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PALEOENVIRONMENTS AND PROVENANCE OF THE CLASTIC SEDIMENTS OF THE LOKOJA-BASANGE FORMATION, BENIN FLANK OF ANAMBRA BASIN, NIGERIA

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ABSTRACT

Paleoenvironmental and provenance study of outcropping sediments exposed at different locations within the Lokoja Basange Formation in the Anambra Basin were investigated to deduce the transportation history, provenance and paleoenvironments of the sediments. Successions of the sandstones, siltstones and shales observed along road cut and river channels were studied to establish their field relationship and characteristics. 11 sandstones samples were selected and subjected to grain size analyses to determine the graphic mean, sorting, skewness, and kurtosis while 10 sandstone samples were analyzed by heavy mineral. Field observation revealed three lithofacies mainly sandstones, siltstones, and shales in the studied sections. The mean, sorting, skewness, and kurtosis have the following ranges (0.07-4.3, 0.78 - 2.20, -1.18 - 0.77, and 0.48 -4.92) respectively. The sandstones ranged from fine-medium-coarse grained exhibiting poor sorting. The sandstones were characterized by angular to sub angular grains having low maturity reflecting short transportation history and fluvial depositional environments in a low energy setting. Most of the sandstones are finely skewed and leptokurtic while few samples exhibits very coarse skewed and platykurtic. The siltstones and shales suggest a coarsening upward progradational pattern and may indicate a deltaic sedimentation. Heavy mineral assemblages observed in the sandstones include zircon, rutile, magnetite, topaz, and tourmaline which suggests provenance from igneous and metamorphic sources from the Precambrian Basement Complex of Nigeria.
Keywords: *Basin, fluvial, provenance, paleoenvironment, sandstone*

INTRODUCTION

The Bida Basin also known as the Middle - Niger Basin and the Anambra Basin (Fig.1a) are among the inland sedimentary basins in Nigeria. Several authors concurred that the Bida and Anambra Basins origin are linked to the tectonic development of the Benue Trough, which commenced in the early Jurassic to early Cretaceous period with the formation of the Gulf of Guinea. The Bida basin is an intracratonic structural basin trending NW-SE and is next to the Sokoto Basin in the northwest and the Anambra Basin in the southeast. It has sedimentary fill of 3500 m (Ojo, 1984; Udensi and Osazuwa, 2004). It is likely that the basin-wide facies alterations in the Bida Basin are responsible for the division of the basin into the southern and northern sub-basins (Jones, 1958; Braide, 1992).

The Lokoja-Basange Formation has been widely debated in terms of the stratigraphic location within the Lokoja-Sub basin in the Bida Basin and the eastern part of the Anambra Basin due to the connectivity and proximity of these two basins. These basins are currently being explored for hydrocarbon prospectivity. Several investigations have been carried out in these two basins, some of which have focused on the sedimentological characterization and hydrocarbon generation potential of the Campano-Maastrichtian sediments in the basins (Adeleye and Dessauvagie, 1972; Adeleye, 1989; Ojo and Akande, 2009; Ogala, 2011; Akinyemi *et al.,* 2014; Okoro and Igwe, 2018; Ojo *et al.,* 2020; Salufu and Oladapo, 2022). However, recent studies in Bida basin by (Aigbadon *et al.,* 2023; Aigbadon *et al.,* 2022, Ojo *et al.,* 2021; Ojo and Akande, 2020; Rahaman *et al;* 2019), have led to the reconstruction of the stratigraphic framework due to various views about the stratigraphic nomenclature of the type sections in different locations within the basin including the less accepted nomenclature of the stratigraphic unit called Lokoja-Basange Formation. The present study covers Igarra, Auchi, Sabongida Ora, Uzebba and Ifon areas, showing good exposures of Cretaceous sediments along channel and road cuts. This study aimed at using sedimentological tools to provide additional geologic information on provenance, transportation history and paleoenvironments of the clastic sediments exposed at these locations and provide valuable information to unravel its correct stratigraphic position.

1.1 Evolution and Stratigraphy of the Bida Basin and Anambra Basin

The development of the Bida Basin and Anambra Basin are related through tectonism through the opening the South Atlantic during the separation of South American and African plate in the Mesozoic. A tiny outcrop of crystalline foundation rocks to the west separates the area from the Sokoto Basin's continental layer, and the Anambra Basin is to the east. The Bida Basin is in a gently sloping depression having sedimentary layers are 3500m meters (Osokpor and Okiti, 2013; Ojo and Ajakaiye, 1989). Unfolded post-tectonic molasse facies and thin marine strata make up these levels. Geophysical data, borehole logs, and Landsat image interpretation show that the basin is flanked by northwest-southeast trending linear faults (Kogbe, 1989). A detailed facies investigation shows rapid basin-wide transitions from alluvial fan to flood-basin and deltaic facies.

