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PEBBLE MORPHOMETRY AND SIEVE ANALYSIS: TOOLS IN DETERMINING THE DEPOSITIONAL ENVIRONMENTS OF SEDIMENTS IN ORON AND ENVIRONS

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ABSTRACT

Pebble morphometry and grain size analysis were carried out in parts of Benin Formation exposed along Oron and environs to determine the depositional environment of the sediments. Quartz pebbles (900 pebbles) collected from 60 different locations around stream channels and quarries were subjected to axial measurement of long (L), short (S) and intermediate (I) axis. Fifteen (15) sediments were further subjected to sieve analysis. Results from morphometric studies shows that the pebbles are dominantly compact-bladed (CB) and elongate (E) with mean values for flatness ratio (FR), elongation ratio (ER), maximum projection sphericity index (MPSI), oblate-prolate index (OPI) and braided ratio (BR) as 0.48, 0.61, 0.67, 3.54 and 0.63 respectively with mean roundness value of 32%. Sieve analysis revealed that the sediments are dominantly medium-grained, well sorted, skewed to near symmetrical and leptokurtic to mesokurtic. Bivariate Plots of roundness versus elongation ratio, sphericity versus OP index, FI versus MPSI, and skewness versus sorting indicates deposition of the sediments predominantly in the fluvial environment. Thus, this study showed that the sediments in Benin Formation were deposited by fluvial depositional processes.

KEYWORDS: Pebbles morphometry, fluvial environment, Oron,

1.0 INTRODUCTION

Knowledge of particle morphology utilizing quartz pebble is considered as an aspect of textural lithologic description and provides information to aid in paleoenvironmental interpretation (Pettijohn, 1975). Pebble morphometric investigations relies on various independent and dependent functions of coefficient of flatness ratio (FR), elongation ration (ER), maximum projection sphericity index (M.P.S.I), oblate-prolate index (OPI), roundness (%), pebble forms and bivariate plots to aid in the determination of the environment of deposition [Folks, 1966, 1974, Folks et al, 1970, Hibbard, 2002). Particles shape and sphericity are strongly controlled by composition as the particles were liberated from parent rocks and the antecedent properties of the depositing medium, hence, yielding invaluable information about the energy conditions and the environment of deposition (Okon et. al., 2018, Okon and Ojong, 2019). The form and roundness of the pebbles is also a function of their physical strength as well as the effective distance of travel from their source. The study area; Oron and environ belong to the Benin Formation of the Niger Delta sedimentary basin (Murat, 1972). Previous work on Pebble morphometry in the Benin Formation (Ephraim and

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Odumodu 2015) was concentrated in the Nsie area of the Benin Formation with recommendations made for further studies to be conducted in other parts of the Formation. Hence, this study is intended to investigate the depositional environments of sediments in oron and environs of the Benin Formation. The area under study is located between latitude $4^0$45'0"N to $4^0$50'0"N and longitude $8^0$11'5"E to $8^0$19'0"E of the Greenwich Meridian and covers an area extend of approximately 134km^2.

2.0 LOCATION AND GEOLOGY

The study area (Fig. 1) belongs to the Benin Formation of the Niger Delta sedimentary basin whose origin is attributed to the basement tectonic associated with crustal divergence and translation during the Late Jurassic to Early Cretaceous continental rifting leading to the opening of the south Atlantic. (Avbovbo, 1978, Doust and Omatsola, 1990, Ekweozor and Daukoro, 1994). The major lithostratigraphic units in this basin comprise of the basal Akata Formation overlain by the paralic Agbada Formation and the top, largely continental lithofacies unit, the Benin Formation (Zaborski, 1998). While the basal unit consists predominantly of prodelta, the transitional Agbada Formation is made up of an alternation of sands and shales. Poorly indurated sands and sandstones are the major constituents of the Benin Formation (Murat, 1972). The present study was conducted on pebbles and sediments from the Benin Formation, which generally consist of unconsolidated and friable sands with intercalations of clay lenses.

