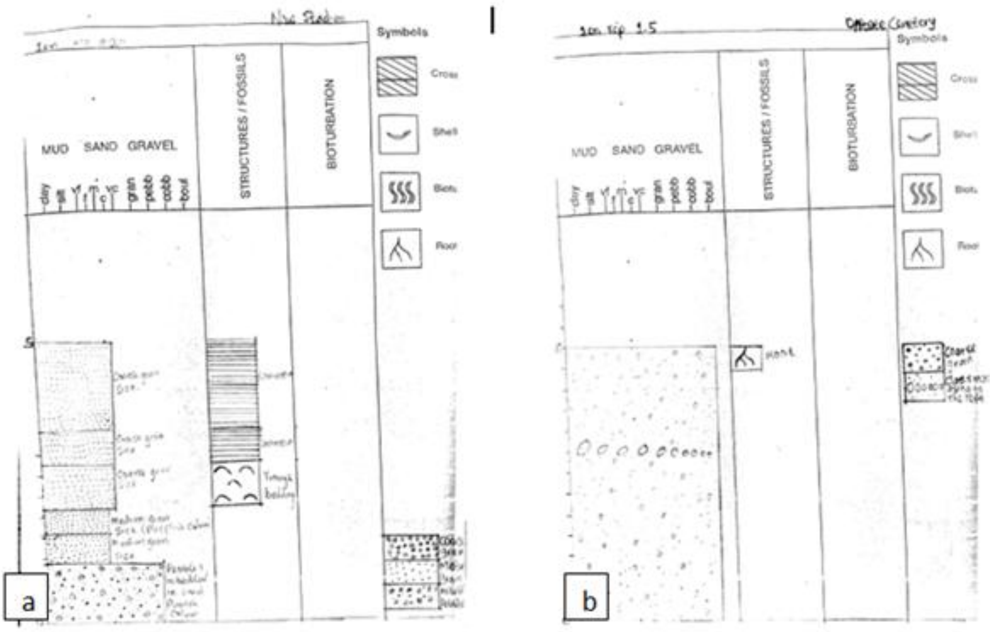

Fig. 7. (a) Lithologic section of the Lokoja Formation exposed at the NE direction of the New Stadium. (b) Figure 4.5: Lithologic section of the Lokoja Formation exposed at opposite Cemetery, Kabawa

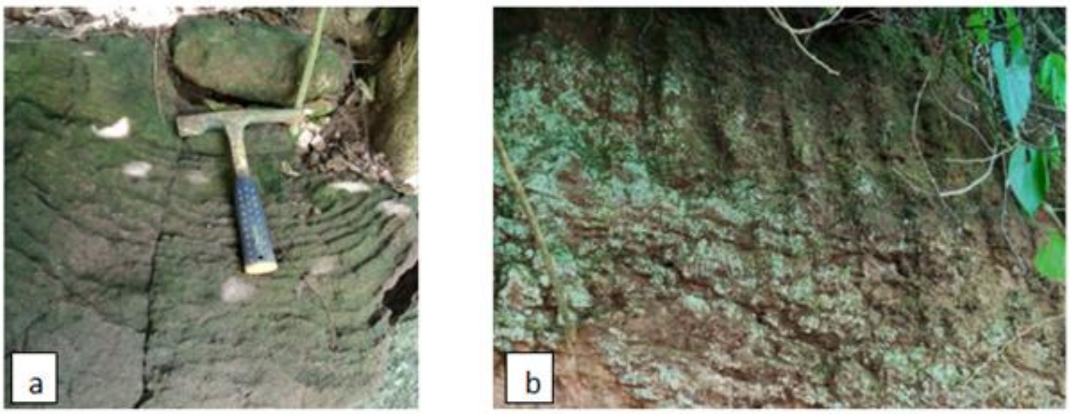

Fig. 8. (a) Visible wavy structure in the claystone facies at mount Patti (N 07 º 49' 08" E 006 º 43' 59.0"). (b) Visible woody-like structure in the claystone facies at mount Patti (N 07 º 49' 08" E 006 º 43' 59.0")

