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Discrimination of Depositional Environment Using Statistical Parameters of Conglomeratic Outcrop Sections, Obubra Southeastern Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author DOI formulated and supervised the research. Author DOI supervised the field work. Authors FKO and UCE carried out the research and prepared the manuscript with contributions from other co-authors.

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ABSTRACT

Statistical analyses reveal information of the hydrodynamics and environments of deposition of sedimentary rocks. The sediments of the outcrop sections from Uwakande 1, Obubra southeastern Nigeria were studied for their textural variations. Grain size analysis, and pebble morphogenesis carried out shows that the sediments are coarse to very coarse in size, poorly sorted, and very positively skewed. This in conjunction with the various bivariate plots employed, aid in discriminating between beach and river depositional environments. Pebble morphometric analysis of the conglomerates showed that the mean values of the various morphometric parameters range as follows: flatness ratio (S/L = 0.397 to 0.514), elongation ratio (I/L = 0.657 to 0.784), maximum projection sphericity (ΨP = 0.605 to 0.899), Oblate-Prolate index (ŌP = -1.738 to 1.594), coefficient of flatness (39.70 to 51.37), and roundness (-0.367 to 0.722). This study is significant in providing evidence of fluvial conditions during the deposition of the Eze-Aku Formation in the Turonian, and reveals the type of transporting medium; the mode of sediment deposition; as well as the environment into which the sediments encountered in the study area were deposited.

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Keywords: Fluvial; conglomerates; environment; pebbles; deposition; sandstone; sedimentary; morphometric.

1. INTRODUCTION

The characteristic properties of sedimentary rocks are generated through the combined action of various physical, chemical, and biological processes that make up the sedimentary cycle. Sedimentary processes and conditions that constitute the depositional environment play primary roles in determining the textures, structures, bedding features, and stratigraphic characteristics of sedimentary rocks. Environmental analysis thus involves identifying response elements or properties that have environmental significance [1]. Environment of deposition is the location in which sediment deposition occurs. It can be defined in terms of physical, chemical, biological or geomorphic variables and is characterized by a unique set of processes operating at a specified rate and intensity which impart sufficient imprints on the sediment, so that a characteristic deposit is produced [2]. Depositional environment parameters can be grouped into three: physical, biological, and chemical. The physical processes are the most important as it provides the most basic information for interpretation of depositional environment [2]. In studying ancient sediments, it is important to record all the primary sedimentary structures, grain features and parameters, and try to interpret the hydrodynamic conditions under which the unit(s) was/were probably deposited. Systematic presentation and analysis of grain size data provide basis for the reconstruction of sedimentary processes including identification of depositional environment [3]. Examination of textural parameters allows drawing lines characteristic of both deposits from various sedimentary environments and deposits from one single environment but with different histories as to their transport dynamics [4]. This study presents an aspect of the interpretation of depositional environment of the Turonian Eze-Aku Formation.

1.1 Brief Geology of the Study Area

The study area is located at mile 6 (popularly called Tank) in Obubra, southeastern Nigeria. It is bounded by few other major villages such as Ogada 1 and 2, Imabana Iyamitet, and Uwakande 1; and lies between longitudes 8°19'E and 8°23'E; and latitudes 6°2'N and 6°7'N (Fig. 1). It covers an area of about 68.25 square kilometers. Good outcrop exposures are seen at stream channels, and local gravel mining sites.

The study area falls between the South Eastern Benue Trough and Ikom-Mamfe Embayment. Its geologic evolution dates back to the Albian (Middle Cretaceous) times, with the deposition of Mamfe Formation which is a member of the Asu River Group. This is predominantly a fluviatile clastic sequence. The type locality of the Mamfe Formation is on the bank of Cross River at Mamfe near Cameroun Republic, where about 800 m of massive arkosic sandstones with Marl, sandy limestone and shale intercalations are exposed [5]. The sequence on the Nigerian part of this basin comprises of conglomeratic immature arkosic cross-bedded coarse-medium sandstones and mudstones [6]. The Asu River Group which lies uncomformably on the basement represents the oldest stratigraphic unit exposed in the area. It is characterized by a thick sequence of marine shale with inter bedded siltstones and minor bands of sandstone and limestone.

The Turonian period marked the beginning of another marine transgression. During this period, the mantle upwelling resulted in the deposition of the Eze-Aku Formation [7]. The Turonian consists of fossiliferous marine series outcropping throughout the Benue Trough. This formation comprises of the Amasiri sandstone and the Ezillo Formation members. They consist of hard grey and black calcareous shale, limestone and siltstone. Locally the shale grades into sandstone [8]. The sandstone outcrops extend from Afikpo through Ugep, and then to Apiampu.

