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Research Paper

Heavy mineral analysis of the Cretaceous Lokoja Formation exposed around Karara- Banda area, North Central Nigeria

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ABSTRACT: *Field observation and heavy mineral analysis of the Cretaceous Lokoja Formation exposed around Karara-Banda area was carried out to determine the mineralogical composition of the sediments. The field observation shows that the Lokoja Formation is unconformably overlain by the basement complex. It is made up of sandstones, pebbles, clast-supported sandstone, siltstones, and claystones with grain sizes varying from coarse to fine within Karara-Banda outcrops. The conglomerates are found near the base of the outcrop. Heavy mineral separation was employed to determine the sediment provenance including the spatial patterns. The heavy material contained zircon, rutile, tourmaline, sillimanite, kyanite, and other less opaque minerals. For the selected samples, Zircon, Tourmaline and Rutile (ZTR) index range from 30% to 40%, with an average of 38%. The majority of the sediments are mineralogically immature to sub mature since the Zircon-Tourmaline-Rutile maturity index is less than 75%. The results show that the collected samples from the basin are deposited after short travel in an oxidizing environment under a fluvial system while the pebble are the product of neighbouring basement rocks of western and northern Nigeria.*
KEYWORDS: *Bida Basin, conglomerate, heavy minerals, pebble and maturity*

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I. INTRODUCTION

Bida is one of Nigeria's interior boundary basins (Figure1). The Bida Formation is at the bottom of the Bida Basin's conventional stratigraphy in the northern sector, followed by the Sakpa, Enagi, and Batati Formations[1]. The Bida Basin, which stretches from northwest to southeast in Nigeria, has been one of the country's most important frontier sedimentary basins [2, 3].Olaniyan and Olobaniyi [4]identified various sedimentological features of the Lokoja and Bida Sandstones, which they regarded as continental deposits with lateral equivalents. According to Ladipo [5], the Lokoja Sandstone possesses petrological characteristics. The unconformity series about 7 km west of Felele town was recognized by Olaniyan and Olabaniyi [4]as eroded contact with conglomeratic sandstone covering the worn basement. Allen [6]examined the origins and categorization of recent alluvial materials along the Niger River in terms of heavy mineral content.

The IntracratonicBida Basin (also known as the Nupe or Middle Niger Basin) is a Nigerian frontier sedimentary basin located in the country's middle region. It's a basin with a northwest-southeast trend that is connected to the Anambra Basin. It stretches 400 kilometers from Kontagora, Niger State to Dekina, Kogi State, and is 160 kilometers wide. In the basin's central part, sedimentation began in the Campanian and lasted throughout the Maastrichtian, with fills ranging in thickness from 3.5 to 4.5 km. Several research papers have been published on the evolution and stratigraphy of the basin. The Bida Basin has been linked to the aulacogen Benue Trough of Nigeria, which resulted from the divergence of the South American and African continents in the Late Jurassic. As a result of this rifting, the Bida Basin floor is made up of a variety of horst and graben formations.

Falconer [7]was one of the earliest researchers that characterize and analyse the basin's Upper Cretaceous rocks. Jones [8],also separated the series into two age-equivalent sub-basins: the southern Lokoja sub-basin and the centre Bida sub-basin.

The paleoenvironment for Patti Formation in southern Bida Basin was interpreted as marginal marine to brackish water based on fossil studies and analyses of sediments [1,3,9, 10]. Aigbadon [11, 12 and 13] noted that the Patti Formation is mainly of fine-grained sandstone, mudstones, fissile shales, and concretions, and interpreted the depositional units as shallow-deep marine. Notably published works on the southern Bida Basin were based on granulometric and pebbles analyses of sediments with less emphasis on sediments provenance. This research is aimed at using heavy mineral separation to determine the sediment provenance of the study area. Presently, the southern Bida Basin has begun to attract attention because of the exploration for oil and gas in the sedimentary basins of north-central Nigeria. Although, the basin is still considered a frontier basin, it is the least researched frontier sedimentary basin in the country. The current development of the intensive search for solid and liquid mineral deposits as well as new exposure of Karara and Banda outcrops in the basin has led to the evaluation of heavy minerals in the study area. Hence more research is needed in this regard.

