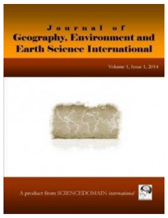

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Granulometry, Pebble Morphometry and Petrographic Studies as Indicators of Paleodepositional Environments of the Mamfe Formation in Ikom-Mamfe Embayment, South Eastern Nigeria

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Authors' contributions

This study was carried out in collaboration between all authors. Author AO designed the study in collaboration with author NUE and performed the statistical analysis, he also wrote the protocol and the first draft of the manuscript. Author EEO managed the analyses and literature searches for the study. All authors read and approved the final manuscript.

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ABSTRACT

Grain size distribution, pebble morphometry and petrographic analyses were carried out on samples collected from Mamfe Formation, Ikom-Mamfe Embayment, southeastern Nigeria to determine textural parameters, provenance and paleoenvironment. The results from grain size analysis show that mean grain size, inclusive standard deviation, graphic skewness and kurtosis yielded average values of 0.94ϕ, 1.30ϕ, 0.1, and 1.20 respectively. These results show that the sandstones have representatives of fine to coarse grain sizes; they are poorly sorted with dominance positively skewed suggesting a fluvial origin for the sediments. Bivariate analysis also infers that the

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sandstones were deposited in fluvial regime. The mean values of pebble morphometric parameters including elongation ratio (ER), flatness ratio (FR), maximum projection sphericity index (MPSI), oblate-prolate index (OPI) and sphericity (S) all fall within acceptable limits for fluvial deposits. The mean roundness suggests fluvial action, also indicated by the shape of the pebbles. Plots of Sphericity vs. OP index and particle form triangular diagram also indicates the pebbles were shaped predominantly by fluvial action. Petrographic study reveals quartz as the dominant framework grain, followed by feldspar and rock fragment. The sandstones are texturally and mineralogically immature. The sandstone of the Ikom-Mamfe Embayment is classified as arkosic-subarkosic arenites sourced from uplifted basement rocks and deposited in a humid climatic condition.

Keywords: Grain size; Ikom-Mamfe embayment; provenance; sandstones; elongation ratio.

1. INTRODUCTION

The Ikom- Mamfe sedimentary basin formed in response to processes associated with the Gondwana land break-up and subsequent separation of South America and African plates. The basin displays a regional trend in the NW-SE direction, with a length of 120 km and width of 60 km. It is bounded to northeast and southwest by the Obudu Plateau (part of the Bamenda Massif) and Oban Massifs respectively (Fig. 1). The sedimentary fill is largely sandstone,

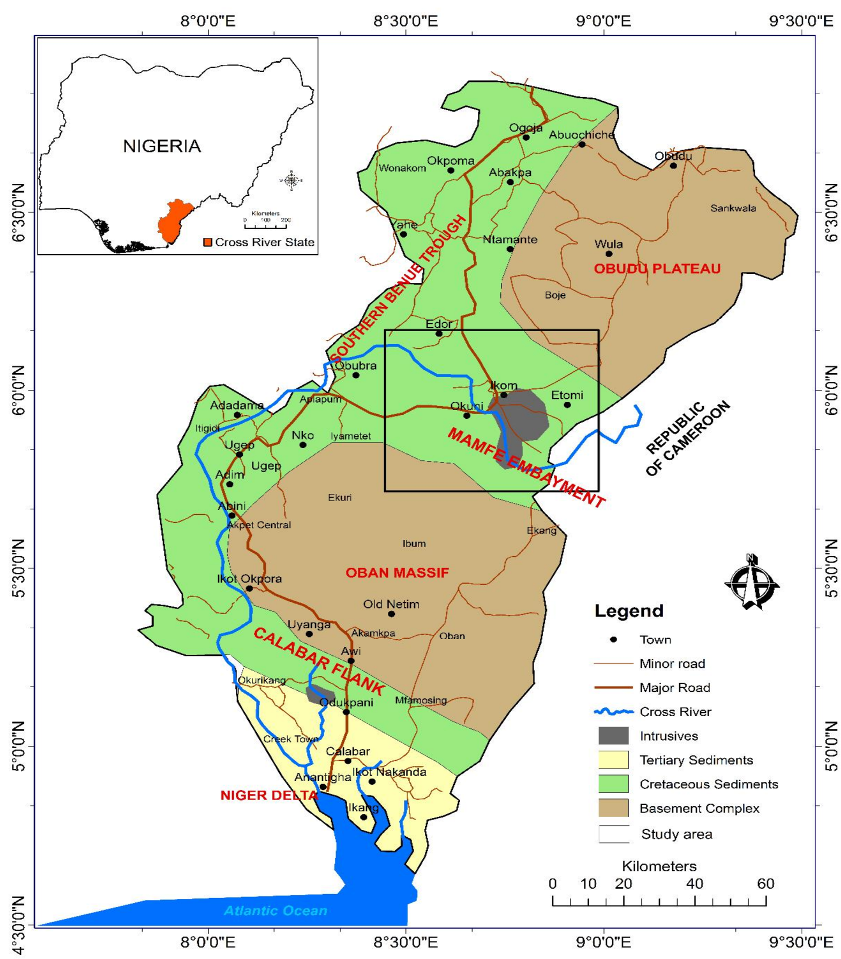

Fig. 1. Map of Cross River State showing the Ikom-Mamfe Embayment, (inset: Map of Nigeria showing Cross River State)

mudstone, siltstone, shale, metacarbonate, microconglomerate and polygenic conglomerate from Aptian - Albian age [1-3]. The lithic fills of the basin consist of the Asu River Group which is predominantly a fluviatile clastic sequence referred to as Mamfe Formation [4]. The present study utilizes textural analysis (sieve analysis and pebble morphometric analysis of the sandstone and conglomerates) to deduce the depositional environments of the Mamfe Formation.

