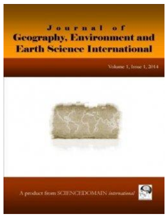

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Determination of the Depositional Environment of Outcrop Section at Odoro Ikpe South Eastern Nigeria Using Pebble Morphometry

C. O. Onwuegbuchulam[1], V. N. Nwugha[2], D. O. Ikoro[1], A. C. Ezebunanwa[1*] and K. O. Osibe[3]

[1]Department of Geology, Federal University of Technology Owerri, Imo State, Nigeria.
[2]Department of Basic Sciences, Alvan Ikoku Federal College of Education Owerri, Imo State, Nigeria.
[3]Department of Soil Science, Federal University of Wukari Taraba State, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. Author COO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors VNN and DOI managed the analyses of the study. Author DOI managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The depositional Environment of Odoro -Ikpe, South East Nigeria was interpreted using pebble morphometry and sieve analysis. A field observation, sieve analysis and pebble morphometric analysis was carried out on the area which comprises of conglomerate, pebbles, sand stone and intercalation of shale's and clay. The lithofacies observed are lateralitic layer, pebbly sand, alternating layers of sand and conglomerates and layers of massive sand stone. The graphic mean and skewness of the grain size analysis shows that the sediments are very coarse which indicates a high energy environment. Graphic standard deviation gives a clue that the sediment were very poorly sorted, which is indicative of a fluvial deposit with high energy , while kurtosis result revealed very coarse sediment deposits. This implies that the particles were not transported very far. Pebble

**Corresponding author: E-mail: anthonyeze00@gmail.com;*

analysis shows the geometric forms and this was deduced from the plot on shape measurement triangle. The shape is compact bladed which is common with river deposits. The bivarate plot of mean diameter against standard deviation also indicated a fluvial environment as well as bivarate plots of co-efficient of flatness against sphericity and maximum projection sphericity against oblate, prolate index which comprises of river and beach environment. All results showed or indicated that the environment of deposition was of river.

Keywords: Depositional environment; outcrop section; pebble morphometry.

1. INTRODUCTION

Today there are numerous description indices for clastic shape and size each one trying to show the influence of dynamic conditions and clastic petrography that are mobilized in certain transportation of depositional environment and their shapes at certain moments. Sediments are solid minerals and rock grains which are derived from weathering, transported by mobile medium and are being deposited in a sedimentary basin. The characteristic properties of sedimentary rocks are generated through the combined action of various physical, chemical, and biological process that make up the sedimentary cycle.

The environment of deposition is the location in which deposition occurs, such environment of deposition includes braided river environment, upper deltaic deposits to a spectrum of depositional environment ranging from fluvio lacustrine, deltaic, estuarine, and lagoonal to marine etc. Thus a depositional environment can be defined in terms of physical, chemical, biological or geomorphic variables, (Leckie and Singh, 1991) and is characterized by a unique set of processes operating at a specified rate and intensity which imparts sufficient imprints on the sedimentary processes of weathering, erosion, and transport may also leave distinctive imprints on particles, in the form of fractures, worn surface, and particular surface textures. The facie characterization of the outcrop section has a lot to do with the deposition of the sediments and mineral contents to some extent.

Pebble morphometry is one of the methods used to investigate shapes of pebbles, there are numerous parameters for describing the shape. However, Ekwueme, [1] used the term “form” for overall particles shape to be obtained from measurement of the three orthogonal axis. Shape is taken to include every aspect of external morphology that is, over all shape, roundness, smoothness and surface texture. These analyses were carried out on pebble to determine the degree of abrasion/ roundness, surface features and general shape of pebble grain which helps us to determine the environment of deposition.

2. LOCATION AND PHYSIOGRAPHY

The study area is a remote village of Odoro-Ikpe which lies within the latitudes 5º21’N - 5º33N and longitudes 7º44’E - 8º581E (Fig. 1) in the rain forest vegetation. The elevation of the top outcrop is 309 ft and the elevation of the bottom outcrop is 42 ft with thickness of out crop for location one (1) 1.2 m, 1.8 m, 2.8 m, location two (2) 1.7 m, 0.8 m, 0.9 m and location three (3) 0.15 m, 0.8 m, 1.74 m. Accessibility is highest when most of the streams and marshy area are dried up during dry season because of the bad road network. At Ini where the land is intensely dissected into rugged topographic terrain with high lands, elevated sands, streams and undergrowth of shrubs/plants, generally makes it difficult to walk on pathways into areas of interest. Area under study is drained by two rivers; the north-eastern and south-eastern are drained by the Cross River while the north-western is drained by the Kwa-Iboe River. Most of other streams that are found in the area are seasonal that is; they dry up during the dry season. The flow direction of these streams and rivers are to the north-west and south. The streams are characterized by igneous intrusion and laminated shale as the bedrocks. In general, the topography of the area controls the drainage as the direction of flow is always determined by height difference. Weathering and erosion constitutes the major soil forming agents in the area. The debris derived from the weathering of the intrusive rocks is mainly lateritic while the erosion and weathering of the shale bed provides excellent humus due to incorporation of decayed organic materials. The soil in the area has colour ranging from black to dark reddish and they have high clay content. The prevalent climate conditions is marked by two main season, the wet season which last from April to October while the dry season commence in November when the dry continental North East wind blows from the Mediterranean sea across the Sahara desert

