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Pebble morphometric investigations on pebbles belonging to the Benin formation at NSIE and environs, Southeastern Nigeria

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ABSTRACT

Pebbles samples collected from a burrow pit located along Eket – Oron expressway in Nsie and environs of southeastern Nigeria were subjected to pebble morphometric analysis in order to diagnose the environment of formation. Results indicate predominance of fluvial processes, with flatness ratio (FR) = 0.54 ± 0.13, elongation ratio (ER) = 0.73 ± 0.14, maximum projection sphericity index (M.P.S.I) of 0.73 ± 0.09 (fluviatile) and oblate-prolate index of 1.3 ± 5.4 (fluvial). Also, compact (C), compact bladed (CB), compact elongate (CE) and elongate (E) pebble forms which are common within the study area supplied additional strand of evidence in support of fluvial setting. In Addition, plots of roundness versus elongation for the pebbles shows 16% of the pebbles in the littoral field, 6% in the transitional field and 24% in the fluviatile field. Furthermore, bivariate plot of flatness ratio (FR) versus maximum projection sphericity index (M.P.S.I) shows majority of the pebbles falling within the fluvial field, and scatter plot of sphericity versus O.P index shows 75% of the pebbles from Nsie and environs occurring within the river environment and 25% within the beach part of the plot. All these features indicate deposition under fluvial regime. Thus, the study shows that the Benin Formation formed as a result of mostly fluvial depositional processes.

Key words: Pebbles Morphometry, Fluvial environment, Nsie, Nigeria

INTRODUCTION

Pebble morphometry have been used in several instances to determine the environment of deposition of sediments in sedimentary basins both in Nigeria and other parts of the world. Odumodu and Israel [1] used lithofacies analysis, sand textural analysis and pebble morphometric analysis to show that the Ogwashi-Asaba Formation in the Anambra Basin were formed in a fluvial environment. Olugbemiro and Nwajide [2] used grain size distribution and particle morphogenesis to decipher that fluvial setting that brought about the formation of the Bida and Enagi Formations in the Bida Basin. Odumodu and Ephraim [3] carried out pebble morphometric analysis which revealed a beach environment with influx of fluvial regimes for the deposition of the Nsukka Formation in Ohafia area.

Pebble morphometric investigations relies on various independent and dependent functions. As an independent function, the coefficient of flatness ratio (FR), elongation ration (ER), maximum projection sphericity index (M.P.S.I), oblate-prolate index (OPI), roundness (%) and pebble form have been used as indices for the determination of environment of deposition. As dependent variables, scatter plots of maximum projection sphericity index (M.P.S.I) versus oblate-prolate index (OPI), roundness (%) versus elongation ratio (ER) and geometric form diagram have been used in determining the environment of deposition.

The present study utilizes information drawn from morphometric analysis of pebbles to infer the depositional environment of the Benin Formation in Nsie and environs.

GEOLOGICAL BACKGROUND

Major sedimentary basins located in southern Nigeria includes, but not limited to: The Niger Delta Basin, Calabar Flank, Anambra Basin, Mamfe Embayment, Afikpo Syncline, Abakaliki Anticlinorium (Fig. 1) [4]. The study area, Nsie and environs (Fig. 2), which occur within the Niger Delta basin is underlain by Pliocene to Recent Benin Formation [5], previously referred to as coastal plain sands [6, 7]. Short and Stauble [8] recognised three diachronous units that makes up the Niger Delta Basin. This division comprised an overall downward transition from continental sands and gravels (Benin Formation) through sand-shale paralic sequence (Agbada Formation) to marine pro-delta shales (Akata Formation). The present study was conducted on pebbles from the Benin Formation, which generally consist of unconsolidated and friable sands with intercalations of gravely units and clay lenses of a total thickness of about 2,000m [9]

