

# Environmental Reconstruction and Maturity Assessment of Beach Sand: Insights from the Sapele Bypass, Benin Region, Nigeria

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## ABSTRACT

The Beach sand, Obedoluogbeyi and Idogbo communities along Sapele bypass in Benin Region, Nigeria were studied for environmental and maturity indices. Forty (40) samples were collected and experimentally analysed for textural characteristics heavy minerals composition, pebble morphology and petrographic thin section.

The examination of heavy minerals showed that the major deposit of heavy minerals was opaque. The graphic mean (average 1.542) revealed that medium to coarse sand size sediments predominated which are moderately to well sorted (average 1.141), typical of Continental paleo-environment. The graphic skewedness (average 3.445) typifies a period of a balance between erosion and deposition of the sediments with the majority of the sediments being substantially coarsely skewed and a small amount of strongly finely skewed sediments. In the graphic kurtosis (3.64), are consistent with mesokurtic to leptokurtic sand grains, characteristic of an intermediate to high energy ancient fluvial depositional environment. The sand was compositionally mature ( $Qtz > 90\%$ ), mineralogical mature (MMI average = 18.66) and chemically immature sub-mature ( $ZTR = 70.10$ ). The ancient environment of the deposition from the average of the sorting value is typical of a continental origin. This finding is authenticated by the environmental discrimination plots which also confirm a continental environment of deposition for the coastal plain sand. The fluvial or continental origin indicates past river processes, which helps to reconstruct regional paleoenvironment. Textural and compositional maturity suggests significant transport and sorting by water. The mineralogical maturity provides insights to source rock weathering or recycling. Overall, understanding the origin and maturity, guides exploration strategies.

**Keywords:** Beach Sand, Benin Region, Compositional maturity, Chemical Maturity, Continental Environment

## INTRODUCTION

The physical characteristics of the Benin Region which are relevant for the purpose of this investigation are hereby discussed in terms of those factors which (Ajakaiye and Oti, 2016) identified as the environment of weathering. They include the geological foundation and rock types, types and density of plant cover, availability of readily weatherable rocks, and tropical humid climate with seasonality of rainfall or alternating wet and dry seasons and topography amongst others (Anyanwu et al., 2022). According to Ikhile, (2016), the geology, geomorphologic processes and landforms of the Benin Region have their interplay and/or interconnections with weathering. In a broad term, the geomorphology includes aspects of the geology and relief while the hydrology embraces aspects of the drainage and water resources.

Coastal environments are dynamic systems that record changes in sea level, climate, and human activity through sediment deposits. The Sapele Bypass in Benin Region, Nigeria, is key area for studying these processes, given its location in a Niger Delta coastal setting, Ilevbare and Agbaje, (2026). This study focuses on reconstructing

the environmental history and assessing the maturity of beach sands in this region. By analysing sediment characteristics such as grain size, mineralogy and morphology, we aim to unravel the depositional processes and transport mechanisms shaping this coastline. Understanding these factors is crucial for coastal management, erosion mitigation and predicting responses to future environmental changes in this vulnerable area. The insights gained can inform sustainable development strategies for Nigeria's coastal zones.

### **Regional Geology of Benin Region Sediments**

The Benin Region is underlain by sedimentary formation of the South Sedimentary Basin. The geology is generally marked by top reddish earth, composed of ferruginised or literalized clay sand. (Ikhile, 2016) first used the term Benin sand to describe the reddish earth underlain by sands, sandy clays and ferruginised sandstone that mark the Paleo-Coastal Environment of Paleocene-Pleistocene Age. These sediments spread across the southern fringes of the Anambra Basin and marking the upper facies off-flaps of the Niger Delta. (Anyanwu et., 2022) used the name Coastal plain sands to describe the formation of red earth underlain by sands and clays that mark an ancient coastal plain environment now exposed in Calabar, Owerri, Onitsha and the Benin Region with the age Oligocene-Pleistocene.

However (Adegoke and Akande, 2017) reinstated the name Benin formation to identify the reddish-brown-yellow generally white sands often with clayey and pebbly horizons with type-locality around Benin. This is also referenced at Calabar and other parts of South Eastern Nigeria. The formation was further established by well logging of Etete 1, well drilled on-shore east of River Niger by Shell Nigeria. Petroleum Development Company (SPDC) and described by (Anyanwu et al., 2022). The formation is about 1830 m thick at the seashore but thins landwards. The sedimentary suits of the Benin Formation dip 2° - 8° south. Geologically, the Benin Region comprises of 1) the Benin formation; 2) alluvium; 3) drift/top soil and 4) Azagba-Ogwashi (Asuba-Ogwashi) formation.

### **The Benin Formation**

It is assigned to the Oligocene-Pleistocene period in the continent of Africa and to the Oligocene-Pleistocene recent at the sub-oceanic (Ajayi and Oti, 2016). This formation is characterized by top reddish to reddish brown lateritic massive fairly indurate clay and sand. This is often marked with reticulate mud cracks. This caps the underlying more friable pinkish-yellowish white often gravelly-pebble sands clayey soils, sands and clay (Akujeze 2004). The sedimentary sequences are poorly bedded with discontinuous clay horizons at various depths. It is estimated to be about 800m thick under Benin City and about 1,830m near the sea shore sections of the formation. They are exposed at various erosion sites, sand quarry sites, and road cuttings. The Benin formation covers 95% of the region, (Khan et al., 2022).

### **Alluvium**

These are found along Ikpoba and Ovia flood plains. They are made up of grayish-dirty white-yellowish-white sands, silts, clayey sands, gravels and even wood-plant materials. These have been washed down the river valley and deposited at the river banks. They are recent deposits. (Overare and Osokpo, 2020).

### **Drift/Top Soil**

Drifts are sediments still in the process of transportation or movement. They are made up of light brown-yellowish silt, mudflows and sands derived from the weathering of the parental Benin Formation. Drifts are washed down by fluvial agents especially the storms and floods dominating the wet season of the region. The drifts are not part of the solid geology (Boboye and Chidebere, 2013). But they are mainly derived and reworked materials and loads dropped by moving floods. Drifts cover roadsides; fill up areas, concealing the underlying geology. Drifts vary from very thin veneers to up to 0.55 m. The drifts cover about 2% of the urban area. Where the drifts are stabilized soil profile formation is developed. (Muller et al., 2020).

### Azagba-Ogwashi (Asaba-Ogwashi) Formation

The Azagba-Ogwashi formation has been missing spelt as Ogwashi-Asaba formation (Adegoke and Akande, 2017), It consists of clays, sands and grits and seams of lignite alternating with gritty clays. It grades upwards into the Benin Formation. The Ogwashi-Asaba formation is exposed in stream channels at the northern parts of the Benin Region, west of Ekiadolor-Iwu and 4 km east of Utekon and north of Azalla, (Akujjeze, 2004).