2. MATERIALS AND METHODS

Representative samples collected from 8 beds of 2 exposed outcrop sections were disaggregated and sieved through 4mm screen to separate the gravels from sand for pebble morphometric analysis and granulometric analysis respectively. In this work, simple dry sieving method of granulometric analysis was used. This is the simplest of all the methods of particle size analysis. It involves the separation of the sand grains into different size ranges. The statistical parameters used in the granulometric analysis are important for the interpretation of the grain size data. This gives an idea of the average diameter, uniformity, degree of sorting, asymmetry and peakedness of grains.

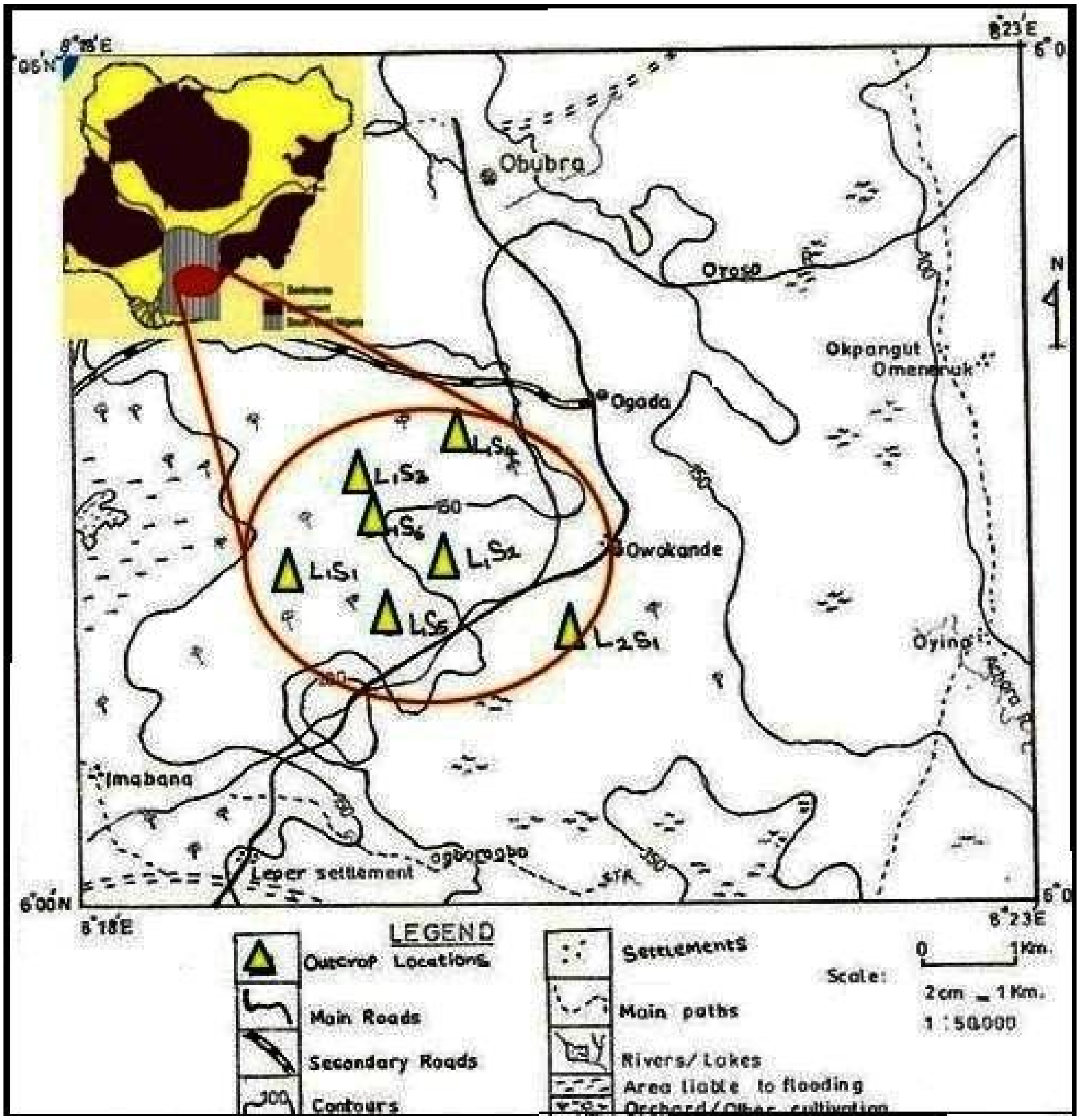

Fig. 1. Location map of the study area

Also pebble morphometric method of [9] adopted by [10], was also used in this study. It is an analysis carried out on pebbles and cobble sized grains to determine the degree of abrasion/roundness; surface markings that could be as a result of sedimentation processes; surface features and general shape of the pebble grain (sphericity). [9] used the term form for overall particle shape that can be obtained from measurement of the three orthogonal axes of the pebbles, and plotted on a form triangle (Fig. 4). In this method, measurements of the three mutually perpendicular diameters (axes), that is the long axis (L), intermediate axis (I) and short axis (S) of each pebble were made.

Pebbles collected from the logged conglomerates outcrop sections were used in this study. These pebbles were found to be very abundant as dispersed pebbles and thin beds in the pebbly, cross stratified sandstone units. The surface of the pebbles were cleaned with brush to remove dust particles that may cling to the pebbles and add error to the dimension of the pebble, hence a reason for their removal. The dimensions of the pebbles were measured with veneer caliper. Sampling was done in such a way as to represent all the facies hosting pebbles. Fifteen largest pebbles extracted at random from the sandstone beds were sampled, out of which the best ten were selected to form a batch for analysis. Eighty (80) pebbles were assembled into eight (8) batches and studied for morphometric indices. The values obtained were used for computing the statistical parameters such as proposed by [11,12,10].

The shape, roundness, surface texture etc of pebbles has been intensively studied by many geologists. They came up with lots of statistical parameters which include Flatness ratio (***S/L***), Elongation ratio (***I/L)***, Maximum Projection Sphericity index ($\frac{3\sqrt{S^2}}{IL}$), Wentworth ratio ($\frac{L-I}{L-S}$), and Oblate–Prolate index ($\frac{10\left(\frac{L-I}{L-S}\right)-0.5}{\frac{S}{L}}$).

