



Science Forum (Journal of Pure and Applied Sciences)

journal homepage: <https://atbu.edu.ng/science-forum/>



Paleoenvironments, Texture and Mineralogy of Sandstones of Bida Formation exposed at Doko and a quarry along Bida-Minna Road, Northern Bida Basin, North Central Nigeria: Implication on Reservoir Quality.

¹Adeoye J. A., ²Haruna, K.A., ³Akintokewa, O.C., ¹Mahmoud A. A., ¹Yerima, A. M., ¹Danlami M. H., ¹Obaje N. G. and ²Umar, A. M.

¹Department of Geology and Mining, Ibrahim Badamasi University, Lapai, Niger State, Nigeria

²Department of Chemical and Geological Science, Al-Hikmah University, Ilorin, Kwara State, Nigeria

³Department of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria

ABSTRACT

Paleoenvironments, texture and mineralogy of sandstones belonging to the Campanian – Maastrichtian Bida Formation exposed at Doko and Quarry along Bida-Minna road, northern Bida Basin, northcentral Nigeria, were investigated through grain size, petrographic studies and X-ray diffraction to deduce their preliminary reservoir properties. Grain size statistical variables (average mean, standard deviation, skewness and kurtosis) for Doko sandstones are 0.55 mm, 1.44 mm, -0.02 mm and 0.98 mm and Quarry sandstones are 0.83 mm, 1.06 mm, 0.06 mm and 1.28 mm. Average quartz, feldspar and rock fragment minerals in Doko and Quarry are 61 %, 29 % and 9.9 % and 69 %, 10 % and 21 % respectively. Non-opaque heavy minerals which are generally less than the opaque include zircon, tourmaline and rutile with lesser garnet, apatite and monazite. And the XRD shows quartz, orthoclase, muscovite, kaolinite, vermiculite, albite, goethite, and garnet in order of decreasing concentration. The sandstones are generally bioturbated, cross stratified, poorly sorted, with dominance of medium to coarse grain texture. They possess angular to sub-angular mineral grain shapes, except for the conglomeratic sandstones that consist of sub-rounded to rounded pebble sizes. Mineral petrography reveals that the sandstones across the study areas are sub-litharenite to arkosic sandstones with short history of transportation and deposition by fluvial settings. Their texture and mineral composition being immature to sub mature is not favourable for a reservoir or an aquifer because of high matrix that can block the poor spaces and cementing materials that will enhance cementation at deeper depth. This will drastically reduce their porosity and permeability quality. The sandstones of Bida Formation deposited at Doko are the most preferable for hydrocarbon reservoir and aquifer due to their better textural and mineralogical features compared to the ones at the quarry along Bida-Minna Road, northern Bida Basin.

ARTICLE INFO

Received 08 March 2023

Received in Revised form

12 May 2023

Accepted 12 May 2023

Published 30 October 2023

Available Online 30 October 2023

KEYWORDS

Texture,
Sandstones,
Mineralogy,
Paleoenvironments,
Reservoir.

1. Introduction

Bida Basin (Fig. 1) is one of the inland sedimentary basins in Nigeria located in North-Central area of Nigeria almost perpendicular to the Benue Trough. Its south eastern end is adjacent to Anambra Basin and the northwest end to Illumenden (Sokoto) Basin. Bida Basin has rock succession from the late Cretaceous transgressive and regressive events

and geographically divided into northern and southern part due to the wide variation and spread of the rocks. The basin has received the attention of many researchers in the last four decades with focus on the tectonic evolution, stratigraphy, sedimentology, mineral, water and energy resources (Adeleye, 1973, 1974, Braide, 1992, Jan Du Chene, 1978, and Olaniyan and Olobaniyi, 1996, and Ojo, 2010).

*Corresponding Author: Adeoye J. A Department of Geology and Mining, Ibrahim Badamasi University, Lapai, Niger State, Nigeria
jamesadejimi@gmail.com, .

Aspect of the petroleum system assessment of the Bida Basin are not left out as past and current studies are bringing in new and encouraging reports on its depth to basement and petroleum potential along with other Nigerian Inland basins (Idowu and Enu, 1992Q, Braide, 1992, Ojo, 1992, Obaje 2004, Akande, 2005). The exploration activities in the inland basins has not yield significant results in terms of commercial hydrocarbon till date principally because of some missing knowledge on the geologic structure, petroleum system elements and processes commonly responsible for oil and gas accumulation. This study therefore investigated

sandstones belonging to Bida Formation that are exposed at a quarry along Bida-Minna Road, and Doko village in the Northern part of the basin. They were subjected to grain size, thin section, heavy mineral and X-ray diffraction studies to evaluate the impact of their paleoenvironments, texture and mineralogy characteristics quality suitable for hydrocarbon reservoir or aquifer for underground water. The results from this study should add more valuable information on de-risking part of the basin for hydrocarbon or underground water exploration and exploitation efforts.

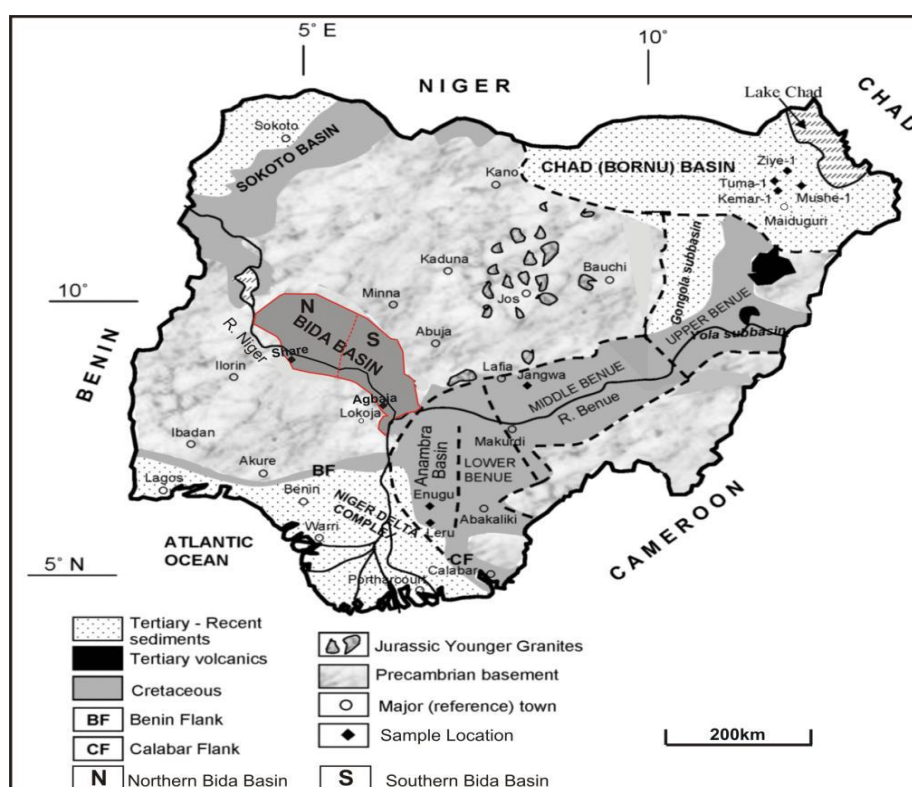


Figure 1 Generalized geological map of Nigeria showing the crystalline basements and sedimentary basin with emphasis on the Bida Basin (Red box) (After Obaje et al., 2009)

2. Origin and Tectonic Evolution of the Bida Basin

Bida Basin occupies parts of Niger, Kwara, Kogi States and Federal Capital Territory all in the North Central Nigeria. It stretches from the River Niger and Kotangora town axes in the north to the south at Lokoja (Fig. 2). It has a down warped and gently folded structures between the Illumenden and Anambra basins filled with

Campanian -Maastrichtian marine to fluvatile rock succession. The West-Central African rift system which became active during the Gondwanaland breakage in the Cretaceous era which was believed to be responsible for formation of Gulf of Guinea basins and Benue Trough also impact on the Bida Basin (Genick, 1972).