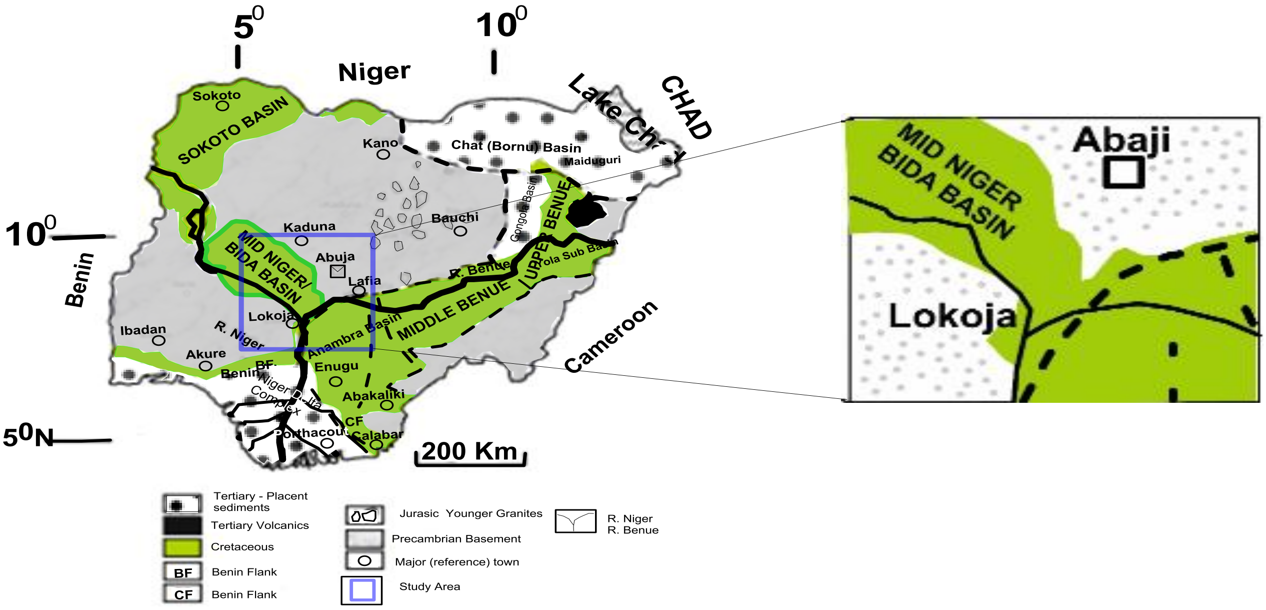


Fig. 1: Nigeria's geological map showing the study area, Basement complex, Younger granites, and sedimentary platform. Adapted from [14]

II. GEOLOGIC SETTING

The Bida basin is an NW-SE trending frontier basin that flows from Shegwa (NW) to Dekina (SE). It extends for about 350 kilometers and ranges in width from 75 to 150 [15]. The deposition and stratigraphy of the upper Cretaceous strata of the Bida Basin were studied and reported by several authors [1,5,14, 16,-19]. From the north to the south of the basin, Adeleye and Dessauvagie[20] identified four mappable stratigraphic strata and their counterparts. The Nupe Group [14, 17] opined a two-fold subdivision of the Middle Niger Embayment's geologic sequence, which includes the northern Bida and Lokoja sub-basins. The Late Cretaceous (Campanian–Maastrichtian in age) strata in the Bida Basin are known as the Nupe Sandstone [2]. According to Jones [21], the southern Bida Basin contains the CampanianLokoja Sandstone (mainly conglomerate and sandstone), the Maastrichtian Patti Formation (shale, claystone, and sandstone), and the Agbaja Ironstone. Their lateral stratigraphic equivalents in the northern Bida Basin are the Bida Formation (conglomerate, sandstone), Enagi Formation (siltstone, claystone, and sandstone), and Batati Formation (siltstone, claystone, and sandstone) (Figure 2).

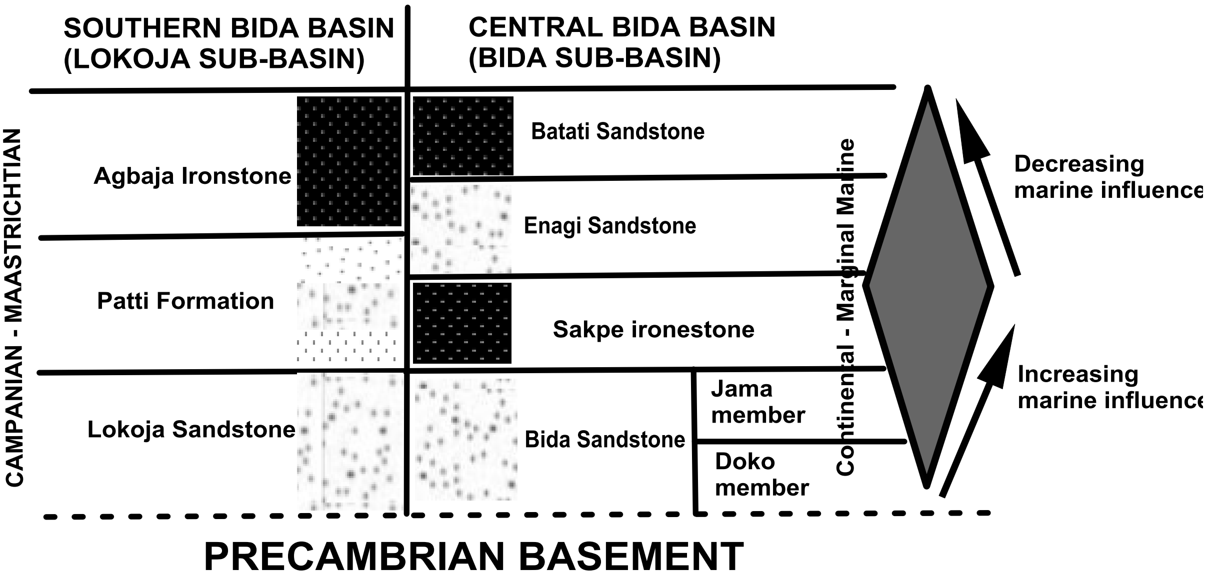


Figure 2: Stratigraphic Succession of the Bida Basin (Redrawn after [14])

Southern Bida Basin (Lokoja Sub-Basin)

The Bida Basin whose origin is related to the opening of the south Atlantic comprises a series of Cretaceous and later rift basins in central and West Africa[14]. It is generally divided into northern and southern BidaBasin, each varies in lithostratigraphy succession (Figure 2)

There are three different formations in the southern Bida Basin, all of which are Campanian to Maastrichtian in age [16,20, 22]. The three formations are the Lokoja Sandstone, Patti Formation, and upper Agbaja Ironstone.

