IJESKA
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International Journal of Earth Sciences Knowledge and Applications
journal homepage: http://www.ijeska.com/index.php/ijeska
e-ISSN: 2687-5993

Research Article https://doi.org/10.5281/zenodo.15341410

Paleoenvironment of Deposition and Maturity of Coastal Plain Sand in Okomu, Benin Formation, Niger Delta Basin, Nigeria

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Article history
Received 06 November 2024
Accepted 01 February 2025
Published 30 April 2025

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How cite
Ilevbare, M., Vangerwua, M.A., Agbaje, Y.O., Ore, o.T., Olutomilola, O.O., 2025. Paleoenvironment of Deposition and Maturity of Coastal Plain Sand in Okomu, Benin Formation, Niger Delta Basin, Nigeria. International Journal of Earth Sciences Knowledge and Applications 7 (1), 11-24. https://doi.org/10.5281/zenodo.15341410.

Abstract
The ancient environment and maturity of the coastal plain sands, Benin formation in the Niger Delta basin were evaluated using petrographic studies and grain size characteristics. The heavy minerals were both opaque and non-opaque minerals. The graphic mean (average 1.45) revealed that medium to coarse sand size sediments predominate which are moderately too well sorted (average 0.886), typical of Continental paleo-environment. The graphic skewedness (average 0.076) typifies a period of balance between erosion and deposition of the sediments with most of the sediments being substantially coarsely skewed and a small amount of strongly finely skewed sediments. The graphic kurtosis (1.12) is consistent with platykurtic to leptokurtic sand grains, characteristic of a medium to high energy fluvial depositional environment. The Sediments were compositionally mature (Qtz >90%), mineralogical super-mature (Mineralogical Maturity index, MMI average = 22.49) and chemically immature to sub-mature (Zircon Tourmaline Rutile Index (ZTR) = 71.90). The ancient environment of the deposition from the average of the sorting value is typical of a continental origin (river or fluvial sediments). This finding is authenticated by the environmental discrimination plots which also confirm a continental ancient environment of deposition for the coastal plain sands.

Keywords
Continental origin, Niger Delta Basin, maturity, coastal sand, ancient environment

Abbreviations

DPX: Dibutylphthalate Polystyrene Xylene
MMI: Mineralogical Maturity index
OKU: Okomu
QFL: Quartz, Feldspar and Lithic
ZTR: Zircon Tourmaline Rutile index

1. Introduction

Analyzing the texture of fluvial sediments offers valuable insight into their inherent properties and the environments in which they were deposited. Additionally, such studies help to explore the characteristics and energy dynamics of the various agents responsible for transporting the sediments (Rao et al., 2005; Irudhayanathan et al., 2011). The intricate coastal processes, both past and present, have left distinct marks on the sediments. In this context, the sedimentological study of river and beach sediments is crucial for understanding the depositional history of a given region (Nimalanathan and Rajamanickam, 2007). Sedimentologists focus on three key aspects of particle size: (a) the techniques for measuring grain size and categorizing it using a grade scale, (b) methods for analyzing grain size data and presenting the results in graphical or statistical formats, and (c) the genetic implications of these data (Boggs, 1995). Heavy minerals like garnet, ilmenite, sillimanite, monazite, and zircon are of significant economic importance due to their industrial applications (Karikalan et al., 2001). The various mechanical and chemical processes that quartz sand grains undergo are evident from their surface features. These features are documented and classified based on the depositional environment (Krinsley and Doornkamp, 2011). Numerous studies have emphasized the importance of grain size analysis in reconstructing ancient depositional environments and understanding sediment dynamics.

Researchers like Boboye and Chidiebere (2023) and Harry et al. (2022) have identified different environmental conditions ranging from fluvial to beach and shallow marine settings using palynological and sedimentological data. In contrast, authors such as Ilevbare and Imasuen (2020), Ilevbare and Omodolor (2020) and Enyioko et al. (2022) have inferred paleo-environmental conditions from textural characteristics. On the other hand, Ajadi et al. (2022) and Dora et al. (2011) have investigated ancient environments and provenance through sedimentological and geochemical evidence.

This study is distinctive in that it aims to reconstruct the paleoenvironment of deposition and assess the maturity of coastal plain sediments, with a focus on understanding the geological history, depositional processes, and post-depositional modifications that have shaped the sedimentary succession.

1.1. Location of the Study Area

The study area is Okomu Sandstone in Edo State (Fig. 1). It is located between Latitude N06°22’22.6” to N6°22’19.8” and the Longitude is located between E05°14’22.9” to E05°14’21.6”.

2. Regional Geology of Niger Delta Basin

The Niger Delta Basin is a complex and dynamic sedimentary system situated in southern Nigeria. It is recognized as a significant hydrocarbon province, with recoverable oil reserves estimated at 34.5 billion barrels and 93.8 trillion cubic feet of natural gas (Tuttle et al., 1999).

This basin originated from the breakup of the Gondwana supercontinent during the Mesozoic era. The formation of the Atlantic Ocean led to the development of a series of extensional basins along the African margin, including the Niger Delta Basin. Sediments within the basin have been deposited through various processes, such as riverine, wave, and tidal activities.

Additionally, tectonic forces have influenced the region, resulting in folding, faulting, and uplift (Anyanwu et al., 2022). The basin contains a thick sequence of sedimentary rocks, with ages ranging from the Cretaceous to the Recent. The oldest layer is the Cretaceous Akata Formation, composed primarily of shales and sandstones. Above this lies the Agbada Formation, which is the principal oil-bearing unit and consists of sandstones, shales, and limestones. The youngest stratigraphic unit is Benin Formation, composed of fluvial sediments (Ilevbare and Omorogieva, 2021).

