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Morphometry and Paleoenvironment of Pebbles from the Agbani Sandstone, southeast Nigeria

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Abstract

Pebbles from outcrops of Agbani sandstone at Amuri town southeast Nigeria were subjected to morphometric analysis in order to investigate the depositional environment. The pebbles are sub-rounded to well-rounded, monomictic, and matrix-supported sandy conglomerates. Morphometric analysis indicates the following range values: The Flatness Ratio (FR) 0.23 to 1.24 (average = 0.61), Elongation Ratio (ER) 0.40 – 1.43 (Average = 0.81), Flatness Index 0.36 to 1.03 (average = 0.81), Maximum Projection Sphericity Index (M.P.S.I) 0.44 to 1.03 (average = 0.77), Oblate–Prolate Index -4.9 to 15.89 (average = 0.11), roundness 30 and 85% (average = 56.9%), and preponderance of equant/spherical pebbles are indicative of fluvial process. The dominant forms of the pebbles are the compact, compact-bladed, compact platy, and bladed forms which are synonymous with fluvial setting. The bivariate plots indicated that river processes deposited the pebbles while some of the pebbles might have also been deposited in a transitional environment. The roundness of the pebbles suggests a long distance travel and random orientation suggests turbulence or bedload deposits under low energy environment.

Keywords: *Agbani sandstone, Environment, Fluvial, Pebbles, Roundness.*

1. Introduction

The utilisation of pebble indices in paleo-environmental analysis has been established and observed to be valuable, in both modern and ancient pebble deposits (Dobkins and Folks, 1970; Stratten, 1974). A pebble is a clastic coarser, loose gravel material with a particle size of 4 to 64 millimetres (-2 to -6 Phi) based on the Udden-Wentworth scale. When pebbles are lithified, they are called pebble conglomerates. The nature of sediment varies in origin, size, shape, and composition; particles such as grains and pebbles may be derived from the erosion of older rocks or directly ejected from volcanoes (Nichols, 2009). The rounding of gravel results from abrasion in transport by streams, glaciers, and sea waves. Pebbles mutually abrade each other, defining the time evolution for the abraded pebble and for the abrading environment, represented by other particles subject to particle transport (Domokos and Gibbons, 2012). Because of changing conditions, gravel formations generally are more limited and more variable in coarseness, size, and configuration than sand or clay deposits sediments. The size, shape, and distribution of particles all provide clues to how the materials were carried and deposited (Nichols, 2009). It has been shown and proved that pebble morphometric parameters may be helpful, as additional indicators, in deciphering the processes of transport and depositional environment (e.g., Sneed & Folk, 1958; Lutig, 1962; Sames, 1966; Dobkins & Folk, 1970; Stratten, 1974; Gale, 1990, 2021; Widera, 2010; Okoro et al., 2012; Odumodu & Israel, 2014; Ocheli et al., 2018; Madi & Ndlazi, 2020; Oluwajana et al., 2021).

Zigede et al. (2015) studied the paleoenvironment of sandstones within Enugu State University of Science and Technology, Agbani Campus using pebble morphometry and textural analysis. The authors utilized only fifteen pebbles and the Maximum Projection Sphericity Index (MPSI), Flatness Index (FI), and Oblate-Prolate Index (OPI) for their analyses.

This study aims to carry out a morphometric analysis of pebbles in the Agbani sandstone to infer the depositional environment. The scope entails measuring the pebble roundness, Elongated Ratio (ER), Flatness ratio (FR), Coefficient of Flatness (CF), Maximum Projection Sphericity Index (M.P.S.I), Oblate-Prolate index (OPI), Flatness Index (FI), long (L), Intermediate (I), Short axes (S) and using bivariate and ternary plots.

2. The Study Area

The study area is located in Nkanu-West local government area, southeast of Enugu State and lies within latitudes 6^0 15. 53^1N and 6^0 15. 53^1N and longitudes 7^0 31. 32^1 E and 7^0 31. 23^1 E in the Lower Benue Trough (Figure 1). The major access route to the area is by a roadcut linking Enugu Port Harcourt expressway to Ebonyi through Ozilla, Obe, Umueze, Agbani, Akpugo, and a minor road linking Agbani to Amurri. The Benue Trough is comprised of three segments: The Lower, Middle and Upper (Fig. 2). The study area is located in the southern part of the Lower Benue Trough. There is no obvious definition for each segment, the major towns, localities, or settlements that form the hub of various areas. They are widely conveyed in published materials (Petters, 1982; Nwajide, 1990; Idowu and Ekweozor, 1993).