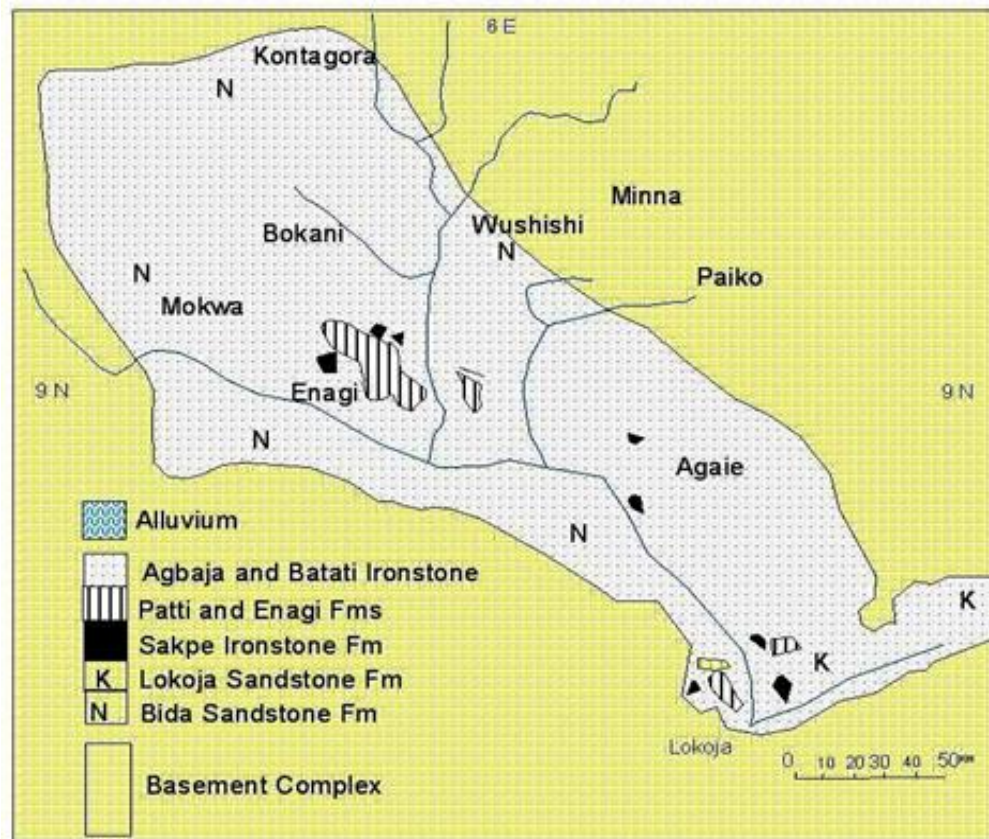


Figure 2 Geological map of the northern Bida Basin (After Obaje, 2011)

Bida Basin has also been described as a northwesterly extension of the Anambra Basin (Fig. 1) (Akande et al., 2005) with northwest trending belt of Upper Cretaceous sedimentary rocks that were deposited by the South Atlantic Ocean incursion after the events of basement subsidence, rifting and drifting.

Sedimentary rock successions in Bida Basin has been estimated up to about 2000m thick (Ojo and Ajakaye, 1976) comprising conglomerates, sandstones, siltstones, mudstones, claystone, shale, coal seams, and low-grade sedimentary ironstones. These lithologies make up the stratigraphy in the northern (Bida, Sakpe, Enagi and Batati formations) and southern (Lokoja, Patti and Agbaja formations) segments of the basin (Jones, 1958, Adeleye 1972, Adeleye and Dessauvage, 1972, Olugbemi and Nwajide, 1997 and Braide, 1998). These Bida sedimentary units have been assigned a Campanian - Maastrichtian age (Rayment, 1965, Deklasz, 1978, Adeleye, 1979).

3. Stratigraphic Setting and Paleogeography of Bida Basin

The stratigraphic succession of the Bida Basin (Adeleye, 1973) comprises of two divisions, Northern (Sub Basin) division and Southern Bida Basin (Sub Basin) or Lokoja (Sub-Basin) division (Fig. 3)

The northern segment of Bida Basin where this study took place have four recognized formations, namely; the Bida (divided into the Doko and Jima members), the Sakpe, the Enagi, and the Batati formations. They are equivalent of the three formations in the southern part of the basin comprising the Lokoja Formation (mainly sandstones and conglomerates) which unconformably overly the Pre-Cambrian to Lower Paleozoic basement gneisses and schists. Lokoja Formation is overlain by the Patti Formation consisting of alternating shales, siltstones, claystones and sandstones and capped by the Agbaja Formation which are essentially package of claystones, concretionary siltstones and ironstones.

AGE	NORTHERN BIDA BASIN			SOUTHERN BIDA BASIN		DEPOSITIONAL ENVIRONMENTS	
MAASTRICHTIAN	Batati Formation		---	Agbaja Formation		Continental to Shallow Marine Deposits	
	Enagi Formation			Patti Formation		Brackish to Shallow Deposits Marine	
	Sakpe Formation						
CAMPANIAN	Bida Formation	Jima Member	---	Lokoja Formation	Claystone Member	Continental Deposits	
		Doko Member			Sandstone Member		
					Basal Conglo - merate Member		
PRE-LOWER PALEOZOIC	+	+	+	+	+	+	+
	+	+	+	+	+	+	+

Figure 3 Stratigraphic successions in the Bida Basin (After Obaje et al., 2009)

Bida Formation is divided into Doko and the Jima Members which are predominantly sandstones. The Doko Member underlies the Jima Member, and the two rock units show gradational relationships of sandstones, breccia and argillaceous rocks (Braide, 1992 Obaje, 2013). The field work data and previous studies shows that Doko sandstones are poorly sorted, and consist angular to sub-angular grains, ripple marks and large-scale cross beddings structures prominent in the Doko Member at Doko village. Bioturbation structures consisting mainly of *Thalassinoides* and *Ophiomorpha* burrows indicate some occasional marine inundations into the generally braided fluvial channel deposits of the Doko Member. Jima Member are essentially sandstones, siltstones and claystones. Trace fossils comprising mainly *Ophiomorpha* burrows and *Thalassinoides* are very noticeable on the outcrop at Jima village just as Doko Members suggestive of possible shallow marine sub tidal to intertidal influence during sedimentation. The cross-stratified sandstones may be suggestive of

deposition mainly in the point-bar and meander-bar sub-environments (Allen, 1970, Obaje, 2013).

