

ORIGIN AND SANDSTONE CLASSIFICATION OF THE UPPER CRETACEOUS LOKOJA SANDSTONE IN SOUTHERN BIDA BASIN, AS DETERMINED FROM GEOCHEMICAL DATA

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ABSTRACT

This study was carried out with a view of using an innovative approach (strictly geochemical) in determining the origin of Sandstone Formation within the Southern Bida Basin. The Lokoja Formation (Sandstone) unconformably overlies the basement complex. It consist of sandstones, which crop out around Lokoja area between Felele and Koton-Karfi. Field observations show that lithology includes conglomerates at the base, with coarse-grained to fine-grained sandstones, siltstones and claystones overlying it. Analysis of the collected ten (10) outcrop samples from the study area aided in the deduction of geochemistry, classification and period of deposition of the sandstone facies of the Lokoja Formation. The geochemical analysis revealed the major oxides and the heavy minerals that are present in the samples. From the geochemical analysis of the samples at different locations revealing the major oxides, the percentage of SiO₂ in the selected sample compared to the other oxides is very high. Al₂O₃, Fe₂O₃, CaO, MgO, MnO, P₂O₅, K₂O, Na₂O and SO₃ were all found to decrease as SiO₂ increases. A major reason for this is clastic mixing. The low values observed from the result of ratio of SiO₂/ Al₂O₃ indicate that the collected samples have a high degree of clayness, which can suggest mineralogical immaturity. Al₂O₃/ (CaO+MgO+Na₂O+K₂O) ratio has been reported useful in the determination of stability of mobile oxides. This was applied in this work, where positive values obtained (2.73 to 8.27) indicate the presence of stable mobile oxides in the Lokoja Formation sandstone facies. The Zircon Tourmaline Rutile (ZTR) Index for the selected samples range from 30% to 44% with an average of 38%. All the selected samples have Zircon –Tourmaline –Rutile maturity index less than 75% suggesting that nearly all the sediments are mineralogically immature to sub mature. The heavy minerals recovered from the selected samples of the Lokoja sandstone show that the origin of the collected samples from the basin is mainly sedimentary.

KEYWORDS: Provenance, Bida Basin, Geochemical, Maturity, Stability, Clayness.

INTRODUCTION

The Mid-Niger Basin otherwise known as the Bida basin or the Nupe basin is classified as an intracratonic basin which trends in a Northwest-Southeast direction (Figure 1). It is separated in the Northeast and Southwest by the basement complex and merges with the Anambra and Sokoto basin to the Southeast and Northwest respectively. The basin has undergone interesting episodes of geological events, giving rise to a system of linear faults occurring around it. According to Kogbe et al., (1983) and Udensi and Osazuwa, (2004), the fault system trends in a Northwest-southeast direction. This has been determined using interpretations from Landsat images and borehole logs, as well as geophysical dataset.

Previous workers in the basin of study include; Adeleye (1973), Jan du Chene et al., (1979), Ojo (1984), Ojo and Ajakaiye (1989), Ladipo et al., (1994), Abimbola (1997) and Akande et al., (2005). These researchers have focused on gravity studies and

micropaleontological studies with few investigation being made on hydrocarbon prospectivity.

Micropaleontological studies which documented the palynomorph and foraminifera associations lead to a general belief that the Cretaceous sedimentary successions of the Lokoja sandstone and Patti Formation were deposited in a continental to marginal marine and marsh environment. The work of Braide (1992b) on paleogeographic reconstruction within the Nupe basin has suggested that lacustrine environments were once widespread across the basin. This paleo-environmental condition occurred at the basin's axis and close to the margins, indicating that the depocenter must have migrated during the basin's depositional history and subsided rapidly to accommodate sedimentary fills of about 3.5 km thickness.

In this study, we have applied the use of geochemical data in determining the provenance of the rock units as well as its maturity. The work is focused on the outcropping section of the Lokoja Formation as exposed along Lokoja-Abaji Road.

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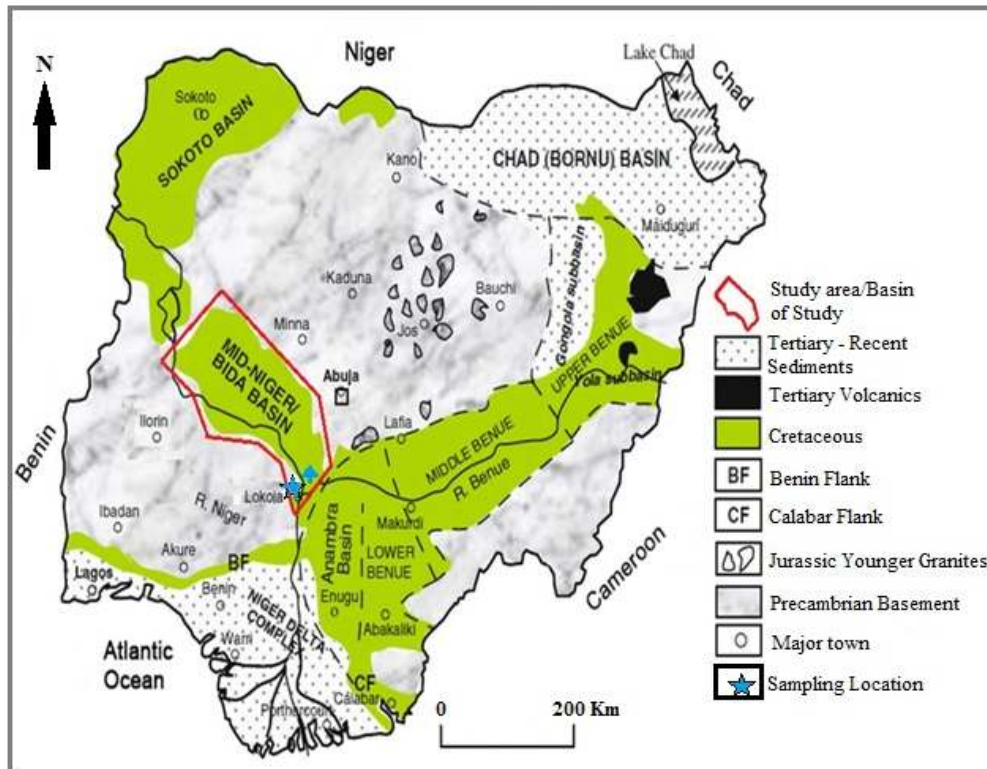


