PEBBLE MORPHOMETRIC ANALYSIS AND DEPOSITIONAL ENVIRONMENT OF THE BASAL CONGLOMERATES OF BIDA SANDSTONE EXPOSED AROUND ZUNGERU, NW NIGERIA

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ABSTRACT

The basal conglomerate lithofacies of Bida Formation is common along the basin margin where it overlies the rocks of the basement complex in Zungeru area, northwestern Nigeria. The conglomerate lithofacies contains abundant pebbles of vein quartz and the clasts of these pebbles were selected for morphometric study to determine their depositional environment. A total of 190 pebbles were selected from nineteen weathered outcrops for this study. The three mutually perpendicular axes; long, intermediate and short axes were measured and the roundness estimated with the aid of a roundness image set. Form names were obtained using triplot to generate Sneed and Folk diagram. Morphometric parameters such as size, flatness ratio, elongation ratio (ER), maximum projection sphericity index (MPSI), form geometry and oblate-prolate index (OPI) were computed. The bivariate plots of morphometric parameters such as coefficient of flatness versus MPSI, and MPSI versus OPI indicate that the pebbles were deposited in fluvial environment but bivariate plot of roundness versus elongation ratio showed that they were deposited in littoral (marine) environment. The dominance of bladed shape pebbles in the conglomerate lithofacies indicates that the basal conglomerates of Bida Formation exposed in Zungeru area is sourced from the surrounding basement such as schists and gneisses rich in vein quartz fills. It is concluded that these sediments are products of fluvial deposition with some marine influence.

Keywords: Bida basin, Bida Formation, Zungeru, Conglomerate, Morphometric, depositional, bivariate plot, fluvial

1. INTRODUCTION

In detrital sedimentary rocks, the surface characteristics of the grains make up the particle morphology, or form. These forms were acquired by the sedimentary grains during denudation processes such as weathering, erosion and transportation (Benn, 2010; Dumitriu *et al.*, 2011).

Variety of shape indices and diagrammatical presentations of pebble shapes have been proposed (e.g. Wentworth, 1922; Krumbein, 1941; Sneed and Folk, 1958; Dobkins and Folk, 1970; Blott and Pye, 2008). Data generated through morphometric analysis can be used to give important insight on sediment source origin, transportation history and sedimentation processes as well as in paleo-environmental determination (e.g. Hurst *et al.*, 2010; Tamrakar and Shrestha, 2008; Lindsey *et al.*, 2007; Graham and Midgley, 2000; Attal and Lavé, 2006). A variety of Conglomerate lithofacies have been reported in the northern part of Bida basin (Braide, 1992; Okosun *et al.*, 2009) but the one of interest in the present work is the conglomerates that occupy the base of the Bida Formation. This unit overlies the basement complex rocks directly and mostly outcrop near the margins of the basin. Even though their environmental implications were briefly discussed (Braide, 1992; Okosun *et al.*, 2009), information regarding pebble morphometry is lacking on these sediments. The purpose of the study is to analyse the shapes and forms of vein quartz pebbles in the coglomerate lithofacies exposed near Zungeru (NW Nigeria) and use the information to evaluate their depositional environment.

2. LOCATION AND GEOLOGICAL SETTING

The study area falls within latitude N09⁰46'54" and longitude E006⁰08'31" on Zungeru Sheet 163NW, northwestern Nigeria. The area is located about 1.5 km SW of Zungeru town. The study area is accessible through major roads like the Minna-Zungeru, Zungeru-Wushishi and the Zungeru-Kontagora in the north, west and southeast respectively. It is also accessible by innumerable minor roads and footpaths. By rail, it is accessible by Zungeru-Minna-Kano rail line to the north and Zungeru-Lagos rail line to the south.

Bida basin, one of the inland basins of Nigeria, is often described in terms of northern and southern Bida portions. Four lithostratigraphic units were recognised in the northern part of the basin (Adeleye, 1974; Adeleye and Dessauvagie, 1972; Figure 1). From the base they include the Bida Formation, the Sakpe Ironstone, the Enagi Siltstone and the Batati Formation. The Lokoja, Patti and Agbaja formations constitute laterally correlatable units from the southern part of the basin (Figure 1).