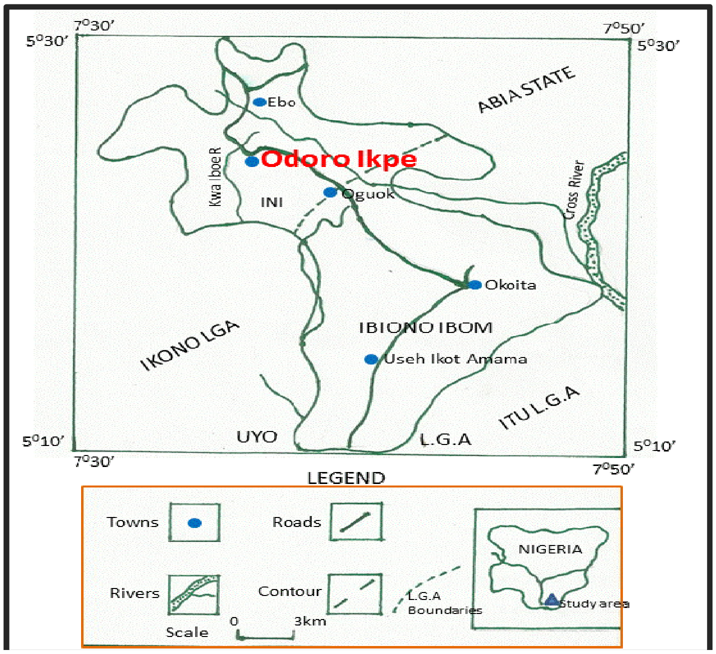


Fig. 1. Location map of the study area

and down the South Eastern part of Nigeria.The wet season is characterized by double maxima of rainfall. The first peak occurs in July and the second occur in September with mean annual rainfall of about 2152 mm Monanu and Inyong (1975). Violet storms are predominant in months of June, July September and October, the heavy rainfall and storm result in flooding, soil leaching and erosion. A short spell of dry season referred to as August break as often felt in August , it is caused by deflection of the moisture laden, watery trade wind by cold canary current due to vagaries of weather, the August break some time occurs in July or early September. During the dry season, humidity is low and clouds are absent. The effect of the desiccating north easterly wind (Harmattan) is felt within the period average monthly temperature are highly throughout the year a mean annual temperature of 32ºC is observed. The vegetation is thick with tall trees, grasses and shrubs. It is typical rain forest vegetation and is primarily influenced by the climate condition of study area. Natural vegetation in some parts of the study area has been destroyed due to building and road path e.tc.

2.1 Geology of the Study Area

The area falls within the Benin Formation in the Niger Delta basin (Fig. 2). This formation constitutes mainly of sand stones which makes up 90% of it and it stretches from the west through the Niger delta and extends up north towards part of the Anambra basin where it transverses to the Mamu Formation. The sandstone of this Formation is also intercalated with shale units and there is poor sorting of the unit grains which include the fine sand, coarse sand, sub angular to well-rounded pebbles, gravels and the angular cobbles units. The presence of light streak and wood fragments suggests that they are mainly of continental deposit of upper deltaic environment. The variability of the shallow water deposition is indicated basically by most structural units that could be spotted within the Benin Formation. The thickness of this Formation ranges from about 6000ft and above. Just little collection of hydrocarbon could be found within this Formation. In addition to a surface formation the Benin Formation crops out widely at surface across the delta province. The sand and sandstone are poorly sorted, and partly unconsolidated white or yellowish brown because of limonitic coats. Lignite occurs in thin streaks or a finely dispersed fragment. Heamatite and feldspar grain are common. The members of the Formation are grayish brown shales, sand, silt plant remains and sand dispersed lignite. Shales constitute only a very small part of the sequence.

