Original Research Article

LITHOFACIES ANALYSIS AND PALEAOENVIRONMENT OF DEPOSITION OF LOKOJA FORMATION, SOUTHERN BIDA BASIN, NORTH CENTRAL, NIGERIA

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 analsysis. 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) values shows 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 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.

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Keyword: Litho-facies, depositional environment, Lokoja Formation, Southern Bida Basin.

1.0 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 (Obaje, 2009). 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 (Jones, 1958). According to Sanni *et al.* (2016), 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 (Obaje *et al.*, 2011; Udensi and Osazuwa, 2004; Okoro and Ezeh, 2010; Obaje *et al*., 2004; Akande *et al*., 2005; Ehinola *et al*., 2005). However, this

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studies 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.

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2.0 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. It is located along the strike of Mount Patti within Lokoja town and it spans across Latitude N 70 50' 00" to N 70 47' 19.47" and Longitude E 0060 41' 34.26" to E 0060 7' 59.94". 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 (Odigi, 2000). 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 (Imasuen *et al.*, 2013). 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 (Obaje, 2009). 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 degree-celcius, with about 747 mm of precipitation fall annually.

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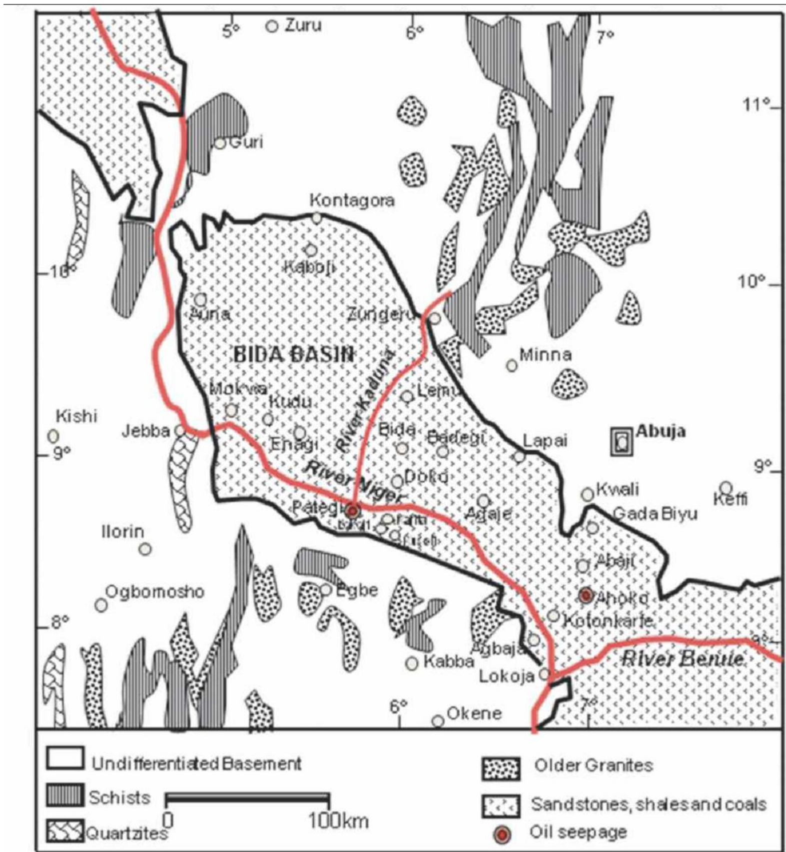

Figure.1.0: Geological and Location Map of Bida Basin and Environs (Obaje *et al*., 2011)

3.0 Methodology

Field mapping and laboratory analyses were employed in this study.

3.1 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 the study area 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

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camera. Sandstone and conglomerate samples were obtained from the study area for further laboratory analysis.

3.2 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.

3.2.1 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	Lutig (1962)
Elongation Ratio (E.R)	I/L	Lutig (1962)
Maximum Projection Sphericity Index (M.P.S.I)	$(S^2/LI)^{1/3}$	Sneed and Folk (1958)
Oblate – Problate (OP) Index	10[(L-I/L-S)-0.50]S/L	Dobkins and Folk (1970)
Roundness	Visual estimation	Sames (1966)

3.2.2 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.