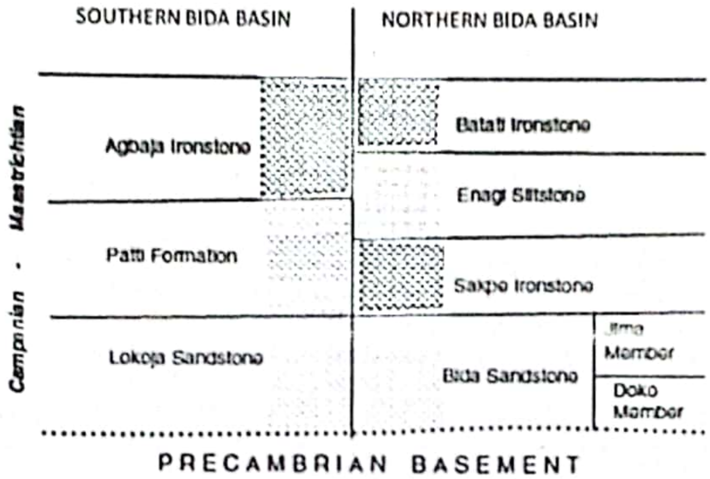


Fig. 1: Generalized stratigraphic subdivisions in the Bida basin (modified after Obaje, 2009).

The studied conglomerate lithofacies overlies the basement directly in Zungeru, Chechehi and Wushishi areas. The typical conglomerate unit is essentially a matrix-gravel mix in which the larger grains are very angular through sub-rounded granule to fine pebble-sized clasts of vein quartz, and in some cases weathered feldspars and clay chips are present. Cobbles and boulders are also common. Lithologies of the matrix vary from fine sand through silt to clay. Textural characters are poor sorting and matrix-support as well as crude bedding to massive appearance (Ajibade *et al.*, 2008; Okosun *et al.*, 2009).

3. MATERIALS AND METHODS

A total of 190 vein quartz pebbles were selected from 19 different locations of the conglomerates exposures within the study area. Locations of outcrops were obtained using GPS. The study involved the use of vernier calliper to measure the Long (L), Intermediate (I) and Short (S) axes of the selected pebbles following the guidelines of Stratten (1973) and Folk (1980). Morphometric parameters were obtained by adopting the formulas suggested by Luttig (1962) for determining the Flatness Ratio (FR), Coefficient of Flatness and Elongation ratio (ER); and Dobkins and Folk (1970) for evaluating the Oblate-Prolate Index (OPI). Maximum Projection Sphericity Index (MPSI) and Roundness of pebbles were computed according to procedures of Sneed and Folk (1958) and Sames (1966) respectively (Table 1). Tri-plot, an excel spreadsheet developed by Graham and Midgley (2000), was used to produce the Sneed and Folk triangular diagram (form name). Table 1 shows the morphometric parameters used in this work. The following parameters were plotted on a scatter plot, MPSI vs. OP Index (Dobkins and Folk, 1970), Coefficient of flatness vs. MPSI (Stratten, 1973) and Roundness vs. ER (Sames, 1966) to aid identification of the environment of deposition of the pebbles. The pebble samples were collected and measured in batches of ten (10). The dimensions of the vein quartz pebbles are presented on a data sheet for morphometric analysis according to Lambert-Aikhiobare and Olayinka (2009).

Table 1: Various formulas used in computation of the morphometric parameters.

PARAMETERS	FORMULA	AUTHORS
Flatness Ratio (FR)	Short axis/long axis (S/L)	Luttig (1962)
Coefficient of Flatness	S/L × 100	Stratten (1974); Els (1988)
Elongation Ratio (ER)	I/L	Luttig (1962)
Forms	L-I/L-S	Sneed and Folk (1958)
Maximum Projection Sphericity Index (MSPI)	$(S^2/LI)^{1/3}$	Sneed and Folk (1958)
Oblate-Orolate Index (OP)	10(L-I-0.5)/(L-S)/(S/L)	Dobkins and Folk (1970)
Form Names	Triangular Sphericity diagram	Sneed and Folk (1958)
Roundness %	Visual estimationof the pebbles	Sames (1966)

4. RESULTS PRESENTATION AND DISCUSSION

4.1 Results Presentation

4.1.1 Field Observations

The conglomerates directly overlie the precambrian basement complex rocks (Fig. 2a, b) and consists predominantly of vein quartz pebbles whose grain size are in order of millimetres to few centimetres (a maximum of 3.75 cm longest axis recorded) with subordinate amount of metaquarzite and metamorphic rock fragments, mainly schist. The quartz pebbles generally display angular to subrounded shapes while the metaquartzites commonly occur as equant pebbles and the schist pebbles are essentially disc to tabular shaped (Figure 2e and f). Both grain-supported (Figure 2c) and matrix-supported fabrics (Figure 2d) are displayed by the conglomerates but the later predominate. The conglomerate unit is averagely