2. MATERIAL AND METHODS OF STUDY

A total of 26 loose and poorly consolidated sand samples and pebbles in batches of 10 each were collected from different locations (Fig. 2). Grain size analysis was carried out on the loose and poorly consolidated sandstones and finally, using the Ro-Tap sieve shaker with a screen type of phi-interval and diameter of 8 inches and sieving carried out for 15 minutes [5].

The fractions retained on each screen were weighed using a weigh balance. The measured weights were recorded in a format prescribed by Folk [6], then the weight and percentages retained were to prepare cumulative curves for which the statistical parameters, such as graphic mean, inclusive skewness, Graphic kurtosis and inclusive standard deviation [7] were calculated.

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

Inclusive Standard deviation (Sδi) =

$$\frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_{5}}{6.6}$$

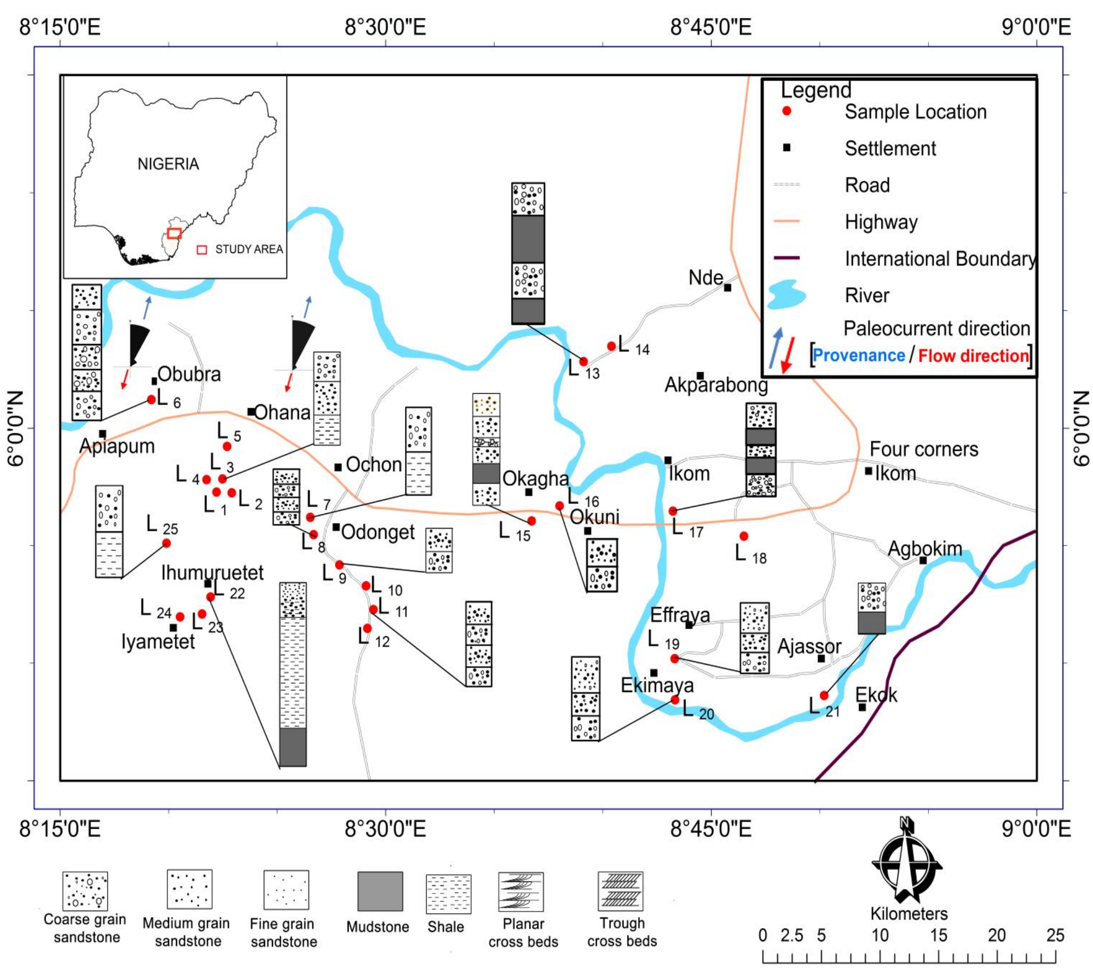

Fig. 2. Sample location map of the study area

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

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

Table 1. Grain size parameters and descriptive terminologies (Folk and Ward, [7])