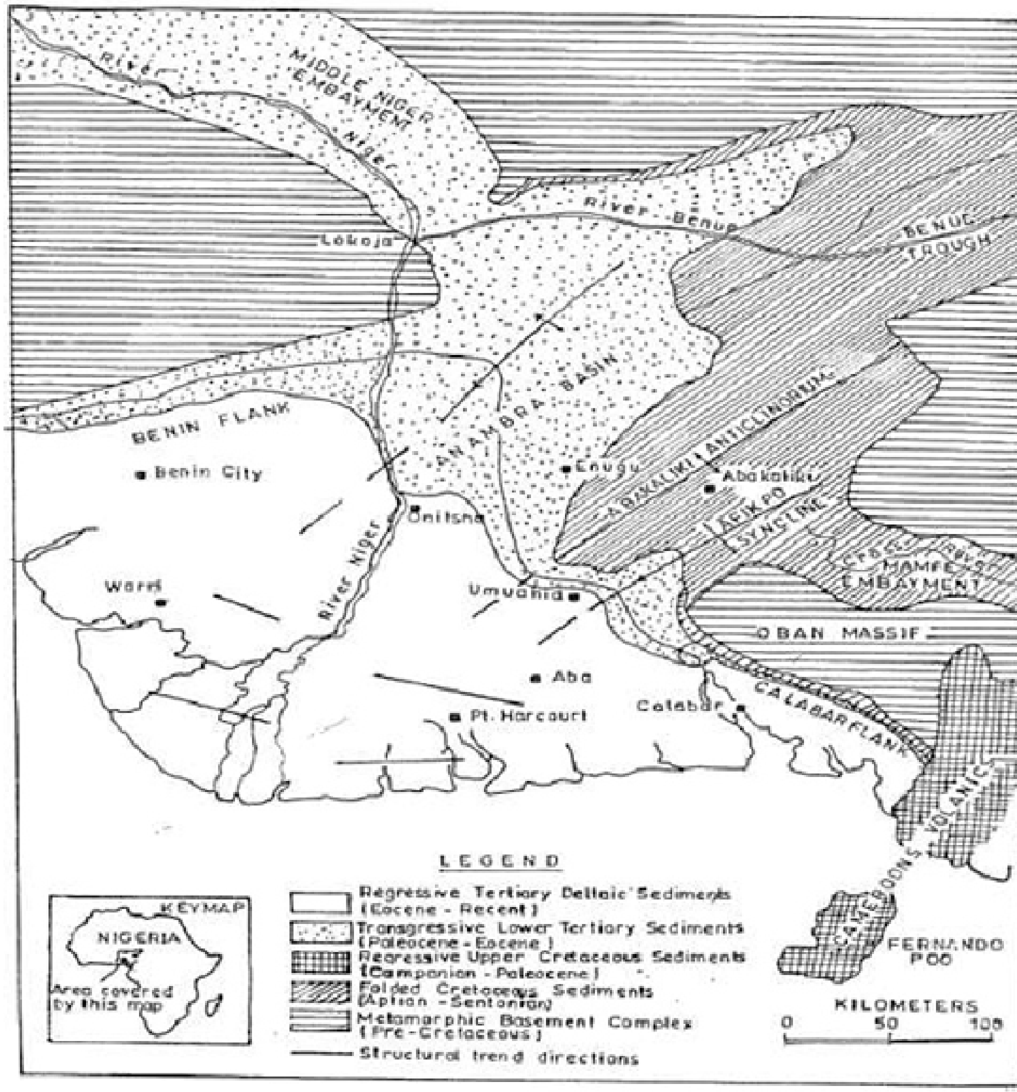


Fig. 2. Structural units of Niger Delta Basin (Short and Stauble 1967)

3. METHODOLOGY

A field mapping and collection of data was carried out within the study area. The study area was divided into three locations: 1, 2 and 3. The samples for the analysis were first disintegrated by gentle crushing using mortar and pestle. It was then coned sub-divided into four equal parts on the work sheet and collected for the sieving proper. Quartzose pebbles collected from the outcrops were washed and numbered. Broken pebbles were excluded. The indurate samples were crushed mechanically to disintegrate them, and sieved using a set of sieve arranged/stacked vertically with the coarsest sieved at the top and finest at the bottom, with a pan using an electrical shaker for about fifteen (15) minutes. At the end, each sieving material from different mesh size was poured carefully onto a glazed paper placed on top of electronic balance pan and the weight recorded. Cumulative graph were plotted and the different phi (ϕ) values, were derived from each sample together with the various statistical parameters [2,3] were presented in (Tables). Also a total of one hundred pebbles from different locations were collected. The long (L), intermediate (I) and Short (S) axes of pebbles were measured using Vernier Caliper, forms and their roundness were evaluated. The mean values of morphometric parameters were calculated from equations (1) to (6). Then, Lithostratigrafic sections of the locations were drawn. Particle-size analysis or pebble morphometry comprises of the measurement and analysis of the three particle axes that define the three-dimensional shape of a particle. For many applications, it is much more convenient to characterize particle size by only one variable, such as the length of the intermediate particle axes or the size of the sieve on which a particle was retained. Once the sizes of particles are determined, they are statistically analyzed, so that particle size distributions and statistical parameters characterizing them can be compared. The mean particle size on a stream bed, a particular particle-size percentile, a characteristic large particle size, as well as the entire spectrum of particle sizes all affect the hydraulics of flow as well as bed load transport rates. Studies concerned with the mechanics of particle entrainment, particle transport and deposition need to include the description and comparison of particle shapes. Pebble morphometric studies involves measurement of the three mutually perpendicular axes, the long (L), intermediate (I), and short (S) axes of pebbles from pebbly sandstones, Galloway (1975) using some set of instruments which include: The venire calipers, G-cramp and the rulers. Thus measurement and computation are used to interpret the depositional environment of the pebble which also serves as indicator to current flow direction. The three mutually perpendicular axes of each pebble were measured and the roundness estimate with the aid of a roundness image set. Morphometric parameters such as size, flatness ratio, elongation ratio, maximum projection sphericity, form geometry and oblate index were computed using equations (1) to (6).

