Field characteristics and aspects of the Sedimentology of the Lokoja Basal Sandstone in the Bida Basin, Nigeria: Implications for Paleodepositional Environment.

Abstract

The Lokoja Basal Sandstone, well-exposed in road cuts along the Okene–Abuja highway, was examined to characterize its sedimentological attributes and depositional history. This Campanian to Maastrichtian unit consists of alternating sandy, clayey, and conglomeratic beds, reflecting shifts in depositional energy and sediment supply. The sandstone varies in grain size from very fine to coarse (0.0063 mm – 4 mm), with occasional pebble-sized fractions, indicating periodic episodes of higher energy conditions. Pebbly horizons and conglomeratic interbeds further attest to the fluctuating hydrodynamic conditions during deposition.

Sedimentary structures within the succession are dominated by bimodal cross-stratification with north and south azimuths. This bidirectional paleocurrent pattern suggests differing flow regimes. The cross-stratified sand bars are composed of angular to subangular grains. The presence of angular to subangular pebbles points to a short transport distance. Such textural immaturity, coupled with the dominance of high-angle cross-stratification, indicates deposition under a high-energy fluvial regime and short transport distance.

Collectively, the textural and structural features of the Lokoja Basal Sandstone support its interpretation as a product of deposition within river channels and their associated sub-environments (e.g., point bars, mid-channel bars, and channel lags), typical of a dynamic fluvial system. This study presents new sedimentological data from fresh road-cut exposures of the Lokoja Basal Sandstone along the Okene–Abuja highway. By integrating detailed grain size statistics, roundness and sorting analyses, and paleosol observations, we refine the interpretation of the Campanian–Maastrichtian depositional environment of the southern Bida Basin. These results provide an updated framework for understanding fluvial dynamics and sediment dispersal in this under-documented region.

Keywords

Sandstone;Pebble; Depositional environment; Textural maturity; Facies association; Lokoja Sandstone; Bida Basin

1.0.Introduction

Sedimentological studies hold the key to unraveling the Earth's history. It presents information on the provenance (source), source area weathering, transportation history, climate, depositional conditions, post-depositional processes, and physical, chemical, and geomechanical properties of sedimentary rocks. The analysis of sedimentary rocks and the interpretation of sedimentary processes are fundamental in reconstructing ancient sedimentary environments. Understanding the special and temporal distribution of sedimentary rocks and their properties is important in mineral, oil, and gas exploration. This is because sedimentological properties are linked to compositional, petrophysical, and geomechanicalproperties of sedimentary rocks (Folk and Ward, 1957). Sedimentary rocks' properties, such as grain size, shape, sorting, skewness, and kurtosis, are indicators of maturity, depositional environments, and hydrodynamic conditions influencing sediment deposition (Nton and Adamolekun, 2016).

In the central part of Nigeria is the Campano-Maastrichtian Bida (or Mid-Nige/Nupe) Basin, which is a northwest-southeast-trending trough, whose width ranges from 75 to 150 km, and is about 350 km long (Adeleye,1989). It lies between the areas of Kontagora in central Nigeria and the Benue Trough (south of Lokoja). The oldest sedimentary fill of the basin lies unconformably on the Precambrian Basement Complex (PBC) rocks and is also bordered by it in the northeast and southwest parts. Thick molasse formation covered by either one or two thin, unfaulted marine sediments flanked the sedimentary fill (Adeleye, 1974). The formation is viewed as a large shallow deformity with the development of the basin related to tectonism of the Late Cretaceous (Santonian) in southeastern Nigeria and in the Benue region. The existence of a network of linear faults with the same NWSE trend is also indicated in the form of Landsat imagery, borehole logs, and a geophysical survey (Kogbe*et al.*, 1983).Lokoja Sandstone forms the basement of the basin with lateral contact on the exposed crystalline basement in the southwest. Also, the crystalline basement separates the Bida Basin from the Sokoto Basin,in the northwest, and the Anambra Basin in the southeast.

The first cogent reconnaissance geologic surveys in the Bida Basin have been made by Falconer (1911) and Jones (1955; 1958). Subsequently, the first detailed stratigraphic and sedimentological regional studies were carried out by Adeleye (1971,1973,1974). Jan du Chene *etal*. (1978) gave the oldest record of the upper Cretaceous palynomorphs of the southern Bida Basin.Kogbe et al. (1981, 1983) and Ojo (1984) gave geophysical evidence in support of a rift-based origin of the basin. More recently, the Lokoja Formation and the Bida Sandstone have been studied using several methodologies, including sedimentology, petrography, geochemistry, geophysics, and hydrogeology. Olugbemiro and Nwajide (1997) and Olaniyan and Olobaniyi (1996) state that the Lokoja Formation, as well as the Bida Sandstone, are of a continental lithologic and sedimentological nature.