3.2 Pebble Morphometry

The results obtained from the morphometric analysis of pebbles from Lokoja Formation are presented in Fig. 9-11. The coefficient of flatness in the study area indicated that the pebbles are of fluvial origin as it consist of over 90% above fluvial limit and [11] gave <45% to be beach while >45% to be fluvial. The elongation ratio indicated that the pebbles are of fluvial origin as over 90% has values between 0.6-0.9, [19]gave the value of 0.6-0.9 for fluvial. Maximum Projection Sphericity Index (MPSI) of the pebbles analysed showed that about 95% were below 0.66 and this indicate beach origin as [13] gave <0.66 for beach and >0.66 for fluvial. Oblate Prolate Index (OPI) values shows significance of fluvial deposit with minimal beach using Sneed and [12] limit (Beach<-1.5, Fluvial>-1.5). Generally, the pebble morphometry data and the bivariate plots of sphericity against oblate-prolate index and plots of coefficient of flatnesss and sphericity revealed that the Lokoja Formation is dominantly of fluvial origin with little beach (marine) influence.

3.3 Granulometric Analysis

The granulometric analysis result for the grain size analysis is presented in Table 3 and the particle size distribution curve for each sample collected are presented in Figs. 12 and 13. The percentile values which are used in the derivation of parameters like the graphic mean, sorting, skewness and kurtosis as derived from the particle size distribution curve is showed in Table 4. Data interpreted from the calculated values of graphic mean, sorting, skewness and kurtosis for the study area is presented in Table 5. The value of graphic mean ranges from -1.33 to 1.02 and this further inferred that the grain size of the sandstone of the Lokoja Formation ranges from medium to very coarse grained. Sorting values ranging from 0.72 to 1.41, these values are indicative of moderate to poor sorting. The skewness values ranges from -1.01 to 0.36 which indicated that the sandstone is nearly symmetrical, strongly fine skewed and strongly coarse skewed. These inferences are based on the extensive work of [20,21,22]. The results of the grain size parameters for graphical measures of skewness (SK) and kurtosis (K) for the granulometricc analysis result after [16] is presented in Table 5.

The values of kurtosis ranges from 1.0 to 4.08 which indicated mesokurtic to extremely leptokurtic. The values of graphic mean and skewness were further plotted against the standard deviation (Fig. 14); this showed that the study area is dominantly of fluvial origin using [20] graphical interpretation.

