PRINT ISSN 1119-8362
Electronic ISSN 2659-1502

Full-text Available Online at
https://www.ajol.info/index.php/jasem
http://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 26 (11) 1835-1842 November 2022

Field and Sedimentological Studies of Nataco-Banda Sediments of Lokoja Formation, Southern Bida Basin, Nigeria: Implication for Depositional Environment

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ABSTRACT: The study area falls within the Lokoja Formation of the Southern Bida Basin. The objective of this study was to evaluate the field characteristics and sedimentological parameters of depositional environment of the Nataco-Banda Sediments of Lokoja Formation, Southern Bida Basin, Nigeria using appropriate techniques such as granulometric and pebble morphometric analysis. Field studies revealed a repeated alternating sequence of conglomeratic and pebbly to coarse-grained sandstone and overbank fine sediment that is indicative of a braided fluvial source while the presence of crossbedding is suggestive of tidal influence. The morphometric analysis shows a fluvial setting where pebbles plot in the river area than the beach area. Environmental discrimination formulae for Y1, Y2 and Y3 indicated the dominance of Beach and Shallow agitated marine in both Y1 and Y2, respectively, while the almost equal percentage values of Y3 in both fluvial and shallow marine settings are highly suggestive of a shallow marine environment that is largely influenced by fluvial deposition.

DOI: **https://dx.doi.org/10.4314/jasem.v26i11.15**

Cite this paper as: ALEGE, T. S; OMADA, J. I; UCHENDU, K (2022). Field and Sedimentological Studies of Nataco-Banda Sediments of Lokoja Formation, Southern Bida Basin, Nigeria: Implication for Depositional Environment. *J. Appl. Sci. Environ. Manage.* 26 (11) 1835-1842

Keywords: Granulometry; pebble morphometric analysis; sedimentology; diagenesis

The study of sedimentary rocks and the processes by which they are formed, includes and is related to a large number of phenomena. Sedimentology includes the five fundamental processes defined by the term sediaentation -weathering, erosion, transportation, deposition and diagenesis. Sedimentology shares with geomorphology the study of the surface features of the earth (Wolf and Benedict, 1964). Adeleye (1971 and 1974) studied the stratigraphy and sedimentation process of the Upper Cretaceous rocks in the basin. Omali and Imasuen (2011) did a sedimentological characterization of the Lokoja Sandstone while Alege and others (2020) undertook sedimentologic, lithofacies, palynofacies and sequence stratigraphic of the successions within the basin. The study area is located in the Nataco-Banda area of Lokoja, Kogi State (Fig. 1a), where good exposures are accessible through road-cuts, stream channels and mining sites. This study focuses on the field and sedimentological characteristics of the Cretaceous sedimentary rocks of Lokoja Formation in the Southern Bida sub-basin.

MATERIALS AND METHODS

Description of study area: The Southern Bida Basin is a NW-SE trending Upper Cretaceous rocks extending from Kotongora areas to some extent beyond Lokoja in the south (Ojo and Akande, 2009). The area of study is located on the exposures of Banda-Nataco area of Lokoja, Kogi State in the North-Central part of Nigeria within latitudes $07^{0}46'0''$N to 070 55'0N and longitudes $006^{0}42'0'$E to 006^{0} 48'0"E part of sheet Lokoja Sheet 247NW. The area is accessible by major roads and some minor roads. The area was mapped on a scale of 1:25,000 and the areal extent is about 12km2 (Fig.1a, b). The Bida Basin is a northwestern extension of the Anambra Basin (Akande *et al*., 2006). The stratigraphic succession of Bida Basin comprises a Northern Bida Basin and Southern Bida Basin (Fig. 2). The basin fill consists of a northwest trending belt of

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Upper Cretaceous sedimentary rocks that were deposited as a result of block faulting, basement fragmentation, subsidence, rifting and drifting consequent to the Cretaceous opening of the South Atlantic Ocean (Obaje *et al*, 2011). The Southern Bida Basin is made up of three formations from oldest to youngest; the Lokoja, Patti and Agbaja Formations. The Lokoja formation is the oldest stratigraphic sequence in the Southern Bida Basin, and is made up of lithologies of conglomerates, coarse to fine-grained sandstones, siltstone, and poorly sorted claystones often cross-stratified and generally compositionally immature. This Formation rests unconformably on the Precambrian Basement Complex.