3. RESULTS AND DISCUSSION

From grain size analysis results of 8 samples (Table 1), the skewness values indicate that 12.5% of the samples are positively skewed, and 87.5% are strongly positively skewed. The kurtosis values indicate that 25% of the samples are mesokurtic, 25% are platykurtic, and 50% are leptokurtic. Sorting values indicate that 12.5% are moderately sorted while 87.5% of the samples are poorly sorted.

The mean values of the various morphometric parameters range as follows: flatness ratio (S/L = 0.397-0.514), elongation ratio (I/L =0.657-0.784), maximum projection sphericity (ΨP = 0.605-0.899), Oblate Prolate index (Ō P = -1.738 to 1.594), coefficient of flatness (39.70-51.37), roundness = 0.367-0.722 (Table 1). Considering the mean geometric forms, 12.5% are compact, 37.5% compact bladed, and 50% of the samples are bladed (Table 2).

From the graphic mean of the sieve analysis results, it can be deduced that the sediments are made up predominantly of coarse sand and a small amount of very coarse sand (values ranges from -0.003 to 0.33) which lies between coarse sands and granules on the Wentworth scale. According to [13], this indicates high energy depositional environment. It also indicates that the sediments were deposited at the stream channels when the energy and competency of the transporting medium has decreased, and thus coarser sediments are being deposited.

The mean grain size in a deposit is largely a function of the energy of the processes controlling transport and deposition; that is particles are segregated according to their hydrodynamic behavior which depends on size, specific gravity and shapes [14]. The graphic standard deviation gave a clue to the sediment sorting. It is indicative of the hydrodynamic conditions operating in the transporting medium and also suggestive of the distance of travel [15]. 87.5% of the sediments are poorly sorted, while 12.5% are moderately well sorted. The poor sorting is related to a decrease in velocity of the transport medium.

About 12.5% are positively skewed while 87.5% of the samples are very positively skewed. The average skewness of (+0.61) corresponds to very positively skewed, indicating that coarse particles exceed fines.

Kurtosis results show that 25% of the samples are platykurtic; 25% are mesokurtic; while 50% are leptokurtic. The variation in the range of values of kurtosis indicates that the sediments were deposited at different regimes of deposition.