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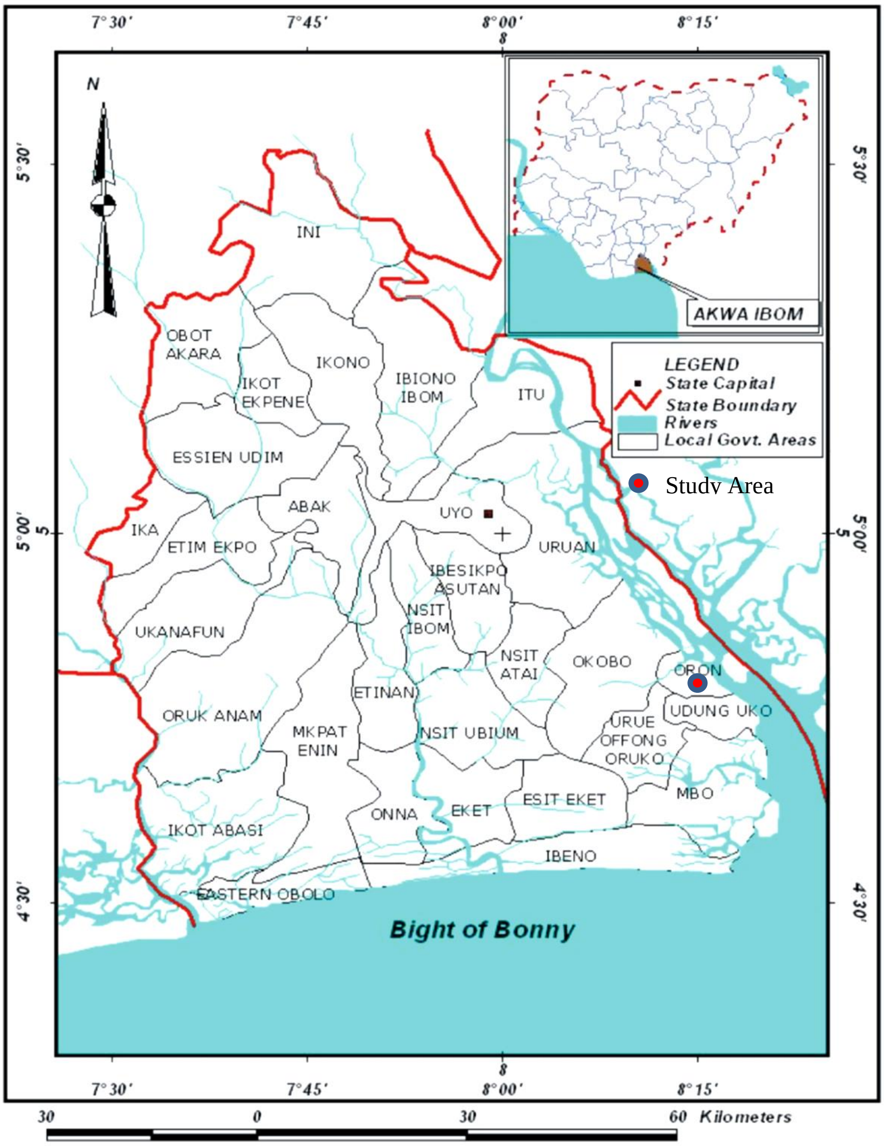


Figure 1: Map showing the study area

3.0 MATERIALS AND METHODS

Pebble morphometry methods of Sames (1966) and Sneed and Folk (1958); have been used in this study. Over 900 pebbles (vein quartz species 5.00 mm – 23.00 mm in size) (Fig. 2) were collected from different outcrop sections, stream channels and burrow pit in the study area. The collected pebbles were screened to exclude cracked and broken pebbles and those with lithologic in-homogeneities. At the end of the exercise, the selected pebbles were washed and numbered appropriately according to their group identity and subjected to axial measurement of the long (L), short (S) and intermediate (I) axes using the Vernier caliper (Folks, et al., 1970). The recorded values were used to determine the various morphometric parameters such as: Elongation ratio (ER), flatness ratio, (FR), flatness index (FI), braided ratio (BR) maximum projection sphericity index (MPSI), and oblate-prolate index (OPI). The form of the pebbles was also determined using the ternary method of Sneed and Folk (1958). Roundness of the pebbles was estimated using the Power (1953) roundness chart and its accuracy was ensured with direct measurement of the roundness of randomly selected pebbles using the well roundness equation as outlined in Power (1953). Fifteen (15) unconsolidated sediments were also subjected to sieve analysis. The samples were dried, disaggregated and sieved using sieve shaker. The weight retained for sieved samples were tabulated in accordance to Folk, (1974) and bivariate plots were performed.

4.0 RESULTS AND DISCUSSION

The results of pebble morphometry measurements of the vein quartz pebble suites and sieve analysis of sediments in the study area are shown on Tables 1 and 2 respectively. The relevant parameters used are:

- coefficient of flatness, S/L (Stratten, 1974).
- elongation ratio, I/L (Sames, 1966; Lutig, 1962).
- maximum projection sphericity $(S^2/LI)^{1/3}$ (Sneed and Folk, 1958) .
- oblate – prolate index. (OPI) 10{(L – I)/L – S) - 0.50}/ {S/L} (Folk et al., 1974)
- form, (L – I/L – S) (Sneed and Folk, 1958, Ward, 1990, Worden, 2003). Shapes were obtained using the triangular sphericity - form diagram of Sneed and Folk (1958).
- the roundness of each pebble was estimated using power roundness chart.
- Mean(m_z): $(\phi 16+\phi 50+\phi 84)/3$ (Folk et al.,1974, Krumbein and Pettijohn, 1961)

From the results, coefficient of flatness ratio (FR) range from 0.19 – 0.73 with mean value of 0.48, elongation ratio (ER) range from 0.23 – 0.84 with mean of 0.61, maximum projection sphericity (MPS) varies from 0.40 – 0.86 with a mean of 0.67, oblate-prolate index (OPI) range from -9.44 – 13.85 with a mean of 3.54 while roundness (ρ) varies from 10% - 80%. Dobkin and Folk (1970) studied pebbles shaped by river and beach processes in Tahiti-Nui and suggested that pebble suites with mean sphericity of 0.65 and less indicates beach processes while those with sphericity values above 0.65 are shaped by fluvial processes. The pebble suites from oron and environ with maximum projection sphericity mean values of 0.67 are indicative of fluvial process. Stratten (1974) used coefficient of flatness to discriminate between fluvial and beach pebbles. He noted that fluvial pebbles have coefficient of flatness of 45% and above, thus, the coefficient of flatness for Oron and environ pebble suites with mean value of 48% depict fluvial regime. Dobkins and Folk (1970) and Sneed; Folk (1958) and Miall, 1978, also identified shape classes (Form) 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 observed in the studied area are dominantly compact elongate (CB) and elongate (E) (Table 1) indicative of a dominant fluvial setting (Fig 3). Roundness is a poor indicator of environment. Sneed and Folk (1958) also observed that pebble roundness increased downstream from river to beaches. The roundness of pebbles under hydrodynamic transport has been observed to be a function of both inherited and acquired (environmental) factors (Friedman, 1967, Folks, 1966, Krumbein, 1941, Lindhohm, 1987, Powers, 1953). Roundness of less than 35% typifies fluvial environments while roundness greater than 45% characterizes littoral environments. Dobkin and Folk (1970) and Sames (1966) used plots of maximum projection sphericity (MPS) versus oblate - prolate index (OPI), roundness (P) versus elongation ratio (ER) and flatness index versus maximum projection sphericity (MPSI) to discriminate environment of deposition. Plots of MPSI versus OPI (Fig 4), FI versus MPSI (Fig 5) and roundness (ρ) versus elongation ratio (ER) (Fig 6) all indicate pebbles dominantly within the fluvial regime. Results from sieve analysis (Table 2) and bivariate plot of skweness versus sorting (Fig 7), sorting versus mean grain size (Fig, 8) and Kurtosis versus sorting (Fig 9) also indicates the sediments as been product of fluvial processes.