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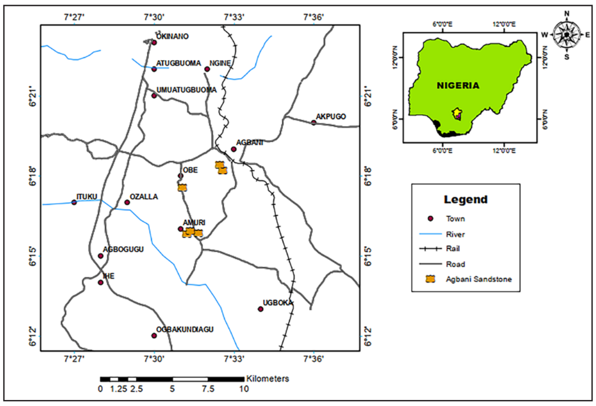

Figure 1. Location map of the study area.

The origin of the basin is generally linked to the Santonian tectonics of the Abakaliki-Benue Basin, during which an N-S compression between the African and Europeans plates folded the Abakaliki Anticlinorium (Maluski et al., 1995). The structural evolution of the Lower Benue Trough has been described by Binks and Fairhead (1992), Obi et al. (2001), Obi and Okogbue (2004). Prior to the tectonic event the Lower Benue Trough was a thinly covered platform by sediments. The folding of the anticlinorium laterally shifted the depositional axis into the Anambra platform which then began to accumulate sediments shed largely from the Abakaliki Anticlinorium (Murat, 1972; Hoque and Nwajide, 1984; Amajor, 1987). The Benue Rift was known as the failed arm of a trilete fracture (rift) system (Figure 2), during the breakup of the Gondwana supercontinent and the opening of the Southern Atlantic Ocean during the Jurassic (Hoque and Nwajide, 1984).

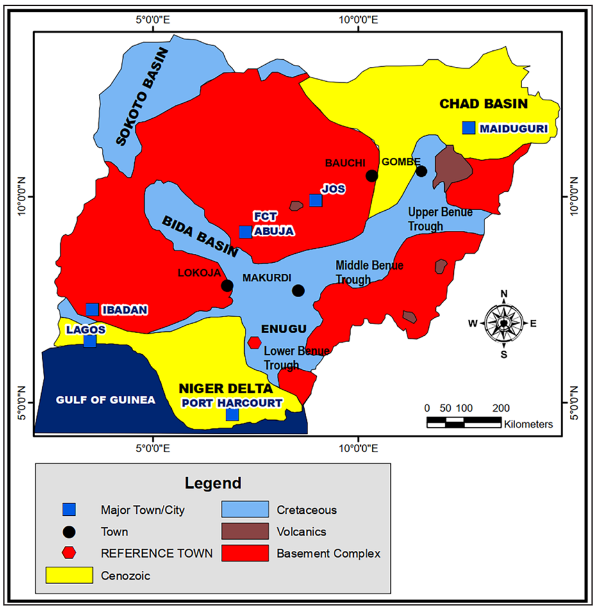

Figure 2. Map of the Benue Trough showing the study location. (Modified from Obaje et al., 2009).

The initial syn-rift sedimentation in the embryonic trough occurred during the Aptian to early Albian and comprised alluvial fans and lacustrine sediments of the Mamfe formation in the Southern Benue Trough (Obaje, 2009). Ojoh and Popoff (1989) established three principal subsidence trends in the region: It was high during the Albian, low in the Cenomanian, and high during the Turonian-Coniacian. According to Ramanathan and Fayose (1990), the Benue Trough has four key depositional cycles that are concomitant with transgression and regression: The first cycle occurred between Middle Albian to Upper Albian and postulated to be the result of the opening of the South Atlantic Ocean, the second ranged from Upper Cenomanian to Middle Turonian, the third spanned from the Upper Turonian to the Lower Santonian and concomitant with the deposition of Awgu shale and Agbani sandstone, and the fourth cycle marked the transgressive Campanian-Maastrichtian stage in the Lower Benue Trough (Figure 3).