Figure 1: Geologic map of Nigeria showing location of the Bida basin (Redrawn from Adeniyi 1985; Udensi and Osazuwa 2004).

LOCATION OF STUDY AREA

The area of study is located within and around Lokoja in Kogi State in the North-central part of Nigeria. Its coordinate lies within latitudes $07^{\circ}46'0''N$ to $07^{\circ}55'0''N$ and longitudes $006^{\circ}42'0''E$ to $006^{\circ}48'0''E$ (Figure 2). The studied sections are road cut outcrops along the Lokoja-Abaji road. The area is traversed by major road and numbers of minor roads. It is also drained and traversed by a number of streams and some rivers.

STRATIGRAPHIC SETTING AND PALEOGEOGRAPHY

The stratigraphic setting can be explained based on two sub-basins within the Nupe Basin – the Northern Bida basin and southern Bida basin or Lokoja sub-basin. Sedimentary fills within the Nupe basin were deposited as a result of block faulting, basement fragmentation and subsidence which was followed by rifting at the opening of the South Atlantic Ocean during the Cretaceous. The collapse of the Mid-Niger and Anambra Platforms resulted in the depositional cycle housing marine shales of the Campanian Nkporo and Enugu

Formations of the Anambra basin, which may have some lateral equivalents within the Lokoja Formation (Obaje, 2009).

Lithostratigraphy and Depositional Environments

Adeleye and Dessauvage (1972) documented four mappable stratigraphic units in the central parts of the Bida basin (Around Bida town). This includes; the Bida Sandstone, the Sakpe Ironstone, the Enagi Siltstone and the Batati Formation. These units are correlatable with litho-units in the southern part of the Bida basin (Figure 3).

In the southern part, rock exposures of sandstones and basal conglomerates of about 300 m thickness overlie the Precambrian basement rocks. The exposures of sandstones is overlain by alternating shales, siltstones, sandstones and claystones of the Patti Formation (Figure 4). The Patti Formation has a considerable thickness of 70-100 m in the Koton-Karfi and Abaji areas, and in turn succeeded by ironstones, claystones and siltstones of the Agbaja Formation. The stratigraphy of the southern part of the Bida basin which is the point of interest will be described in the next subsection.