The Bida Basin is divided into two geographic regions, namely the northern and southern Bida basins. According to Ojo and Akande (2003), the Campanian Lokoja Formation is the oldest unit in the southern Bida Basin. It is composed primarily of alluvial to fluvial channel sandstones with some minor claystone. In the northern Bida Basin, it is the stratigraphic equivalent of the Bida Formation (Fig. 1b). Following this, the Maastrichtian Patti was deposited in Coastal swamps, tidal marshes, tidal channels, and shoreface environments. There are two main components to this formation: sandstone and shale-clay. Various types of sandstone, including fine-to medium-grained sandstone and some coarse-to very coarse-grained sandstone, make up the sandstone member of the shoreface and tidal facies association. According to Ojo and Akande (2009), the shale-clay component is made up of several swamp to marsh facies, including shale, lignite, ironstone, siltstone, and claystone. The Enagi Formation is the northern Bida Basin's lateral counterpart to the Patti Formation. The sequence was topped by the Agbaja Formation, which is the northern analogue of the Batati Ironstone; its likely date is late Maastrichtian (Adeleye, 1989). The stratigraphic successions in the northern and southern regions of the basin are closely related to one another, with the basis being the lithological and depositional features. This correlation has now been extended to the Anambra Basin in the southeast. In the western part of Anambra Basin, the stratigraphy comprises the Lokoja-Basange Formation, which is the oldest formation in the area. It dates back to the Campanian period and is characterized by continental facies. The Lokoja-Basange Formation is considered a lateral equivalent of both the Nkporo Formation and the Enugu Formation, as suggested by (Obaje *et al.* 2022). The Lokoja-Basange Formation is situated unconformably on top of the Neoproterozoic basement rocks in the study area. The Mamu Formation is situated above the Lokoja-Basange Formation. In the Upper Cretaceous, fluctuations in sea level dictated the direction of these lateral equivalents, which show continuous depositional phases running north to northwest and south to north. The Nkporo and Enugu Formations are particularly oldest in the Anambra Basin's eastern half; they are defined by brackish water and prodelta facies. They represent the beginning of the basin's marine regression and span the time from the Campanian to the Early Maastrichtian (Odunze and Obi, 2013). There is a conformable link between the Mamu Formation and the Nkporo Formation. Deposition of marginal marine facies is a hallmark of the Mamu Formation, which dates back to the Maastrichtian period and marks a transition from continental to marine influences (Nwajide, 1990; Nwajide, 2005).

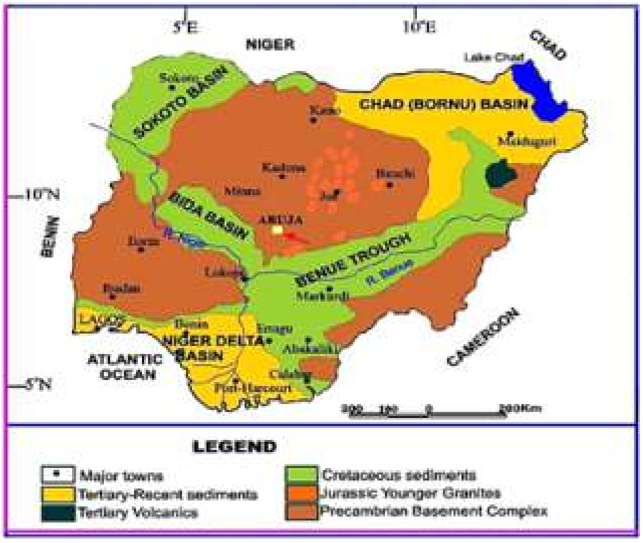


Figure 1a: Geological Map of Nigeria showing location of study modified after (Obaje *et al.,* 2004)

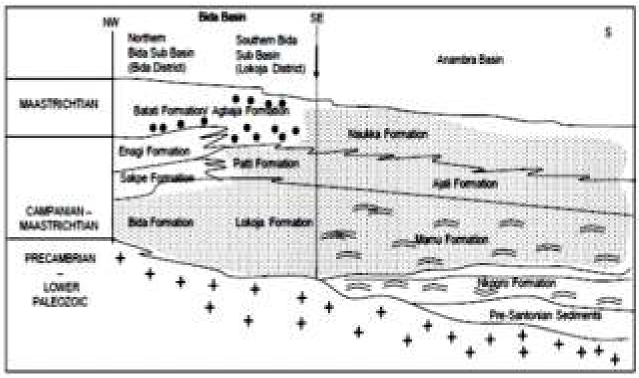


Figure 1b. Generalized Stratigraphy of the Bida Basin and the contiguous Anambra Basin after (Ojo *et al.,* 2021)

2.0 Materials and Methodology

The Methodology involved field study and laboratory analysis. Field study were carried out on outcrop locations specifically on road cut exposures along Igarra, Auchi, Sabongida Ora, Uzebba and Ifon areas. Six lithostratigraphic sections which cover Lokoja Basange Formation and Mamu Formation in the Anambra basin exposed along the traverses mentioned above were logged and sampled (Fig. 2 to Fig. 7) with attention on changes in lithology, texture, colour, grain size, shape, sorting, bedding, thickness, weathering characteristics and structures. The samples were observed physically and were collected to represent each lithology in the sections. Measurements of each bed's thickness were done with the collection of fresh samples of each lithological unit, packed in durable sample bags and labeled accordingly. The samples were taken to Kwara State University (KWASU) geological workshop for grain size analysis and heavy mineral constituent analyses. Eleven samples were selected for grain size analyses. Lumped samples were disaggregated by hand before weighing. The analysis was carried out by using the following set of sieves (1.6mm, 0.44mm, 1.25mm, 0.112mm, 0.09mm and 0.063mm) and sieve shaker machine. The sieves were arranged according to decreasing mesh sizes with the smallest opening at the bottom and the pan which collects the finest grain, and the top is covered with lid. The sieves and the bottom pan were fastened to the mechanical shaker, and 100g of the samples was poured into the upper sieve. The machine (sieve shaker) was allowed to shake for ten (10) minutes. The sediments retained in each of the sieve and the bottom pan was weighed and their weight recorded.

The statistical parameters such as Graphic mean (Mz), Graphic standard deviation (sorting) (σ1), Inclusive graphic skewness (Ski), and Graphic kurtosis (KG) of each of the samples are presented in (Table 1). The statistical parameters of the grain size frequency distribution were obtained and computed by the method of Folk and Ward (1957). The cumulative curves plotted for various samples are presented in (Figs. 10a-10c, 11a-11c and 12a-12d). Quantitative graphical values of percentiles from various samples obtained from the cumulative frequency curve are presented in (Table 2).