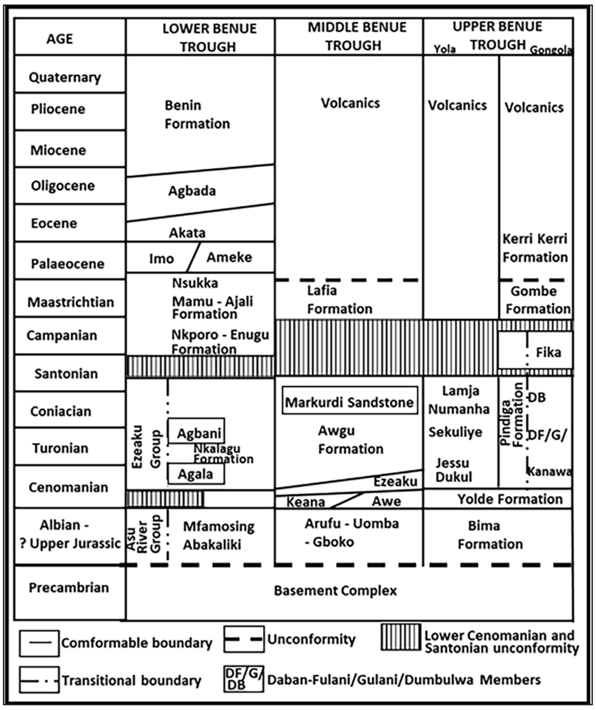

Figure 3. Stratigraphy of the Benue Trough (from Abubakar, 2014)

The Agbani sandstone is the siliciclastic facies of the Santonian sediment influx that ended the Coniacian-Santonian marine sedimentation (Nwajide, 2013). The sandstones are white, medium to coarse grained, poor to moderately sorted and cross laminated, depicting a fluviatile environment as a result of regression during Coniacian to Lower Santonian (Agagu and Ekweozor, 1982). The Agbani sandstone is a rough time equivalent of the Agwu shale (Reyment, 1965). It is a NE-SW trending lensoidal sandstone body which is difficult to trace and map laterally due to poor exposures; it is estimated to be 40 km long and 10 km wide with an exposed thickness of 30-50 m (Agumanu, 2011). Amuri, the study area, has an elevation of about 140m above sea level. The Coniacian Agbani sandstones exposed at Amuri are coarse grained, poorly sorted and contain sub-rounded to well-rounded quartz pebbles with random orientation.

3. Materials and Methods

More than three hundred pebbles were collected from three different outcrops at Amuri. These pebbles were washed, screened to exclude pebbles that were cracked or broken, numbered, and sent to the laboratory for analysis: Only isotropic pebbles that have high resistance to wear were considered representative of the pebbles (Figure 4).

Figure 4. Field photograph of the pebbles at Amuri

Measurements of the scale of the long (L), intermediate (I), and the short axes (S) of the pebbles were made using a Vernier Caliper. The dimension of pebble axes is based on the method suggested by Folk (1980). Pebble roundness were also estimated based on the set of pebble images given by Powers (1953); the image set is based on the proportion of the grain surface that is convex.

From the measurements of pebble axes and roundness, the following morphometric parameters were determined: Flatness Ratio (FR), Elongation Ratio (ER), Coefficient of Flatness (CF), Flatness Index (FI), Maximum Projection Sphericity Index (MPSI), and Oblate-Prolate index (OPI).

Flatness Ratio (FR) is the ratio between the short axis to the long axis (Lutig, 1962) and is evaluated via equation 1:

$$FR = \frac{S}{L} \quad (1)$$

Elongation Ratio (ER) is the ratio between the intermediate to the long axis based on Lutig (1962) and is evaluated via equation 2:

$$ER = \frac{I}{L} \quad (2)$$

The Coefficient of Flatness (CF) was determined usingequation 3 (Lutig, 1962):

$$CF = \frac{S}{L} \text{ x } 100 \quad (3)$$

Equation 4 by Illenberger (1991) was utilized to obtain the Flatness Index (FI) and expressed as:

$$FI = \frac{L-I+S}{L} \quad (4)$$

The measure of equidimensionality (sphericity) of the pebbles was determined using the Maximum Projection Sphericity Index (Sneed and Folk, 1958); it is the cube root of the ratio between the square of the short axis and the product of the long and intermediate axis and calculated via equation 5:

$$MPSI = \sqrt[3]{\frac{S^2}{LI}} \quad (5)$$

The Oblate-Prolate (OP) index shows how close the intermediate (I) axis of a pebble is to the short axis or long (L) axis (Dobkins and Folk, 1970). The Oblate-Prolate Index (OPI) is given by equation 6:

$$OPI = 10\left[\frac{L-I}{L-S} - 0.50\right] S/L \quad (6)$$

The mean and standard deviation of each of the indices were 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 (Odumodu and Ephraim, 2007). Sneed and Folk's sphericity form diagram (1958) and Zingg's shape classes (1935) were used to determine the form name of each pebble set. These parameters were used independently to interpret the paleoenvironment of deposition and as dependent variables in binary plots such as MPSI vs OPI (Dobkins and Folk, 1970); Flatness index vs MPSI (Folk, 1955), and Roundness vs elongation.