Mean size (M_Z)	Sorting (δ_i)	Skewness (S_{KI})	Kurtosis (K_G)
Coarse sand (0-1 ϕ)	Very well sorted <0. 35	Strongly fine skewed +0.3 to +1.0	Very platykurtic <0.67
	Well sorted 0.35–0.50	Fine skewed +0.1 to +0.3	Platykurtic 0.67–0.90
Medium sand (1-2 ϕ)	Moderately well sorted 0.50–0.70	Symmetrical +0.1 to -0.1	Mesokurtic 0.90–1.11
	Moderately sorted 0.70–1.00	Coarse skewed -0.1 to -0.3	Leptokurtic 1.11–1.50
	Poorly sorted 1.00–2.00	Strongly coarse skewed -0.3 to -1.0	Very leptokurtic 1.50–3.00
Fine Sand (2-3 ϕ)	Very poorly sorted 2.00–4.00		Extremely leptokurtic >3.00
	Extremely poorly sorted >4.00		

The statistical calculation of the grain size parameters was compared with the descriptive terminologies (Table 1) of Folk and Ward [7]. These parameters and bivariate plots from the derived parameters were used for environmental interpretation following the works of [6,7,8,9].

For the pebble morphometry analysis, the three mutually perpendicular axes of the long (L), short (S) and intermediate (1) axes were measured with vernier calliper as suggested by Folk [6] and Krumbein [10]. Roundness was estimated visually using the powers estimation chart [11]. Morphometric parameters were obtained from the L, I and S values; these include the Flatness ratio (FR = S/L) and Elongation Ratio (ER) of Lutig [12]. Projection sphericity index [13] and OP-Index [14] were evaluated averagely in each location to determine the depositional environments of the pebbles.

Thin section petrography was also carried out on fourteen consolidated sandstones of the Mamfe Formation. The thin section petrography was used to analyse the mineral and textural characteristics of the rocks, which gives deductions about provenance, transportation history, the mineralogical and textural maturity of the sandstones. The consolidated sandstones were cut into thin sections and with the aid of a Zeiss petrological microscope, the individual grains represented were identified and counted. Based on the counts, the percentage framework elemental composition of the rocks with emphasis on quartz, feldspar and rock fragment (QFL) [15] was determined and the mineralogical classification of Mamfe Formation sandstone was carried out.

3. RESULTS AND DISCUSSION

3.1 Grain Size Analysis

The sieve analysis results of the 26 loosely compacted sandstone samples in the study area are presented in Table 2. The results show that the sandstone has graphic mean size ranging from -1.77ϕ to 1.80 ϕ with an average mean size of 0.94 ϕ. Majority of the analysed samples could be described as medium grain, coarse grain, very coarse grain and gravel. Particle size distribution is of great importance to the reconstruction of the transport history of the sediments from the source area to the depositional sites. Standard deviation values from the study area range from 0.73ϕ to 1.93ϕ with a mean value of 1.30 ϕ indicating moderately to poorly sorted, classified as deposition in a fluvial environment [16]. Skewness values range from -0.08 to 0.45 with mean values of 0.1, indicating dominance if near symmetrical and positively skewed. Poor sorting and positive skewness values of analysed samples suggest deposition in a fluvial environment.

Table 2. The result of grain size analysis and their corresponding interpretation