Figure 2. (a, b, c and d) photograph of subangular to rounded pebbles in the study area

Table 1: Result for mean values of 60 batches of pebble morphometric parameters for Oron and environ

S/N	D_L (mm)	D_I (mm)	D_S (mm)	L-I (mm)	L-S (mm)	L-I/L-S (mm)	FR (mm)	ER (mm)	FI (mm)	BR (mm)	MPSI (mm)	OPI (mm)	Rs (mm)	FORM (mm)
1	2.4	1.8	1.4	0.6	1.0	0.60	0.58	0.75	58	0.6	0.77	1.72	30	CB
2	5.4	2.1	1.4	3.3	4.0	0.83	0.26	0.39	26	0.83	0.56	12.69	45	CB
3	2.7	1.6	1	1.1	1.7	0.65	0.37	0.59	37	0.65	0.61	4.05	35	B
4	2.6	1.9	1.2	0.7	1.4	0.50	0.46	0.23	46	0.67	0.66	0.0	40	E
5	2.9	1.7	1.2	1.2	1.7	0.71	0.41	0.59	41	0.71	0.66	5.12	30	E
6	2.3	1.4	1.1	0.9	1.2	0.75	0.48	0.61	48	0.75	0.72	5.2	20	CB
7	2	1.7	1	0.3	1.0	0.30	0.5	0.85	50	0.38	0.67	-2.4	10	E
8	4	2	1.3	2.0	2.7	0.74	0.33	0.5	33	0.74	0.6	7.27	30	E
9	2.7	1.5	1.2	1.2	1.5	0.80	0.44	0.56	44	0.8	0.71	6.82	35	CB
10	4.1	2.1	1.1	2.0	3.0	0.67	0.27	0.51	27	0.67	0.52	6.3	10	B
11	2	1.3	0.8	0.7	1.2	0.58	0.4	0.65	40	0.58	0.63	4.25	50	E
12	3.9	2.4	1.7	1.5	2.2	0.68	0.47	0.62	47	0.68	0.68	4.1	30	E
13	3.3	2.4	1.6	0.9	1.7	0.53	0.48	0.73	48	0.53	0.69	0.63	30	B
14	2.6	1.3	0.9	1.3	1.7	0.76	0.35	0.5	35	0.53	0.62	0.86	20	E
15	3.9	2.6	0.9	1.3	3.0	0.43	0.23	0.67	23	0.3	0.43	-8.7	30	E
16	2.4	1.6	1.3	0.8	1.1	0.73	0.54	0.67	54	0.73	0.76	4.26	50	CB
17	2.6	1.4	0.9	1.2	1.7	0.71	0.35	0.54	35	0.71	0.61	6	30	E
18	2.6	1.9	0.5	0.7	2.1	0.33	0.19	0.73	19	0.33	0.73	-8.95	75	VB
19	3.3	2.1	1.3	1.2	2.0	0.60	0.39	0.64	39	0.6	0.6	2.56	50	E
20	2.6	1.9	1	0.7	1.6	0.44	0.38	0.73	38	0.44	0.59	-1.8	75	CB
21	4.6	2.2	1.6	2.4	3.0	0.80	0.3	0.48	35	0.8	0.63	8.57	30	CB
22	1.9	1.6	1.1	0.3	0.8	0.38	0.58	0.84	58	0.38	0.74	-2.1	50	CB
23	2.3	1.5	1.3	0.8	1.0	0.80	0.57	0.65	57	0.8	0.76	5.26	80	CB
24	3.2	1.7	0.8	1.5	2.4	0.63	0.25	0.53	25	0.63	0.4	5.2	10	VE
25	3.3	1.5	1	1.8	2.3	0.78	0.3	0.45	30	0.58	0.59	9.27	45	CB
26	3.8	2	1.3	1.8	2.5	0.72	0.34	0.53	34	0.72	0.61	6.47	40	B
27	4.5	2.2	1.6	2.3	2.9	0.79	0.36	0.49	36	0.79	0.64	8.06	40	E
28	2.7	1.9	0.9	0.8	1.8	0.44	0.33	0.7	33	0.44	0.54	-1.82	30	CB
29	3.8	1.4	1	2.4	2.8	0.86	0.26	0.37	26	0.86	0.57	13.85	45	CB
30	2.3	1.7	1.1	0.6	1.2	0.50	0.48	0.74	48	0.5	0.68	0	60	E