4. Results

The pebbles are in a coarse sandstone (Figure 4). The pebbles are sub-rounded to well-rounded monomict (Figure 5), matrix-supported sandy conglomerates. The result, obtained from the morphometric analysis of the pebbles, is shown in Table 1: the long axis of the pebbles ranges from 0.41 to 3.30 cm in length with an average of 1.08 cm, while the intermediate and short axes range from 0.31 to 2.20 cm, and 0.20 to 1.52 cm, with averages of 0.86 cm and 0.65 cm respectively. The Flatness Ratio (FR) ranges from 0.23 to 1.24 (average = 0.61). The Elongation Ratio (ER) ranges between of 0.40 – 1.43 (Average = 0.81). The Flatness Index range from 0.36 to 1.03 (average = 0.81). The maximum projection sphericity index (M.P.S.I) range from 0.44 to 1.03 (average = 0.77), while the Oblate–Prolate Index ranges between -4.9 to 15.89 (average = 0.11). The particle roundness for the pebbles under investigation ranges between 30 and 85%, (average = 56.9%) and indicates sub-rounded to well-rounded status.

Figure 5. Pebbles studied.

Table 1. Summary of pebble measurements and morphometric parameters

Morphometric Parameters	Pebble Sets S-1 (n = 100)	Pebble Sets S-2 (n = 100)	Pebble Sets S-3 (n = 100)	Total Pebble Sets (n = 300)		
	Average	Average	Average	Minimum	Maximum	Average
Long axis (L) cm	0.76	0.96	1.52	0.41	3.3	1.08
Intermediate axis (I) cm	0.58	0.76	1.23	0.31	2.2	0.86
Short axis (S) cm	0.42	0.58	0.95	0.2	1.52	0.65
Mean size	0.59	0.77	1.23	0.34	2.19	0.86
Roundness (%)	56.9	60.65	53.15	30	85	56.9
Flatness Ratio (F.R)	0.57	0.62	0.64	0.24	1.25	0.61
Elongation Ratio (E.R)	0.77	0.81	0.83	0.4	1.43	0.8
Flatness Index	0.79	0.81	0.62	0.36	1.03	0.81
M.P.S.I	0.74	0.78	0.79	0.44	1.03	0.77
O.P. Index	0.11	-0.04	0.25	-4.9	15.89	0.11

Sneed and Folk (1958) diagram revealed two dominant forms for the pebbles examined (Figure 6). The result shows that the dominant shapes are the compact-bladed (28.33%) and the compact (26.67%) forms. Other notable forms are bladed (14.67%) and compact platy (11.55%). The distribution of the various pebble forms as defined by Sneed and Folk (1958) is presented in Table 2.

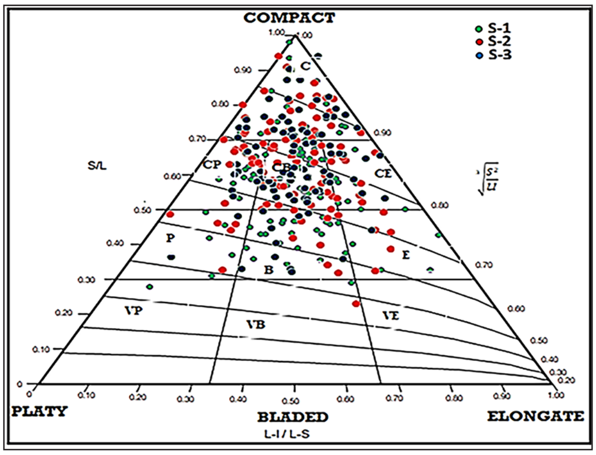

Figure 6. Sphericity-form diagram of the pebbles studied (after Sneed and Folk, 1958)
C = Compact, P = Platy, B = Bladed, E = Elongate, CP = Compact-platy, CB = Compact-bladed, CE = Compact-elongate, VP = Very-platy, VB = Very-bladed, VE = Very-elongate