S/No	Locations	Codes	Graphic Mean		Sorting		Skewness		Kurtosis	
			Value (ø)	Interpretation	Value (ø)	Interpretation	Value	Interpretation	Value	Interpretation
1	Obubra Top	OB3	-0.61	Very Coarse Sand	1.68	Poorly Sorted	0.00	Near Symmetrical	0.93	Mesokurtic
2	Obubra Middle	OB2	-1.77	Gravel	1.87	Poorly Sorted	0.40	Strongly Positive Skewed	1.17	Leptokurtic
3	Obubra Base	OB1	0.13	Coarse Sand	1.34	Poorly Sorted	0.10	Near Symmetrical	1.26	Leptokurtic
4	Obubra Sand	OB4	-2.53	Gravel	1.71	Poorly Sorted	0.16	Positive Skewed	0.97	Mesokurtic
5	Nde Sand	ND1	0.96	Coarse Sand	0.95	Moderately Sorted	-0.02	Near Symmetrical	1.33	Leptokurtic
6	Nde 13B	ND13B	1.69	Medium Sand	1.59	Poorly Sorted	0.02	Near Symmetrical	1.06	Mesokurtic
7	Okagha	OKH1	1.54	Medium Sand	1.05	Poorly Sorted	0.12	Positive Skewed	1.26	Leptokurtic
8	Okagha Quarry Sand	OKH2	1.20	Medium Sand	1.07	Poorly Sorted	0.00	Near Symmetrical	1.05	Mesokurtic
9	Okagha 15A	OKH15A	1.63	Medium Sand	1.38	Poorly Sorted	-0.02	Near Symmetrical	1.06	Mesokurtic
10	Okagha 15D	OKH15D	1.78	Medium Sand	1.46	Poorly Sorted	-0.06	Near Symmetrical	1.01	Mesokurtic
11	Odonget Sand 1	OD1	0.98	Coarse Sand	1.00	Poorly Sorted	0.03	Near Symmetrical	1.29	Leptokurtic
12	Odonget Sand 2	OD2	1.40	Medium Sand	0.73	Moderately Sorted	0.11	Positive Skewed	1.59	Very Leptokurtic
13	Odonget Sandstone 3	OD3	1.68	Medium Sand	1.18	Poorly Sorted	0.27	Positive Skewed	1.10	Mesokurtic
14	Odonget Sandstone 4	OD4	1.46	Medium Sand	0.95	Moderately Sorted	0.18	Positive Skewed	1.63	Very Leptokurtic
15	Odonget Sandstone LL9	OD5	1.39	Medium Sand	0.83	Moderately Sorted	0.22	Positive Skewed	1.77	Very Leptokurtic
16	Odonget 8A	OD8A	1.46	Medium Sand	1.25	Poorly Sorted	-0.04	Near Symmetrical	1.34	Leptokurtic
17	Odonget 8B	OD8B	1.33	Medium Sand	1.23	Poorly Sorted	-0.04	Near Symmetrical	1.30	Leptokurtic
18	Odonget 9A	OD9A	1.32	Medium Sand	1.20	Poorly Sorted	-0.08	Near Symmetrical	1.04	Mesokurtic
19	Odonget 9B	OD9B	1.74	Medium Sand	1.42	Poorly Sorted	-0.07	Near Symmetrical	1.44	Leptokurtic
20	Odonget 10	OD10	1.80	Medium Sand	1.10	Poorly Sorted	-0.07	Near Symmetrical	1.80	Very Leptokurtic
21	Odonget 11A	OD11A	0.71	Coarse Sand	1.21	Poorly Sorted	0.45	Strongly Positive Skewed	0.93	Mesokurtic
22	Odonget 11B	OD11B	1.12	Medium Sand	1.93	Poorly Sorted	0.27	Positive Skewed	0.87	Platykurtic
23	Okuni 16A	OKN16A	0.57	Coarse Sand	1.37	Poorly Sorted	0.41	Strongly Positive Skewed	1.05	Mesokurtic
24	Okuni 16B	OKN16B	1.11	Medium Sand	1.38	Poorly Sorted	-0.07	Near Symmetrical	1.13	Leptokurtic
25	Ikom 17A	IK17A	1.11	Medium Sand	1.31	Poorly Sorted	0.13	Positive Skewed	1.03	Mesokurtic
26	Ikom 17B	IK17B	1.22	Medium Sand	1.55	Poorly Sorted	0.10	Near Symmetrical	0.91	Mesokurtic

Kurtosis values range from 0.93 to 1.80 with a mean value of 1.20 indicating that the analysed sediments are mainly mesokurtic to leptokurtic. To effectively use the grain size parameter to delineate depositional environments bivariate plots were applied. The application of the works of Folk and Ward [7] and Friedman [17] was adopted for paleoenvironmental interpretation while Friedman [9] was used to differentiate beach from river sands from textural parameters. Bivariate plots of sediments from Mamfe Formation for graphic mean plotted against sorting (Folk, [6]), sorting against skewness (Friedman, [9]), all the plots show that the analysed sediments were predominantly of fluvial origin (Figs. 3 and 4).

3.2 Pebble Morphometry

The result of the pebble morphometric analysis is presented in Table 3. The morphometric parameters show that the pebbles comprise of bladded through compact - bladded pointing to a dominantly fluvial process [13]. Also, the sphericity against (OP) indices of Dobkins and Folks [14] in Fig. 5 points to fluvial process as the dominant depositional process for the pebbles. There are some form indices of quartz pebbles that are diagnostic of depositional, for instance, compact (C), compact bladded (CB), compact elongate (E) point to fluvial depositional environments while platy (P), bladded (B), very platy (VP) and very bladded (VB) are common forms of pebbles in a beach environment [13].

The triangular plot therefore of samples, as presented in (Fig. 5) shows that majority of the pebbles fall into compact bladded and elongate, indicating fluvial-shaping process. Adopting the suggestion of Dobkins and Folk [14], where OP-index for river pebble exceeds –1.5 and the roundness values of the pebbles estimates to subrounded and subangular, the distance of travel of the grains is short and the provenance isn't too far away from the depositional basin. Following (Powers [11]) roundness estimate of values <35% typifies fluvial environments while 45% and above characterizes littoral environments, roundness values from the study area ranges between 16.00-40.50% which is typical of fluvial depositional environment. To buttress more, triangular plot of Sneed and Folk, [13] and Sphericity vs OPI (Fig. 6) all indicate that pebbles in the study area were shaped by fluvial processes [14]. That of beach environment < -1.5, the mean value of most of the pebbles from the study area exceed -1.5 [18].