The major outcrop and exposures of Sakpe Formation is seen at Sakpe village. It is predominantly ironstones. It has sandy claystones at the base, followed by oolitic ironstone which exhibits rapid facies changes across the basin at the top (Adeleye, 1974). Batati Formation is composed of argillaceous, oolitic and goethitic ironstones with ferruginous clay stone and siltstone intercalations. Shale beds occurring in minor proportions, some of which have yielded near shore shallow marine to fresh water fauna. The Batati Formation was mapped and logged in detail at Patti shaba kolo and Edozighi near Bida and at Kandi and Enwan near Gulu. (Adeleye, 1974, Obaje, 2013). The Enagi Formation consists mainly of siltstones and other minor lithologies including sandstone siltstone admixture with some claystones. Fossil leaf impressions and rootlets have been found within the formation. The formation ranges in thickness of between 30 and 60 m.

4. Methodology

4.1 Grain Size Analysis

Grain size study was carried out on fifteen (15) unconsolidated samples. Each weight of 100g of the sample was obtained and put in a set of sieves as follows; 4.00mm, 2.360mm, 1.180mm, 0.600mm, 0.300mm, 0.150mm, 0.106mm, 0.075mm, <0.075mm arranged in an ascending order of sizes on shaker. The set of sieves were then agitated for about 5min to leave fraction of samples in each sieve and pan according to their sizes. The individual weight percentage and cumulative percentage were obtained and graph of phi sizes against cumulative weight percentage were plotted to extract percentiles to calculate statistical parameters for the Graphic Mean (M), Standard Deviation (sorting) (SD), Graphic Kurtosis (K) and Graphic Skewness (SK) based on Folk and Ward (1957).

4.2 Thin Section Petrography

Fifteen (15) loose sandstones samples across the two study areas were also selected and impregnated, mounted on a glass plate with Canada balsam and then grinded to the certain thickness with increasingly finer and finer degrees of abrasion. The glass slip was removed during the process, as well as a small amount of Canadian balsam, which acts as an adhesive, which was placed in the centre and gently heated until the bubbles were driven out. After then, the sample chip was placed on the slide with the flatter side towards the balsam and glass. The last grinding action expands the slide on the opposing side. The sample slice was then heated after being covered in fresh balsam. Finally, the rock slice was carefully covered with an air bubble-free cover slip or slide and pressed down. A thin sample is cut, then placed on a glass slide and honed smoothly with finer abrasive grit until the sample is just 30macro (0.03mm) thick. Mentholated spirit is useful for removing workout cementing substances. These procedures take place with the use of a microscope, which can be a polarizing petrographic microscope, an electron microscope, or an electron microprobe.

4.3 Heavy Mineral

The procedure of Suzuki, (1975) and Mange and Heinz, (1992) which has proved to be a rapid and accurate means of heavy minerals separation was followed. The prepared slides were examined petrographically for non-opaque heavy minerals and on reflected light for opaque heavy minerals. Identification of mineral type was based on optical characteristics such as color, pleochroism, absorption, relief, extinction, and birefringence; others are size, crystal form, and elongation. Therefore, grains were counted in each slide with the size and roundness of each mineral noted. The “ZTR” index which is a quantitative definition of mineral assemblage was calculated using the percentage of the combined zircon, tourmaline and rutile grains for each sample according to the formula below.

$$\text{ZTR index} = \frac{\text{Zircon} + \text{Tourmaline} + \text{Rutile}}{\text{Total NO. of non-opaque heavy minerals}}$$

This formula is referred to as Hubert's (1962) scheme. The calculated index is expressed in percentage to ascertain the mineralogical maturity of the sediment. Accordingly, $ZTR < 75\%$ implies immature to sub mature sediments and $ZTR > 75\%$ indicates mineralogically matured sediments. Apart from the ZTR index, various frequency percentage plot of both pie and bar charts were made for each sample location.

4.4 X-Ray Diffraction (XRD)

The four sandstones sample were crushed and split into two equal halves. One crushed portion was pulverized to 100% passing through 75µm sieve, and submitted for X-ray diffraction. The pulverized fraction was analyzed using Rigaku Miniflex 600 employing Cu-Kα radiation at 2theta angle 2θ – 70°. The non-destructive test method of X-Ray Diffraction is used to examine the structure of crystalline materials. The peaks of an X-Ray Diffraction result provide more about the location of atoms inside a lattice structure, while the breadth of the peaks reveals more about the crystalline size and strain.

5. Results

5.1 Lithologic Description

The Bida Formation’s lithologic section exposed at the quarry along Bida - Minna Road on the co-ordinate of Latitude N 09°07’298’’ and Longitude E 006°07’954’’

(Fig. 4) and at Doko village on the coordinate of Longitude 08° 56’ 7.8’’ N and Latitude 005° 57’ 5.9’’ E (Fig. 5) were accessible by major and minor roads.

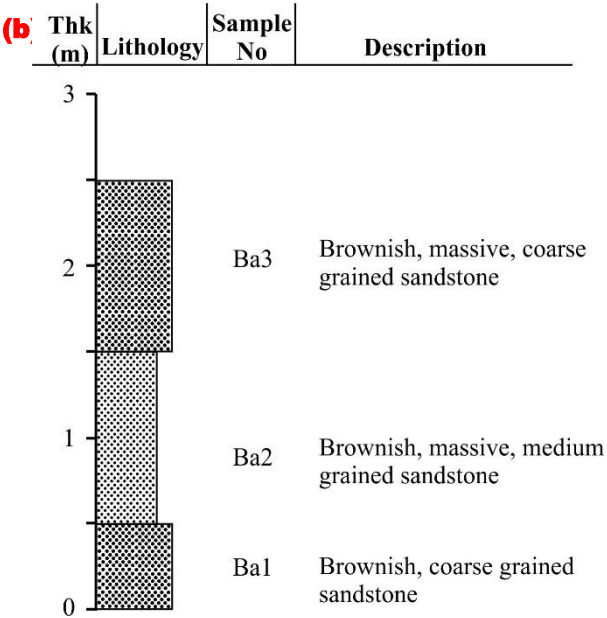


Figure 4 Photograph of (a) the exposed sandstones of Bida Formation at the quarry along Bida-Minna road and (b) the lithologic section of the outcrop in (a).