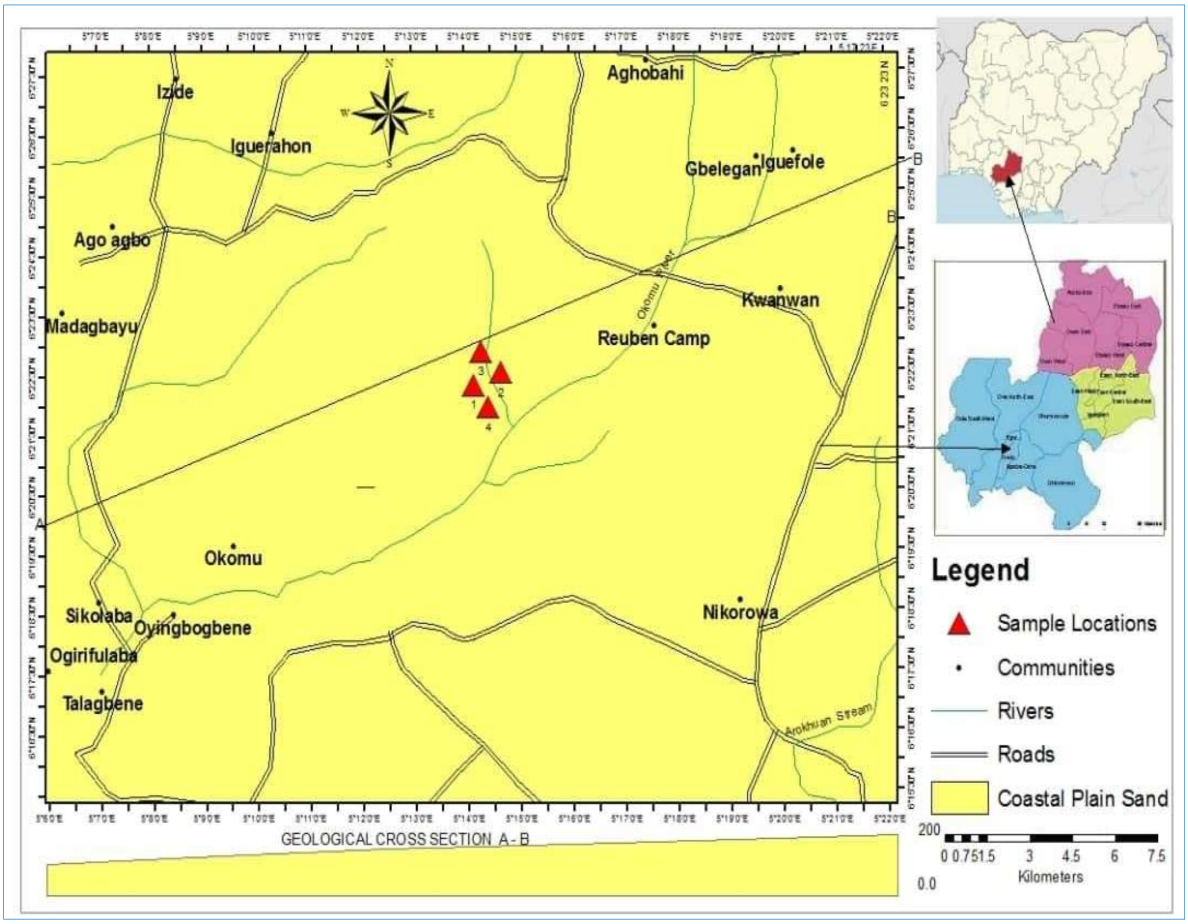

Fig. 1. Geological map of Okomu Coastal Plain sands

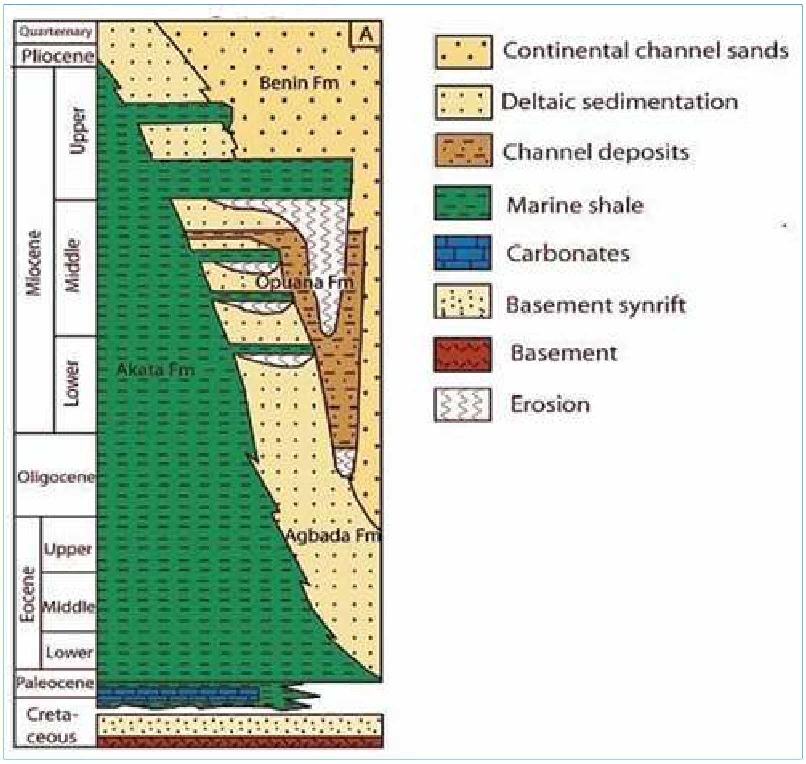

Fig. 2. Stratigraphy of the Niger Delta Basin (modified after Overare and Osokpor, 2020)

The Niger Delta Basin is a critical resource for Nigeria, contributing substantially to the country's revenue through its oil and gas production. Furthermore, the basin supports several key industries, including the oil and gas sector, cement production, and agriculture (Adegoke et al., 2017).

2.1. Tectonic and Sedimentation History

The tectonic evolution of the Niger Delta Basin can be categorized into three distinct periods:

i. Rifting Period (Jurassic-Cretaceous): This phase marks the divergence of the African and South American plates, leading to the formation of the South Atlantic Ocean. It was during this time that the Niger Delta Basin emerged as a failed rift basin.
ii. Sedimentation Period (Cretaceous to Present): Following the rifting phase, the Niger Delta Basin experienced a phase of relative tectonic stability. During this time, sediments delivered by the Niger River and its tributaries accumulated, forming a substantial sequence of sandstones, shales, and carbonates.
iii. Oil and Gas Generation Period (Tertiary): During the Tertiary period, the accumulated sediments in the Niger Delta Basin underwent thermal maturation. This process led to the generation of oil and gas, which are now entrapped within the basin's reservoirs (Overare and Osokpor, 2020; Ilevbare and Omorogieva, 2021).

The sedimentation history of the Niger Delta Basin can be divided into five key sequences:

i. Paleocene-Eocene Epoch: This represents the oldest sedimentary sequence within the Niger Delta Basin, consisting of deep-water shales and sandstones.
ii. Eocene-Miocene Sequence: This is the most significant sedimentary sequence in the basin, characterized by shallow-water sandstones and shales, which serve as the primary reservoirs for oil and gas.
iii. Miocene-Pliocene Period: Comprising continental sandstones and shales, this sequence is the youngest within the Niger Delta Basin.
iv. Pliocene-Pleistocene Epoch: This sequence is made up of shallow-water sandstones and shales and acts as a minor reservoir for oil and gas.
v. Pleistocene to Present: This period features alluvial sediments deposited by the Niger River and serves as an important reservoir for oil and gas (Adegoke et al., 2017; Reijers, 2011).

2.2. Stratigraphy of Niger Delta Basin

The Niger Delta is characterized by early terrestrial deposits within a high-energy saltwater environment. Currently, sediment deposition occurs across three distinct environments: fully terrestrial (fluviatile) conditions, areas where terrestrial and marine influences interact (paralic), and fully marine settings (Diab et al., 2023).19 These conditions have led to the identification of three major stratigraphic units in the subsurface of the Niger Delta, with the Benin Formation being the youngest and the Akata Formation the oldest.

2.2.1. Benin Formation

The Benin Formation is the youngest of the tertiary formations in the Niger Delta. It primarily consists of highly porous, freshwater-bearing sandstones with occasional thin shale interbeds, believed to have originated from braided stream environments. When present, these shale interbeds often contain scattered lignite and plant debris. The formation is thinner along the delta margins and thickens towards the centre of the onshore area, reaching approximately 1,970 meters (1.97 km) in thickness. Research by Short and Stauble (1967) at the Elele-1 well, located 39 km northwest of Port Harcourt, identified the first marine foraminifera at the base of the formation, confirming its non-marine origin. The Benin Formation dates from the Miocene to the Recent.

2.2.2. Agbada Formation
The Agbada Formation is a transitional paralic sequence composed of sandstone and shale, representing deposits from the delta front, distributary channels, and deltaic plain environments. The continental Benin Formation, which lies above it, mainly consists of massive, highly porous, freshwater-bearing sandstones with occasional thin shale interbeds of braided stream origin. These sediments represent upper deltaic plain deposits. The sands and sandstones may correspond to point-bar deposits, channel fills, or crevasse splays, while the shales may represent backswamp deposits (Reijers, 2011). Stratigraphically, these formations are superimposed over time and space and range in age from the Eocene to the Holocene (Fig. 2).