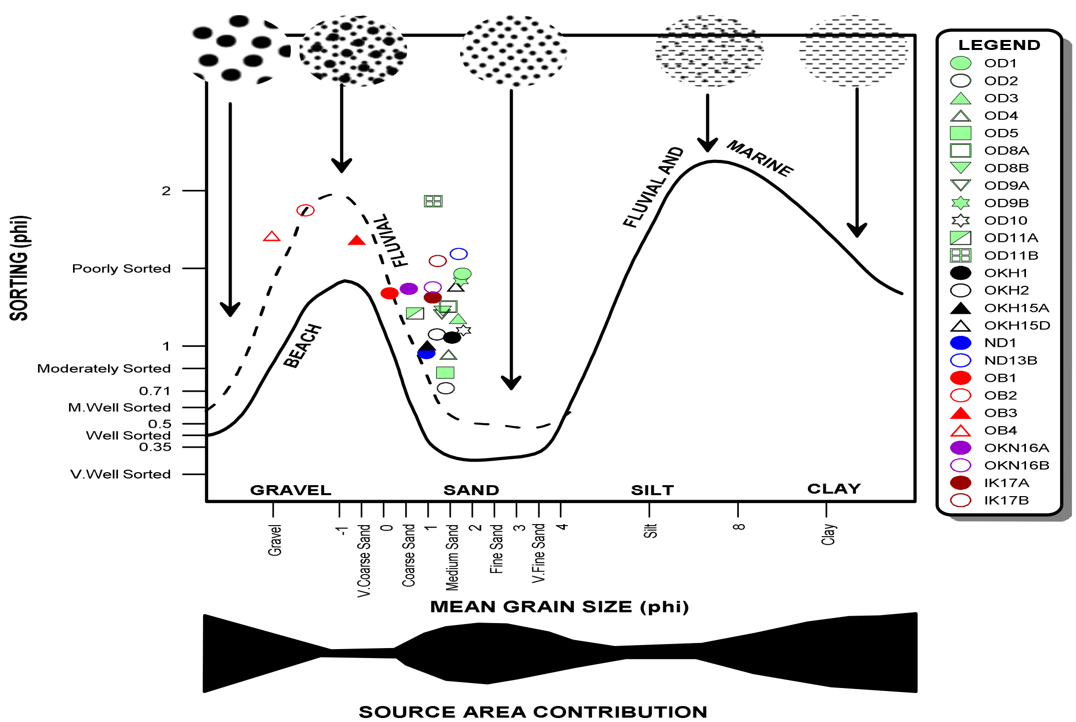

Fig. 3. Mean grain size vs sorting plot (after [6])

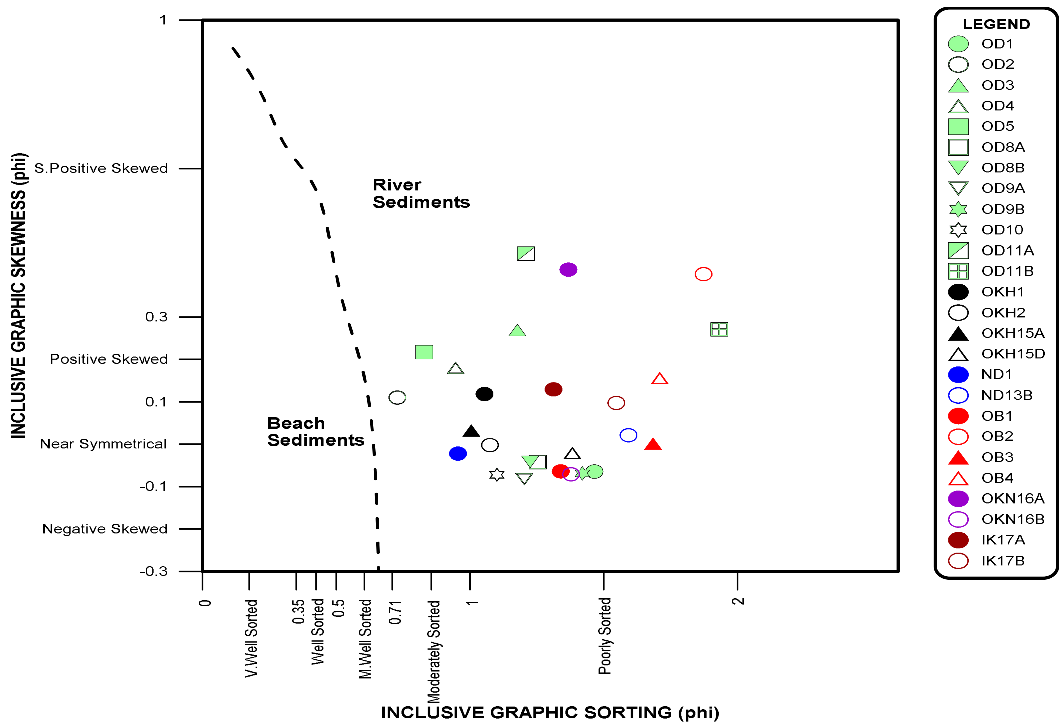

Fig. 4. Grain-size bivariate plot of inclusive graphic skewness vs standard deviation (after Friedman, 1967)