Bivariate plots of mean diameter against graphic standard deviation, after [16] (Fig. 2); and a plot of graphic skewness against graphic standard deviation, after [17] (Fig. 3), clearly show that the sediments were deposited in a fluvial (river) environment. The predominance of coarse sands as can be deduced from the graphical mean indicates a high energy transporting medium [13]. Decrease in the energy resulted in the deposition of these sediments at the lower regime of the river.

Poor sorting and positive skewness are consistent with river sands, whereas beach sands are generally well sorted and negatively skewed [18]. Mixing of sediments under high and low energy conditions affects their sorting [19]. The sediments encountered in this study are poorly sorted and positively skewed, suggesting a high energy fluvial environment. Although river sediments generally have many fine materials, it may happen that in some rivers fine sediments are not available as seen in the study area so that the deposited sediments lack fine grades. Thus it could be inferred that the provenance of the sediments is close to the environment where they were deposited.

Pebble morphometric results show the dominant form (shapes) of the samples obtained from the study. The mean value of elongation ratio ranges from 0.657 – 0.741; flatness ratio ranges from 0.397 – 0.484; maximum projection sphericity index ranges from 0.605 - 0.899; while oblate–

prolate index ranges from -1.738 to 1.044. Elongation ratio values for fluvial environment range from 0.6 to 0.9 [20]. All the elongation ratio values fall within this range.

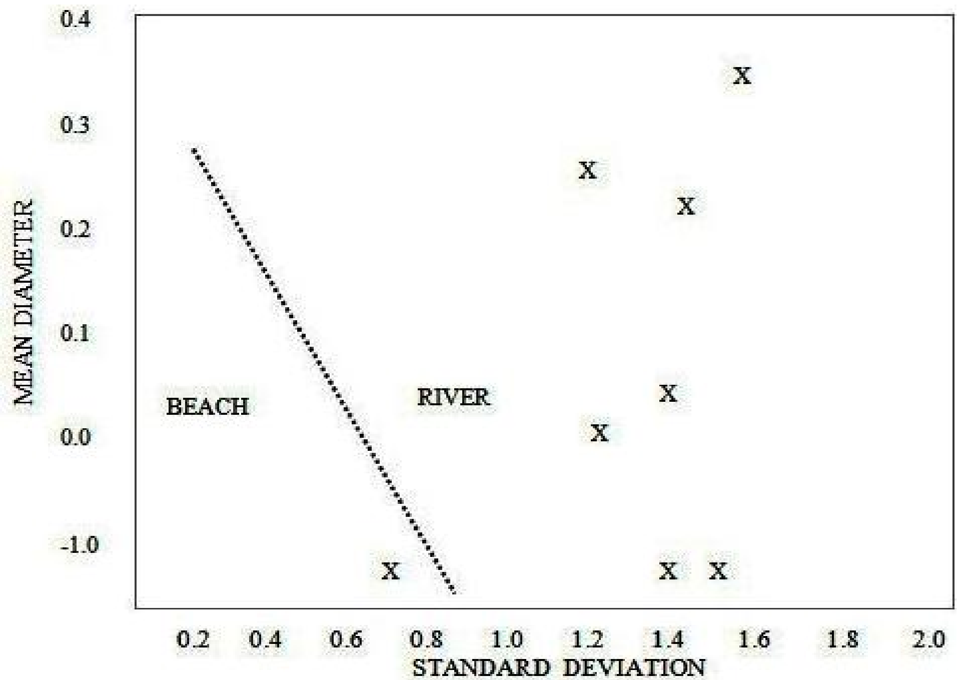

Fig. 2. Plot of mean size against standard deviation [16]