The Lokoja sandstone has been well documented, although with its seemingly unattractive petroleum potential. However, this paper focuses on the provenance deduction and depositional environment interpretation of the Lokoja Sandstone. The study involves lithologic description of outcrop sections, sedimentological characteristics such as texture, sedimentary structures that define their lithofacies types, lithofacies associations, and genetic units of road cuts in the Lokoja area. This would provide valuable datasets that are useful to researchers and explorationists.

2.0. Geology of Bida Basin

The Bida Basin is the area occupied by the so-called Nupe Sandstone(Adeleye, 1971). The Nupe Sandstone has now been renamed the Bida Basin (Adeleye, 1971;Adeleye and Dessauvagie, 1972).In the past, the geological nature of just the southern-most part of the Niger-Benue sedimentary basin, focused on the Niger-Benue confluence, had been only vaguely defined. The area, which is renowned for the thick iron-ore deposits, was part of the early twentieth-century exploration (Falconer, 1911; du Preez, 1952, 1956; Jones, 1955, 1958). Previous studies had focused on general stratigraphy, geomorphology, and petrology, with an unsurprisingly strong bias towards economic geology. Later, Adeleye (1971; 1973) studied sedimentology and stratigraphy throughout the basin with special reference to facies interpretation in the Bida region of the central Niger-Benue area.

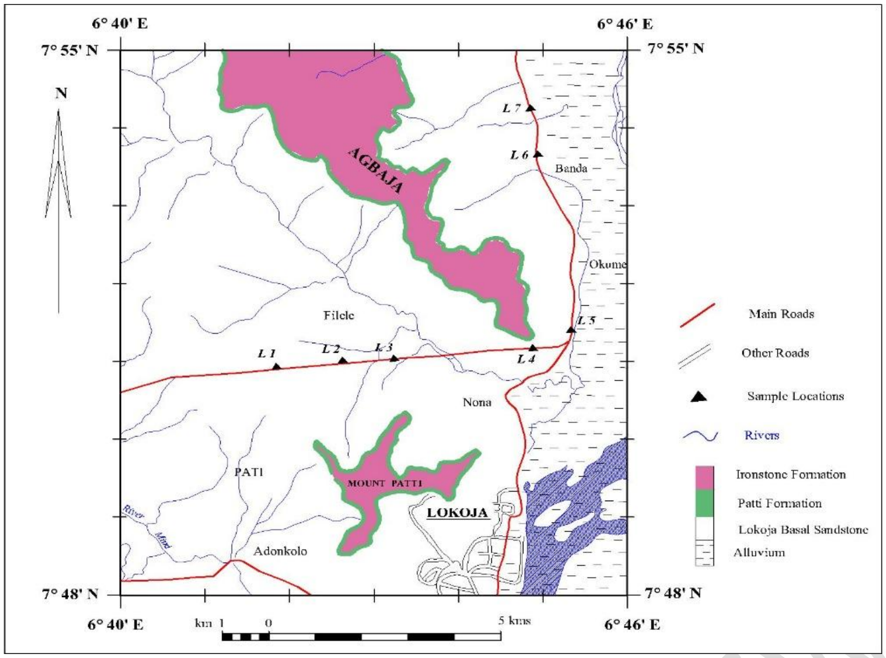

Figure 1: Geological map of Nigeria showing the Bida basin. (After Obaje*et al.*, 2004).

The Niger River flows through the southern edges of the basin in an almost ESE direction. The floodplain in this case is very wide, with a maximum breadth of about 20 km. The palaeorecords indicate that this region is filled with a series of long, shallow lakes that are oriented parallel to the mainstream. The northern Nigeria basement complex is drained by two major distributaries, namely Rivers Kaduna (Wuya) and Gurara, which contribute significant sedimentary input and, thus, constitute the core of large Fadama and rice terrains.

The sedimentary formations are over 300 m, while the basement complex is probably a high-relief buried structure (Jones, 1955).The epeirogenesis that governed the morphology of the basin appears to be very well linked with crustal movements that were experienced during the Santonian tectonism in South-eastern Nigeria and the Benue Trough that was present adjacent to this region. The basin is filled with past-tectonic molasse facies and a thin modern marine layer, which was unfolded.Tertiary uplifts might have distorted the original geometry of the basin, and apparently, such distortion occurred more in the northern part of the basin relative to the southern half of the basin (Benkhelil, 1989).