$$\text{Elongation Ratio} = I/L \quad (1)$$

$$\text{Flatness Ratio} = S/L \quad (2)$$

$$\text{Wentworth Ratio} = L\text{-}I/L\text{-}S \quad (3)$$

$$\text{Waddell Sphericity} = 3\sqrt{IS/L^2} \quad (4)$$

$$\text{Maximum Projection Sphericity (YP)} = 3\sqrt{S^2/LI} \quad (5)$$

$$\text{Oblate Prolate index} = \{10(L\text{-}I\text{-}0.5/L\text{-}S\text{-}0.5)\}/\{S/L\} \quad (6)$$

In Sieve Analysis, the statistical parameters used in the particle size analysis are important for the interpretation of the analysis data. This gives an idea of the average diameter, uniformity, degree of sorting, asymmetry and peak-ness of grains. These parameters are derivable from equations (7) to (9). The graphic mean (GMΦ), is a measure of the average diameter of grains in the sediments, it is expressed as;

$$GM\Phi = 1/3(\Phi16+\Phi50+\Phi84) \quad (7)$$

Where, Φ16 is the 16^{th} percentile, Φ50 is the 50^{th} percentile and Φ84 is the 84^{th} percentile

These are used in conjunction with Wentworth scale for particle size distributions. Also, graphical standard deviation (GSΦ), which is a measure of the degree of sorting, based on Folk [3] formula, the obtained graphic standard deviation gives a clue of the sediment sorting. This gives an idea of the hydrodynamic conditions operating in the transporting medium and also suggest the distance of grain travel [4], it is also called coefficient of sorting and is defined as the degree of scatter or deviation or the tendency of the grains to be of uniform grain size. The Grapic Skewness parameter, (GsΦ), is a measure of the degree of asymmetry of distribution curves, it describes the degree lopsidedness of the distribution. The value could be positive or negative. Graphical skewness can be expressed mathematically as proposed by folk, [3] as;

$$Gs\Phi = \Phi84 + \Phi16 - 2(\Phi95 + \Phi5 - 2(\Phi50)/(2(\Phi84-\Phi16)2(\Phi95-\Phi5) \quad (8)$$

Graphic Kurtosis, (GkΦ), is a measure of the peakedness of the distribution curves. The curve type could be normal, leptokurtic, or platykurtic. According to Krumbrien and Monk [4]; [3] Graphic Kurtosis can be expressed as;

$$GK\Phi = \Phi95\text{-}\Phi5/2.44(\Phi75\text{-}\Phi25) \quad (9)$$

4. RESULTS

From the data obtained from the mechanical sieve analysis, cumulative curves were plotted, Tables 4.1(a,b,c), 4.2 (a,b) and 4.3 as well as Figs. 4.1 (a,b,c,), 4.2(a,b,c),4.3(a,b,c) and 4.4(a,b,c). These are valuable in estimating graphical parameters such as graphical mean, standard deviation, skewness, kurtosis been proposed by Krumbrien and Monk, [4],[3].

Quantitative graphical values for the various percentile and quartiles were obtained from the cumulative curves from various samples as Φ5, Φ16, Φ25,Φ50, Φ75, Φ84 and Φ95

4.1 Description of Lithostratigraphic Sections at Odoro-ikpe

Table 4.1a. Location 1

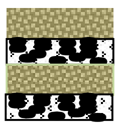
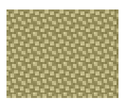
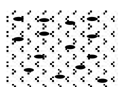
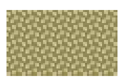
Thickness (m)	Lithology (Cl,Si,Vf,F,M,C,Vc,Gr)	Description	Facies	Inferred environment
14 12		Brownish to red weathered laterite overburden	D	
10 8		Whitish coloured Sandstone and Paraconglomerate interbedded	C	In channel Fluvial deposit
6		White fine grain massive sandstone.	A	In channel fluvial deposit
4		Paracong lomeratic layers	B	In channel fluvial deposit
2		White fine grain massive sandstone.	A	In channel fluvial deposit
0				

Table 4.1b. Location 2

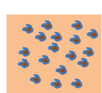
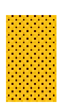
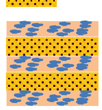
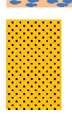
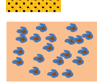
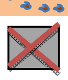
Thickness (m)	Lithology (Cl,Si,Vf,F,M,C,Vc,Gr)	Description	Facies	Inferred Environment
16 14				
12 10		Conglomerate and sandstone	B	In channel fluvial deposit
8		White fine grain massive sandstone.	A	In channel Fluvial Deposit
6		Interbedded sandstone and paraconglomerate	C	In channel fluvial deposit
4		White fine grain massive sandstone.	A	In channel fluvial deposit
2		White Paraconglomeratic sandstone	B	In channel fluvial deposit
0				

Table 4.1c. Location 3

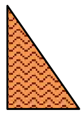
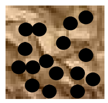
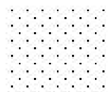
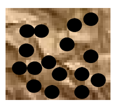
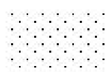
Thickness (m)	Lithology (Cl,Si,Vf,F,M,C,Vc,Gr)	Description	Facies	Inferred Environment
14		Brownish to red weathered laterite overburden		
12				
10		Paraconglomeratic layers	B	In channel fluvial deposit
8				
6		White fine grain massive sandstone	A	In channel fluvial deposit
4		Paraconglomeratic layers	B	In channel fluvial deposit
2		White fine grain massive sandstone.	A	In channel fluvial deposit
0				