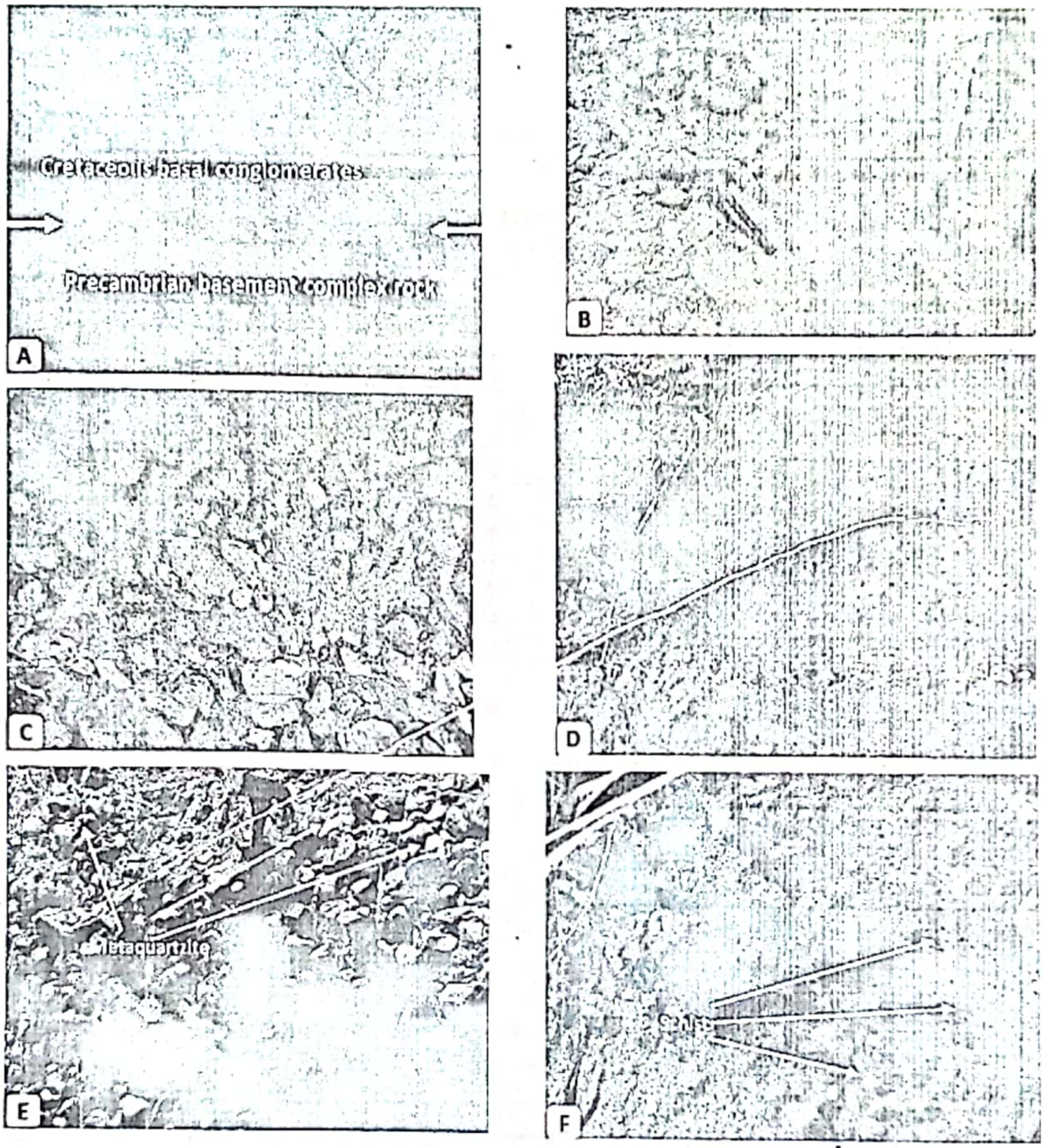


Fig. 3. Outcrop pictures showing typical features of the conglomerates exposed on a stream section near Zungeru NW Nigeria. [A] contact between the conglomerates and the Precambrian basement rocks [B] close-up view of (A); Note: the geologist is standing on the Precambrian basement rocks, [C] grain-support fabric, [D] matrix-support fabric [E] equant/rounded metaquartzite grains, [F] dics shaped schist pebbles