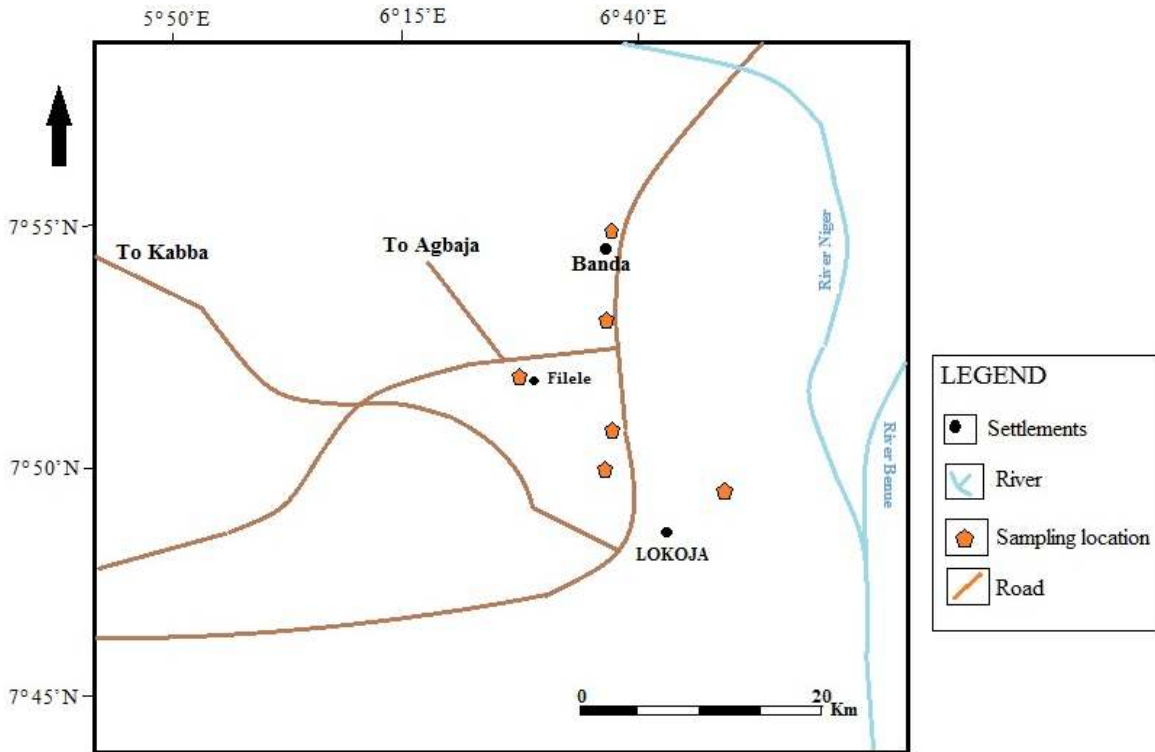


Figure 2: Location map of the study area

AGE	NORTHRN BIDA BASIN		SOUTHERN BIDA BASIN	
MASTRICHTIAN	Batati Formation		Agbaja Ironstone Formation	
	Enagi Formation		Patti Formation	
	Sakpe Formation			
CAMPANIAN	Bida Formation	Jima Member	Lokoja Formation	Claystone (Member)
		Doko Member		Sandstone (Member)
LOWER PALEOZOIC				Basal Conglomerate (Member)

Figure 3: Stratigraphic succession table of Formations within the Bida Basin (Akande et al. 2005)

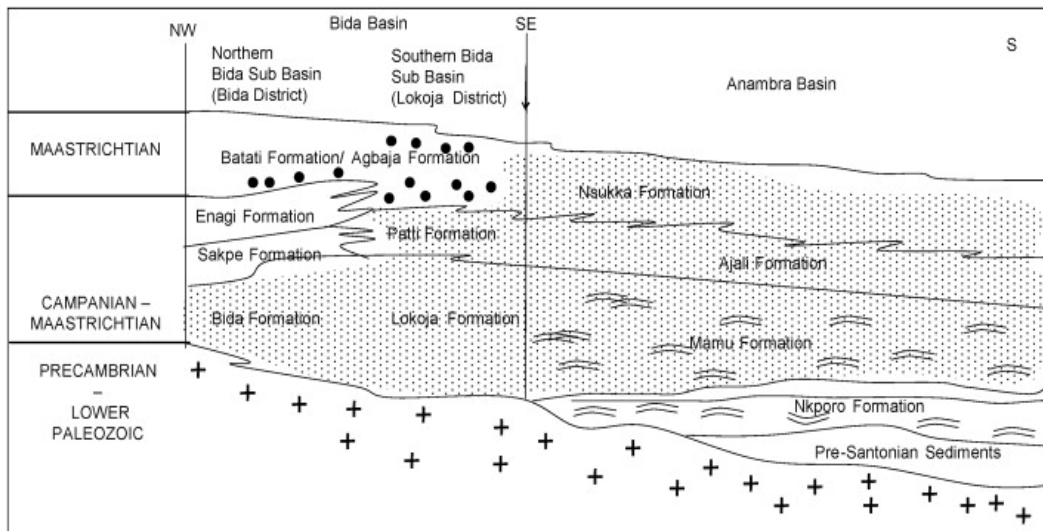


Figure 4: Regional Stratigraphic successions in the Mid-Niger basin (Bida Basin) and their lateral equivalents in the Anambra Basin (Adapted from Obaje, 2009)

STRATIGRAPHY OF THE SOUTHERN BIDA BASIN

Lokoja Sandstone

The Lokoja Formation unconformably overlies the basement complex. It consists of sandstones, which crop out around Lokoja area between Felele and Koton-Karfi. Around this location, conglomerates, coarse false-bedded sandstones, fine to medium-grained sandstone, siltstone and claystone are known to occur. At Felele, conglomeratic sandstones lie directly above the basement rocks. Previous studies have revealed the sub-angular to sub-rounded shape of the cobbles, pebbles and granule sized quartz grains in the lithologic units of the Lokoja Formation (Figure 5).

Patti Formation

Rock exposures of the Patti Formation occur between Koton-Karfi and Abaji. This Formation consists of fine to medium, grey and white sandstone, carbonaceous silts, shale and oolitic ironstones. Siltstone within this formation are characterized by parallel stratification with sedimentary structures such as slumps, load structures and wave ripples. Herringbone cross stratification also occur within the Patti Formation,

just around the fine-grained sandstones. This is an indication of an abrupt change in the current direction when the sands were deposited in the varying environments. The flood plains were first of all formed as the level of water body decreased. Increase in the water body resulted in a shoreface (Figure 5), which is responsible for the deposition of a thin claystone layer. A last portion of the cycle arose from another decrease giving rise to flood plains and sand channels. Trace fossil and plant fragments are preserved in detail. According to Braide (1992b), predominance of argillaceous rocks (as also shown in figure 5) in the Patti Formation requires suspension and settling of finer sediments in a low energy environment.

Agbaja Formation

This Formation is the topmost unit in the southern Bida basin. It serves as a lateral equivalent of the Batati Formation which occurs in the northern Bida basin. A major exposure of the ironstone formation is situated in a town called "Agbaja" where, according to Ladipo et al., (1994), three subfacies have been reported. They are oolitic, concretionary and massive ironstones. The oolites range in thickness from 23 to 44 ft. and have been deposited in a shallow marine environment.