Table 4.2a. Calculated sieve parameters of mean, sorting, skewness and kurtosis of location 1, 2 and 3

Sample	Mean	Sorting	Skewness	Kurtosis
Location 1	0.933	5.5	0.293	0.559
Location 2	2.1	5.63	-0.112	1.2
Location 3	4.433	6.08	-0.375	2.342
Average	2.49	5.74	-0.065	1.367

Table 4.2b. Calculated percentiles from the cumulative frequency curve of location 1,2 &3

Sample	Φ5	Φ16	Φ25	Φ50	Φ75	Φ84	Φ95
Location 1	0	0	0	0.1	2.2	2.5	3.0
Location 2	-1.0	0.1	0.6	1.2	2.0	2.4	3.1
Location 3	-0.5	1.2	1.8	2.3	2.5	2.8	3.5

Table 4.3. Summary of pebble result and parameter for pebble morphometry

Parameter	Environment	
	Fluvial	**Beach/Wave action**
Mpsi	>0.65	<0.65
Opi	>1.5	<1.5
Form	Compact compact-bladed, and compact-elongate	Bladed, very bladed, platy, very platy

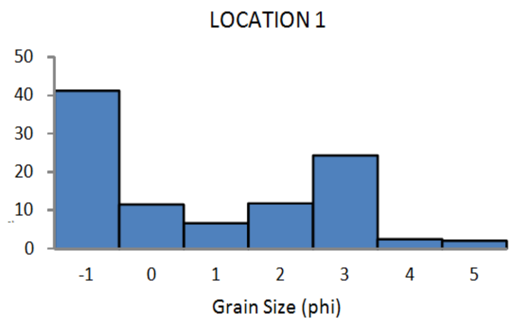