4.1.2 Morphometric Analysis

The results of pebble morphometry are presented in Table 2 while Table 3 shows the summary, i.e. total average, of the calculated pebble morphometric parameters. Scatter plot of MPSI vs. OP-Index is presented in Figure 3 for all samples in all the locations while Figure 4 shows scatter plot of total average (summary) of MPSI vs. OP-index. Figure 5 shows the scatter plot of coefficient of flatness vs. MPSI for all location and Figure 6 shows plot of total average of coefficient of flatness vs. MPSI. Roundness vs. Elongation ratio is presented in Figure 7. Sneed and Folk triangular diagrams for all locations and total average of all the locations are shown in Figures 8a and 8b respectively. Pebble suites in the study area display coefficient of flatness rangeing from 0.17 - 0.77 (average 0.73) and Elongation ratio of 0.33 - 0.97 (average 0.73), and Form with dominant Bladed shape with 31.05% and compact bladed with 17.37% and the Form takes values from 0.08 - 0.98 with mean of 0.51. The MPSI varies from 0.40 - 0.89 with mean of 0.66, Oblate-Prolate Index (OPI) ranges from -3.56 - 3.85 with mean of 0.66 while roundness ranges from 10 - 90% with a mean value of 51.47%.

Table 2: Summary of total average of pebble morphometric parameters for basal conglomerates of Bida Formation exposed around Zungeru NW Nigeria

Location	L(cm)	I(cm)	S(cm)	S/L	I/L	S/L×100	L-I/L-S	MPSI	OPI Index	Form Name	Roundness (%)	Effective radius
1	3.23	2.36	1.53	0.46	0.72	64.45	0.53	0.67	4.44	B	34.00	1.47
2	3.42	2.40	1.64	0.48	0.72	68.34	0.36	0.69	1.08	B	27.50	1.48
3	3.48	2.30	1.32	0.38	0.66	58.47	0.31	0.61	0.44	B	18.00	1.25
4	3.12	2.10	1.16	0.38	0.68	58.45	0.39	0.63	0.81	B	48.50	1.24
5	3.10	2.14	1.27	0.38	0.68	57.84	0.33	0.61	0.89	B	59.50	1.25
6	3.12	2.38	1.35	0.43	0.77	68.85	0.43	0.64	3.48	B	60.50	1.43
7	2.70	1.83	1.08	0.42	0.72	67.08	0.31	0.63	0.38	B	63.50	1.29
8	3.25	2.28	1.34	0.43	0.73	63.76	0.48	0.65	3.68	B	68.00	1.35
9	2.82	1.84	1.22	0.43	0.66	64.97	0.62	0.61	3.13	B	47.00	1.38
10	2.03	1.84	1.18	0.45	0.71	62.88	0.50	0.63	0.11	B	37.00	1.22
11	2.61	2.03	1.22	0.45	0.77	64.64	0.42	0.64	-0.11	B	30.00	1.36
12	2.70	1.89	1.14	0.40	0.71	59.82	0.27	0.51	0.87	B	43.00	1.22
13	2.50	1.80	1.19	0.41	0.72	68.12	0.32	0.61	0.10	B	18.00	1.39
14	3.75	2.81	1.78	0.47	0.75	60.84	0.43	0.63	0.48	B	33.00	1.39
15	3.36	2.72	1.75	0.22	0.82	32.23	0.48	0.78	0.17	CB	56.00	1.80
16	4.35	3.24	2.18	0.34	0.76	35.13	0.21	0.70	0.17	CP	33.00	1.71
17	3.58	2.48	1.83	0.34	0.70	33.74	0.45	0.77	0.62	CB	33.00	1.37
18	3.65	2.82	2.02	0.36	0.78	33.78	0.48	0.76	0.68	CB	42.00	0.67
19	3.10	2.28	1.62	0.34	0.73	33.63	0.35	0.75	0.40	CB	48.00	1.32
Average	3.22	2.52	1.45	0.46	0.73	66.42	0.51	0.66	0.66	B	51.47	1.42

Effective radius = $[(S^*-L)(S^*-I)(S^*-S)S^*]^{1/4}$ where $S^* = (L+I+S)/2$.