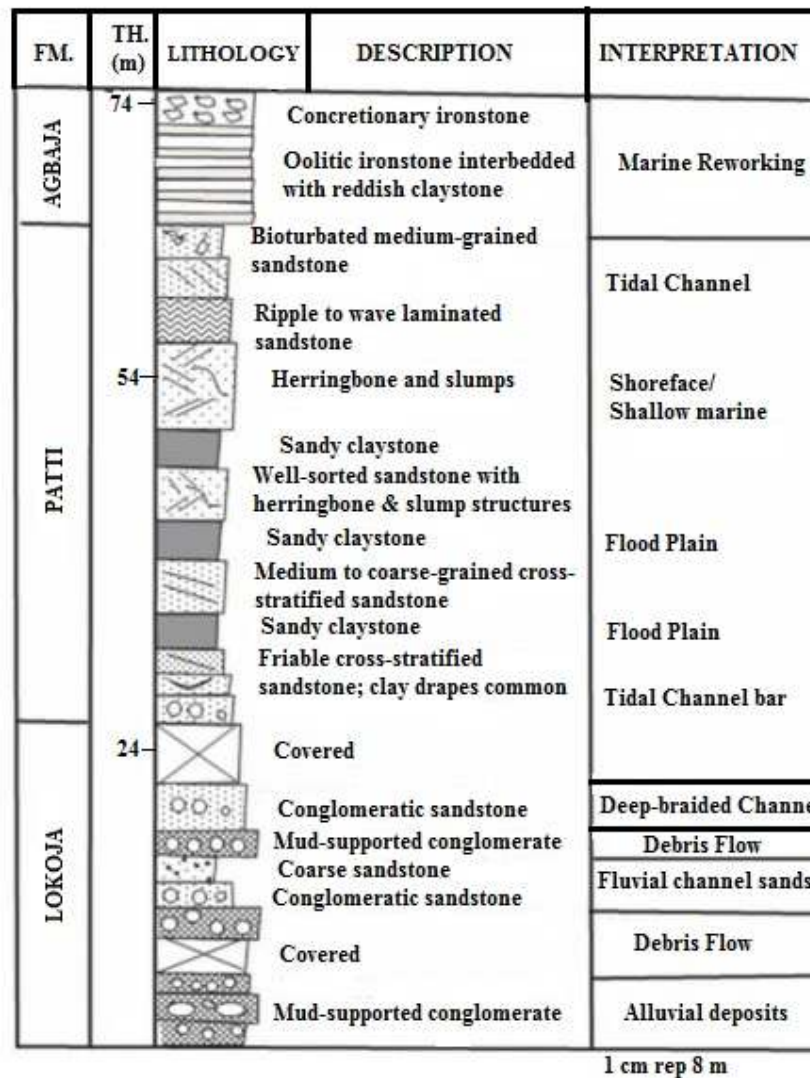


Figure 5: Lithologic description of the Lokoja, Patti and Agbaja Formations (Redrawn from Obaje et al. 2011)

MATERIALS AND METHODS OF RESEARCH WORK

Materials

The field work was carried out appropriately at sandstone road cuts in the study area at different intervals with the use of the following materials, such as base map and field map, Global Positioning system (GPS), compass clinometer, geological hammer, hand lens, sample bag, field notebook, masking tape and marker.

Methods

Field work and Laboratory analysis

The field work started with a reconnaissance survey of the study area (Lokoja) especially the access major and minor roads, drainage channels, the settlement type and also taking note of the minor and major outcrops. The exercise involved collection of fresh samples for further laboratory work/ analysis. Sedimentological characteristics of the Lokoja sandstone was studied and total number of ten (10) representative samples were

The laboratory analysis was carried out on the ten (10) representative samples to determine their texture, mineralogy and chemistry. The laboratory analysis carried out on the sandstone samples is geochemical analysis, involving X-ray Fluorescence (XRF) and Heavy mineral analysis. These were carried out at the Robotic Laboratory of Dangote Cement PLC, Obajana. Ten (10) collected samples from the sampling points were taken to the laboratory for geochemical analysis to determine the major oxides. About 20 g of the sandstone representative sample was weighed using the weighing balance, the weighed representative samples of sandstone were crushed in an electric crusher to reduce the size of the sample for easy milling. After the size of the samples has been reduced by crushing, six (6) pills of the ethylene glycol was added to it for easy binding process of the sample. The ethylene glycol added to the crushed sample is poured into a round metal coated cup and placed in the milling machine. The sample in the milling machine was milled for about 10 minutes for proper pulverization. After that, the pulverized sample is poured into a sample ring in electric presser, which will press and bind the sample for

Six (6) samples from the sampling point, which were separated for heavy mineral analysis, were taken to the laboratory for density separation. The apparatus was set up for the separation, after which the samples were placed in the separatory upper funnel with second clip on while the heavy liquid (Bromoform) was poured into it. The heavy mineral was seen settling down into the Bromoform, while the lighter minerals floats, this was left for about 5 minutes to ensure complete settling of the heavy minerals, the first clip was locked while the second clip was opened. This caused the separated heavy mineral to run into the filter paper inside the other funnel, it was allowed to drain. The remnant was allowed to run through the other filter paper and Bromoform was recovered. The acetone was used to wash through the first and second funnels to clean off the Bromoform. The hot plate was plugged while the glass slide was also placed on the hot plate. Canada balsam was dropped on the glass slide, with the separated heavy minerals being carefully sprinkled on the Canada balsam which allowed it to cool. The slides were later labeled. The heavy mineral was later studied under the petrographic microscope so as to know the varieties of heavy minerals that have been separated. This procedure measure was carried out inside a fume cupboard to avoid contamination and to get accurate deduction of results.

