

Depositional Environment of Tertiary Sediments in Calabar Flank: A Case Study of Pebble Morphometric Analysis Occurring Around 25km of Calabar-Itu Road, Southeastern Nigeria.¹ Itam, Asukwo Essien² Ugar, Samuel Izama³ Obim, N. V^{1, 2, & 3} Geology Department, University of CalabarCorresponding Author email: asukwoitam@gmail.com**Abstract**

Pebble morphometric analysis of some selected beds deposited around 25km of Calabar-Itu Road in Calabar Flank, Southeastern Nigeria, was carried out in order to determine the paleodepositional environment of the pebble suites. A total number of 700 unweathered quartz pebbles were collected from the study area, comprising of 50 samples respectively from 14 locations. The results of the pebble morphometric parameters included: Flatness Ratio (FR), Coefficient of Flatness Ratio (CFR), Elongation Ratio (ER), Maximum Projection Sphericity Index (MPSI) and Oblate Prolate Index (OPI), have average and range values of 0.55 (0.51 - 0.59), 55.32% (50.84 – 59.36%), 0.74 (0.70 - 0.76), 0.73 (0.70-0.77) and 1.50 (0.10-2.39) respectively. These values were inferred from those pebbles within the study area and were mostly found to have been deposited in a fluvial setting than in beach. Roundness values average 44.26% and ranges from 38.27% to 58.94% showing fluvial setting, while the various bivariate plots of the pebble parameters and forms show a mixing of both fluvial and beach/marine settings for pebbles found within the investigated area.

Keywords: Pebble morphometric, Calabar Flank, paleodepositional environment, quartz pebbles, fluvial setting.

Introduction

The study of clastic grain size analysis has proven to be a good reliable tool in inferring paleodepositional environment (Nwajide and Hoque 1982; Inyang and Enang, 2002; Inyang *et al.*, 2014; Itam *et al.*, 2015; Zarma *et al.*, 2015; Itam and Ugar, 2016; Essien *et al.*, 2017, Madi et al ;2020; Oluwajana *et al.*2021 and Ogbe *et al.*2023.) This approach had been used to carry work especially on some outcrops which are devoid or almost totally barren of paleoenvironmental fossil indicators. In highly ferruginised sand/conglomerate units, where the sand is highly weathered and cannot be used to infer the paleodepositional condition, pebbles have proven to be a better tool in deciphering the environment where the sediments were deposited.

With the growing population in Cross River State of Southeastern Nigeria, different road networks are opened up for accessibility. This has led to the discovery of unknown conglomeratic beds which occurred close to a shale unit as shown in Ikot Nkpara Otop (Figure 1). There has been controversy about the depositional setting of this outcrop by many scholars in geology. The present study will attempt for the first time, to use the various pebbles exposed in Ikot Nkpara Otop around 25km of Calabar-Itu Road, in Calabar Flank Southeastern Nigeria to unravel the paleodepositional unit of this suite of sediments