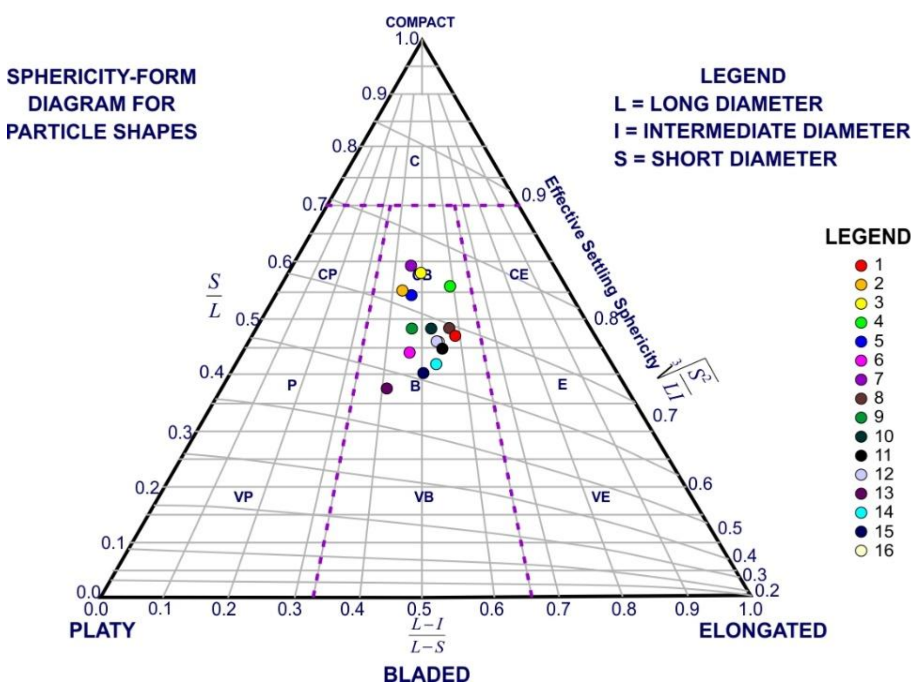

Fig. 5. Particles shape triangular diagram (after [13])

C = Compact, CE = Compact Elongate, CP = Compact platy, CB = Compact bladded, E = Elongate, P = Platy, B = Bladded, VP = Very platy, VB = Very Bladded, VE = Very Elongate

Table 3. Results of pebble morphometry

Location	Village name	Long (cm)	Int. (cm)	Short (cm)	Flatness Ratio S/L	Elongation Ratio I/L	Form (L-I)/(L-S)	Effective Settling Sphericity (MPSI) [(S^2/LI) ^1/3]	OP Index [10((L-I/L-S)-0.5)/(S/L)]	Sphericity [(IS/L^2) ^ (1/3)]	%Roundness	Roundness grades
1	Obubra	3.35	2.30	1.57	0.48	0.72	0.52	0.68	0.80	0.70	40.36	Subrounded
2	Obubra	2.77	2.24	1.53	0.54	0.81	0.43	0.71	-1.68	0.76	40.30	Subrounded
3	Obubra	3.43	2.79	2.04	0.59	0.81	0.48	0.76	-0.55	0.78	41.00	Subrounded
4	Obubra	3.21	2.37	1.80	0.57	0.75	0.57	0.75	1.49	0.75	40.50	Subrounded
5	Obubra	3.30	2.60	1.79	0.55	0.79	0.49	0.72	-0.51	0.75	42.10	Subrounded
6	Obubra	3.43	2.54	1.51	0.45	0.76	0.44	0.64	-1.39	0.69	38.64	Subrounded
7	Obubra	3.06	2.43	1.78	0.59	0.80	0.51	0.75	-0.15	0.77	26.50	Subangular
8	Obubra	3.11	2.18	1.51	0.50	0.72	0.56	0.70	1.32	0.71	27.73	Subangular
9	Obubra	3.10	2.35	1.50	0.50	0.78	0.44	0.68	-1.37	0.73	19.55	Subangular
10	Obubra	3.05	2.22	1.48	0.49	0.72	0.54	0.69	0.78	0.70	37.50	Subrounded
11	Ochon	3.01	2.14	1.39	0.46	0.72	0.53	0.67	0.60	0.69	16.00	Subangular
12	Ochon	2.39	1.66	1.07	0.48	0.71	0.56	0.68	1.41	0.69	18.10	Subangular
13	Effraya	2.69	2.00	1.01	0.38	0.74	0.42	0.58	-2.35	0.65	23.00	Subangular
14	Effraya	2.08	1.43	0.87	0.43	0.69	0.57	0.63	0.64	0.66	26.50	Subangular
15	Effraya	2.61	1.83	1.05	0.43	0.70	0.54	0.63	0.59	0.66	21.00	Subangular
16	Effraya	1.63	1.13	0.73	0.43	0.72	0.55	0.63	-2.32	0.66	28.60	Subangular