RESULTS AND DISCUSSION

Table 1: Concentration of major elements of sandstone samples collected from Lokoja at different locations.

SAMPLE ID	%wt. SiO ₂	%wt. Al ₂ O ₃	%wt. Fe ₂ O ₃	%wt. CaO	%wt. MgO	%wt. MnO	%wt. P ₂ O ₅	%wt. K ₂ O	%wt. Na ₂ O	%wt. SO ₃	%wt. TOTAL	%wt. LOI
FL OK R1	72.34	12.70	1.24	0.24	0.10	0.01	0.47	1.30	1.40	0.02	89.82	10.18
FL OK R2	73.65	13.36	0.04	0.13	0.09	0.01	0.47	0.62	1.56	0.01	89.94	10.06
FL OK R3	73.46	13.39	0.37	0.15	0.21	0.01	0.47	1.08	0.44	0.01	89.59	10.41
FL OK R4	75.36	10.52	0.89	0.79	0.27	0.01	0.47	1.20	1.59	0.01	91.11	8.89
MT PATTI	80.25	9.67	1.57	0.18	0.12	0.00	0.46	0.40	0.47	0.00	93.12	6.88
FL AB R1	82.37	7.88	1.91	0.18	0.07	0.00	0.47	0.53	0.54	0.00	93.95	6.05
FL AB R2	73.73	11.65	2.11	0.29	0.17	0.01	0.47	0.73	0.79	0.00	89.95	10.05
FL AB R3	78.39	9.11	2.26	0.16	0.09	0.00	0.46	1.54	0.39	0.00	92.40	7.60
FL AB R4	75.35	10.88	1.85	0.25	0.18	0.01	0.47	0.57	0.77	0.02	90.35	9.65
FL AB R5	74.34	10.98	1.75	0.25	0.11	0.00	0.46	1.55	1.13	0.00	90.57	9.43
MIN	72.34	7.88	0.04	0.13	0.07	0.00	0.46	0.40	0.39	0.00	89.59	6.05
MAX	82.37	13.39	2.26	0.79	0.27	0.01	0.47	1.55	1.59	0.02	93.95	10.41
MEAN	75.92	11.01	1.39	0.26	0.14	0.006	0.47	0.95	0.90	0.007	91.08	8.92

FL OK (R1-R4) = FILELE OKENE ROAD (1-4)

MT PATTI = MOUNT PATTI

FL AB (R1-R5) = FILELE ABUJA ROAD (1-5)

MIN = MINIMUM VALUE

MAX = MAXIMUM VALUE

Harker diagrams are useful in comparing the abundances of the major oxides along a common axis. (Figure 6). They are variation diagrams where concentrations of specific oxides are plotted against those of SiO₂ (on the x-axis). The plots for this study show irregular trends indicating that the weathered particles/sediments are of different sources. The plot of SiO₂ vs. Na₂O (Figure 7) shows that there is a very low correlation with Na; the extrapolated regression equation

XRF (Major Oxides) Analysis results

Result of inorganic geochemical analysis of Lokoja sandstone carried out is shown in table 1. The XRF analysis reviewed for 10 elements which were major oxides are silicon dioxide (SiO₂), aluminum oxide (Al₂O₃), iron oxide (Fe₂O₃), calcium oxide (CaO), magnesium oxide (MgO), manganese oxide (MnO), phosphorous oxide (P₂O₅), potassium oxide (K₂O), sodium oxide (Na₂O) and sulphur oxide (SO₃). An inspection of this results shows that there is dominance of silicon dioxide (SiO₂) which varies from 82.37-72.34% with an average of 75.92%. According to Lindsey (1999), silica enrichment is a measure of sandstone maturity, and is a reflection of the duration and intensity of weathering and destruction of other minerals during transportation. The variation of SiO₂ content is probably due to variation in grain sizes and diagenesis. The Aluminum oxide (Al₂O₃) which is the second dominant oxide ranges from 13.39-7.88% with an average of 11.01% and is due to weathering effects (Malpas et al. 2001). Fe₂O₃ ranges from 2.26-0.04% with a mean of 1.39%, and according to Lindsey 1999, the concentration of iron oxide (FeTO₃, total iron as Fe₂O₃) is the net result of provenance and processes that concentrate and preserve detrital ferromagnesian and iron minerals (mainly amphibole, mica, illite, ilmenite, and magnetite) and their alteration products (chlorite, hematite and some clays).

did not pass through the origin; this being attributed to a small Na₂O contribution from the clay minerals.