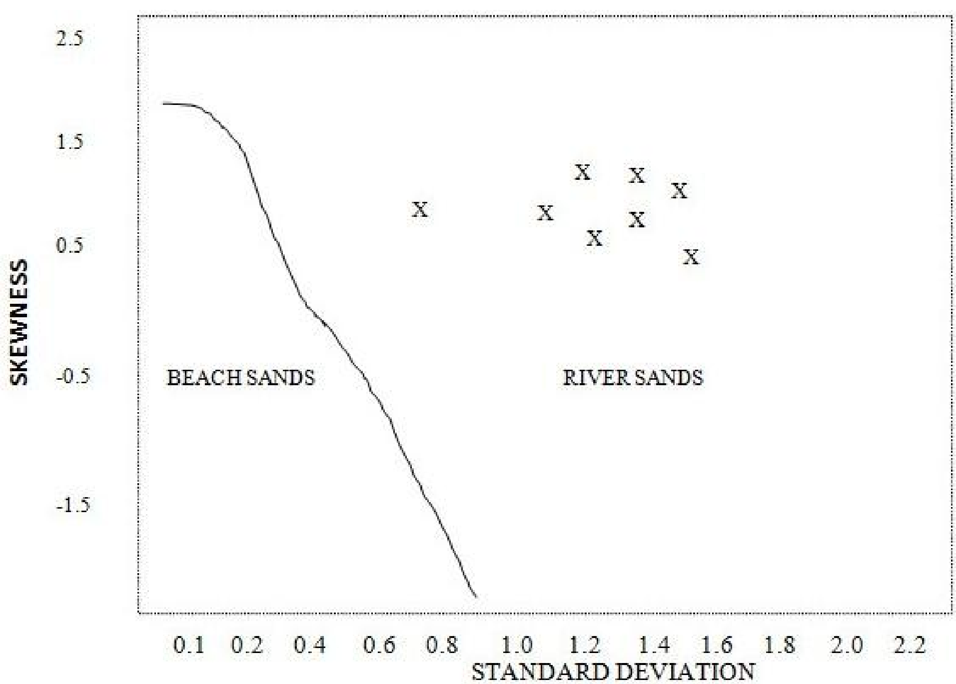

Fig. 3. Plot of skewness against standard deviation [17]

Table 1. Summary of sieve analysis result

Sample number	ϕ_5	ϕ_{16}	ϕ_{25}	ϕ_{50}	ϕ_{75}	ϕ_{84}	ϕ_{95}	GM_Z	$G_{SD\phi}$	$G_{SK\phi}$	$G_{K\phi}$	Remarks
$L_1S_1B_1$	-1.25	-1.15	-1.05	-0.20	0.90	1.45	2.45	0.03	1.21	+0.35	0.75	PS,VPSK,P
$L_1S_1B_2$	-1.25	-1.11	-1.09	-0.90	-0.50	0.20	1.15	-0.003	0.69	+0.69	1.05	MWS,VPSK,M
$L_1S_2B_1$	-1.35	-1.25	-1.22	-1.00	0.55	1.70	3.78	-0.18	1.52	+0.85	1.19	PS,VPSK,L
$L_1S_2B_2$	-1.40	-1.24	-1.15	-1.00	0.05	1.00	2.88	0.25	1-21	+0.80	1.46	PS,VPSK,L
$L_1S_2B_3$	-1.36	-0.90	-0.75	-0.30	0.45	1.20	2.80	0.00	1.16	+0.71	1.46	PS,VPSK,L
$L_1S_3B_1$	-1.37	-1.20	-1.10	-0.25	1.05	1.65	3.30	0.20	1.42	+0.43	0.89	PS,VPSK,P
$L_1S_3B_2$	-1.42	-1.26	-1.19	-1.01	0.65	1.40	3.35	-0.29	1.39	+0.82	1.06	PS,VPSK,M
$L_2S_1B_2$	-1.25	-1.05	-0.75	0.25	1.18	1.80	4.05	0.33	1.52	+0.26	1.13	PS,PSK,L
Mean	-1.33	-1.15	-1.03	-0.55	0.54	1.30	2.97	0.04	1.27	+0.61	1.13	

PS – Poorly sorted; MWS – Moderately well sorted; PSK – Positively skewed; VPSK – Very positively skewed; P – Platykurtic; M – Mesokurtic; L – Leptokurtic; LSB – Location, Section, and Bed

Table 2. Mean values of pebbles measured

Sample number	$\frac{I}{L}$ (cm)	$\frac{S}{L}$ (cm)	$\frac{S}{L}X100$	$\frac{L-I}{L-S}$	$\frac{3\sqrt{S^2}}{LI}$	$\frac{10\left(\frac{L-I}{L-S}\right)-0.5}{\frac{S}{L}}$	Form	Mean roundness
$L_lS_1B_1$	0.657	0.414	41.40	0.714	0.899	1.043	C	0.566
$L_1S_2B_1$	0.681	0.418	41.80	0.581	0.688	0.862	B	0.394
$L_1S_2B_2$	0.710	0.397	39.70	0.517	0.605	-0.798	B	0.367
$L_1S_3B_1$	0.716	0.484	48.40	0.565	0.695	1.044	B	0.500
$L_1S_4B_1$	0.741	0.401	40.10	0.428	0.618	-1.738	B	0.526
$L_1S_5B_1$	0.784	0.514	51.37	0.456	0.688	-1.503	CB	0.546
$L_1S_6B_1$	0.711	0.508	50.79	0.584	0.737	1.594	CB	0.600
$L_2S_1B_2$	0.758	0.491	49.18	0.487	0.677	-0.415	CB	0.406
Mean	0.720	0.453	45.30	0.542	0.701	0.011		0.488

