



Granulometric and Pebble Morphometric Analyses of Sandstone Lithofacies of the Ameki Formation in Northeastern Part of Akwa Ibom State, Niger Delta, Nigeria

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Abstract

Sandstone lithofacies of the Ameki Formation outcrop extensively in the northeastern part of Akwa Ibom State, Niger Delta Basin, Nigeria. The aim of this study is to reconstruct the depositional milieu of the sandstone lithofacies. Granulometric and pebble morphometric analyses were used to achieve this. Pebble morphometry analysis of 200 unbroken quartz pebbles indicates that the mean values of the various morphometric parameters ranged as follows: flatness ratio ($S/L = 0.31 - 0.67$), elongation ratio ($I/L = 0.58 - 0.78$), maximum projection sphericity ($\Psi_p = 0.54 - 0.73$), Oblate-Prolate index ($\bar{O}\bar{P} = -0.73 - 5.41$) and coefficient of flatness (31.49 – 53.15). These values are in agreement with those of modern beach pebbles, which are recommended for characterizing such a depositional environment. Bivariate plots of coefficient of flatness versus maximum projection sphericity and maximum projection sphericity versus oblate-prolate index also support beach environment of deposition. Granulometric analysis of 25 sandstone samples showed the samples to be well sorted and negatively skewed with sorting values ranging from 0.1 to 0.39 phi, which suggests a beach depositional environment. Bivariate plots of skewness versus sorting and mean grain size versus sorting also show the majority of the samples plotted within the beach depositional realm. Interpretation of granulometric and pebble morphometric analyses data indicate that the sandstone lithofacies of the Ameki Formation in northeastern part of Akwa Ibom State was deposited in a beach environment.

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1.0 Introduction

The study area lies within the northeastern part of Akwa Ibom State, Niger Delta Basin, Nigeria and is located between longitudes $7^{\circ} 41' - 8^{\circ} 00'E$ and latitudes $5^{\circ} 07' - 5^{\circ} 30'E$ (Fig. 1). The Sandstone lithofacies of the Ameki Formation abound the northeastern part of Akwa Ibom State as an extension of the Paleogene sedimentary deposit of Nigeria, where they are being quarried for construction purposes. Petters (1989) noted that the Paleogene Sedimentary sequence remains the oldest sedimentary deposit in the Niger Delta Basin. Ekwenye (2014) recognized Nanka and Nsugbe Formations as the lateral equivalents of the Ameki Group. Nwajide (1980) noted that the formation conformably overlies the Imo Formation. Reyment (1965) described the type locality of the Ameki Formation between miles 73 and 87 along the road section left behind during the eastern railway construction at Ameki town, and asserted that the formation is composed of rapidly alternating shale, sandy shale, mudstone and clayey sandstone and also has fine-grained fossiliferous sandstone with thin limestone beds. The age of the formation has been variously considered to be Early Eocene (Reyment, 1965).

Adegoke *et al.* (1980) and Ekwenye *et al.* (2020) among others indicated that the Ameki Formation is composed of rapidly alternating shale, sandy shale, mudstone, clayey sandstone and fine-grained fossiliferous sandstone with thin limestone beds, and that the deposition of this formation spanned throughout most of the Eocene. Reyment (1965) considered the age of the formation to be Early Eocene, while Adegoke (1969) included Early to Middle Eocene. The depositional environment was interpreted as estuarine, lagoonal, and open marine, based on the faunal content (Reyment, 1965). Other schools of thought had overtime classified the

Ameki Formation as fluvial channel deposit while many other scholars have assigned a marine paleoenvironment to this deposits (Reyment, 1965; Adegoke, 1969; Nwajide, 1980; Arua, 1986; Petters, 1989; Oboh-Ikuenobe *et al.*, 2005; Udo and Mode, 2013a; Udo and Mode, 2013b; Ekwenye *et al.*, 2014, 2015; Ekwenye and Nichols, 2016; Udo *et al.*, 2020; Udo and Udofia, 2020; Asuaiko *et al.*, 2022). Harry *et al.* (2017) documented the baseline estuarine oceanographic effects on benthic foraminifera in Qua Iboe, Eastern Obolo and Uta Ewa/Opobo River estuaries, South Eastern Nigeria while the Geomechanical properties of the reservoirs in southern Nigeria was reported by Harry *et al.* (2018), establishing the Geomechanical behavior of associated reservoirs within the southern Niger Delta.