Ten samples were subjected to heavy mineral analyses. An apparatus consisting of a retort stand, separating flask, glass rod, conical flask, wash bottle and funnel was set up. Materials used were liquid bromoform (heavy liquid), acetone and filter paper. Liquid bromoform was poured into the separating funnel (with tap locked) and the sample was poured into the liquid. The mixture was stirred vigorously with the glass rod. The heavy minerals were then drained into the receiving funnel with filter paper. The conical flask at the bottom was used to collect the drained bromoform. The heavy minerals retained in the filter paper were then washed with acetone and then dried. Identification of minerals was done by using the binocular microscope and the polarizing microscope.

3.0 Results and Discussion

3.1 Litho-stratigraphic Description of Outcrop Samples

Six locations were logged and described to reveal the facies and their characteristics. Lithologies such as sandstones, siltstones and shales were observed at various locations (Figs. 2 - 7) and each facies having distinct characteristics in terms of texture, structure, mineralogy and colour.

3.2 Sandstone Facies

The sandstone facies were observed at Locations 2, 5, 7, and location 14 along Ekpeshi-Auchi road, Sabongida-Ora Road, Ori Ohen, and at Itobe (Figs. 2, 3,4, 6 and 7). The sandstones occur as low-lying outcrop and were exposed by road cut. The thickness of the sandstone beds varies from each location and range between 0.3 – 2m. At location 2 and location 7, the sandstones exhibit a fining upward (transgressive) sequence with thin lamination which may suggest fluvial deposition. The colour of the sandstones beds varies from light to reddish brown coloration due to due to ferruginization as a result of oxidation. There was no indication of preservation of fossil and the grains were sub-angular to angular indicating short transportation from the source area. These locations suggest they are part of the Lokoja-Basange Formation.

The Lokoja- Basange Formation overlies the basement unconformably with a coarse to gritty, locally conglomeratic angular sandstone. The basal sandstone is followed by an alternation of purple – grey, usually sandy but occasionally very pure, waxy clays and white sandstones which grades from bottom – top, from gritty and coarse to very fine-grained sandstones and siltstones (Tattam, 1944). At location 5, (Fig. 3) the sandstones are coarse-medium grained to coarse grained and form coarsening upward sequence with the underlying siltstone units.

At location 14, the sandstones are light brown, reddish brown in colour, ferruginous pebbly sandstones and have thickness of 2.96m. The pebbly nature of the deposits increases up the succession i.e beds at the bottom are mainly coarse sand but get pebbly at the top. The beds are laminated by kaolinitic materials (clay clast). They exhibit gradational contact with the very coarse sandstone laterally. The sandstone unit at this location showed cross stratification and flaser lamination.

3.3 Siltstone Facies

The siltstones occur in outcrop along Ekpeshi-Auchi road specifically in location 5 and 9 (Figs. 3 and 5). The siltstones are light brown. The siltstone beds vary in thickness from 0.4m- 2m. It is composed mainly of quartz and clay as matrix. The siltstone bed directly overlies the alternating beds of shale and exhibit coarsening upward sequence (prograding) pattern which may suggest fluvio-deltaic deposition. These outcrops are characteristics of Mamu Formation.

3.4 Shale Facies

The Mamu Formation of Anambra basin is represented here, and the shale exist at location 9 (Fig.5) along Auchi-Ekpeshi road and along Ifon-Sabongida Ora road before Uzebba village. The shale is fissile and has a thickness of 4m. The carbonaceous shale has a dark gray colour due to concentration of organic matter. This suggests a high level of biological productivity and low energy condition during deposition. It consists largely of clay minerals and micas. Fossils such as floral remains were present.

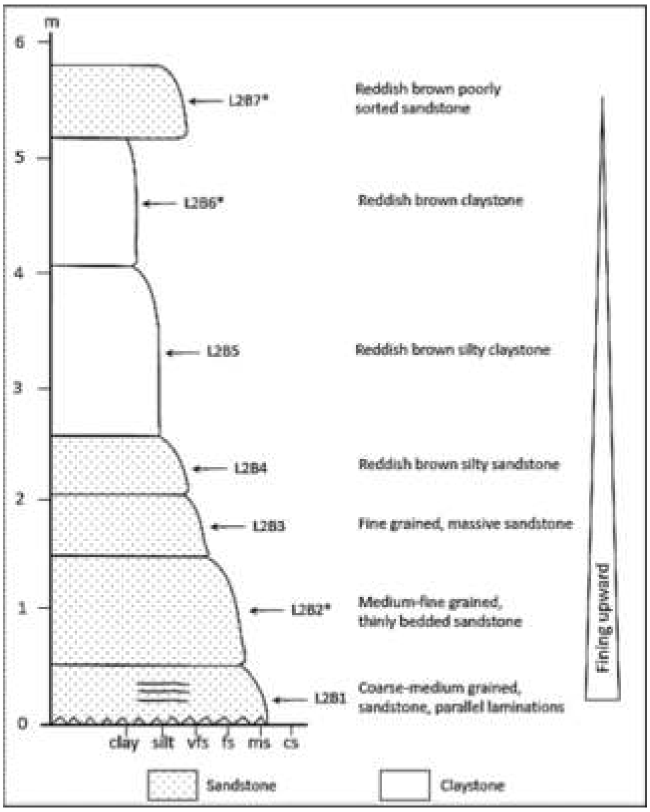


Figure 2: Lithological Succession of Lokoja-Basange Formation exposed at Ekpeshi village, along Auchi-Uzebba road. Coordinate 7° 0' 12" N, 5° 54' 32"E