Table 2. Form classification for the pebbles studied (after Sneed and Folk, 1958)

Form	Count	Percent
Compact	80	26.67
Compact-Platy	34	11.33
Compact-Bladed	85	28.33
Compact-Elongate	30	10
Platy	12	4
Bladed	44	14.67
Elongate	12	4
Very-Platy	1	0.33
Very-Bladed	2	0.67
Very-Elongate	0	0
TOTAL	300	100

5. Discussion

The pebbles examined are quartzose, with a mean size of 0.86 cm (8.6 mm). The sub-rounded to well-rounded nature of the pebbles suggests a long-distance journey from the source (extra formational). According to Madi and Ndlazi (2020), pebbles that are quartzose in composition are common river pebbles that have traveled for a long distance.

Geometric forms depict the three-dimensional aspects of a pebble utilized for their classification. Sneed and Folk (1958) proposed ten geometric forms: compact, compact platy, compact bladed, compact elongated, bladed, elongated, platy, very platy, very bladed, and very elongated that are diagnostic of certain environments. The compact (C), compact platy (CP), compact bladed (CB), and compact elongated (CE) pebbles are diagnostic of fluvial environments. Platy, bladed, and elongated pebbles are diagnostic of a transitional environment, while very platy, very bladed, and very elongated are diagnostic of a marine (beach) environment (Ocheli et al., 2018). The distribution of the various pebble forms as defined by Sneed and Folk (1958) is presented in Table 2 and Figure 6 which revealed that the dominant shapes are the compact-bladed (28.33%) and the compact (26.67%). Other notable forms are bladed (14.67%) and compact platy (11.55%), these percentages suggest a fluvial environment. Because river and beach environments contain bladed pebbles, the bladed forms were probably deposited under tidal influences, which is suggestive of a fluvial–tidal (transitional) environment of deposition

The mean roundness value of 57% for the studied samples falls within the 55 - 65% range which Lutig (1962) depicted as typifying fluvial pebbles and below 80 - 95% range for marine pebbles. This mean roundness value also shows that the pebbles are predominantly rounded, suggesting a long travel distance. The pebbles are scattered in the Agbani sandstone with no definite orientation; this suggests turbulence or bedload deposits under low energy. According to Tucker (2011), rocks with a uniform composition and structure, such as several granites, dolerites, and thick-bedded sandstones will give rise to equant/spherical pebbles, thin-bedded rocks will generally form tabular and disc-shaped clasts, and highly cleaved or schistose rocks such as slates, schists or some gneisses will generally form bladed or rod-shaped pebbles. Figure 7 shows that 70% of the pebbles are plotted in the equant/spherical zone, the discoidal/tabular forms make up approximately 17%, and the rod-shaped constitute about 10% of the pebbles. The equiaxial nature of the pebbles signifies a propensity towards sphericity, which decreases downstream. Consequently the high amount of equant/spherical pebbles signifies a fluvial influence. According to Barudžija et al. (2020), homogeneous rocks such as massive limestones, dolomites, quartzites, or marbles form sphere, and disc pebble shapes. The distribution of pebbles' shapes into mainly disc-, rod-, and sphere-shaped may signify different clast fabrics and multiple sources (e.g., Sremac et al., 2018; Barudžija et al., 2020). The Flatness Ratio for the pebbles ranges between 0.23 and 1.24 with an average of 0.61. The percentage of Flatness Ratio can be used to discriminate between fluvial and beach pebbles, a value of more than 45% is indicative of fluvial pebbles (Stratten, 1974). The majority of pebbles (87%) have values more than 45%, suggesting a fluvial environment. The Elongation Ratios for the samples range from 0.40 to 1.43 (average = 0.8). According to Hubert (1968); the elongation ratio values for fluvial environment range between 0.6 and 0.9. The majority of the values of elongation ratio, obtained (> 80%) for the pebbles in this study, fall within Hubert's range for fluvial environment.