The Patti Formation consisting of sandstones, and shales usually with bioturbated ironstones, siltstones, and claystones interbeds lying conformably on the Lokoja Formation. The Agbaja Ironstone is the youngest rock sequence overlying the Patti Formation. It forms a cap for the Campanian-Maastrichtian sediments in the Southern subbasin while serving as a lateral equivalent of the Batati Formation on the northern subbasin.

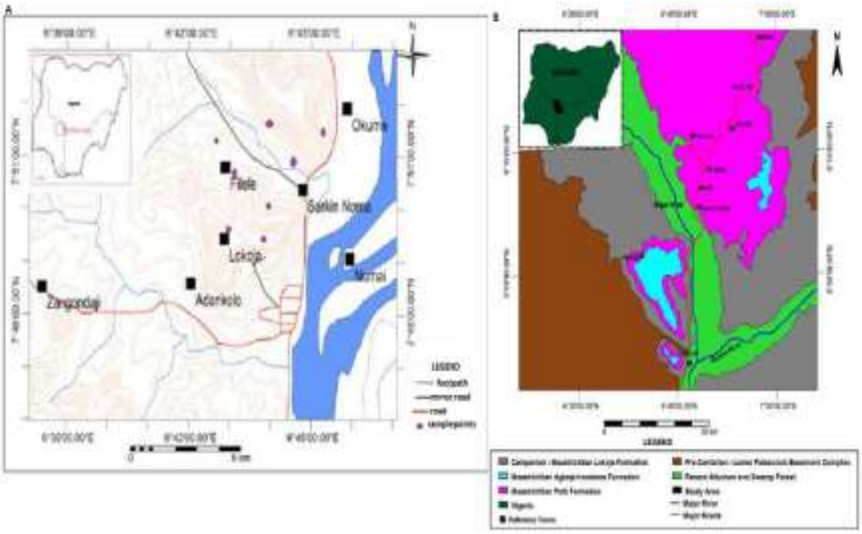

Fig.1: a) Topographic map of the Banda-Nataco area showing the sample points. b) Geologic map of the Mid-Niger Basin (After Odoma et al., 2015)

Sample Collection, Treatment and Analysis: A total of nineteen (19) composite samples from the Lokoja Formation outcropping in the Felele, Nataco and Banda areas in Lokoja Kogi State were collected and measured to investigate their field characteristics, textural and lithologic variations, as well as their pebble morphometry.

Samples were carefully disaggregated with the use of a rubber-padded pestle and mortar. The weight of the selected empty sieves (4.0mm, 3.35mm, 2.0mm, 1.18mm, 600µm, 425µm, 150µm, 75µm, 63µm, and pan) was obtained using weighing balance and placed in sieves arranged in order of decreasing mesh sizes and shaken. The sediments retained in each of the sieves and the bottom pan were weighed and their weight recorded.

Other grain size parameters like mean, sorting, skewness and kurtosis were calculated using the method by Folk and Ward (1957). These were further used as independent functions and sometimes combined in multivariate analysis by Linear Discriminate Function (LDF) to deduce the depositional settings.

A total of two hundred (200) pebbles were collected, washed, dried and the broken pebbles removed. Measurement was done using the vernier calliper after Krumbeins (1941) method. The Long (L), Intermediate (I) and Short (S) axes of the pebbles were measured. Pebble indices such as flatness ratio (FR), Flatness index (FI), Elongation ratio (ER), Maximum Projection Sphericity Index (MPSI) and Oblate Prolate Index (OPI) were undertaken with the visual estimation of pebbles roundness using the roundness chart of powers (1953).