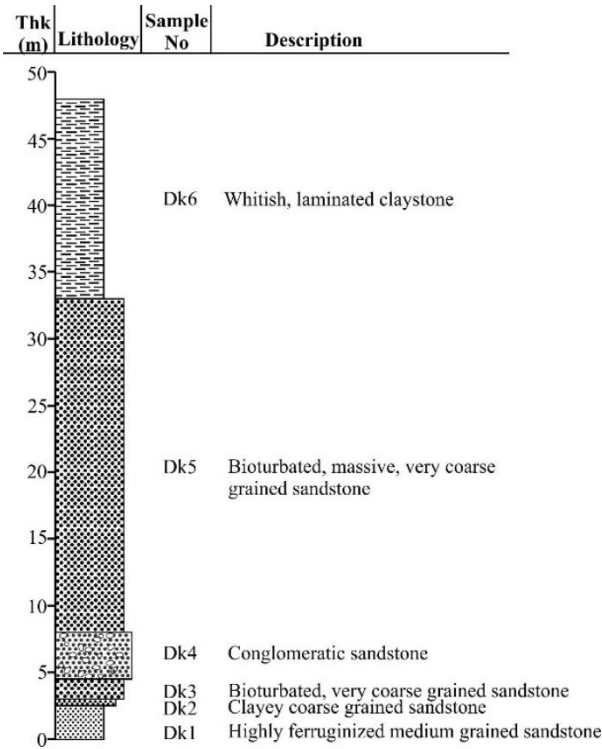


Figure 5 Lithologic section of Doko Member of Bida Formation exposed at Doko village, northern Bida Basin

This section at the quarry is about 2.5m thick while the composite log is about 48 m thick at Doko village comprising of conglomerate, different grain sizes of sandstones and claystone (Fig. 5). Sandstone is the most dominant lithology with about 33m thickness at Doko village and claystone are scarcely exposed.

Claystone

Claystone is one of the lithologies of Bida Formation found at the upper most part of the section of the study area at Doko village (Fig. 6). It is about 15 m thick, laminated, whitish while other parts are weathered with brownish colouration. Claystone are the finest of clastic sedimentary rocks which are commonly formed in a quite water environment where suspended very fine-grained sediments settles. Such depositional environments include flood plain in a fluvial system, lacustrine to the deep marine.



Figure 6 Field photograph of the claystone of Bida Formation outcropping at Doko village

Sandstones

Sandstones is the most dominant lithology across the study areas from about 2.5 m thickness at the quarry along Bida - Minna road and 33 m thickness at Doko village. There are five (5) mappable sandstones beds with distinct textural features in Doko section and three (3) beds at Bida-Minna road ranging from medium, coarse, very coarse and conglomeratic grain sizes.

Medium grained sandstone is about 1 m to 2.5 m thick characterized by light brown colour in the quarry section but reddish brown in Doko section (Fig. 7a). They are generally poorly sorted with lot of argillaceous materials. The coarse-grained sandstones occur at the base and top part of the quarry section while it was only encountered at the base of Doko section (Fig. 7b). They are clayey, brownish, laminated and bioturbated with thicknesses ranging between 0.5m to 2 m at the two study locations. The very coarse-grained sandstone is the most abundant of all the sandstones with thickness of about 25m at Doko (Fig. 7c). It contains plenty of clay pods that was assumed to be product of reworked claystone or large crystals of feldspar weathered and converted to kaolinites (Fig. 7c). This sandstone is poorly sorted with visible quartz mineral grains that are angular to sub-angular and in shape. Ripple mark structures were observed at the basal part of the section and cross stratification at the upper most part. They are strongly bioturbated with clear indication of burrows of organism such as *Thassalinoides* and *Ophiomorpha*. The 4 m thick conglomeratic sandstones consist pebble size quartz mineral grains that are sub-rounded to well-rounded in shape (Fig. 7d).

5.2 Grain Size

Grain size is an important element of texture and their distribution have long been used for determining environment of deposition. Texture is one of the physical properties of rock and a direct product of sedimentary processes (Passega and Boggs, 1977 and 1995) commonly deduce from the physical inspection and statistical parameters such as mean, standard deviation (sorting) skewness and kurtosis.



Figure 7 Field photograph of the sandstones of Bida Formation outcropping at Doko village. (a.) Medium grained sandstones with mega cross bedding structure, (b.) Brownish bioturbated (Yellow dotted circle and thick arrow) coarse grained sandstones, (c.) Brownish very coarse-grained sandstones with clay pod, (d) Ferruginized conglomeratic sandstones

Table 1 Grain size distribution results and interpretation

S/N	SAMPLE NO	RESULTS				INTERPRETATION			
		M	SD	SK	K	Mean	Standard Deviation	Skewness	Kurtosis
1	BA1	0.02	1.00	0.06	1.73	Coarse sand	Poorly sorted	Symmetrically skewed	V. leptokurtic
2	BA2	0.90	0.58	0.10	1.64	Coarse sand	Poorly sorted	Negatively skewed	Leptokurtic
3	BA3	1.13	1.29	0.03	0.80	Medium sand	Poorly sorted	Symmetrically skewed	Platykurtic
4	BB4	1.27	1.36	0.06	0.96	Medium sand	Poorly sorted	Symmetrically skewed	Mesokurtic
5	DK2	0.23	1.35	0.15	1.24	Coarse Sand	Poorly Sorted	Positively Skewed	Leptokurtic
6	DK3	1.30	2.08	-0.17	-0.47	Medium Sand	Very Poorly Sorted	Negatively Skewed	V. Platykurtic
7	DK4	-0.37	1.38	0.14	1.35	Very Coarse Sand	Poorly Sorted	Positively Skewed	Leptokurtic
8	DK5T	0.69	1.42	-0.12	1.51	Coarse Sand	Poorly Sorted	Negatively Skewed	V. Leptokurtic
9	DK5B	0.90	0.99	-0.11	1.26	Coarse Sand	Moderately Sorted	Negatively Skewed	Leptokurtic

M-Mean, SD- Standard Deviation, SK-Skewness, and K-Kurtosis, V-Very

The Bida sandstones in this study have mean ranging from 0.02 ϕ to 1.27 ϕ (mean 0.83 ϕ), standard deviation (sorting) values ranging from 0.58 ϕ to 1.36 ϕ (mean 1.1 ϕ), skewness of 0.03 ϕ to 0.10 ϕ (mean 0.06 ϕ), and kurtosis values of 0.80 ϕ to 1.73 ϕ (mean 1.3 ϕ) (Table 4.1).

5.3 Thin Section Petrography

The mineral constituents and textural composition of sandstones are easily accessible and examined in thin section petrography for deducing their provenance, transportation history, tectonic setting, maturity and even depositional environments. Bida sandstones at Doko and quarry showed quartz as the most abundant detrital

mineral having value ranging from 51 % to 77 % and 61 % to 69 % respectively (Table 2). The quartz grains are angular to sub-angular with a lot of monocrystalline grain (Fig. 8). Feldspars constituents range from 4 % to 16 % at Doko but 22 % to 40 % at the quarry (Table 2). Alkali feldspar (orthoclase) and plagioclase feldspar (albite) predominate over microcline in the quarry sandstones because of the parallel twinning features that are more abundant than the cross-hatch twinning of the microcline. X-ray diffraction further confirms the abundant of orthoclase, kaolinite, vermiculites and albites. Rock fragment make up to 10 % to 28 % at Doko and 9 % to 10 % at the quarry (Table 2).