Many authors (Friedmann 1961, Stratten 1974, Dobkin and Folk, 1970), among others had earlier shown that the application of morphometric parameters on unbroken sedimentary pebbles yields invaluable information about ancient energy conditions and the environment of deposition. Boggs (2006) maintained that paleo-environmental analyses should involve the determination of responsible elements that have environmental significance. Ocheli *et al.* (2018) integrated granulometric and pebble morphometry of late Cretaceous rocks to delineate depositional processes and paleo-environment of the study area. Boggs (2006) noted that Pebble morphometric parameters have proven to be good indicators adequate to distinguish depositional environments, hence their significance in reconstructing ancient sedimentary environment and that the textural and structural characteristics of sandstones and conglomerates gives distinct depositional arrays under a particular set of environmental conditions.

The Agbada Formation of the Niger Delta is

referred to as the down-dip continuation of the outcropping Ameki Group and Ogwashi Formation (Short and Stauble, 1967). Unlike the Akata, Agbada and Benin Formations of the Niger Delta which have received global recognition, significant exploration and outstanding academic attention mainly due to their economic support for commercial exploration and production of oil and gas, the Ameki Formation in the northeastern part of Akwa State has not received much attention.

Apart from regional studies on Ameki Formation, there is no published work on the sandstone lithofacies of the Ameki Formation in the northeastern part of Akwa Ibom State. Therefore, there is a need for this research work to be carried out in order to characterize the deposit. The aim of this research work is to reconstruct the depositional environment of the sandstone lithofacies of the Ameki Formation.

