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Pebble Morphometric studies of the Cretaceous Lokoja Formation exposed around Karara-Banda area, North Central Nigeria

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ABSTRACT

Field study, Pebble morphometry and X-ray diffraction analyses of the Cretaceous Lokoja Formation have been carried out in the Karara-Banda region of Bida Basin. These analyses aimed to understand the transportation distance, mineralogical composition, sediment maturity and depositional environment of the formation. The Basement complex is unconformably overlain by the Lokoja Formation according to field observations. It is made up of sandstones that may be found in the Lokoja area between Karara-Banda. Conglomerates are found near the base of the lithology, followed by sequences of coarse-grained to fine-grained sandstones, siltstones, and claystones. One hundred pebbly and pebbly sandstone samples were collected from four outcrops in the study area. Pebble Morphometric analysis indicate clear evidence of river transport sediment for the studies Lokoja Formation based on mean sphericity of > 0.66 as well as MPSI and OPI values. The results show that the sediments in the basin are deposited after short travel in an oxidizing environment under fluvial system while the pebbles are products of neighbouring basement rocks of western and northern Nigeria.

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INTRODUCTION

The Bida is among Nigeria's inland frontier basins and divided into northern and southern parts (Obaje et al., 2011; Aigbadon et al., 2022a, Ozulu et al., 2023). The Bida Formation is at the bottom of the Bida Basin's conventional stratigraphy in the northern axis, followed by the Sakpe, Enagi, and Batati Formations respectively (Obaje et al., 2020). Falconer (1911) was among the first to identify and examine the upper Cretaceous rocks of the Bida Basin. The series was divided into two age-equivalent sub-basins by Jones (1958); the Southern Lokoja sub-basin and also the central Bida sub-basin. Russ (1930), Adeleye, and Dessauvagie (1972) created the name Nupe Group to characterize the geologic sequence with both the northern and southern Bida Basins

Adeleye and Dessauvagie (1974), Jones (1958), and Obaje (2009) described the basin's general strata with the Lokoja Formation at the base, the Patti Formation is above it, and the Agbaja Ironstone which capped the Lokoja sub-basin. Central Bida sub-basin, Bida Formation is unconformably overlain by Sakpe Ironstone and Enagi Siltstone, and is topped with Batati Ironstone. Several studies on pebble, pebble sandstone morphometric have been conducted on Bida Basin as discussed by (Nton and Ademolakun, 2016; Aigbadon at al. 2022 b; Ocheli at al., 2018). They used morphometric parameters analyzing the transportation history, mineralogical maturity of the sediment and their depositional environment in the basin.

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But outcrops studies on pebbles analysis has not be done on Banda Karara axis of the basin. This study will use outcrop studies, textural and XRD analysis on the outcrops in deducing sediment history and paleodepositional processes lacking in the study area.

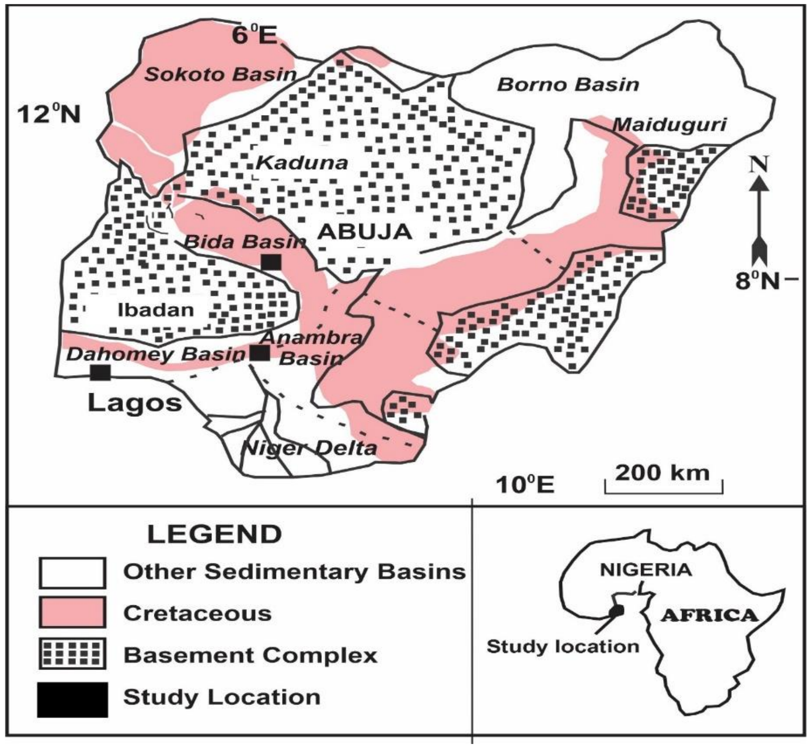

Figure 1: Geological map depicting the study area [modified after Aigboadon et al.2022a]

Geological Setting

The Bida basin is a NW-SE trendiest inland basin that stretches from Shegwa (NW) to Dekina (SE). It stretches for around 350 kilometers and ranges in breadth from 75 to 150km (Rahaman, 2019). The sedimentation and stratigraphy of the upper Cretaceous strata of the Bida Basin were studied by (Adeleye, 1974, 1976; Ladipo, 1988; Abimbola, 1997; Braide, 1992a; Obaje, 2009; Obaje et al., 2011). Adeleye and Dessauvagie (1972); Obaje et al. (2009) identified four mapable stratigraphic units and their equivalents that extended from the north to the south of the basin within Campanian to Maastricthian. Campanian Lokoja Sandstone (mainly conglomerate and sandstone), the Maastrichtian Patti Formation (shale, claystone, and sandstone), and the Agbaja Ironstone with their lateral stratigraphic equivalent in the northern Bida Basin include the bottom Bida Formation (conglomerate, sandstone), Sakpe Ironstone, Enagi Formation (siltstone, claystone, and sandstone), and Batati Formation (siltstone, claystone, and sandstone) (Fig. 2).

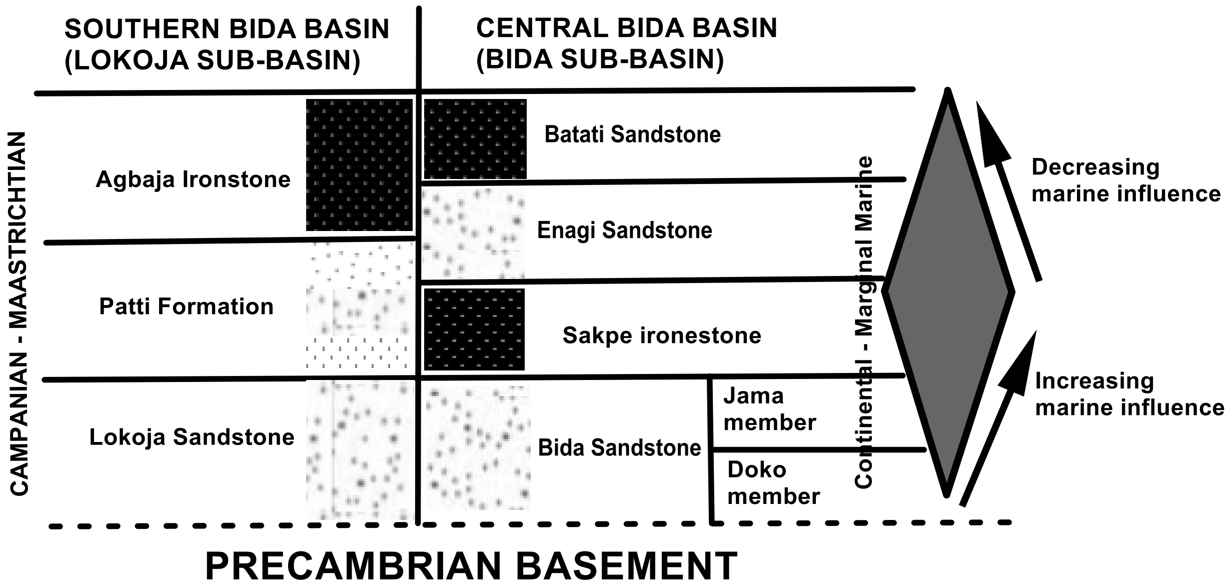

Figure 2: Stratigraphic Succession in the Bida Basin (Redrawn after Obaje, 2009)

Southern Bida Basin (Lokoja Sub-Basin)

Three formations have been identified in the southern Bida Basin that is Campanian to Maastrichtian in age (Adeleye and Dessauvagie, 1972; Agyingi, 1991). The formations are the Lokoja Sandstone, Patti Formation, and upper part Agbaja Ironstone.

The Lokoja Sandstone

Adeleye and Dessauvagie proposed the name Lokoja Sandstone because it lays unconformably on upper edge of Precambrian foundation rocks. Falconer (1911) named the Lokoja series after the Upper Cretaceous sedimentary rocks were discovered at Lokoja with it's Bida Sandstone's lateral counterpart. In this formation, basal conglomerates and sandstone are closely partially filled with siltstone and claystone. They are poorly sorted feldspathic sandstones with interbedded siltstone and claystone. 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. Alluvial and banks processes were assumed to have formed the sandstones and conglomerates in a continental context (Akande et al., 2005).