The stratigraphic succession which has been preserved in the Mid-Niger (Nupe) Basin as originally determined by Adeleye (1973), can be envisaged as consisting of two major structural-stratigraphic regions, viz., the Northern Bida sub-basin and the Southern Bida (or Lokoja) sub-basin (Fig. 2). Geographically, the two sub-basins have a consistent northwest trending that belongs to the Upper Cretaceous sedimentary of a geographical structure which represents the northwestern extension of the Anambra Basin (Akande *et al.*, 2005). They have formed as a result of a very intricate combination of basement faulting, block rotation, episodic subsidence, rifting, and lithospheric drifting elements linked to the Atlantic Cretaceous opening. Also, there is a dextral and sinistral shearing along the adjacent NE-SW-tending Benue Trough, which is seen to be transmitted in more or less orthogonal N-S and NW-SE faulting zones so that the axis of the Mid-Niger Basin can be localized here nearly at right angles to the Benue system (Benkhelil, 1989).

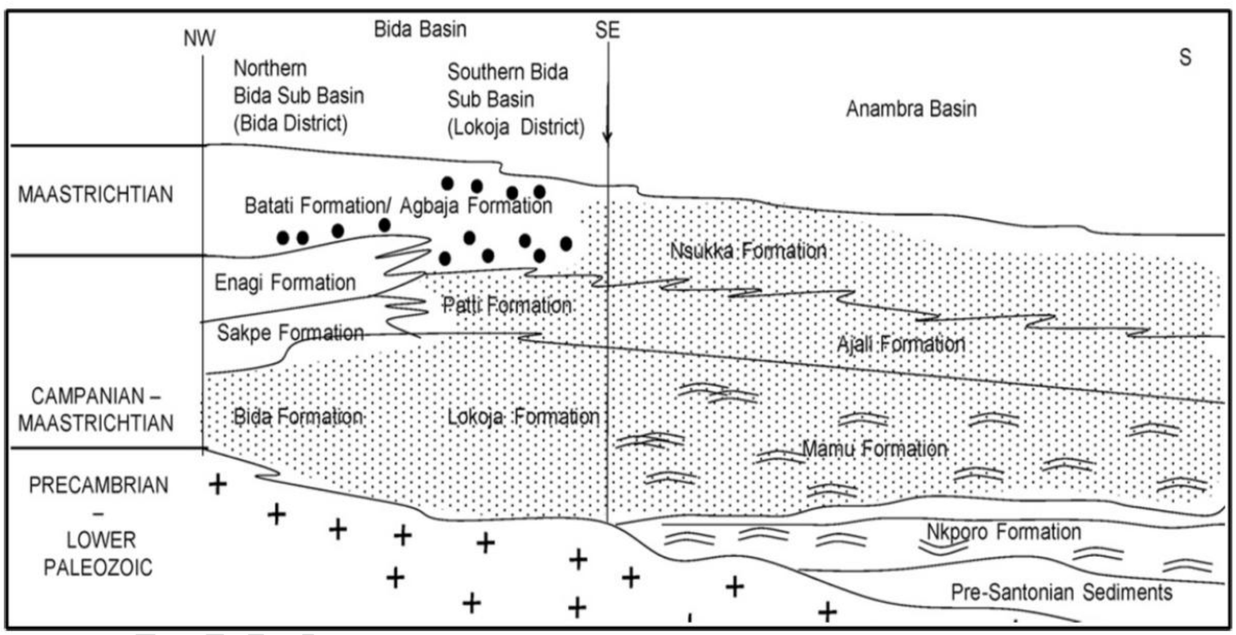

Figure 2: Regional Stratigraphic Successions in the Bida Basin and Restored NW-SE-S StratigraphicRelationships from the Bida Basin to the Anambra Basin (After Akande *et al.*, 2005).

2.1. Lithostratigraphy and Depositional Environment

2.1.1. Bida Sandstone

In the centre, two are identified that are members of the Bida Sandstone, namely the about 183m thick Doko Member and the about 90m thick Jima Member (Adeleye, 1972). The basal piece is the Doko Member and is principally composed of very poorly sorted pebbly arkoses, subarkose, and quartzose sandstones. These have been believed to have been deposited in a braided alluvial fan environment. Cross-stratified quartzose sandstones, siltstones, and claystones are the dominant Jima Sandstone Member. Trace fossils have also been found in abundance (as also in the above overlying Sakpe ironstone Formation), indicative of possible shallow marine sub-tidal to inter-tidal action during deposition. The Jima Sandstone Member is therefore taken to be a more distal equivalent of the upper portion of the Lokoja Sandstone that has already been recorded to have such similar features.