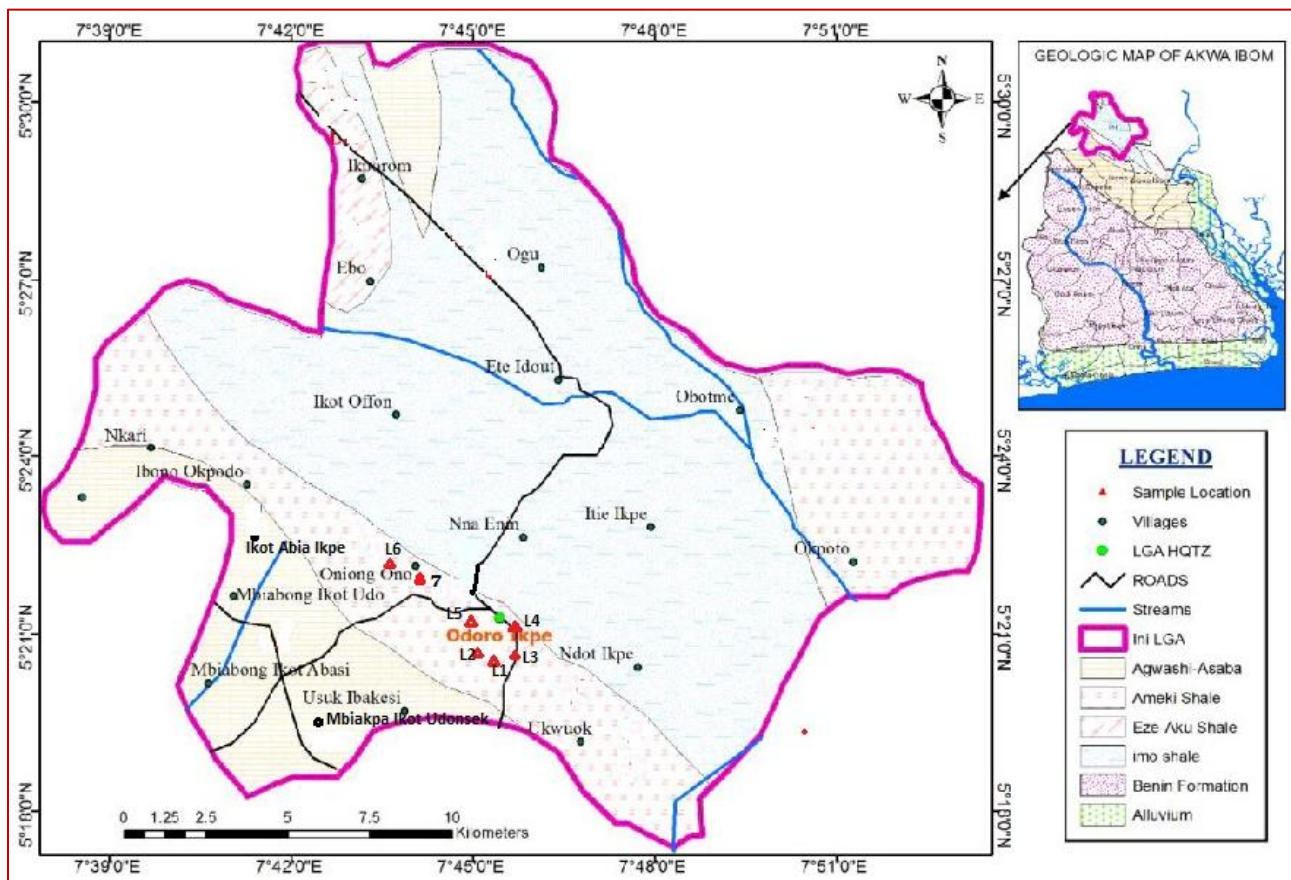


Fig. 1: Geology/Sample location map of the study area, modified after Asuaiko *et al.* (2022)

2.0 Geologic Setting

The study area falls within the Niger Delta Basin. Three depositional cycles affected the southern sedimentary basins of Nigeria. The first began with a marine incursion in the middle Cretaceous

and was terminated by a mild folding phase in the Santonian period. The second included the growth of a proto-Niger Delta during the Late Cretaceous and ended in a major Paleocene marine transgression. The third cycle, from Eocene to Recent, marked the continuous growth of the

main Niger Delta (Short and Stauble, 1967; Murat, 1972; Udofia and Udo, 2021; Udo *et al.*, 2023a; Udo *et al.*, 2023b). Ekwenye *et al.* (2020) noted that the stratigraphic succession of the Niger Delta consists of the Paleogene Sedimentary system, comprising the Imo Formation, Ameki Group, and Ogwashi Formations and that sedimentation in the basin began with the transgressive Imo Formation (Paleocene) which agrees with the assertion of Reyment (1965) that Imo Formation is the oldest outcropping lithostratigraphic unit of the Niger Delta Basin and is laterally equivalent to the subsurface Akata Formation in wells. According to Reyment (1965) Imo Formation consists of blue-grey clays, shallow-marine shale and sandstone, limestone and calcareous sandstone. Arua (1980) suggested littoral to neritic conditions of deposition for the Imo Formation while Okeke and Umeji (2016) deduced a middle to outer neritic-zone environment based on the abundance of gonyaulacacean cysts within the Imo Formation. Stevens *et al.* (2011) also deduced a foreshore and shoreface zone of beaches and bars for the formation.

Nwajide (1980) noted that Ameki Formation conformably overlies the Imo Formation and that the Ameki Group consists of the Nanka sand, Nsugbe and Ameki Formations. Ekwenye (2014) described Nanka and Nsugbe Formations as lateral equivalents of the Ameki Group. Adegoke *et al.* (1980) and Arua (1980) described the Ameki Formation, as being composed of rapidly alternating shale, sandy shale, mudstone and clayey sandstone. Reyment (1965) described it as consisting of a series of highly fossiliferous grey-green sandy clays with calcareous concretions and white clayey sandstones with the lower part consisting of fine to coarse sandstones and intercalations of calcareous shale and thin, shelly limestone, the upper with coarse, cross-bedded

sandstones and bands of fine sandstones and sandy clays. The depositional environment of the Ameki Formation has been interpreted as estuarine, lagoonal, and open marine, based on some faunal constituents. Nwajide (1980) and Arua (1986) suggested environments that ranged from nearshore (barrier ridge - lagoonal complex) to intertidal and subtidal zones of the shelf environments, whereas Fayose and Ola (1990) suggested that the sediments were deposited in marine waters of depths between 10 m and 100 m.

The Ogwashi Formation described by Parkinson (1907) as Lignite Series, conformably overlies the Ameki Group with a type locality in Ogwashi community in Delta State. Ekwenye *et al.* (2020) noted that the formation correlates with the upper Agbada Formation while the Lower Agbada Formation correlates with the Ameki Group (Short and Stauble, 1967). Kogbe (1976) described the Ogwashi Formation (Eocene-Oligocene) as comprising an alternation of coarse-grained sandstone, lignite seams, and light-colored clays of continental origin while Ekwenye and Nichols (2016) described it as a tidally-influenced coastal-plain deposit due to the high degree of bioturbation in the basal matrix-supported conglomerate and sandstone facies. Reyment (1965) suggested an Oligocene-Miocene age to the formation. The youngest rock stratigraphic unit is the Benin Formation of possible Miocene to Recent age. The unit consists predominantly of yellow and white continental sand, alternating with pebbly layers and a few clay beds (Reyment, 1965).

