

Discrimination of Depositional Environment using Statistical Parameters

of Conglomeratic Outcrop Sections, Obubra Southeastern Nigeria.

ABSTRACT

Statistical analyses reveal information of the hydrodynamics and environment 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 show 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 ($\Psi P = 0.605$ to 0.899), Oblate-Prolate index ($\bar{O}P = -1.738$ 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.

Keywords: *Fluvial, Conglomerates, Environment, Pebbles, Deposition, Sandstone, Sedimentary, Morphometric.*

26 1.0 INTRODUCTION

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

46 1.1 BRIEF GEOLOGY OF THE STUDY AREA

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

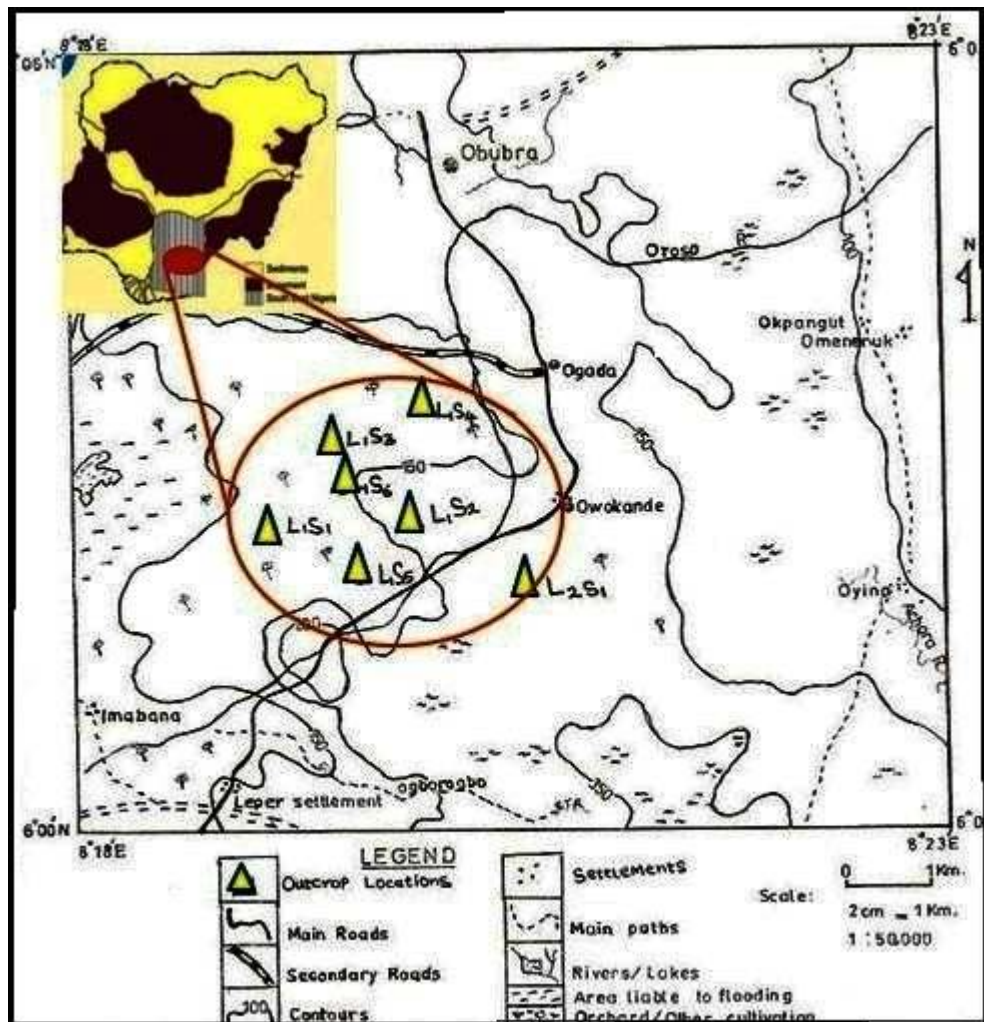


Figure 1: Location map of the study area.