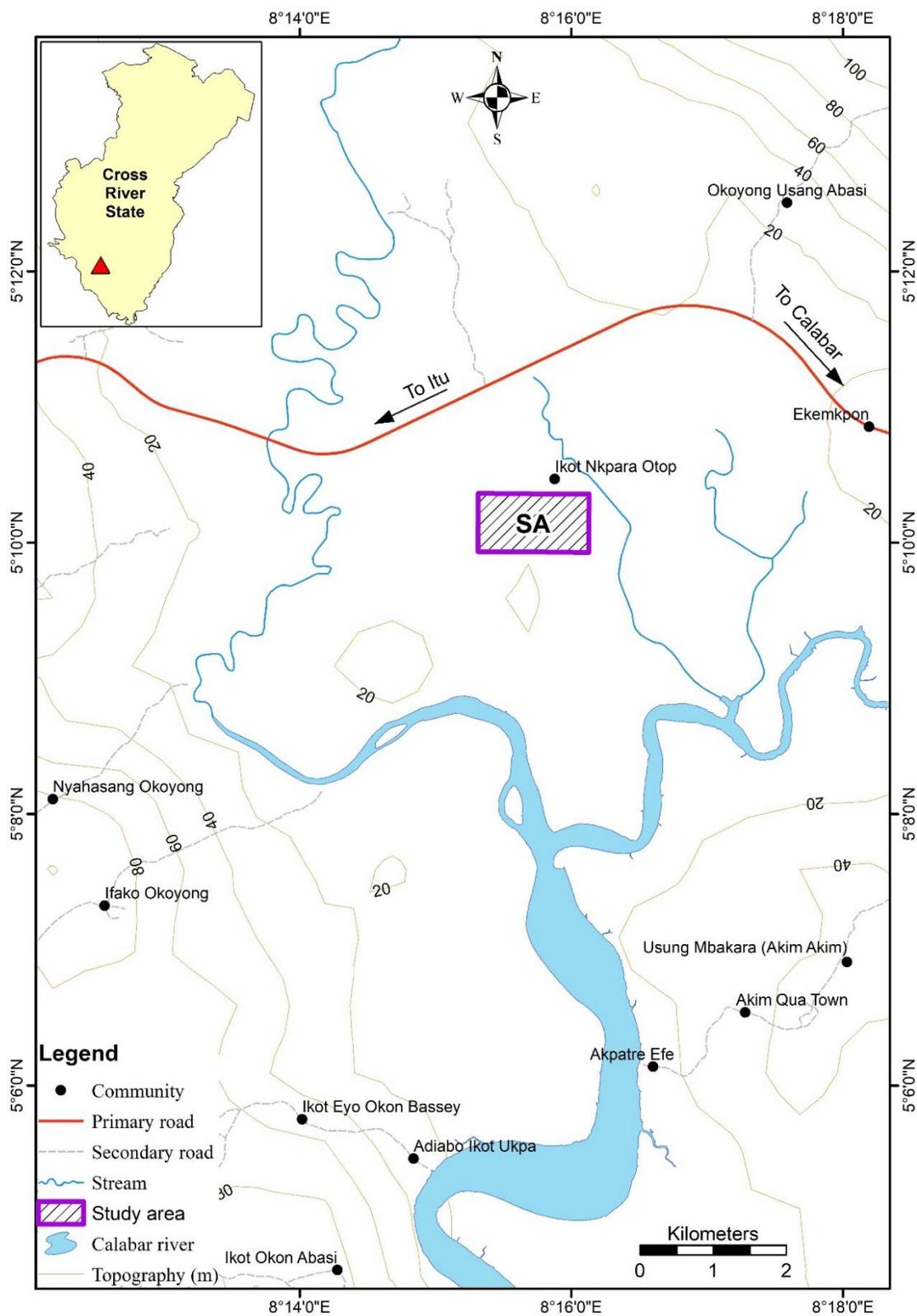


Figure 1: Map showing the location of the study area

Location of the study area

The study area Ikot Nkpara Otop, located around 25km of Calabar-Itu Road in Calabar Flank in Odukpani Local Government Area of Cross River State, Southeastern Nigeria. The region of the mapped area is bounded by latitudes $05^{\circ} 10' 11.6''$ and $05^{\circ} 10' 47.1''$ North of the Equator and Longitudes $008^{\circ} 15'$ and $008^{\circ} 22' 17.8''$ East of the Greenwich Meridian (Figure 1)

Geological setting of the study area

The Calabar Flank is an epirogenic sedimentary basin in Southeastern Nigeria (Murat, 1972). The basin according to Nyong (1995) is bounded by the Oban Massif in the north with the Calabar hinge line separates the basin from the Niger Delta basin in the south and the Ikpe Platform and Cameroon Volcanic Line (CVL) delineates it in the west and east respectively (Figure 2). The origin of this basin is associated with the opening of the South Atlantic in the Cretaceous times when the South American plate drifted away from African plate.