MATURITY

Maturity can be reflected in finer grain sizes; however it is actually clay content that is more directly related to lack of maturity. Maturity is reflected best in quartz, rock fragments, feldspars and grain size. The low values given from the ratio of SiO₂/Al₂O₃ indicate that all the

samples have high degree of clayness, which can suggest mineralogical immaturity. Maturity of sandstones can be reflected by the SiO_2/Al_2O_3 index. High ratios indicate mineralogically mature (quartzose, rounded) samples, while low ratios represent chemically immature samples (Potter, 1978). From Table 2, the sandstones have SiO_2/Al_2O_3 ratios of between 5.50 and 10.45 with an average of 7.12, this low ratios represents chemically immature samples. $Na_2O + K_2O$ (alkali content) is a measure of the feldspar content and also applicable for index of chemical maturity. The alkali content is between 0.87 and 2.79, with an average of 1.86 shows the presence of feldspars and low chemical maturity. The Fe_2O_3/K_2O ratio ranges from 0.33 to 3.93 having an average of 1.86; samples with low SiO_2/Al_2O_3 ratio and a higher Fe_2O_3/K_2O ratio should be mineralogically less stable. $Al_2O_3/(CaO+MgO+Na_2O+K_2O)$ ratio can be used in determining the stability of mobile oxides as proposed by Gill and Yamane (1996). From the positive values obtained (2.73 to 8.27), it shows that there are stable mobile oxides in the Lokoja Formation sandstone facies. $CaO+MgO/Al_2O_3$ molecular weight ratio was used to determine calcification in the Lokoja Sandstone facies as proposed by Gill and Yamane (1996).

The concentrations of three major oxide groups have been used to classify sandstones: silica and alumina, alkali oxides, and iron oxide plus magnesia. Blatt et al., (1972), Pettijohn et al., (1972) and Herron (1988) examined the importance of these major oxide variables. In using the same ratios of oxides (as presented in table 2), Lindsey (1999) proposed a set of guidelines for

chemical classification of sandstones. In this case, range of log values are considered. The following are the conditions which must be met to categorize the sandstones;

1. If $\log (SiO_2/Al_2O_3) \geq 1.5$, then the sandstone is classified as Quartz Arenite
2. For the sandstone to be classified as Greywacke, $\log (SiO_2/Al_2O_3)$ must be less than 1 and $\log (K_2O/Na_2O) < 0$
3. When $\log (SiO_2/Al_2O_3)$ is less than 1.5, $\log (K_2O/Na_2O) \geq 0$ and $\log ((Fe_2O_3+MgO)/(K_2O+Na_2O)) < 0$, the sandstone is classified as Arkose (including subarkose)
4. In a situation where $\log (SiO_2/Al_2O_3) < 1.5$ and either $\log (K_2O/Na_2O) < 0$ or $\log ((Fe_2O_3+MgO)/(K_2O+Na_2O)) \geq 0$. The sandstone will be classified as Lithic arenite (Sub greywacke)

Based on the above, the average value of $\log (SiO_2/Al_2O_3)$ for the Lokoja sandstone is 0.84. This value is less than 1.5, so the possibility of the sandstone being a quartz arenite has been excluded. The mean value of $\log (K_2O/Na_2O)$ for the studied area is 0.03, this means condition 2 does not hold since it is not less than 0 (Even though $\log (SiO_2/Al_2O_3)$ is less than 1).

Condition 3 looks more of it, as average value of $\log (SiO_2/Al_2O_3)$ is less than 1.5 and $\log (K_2O/Na_2O) \geq 0$. At the same time, average values of $\log ((Fe_2O_3+MgO)/(K_2O+Na_2O))$ is - 0.03, which is less than 0. These support the arkose classification conditions. Hence, the Lokoja Sandstones are classified as Arkoses.