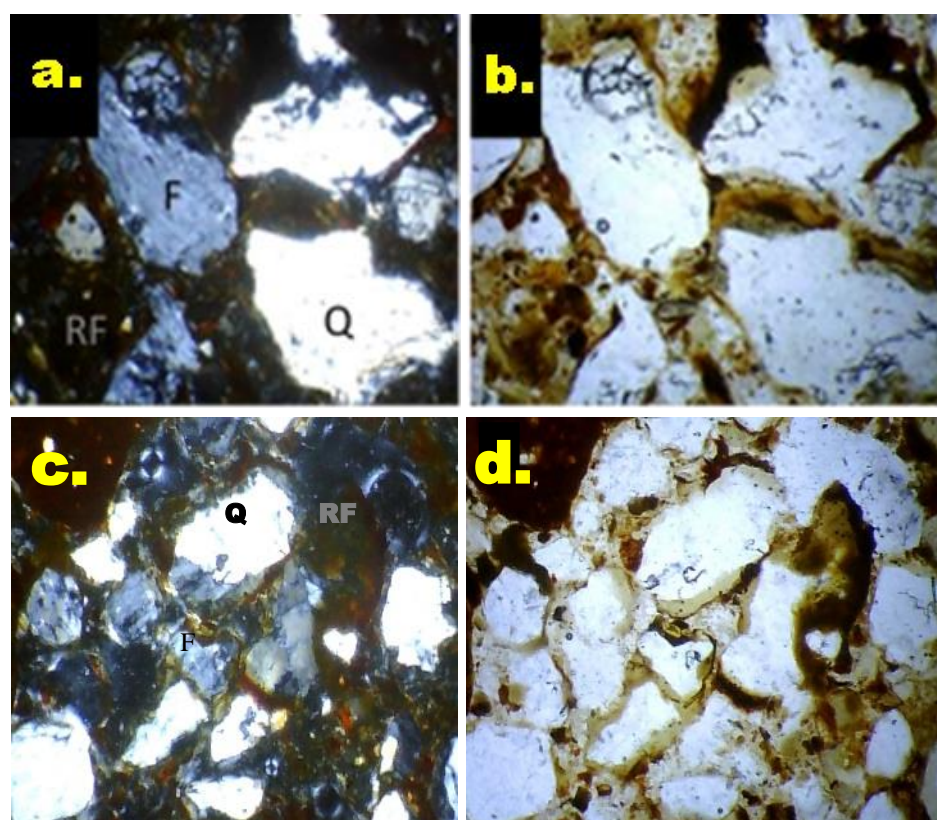


Figure 8 Representative photomicrograph of sandstone of Bida Formation from study areas of northern Bida Basin (a., c. under cross polar and b., d. under plane polar)

Table 2 Modal analysis results of the mineral constituents of Bida sandstones in thin section.

S/N	Sample	Quartz (%)	Feldspar (%)	Rock Fragments (%)
1	BA1	65	25	10
2	BA2	69	22	9
3	BB4	61	30	9
4	BB1	64	21	15
5	BC2t	56	38	6
6	BC2m	62	27	11
7	BC2b	51	40	9
8	DK1	77	4	19
9	DK2	57	16	27
10	DK3	85	5	10
11	DK5	56	16	28

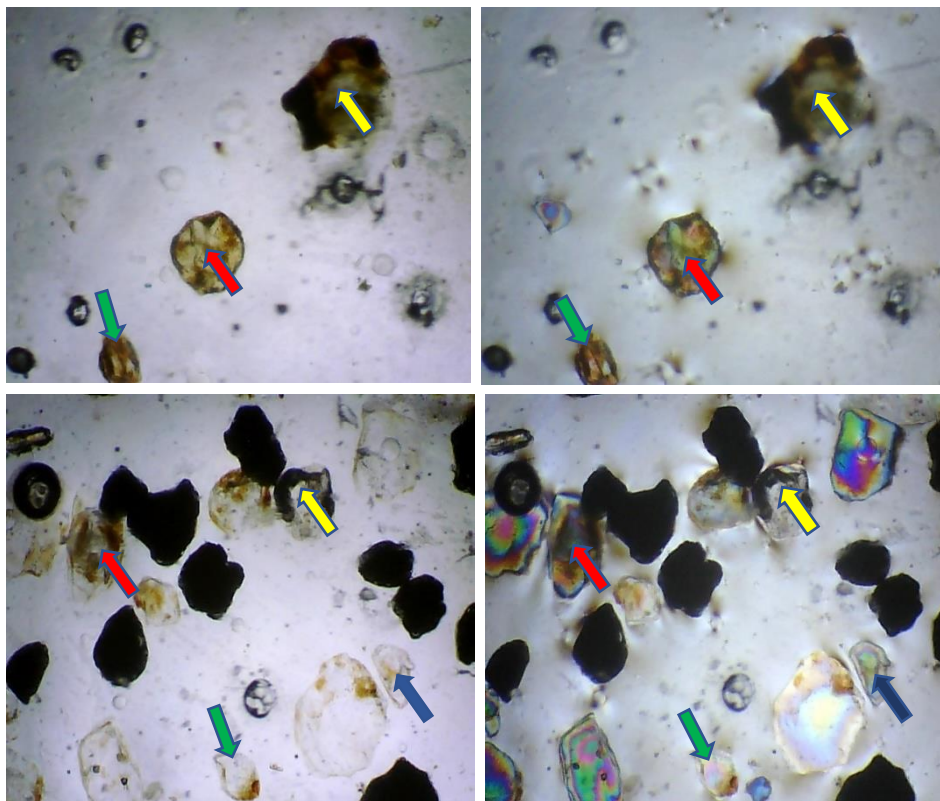


Figure 9 Representative photomicrograph of heavy mineral in sandstones of Bida Formation from the study area of northern Bida Basin (blue arrow indicates Zircon mineral, green arrow indicates monazite, yellow arrow indicates rutile and the red arrow indicates tourmaline)

5.4 Heavy Mineral

Heavy mineral assemblage consists of both opaque and non-opaque. The non-opaque heavy mineral consists of zircon, tourmaline, rutile, garnet, apatite and monazite (Fig. 9).

Zircon ranges from sub angular to angular and it is colourless in most case. Tourmaline occurs in tubular

forms and both greenish and brownish varieties are present. Rutile is reddish brown and rounded to sub angular. There is no much variations in the heavy mineral assemblage across the samples of Bida sandstone in the study areas. The ZTR index value of the sandstone ranges from 53% to 65%.