RESULTS AND DISCUSSION

*Field characteristics***:** Four locations (A, B, C and D) were mapped in the study area (Fig. 1a) and the outcrops have similar facies characteristics (Fig. 3). The exposure in Location A is composed of seven members. The sandstone in each bed ranges from brown-grey, dark brown, pink, and grey to light brown. It is a matrix-supported conglomeratic sandstone with the alignment of cobbles. The textures are generally coarse to medium grained with cross-beddings interbedded with pebbles. Dark brown, lateritic clay is also present on the overburden.

Location B comprises four beds with matrix-supported conglomeratic sandstone. It ranges in colour from milky to white, brown to grey. The beds are composed of sandy claystone, with an overburden of ironstone. Texture ranges from coarse to medium grain size.

Location C consists of brown to grey, grey to light brown coarse-grained sandy claystone with the alignment of pebbles. The beds consist majorly of matrix-supported conglomeratic sandstone.

Location D beds range from grey to white, pinkish, brownish in colour. The beds are colour-beaded pebbles and capping of brownish ironstone which is brownish and composed mainly of boulders that are angular to subangular.

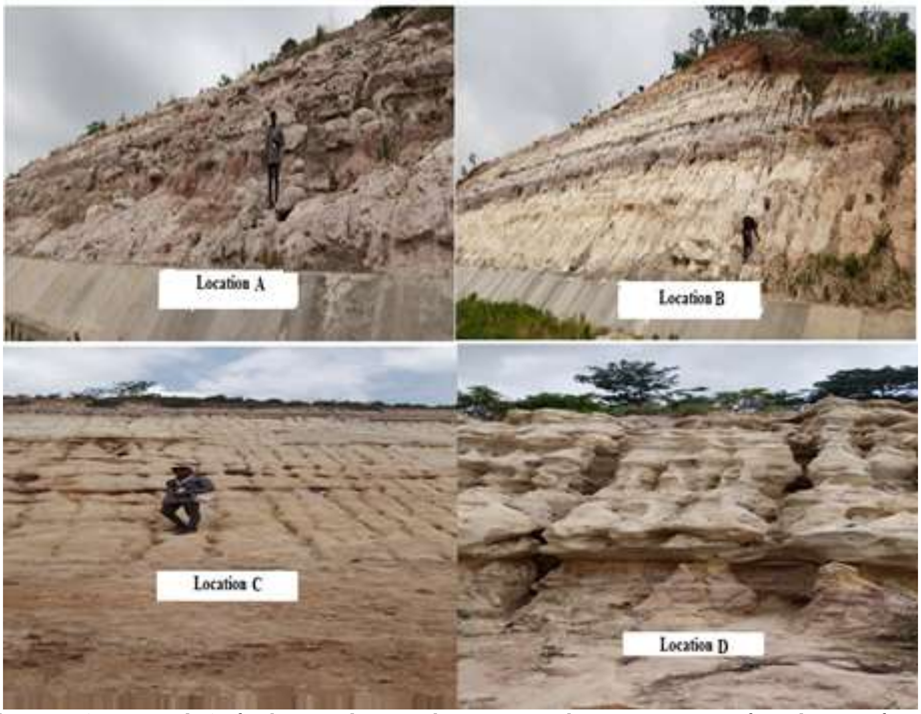

Fig 3: Measured sections (A, B, C and D) of Lokoja Sandstone in the Nataco-Banda area, comprising of conglomerate facies overlain by the sandstone facies.

Sedimentary Facies Units: Two (2) facies units are identified based on the field studies of the textures and structures in the study area: a). Conglomerate facies b). Sandstone facies

a. Conglomerate facies: This forms the older unit of the facies in the measured section (Fig. 3). It overlies the Basement Complex non-conformably and occurs as grain supported conglomerate subfacies with colour ranging from brown to grey to light brown. This subfacies is observed in all locations of the study area making sharp contact with the overlying graded matrix supported conglomerate subfacies with the alignment of cobbles. In the studied section from Nataco to Banda, the conglomerates are massive with supporting matrix that grades into poorly sorted muddy sediments towards the upper part of the section.

b. Sandstone facies: The sandstone facies occurs in all four locations of the study area. They are made up of grey, coarse-grained, poorly to moderately sorted, near-symmetrical to positively skewed, platykurtic to mesokurtic, massive sandstone. This facies overlies the basal conglomerate facies (Figure 3) in the upper part of the sections. They occur as massive cross-bedded pebbly sandstone subfacies that show repeated upward cycle which begins with conglomerates (Fig. 2) in which clasts are pebble to cobble-sized and oriented parallel to the bounding surfaces where they make erosive contact with the lower bed.