31	3.4	2.1	1.2	1.3	2.2	0.59	0.35	0.62	35	0.59	0.59	2.57	30	CB
32	3.7	2.7	1.6	1.0	2.1	0.48	0.43	0.73	43	0.48	0.64	-0.47	10	E
33	2.8	1.5	0.9	1.3	1.9	0.68	0.56	0.54	56	0.68	0.58	5.63	45	CB
34	3.3	2.2	1.1	1.-1	2.2	0.50	0.33	0.67	33	0.5	0.55	0	40	B
35	2.8	2.1	1	0.7	1.8	0.39	0.36	0.75	36	0.39	0.55	-3.06	50	CB
36	4.4	1.9	1.4	2.5	3.0	0.83	0.31	0.43	31	0.83	0.62	10.65	40	E
37	3	1.5	1.2	1.5	1.8	0.83	0.4	0.5	40	0.83	0.62	8.25	30	E
38	3.2	2.1	1.6	1.1	1.6	0.69	0.5	0.66	50	0.69	0.72	3.8	50	CB
39	2.2	1.8	1.6	0.4	0.6	0.67	0.73	0.82	73	0.67	0.86	2.33	60	C
40	3.5	1.5	1.2	2.0	2.3	0.87	0.34	0.43	34	0.87	0.65	10.88	45	E
41	2.6	1.6	1.2	1.0	1.4	0.71	0.46	0.62	46	0.71	0.7	4.57	30	CB
42	3.6	2	1.1	1.6	2.5	0.64	0.56	0.56	56	0.64	0.55	4.52	40	B
43	2.6	2	1.6	0.6	1.0	0.60	0.62	0.77	62	0.6	0.79	1.61	50	CB
44	3.3	1.9	1.7	1.4	1.6	0.88	0.52	0.58	52	0.88	0.77	7.31	30	CB
45	2.2	1.6	0.4	0.6	1.8	0.33	0.28	0.73	28	0.33	0.56	-9.44	40	VB
46	2.2	1.5	1.1	0.7	1.1	0.64	0.5	0.68	50	0.64	0.72	2.8	30	CB
47	3	2.2	1.8	0.8	1.2	0.67	0.6	0.73	60	0.67	0.79	2.83	50	CB
48	3.5	2.6	1.5	0.9	2.0	0.45	0.43	0.74	43	0.45	0.63	-1.16	80	E
49	2.5	1.7	1.2	0.8	1.3	0.62	0.48	0.68	48	0.62	0.7	2.5	20	E
50	2.5	1.4	0.9	1.1	1.6	0.69	0.36	0.56	36	0.69	0.61	5.28	40	E
51	2.5	1.9	1.5	0.6	1.0	0.60	0.6	0.76	60	0.6	0.51	1.67	40	CB
52	2.7	1.3	1.1	1.4	1.6	0.88	0.41	0.48	41	0.88	0.7	9.27	40	E
53	3.8	1.5	1	2.3	2.8	0.82	0.56	0.34	56	0.89	0.59	13	30	B
54	3.7	1.9	0.8	1.8	2.9	0.62	0.22	0.51	22	0.62	0.45	5.45	50	VE
55	2.2	1.6	0.9	0.6	1.3	0.46	0.41	0.73	41	0.46	0.61	-0.98	60	E
56	2.3	1.8	0.9	0.5	1.4	0.36	0.39	0.78	39	0.36	0.58	-3.59	30	B
57	2.6	2	1.6	0.6	1.0	0.60	0.62	0.77	62	0.6	0.79	1.61	50	CB
58	2.7	2	1.2	0.7	1.5	0.47	0.44	0.74	44	0.47	0.64	5.45	60	E
59	4.5	2.6	1.7	1.9	2.8	0.68	0.38	0.58	38	0.68	0.63	4.74	40	E
60	2.9	1.2	1.1	1.7	1.8	0.94	0.38	0.41	38	0.94	0.70	11.58	30	E
Mean	3.1	1.9	1.2	1.2	1.9	0.64	0.48	0.61	48	0.63	0.67	3.54	32	-

Explanation: E= Elongation, B= Bladed, C= Compact, CB= Compact Bladed, VE= Very Elongated, VB= Very Bladed