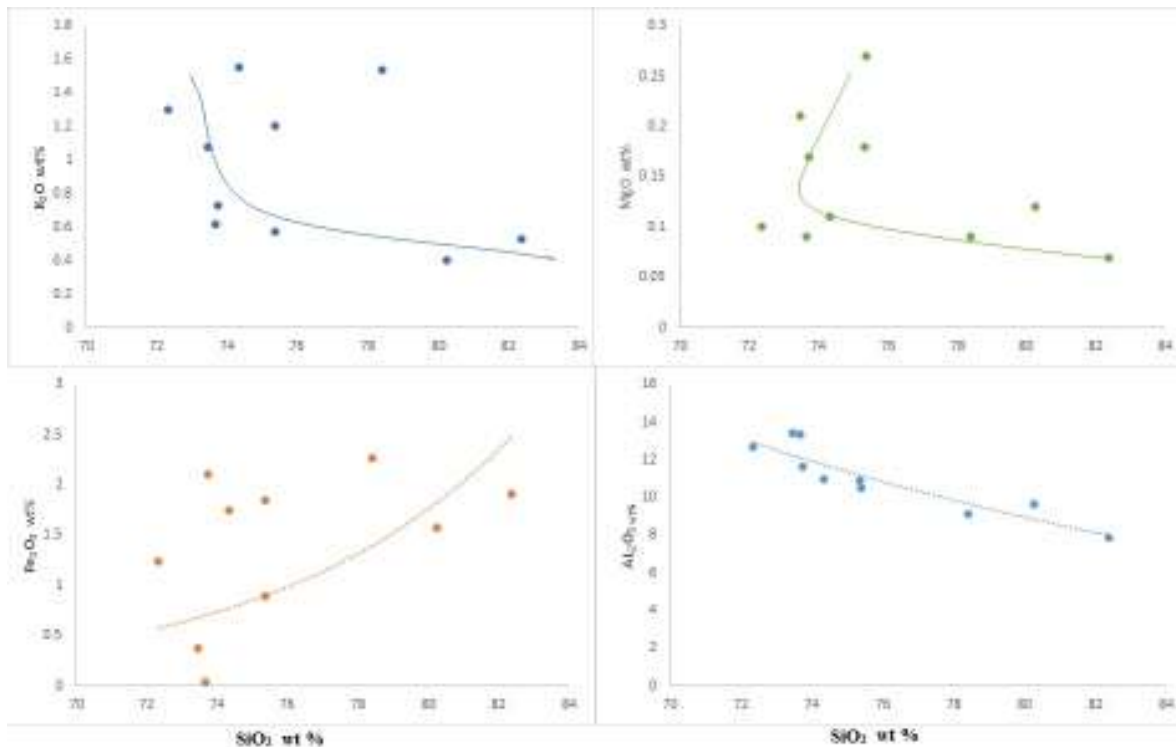


Figure 6: Harker diagram of oxides within the study area

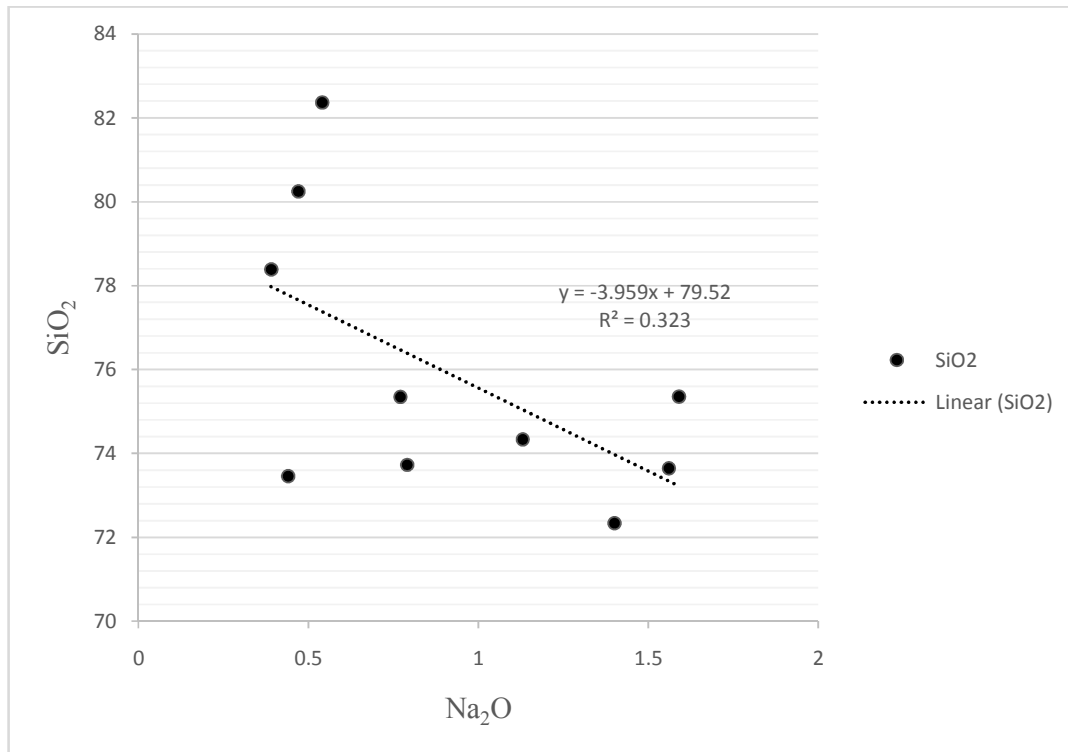


Figure 7: Plot of SiO₂ against Na₂O for the Lokoja Sandstone.

Table 2: Concentration ratios of major elements of sandstone samples collected from Lokoja at different locations.

SAMPLE ID	% wt SiO ₂ / Al ₂ O ₃	% wt Na ₂ O + K ₂ O	% wt Fe ₂ O ₃ / K ₂ O	% wt CaO + MgO	% wt CaO + MgO + Na ₂ O + K ₂ O	% wt Al ₂ O ₃ / CaO + MgO + Na ₂ O + K ₂ O	% wt CaO + MgO / Al ₂ O ₃
FL OK R1	5.69	2.70	0.95	0.34	3.04	4.18	0.03
FL OK R2	5.51	2.18	0.33	0.22	2.40	5.57	0.02
FL OK R3	5.50	1.52	0.34	0.36	1.88	7.12	0.03
FL OK R4	7.16	2.79	0.74	1.06	3.85	2.73	0.10
MT PATTI	8.29	0.87	3.93	0.30	1.17	8.27	0.03
FL AB R1	10.45	0.07	3.60	0.25	1.32	5.97	0.03
FL AB R2	6.33	1.52	2.89	0.46	1.98	5.88	0.04
FL AB R3	8.60	1.93	1.47	0.25	2.18	4.18	0.03
FL AB R4	6.92	1.34	3.25	0.43	1.77	6.15	0.04
FL AB R5	6.77	2.68	1.13	0.36	3.04	3.61	0.03

MIN	5.50	0.87	0.33	0.22	1.17	2.73	0.02
MAX	10.45	2.79	3.93	1.06	3.85	8.27	0.10
MEAN	7.12	1.86	1.86	0.40	2.26	5.37	0.04

Heavy Mineral Analysis Results

The result of the heavy mineral analysis of Lokoja sandstone carried out is shown in table 3. The analysis was carried out on six (6) samples where 12 heavy minerals were discovered; Zircon, Tourmaline, Topaz, Rutile, Staurolite, Kyanite, Sillimanite, Shene, Garnet, Andalusite, Opaque, Quartz.