2.1.2. Sakpe Ironstone

The formation is further divided into two members, the Wuya and Baro members of ironstone, with each possessing a thickness of approximately 5m (Adeleye, 1973). Wuya ironstone Member is an Oolitic and pisoliticironstone consisting primarily ofa small amount of sandy claystone at the base locally. The Baro Ironstone is very oolitic in nature and also has a very fast facies.

2.1.3. EnagiSilstone

It is predominantly comprised of Siltstone and is also matched with the Patti Formation of the Lokoja sub-basin. Other subsidiary lithofacies are sandstone,siltstone mixture, and claystones. Within the formation, fossil leaf impressions and rootlets have been discovered, having a thickness that stretches to 30m and 60m. The quartz mineral, feldspars, and clay minerals remain the lithology.

2.1.4. The Batati Ironstone

It is the topmost stratum of the Bida Basin and is made of argillaceous, oolitic, and geothitic ironstones. The ferruginous claystone and siltstone intercalation and shaly beds are also found as a subsidiary stratum with some of them retrieved near shore shallow marine to freshwater fauna (Adeleye, 1973). The Adozzhigi Ironstone and the Kutigi Ironstone are two well-known members.

2.1.5. Lokoja Formation

Lithologic members of this formation are conglomerates, coarse to fine grained sandstones, siltstones, and claystones in the Lokoja area. The subangular and semi-round clusters of cobbles, pebbles, as well as granule quartz grains in units are commonly found in a clay matrix. Both thegrain-supported and matrix-supported conglomerates occur in identifiable beds at the bottom of individual cycles in outcrops. The sandstone units are commonly cross-stratified, poorly sourced in general, and consist of quartz with feldspar, and hence are texturally immature in mineralogy. The overall features of this sequence, particularly the fining upwards nature, compositional and textural immaturity, and singular trend of the paleocurrents, indicate that the sequence was deposited in a fluvial depositional environment mostly by braided streams with the sands being deposited as channel bars due to the varying velocity of the flow. The fine grained sandstones, the siltstones, and the clays portray the deposits on flood plain over the bank. But according to Petters (1986), some of the diverse arenaceous foraminifera have been reported to occur in some of the clayey intervals of the Lokoja Formation, pointing to some of the shallow marine influence. These foraminiferal microfossils, identified by Petters (1986), however, occur more in the overlying Patti Formation, where deposition was done in shallow marine conditions, which is believed to have occurred more.

The unconformably overlapping basal unit of the Basement Complex is the Lokoja Formation, which is a lateral equivalent of the Bida Sandstone. It is made up of subangular to subrounded quartz pebbles with clay holding them. Letters in this formation include conglomerates, fine to very coarse-grainedsandstone, siltstones, and claystones. Mainly sandstone facies are mostly coloured because of the milky white to purple, massive to cross-stratified. They are also badly sorted and are a mixture of quartz and feldspar, thus texturally and mineralogically immature (Ojo, 1992). Such a formation comes out between Lokoja and Koton Karfi, and it is interpreted as a continental (alluvial fan) deposit (Adeleye, 1989; Braide, 1992).

2.1.6. Patti Formation

The Patti formation measures between 70-100m thick and can be observed between KotonKarfi and Abaji, and it overlies the basal Lokoja Formation. It is made up of sandstones, silty rocks and claystones, and shales. The formation is majorly a fine-grainedextending laterally to form the Enagi siltstone and sections of the Sakpe Ironstones in the central Bida Basins. The siltstones tend to be parallel-bedded, and normally illustrate features of large-scale, large slump characteristic of slope-unstability. This formation is a mineralogically and texturally mature sandstone unit, unlike the Lokoja Formation (Ojo, 1995).

In the Central Bida Basin region,Batati ironstones are the lateral counterparts of Agbaja Ironstone in the Lokoja region.

2.1.7. Agbaja Ironstone

This is the lowest Oolitic ironstone formation in the southern Bida Basin, which overlies the Patti Formation. The Campanian-Maastrichtian deposits are shielded by Agbaja Ironstone,whichformsthe lateritic capping. It is well revealed at Agbaja where three sub-facies, i.e.,oolitic, concretional, and massive ironstones, have been stated. It is graded at about 20m. Ladipo et al. (1994) indicated the action of the sea waves that re-worked Kaolinitic mud into concentric oolites that are commonly found having nuclei or siderite that are now replaced by iron oxides.