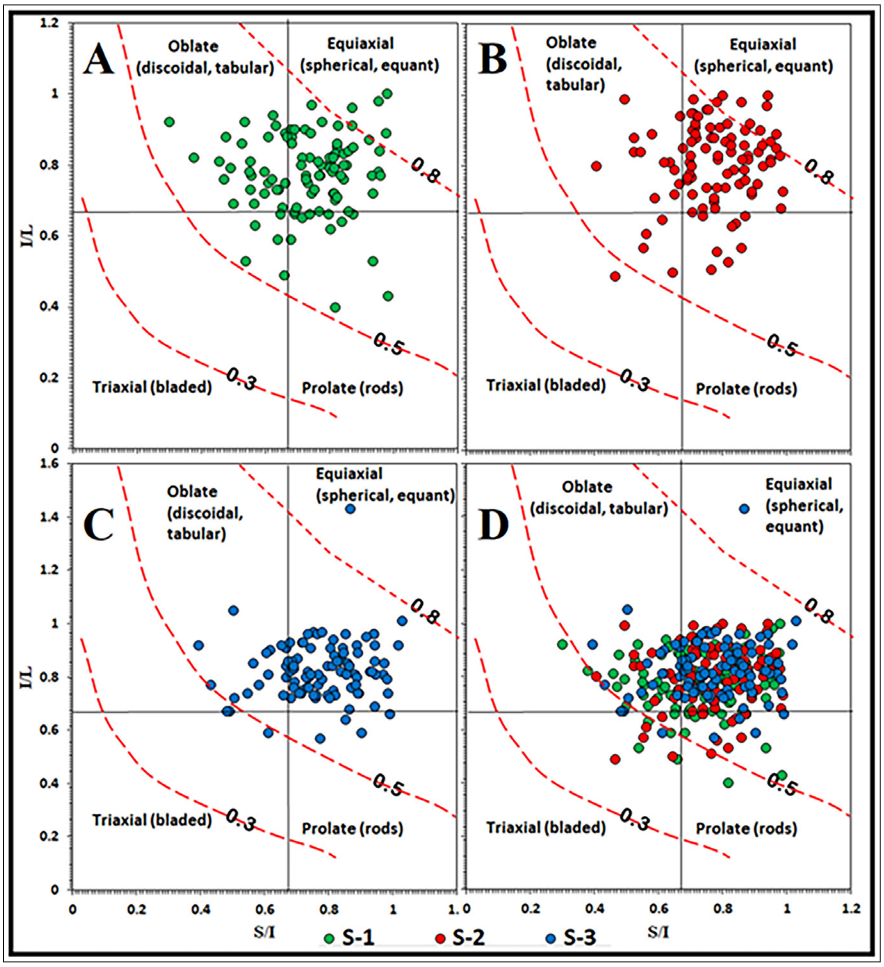

Figure 7. Classification of Amuri pebble shapes, after Zingg (1935) showing lines of equal Wadell (1932) sphericity. Curves represent grains of the same sphericity by the formula . A, B and C represents plots of the outcrops S-1, S-2 and S-3 respectively, while D is a combination of the three.

The Maximum Projection Sphericity Index (MPSI) for the pebbles fall within 0.44 and 1.03 with a mean of 0.77. According to Dobkin and Folk (1970), Hubert (1968), and Sneed and Folk (1958), the maximum projection sphericity of pebbles is generally high for fluvial environment than for beaches. Pebbles whose values fall within 0.65 and above were likely deposited via fluvial processes, while pebbles whose values fall below 0.65 are indicative of a beach environment (Dobkins and Folk, 1970). The percentage of pebbles with maximum projection sphericity values greater than 0.65 is approximately 90%, indicating a fluvial setting. 99.7% of the measured pebbles have flatness index values greater than 45% which indicate deposition by fluvial-influenced processes. The values for the Oblate-Prolate Index (OPI) range from -4.9 to 15.89 with 88% above -1.5 which Dobkins and Folk (1970) classified as fluvial. The bivariate plot of Flatness Index against Maximum Projection Sphericity Index (Figure 8), Coefficient of Flatness against Maximum Projection Sphericity Index (Figure 9), and bivariate plot of Maximum Projection Sphericity Index against Oblate-Prolate Index (Figure 10) for the pebbles show that majority of the pebbles plotted in the fluvial zone. This suggests that the pebbles were largely deposited by river processes while some of the pebbles might have also been deposited in a transitional environment.