Patti Formation

Patti Formation was coined by Adeleye and Dessauvagie (1972). Fine to medium-grained grey and white sandstones, clays and carbonaceous silty clay and shales, oolitic ironstone, and light impurity coal seams lie directly on top of the Lokoja Sandstone in this formation. Between Kotonkarfi and Abaji, the argillaceous rocks (shale, siltstone, and claystone) are extensively exposed in this structure, according to Obaje et al. (2011) Parallel laminae are abundant in Patti Formation siltstones, with wavy ripples of soft sediments, deformational structures (e.g. slumps), convolute laminations, and load structures.

Trace fossils (especially Thalasinoides) are commonly preserved. The claystones interbedded are big and kaolinitic in composition. The oolitic ironstones have a thickness of 7 to 16 m, whereas the visible thickness is 70 m (Jones, 1958). According to Agyingi (1993), such strata have a thickness ranging up to 220 m, reflecting a meandering river landform. The type locality is Mount Patti in Lokoja. It's the lateral equivalent of the Enagi Sandstone in the northern Bida Basin. According to Akande et al. (2005), this sandstone of the Patti Formation is mineralogically well developed than that of the Lokoja Formation. Jan Du Chene et al. (2005) attributed a Maastrichtian age to palynofossils obtained from a roadside exposure north of Lokoja based on palynofossils. Mebradu (1986) postulated a Maastrichtian dating for the same or at least surrounding exposures based on palynofossils and foraminifers. The sequence's overall characteristics, particularly its fining upwards character, compositional and textural immaturity, and unidirectional paleocurent trends, point to a fluvial depositional environment dominated by braded streams and water sands deposited as channel bars as a result of fluctuating flow velocity Ayinla (2016).

The Agbada Ironstone

Adeleye and Dessauvagie (1972) proposed Agbaja Ironstone. This formation forms a durable cover for the Campanian–Maastrichtian layers in the southern Bida Basin and is a lateral equivalent of the Batati Ironstone mostly in northern sub-basin. In this formation, sandstones and claystones are partially filled with oolitic, concretionary, and massive ironstone strata. The sandstones and claystones were interpreted as altered by the sea abandoned channel sands and over bank deposits, resulting in massive concretionary and oolitic ironstones (Ladipo et al., 1994).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 (Braide, 1992b; Olaniyan and Olobaniyi, 1996). During the deposition of the Agbaja Ironstones in the southern Bida Basin, the maritime inundations appear to have persisted (Ladipo et al., 1994). Within the Agbaja Ironstone, Abimbola (1997) identified three facies. These are the following:

- At the top, there is a breccias mud-ironstone with angular to sub-angular detrital grains and angular clasts predominantly made up of kaolinitic false ooids with faint replacement goethite rings.

- Pisoidal pack-ironstone with a goethite core and a haematite rim, formed of relatively dense pisolites containing goethite, minor haematite, and relict kaolinite. The matrix is made up of kaolinite.

- Spherical ooids of kaolinite, kaolinite goethite, or haematite within a kaolinite matrix at the bottom of an ooidal pack-ironstone. Adeleye (1973) argued that the ooidal and pisolitic ironstones originated in high-energy, subtidal beach line habitats advancing into fluviatile and swamp areas, akin to Minette-Type deposits.

3 Materials and Method

3.1 Field studies

In the study regions, a field examination was conducted to examine and describe exposed rock units, log their vertical sections, and identify the lithofacies in the studied outcrop units. Repeated logging was done on four lithologic regions on Karara Banda axis of the Basin. The lithology, textures, and sedimentary formations were examined in the four lithologic sections after methods adopted in published works by (Aigbadon et al., 2022 b; Okolo et al., 2020; Aigbadon et al., 2023). Photographs were taken of the research area's rock exposures, and samples of pebbles and sandstone were gathered for laboratory investigation.

3.2 X-ray Diffraction (XRD)

The x-ray diffractometer method was used for Mineralogical analyses of samples in order to determine the mineralogical composition. This was done in accordance with published sources (Aigbadon et al., 2022 b; Aigbadon et al., 2023).

3.3 Pebble morphometry Analysis

200 pebbles were sampled random from the four outcrops within the research area and they were properly labelled. Only quartzose pebbles with a medium diameter over 4 mm because of strong resistance to abrasion were chosen for the analysis prior to measurements. The long (L), intermediate (I), and short (S) axes of each of the quartzose pebbles were measured using the vernier callipers in accordance with Ocheli et al. (2018), Zingg, 1935, and Krumbein, 1941 (Table 1). By visual comparison with picture charts, the pebble's roundness was assessed (Same, 1966).

4. Results

Table 1: **Formulae used in Computation of Morphometric Parameters**

PARAMETERS	FORMULA	AUTHORS
Flatness ratio(FR)	Short axis/long axis (S/L)	Luttig(1962), Aigbadon et al., (2022 b), Ocheli et al.,(2018)
Elongation ratio(ER)	I/L	Luttig(1962)
Forms	L-I/L-S	Sneed and Folk(1958)
Maximum projection sphericity index	(S2/LI)1/3	Sneed and Folk(1958)
Obate-Prolate Index (OPI)	10(L-I-0.5)/(L-S)/(S/L)	Dobkins and Folk(1958)
Roundness%	Visual estimate of the pebbles	Sames(1966)

Table 2: Pebble Morphometric Data for outcrop1

samples	Long	short	Intermediate	S/L	I/L	L-I/L-S	MPSI	OPI INDEX	ROUNDNESS %
A1	4.9	2.3	3.3	0.47	0.67	0.62	0.69	2.88	30%
A2	3.9	1.7	3.4	0.44	0.95	0.23	0.60	0.00	50%
A3	5.3	1.7	4.2	0.32	0.79	0.31	0.51	2.31	30%
A4	3.9	2.9	3.8	0.74	0.97	0.1	0.83	-2.28	50%
A5	4.4	1.8	4.2	0.41	0.95	0.72	0.56	-0.98	30%
A6	4.2	2.8	4	0.67	0.95	0.13	0.78	-0.98	50%
A7	3.6	1.9	3.1	0.53	0.86	0.29	0.68	0.00	50%
A8	4.3	2.2	3.7	0.51	0.86	0.29	0.67	0.32	50%
A9	4.1	2.3	3.6	0.56	0.88	0.28	0.71	0.00	50%
A10	3.5	2.1	3.3	0.6	0.94	0.14	0.72	-1.34	30%
A11	4.9	2.6	4.6	0.53	0.94	0.13	0.67	-0.16	30%
A12	2.8	2.0	2.1	0.75	0.75	0.87	0.88	1.54	30%
A13	4.4	1.9	3.4	0.43	0.77	0.4	0.62	1.39	30%
A14	2.6	1.5	2.3	0.58	0.88	0.27	0.72	-1.16	40%
A15	3.3	2.2	3.2	0.61	0.97	0.77	0.72	-1.92	50%
A16	3.7	2.2	3.4	0.54	0.92	0.18	0.68	-0.76	50%

A17	3.2	2.2	3.0	0.63	0.94	0.67	0.72	-1.55	50%
A18	3.7	1.8	3.4	0.49	0.92	0.16	0.64	-0.76	30%
A19	3.7	2.2	3.4	0.59	0.92	0.2	0.73	-0.91	30%
A20	3.5	2.4	2.7	0.68	0.77	0.73	0.85	1.53	70%
A21	2.2	1.4	2.1	0.64	0.95	0.13	0.75	-3.07	40%
A22	4.2	1.5	3.0	0.36	0.71	0.44	0.56	1.91	40%
A23	2.7	1.5	2.1	0.56	0.78	0.5	0.63	0.54	50%
A24	5.5	1.7	4.5	0.31	0.82	0.26	0.49	7.01	30%
A25	4.2	1.5	3.3	0.36	0.78	0.33	0.55	1.09	50%
A26	3.6	1.3	3.5	0.42	0.97	0.43	0.51	-1.31	50%
A27	3.6	1.5	2.9	0.26	0.81	0.33	0.59	0.62	40%
A28	4.1	1.1	3.3	0.82	0.80	0.27	0.45	0.94	30%
A29	2.8	2.3	2.6	0.82	0.93	0.4	0.89	-1.62	50%
A30	4.1	1.7	3.5	0.41	0.85	0.25	0.59	0.32	30%
A31	3.8	2.2	3.3	0.59	0.87	0.31	0.73	0.00	50%
A32	4.1	1.9	3.9	0.46	0.95	0.91	0.61	-0.93	50%
A33	4.4	1.8	4.1	0.59	0.93	0.12	0.56	-0.59	40%
A34	2.5	1.5	2.3	0.6	0.92	0.2	0.73	-1.87	40%
A35	3.1	2.0	3.1	0.65	0.97	0.91	0.75	-2.78	50%
A36	3.8	2.2	3.5	0.58	0.92	0.19	0.71	-0.79	30%
A37	4.0	1.4	3.4	0.35	0.85	0.23	0.52	0.28	40%
A38	3.2	2.2	3.0	0.69	0.94	0.2	0.79	1.78	40%
A39	3.1	1.1	2.7	0.35	0.87	0.2	0.52	-0.44	50%
A40	3.1	2.3	3.0	0.74	0.97	0.13	0.83	-2.13	50%
A41	4.7	2.5	4.0	0.53	0.85	0.32	0.69	0.51	50%
A42	6.2	2.0	5.9	0.32	0.95	0.71	0.48	-0.39	40%
A43	3.9	2.0	2.9	0.56	0.74	0.53	0.71	3.45	50%
A44	4.2	2.1	3.9	0.5	0.74	0.14	0.65	0.58	50%
A45	5.4	2.0	5.2	0.37	0,93	0.59	0.52	-0.64	30%
A46	5.1	2.4	5.0	0.47	0.96	0.37	0.61	-1.01	30%
A47	3.8	2.2	3.7	0.58	0.98	0.06	0.70	-1.58	30%
A48	4.3	2.3	3.8	0.53	0.97	0.5	0.69	0.00	50%
A49	4.0	2.3	3.5	0.58	0.88	0.29	0.72	0.00	40%
A50	3.6	2.0	3.4	0.56	0.87	0.12	0.69	-1.23	50%