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 fluvial clastic sequence. The type locality of the Mamfe Formation is on the bank of Cross River at Mamfe near Cameroun Republic, where about 800m 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 uncomfortably 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.

2.0 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.

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 (figure 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 ($\frac{10(\frac{L-I}{L-S})-0.5}{\frac{S}{L}}$).

3.0 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% is 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 ($\Psi P = 0.605-0.899$), Oblate Prolate index ($\bar{O} P = -1.738$ to 1.594), coefficient of flatness ($39.70-51.37$), roundness = $0.367-0.722$ (table 1). Considering the mean geometric forms, 12.5% were compact, 37.5% compact bladed, and 50% of the samples were bladed (table 2).

115 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 ₁ S ₁ B 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 ₁ S ₁ B 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 ₁ S ₂ B 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 ₁ S ₂ B 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 ₁ S ₂ B 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 ₁ S ₃ B 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 ₁ S ₃ B 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 ₂ S ₁ B 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	

116

117 **Legend**

118 PS – Poorly sorted

119 MWS – Moderately well sorted

120 PSK – Positively skewed

121 VPSK – Very positively skewed

122 P – Platykurtic

123 M – Mesokurtic

124 L – Leptokurtic

125 LSB – Location, Section, and Bed

126

127 TABLE 2: MEAN VALUES OF PEBBLES MEASURED

Sample Number	$\frac{I}{L}$ (cm)	$\frac{S}{L}$ (cm)	$\frac{S}{L} \times 100$	$\frac{L-I}{L-S}$	$\frac{3\sqrt{S^2}}{LI}$	$\frac{10\left(\frac{L-I}{L-S}\right) - 0.5}{\frac{S}{L}}$	Form	Mean Roundness
L ₁ S ₁ B ₁	0.657	0.414	41.40	0.714	0.899	1.043	C	0.566
L ₁ S ₂ B ₁	0.681	0.418	41.80	0.581	0.688	0.862	B	0.394
L ₁ S ₂ B ₂	0.710	0.397	39.70	0.517	0.605	-0.798	B	0.367
L ₁ S ₃ B ₁	0.716	0.484	48.40	0.565	0.695	1.044	B	0.500
L ₁ S ₄ B ₁	0.741	0.401	40.10	0.428	0.618	-1.738	B	0.526
L ₁ S ₅ B ₁	0.784	0.514	51.37	0.456	0.688	-1.503	CB	0.546
L ₁ S ₆ B ₁	0.711	0.508	50.79	0.584	0.737	1.594	CB	0.600
L ₂ S ₁ B 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