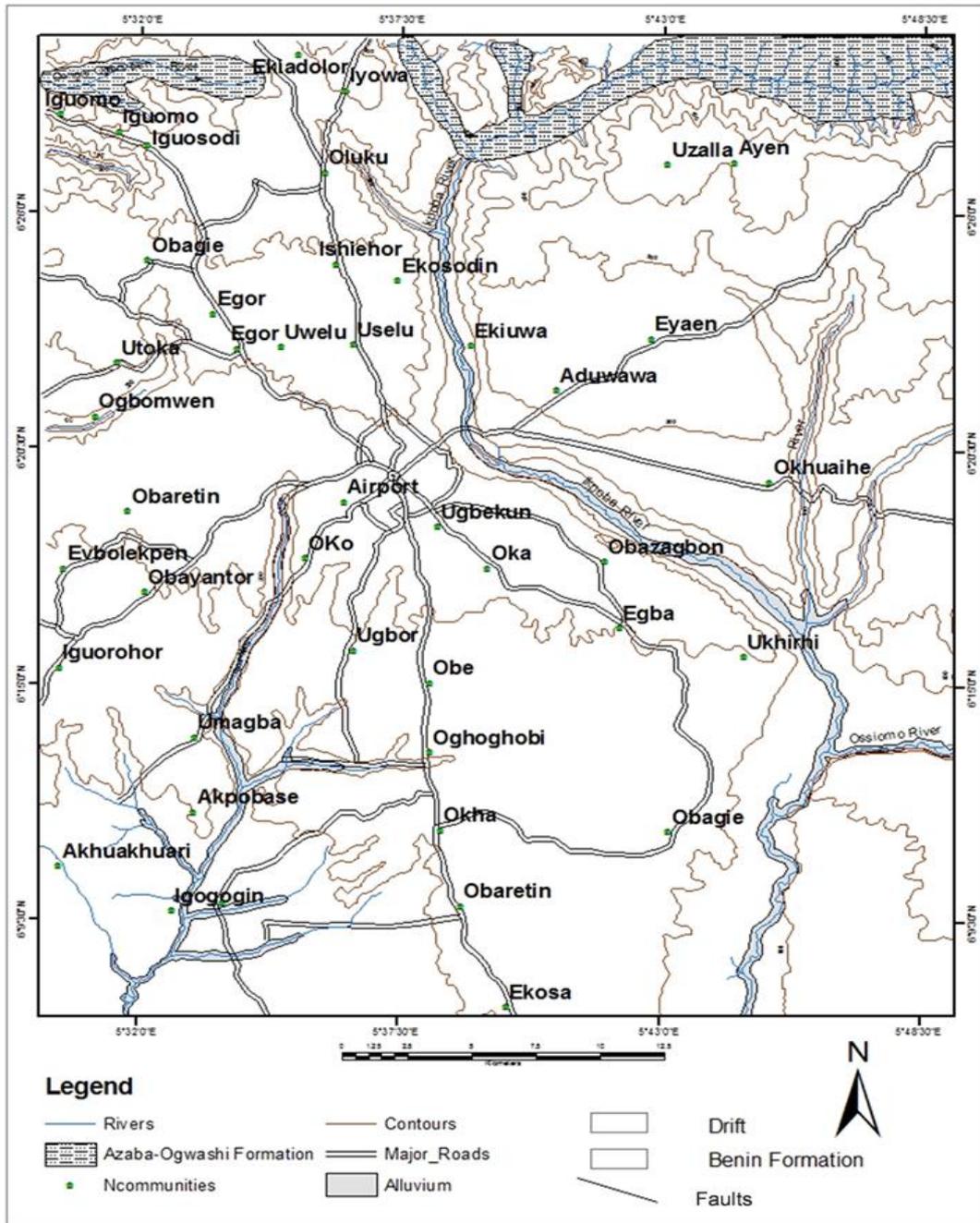


Figure 1. Benin Region Geological Map (after Akujjeze, 2004).

### Location of the study Area

The study area is Obedolougbeyi and Idogbo Benin City, Nigeria. The area is highly accessible with major and minor roads, together with other adjoining roots. The location map was generated using the GPS Co-ordinates obtained from the field studies.

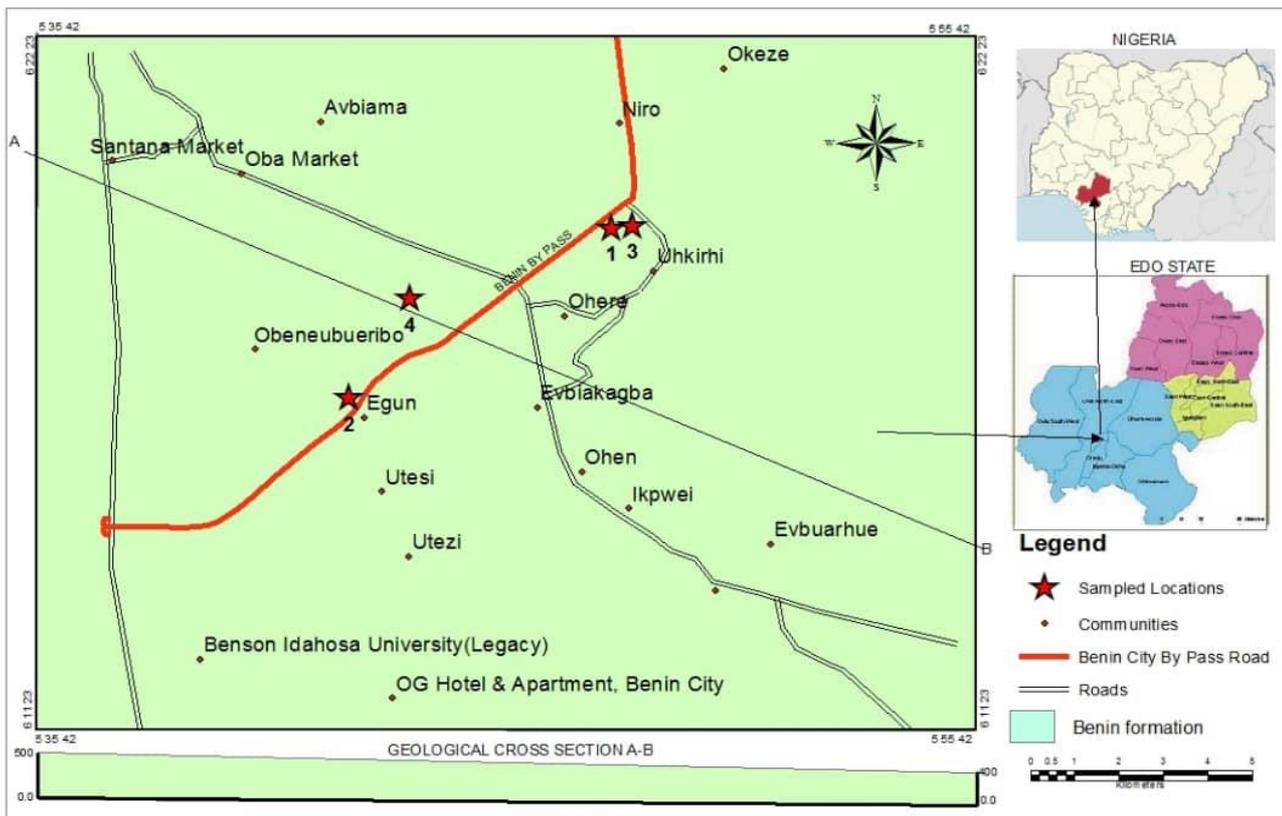


Figure 2. Geological Map of obedoluogbeyi and Idogbo Sand



Figure 3. Field photograph of Idogbo (a, c) and Obeduologbeyi (b, d)

## MATERIALS AND METHOD

### Materials

Methods of investigation involved both field study and laboratory analyses. Forty (40) fresh sediment outcrop samples were collected from Obedoloubeyi and Idogbo along Sapele Bypass in Benin Region, Nigeria. Of these 40 Samples, 15 were analysed for grain size analysis (the sample number represents variability across outcrops, sufficient for statistical trends), 10 were analysed for thin section analysis (for detailed mineralogy insights and as such fewer samples needed), 10 were analysed for pebble morphology (focused on samples with sufficient pebbles for transport and environmental clues) and 5 were analysed for Heavy Minerals analysis (small subset for cost-effective provenance information). Chip and Grab sampling methods were adopted. Hammer, chisel, GPS, and sample bags were used. The collected samples were analysed for grain characteristics, petrographic studies (thin section and heavy mineral analyses).

### Methods

#### Grain Size Analysis

Fifteen (15) samples were analysed for grain size analysis. The grain size analysis test is done to determine the percentage of each size of grain that is conducted within a soil sample. The procedure of Friedman (1979) was adopted the sieving and the statistical model of Folk and Ward (1957) was employed to derive textural characteristics.