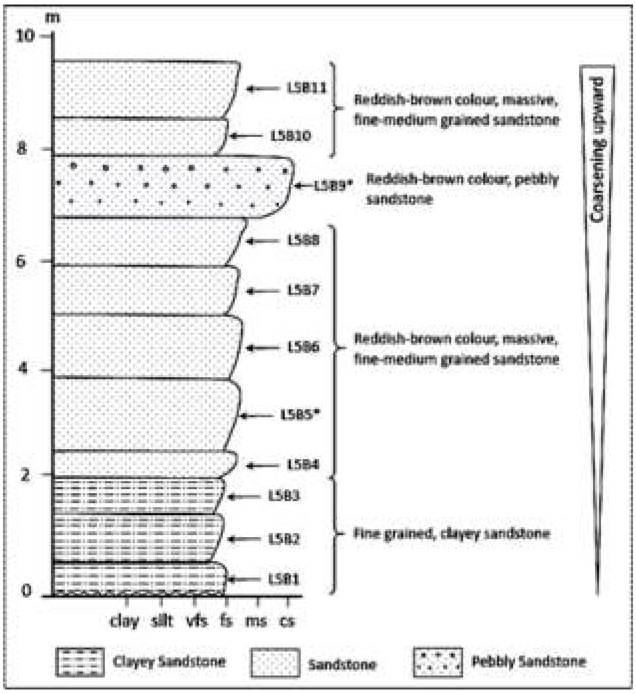


Figure 3: Lithological Succession of Lokoja-Basange Formation exposed at Ekpeshi, Auchi –Uzebba road. Coordinate 7° 4' 26" N, 6° 15' 22"E

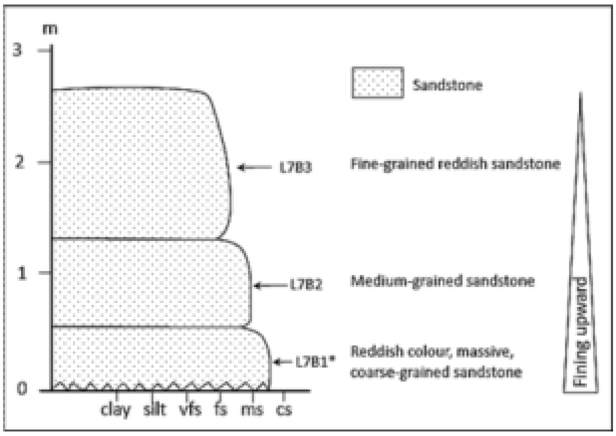


Figure 4: Lithological succession of Lokoja-Basange Formation exposed along Sabongida-Ora Road. Coordinate 6° 56' 48"N, 5° 54' 52" E

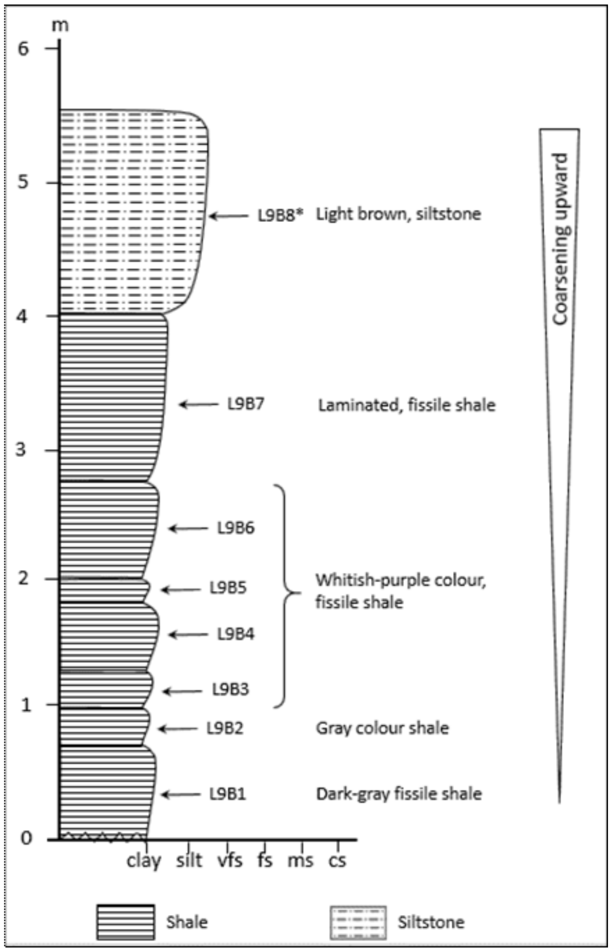


Figure 5: Lithological Succession of Lokoja-Basange Formation exposed at Ekpeshi, Auchi- Uzebba road. Coordinate 6° 59' 53"N, 5° 54' 12"E

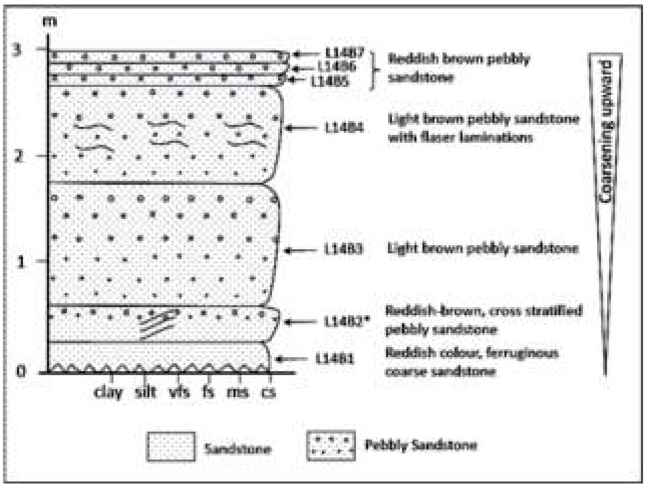


Figure 6: Lithological Succession of Lokoja-Basange Formation exposed at Ori-Ohen. Coordinate 6° 57' 47"N, 5° 44' 38"E

