Communication in Physical Sciences, 2023, 9(4): 465-482

Geology, Geochemical and Petrographic Studies of Lokoja Sandstone Facies: Implications on Source Area Weathering, Provenance and Tectonic Settings

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Received: 02 May 2023/Accepted 25 August 2023/Published 28 August 2023

Abstract: *The examination of the geology, petrographic and geochemical profiles of the Lokoja sandstone facies is the primary goal of this research. The objectives include carrying out geochemical analysis on the Lokoja sandstone facies, carrying out X-ray fluorescence (XRF) analysis within the Lokoja sandstone facies, carrying out X-ray diffraction (XRD) analysis within the Lokoja sandstone facies and the determination of the petrographic of the Lokoja sandstone facies. A few thin oolitic iron stones and coarse-grained cross-bedded sandstone make up the geology of the study area, along with pebbly clayey grit and sandstone. Rarely exposed has been identified as a basal conglomerate composed of well-rounded quartz pebbles embedded in a white clay matrix. ranging from 100 and 300 meters in thickness, depending on the relief of the Basement Complex floor beneath. The methods used in carrying out this project research include granulometric, geochemical, and petrographic analysis. The result from the granulometric analysis was used to construct the lithology log. The log helps to determine the paleo-environmental and depositional sequence of the study area. The XRD/XRF analysis shows Quartz and Orthoclase Feldspar, as the predominant mineral assemblage recommending a low weathering contour for the Lokoja sandstones. The mineralogical composition of sandstones was detected using XRD and XRF analyses. The XRD profile of the Lokoja Sandstone A which is situated around the Nataco area consists of the following mineral obtained during the XRD: quartz, orthoclase, muscovite, kaolinite, osumilite, illite, chlorite and garnet respectively with varying percentages. The major minerals obtained from the results were quartz (67%) and orthoclase feldspar (11%). Geochemical signatures of clastic sediments can be employed to interpret the provenance nature of the deposits. The Al_2O^3 /TiO_2 for Lokoja sandstone, claystone and shale facies of Patti Formation are 52.43 wt %, 14.21 wt %, 10.02 wt % and 10.25 wt % equally. This proportionality suggests felsic source rock for the Lokoja Sandstone and intermediate source rock for the Patti sediments. The Geology (distribution), Provenance, Weathering, Tectonic context and redox proxy of the Lokoja Sandstone, Middle-Niger basin have been determined using integrated petrographic, granulometric and geochemical advent. Major elements geochemistry and their ratios affirmed that the Lokoja sandstone is predominantly mature lithic arenites including sub-greywacke and protoquartzites impact of felsic igneous provenances on the static basin.*

Keywords: *X-ray fluorescence (XRF), X-ray diffraction (XRD), Sandstone, Provenance, Weathering, Tectonic context and Redox proxy*

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1.0 Introduction

The Bida Basin is an intracratonic basin with rift-related origins and approximately 3.5 km of flat-lying clastic deposits, is found in Nigeria near the confluence of the rivers Niger and Benue with trending of The northwest-southeast direction (Udensi and Osazuwa, 2004). It is physically perpendicular to the Anambra Basin in the southeast but to the northwest, it is next to Sokoto Basin. Sedimentation was vigorous in these basins during the Campanian-Maastrichtian epoch in Nigeria (Godwin *et al*., 2023a). The sandstones are found throughout the connection of the rivers Niger and Benue, primarily where road cuttings on the Lokoja-Abuja and Lokoja-Agbaja highways have exposed the Lokoja formation. The Lokoja Formation was recently exposed in areas where it had not previously been exposed or investigated thanks to the construction or expansion of the highway.

From the perspective of hydrocarbon prospectively, the Lokoja Formation is unique and merits detailed study because it is the earliest stratigraphic unit deposited unconformably on the basement rocks and thus provides a key to the geologic history and paleotectonic setting of the depositional basin. Also, because it is predominantly composed of sandstone, minor conglomerate, and is close to carbonaceous shales of the younger Patti Formation, it offers reservoir potential (Vrbka *et al*., 1999). Bida Basin is among the marginal basins in Nigeria being considered for exploration and exploitation to drive the Government's aim of 40 bbl Oil reserve with contributions from interior basin resources.

Given the aforementioned context, it is nevertheless quite concerning that the Lokoja formation remains not much studied. In fact, on the features, stratigraphy (lateral and vertical extent), and paleoenvironments, there are divergent views. Without taking into account their source histories, sedimentological features, or paleoenvironments, Jan du Chene *et al*., (1978), Braide (1992), and most recently Rahaman *et al*. (2019) combined all of the sandstones, shales, and claystone in the Southern Bida basin into one stratigraphic unit or formation known as Lokoja Sandstone. Ojo and Akande (2003, 2009), on the other hand, not only supported the earlier subdivisions (Lokoja and Patti formations) by Jones (1958) but also provided more evidence in favour of the division of the sandstones into various mappable packages. Based on sedimentological characteristics and fundamental petrology, Ojo and Akande (2003) characterized the depositional facies of the Lokoja formation (Alluvial and braided facies) with the petrographic features of the sandstone. One of the disadvantages of the Lokoja formation is that it mostly consists of sandstone, eliminating the possibility of dating fossils, in contrast to the shale of the Patti formation, which has been geochemically described and even dated (Agyingi, 1993; Ojo and Akande, 2003; Godwin *et al*., 2023b). The previous work was centred on an elemental composition examination of the Lokoja Formation's sandstones in the sense of chemostratigraphy in this context.

It has been documented in the literature that geochemical tools may be used to assess the origin and tectonic context of sandstones (Bhatia, 1983; Armstrong-Altrin *et al*., 2004; Ayala *et al*., 2021). Geochemistry has been established as a significant tool in the determination of the fundamental characteristics of source rocks, the tectonic context of the emplacement of sedimentary products, and the extent of weathering (Armstrong-Altrin *et al*., 2004; Aigbadon *et al*., 2023a). It is possible to constrain source weathering, tectonic setting, and origin by examining the abundance of major, trace, and rare earth element compositions in sedimentary rocks and their ratios.

The Bida Basin: is one of the largest inland sedimentary basins in Nigeria, lies perpendicular to the main directions of the Benue Trough and the Niger Delta basin of Nigeria and is oriented in a northwest-southeast location. It is commonly seen as the northeastern extension of the Anambra Basin, both of which served as key deposition sites during the third major transgression period in southern Nigeria in the Upper Cretaceous (Obaje *et al*., 2011). According to magnetic data, its sedimentary fill is approximately 4700 meters (Udensi and Osazuwa, 2004).

The Upper Cretaceous Lokoja Formation's facies relationship and depositional habitats, as well as the sedimentology and depositional environment of the Patti formation in the Bida basin, were both part of reports by Ojo and Akande in 2003. However, they restricted their analysis to palaeocurrent, textural, and field connection traits. According to reports (Bhatia, 1983; Roser and Korsch., 1986), the chemical composition of clastic sedimentary rocks is a result of a complex interplay of 346 different variables, including the type of source rocks, source area weathering, and diagenesis. Furthermore, different tectonic environments have different provenance features and distinctive sedimentary mechanisms, making the tectonic setting of a sedimentary basin the overall primary control of the physical characteristics of sedimentary rocks (Dickinson, 1985; Osae *et al*., 2006). To estimate the origin, tectonic settings, and the palaeodepositional environment in the sediments of the Lokoja Sandstone of southern Bida Basin, the current work incorporates data from outcrop investigations, sedimentology, petrography, and elemental geochemistry. There is little question that these results will offer further details that scholars and explorers will find beneficial.