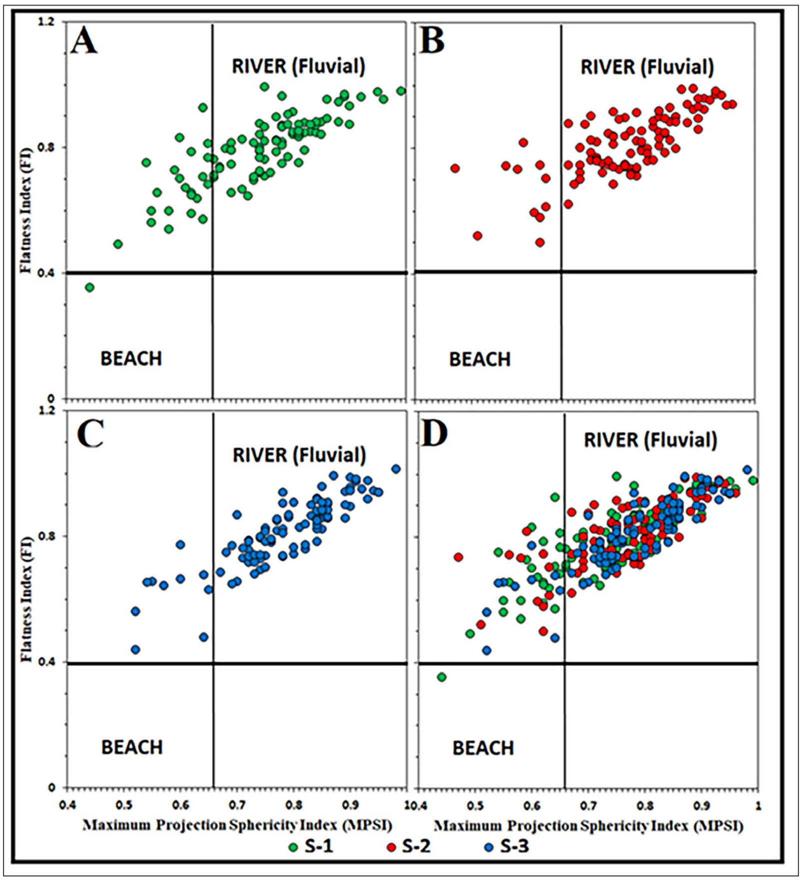

Figure 8. Bivariate plot of Flatness Index (FI) against Maximum Projection Sphericity Index of the studied pebbles (After Dobkins and Folk, 1970). A, B and C represents plots of the outcrops S-1, S-2 and S-3 respectively, while D is a combination of the three.

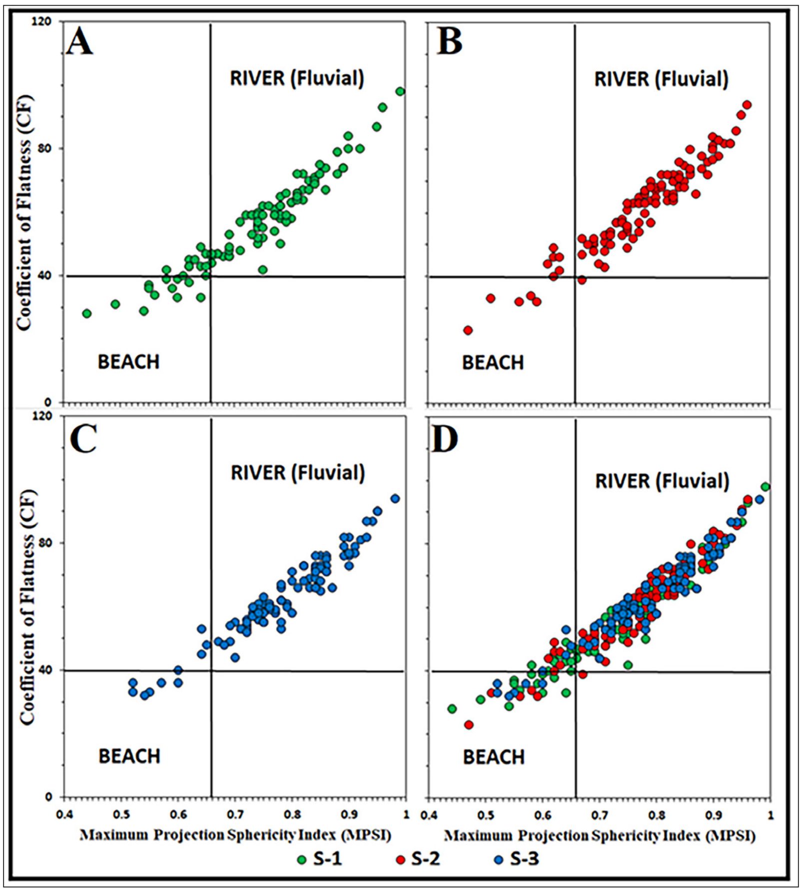

Figure 9. Plot of Coefficient of Flatness against sphericity of the studied pebbles (After Stratten, 1974). A, B and C represents plots of the outcrops S-1, S-2 and S-3 respectively, while D is a combination of the three.