2.2. Economic Geology of Bida Basin

The basin is the locus of Minette-type Ironstones in Nigeria and of higher value than that of the N.W. Europe. The topmost lithology, the Batati and the Agbaja Formation, are generally easier to mine because of the relatively thin overburden. It is not so with the Sakpe Ironstones, which is intra-stratified within the sediments of the basin. Since similar ores have been successively processed and economically worked for at least two centuries, the formations are vital to the Nigerian economy.

Secondly, within the basal sandstones, there are some persistent Kaolinitic deposits that can be considered for ceramics (Adeleye, 2014).

3.0. Materials and Methodology

The study area is the lower part of the Lokoja Basal Sandstone. The road construction provided road cuts, which are good exposures of the formerly poorly exposed Lokoja Basal Sandstone, hence the need for it to be studied. GPS readings of each location were taken, and the heights of accessible locations were measured.The Lithologic description of the sections of each location was studied with respect to grain size, colour, angularity, thickness of each bed, texture, mineralogy, and the sand/shale ratio. Structures like cross-stratification, paleo-channels, and rapid lateral facies changes were observed and studied.Photographs of the sections/road cuts and structures were taken. The Lithologic logs were prepared based mostly on the observed field observation, which was later improved upon through laboratory studies.

The planar, small-scale, large-scale, and scoop-shaped cross-stratification surfaces of stratification under study herein are defined in line with Allen (1963a, p.98). The size distributions of sands have been determined based on Wentworth (1922).

The roundness and particle geometry are estimated by comparison to standard grains provided by the Geological Specialty Company, Texas. The disaggregated clasts have been studied using the binocular microscope, and lithological descriptions have been derived. The sandstone type used is the Allen (1965).

3.1. Lithological Study and Description

There were fifteen (15) outcrop samples picked from the road cuts along the Okene-Abuja highway, as regards the lithology. The samples were numbered according to the location and kept in the sample bags for proper documentation.

Pebbles of quartz were obtained at different positions in order to determine their relative distances from the source(s).

Figure 3: A picture of a location close to the new Lokoja market, along the Okene-Abuja highway, showing its vertical extent (the man is 1.8m tall)

Spot samples of the sandstone sections were collected,packed into the sample bags, and labeled appropriately. The samples were taken starting from the lowest/oldest bed to prevent contamination, and also, weathered samples were avoided. Each of the samples collected was studied with unaided eyes and hand lenses in the field.

3.2. Grain size analysis

After field work was done in the study area, the samples were taken to the laboratory for further and better description of the exposures at the road cuts. The following procedures were followed after the sample's descriptions: The sample preparation for sedimentological analysis started with the disaggregation of the samples by soaking 100 g in water for one week, and thereafter decanted. More water was added to the samples and made to pass through the 0.063mm sieve to separate the sands and coarser materials from the argillaceous materials (silts and clays). Disaggregated sediments were then dried on a hot-plate to expel the moisture contained.

After drying, the sediments were weighed again to determine the percentage of sand to clay amount of the sediments. Afterwards, the roundness, grain size, sorting, mineral content, and texture of the sediments were studied. This was studied under a reflected light binocular microscope (sorting and grain-size). The textural analysis followed standard methods of grain size analysis. The cumulative frequency curves were plotted, and the statistical parameters were calculated according to Folk and Ward (1957).

Thin sections of some selected samples were prepared and studied under a reflected light binocular microscope. This revealed the information on the modal composition of the sandstone. Lithologic characteristics of the studied samples were then carefully noted and documented based on the observed textural and or compositional characteristics.

4.0. Results

4.1. Field relationship and sedimentological properties of the Formation

The Formation is composed generally of sandstone, conglomerates, and argillaceous materials (silts and clays). There is observed rapid lateral facies changes from the pebbly/conglomeratic sandstone at the base to the fine-grained sandstone/siltstone and claystone at the top (Fig. 4 a). This fining upward sequence of facies continues to the overlying Patti Formation. The grain size ranges between medium to coarse grains (0.0063 - 4); the sandstones are generally angular to subangular. The Formation shows a general fining upward sequence (Fig. 3). The basal unit of some parts of the Formation shows weathered gneissic bedrock, which means a Nonconformity is present (Fig. 4 b), and in the other parts, it is not visible. The weathered gneissic bedrock consists of granitic pegmatite and quartz pegmatite. There is a general occurrence of purplish or brownish paleosoil in the Formation and scattered pebbles of quartz (Figure 5 a and b). The quartz pebbles have colours ranging from glassy, smoky, milky, and light brown in colour. The Formation shows an irregular conglomeratic base as a boundary between each unit of the road cuts, and also rapid lateral facies changes. There are lots of feldsparthic grains in the Formation. Some parts of the Formation show cross-stratification of both the northerly and southerly azimuth (Figure 6 a and b). There are also rare occurrences of ferruginised zones of yellowish to brownish colour (Fig. 6 b).