Table 3: Pebble Morphometric Data for outcrop location 2

samples	Long	short	intermediate	S/L	I/L	L-I/L-S	MPSI	OPI INDEX	ROUNDNESS
B1	5,4	2.4	2.7	0.44	0.5	0.9	0.73	5.06	30%
B2	7.0	2.0	2.7	0.29	0.38	0.86	0.59	5.86	30%
B3	5.4	2.6	2.7	0.48	0.5	0.96	0.77	5.29	50%
B4	4.9	2.0	2.9	0.41	0.59	0.69	0.66	3.68	40%
B5	4.7	1.8	3.2	0.38	0.68	0.52	0.74	2.49	30%
B6	4.9	2.2	3.1	0.45	0.63	0.67	0.68	10.99	50%
B7	4.7	2.2	2.4	0.47	0.51	0.92	0.75	4.90	40%
B8	3.1	1.8	2.4	0.58	0.77	0.54	0.76	0.97	30%
B9	4.8	2.1	2.2	0.44	0.46	0.96	0.75	5.42	40%
B10	3.2	1.8	2.3	0.56	0.72	0.5	0.76	1.82	50%
B11	4.3	1.3	1.4	0.30	0.33	0.96	0.65	6.14	30%
B12	4.5	1.5	2.2	0.33	0.49	0.77	0.61	4.49	30%
B13	5.0	2.5	2.8	0.5	0.56	0.88	0.76	4.5	70%
B14	4.8	2.0	2.2	0.42	0.42	0.93	0.73	5.30	50%
B15	5.2	2.2	2.3	0.17	0.44	0.97	0.73	4.97	30%
B16	3.7	1.5	2.2	0.41	0.59	0.68	0.65	3.24	30%
B17	4.3	1.5	1.8	0.35	0.42	0.89	0.66	5.29	30%
B18	4.9	1.3	1.7	0.27	0.35	0.89	0.59	5.94	40%
B19	3.2	1.5	1.9	0.47	0.59	0.76	0.72	3.21	70%
B20	3.7	2.0	2.4	0.54	0.65	0.76	0.77	3.05	30%
B21	5.2	1.2	2.2	0.23	0.42	0.75	0.50	5.08	30%
B22	4.8	1.8	4.3	0.38	0.89	0.17	0.54	0.00	30%

B23	4.3	1.8	2.5	0.42	0.58	0.72	0.67	3.67	30%
B24	3.1	1.7	2.3	0.55	0.74	0.62	0.74	1.38	50%
B25	4.6	2.2	2.3	0.48	0.5	0.96	0.77	5.08	40%
B26	4.1	1.7	2.4	0.41	0.59	0.71	0.31	3.53	30%
B27	4.0	1.8	2.2	0.45	0.59	0.82	0.72	4.08	40%
B28	4.2	1.6	2.5	0.38	0.55	0.65	0.62	3.34	50%
B29	3.1	2.1	2.2	0.68	0.59	0.9	0.86	2.72	40%
B30	3.0	1.6	2.9	0.53	0.71	0.07	0.65	-1.52	70%
B31	3.8	1.6	2.9	0.42	0.97	0.41	0.61	1.28	50%
B32	4.5	1.1	1.6	0.24	0.76	0.85	0.55	5.66	40%
B33	4.4	1.5	1.7	0.34	0.35	0.93	0.30	5.66	30%
B34	2.6	1.9	2.5	0.53	0.38	0.64	0.74	2.26	30%
B35	3.8	1.3	1.5	0.34	0.69	0.92	0.66	5.36	50%
B36	4.8	2.3	2.5	0.38	0.39	0.92	0.70	4.81	30%
B37	3.0	1.1	2.3	0.37	0.52	0.37	0.56	0.77	40%
B38	3.9	1.2	2.3	0.31	0.77	0.59	0.54	3.12	50%
B39	3.8	2.0	2.7	0.53	0.59	0.61	0.75	2.19	40%
B40	3.6	1.7	1.9	0.47	0.71	0.89	0.79	4.28	50%
B41	4.3	2.4	2.7	0.56	0.53	0.84	0.68	3.72	50%
B42	4.0	1.6	2.0	0.4	0.63	0.83	0.71	4.46	50%
B43	3.4	1.9	2.9	0.56	0.5	0.33	0.63	0.00	30%
B44	4.2	1.5	2.1	0.71	0.85	0.78	0.83	5.10	40%
B45	4.2	3.0	3.1	0.71	0.5	0.92	0.64	2.89	30%
B46	5.3	2.0	2.9	0.37	0.74	0.73	0.82	4.17	30%
B47	4.2	2.4	2.5	0.57	0.55	0.94	0.64	4.24	30%
B48	4.7	1.7	2.4	0.36	0.59	0.77	0.71	4.40	50%
B49	4.6	1.9	2.2	0.41	0.51	0.89	0.62	4.97	30%
B50	3.3	1.3	2.2	0.39	0.48	0.55	0.66	2.15	40%

Table 4: Pebble Morphometric Data for Location 3

samples	Long	short	Intermediate	S/L	I/L	L-I/L-S	MPSI	OPI INDEX	ROUNDNESS
C1	5.0	2.9	3.0	0.58	0.6	0.95	0.82	4.52	50%
C2	4.0	2.4	2.9	0.6	0.73	0.69	0.79	1.69	40%
C3	4.5	2.2	2.9	0.49	0.64	0.69	0.76	3.21	30%
C4	4.9	2.6	3.3	0.53	0.67	0.69	0.75	3.12	40%
C5	4.7	2.0	2.1	0.43	0.45	0.96	0.74	5.67	30%
C6	2.7	2.4	2.3	0.89	0.85	0.86	0.98	-1.77	40%
C7	3.8	2.5	2.7	0.66	0.71	0.85	0. 85	2.79	40%
C8	6.1	1.9	2.1	0.31	0.34	0.95	0.66	6.35	30%
C9	5.1	1.8	2.2	0.35	0.43	0.88	0.66	5.37	50%
C10	5.6	2.2	3.1	0.41	0.55	0.7	0.67	4.29	40%
C11	4.4	2.4	3.0	0.55	0.68	0.70	0.76	2.92	50%
C12	4.5	1.8	2.6	0.4	0.58	0.86	0.65	3.70	30%
C13	3.5	1.4	1.7	0.4	0.49	0.74	0.69	4.42	30%
C14	5.7	1.4	2.5	0.25	0.44	0.62	0.52	5.04	30%
C15	3.0	1.7	2.2	0.57	0.73	0.65	0.76	1.48	50%
C16	5.4	2.8	3.7	0.52	0.68	0.91	0.73	6.28	40%
C17	4.5	1.3	1.6	0.29	0.37	0.43	0.62	0.21	40%
C18	3.1	1.7	2.5	0.55	0.81	0.71	0.72	3.46	40%
C19	4.3	1.9	2.6	0.44	0.60	0.72	0.56	4.86	40%
C20	4.5	0.9	1.9	0.2	0.45	0.83	0.40	5.24	30%
C21	6.0	2.0	2.7	0.33	0.59	0.76	0.63	3.21	30%
C22	3.2	1.5	1.9	0.47	0.59	0.9	0.72	4.46	40%
C23	3.7	1.7	1.9	0.46	0.64	0.71	0.74	3.17	40%
C24	4.2	2.1	2.7	0.5	0.55	0.64	0.32	3.86	50%
C25	5.1	1.5	2.8	0.29	0.69	0.71	0.54	2.26	30%
C26	3.2	1.8	2.2	0.56	0.38	0.71	0.77	5.55	50%
C27	3.7	1.3	1.4	0.35	0.26	0.97	0.69	6.62	50%
C28	4.3	1.0	1.1	0.23	0.78	0.78	0.59	3.43	30%
C29	3.3	1.5	1.9	0.45	0.41	0.84	0.71	5.22	50%
C30	4.4	1.3	1.8	0.29	0.55	0.94	0.67	4.38	30%
C31	3.8	2.0	2.1	0.53	0.82	0.35	0.82	0.39	30%