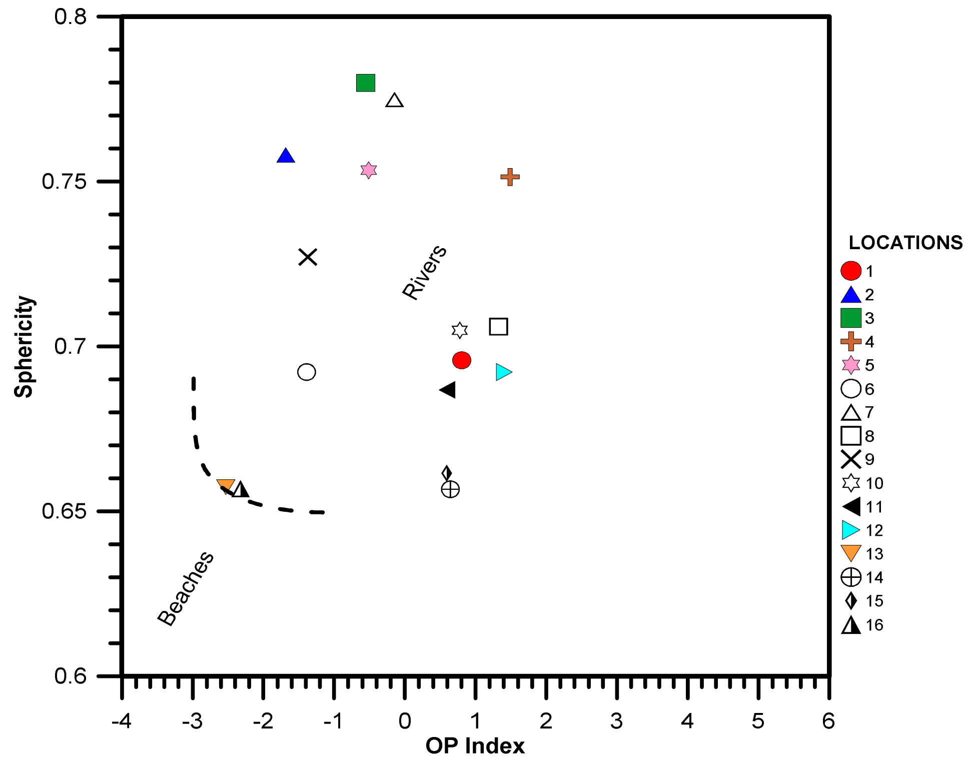

Fig. 6. Sphericity against OP index plot of samples in the study area (after [14])

3.3 Thin Section Petrography

The result of the thin section analysis is presented in Table 4. Photomicrographs of the sandstones show abundant polycrystalline quartz (Fig. 7a, b) and often the quartz grains show overgrowth indicating late stage diagenetic alteration of sediments and a more likely metamorphic source for the grains.

The grains are mostly subrounded to subangular reflecting their nearness to provenance. The feldspar in the sandstone have been considerably affected by weathering and was in different stages of decomposition, evident in whitish and chalky stains of the sandstones. The feldspars identified include microcline and albite (Fig. 7c, d). The altered feldspars give rise to kaolinite cement. Blatt et al. [19] have reported authigenic precipitation of kaolinite in the fluvial environment, such conditions are analogous to the settings in this study. Based on Pettijohn [15] mineralogical classification, the sandstone is classified as subarkosic – arkosic arenites (Fig. 8).

The sandstones are also believed to be texturally and mineralogically immature. Micaceous minerals also occur in abundance, evident in the loosely consolidated samples appearing as flakes or sheets (muscovite), though muscovite is more abundant than biotite in the analysed samples. The percentage concentration of rock fragment is far less than that of quartz and feldspar. They are also angular – subangular in shape and appear smaller in size than quartz and feldspar grains. The varieties of rock fragments recognized are metamorphic (Fig. 7 e, f) and igneous rock fragments (however, sedimentary rock fragments appear fewer). The cement materials present acts as void fillers consisting mainly of authigenic silica [20]. The cement in some cases appears brownish, yellow or reddish in colour. The matrix is made up of clay minerals and interstitial silt-sized quartz, feldspar, rock fragment and heavy minerals. The provenance of the sandstone with respect to tectonic setting and transportation history is interpreted as a continental block provenance [21]. The QFRf ternary plot (Fig. 9) shows that the sandstones of the Mamfe Formation are of continental block provenance and recycled orogeny. According to Dickinson and Suczek [22], framework components of sandstones are genetically linked to the geodynamic environment of the source area, this is evident in the angularity of the sediments with the relative substantial matrix in the study area. The sediments typically are of a topographic high and uplifted source where sediments shed from faulted and uplifted basement fragments deposited proximally without much transportation.