2.2.3. Akata Formation
The Akata Formation is considered the oldest and deepest unit in the Tertiary Niger Delta sequence. It is composed predominantly of medium- to dark-grey shale, forming a continuous marine unit. The shales are not fully compacted and may contain lenses of overpressured siltstone or fine-grained sandstone. The formation's thickness varies between 600 and 6,000 meters (Spina and Mazzoli, 2023). The Akata Formation hosts a diverse foraminiferal fauna, with planktonic foraminifera comprising over 50% of the microfauna. Due to the homogeneity of the deeply buried shales, suggested that the Akata Formation could serve as the primary source rock for the oil found in the Niger Delta. The formation is dated as from the Eocene to the Recent (Spina and Mazzoli, 2023).

3. Materials and Methods
3.1. Sample Collection
Samples were collected at an interval of 1.0 m in 4 different locations all within Okomu National Park in Benin Formation, Niger Delta Basin (Fig. 3). A total of 20 samples were analyzed for grain size analysis, 15 samples for thin section analysis and 10 samples for heavy mineral analysis.

Fig. 3. Field photographs of Okomu Coastal Plain sands, Nigeria

3.2. Grain Size Analysis
50 g was weighed and mechanically sieved at the Sedimentology Laboratory, Department of Geology, University of Ibadan, Nigeria. Mean, sorting, skewedness and kurtosis were thereafter computed from the recorded weight percentages of the sieves and pan.

3.3. Thin Section Analysis

The samples were air dried for 24 hours and then impregnated with epoxy and subsequently left to cure for 24 hours. The cured sample was trimmed to fit on a glass slide, and the samples smoothened using water and silicon carbide (600 grits) on a glass plate. The samples were thereafter bonded to the glass slide using epoxy on the hot plate for 24 hours, trimmed to 50 micron and lapped to 30 micron using silicon carbide and water. Mineral identification and textural analysis, point counting of mineral grains were conducted on the slides using a transmitted light microscope at the Sedimentology laboratory of the Department of Geology, University of Benin, Nigeria.

3.4. Heavy Mineral Analysis

The experimental procedure included pouring 5 g of air-dried sample into an already mounted separating funnel filled to ¾ of its volume with bromoform. The heavy minerals contained in the samples which sunk to the bottom of the funnel were collected in filter paper, washed with acetone to remove all the bromoform, and mounted on a clean glass slide using Dibutylphthalate Polystyrene Xylene (DPX) mountant. Mineral identification and textural analysis, point counting of mineral grains were conducted on the slides using a transmitted light microscope at the Sedimentology Laboratory of the Department of Geology, University of Ibadan, Nigeria.

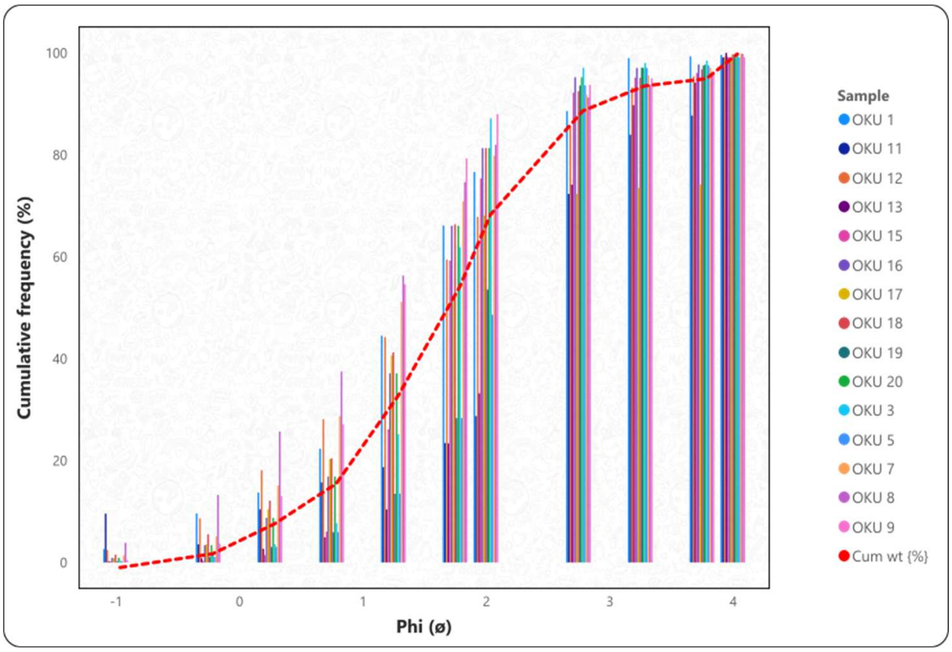

Fig. 4. Cumulative frequency versus Phi of Okomu sands

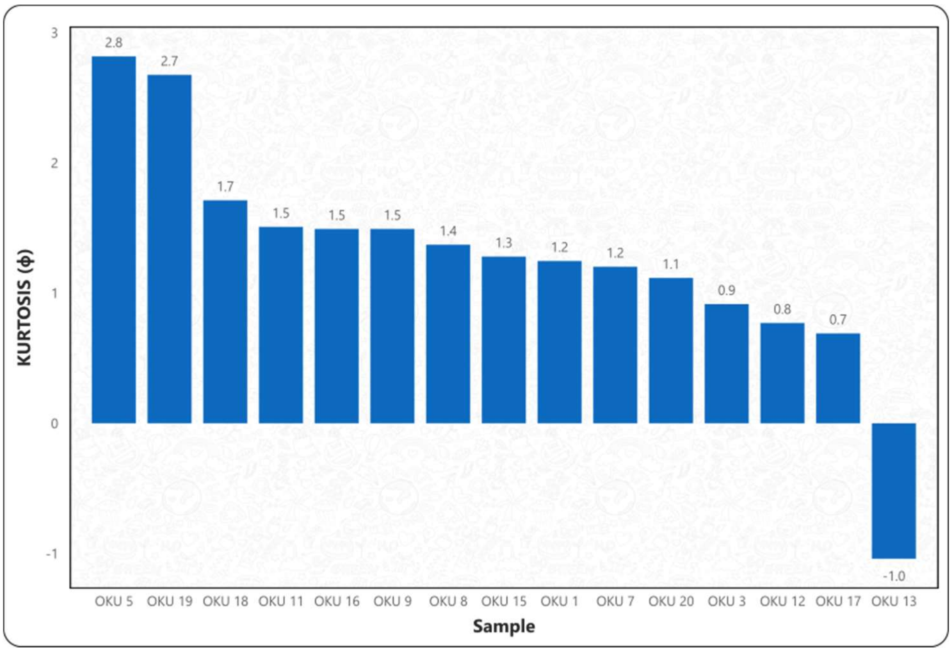

Fig. 5. Kurtosis versus sample location for Okomu sands

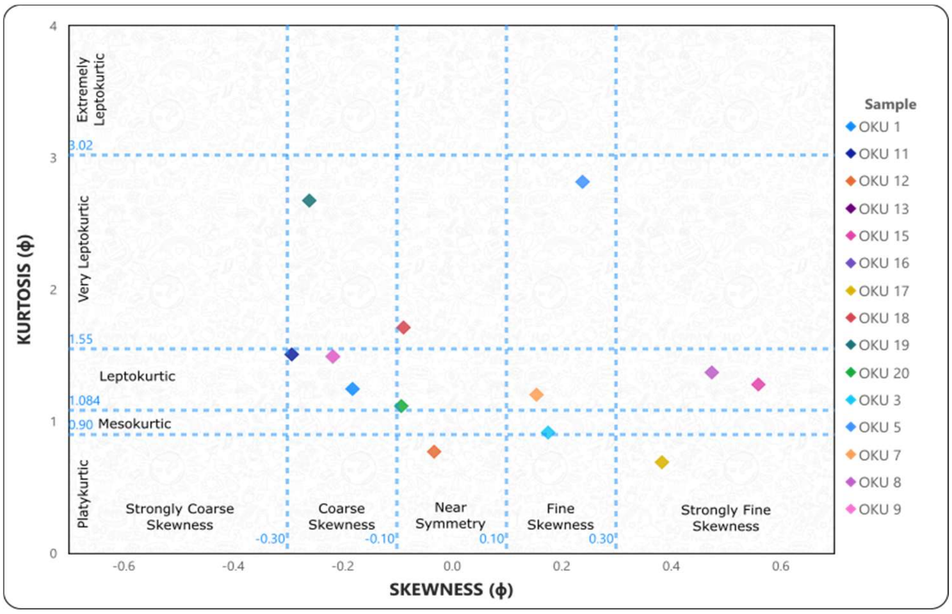

Fig. 6. Kurtosis versus skewedness

The environmental discrimination bivariate plots both indicate that the coastal sands are from rivers/fluvial origin with little or no contribution from wave or tidal activities. (Figs. 7 and 8).