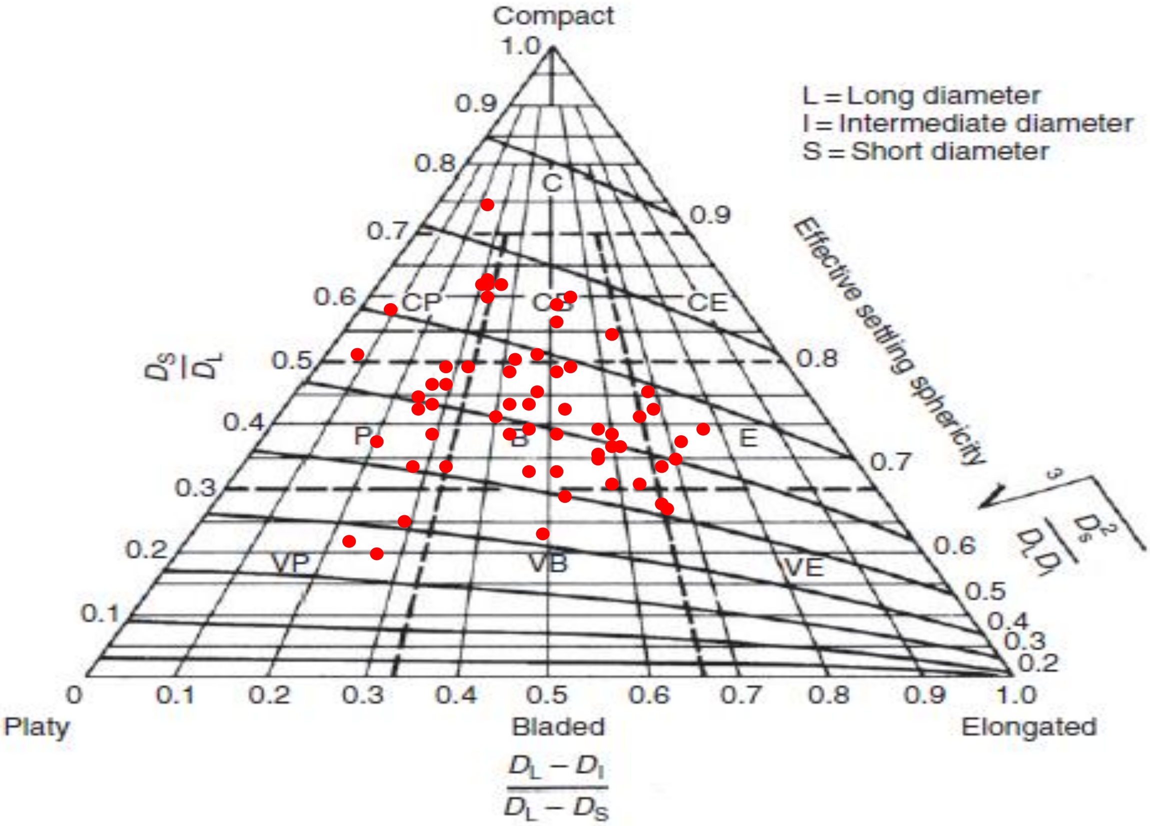


Figure 3: Spehericity – Form diagram for particle shapes after (Sneed and Folk 1958) C=Compact; CP=Compact-Platy; CB=Compact-Bladed;CE=Compact-Elongate; P=Platy; B=Bladed; E=Elongate; VP=Very Platy; VB=Very Bladed; VE=Very Elongate)

