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Paleoenvironmental Analysis of Sandstone Deposits within ESUT Agbani Campus, Enugu State, Nigeria, using Pebble Morphometry and Textural Analysis

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Abstract
Pebble morphometric and textural analysis were carried out on the sandstone deposits within the Agbani Campus of Enugu State University of Science and Technology (ESUT) in an attempt to reconstruct the paleoenvironment of deposition. The area has four major lithological units which include: Coarse Sandstone, Medium Sandstone, Clayey Shale and Very Fine to Fine Sandstone. A total of ninety fresh Quartz pebbles (fifteen each from six locations) were collected for Pebble analysis and five sandstone samples were collected for sieve analysis. Morphometric parameters such as size, flatness ratio, elongation ratio, maximum projection sphericity, form geometry and oblate index were computed. Bivariate scattergrams of roundness versus oblate-prolate index were also plotted.Results show that the coefficient of flatness for the area range from 45.76 to 226.6 while mean values of sphericity and oblate prolate index ranges from 0.061 to 7.615 and 0.746 to 18.872 respectively. These values suggest fluvial origin for the pebbles. Scatter plots of coefficient of flatness versus sphericity and sphericity versus oblate-prolate index suggests that the pebbles were formed in a fluvial environment. Bivariate plots of sand-textural parameters such as simple skewness against simple standard deviation also suggest that the sediments are more of a fluvial and partly shallow marine environment. The widespread of Orphiomopha, Skolitus and Rhizocolarium in the area supports the idea of a near shore depositional environment.
Keywords: Pebble Morphometry, Paleoenvironment, Coefficient of Flatness, Oblate-prolate Index, Roundness

1. INTRODUCTION

Enugu State University of Science and Technology Agbani campus lies within latitudes $6^{\circ}\ 17^{1}\ 28.8^{11}$E to $6^{\circ}\ 18^{1}\ 50.4^{11}$ E and longitudes $7^{\circ}\ 31^{1}\ 12^{11}$ and $7^{\circ}33^{1}\ 0^{11}$, with an area of about 9.24075km^{2} in Nkanu West local government area, Enugu state, Nigeria (figure 1). The study area is bounded by four surrounding communities, Obe in the west, Agbani to east, Umueze to the north and Amurri to the south. The major access route to the area is a bye cut road linking Enugu Portharcourt express way to Ebonyi through Ozalla, Obe, Umueze, Agbani, Akpugo (figure 2) and a minor road linking Agbani to Amurri.

While within the study area, outcrops/exposures can be located along constructed major roads in the school, minor unconstructed roads and foot paths. Some pebbly beds are also exposed in several locations within the area. This paper reports the results of the study of pebbles from these locations which together with other evidence from sand textural study has been used to decipher the paleodepositional environment

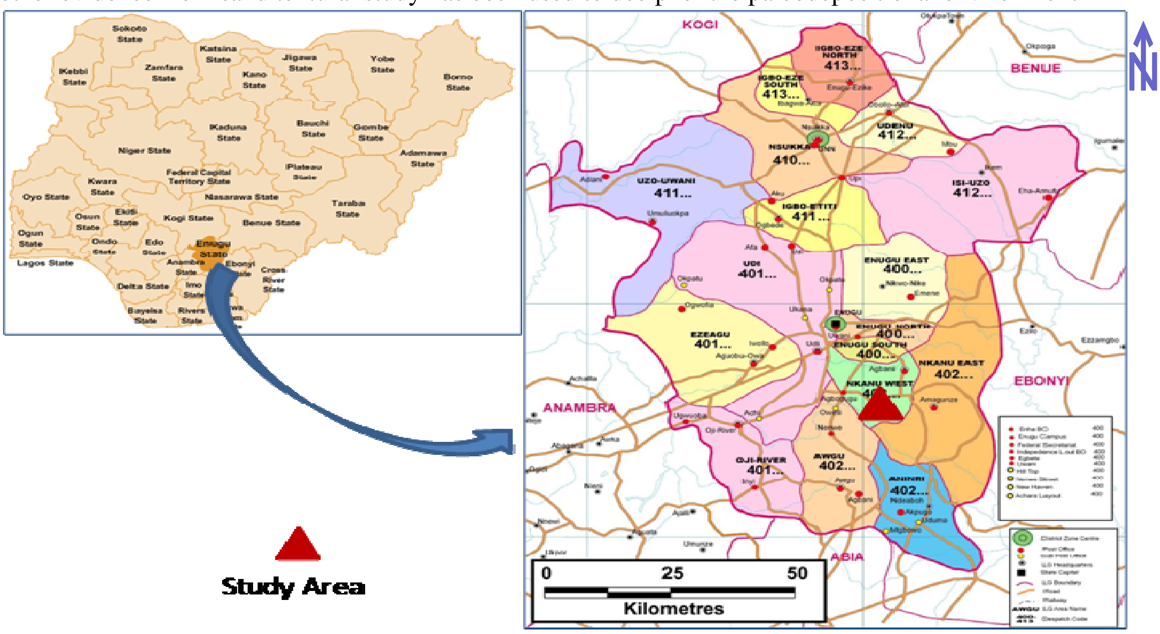

Figure 1: Map of Nigeria and Enugu State showing study area
(www.nigeriazipcodes.com)

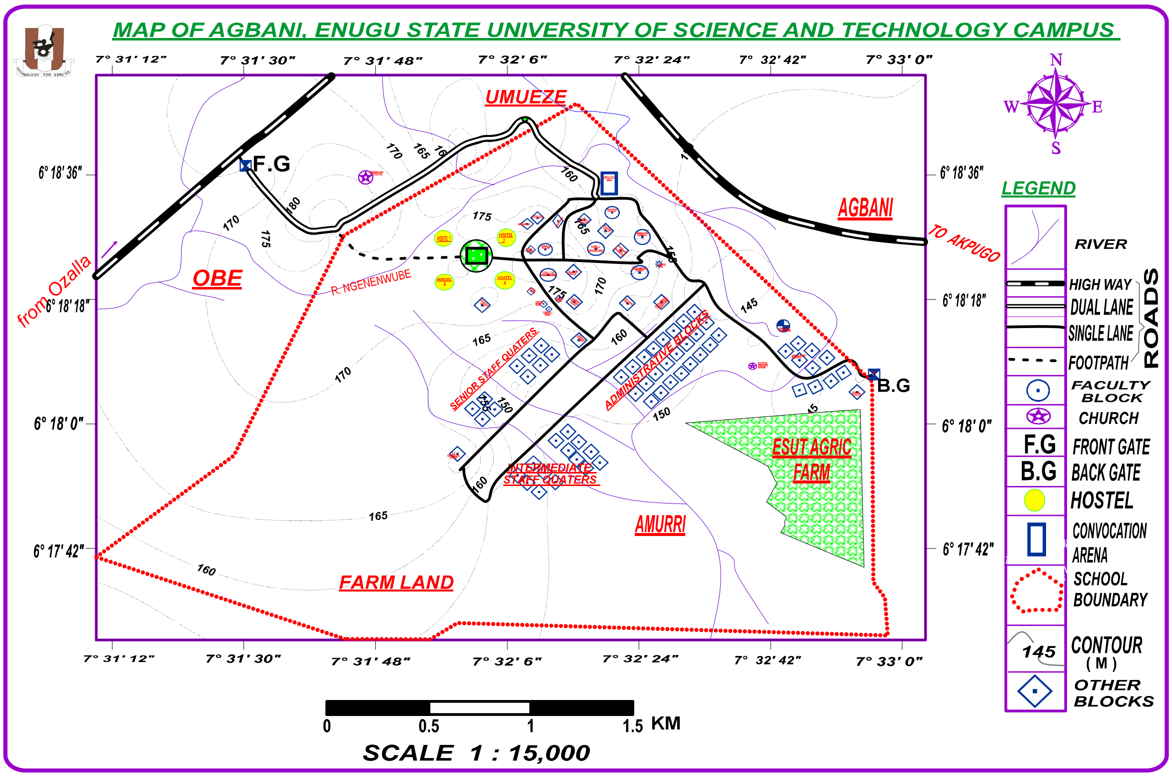

Figure 2: Topographic Map of the Study Area

2. PHYSIOGRAPHY

The study area has an undulating topography, ranging from 140m to 190m above sea level (ASL), and having its highest peak around the Social Science Faculty and School main park junction near the front gate, and its lowest spots very close to Amurri (figure 3). The topography of the areas boarding this study area: in the west is the Udi highlands of about 5000ft (1524m) ASL and in the south is the Amurri Akpugo lowlands of about 250ft (76m) ASL (Okonkwo and Odoh, 2014).