The data points of the grains plot are mostly in coarse skewedness to strongly fine skewedness and moderately well sorted to moderately sorted grains (Fig. 9). The bar chart (Fig. 10) shows the sorting against the sample location with OKU17 > OKU12 > OKU12 > OKU11 > OKU8 > OKU7 > OKU18 > OKU16 > OKU9 > OKU13 > OKU20 > OKU19 > OKU5 > OKU15 > OKU3.

4.1. Textural Attributes

Folk (1980) categorized sorting values as follows: 1-3 ϕ for sand, 0.25–0.5 ϕ for beach sand, and 0.35-1.0 ϕ for fluviatile or shallow marine sand. The sorting values observed in this study range from 0.514 to 1.350, with an average of 0.886 (Table 1), suggesting that the coastal sands are predominantly of fluvial origin, with a mixture of shallow marine and beach sands, according to Folk's environmental classification scheme. This interpretation is further supported by the environmental plots shown in Figs. 7 and 8. The sorting versus mean bivariate chart (Fig. 10) indicates that the grains are moderately to well sorted. The results presented in this study contradict the findings of Harry et al. (2022) but align with those of Fontana et al. (2019). Extremely high or low kurtosis values suggest that the sediments may originate from multiple sources and are likely deposited in high-energy environments. The variations in kurtosis values reflect the flow characteristics of the depositional medium (Ray et al., 2006).