The procedure for sieve analysis is detailed below:

- ❖ The sieve weight and pan were measured and recorded.
- ❖ The dried sand weight was measured and recorded.
- ❖ Sieve brush was used to clean sieves and assembled. Measured soil samples were
- ❖ Carefully poured into the top sieve and duly covered.
- ❖ Place sieve stack in the automatic sieve shaker leave for one minute.
- ❖ Remove the stack from the shaker, weigh and record- that is, the weight of the bottom pan and the fine sand is retained.

Next, the computation stage, the mass of sand retained on each sieve were obtained by subtracting the weight of the empty sieve from the mass of the sieve, plus retained sand, which was recorded as weight retained on the data sheet.

The sum of these retained masses should approximately equal the initial mass of the sand sample. A loss of more than two percent is unsatisfactory.

The percentage retained on each sieve was calculated by dividing the weight retained on each sieve by the original sample mass.

The percentage passing was determined by starting with 100 percent and subtracting the percent retained on each sieve as a cumulative procedure.

A semi-logarithmic plot of grain size versus percent finer was then drawn from which the grain size parameters were plotted.

### Thin Section Sample Preparation

A thin section is useful for analysis in mineralogy. It provides invaluable insight and details into mineral compositions and rock formations. Ten (10) samples were analysed for thin section analysis.

Fresh loose samples were air dried for 24 hours, the samples were then impregnated with epoxy A and B and left to cure for at least 24 hours, the cored sample is then trimmed to fit on a glass slide, the trimmed surface is lapped on the glass plate using water and silicon carbide 600grits, this is done so as to have a very smooth surface for bonding with the glass slide. One surface of the glass slide is also lapped and made smooth for bonding with the sample. The sample is then bonded to the glass slide using epoxy on the hot plate, this is allowed to bond for 24 hours, the sample is then trimmed to 50 $\mu$ m on the glass slide using the cut-off saw machine and later transferred to the lapping plate and lapped to 30 $\mu$ m using silicon carbide and water, at 30micron the slide is ready for study under petrographic microscope (Mohammed *et al.*, 2018, Enyioko *et al.*, 2022). Ingersoll *et al.*, (1984) counting method, which was also adopted by Tijani *et al.*, (2010) was employed for the mineral grain's compositional analysis, and the modal analysis, the Dickinson (1970) method of counting over 300 points per thin section was used.

### Heavy Mineral Sample Preparation

Heavy minerals are generally identified on the basis of their optical properties under the polarizing microscope (Schonig *et al.*, 2018). Five (5) samples were analysed for heavy mineral analysis.

Fresh samples were air dried for 24 hours, a separating funnel was mounted and filled to three-quarter (3/4) full of bromoform, the soil sample is then poured into the separating funnel and stirred, the heavy minerals contained in the samples will sink to the bottom of the funnel and later will be collected in a filter paper, this is rinsed in acetone to make it bromoform free. The heavy mineral is mounted on a clean glass slide using DPX mountant and ready for study (Osazuwa and Saka, 2016).

### Pebble Morphometric Analysis

Ten (10) outcrop samples were analysed for pebble morphometric analysis following the procedure detailed below;

- ❖ Pebble Morphometric analysis was carried out from a weighed 200g of sand out of which 80 pebbles were selected.
- ❖ The collected pebbles were later screened to exclude pebbles that were cracked or freshly broken. These pebbles were washed, numbered and transported to the laboratory.
- ❖ The analysis involved the measurement of the magnitude of the long axes (L), intermediate axes (I) and short axis (S) of the pebbles, using vernier caliper. Other relevant data were computed from the generated data.

## RESULTS AND DISCUSSION

### Results

The data obtained from grain size analysis of each sample were presented in the form of histogram, cumulative frequency curve. The textural parameters such as mean, median, sorting, skewedness and kurtosis for each sample were statistically determined. The results of grain size, thin section, heavy mineral analysis and compositional maturity are presented in tables and chart and plot below for easy comprehension and interpretation.

Table 1 Granumetric analysis (Median, Mean, Sorting, Skewedness, Kurtosis)

S/N	MEAN	MEDIAN	SORTING TYPE	SKEWNESS TYPE	KURTOSIS TYPE
IDG 1	1.67	1.5	1.03	-1.696	1.43
IDG 2	1.25	1.25	1.68	0.06	34.5
IDG 3	1.42	1.25	1.40	-0.05	1.56
IDG 4	1.42	1.25	1.34	0.1	1.56
IDG 5	1.17	1.25	1.04	1.04	1.31
IDG 6	1.60	1.50	1.38	0.08	0.97
IDG 7	1.92	1.75	1.25	0.36	1.13
IDG 8	1.17	1.25	1.16	0.35	1.95
OBY 11	1.83	1.50	1.24	0.93	2.80
OBY 12	1.5	1.25	0.29	0.07	1.39
OBY 13	1.96	2.75	0.06	0.12	1.43
OBY 14	1.58	1.25	1.05	0.31	1.19
OBY 15	1.5	1.5	1.004	0.711	1.557
OBY 16	1.67	1.5	1.22	0.59	1.36
OBY 17	1.47	1.25	0.48	0.47	1.5
AVERAGE	1.542	1.47	1.141	3.445	3.64

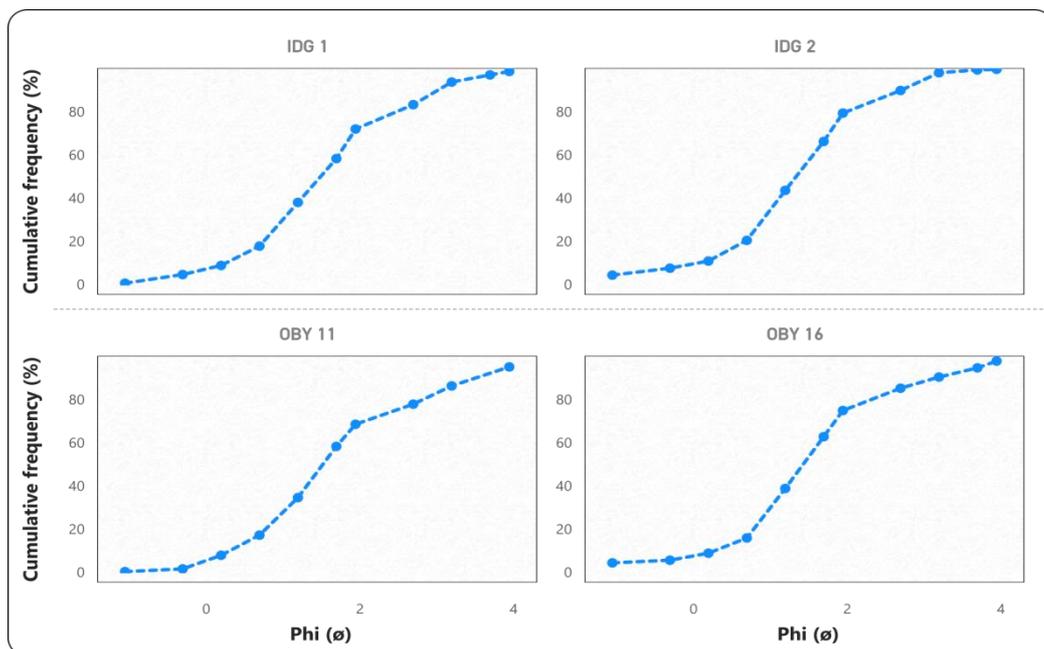


Figure 4. Cumulative frequencies versus Phi

The chart of cumulative frequency vs. phi curve gives insights into about sediments transport, depositional environments, sediments sources and sedimentary processes is given as a sigmoidal curve, (Figure 4).

A sigmoidal curve suggests as well-sorted sediment deposit with a distinct peak or mode in grain size distribution. In a sigmoidal curve, the cumulative percentage of grains increases gradually at smaller grain sizes, accelerates in the middle range and then levels off as it approaches larger grain sizes. The environment of deposition tends to promote the sorting and selective transport of sediments particles, resulting in a well-defined grain size distribution.