The following goals of this study include studying the geology, geochemistry, and petrographic research of the Lokoja sandstone facies, as well as their implications for origin area weathering provenance and tectonic settings:

(i) To conduct out geochemical study on the Lokoja sandstone facies.

(ii) To perform X-ray fluorescence (XRF) analyses on the Lokoja sandstone facies.

(iii) To carry out X-ray diffraction (XRD) studies on the Lokoja sandstone facies.

(iv) To carry out Petrographic analysis on the Lokoja sandstone facies.

The Geology, Geochemical and Petrographic investigations of Lokoja sandstone facies and their consequence on source region weathering origin and tectonic settings had not been established. This is owing to an inadequate understanding of sandstone facies (complete and credible current geochemical data on Lokoja sandstone facies).

1.1 Geology and the location of the study area

The research region includes road cut outcrop along the Lokoja-Abuja highway (fig. 1) and is located between latitudes 07° 51' and 08° 26' and longitudes 006° 41' and 006° 56'.

The area shown on the map (see fig. 1) is classified as the sedimentary environment in the geological map of Nigeria. It is situated in the country's southwest and is made up of three distinct lithologies, including the Lokoja Formation, Agbaja ironstone, and Patti Formation (see fig. 1).

The Lokoja Formation is the oldest in the lower Bida Basin overlapping the basement complex, it is composed of sandstone, they are located near Lokoja and Felele, the formation is mainly noted for its pebbly quality in nature. and Koton-karfe, they are coarse-grained combined with a coarsening upwards sequence, they are darkish brown and are composed of cobbles, pebbles etc. that are sub-angular to sub-rounded in form (Atabo *et al*., 2023, Aigbadon *et al*., 2023b).

(i) The Patti Formation

These formations are distinguished by fine-medium pinkish-white, greyish-grey, and siltstone as well as oolitic ironstone. They appear in a fining upward succession and cross-stratification and slumps were noted as sedimentary features., which must have occurred as a result of changes in the current directions at the time when the sand was deposited (Mu'awiya *et al.*, 2022b).

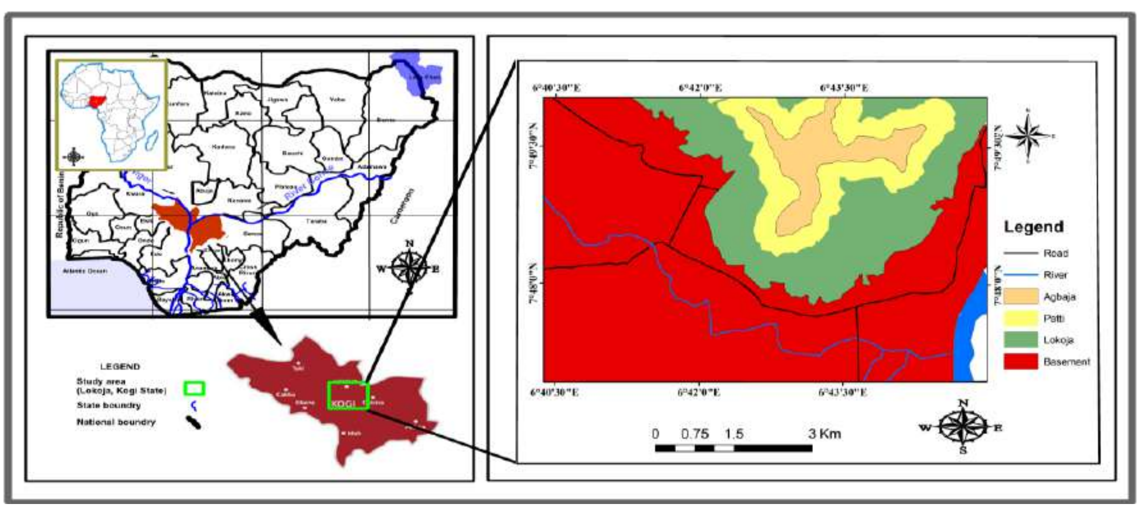

Fig. 1: Geological map of the research area showing different geology (Modified after Ibrahim *et al.*; 2023 Mu'awiya *et al.*, 2022a).

(ii) The Agbaja ironstone

Agbaja Ironstone is the topmost layer overlying both the Lokoja and the Patti Formations. It is composed of oolitic ironstone; it is coarse-grained, poorly sorted, and reddish to brown (Godwin *et al.*, 2022).

(i) The Lokoja formation

Clastic sediment geochemical markers can be used to determine the sediment's provenance, according to several reports (Armstrong-Altrin *et al.*, 2004). For mafic igneous rocks, the Al2O3 / TiO2 ratio rises to 8, for intermediate rocks it rises to 21, and for felsic igneous rocks, it rises to 70.

2.0 Materials and Methods

Desk studies and field surveys were adopted for this study to determine the geochemical and petrographic analyses of the Lokoja sandstone facies (see fig. 2). The exposed Lokoja formation sandstone samples were taken along the Lokoja-Abuja express road.

Petrographic analysis, X-ray fluorescence analysis, X-ray diffraction analysis, and Geochemical analysis (Granulometric analysis) were also conducted during the research processes.