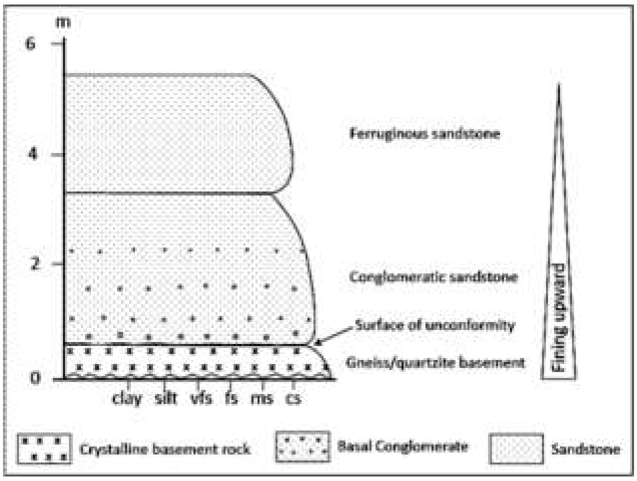


Figure 7: Lithological Succession of Lokoja-Basange Formation exposed at Ori-Ohen. Coordinate 6° 57' 30"N, 5° 44' 14"E

3.5 Grain Size Distribution and Paleoenvironmental Reconstruction

Vischer (1969) and Friedman (1979) has indicated the importance of using grain size distribution to deduce paleo-environmental inferences. Though it has been suggested that using particle size distribution for paleo-environmental reconstruction should be combined with other sedimentological parameters such as facies association and sedimentary structures for accurate results due to limitations from grain size distribution (Amaral and Pyrol, 1977; Selley, 1985; Tucker, 1988). The statistical data obtained (Table 1) suggest that the sandstones are characterized by fine grained sand, medium grained and coarse-grained.

3.6 Sorting and Transportation History

The statistical parameter (standard deviation) is the spread (sorting) of the sizes around the average. It shows the effectiveness of transporting medium in separating grains of different sizes. The sediments range from moderately sorted to poorly sorted and very poorly sorted and this is an indication that the sediments have not been transported from the source area for long distance before deposition. The poorly sorted sand indicates bedload transportation, less winnowing and abrasion. The prevalence of poorly sorted sands and unimodal grain size variation suggest a low energy unidirectional fluvial system of deposition.

The skewness of a deposit is sensitive to the type of depositional environments. The sandstones are characterized by relatively poor sorting and positive skewness/strongly fine skew is indicative of river sand (Friedman, 1961; Friedman, 1979). Okoro (1995) reported that negative skewness gives indication of marine reworking in the continental shelf settings. However, in the samples analyzed, there was no evidence of marine reworking.

The kurtosis revealed that the sediments range from very and extremely leptokurtic to very platykurtic. The leptokurtic nature of the sediments reveals water laid sediments and low energy condition.

3.7 Provenance and Paleoenvironments

Heavy minerals are used for provenance studies, correlation of sedimentary strata of one environment with another and to characterize facies of different of different localities. The provenances of the sediments are deduced from the heavy mineral analyses. The following minerals were identified tourmaline, magnetite, zircon, topaz, hematite, sphene, sillimanite and rutile (Fig. 13 and Fig.14). Table 3 shows the distribution of heavy minerals in the samples. The heavy minerals mentioned above occurs as detrital grains in the samples which suggest that the sediments are young and were derived from igneous and metamorphic rocks probably from the Basement Complex of Southwestern and North central Nigeria. tourmaline, zircon, sphene, topaz are opaque minerals typical of igneous rocks. Staurolite, rutile, sillimanite and garnet suggest metamorphic origin. The sediments are thought to be from mixed sources. The presence of hematite in the sediments suggests oxidation condition during deposition in a fluvial setting.

The paleoenvironments were deduced from the bivariate plots of skewness vs standard deviation (sorting) and also mean vs standard deviation (Fig. 8 and Fig. 9) indicating that the majority of the sediments were deposited in a fluvial environment.

Table 1: Statistical data obtained from grain size analysis (Folk and Ward, 1957)

S/N	Sample code	Mean	S.D	Skewness (S_{k1})	Kurtosis (K_G)
1	L2B2	0.07	1.22	0.38	1.61
2	L2B6	4.3	0.93	- 1.18	0.41
3	L2B7	2.83	1.30	0.46	1.17
4	L5B5	2.47	0.78	0.23	4.10
5	L5B9	0.6	1.12	0.77	2.68
6	L7B1	3	1.23	0.40	1.64
7	L8B1	2.57	1.32	0.17	1.76
8	L9B8	3.9	1.06	- 0.38	0.94
9	L14B1	1.47	2.20	0.42	0.53
10	L14B2	0.27	1.05	0.51	4.92
11	L15B1	1.53	2.15	0.47	0.48

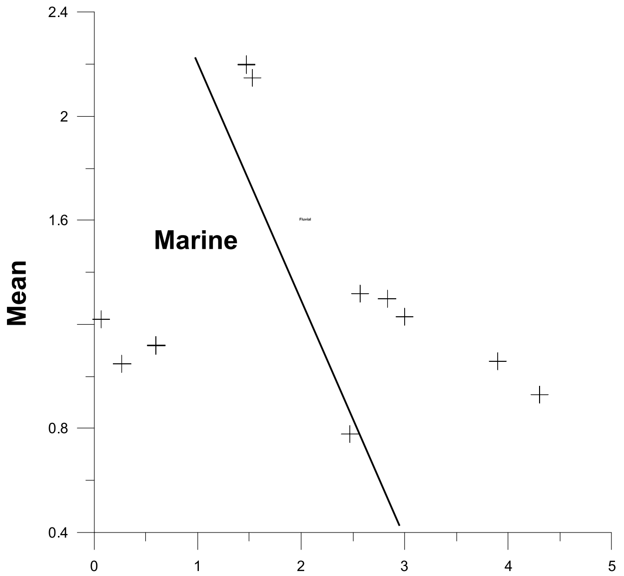


Figure 8: Bivariate plots of (a) Mean versus standard deviation. (after Folk and Ward, 1957; Friedman, 1961)

