RESEARCH ARTICLE

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Petrography and Heavy Mineral Studies of Lokoja Formation along Mount Patti North Central Nigeria: Implication for provenance Studies

Mu'awiya B. Aminu, Simon D. Christopher, Changde A. Nanfa, Ahmad T. Dahiru, Andarawus Yohanna, Nengak Musa, and Simon Tobias

ABSTRACT

The Southern Bida basin consists of the Lokoja, Patti, and Agbaja formations. This study focuses on the Lokoja formation and samples gotten were used for petrography and heavy mineral analysis. Results of all analytical techniques employed in the study are presented here. A critical assessment of each set of results and their integration aided the proper interpretation and useful discussion. This study focuses on the Southern Bida Basin, specifically the Lokoja Formation because the exposures of Patti are poorly exposed. Outcrop samples were obtained from the exposed sections of the study area in Kabawa and Robinson street, respectively. Different features were observed, such as the thickness of the exposure, the nature of the lithology, color, and sedimentary structures. The dominant lithologies in the area include sandstone and ironstone. The sandy facies are generally arkosic characterized by poorly sorted very fine to conglomeratic sandstone sequence. Laboratory investigations of samples included petrography and heavy mineral analysis. Sandstone samples were collected from the study area. Each sample was divided into two parts: the first part for petrographic studies and the second part for heavy mineral analysis.

Keywords: Basin, Conglomeratic Sandstone, Sandstone, Sedimentary Structure, stratigraphy.

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I. INTRODUCTION

The Bida Basin, known also as the Nupe Basin or Mid-niger basin, is located in the West-central part of Nigeria. The Bida basin is a NW-SE stretching intracratonic basin structure extending from a slightly Southern part of Kontagora in Niger State in the north to an area somewhat past Lokoja (Kogi State) in the South. The stratigraphy of the Bida basin involves the Bida sandstone at the base, successively followed upward by the Sakpe, Enagi and Batati formations in the North/Central Bida basin while Patti, Agbaja and Lokoja arrangements establish sidelong reciprocals in the Bida basin. The Basin of the Southern middle Niger comprises of three late Cretaceous formations, the Patti formation, the Agbaja formation and the Lokoja Sandstone formation respectively [24].

The Intracratonic Bida Basin (Nupe or Middle Niger Basin) is one of the inland sedimentary basins of Nigeria, located roughly at the mid-central Nigeria (Fig. 1). It is a northwest-southeast trending basin contiguous with the Anambra Basin. It extends from Kontagora, Niger State to Dekina, and Benue State with a length of about 400 km and a width approximating 160 km. Sediment accumulation in the basin commenced from Campanian and continued through the Maastrichtian with fills ranging between 3.5 and 4.5 km thickness at the extreme part of the basin. [1] Several works have been done on the evolution and stratigraphy of the basin.

On the basis of geographical and lateral facies variation, the basin has been divided into the northern and southern sub-basins. The oldest sedimentary unit, in the southern Bida-basin non-conformably lying on the Precambrian to the Lower Paleozoic crystalline Basement Complex is the fluviatile Lokoja Formation. Observations at the base of Agbaja Plateau and also at the Ahoko village exposures indicate mixed marine and continental deposition environments for the Patti Formation. Literature accounts have it that the formation consists of sandstones, siltstones, mudstones, and shale in intercalation with bioturbated ironstones. The Patti Formation marine sequence is exposed to a deserted mine in a village known as Ahoko near the Lokoja-Abuja highway. The Agbaja Ironstone covers the sequence of sediments in the southern Bida Sub-basin. The. Agbaja Ironstone is a fair intercalation of sandstones, claystones and oolitic/massive ironstones [2] interpreted the sequence of the formation as abandoned channel sands and over bank deposits with marine influence resulting in the formation of the massive concretionary and oolitic ironstones.

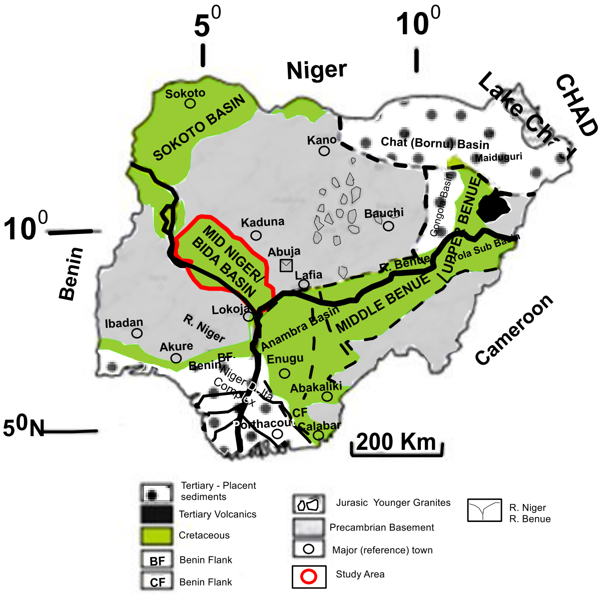

Fig. 1. Geological map of Nigeria and locations of the investigated samples (After [1]).

II. Geological Settings

A. *Physical-geographical and Geological Characteristics*

1) *Geographical Location*

The study area is located along the strike of Mount Patti within Lokoja town, and it spans across Latitude N 70º 50′ 00″ to N 7º 47′ 19.47″ and Longitude E 006º 41′ 34.26″ to E 006º 7′ 59.94″. Samples were taken from six different exposures at Lokoja town which are two exposures from opposite Cemetery, Robinson Street at Kabawa, Mount Patti, Ayoola Ajao Avenue GRA, and back of the new stadium in Lokoja, Kogi State.

It is easily located and accessible though highways, both state and federal highways as well. not far from the conflux of River Niger and Benue; the area is located between a large flowing body of water and a hill; the River Niger and Mount Patti which streamlined the settlement to a linear one and has a modifying consequence on the climate.

The climatic condition of Kogi state is known as a local steppe climate. It has an annual rainfall that ranges between 1100 mm and 1300 mm. The rainy season usually starts exactly around April and ends in October. The dry season which lasts from November to March, is very dusty and cold as a result of the north easterly wind, which brings in the harmattan. The average temperature in Kogi state is 26-8 ºC, about 747 mm of precipitation fall annually. The driest month is January, there is 0 mm of precipitation. In August the precipitation reaches its peak, with an average of 236 mm. April is the warmest peak.

The vegetation of the study area is of Guinea Savannah or parkland Savannah Belt with tall grasses and some trees. The vegetation of the area is green during the rainy season with tall leaves and fresh grasses, while in the dry season, the land is open during, showing charred trees and the remains of burnt grasses. The trees grow in clusters and are approximately up to six meters tall, interspersed with grasses growing up to about three (3) meters.

For an area located within the lower limit of the River Niger, relief is typically defined by the water body. Hence, the land rises gently from the river forming the water shed and influencing the relief and vice versa. The mean elevation at the base of the River Niger is about 40 m and rises to 60 m above the sea level along the Lokoja-Ajaokuta road. This shows that the relief is mainly a gentle slope plain with localized thickness close to the road, which is expected for road works construction. The rising of the land towards nearby hills significantly controls the pattern relief ruggedness and to a great extent the hydrology of the area. The Mount Patti is a 1503 feet (458 m) high forming the highest peak in the study area.

The principal drainage system in Lokoja is the River Niger with extensive river bed floodplain that are used for the all year-round agricultural activities. Aside the river Niger drainage system, there are several tributaries that drain into the river Niger with extensive flood plain.

The study area is a rural area with nucleated settlement which ranges from linear to dispersed settlement. The major occupation of the inhabitants of the study area (Kabawa) is, farming, trading, weldering and crafting.

An attempt to perform sedimentological interpretations of sections in parts of the Southern Bida Basin was conducted by [3]-[5] Fluvial depositional models were attributed to the Lokoja Formation and parts of the Patti Formation which indicate some relatively good quality reservoir rocks in the portions of these formations according to that study.

It was [6] who reported the occurrence of a relatively low diversity arenaceous foraminifera from the clayey intervals of the Lokoja Formation which indicates a superficial marine influence. According to the study, detected foraminifera microfossils are, however, prevalent in the overlying Patti

Formation where shallow marine depositional conditions are known to have thrived.

[7] carried out research on the Agbaja Formation and reported that the sandstones and claystones are interpreted as abandoned channel sands and over bank deposits which is relatively influenced by marine reworking to be transformed into the massive concretionary and oolitic ironstones observed.

[8] carried out studies on the lithostratigraphic units around Lokoja & environs in order to determine provenance studies through petrography and heavy mineral analysis of part of Agbaja-Lokoja formation, Bida basin, NW Nigeria, they conclude that Bida Basin Comprises three sedimentary facies assemblages characterized the sediments of the Lokoja and Agbaja formations. They are the conglomerate, sandstone/siltstone, and claystone facies. The conglomerate facies are expressed as massive grain matrix support conglomerate, graded conglomerate as well as crossed stratified to massive sandstones with implications of debris flow, alluvial fan, braided channel, and stream deposits respectively. The fine gained/siltstone as well as the herringbone and bioturbated sandstone sub-facies virtually present the extension of the fluvial sedimentation into the flood plain and shallow marine area where tidal effect held away.

The origin of the Bida Basin is related to the tectonic evolution of the Benue Trough, which started in the early Jurassic to early Cretaceous with the opening of Gulf of Guinea.