Figure 4: (a) Photograph showing rapid lateral facies change (The man is 1.8m tall), (b) Photograph showing non-conformity at the base of the section. (The man is 1.6m tall).

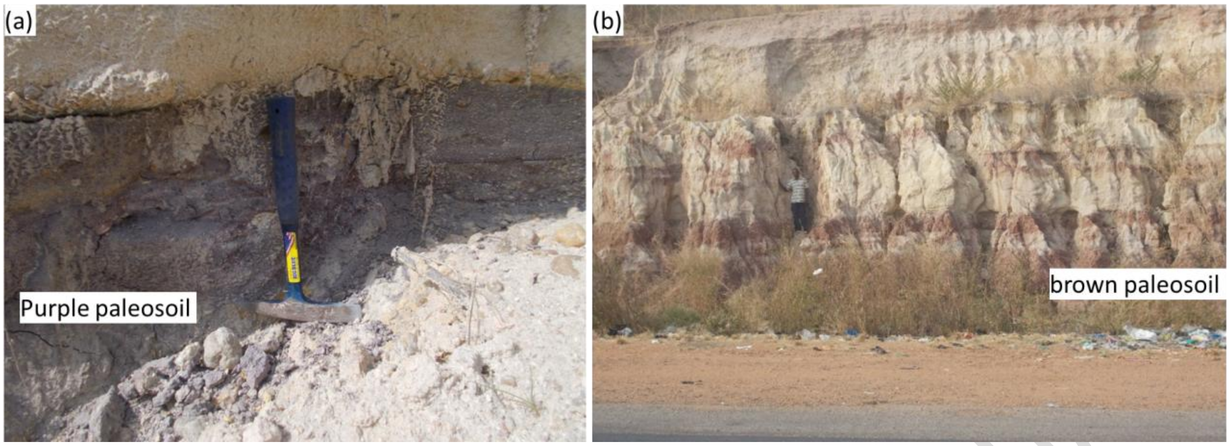

Figure 5. Photograph showing paleosoils; (a) Purple paleosoil. (b)Brown argillaceous paleosoil unit at FileleJunction. (The man is 1.8m tall).

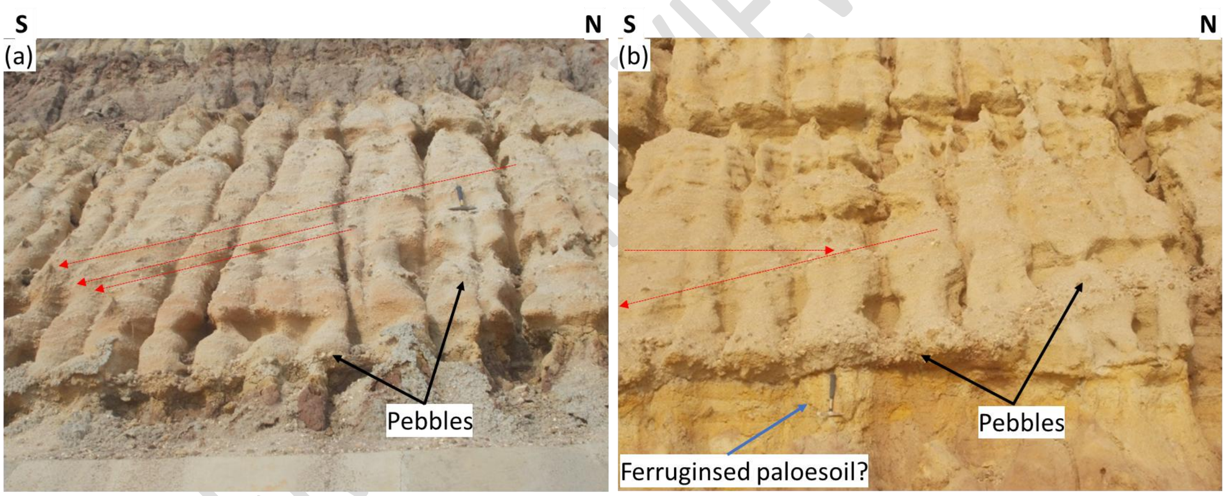

Figure 6(a and b). Photograph showing cross-stratification in the southerly and northernly azimuths; (No scale due to inaccessibility). The hammer in b is resting on a ferruginised layer (ferruginisedpaleosoil?).