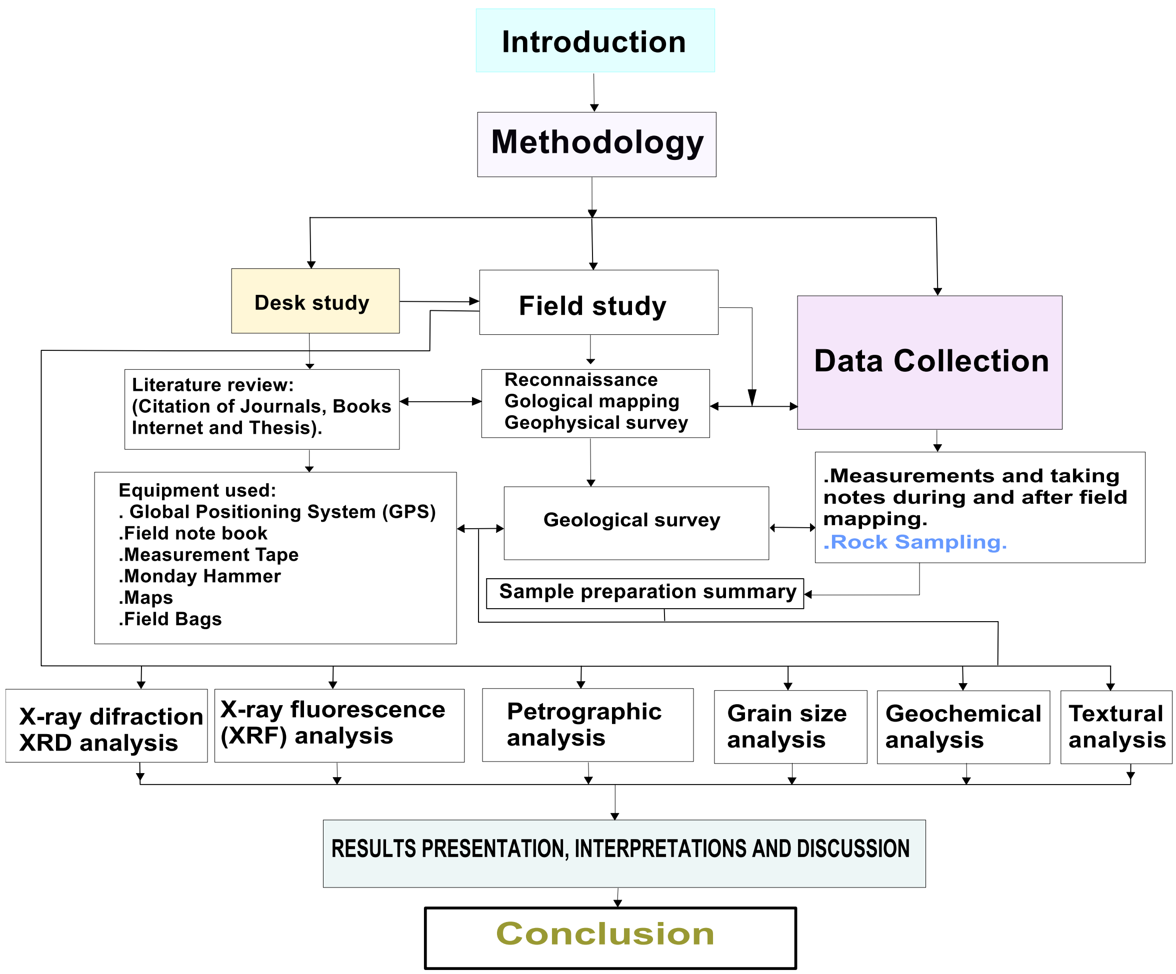

Fig. 2: Flow Chart of the Methodology adopted for this study (Modified after Mu'awiya *et al.*, 2022a. Mu'awiya *et al.*, 2022b)

The study was conducted in four (4) stages, including:

(i) Desk study

This involves the evaluation of geologic reports on different components of the Precambrian Basement Complex of Nigeria, particularly the North-Central Basement Complex and Bida Basin from past studies specifically in the field of this research (Literature Review) see fig. 2.

(ii) Field Study/Survey

This operation took place twice and lasted a total of four (4) days. The reconnaissance survey was carried out from February 21 until February 23, 2022. The initial fieldwork took place from March 2–3, 2022, and the detailed investigation took place from April 4–14, 2022.

2.1 *Granulometric analysis (sieve analysis)*

The particle size distributions were mechanically measured by agitating 100 g of each sample for 20 minutes in a Durham Geo Slope shaker equipped with a set of sieves. In order of mesh size, the following British Standards were used using a sieve: 2.00 mm, 1.18 mm, 0.85 mm, 0.60 mm, 0.425 mm, 0.30 mm, 0.0025 mm, 0.50 mm, 0.10, 0.075 mm, and 0.0063 mm. For statistical analysis, the proportion of each mesh size was weighed using the method developed by Folks and Ward (1957).

2.2 Petrographic analysis

To assist with disaggregation, each sample was mixed into a solution with water in glass cylinders, stirred appropriately, and then left approximately for 10 minutes. The samples were then completely deflocculated by soaking them in a 30% hydrogen peroxide (H_22O_2) solution. To observe petrology under a microscope, the heavy minerals were segregated by panning and mounted on glass slides.

2.3 Geochemical analysis

The method employed reports concentration as % oxides for key elements and ppm for minor elements using a PW1480 X-ray fluorescence spectrometer with a Rhodium tube as the X-Ray source.

2.4 *X-ray diffraction (XRD) analysis*

The XRD analysis was carried out by using XRD machine with model number Rigaku Ultima III XRD.

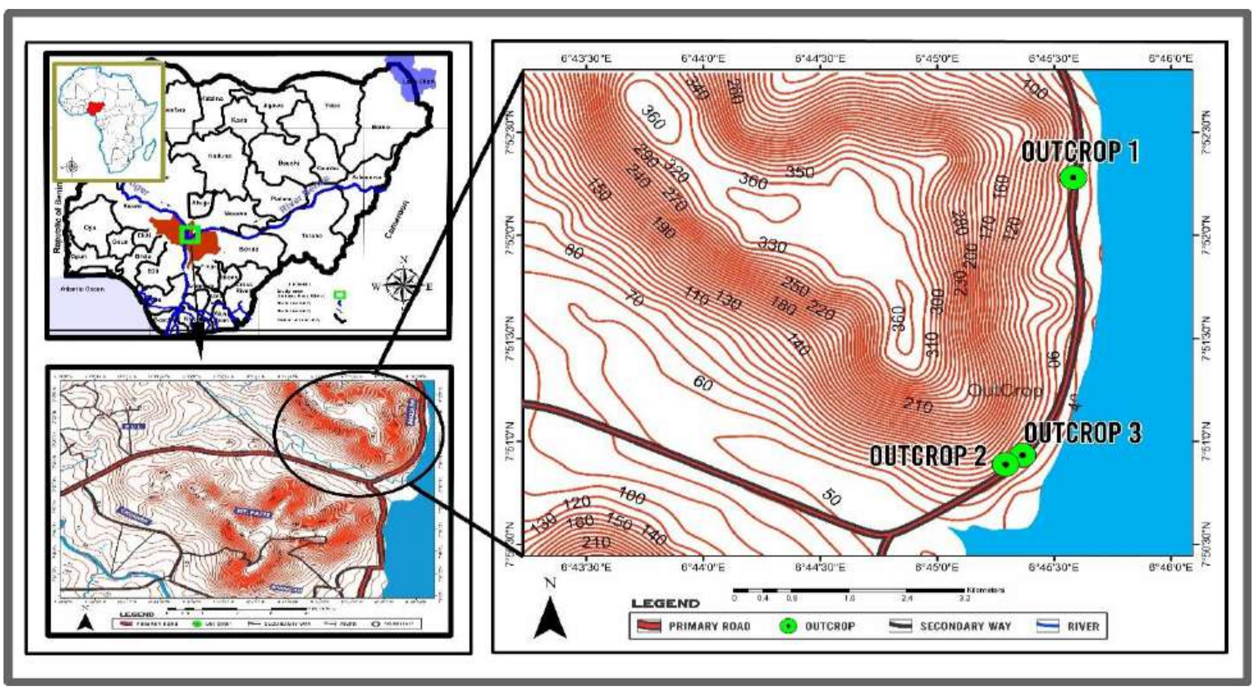

Fig. (3): Map of Lokoja showing the samples outcrops

3.0 Results and Discussion

The Lokoja Formation is made up of coarse-grained cross-bedded sandstone, pebbly clayey sand and sandstone, and a few small oolitic iron stones. It ranges in width from 100 to 300 meters (Desauvagie, 1975). The Patti Formation is composed of a series of fine- to medium-grained, grey and white sandstones, carbonaceous siltstone, claystone, shale, and oolitic ironstone. White grittier materials are typically clay and thin coal seams might be found. According to Jones (1958), there is a 70m maximum exposed thickness. In comparison to sandstone from other regions of the world, Lokoja sandstone has a higher than usual SiO_2 content. A further indicator of the involvement of oxidation, hydration, and leaching processes during weathering is the high value of Fe_2O_3 in the deposits (Simon *et al*., 2022).

According to bivariate scatter plots based on Friedman (1969), Folk and Ward (1957), and Omali *et al*. (2011), the Lokoja Sandstone is composed of river sand and fluvial material deposited by low energy currents.

3.1 Granulometric analysis
The lithology

The results obtained from the granulometric analysis were used to construct the lithology log. The log aided in the determination of the paleo-environmental and depositional sequence of the study area.