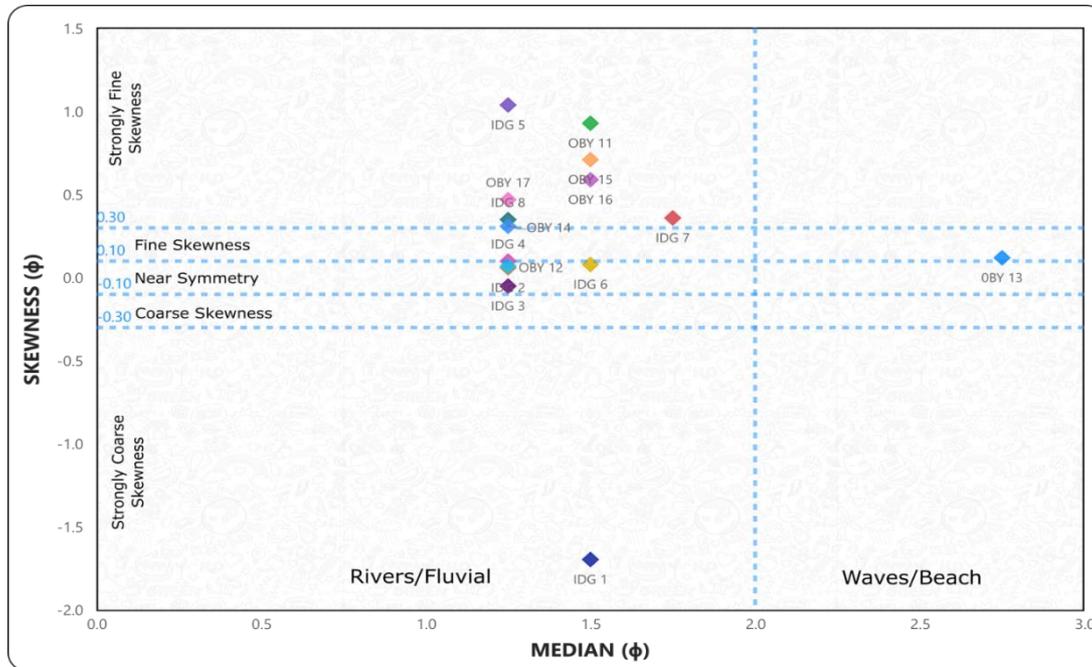


Figure 5 Skewedness versus median (after Ilevbare and Omodolor, 2020).

This chart both indicates the skewedness as being mostly fine to strongly fine skewed with an origin of the sediments being from fluvial source such as rivers; however, a minority came from waves and beaches, (Figure 5).

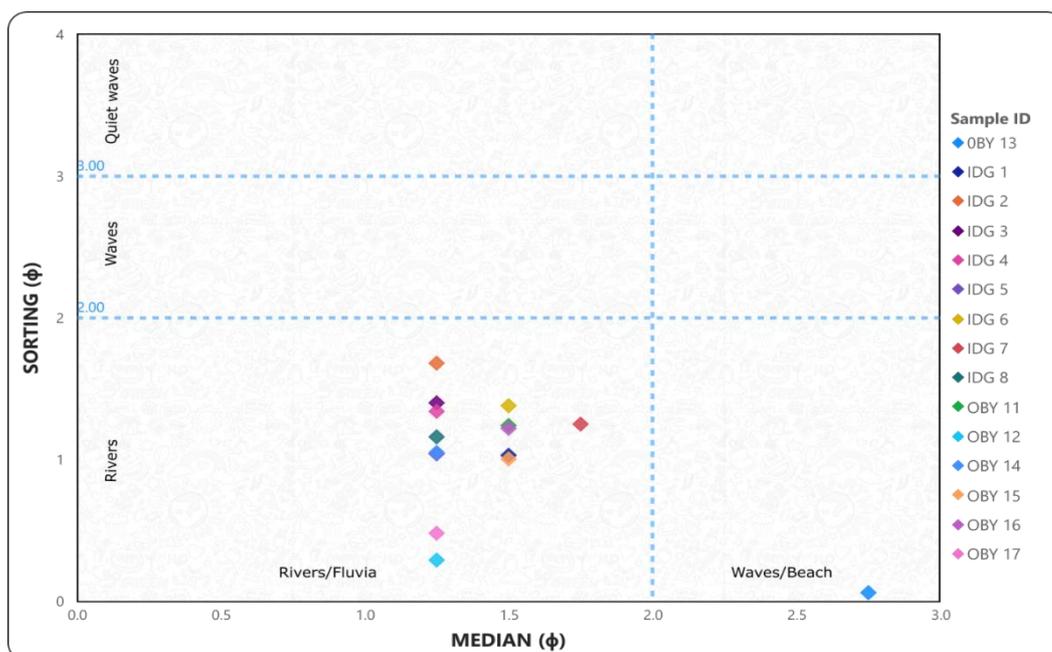


Figure 6 Sorting versus median (After Ilevbare and Imasuen, 2020)

The plot of sorting against median (Figure 6) reveals that the sediment was deposited in a riverine/fluvial environment.

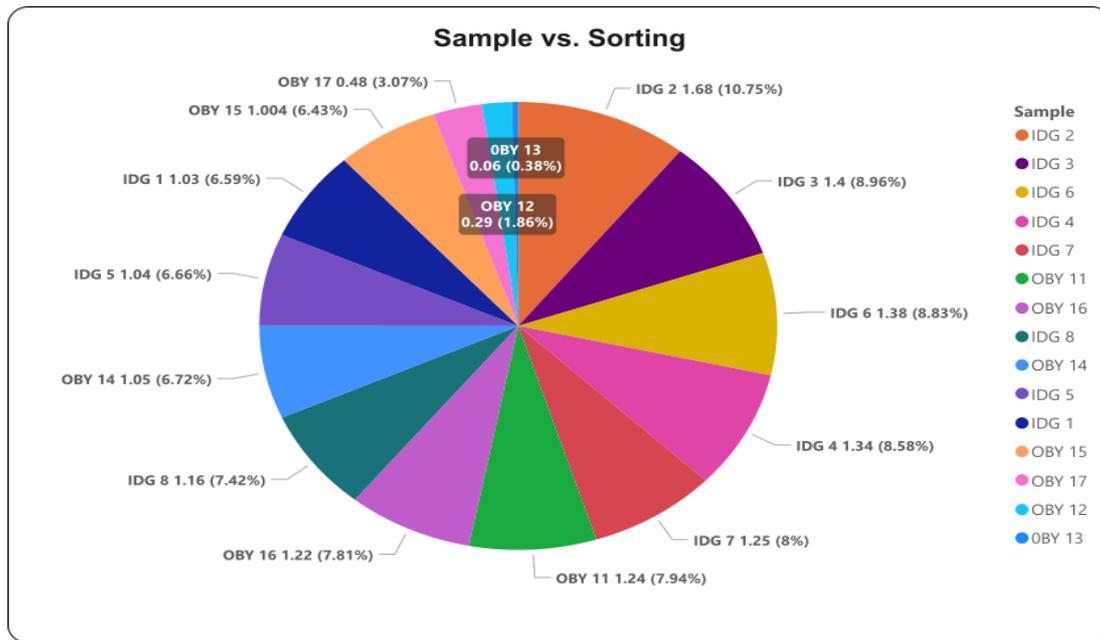


Figure 7. Chart showing the sorting of the coastal sand

This pie chart (Figure 7) shows that the highest Sorting is at IDG 2 (1.68) and IDG 3 (1.4), the least value of sorting is OBY 15 (1.004) and OBY 17 (0.48) and this implies that the sorting is moderately to well sorted.