The table below shows the result of the laboratory analysis carried out on fifteen (15) samples collected from the Lokoja Formation of Bida Basin.

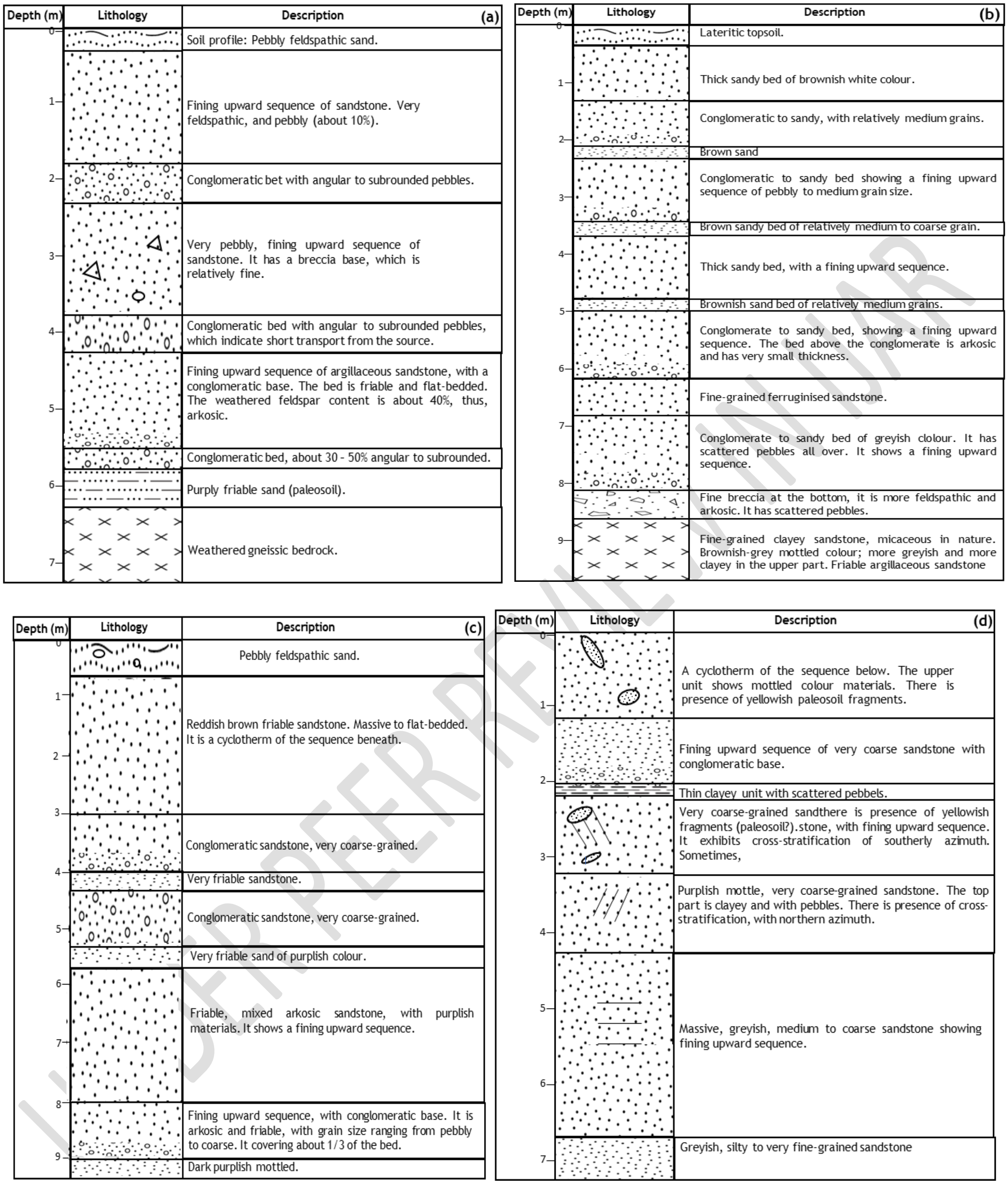

Figure 7 (a-d). Lithologic sections and descriptions of the outcrop locations 1, 3, 4, and 5.

Table 1. Laboratory results for the analyzed samples.