The Bida Basin, according to [8] is a NW-SE trending inland basin, which extends right from Shegwa (NW) to Dekina (SE), approximately, about 350 km long and varies in width from 75 to 150 km. In ground plan, roughly elliptical and runs perpendicular to western margin of the NE-SW trending Benue Trough Complex. Unlike other sedimentary basins in Nigeria, it is distinguished by the absence of volcanics, carbonates and mainly of Tertiary age, it has been revealed by a series of dedicated fieldworks carried out over the period of past four years that the basin is underlain by fundamentally mainland silt with a moderately minor event of minimal/shallow marine to a freshwater flood-plain store. The underlying basin fill is described generally by a few patterns of straightforward yet amalgamated or potentially stacked aggregates (alluvial fan) systems onto the proximal setting of the basin which is developed from many single brook breaches. However, these conglomerates direct over the Basement Complex and display a fine upward sequence. This unit is generally accepted and referred to as the Lokoja/Bida Sandstone as well. The Lokoja/Bida Sandstone is overspread straight by the oolitic/pisolitic ironstone of the Agbaja/Sakpe Ironstone which thusly is prevailed by an arrangement of rocks alluded to as the Patti/Enagi Formation, which is dominantly elaborate fine to a medium-grained grey and white sandstones grey clays carbonaceous silts shales, and ubiquitous concretionary ironstone bands as well. However, the observation in question is not in conformity with the widely accepted view of previous workers preceding it, according to which the Agbaja Ironstone is considered the youngest formation in the basin. It is also revealed by this study that, the succession of rocks ordinarily used to characterize the Patti Development doesn't really exist at the area of Mount Patti in Lokoja, rather it is found in street cut sections quarries and boreholes around the Ahoko Town. Adhering to the guidelines for stratigraphic nomenclature it is therefore recommended that the name Patti Formation should be changed to Ahoko Formation. Also made for the basin, was a new geological map which clearly demonstrates the relationship of the formations [9]

The stratigraphic progression of the mid Niger basin which altogether is referred to as the Nupe group [10] comprises of a twofold Northern Bida basin (Sub-Basin) and Southern Bida Sub-Basin or Lokoja Sub-Basin (Fig. 2) the latter is assumed to be a North Westernly extension of the Anambra Basin [11]. The basin fill includes a northwest moving belt of Upper Cretaceous sedimentary rocks that were kept because of square faulting cellar fragmentation subsidence rifting and floating subsequent to the Cretaceous opening of the South Atlantic Ocean. Significant horizontal (sinistral) movements along the Upper east Southwest pivot of the neighboring Benue Box have been meant the North–South and North westerly shear zones which structure Mid-Niger bowl opposite to the Benue trough [12]. The Sedimentary fill of the Benue box comprises of three unconformity-limited depositional progressions though [6].

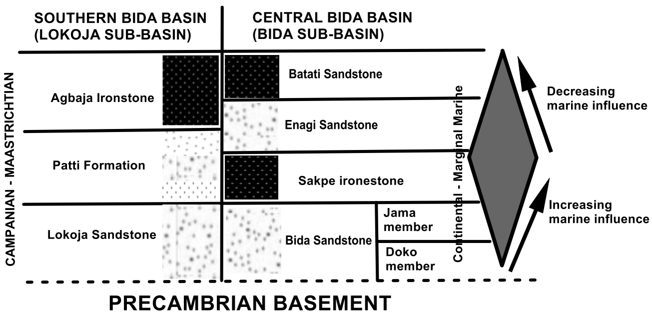

Fig. 2. Stratigraphy of Bida Basin (Modified from [13]).

B. Tectonic Setting

The Bida Basin whose origin is related to the opening of the south Atlantic comprises of a series of Cretaceous and later rift basin in central and west Africa. (Fig. 2) It is generally divided into northern and southern Bida Basin, each varies in litho stratigraphy succession [10]. The southern Bida Basin in particular, which specifically is the focus of this study, extends right from the confluence of the Niger-Benue River at Lokoja through Abaji, near the Federal Capital Territory. It is made up of three formations from oldest to youngest, Lokoja, Patti and Agbaja formations. The Lokoja Formation on the other hand, is the oldest stratigraphy unit in the southern Bida Basin and unconformably overlies the Precambrian Basement Complex.

The Southern Bida Basin, which is precisely the focus of this study, stretches right from the conflux of the Niger-Benue River at Lokoja extending to Abaji, close to the Federal Capital Territory. It is made up of three formations from oldest to youngest: Lokoja, Patti and Agbaja formations.

The Lokoja Formation is the oldest stratigraphic succession in the southern Bida Basin and unconformably overlies the Precambrian Basement Complex. It consists of basal conglomerate, subrounded to well-rounded quartz, feldspar, pebbles, and cobbles, especially at the sediment–basement contact. The pebbles are embedded in whitish clayey matrix. The basal conglomerate is overlain by fine to very coarse grained conglomeritic sandstone, coarse-grained, cross bedded sandstone, and few thin oolitic iron stones. The sandstones are continental deposits, which are poorly sorted, composed mainly of quartz and feldspar and as such, are texturally and mineralogically immature [14]. The general characteristics of this succession, the fining upward motif especially, the compositional and texturally immature and unidirectional paleocurrent trends, suggest a fluvial depositional environment dominated by braided streams with sand deposits as channel bars consequent to fluctuating flow velocity. The fine grained- sandstones, siltstones and clays represent flood plain over bank deposit. [15] reported that, from clayey intervals of the Lokoja formation, the occurrence of some low variety arenaceous foraminifera indicate some shallow marine influence. This foraminiferal micro fossil asserted by the author, are however, not common in the overlying Patti Formation where shallow marine depositional conditions are known to have prevailed more.

The Patti Formation conformably overlies the Lokoja Formation and comprised up to 100 m thick sequences of fine to medium-grained, grey, and white sandstones, shale, siltstone, claystone, coaly units and oolitic ironstone exposed in between Korton-Karfi and Abaji [16]. The formation extends to the northern Bida basin to form the Sakpe Ironstone and Enagi Formation (Fig. 2). The maximum exposed thickness is exactly 70 m while the oolitic ironstones range from 7-16 m thick. Report was made by [17] that the associated claystone is kaolinite and sourced from the nearby basement rocks while the organic matter is terrestrial, immature with potentiality of generating gas at appropriate maturation. A Maastrichtian (and possibly Senonian) age was thus assigned to the formation based mainly on correlation with other formations. As reported by [16] the associated sandstone units are more mineralogically and texturally matured compared to the Lokoja Formation. The Patti Formation is considered as flood plain deposits which developed into tidally influenced lacustrine facies in parts of the basin.

The youngest rock sequence in the area is the Agbaja ironstone which overlies the Patti Formation. This forms the protective lateritic capping, consisting of oolitic to pisolitic, concretionary and massive ironstone facies, with a thickness of 20 m [18]. It made up the horizontal comparability of the Batati Ironstone of the northern Bida bowl and saved in a mainland shallow marine climate. The marine immersions seem to proceed all through the time of statement of the Agbaja Ironstone in the southern Bida Basin.

The inconsistent event of surface openings of the Agbaja Ironstone just as the Batati formation and it's coordinately close contoural relationship to the Patti and Lokoja formations wherever its occurrence is witnessed indicates that the Agbaja Ironstone occupies 'rifted sinks' (grabens) in the southern Bida Basin. These areas present the thickest sediment piles, just like in the northern Bida basin. and as such, the most prospective for hydrocarbons in the Southern Bida Basin. They are actually rifted structures, the areas may rightly be interpreted as synforms though, where the Agbaja Ironstones is deposited in the grabens and eroded on the horsts.

III. Materials and Methods

A. Methods

The Methods employed in this study were field mapping and laboratory analyses. The field work involved logging of the exposure, measurement of bed thickness and sample collection. Bedding characteristics in terms of texture and lithology were studied in the field. Data, such as elevation, longitude and latitude of each location was obtained using the GPS (Global Positioning System). Images of outcrop and the structures on them were also taken using the camera. Laboratory investigations of samples included petrography and heavy mineral analysis. Sandstone samples were collected from the study area. Each sample was divided into two parts: one part for petrographic studies and the other part for heavy mineral analysis.

The field work was carried out in June, and it was done in most part of Mount Patti and environs. Six exposures were studied in this work, which is located at opposite cemetery, Robinson Street at Kabawa, Ayoola Ajao Avenue at GRA, Mount Patti and NE direction of the New Stadium in Lokoja town. The major formation encountered was the Lokoja Formation which majorly consists of sandstone beds which are fluvial.

A geological hammer used in chipping, breaking, and taking rock samples is the basic tool in sample materials. A chisel is employed to support the hammer to create fractures in the rock for easy breakage. A Global Positioning System (GPS) was used in taking accurate reading of the longitude and latitude and the geographic positions of exposures on the field. A field notebook is used to record various sample locations and representations of geological information of the field and representation of lithologic section of each sample locations were drawn. A digital camera was used in taking pictures of this rock in-situ and interesting features to serve as backup memory in addition to the field notebook. Based on the in-situ observations, textural and compositional studies of the exposure, tentative names were given to rock samples taken from the outcrop. Attempts were also made to determine the geologic history to explain the sequence of events as it affects rocks in the area. Finally, samples were taken with the aid of sledge hammer, a sample bag is then used to carry properly labelled samples, which were taken for petrographic preparation and other analysis.

Exposed stratigraphic successions in some areas were logged and beds identifications were solely based on sediment grain sizes, textures, colour and sedimentary structures. The logging was carried out with the aid of a measuring tape extended from bottom to top of each bed and recorded at intervals keeping into cognizance the forward extension of each bed so as to obtain the accurate thickness.

B. Processing and Analysis of the Samples

The laboratory studies involved petrographic and heavy mineral analysis. The examinations of the prepared thin sections were under the petrographic microscope to identify mineral assemblages. The optical properties of minerals such as colour, cleavage, relief, etc. under plane polarized light (PPL) and birefringence, extinction under cross polarized light (XPL) also studied. Detailed description of the mineral composition and textural characteristics were interpreted.

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C. Techniques for Preparation of Thin Section

In the laboratory, a total of six fresh soil sample were air-dried and impregnated using epoxy A and B. The impregnated samples were trimmed using the GTS cut-off saw and making sure one surface of the sample is made very flat. The flat surface is lapped on a glass plate using carborrundium of size 600 grid. One surface of a glass slide is also lapped on a glass slide. The lapped surface of the sample and that of the slide is then bonded using epoxy, this is to dry, and the sample is later treated to 50 microns on the slide using cut-off saw. The slide is then transferred to the CL 50 lapping machine to reduce the size of the sample to 30 microns. The slide is then covered using Canada Balsam and cover-slid. Then the slide is now ready for study under the petrographic microscope.