128

129 **LEGEND**

130 B – Bladed

131 C – Compact

132 CB – Compact Bladed

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

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

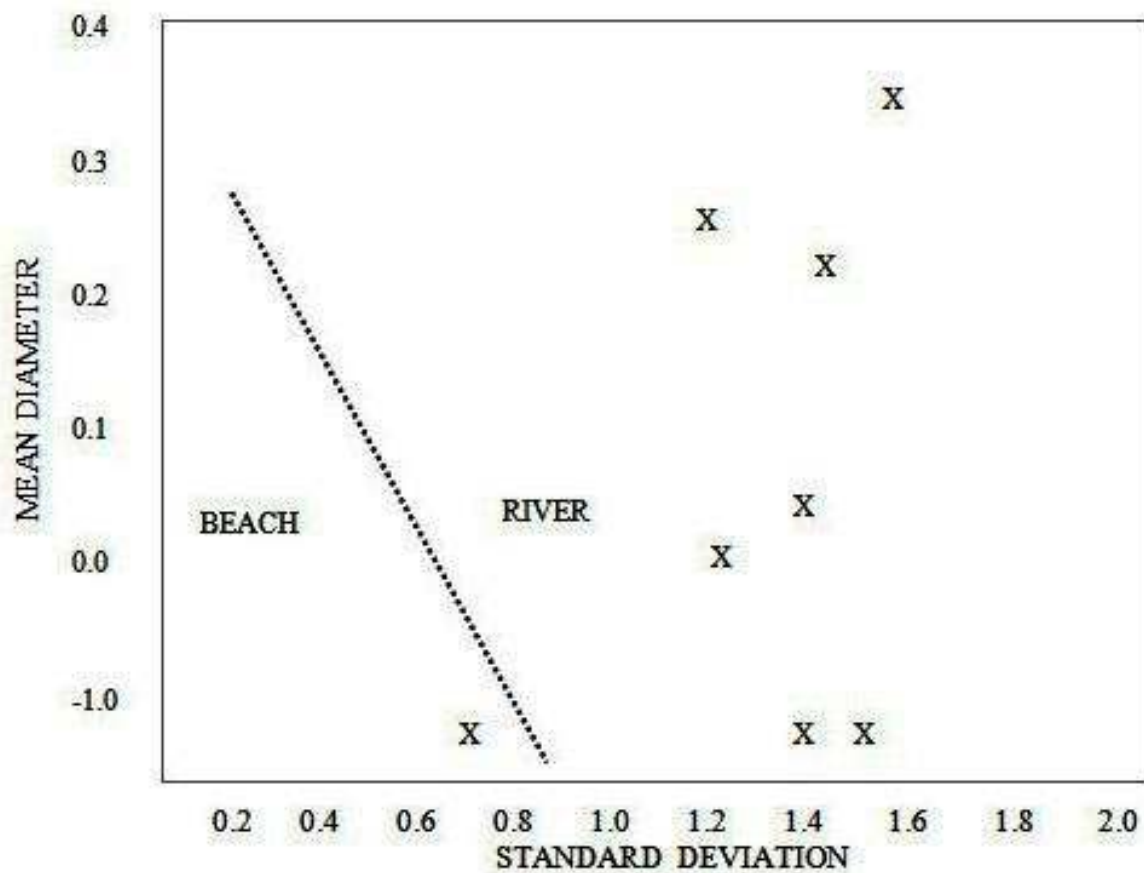
150 About 12.5% are positively skewed while 87.5% of the samples are very positively skewed. The average
151 skewness of (+0.61) corresponds to very positively skewed, indicating that coarse particles exceeds fines.

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

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

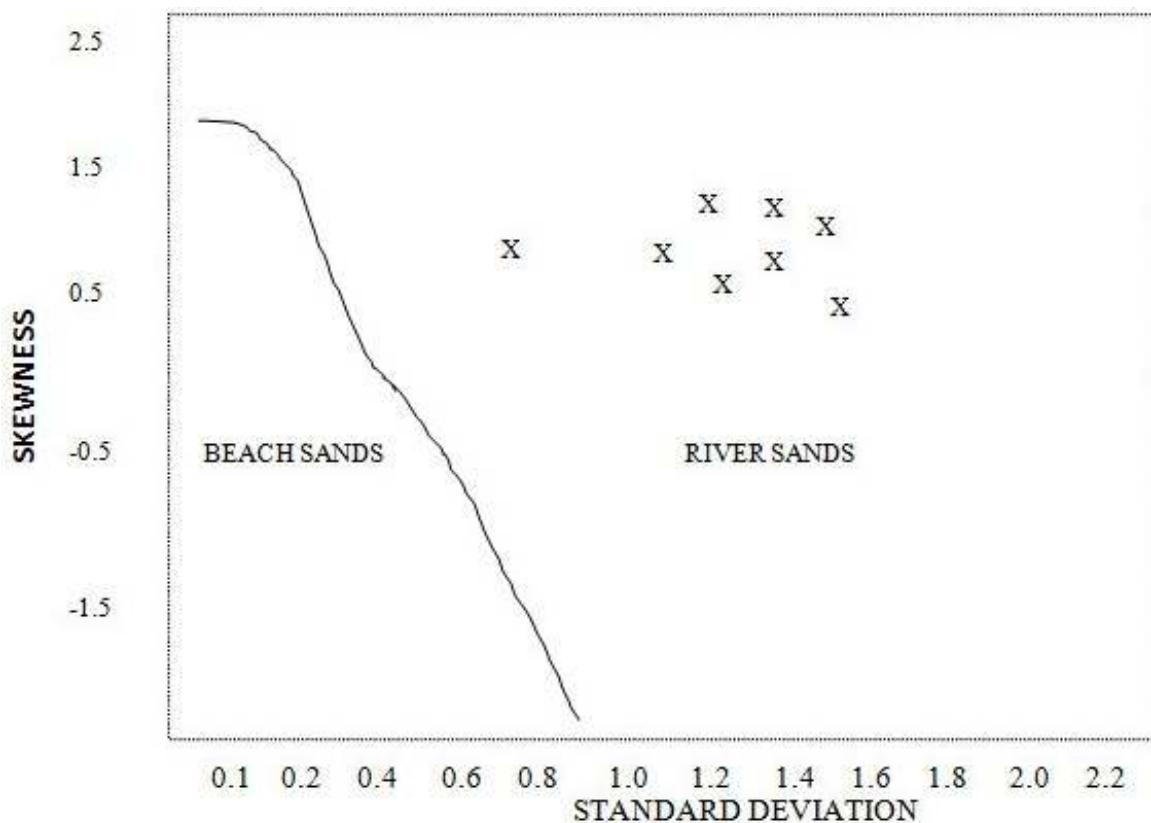
160 Poor sorting and positive skewness are consistent with river sands, whereas beach sands are generally well
161 sorted and negatively skewed [18]. Mixing of sediments under high and low energy conditions, affects the
162 sorting of sediments [19]. The sediments encountered in this study are poorly sorted and positively skewed,
163 suggesting a high energy fluvial environment. Although river sediments generally have many fine materials, it
164 may happen that in some rivers fine sediments are not available as seen in the study area so that the