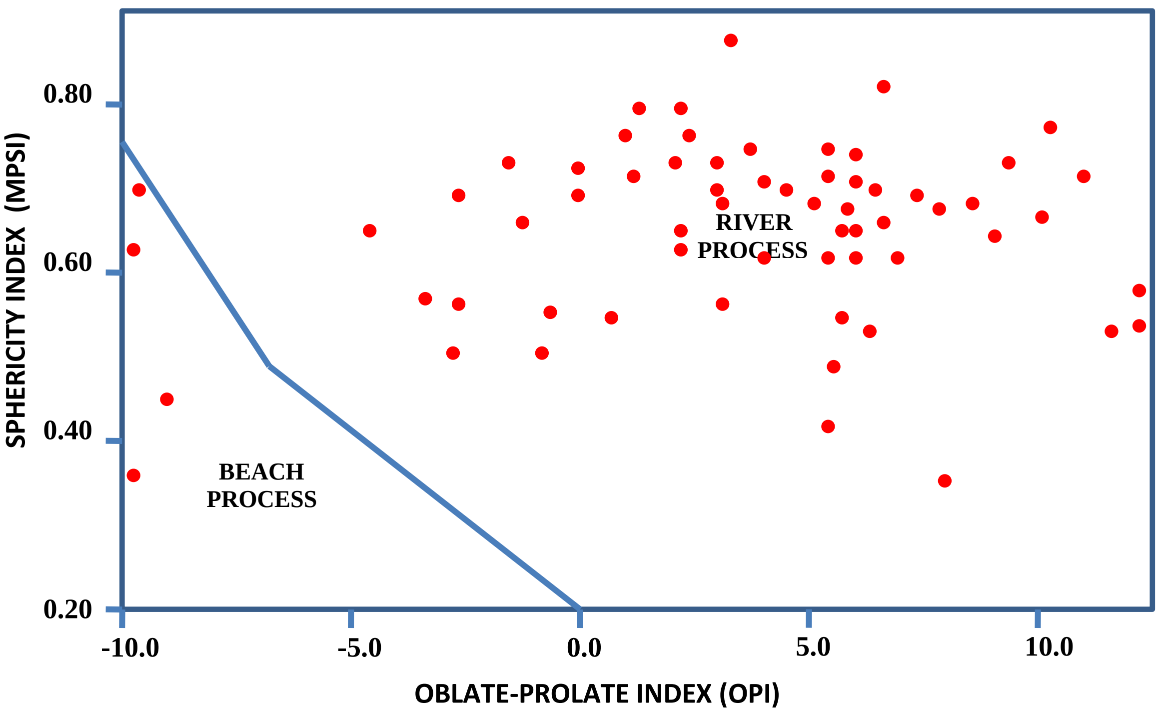
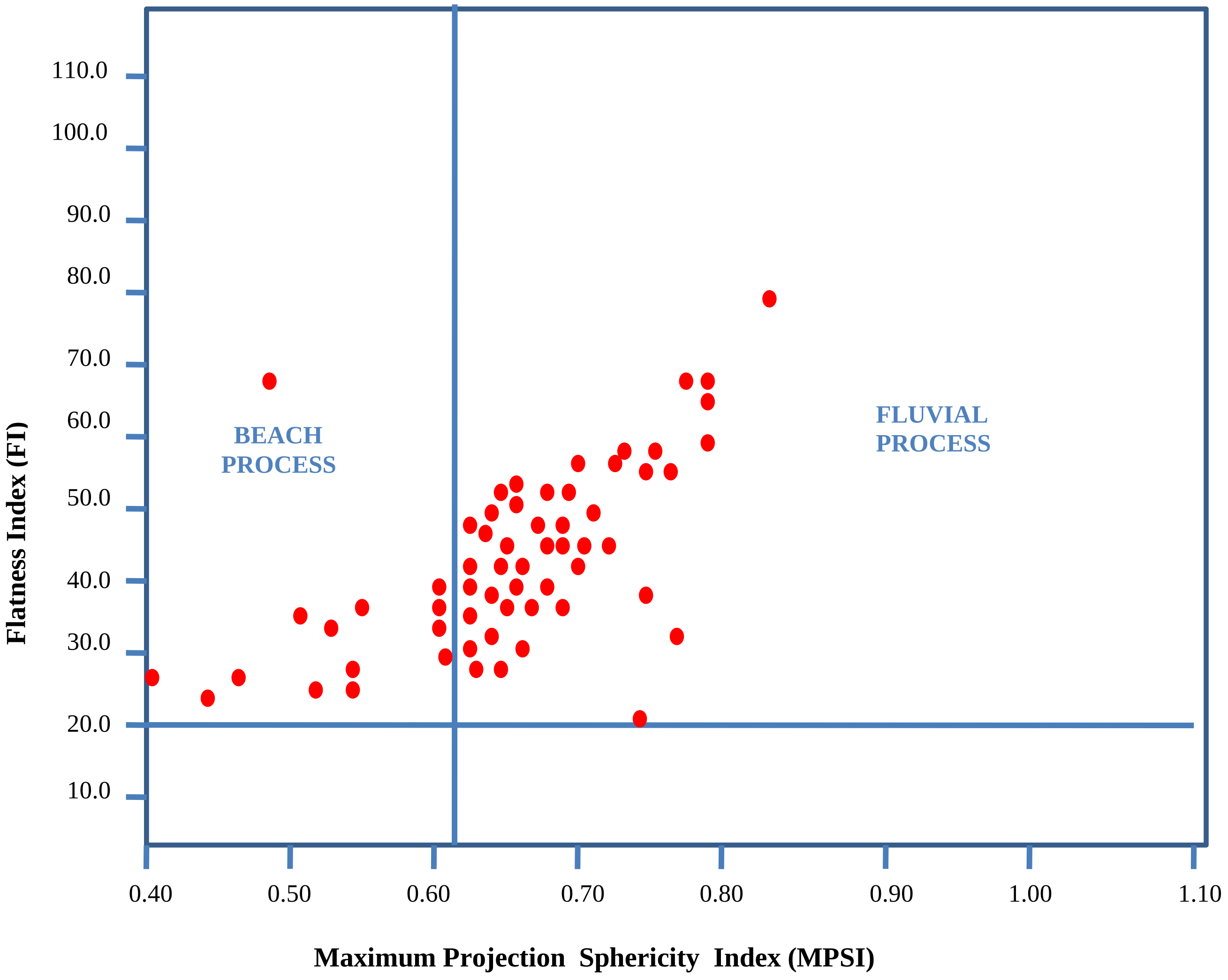


Figure 4: A plot of MPS versus OPI after (Dobkins and Folk 1970)


110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
Flatness Index (FI)
BEACH PROCESS
FLUVIAL PROCESS
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
Maximum Projection Sphericity Index (MPSI)