D. Heavy Mineral Analysis

Gravity method was utilized for the separation of heavy mineral. The prepared sample was sieved in order to obtain grains with (1-4Ø) or (1/2-1/16 mm) in size. Then weigh 20 gm of the sample. Tetrabromoethane $C_2H_2Br_4$ (Bromoform) was poured into upper (separator) funnel. The funnel was about ½ full (this analysis was carried out under a well-ventilated hood because the heavy liquid and its funnels are toxic). Then the sample was poured into the Bromoform and stirred thoroughly in order to make all the particles wet and disperse air bubbles. The particles are then allowed to settle, stirred periodically so that the particles will not adhere to funnel wall. The funnel was covered with a watch glass to reduce evaporation of a heavy liquid. When the heavy minerals settled to the bottom of separatory funnel, the pinch-cock was opened to allow heavy mineral particles to drop onto filter paper in lower funnel. After that, the pinch-cock was closed so that minerals floating in remaining heavy liquid will remain in the separatory funnel. After the heavy liquid drained from filter paper into used heavy liquid bottle below it, the paper was removed and placed upside down in porcelain dish or large watch glass containing acetone. Plastic squeeze bottle containing acetone was used to wash into the dish any particles which adhere to the filter paper and decant excess acetone into fluid waste container. The heavy mineral fractions were dried and labelled, and fractions were retained for compositional determination and provenance analysis, (Microscopic study). The remaining heavy liquid was drained through filter paper in the lower funnel and into the used heavy liquid bottle below. The light minerals were retained on the filter paper. After that, the distilled water was poured into the bottle of used heavy liquid. Water and acetone make a low density mixture which can be separated from the heavy liquid easily, and then the heavy liquid can be used on other time.

Heavy minerals can be studied under binocular microscope or you can make a slide to study the polished surface of the heavy grains, then recognition and interpretation for their provenance. But for the purpose of this study, the slides were studied under the petrographic microscope using both PPL and XPL.

IV. RESULTS

A. Stratigraphy of the Study Area

The stratigraphy of the study area is made up of three lithostratigraphy units and they include Lokoja Formation, Patti Formation, and Agbaja Formation. This research focuses on the Lokoja Formation because the exposures of the Patti are not clearly exposed.

Location 1
N 07º 49′ 13″
E 006º 44′ 42.6″
Elevation: 79ft
Accuracy: 20.7 m

The exposure is located Opposite Cemetery in Kabawa and is estimated to be about 6 m. The lithofacie encountered in this exposure is a massive sand with clasts embedded in it. The clasts were seen to increase in size towards the left. There were heaps of ironstones of different sizes, mostly weathered at the top of the exposure which was suspected to be deposited there by erosion. Viewing the ironstones on a closer level, some ironstones were identified to have visible holes in them like burrows, some with greyish colored grains in them, and some with visible silt size grains in them. On the main exposure, visible laminations were seen. Some parts of the exposure were covered with vegetation.

Plate 1 (a). Massive sand stone exposure at location 1 (Kabawa) (Long. E 006º 44′ 42.6″, Lat. N 07º 49′ 13″).

Plate 1 (b). Clasts embedded in the massive sandstone exposure at location 1.

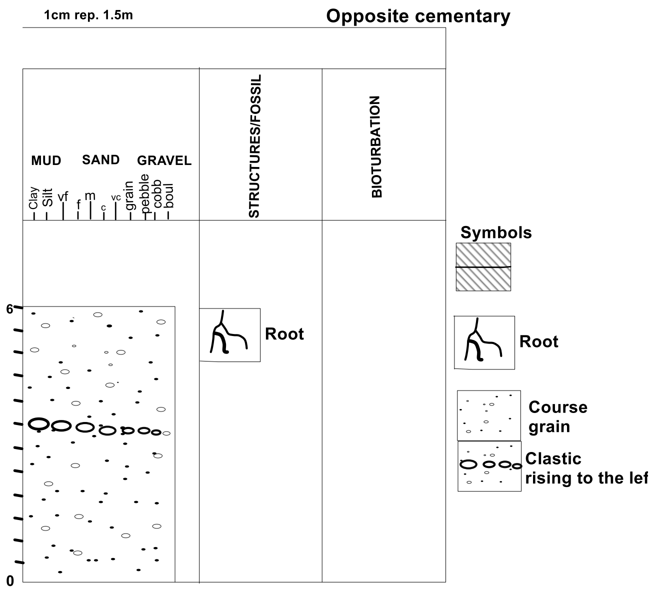

Fig. 3. Lithological section of the Lokoja Formation exposed at Opposite Cemetery, Kabawa.

Location 2
N07º 49′ 14.0″
E 006º 44′ 43.4″
Elevation: 71.8 m
Accuracy: 15.0 ft

A sloppy hill estimated to about 7 m. It has clasts imbedded in it. Located beside the massive sand exposure in Location 1.

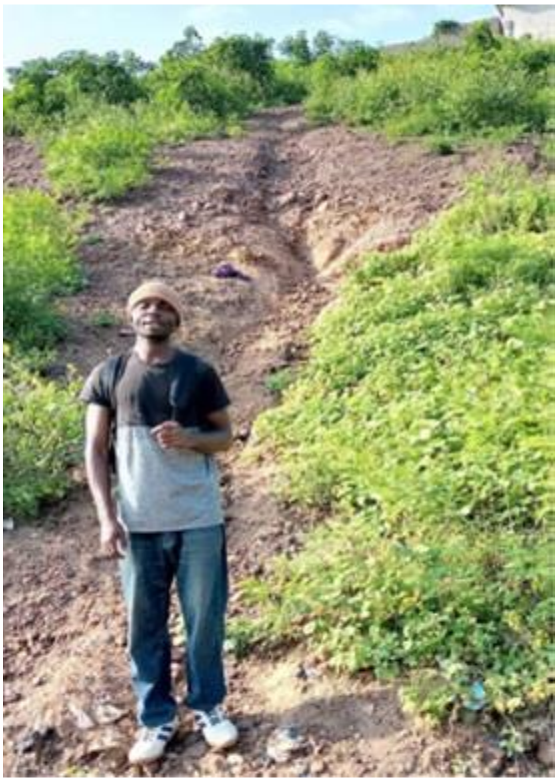

Plate 2 (a). Sloppy hill beside location 1 (Long. E 006º 44′ 43.4″, Lat. N 07º 49′ 14.0″).

Plate 2 (b). Clasts embedded in the hill.

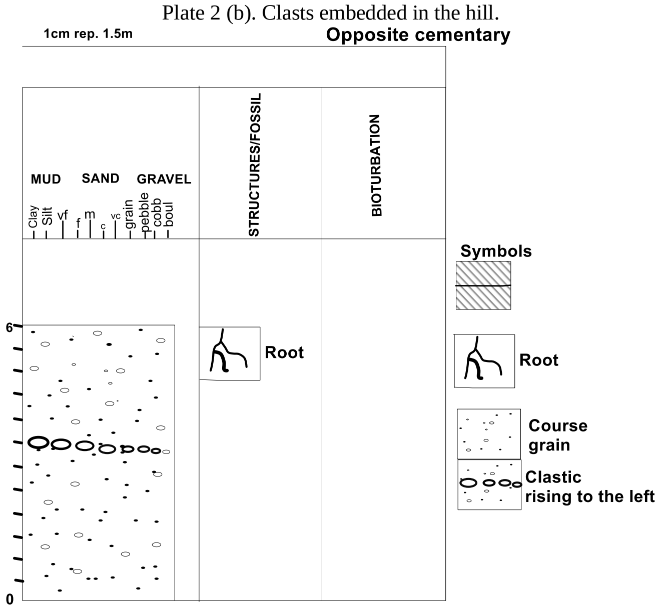

Fig. 4. Lithologic section of the Lokoja Formation exposed at Hill, Kabawa.

Location 3
N 07º 48′ 46.8″
E 006º 44′ 40″,
Elevation: 74.4 ft
Accuracy: 20.1 m

The exposure is estimated to be about 5.5 m. Milky white in colour. Visible laminations were observed but covered by roots of trees. Clasts were imbedded in the exposure. The lithofacie encountered is a conglomeratic sandstone. On one side of the exposure, Herringbone stratification was very visible.

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Plate 3 (a). Sandstone exposure at Robinson Street (Long. E 006º 44′ 40″, Lat. N 07º 48′ 46.8″).

Plate 3 (b). Herringbone structure at Robinson Street.

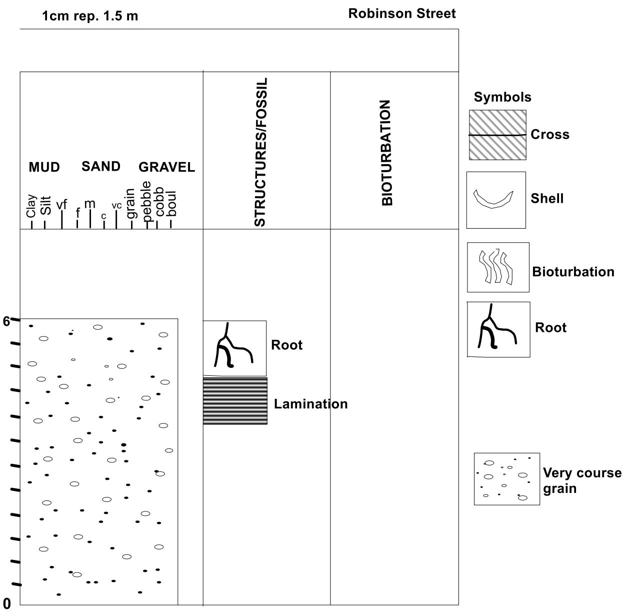

Fig. 5. Lithologic section of the Lokoja Formation exposed at Robinson Street, Kabawa.

Location 4

In this location we encountered numerous exposures with different lithofacies.

At the bottom:
N 07º 49′ 08″
E 006º 43′ 59.0″
Elevation: 236. 0m
Accuracy: 13.1ft

At the bottom, an exposure with visible coarse grains was identified. It doesn't look like a sedimentary rock.

At Point 1:
N 07º 49′ 02.9″
E 006º 43′ 38.3″
Elevation: 243.7 m
Accuracy: 14.7 ft

Sandstone with ironstone of small sizes on top of it. The sandstone has clasts imbedded in it. The clasts vary in sizes and are scattered in it.