165 deposited sediments lack fine grades. Thus it could be inferred that the provenance of the sediments is close to
166 the environment where they were deposited.



167
168 **Figure 2:** Plot of Mean size against Standard Deviation [16].

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170

171 **Figure 3:** Plot of Skewness against Standard Deviation [17].

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173 Pebble morphometric results show the dominant form (shapes) of the samples obtained from the study. The
 174 mean value of elongation ratio ranges from 0.657 – 0.741; flatness ratio ranges from 0.397 – 0.484; maximum
 175 projection sphericity index ranges from 0.605 - 0.899; while oblate–prolate index ranges from -1.738 to 1.044.
 176 Elongation ratio values for fluvial environment range from 0.6 to 0.9 [20]. All the elongation ratio values fall
 177 within this range.

178 Maximum projection sphericity of pebbles are generally high for fluvial (river) environment than for beaches,
 179 [10]; [20]; [9]. An imaginary “magic line” exist which distinguish pebble shape produced by surf processes from
 180 that which occur during fluvial transport. The range of value for this “magic line” is from 0.65 to 0.66 [10].
 181 Pebbles whose value fall within 0.65 and above connote river environment. Pebbles whose values fall below
 182 0.65 denote beach environment. All the values of maximum projection sphericity fell above 0.65. This is an
 183 excellent indication of fluvial action. The elongation ratio as well as the maximum projection sphericity result
 184 indicated fluvial setting.

185 The difference in oblate–prolate index between the river and beach are not as marked as much as sphericity
186 difference. Thus, if the oblate–prolate index for a suite of ten pebbles falls below -2, it is about 87% certain that
187 they are of beach environment, and if the values falls between -1 and +5, it is 69% certain that they are of
188 fluvial environment. From my results, the value ranges between -1.783 and 1.594. It therefore follows that the
189 pebbles are all of fluvial origin.