The Lokoja Sandstone

Adeleye and Dessauvagie [20] proposed the name Lokoja Sandstone because it sits unconformably on top of Precambrian foundation rocks. The Lokoja series was named by Falconer [7]after the Upper Cretaceous sediment found at Lokoja and its Bida Sandstone's lateral counterpart. The formation is made up of basal conglomerates and sandstone with finely interbedded siltstone and claystone. They are feldspathic sandstones of interbedded siltstone as well as claystone that are generally poorly sorted. The basal conglomerate is made up of quartz and feldspar pebbles and cobbles that are subrounded to well-rounded and embedded in a yellowish clay matrix. The sandstones are arranged in a fining upward order. The sandstones and conglomerates were believed to have originated in a continental setting with alluvial and braided stream processes [9].

Patti Formation

Patti Formation was invented by Adeleye and Dessauvagie [20]. Fine to medium-grained grey and white sandstones, clays including carbonaceous silts, and shales make up the formation, oolitic ironstone, and thin impure coal seams that sit directly on top of the Lokoja Sandstone. Between Kotonkarfe and Abaji, the argillaceous strata (shale, siltstone, and claystone) of this formation are well known, according to Obaje[1] Parallel laminae are frequent in Patti Formation siltstones, which may occasionally display undulating ripples of weak sediment deformational structures. (e.g., slumps), convolute laminations, load structures, and trace fossils (especially *Thalasinoides*) are frequently preserved. The claystoneinterbedded are massive and kaolinitic in composition. The oolitic ironstones have a thickness of 7 to 16 m, whereas the visible thickness is 70 m (Jones, 1958). These strata have a thickness of up to 220 m, according to Agyingi[23], implying a meandering river depositional environment, Mount Patti, in Lokoja, is the type locality. It's the northern Bida Basin's lateral equivalent of the EnagiSandstone. The sandstone of the Patti Formation is mineralogically more developed than that of the Lokoja Formation [[9]. The Patti Formation's prevalence of argillaceous rocks (siltstone, shale, and claystone) implies low-energy conditions with few sources of water [24]. The presence of land plant components indicates that freshwater conditions are prevalent. The overall qualities of the sequence especially its fining upwards nature, compositional and textural immaturity point to a fluvial depositional environment dominated by braided river systems and water sands deposited as channel bars as a result of fluctuating flow velocity [25].

The Agbada Ironstone

Adeleye and Dessauvagie[20] suggested the Agbaja Ironstone formation, which is a lateral analogue of the Batati Ironstone in the northern sub-basin, creates a permanent cover for the Campanian–Maastrichtian sediments in the southern Bida Basin. Sandstones and claystone are mixed with oolitic, concretionary, and massive ironstone strata. The sandstone and claystone were thought to be reworked by the sea from abandoned channel sands and over bank deposits, resulting in massive concretionary and oolitic ironstones [26]The dominantly continental environment of the higher portions of the Lokoja Sandstone and the Patti Formation was also believed to have been influenced by minor marine impacts [4, 24]. Maritime inundations likely to have continued during the deposition of the Agbaja ironstones in the southern Bida Basin [26]. Within the Agbaja Ironstone, Abimbola [18] identified three facies. These are:

- • A kaolinitic mud-ironstone with angular to sub-angular detrital grains and angular clasts largely at the top is made up of kaolinitic fake ooids with tiny replaced goethite rings.
- • Pisoidal pack-ironstone is composed of densely packed pisolites containing goethite, minor haematite, and relict kaolinite, with a goethite core and a haematite rim. Kaolinite makes up the matrix.
- • Ooidal pack-ironstone having spherical ooids consisting of kaolinite, kaolinite goethite, or haematite inside a kaolinite matrix at the bottom.

Adeleye[16] argued that the ooidal as well as pisolitic ironstones, originated in high-energy, subtidal beach line habitats advancing within fluviatile and swamp areas, akin to Minette-Type deposits.

III. MATERIALS AND METHODS

A total of 10 sediment samples from Lokoja Formationexposed around Karara- Banda along Lokoja-Abuja express road were subjected to heavy mineral analysis. The analysis was carried out at the Nigerian Geological Survey Agency (NGSA), Kaduna Nigeria.