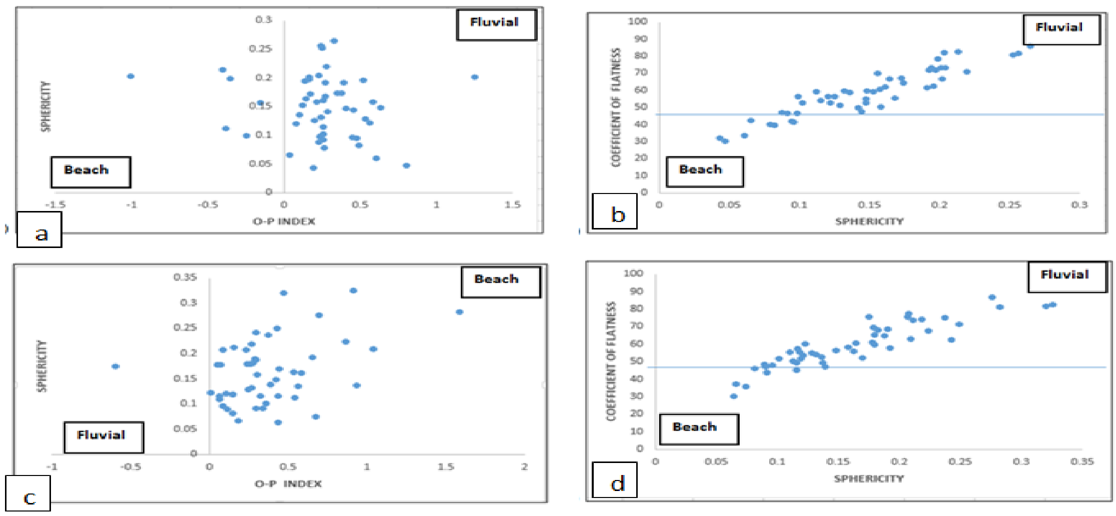

Fig. 9. (a) Scattered Plot of sphericity against O-P Index showing separation of beach field from the fluvial field of the Pebble Forms at Opp. Cemetery; (b) Scattered plot of coefficient of flatness against sphericity of the Pebble Forms at Opp. Cemetery; (c) Scattered Plot of sphericity against O-P Index showing separation of beach field from the fluvial field of the Pebble Forms at Robinson Street; (d) Scattered plot of coefficient of flatness against sphericity of the Pebble Forms at Robinson Street

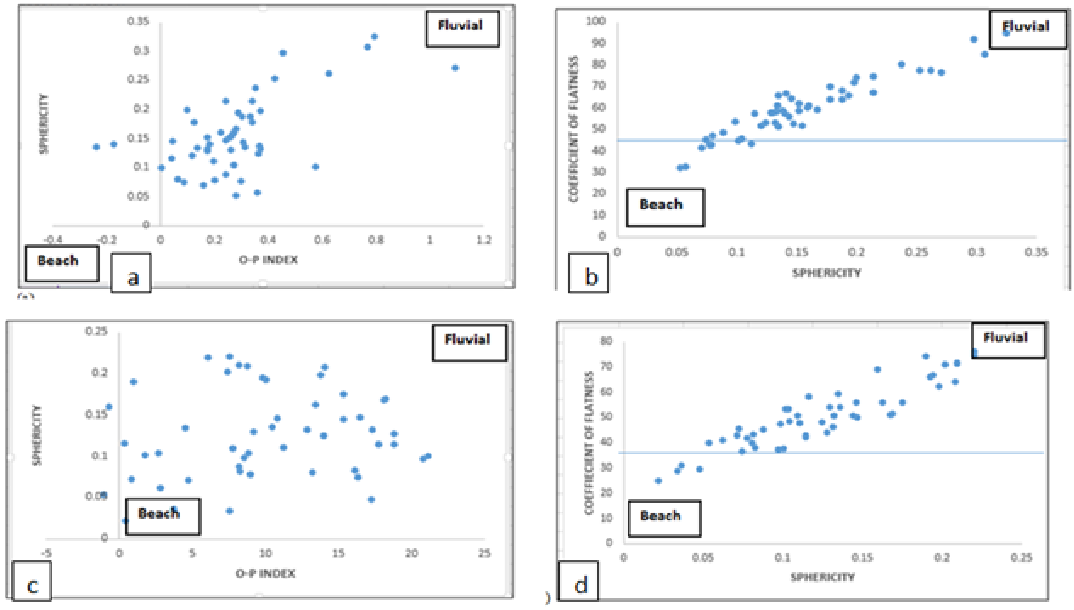

Fig. 10. (a) Scattered plot of sphericity against O-P Index showing separation of beach field from the fluvial field of the Pebble Forms at Hill; (b) Scattered plot of coefficient of flatness against sphericity of the Pebble Forms at Hill; (c) Scattered plot of sphericity against O-P Index showing separation of beach field from the fluvial field of the Pebble Forms at GRA; (b) Scattered plot of coefficient of flatness against sphericity of the Pebble Forms at GRA