Table 3: Summary of the Pebble Morphometric Parameters

Morphometric Parameters	Total Mean Pebble Sets
Flatness ratio (F.R)	0.46
Elongation ratio (E.R)	0.73
Maximum Projection Sphericity Index (M.P.S.I.)	0.66
Oblate-Prolate Index (O.P.I.)	0.66
Roundness (%)	51.47
Pebble Size (Magnitude)	3.22

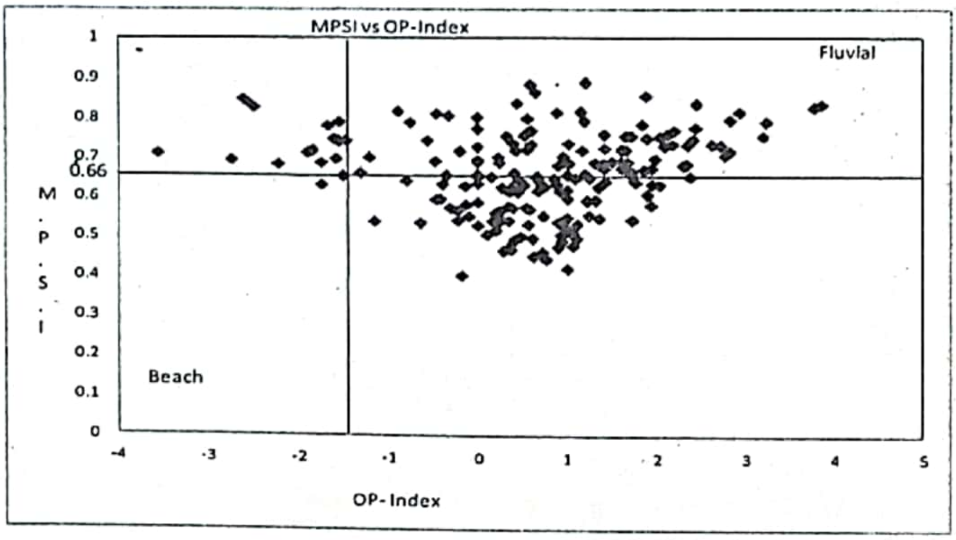


Fig. 3: Scatter Plot of M.P.S.I vs O.P.I for Location 1-19 (raw data).

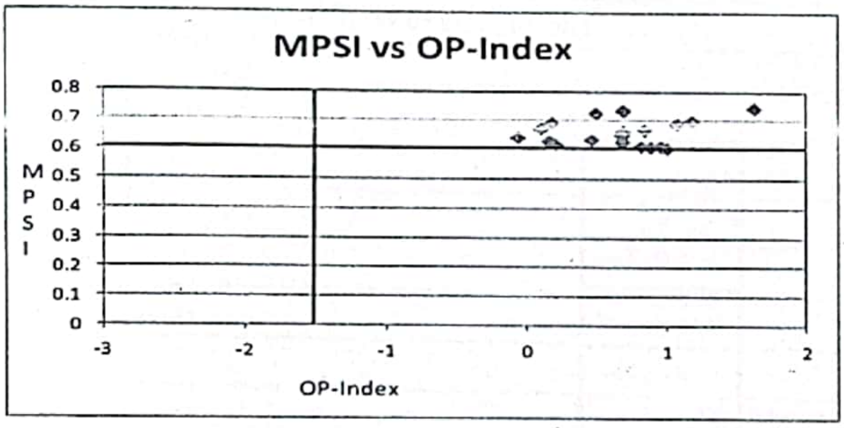


Fig. 4: Scatter Plot of Total Average of M.P.S.I. vs. O.P.-Index for Location 1-19.

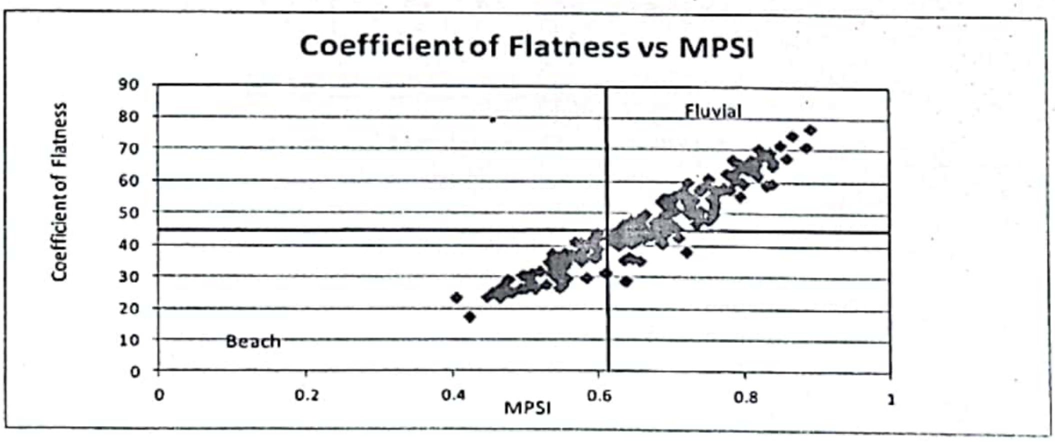


Fig. 5: Scatter Plot of Coefficient of Flatness vs. M.P.S.I for Location 1-19 (raw data).