Table 2. Compositional maturity of the coastal plain sand

Sample No.	Quartz (grain type)	Angular/Boundary	No of Count	Ratio of Polyxtaline to Monoxtaline	Compositiona l Maturity
IDG 6	Polycrystalline	Angular to subangular	60	60:52	Super mature (= 93% Qtz)
	Monocrystalline	Rounded to subrounded	52		
IDG 7	Polycrystalline	Angular to subangular	51	51:48	Super mature (=93% qtz)
	Monocrystalline	Rounded to subrounded	48		
IDG 8	Polycrystalline	Angular to subangular	61	61:55	Super mature (=92% qtz)
	Monocrystalline	Rounded to subrounded	55		
IDG 9	Polycrystalline	Angular to subangular	58	58:43	Super mature (=93% qtz)
	Monocrystalline	Rounded to subrounded	43		
IDG 10	Polycrystalline	Angular to subangular	59	59:45	Super mature (=92% qtz)
	Monocrystalline	Rounded to subrounded	45		
OBY 11	Polycrystalline	Angular to subangular	60	60:54	Super mature (=93% qtz)
	Monocrystalline	Rounded to subrounded	54		
OBY 12	Polycrystalline	Angular to subangular	57	57:44	Super mature

	Monocrystalline	Rounded to subrounded	44		(=93% qtz)
OBY 13	Polycrystalline	Angular to subangular	59	59:49	Super mature (=92% qtz)
	Monocrystalline	Rounded to subrounded	49		
OBY 14	Polycrystalline	Angular to subangular	53	53:49	Super mature (=91% qtz)
	Monocrystalline	Rounded to subrounded	49		
OBY 15	Polycrystalline	Angular to subangular	56	56:48	Super mature (=93% qtz)
	Monocrystalline	Rounded to subrounded	48		

Table 3 Zircon-Tourmaline-Rutile (ZTR) Index

Sample No.	Zircon	Rutile	Tourmaline	Sillimenite	Garnet	Apetite	Opaque	ZRT Index
IDG 7	10	7	10	3	3	4	23	72.97
IDG 8	11	8	9	5	4	3	20	70.0
OBY 18	9	10	9	6	2	4	22	70.0
OBY 19	9	9	10	5	3	4	25	70.0
OBY 20	10	8	9	4	5	4	22	67.5
Total	49	42	47	23	17	19	112	350.47
Average	9.8	8.4	9.4	4.6	3.4	3.8	22.4	70.094

The heavy minerals were analysed 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 (70-75; ~71.9). The data revealed that opaque was the dominant deposit of Heavy Minerals > Zircon > Rutile/Tourmaline > Sillimanite > Apatite > Garnet. This inference is corroborated by (Figure 9)

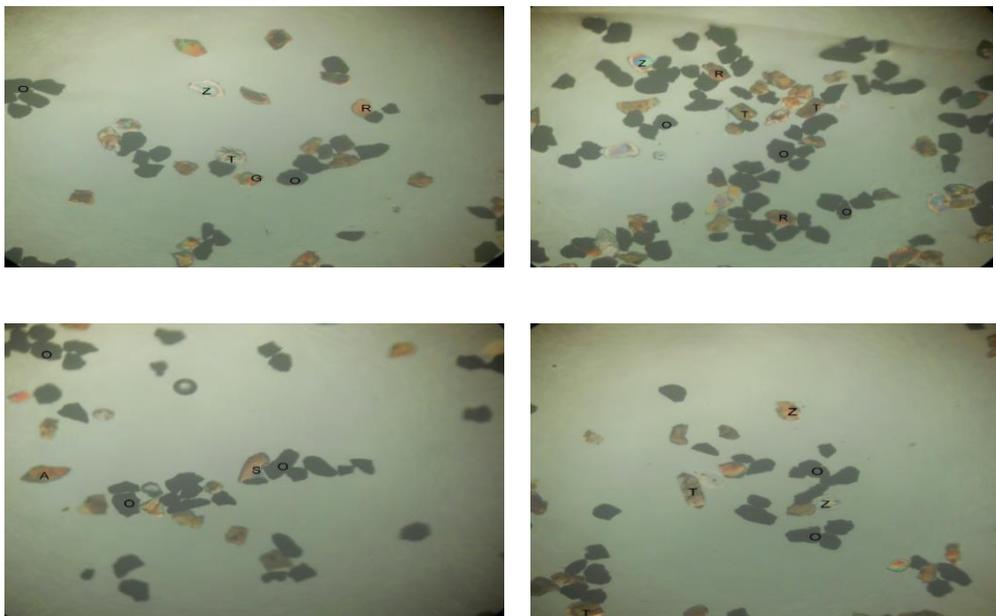


Figure 9. Microphotographs of heavy minerals of the Beach Sand under crossed polarized light

In Figure 9 above, O, R, S, Z, G represents, Opaque minerals, Rutile, Toumaline, Silliminite, Zircon and Garnet respectively while Figure 10 presents the thin section of the sand under plane and crossed polarisers with Q, F and HM for Quartz, Feldspars and Heavy Minerals as the dominant minerals.

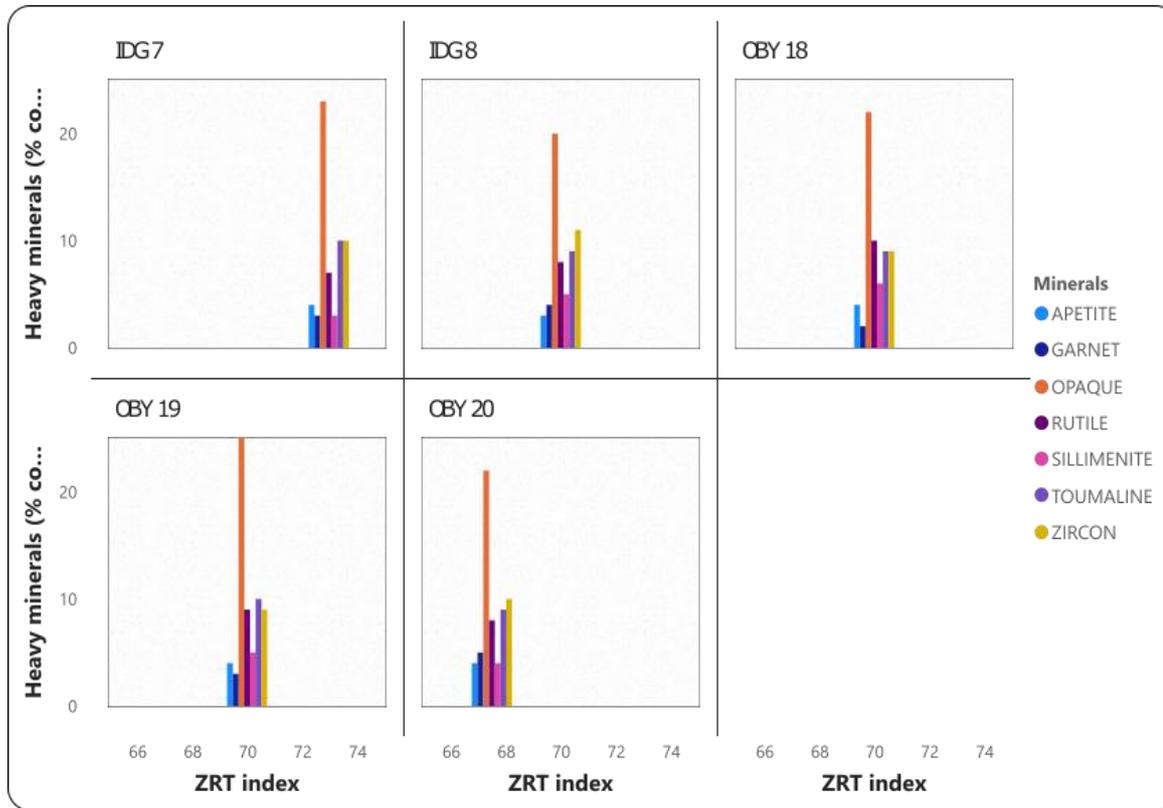


Figure 8. Chart of heavy mineral analysis of the Beach Sand

Table 4 Mineral Maturity of the Beach Sand

Sample No.	Quartz	Feldspar	Rock fragment	FSP + RF	MMI FSP+RF/Q	Mineral maturity index(MMI)
IDG 6	93	2	2	4	93/4	23.25
IDG 7	93	3	2	5	93/5	18.6
IDG 8	92	3	3	6	92/6	15.33
IDG 9	93	2	3	5	93/5	18.6
IDG 10	92	2	3	5	92/5	18.4
OBY 11	93	3	2	5	93/5	18.6
OBY 12	93	2	3	5	93/5	18.6
OBY 13	92	3	2	5	92/5	18.4
OBY 14	91	3	2	5	91/5	18.2
OBY 15	93	2	3	5	93/5	18.6
AVERAGE	92.5	2.5	2.4	5		18.658

Table 5 Maturity scale of sandstone: Limiting % of Q and (F + RF) and Maturity stage (Ilevbare et al., 2025).