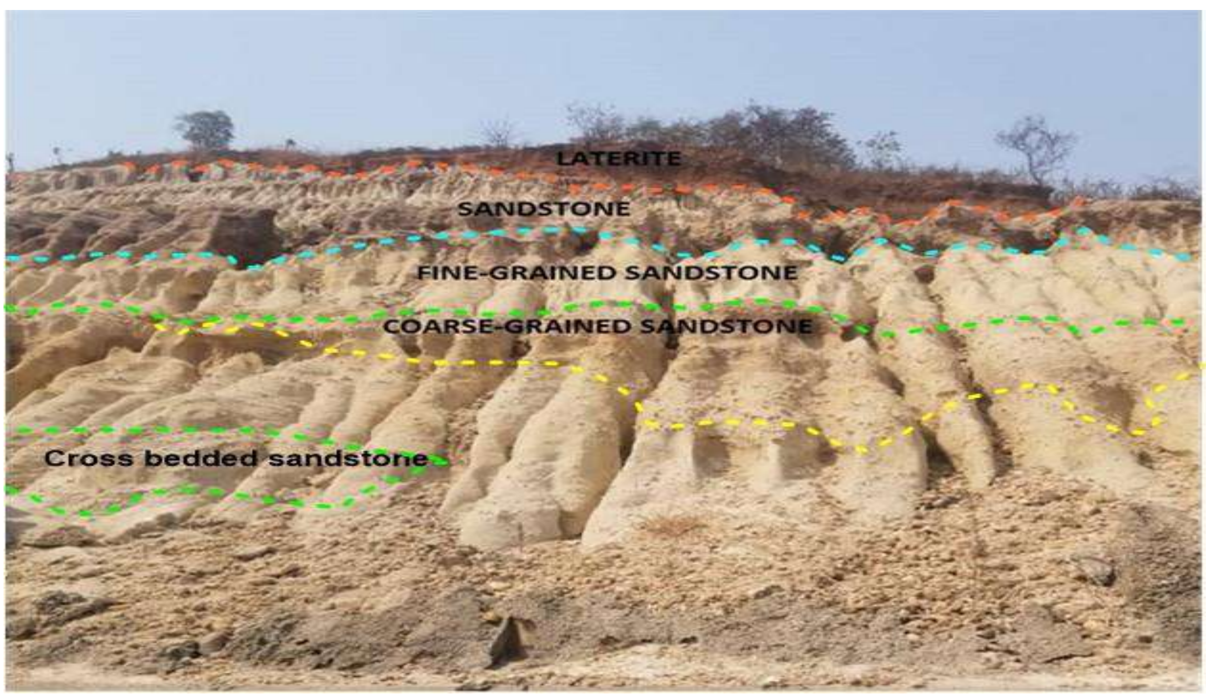

Plate 1: The photograph of sandstone exposure on outcrop One (1) N 07^{0}52' 16.8'' E 006^{0}45'34.9''

The outcrop 1 above with coordinates N07^{0}52' 16.8'' E006^{0}45'34.9'', has an elevation of 58.1m. From the litho log, it shows 9.5m to7.5m has brownish greyish moderate to fine-grained sandstone ranging 7.5m to 5.4m has greyish moderate to coarse-grained sandstone, ranging from 5.4 m to 4.6m has brownish, whitish medium to coarse sandstone, from about 4.6m to 2.8m has greyish medium toward fined grained sandstone and from about 2.8m down has coarse greyish sandstone.

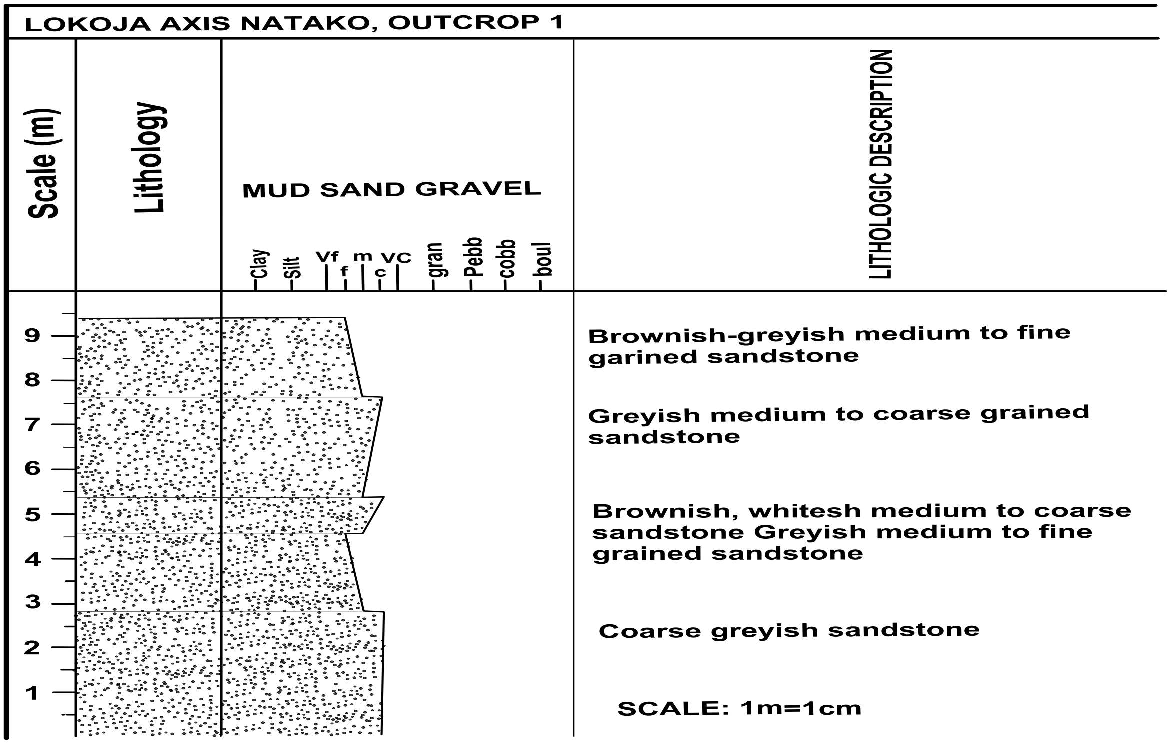

Fig. (4): The Litho log of Outcrop 1

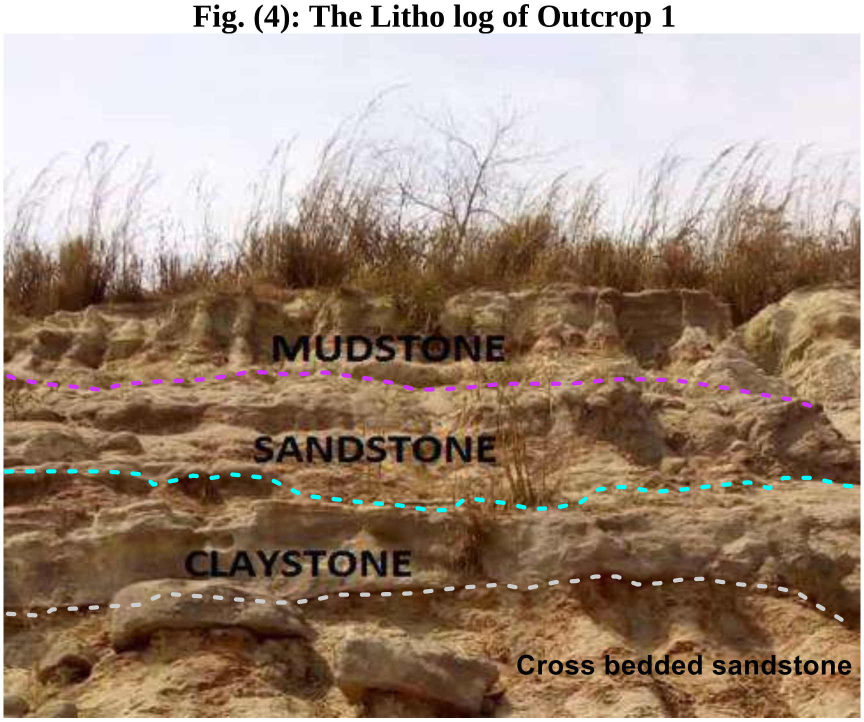

Plate (2): Photograph of sandstone exposure on outcrop two (2) N 07^{0}32' 30.8'' E 006^{0}45'35.8"