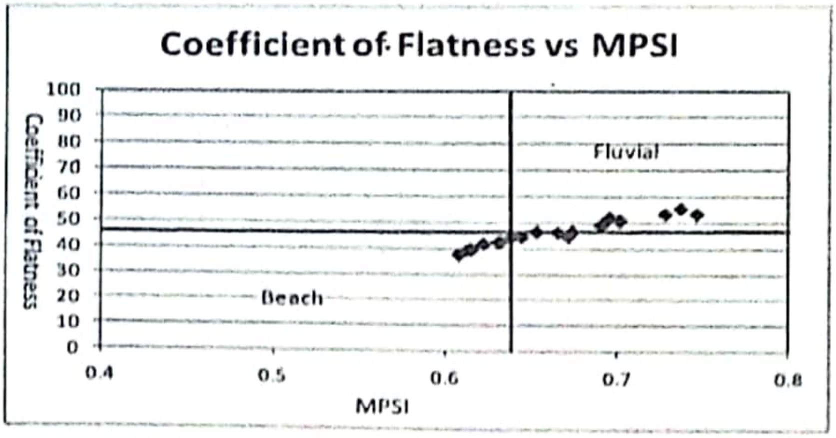


Fig. 6: Scatter Plot of Total Average of Coefficient of Flatness vs. M.P.S.I. for Location 1-19

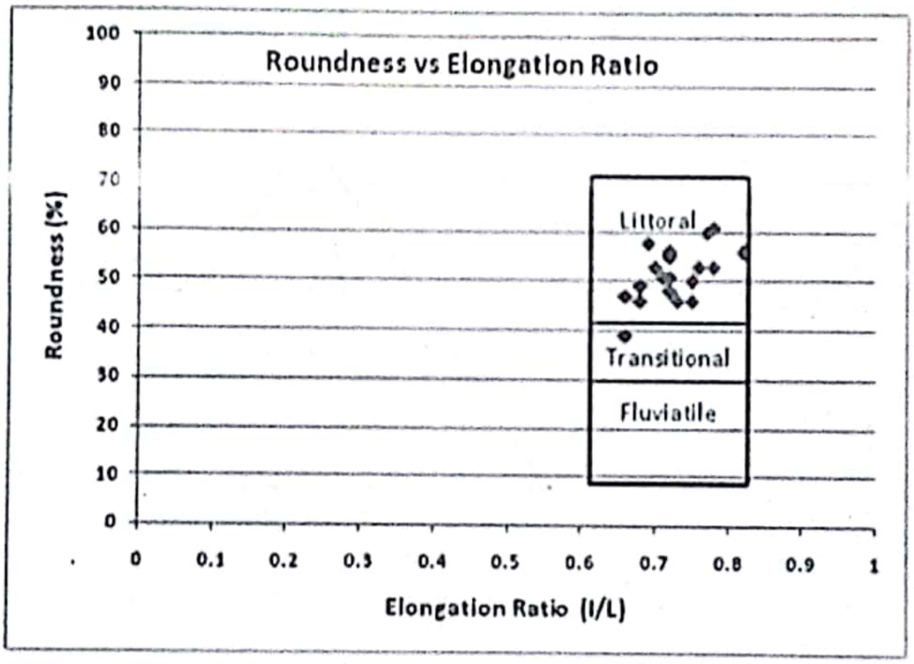
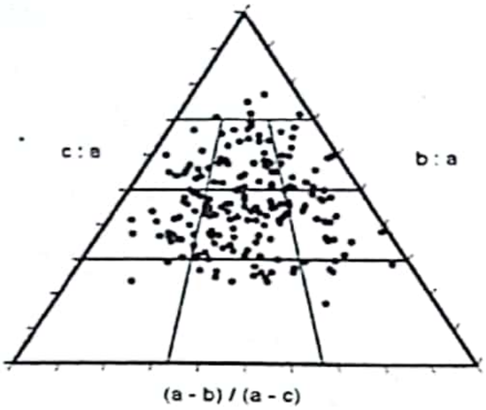
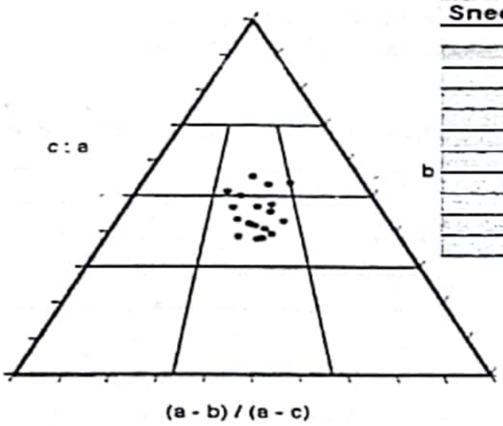