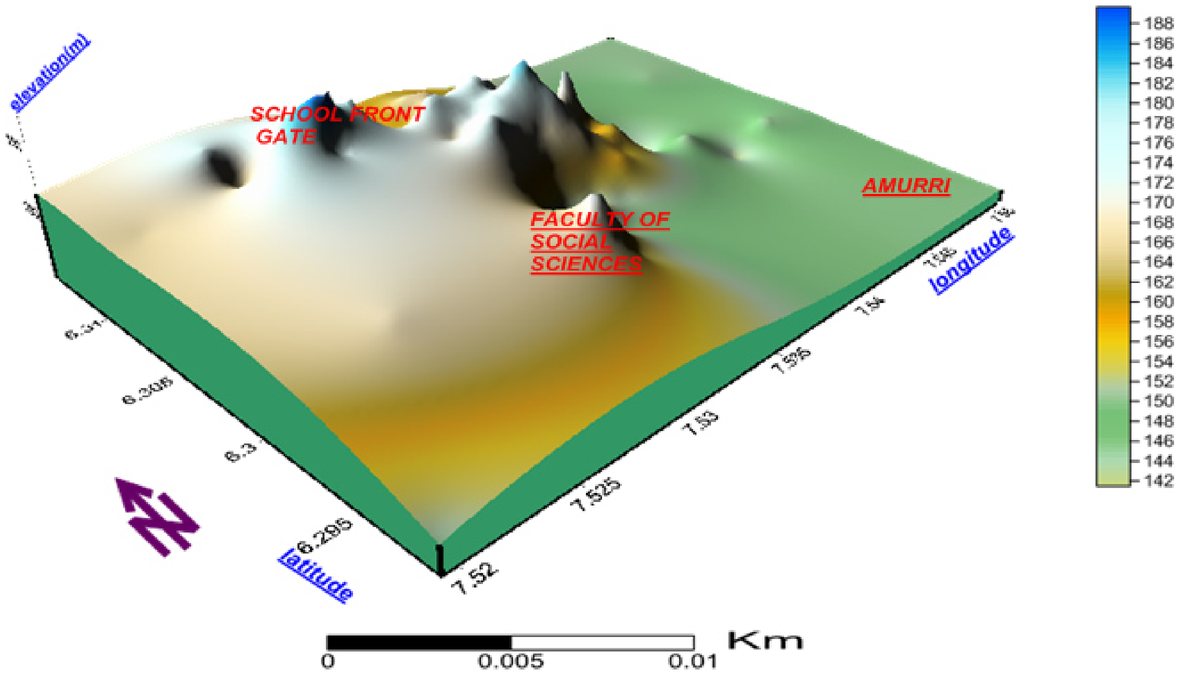

Figure 3: Elevation map of study area

3. GEOLOGY

The study area lies within the Agbani sandstone which is part of the Lower Benue Trough of Nigeria. The Sandstone is the arenaceous component of the Santonian fluvial classic influx that terminated the Conatian-Santonian marine sedimentation (Nwajide, 2012), The Agbani lithofacies are mainly white, medium to coarse, Pebbly (quartz and clay chips), poorly sorted sandstone occurring above the Agwu shale, showing westerly dips up to 20° and fluviatile depositional conditions (Nwajide, 2012). The Agbani sandatone is a rough time equivalent of the Agwu shale (Reyment, 1965) characterized by Palynomorphs (Oloto and Egbuachor, 2013).

Two major lithologies are present in the study area, they are shale and sandstone. The shale is light grey in colour with high clay content at the surface but bluish grey at erosion cut points, fissile and contains brownish iron stains. The Sandstone facies is more extensive and consists of four sub-facies: the Coarse, Medium, Fine and Very Fine Sandstone, (figure 4).

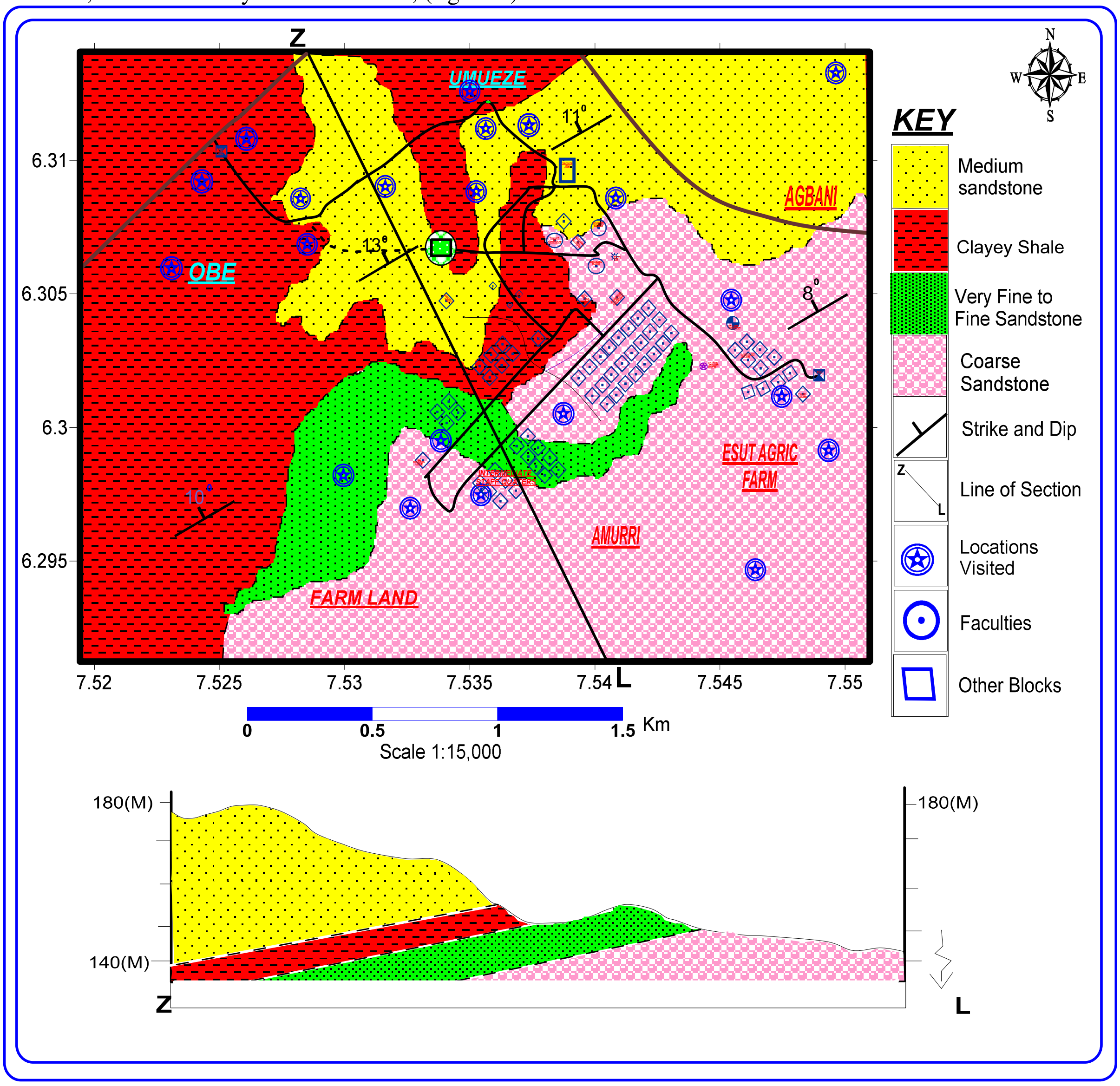

Figure 4: Geologic map of study area and Outcrop locations.

4. MATERIALS AND METHOD

Pebble morphology and Sieve analysis were carried out on fresh Quartz pebbles and sandstone samples found in the study area, in attempt to reconstruct the paleoenvironment of deposition.

4.1. PEBBLE MORPHOLOGY

15 unbroken fresh quartz pebbles were picked at random beneath the pebbly beds at six different locations within the study area. The samples were washed and numbered. Pebbles sampled include only pebbles with isotropic constitution and high resistance to wear. The Micrometer screw gauge was used to obtain (Long, L;

Intermediate, I and Short, S) axes of each pebble, then the following indices were calculated and compared with index values of Dobkins and Folk(1970).

1. Maximum Projection Sphericity (MPS) = $\frac{S^2/LI}{L/S}$
2. Flatness Index(FI) = (S/L) 100
3. Oblate Prolate Index(OPI) = $\frac{(L-I/L-S) - 0.5}{S/L}$

The pebbles were also grouped into half – phi size classes according to the intermediate axes of pebbles. Roundness of pebbles were determined using a visual comparison with chart images compiled by Sames, (1966)

4.2. SEIVE ANALYSIS

The sieve analysis was carried out using a British standard set of sieve, a jarring machine and a triple beam balance. The sands were jarred once for about fifteen minutes and graphs of percentage passing against sieve sizes were plotted.

Graphs of cumulative frequency plot on the log probability paper for each sample were plotted (fig.18-22), following the method of Visher (1969). From the cumulative plots, critical percentile phi values (ϕ5, ϕ16, ϕ25, ϕ50, ϕ75, ϕ84, ϕ95) were obtained and used to compute the univariate statistical parameters (table 1). Mean size (Mz); the mean of the diameter at three points on the curve , Sorting (σ^2); a measure of sediment dispersion about the average, Skewness (ski); a measure of the asymmetry of the frequency distribution and Kurtosis (Ku); a measure of the peakedness of a curve.(see table 1)

Table 1: British Standard Seive

PARAMETERS	FORMULA	INTERPRETATION
M_Z	(ϕ16 + ϕ50 + ϕ84)/3	0 – 1 COARSE SAND
		1 -2 MEDIUM SAND
		2 – 3 FINE SAND
σ_1	(ϕ84 - ϕ16)/4 + (ϕ95 - ϕ5)/6.6	> 0.35 VERY WELL SORTED
		0.35 – 0.50 WELL SORTED
		0.50 – 1.0 MODERATELY SORTED
		1.0 – 2.0 POORLY SORTED
		2.0 – 4.0 VERY POORLY SORTED
		< 4.0 EXTREMELY POORLY SORTED
SKI	$\frac{(\phi16+\phi84 - \phi50\ \phi16)}{2(\phi84 + \phi16)} + \frac{(\phi5 + \phi95 - 2\phi50)}{2(\phi95 + \phi5)}$	1.0 – 0.3 VERY POSITIVELY SKEWED
		0.3 – 0.1 POSITIVELY SKEWED
		0.1 – 0.01 SYMMETRICAL
		0.01 – (-0.1) NEGATIVELY SKEWED
		-0.1 – (-0.3) VERY NEGATIVELY SKEWED
K_G	$\frac{\phi95 + \phi5}{2.44(\phi75 + \phi25)}$	< 0.67 VERY PLATYKURTIC
		0.67 – 0.90 PLATYKURTIC
		0.90 – 1.11 MESOKURTIC
		1.11 – 1.50 LEPTOKURTIC
		1.50 – 3.0 VER LEPTOKURTIC
		> 3.0 EXTREMELY LEPTOKURTIC

Bivariate (fig.23 and 24) and multivariate (table 9) combinations of these parameters were used to delineate the paleoenvironment of deposition.