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Test procedure:

i. Take a representative oven dry sample of soil that weighs about 120g.
ii. Crush the lump and not the particles if soil particles are lumped or conglomerated, using the agate mortar and pestle.
iii. Determine the mass of the sample accurately. W_t. (g).
iv. 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.
v. Make sure the sieves are clean; if many soil particles are stuck in the openings try to bring them out using brush.
vi. Pour the soil from step (iii) into the stack sieves from the top and place the cover, put the stack in the sieve shaker and fix the clamps, adjust the time on 10minutes and switch on the shaker from the source.
vii. Stop the sieve shaker and measure the mass of the retained soil for each sieve.
viii. The data derived are then recorded in a table.

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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.

Table 2: Formulas needed for determining the various granulometric parameters.

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	FORMULAR USED	SOURCE
GRAPHIC MEAN	M = $\frac{\varphi16+\varphi50+\varphi84}{3}$	Folk and Ward (1957)
SORTING	D = $\frac{\varphi84-\varphi16}{4}+\frac{\varphi95-\varphi5}{6.6}$	
SKEWENESSES	S = $\frac{\varphi84+\varphi16-2(\varphi50)}{2(\varphi84-\varphi16)}+\frac{\varphi95+\varphi5-2(\varphi50)}{2(\varphi95-\varphi5)}$	
KURTOSIS	K = $\frac{\varphi95-\varphi5}{2.44(\varphi75-\varphi25)}$	

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4.0 Result and Discussion

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The study centred on the Lokoja formation and 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.

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4.1 Description of Lithofacies.

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The Lokoja Formation consists of three lithofacies associations. These are conglomerate, sandstone and siltstone/ mudstone facies.

4.1.1 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 (figure 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 (figure 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 (figure 3a) consist of Clasts supported 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 (figure 3b). The lithologic log for both exposures are given in figure 4a and 4b.

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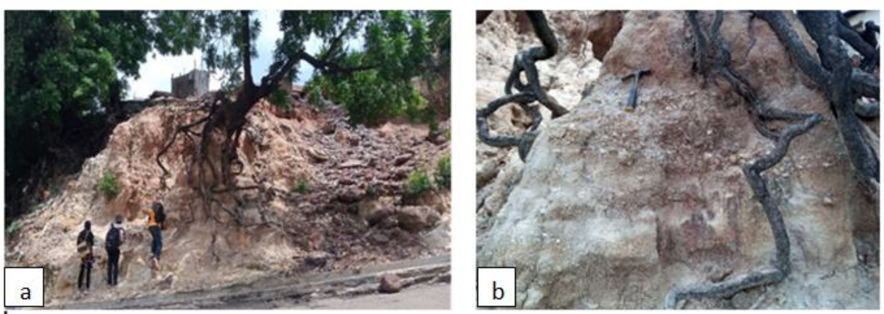

Figure 2: (a) Matrix supported Conglomerate facies of Lokoja formation at Robinson Street (N 07º 48' 46.8" E 06 º 44' 40"). (b)) Clasts embedded in the pebbly sandstone Conglomerate facies at Robinson Street (N07º 48' 46.8" E 06 º 44' 40")