Fig. 7: Scatter Plot of Total Average of Roundness vs. Elongation Ratio for all Locations.



Sneed & Folk classes	Count	Percent
Compact	5	2.63
Compact-Platy	12	6.32
Compact-Bladed	33	17.37
Compact-Elongate	16	8.42
Platy	25	13.16
Bladed	59	31.05
Elongate	19	10.00
Very-Platy	2	1.05
Very-Bladed	13	6.84
Very-Elongate	6	3.16

Fig. 8a: Sneed and Folks Triangular Diagram for basal conglomerates of Bida Formation exposed around Zungeru NW Nigeria (Graham and Midgley, 2000). (Note: Letters a, b and c represent the long, intermediate and short orthogonal axes of each particle respectively).



Sneed & Folk classes	Count	Percent
Compact	0	0.00
Compact-Platy	0	0.00
Compact-Bladed	4	21.05
Compact-Elongate	1	5.26
Platy	0	0.00
Bladed	14	73.68
Elongate	0	0.00
Very-Platy	0	0.00
Very-Bladed	0	0.00
Very-Elongate	0	0.00

Fig. 8b: Sneed and folk Diagram for Total Average of Samples (Graham and Midgley, 2000)

4.2 Discussion

The predominance of vein quartz and the presence of metaquartzite classifies the studied interval as a quartzose conglomerate (Boggs, 2009). This type of conglomerate is formed by the destruction of large volume of rocks (mainly metamorphic and some igneous rocks) rich in quartz filled veins (Pettijohn, 1975; Boggs, 2009). It has been suggested that the vein quartz were concentrated by the destruction of the less stable primary igneous or metamorphic rocks. Vein quartz rich conglomerates in the geologic record were commonly concentrated by fluvial processes but wave-reworked examples have been reported (Boggs, 2009).

Dobkins and Folk (1970), Lutig (1962), Sames (1966), Stratten (1974), Els (1988), Illenberger and Redding (1993), Barret (1980) and Nwajide and Hoque (1985) demonstrated the importance of pebble morphometric studies in the determination of paleoenvironment. The following parameters serve independent functions for environmental interpretation; they are coefficient of flatness (FR), Elongation ratio (ER), Maximum Projection Sphericity Index (MPSI), Oblate-Prolate Index (OPI), roundness and form. On the other hand scatter plots of

MPSI vs. OPI, Coefficient of flatness vs. MPSI and roundness vs. ER are used in interpretation as dependent variables.

Nwajide and Hoque (1985) show that the magnitude of the long axis of pebble determines the size. The mean size of pebbles in this study is 3.22 cm (Table 3) which is indicative of fluvial origin (Nwajide and Hoque, 1985). .

Dobkin and Folk (1970) suggested that pebble suites with mean MPSI of 0.65 and less indicate beach processes while those with values above 0.65 are shaped by fluvial processes. The mean MPSI value obtained for the study area is 0.66 (Tables 2 and 3) and this is indicative of fluvial process. The mean OPI of 0.66 is also indicative of fluvial transport. Mean coefficient of flatness of 46.02% (Tables 2 and 3) indicates fluvial action as dominant depositional process (Stratten, 1974). The mean form index of 0.51 and Bladed form (B) (Figures 8a & b) indicate fluvial shaping of grain with indication of marine influence for the conglomeratic lithofacies of Bida Formation in Zungeru area. Table 4 shows that 28.42% of pebbles indicate fluvial, 50.53% are non-diagnostic and 21.05% indicates pebble shaped in marine environment, and this also lends credence to marine-influenced fluvial processes.