5. RESULTS AND DISCUSSIONS

The results of pebble morphometric analysis for various locations within the study area are shown in the tables 2 to 7 and figures 5 to 16 below.

Results show that sixty seven (73.7%) of the samples had MPS (maximum prolate sphericity) greater than 0.65, all the ninety samples (100%) had FI(flatness index) greater than 45%, and seventy six (83.3%) had an OPI (oblate prolate index) greater than 1.5. indicating that the area is predominantly a fluvial (meandering river) environment.

Bivariate plots of individual MPS against OPI show that fifty five pebbles (60.5%) fall within the fluvial environment, thirty pebbles (33%) fall into undiscriminated environment(surf), while only five(5.5%) fell within the shallow marine environment. The plots of FI against MPS show that sixty nine pebble samples (75.9%) fell within the fluvial environment, twenty one (24.1%) fell within a non discriminated (surf) environment.

The result of sieve analysis show that the sediments in question seem to have travelled relatively far from their source (observing the horizontal extent of the graphs) and comprised basically of sandstone with little proportion of silt. From the relatively high sloping pattern of the curves (Figures18-22), it can be deduced that the sediments ranges from poorly to moderately sorted. Applying the formula on table 1, the samples yielded medium size sands, moderate and poor sorting, symmetrical skewness and very platy Kurtic Kurtosis. These data were used for bivariate plots of skewness against sorting/standard deviation and mean size against standard deviation (Figures 23-24). From their graphs, all the samples lie within the fluvial environment.

The Sphericity – form diagram, (figure 17) for the sandstone pebbles also show that majority of the pebbles yielded a compact (C), compact elongate (CE) and compact bladed (CB) class shape which is diagnostic of river action.

Table 2: Morphology result for pebbles around University Library (P.S1)

S/N	MPS	INTERPRETATION	FI	INTERPRETATION	OPI	INTERPRETATION
1	0.226	SHALLOW MARINE	48.2	FLUVIAL	0.959	SHALLOW MARINE
2	0.642	SHALLOW MARINE	64.8	FLUVIAL	0.755	SHALLOW MARINE
3	0.614	SHALLOW MARINE	62.7	FLUVIAL	3.311	FLUVIAL
4	1.349	FLUVIAL	92.8	FLUVIAL	5.557	FLUVIAL
5	1.236	FLUVIAL	75.3	FLUVIAL	2.851	FLUVIAL
6	0.929	FLUVIAL	79.1	FLUVIAL	2.195	FLUVIAL
7	0.846	FLUVIAL	71.1	FLUVIAL	2.097	FLUVIAL
8	0.697	FLUVIAL	79.9	FLUVIAL	0.746	FLUVIAL
9	0.591	SHALLOW MARINE	72.8	FLUVIAL	1.069	SHALLOW MARINE
10	0.576	SHALLOW MARINE	65.1	FLUVIAL	1.528	FLUVIAL
11	0.946	FLUVIAL	70.9	FLUVIAL	2.316	FLUVIAL
12	1.386	FLUVIAL	93.1	FLUVIAL	1.986	FLUVIAL
13	1.095	FLUVIAL	83.1	FLUVIAL	2.798	FLUVIAL
14	0.646	SHALLOW MARINE	72	FLUVIAL	1.451	SHALLOW MARINE
15	0.564	SHALLOW MARINE	73.8	FLUVIAL	0.806	SHALLOW MARINE

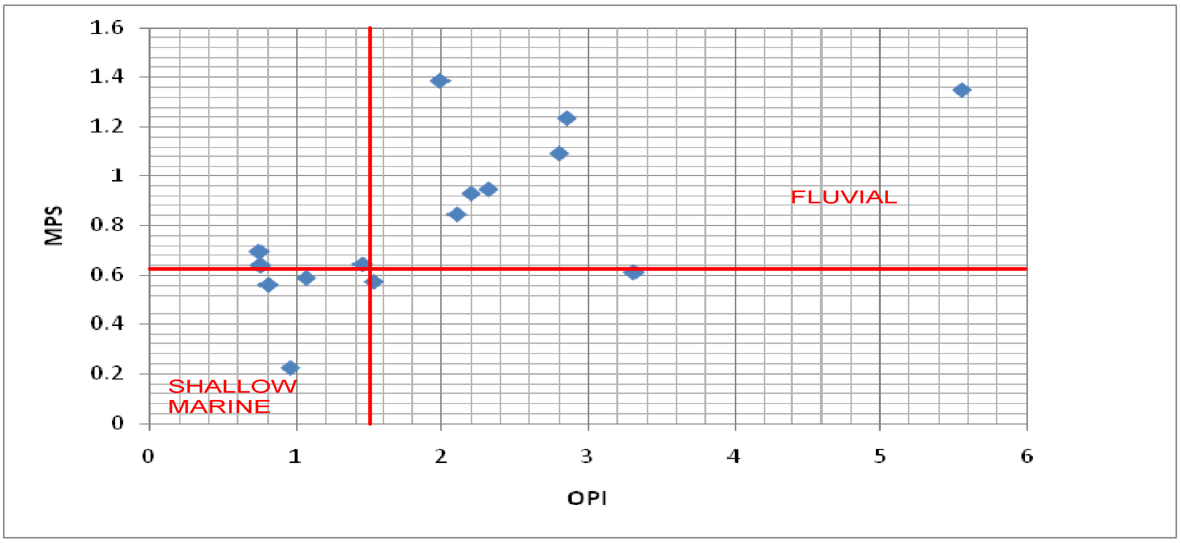

Figure 5: Bivariate plot of MPS against OPI (P.S1)

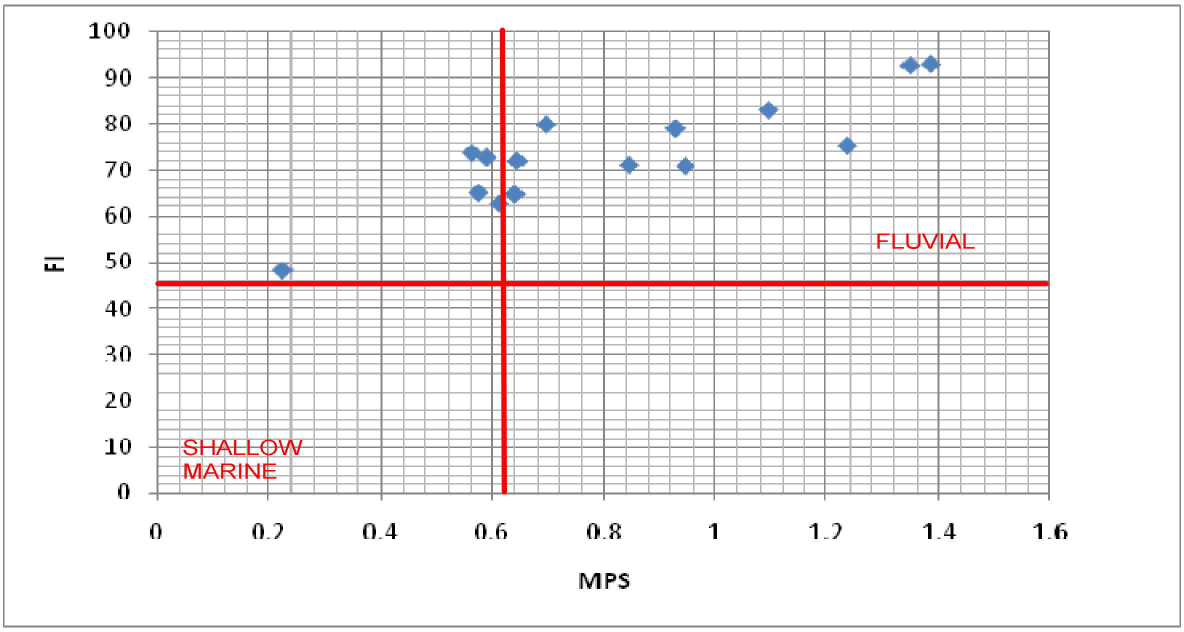

Figure 6: Bivariate plot of FI against MPS (P.S1).

Table 3: Morphology result for pebbles around AFRIHUB (P.S2)

S/N	MPS	INTERPRETATION	FI	INTERPRETATION	OPI	INTERPRETATION
1	1.805	FLUVIAL	87	FLUVIAL	4.044	FLUVIAL
2	0.645	SHALLOW MARINE	71.2	FLUVIAL	1.442	SHALLOW MARINE
3	1.179	FLUVIAL	84.2	FLUVIAL	3.114	FLUVIAL
4	0.521	SHALLOW MARINE	62.5	FLUVIAL	1.491	SHALLOW MARINE
5	1.474	FLUVIAL	81.9	FLUVIAL	3.624	FLUVIAL
6	1.125	FLUVIAL	72	FLUVIAL	2.622	FLUVIAL
7	0.913	FLUVIAL	80.2	FLUVIAL	2.116	FLUVIAL
8	0.609	SHALLOW MARINE	61.9	FLUVIAL	1.782	FLUVIAL
9	0.563	SHALLOW MARINE	61.5	FLUVIAL	1.667	FLUVIAL
10	0.962	FLUVIAL	85	FLUVIAL	2.248	FLUVIAL
11	1.614	FLUVIAL	89.7	FLUVIAL	5.424	FLUVIAL
12	0.834	FLUVIAL	68.1	FLUVIAL	2.126	FLUVIAL
13	0.904	FLUVIAL	81.6	FLUVIAL	2.043	FLUVIAL
14	0.987	FLUVIAL	69.7	FLUVIAL	2.395	FLUVIAL
15	0.061	SHALLOW MARINE	87.4	FLUVIAL	2.792	FLUVIAL