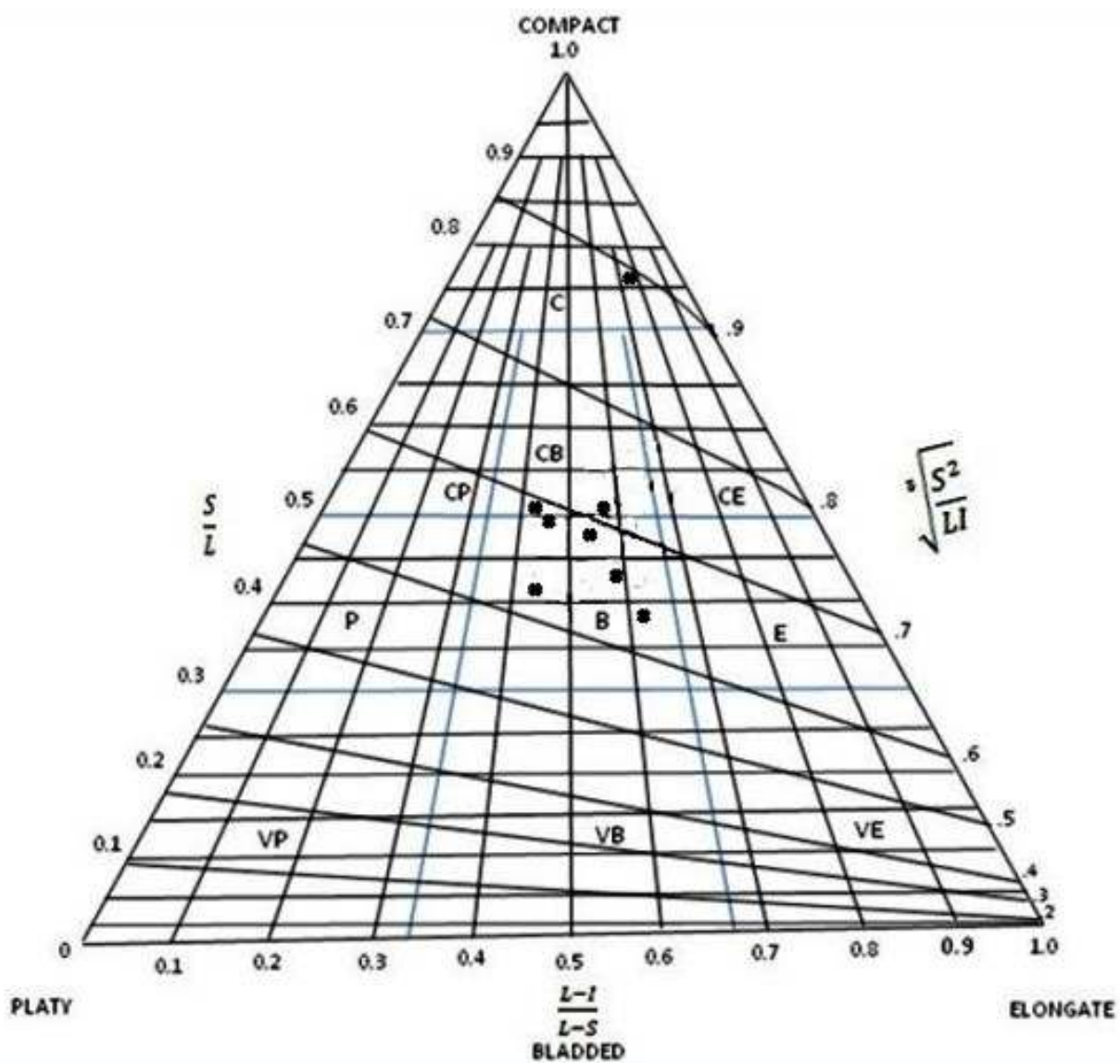
190 [9], established pebble classification scheme which describe the three dimensional aspect of a pebble. These
191 geometric forms include: compact, compact bladed, compact elongated, compact platy, bladed, elongated,
192 platy, very platy, very bladed and very elongated. The dominant forms for river pebble are compact, bladed,
193 compact bladed and compact elongated. Forms for beaches are platy, very platy, bladed and very bladed.
194 Results of this research fall within bladed, compact and compact bladed, and clearly indicates that the pebbles
195 were deposited in a fluvial environment as seen in the sphericity form diagram (figure 4).