Table 3 The average values of heavy mineral in the sandstones of the Bida Formation in the study areas

S/N	Samples	Zircon	Monazite	Tourmaline	Rutile	Garnet	Apatite	Opaque
1	BA1	4	2	10	2	2	5	23
2	BA2	26	8	7	3	4	7	19
4	BA3	11	4	2	2	4	5	27
5	BB1	7	3	6	3	2	9	36
6	BB4	9	6	4	4	0	8	31
7	DK3	2	5	4	3	-	0	82
8	DK3	5	5	2	2	-	0	89
9	DK5t	7	5	5	4	-	1	52
10	DK5m	7	4	2	3	-	6	64

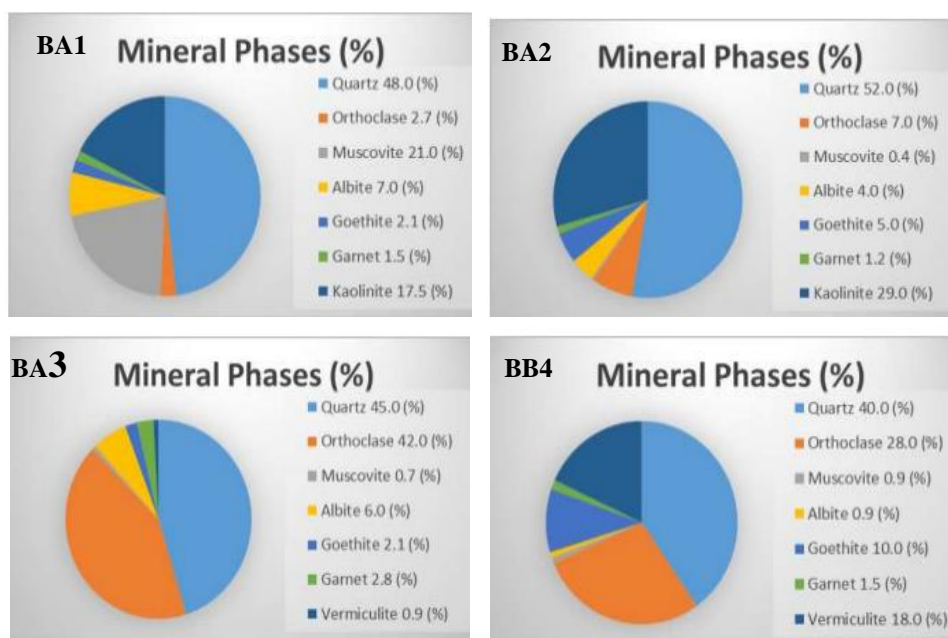


Figure 10 Mineral constituents and their quantity in the studied Bida sandstones through X-ray diffraction analysis

5.5 X-Ray Diffraction

X-Ray diffraction analysis results as presented in the pie chart (Fig. 10) show that quartz mineral is low ranging from 40 % to 52 %. Orthoclase ranges from 2.7 % to 42 % generally in all the samples but is noteworthy that the basal sample BA1 that has low value of 2.7 % orthoclase has the highest muscovite constituents of about 21 %. Kaolinite of 17.5 % to 29 % dominate sample BA1 and BA2 while vermiculite was found in BA3 and BB4 to be 0.9 % and 18 % respectively. Other identified minerals include albite, goethite, and garnet.

6.0 Discussion

Sediments are usually transported for either short or long distance till where they could no longer be further moved though could be reworked or becomes rock as the process of diagenesis begins. Their texture, structure, and mineral constituents earlier determined by provenance and transportation process may be preserved or altered in their depositional site by various conditions ranging from climate, temperature, oxygen level, water depth, topography etc. The sequence or rock assemblages such as fining upward succession of the sandstones is the first visible attribute suggesting contribution of fluvial processes in the Doko outcrop. Fluvial influence can also be asserted by the dominance of cross stratification

structures, clay pod from reworking of claystone and poor sorting texture, and symmetrically skewed behaviour of river sands with moderate flow of energy during transportation and deposition (Friedman 1967, Selley 1985, Tucker 1985). Sandstone, a typical siliciclastic sedimentary rock is mostly found in wide depositional environments ranging from beach, shelf, delta, flood plain, and channels. The trace fossils of worms could be an indication of some marine shelf influence as supported by one of the sand plotted in beach environments.

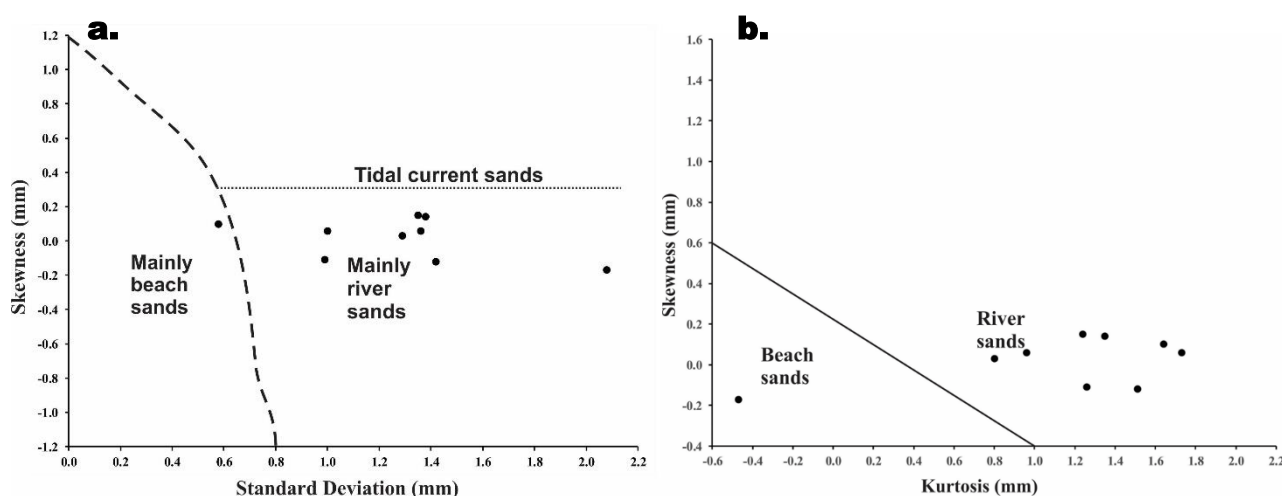


Fig 12 Bivariate plot of (a.) skewness versus standard deviation, and (b.) skewness versus kurtosis of the studied sandstones, northern Bida Basin

Those various depositional environments can be inferred from bivariate plots of grain size statistical parameters of skewness versus standard deviation, mean versus standard deviation and skewness versus kurtosis which was adopted in this study (Friedman 1967, 1979, Moila and Wester 1968, Ojo 2012 and Adeoye et al., 2022). All the plots (Fig.12 a, b) indicate river as the main agent of transportation in a fluvial environment.

Quartz is the most dominant mineral grain in the studied Bida sandstones with modal percentage ranging from 51 % to 85 % suggesting the rocks are indeed sandstones. The quartz minerals are generally angular to sub-angular in the quarry area but the

conglomeratic sandstones have more of sub rounded to rounded pebble size quartz grain. The feldspar constituents of about 21 % to 40 % quantity in the sandstones from quarry study area which is higher than the 4 % to 16 % in Doko is suggestive that the quarry sandstones are closer to the parent rock than those of Dokos. These mineral's modal values were plotted on the quartz-feldspar-rock fragments (Folk, 1974 and Adeoye et al., 2022) (Fig. 11a) and quartz-feldspar-lithic components tri-plots (Figure 11b) (Pettijohn, 1975). The tri-plots are very useful in discriminating and classification of sandstones into various types based on the quantity of the mineral components.