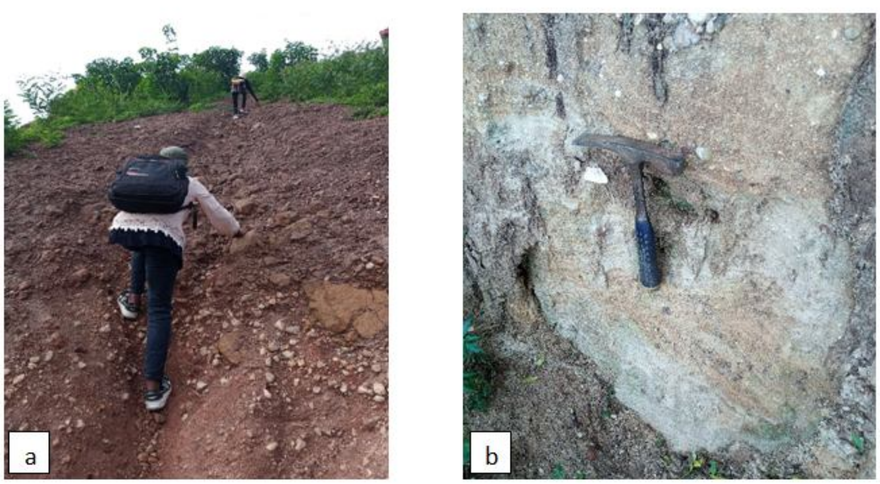

Figure 3: (a) Clasts supported fabric (paraconglomerate) exposed around in the Conglomerate facies in the hill at Kabawa (N 07 º 49’ 14.0” E 006 º 44’ 40”). (b) Herringbone Cross bedding in the conglomerate facies at Robinson Street (N 07º 48’ 46.8” E 06 º 44’ 40”)

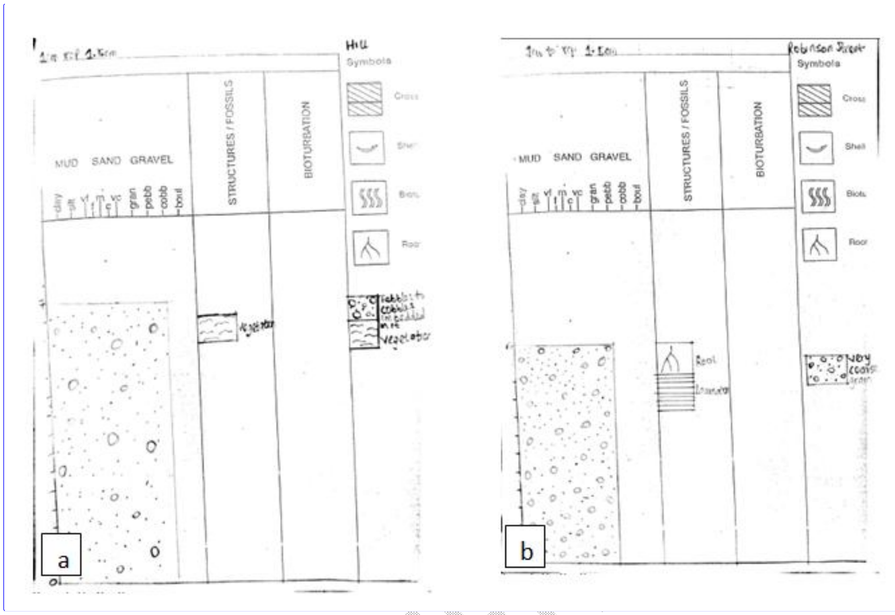

Figure 4: (a) Lithologic section of the Lokoja Formation exposed around Kabawa. (b) Lithologic section of the Lokoja Formation exposed at Robinson Street, Kabawa.

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4.1.2 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 occurs at the middle (bed 3) of the exposure at Ayoola Ajao Avenue in GRA (figure 5a). This 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.

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The cross stratified pebbly sandstone sub-facies (figure 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.