Fig. 4.1(a). Histogram plot of location 1

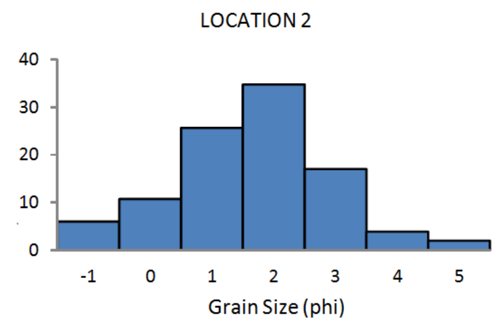


Fig. 4.1(b). Histogram plot of location 2

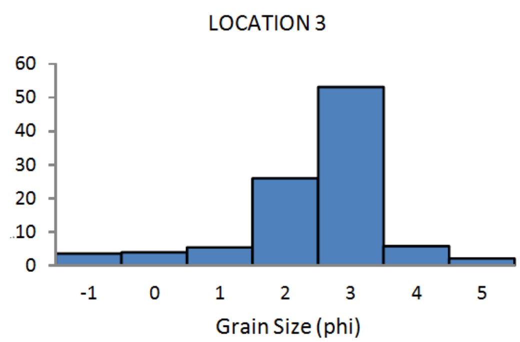


Fig. 4.1(c). Histogram plot of location 3

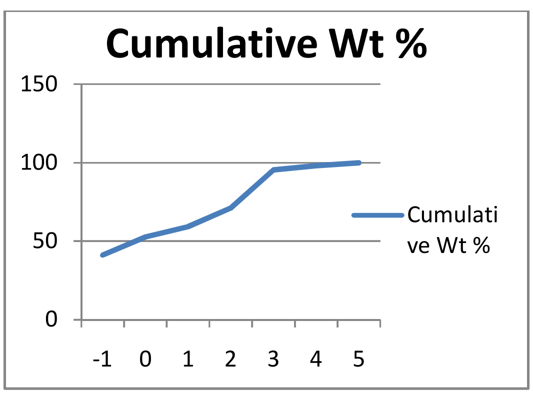


Fig. 4.2(a). Cumulative weight % of grain size of location 1

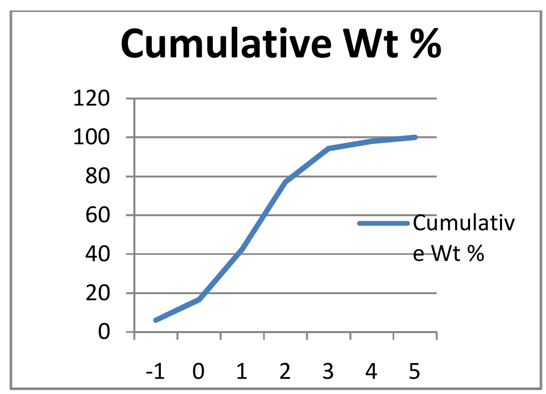


Fig. 4.2(b). Cumulative weight % of grain size of location 2

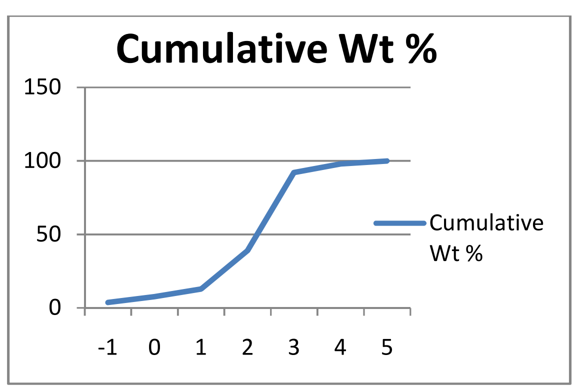


Fig. 4.2(c). Cumulative weight % of grain size of location 3

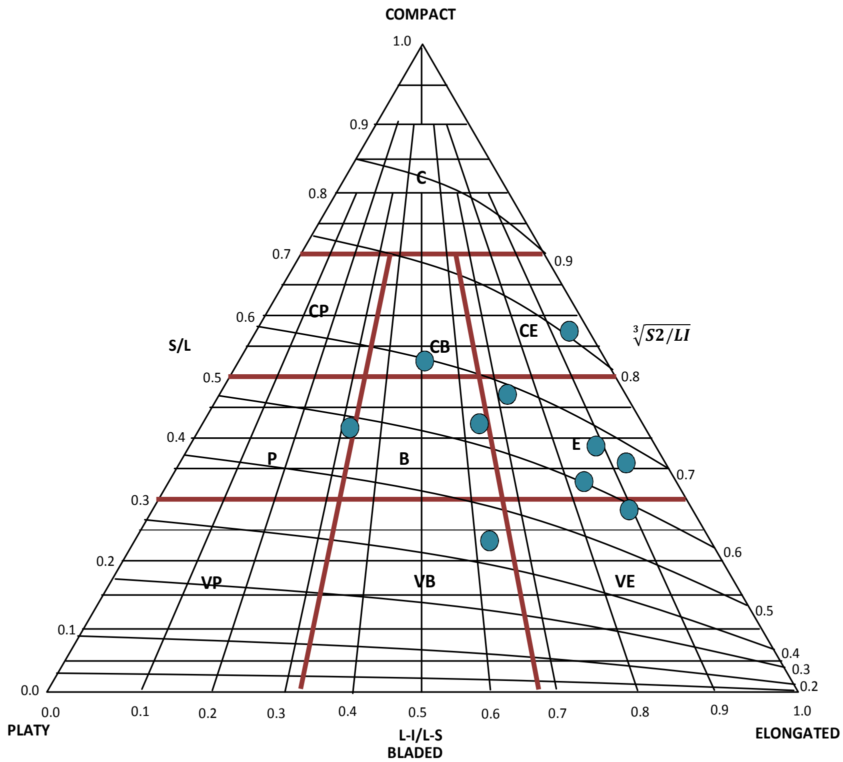


Fig. 4.3(a). Sphericity-form diagram for particle shapes (location3)(after dobkins& folk, 1970)

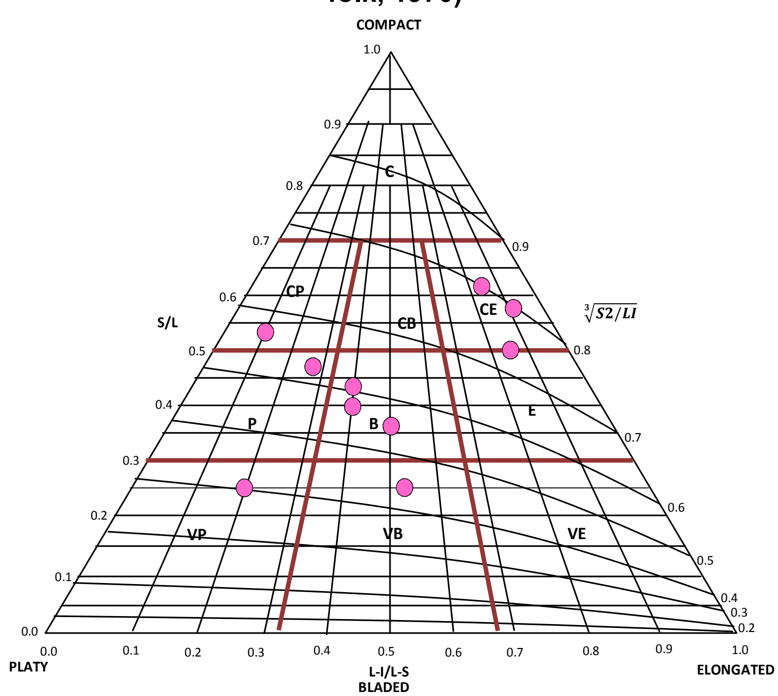


Fig. 4.3(b). Sphericity-form diagram for particle shapes (location 2) after Dobkins & folk, 1970)