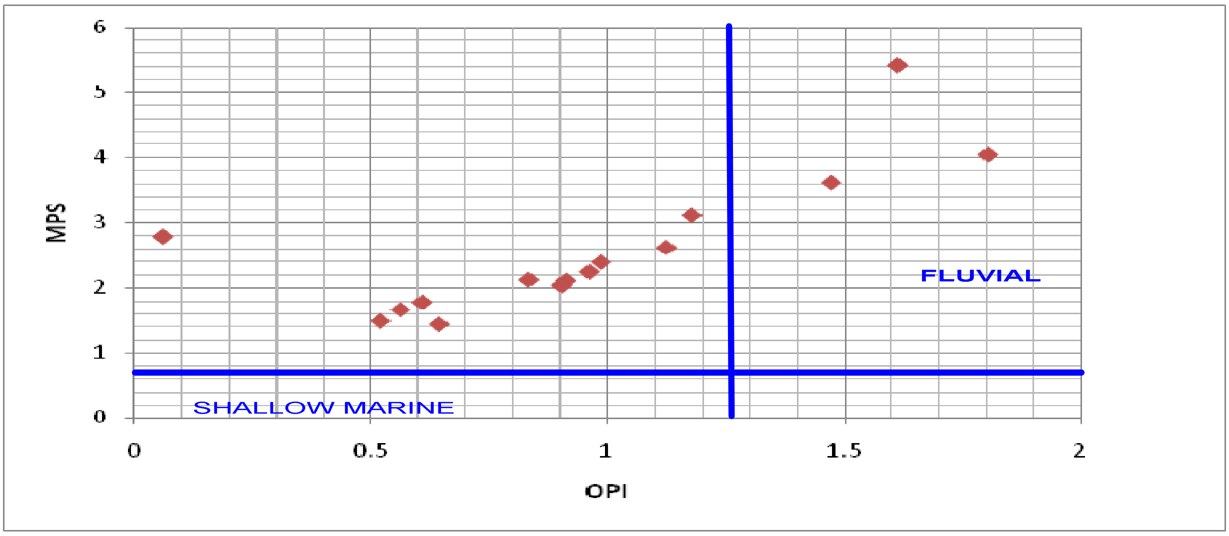

Figure 7: Bivariate plot of MPS against OPI (P.S2).

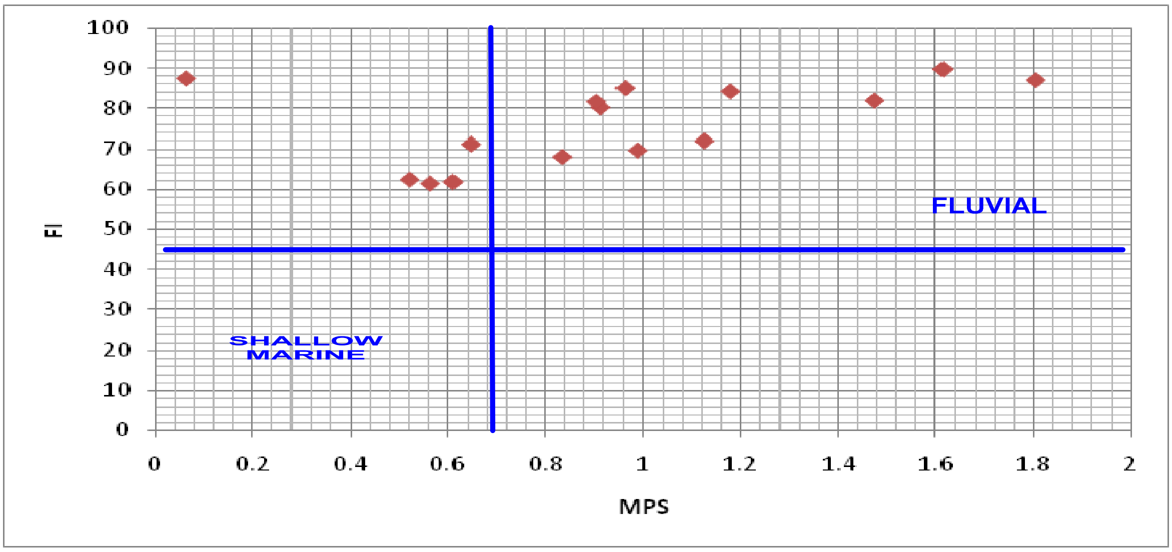

Figure 8: Bivariate plot of FI against MPS (P.S2).

Table 4: Morphology result for pebbles around General Studies Block (P.S3).

S/N	MPS	INTERPRETATION	FI	INTERPRETATION	OPI	INTERPRETATION
1	0.567	SHALLOW MARINE	61.9	FLUVIAL	1.661	FLUVIAL
2	0.793	FLUVIAL	78.1	FLUVIAL	1.694	FLUVIAL
3	2.083	FLUVIAL	59.4	FLUVIAL	2.892	FLUVIAL
4	2.736	FLUVIAL	64.9	FLUVIAL	3.186	FLUVIAL
5	1.045	FLUVIAL	79.6	FLUVIAL	4.925	FLUVIAL
6	3.344	FLUVIAL	70.2	FLUVIAL	3.594	FLUVIAL
7	1.192	FLUVIAL	49.2	FLUVIAL	2.586	FLUVIAL
8	5.194	FLUVIAL	80.4	FLUVIAL	5.096	FLUVIAL
9	5.461	FLUVIAL	81.2	FLUVIAL	0.82	SHALLOW MARINE
10	3.221	FLUVIAL	68.5	FLUVIAL	3.446	FLUVIAL
11	2.658	FLUVIAL	64.3	FLUVIAL	3.149	FLUVIAL
12	4.588	FLUVIAL	77.1	FLUVIAL	4.449	FLUVIAL
13	5.087	FLUVIAL	79.8	FLUVIAL	4.96	FLUVIAL
14	3.521	FLUVIAL	70.6	FLUVIAL	3.631	FLUVIAL
15	7.615	FLUVIAL	91.3	FLUVIAL	11.014	FLUVIAL

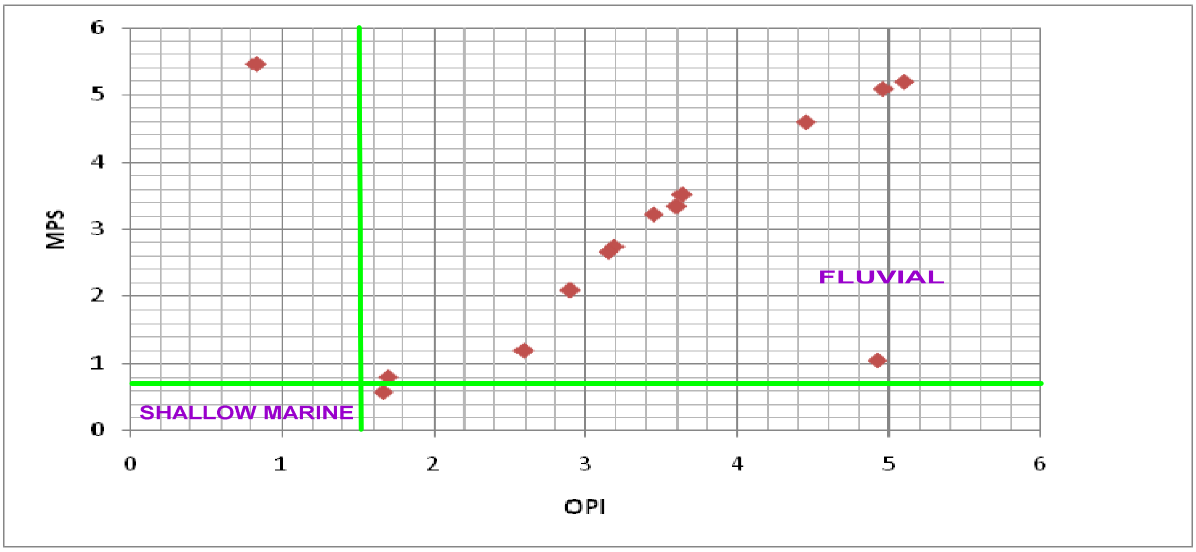

Figure 9: Bivariate plot of MPS against OPI (P.S3).

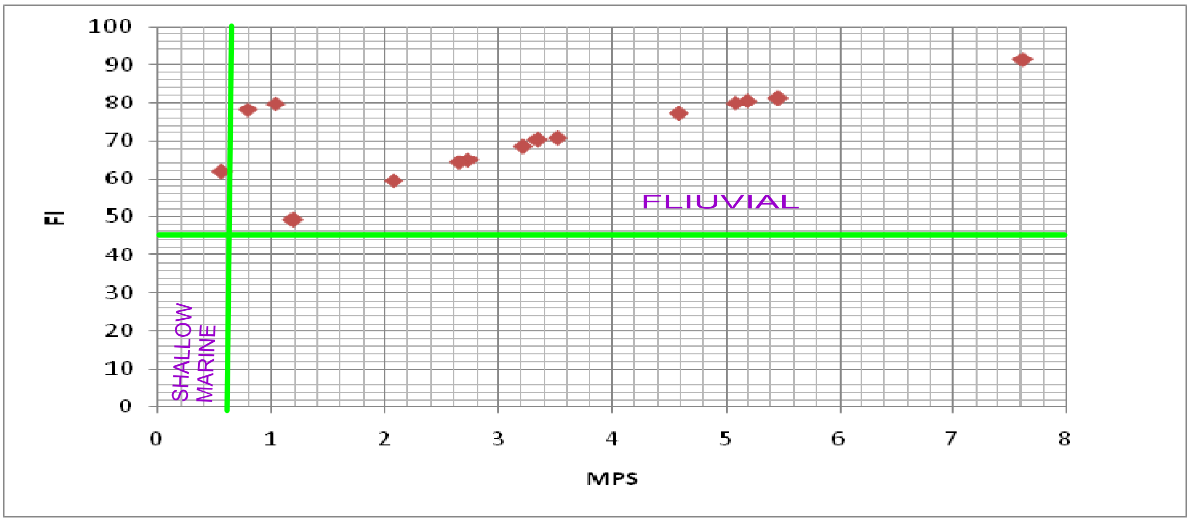

Figure 10: Bivariate plot of FI against MPS (P.S3).