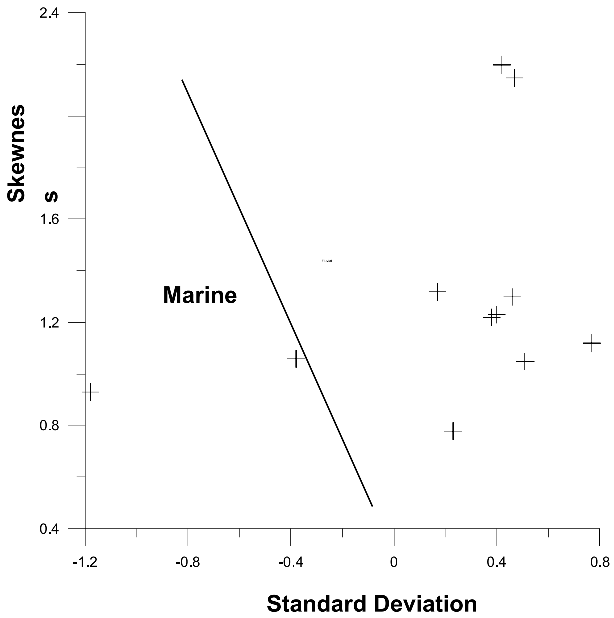


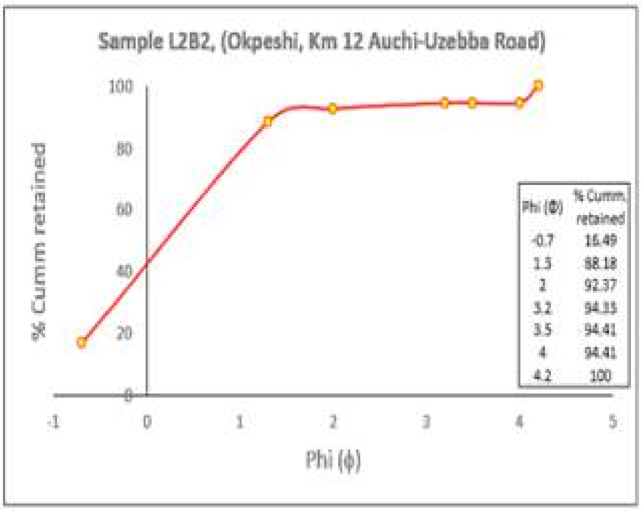
Figure 9: Bivariate plots of skewness versus standard deviation (after Folk and Ward, 1957; Friedman, 1961)

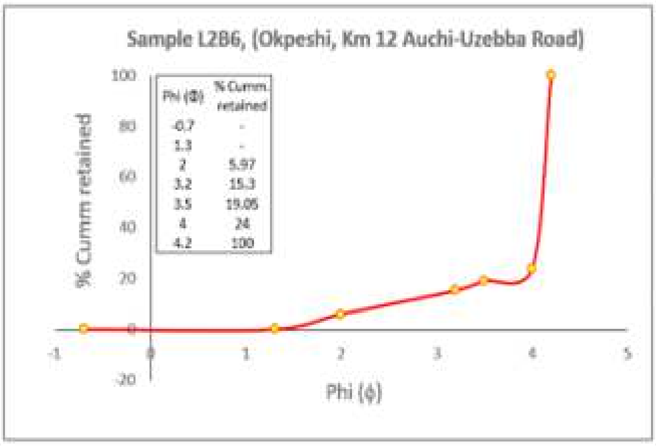
Table 2: Interpretation of the grain Size distribution parameters of the samples analyzed.

S/N	Sample code	Mean (Mz)	S.D (σ_1)	Skewness (S_{k1})	Kurtosis (K_G)
1	L2B2	Coarse grained sand	Poorly Sorted	Very Fine Skewed	Very Leptokurtic
2	L2B6	Silt	Moderately sorted	Very Coarse Skewed	Very Platykurtic
3	L2B7	Fine grained sand	Poorly Sorted	Very Fine Skewed	Leptokurtic
4	L5B5	Fine grained sand	Moderately sorted	Fine Skewed	Extremely Leptokurtic
5	L5B9	Coarse grained sand	Poorly Sorted	Very Fine Skewed	Very Leptokurtic
6	L7B1	Fine grained sand	Poorly Sorted	Very Fine Skewed	Very Leptokurtic
7	L8B1	Fine grained sand	Poorly Sorted	Fine Skewed	Very Leptokurtic
8	L9B8	V. Fine grained sand	Poorly Sorted	Very Coarse Skewed	Mesokurtic
9	L14B1	Medium grained sand	Very Poorly Sorted	Very Fine Skewed	Very Platykurtic
10	L14B2	Coarse grained sand	Poorly Sorted	Very Fine Skewed	Extremely Leptokurtic
11	L15B1	Medium grained sand	Very Poorly Sorted	Very Fine Skewed	Very Platykurtic

Table 3: Relative distribution of the heavy minerals in the analyzed samples

SAMPLE	Tourmaline	Zircon	Topaz	Rutile	Sphene	Sillimanite	Magnetite	Hematite
L14B2	-	very abundant	present	present	-	rare	-	-
L5B9	Very abundant	abundant	-	Present	-	rare	abundant	present
L2B6	Present	-	-	abundant	-	-	Very abundant	-
L2B2	-	present	abundant	-	-	-	abundant	-
L2B7	-	abundant	-	-	-	present	Very abundant	-
L8B1	-	-	-	-	-	-	Only constituent	-
L9B9	Abundant	Abundant	-	-	-	Rare	Present	-
L5B5	-	Present	Rare	-	-	-	Very abundant	Abundant
L7B1	-	-	Present	-	Abundant	Abundant	Present	-
L15	-	present	rare	-	Present	-	Very abundant	Abundant