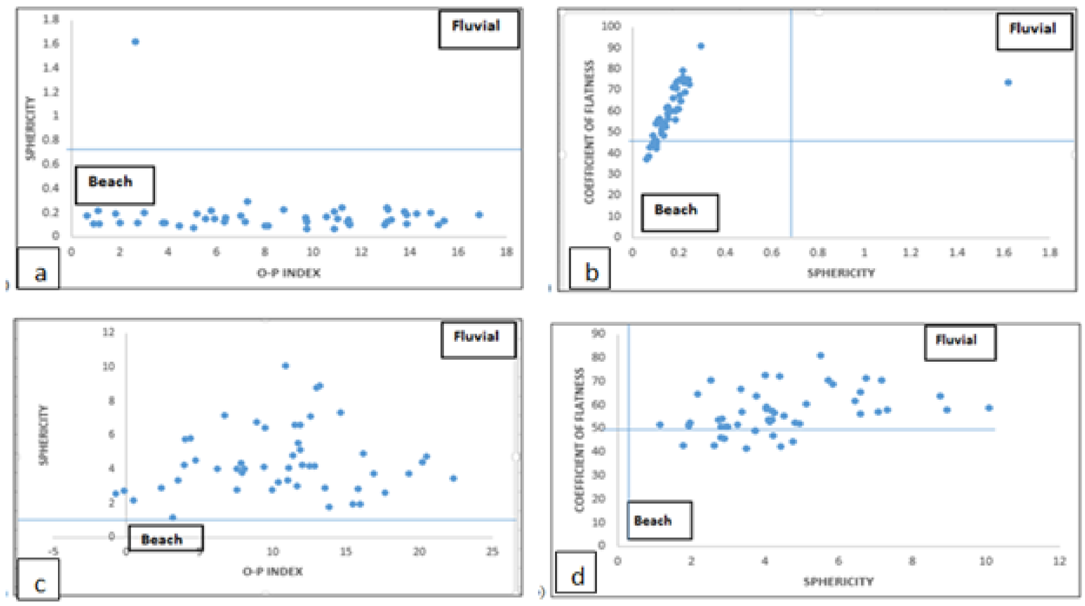

Fig. 11. Scattered Plot of sphericity against O-P Index showing separation of beach field from the fluvial field of the Pebble Forms at Mount Patti; (b) Scattered plot of coefficient of flatness against sphericity of the Pebble Forms at Mount Patti; (c) Scattered Plot of sphericity against O-P Index showing separation of beach field from the fluvial field of the Pebble Forms at New Stadium; (b) Scattered plot of coefficient of flatness against sphericity of the Pebble Forms at New Stadium

Table 3. Grain size analysis data for the study area sandstone

	Cumulative weight retained (%)							
Sieve size	Location A	Location B	Location C	Location E1	Location E2	Location F	Location G1	Location G2
4mm	0.34	31.66	2.09	2.18	0.42	0	0	0.76
2mm	4.20	0.694	17.33	6.37	10.34	1.42	2.35	7.89
1 mm	21.66	83.64	44.05	20.96	47.09	30.33	10.56	31.72
0.5mm	52.31	95.99	72.44	68.49	83.09	78.57	35.94	70.81
0.25mm	86.57	99.08	92.37	89.78	94.76	91.79	79.65	89.18
0.125mm	97.15	99.75	98.07	96.99	98.93	98.82	96.5	96.9
0.063mm	100	100	100	99.76	100	100	71	99.75
Bottom pan				100			100	100

Table 4. Percentile values from Cummulative Curves of Sandstone samples in the study area

Sample Number	Φ5	Φ16	Φ25	Φ50	Φ75	Φ84	Φ95
Location A	-1.8	-0.2	0.1	0.1	1.3	1.8	2.7
Location B	-3	-2.5	-2.2	-1.6	-0.5	0.1	1.0
Location C	-1.8	-1.1	-0.5	0.1	1.1	1.37	2.45
Location E1	-1.2	-0.29	0.15	0.65	1.25	1.65	2.5
Location E2	-1.55	-0.95	0-0.7	0.05	0.7	1.05	2.1
Location F	-0.85	-0.5	-0.3	0.45	0.9	1.4	2.55
Location G1	-0.8	0	0.6	1.05	1.65	2	2.6
Location G2	-1.2	-0.7	-0.3	0.1	0.8	1.5	2.7