A. Methods

Heavy mineral analysis in this study was after the procedure of Suzuki [27] and Mange and Maurer [28] for heavy mineral separation. The heavy liquid, Bromoform (CHBr3) with a density of 2.9 g/cc and viscosity of 0.068 was used. The samples were air-dried for a week to remove any moisture content. Thereafter, the sediments were gently disaggregated by squeezing between fingers and filter paper or mortar and pestle in the case of hard samples to free individual grains. Each sample of 70 g was weighed and sieved to obtain 62.5–500 microns size grains. The individual sample was then poured into the bromoform (CHBr3) and stirred thoroughly to free the samples of air bubbles. The particles were made to settle for about 20 minutes, stirring intermittently to prevent the particles from adhering to funnel wall. The heavy crop was several times washed in excess acetone and distilled water and allowed to dry and labelled appropriately. In all, 13 permanent mounts were made on slides using coupled resin. Mineral identification on the basis of their optical properties as proposed by Mange and Maurer [28] and Lindholm [29] was conducted on the samples. More than 100 grains were counted from each slide for statistical analysis. Rock fragments, unidentifiable grains as well as authigenic and opaque minerals were excluded from the total sum to obtain uniform, comparable data on transparent assemblages for the characterization of mineralogical provinces. The sum of transparent minerals was recalculated to a value of 100% and the abundance of each heavy mineral species was scaled properly. The “ZTR” index which is the combined percentage of zircon, tourmaline and rutile among the non-opaque heavy minerals, omitting micas and authigenic species was calculated using Hubert [30] formula below:

$$\text{ZTR index} = \frac{\text{Zircon + Tourmaline + Rutile}}{\text{Non-Opaque}} \times 100$$

ZTR index was calculated for the samples to ascertain their mineralogical maturity. According to Hubert [30], ZTR index <75% implies immature to sub mature sediments and ZTR >75% indicates mineralogically matured sediments.

IV. RESULTS AND DISCUSSION

A. Results

Heavy mineral concentration in the Lokoja Formations is classified into opaque and non-opaque constituents. The opaque parts are generally referred to as iron-stained heavy minerals which require further chemical analysis to allow investigation under petrographic microscope. This chemical analysis, however, is beyond the scope of the present investigation and no further serious attention apart from statistical consideration is accorded to this category of heavy minerals. The recovered non-opaque components of the Lokoja Formation exposed around Karara- Banda areaalong Lokoja- Abuja express road include the following: zircon, tourmaline, rutile, sillimanite, kyaniteanatase and some opaque minerals like magnetite, ilmenite and minor pyrite. (3a–3t).

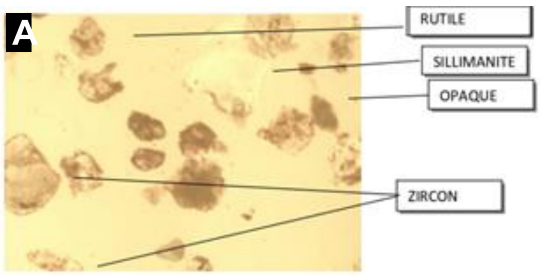
The proportion of heavy mineral recovered to the volume of sediment analysed is generally low, though on the average it may support fairly significant economic prospect. Information on the proportion of the heavy minerals recovered from the Lokoja Formation is provided in Tables 1, 2 and Tables 3, it also shows the calculated ZRT% index results. The summary of the identification criteria and the significant characteristics of each of the recovered heavy minerals are as follow:

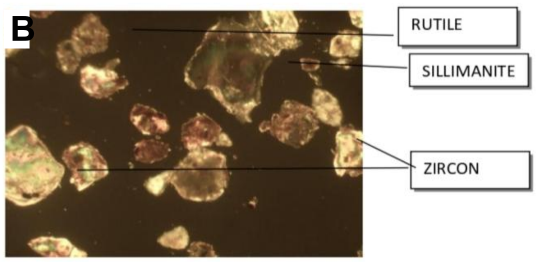
Zircon: Zircon grains (3a to 3j) are rounded to sub-round and some-times contains fluid and mineral inclusions. Prismatic grains frequently showed zonation identified by fine bands parallel to the crystal boundary (3a). The colourless varieties are more in abundance than the coloured varieties. The grains are easily identifiable owing to their very high relief and they are surrounded by black halo (3a- j). The pleochroism is weak and birefringence is strong.

Tourmaline: Tourmaline grains (3c, 3e, 3f, 3k, and 3m) are prismatic, elongated, oval-shaped, spherical, euhedral, sub-hedral to irregular in shapes, with terminations at one or both ends of prismatic variety and sometimes colourless. Colour zoning is frequent, pleochroism, sharp and distinctive.