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 = 19-9.0 Mature
Q = 75 - 50% (F + RF) = 25-50%	MI = 3.0 -1.0 Immature
Q 50% (F + RF) < 25-50%	MI< 1 Extremely Immature

The mineralogical maturity index (MMI) is determined using the expression:

$$MMI = \frac{\text{Proportion of Quartz}}{\text{Proportion of F + proportion of RF}}$$

Sediments with high MMIs are derived from older, more weathered rocks while sediments with low MMIs are typically derived from younger, less weathered rocks. The coastal plain sand in this study is mostly mature (15.33-23.25) sand with an average of ~18.7 (Table 5).

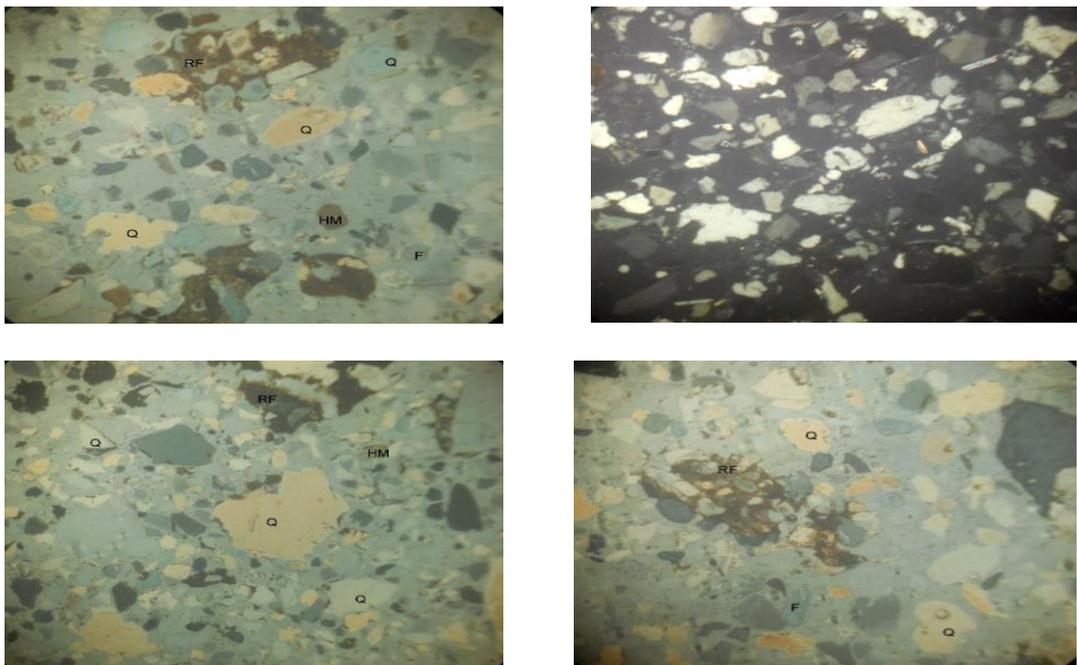


Figure 10 Microphotographs of thin sections of coastal sand under plain and crossed polarized light

Table 6 Mineral Maturity of Beach Sand Studied

Ilevbare and Omodolor, (2020)	Percentage Range (%)	This study
QUARTZ	95-90	92.5
F + RF	10-5	5
MMI	19-9.0	18.685
Maturity	Mature	Mature

The standard for comparison for the mineralogical maturity index is here provided, (Table 6) while the pebble morphology characteristics for the Beach Sand are detailed in Table 7.

Table 7 Pebble Morphology of the Beach Sand

Sample	L (cm)	I (cm)	S (cm)	S/L	I/L	OP Index	Form Name	Roundness s%	Bladed form (L-1)/(L-5)	Maximum Projection Sphericity
IDG 1	1.31	0.91	0.58	0.44	0.69	-2.52	B	20	0.48	0.50
IDG 2	1.29	1.00	0.67	0.52	0.78	-0.76	B	20	0.45	0.75
IDG 3	1.43	0.92	0.62	0.43	0.64	-0.86	CB	20	0.52	0.70
IDG 4	1.65	0.99	0.69	0.42	0.60	-2.88	CB	20	0.30	0.68
IDG 5	1.39	1.52	0.78	0.56	1.09	-1.40	B	30	0.41	0.70
OBY 16	1.43	0.94	0.57	0.40	0.66	-4.11	P	20	0.32	0.67
OBY 17	1.67	0.50	0.63	0.38	0.30	-1.55	CB	30	0.42	0.72
OBY 18	1.49	0.04	0.65	0.44	0.70	0.91	B	20	0.54	0.65
OBY 19	1.28	0.92	0.71	0.55	0.72	-3.81	B	30	0.74	0.80
OBY 20	1.69	1.20	0.85	0.50	0.71	1.60	P	20	0.58	0.70
AVERAGE	1.463	0.894	0.675	0.464	0.689	-1.538		23	0.479	0.689

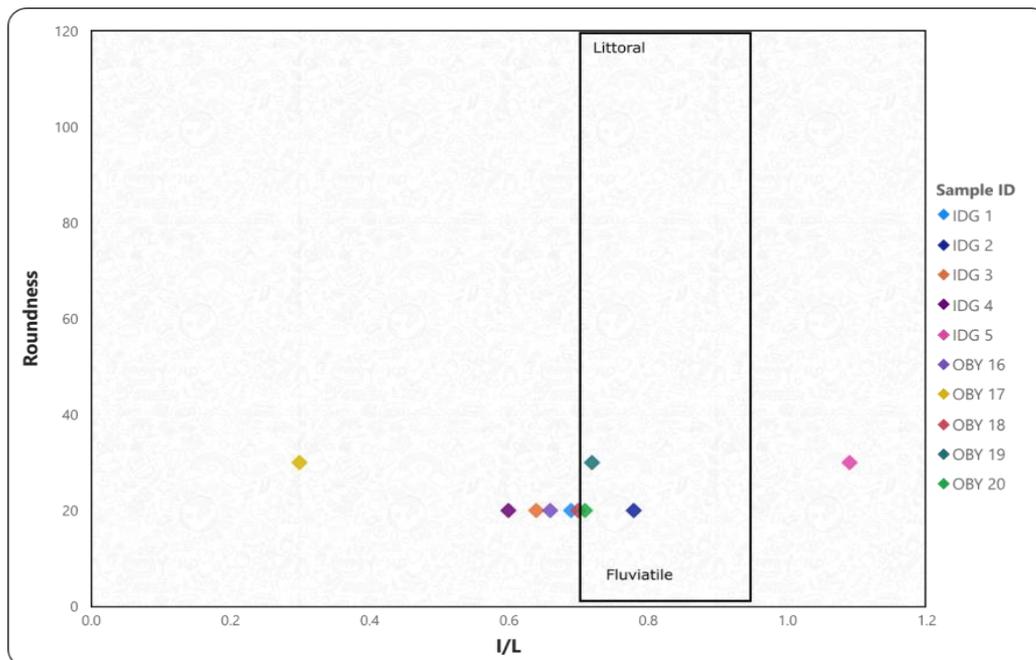


Figure 11. Roundness versus I/L (after Ilevbare et al., 2025)

The sphericity versus oblate - probate index (Figure 11) shows that 97% of data points again plot in the fluvial/riverine environment. This again, confirms the environment of deposition of Beach Sand as fluvial.