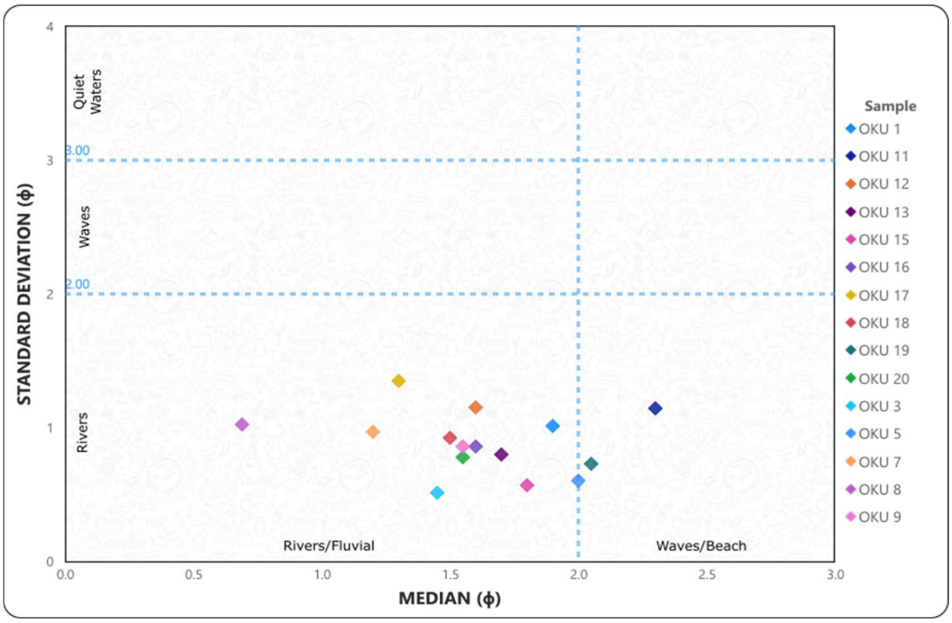

Fig. 7. Standard deviation versus median

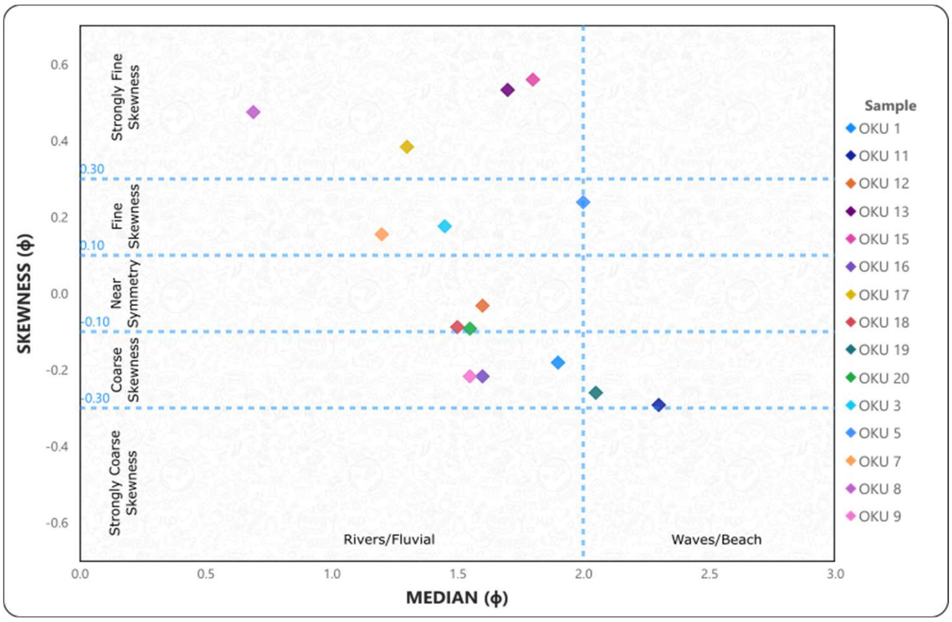

Fig. 8. Skewedness versus median

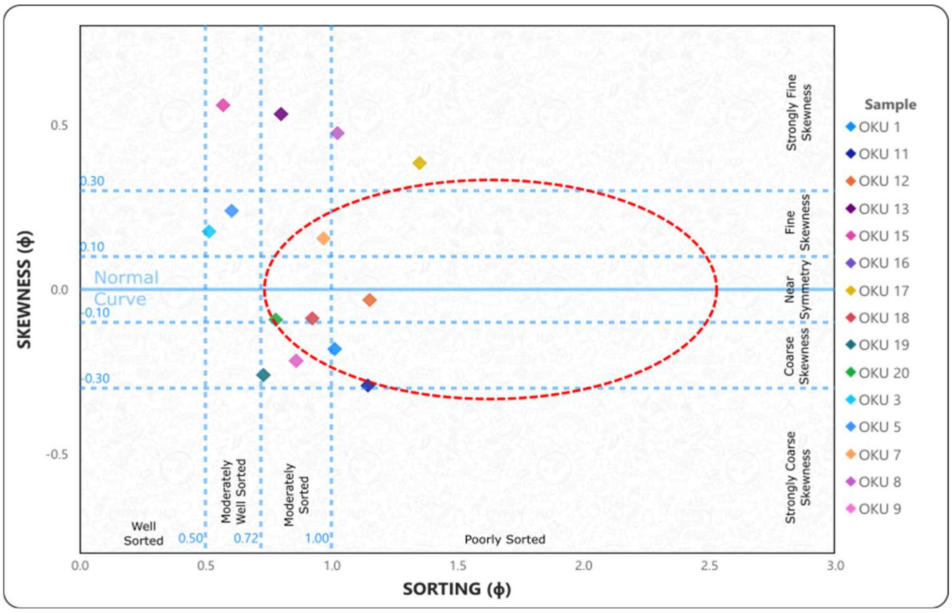

Fig. 9. Skewedness versus sorting

Most sands exhibit leptokurtic characteristics and display either positive or negative skewness. This phenomenon can be explained by the presence of two distinct grain populations within the sand: a dominant population and a much smaller, subordinate coarse population (leading to negative skewness) or fine population (leading to positive skewness) (Ilevbare and Imasuen, 2020). The prevalence of platykurtic and leptokurtic sediments, with values ranging from -1.040ϕ to -2.675ϕ and averaging around 1.283ϕ, indicates compositionally and mineralogically mature sand.

Plotting kurtosis against skewness (Fig. 6) serves as a highly effective tool for interpreting sediment genesis by quantifying the normality of the grain size distribution (Folk, 1980). In the case of the coastal plain sands, the data points fall within the platykurtic to leptokurtic range (Fig. 6).

According to Ilevbare and Imasuen (2020), extreme kurtosis values, whether high or low, suggest that some sediments achieved sorting in a high-energy environment. Therefore, the results showing platykurtic to leptokurtic characteristics imply that the coastal sediments were deposited in environments with intermediate to high energy, confirming the fluctuating energy conditions during sediment deposition.

4.2. Compositional Maturity of Coastal Plain Sands

Here again from the compositional maturity, the samples are investigated to be super mature (>90%) with dominant polycrystalline crystal structure.

In Table 2, most of the sands were of the polycrystalline grain type with sphericity index of angular to sub-angular grains.

The monocrystalline sands were less and had rounded to sub-rounded grain boundaries. Also observed was that the ratio of polycrystalline to monocrystalline which in all cases was greater than one, indicating that the coastal plain sands were less resistant to weathering with an intermediate transportation history.

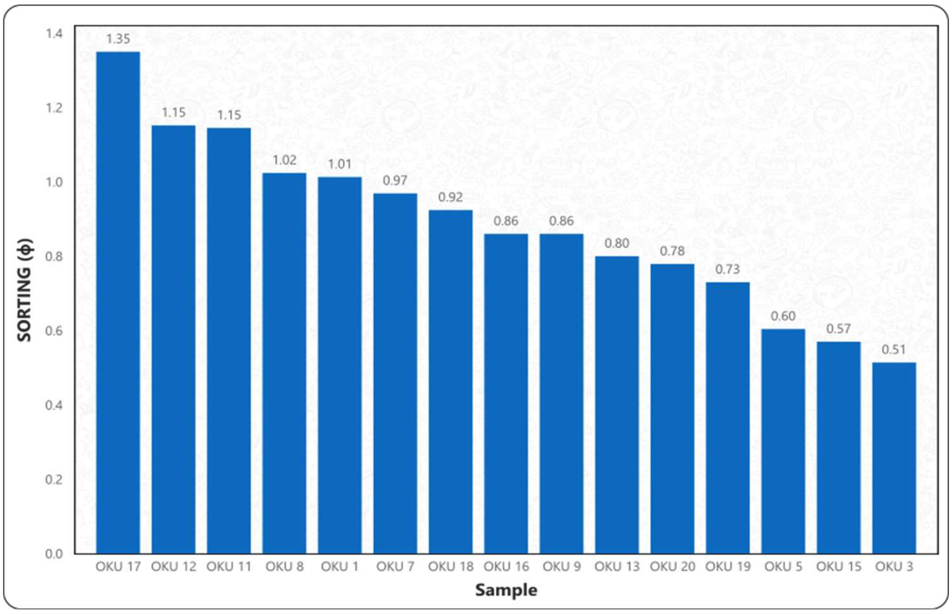

Fig. 10. Sorting versus sampled location

Table 1. Sedimentology characteristics of Okomu sands

Sample	Median	Mean	Sorting	Skewness	Kurtosis
OKU 1	1.90	1.67	1.013	-0.181	1.246
OKU 3	1.45	1.53	0.514	0.176	0.915
OKU 5	2.00	1.88	0.604	0.239	2.817
OKU 7	1.20	1.21	0.969	0.155	1.202
OKU 8	0.69	0.94	1.024	0.475	1.371
OKU 9	1.55	1.31	0.860	-0.217	1.492
OKU 11	2.30	2.21	1.145	-0.292	1.508
OKU 12	1.60	1.50	1.152	-0.032	0.770
OKU 13	1.70	2.16	0.800	0.533	-1.040
OKU 15	1.80	1.66	0.570	0.560	1.280
OKU 16	1.60	1.31	0.860	-0.217	1.492
OKU 17	1.30	1.72	1.350	0.384	0.690
OKU 18	1.50	1.34	0.924	-0.088	1.712
OKU 19	2.05	1.91	0.730	-0.260	2.675
OKU 20	1.55	1.48	0.779	-0.092	1.116
AVERAGE	1.61	1.59	0.886	0.076	1.283

The depositional environment of sediment can be inferred by analyzing the distribution of angular to sub-angular particle sizes. For example, the presence of angular to sub-angular grains in sediment may suggest deposition in a somewhat turbulent environment, such as a river or stream (Kundu, 2023).

This is further supported by a higher ratio of polycrystalline grains, which is indicative of the turbulent conditions typical of a continental river or fluvial environment and further corroborated by ternary diagram (Fig. 12) that confirms it as quartz arenite (Ilevbare and Imasuen, 2020).

In addition to identifying the depositional environment, the degree of grain rounding can provide insights into the age of sediment. Generally, older sediments tend to be more rounded than younger ones, as they have had more time to be transported and subjected to erosion. The degree of rounding can also offer clues about the sediment's source. For instance, sediments derived from bedrock composed of angular rocks typically contain angular grains, while those originating from bedrock with rounded rocks are more likely to consist of round grains (Pokhrel et al., 2024).

The quartz, feldspar and lithic (QFL) ternary diagram of the coastal sands indicate that the sediments are of sublitharenite and quartzarenite (Fig. 12).

The mineral composition of the coastal plain sands shows a predominance of quartz with feldspar, rock fragments and cement in appreciable amounts while the others seem to be in small or trace amounts as evident in Fig. 13.