C32	3.4	1.7	2.8	0.5	0.92	0.27	0.67	-1.06	70%
C33	3.8	2.7	3.5	0.71	0.36	0.94	0.82	5.92	50%
C34	4.7	1.5	1.7	0.32	0.38	0.93	0.66	5.60	30%
C35	4.0	1.3	1.5	0.33	0.51	0.68	0.66	4.15	50%
C36	4.7	1.3	2.4	0.28	0.69	0.54	0.53	2.34	40%
C37	4.2	1.8	2.9	0.43	0.36	0.97	0.28	5.99	50%
C38	4.5	1.5	1.6	0.33	0.53	0.78	0.68	4.23	50%
C39	4.5	1.8	2.4	0.4	0.36	0.93	0.67	6.23	40%
C40	6.4	2.0	2.3	0.31	0.54	0.86	0.65	4.64	30%
C41	5.2	2.4	2.8	0.48	0.39	0.97	0.73	3.11	50%
C42	5.3	2.0	2.1	0.38	0.6	0.62	0.26	3.29	30%
C43	4.5	1.6	2.7	0.35	0.58	0.89	0.78	4.07	30%
C44	4.0	2.1	2.3	0.5	0.61	0.93	0.82	3.64	30%
C45	3.3	1.9	2.0	0.58	0.69	0.56	0.27	2.49	50%
C46	4.5	2.0	3.1	0.44	0.6	0.76	0.72	3.54	50%
C47	4.0	1.9	2.4	0.47	0.42	0.92	0.69	5.18	50%
C48	3.8	1.4	1.6	0.37	0.5	0.88	0.72	4.09	40%
C49	3.0	1.3	1.5	0.43	0.5	0.88	0.64	2.95	50%
C50	3.8	2.6	2.7	0.68	0.71	0.92	0.87	3.18	50%

Table 5: Pebble Morphormetric Data for outcrop location 4

samples	Long	short	Intermediate	S/L	I/L	L-I/L-S	MPSI	OPI INDEX	ROUNDNESS
D1	4.8.	2.6	3.6	0.54	0.75	0.55	0.73	2.06	30%
D2	3.8	2.3	2.4	0.60	0.63	0.93	0.39	3.72	40%
D3	6.0	1.9	4.6	0.32	0.77	0.34	0.51	1.67	30%
D4	5.0	2.4	3.0	0.59	0.6	0.73	0.73	4.18	40%
D5	4.2	2.0	3.0	0.48	0.71	0.55	0.68	2.16	30%
D6	5.1	2.6	3.4	0.51	0.67	0.68	0.73	3.18	30%
D7	4.6	2.9	3.0	0.62	0.65	0.94	0.85	3.93	40%
D8	3.7	3.3	3.4	0.57	0.92	0.75	0.95	-0.99	70%
D9	4	1.8	2.5	0.45	0.63	0.68	0.69	3.13	40%
D10	5.2	2.9	3.1	0.55	0.59	0.91	0.81	4.44	40%
D11	6.3	3.3	3.3	0.52	0.52	0.9	0.81	5.45	40%
D12	3.7	2.3	3	0.62	0.81	0.5	0.78	0.75	40%
D13	5.5	2.5	3.6	0.45	0.65	0.63	0.68	3.20	30%
D14	4.6	1.3	2.7	0.28	0.59	0.58	0.51	3.31	40%
D15	6.7	4.3	4.5	0.64	0.67	0.92	0.85	5.57	30%
D16	5.0	2.3	4	0.46	0.8	0.37	0.64	1.27	30%
D17	4.4	2.9	3.0	0.66	0.68	0.93	0.86	3.62	50%
D18	5.2	3.2	3.5	0.62	0.67	0.85	0.83	3.73	40%
D19	3.1	2.4	2.5	0.77	0.81	0.86	0.91	0.79	50%
D20	7.7	3.2	3.6	0.42	0.47	0.91	0.72	5.66	40%
D21	3.8	2	3.4	0.53	0.89	0.22	0.68	-1.32	40%
D22	4.3	2	3.0	0.47	0.69	0.57	0.86	2.47	50%
D23	5	2.8	2.5	0.56	0.5	0.45	0.88	5.43	50%
D24	3.5	2.2	2.0	0.63	0.57	0.76	0.81	4.41	40%
D25	4.4	2.6	2.9	0.59	0.66	0.83	0.93	3.49	50%
D26	4.6	3.1	2.6	0.67	0.57	0.33	0.78	5.01	40%
D27	4.6	2.4	2.6	0.57	0.57	0.91	0.51	5.29	40%
D28	4.4	1.4	3.3	0.32	0.75	0.37	0,84	1.52	50%
D29	3.2	2.1	2.3	0.66	0.72	0.82	0.70	2.21	40%
D30	3.9	1.8	2.4	0.46	0.62	0.71	0.72	3.26	50%
D31	3.3	2.0	3.2	0.61	0.97	0.07	0.68	-1.92	40%
D32	4.2	2	3	0.47	0.71	0.55	0.76	2.15	50%
D33	4.2	2.6	3.9	0.62	0.93	0.19	0.70	-1.77	50%
D34	4.1	1.8	2.3	0.44	0.56	0.78	0.67	3.93	50%
D35	3.5	1.7	2.8	0.49	0.8	0.39	0.71	0.75	30%
D36	5.1	2.5	3.4	0.49	0.67	0.65	0.81	3.09	50%
D37	3.7	2.6	3.4	0.70	0.92	0.27	0.53	-1.06	40%
D38	5.0	1.8	4.3	0.36	0.86	0.22	0.64	0.46	40%
D39	5.5	2.3	3.7	0.24	0.67	0.56	0.53	2.63	40%
D40	3.4	1.8	2.9	0.53	0,85	0.31	0.54	0.41	40%

D41	3.9	1.2	2.4	0.31	0.62	0.56	0.59	2.83	50%
D42	4.1	1.7	3.3	0.41	0,80	0.33	0.62	0.88	50%
D43	2.9	1.2	2.1	0.41	0.72	0.47	0.74	1.25	40%
D44	4.3	2.1	2.5	0.48	0.58	0.82	0.72	3.45	50%
D45	3.3	1.8	2.6	0.55	0.79	0.47	0.88	0.86	40%
D46	3.9	2.9	3.2	0.74	0.82	0.7	0.68	1.14	50%
D47	4.1	1.8	2.5	0.44	0.61	0.69	0.62	3.33	40%
D48	5.1	2.2	3.9	0.43	0.76	0.41	0.62	1.69	50%
D49	4.3	1.7	2.8	0.39	0.65	0.58	0.62	2.75	50%
D50	4.8	2.7	3.7	0.56	0.77	0.53	0.74	1.82	40%