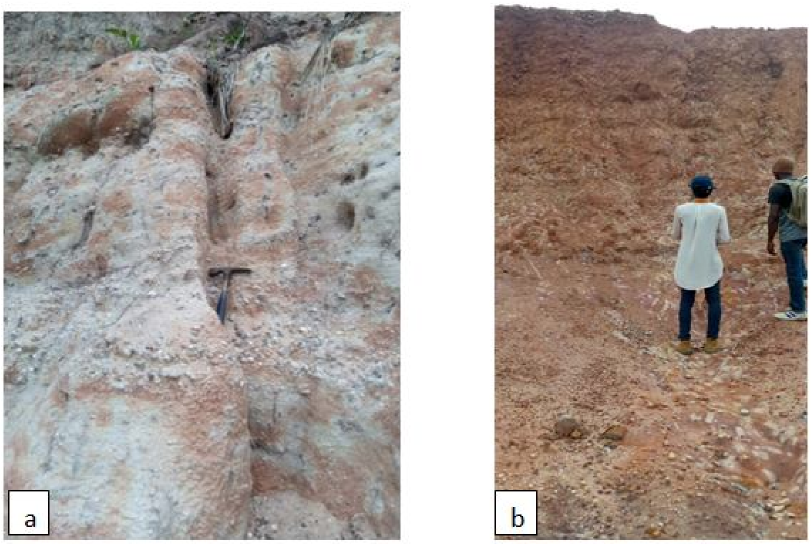

Figure 5: (a) Biorturbated pebbly sandstone sub- facies in Ayoola Ajao Avenue, GRA (N 07 º 48’ 15.2” E 006 º 43’ 27.8”); (b) Trough crossbedding ion cross stratified pebbly sandstone sub-facies behind New stadium (N 07 º 48’ 59.8” E 006 º 42’ 29.7”).

Massive pebbly to coarse grained sandstone sub-facie with an average thicknesss of 6m was identified in the exposure at opposite cemetery Kabawa (figure 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 figure 6b, 7a and 7b.

Figure 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.

4.1.3 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 (figure 8a). At another section, a bioturbated weathered feature was recognised on this facies. At another section, a wavy structure was recognised (figure 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; Braide (1992), Ojo and Akande (2003), Akande *et al.* (2005), etc.

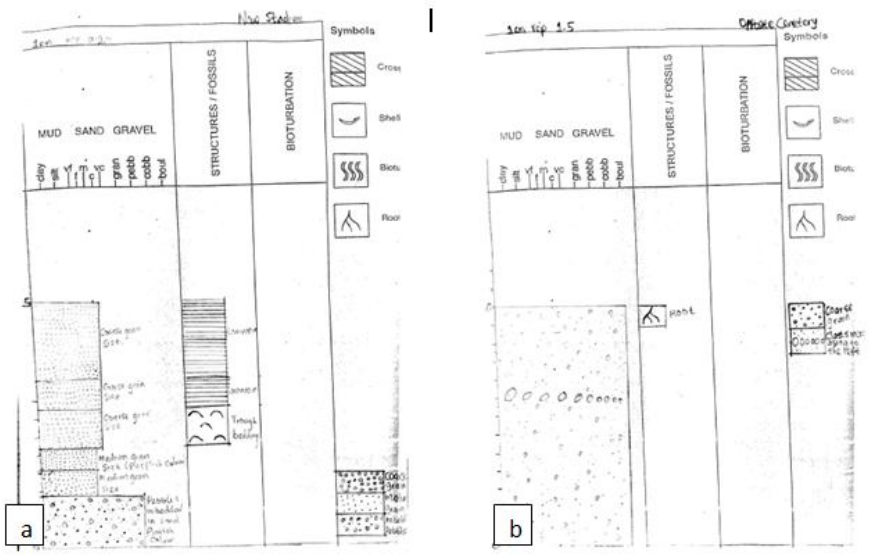

Figure 7: (a) Lithologic section of the Lokoja Formation exposed at the NE direction of the New Stadium. (b) Figure 4.5: Lithologic section of the Lokoja Formation exposed at opposite Cemetery, Kabawa.