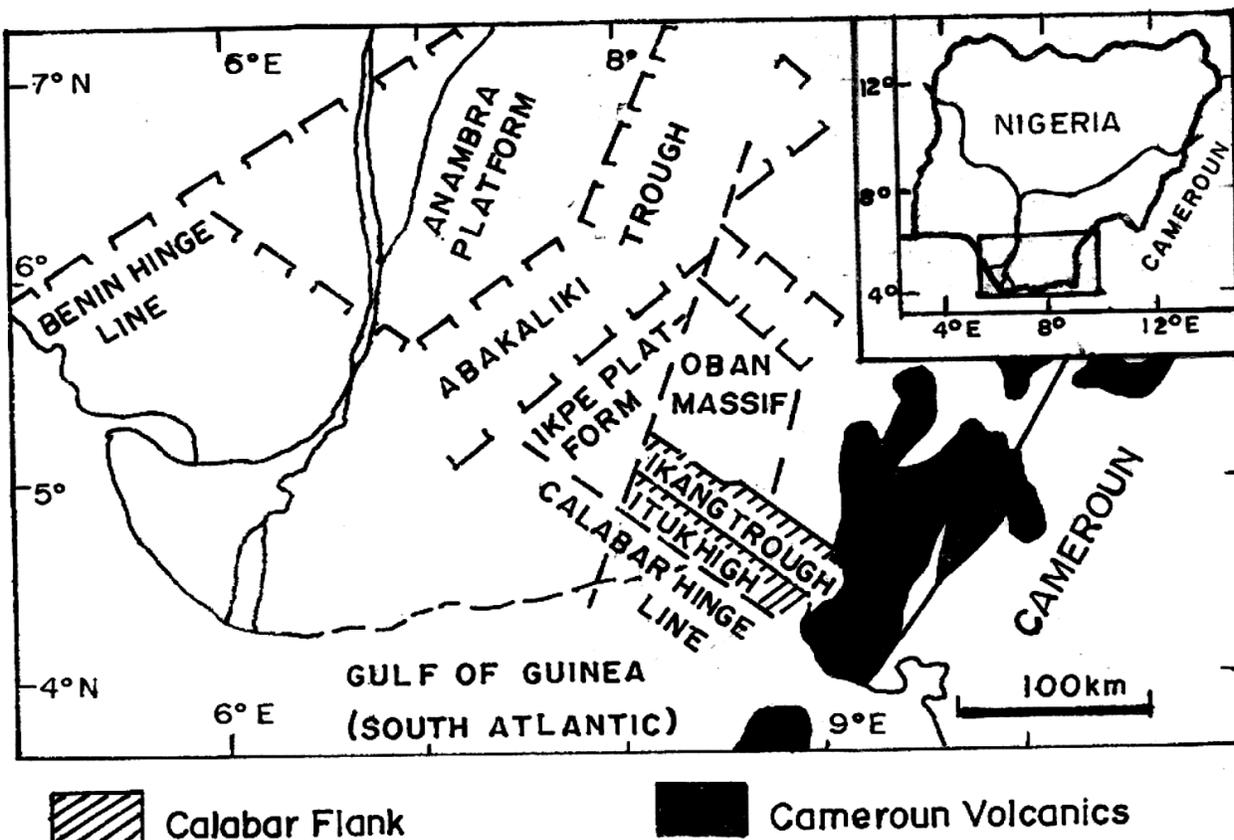


Figure 2: Geologic sketch map of south – eastern Nigeria showing Calabar

Flank (Modified after Nyong and Ramanathan, 1985).

The major structural elements within the basin include the Ikang Trough (Graben structure) and Ituk High (Horst) which were mobile depression and stable mobile submarine ridge that influenced the distribution sedimentary facies (Murat, 1972 and Nyong, 1995).

The stratigraphic succession in the Calabar Flank is shown in table 1. Sediment thickness is over 3500m with the onlap of the outcropping units exposed along the fringes of the Oban Massif Basement Complex. The formations are best exposed along Calabar – Ikom road and a succession consists of five (5) Cretaceous and one (1) Tertiary lithostratigraphic units. Awi Formation is the oldest basal unit and sits

nonconformably on the basement complex of Oban Massif. The formation is Aptian in Age (Adeleye and Fayose, 1978). This is overlain by Mfamosing Limestone of Middle- Upper- Albian age (Petters, 1982) deposited during the first marine transgression in the South Atlantic. This in turn is succeeded by Late Albian- Cenomanian to Turonian, Ekenkpon Shale (Ukpong, and Ekhaliu 2015; Una *et al.*, 2017 and Itam *et al.*, 2019).

Table 1: Lithostratigraphic correlation between Calabar Flank, Abakaliki Trough, Anambra Basin and the Middle Benue Trough (Petters *et al.*, 2010)