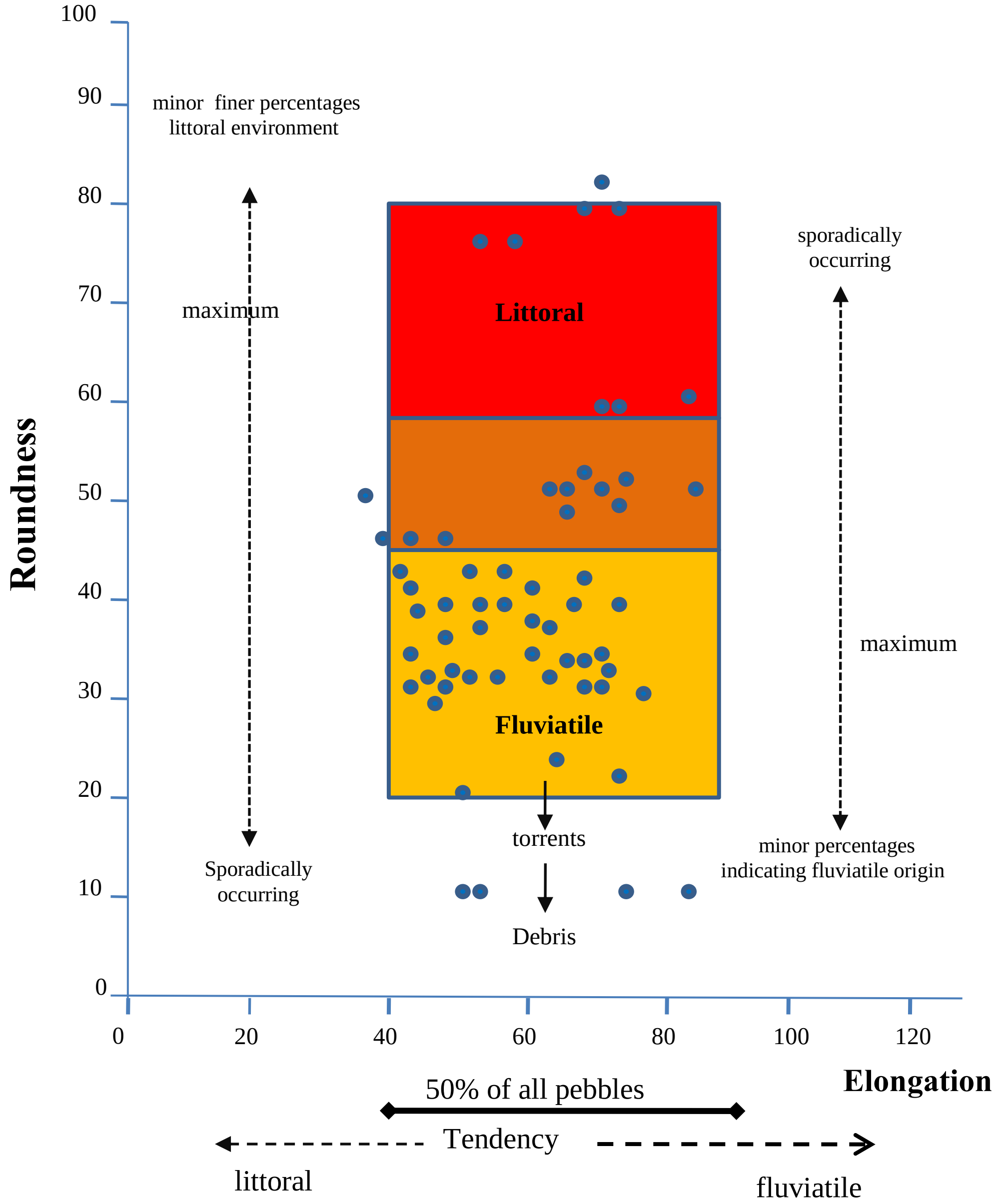


Figure 5: Plot of FI against MPSI (Folk 1966)

Figure 6: Environmental determination chart showing distinction between strongly fluvial processes and littoral process after (Folk 1966)

Table 2: Summary of interpretations of grain size diagnosis for sieve analysis

Sample location	Mode (mm)	Median (mm)	Mean (mm)	Sorting (mm)	Kurtosis (mm)	Skewness (mm)	interpretation
1	1.75	1.6	1.15	1.11	1.09	-0.53	mg, ps, scs, m
2	1.75	1.65	1.15	1.13	1.19	-0.23	mg, ps, scs, l
3	1.75	1.5	1.43	1.10	1.41	0.082	mg, ps, ns, l
4	1.70	1.5	1.20	1.20	1.17	'-0.25	mg, ps, cs, l
5	1.75	1.6	1.18	1.25	1.17	0.20	mg, ps, fs, l
6	1.7	1.25	1.18	1.26	1.15	-0.22	mg, ps, cs, l
7	1.70	1.5	1.66	1.07	1.23	0.06	mg, ps, ns, l
8	1.75	1.6	1.75	1.15	1.05	0.15	mg, ps, fs, m
9	1.75	1.5	1.45	1.20	1.20	-0.45	mg, ps, scs, l
10	1.70	1.6	1.50	1.15	1.15	0.05	mg, ps, ns, l
11	1.70	1.5	1.15	1.23	1.10	0.25	mg, ps, fs, l
12	1.75	1.5	1.15	1.25	1.25	0.05	mg, ps, ns, l
13	1.75	1.6	1.18	1.05	1.05	0.08	mg, ps, ns, m
14	1.75	1.5	1.18	1.10	1.20	0.23	mg, ps, fs, l
15	1.70	1.6	1.20	1.20	1.15	0.25	mg, ps, fs, l
Mean	1.73	1.53	1.30	1.16	1.17	0.06	mg, ps,ns, l
Explanation: mg = medium grained, ps = poorly sorted, scs = strongly coarse skewed, ns = negative skewed, cs = coarse skewed, fs = fine skewed, m = mesokurtic, l = leptokurtic,							