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

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

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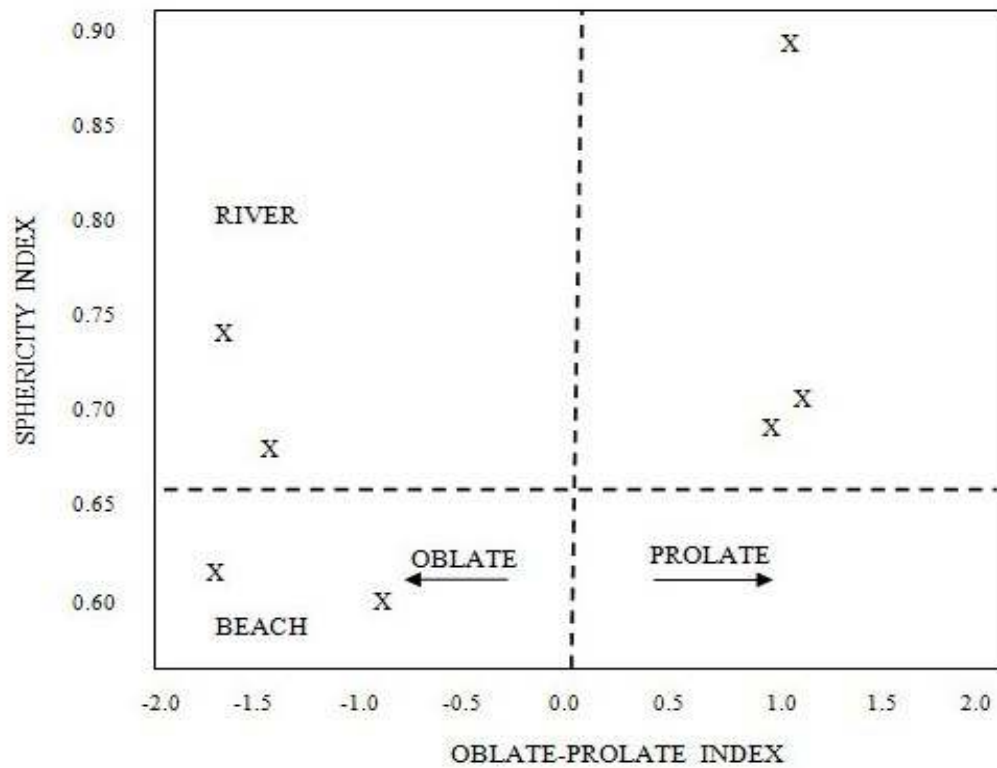
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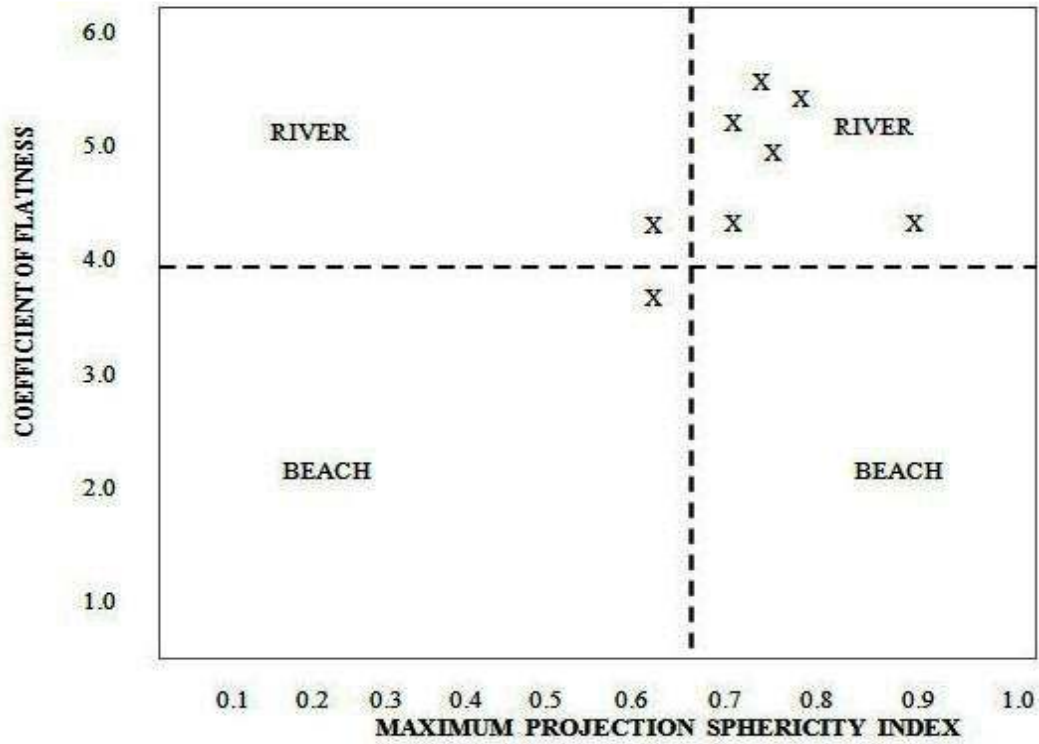
208 **Figure 4:** Form diagram for particle shapes [9].