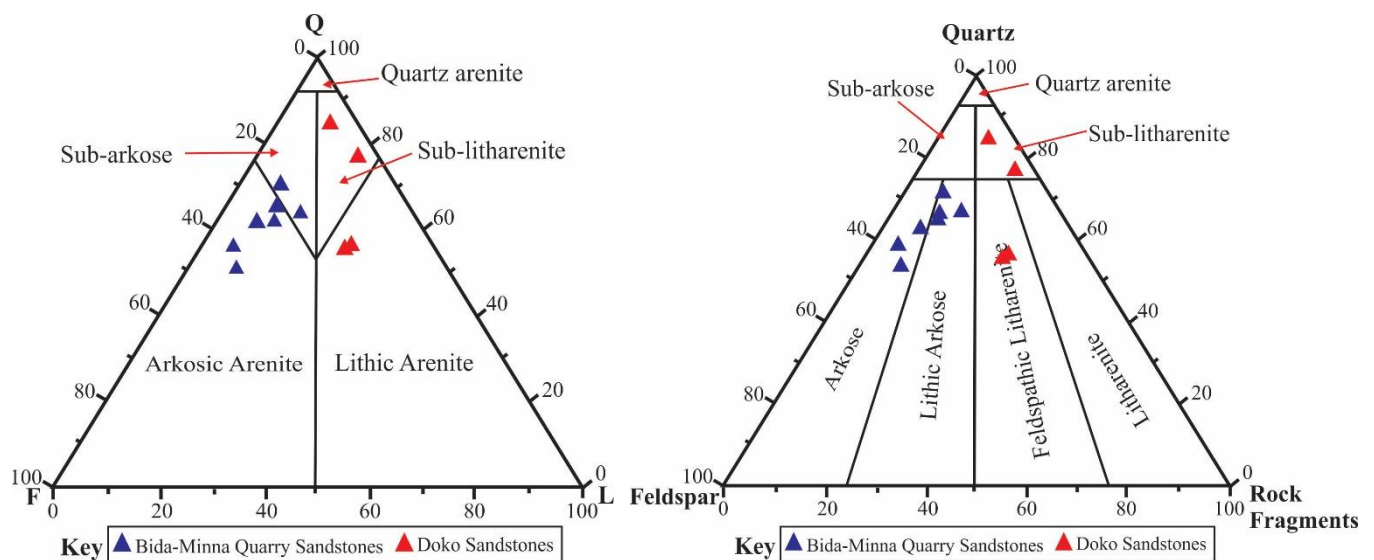


Figure 11 Ternary plot of quartz (Q), feldspar (F) and rock fragment/Lithics (L) for the classification of sandstones of Bida Formation, northern Bida Basin (a.) Modified after Pettijohn, 1975, and (b.) Modified after Folks, 1974

They are all classified as lithic arkose, arkose and arkosic arenite. Sandstones index values of Zircon-Tourmaline-Rutile (ZTR) is suggestive of the maturity of their mineral components, and is expressed in percentage. If less ($<$) than 75%, it implies immature to sub mature sediments and greater ($>$) than 75% indicates mineralogically matured sediments. The Zircon-Tourmaline-Rutile (ZTR) index of the sandstones range from 53% to 65% suggesting that they have immature to sub mature mineralogy. ZTR values indicating immature to sub mature mineralogy aligns with the grain size poor sorting, feldspar and clay mineral components, petrographic arkosic and angular to subangular grain shapes of the sandstones suggest they have immature to sub-mature textures and mineralogy.

X-ray diffraction results revealed dominant clay minerals in quarry sandstones to include orthoclase, kaolinite, vermiculite and albites. Clay matrix commonly recrystallize in sandstones and changes in the sequence of smectite to illite to sericite and finally muscovite (Chima et al 2018). This level of diagenetic changes has not really occurred in the studied sandstones as the concentration of muscovite is very low (Fig, 10). Goethite, an iron oxide forms a cementing material along with clay minerals in the sandstones. This cement tends to fill up the pore spaces within the sandstone grains. The presence of angular to subangular mineral grain shapes and high clay or feldspar contents in the studied sandstones are probably due to short transportation distance of sediments from their source area. These immature to sub-mature textural features and mineral constituents in the sandstones from the quarry are not favourable for reservoir quality because of their tendencies of clogging or blocking the pore spaces and enhancing cementation during diagenesis. This will rapidly reduce the permeability of the sandstones. Doko sandstones facies will be a better hydrocarbon reservoir

or aquifer due to their more mature mineralogy and texture characterized by the dominance of medium to coarse grained grain sizes with less feldspar and clay mineral particles.

7.0 Conclusions

Sandstones of Bida Formation have been investigated through grain size, XRD, thin section and heavy mineral petrography to evaluate their reservoir and aquifer quality from paleoenvironments, texture and mineralogy composition. The sandstones are brownish to reddish colour which is as a result of weathering of iron minerals such as goethite and haematite. They are strongly bioturbated, poorly sorted, with dominance of medium to coarse grain texture. Most of the sandstones have angular to sub-angular mineral grain shape, except for the conglomeratic sandstones that consist of sub-rounded to rounded pebble size mineral grains. Minerals such as orthoclase and clay minerals like kaolinites, albite and vermiculites are present more significant in the quarry sandstones than Doko members. Mineral petrography reveals that the sandstones across the study areas are generally sub-litharenite to arkosic sandstones with short history of transportation and deposition by fluvial settings. Their texture and mineral composition being immature to sub mature is not favourable for a reservoir or aquifer because there are a lot of matrix that can block the pore spaces and cementing material that will enhance cementation at deeper depth, thereby drastically reducing the porosity and permeability quality of the sandstones. Doko sandstones, Bida Formation is most preferable for hydrocarbon reservoir and aquifer due to their better textural and mineralogical features compared to the ones at the quarry along Bida-Minna Road, northern Bida Basin.