B – Bladed; C – Compact; CB – Compact Bladed

Maximum projection sphericity of pebbles is generally high for fluvial (river) environment than for beaches, [10,20,9]. An imaginary “magic line” exist which distinguish pebble shape produced by surf processes from that which occur during fluvial transport. The range of value for this “magic line” is from 0.65 to 0.66 [10]. Pebbles whose values fall within 0.65 and 1.00 connote river environment. Pebbles whose values fall below 0.65 denote beach environment. All the values of maximum projection sphericiy fell above 0.65. This is an excellent indication of fluvial action. The elongation ratio as well as the maximum projection sphericity result indicated fluvial setting.

The difference in oblate–prolate index between river and beach sediments are not as marked as much as sphericity difference. Thus, if the oblate–prolate index for a suite of ten pebbles falls below -2, it is about 87% certain that they are of beach environment, and if the values falls between -1 and +5, it is 69% certain that they are of fluvial environment. However, Oblate-Prolate Index results from this research show values which range between -1.783 and 1.594. It therefore follows that the pebbles are all of fluvial origin.

[9], established pebble classification scheme which described the three dimensional aspect of a pebble. These geometric forms include: compact, compact bladed, compact elongated, compact platy, bladed, elongated, platy, very platy, very bladed and very elongated. The dominant forms for river pebbles are compact, bladed, compact bladed and compact elongated. Forms for beaches are platy, very platy, bladed and very bladed. Results of this research fall within bladed, compact and compact bladed, and clearly indicates that the pebbles were deposited in a fluvial environment as seen in the sphericity form diagram (Fig. 4).

From the bivariate plots of maximum projection sphericity against oblate–prolate index (Fig. 5); coefficient of flatness against sphericity (Fig. 6); and roundness against maximum projection sphericity (Fig. 7), there is clear indication that the pebbles were deposited in a fluvial environment.

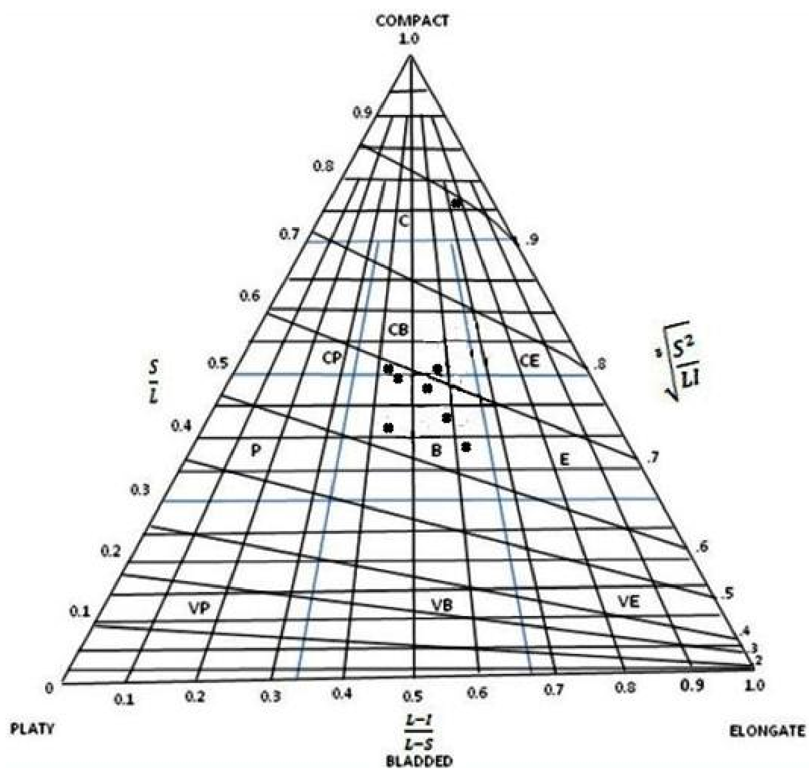

Fig. 4. Form diagram for particle shapes [9]