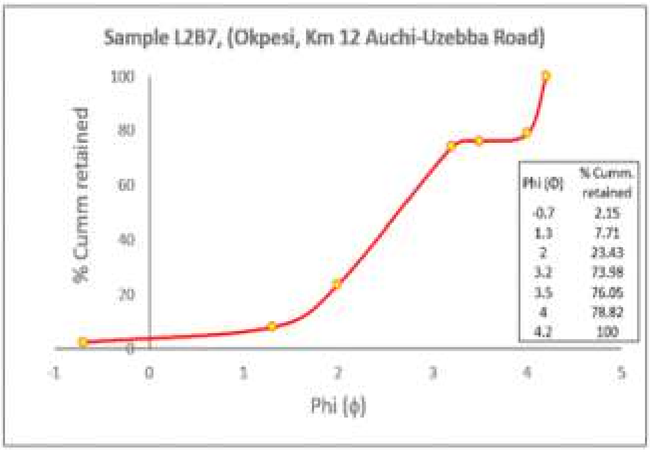
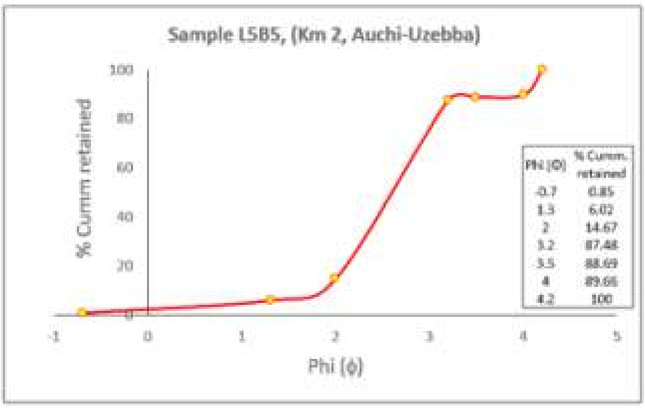
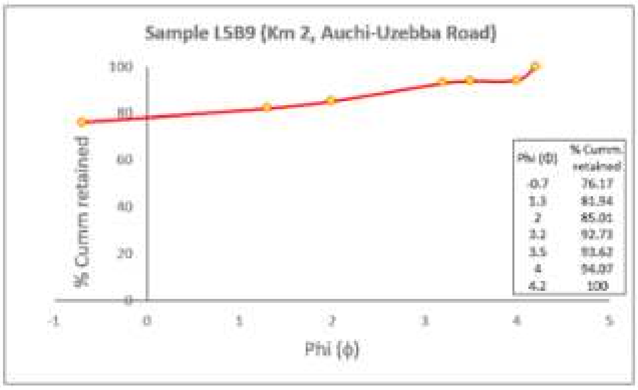


Figure 10: Cumulative frequency curve for sample (a) L2B2 (b) L2B6 (c) L2B7





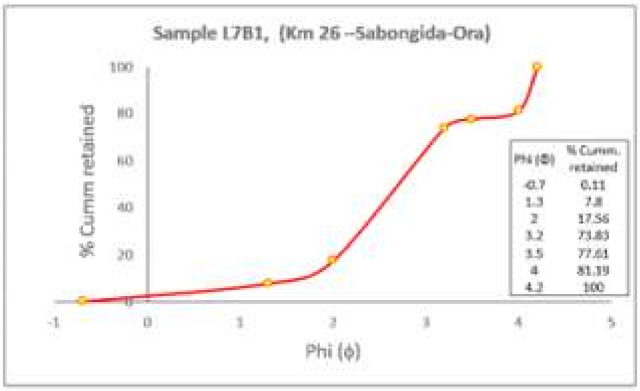
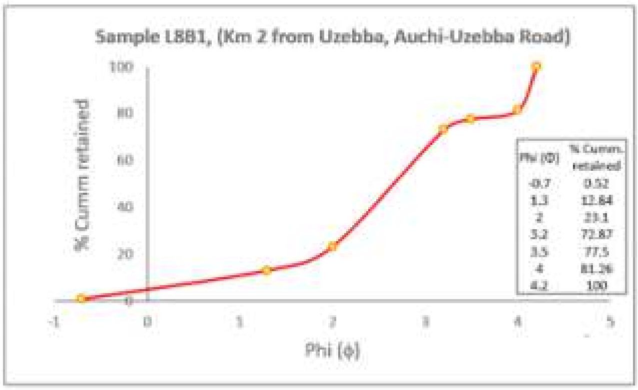
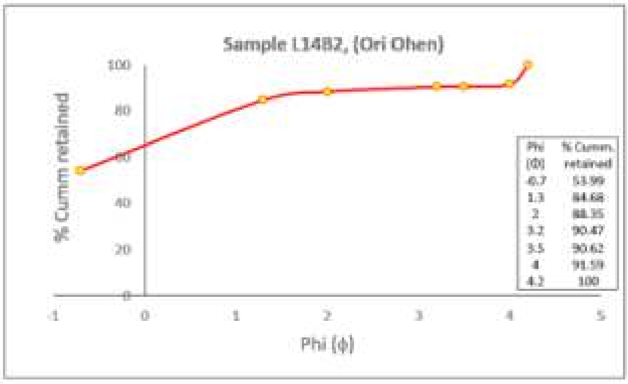
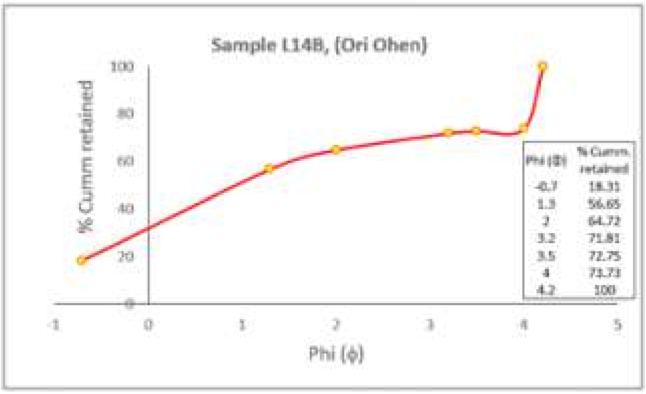