MATERIALS AND METHODS

The study area is delimited by latitude 4^{o}42'N and 4^{o}47'N and longitude 008^{o}01'E and 008^{o}05'E (Fig. 2), situated in Nsie in present-day Akwa Ibom State of Nigeria. Over 100 pebble samples were collected from a burrow pit located along Eket – Oron expressway. In the burrow pit, various sizes of pebbles were randomly oriented. The collected pebbles were later screened to exclude pebbles that were cracked or freshly broken. By the end of the exercise, a total of fifty (50) samples comprising pebbles of isotropic constitution and high resistance to wear were considered representative of the pebble bed in the study area, and therefore adopted for the pebble morphometric analysis. These pebbles were washed, numbered, and transported to the laboratory for analysis. The analysis involved the measurement of the magnitude of the long axes (L), intermediate axes (I) and the short axes (S) of the pebbles using Venier Caliper [10, 11]. Other relevant data were computed from the generated data (Table 1). Some of the computed data includes indices such as: Flatness Ratio (FR), which is the ratio between the short axes to the long axes, and Elongation Ratio (ER), which is the ratio of the short to the intermediate axis [12]. The measure of equidimensionality (sphericity) of the pebbles was determined using the Maximum Projection Sphericity Index (MPSI) [13]. Others including, the Oblate Prolate index (OPI) [14] and Roundness [15] were estimated. Oblate Prolate (OP) index shows how close the intermediate (I) axis of a pebble is to the short axis or long (L) axis [14]. Roundness, which is the estimation that counts the percentage of convex parts of a pebble along its external circumference, was estimated with the aid of the charts of Sames [15] (Fig 3). The mean and standard deviation of each of the indices was calculated and computed. Form measures the relationship between the three mutually perpendicular axes of a pebble. It is used to accommodate the fact that particles having the same numerical value of maximum projection sphericity may have different ratios between their three axes [3, 16]. The sphericity form diagram of Sneed and Folk [13] was used to determine the form name of each pebble set.

RESULTS

The results obtained from the morphometric analysis of pebbles from the Benin formation is presented in Table 2, while Table 3 contain the summary of morphometric data, characteristics and environmental diagnosis for the pebble morphometric analysis. As shown in Fig. 3, the mean flatness ratio (FR) for the pebbles from Benin Formation is 0.54 ± 0.13. Similarly, elongation ratio (ER) has values within the range of 0.39 – 1.17 with mean value of 0.73 ± 0.14, and roundness has values ranging from 10% to 90% with mean value of 45.5%. The degree of roundness for each pebble set from the Benin Formation and its mean are shown in Table 4. Indications from the results (Table 4) is that pebbles from the Benin Formation range from subangular to well rounded. The mean maximum projection sphericity index (M.P.S.I) for pebbles from the Benin Formation is 0. 73 ± 0.14 with range of 0.48 to 0.94. The Oblate – Prolate index values for the Benin Formation range from -18 to 12.55 with mean value of 1.33 ± 5.4. The dominant pebble forms are given in Table 3.

DISCUSSION/ PALEOENVIRONMENTAL ANALYSIS

The mean elongation ratio (ER) for the pebbles from Nsie and environs is 0.73 ± 0.14 which falls within the 0.65 – 0.75 range of Lutig's torrent type flowing water or brooks and rivulets. The mean flatness ratio (FR) calculated for the pebbles from Nsie and environs (0.54± 0.13) falls beyond the fluviatile range of 0.25 – 0.35 and slightly above the marine range of 0.40 - 0.50 [12].

Table 1: Computed and Estimated Morphometric Properties Used in the study

Morphometric Indices	Formula	Author
Flatness Ratio (F.R)	S/L	Lutig (1962)
Elongation Ratio (E.R)	I/L	Lutig (1962)
Maximum Projection Sphericity Index (M.P.S.I)	$\left(S^2/_{LI}\right)^{1/3}$	Sneed and Folk (1958)
Oblate – Prolate (OP) Index	$10\left[\frac{L-I}{L-S} - 0.50\right]S/_L$	(Dobkins and Folk (1970)
Roundness	Visual estimation	Sames (1966)

Table 2. Morphometric Data of Benin Formation Pebbles from Nsie Area of Southeastern Nigeria