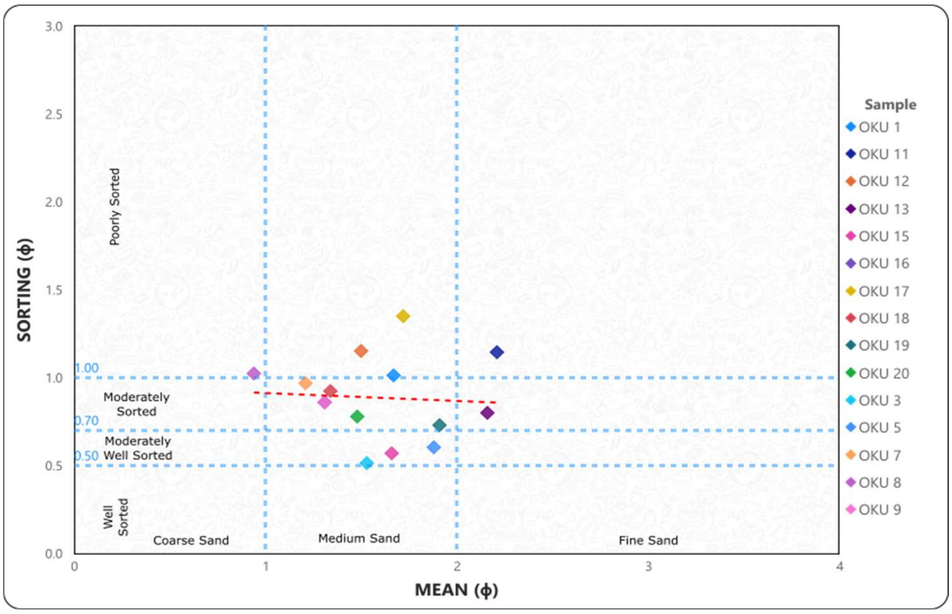

Fig. 11. Sorting vs Mean of Okomu sands

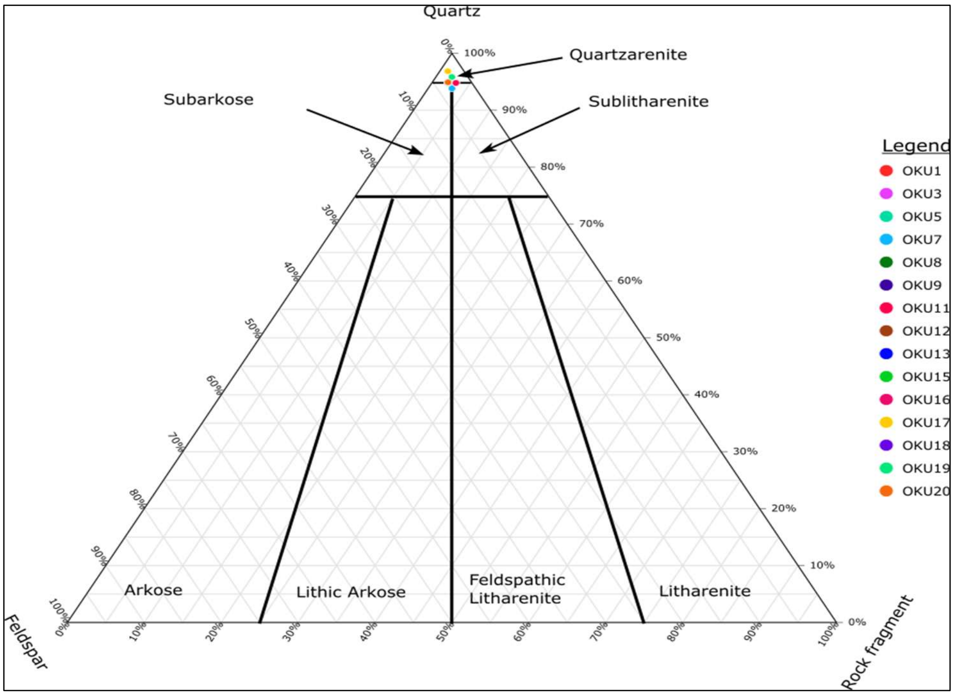

Fig. 12. QFL Ternary Diagram of Okomu sands

4.3. Chemical Maturity of the Okomu Sands

The heavy minerals were analyzed as follows: zircon (8-11; ~9.6), rutile (8-10; ~9), tourmaline (8-10; ~9), sillimenite (3-5; ~4), garnet (2-4; ~3.2), apatite (3-4; 3.6), opaque (20-24; ~22.1), ZTR index (70-75; ~71.9) (Fig. 14). The data revealed that opaque was the dominant deposit of heavy mineral > zircon > rutile/tourmaline > sillimenite > apetite > garnet (Table 3). The composition of heavy mineral assemblages in sediments offers valuable insights into the provenance and the weathering processes affecting the source area of the rocks or sediments (Ilevbare and Omorogieva, 2021). Zircon is a chemically inert mineral that is highly resistant to weathering. It is commonly found in igneous rocks and remains a prevalent component in sedimentary deposits, particularly in most sands.

Tourmaline, typically associated with granitic pegmatites—coarse-grained igneous rocks—appears less frequently in sedimentary rocks as detrital grains, which are transported and deposited by water or wind. Garnet and sillimanite (as noted in Table 3) are predominantly found in metamorphic rocks, with less frequent occurrences in igneous and sedimentary formations. Sillimanite is often found in association with garnets. The presence of these four heavy minerals suggests that the provenance of the Okomu coastal plain sands is mainly of igneous and metamorphic origin.

The ZTR index serves as a geochemical indicator useful for identifying the source and composition of sediments in rocks. It plays a significant role in interpreting the provenance of sedimentary basins, conducting paleogeographic reconstructions, and understanding the processes of sediment transport and deposition (Ilevbare and Imasuen, 2020; Pettijohn, 1975). According to Mange and Maurer (1992), a ZTR index of less than 75% indicates immature to submature sediments, while a ZTR index greater than 75% suggests mineralogically mature sediments. In this study, the coastal plain sands exhibit a ZTR index ranging from 70% to 75%, reflecting a combination of immature and submature coastal plain sands. The Zircon > Rutile > Tourmaline > Sillimenite > Garnet > Apatite in decreasing order of heavy mineral concentration with the percentage composition of the opaque minerals been the highest.

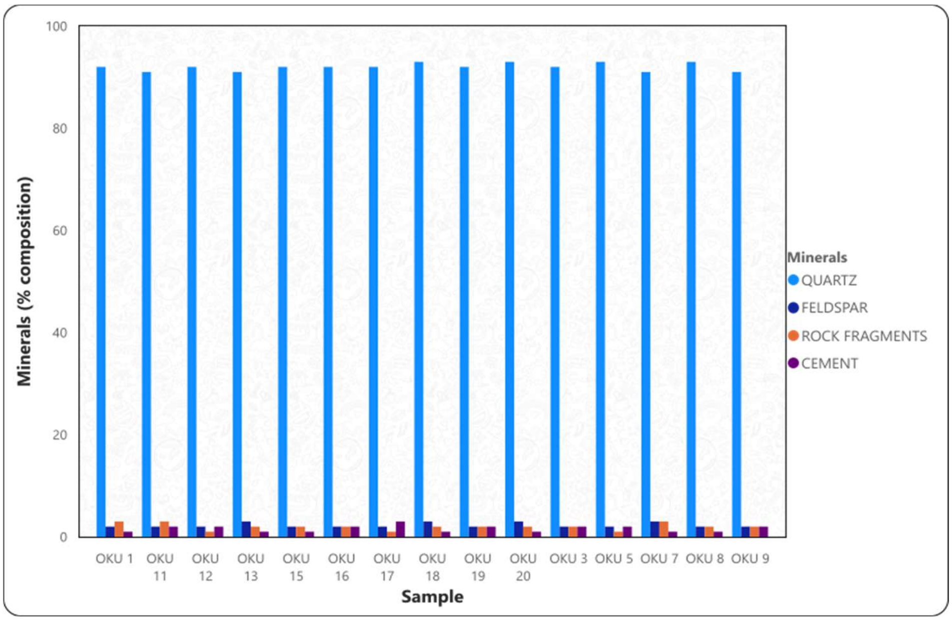

Fig. 13. Mineral composition versus sampled locations

Table 2. Compositional Maturity of Okomu sand

Sample	Quartz (grain type)	Angular/Boundary	No of count	Ratio of polyxtaline to monoxtaline	Textural maturity	Compositional maturity
OKU1	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	62 52	62:52		Super mature (= 92% Qtz)
OKU3	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	59 43	59:43		Super mature (=92% qtz)
OKU5	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	55 50	55:50		Super mature (=93% qtz)
OKU7	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	56 45	56:45		Super mature (=91% qtz)
OKU8	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	60 56	60:56		Super mature (=93% qtz)
OKU9	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	59 53	59:43		Super mature (=91% qtz)
OKU11	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	55 43	55:43		Super mature (=93% qtz)
OKU12	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	54 43	54:43		Super mature (=92% qtz)
OKU13	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	62 52	62:52		Super mature (=91% qtz)
OKU15	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	56 47	56:47		Super mature (=93% qtz)
OKU16	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	63 55	63:55		Super mature (= 92% qtz)
OKU17	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	53 47	53:47		Super mature (=92% qtz)
OKU18	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	54 49	54:49		Super mature (=93% qtz)
OKU19	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	51 45	51:45		Super mature (=92% qtz)
OKU20	Polycrystalline Monocrystalline	Angular to subangular Rounded to subrounded	55 32	55:32		Super mature (=93% qtz)