REFERENCES

- Abimbola F. A., (1997). Petrographic and paragenetic studies of the Agbaja Ironstone Formation, Nupe Basin, Nigeria. *J. Afr. Earth Sci.* 25:169–181.
- Adeleye D. R. (1974). Sedimentology of the fluvial Bida Sandstones (Cretaceous) Nigeria, *Journal of Sedimentary Geology*, vol. 12, p. 1 - 24.
- Adeleye D. R., (1973). Origin of ironstones: an example from the Mid-Niger Basin, Nigeria. *J*
- Adeleye D. R., (1974). Sedimentology of the fluvial Bida Sandstones (Cretaceous) Nigeria. *Sedimentary Geology* 12:1-24.
- Adeleye D. R., Dessauvage TFJ (1972). Stratigraphy of the Mid-Niger Embayment near Bida, NY, 317p.
- Adeniyi J. O. (1985). Ground total magnetic intensity in parts of the Nupe Basin and the adjacent basement complex, Niger State, Nigeria. *Nigerian journal of Applied Science*, vol. 3 p. 67 - 78.
- Adeoye, J. A., Dada S. F. and Akande S. O. (2022). Grain Size and Petrographic Studies of Turonian Sandstones in Orimedu-1 and Ise-2 Wells, Dahomey Basin Southwestern Nigeria. *Nigerian Association of Petroleum Explorationists Bulletin*, vol. 31, No. 2, p. 36 – 49.
- Akande S. O, Ojo O. J, Erdtmann B. D. and Hetenyi M. (2005). Paleoenvironments, Organic petrology and Rock-Eval studies on source rock facies of the Lower Maastrichtian Patti Formation, southern Bida Basin, Nigeria. *Journal of African Earth Sciences*, 41, p. 394-406.
- Allen J. R. L (1970). Physical processes of sedimentation. Allen and Unwin, London, p 248.
- Allen, J. R. L. (1982). Studies in fluvial sedimentation bars, bar complexes and sandstone sheets (low sinuosity braided streams) in the Brownstone Formation (L. Devonian) Welsh borders. *Sedimentary Geology*, 33, 237-283.
- Benkhelil J, (1989). The origin and evolution of the Cretaceous Benue Trough, Nigeria. *J. African. Earth Sci.* 8:251–282.
- Braide SP (1992b). Syntectonic fluvial sedimentation in the central Bida Basin. *J Mining Geology* 28:55–64.
- Chima P., Baiyegunhi C., Liu K., and Gwavava O., (2018) Petrography, modal composition and tectonic provenance of some selected sandstones from the Molteno, Elliot and Clarens Formations, Karoo Supergroup, in the Eastern Cape Province, South Africa.

- Open Geosci. 2018; 10:821–833, <https://doi.org/10.1515/opengeo-2018-0001>.
- De Klasz I (1977). The West African Sedimentary Basins. In: Moullade M, Nairn AEM (eds) The phanerozoic geology of the world. The Mesozoic 1. Elsevier, Amsterdam, pp 371–399.
- Ferré, E.C., Caby, R., Peucat, J.J., Capdevila, R., Monie, P., (1998). Pan-African, post-797 collisional, ferro-potassic granite and quartz-monzonite plutons of Eastern Nigeria. 798 Lithos 45, 225-279.
- Folk RL, Ward WC (1957) A study in the significance of grain size parameter. J Petrol 37: 327-354.
- Folk, R. L. (1974). Petrology of sedimentary rocks. Hemphill, Austin, Texas, 182p.
- Folk, R. L., (1980) Petrology of Sedimentary Rocks. Hemphill Publishing, Austin, TX, 184pp.
- Freidman, G. M. (1979). Differences in size distribution of populations of particles among sands of various origin. Sedimentology, 20, 3-32.
- Friedman G. M. (1961) Distribution between dune, beach and river sands from their textural characteristics. J Sediment Petrol 31:514-529.
- Friedman GM (1967). Dynamic processes and statistical parameter compared for size frequency distribution of beach and river sands. J. Sedimentary petrol. 37:327-354.
- Idowu, J. O., and .Enu, E. I. (1992). Petroleum geochemistry of some late Cretaceous shale from the Lokoja Sandstone of Middle Niger Basin, Nigeria. Journal of African Earth Sciences, 14, 443-455.
- Jan Du Chene R E., Klasz I. D. E., and Archibong E. E., (1978). Biostratigraphic study of the borehole Ojo-1, SW Nigeria, with special emphasis on the Cretaceous microflora. Revue de Micro-palaeontology, 21:123-139.
- Jones MP (1958) Preliminary investigation of the occurrence of Columbite in the Afu Hills
- Ladipo K. O. (1988). Paleogeography, sedimentation and tectonics of the Upper Cretaceous Anambra Basin, south-eastern Nigeria. J. Afr. Earth Sci. 7:865–871.
- Ladipo K. O., Akande S. O., Mucke A (1994) Genesis of ironstones from the Mid-Niger sedimentary basin: evidence from sedimentological, ore microscopic and geochemical studies. J Mining Geology 30:161–168. Lokoja formation in the Southern Bida Basin. J Mining Geology 28:33–44.
- Ladipo K. O., Akande S. O., Mucke A (1994). Genesis of ironstones from the Mid-Niger sedimentary basin: evidence from sedimentological, ore microscopic and geochemical studies. J. Mining and Geol. 30: 161-168.

- McCurry, P. (1976). The Geology of the Precambrian to Lower Paleozoic Rocks of Northern Nigeria – A Review. In: Kogbe, C. A. (Ed.), *Geology of Nigeria*. Elizabethan Publishers, Lagos, pp15-39.
- Obaje N.G, Balogu, D.O, Idris-Nda A, Goro I.A, Ibrahim S.I, Musa M.K, Dantata S.H, Yusuf I, Mamud-Dadi N, and Kolo I.A. (2013). Preliminary integrated hydrocarbon prospectivity evaluation of the Bida Basin in North-central Nigeria. *Petroleum Development Journal*, volume. 3, page 2.
- Obaje N.G, Moumouni, A, Goki N.G, and Chaenda M, (2010). Stratigraphy paleogeography and hydrocarbon resource potential of the Bida Basin in North-central Nigeria, *Journal of Mining and Geology*, volume. 2, page 97-144.
- Obaje N.G., Musa M.K, Odoma A.N, and Hamza H. (2011), The Bida Basin in North-central Nigeria, Sedimentology and petroleum geology, *Journal of Petroleum and Gas Exploration research*, volume, 1, page 1-13.
- Ojo O.J, Akande S.O. (2012). Sedimentary Facies Relationships and Depositional Environments of the Maastrichtian Enagi Formation, Northern Bida Basin, Nigeria. *Journal of Geography and Geology*, Vol. 4, No.1, page 136-139.
- Olaniyan O, Olobaniyi S. B. (1996) Facies analysis of the Bida Sandstone formation around Kajita, Nupe Basin, Nigeria. *J Africa Earth Science* 23:253–256.
- Passega and Boggs (1977 and 1995) Sedimentary Facies Relationships and Depositional Environments of the Maastrichtian Enagi Formation, Northern Bida Basin, Nigeria. *Journal of Geography and Geology*, Vol. 2, No.3, page 100-113.
- Petters S. W. (1978). Middle Cretaceous paleoenvironments and biostratigraphy of the Benue Trough, Nigeria. *Geology. Soc. Amer. Bull.*, 89:151–154.
- Pettijohn, F.J., (1975) *Sedimentary Rocks*, (3rd Edition). Harper and Row, New York, 628pp.
- Rahaman M. A., (1981) Recent advances in the study of the basement complex of Nigeria. *Sediment Petrol* 43:709–727.
- Rahaman M. A., Ocan O (1978) On relationships in the Precambrian Migmatite-gneisses of Nigeria. *Niger J Min Geol* 15:23–32
- Selley, R. C. (1985). *Ancient Sedimentary Environment*, third ed. Cornell University Press, Ithaca, NY, 317p.