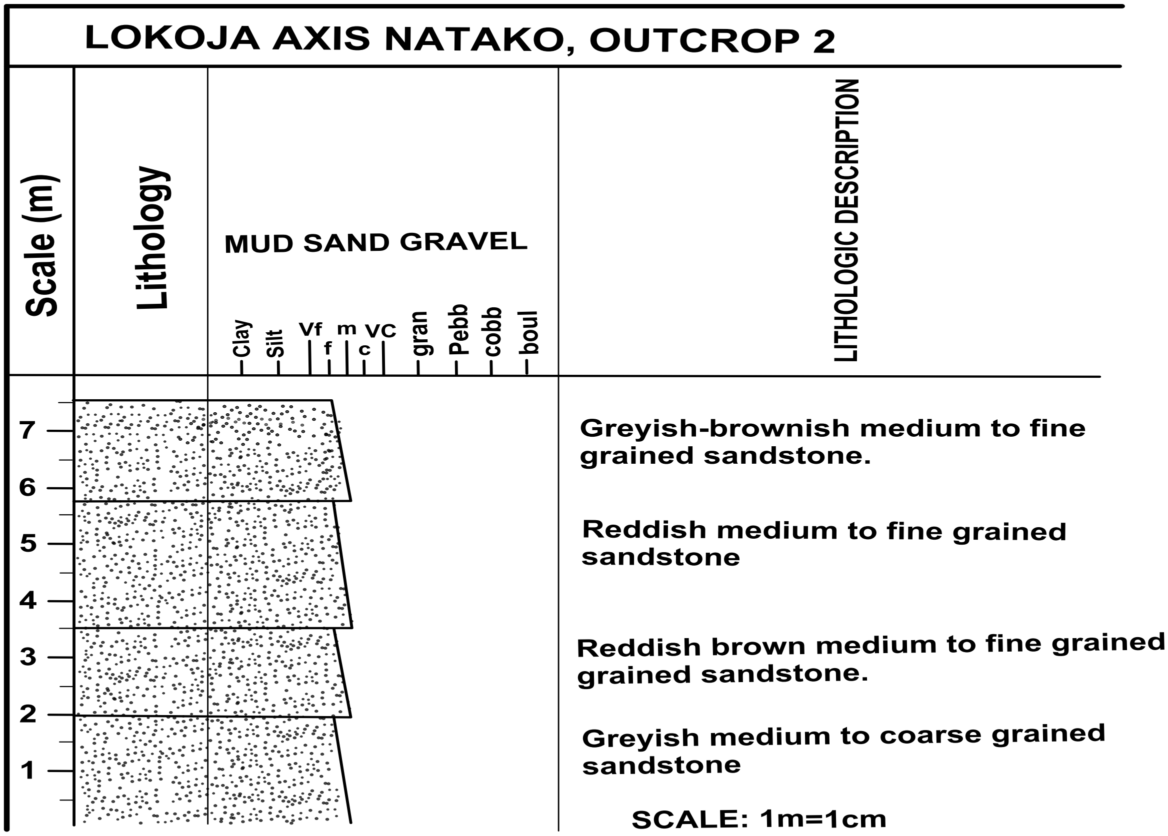

Fig. (5): Litho log for outcrop two (2)

The outcrop 2 above with coordinates N07^0 32' 30.8'' E 006^{0}45'35.8'', with an elevation of 37.4m. It has been observed a greyish-brownish medium to fine-grained sandstone at about 7.5-5.8m, from 5.8m to 3.5m has reddish medium to fine-grained sandstone, from 3.5m to 1.9m show a reddish-brown medium to fine-grained sandstone.

Plate (3): Photograph of claystone/mudstone exposure on outcrop three (3) N 07^{0}50' 56.0'' E 006^{0}45'21.9''

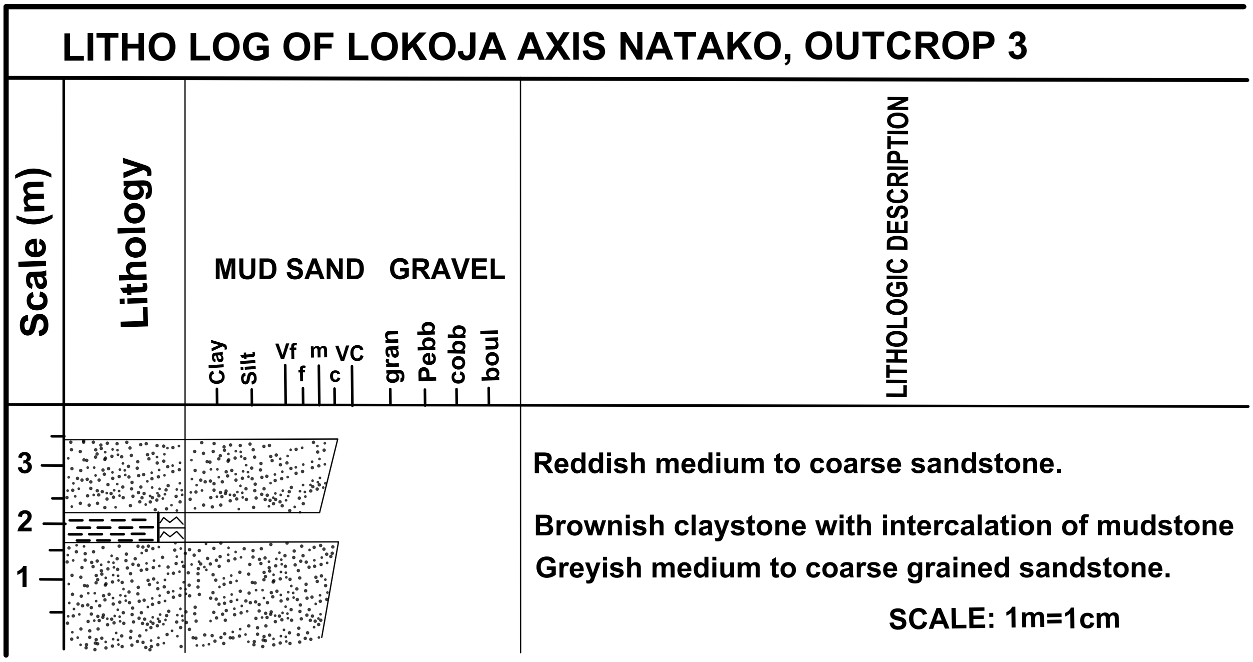

Fig. 6): Litho log for Outcrop Three (3).

The outcrop 3 above with coordinates N07^0 50' 56.0'' E 006^{0}45'21.9'', with an elevation of 63.3m has been observed a reddish medium to coarse-grained sandstone at about 3.4m to 2.2 m, from 2.2m to about 1.6m there is brownish claystone with intercalation of mudstone and the last part from about 1.6m down has greyish medium to coarse-grained sandstone.