AGE	GSN 1957	Reyment 1965	Murat 1972 Anambra - Calabar	Dessauvague 1974 Anambra-Calabar	Petters et al., 1995 Calabar Flank	Petters et al., 2010 Calabar Flank
Quaternary	Coastal Flain Sands		Coastal Flain Sands	Benin Formation		
Pliocene						
Miocene						
Oligocene				Ogwashi - Asaba Formation	Benin Formation	Benin Formation
Eocene	Lignite Formation Beds, Ameki Group			Ameki Formation		
Paleocene	Imo clay shale Group		Ameki Formation	Imo Shale		
Maastrichtian	Lower Eocene measures	Niporo Shales	Imo Shale	Nsukka Ajali Mamu Enugu Shale	Niporo Shale	Niporo Shale
Campanian	Asata - Nkporo Shale group		Nsukka Formation	Nkporo Shales		
Santonian	Agwu - Ndsaboh Shale Group		Nkporo Shale	Agwu Shale		
Coniacian			Agwu	Agbani	New Netim Marl	New Netim Marl
Turonian	Eze - Aiku Shale Group	Eze - Aiku Formation	Eze - Aiku Shale Group	Eze - Aiku	Ekenkpon Shale	Ekenkpon Shale
Cenomanian	Calabar Formation			Odukpani	Mamosing Limestone	Unnamed Shale
Albian	Asu River Group	Odukpani Formation	Asu River Group	Asu River Group	Mamosing Limestone	Mamosing Limestone
Aptian			Basal Grits		Awi Formation	Awi Formation
Precambrian	BASEMENT	COMPLEX	BASEMENT	COMPLEX	BASEMENT	COMPLEX

Subsidence of faulted blocks of horst and graben allowed wide spread deposition of shales with minor marl and mudstone intercalation. The New Netim Marl which is Coniacian in age, succeeded the shale unit. The Santonian period was marked by a major unconformity in the Calabar Flank. Nkporo Shale of Late Campanian to Maastrichtian (Edet and Nyong, 1994 and Itam *et al.*, 2017) capped marine transgression and Cretaceous sedimentation in Calabar Flank. The Tertiary continental sands and gravel of the Benin Formation complete the sedimentation in the basin ((Itam *et al.*, 2016).

Material and methods

A total of seven hundred (700) unweathered quartz pebbles from fourteen (14) different locations, mainly from local abandon quarries and stream channels were sampled from conglomerate and pebbly sandstone units for this analysis. Weathered and broken pebbles were excluded, while fresh samples and pebbles stained with iron minerals were washed, dried and numbered for this research work. Pebble morphometric measurement using vernier caliper method to measure the three mutually perpendicular axes - Long (L), Intermediate (I) and Short (S) axes of pebbles were done (Krumbein, 1941 and Dobkins and Folk 1970). The measured three (3) mutually perpendicular axes (L, I and S) were computed with their indicial values. Form (shape) names of Sneed and Folk (1958), was adopted, while their roundness was evaluated visually based on Sames (1966). The results obtained were compared with those recorded in other localities previously studied.

The formulae used in calculating the various pebble morphometric parameters from the area under investigation are shown:

Flatness Ratio (FR) = S/L (Stratten, 1974)

Coefficient of Flatness Ratio (CFR) or Coefficient of Flatness Index (CFI) = S/L% (Stratten, 1974)

Elongation Ratio (ER) = I/L (Sames; 1966 and Lutig; 1962)

Maximum Projection Sphericity Index (MPSI) = $[S^2/LI]^{1/3}$, (Sneed and Folk; 1958)

Oblate–Prolate Index (OPI) = $110[L-I/L-S]/S/L-0.5$, (Dobbins, and Folk, 1970)

Results and Discussions

Field description of the study area

The lithologic description of study area consists of conglomeratic sandstone, (Figure 3). The conglomeratic sandstone is reddish brown, clast supported to matrix supported, poorly imbricated conglomerate, with coarse – medium, poorly sorted, angular to sub-angular clasts. The base of the section is made of predominantly very coarse sand to granules and graded up to pebbles dominated top (Figure 3). The overall sequence represents coarsening upward succession (negative graded bed).



Figure 3: Lithologic section from the study area

Pebble Morphometric Parameters

The average results of the pebbles morphometric analysis and interpretation from the study locations (14 locations) are summarized and presented in tables 2 and 3.

Table 2: Average pebble morphometric analysis from the study area.