Granulometric Studies: Nineteen samples were sieved and their statistical parameters were determined as presented in Table 1.

Table 1: Grain size distribution and quantitative parameters of Nataco-Banda samples of Lokoja Sandstone.

Sample	Mean (mm)	Sorting (ᶲ)	Skewness (ᶲ)	Kurtosis
LAB1	0.33 Coarse-grained sand	0.86 Moderately sorted	0.1 Fine skewed	0.89 Platykurtic
LAB2	0.8 Coarse-grained sand	1.24 Poorly sorted	-0.02 Near-symmetrical	1.19 Leptokurtic
LAB3	0.93 Coarse-grained sand	1.09 Poorly sorted	-0.14 Coarse skewed	1.00 Mesokurtic
LAB4	0.73 Coarse-grained sand	1.09 Poorly sorted	0.10 Fine skewed	1.05 Mesokurtic
LAB5	0.53 Coarse-grained sand	0.99 Moderately sorted	0.29 Fine skewed	1.32 Leptokurtic
LAB6	0.13 Coarse-grained sand	0.86 Moderately sorted	-0.05 Near-symmetrical	0.91 Platykurtic
LAB7	0.03 Coarse-grained sand	0.84 Moderately sorted	0.1 Fine skewed	0.86 Platykurtic
LBB1	0.06 Coarse-grained sand	1.00 Poorly sorted	0.20 Fine skewed	1.06 Mesokurtic
LBB2	0.63 Coarse-grained sand	0.73 Moderately sorted	0.12 Fine skewed	0.76 Platykurtic
LBB3	0.1 Coarse-grained sand	0.95 Moderately sorted	0.11 Fine skewed	1.15 Leptokurtic
LCB1	0.36 Coarse-grained sand	0.67 Moderately well sorted	0.37 Strongly fine skewed	1.02 Mesokurtic
LCB2	0.73 Coarse-grained sand	1.03 Poorly sorted	0.47 Strongly fine skewed	1.03 Mesokurtic
LDB1	-0.36 Very Coarse-grained sand	1.46 Poorly sorted	-0.29 Coarse-skewed	1.07 Mesokurtic
LDB2	1.56 Medium-grained sand	2.73 Very Poorly sorted	-0.10 Near-symmetrical	0.89 Mesokurtic
LDB3	0.73 Coarse-grained sand	0.89 Moderately sorted	0.17 Fine skewed	1.18 Leptokurtic
LDB4	0.1 Coarse-grained sand	0.71 Moderately sorted	-0.14 Near-symmetrical	0.91 Mesokurtic
LEB1	0.23 Coarse-grained sand	0.80 Moderately sorted	0.13 Fine skewed	1.10 Mesokurtic
LEB2	0.36 Coarse-grained sand	1.24 Poorly sorted	0.15 Fine skewed	1.11 Mesokurtic
LEB3	0.76 Coarse-grained sand	1.27 Poorly sorted	0.11 Fine skewed	0.99 Mesokurtic