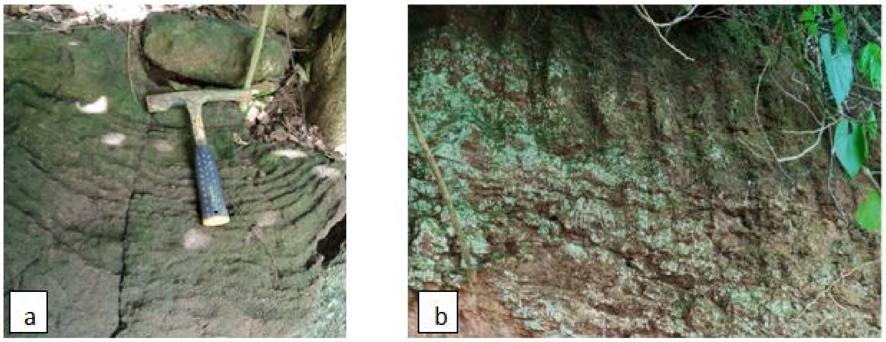

Figure 8: (a) Visible wavy structure in the claystone facies at mount Patti (N 07 º 49' 08" E 006 º 43' 59.0"). (b) Visible woody-like structure in the claystone facies at mount Patti (N 07 º 49' 08" E 006 º 43' 59.0").

4.2 Pebble morphometry

The results obtained from the morphometric analysis of pebbles from Lokoja Formation are presented in figure 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 Lutig (1962) 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, Hubert (1968) 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 Dobkins and Folk (1970) 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 Folk (1958) 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.

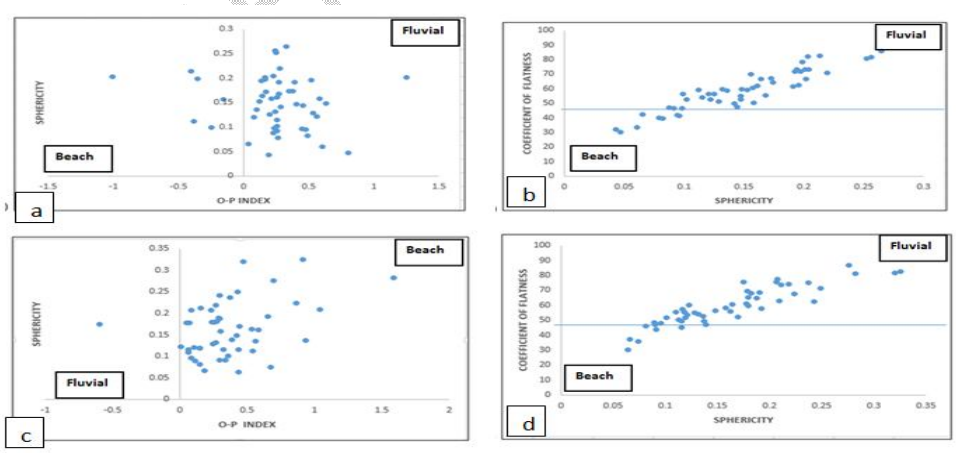

Figure 9: (a) Scattered Plot of sphericity against O-P Index showing separation of beach field from the fluvial field of the Pebble Forms at Opp. Cemetery; (b) Scattered plot of coefficient

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.

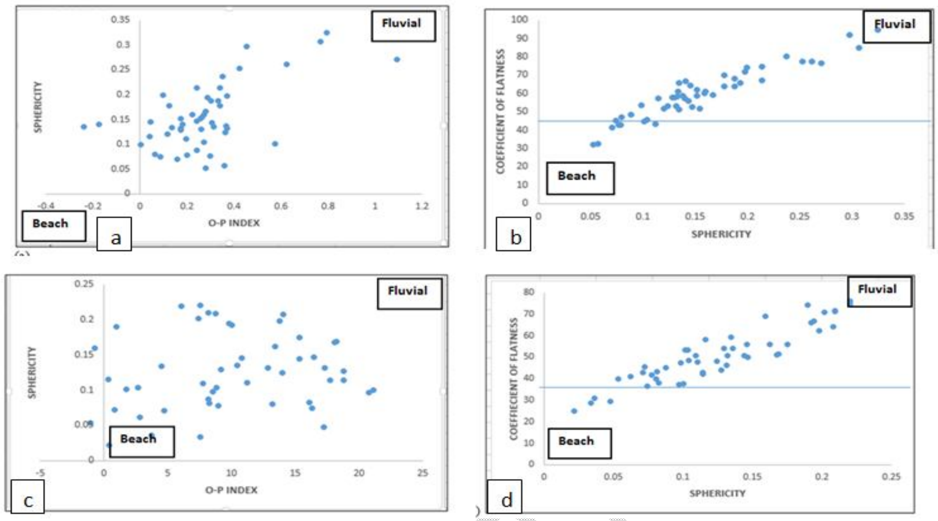

Figure 10: (a) Scattered plot of sphericity against O-P Index showing separation of beach field from the fluvial field of the Pebble Forms at Hill; (b) Scattered plot of coefficient of flatness against sphericity of the Pebble Forms at Hill; (c) Scattered plot of sphericity against O-P Index showing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