3.0 Materials and Methods

An extensive field study covered a total of ten outcrop locations from which twenty-five (25) sandstone samples were collected and 200 pebbles picked at random from distinct pebble horizon and taken to the laboratory for

granulometric and pebble morphometric analyses.

3.1 Granulometric Analysis

Twenty-five sandstone samples were sun-dried and disaggregated using a mortar and pestle. 50g of each of the disaggregated samples was measured using a weighing balance for sieve analysis. Each portion was sieved with a Ro-tap shaker for 15 minutes using a stack of sieves with sieve mesh sizes 1.0 phi apart. The retained sieve fractions were weighed with a weighing balance to an accuracy of 0.1g. From the recorded weight

retained, weight % and cumulative weight % were computed. Using these data, cumulative plots and grain size frequency histograms were drawn. From the graphical plots, values of phi 5 (ϕ_5), ϕ_{16} , ϕ_{25} , ϕ_{50} , ϕ_{75} , ϕ_{84} and ϕ_{95} were obtained. Computation of inclusive graphic standard deviation, inclusive graphic skewness, graphic kurtosis, mean grain size and median diameter were done using the appropriate phi (ϕ) values and the applicable formulae as proposed by Mcmanus (1995) equations 1 to 5 below:

$$\text{Inclusive Graphic Standard Deviation or Sorting } (\sigma_1) = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6} \quad (1)$$

$$\text{Inclusive Graphic Skewness (SKI)} = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_5)} \quad (2)$$

$$\text{Graphic Kurtosis (KG)} = \frac{\phi_{95} - \phi_5}{2.44\phi_{75} - \phi_{25}} \quad (3)$$

$$\text{Median diameter} = \phi_{50} \quad (4)$$

$$\text{Graphic Mean (MZ)} = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3} \quad (5)$$

3.2 Pebble Morphometry

200 unbroken quartz pebbles picked randomly from distinct pebble horizons within identified outcrop locations were washed and numbered. The samples were taken to the laboratory for pebble morphometric analysis. Measurement of

the long (L), intermediate (I), and short (S) axes of each of the pebbles selected were made with a Venier Caliper. From the measurement, the elongation ratio ($\frac{L}{I}$), flatness ratio ($\frac{S}{I}$), maximum projection sphericity (Ψ_p), oblate-prolate index ($\bar{O}\bar{P}$) and coefficient of flatness values were computed.

$$\bar{O}\bar{P} = \frac{10 \left(\frac{L-I}{L-S} - 0.5 \right)}{\frac{S}{L}} \quad (\text{After Dobkins and Folk, 1970}) \quad (6)$$

$$\Psi_p = \frac{\sqrt[3]{S^2}}{LI} \quad (\text{After Sneed and Folk, 1958}) \quad (7)$$

$$\text{Coefficient of flatness} = \frac{S}{L} \times 100 \quad (\text{After Luttig, 1962}) \quad (8)$$

4.0 Results and Discussion

4.1 Granulometric Analysis Result

The granulometric result (table 1) showing the values of mean grain size (Mz), inclusive graphic

standard deviation (σ_1), inclusive graphic skewness (SKI) and graphic kurtosis (KG) is given below.