Sample number	Mineralogy	Roundness	Sorting	Grain size (mm)	Colour	% sand and coarser	% Argillaceous	Thickness (m)
Location 1								
1	Feldsparthic sandstone	Angular to subangular	Moderately sorted	0.5 - 1	Mottled, purple brown and yellow	48.4	15.9	0.7
2	Feldsparthic sandstone	Angular to subangular	Poorly sorted	0.0063 - 4	Creamy	84	16	0.9
3	Geissose bedrock	Angular to subangular	Poorly sorted	0.0063 - 2	Brown	94.9	5.1	0.8
Location 2								
1	Arkosic	Angular to subangular	Moderately sorted	0.0063 - 0.5	Creamy yellow	94.9	5.1	-
2	Arkosic	Angular to subangular	Moderately sorted	0.0063 - 0.5	Creamy yellow	92	8	-
3	Feldsparthic sandstone	Angular to subangular	Moderately sorted	0.0063 - 0.5	Creamy yellow	92.5	7.5	-
Location 3								
1	Arkosic	Angular to subangular	Poorly sorted	0.0063 - 1	Creamy yellow	88.4	11.6	1.12
2	Feldsparthic	Angular to subangular	Poorly sorted	0.0063 - 1	Brown	61.8	38.2	0.85
3	Quartzose	Angular to subangular	Poorly sorted	0.0063 - 2	Yellowish brown	89.2	10.8	0.65
Location 4								
1	Quartzose	Angular to subangular	Moderately sorted	0.0063 - 0.5	Greyish	45.1	54.9	0.34
2	Arkosic	Angular to subangular	Poorly sorted	0.0063 - 2	Brown	15.5	84.5	1.12
Location 5								
1	Quartzose	Angular	Poorly sorted	0.0063 - 1	Whitish	74.9	25.1	0.5
2	Feldsparthic	Subangular to subrounded	Poorly sorted	0.0063 - 4	Brown	81.4	18.6	2.3
3	Feldsparthic	Angular to subangular	Moderately sorted	0.0063 - 0.5	Dark brown	29.6	70.4	1.1
4	Arkosic	Angular to subangular	Poorly sorted	0.0063 - 2	Yellowish brown	82	18	-

5.0. Discussion

The angularity of the pebbles and grains of the formation and the general sorting suggest first-cycle deposits, that is, they have not been reworked and they are not far from their source (Allen, 1970). The influence on the cobbles and pebbles of quartz shows they are not far from the source. Usually, most quartz pebbles after travelling some distance of say 20km are relatively rounded, but in this formation, it is not so; thus, the sediments are not far from the source (Allen, 1970).

The evidence of paleosoils supports that they are not too far from the source. The results of the sand/shale ratio demonstrate that some quiet water must have been present, but not very clean of violent environments (Allen, 1970). This is because of the presence of pebbles found in the clays, which is a result of the high-energy environment of deposition. The argillaceous materials (silts and clays) are products of a quiet water environment; in spite of the high energy condition of deposition, we also have quiet areas. The distribution of the argillaceous facies within the sandy facies suggests a common source but different depositional environments (Adeleye, pers. Com, 2015).

The matrix may be partly detrital and partly diagenetic. Some of the matrices were possibly derived through the decomposition of feldspar grains, as evidenced by the occurrence of weathered feldspars. The presence of coarse grains also suggestsa turbulent water condition.

The cross-stratification of both Northerly and southerly azimuths, the grains of the bars are not well sorted like the beach sediments, and they are also not as rounded as the beach sediments. This suggests that the formation is not marine but fluvial (Allen, 1970). Since the bimodal cross-stratification is not coastal, this means that the units were formed from normal dunes. As a result of the high energy conditions, we have anti-dunes, and we have migration of some bars up-current instead of down-current (Allen, 1970). This cross-stratification was formed from up-current and down-current movements of the sediment bars.

6.0. Conclusions

The analysis of the Lokoja Basal Sandstone (Lokoja Formation) exposed by the road cut along Okene-Lokoja Road in the Bida Basinrevealed that the sedimentary rocks were deposited under non-marine conditions. The poor sorting of the grains of the formation suggests the immaturity of the sediments; also, the grain size is evidence of the immaturity of the sediments. It is relatively coarse-grained. The presence of paleosoils demonstrates their nearness to the source and shore. The grains are generally angular to subangular, which suggests a short transportational system and fluvial depositional environment.The absence of fossils shows the environment is toxic, and there is no preservation of organic materials. Based on the results of the study, the existence of rapid lateral facies changes supports non-marine/non-brackish, fluvial sediments. The bimodal cross-stratification of angular to subangular grains also supports fluvial depositional environments. Thus, the Lokoja Basal Sandstone is an immature sediment of a fluvial depositional environment not far from the source

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