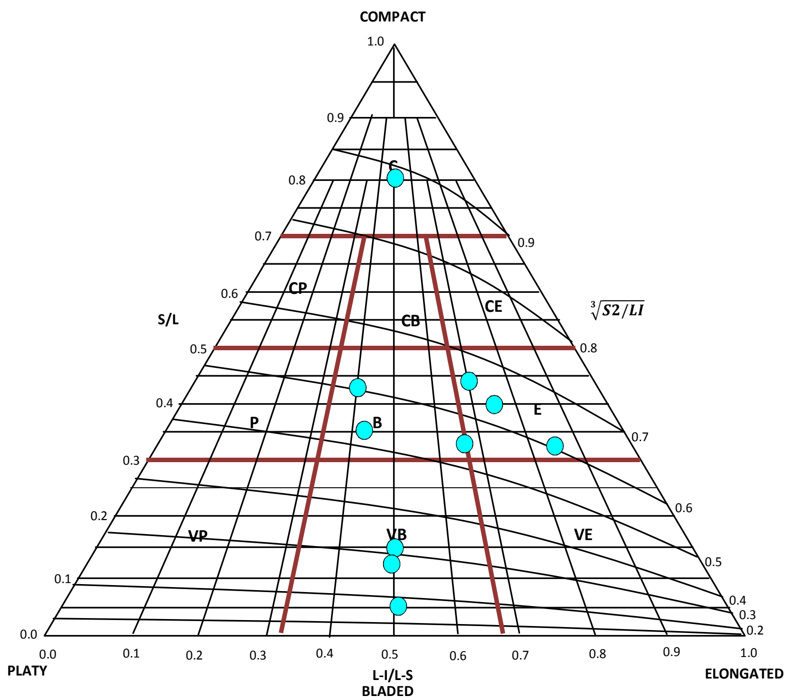


Fig. 4.3(c). Sphericity-form diagram for particle shapes (location3) after Dobkins & Folk, 1970)

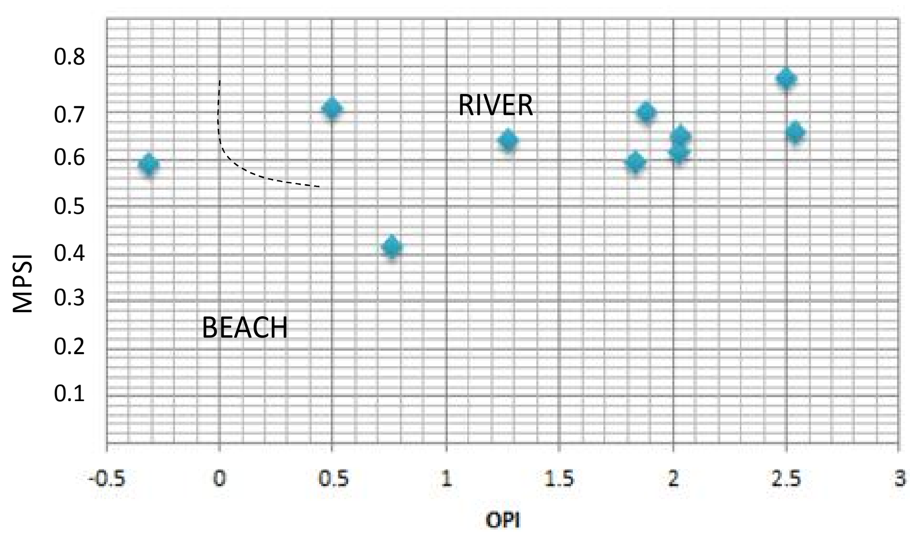


Fig. 4.4(a). Scatter plot of MSPI versus OPI (Location 1) (After Sneed and Folk, 1958)

Two Facies Associations were identified in the study area: The Massive sandstone facies association and Conglomerate facies association. These associations showed that the sediments were deposited in a strongly fluvially influenced environment ranging from channel floor to point-bars in a braided river. The conglomerate facies suggest a mud flow deposit owing to the matrix supported nature and poor sorting. (Bull, 1969; Reineck and Singh, 1980). Clast-supported conglomerate results from deposition of gravel bed load by an energetic aqueous flow that keeps sand in suspension.

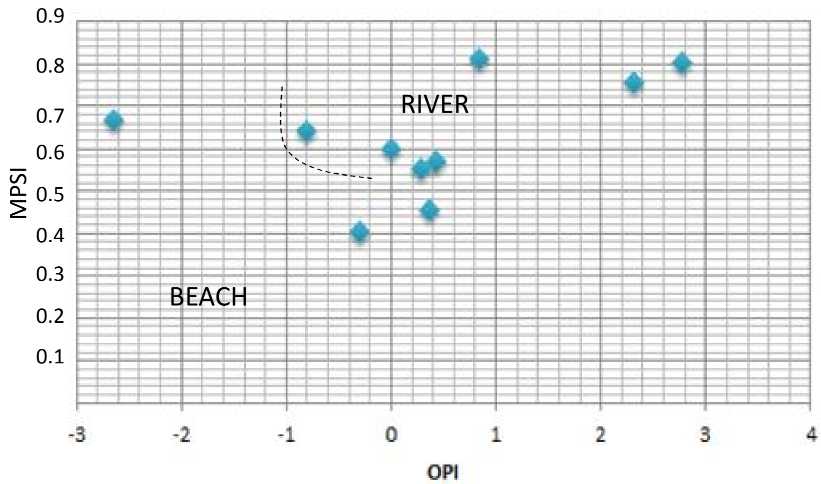


Fig. 4(b). Scatter plot of MSPI versus OPI (Location 2) ***(After Sneed and Folk, 1958)***