The result (Table 1) of the mean size of the sediments exhibit a coarse-grained texture (89.5 %) distributed with values ranging from 0.03 φ to 0.93 φ. Samples LDBI and LDB2 represent 5.26% of the sediment with very coarse-grained sand (-0.36) and medium-grained sand (1.56) respectively (Table 1). The measure of sorting of the sediments varies from moderately sorted (52.6 %) through poorly sorted (42.2 %) to very poorly sorted (5.26%) with a value range of 0.67 to 2.73 φ on an average of 1.08 which implies a mostly poorly sorted sediment. The degree of asymmetry of the grain size distribution have values which vary over a wide range from fine skewed (52.6%), strongly fine skewed (10.5%), near symmetrical (21%), to coarse skewed (10.5%) with values ranging from -0.02 (Near symmetrical) to 0.47 (strongly fine skewed). The graphic kurtosis (KG) measures the degree of flatness of the grain size distribution curve (Folk, 1974). Kurtosis values of analyzed samples vary from mesokurtic (57.9%) through platykurtic (21.1%) to leptokurtic (21.1%) with values ranging from 0.76 to 1.32 φ and with an average value of 1.03φ, suggesting a mesokurtically distributed curves for all the samples.

Pebble Morphometry: A total of two hundred (200) pebbles were collected from the Banda-Nataco study area. The Long (L), Intermediate (I) and Short (S) axes of the pebbles were measured. Pebble indices such as flatness ratio (FR), Flatness index (FI), Elongation ratio (ER), Maximum Projection Sphericity Index (MPSI) and Oblate Prolate Index (OPI) with the visual estimation of pebbles roundness using the roundness chart of powers (1953).

Table 2: Pebble Morphometry (roundness) for Locations A, B, C, and D

Location A Roundness%		Location B Roundness%		Location C Roundness%		Location D Roundness%	
70	70	30	50	70	70	50	30
30	40	30	30	30	50	30	30
70	70	30	30	70	30	30	30
30	30	40	40	70	50	70	30
30	30	30	40	70	50	30	50
30	40	50	30	30	30	50	30
30	40	40	30	30	30	30	30
40	30	30	40	40	30	30	50
30	30	40	50	50	30	30	30
50	30	30	40	30	30	30	70
50	30	30	70	30	30	30	30
30	30	30	50	30	30	40	30
40	40	40	40	30	30	30	70
30	30	30	30	30	30	30	30
50	40	50	50	50	30	30	30
40	40	50	40	50	70	30	30
40	40	30	30	50	70	30	30
30	30	70	70	40	30	70	30
50	50	30	30	50	30	30	30
30	40	30	50	30	30	30	30
70	70	50	30	30	40	30	30
40	50	40	30	30	50	40	30
50	50	30	50	40	50	30	30
30	50	30	30	70	30	50	30
50	40	40	40	70	50	50	30

Morphometric studies of pebbles showed variations in an environment of deposition from fluvial to marine settings for the Lokoja sandstone.

Table 3: Pebble Morphological Analysis Interpretation

Pebble morphometric parameters	Characteristics	Definite limits from previous studies	Interpretation
Flatness Index (FI)	Consist of over 90% above fluvial limit	Beach <45% Fluvial >45%	Fluvial
Elongation ratio	Over 95% has values between 0.6-0.9	Fluvial	Fluvial
Maximum projection Sphericity index(MPSI)	The pebbles analyses about 97% were 0.06	Beach <0.66 Fluvial>0.66	Predominantly fluvial
Oblate prolate (OP)	The OPI shows significant of fluvial deposit with minimal beach	Beach <1.5, Fluvial >1.15	Fluvial dominated
Roundness	60% has values below 0.3 and 40% has values above 0.45	Fluvial <0.35 Littoral >0.45	Mainly fluvial/littoral with few beach pebbles