Table 5: Morphology result for pebbles around Education faculty (P.S4).

S/N	MPS	INTERPRETATION	FI	INTERPRETATION	OPI	INTERPRETATION
1	1.045	FLUVIAL	64.8	FLUVIAL	2.471	FLUVIAL
2	1.151	FLUVIAL	66.4	FLUVIAL	1.482	FLUVIAL
3	0.67	FLUVIAL	59.2	FLUVIAL	2.012	FLUVIAL
4	0.823	FLUVIAL	64.4	FLUVIAL	2.054	FLUVIAL
5	1.979	FLUVIAL	97.2	FLUVIAL	18.872	FLUVIAL
6	0.705	FLUVIAL	71.1	FLUVIAL	1.681	FLUVIAL
7	0.299	SHALLOW MARINE	47.4	FLUVIAL	1.527	FLUVIAL
8	1.151	FLUVIAL	81.2	FLUVIAL	2.888	FLUVIAL
9	2.053	FLUVIAL	104.2	FLUVIAL	2.888	FLUVIAL
10	0.662	FLUVIAL	57.5	FLUVIAL	1.539	FLUVIAL
11	1.12	FLUVIAL	226.6	FLUVIAL	1.071	FLUVIAL
12	0.904	FLUVIAL	82.1	FLUVIAL	2.028	FLUVIAL
13	0.868	FLUVIAL	74.9	FLUVIAL	2.079	FLUVIAL
14	0.672	FLUVIAL	75.5	FLUVIAL	1.279	FLUVIAL
15	1.088	FLUVIAL	73.5	FLUVIAL	2.578	FLUVIAL

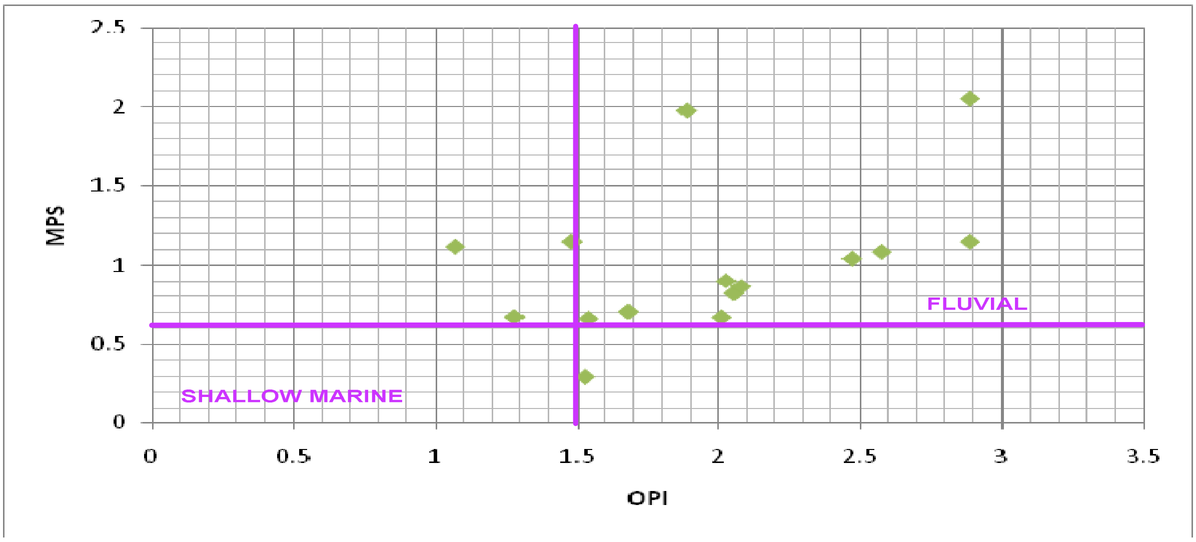

Figure 11: Bivariate plot of MPS against OPI (P.S4).

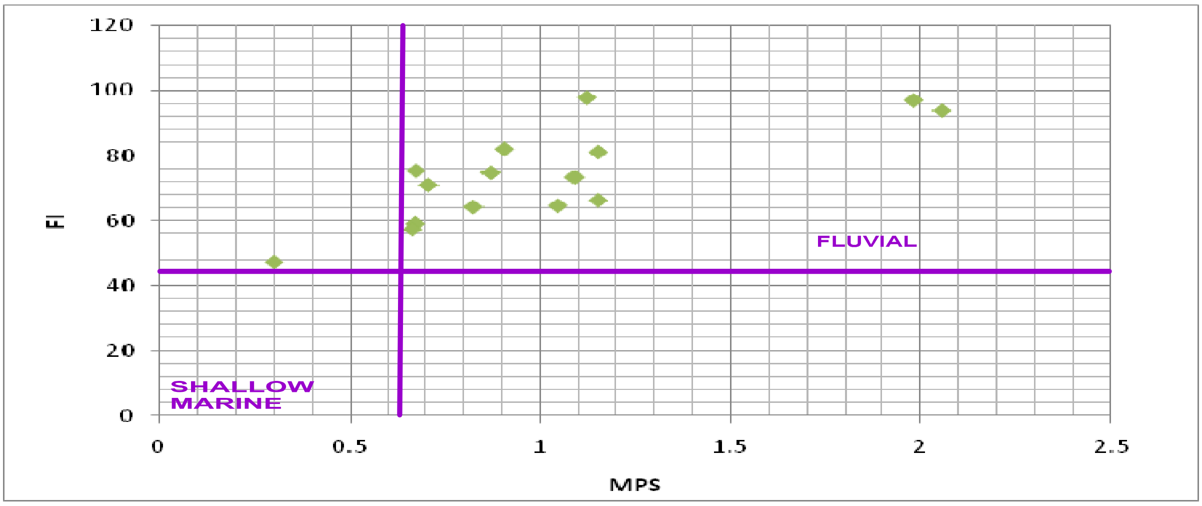

Figure 12: Bivariate plot of FI against MPS (P.S4).

Table 6: Morphology result for pebbles around Zenith Bank (P.S5).

S/N	MPS	INTERPRETATION	FI	INTERPRETATION	OPI	INTERPRETATION
1	1.866	FLUVIAL	96.2	FLUVIAL	13.929	FLUVIAL
2	1.751	FLUVIAL	94.6	FLUVIAL	9.519	FLUVIAL
3	1.499	FLUVIAL	90.7	FLUVIAL	5.391	FLUVIAL
4	1.863	FLUVIAL	90.89	FLUVIAL	6.659	FLUVIAL
5	2.119	FLUVIAL	92.7	FLUVIAL	7.826	FLUVIAL
6	0.343	SHALLOW MARINE	52.4	FLUVIAL	1.374	SHALLOW MARINE
7	1.2	FLUVIAL	76.5	FLUVIAL	2.837	FLUVIAL
8	0.698	FLUVIAL	67.4	FLUVIAL	1.813	FLUVIAL
9	0.526	SHALLOW MARINE	45.76	FLUVIAL	1.555	FLUVIAL
10	0.611	SHALLOW MARINE	63.4	FLUVIAL	1.722	FLUVIAL
11	0.599	SHALLOW MARINE	72	FLUVIAL	1.173	SHALLOW MARINE
12	1.135	FLUVIAL	93	FLUVIAL	8.358	FLUVIAL
13	1.202	FLUVIAL	76	FLUVIAL	2.834	FLUVIAL
14	1.211	FLUVIAL	98.5	FLUVIAL	13.198	FLUVIAL
15	1.511	FLUVIAL	50.26	FLUVIAL	2.011	FLUVIAL

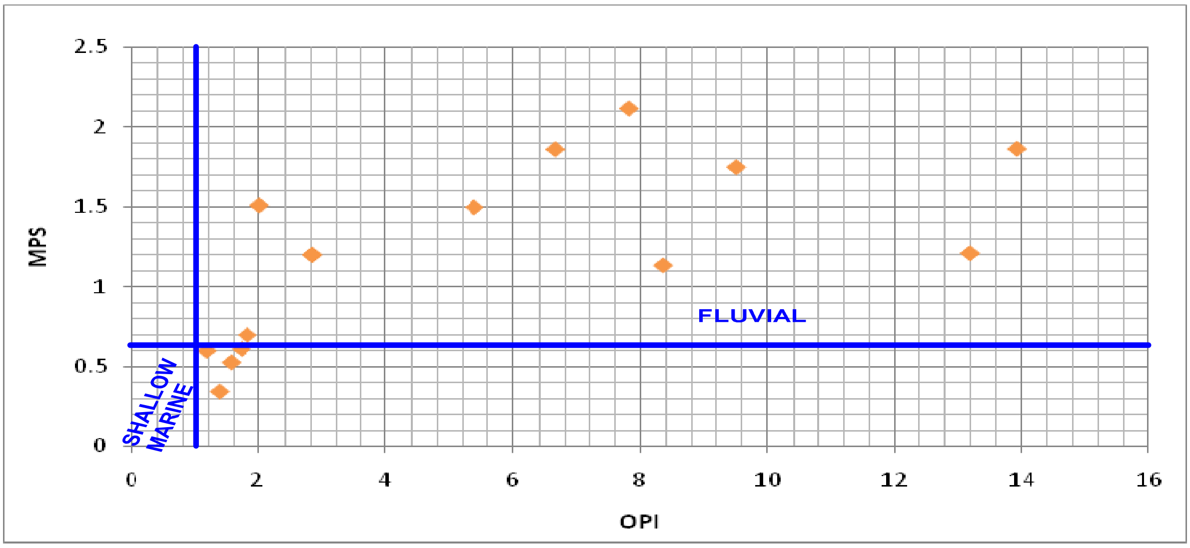

Figure 13: Bivariate plot of MPS against OPI (P.S5).