S/N	Axes (mm)			Roundness (%)	S/L	I/L	$\frac{L-I}{L-S}$	$(S^2/LI)^{1/3}$	OP Index	*Form Name
	L	I	S							
1	2.4	1.8	1.2	80	0.5	0.75	0.5	0.69	0	CB
2	2.4	1.4	1.1	50	0.46	0.58	0.77	0.71	5.87	E
3	2.3	1.9	0.7	20	0.3	0.83	0.25	0.48	-8.21	P
4	3.1	1.9	1.1	40	0.35	0.61	0.6	0.59	2.82	B
5	2.8	1.1	0.9	15	0.32	0.39	0.89	0.64	12.28	P
6	2.4	1.7	0.9	50	0.38	0.71	0.47	0.58	-0.89	CB
7	2.2	1.4	1.2	30	0.55	0.64	0.8	0.78	5.5	CE
8	2.8	1.6	1.1	20	0.39	0.57	0.71	0.65	5.24	E
9	2.8	1.7	1.1	20	0.39	0.61	0.65	0.63	3.74	B
10	2.2	1.7	1.3	30	0.59	0.77	0.56	0.77	0.94	CB
11	2.1	1.5	1	50	0.48	0.71	0.55	0.68	0.95	CB
12	2.7	1.4	1.1	30	0.41	0.52	0.81	0.68	7.67	E
13	2.9	1.2	1.3	10	0.45	0.41	1.06	0.79	12.55	VE
14	2.6	1.6	1	20	0.38	0.62	0.63	0.62	3.25	B
15	2.2	1.7	1.1	20	0.5	0.77	0.45	0.69	-0.91	CB
16	1.8	1.7	1.2	20	0.67	0.94	0.17	0.78	-5	CP
17	1.4	1.1	0.8	50	0.57	0.79	0.5	0.75	0	CB
18	1.5	1.2	1.2	60	0.8	0.8	1	0.93	6.25	CE
19	2	1.7	0.7	10	0.35	0.85	0.23	0.52	-7.69	P
20	2.7	1.5	1.2	20	0.44	0.56	0.8	0.71	6.75	CE
21	2.5	1.8	1.3	80	0.52	0.72	0.58	0.72	1.6	CB
22	1.8	1.4	0.9	80	0.5	0.78	0.44	0.69	-1.11	CB
23	2.2	1.5	1.3	20	0.59	0.68	0.78	0.8	4.7	E
24	1.8	1.4	1.1	50	0.61	0.78	0.57	0.78	1.17	CB
25	2.2	1.5	1.1	40	0.5	0.68	0.64	0.72	2.73	B
26	2.3	1.4	0.8	40	0.35	0.61	0.6	0.58	2.88	B
27	1.7	1.3	0.9	30	0.53	0.76	0.5	0.72	0	CB
28	3	2.2	1.6	20	0.53	0.73	0.57	0.73	1.34	CB
29	1.7	1.4	1.4	60	0.82	0.82	1	0.94	6.07	CE
30	2.8	1.6	1.6	80	0.57	0.57	1	0.83	8.75	E
31	1.9	1.5	1.1	20	0.58	0.79	0.5	0.75	0	B
32	1.7	1.6	0.9	60	0.53	0.94	0.13	0.67	-7.08	CP
33	2.2	1.6	1	40	0.45	0.73	0.5	0.66	0	CB
34	2.1	1.3	1	50	0.48	0.62	0.73	0.72	4.77	B
35	2.1	1.4	1.1	25	0.52	0.67	0.7	0.74	3.82	E
36	1.3	1.2	0.9	60	0.69	0.92	0.25	0.8	-3.61	CP
37	1.5	1.2	1.1	90	0.73	0.8	0.75	0.88	3.41	CE
38	1.2	1.2	0.8	90	0.67	1	0	0.76	-7.5	CP
39	1.6	1.2	0.9	90	0.56	0.75	0.57	0.75	1.27	CB
40	1.2	1.4	1	80	0.83	1.17	-1	0.84	-18	VB
41	1.6	1.4	1	60	0.63	0.88	0.33	0.76	-2.67	B
42	1.9	1.3	1	40	0.53	0.68	0.67	0.74	3.17	E
43	1.6	1.5	1	90	0.63	0.94	0.17	0.75	-5.33	CP
44	1.5	1.2	1	50	0.67	0.8	0.6	0.82	1.5	CB
45	1.7	1.1	1	25	0.59	0.65	0.86	0.81	6.07	CE
46	1.4	1.2	0.9	60	0.64	0.86	0.4	0.78	-1.56	CB
47	2.2	1.4	1	30	0.45	0.64	0.67	0.69	3.67	B
48	2.2	1.3	1.1	30	0.5	0.59	0.82	0.75	6.36	CE
49	1.8	1.4	1.1	50	0.61	0.78	0.57	0.78	1.17	CB
50	1.6	1.4	1.1	90	0.69	0.88	0.4	0.81	-1.45	CB
Mean	**2.1**	**1.5**	**1.1**	**45.5**	**0.54**	**0.73**	**0.55**	**0.73**	**1.31**	
St. Dev.	**0.3**	**0.2**	**0.1**	**24.6**	**0.13**	**0.14**	**0.33**	**0.09**	**5.4**	