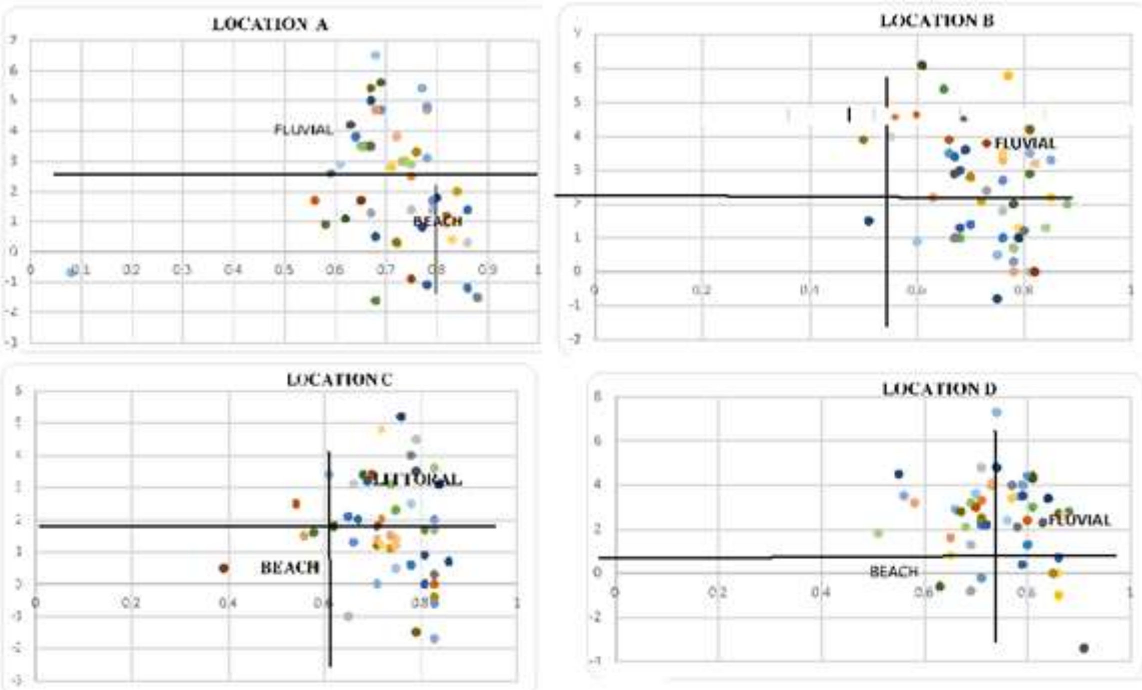

Fig 4: Sphericity against Oblate Prolate Index (OPI) for locations A, B, C and D

The scatter plots of maximum projection Sphericity index (MPSI) against Oblate-prolate index (OPI) indicate river origin for the pebbles. Both grains and matrix-supported conglomerates form recognizable beds at the base of the outcrops. The sandstone units are frequently cross-stratified with the presence of mud cracks in the claystone unit as well as other sedimentary structures (Fig. 3). The repeated alternating sequence of conglomeratic and pebbly to coarse-grained sandstone and overbank fine sediment suggests a braided fluvial origin while crossbedding sedimentary structure attests to the influence of tidal action (Amireh and Abed, 1999; Ojo and Akande, 2012). Similarly, the cumulative textural immaturity and unidirectional trends are also expressive of a fluvial depositional environment dominated by braided streams with sands deposited as channel bars resulting from fluctuating flow velocity. The results of the grain size analysis of the Banda-Nataco exposures of the Lokoja Formation (Table 1) shows that the average graphic mean is coarse-grained in texture. The coarse grain size depicts transportation in a high energy environment by abrasion. The predominance of poorly sorted values with an average of 1.08φ reflects less reworking of the sediment during transport and indicate rapid deposition by the fluvial process (Freidman, 1967). The skewness result reflects a dominance of positively skewed (52.6%) to Near-symmetrical and poorly sorted to moderately sorted grains, an indication of river sands (Fig. 4).