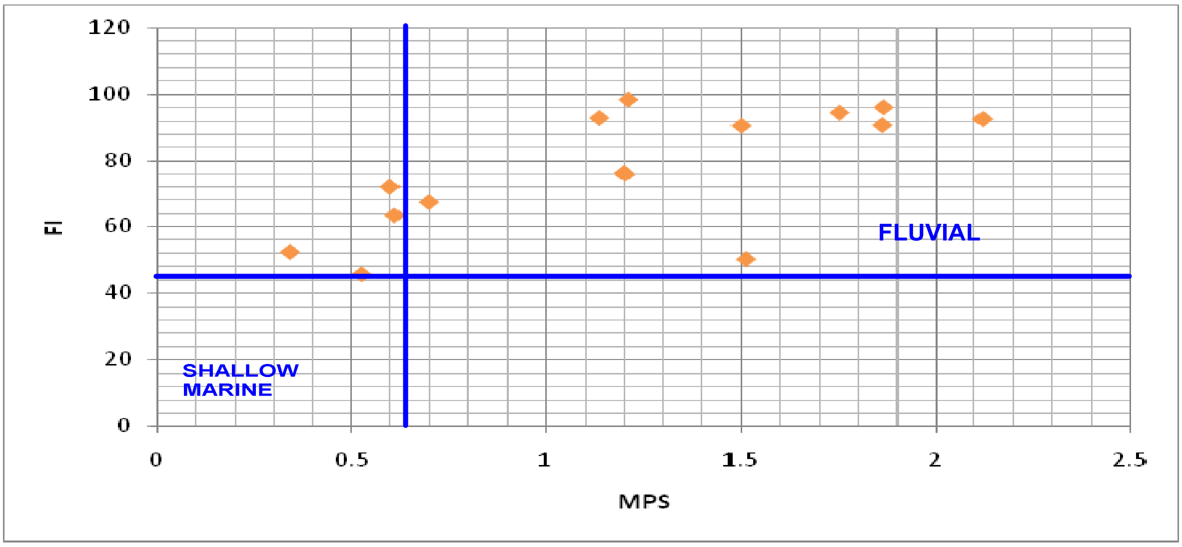

Figure 14: Bivariate plot of FI against MPS (P.S5).

Table 7: morphology result for pebbles OPPOSITE UNIVERSITY AUDITORIUM (P.S6)

S/N	MPS	INTERPRETATION	FI	INTERPRETATION	OPI	INTERPRETATION
1	0.592	SHALLOW MARINE	65.6	FLUVIAL	1.558	FLUVIAL
2	1.666	FLUVIAL	91.8	FLUVIAL	6.536	FLUVIAL
3	1.728	FLUVIAL	98.7	FLUVIAL	34.994	FLUVIAL
4	0.864	FLUVIAL	81.1	FLUVIAL	1.885	FLUVIAL
5	0.406	SHALLOW MARINE	59.8	FLUVIAL	1.134	SHALLOW MARINE
6	0.422	SHALLOW MARINE	60.1	FLUVIAL	1.116	SHALLOW MARINE
7	1.306	FLUVIAL	81.5	FLUVIAL	3.273	FLUVIAL
8	0.962	FLUVIAL	78.5	FLUVIAL	2.311	FLUVIAL
9	0.848	FLUVIAL	104.2	FLUVIAL	1.436	SHALLOW MARINE
10	0.862	FLUVIAL	84.8	FLUVIAL	1.679	FLUVIAL
11	0.519	SHALLOW MARINE	61.2	FLUVIAL	1.535	FLUVIAL
12	0.433	SHALLOW MARINE	57.9	FLUVIAL	1.334	SHALLOW MARINE
13	1.229	FLUVIAL	94.7	FLUVIAL	5.667	FLUVIAL
14	2.081	FLUVIAL	84.2	FLUVIAL	4.762	FLUVIAL
15	1.152	FLUVIAL	76.9	FLUVIAL	2.757	FLUVIAL

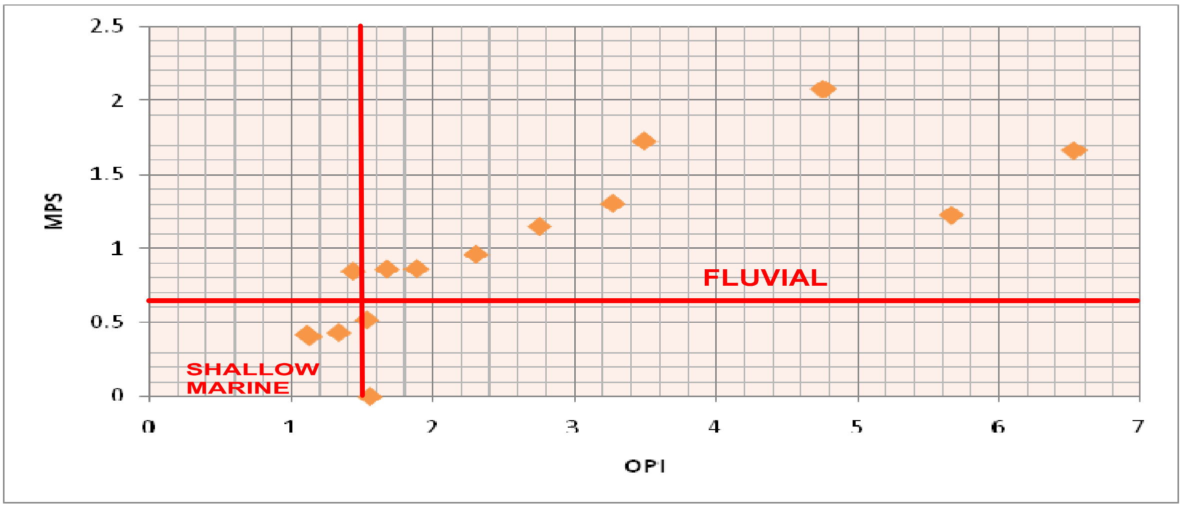

Figure 15: Bivariate plot of MPS against OPI (P.S6).

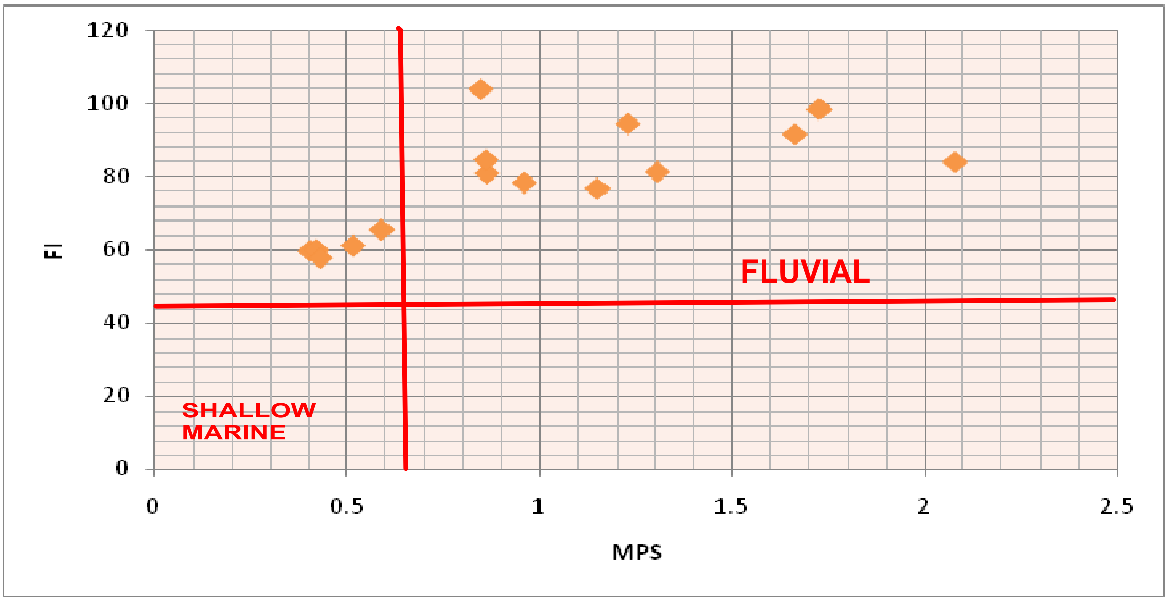

Figure 16: Bivariate plot of FI against MPS (P.S6).