ZTR Index was calculated in order to deduce the mineralogical maturity, suggest sediment maturity and to determine the genesis of the sediment. Therefore, table 3 shows the samples and their non-opaque mineral point counts, the total number of the opaque minerals present. The results of the heavy mineral analysis for the samples collected at Lokoja as presented in Table 3 shows the abundance of mineral present within Lokoja Formation in various locations. The result shows that there is dominance of Tourmaline which varies from 12-28 point counts and average

abundance of Staurolite and Zircon which ranges from 9-15 and 7-16 point counts respectively. Some other mineral have low abundance such as Topaz with 1-6 point counts, Rutile with 3-8 point counts, Kyanite with 2-6 point counts, Sillimanite with 3-7 point counts, Shene with 2-5 point counts, Garnet with 2-6 point counts, Andalusite with 1-4 point counts, Quartz with 5-7 point counts.

The occurrences of these heavy minerals recovered are very important in the interpretation of sediment source rock (Table 4). The heavy minerals of Lokoja Sandstone indicate two main types of primary sources; sedimentary rocks due to its presence of garnets, zircon, tourmaline, rutile and magnetite, and Felsic to intermediate rocks as revealed by the presence of shene, zircon and tourmaline. A third source of metamorphic origin cannot be ruled out as a result of the presence of sillimanite and andalusite.

Table 3: Heavy minerals with their respective non-opaque and opaque minerals

Mineral (%)	S1	S2	S3	S4	S5	S6
Zircon	7	11	9	16	13	8
Tourmaline	15	20	28	14	16	12
Topaz	6	4	1	4	6	6
Rutile	5	3	4	8	4	6
Staurolite	9	12	15	11	9	12
Kyanite	6	4	3	2	3	6
Sillimanite	5	6	3	4	3	7
Shene	5	3	2	3	5	4
Garnet	5	3	5	6	2	5
Andalusite	4	2	1	1	4	4
Opaque	10	12	15	11	14	11
Quartz	7	5	7	9	5	7
Non-opaque	84	85	93	89	84	88

Table 4: Heavy mineral assemblages in rocks indicative of provenance (Feo-codecido 1956)

PROVENANCE	HEAVY MINERAL SUITE
Sedimentary	Rounded zircon, tourmaline, rutile, Shene, magnetite
Low grade metamorphism	Andalusite, Staurolite, corundum
Contact metamorphism	Tourmaline, vessuvianite, wollastonite, chlorite, muscovite, topaz, ziosite
Higher grade metamorphism	Garnet, epidote, zoisite, Staurolite, Kyanite
Hydrothermal metamorphism	Sillimanite, Andalusite, magnetite, illmenite, shene, zircon, biotite
Acid igneous	Monazite, Shene, zircon, tourmaline, rutile, apatite, muscovite, magnetite (opaque)
Basic igneous	illmenite, magnetite, anatase, biotite, dioside, rutile, chromite, olivine
Pegmatite	Tourmaline, berly, topaz, monazite, cassiterite, muscovite.

Zircon-Tourmaline-Rutile (ZTR) Index

The ZTR ratio gives a measure of the degree of dissolution that has occurred (Hubert, 1962). The ZTR index was calculated using the percentage of the combined zircon, Tourmaline and rutile grains for each sample according to the formula below referred to as Hubert's (1962) scheme:

$$\text{ZTR Index} = \frac{\text{Zircon} + \text{Tourmaline} + \text{Rutile}}{\text{Hubert's (1962) Total number of Non-Opaque heavy minerals}}$$

heavy minerals

This index is expressed in percentage and a measure of the maturity of a heavy mineral suite (Pettijohn et al., 1972). In greywackes and arkoses, the ZTR index is between 2-39%, and usually exceeds 90% in quartz arenites (Mange and Maurer, 1992). Accordingly, ZTR <75% implies immature to sub mature sediments and ZTR >75% indicates mineralogically mature sediments. According to Mange and Maurer (1992), the ZTR index values of between 75 and 88% are characteristics of mature sediments.

The ZTR Index for the selected samples range from 30% to 44% with an average of 38%. All the selected sample has ZTR index lesser than 75%. Therefore, the ZTR indices suggest that nearly all the sediments are mineralogically immature. From the heavy mineral recovered from the selected samples of the Lokoja sandstone, it shows that the origin and provenance of the sample collected from the basin is sedimentary (Table 4). The occurrence of Staurolite and Kyanite suggests some negligible contribution from migmatitic gneiss and quartz schist of the adjoining Southwestern Nigeria Basement Complex.

CONCLUSIONS

Sandstone facies of the Lokoja Formation has been categorized using a set of approved guidelines. Further studies showed that sediment supply are from different sources. However, it is evident that the sandstones are rich in silica materials. The sandstones can thus be classified as arkoses. The sandstone has low ratio of SiO₂/ Al₂O₃ which indicate that all the samples have high degree of clayness, which can suggest mineralogical immaturity. The high value of SiO₂ gives a deduction that the sandstone outcrop is not far from the parent rock, which also means it has not undergone much reworking from the source.

The ZTR ratio has an average of 38% which totally indicates that the sediment has a low degree of dissolution. The heavy mineral recovered from the samples indicates that the sediments are stable. The heavy minerals recovered from the selected samples of the Lokoja sandstone show that the possible origins of the samples collected from the study area are from recycling through sedimentary rocks and metamorphic terrain of the adjoining basement complex.

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