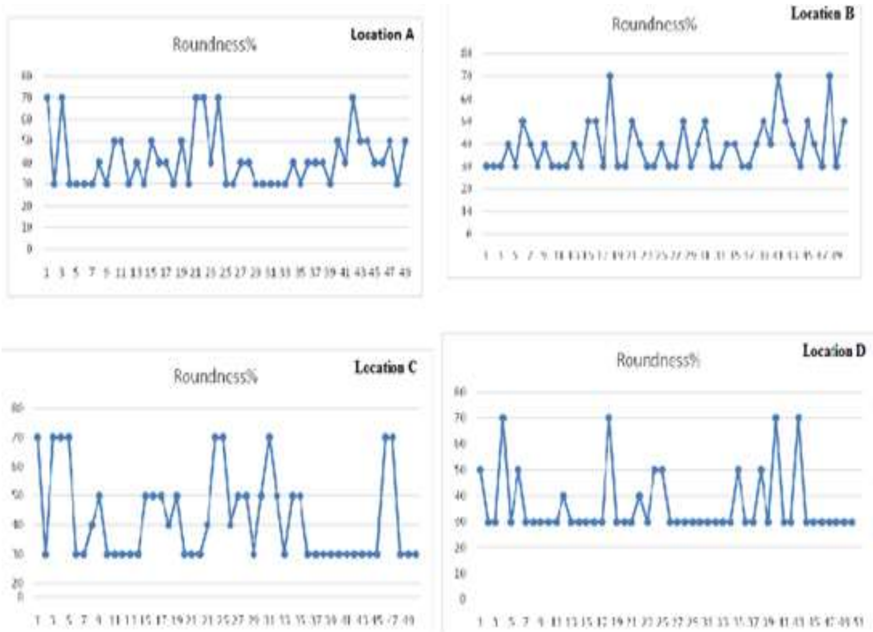

Fig 5: Pebble roundness distribution for Location A, B, C, and D

Table 4: Result of Linear Discriminant Analysis

S/N	Sample ID	Y1	Environment	Y2	Environment	Y3	Environment
1	LAB 1	4.16	Beach	63.26	Shallow agitated marine	-5.26	Shallow marine
2	LAB 2	3.52	Beach	83.68	Shallow agitated marine	-6.34	Shallow marine
3	LAB 3	5.44	Beach	133.73	Shallow agitated marine	-13.05	Fluvial deltaic
4	LAB 4	5.35	Beach	106.40	Shallow agitated zmarine	-9.46	Fluvial deltaic
5	LAB 5	6.40	Beach	112.60	Shallow agitated marine	-10.68	Fluvial deltaic
6	LAB 6	5.38	Beach	88.52	Shallow agitated marine	-9.92	Fluvial deltaic
7	LAB 7	5.41	Beach	64.10	Shallow agitated marine	-6.18	Shallow marine
8	LABB 1	5.56	Beach	68.00	Shallow agitated marine	-6.40	Shallow marine
9	LABB 2	3.40	Beach	93.25	Shallow agitated marine	-9.52	Fluvial deltaic
10	LABB 3	5.09	Beach	58.76	Beach	-4.82	Shallow marine
11	LC B1	5.00	Beach	85.80	Shallow agitated marine	-8.29	Shallow marine
12	LC B2	1.50	Beach	66.68	Shallow agitated marine	-5.48	Shallow marine
13	LD B1	5.77	Beach	60.62	Beach	-7.41	Fluvial deltaic
14	LD B2	5.69	Beach	175.70	Shallow agitated marine	-16.76	Fluvial deltaic
15	LD B3	3.80	Beach	500.98	Shallow agitated marine	-64.98	Fluvial deltaic
16	LD B4	5.26	Beach	71.71	Shallow agitated marine	-7.19	Shallow marine
17	LE B1	0.81	Beach	72.00	Shallow agitated marine	-3.81	Shallow marine
18	LE B2	4.27	Beach	70.58	Shallow agitated marine	-6.07	Shallow marine
19	LE B3	6.23	Beach	137.10	Shallow agitated marine	-14.11	Fluvial deltaic

The kurtosis result shows dominance of Mesokurtic (57.9%) with an average value of 1.03φ is suggestive of compositional immature sandstone (Ilevbare and Imasuen, 2020). The dominance of coarse-grained particles implies strong to moderate energy or fluctuation in the energy of deposition.

The result of the pebbles morphometric analysis (Table 2) of the Banda-Nataco exposures of the Lokoja Formation reveals that the sandstone has low sphericity that ranges from angular to subangular.

The pebbles morphometric analysis shows a fluvial setting of the Banda-Nataco exposure of the Lokoja Formation. Furthermore, scatter plots of the calculated form indices such as MPSI and OPI suggest that pebbles are concentrated more in river areas than the beach area, which indicates a fluvial condition for the pebbles.