3.2 *Geochemistry and petrography*

XRD Profiles signature and Pie Charts of the two Lokoja sandstone samples analyzed.

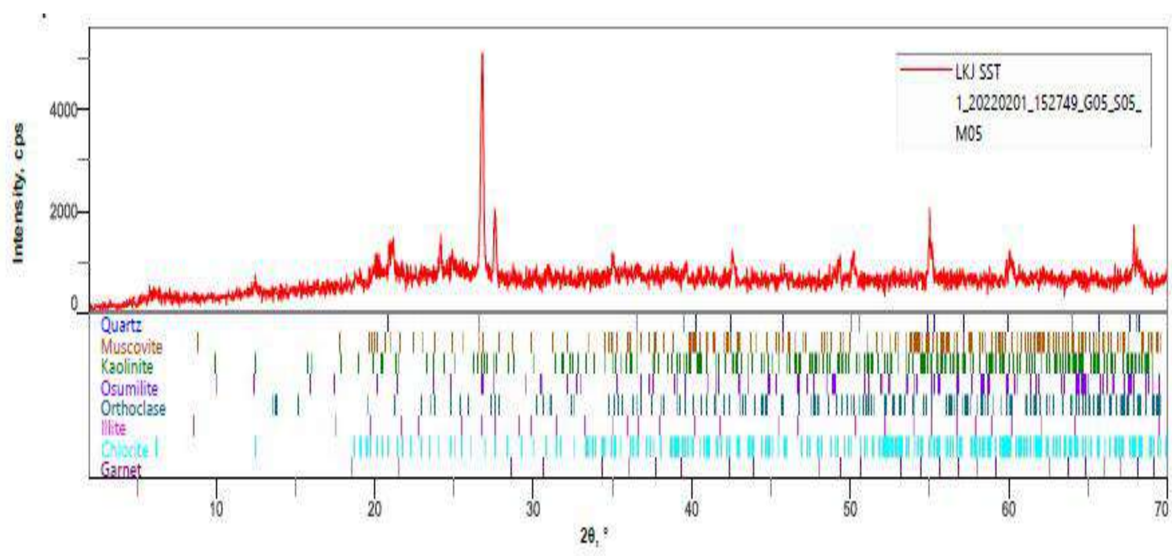

Fig. (7a): The X-ray diffraction (XRD) profile for Lokoja sandstone A

The X-ray diffraction analysis reveals that the mineral association is dominated by Quartz and Orthoclase Feldspar (Fig. 7a & b) characterizing a lowly weathering profile for the Lokoja sandstones.

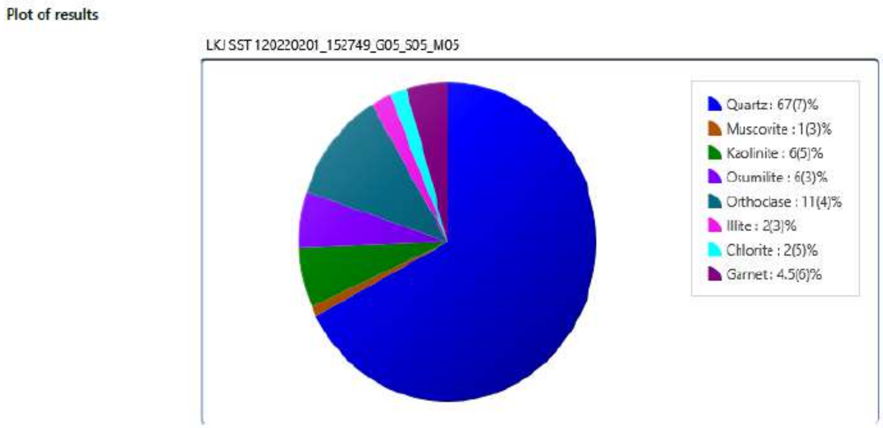

Table of results

Dataset / Weight Fra...	Value, Unit	Quartz	Muscovite	Kaolinite	Osumilite	Orthoclase	Illite	Chlorite	Garnet
LKJ SST 1_20220201...	0	67(7)	1(3)	6(5)	6(3)	11(4)	2(3)	2(5)	4.5(6)

Fig. 7b: A Pie chart of the XRD results for Lokoja sandstone "A"

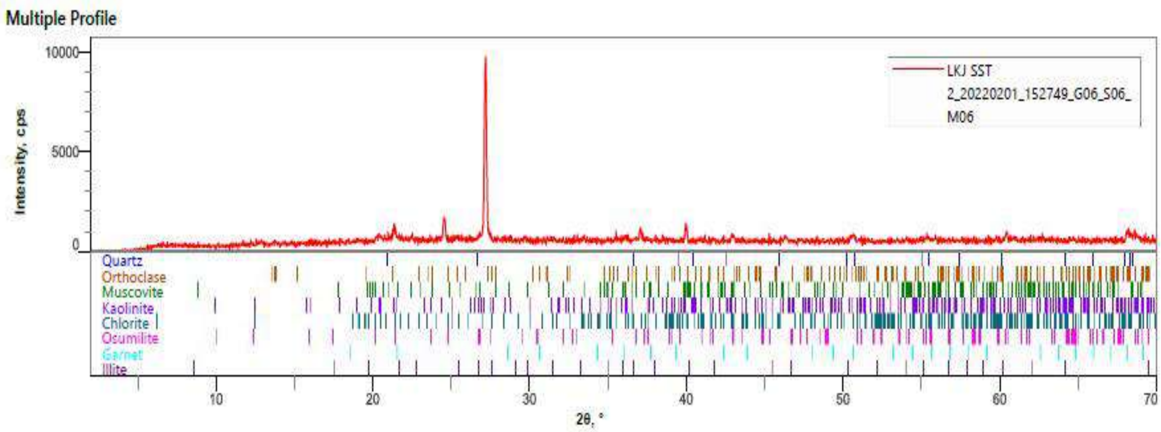

Fig. 8a: XRD profile for Lokoja sandstone B

With a lowly weathering profile of the Lokoja sandstones, X-ray diffraction (XRD) analyses revealed that Quartz and Orthoclase Feldspar dominate the mineral assemblage (Fig. 8a and b).

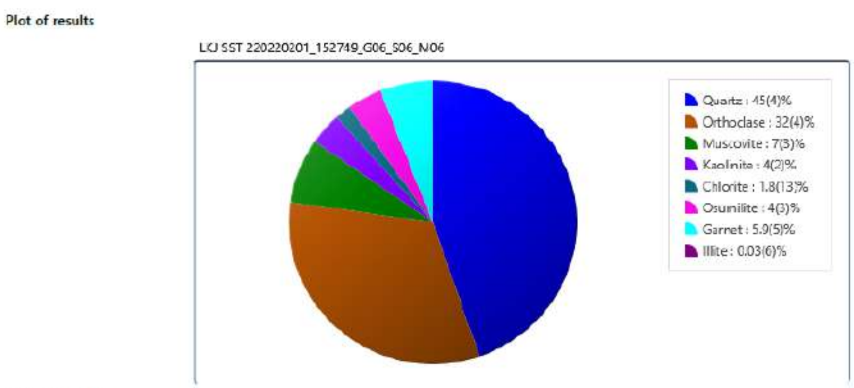

Table of results

Dataset / Weight Fra...	Value, Unit	Quartz	Orthoclase	Muscovite	Kaolinite	Chlorite	Osumilite	Garnet	Illite
LKJ SST 2_20220201...	0	45(4)	32(4)	7(3)	4(2)	1.8(13)	4(3)	5.9(5)	0.03(6)

Fig.: 8b A Pie chart of the XRD results for Lokoja sandstone "B"

The sample consists of the following minerals obtained during the XRD analysis, they include quartz, orthoclase, muscovite, kaolinite, osumilite, illite, chlorite and garnet respectively with varying percentages. The major minerals obtained from the results in XRD were quartz (45%) and orthoclase feldspar (32%) (Fig. 8a and b.