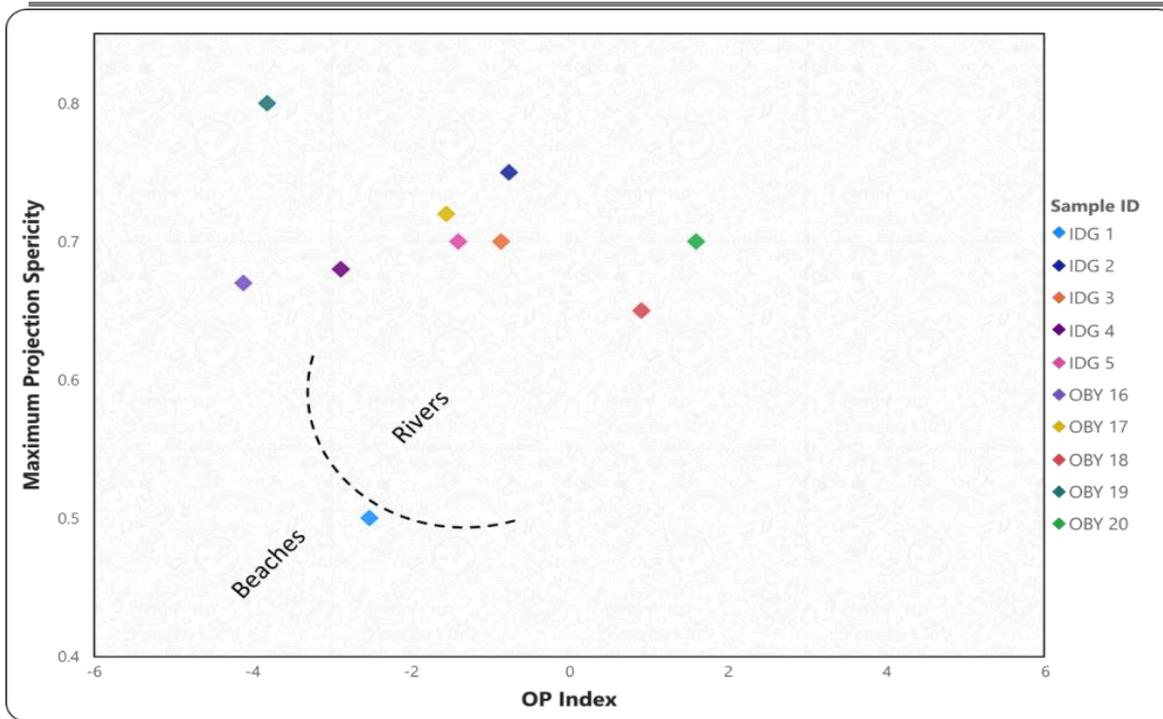


Figure 12. Maximum Projection sphericity versus OP index (after Ilevbare et al., 2025)

The plot of roundness versus  $1/L$  (Figure 12) shows that the Sand is of fluvial This authenticated by the plot of sphericity versus OP index which also confirms a fluvial origin for the coastal sand.

## DISCUSSION

### Sedimentological Characteristics of the Coastal Sand

#### Graphic mean of the coastal plain sand

Graphic mean is a measure of central tendency the verbal limits are: -1.00 to 0.00 for very coarse sand; 0.00 to 1.00 for coarse sand; +1.00 to 2.00 for medium sand; +2.00 to 3.00 for fine sand and +3.00 to 4.00 for very fine sand. The values obtained in this study ranged from (1.2 - 1.96)  $\phi$  with an average of 1.542  $\phi$  (Table 1). The values in general show the dominance of medium to coarse sand size sand.

#### Graphic skewedness of the coastal plain sand

The graphic skewedness measures the systematic of the distribution or predominance of coarse to fine sediments. The negative values denote coarse skewed material whereas the positive value represents more materials in the fine-tail i.e. fine skewed. The verbal limits are: 7.0 to 0.30 for strongly fine skewed; +0.30 to +0.10 for fine skewed; +0.10 to -0.10 for near symmetrical; -0.10 to -0.30 for coarse skewed and < -0.30 for strongly coarse skewed. The values range from (-0.05 - 1.04)  $\phi$  with an average of 3.445  $\phi$  in this study (Table 1). Two out of fifteen samples gave negative values being strongly coarsely skewed; the other thirteen are strongly finely skewed.

Positive skewedness characterizes a beach with deposition of sand, whereas negative skewedness indicates erosion and non-deposition (Akpofure and Akana, 2019). The data points cluster in the near symmetry to coarse skewed region which indicates environments where the effect of erosion and non-deposition are observed with a balance from beaches with deposition. Again, Friedman (1961), found that dune sands are generally positive skewed and could be barrier island, coastal lake or fluvial environment while beach sand are found to be negatively skewed.

## Graphic sorting of the coastal plain sand

Standard deviation versus median size has been used for differentiating among river, wave and slack water processes between beach and dune sands (Friedman, 1961; Miola and Weiser, 1968). The verbal limits are: less than 0.35 being very well sorted; 0.35 - 0.50 being well sorted; 0.5- 0.71 as moderately well sorted; 0.71 - 1.00 as moderately sorted; 1.00 - 2.00 is poorly sorted and more than 2.00 being very poorly sorted. The average sorting for the sand is 1.141  $\phi$  which reveals the coastal plain sand as mainly poorly sorted typical of beach sediments.

Folk, (1965) classified sorting values as: (1-3)  $\phi$  for sand class; (0.25-0.5)  $\phi$  for beach sand and (0.35-1.0)  $\phi$  for fluvial/ shallow marine sand. The values from this study ranges from (0.06 to 1.68)  $\phi$  with an average of 1.141  $\phi$  (Table 1). This indicate that the coastal sand are of fluvial origin with mostly shallow marine sand with an admixture of beach sand, after Folk's environmental discrimination scheme.

## Graphic kurtosis of the coastal plain sand

Extremely high or low kurtosis values is an indication of different sources for the sediment and most likely from high energy environment. The differences in the values for kurtosis reflect the flow characteristics of the deposition medium. (Baruah et al., Ray et al., 2006)

Again, the verbal limits are: <0.67 is regarded as very platykurtic; 0.67–0.90 platykurtic; 0.90 – 1.11 being mesokurtic; 1.11 – 1.50 as leptokurtic; 1.50 – 3.0 is very leptokurtic >3.0 is extremely leptokurtic. Most sand is leptokurtic which is either positively or negatively skewed. The dominance of the platykurtic and leptokurtic sediments (-1.040-2.675)  $\phi$  and an average of ( -1.283)  $\phi$  reflects compositionally and mineralogical mature sand.