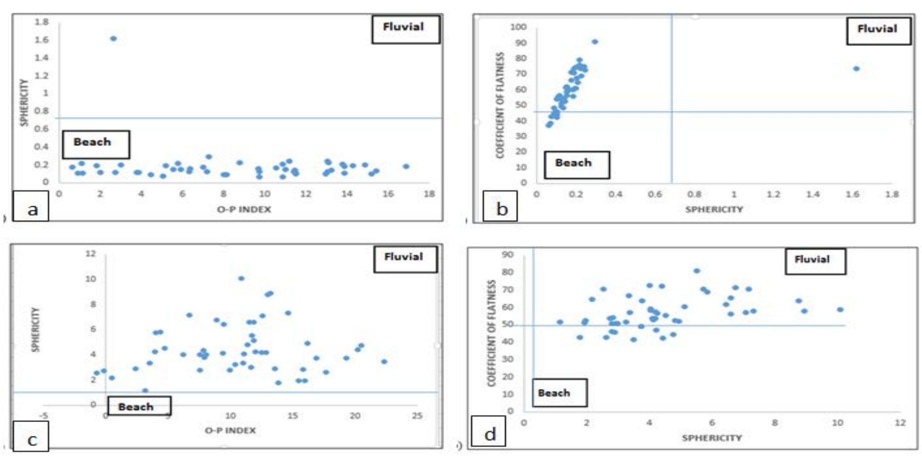

Figure 11: Scattered Plot of sphericity against O-P Index showing separation of beach field from the fluvial field of the Pebble Forms at Mount Patti; (b) Scattered plot of coefficient of flatness against sphericity of the Pebble Forms at Mount Patti; (c) Scattered Plot of sphericity against O-P Index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

4.3 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 figure 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.

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
500 µ	52.31	95.99	72.44	68.49	83.09	78.57	35.94	70.81
250 µ	86.57	99.08	92.37	89.78	94.76	91.79	79.65	89.18
125 µ	97.15	99.75	98.07	96.99	98.93	98.82	96.5	96.9
63 µ	100	100	100	99.76	100	100	71	99.75
Bottom pan				100			100	100

Table 4: Percentiles 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

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Table 5: Table showing data interpreted from calculated values

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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)

Comment [D34]: Remove grid lines from all tables

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 (figure 14); this showed that the study area is dominantly of fluvial origin using Moiola and Wieser (1968) graphical interpretation.