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211 **Figure 5:** Plot of Sphericity against Oblate-Prolate Index [10].



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213 **Figure 6:** Plot of Coefficient of Flatness against Sphericity [21]

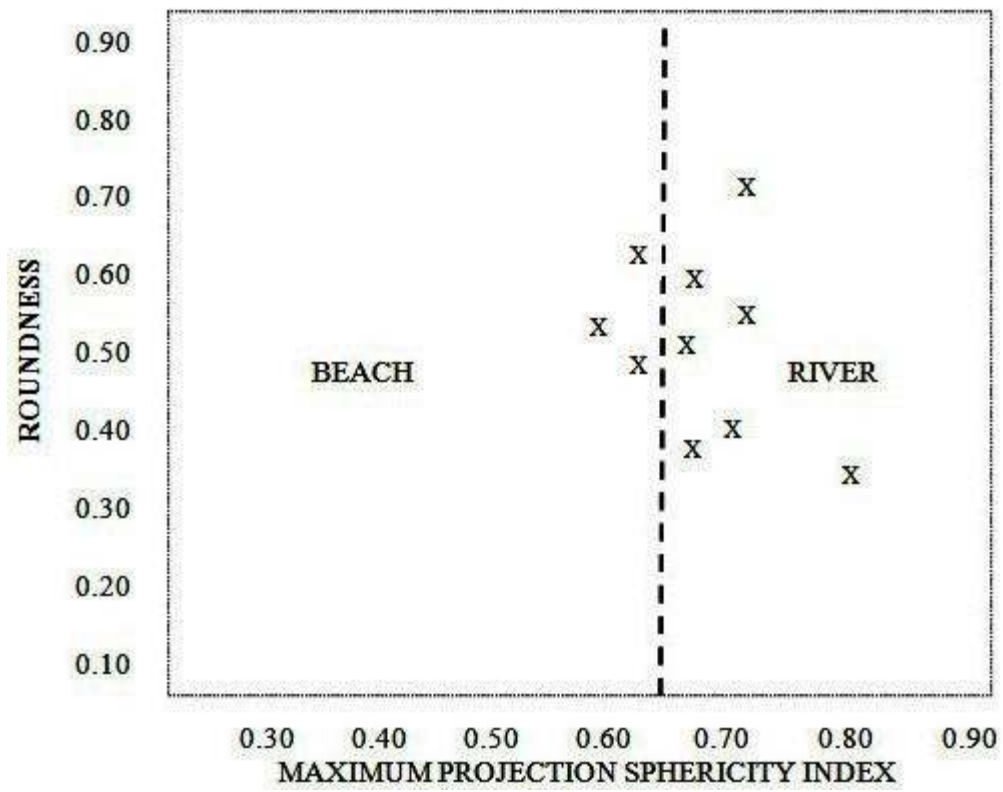


Figure 7: Plot of Roundness against Sphericity [10]

228 4.0 CONCLUSION

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

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