Table 1: Statistical parameters of grain size analysis

Locality/ Sample No.	Φ5	Φ16	Φ25	Φ50	Φ75	Φ84	Φ95	Graphic mean (M _z)	Inclusive Graphic Standard Deviation (σ ₁)	Inclusive Graphic Skewness (SKI)	Graphic Kurtosis (KG)	Remarks
L1S1	1.00	1.50	1.90	2.70	3.40	3.70	4.18	2.63	0.21	-0.37	0.87	FS,VWS,VNS,PK
L1S2	0.80	1.15	1.45	2.40	3.20	3.50	4.15	2.35	0.12	0.30	0.78	FS,VWS, SM,PK
L1S3	1.00	1.00	1.00	0.30	0.50	0.80	1.55	0.03	0.08	-0.40	0.70	CS,VWS,VNS,PK
L2S1	1.10	1.60	2.20	3.04	3.60	4.00	4.60	2.88	0.13	0.30	1.02	FS,VWS,SM,MK
L2S2	1.00	1.50	1.90	2.70	3.40	3.70	4.18	2.63	0.21	-0.37	0.87	FS,VWS,VNS,PK
L2S3	0.95	0.95	1.15	1.20	2.30	2.70	3.80	1.62	0.17	-0.23	1.02	MS,VWS,NS,MK
L2S4	1.00	1.00	1.00	0.35	0.45	0.75	1.55	0.03	0.16	-0.32	0.86	CS,VWS,VNS,PK
L3S1	0.95	1.60	2.20	3.05	3.65	3.95	4.65	2.87	0.23	-0.64	1.05	FS,VWS,VNS,MK
L3S2	0.8	1.15	1.45	2.40	3.20	3.50	4.15	2.35	0.21	-0.30	0.78	FS,VWS,VNS,PK
L3S3	1.10	1.55	1.95	2.60	3.25	3.60	4.25	2.58	0.28	1.00	0.76	FS,VWS,SM,PK
L3S4	0.95	1.05	1.45	2.35	3.20	3.50	4.15	2.30	0.21	0.30	0.75	FS,VWS,VPS,PK
L3S5	1.00	1.00	1.00	1.30	2.40	3.00	4.00	1.77	0.19	-0.38	0.88	MS,PS,VNS,PK
L4S1	1.00	1.80	2.30	3.10	3.65	3.85	4.35	2.91	0.20	0.80	0.82	FS,VWS,SM,PK
L4S2	1.00	1.58	2.20	3.10	3.58	3.60	4.10	2.76	0.12	-0.29	0.49	FS,MS,NS,VPK
L4S3	0.90	1.30	1.65	2.45	3.30	3.70	4.40	2.48	0.39	-0.30	0.87	FS,VWS,VNS,PK
L4S4	1.00	1.00	1.00	1.70	2.60	3.00	3.95	1.90	0.20	-0.38	0.76	MS,VWS,VNS,PK
L5S1	0.95	0.95	1.10	2.00	3.00	3.40	4.30	2.12	0.22	-0.28	0.72	FS,VWS,NS,PK
L5S2	1.60	2.20	2.50	3.10	3.60	3.80	4.18	3.00	0.15	-0.71	0.96	FS,VWS,VNS,MK
L5S3	1.00	0.70	0.30	0.60	1.20	1.55	1.85	0.48	0.19	0.10	0.23	CS,VWS,SM,VPK
L6S1	1.00	1.00	1.00	0.35	0.45	0.70	1.40	0.02	0.28	0.12	0.67	CS,VWS,SM,PK
L6S2	1.00	1.00	1.20	0.10	0.70	1.20	2.00	0.10	0.20	0.10	0.70	CS,VWS,SM,PK
L6S3	1.00	1.00	1.20	2.15	3.10	3.50	4.15	2.22	0.21	0.31	0.68	FS,VWS,PS,PK
L7S1	1.00	1.00	1.00	1.40	2.20	2.70	3.40	1.70	0.16	-0.50	0.82	MS,VWS,VNS,PK
L7S2	1.00	1.00	1.00	-0.8	0.10	0.55	1.10	0.42	0.14	-0.3	0.55	CS,PS,VNS,VPK
L7S3	1.00	0.70	0.30	0.60	1.20	1.55	1.85	0.48	0.19	0.10	0.23	CS,VWS,SM,VPK

Legend: FS-Fine sand, VWS-very well sorted, SM-symmetrical, PK-platykurtic, CS- coarse sand, PS-poorly sorted, VNS-very negatively skewed, VPK- very platykurtic,

The mean grain sizes (M_z) ranged from 0.02 to 3.00 (coarse to fine sand), sorting was in the range of 0.1 to 0.39, indicating very well sorted to well sorted sand, skewness ranged from -0.71 to 1, kurtosis ranged from 0.23 to 1.05 indicating that the samples are very platykurtic and mesokurtic. According to Mcmanus (1995), beach sands are well sorted and negatively skewed while river sands are less well sorted and

usually positively skewed. From the granulometric result, the sorting values indicate that 88% of the samples were very well sorted while 12 % were poorly sorted. 60% of the samples were negatively skewed, 32% were symmetrical while 8% were positively skewed. The well sorted nature of the samples and negatively skewed nature of most of the samples support beach origin.

Comparison of the bivariate plots of mean grain size versus sorting (Fig. 2) and skewness versus sorting (Fig. 3) with similar work by Moiola and Weiser (1968) and Freidman (1961) respectively,

show that the environment of deposition is beach since majority of the points fall within the beach realm.