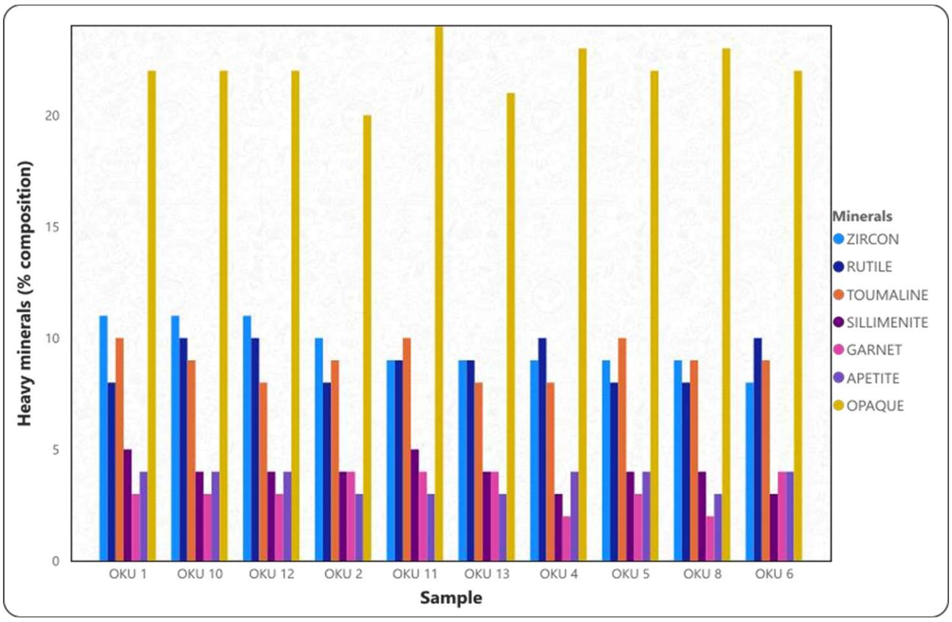

Fig. 14. A composite chart of the heavy mineral in the sands

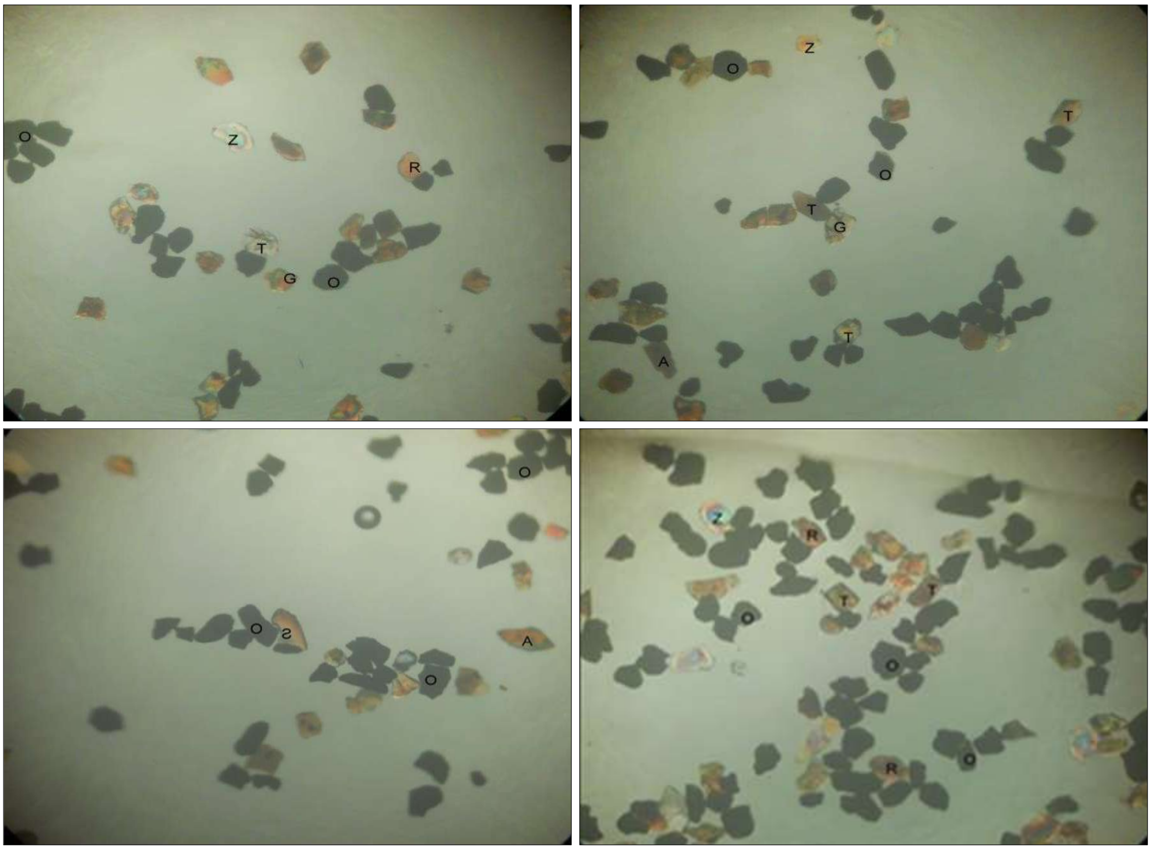

Fig. 15. Microphotographs of heavy minerals of Okomu Sands (*O: opaque minerals, Z: zircon, T: tourmaline, R: rutile, S: sillimenite, A: apatite, G: garnet*)

In Fig. 15, O, R, T, S, Z, G are the heavy minerals, and they represent opaque minerals, rutile, tourmaline, sillimenite, zircon, garnet accordingly.

4.4 Mineralogical Maturity of Okomu Sands

Maturity in sediments is often indicated by finer grain sizes and is most effectively observed in minerals such as quartz, rock fragments, feldspars, and lithics. However, it is the clay content that more directly reflects a lack of maturity. As the proportion of quartz increases, the mineralogical maturity of the sediment also rises, a trend evident in this study (Prothero and Schwab, 2004).

Hoque and Nwajide (1985) proposed a straightforward classification scheme (Table 4) for determining the mineralogical maturity index of sandstone, based on the maturity scale of sandstone. The Mineralogical Maturity Index (MMI) is determined using *Equation 1*.

$$MMI = \frac{Proportion\ of\ Quartz}{Proportion\ of\ F + Proportion\ of\ RF} \quad (1)$$

Sediments with high MMI are derived from older, more weathered rocks while sediments with low MMI are typically derived from younger, less weathered rocks. The results from Table 5; quartz (91-93; ~92) was the dominant mineral in this study followed by feldspar (2-3; ~2.26), rock fragments (1-3; ~2), cement (1-3; ~1.6), cement together with rock fragments (1-3; ~4.26), FSP (3-6; ~5.1) and the MMI of (15.16-31.00; ~ 22.49) suggests a mineralogical mature to super mature coastal plain sands (Table 4).