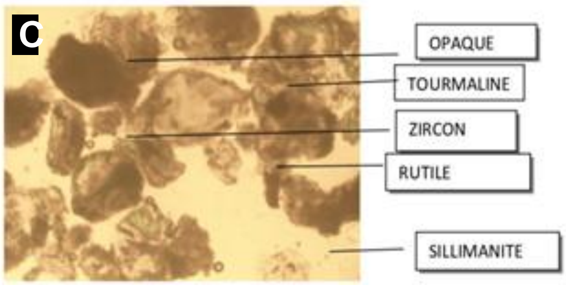
Rutile: Rutile (3a- 3j) appeared as small and sub-rounded slender prisms with well-developed terminations. A thick halo surrounds the grains because of their extremely high refractive indices. Grains are mostly brownish red to brownish black in colours and show distinct pleochroism

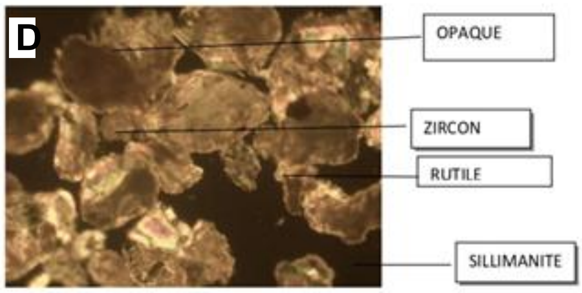
Sillimanites: Sillimanites (3a-3k and 3s) are long, slender, prismatic or irregular in shapes. Sillimanites show distinct cleavage, pleochroic (pale brown to pale yellow), parallel extinction, shows brilliant second and third order interference colours with yellow, green and pink as a dominant shade; slight twinkling is noticeable on rotation.



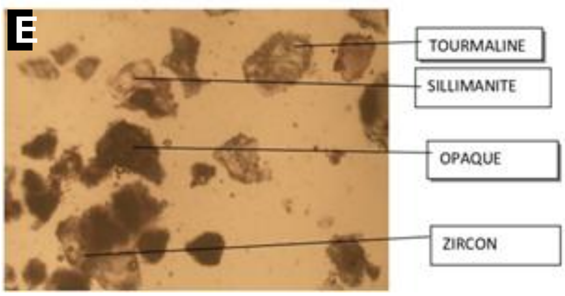


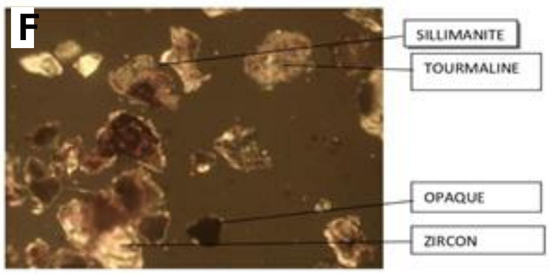
3a: Photomicrograph of Sample A from Location 1 under PPL3b::Photomicrograph of Sample A from Location 1 under XPL



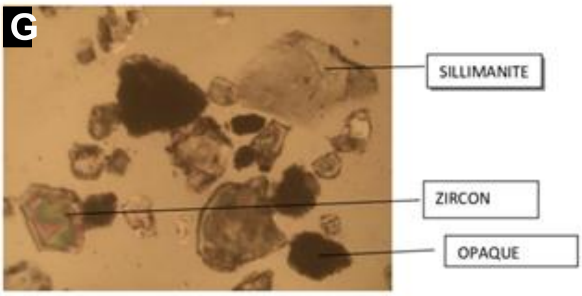


3C: Photomicrograph of Sample B Location 1 under PPL 3D: Photomicrograph of Sample B Location 1 under XPL

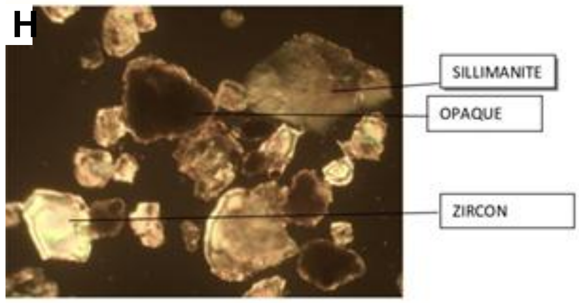




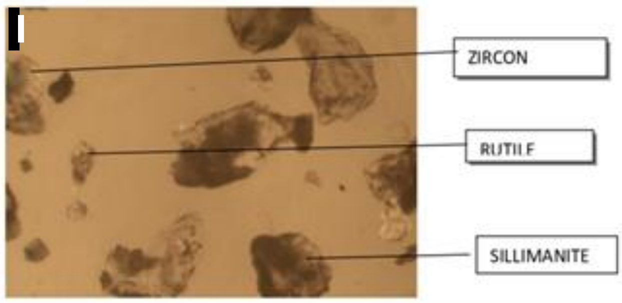
3e: Photomicrograph of Sample B Location 1 under PPL 3f: Photomicrograph of Sample C Location 1 under XPL



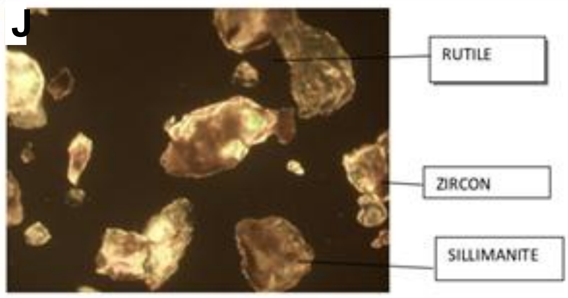
3g: Photomicrograph of Sample A Location 2 under PPL