At Point 2:
N 07º 49′ 09.02″
E 006º 43′ 56.9″
Elevation: 321.8 m
Accuracy: 13.6 ft

The exposure here looks like a contact between a rock that looks like a basement rock lying on top of a sedimentary rock. The rock that looks like a basement rock is inclined on top of the sandstone with a massive clay stone imbedded in it.

At Point 3:
N 07º 49′ 08.9″
E 006º 43′ 59.0″
Elevation: 306.2 m
Accuracy: 15.2 ft

In this exposure, there are clasts imbedded in it. The clasts ranges from conglomerate to boulder size.

At Point 4:
N 07º 49′ 08.1″
E 006º 44′ 00.5″
Elevation: 341.5 m
Accuracy: 19.9 ft

This exposure has parallel stratification. Clay stone is present.

It is brownish in colour. At some part, ironstone is imbedded in the claystone. At another part, it seems as though woody/plant material involving for the most part land determined natural matter which proposes winning new water condition. Towards the left side of the exposure the clasts that was once on top of the exposure becomes imbedded in it and becomes large. A part of the exposure has ironstone and on top of it is weathered claystone with visible grains which are coarse. After breaking the claystone, insitu is pure clay.

At Point 5:
N 07º 49′′ 12.2″
E 006º 44′ 01.1″
Elevation: 388.3 ft
Accuracy: 16.8 m

Location 5

N 07º 48′ 15.2″
E 006º 43′ 27.8″,
Elevation: 168.3m
Accuracy 15.0 ft

This exposure is estimated to be about 4m. There are artificial structures caused by excavator. It is made up of coarse grains. There is vegetation on top of the exposure.

Plate 4 (a). Exposure at point 2 Mount Patti (Long. E 006º 43′ 56.9″, Lat. N 07º 49′ 09.08″).

Plate 4. (b) Exposure at point 3.

Plate 4 (c). Exposure at point 5.

Plate 4 (d). Exposure at point 6.

Plate 5. Sandstone exposure at Ayoola Ajao Avenue, GRA.) (Long. E 006º 43′27.8″, Lat. N 07º 48′ 15.2″).

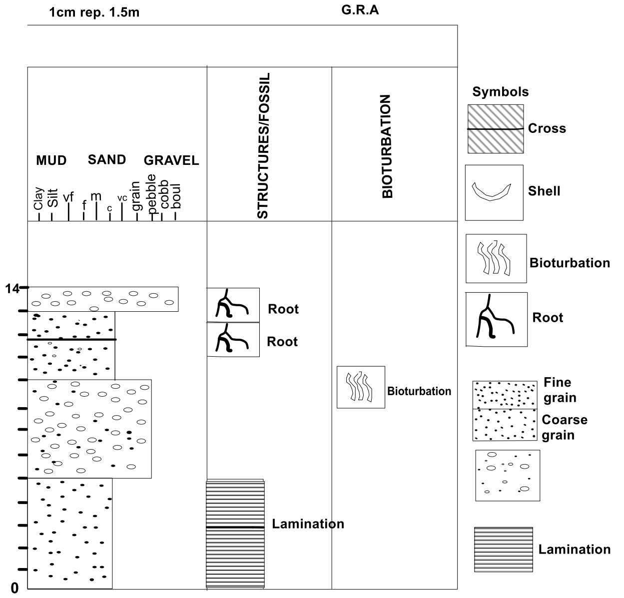

Fig. 6. Lithologic section of the Lokoja Formation exposed at Ayoola Ajao Avenue, GRA.

Location 6
N 07º 48′ 59.8″
E 006º 42′ 29.7″
Elevation: 192.5 m
Accuracy: 13.4 ft

This exposure has ironstone at the top of it with clasts as well. Artificial structure caused by excavator. Approximately 5 m in total height. Trough bedding is visible. It has evidence of red coloration caused by iron clasts imbedded in it. Visible breakage that looks like mud crack.

Plate 6 (a). Sandstone exposure at the NE direction of the New Stadium. (Long. E 006º 42′ 29.7″, Lat. N 07º 48′ 59.8″).

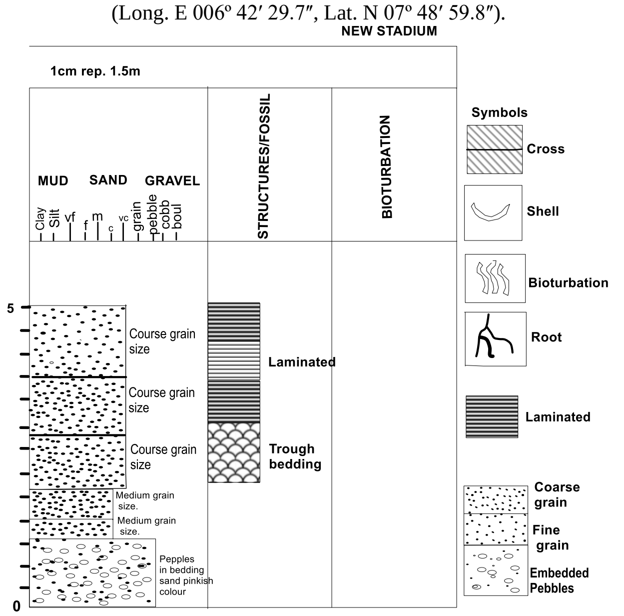

Fig. 7. Lithologic section of the Lokoja Formation exposed at the NE direction of the New Stadium.

V. Petrography

To analyze the miniature textural and mineralogical highlights in the dainty part of a stone with higher goal than that of the bare eye, a magnifying lens was utilized. A microscope has two systems of lenses. The first lens system (objective) produces a magnified image of the object. This real image is viewed by the second lens system (Ocular or eyepiece) that also provides further magnification.

Six (6) Samples from the study area were selected for thin section petrographic examination, in order to determine their textural features, mineral composition, mineralogical maturity and provenance area. Thin section slides of these samples with their qualitative and quantitave dare presented below (Plate 7-18).

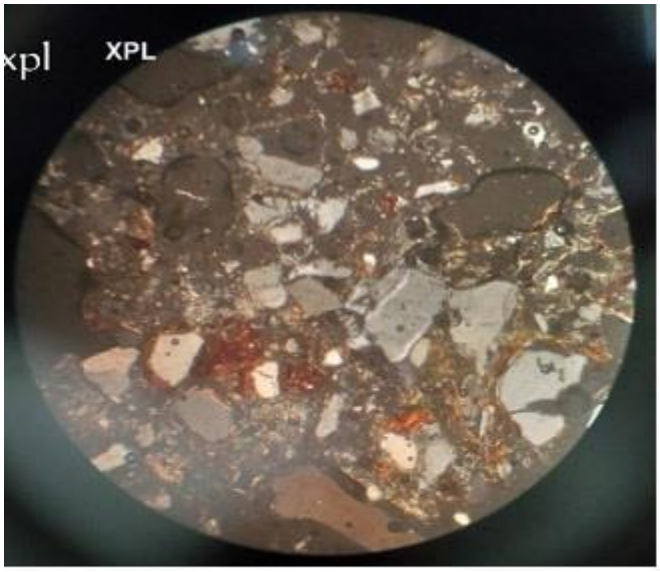

Plate 7. Photomicrograph of Lokoja sandstone location 1 (Hill) (Long. E 006º 44′ 43.4″, Lat. N 07º 49′ 14.0″) under XPL (Q – Quartz, F – Feldspar, RF – Rock fragment).

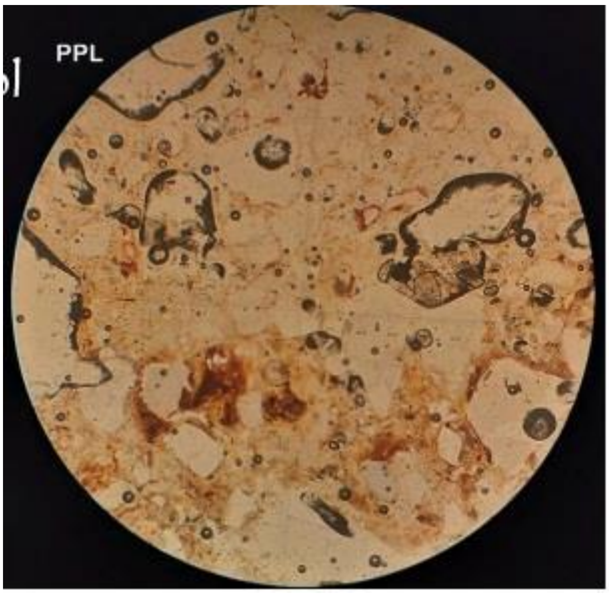

Plate 8. Photomicrograph of Lokoja sandstone location 1 (Hill) (Long. E 006º 44′ 43.4″, Lat. N 07º 49′ 14.0″) under PPL.

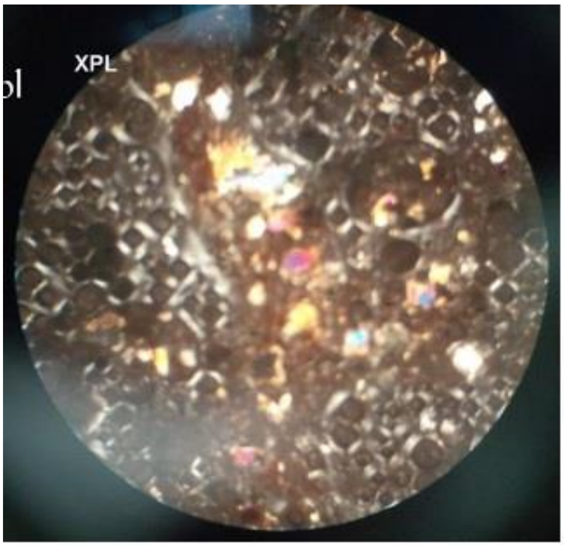

Plate 9. Photomicrograph of Lokoja sandstone location 2 (Mount Patti) (Long. E 006º 43′ 59.0″, Lat. N 07º 49′ 08″) under XPL (Q – Quartz, F – Feldspar, RF – Rock fragment).