**CE = COMPACT ELONGATE, E = ELONGATE, C = COMPACT, CB = COMPACT BLADED, CP = COMPACT PROLATE, P = PROLATE, VE = VERY ELONGATE, VB = VERY BLADED AND B = BLADED*

Table 3. Summary of Environmental Diagnosis for pebble morphometric analysis of the Benin sandstones

MORPHOMETRIC INDICES	CHARACTERISTICS	ENVIRONMENTAL INDICATIONS
Flatness ratio	Average value = 0.54	Fluviatile
Elongation ratio	Average value = 0.73	Fluviatile
Maximum Projection Sphericity	Average value = 0.73	Fluviatile
Oblate prolate	Average value =1.3	Fluviatile
Roundness	Average value =45.5%	Fluviatile
Dominant pebble forms	Compact (C), compact bladed (CB), compact elongate (CE) and elongate (E)	Fluviatile
Plot of flatness ratio (FR) versus maximum projection sphericity	80% fluvial and 20% beach	Fluviatile
Plot of roundness against elongation ratio	16%littoral, 6% transitional zone and 24% fluviatile	Fluviatile
Plot of OP index against sphericity	Cluster in fluviatile area	Fluviatile

Table 4. Degree of roundness for Benin sandstone pebbles at Location

	Angular – subangular 0 -25%	Subrounded 30 – 40 %	Rounded – well rounded 45 – 80%
Roundness (%)	35%	50%	15%

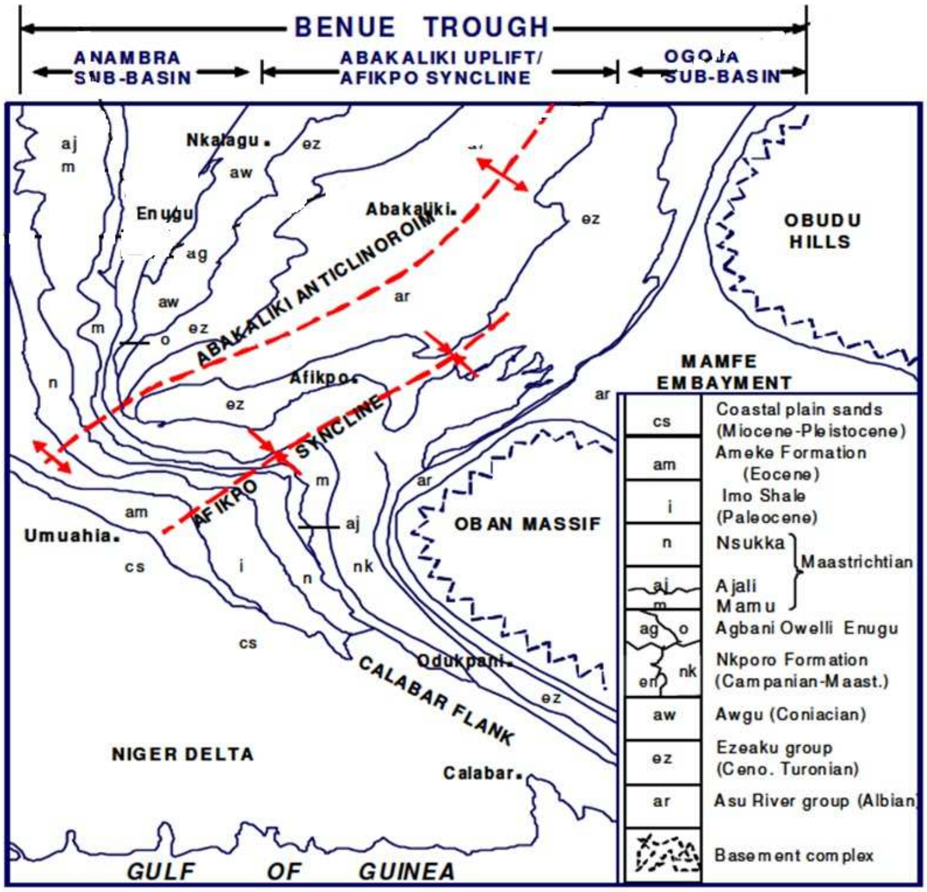

Fig. 1. Sketch geologic map of southeastern Nigeria showing the various sedimentary basins in the region (modified after Ofomata, 1973)