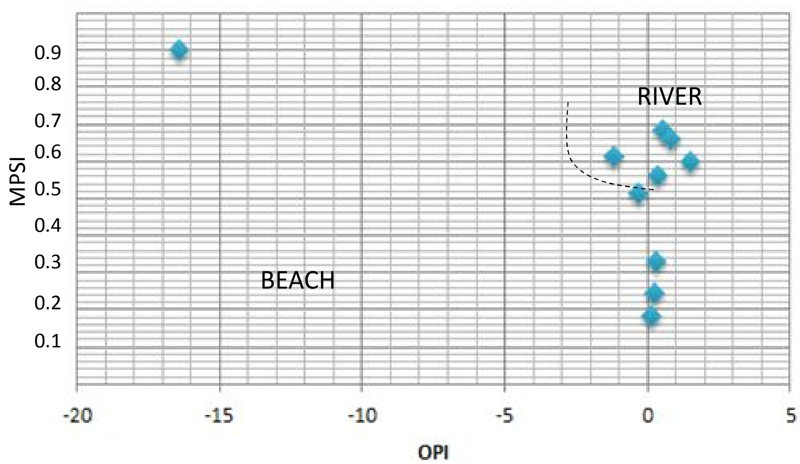


Fig. 4.4(c). Scatter plot of MSPI versus OPI (Location 3) ***(After Sneed and Folk, 1958)***

The Massive sandstone facies Association may have resulted either from a continuously sedimentation for a relatively short time or bioturbation of the early formed stratification. Channeling is common (Lowe, 1975). Massive sandstone also indicates rapid deposition of a large amount of sand from a fluidized flow [5].

Roundness is an indication of the extent of abrasion, determined by the distance of transportation of pebbles rather than the depositional environment. Visual inspection and characterization of the roundness for the pebbles showed that they are dominantly sub-angular indicating short distance of travel.

The overall grain size interpretation as shown in Table 4.1, revealed that sediments from the study area are fine grained with average value of 2.49, extremely poorly sorted with average value of 5.74, fine skewed with average of -0.065 and very leptokurtic with average value of 1.367. Also, the Histogram plots, Figs. 4.1(a),4.1(b), and 4.1(c) of the individual weight percent against the phi scale, Table 4.2 showed that the sandstones in the study area are majorly unimodal with population clustering within the 1Φ and 3Φ, intervals. An inspection of the cumulative frequency curves, Figs. 4.2(a), 4.2(b), and 4.2(c) of the studied samples showed that most of the samples are clustered around the traction and saltation population (Visher, 1969). The segment of the curve above the 4Φ break, which represents the percent of silt and clay present in a sample, is quite small.

The pebble samples from which environmentally diagnostic parameters were calculated, for the Pebble morphometric study are shown in Table 4.3. Considering pebbles of all sizes together, river pebbles have an average sphericity of 0.684 +/- 0.006, low energy beach 0.640 +/-0.08, and high energy beach 0.584 +/- 0.06, Figs. 4.3 and 4.4, (Dobkins and Folk, 1970). The measure of sphericity was determined using the Maximum Projection Sphericity Index (MPSI). The mean MPSI value of 0.56 was recorded for all the location. These indicates low energy beach (Sneed and Folk, 1958). The scatter plots of MPSI versus OPI, Figs. 4.4(a), 4.4(b) and 4.4(c) suggest that the pebbles are influenced more by both fluvial processes than beach processes. The Oblate-Prolate Index (OPI) is based mainly on the value (L-I)/(L-S) which defines whether the intermediate axis (I) is closer in size to the short (S) or long (L) axis. Perfect blades have OPI = 0.0, all discs wherein I is closer to L will have negative OPI values, and all rods wherein I is closer to S will have positive OPI. The average OPI for all the locations is 0.143 which is indicative of fluvial transport.

Form describes the 3-dimension aspect of a pebble. Ten verbal classes were established by Sneed and Folk (1958). As shown by Dobkins and Folk (1970), the form most indicative of fluvial actions are Compact, Compact-Bladed, and Compact-Elongate, whereas bladed, very bladed and platy are all indicative of beach action. The Sphericity-Form diagram shows variability in environmental control.

6. CONCLUSION

The area under study is a sedimentary terrain and it environmentally form parts of the earth surface which are physically, chemically and biologically distinct from its adjacent areas. This work has emphasized thoroughly that a lot of processes come into play in this sedimentary environment. The depositional process is a product of the environment, which in turn is controlled by: Climate Geography, Tectonic setting and Sediment supply. The present study based on grain size distribution, lithofacies analysis and pebble morphometry have shown that the sands and pebbles of Odoro-Ikpe and environs of the Benin Formation in the Niger Delta are products of fluvial and beach deposition. The overall grain size interpretation shows that sediments from the study area are fine grained with average value of 2.49, extremely poorly sorted with average value of 5.24, fine skewed with average of 0.2 and very leptokurtic with average value of 1.367 The positive skewness values is indicative of fluvial deposition. Evidence from lithofacies description and succession of facies in the field suggest deposition in a fluvial environment ranging from channel floor, point bar to braided channel in a braided river. Pebble morphometric analysis indicates variability of depositional process alternating between fluvial and beach.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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