The X-ray diffraction analysis also shows that the mineral group is overpowered by quartz and orthoclase feldspar characterizing a lowly weathering profile for the Lokoja sandstones. The mineralogical composition of sandstones was realized using XRD and XRF analysis. Minerals obtained during the XRF analysis with their chemical formula and merit figure, include quartz, orthoclase, muscovite, kaolinite, osumilite, illite, chlorite and garnet respectively with varying percentages.

Table I: Oxide and Elemental Composition result of the sandstone in the study area

Components or Oxides	Concentration (wt. %) Lokoja sandstone A	Concentration (wt. %) Lokoja sandstone B	Element	Concentration (wt. %) Lokoja sandstone A	Concentration (wt. %) Lokoja sandstone B
SiO_2	68.811	79.920	O	48.544	50.305
V_2O_5	0.050	0.015	Mg	0.000	0.000
Cr_2O_3	0.048	0.145	Al	9.336	6.677
MnO	0.033	0.001	Si	32.165	37.358
Fe_2O_3	8.127	3.439	P	0.000	0.000
Co_3O_4	0.036	0.024	S	0.054	0.000
NiO	0.002	0.044	Cl	0.599	0.694
CuO	0.040	0.028	K	2.227	1.412
Nb_2O_3	0.007	0.007	Ca	0.692	0.644
MoO_3	0.002	0.005	Ti	0.359	0.197
WO_3	0.001	0.005	V	0.028	0.008
P_2O_5	0.000	0.000	Cr	0.033	0.099
SO_3	0.135	0.000	Mn	0.026	0.000
CaO	0.969	0.900	Fe	5.684	2.405
MgO	0.000	0.000	Co	0.027	0.018
K_2O	2.682	1.700	Ni	0.001	0.034
BaO	0.127	0.069	Cu	0.032	0.022
Al_2O_3	17.639	12.615	Zn	0.003	0.000
Ta_2O_5	0.010	0.013	Zr	0.051	0.014
TiO_2	0.598	0.329	Nb	0.005	0.006
ZnO	0.004	0.000	M_o	0.001	0.003
Ag_2O	0.010	0.029	Ag	0.010	0.027
Cl	0.599	0.694	Sn	0.000	0.000
ZrO_2	0.069	0.019	Ba	0.113	0.061
SnO_2	0.000	0.000	Ta	0.008	0.010
			W	0.001	0.004

Table I above shows the result from X-ray fluorescence (XRF) analysis, with corresponding average compositions, the values are shown as weight percentages. From the oxide concentration, SiO_2 has an average value of 74.3655 wt %, Al_2O_3 with an average value of 15.127 wt %. The average K_2O value is 2.191 wt %., Fe_2O3 has an average concentration is 5.783 wt % and CaO value is 0.9345 wt %. The values for MgO vary from 0.00 weight percent to 0.00 weight percent, with an average of 0.0.00 wt percent. TiO2 and P2O5 concentrations vary from 0.329 weight percent and 0.000 weight percent, respectively (See Table I). The high amount of Fe_2O_3 in the sediments is a sign of oxidation, hydration, and leaching events engaged during weathering, and the median SiO_2 concentration in Lokoja sandstone remains elevated compared to those from other regions of the world.

3.3 *Petrographic analysis*

An optical microscope is used to identify the minute textural and mineralogical characteristics in the thin section of the rock with a resolution more than that of the human eye. For thin section petrographic investigation, two (2) samples from the research region were chosen efficiently to evaluate their mineral composition, mineralogical maturity, and likely provenance. In Plates 4 and 5, the photomicrographs are shown.

3.4 *Sandstone Petrography*

Quartz is a prominent mineral that makes up a sizable portion of the sandstone grains. The sample's average quartz content comes from "Location 3 Bed 3 and Location 4 Bed 4" and is 80%. In contrast to feldspars, which are grey in hue, quartz crystals are often white and transparent. The sandstones contain quartz grains that are both monocrystalline and polycrystalline. Some monocrystalline grains have an undulose extinction tendency. Undulose extinction is an indication of stress drain creation in the metamorphic parent rock. The majority of the grains of monocrystalline quartz are sub-rounded to sub-angular in appearance. Quartz is primarily mono-crystalline, though some of the samples used for the study do contain polycrystalline quartz. In contrast to the polycrystalline quartz, which displays signs of reworked sediments, monocrystalline quartz exhibits straight extinction. Weathered feldspar present in the sample is about 5% respectively, with 15% opaque minerals (see plates 4 and 5).

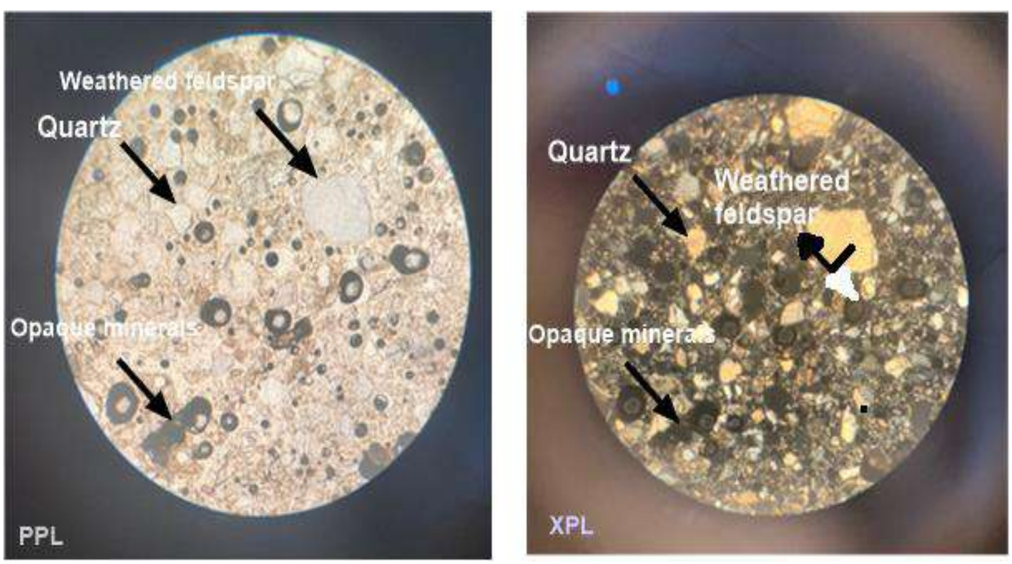

Plate 4: Photomicrograph of Quartz grains from Location 3 Bed 3 showing Angular to sub-rounded quartz grains under PPL and XPL