Dobkins and Folk [14] identified shape classes (Form) of Sneed and Folk [13] that are diagnostic of certain environments. Accordingly, compact (C), compact bladed (CB), compact elongate (CE) and elongate (E) pebbles are diagnostic of fluvial environments, while platy (P), bladed (B), very bladed (VB) and very platy (VP) are more common in beach environments. The pebble forms common in the studied area are Compact (C), compact bladed (CB), compact elongate (CE) and elongate (E) (Table 3) which indicate a fluvial setting for the pebbles.

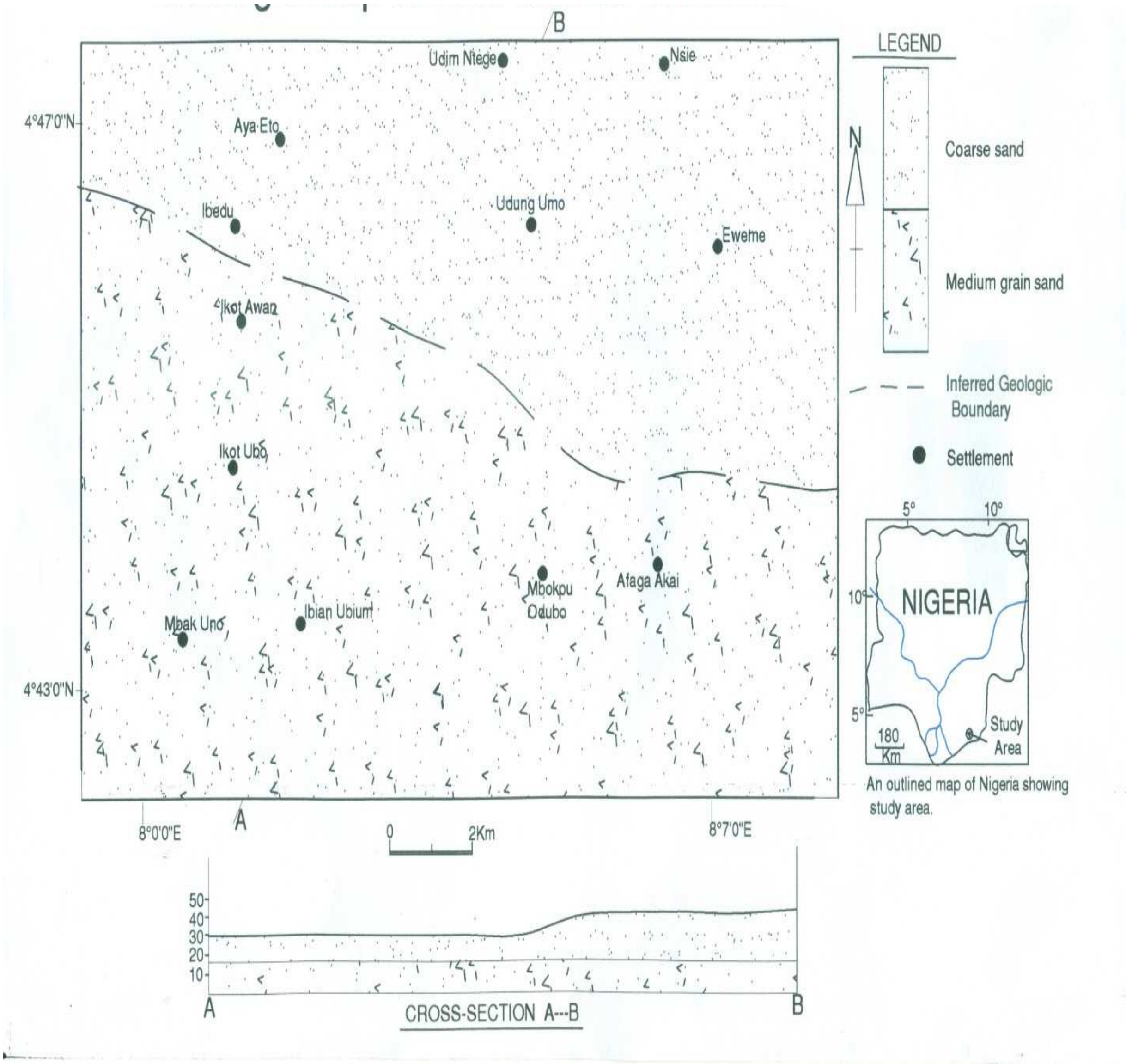

Fig. 2. Geologic map of Nsie and environs, southeastern Nigeria

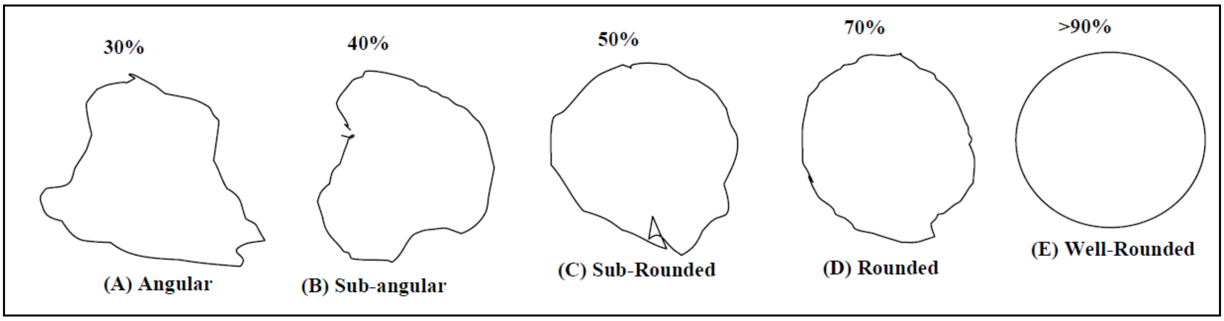

Fig. 3. Roundness grades of pebbles after Sames (1966)