N	LOCATIO N	L(cm)	I (cm)	S (cm)	FR	CFR (%)	ER	L-I/L- S	MPSI	OPI	R/%
50	L1	3.28	2.23	1.63	0.59	58.93	0.70	0.59	0.72	2.39	46.50
50	L2	2.77	1.98	1.45	0.54	54.33	0.73	0.58	0.73	1.61	45.50
50	L3	2.50	1.80	1.33	0.54	54.27	0.74	0.59	0.74	1.56	50.28
50	L4	2.57	1.93	1.36	0.54	54.09	0.76	0.53	0.72	0.32	41.00
50	L5	2.38	1.78	1.20	0.51	51.49	0.76	0.51	0.70	0.10	50.50
50	L6	2.43	1.76	1.25	0.53	52.88	0.74	0.54	0.72	1.08	39.80
50	L7	3.01	2.13	1.59	0.55	54.69	0.73	0.57	0.74	1.66	48.00
50	L8	2.94	2.07	1.57	0.55	54.60	0.72	0.63	0.74	2.31	32.60
50	L9	3.13	2.25	1.65	0.53	53.46	0.73	0.58	0.73	1.38	47.60
50	L10	2.99	2.06	1.49	0.51	50.84	0.71	0.59	0.71	1.83	30.00
50	L11	2.52	1.87	1.39	0.57	56.63	0.75	0.60	0.75	1.60	48.30
50	L12	2.46	1.75	1.30	0.54	53.93	0.72	0.60	0.74	2.03	40.00
50	L13	2.80	2.09	1.63	0.59	59.03	0.76	0.60	0.77	1.45	47.50
50	L14	2.41	1.82	1.41	0.59	59.36	0.76	0.60	0.77	1.63	52.00
	AVE	2.73	1.97	1.41	0.55	55.32	0.74	0.58	0.73	1.50	44.26

Legend: = Number of pebbles L= Long axis, I = Intermediate axis, S =Short axis, FR = Flatness Index, CFR =Coefficient of Flatness Index, ER = Elongation Ratio, MPSI =Maximum Projection Sphericity Index, OPI = Oblate Prolate Index, R =Roundness and AVE = Average

Table 3: Characteristic features and paleoenvironmental significant of the 700 computed pebbles morphometric parameters.

Pebble morphometric parameters	Characteristics	Defined limits from previous studies	Implication for depositional environment/ processes
Roundness(R)	15% has values below 0.35, while 35% has values above 0.45	Sames,1966 Fluvial (< .35%) Littoral (>0.45%)	Mainly littoral/beach action with little fluvial
Flatness Index (FI)	FI consists of 80% exceeds fluvial limit and 20% below this limit	Lutig, 1962 Beach (<45%) Fluvial (> 45%)	Fluvial processes
Elongation Ratio (ER)	Over 79% has values between 0.60 -0.90	Hubert,1968 Fluvial (0.6-0.9)	Dominantly Fluvial processes
Maximum Projection Sphericity Index (MPSI)	80% of the sampled quartz pebbles have MPSI values above the imaginary limit (0.66)	Dobkins and Folk, 1970 Beach (< 0.66) Fluvial (> 0.66)	Predominantly fluvial action above beach
Oblate Prolate Index (OPI)	OPI consists of over 75% above fluvial limit and 15 % below the threshold value of -1.5	Sneed and Folk,1958 Beach (< -1.5) Fluvial (> -1.5)	Dominantly fluvial with few beach/wave influences.
Form Geometry	21%B,9%C,21%CB,18%CE, 8%CP,14%E,6%P,2%VB,1%VE and 1%VP	Sneed and Folk, 1958; Dobkins. and Folk, 1970 and Gale, 1990. Fluvial (C, E, CB, CE) Beach (B, P, VB, VP)	Dominantly fluvial over beach influences.

Roundness

Roundness is the overall smoothness of a particle. Sneed and Folk (1958) working on quartz pebble observed that roundness increases from rivers to beaches. The upper and lower limit of pebbles shaped by fluvial and littoral/ beach processes are placed at 35% (from 35% and below) and 45% (from 45% and above) respectively (Sames,1966). The roundness of 700 pebble values measured from the study area ranges from 38% to 59% indicating beach processes (Tables 2 and 3).

Flatness

The flatness ratio (FR) as defined by Lutig (1962), is the ratio of the short to long axis ($FR = S/L$) and the Coefficient of Flatness Ratio (CFR) is the percentage of the flatness ratio ($CFR = S/L * 100$). The flatness ratio values of the analyzed pebbles range from 0.51 to 0.59 (Table 2) with 31% of the values of the 700 analyzed pebbles lying within the marine range of (0.40 – 0.50) following Lutig (1962) and 60% and 9 % slightly above and below this marine range (Table 3). Coefficient flatness ratio values range from 44% to 67% and is within the marine to fluvial range of Lutig (1962) values. This result shows that flatness values of pebbles have fluvial and marine processes in shaping them.