Pebble plots to determine the environments using MPSI vs. OP index

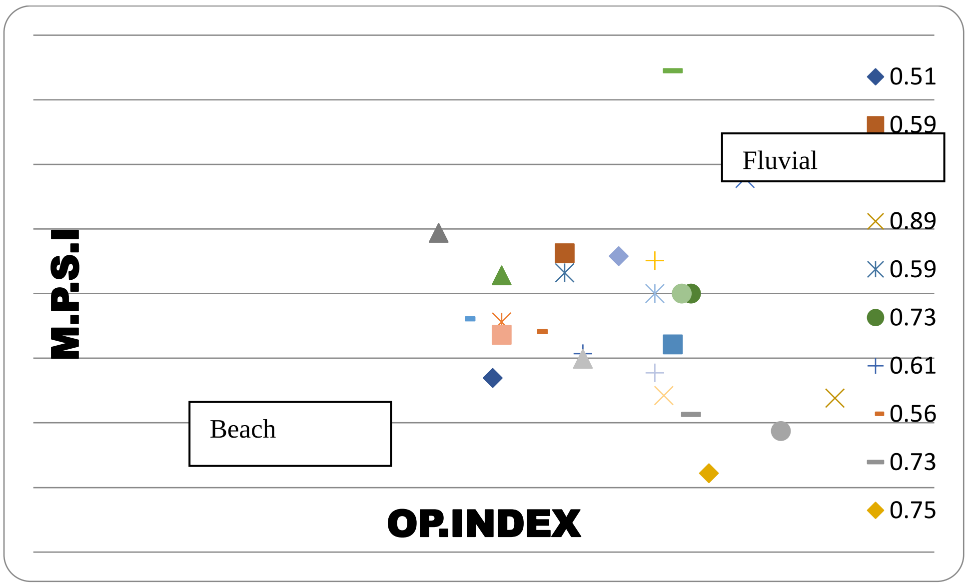

Figure2: **Pebble plots of MPSI vs OP index for outcrop 1**

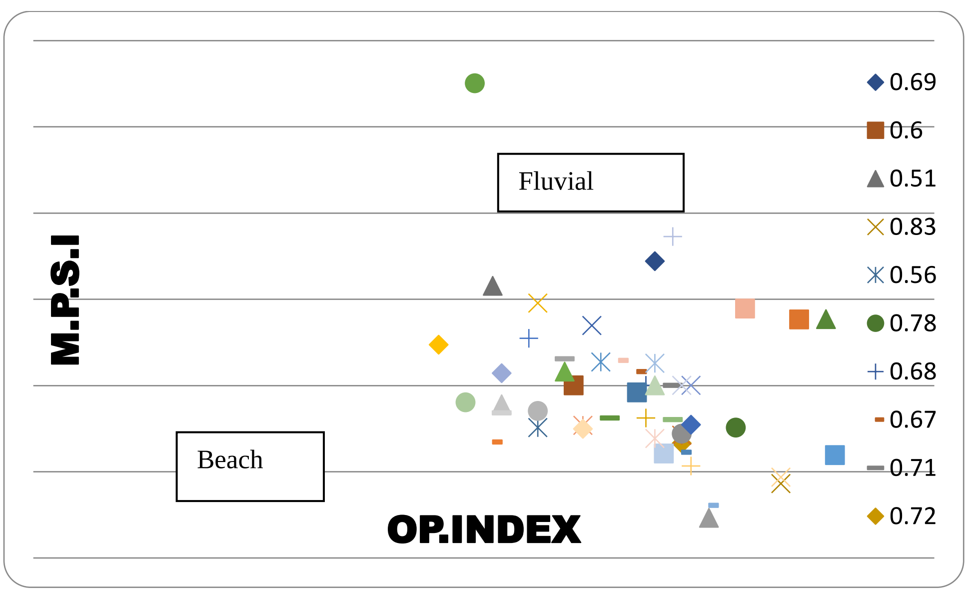

Figure 3: Pebble plots of MPSI vs. OP index for outcrop 2

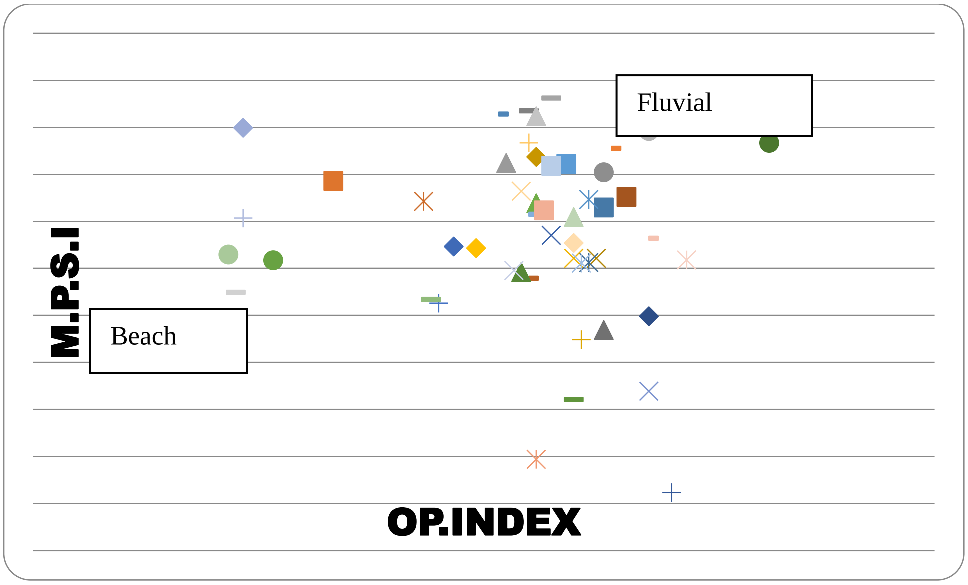

Figure 4: Pebble plots of MPSI vs. OP index for outcrop 3

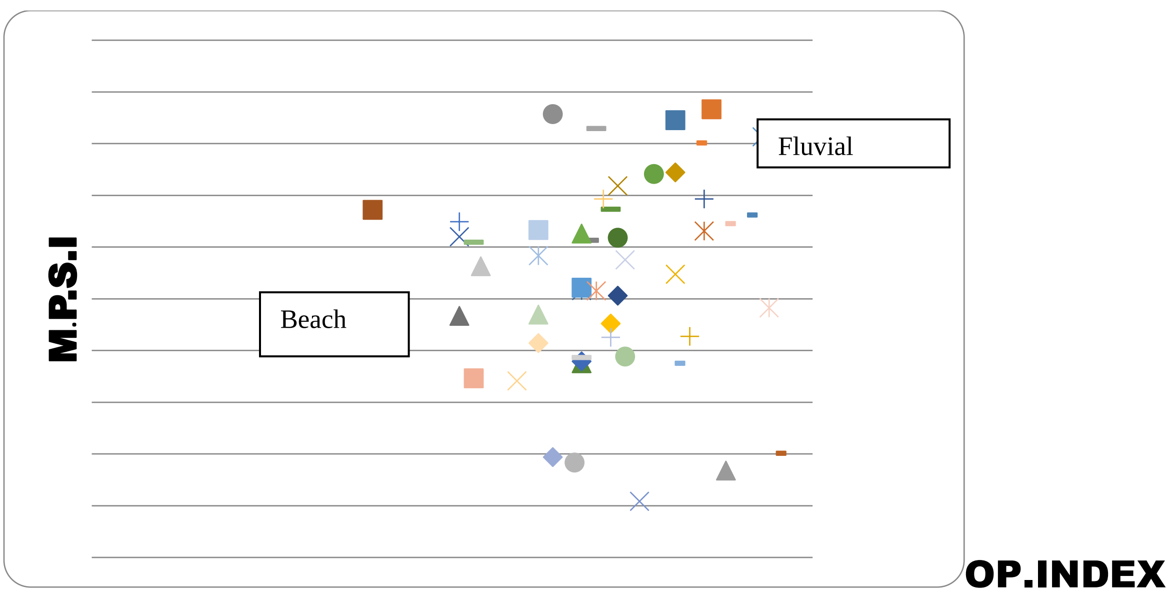

Figure 5: Pebble plots of MPSI vs. OP index for outcrop 4

From the pebble plots of MPSI vs. OP index from all outcrop sections in the basin depicts that pebbly sandstone units falls on fluvial - beach field (Fig. 2-5).

Results obtained from XRD Analysis

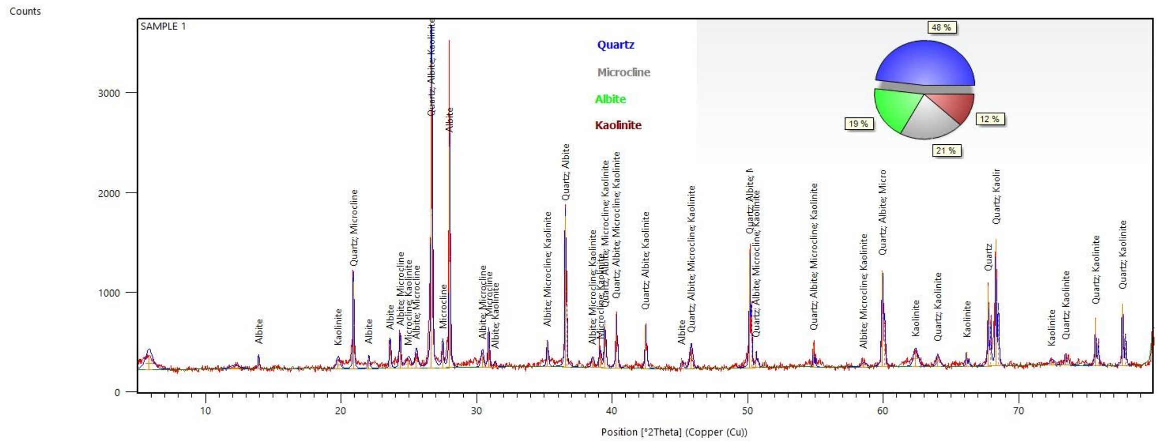

Figure 6(a): XRD Result for Sample 1 outcrop 1

From the XRD result, Quartz contains 48% of the sandstone and it depicts a submatured, other includes microcline 21%, albite, 19% and kaolinite 12%, respectively.

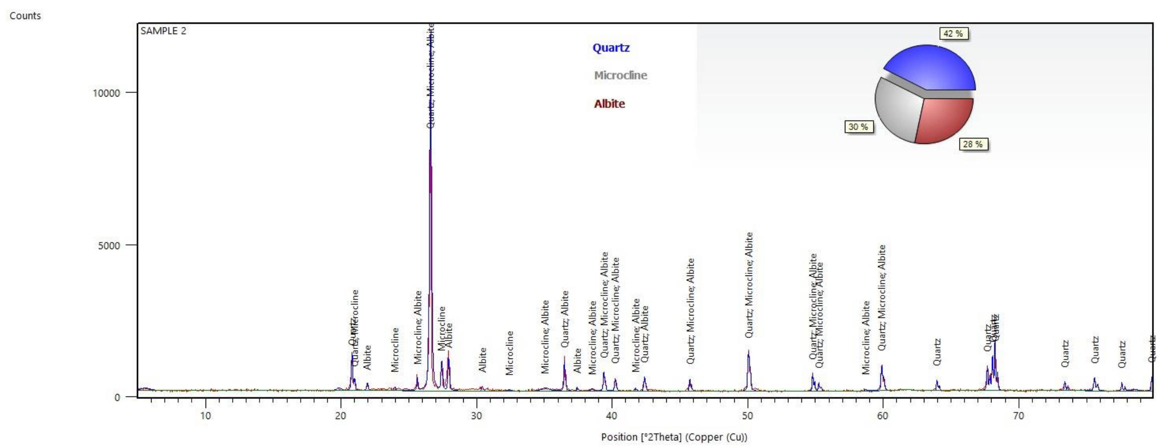

Figure 6(b) XRD Result for Sample 2 for outcrop 1

From the XRD result, Quartz contains 42%, Microcline 30%, Albite 28%. 42% of Quartz depicts submatured sandstone.