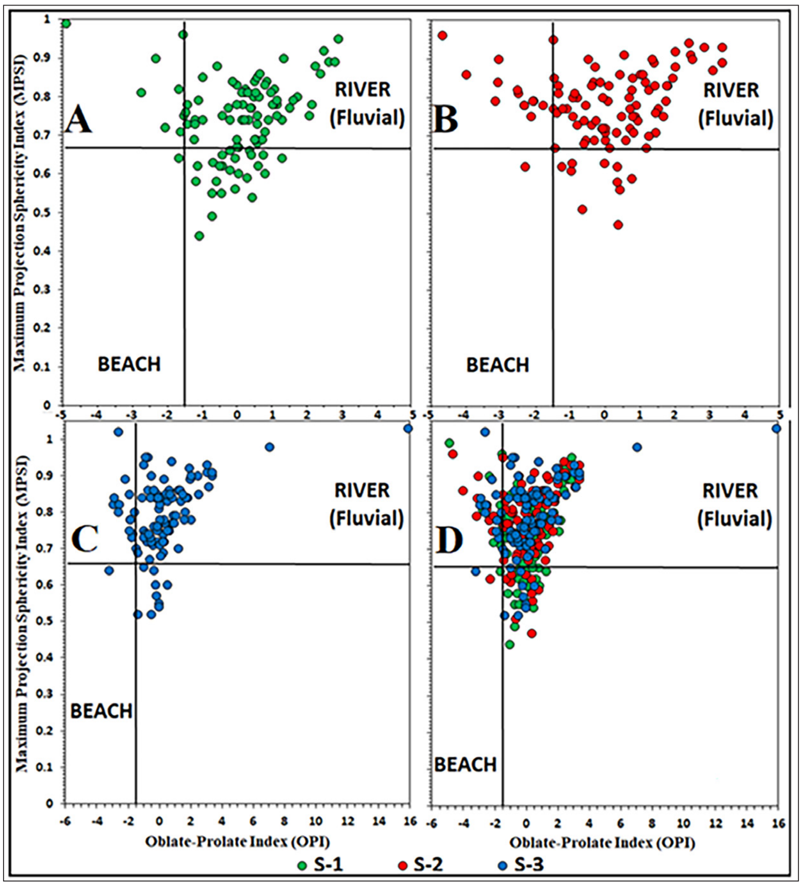

Figure 10. Bivariate plot of Maximum Projection Sphericity against Oblate-Prolate Index of the pebbles studied (After Dobkins and Folk, 1970). A, B and C represents plots of the outcrops S-1, S-2 and S-3 respectively, while D is a combination of the three.

6. Conclusion

1. The Coniacian Agbani sandstones exposed at Amuri contain quartz pebbles with no definite orientation and are sub-rounded to well-rounded. The pebbles are monomict, matrix-supported sandy conglomerates.
2. The rounded nature of the pebbles suggests a long distance travel from the source.
3. The mean roundness (57%), Flatness Ratio (0.61), Elongation Ratios (0.8), Maximum Projection Sphericity Index (0.77), Oblate-Prolate Index (0.11), and preponderance of equant/spherical pebbles suggest a fluvial setting.
4. The dominant shapes are the compact-bladed (28.33%), compact (26.67%), bladed (14.67%), and compact platy (11.55%). These percentages suggest a fluvial dominant environment.
5. Bivariate plots of Flatness Index against Maximum Projection Sphericity Index, Coefficient of Flatness against Maximum Projection Sphericity Index, and bivariate plot of Maximum Projection Sphericity Index against Oblate-Prolate Index for the pebbles suggest that the pebbles were largely deposited by river processes while some of the pebbles might have also been deposited in a transitional environment.
6. The pebbles are scattered in the sandstone and this suggests turbulence or bedload deposits under low energy.

Declaration

This paper has not been submitted/ published elsewhere in the same form, in English or in any other languag. The paper is the original work of the author(s) and not copied (in whole or in part) from any other work.

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