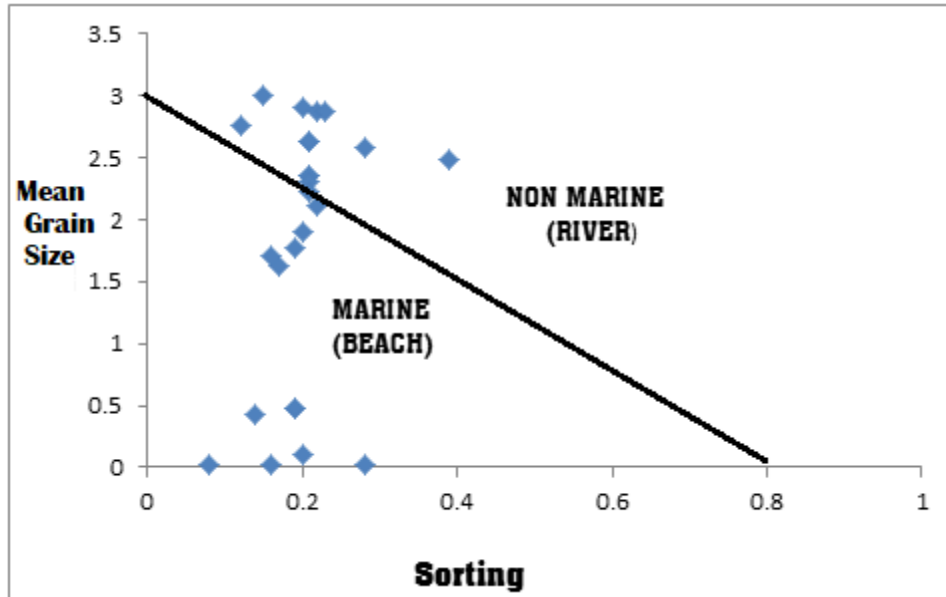


Figure 2: Plot of mean grain sizes versus sorting after Moiola and Weiser (1968)

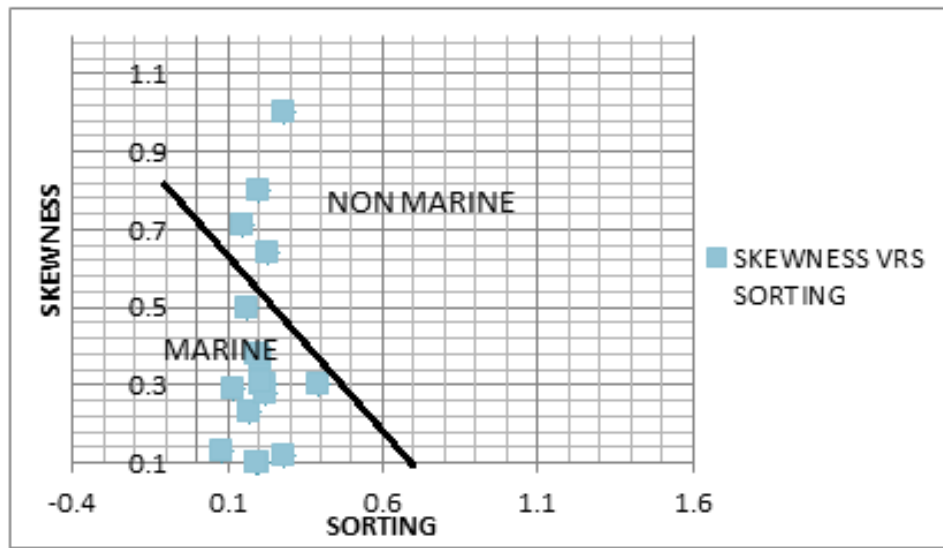


Figure 3: Bivariate plot of Skewness versus Sorting after Friedman (1961)

4.2 Pebble Morphometric Analysis Result

Pebble morphometry has been used by Dobkin and Folk (1970), Stratten (1974), Lutig (1962) Sneed and Folk (1958), Same (1966) and Petters

(1989) to aid depositional environment diagnosis. The mean values of the various morphometric parameters (Table 2) ranged as follows: flatness

ratio ($\frac{S}{L} = 0.31 - 0.67$), elongation ratio ($\frac{I}{L} = 0.58 - 0.78$), maximum projection sphericity ($\Psi_p = 0.54$). According to Dobkin and Folk (1970), particular gravel clasts shape concentrate in particular environments, for example disc-shaped clasts accumulate on beaches while rollers or elongate clasts and bladed type accumulate in rivers. From the result obtained (Table 2 and Fig. 6), 90% of the samples were compact bladed, 5% bladed while 5% were compact elongated, which means that the environment of deposition is likely to be beach.