Plate 10. Photomicrograph of Lokoja sandstone location 2 (Mount Patti) (Long. E 006º 43′ 59.0″, Lat. N 07º 49′ 08″) under PPL.

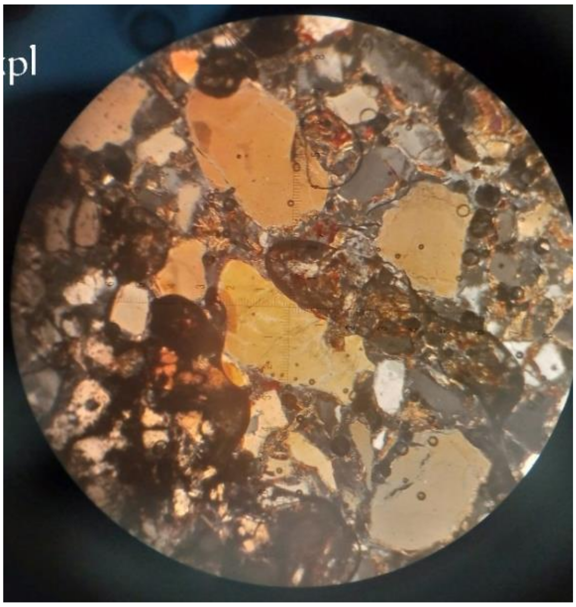

Plate 11. Photomicrograph of Lokoja sandstone location 3 (Stadium) (Long. E 006º 42′ 29.7″, Lat. N 07º 48′ 59.8″) under XPL (Q – Quartz, F – Feldspar, RF – Rock fragment.

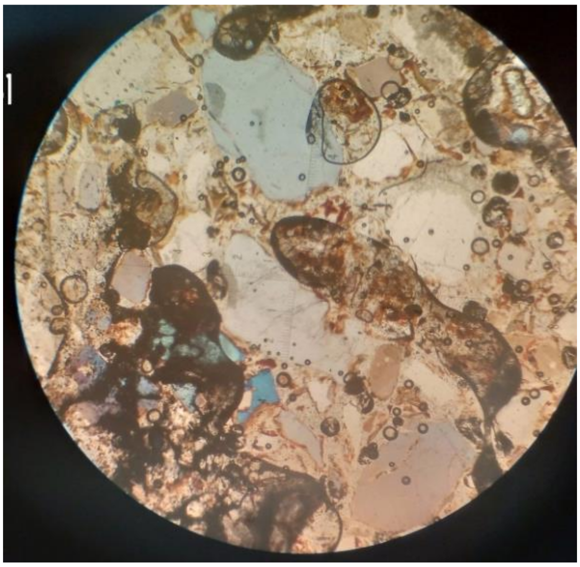

Plate 12. Photomicrograph of Lokoja sandstone location 3 (Stadium) (Long. E 006º 42′ 29.7″, Lat. N 07º 48′ 59.8″) under PPL.

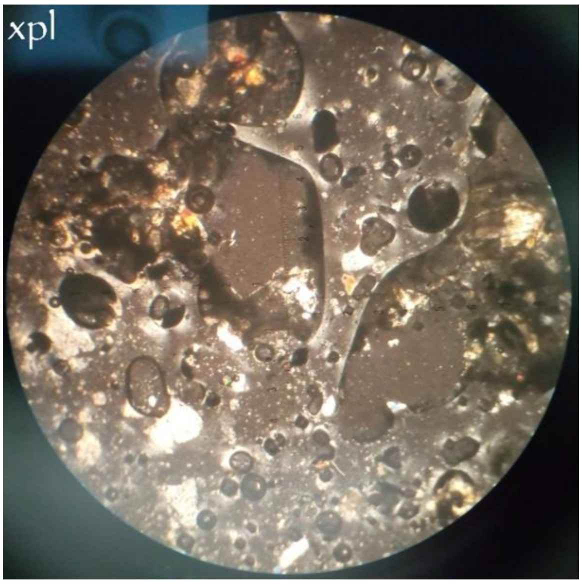

Plate 13. Photomicrograph of Lokoja sandstone location 4 (Robinson) (Long. E 006º 44′ 40″, Lat. N 07º 48′ 46.8″) under XPL (Q – Quartz, F – Feldspar, RF – Rock fragment).

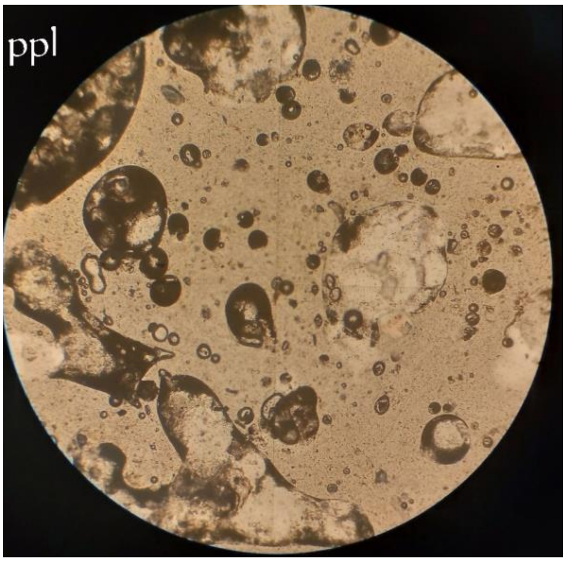

Plate 14. Photomicrograph of Lokoja sandstone location 4 (Robinson) (Long. E 006º 44′ 40″, Lat. N 07º 48′ 46.8″) under PPL.

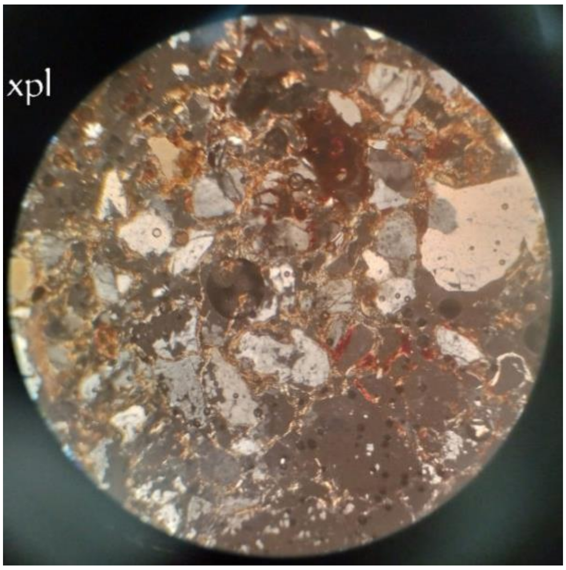

Plate 15.: Photomicrograph of Lokoja sandstone location 5 (Kabawa) (Long. E 006º 44′ 42.6″, Lat. N 07º 49′ 13″) under XPL (Q – Quartz, F – Feldspar, RF – Rock fragment).

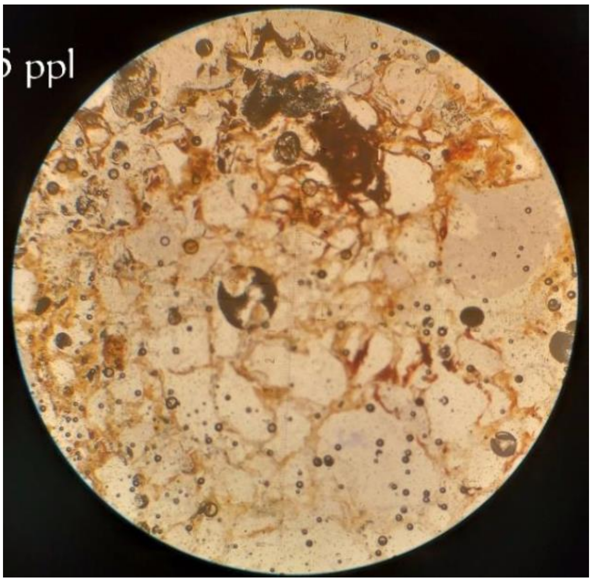

Plate 16. Photomicrograph of Lokoja sandstone location 5 (Kabawa) (Long. E 006º 44′ 42.6″, Lat. N 07º 49′ 13″) under PPL.

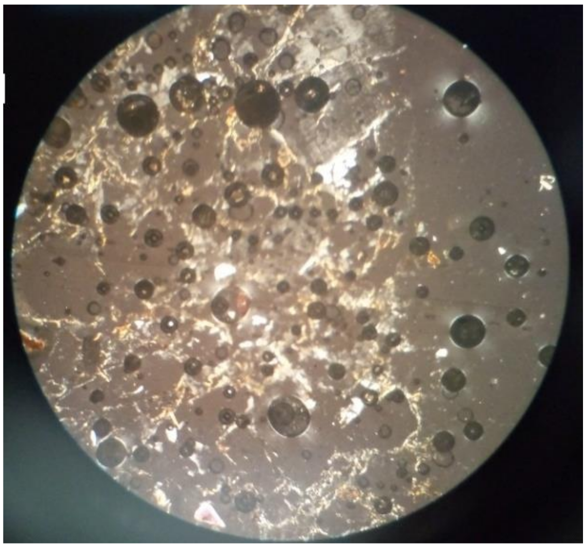

Plate 17. Photomicrograph of Lokoja sandstone location 6 (GRA) (Long. E 006º 43′ 27.8″, Lat. N 07º 48′ 15.2″) under XPL (Q – Quartz, F – Feldspar, RF – Rock fragment).