Elongation Ratio

The elongation ratio (ER) is expressed as the ratio of intermediate to the long axis ($ER = I/L$; Lutig, 1962). Elongation ratio values of the study pebbles ranging between 0.70 and 0.83 with average value of 0.74. (Table 3). According to Hubert (1968), fluvial influences fall between 0.6 to 0.9 and the analyzed pebbles values indicate fluvial origin.

Sphericity

This is a measure of how closely the grain shape approaches that of a sphere. In this present study, the maximum projection sphericity index (MPSI) was used and is expressed as the cube root of the ratio between the square of the short axis and the product of the long and intermediate axis [$MPSI = (S^2 / LI)^{1/3}$], inclined with Sneed and Folk, (1958). According to Dobkins and Folk (1970) who analyzed pebbles shaped by river and beach influences in Tahiti-Nui and evaluated that the average sphericity of fluvial pebbles is 0.68 while that of pebbles in low energy and high energy beaches are 0.64 and 0.58 respectively. On the basis of their findings, they postulated that pebble suites with average sphericity less than 0.66 indicate beach processes while those with values above 0.66 are shaped by river/fluvial processes. From this study the mean and range values of MPSI of the pebbles under investigation are 0.73 and 0.62 – 0.87 indicating 80% of analyzed pebbles have values of MPSI greater than 0.66; while 20% fall below 0.66 (Table 3) which infer fluvial origin. It reflects that the pebbles were transported in a fluvial medium.

Oblate-Prolate Index

The oblate-prolate index (OPI) measures how closely the intermediate axis approaches the long axis or the short axis. The mathematical expression of OPI according to Dobkins and Folk (1970) is given as $OPI = [10(L-I)/(L-S) - 0.5] / S/L$. Thus if the long (L) axis is exactly half-way between the intermediate (I) and short (S) axis, the value of $(L-I)/(L-S)$ is 0.5 and the OPI is zero. The computed value of OPI from 700 pebbles from 14 locations ranges from -1.52 to 2.31 and average value of 1.50. The analyzed pebbles show that greater than 75% of analyzed pebbles have values more than -1.50 which is the threshold value that separate pebbles influence by fluvial processes from beach products (Dobkins and Folk, 1970).

Form

Pebble form is a measure of the relation between the three mutually perpendicular dimensions of a pebble and is used to show that particles having the same numerical value of maximum projection sphericity may have different ratios between their three axes. According to Sneed and Folk (1958), Dobkins and Folk (1970) and Gale (1990), Itam and Ugar (2016), inferred Compact (C), Compact Bladed (CB), Compact Elongate (CE) Elongation (E) forms are most indicative of fluvial action, whereas Bladed (B), Platy (P), Very Bladed (VB) and Very Platy (VP), and are diagnostic of beach setting. The predominant percentage occurrence of the form names for 700 computed pebbles have Compact (9% C), Compact Bladed (21% CB), Compact Elongate (18% CE) and Elongation (14% E) which account for 62% in the study area over Bladed (21% B), Platy (6% P), Very Bladed (2% VB) and Very Platy (1% VP), accounting for 30%, infer more fluvial activity than the beach influence in the study area (Table 3 and Figure 4)