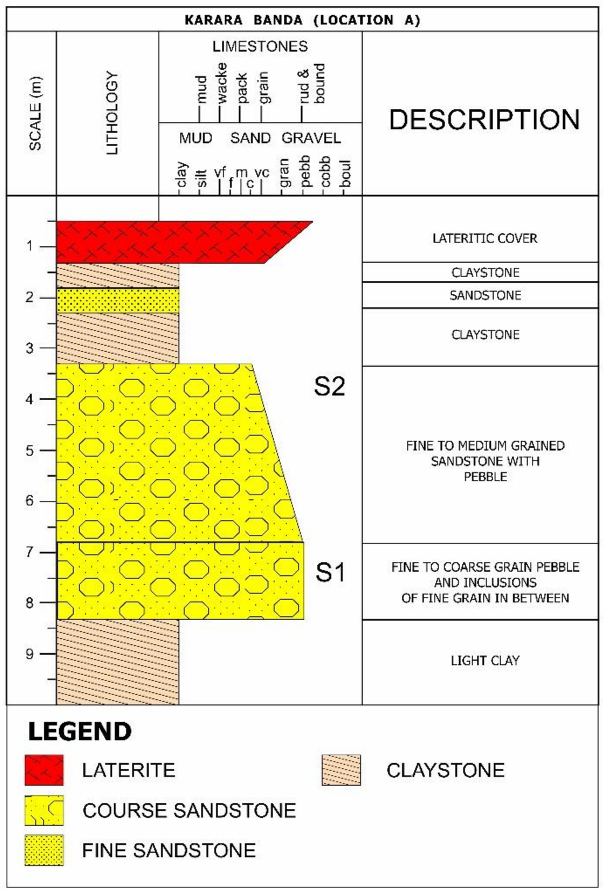

Figure 6(c): Litholog and description of exposure of outcrop 1 of Karara- Banda area in Southern Bida Basin, along Lokoja-Abuja express way.

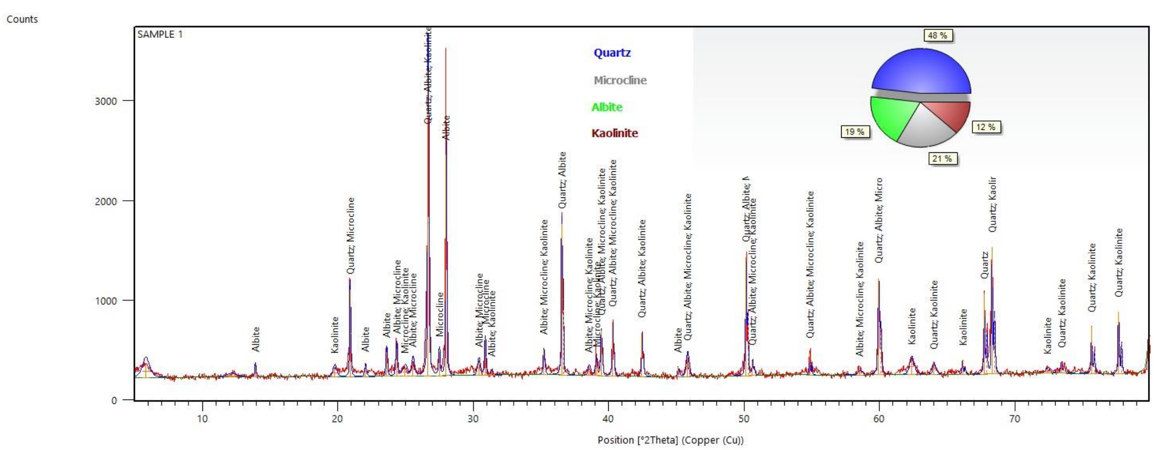

Figure 7 (a): XRD Result for Sample 1 for outcrop 2

From the XRD result, Quartz contains 48%, Microcline 21%, Albite 19% and Kaolinite 12%, respectively. But quartz of 48% show submatured sandstone.

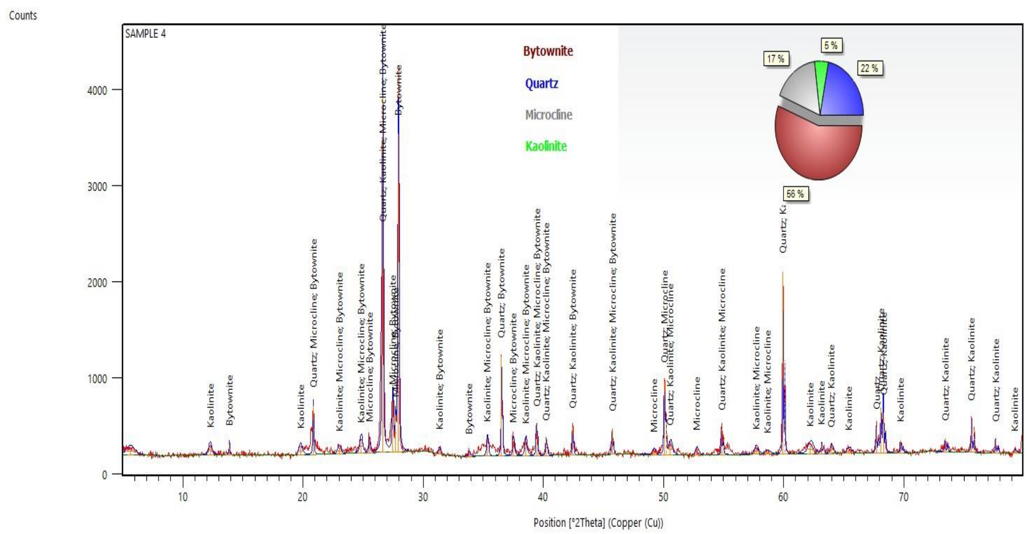

Figure 7 (b): XRD Result for Sample 2 for outcrop 2

From the XRD result, Quartz contains 22%, Microcline 17%, Kaolinite 5% and Bytownite 56%. The quartz content of 22% and bytownite of 56% depicts immature sandstone.

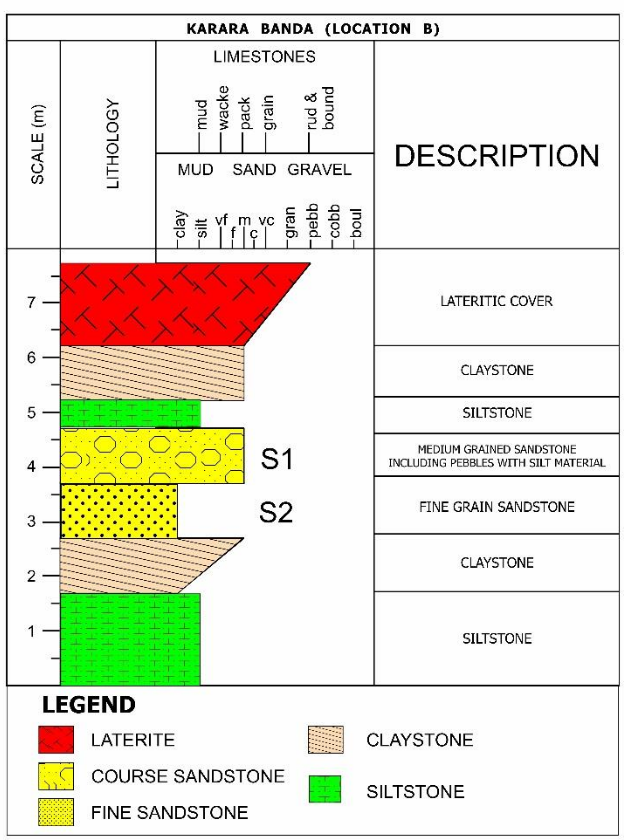

Figure 7 (c): Litholog and description of exposure of outcrop 2 of Karara- Banda area in Southern Bida Basin, along Lokoja-Abuja express way

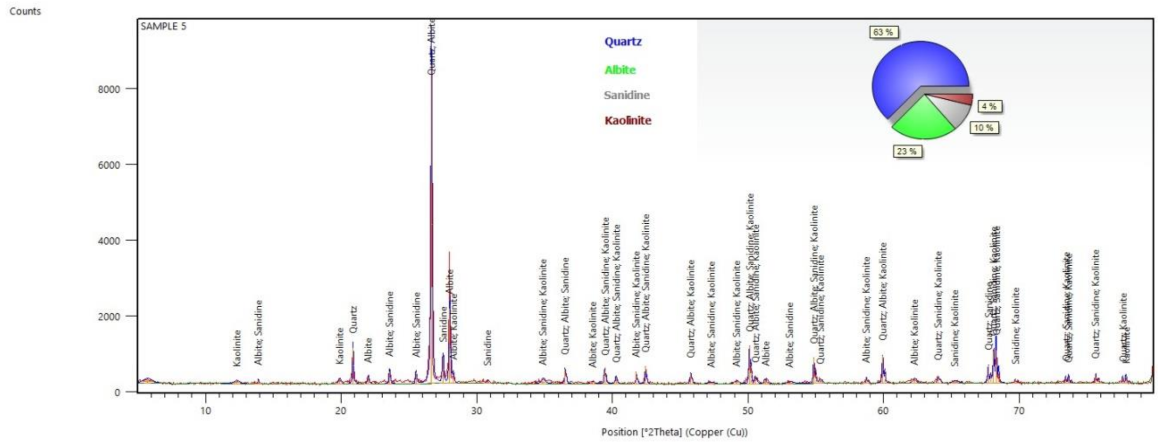

Figure 8 (a): XRD Result for Sample 1 for outcrop 3

From the XRD result, Quartz contains 63%, Albite 23%, Sanidine 10% and Kaolinite 4%. 63% of quartz content in the sandstone units depicts fairly matured sandstone.