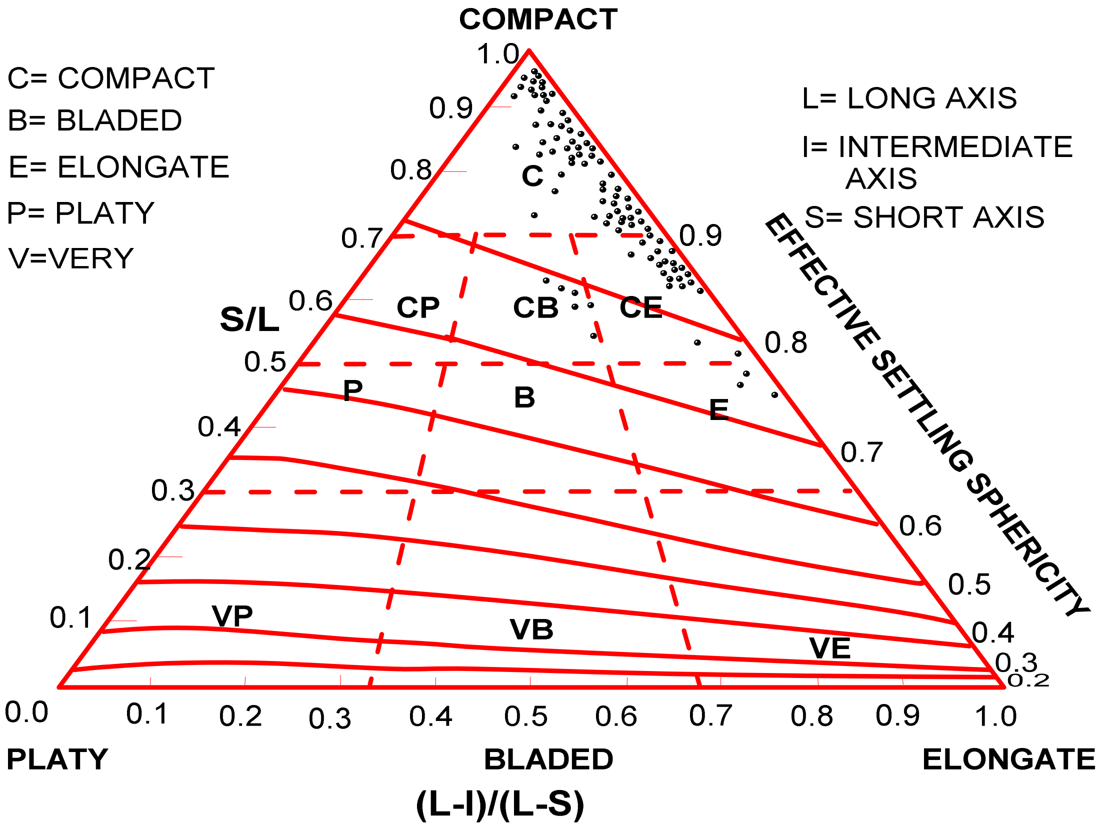

Figure 17: Sphericity – form diagram after Sneed and Folk (1958) for the sandstone pebbles.