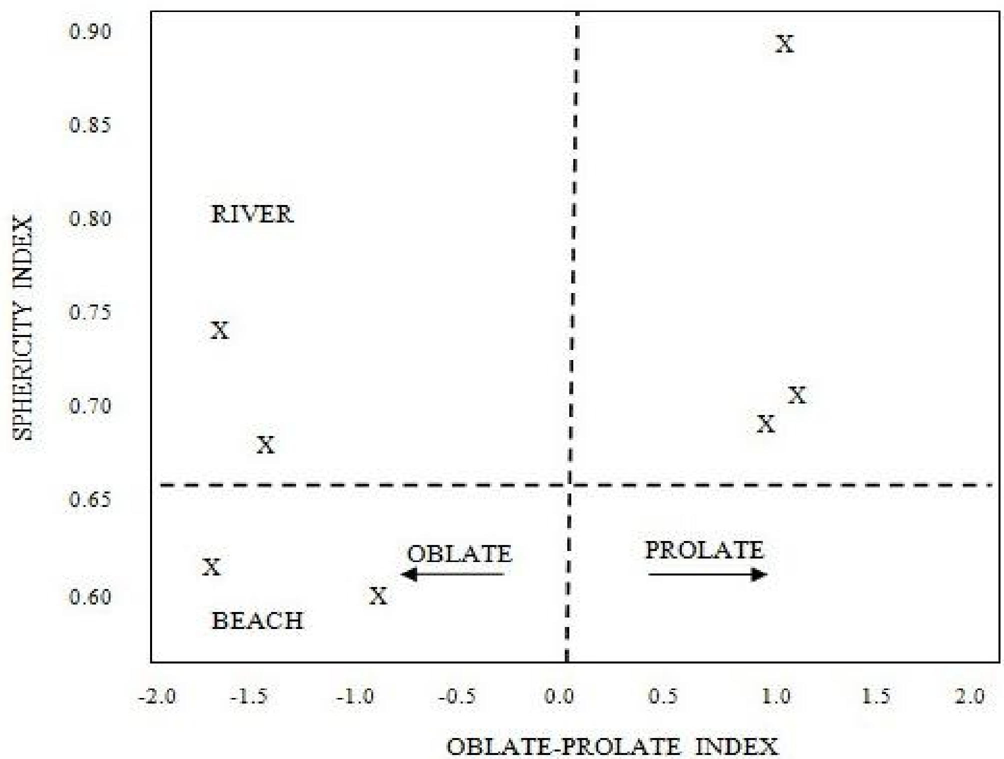

Fig. 5. Plot of sphericity against oblate-prolate index [10]

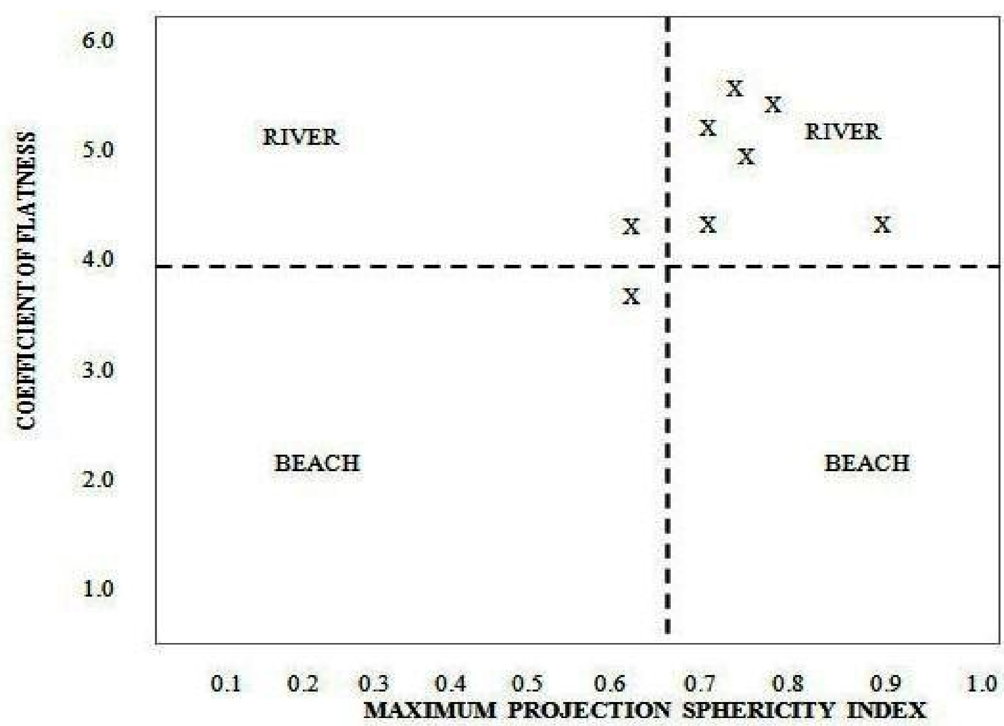

Fig. 6. Plot of coefficient of flatness against sphericity [21]