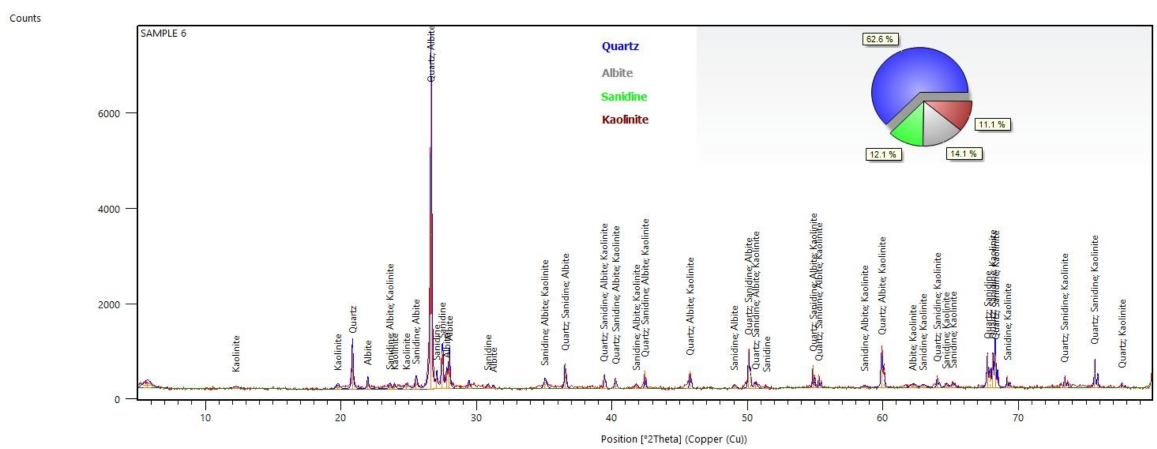

Figure 8 (b): XRD Result for Sample 2 for outcrop 3

From the XRD result, Quartz contains 62.6%, Albite 14.1%, Sanidine 12.1% and Kaolinite 11.1%, respectively**.** The quartz content of 62.6% in the sandstone indicates moderately matured.

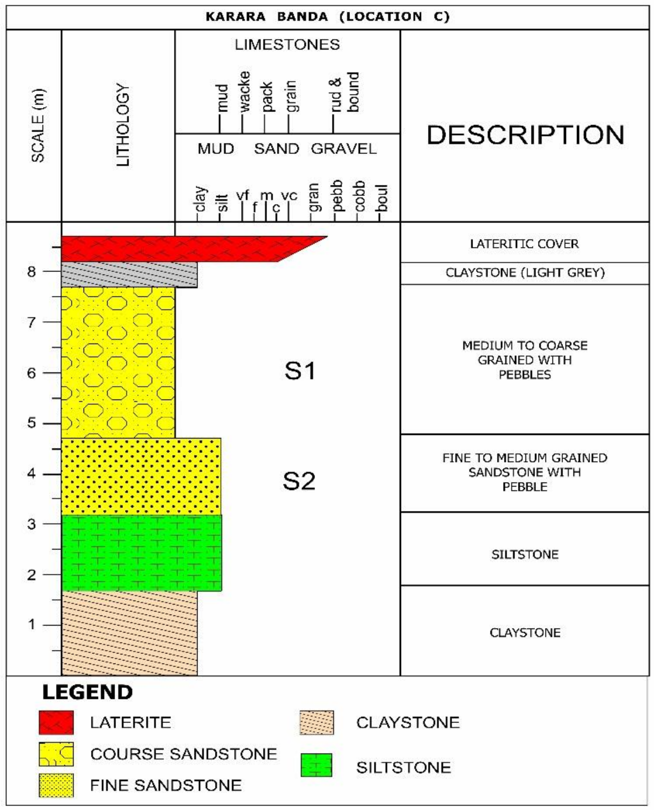

Figure 8 (c): Litholog and description of exposure of outcrop 3 of Karara- Banda area in Southern Bida Basin, along Lokoja-Abuja express way

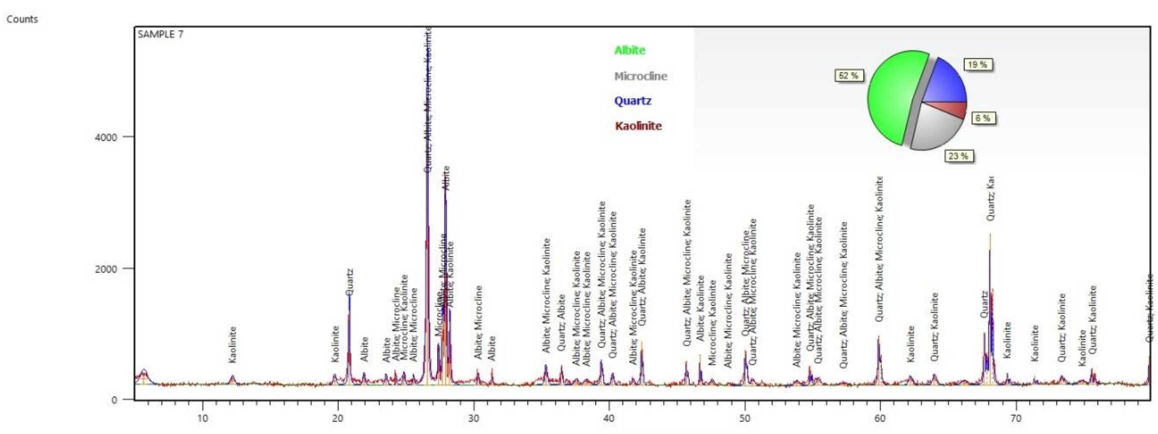

Figure 9(a): XRD Result for Sample 1 for outcrop 4

From the XRD result, Quartz contain 19%, Microcline 23%, Albite 52% and Kaolinite 6%, indicating the sandstone original sources or parent rock is likely from metamorphic sources.

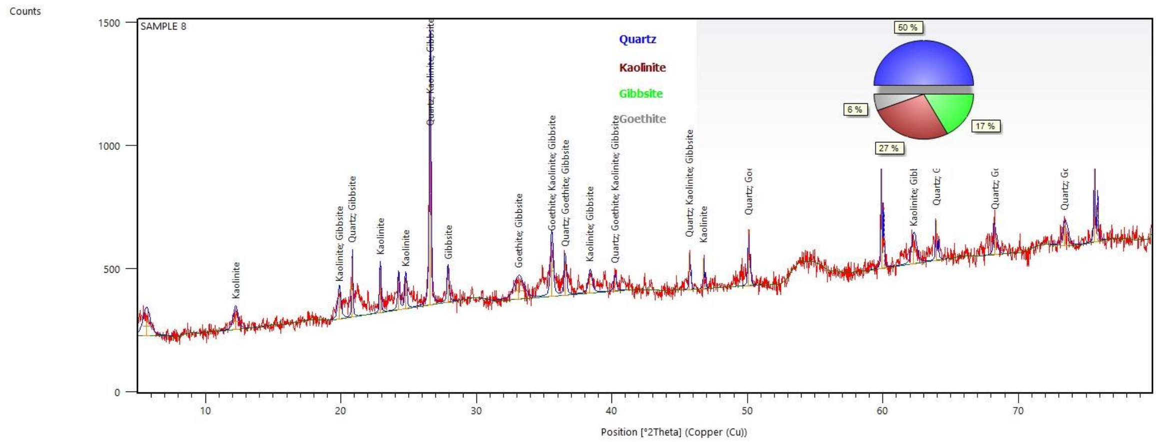

Figure 9(b): XRD Result for Sample 2 for outcrop 4
From the XRD result, Quartz contain 50%, Goethite 6%, Gibsite 17% and Kaolinite 27% , this indicating the sandstone is rich in quartz and submatured.