Figure 11: Cumulative frequency curve for sample (a) L5B5 (b) L5B9 (c) L7B1







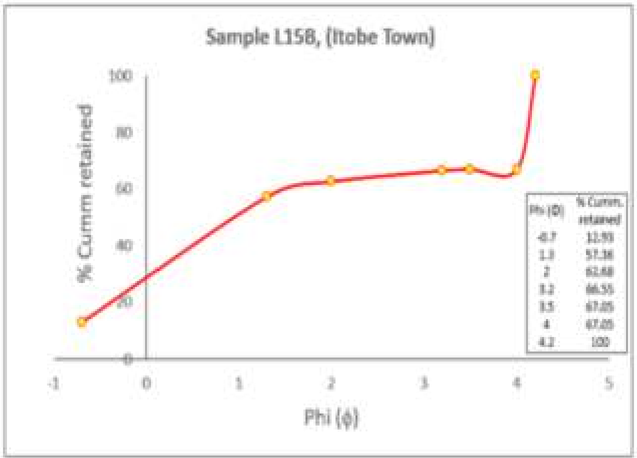


Figure 12: Cumulative frequency curve for sample (a) L8B1 (b) L14B2 (c) L14B1 (d) L15B

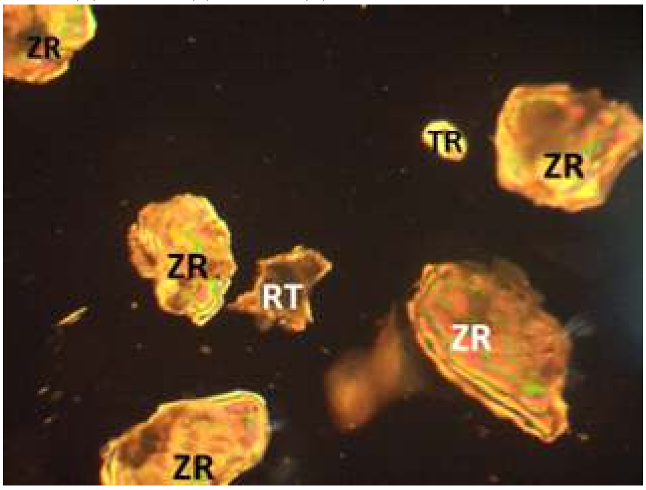


Figure 13: Photomicrograph of heavy mineral of sample (L5B9) showing ZR (Zircon), RT (Rutile) and TR (Tourmaline)

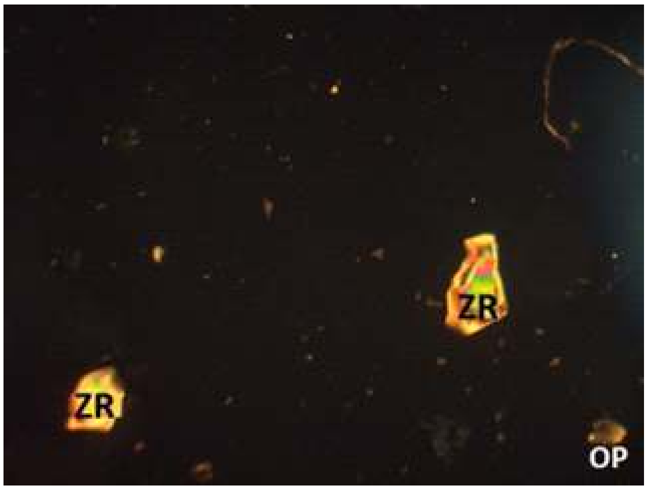


Figure 14: Photomicrograph of heavy mineral of sample (L5B5) showing ZR (Zircon) and OP Opaque mineral in groundmass

4.0 Conclusion

Field observations from the studied sections exposed along road cut revealed sandstones, siltstones, and shale facies. The sandstones vary texturally from fine to medium and coarse grained. The grain size parameters (mean, standard deviation, skewness, and kurtosis) obtained indicated that the sandstones are poorly sorted and immature suggesting river deposit. The very fine skewness and very leptokurtic nature of the sandstones indicated mode of transportation is associated with low energy condition. The poor sorting and angularities of the grain size indicate short transportation history and proximity to the source area. The ranges in texture of the sediments suggest fluctuating energy condition of the transporting medium from low energy depositing the fine grain sand, silts and shale sediments by suspension and saltation mechanism due to excess winnowing while high energy deposits the medium grained and coarse-grained sandstones. The depositional patterns also suggest fluvio-deltaic sedimentation as confirmed by the coarsening upward sequence in most of the sections. The recovery of heavy mineral such as zircon, rutile, tourmaline, sphene, sillimanite and staurolite from the sandstones suggest provenance from igneous and metamorphic terrains probably from the Basement complex rocks of southwestern and northcentral Nigeria. It can be concluded that the sediments in the study areas exhibits sedimentologic properties which are related to their source and availability of different sizes of parent materials.

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