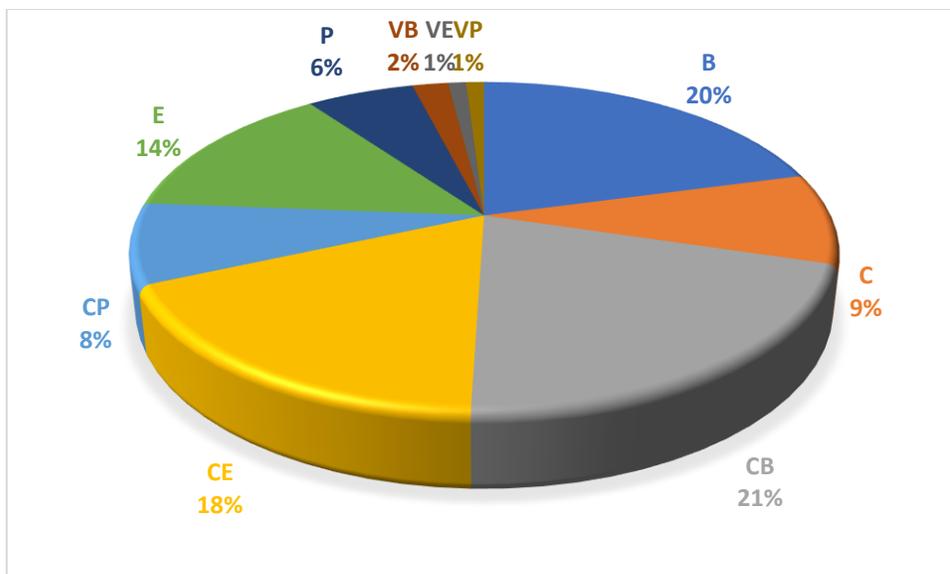
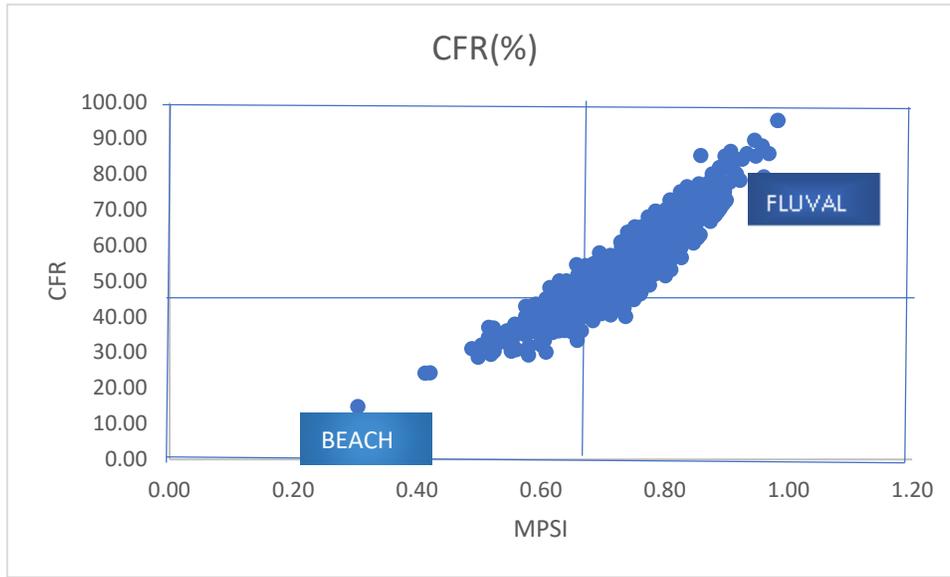


Figure 4: Pie chart showing form names from the area under investigation.

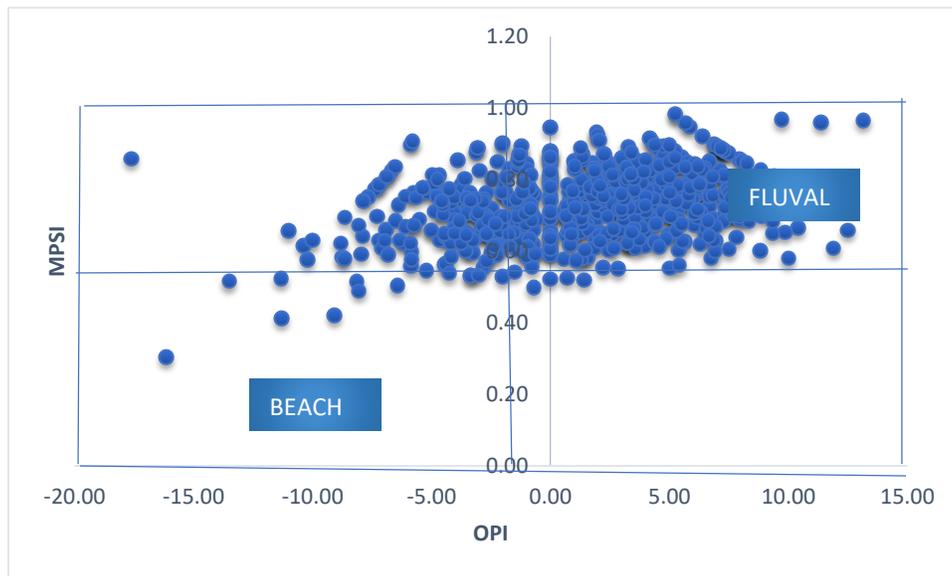
Bivariate

The bivariate plots were constructed from the pebble suite in the present study (Figure 5), from the Straiten (1974), bivariate plots of coefficient of flatness ration (CFR) against maximum projection sphericity index (MPSI) in figure 5a. This shows a linear plot, having more plots on the uppermost portion than on the lower side (Inyang *et al.*, 2014 ; Itam and Ugar, 2016 ; Ogechukwu and Odumodu,2019; Oluwajana *et al.*2021 and Ogbe *et al.*2023), and this is common in most fluvial sediment settings. In figure 5b, the MPSI was plotted against OPI and majority of the plots fall above the lower limit lines of 0.66 and -1.5 of maximum projection sphericity index and oblate prolate index (Dobkins and Folk, 1970) respectively. This condition shows that the pebbles were shaped predominantly by river influence with little beach activity.