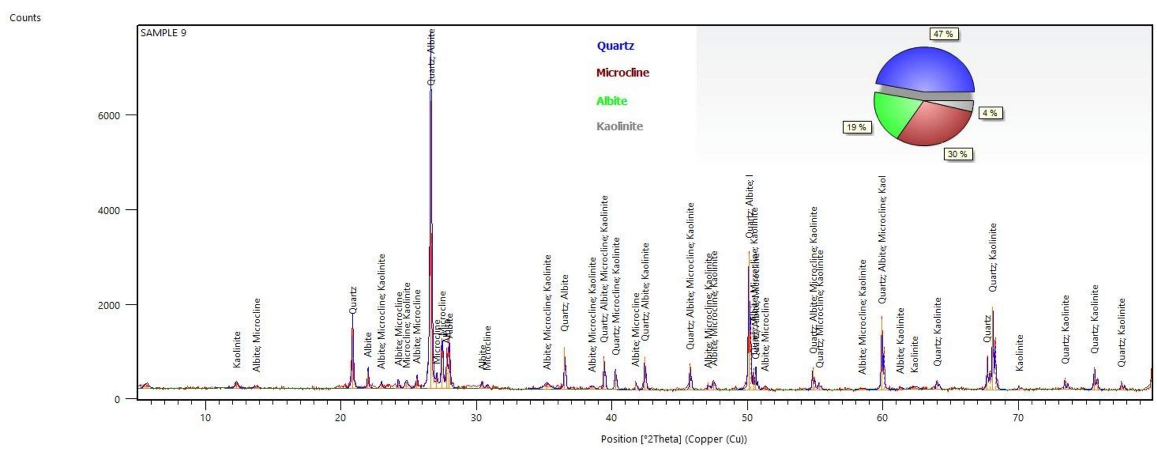

Figure 9 (c): Sample 3 for outcrop 4
From the XRD result, Quartz contains 47%, Microcline 30%, Albite 19% and Kaolinite 4%. The composition of quartz indicate it is immature

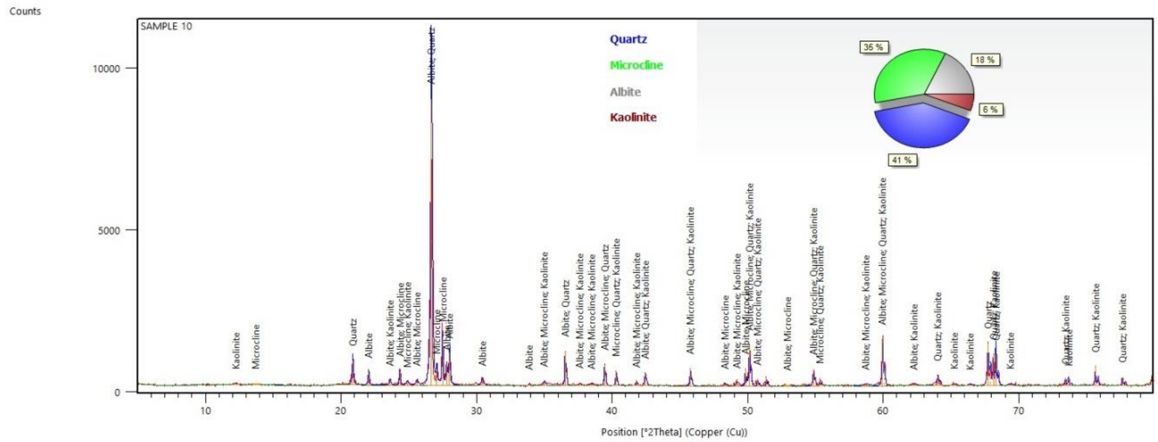

Figure 9(d): XRD Result for Sample 4 for outcrop 4

From the XRD result, Quartz contains 41%, Microcline 35%, Albite 18% and Kaolinite 6% respectively, indicating that the quartz content is immature.

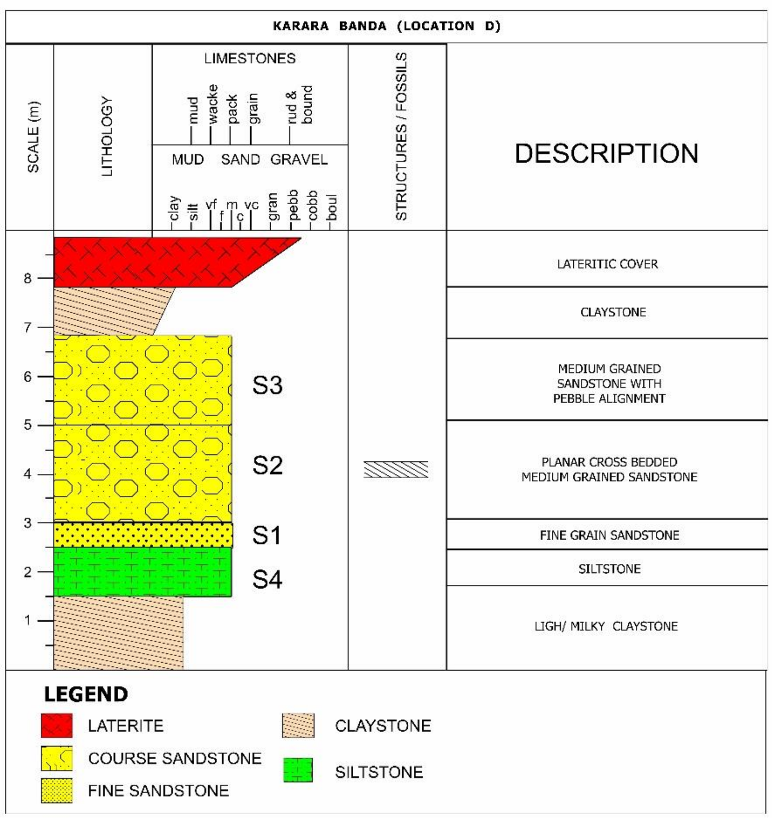

Figure 9(e): Litholog and description of exposure of outcrop 4 of Karara- Banda area in Southern Bida Basin, along Lokoja-Abuja express way

5. Discussion

A comprehensive analysis of the Cretaceous Lokoja Formation in the Karara-Banda region included the plotting of various calculated form indices, such as MPSI vs. OPI and Roundness. These plots effectively illuminated the fluvial-shore face paleoenvironment of the study area, in line with findings by Aigbadon et al. (2022a and 2022b).

It is worth noting that certain pebble form indices have been recognized as reliable indicators of transport medium and the environments in which clast particles were shaped. According to Dobkins and Folk (1970), a mean sphericity of 0.66 serves as the lower limit for pebbles derived from fluvial processes. Additionally, they suggested that the mean oblate-prolate index for river pebbles should exceed -1.5, while lower values are characteristic of beach pebbles. The mean values of MPSI and OPI obtained for the Lokoja Formation comfortably fall within the range of river transport sediments.

To delve further into the assessment of pebble characteristics, the maximum projection sphericity index (MPSI) was employed to estimate pebble equidimensionality (sphericity). An MPSI value of 0.66 distinguishes between beach and river pebbles. The obtained mean MPSI values of 0.71, 0.66, 0.73, and 0.70, which exhibit compact blading, strongly suggest a fluvial origin for these pebbles. The mean elongation ratios of 0.54, 0.51, and 0.60 indicate different types of currents, ranging from river channels (equal to prelate) to littoral channels (dissocial pebbles). The scatter plots of MPSI vs. OPI clearly indicate that the pebbles are concentrated more in the river region than in the beach area, providing further evidence of a fluvial condition.

Roundness, which measures abrasion influenced by the distance of pebble travel rather than the depositional environment, was also examined. The sandstones displayed roundness scores ranging from 30 to 70%, indicating an angular to rounded nature. Predominantly sub-rounded pebbles suggest a limited travel distance, as evidenced by the overall average roundness of 41.8% (0.418). This suggests that the sandstone likely originated from the weathering of nearby basement rocks in western and northern Nigeria.

The integration of pebble morphometry parameters and X-ray diffraction (XRD) results further establishes the potential of the sandstone facies in outcrops 3 and 4 as fair reservoirs. The XRD results (figures 6-9) reveal that quartz is the dominant mineral in nearly all the sandstone reservoirs, with quartz content ranging from 19% to 63%. The presence of clay minerals, primarily kaolinite, is also detected, albeit at relatively low percentages (ranging from 4% to 27%). These clay minerals are unlikely to significantly compromise the reservoir's quality.

Taking into account the characteristics of the pebbles and the XRD results, the sandstone facies of the Lokoja Sandstone hold promise as potential reservoirs for the basin.

Conclusions

The paleodepositional environments of Lokoja Sandstone in Southern Bida Basin were evaluated using pebbles and mineral analysis. Based on the scattered plot, the pebble morphometric analysis indicates a river depositional environment for the Lokoja formation.

The textural characteristics and mineral analysis (XRD) depicts a moderate to immature sandstone with fair quality. The study further revealed mineralogical and textural characteristics and depositional system/settings a primary factor controlling sandstone reservoir quality of Lokoja Formation in the study area.

Abbreviation

Mean= x= £x/n Dobkin and Folk (1970)
The standard deviation of any integer from the mean is denoted by x.
n= the number of samples in the population

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Conflict of Interest

There is no conflict of interest

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