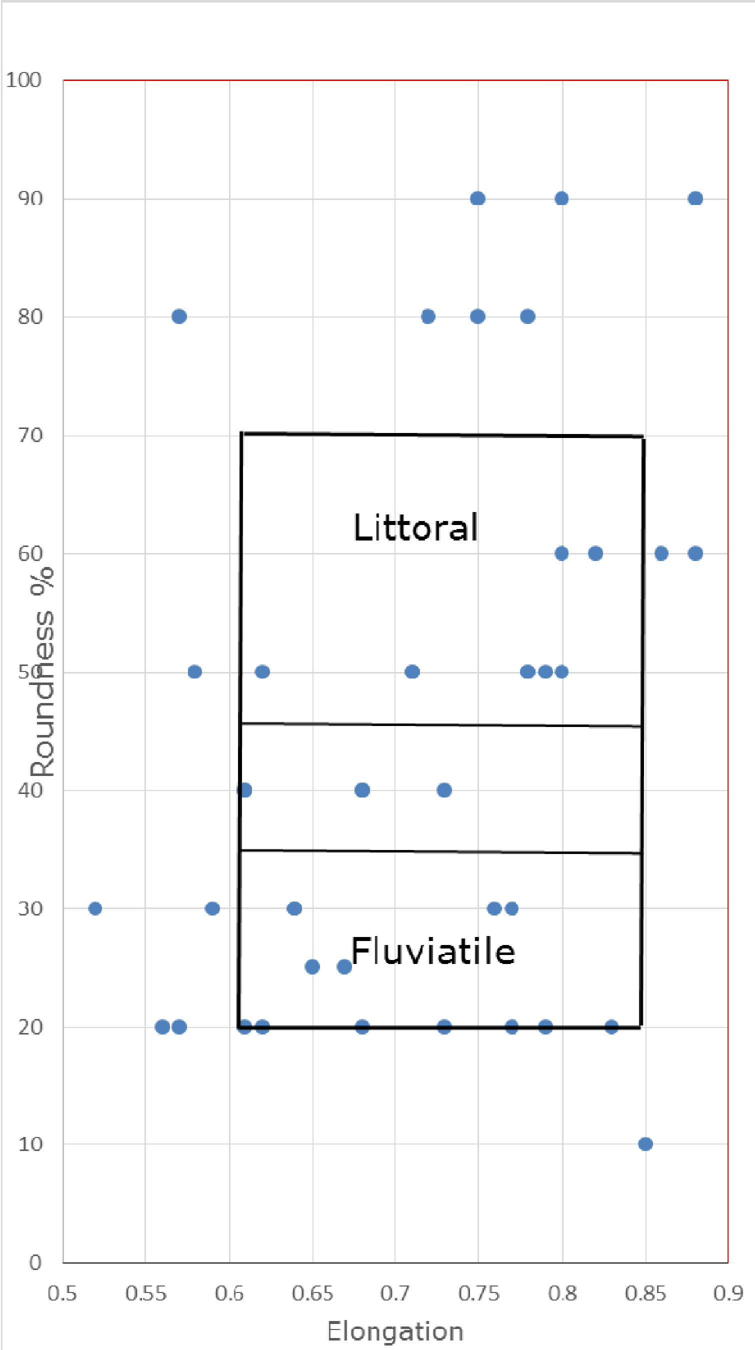

Figure 4: Plot of roundness against elongation ratio for pebbles from Nsie and environs in southeastern Nigeria

Roundness is a poor indicator of depositional environment, Sneed and Folk (1958) observed that pebble roundness increased downstream from river to beaches , roundness of less than 35% typifies fluvial environment while roundness of more than 45% characterizes littoral environments [15]. The average roundness value of the pebbles from the study area is 45.5% ± 24.6 with 70% of the pebble suite having roundness varying from 20 – 43%. This result strongly suggests a fluvial environment of deposition.

The sphericity (M.P.S.I) value for the Benin Formation pebbles (0.73 ± 0.09) fall above the 0.66 sphericity line that separates beach and river pebbles. Lower sphericity values are typical of beach pebbles while higher sphericity values indicate fluvial setting [14]. The sphericity value of Nsie and environs is 0.73 ± 0.09 which is way above the 0.66 line and therefore indicative of a likely fluviatile origin.