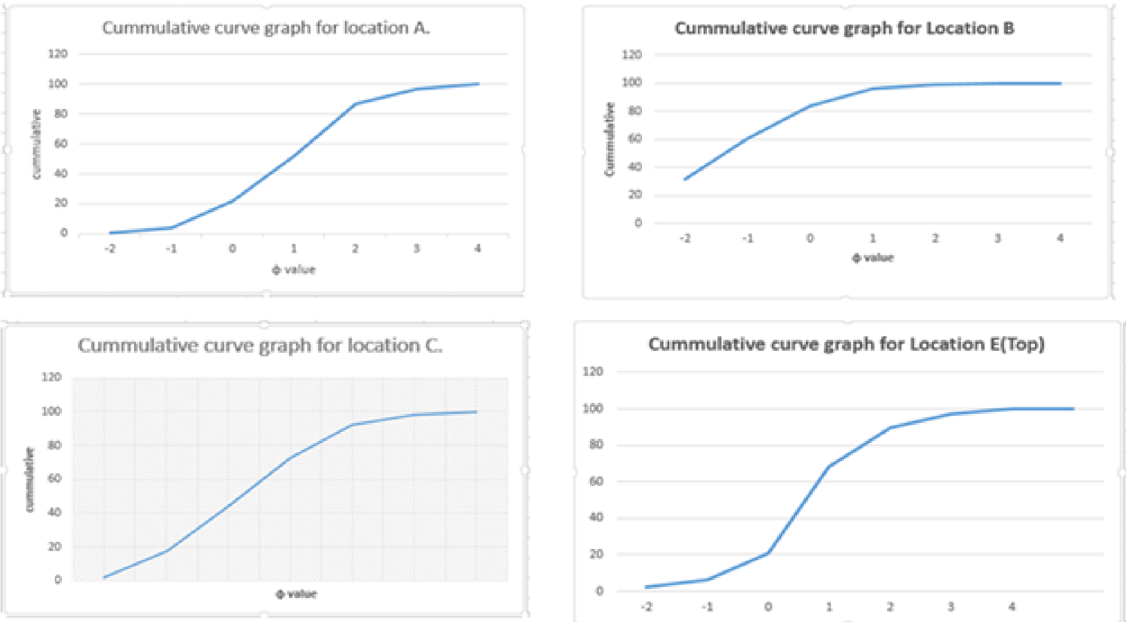

Fig. 12. Particle size distribution curve for Location A (Opposite Cemetery), Location B (Robinson Street), Location C (Hill) and Location E Top or E1 (GRA)

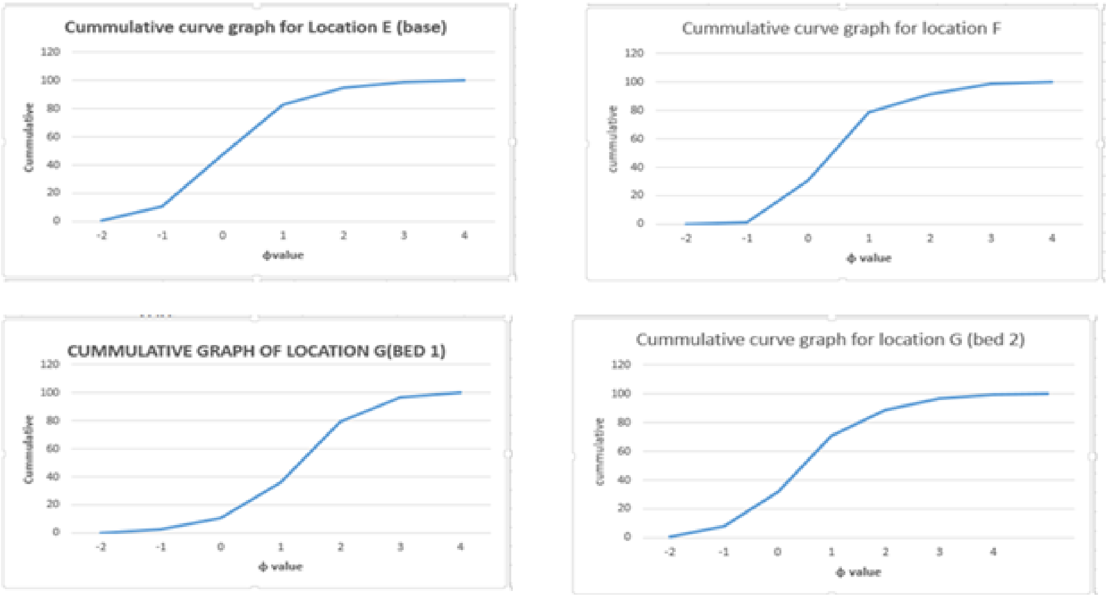

Fig. 13. Particle size distribution curve for Location E Base or E2 (GRA), Location F (Patti), Location G1 (New Stadium) and Location G2 (New Stadium)