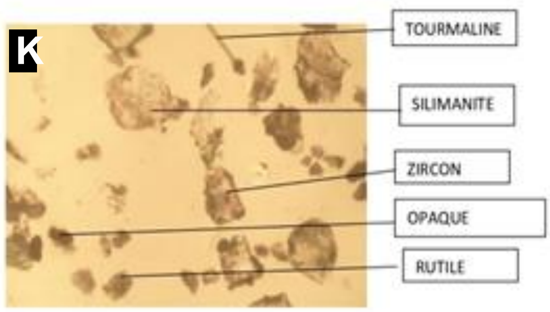
3h: Photomicrograph of Sample A Location 2 under XPL



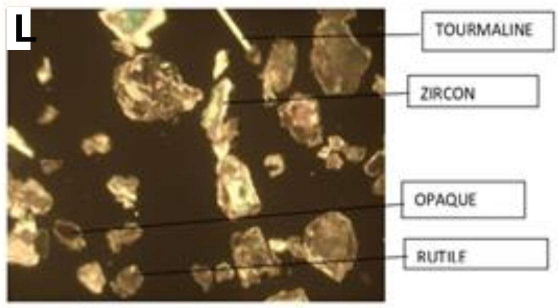
3i: Photomicrograph of Sample B Location 2 under PPL



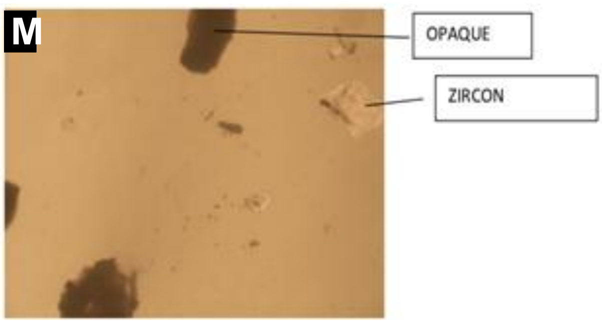
3j: Photomicrograph of Sample B Location 2 under XPL



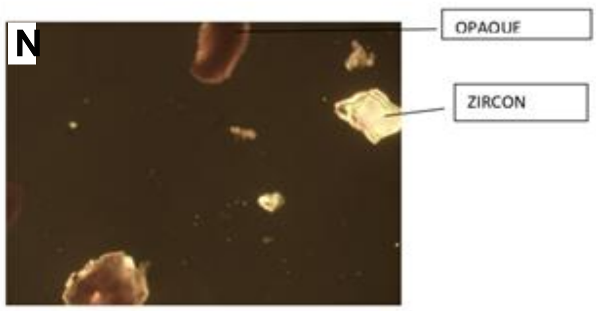
3k: Photomicrograph of Sample C Location 2 under PPL



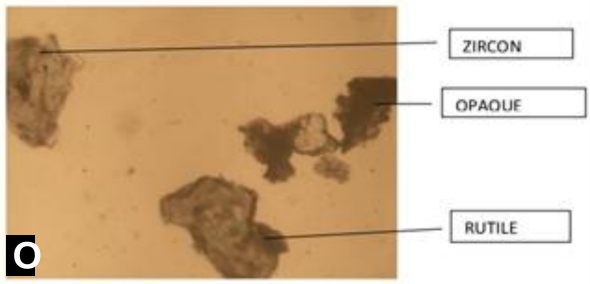
3l: Photomicrograph of Sample C Location 2 under XPL

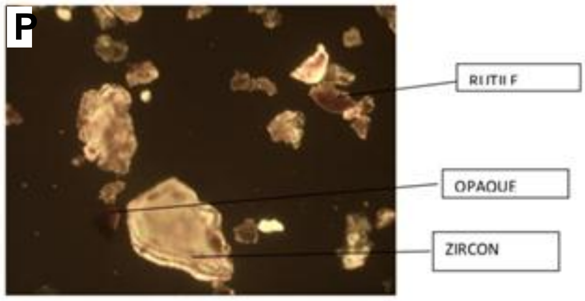


3m: Photomicrograph of Sample A Location 3 under PPL



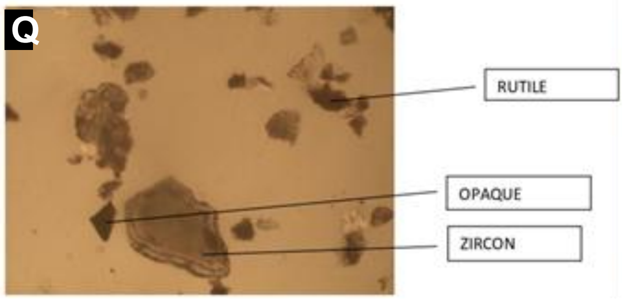
3n: Photomicrograph of Sample A Location 3 under XPL