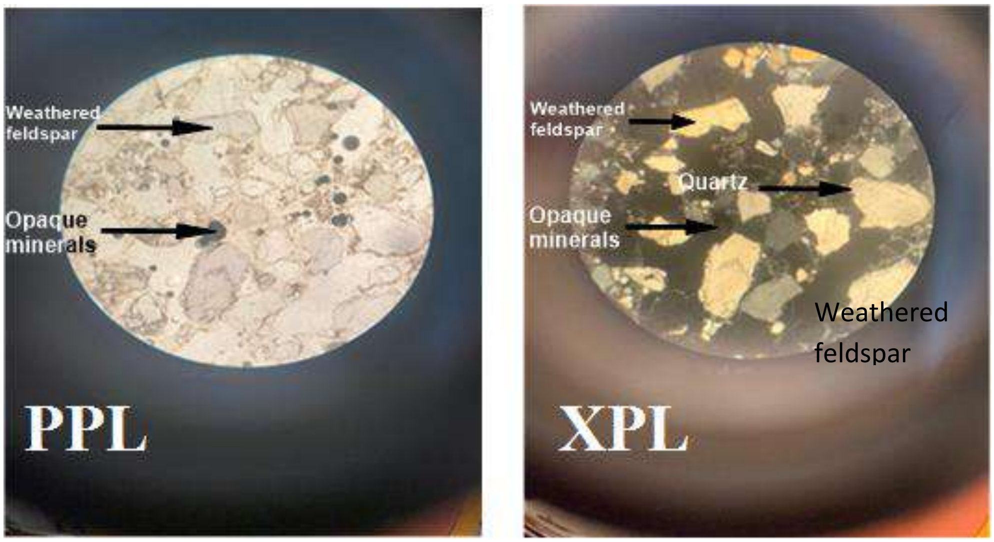

Plate 5: Photomicrograph of Quartz grains from Location 4 Bed 4 showing Angular to sub-rounded quartz grains under PPL and XPL

Table II: Modal Analysis of sandstone obtained from petrographic analysis

Sample	Q (%)	F (%)	L (%)	Mineralogical maturity index [Q/(F+L)]
L3 B3	80	5	15	4.0
L4 B4	75	10	15	3.0

Table III: Maturity of sandstone (Nwajide and Hoque, 1985)

Q=>95% (F+O)= 50%	MI=> 19 super mature
Q=> 95-90%(F+O)=5-10%	MI=19-9.0 Sub mature
Q=>90-75% (F+O)= 10-25%	MI=9.0-3.0 sub mature
Q=>75-50% (F+O) = 25-50%	MI=3.0-1.0 Immature
Q=<50	MI<-1
(F+L)>50%	Extremely immature

(Q= Quartz, F= Feldspar, L=Rock Fragments, MI= Maturity Index)

Maturity: The (MMI) was used to calculate the sediments' maturity. According to the formula MMI = (proportion of Q+z/(proportion of Fsp + proportion of opaque minerals), the research sample is considered to be mineralogically immature sediments since the MMI value is less than 4.0 but larger than 1.0.

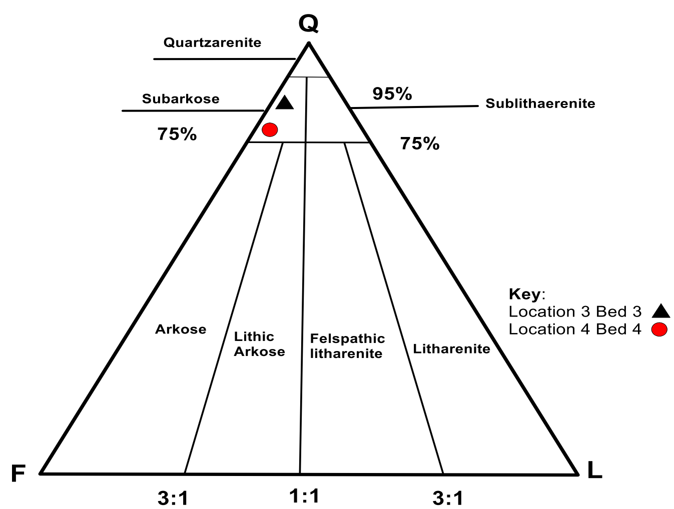

Fig.8: QFL Ternary plot of sandstone in the study area

3.5 Grain size distribution

Grain size distribution is the passing % a number for the individual sieve diameters

Bivariate scatter plots based on Friedman (1969), and Folk and Ward (1957) illustrate that the Lokoja sandstone is of river sand & fluvial deposited by low energy currents which coincided with some previous studies such as that reported by Omali *et al*., (2011).

3.6 Geochemical (XRD/ XRF analysis)

The XRD/XRF analysis shows quartz and orthoclase feldspar, as the dominant mineral assemblage suggesting a low weathering profile for the Lokoja sandstones.

The mineralogical composition of sandstone was detected using XRD and XRF analyses.

The Lokoja Sandstone A which is located around the Nataco area consist of the following mineral obtained during the XRD (Fig.: 7a & b), they included quartz, orthoclase, muscovite, kaolinite, osumilite, illite, chlorite and garnet respectively with varying percentage. The major minerals obtained from the results were quartz (67%) and orthoclase (11%) (see fig. 7a and b).

The Lokoja Sandstone B located around the Nataco area consist of the following minerals obtained during the XRF analysis with their chemical formula and merit figure, they include quartz, orthoclase, muscovite, kaolinite, osumilite, illite, chlorite and garnet respectively with varying percentage. In XRD analysis, the major minerals obtained from the results were quartz (45%) and Orthoclase feldspar (32%) (Fig.: 8a and b).

3.7 Source area weathering

Siliciclastic sedimentary rocks examined in different parts of the world demonstrate that their chemical composition is highly reliant on the weathering events at the source rock area. The Patti Formation samples' unexpectedly higher values clearly show that the primary source material(s) must have undergone a significant amount of weathering and reworking, which removed the feldspar and ferromagnesian minerals, as amply demonstrated by the major element geochemistry. In contrast to the Lokoja Sandstone, the Patti Formation sediments were formed by primary weathering and reworking of the parent materials from highly weathered and chemically developed terrain.

3.8 *Provenance*

Clastic deposits include geochemical markers that can be used to infer the sediment's source. The Al_2O_3 / TiO_2 for Lokoja sandstone, claystone and shale facies of Patti Formation are 52.43 wt %, 14.21 wt %, 10.02 wt % and 10.25 wt % accordingly. Thus, these ratios imply intermediate source rock for the Patti Sediments and felsic source rock for the Lokoja Sandstone.

Studies on the provenance of sediments have found that plenty of Cr and Ni in siliciclastic sediments is a useful tool. As described, a low Cr content implies felsic provenance, whereas high levels of Cr and Ni are related to ultramafic rock-derived sediment. In this study, Cr and Ni contents are minor in all the samples under analysis and consequently reflect a felsic provenance.

3.9 Tectonic setting

Clastic deposits have been the subject ofseveral different tectonic setting discriminating diagrams that employ the composition of main oxides. The Lokoja sandstone belongs to the Oceanic Island Arc (OIA), Active Continental Margin (ACM), and Passive Margin (PM) tectonic settings.

4.0 Conclusion

The petrographical result (quartz, feldspar, and micas, and SiO>55%) reflect from the observed mineralogical composition and major elements geochemistry and their proportion proved that the Lokoja sandstone is predominantly mature lithic arenites comprising sub-greywacke and proto quartzites impacted by felsic igneous provenances on the passive basin. It has been recommendated that the geological mapping should always be carried out at the peak of dry season and also further geochemical research should be done.

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Data availability

All data used in this study will be readily available to the public.

Consent for publication

Not Applicable

Availability of data and materials

The publisher has the right to make the data Public.

Competing interests

The authors declared no conflict of interest.

Funding

The authors declared no source of funding

Authors' contributions

All the authors contributed to all section of the work