The roundness is an indication of the extent of abrasion (ability to wear or rub off) determined by the distance of transportation of pebbles rather than the depositional environment. The measured pebbles' roundness results show that 83% of the pebbles vary from angular to subangular, while the remaining percentage plot within rounded to subrounded. This result is indicative of textural immaturity, suggestive of close provenance. The scatter plots of the calculated pebbles (Figure 5) show the majority of the pebbles plot in the fluvial environment of deposition.

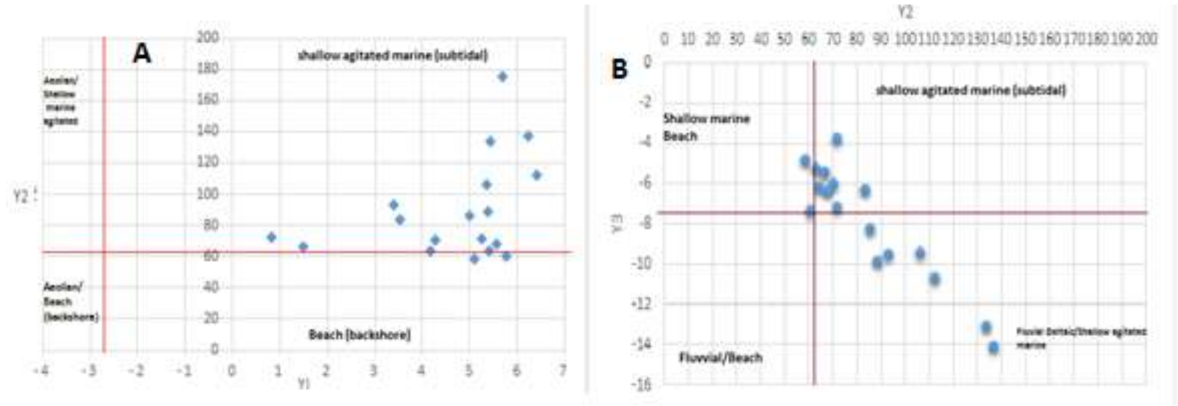

Fig 6: (a) Bivariate plot of Y1 Vs Y2 and (b) Y2 Vs Y3 plot for the Lokoja Sandstone in the study area (after Sahu 1964).

The Y1 equation according to Sahu (1964) was used in the discrimination between aeolian and littoral (intertidal zone) environments. The equation suggests that when Y1 is less than – 2.7411, it is an Aeolian deposit, and if Y1 is greater than – 2.7411, a beach environment. From the result of the linear discriminant function analysis of the Banda-Nataco exposures of the Lokoja Formation (Table 4), all (100%) values of Y1 are greater than – 2.7411 (Table 4) indicating a beach environment. According to Sahu (1964), the value of Y2 greater than 63.3650 is indicative of a shallow agitated marine environment is inferred. Thus, a shallow agitated marine environment is suggested since Y2 is 89.47% of values of Y2 (Table 4).

The Y3 equation was used for the discrimination between shallow marine (subtidal) and fluvial deltaic environments. The results of the analysis revealed that 52.63% of the plotted Y3 values are suggestive of a shallow marine environment while 47.37% % has Y3 values less than -7.419 indicative of a fluvial deltaic setting (Fig. 6). By implication, the almost equal percentage values of Y3 in both fluvial and shallow marine setting is suggestive of a shallow marine environment that is largely influenced by fluvial deposition.

Conclusion: The field associations and sedimentological studies of the Nataco-Banda outcrops of the Lokoja Formation have been studied. Results of the granulometric analysis show a mix of poorly to moderately sorted, positively skewed mesokurtic to platykurtic coarse-grained conglomerate and sandstone facies suggestive of strong to moderate energy of deposition. Pebble morphometric analysis indicates the dominance of the fluvial environment while the linear discriminate analysis suggests a shallow agitated marine environment that is strongly influenced by fluvial deposition (fluvial-deltaic).

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