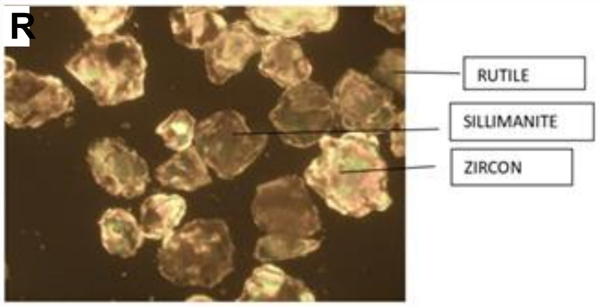




3o: Photomicrograph of Sample A Location 4 under PPL

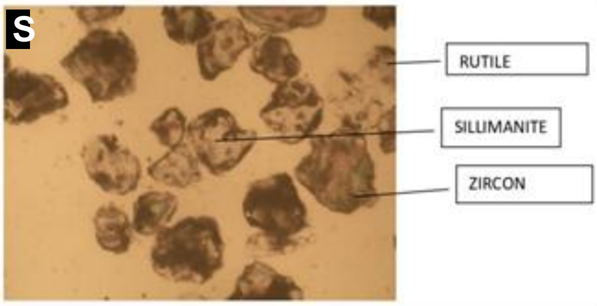
3p: Photomicrograph of Sample A Location 4 under XPL

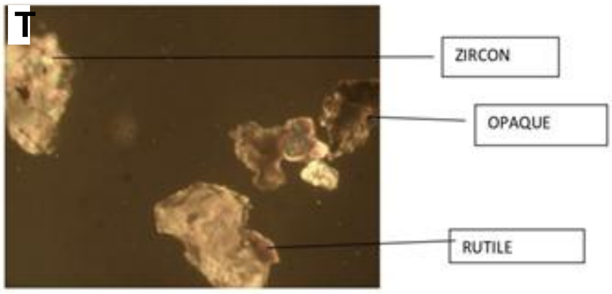




3q**: Photomicrograph of Sample B Location 4 under PPL**

3r: Photomicrograph of Sample B Location 4 under XPL





3s**: Photomicrograph of Sample C Location 4 under PPL**

3t: Photomicrograph of Sample C Location 4 under XPL

Table 1: Z ircon Tourmaline Rutile Percentage and ZTR Index

Sample (Location 1)	Zircon index (%)	Tourmaline Index (%)	Rutile Index (%)	Total non – opaque Index (%)	ZTR Index (%)
Sample A	25	16	13	87	62
Sample B	23	5	10	64	59
Sample C	15	11	9	79	44

Table 2: Zircon Tourmaline Rutile Percentage and ZTR Index

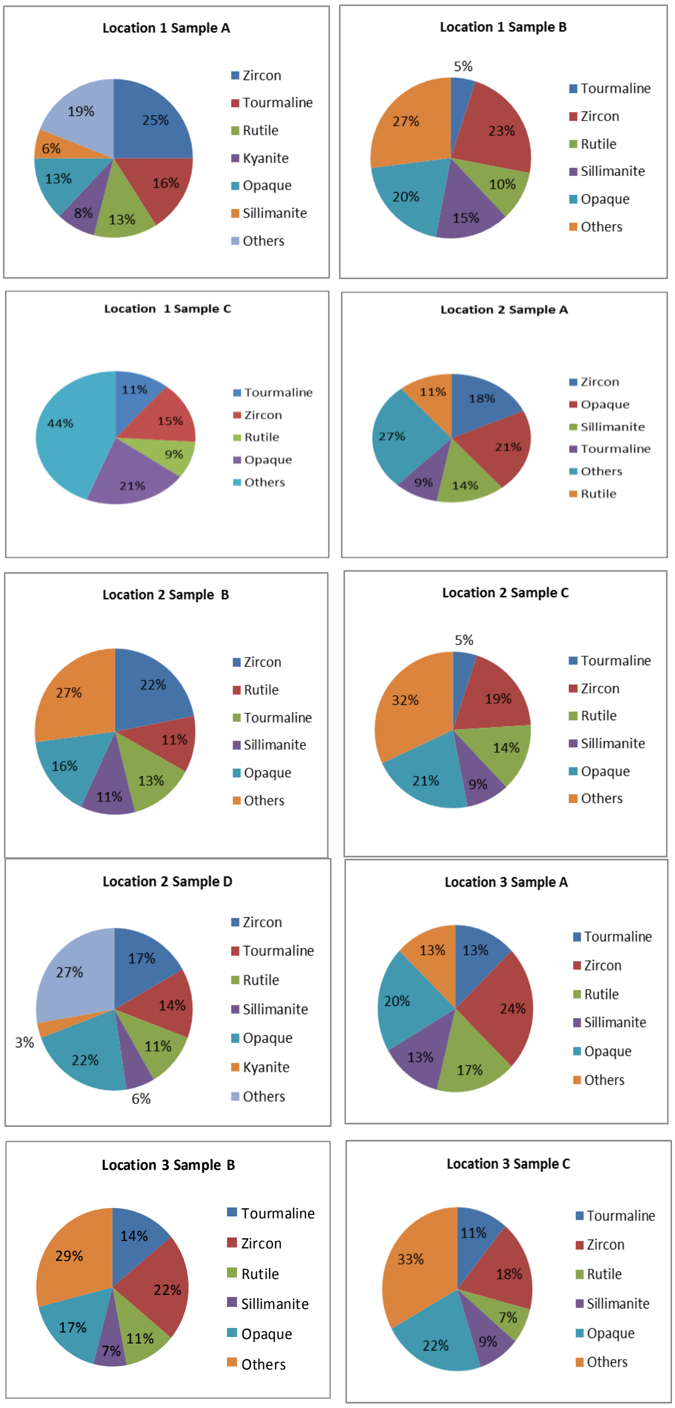
Sample (Location 2)	Zircon index (%)	Tourmaline Index (%)	Rutile Index (%)	Total non-opaque Index (%)	ZTR Index (%)
Sample A	18	9	11	79	48
Sample B	22	13	11	84	55
Sample C	19	5	14	79	48
Sample D	17	14	11	79	53