Pebble roundness is not necessarily good diagnostic of depositional environment because of abrasion and also not reflection of distance travelled from the provenance setting (Ogala *et al.*, 2010 and Ogechukwu and Odumodu,2019), but when combine with other parameters it may be of added advantage in signposting palaeodepositional setting. Therefore, the plot of roundness (R%) versus elongation ratio (ER) as shown in figure 5c, using the discriminate values of Sames (1966) and Hubert (1962), indicates mixed influential processes of fluvial and beach actions This result is in agreement with the work of Itam and Ugar (2016) using grain size to infer paleodepositional environment of Benin Formation in the Southern Sector of the same basin.



5A



5B

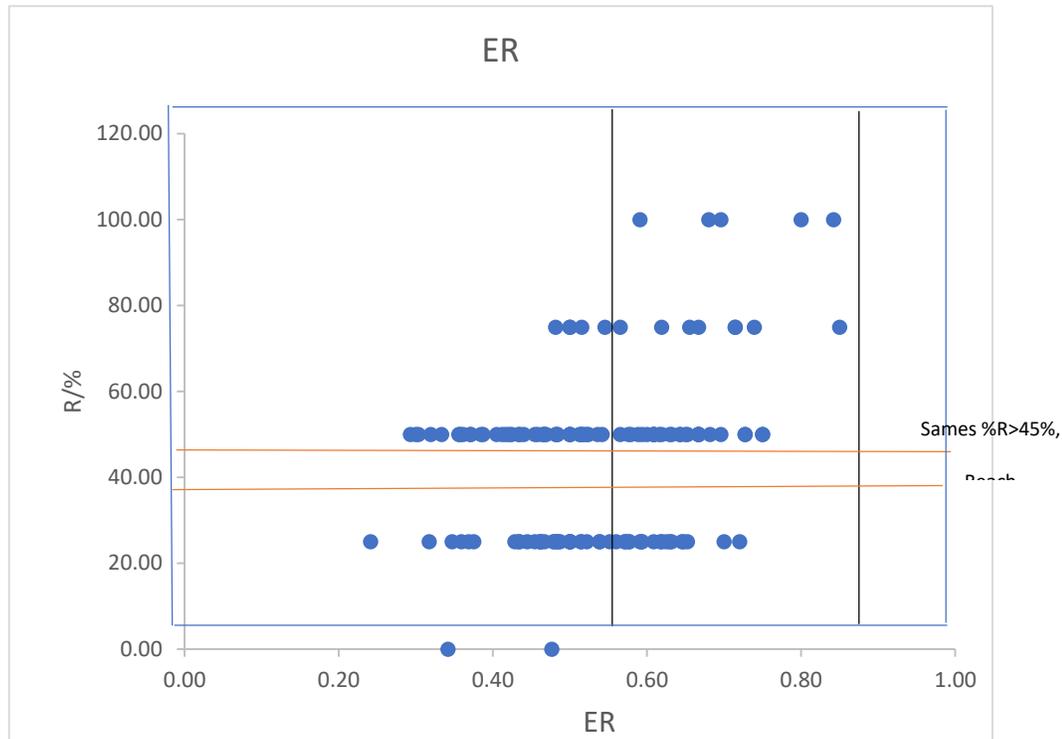


Figure 5: Bivariate plots of: (a) FI against MPSI (b) MPSI against OPI (c) R against ER

Conclusion

Pebble morphometric analysis from Ikot Nkpara Otop located around 25km of Calabar-Itu Road of Calabar Flank in Odukpani Local Government Area of Cross River State, Southeastern Nigeria, was carried out to infer palaeodepositional setting of the sediment suites. The results obtained have proven beyond doubt to be good indicators in distinguishing paleodepositional environment especially where fossils environmental indicators are lacking. The use of pebble morphometric parameters, with their different bivariate plots have shown that pebbles from the study area were shaped mainly from fluvial environmental setting.

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