In a comparative study of gravels obtained from beaches and rivers in Southern Africa, Stratten (1974) found that fluvial pebbles have mean coefficient of flatness of more than 45 and that their mean sphericity exceeds 0.65. Dobkin and Folk (1970) in their study of basalt pebbles in rivers and beaches in Tahiti-Nui, arrived at a lower limit of 0.66 for the mean sphericity of fluvial pebbles, a figure very close to that of Stratten (1974).

– 0.73), Oblate prolate index ($\bar{O}\bar{P} = -0.73 - 5.41$), coefficient of flatness (31.49 – 53.15).

Dobkin and Folk, 1970 also found that the mean oblate – Prolate index of fluvial pebbles exceeds – 1.5, whereas the value of beach pebbles is lower. Therefore, the following values indicate the lower index limit for pebbles shaped in fluvial environment: Sphericity (0.65), Coefficient of flatness (45), Oblate – Prolate index (-1.5).

From the result (Table 2) the mean values of the above three indices from most of the sample are well below the lower limits for fluvial pebbles thus indicating a beach origin of sedimentation. Comparison of the bivariate plot of coefficient of flatness against maximum projection sphericity (Fig. 5) with similar work by Stratten (1974) shows that majority of the points lie in beach environment. Also, comparison of the bivariate plot of maximum projection sphericity versus Oblate – Prolate index (Fig. 4) with similar work by Dobkin and Folk (1970) shows most of the points plotting within the beach realm.

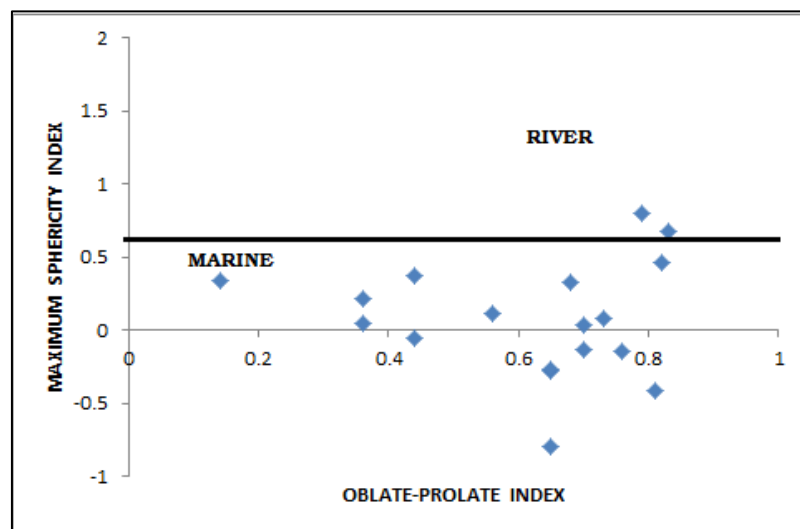


Fig. 4: Plot of maximum projection sphericity versus oblate-prolate index after Dobkin and Folk (1970)