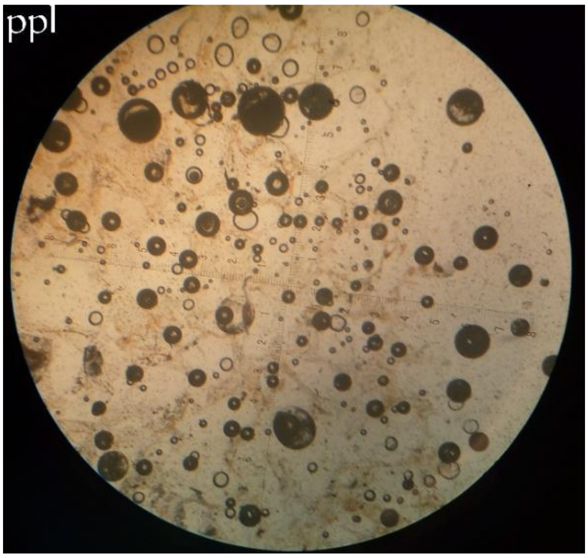

Plate 18. Photomicrograph of Lokoja sandstone location 6 (GRA) (Long. E006º 43′27.8″, Lat. N07º 48′ 15.2″) under PPL.

TABLE I: AFTER EFFECT OF PETROGRAPHY INVESTIGATION OF DELEGATE SANDSTONES FROM THE REVIEW REGION SHOWING ASSESSED MINERALOGICAL CREATION IN PERCETANGES.

Sample No.	mQ	pQ	Q	F	RF
1	33	32	65	25	10
2	53	2	55	5	40
3	30	20	50	45	5
4	60	10	70	28	2
5	40	20	60	30	10
6	65	10	75	10	25

Key: mQ – monocrystaline quartz, pQ – Polycrystaline quartz, Q – Quartz, F – Feldspar, RF –Rock fragment.

TABLE II: MODAL ANALYSIS OF SANDSTONE OBTAINED FROM PETROGRAPHY

Sample No.	Quartz (Q)%	Feldespar%	Rock Fragment (RF) %	Mineralogical Maturity index (MMI) (Q/F+L)
1	65	25	10	1.9
2	55	5	40	1.2
3	50	45	5	1.0
4	70	28	2	2.3
5	60	30	10	1.5
6	75	10	15	3
Average	375	143	82	

A. Heavy Mineral Analysis

Heavy mineral analysis was carried out on fived (5) samples from different locations of the study area which were suspended into slides to be viewed under the microscope for further analysis using both Cross Polarized Light (**XPL**) and Plane Polarized Light (**PPL**). From the heavy mineral photomicrograph, it was observed the accessory heavy minerals are composed mainly of Tourmaline. Two main mineral groups: the opaque and non-opaque were observed in the sandstone samples in the various locations as indicated in the photomicrograph below. The non-opaque and translucent minerals include zircon, tourmaline, rutile, staurolite, kyanite, and apatite.

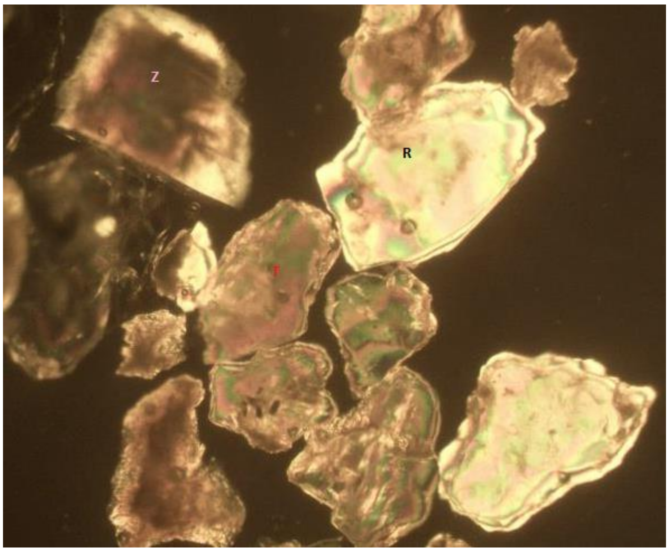

Plate 19. Photomicrograph of heavy minerals in Lokoja sandstone (LA) showing Zircon (Z), Tourmaline (T), Rutile (R) under XPL (Long. E 006º 44′ 42.6″, Lat. N 07º 49′ 13″).

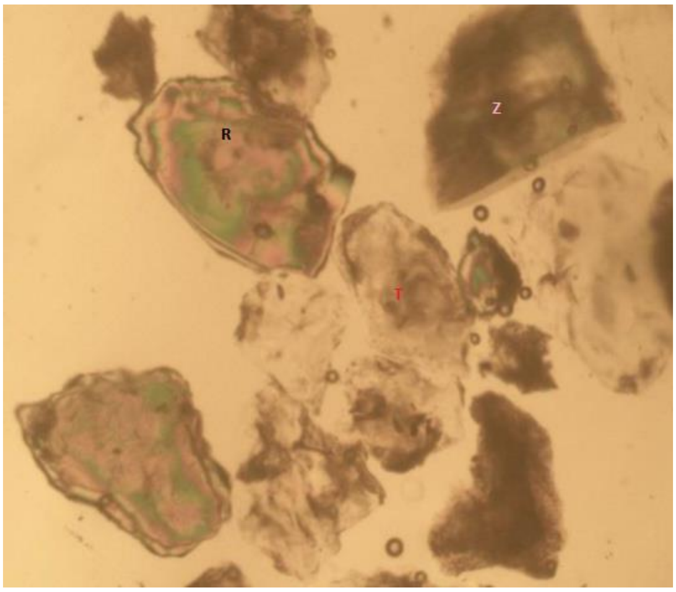

Plate 20. Photomicrograph of heavy minerals in Lokoja sandstone (LA) showing Zircon (Z), Tourmaline (T), Rutile (R) under PPL (Long. E 006º 44′ 42.6″, Lat. N 07º 49′ 13″).

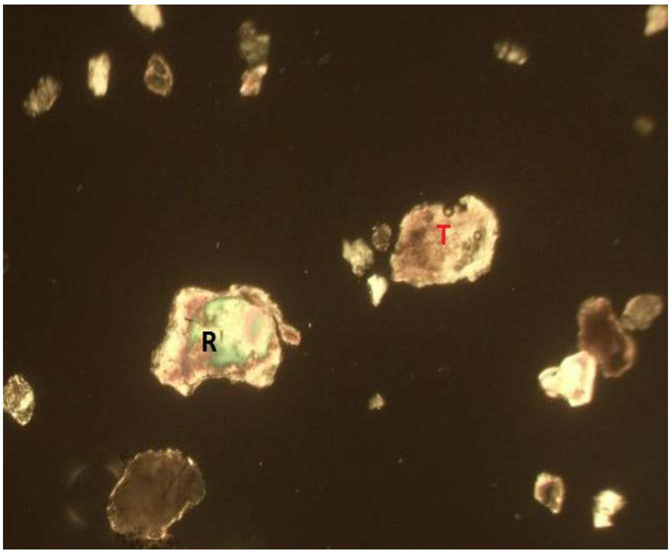

Plate 21. Photomicrograph of heavy minerals in Lokoja sandstone (LB) showing Zircon (*Z*), Tourmaline (*T*), Rutile (*R*), Monazite (*M*) under XPL (Long. E 006º 44′ 40″, Lat. N 07º 48′ 46.8″).

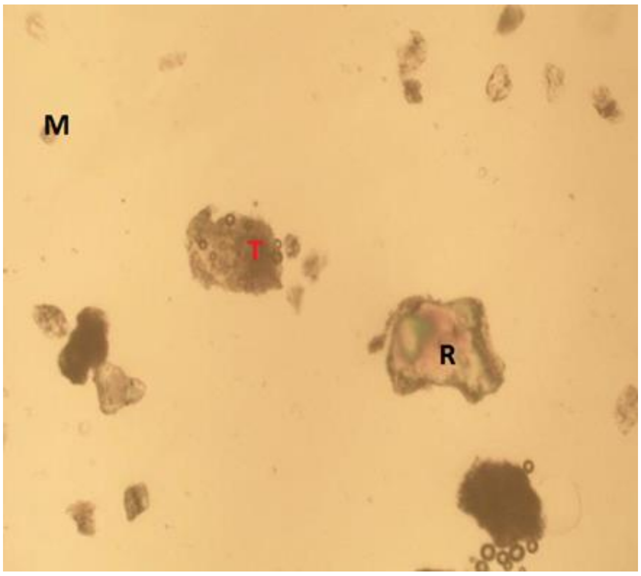

Plate 22. Photomicrograph of heavy minerals in Lokoja sandstone (LB) showing Zircon (*Z*), Tourmaline (*T*), Rutile (*R*), Monazite (M) under PPL (Long. E 006º 44′ 40″, Lat. N 07º 48′ 46.8″).

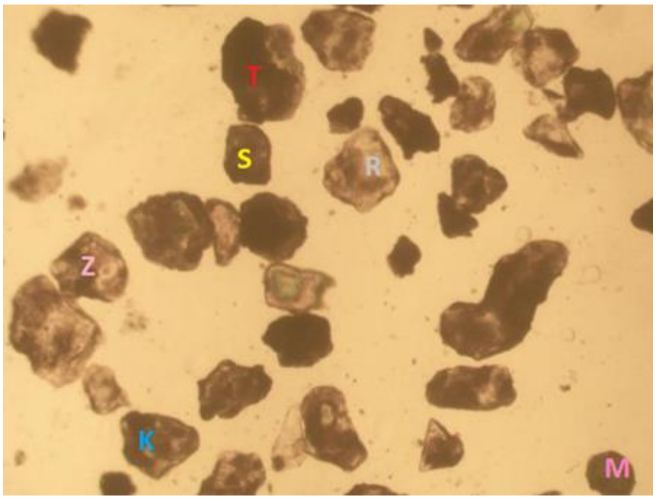

Plate 23. Photomicrograph of heavy minerals in Lokoja sandstone (LC) showing Zircon (*Z*), Tourmaline (*T*), Rutile (*R*), Monazite (*M*) Kyanite (*K*), Staurolite (*S*) under XPL (Long. E 006º 43′ 59.0″, Lat. N 07º 49′ 08″).