Turker (2011) emphasized that the shape of the pebbles is largely a reflection of composition and any planes of weakness (such as bedding/lamination, cleavage or jointing) in the rocks from which sediments are sourced. According to him, rocks with a uniform composition and structure, such as many granites, dolerites and thick 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. Thus, the larger percentage of bladed shape or form pebbles in this study indicates that the conglomerate sediment in Zungeru is sourced from the surrounding basement, consisting possibly of schists and gneisses.

Table 4: Showing percentage distribution of pebbles.

Fluvial			Non-diagnostics				Marine		
C	CB	CE	B	E	VE	CP	P	VP	VB
5	33	16	59	19	6	12	25	2	13
28.42%			50.53%				21.05%		

Roundness indicates the extent of travel and abrasion of pebble. The pebble roundness values estimated for this study range from 10 - 90% (angular to well rounded), and the mean roundness of 51.47% (0.515) shows that the pebbles are dominantly sub-rounded which indicates relatively short distance of travel. It also reveals that the pebble might have been transported from the weathering of the basement rocks around the study area (Odumodu and Odumodu, 2012).

Dobkin and Folk (1970) as well as Sames (1966) identified environments of deposition using scatter plots of MPSI vs. OPI (Figures 3 & 4) and Roundness vs. ER (Figure 7). Plots of MPSI vs. OPI (Figures 3 & 4) and plot of coefficient of flatness and MPSI (Figures 5 & 6) indicates fluvial setting with marine influence. The plot of roundness versus ER indicates littoral (marine) environment (Figure 8), possibly suggesting marine influence during the deposition of the sediments.

In this study we introduced a new parameter, '*effective radius*', which is defined as the radius of an approximate sphere a pebble assumes when all its edges have been abraded and worn out during transportation process. We found that there is a strong positive correlation ($r = 0.791$) between our effective radius parameter and maximum projection sphericity index (MPSI) of Sneed and Folk (1970). We propose that effective radius parameter could be environment of deposition indicator on the basis of its good correlation with the MSPI. Figure 9 shows the relationship between effective radius parameter and MPSI, and reveals that the minimum MPSI value for the studied vein quartz pebbles is about 0.57, which is 13.6% lower than the average MPSI value (0.66).

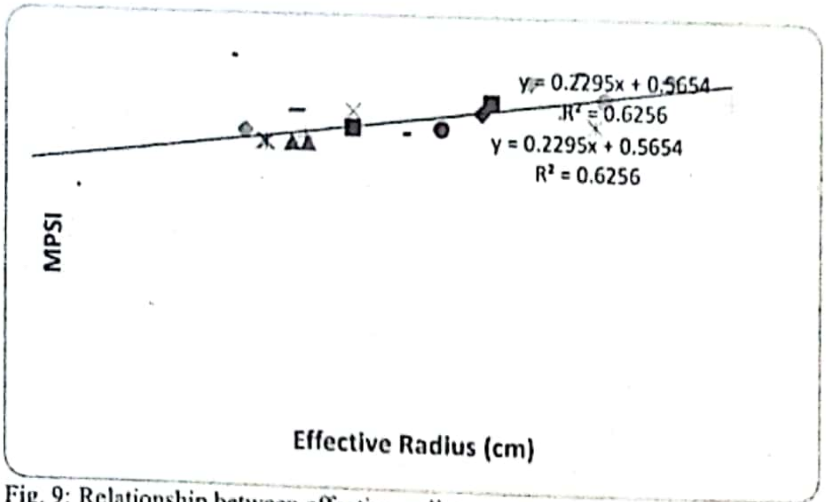


Fig. 9: Relationship between effective radius parameter and MPSI for the studied pebbles

5. CONCLUSIONS

The basal conglomerates of the Bida Formation outcropping in a stream around Zungeru (NW, Nigeria) can be classified as quartzose conglomerate based on the predominance of vein quartz pebbles. The bivariate plots of morphometric parameters such as coefficient of flatness versus MPSI and MPSI versus OPI indicate that the pebbles are deposited by fluvial processes. However, the bivariate plot of roundness versus elongation ratio showed that the vein quartz pebbles were deposited in littoral (marine) environment. The dominance of bladed shape pebbles in this study indicates that the conglomerate sediment in Zungeru is sourced from the surrounding basement such as schists and gneisses. Thus, we concluded that the conglomerate lithofacies of Bida Formation in Zungeru area are products of fluvial deposition with some marine influence.

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