## Maturity and Ancient Environment of the Beach Sand

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

In Table 2 above, the compositional maturity of fifteen (15) sample locations was analysed. It was investigated that majority of the samples were of the polycrystalline grain type; they were also found to be angular to sub-angular. The monocrystalline samples were less and had rounded to sub-rounded boundaries. Also observed was that the ratio of polycrystalline to monocrystalline was higher in all samples (the least being 51:48 and the highest, 61:55). The depositional conditions of angular to sub-angular grain sizes provide valuable insights into the processes and environments in which sedimentary rocks were formed. Since erosion and transportation processes have not had enough time to round the grains, they are typically found close to the sediment source area. It is possible that deposition took place very near to the original sediment source given the presence of angular to sub-angular grains. Indicators of high-energy depositional environments include angular grains, such as steep slopes, swiftly moving rivers, or near shore regions exposed to powerful wave action. Sediment transport is more likely to happen in these dynamic environments without much rounding or abrasion (Yusuf et al., 2020) the retention of angular to sub-angular grains points to a quick deposition process with little transportation. When sediments are quickly deposited, rounding and sorting processes have less time to take place, which results in the retention of angularity. Gravel bars, alluvial fans, and debris flows are just a few examples of sedimentary structures that are frequently linked to angular to sub-angular grain sizes. These structures are commonly formed by fast-moving sediment-laden fluids or mass wasting events, which result in the deposition of relatively coarse, angular sediments. In some circumstances, angular to sub-angular grains may suggest reworking or disruption of previously deposited sediments. Some sedimentary deposits influenced by tectonic activity or glaciation might be disrupted, resulting in the preservation of angular grains during later deposition. It is possible to determine the depositional environment of sediment by interpreting the distribution of angular to sub-angular particle sizes. For instance, it can be assumed that a sediment was deposited in a somewhat turbulent environment, like a river or stream, if the sediment is observed to contain angular to sub-angular grains, (Khan et al., 2022). The degree of rounding can be used to determine the age of sediment in addition to the depositional environment. In general, older sediments tend to be more rounded than younger sediments. Older sediments have had more time to be

transported and eroded, which is why. The degree of rounding can also be used to infer the source of sediment. For instance, sediments formed from bedrock made up of angular rocks typically include angular grains. Round grains are more common in sediments that come from bedrock made up of rounded rocks; (Mc Lennan et al., 1993) Grain sizes that are rounded to sub-rounded can provide important information about the depositional circumstances of sedimentary rocks. Grain sizes ranging from rounded to sub-round are frequently seen in sediments that have experienced extensive transportation. The degree of rounding reveals how far the sediment has traveled from its source. The longer the transportation distance, the more rounded the grains tend to become due to abrasion and attrition during transport. In low to moderate energy depositional environments like meandering rivers, deltas, beaches, or offshore regions, rounded to sub-rounded grain sizes are frequently found. These environments have relatively lower energy levels than high-energy ones, allowing sediment to be transported farther and to go through rounding processes. Rounded to sub-rounded grain sizes are commonly found in sedimentary rocks that were deposited in fluvial (river), lacustrine (lake), and marine environments. They can also be discovered in glacial outwash and till deposits. Abrasion and attrition must have time to take place before grains can be rounded. Longer periods of deposition are suggested by sediments with rounded to sub-rounded grains, allowing for enough time and movement to produce the observed degree of rounding. In intermediate to fine-grained sediments, where the grains are more vulnerable to abrasion during transport, rounded to sub-rounded grains are frequently encountered. Even after extensive transportation, coarser grains may still have some angularity. Rounded to sub-rounded grains may signify a depositional environment that is reasonably steady or quiet. These conditions let grains to undergo extensive rounding processes since sediment is not continuously reworked or disturbed, (Ilevbare, et al., 2020).

Zircon (figure 7) is a valuable material with a variety of uses in jewelry, industry and nuclear power as a coolant. It is a hard mineral with a Mohr's hardness of 7.5, chemically inert and resistant to weathering. It is commonly found in igneous rocks and persists in sedimentary deposits as a common constituent of most sands. Rutile is commonly found in rocks that contain titanium. It is a relatively hard mineral with a Mohr's hardness of 6 to 6.5, and has a high specific gravity. It has a wide range of applications: electronics, ceramics, pigments and plastics.

Tourmaline (Figure 8) is a complex borosilicate highly valued as a gemstone and used in jewelry and may also exhibit electrical properties under certain conditions. Tourmaline is commonly found in granitic pegmatite's, which are coarse-grained igneous rocks and less commonly in sedimentary rocks as detrital grains transported and deposited by water or wind.

It has a hardness of 7 to 7.5 on Mohr's scale of mineral hardness.

Garnet (Figure 8) is typically found in metamorphic rocks and less commonly in igneous and sedimentary rocks. They are used as gemstones for their beauty, and their durability. They also have valuable industry applications such as abrasives, water jet cutting and filtration media. Sillimenite has a good cleavage and a hardness of 6.5 to 7.5 on the Mohr's scale. It is well associated with other metamorphic minerals such as garnet. It is often employed in the production of refractory materials. Apatite mineral has a hardness of 5 on the Mohr's scale. It is used widely in the production of fertilisers as a rich source of phosphorus, and geological dating as well as in gemstones. The ZTR (Zircon-Tourmaline-Rutile) index is a geochemical indicator that helps identify the source and composition of sediments in rocks. They basically useful in construing the provenance of sedimentary rocks basin analysis, paleogeographic reconstructions and understanding sediments transport and deposition process.

The ZTR ratio % of Ultra-stable Zircon, Rutile and Tourmaline in the total non-opaque heavy mineral fraction) gives a measure of the degree of dissolution of heavy minerals that has occurred. This index is expressed in percentage and a measure of maturity of heavy mineral suite. Accordingly,  $ZTR < 75\%$ , implies immature to sub-mature sediments and  $ZTR > 75\%$  indicate mineralogical matured sediments (Pettijohn et al., 1975; Mange and Maurer, 1992). The coastal plain sands of this study records ZTR values of 70-75% reflecting a mixture of immature and sub-mature sediments (Table 4).

In figure 10, above QF, RF represents quartz, feldspar, and rock fragments respectively. Maturity can be reflected in finer grain sizes. Maturity is reflected best in quartz, rock fragments, and feldspars and lithic. However, it is actually clay content that is more directly related to lack of maturity. As the percentage of quartz increases,

the mineralogical maturity does too which is seen in this research (Prothero, 2004). Nwajide and Hoque (1985) provided a simple classification scheme (Table 5) to ascertain the mineralogical maturity index of Sandstone using the maturity scale of sandstone.

Using the reference data above, it can therefore be inferred those coastal sands, following Ilevbare and Omodolor, (2020) mineral maturity classification scheme is mineralogical mature to super mature (Table 4.4), this corroborates with result of the mineral composition which is also super mature.

The result of the Ilevbare et al., (2025) plot of roundness vs. elongation shows that 99% of data points plot in the fluvial environment (figure 11). This indicates a fluvial ancient environment of deposition for the coastal sand.

## CONCLUSION

The quartz arenite Beach sand of Obedoluogbeyi and Idogbo in Benin Region, Nigeria is predominantly medium sand, moderately well sorted, coarse to strongly fine skewed and leptokurtic grains which typifies, a likely dynamic environment with varying energies, a mixed or fluctuating transport energies with sorting and grain size which could influence porosity/permeability (if the pores are interconnected) decent potential for hydrocarbon system of continental (fluvial) ancient environment. In addition, the mineralogical maturity index (MMI) of 18.66 both indicate mineralogical matured sediments while a Zircon – Tourmaline – Rutile (ZTR) index of 70.10%, which indicate a chemically sub-mature to immature sand; and the mineralogical maturity index, textural characteristics and modal composition of the sand all points to a textural, compositional and mineralogical matured sand. By implication, chemical immaturity to sub-maturity indicates limited chemical alteration post-deposition, possibly rapid burial or low post-depositional weathering.

Conversely, the mature aspects point to a felsic source and/or recycling; chemical traits suggest limited breakdown of less stable minerals. Also, chemically immature sands may have more reactive minerals, influencing diagenetic changes.

The fluvial or continental origin indicates past river processes, which helps to reconstruct regional paleoenvironment. Textural and compositional maturity suggests significant transport and sorting by water. The mineralogical maturity provides insights to source rock weathering or recycling. Overall, understanding the origin and maturity, guides exploration strategies.

## Declarations

Competing interests, the authors declare no competing interest.

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