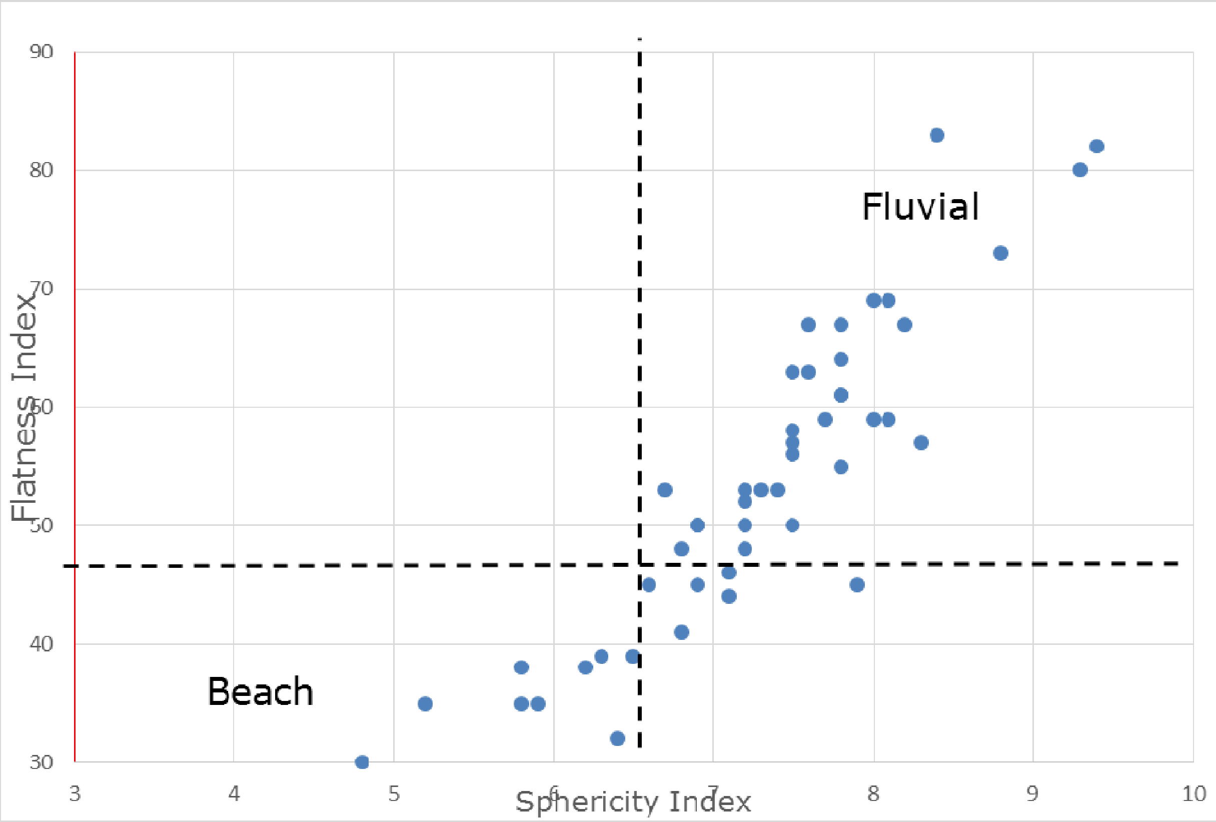

Figure 5: Bivariate plot of Flatness Index and Sphericity Index for pebbles from Nsie and environs in southeastern Nigeria
(Note that the broken lines indicate the lower limits of 0.65 for sphericity and 45 for flatness index as determined by Stratten [17])

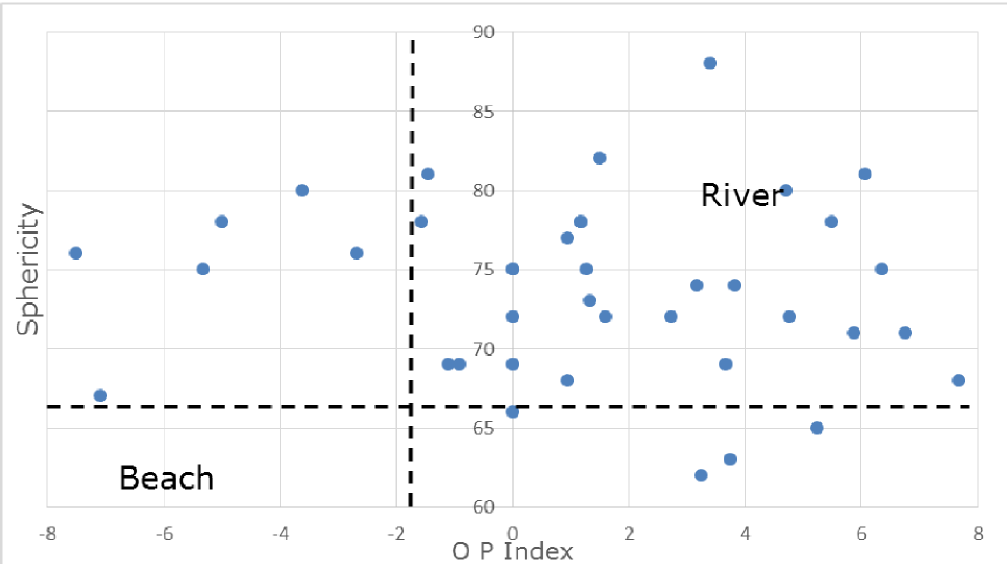

Figure 4: Plot of sphericity against OP index showing sepration of beach field from the river field

Various bivariate plots also agree with a fluvial setting for the investigated pebbles. For instance, the plot of roundness versus elongation for the pebbles (Fig. 4) following Sames [15], shows 16% of the pebbles in the littoral field, 6% in the transitional field and 24% in the fluviatile field. Similarly, the bivariate plot of Flatness Ratio (FR) versus Maximum Projection Sphericity Index (M.P.S.I) shows majority of the pebbles falling within the fluvial field (Fig. 5). Furthermore, the scatter plot of sphericity versus O.P index (Fig. 6), which is more diagnostic of fluvial depositional environment, shows 75% of the pebbles from Nsie and environs occurring within the river environment and 25% within the beach part of the plot. Indication therefore is that the pebble beds in Nsie and environs, belonging to the Benin Formation were formed under a fluvial regime.

CONCLUSION

The present study based on pebble morphometric indices of Sphericity (M.P.S.I), Oblate-Prolate Index (O.P.I), Flatness Ratio (FR), Elongation Ratio (ER), Roundness (%) and Pebble Form have confirmed that the sandstone units of Benin Formation was deposited in a high energy fluvial (river) setting. Further studies would involve pebbles belonging to the Benin Formation in other area.

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