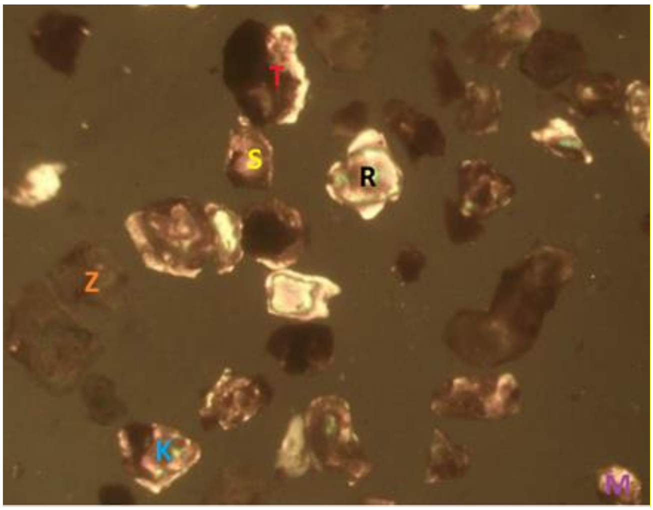

Plate 24. Photomicrograph of heavy minerals in Lokoja sandstone (LC) showing Zircon (Z), Tourmaline (T), Rutile (R), Monazite (M) Kyanite (K), Staurolite (S) under PPL (Long. E 006º 43′ 59.0″, Lat. N 07º 49′ 08″).

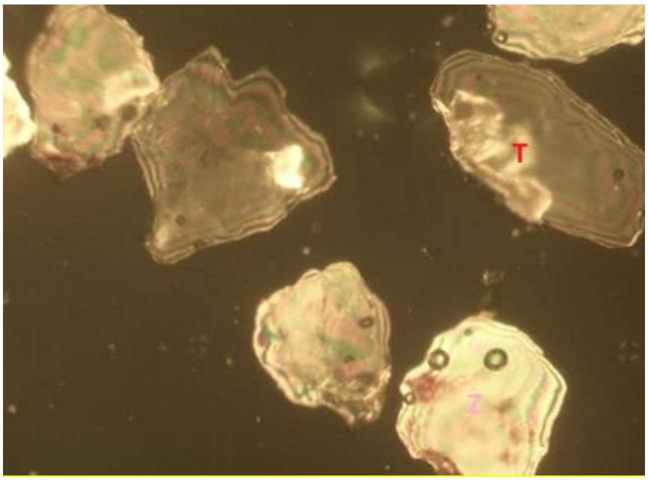

Plate 25. Photomicrograph of heavy minerals in Lokoja sandstone (LD) showing Zircon (*Z*), Tourmaline (*T*), Rutile (*R*), under XPL (Long. E 006º 43′ 27.8″, Lat. N 07º 48′ 15.2″).

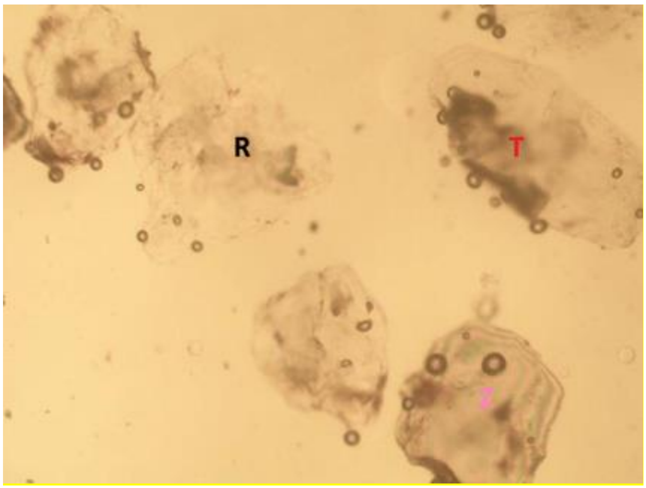

Plate 26. 1Photomicrograph of heavy minerals in Lokoja sandstone (LD) showing Zircon (*Z*), Tourmaline (*T*), Rutile.

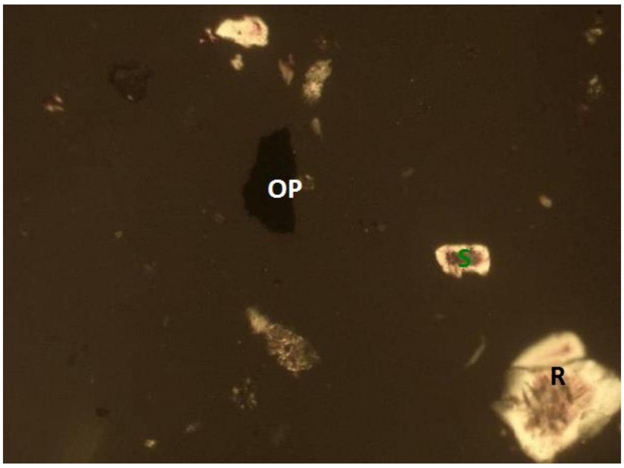

Plate 27. 1Photomicrograph of heavy minerals in Lokoja sandstone (LE) showing Zircon (*Z*), Tourmaline (*T*), Rutile (*R*), Opaque (*OP*), Staurolite (*S*) under XPL (Long. E 006º 42′ 29.7″, Lat. N 07º 48′ 59.8″).

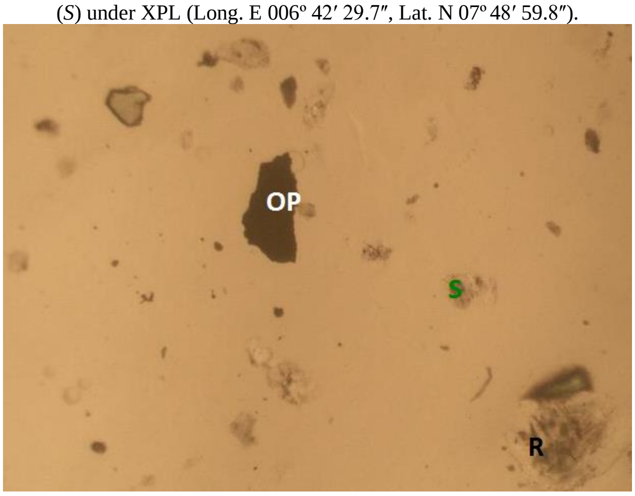

Plate 28. Photomicrograph of heavy minerals in Lokoja sandstone (LE) showing Zircon (*Z*), Tourmaline (*T*), Rutile (*R*), Opaque (*OP*) under PPL (Long. E 006º 42′ 29.7″, Lat. N 07º 48′ 59.8″).

TABLE III: Percentage Composition of the Non-opaque and Opaque Heavy Mineral Suites in the Study Area

Sample Number	Z	T	R	M	S	K	A	OP	TOTAL	Z+T+R	ZTR Index (%)
LA	4	34	14	5	3	1	0	0	61	52	85.2
LB	4	45	17	5	5	1	0	3	80	66	82.5
LC	13	255	16	14	7	2	-	6	313	284	90.7
LD	9	71	2	10	6	4	-	4	106	82	77.4
LE	1	7	7	4	3	1	1	1	25	15	60
Total	31	412	56	38	24	9	1	14	585		79. 2
%	5.3	70.4	9.6	6.5	4.1	1.5	0.2	2.4			
Average ZTR% Index =79.2% Opaque 14, Non-Opaque =571%											

Key: Z – Zircon, T – Tourmaline, R – Rutile, M – Monazite, S– Staurolite, K – Kyanite, A – Apatite, OP – Opaque, ZTR Index – Zircon, Tourmaline, Rutile Index.

B. Interpretation of Result

1) Petrography

TABLE IV: Maturity of Sandstone [19]

Q => 95% (F+RF) = 50%	MI = ≥ 19 Super mature
Q => 95 - 90% (F+RF) = 5 - 10%	MI = 19 - 9.0 Sub mature
Q => 90 - 75% (F+RF) = 10 - 25%	MI = 9.0 - 3.0 Sub Mature
Q => 75- 50% (F+RF) = 25 - 50%	MI = 3.0 – 1.0 immature
Q = <50	MI ≤ 1
(F+RF) > 50%	Extremely immature

(Q – Quarts, F – Feldspar, RF – Rock fragment, M– Maturity index).

Maturity: Maturity of the sediment was determined using the (MMI). The mineralogical maturity index (MMI) from table II ranges from 1.0 to 3 which falls under immature sandstone of [19]. Hence the studied sample are said to be mineralogical immature sandstones.

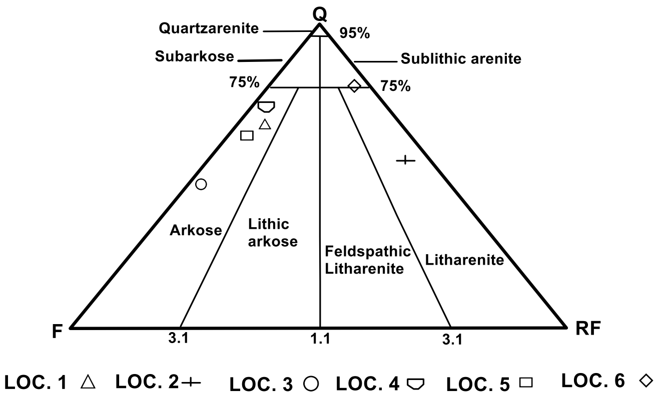

Fig. 8. QFL Ternary Plot of Sandstone in the Study Area., After [20] 4 (This shows the sandstone to be Arkosic, sublithic arenite and litharenite).

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2) Heavy mineral

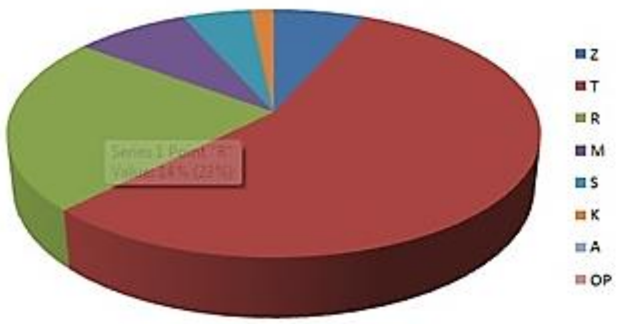

Fig. 9. Percentage (%) of each heavy mineral in LA (Opposite cemetery).