Table 3: Zircon Tourmaline Rutile Percentage and ZTR Index

Sample (location 3)	Zircon index (%)	Tourmaline Index (%)	Rutile Index (%)	Total non-opaque	ZTR Index (%)
Sample A	19	10	13	62	68
Sample B	22	14	11	83	57
Sample C	18	11	7	78	46

B. Discussion

The percentage proportions of the non-opaque heavy mineral constituents of the Lokoja Formation exposed around Karara-Banda show the dominance of zircon (4). Tourmaline is the second most abundant of the recovered minerals. Rutile comes next in the Lokoja Formation of the study area.



Figs.4: Percentage Estimate of Heavy Minerals in the study area

Sillimanite is present in all the samples of the Lokoja Formation except only in sample Location 1 Sample C (Figures.4). Consequent to the proportion of the constituent heavy mineral in the studied sections, the sediments of the Lokoja Formation are considered generally stable as they are dominated by ultra-stable and stable minerals (Figures. 4).

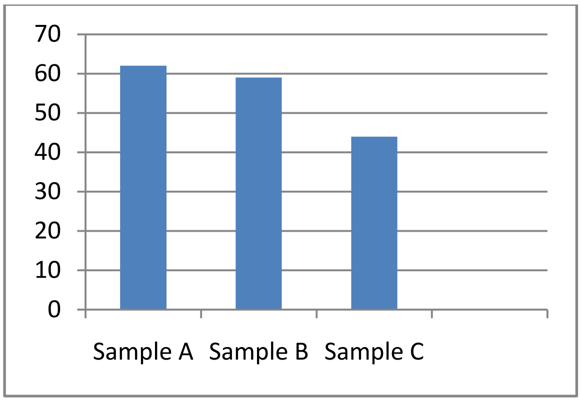


Fig. 5a: Bar Chart of ZTR Index % of Location 1

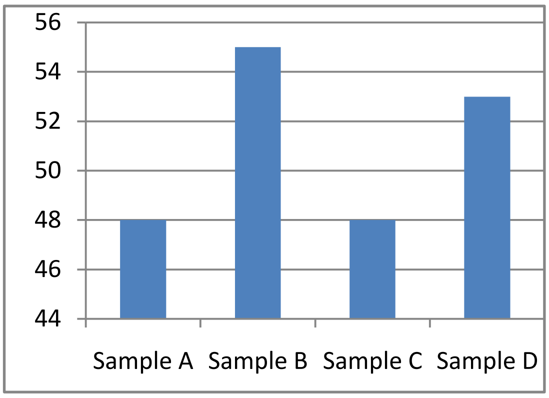
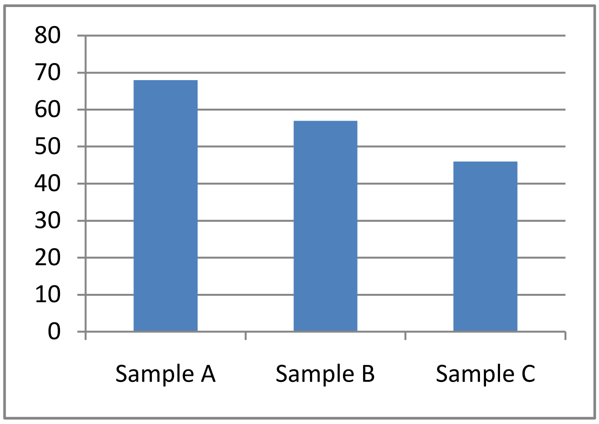


Fig.5b: Bar Chart of ZTR Index % of Location2



5c: Bar Chart of ZTR Index % of Location 3

The calculated ZTR% index for the Lokoja formation in Location 1 ranges from 44% to 62% (fig.5a), whereas it ranges from 48% to 55% in Location 2 (fig.5b) and 46% to 68% in Location 3(fig.5c). Four (4) samples from the Lokoja Formation exposed atKarara- Banda has ZTR% index of <50%. This low ZTR index indicates that the samples of the Lokoja Formation of Karara-Banda are mineralogically immature. The ZTR index of six (6) samples in the study location shows slight improvement having ZTR >50%. These show the comparative mineralogical maturity advantage of the sediments over the other four samples. (Figures. 4 and 5; Tables 1, 2 and 3).

V. CONCLUSIONS

The heavy mineral analysis was used to investigate the sandstone facies of the Lokoja Formation exposed at Karara-Banda. The research reveals that the sediments are from various sources. The ZTR indices indicated that the Lokoja Formation's sediment suite was immature. Heavy minerals found in the samples indicate that the sediments are stable. The heavy minerals obtained from selected Lokoja sandstone samples indicate that the samples taken from the research location may have originated through recycling via sedimentary rocks and metamorphic rocks of the adjacent basement complex.

ACKNOWLEDGEMENT

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