In Fig. 16, Q, F, RF and HM represent quartz, feldspar, rock fragments and heavy minerals, respectively.

Table 3. Heavy minerals (%) and ZTR index of Okomu sands

S/N	Zircon	Rutile	Tourmaline	Sillimanite	Garnet	Apatite	Opaque	ZTR
OKU 1	11	8	10	5	3	4	22	70.73
OKU 2	10	8	9	4	4	3	20	71
OKU 4	9	10	8	3	2	4	23	75
OKU 5	9	8	10	4	3	4	22	71
OKU 6	8	10	9	3	4	4	22	71
OKU 8	9	8	9	4	2	3	23	74.2
OKU 10	11	10	9	4	3	4	22	73.1
OKU 11	9	9	10	5	4	3	24	70
OKU 12	11	10	8	4	3	4	22	72.5
OKU 13	9	9	8	4	4	3	21	70.2
TOTAL 605)	96	90	90	40	32	36	221	718.73
AVERAGE	9.6	9	9	4	3.2	3.6	22.1	71.9

Table 4. MMI standard (Hoque and Nwajide, 1985)

Percentages ranges of quartz and rock fragments	MMI interpretation
Q = ≥95% (F + RF) = 50%	MI = ≥19 Super mature
Q = 95 – 90% (F + RF) = 5-10%	MI = 19 -9.0 mature
Q = 95 – 75% (F + RF) = 10-25%	MI = 9.0 -3.0 Sub-mature
Q = 75 – 50% (F + RF) = 25-50%	MI = 3.0 -1.0 Immature
Q 50% (F + RF) < 25-50%	MI≤ 1 Extremely immature

Table 5. MMI of Okomu sands

Sample	Quartz	Feldspar	Rock Fragments	Cement	Cement + RF	FSP	MMI	Mineralogical Index of Maturity
OKU 1	92	2	3	1	1	5	92/5	18.40
OKU 3	92	2	2	2	2	4	92/4	23.00
OKU 5	93	2	1	2	2	3	93/3	31.00
OKU 7	91	3	3	1	1	6	91/6	15.16
OKU 8	93	2	2	1	1	4	93/4	23.25
OKU 9	91	2	2	2	2	4	91/4	22.75
OKU11	91	2	3	2	2	5	91/5	18.20
OKU12	92	2	1	2	2	3	92/3	30.66
OKU13	91	3	2	1	1	5	91/5	18.20
OKU15	92	2	2	1	1	4	92/4	23.00
OKU16	92	2	2	2	2	4	92/4	23.00
OKU17	92	2	1	3	3	3	92/3	30.66
OKU18	93	3	2	1	1	5	93/5	18.60
OKU19	92	2	2	2	2	4	92/4	23.00
OKU20	93	3	2	2	1	5	93/5	18.60
AVERAGE	92	2.26	2	1.6	4.26	5.1		22.49

Table 6. Comparing the mineralogy maturity index of the sands with the standard

Hoque and Nwajide (1985)	Percentage range (%)	This study
Quartz	95 – 90	92
F + RF	5 – 10	4.26
MMI	19 – 9.0	22.49
Maturity	Mature	Mature to super mature

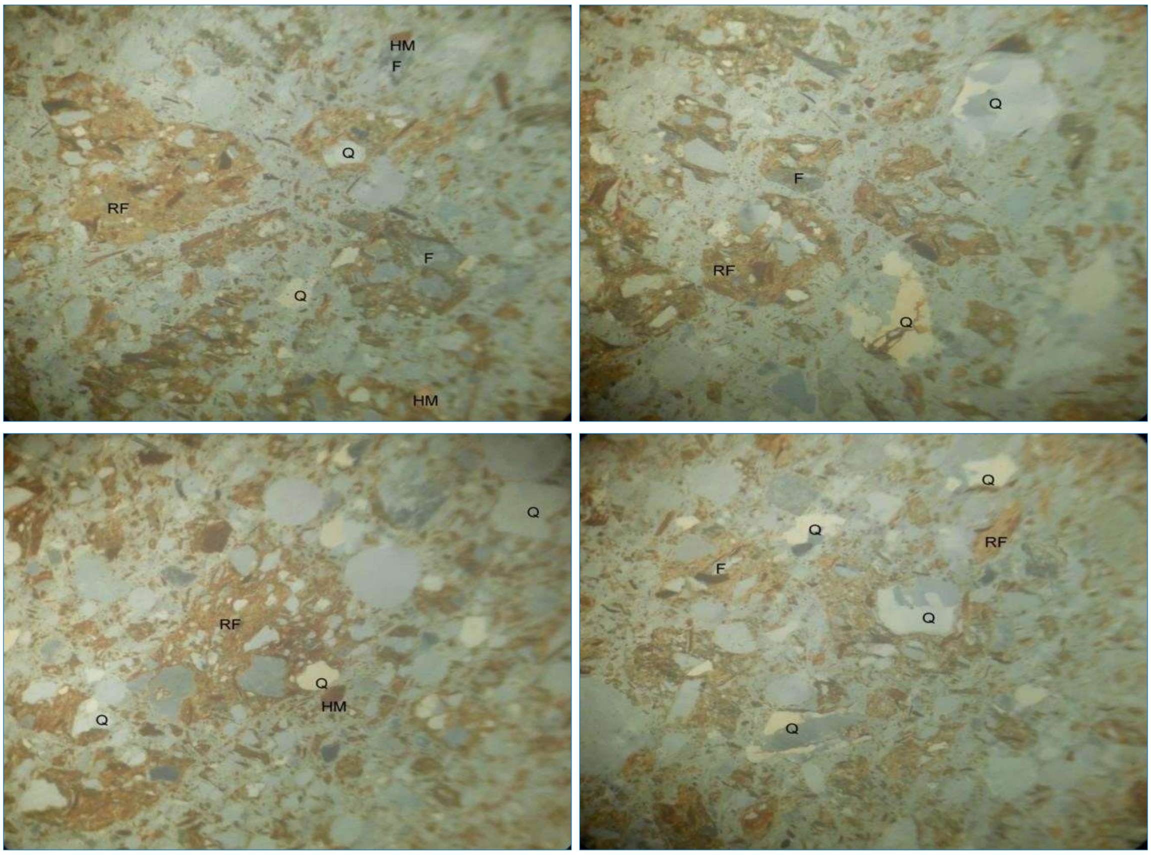

Fig. 16. Microphotographs from thin section analysis of Okomu sands under plain polarized light (*Q: quartz, F: feldspar, HM: heavy minerals, RF: rock fragments*)

5. Conclusion

Based on sedimentology and geochemical study in order to determine the paleoenvironment of deposition, assess the maturity of the coastal plain sediments, including the evaluation of textural, mineralogical and geochemical characteristics, this conclusion may be drawn:

i. The coastal plain sands of Benin formation are a quartz arenite and sublitharenite, of continental fluvial and/or river origin.
ii. The coastal plain sands are compositionally and texturally super mature and mature, mineralogical mature to super mature and chemically immature to sub - mature coastal sands.
iii. The textural characteristics reveal that the sand sediments were deposited in a period when the rate of sedimentation and erosion were in equilibrium in a moderately high energy ancient environment.

Acknowledgements

The authors acknowledge the natives and management of Okomu National Reserve for granting us access into their premises to collect the outcrop samples that were used for this research.

Conflict of Interest

The authors affirm that there is no conflict of interest.

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