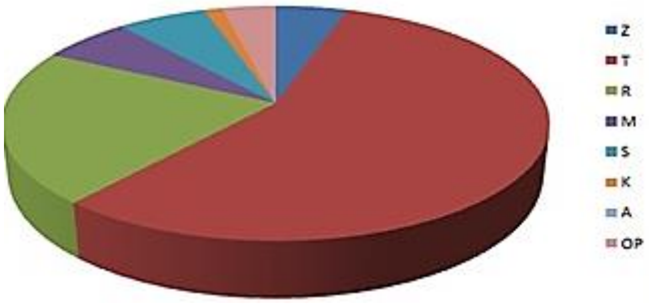

Fig. 10. Percentage (%) of each heavy mineral in LB (Robinson Street).

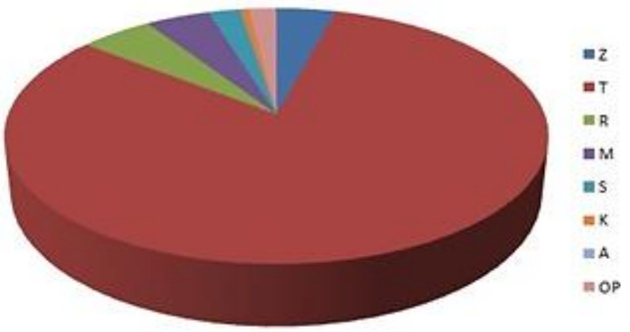

Fig. 11. Percentage (%) of each heavy mineral in LC (Mount Patti).

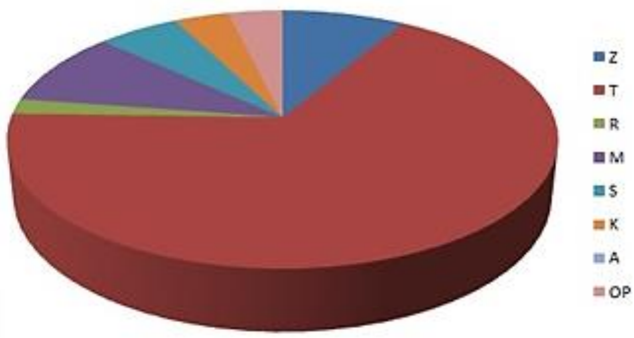

Fig. 12. Percentage (%) of each heavy mineral in LD (GRA).

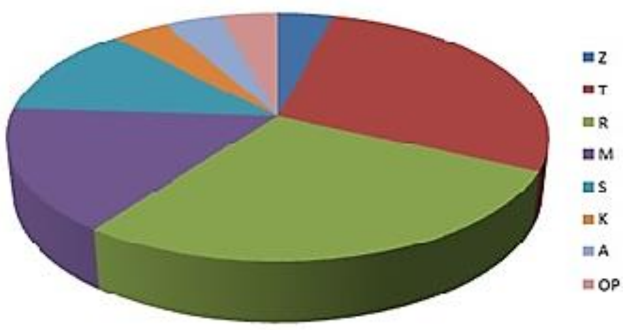

Fig. 13. Percentage (%) of each heavy mineral in LE (Stadium).

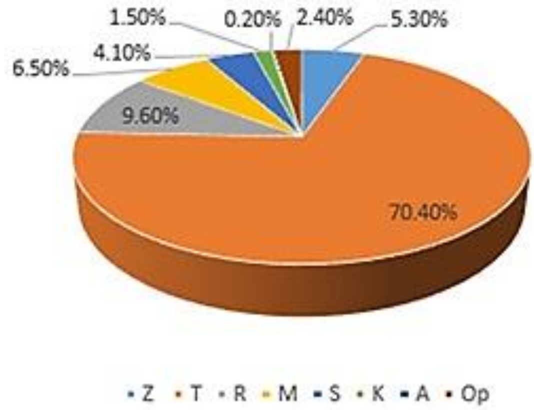

Fig. 14. Overall percentage (%) of each heavy mineral.

Petrography analysis showed that sandstones facies from Lokoja Formation are composed of mostly quartz and feldspar, most of the quartz grains are monocrystaline and few polycrystalline. The quartz is mostly subhedral and anhedral with straight and embaued boundaries. Most of the grains are equant while others are elongated. Most of the equant grains exhibited straight extinction while elongated grains commonly showed undulose extinction. Undulose extinction is characteristic of transformative source rock that has been exposed to pressure during disfigurement. There are few amount of rock fragments. The rock fragments are mostly metamorphic in origin.

Generally, the grains show variation from sub angular to sub rounded which suggests different distance of provenance areas for the sediments. The matrix is composed of clay minerals essentially in almost all the samples observed. The clay matrix could have formed from weathered feldspar grains either insitu or transported into the basin by suspension.

The maturity of the sediment shows that it is minerallogically immature as depicted from the Mineralogical Maturity Index calculation; MMI= (Proportion of Qtz)/ (Proportion of Fsp=Proportion of R.F).

Since MMI value ranges from 1.0 to 3.0 as calculated above; hence the studied samples are said to be mineralogically immature sediments which also corresponds to [19] immature sandstone.

To group the sandstone, detrital method of Quartz(Q), Feldspar(F), and rock fragments (RF) was plotted on Folk’s (1974) QFR Ternary diagram (Fig. 8). This scheme classifies the sandstone as arkosic, sublithic arenite and litharenite.

3) Heavy Mineral Analysis

The heavy mineral analysis conducted on the five (5) representative samples revealed the presence of zircon, tourmaline, rutile, staurolite, monazite, kyanite, apatite and opaque minerals (Table III). The non-opaque minerals include tourmaline, zircon, rutile, staurolite, monazite, kyanite and apatite. Tourmaline is in a very high percentage in all the samples. Table 2 shows the composition of each mineral in each sample and the Zircon, Tourmaline, Rutile, (ZTR) percentage index calculated for each sample. A significant amount of tourmaline is present as dominant non-opaque ultra-stable mineral. Tourmaline is readily recognized in thin section by its high relief, Greenish brown appearance, absence of cleavage and it strong pleochroism. It forms about

70% of the heavy mineral suite in all the sandstones. The predominance of super stable weighty minerals over the metastable and temperamental assortments was plainly demonstrated by the outcome. Table III shows the proportion of each mineral in each sample. The Zircon, Tourmaline, Rutile (ZTR). Percentage index is included in Table III. The Zircon, Tourmaline, Rutile (ZTR) Finding the ratio of the combined proportion of Zircon, Tourmaline and Rutile to the weight of all the transparent heavy minerals present, index of mineralogical [21] was calculated for the analysed samples.

Tourmaline exhibiting the highest individual mineral percentage of exactly 70.4% is commonly euhedral. It is a prevalent detrital heavy mineral in sedimentary rocks. Thus, varieties of tourmaline are used as gemstones.

Rutile (9.6%) which is next to tourmaline is relatively abundant in most samples. It is known to occur as a small reddish brown prismatic to acicular crystals with a relatively high relief and high interference colours. Rutile, according to [22], is a non sillicate mineral which occurs as an accessory constituent of igneous rock and many granites as well as their metarmorphic derivatives such as gneiss and amophiboles. Rutile is often used as a source of titanium.

Zircon (5.3%) is recognized in thin section by its high relief, colourless appearance, prismatic habit as well as it very high interference colour. Its shape is only fairly mechanically altered (commonly euhedral to subhedral) due to their stability and lack of good cleavage. They appear commonly colourless.

Staurolite (4.1%) is a nessosillicate mineral with a white streak and is red brown to black. It is one of the index minerals used in temperature estimation, depth and pressure at which a rock undergoes a metamorphism. It is a regional metarmorphic mineral of intermediate high grade and it often occurs alongside kyanite.

The contingency of a source rock being an igneous rock is relatively very low because augite, olivine, diopside or hypersthenes are largely absent in the mineral assemblage [23]. Instead, tourmaline, rutile, monazite and zircon occur in relatively fairly large quantities which are indicative of metarmorphic rock source. [21] proposed that the non-opaque or transparent non-micaceous heavy mineral assemblage of the quartz mineral assemblage of the quartz arenite is predominantly zircon, tourmaline, rutile and these grains are very concentrated in sandstones by prolonged abrasion. Chemically stable minerals normally provide insufficient quantities by most granitic rock low rank metarmorphic source independence. Thus, the ZTR index is of modification or maturity of entire heavy minerals assemblage.

The highest value of ZTR (90.7%) is recorded in LC (Mount Patti) while the lowest value (60%) is found in LE (NE direction of the New Stadium). The heavy mineral present are typical of metarmorphic source of the nearby basement complex.

VI. Conclusion

The petrographic data studied reveals that the sandstones consist of mainly quartz and feldspar. Texturally, the sandstone ranges from moderate to coarse grain, angular to subrounded, and moderately to poorly sorted. Therefore, the sandstone within the Lokoja Formation is medium to coarse grained, angular to subrounded, from poorly to moderately sorted arkose immature sandstone, with the quartz showing both monocrystaline and polycrystalline crystals depicting its derivation mainly from metamorphic origin.

From the petrographic data studied, the Lokoja Sandstone is mineralogically immature due to its high feldspar content.

The presence of opaque and non-opaque mineral was shown by heavy mineral aggregation. The opaque minerals encountered 2.4% while non-opaque minerals include zircon, tourmaline, rutile, monazite, staurolite, kyanite and apatite dominated the assemblage. The heavy mineral observed from the slide under the microscope appears to be mostly sub angular to angular which indicates that the provenance is not too far from the basin which it was deposited.

From the heavy mineral analysis, the presence of minerals such as zircon, tourmaline, and rutile, which are mainly igneous and metamorphic minerals coupled with monazite has shown that sandstones of Lokoja Formation have been derived principally from metamorphic rock.

VII. Recommendation

The geological field mapping should always be carried out at the peak of the dry season (January or February). Motorable roads should be constructed in the area to ensure easy execution of the geological field mapping.

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Special thanks to Yuniela Diaz (Neki) you are also unforgettable and thank you for your maximum supports and prayers. Lastly to my beautiful wife (Ainau A.K.A Alma Gemela) who is carrying my unborn child, I do love you ‘un monton’ may you deliver the baby in good health condition (both), Ameen.

Conflict Of Interest

There is no conflict of interest by the authors to publicize.

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