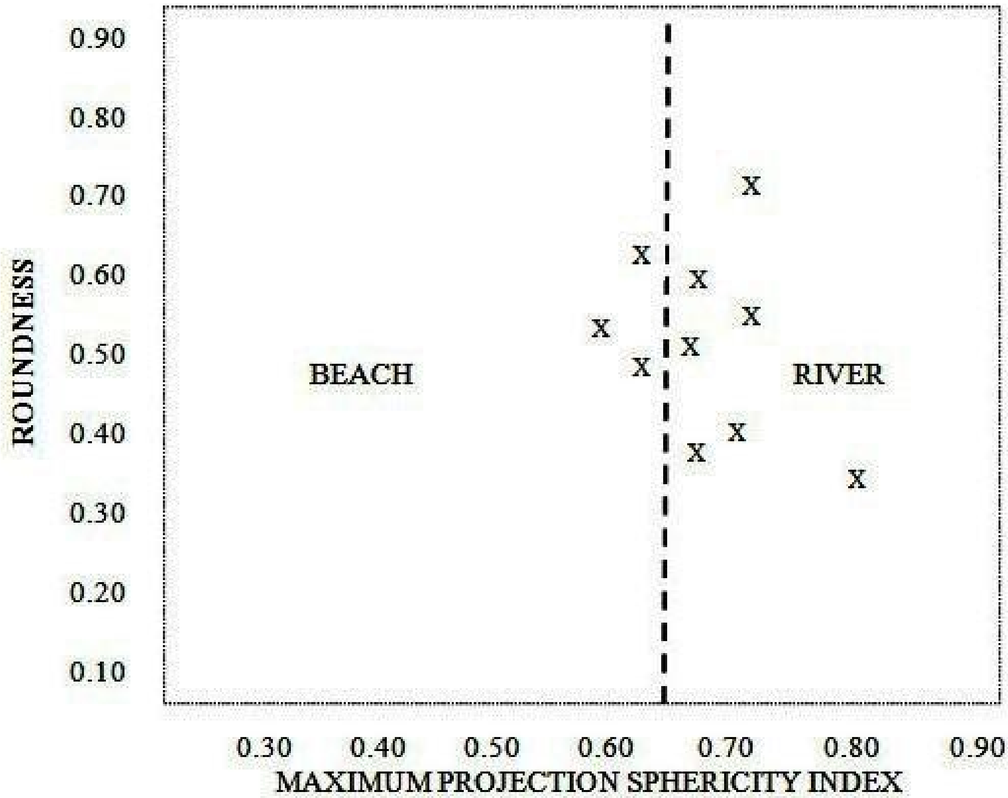

Fig. 7. Plot of roundness against sphericity [10]

The sedimentary structures observed in the area include planar bedding showing repetitive layers of planar to slightly inclined pebbly and orthoconglomeratic sandstone bedforms. The layering was interpreted to be the effect of changing strength of the depositing medium. The large clast sizes are known to be transported at the upper flow regime of a river system by traction or saltation action. The beds on top and below have sharp contacts, distinguished by the sharp or obvious contrasts in grain size between adjacent beds. Bioturbation marks are absent.

4. CONCLUSION

Primary sedimentary structures and texture of sediments provide information about the medium, mode of transport, and energy conditions at the time of deposition. The coarse to very coarse grained nature of the sandstones encountered, as well as the absence of fossils and trace fossils are suggestive of deposition in a high energy fluvial environment. Also, bivariate and multivariate analyses indicate diversity in depositional environments. However textural characteristics of sand grains, pebble shapes and other morphometric properties employed in this study reveal that the conglomeratic sandstone deposits at Uwakande 1, Obubra Southeastern Nigeria was deposited by a dominantly high energy fluvial (river) depositional system. It is important to note that no single discrimination method, such as statistical analysis, bi-variant or multi-variant plots is effective in identifying similar environments using grain size statistical parameters. However, it is recommended that discrimination between similar environments should be based on a combination of different methods rather than a single one.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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