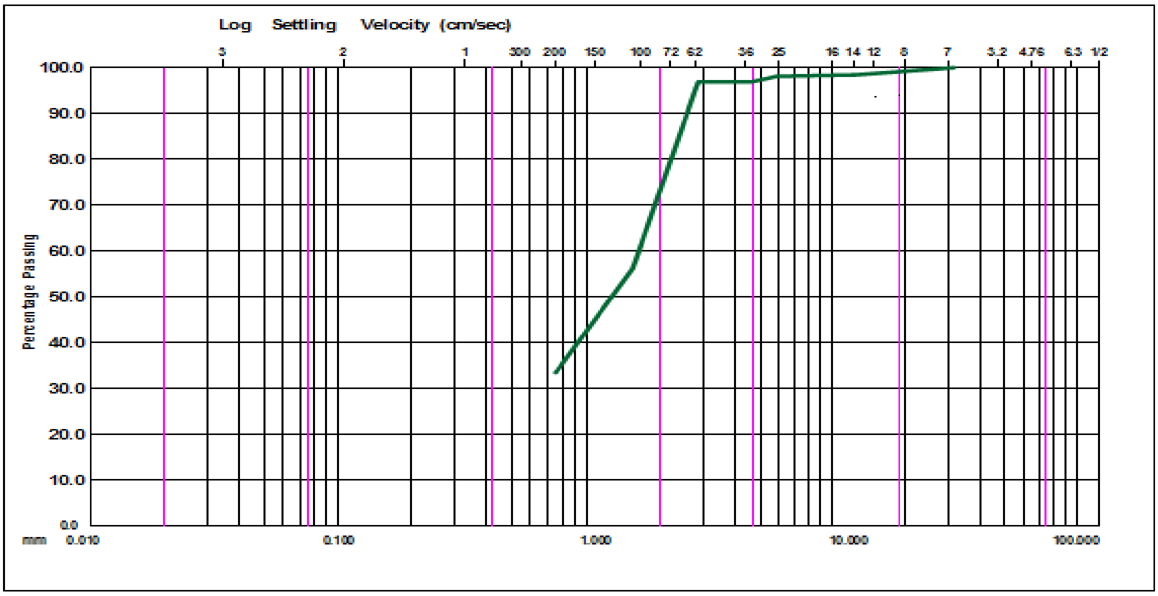

Figure 18: a plot of percentage passing against sieve size for SAMPLE 1

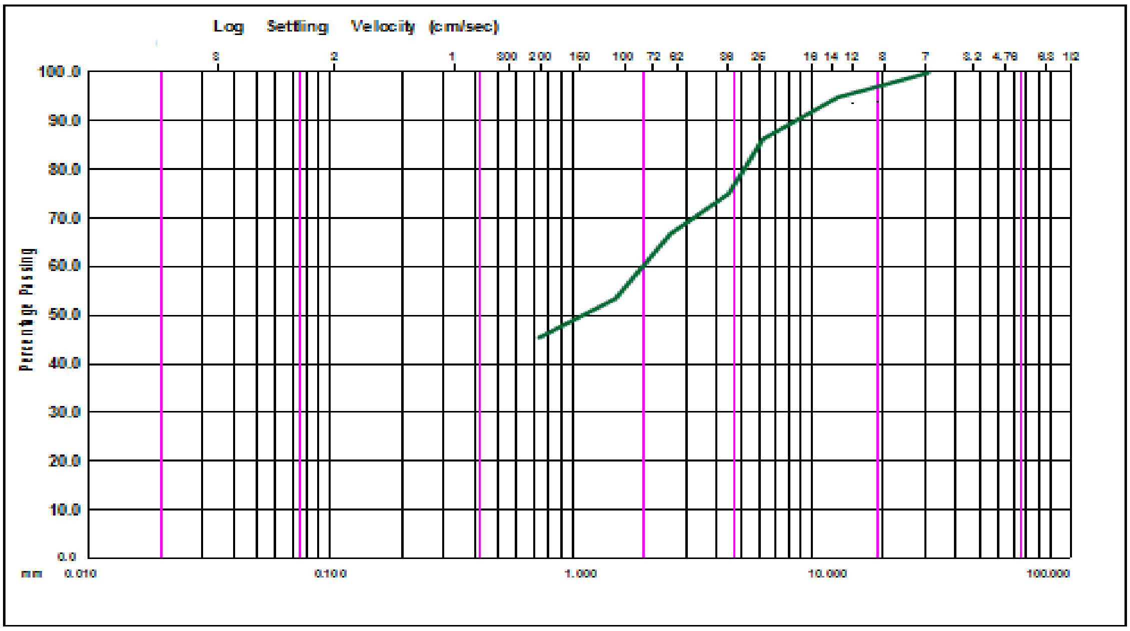

Figure 19: a plot of percentage passing against sieve size for SAMPLE 2

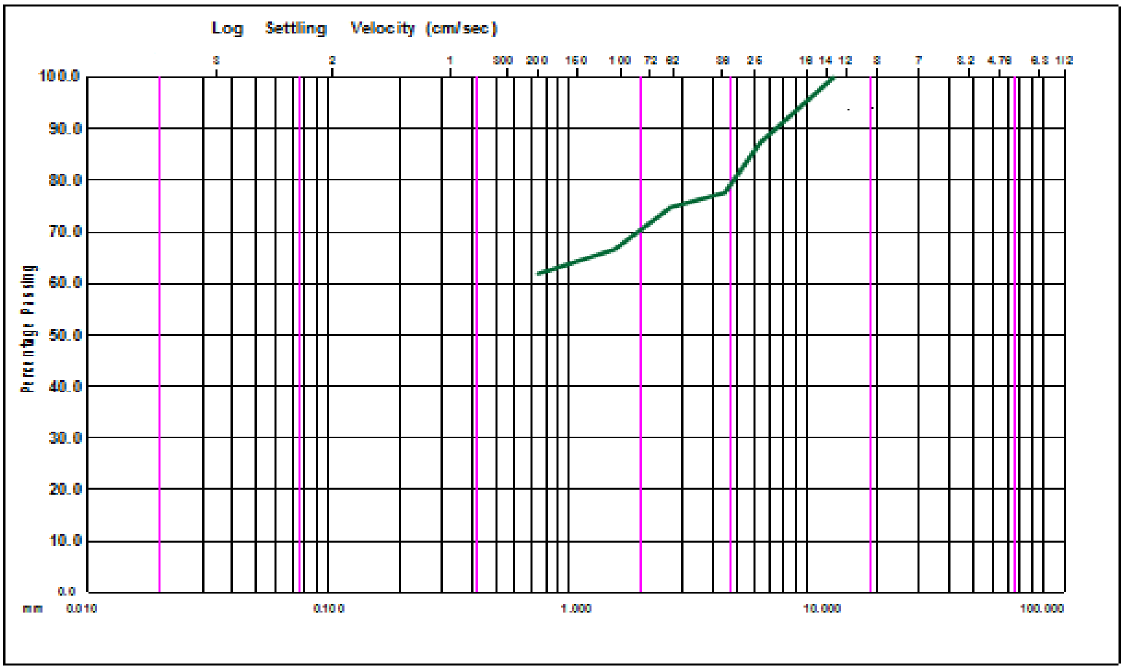

Figure 20: a plot of percentage passing against sieve size for SAMPLE 3

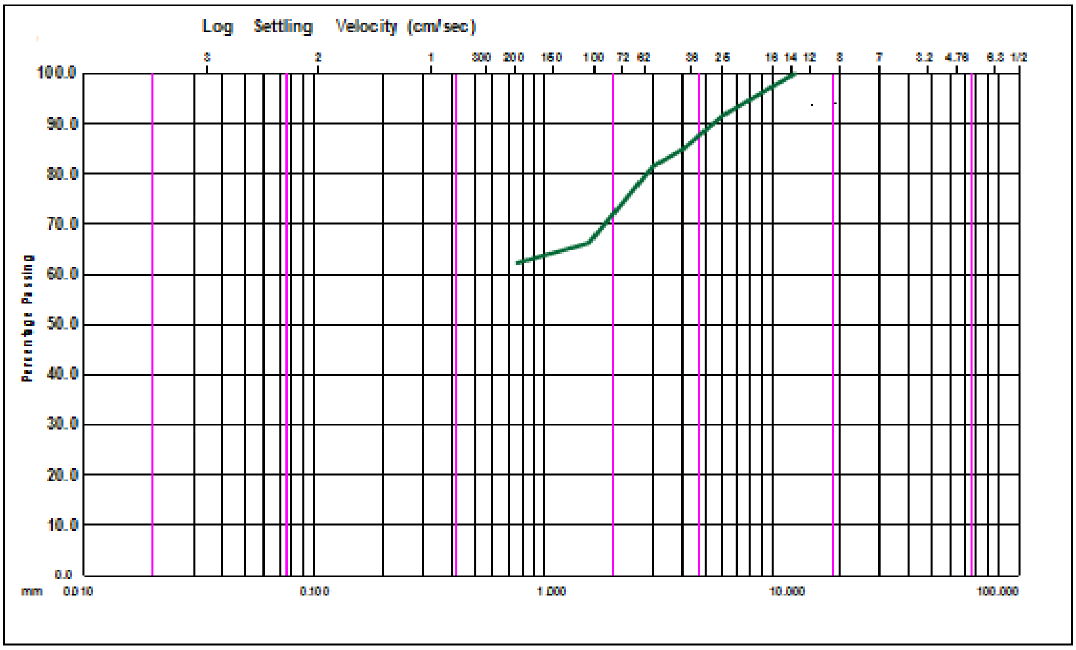

Figure 21: a plot of percentage passing against sieve size for SAMPLE 4

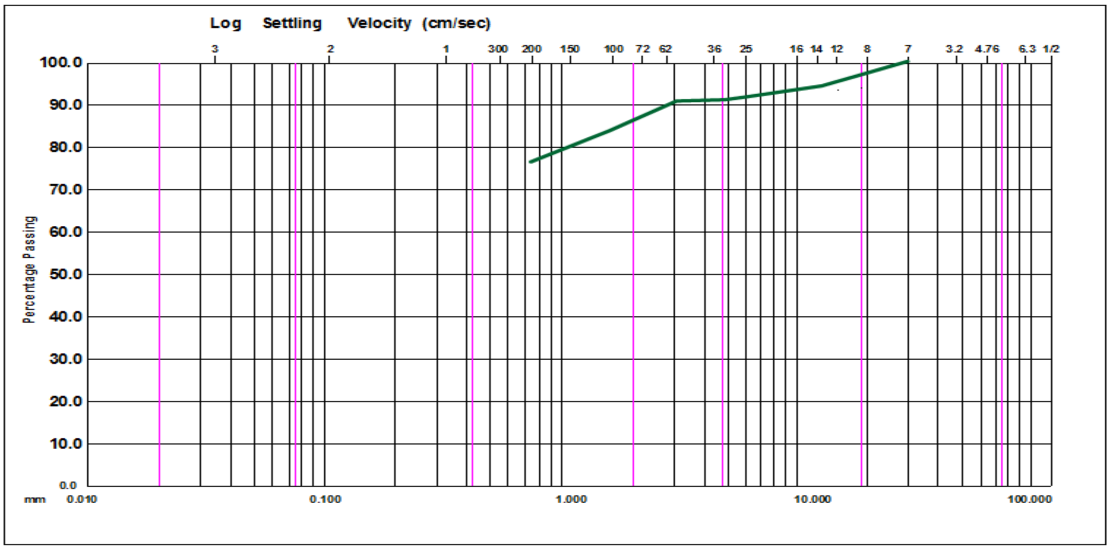

Figure 22: a plot of percentage passing against sieve size for SAMPLE 5

Table 7: sample univariate/ textural parameter table

Sample	Mz (MEAN SIZE)	σ^2 (SORTING)	Ski (SKEWNESS)	K_G (KURTOSIS)
S1	1.198 Medium sand	0.9799 Moderately sorted	-0.0103 symmetrical	0.4714 Very platy kurtic
S2	1.0421 Medium sand	0.9681 Moderately sorted	0.0322 symmetrical	0.4622 Very platy kurtic
S3	1.0161 Medium sand	0.8642 Moderately sorted	-0.021 symmetrical	0.4112 Very platy kurtic
S4	1.5134 Medium sand	1.2133 Poorly sorted	0.0454 symmetrical	0.4721 Very platy kurtic
S5	1.1461 Medium sand	0.9993 Moderately sorted	0.0402 symmetrical	0.4642 Very platy kurtic

BIVARIATE PARAMETER RESULTS

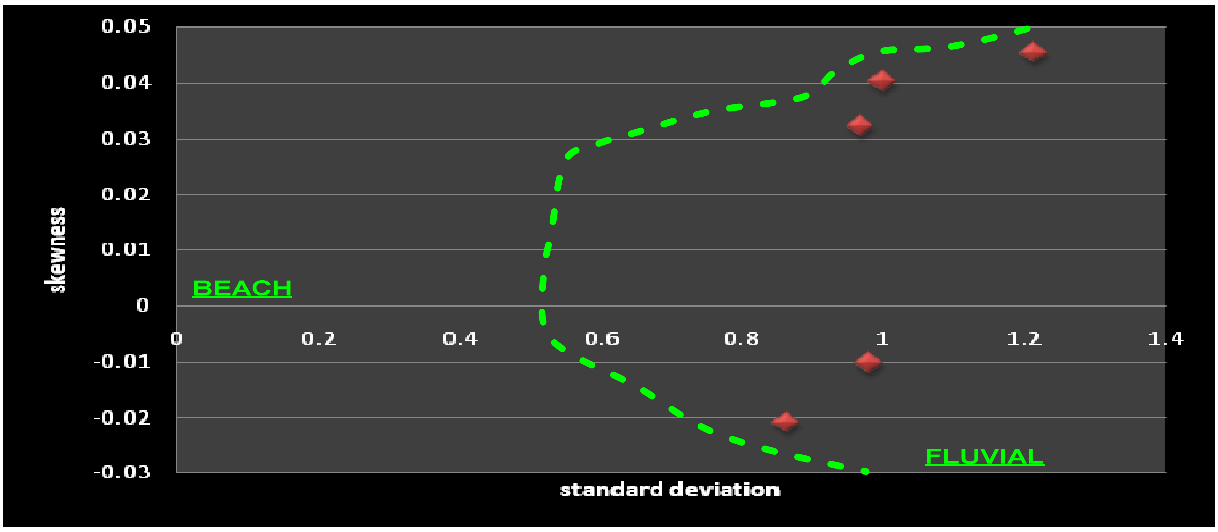

Figure 23: Plot of skewness against sorting.

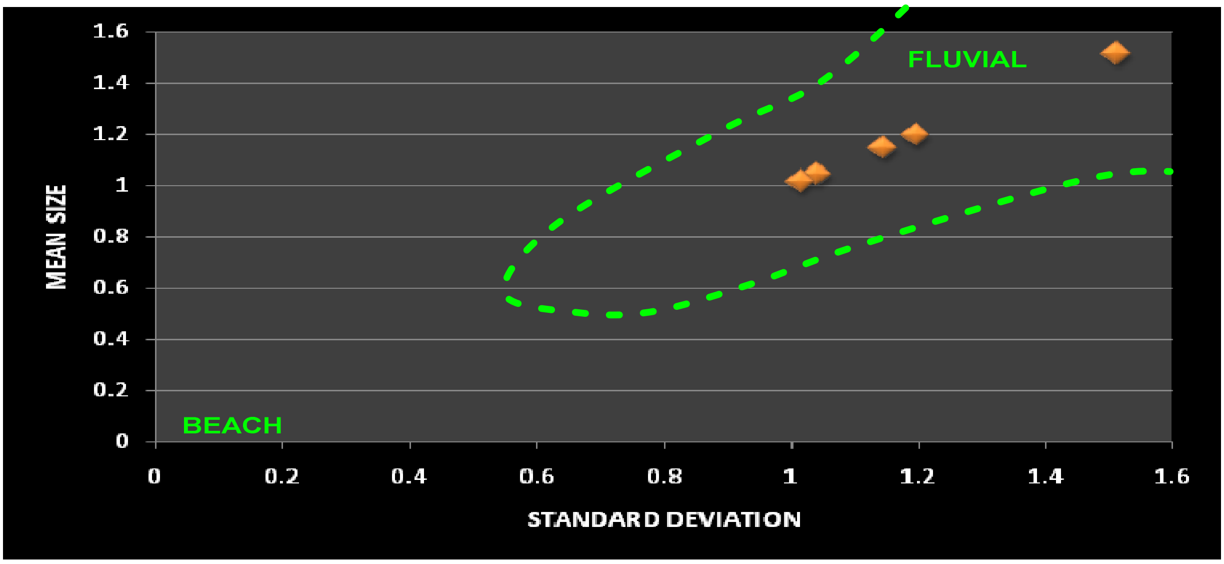

Figure 24: Plot of mean size against standard deviation.

From figure 23 modfied after Friedman (1961), all of the samples are fluvial and from figure 24 after Miola and Weiser (1968), the entire sandstone fell into the fluvial region.

6. CONCLUSIONS

On the basis of pebble form indices, it is evident that the pebbles were shaped in fluvial environment. Majority of the pebbles also yielded a compact, compact elongate and compact bladed class shape which is diagnostic of long distance river action (fluvial environment).

Results from sieve analysis show that the sediments is made up of medium size sands, poorly to moderately sorted, symmetrical skewness and very platy Kurtic Kurtosis (table 8). These data were used for bivariate plots of skewness against sorting/standard deviation and mean size against standard deviation (figures 23 and 24). All the graphs depict fluvial depositional environment for the sediments. The widespread of Orphiomopha, Skolitus and Rhizocolarium in the area (Plates1-3) supports the idea of a near shore depositional environment

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Plate 1: Orphiomopha burrows.

Plate 2: Skolitus fossil impression (notice the smooth edges).

Plate 3: Fossil imprints of Rhizocolarium.