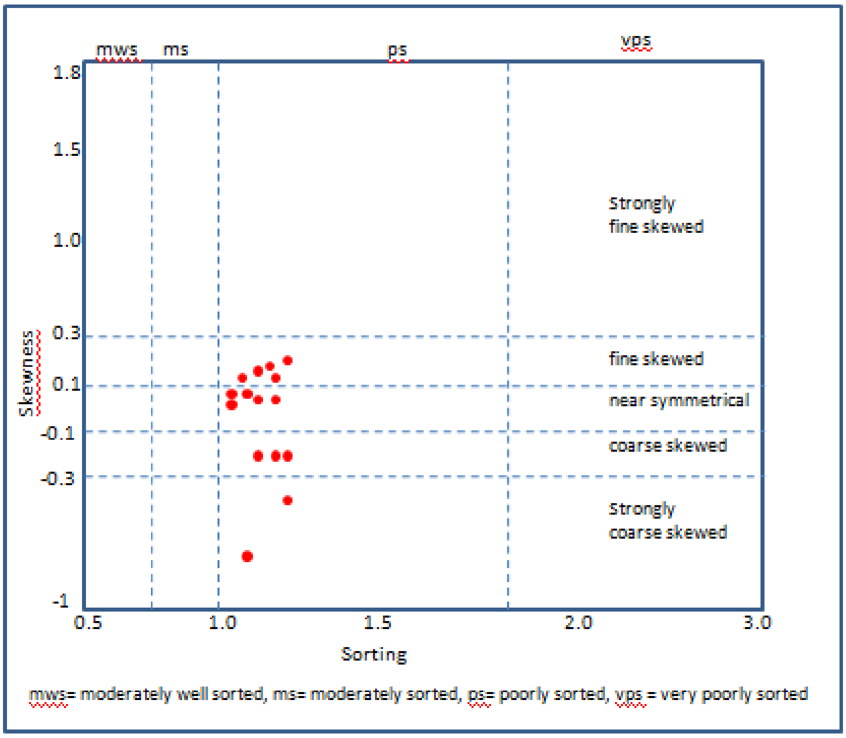


Figure 7: Grain size bivariate plot of skeweness versus sorting showing sorting of grains (Folk et al., 1970)

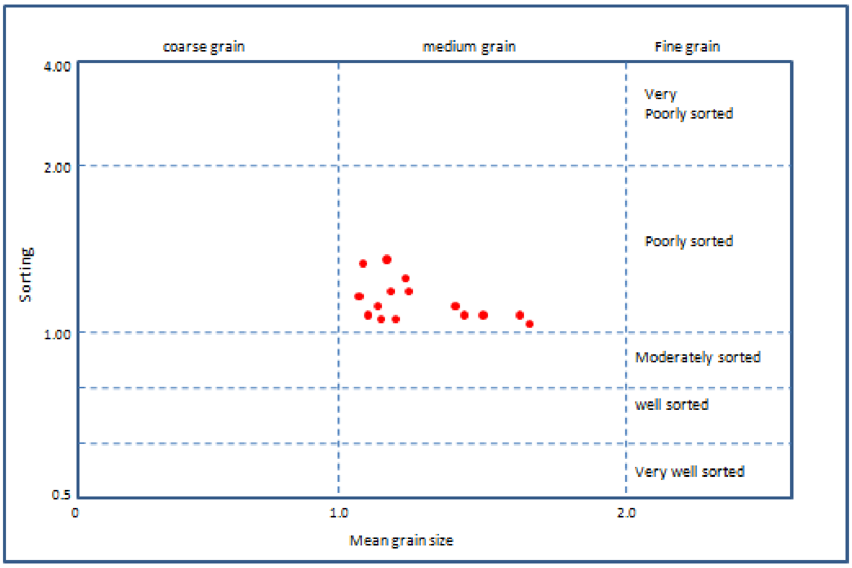


Figure 8: Grain size bivariate plot of sorting versus mean grain size showing sorting of grains (Folk et al., 1970)

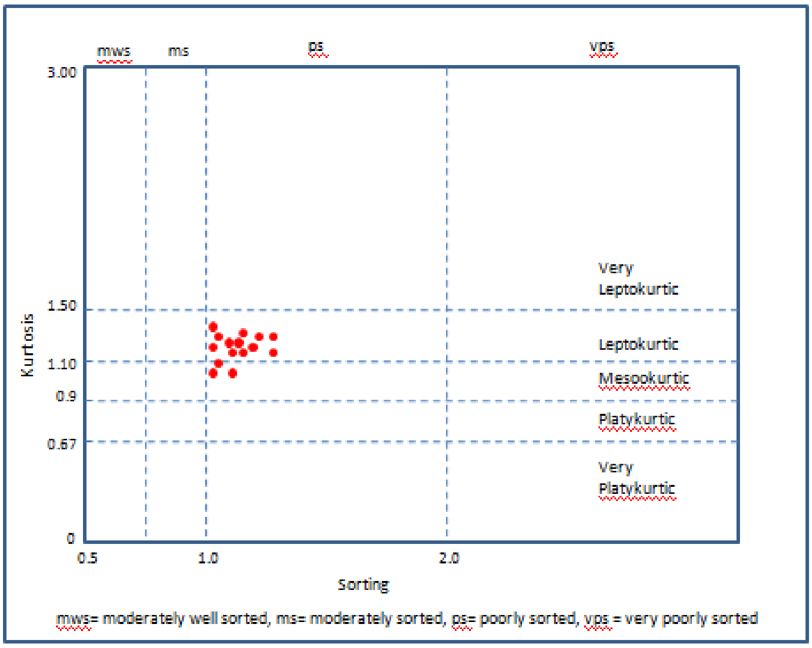


Figure 9: Grain size bivariate plot of Kurtosis versus sorting showing sorting of grains (Folk et al., 1970)

CONCLUSION

Pebble morphometric indices of sphericity (MPSI), oblate-prolate index (OPI), flatness index (FR), elongation index (ER), roundness (P) and form have proven useful together with grain size study in deciphering the depositional environments of the sediments in Oron and environ of the Benin Formation. The depositional processes responsible for shaping the pebbles and the environment that prevailed during past geological times was characterized from the study of the clast morphology. Fluviatile process with some overlapping littoral influence has been shown to be responsible for the variation in clast morphology of the conglomerates in this Formation. Integrated results from morphometric and sieve studies suggest a typical fluvial setting for the sediments in Oron and environ of the Benin Formation. Findings from this study are in conformity with findings from Ephraim and Odumodu (2015) carried out in Nsie area of the Benin Formation confirming that the sediments in Benin Formation were deposited dominantly by fluvial processes.

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