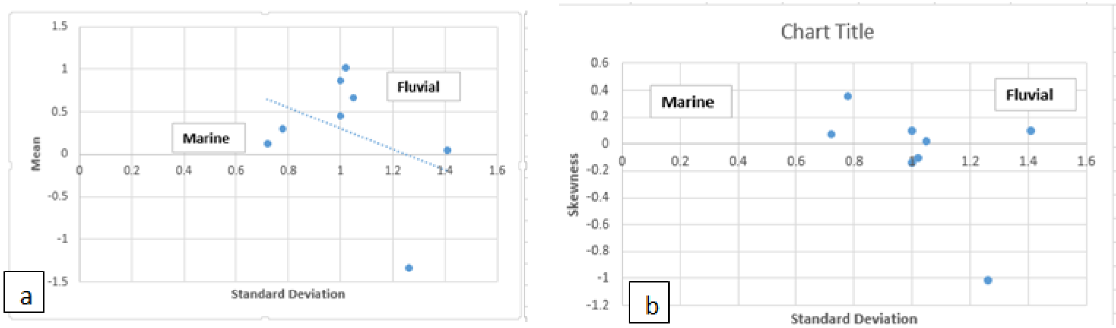

Fig. 14. (a) Plot of Mean against Standard Deviation. (b) Plot of Skewness against Standard Deviation

Table 5. Table showing data interpreted from calculated values

Sample number	Graphic mean	Sorting	Skewness	Kurtosis
Location A	Coarse Grained (0.87)	Poorly Sorted (1)	Coarse Skewed (0.14)	Leptokurtic (1.17)
Location B	Very Coarse Grained (-1.33)	Poorly Sorted (1.27)	Strongly Coarse Skewed(-1.01)	Extremely Leptokurtic (4.08)
Location C	Coarse Grained (0.12)	Moderately Sorted (0.72)	Near symmetrical (0.07)	Leptokurtic (1.33)
Location E1	Coarse Grained (0.67)	Poorly Sorted (1.05)	Nearly Symmetrical (0.02)	Very Leptokurtic (2.53)
Location E2	Coarse Grained (0.05)	Poorly Sorted (1.41)	Nearly Symmetrical (0.1)	Mesokurtic (1.1)
Location F	Coarse Grained (0.45)	Poorly Sorted (1)	Nearly Symmetrical (0.1)	Mesokurtic (1)
Location G1	Medium Grained (1.02)	Poorly Sorted (1.02)	Nearly Symmetrical (-0.1)	Leptokurtic (1.33)
Location G2	Coarse Grained (0.3)	Moderately Sorted (0.78)	Strongly fine skewed (0.36)	Very Leptokurtic (1.73)

4. CONCLUSION

The Lokoja Formation within the study area comprises of conglomerate, pebbly sandstone, sandstone and siltstone/mudstone facies which displayed lithological characteristics, sedimentary structures and textural variation that indicate alluvial deposit which might have prograded through braided streams to nearshore marine conditions. The pebble morphometry data and the bivariate plots of sphericity against oblate-prolate index and plots of coefficient of flatnesss and sphericity revealed that the Lokoja Formation is dominantly of fluvial origin with little beach (marine) influence. The value of graphic mean inferred that the grain size of the sandstone of the Lokoja Formation ranges from medium to very coarse grained, the sorting values indicated moderate to poor sorting and the skewness values indicated that the sandstone is nearly symmetrical, strongly fine skewed and strongly coarse skewed. The values of kurtosis indicated mesokurtic to extremely leptokurtic. The plot of graphic mean and skewness, each plotted against the standard deviation further showed that the study area is dominantly of fluvial origin. This study was necessary since reconstruction of depositional environments enables us to observe the climate of past life, forms and geography of the past.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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