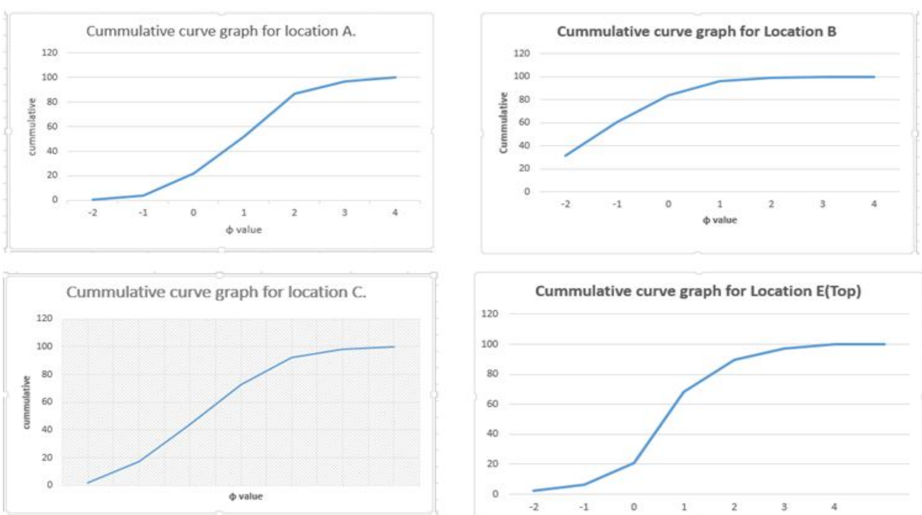

Figure 12: Particle size distribution curve for Location A (Opposite Cemetery), Location B (Robinson Street), Location C (Hill) and Location E Top or E1 (GRA).

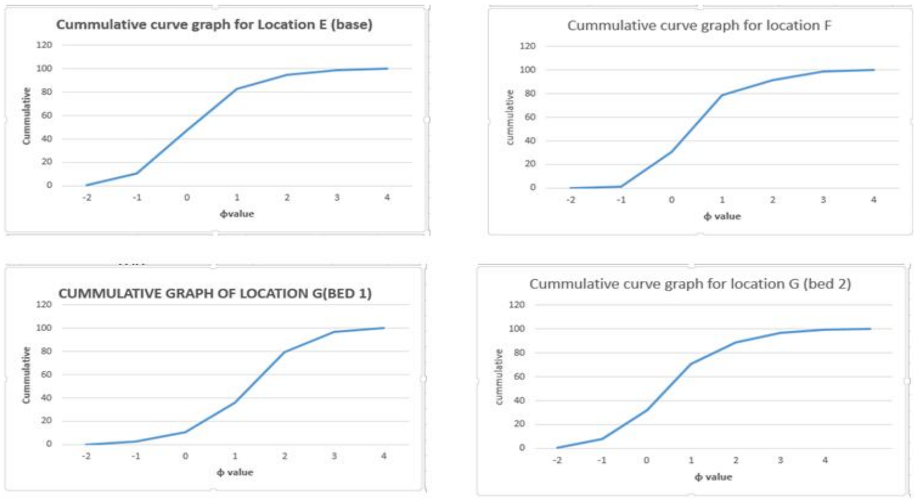

Figure 13: Particle size distribution curve for Location E Base or E2 (GRA), Location F (Patti), Location G1 (New Stadium) and Location G2 (New Stadium).

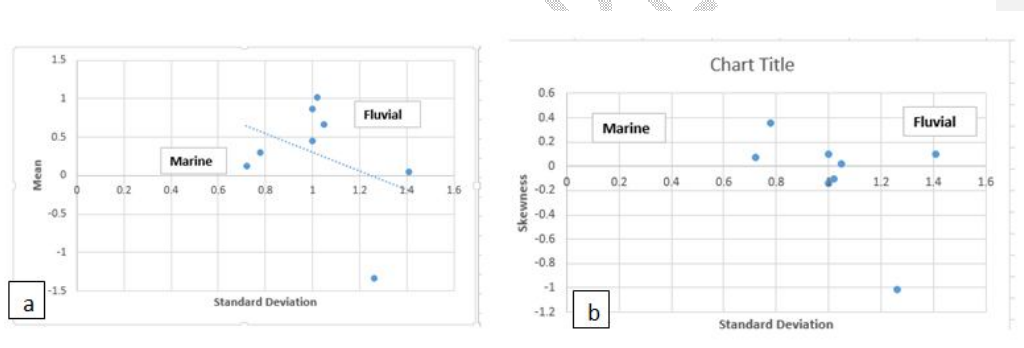

Figure 14: (a) Plot of Mean against Standard Deviation. (b) Plot of Skewness against Standard Deviation.

5.0 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.

Comment [D35]: Has this finding any economic or social implication? Explain further.

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Comment [D36]: Only two out of the twenty literature sources you listed are within ten years of publication. Update your literature to recent relevant publications.

Furthermore, write down each of your literature sources in the order specified by the journal.

Again, the list of literature should follow a numerical order as they appeared in the text. Refer to your author guidelines for guidance.