Table 2: Mean Values of Pebbles Measured

Sample Number	L(cm)	I (cm)	S (cm)	I/L	S/L	L-I/L-S	ΨP	$\bar{O}\bar{P}$	Coefficient of flatness	Form
L1S1	3.27	1.93	1.34	0.60	0.42	0.699	0.67	4.76	42.57	CB
L1S2	3.27	1.93	1.34	0.60	0.42	0.699	0.67	4.76	42.57	CB
L1S3	2.17	1.45	0.84	0.67	0.39	0.56	0.59	-0.09	39.10	CB
L2S1	3.37	2.47	1.66	0.75	0.50	0.49	0.69	-0.07	50.17	CB
L2S2	3.31	2.52	1.59	0.77	0.49	0.44	0.67	-0.11	48.52	CB
L2S3	2.67	1.82	1.25	0.69	0.48	0.95	0.67	0.69	48.00	CE
L3S1	4.07	2.26	1.59	0.73	0.42	0.46	0.65	-0.73	41.88	CB
L3S2	3.11	1.81	1.00	0.59	0.31	0.616	0.54	3.39	31.49	CB
L7S1	3.36	2.28	1.41	0.70	0.43	0.50	0.64	0.62	43.00	CB
L7S2	2.78	1.75	1.34	0.65	0.51	0.70	0.73	4.48	51.16	CB
L7S3	2.87	2.05	1.42	0.78	0.52	0.44	0.70	-0.08	52.19	CB
L8S1	2.38	1.61	1.44	0.62	0.67	0.46	0.63	-0.39	42.00	CB
L8S2	3.79	2.67	1.59	0.73	0.42	0.46	0.63	-0.73	41.88	CB
L8S3	2.72	1.8	1.19	0.70	0.48	0.55	0.70	0.20	48.00	CB
L9S1	6.63	4.58	4.48	0.74	0.53	0.38	0.72	0.17	53.15	CB
L9S2	4.99	2.94	2.13	0.61	0.45	0.68	0.68	5.41	45.00	CB
L9S3	3.3	1.95	1.25	0.61	0.38	0.66	0.63	4.12	38.96	CB
L10S1	2.14	1.5	1.06	0.70	0.50	0.61	0.70	2.21	49.53	CB
L10S2	3.06	1.75	1.21	0.58	0.40	0.71	0.65	5.30	40.00	B
L1S3	2.48	1.86	1.19	0.75	0.49	0.46	0.63	-0.73	41.88	CB

Legend: CB-compact, B-bladed, CE-compact elongated

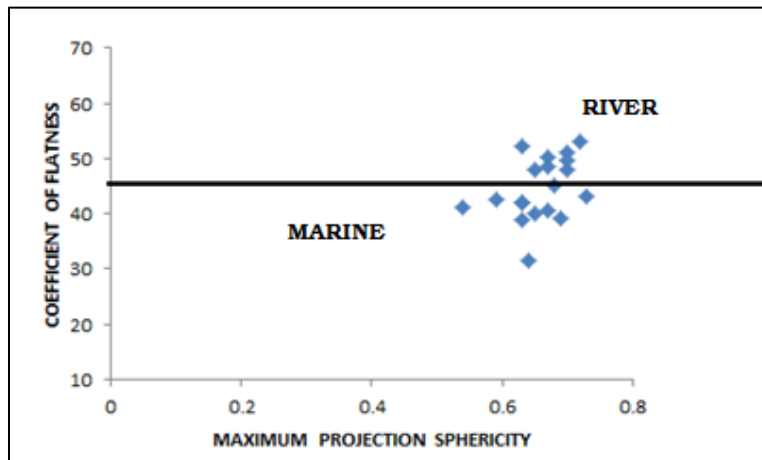


Fig. 5: Plot of coefficient of flatness versus maximum projection sphericity after Stratten (1974)

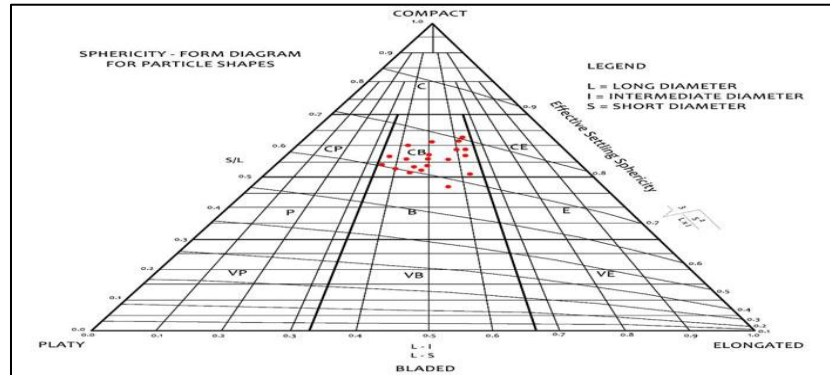


Fig. 6: Sphericity form diagram for particle shapes after Sneed and Folk (1958). Each point is a plot of ten pebbles

5.0 Conclusion

The shapes of the pebbles in the study area were bladed, compact bladed and compact elongated which suggests beach origin according to Dobkin and Folk (1970). The mean values of the various morphometric parameters are below the uppermost limit for beach pebbles thus lending credence to beach depositional environment. Also, majority of the sand samples were well sorted and negatively skewed which indicates beach depositional milieu. In conclusion, this study reveals that the sandstone lithofacies of the Ameki Formation in the northeastern part of Akwa Ibom State, Niger Delta Basin, Nigeria was likely deposited in a beach environment.

Conflict-of-Interest Disclosure: There was no financial conflict of interest.

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