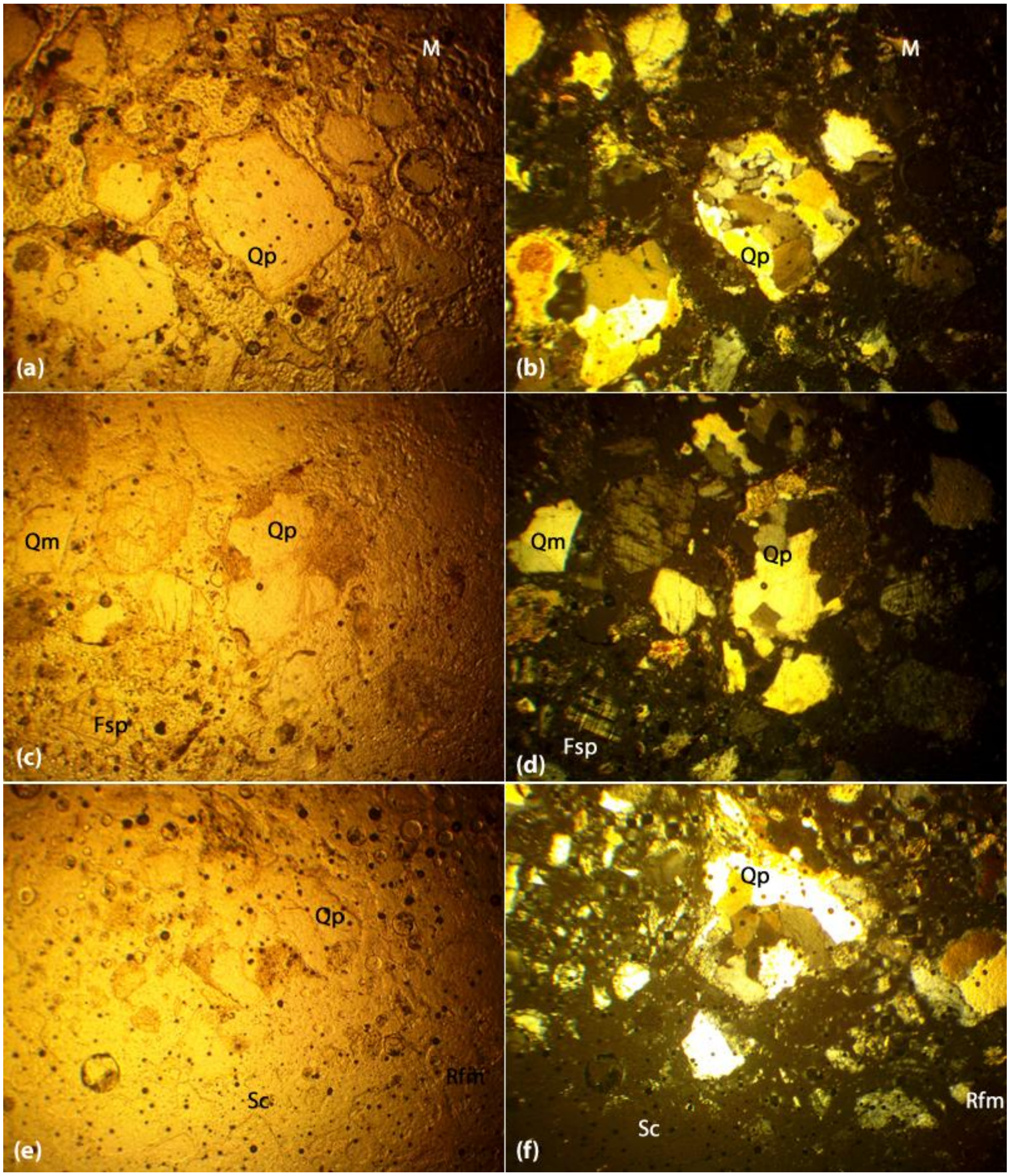

Fig. 7. (a, b) Photomicrograph showing polycrystalline quartz grain (Qp) and muscovite (M) in the arkosic sandstone at Loc 16a (Okuni area); (c, d) photomicrograph showing microcline feldspar (fsp) and monocrystalline quartz (Qm) in the arkosic sandstone at Loc 17a (Ikom area) and (e, f) photomicrograph showing metamorphic rock fragment (Rfm) held tight by silica cement (Sc) in the subarkosic sandstone (Loc 9a) in Odonget

Note: a, c, and e are in plane polarized light while b, d and f are in cross-polarized light for the minerals respectively; the magnification is x40 for all photomicrographs

Table 4. Percentage of framework composition of the sandstones in the study area

S/N	Sample no.	Location	% Quartz			% Feldspar			% Mica			Others			%Recalculated framework composition			Rock Name
			MQ	PQ	TQ	M	P	TF	MC	BI	R.F	Zircon	Matrix	Cement	Q	F	R.F	
1	8A	Odonget	42	18	60	10	9	19	7	-	9	-	12	-	68	22	10	Subarkosic arenites
2	8B	Odonget	85	48	133	26	10	36	6	8	22	-	32	-	70	19	11	Subarkosic arenites
3	9A	Odonget	73	28	101	21	30	51	4	16	22	-		16	58	29	13	Subarkosic arenites
4	9B	Odonget	84	25	109	38	10	48	14	6	39	-	3	3	56	24	20	Subarkosic arenites
5	10	Odonget	98	25	123	40	21	61	14	8	28	-	30	44	58	28	14	Arkosic arenites
6	11 A	Odonget	62	33	95	18	9	27	13	6	19	4	6	20	67	19	14	Subarkosic arenites
7	11 B	Odonget	54	20	74	17	10	27	3	6	11	-		12	66	24	10	Subarkosic arenites
8	13A	Nde	106	61	167	30	15	45	8	-	17	-	10	-	73	20	7	Subarkosic arenites
9	15A	Okagha	61	47	108	40	28	68	13	-	25	2	--	20	54	34	12	Arkosic arenites
10	15D	Okagha	63	41	104	16	20	36	35	20	25	6	28	4	63	22	15	Subarkosic arenites
11	16A	Okuni	25	7	32	21	18	39	8	18	26	4		10	37	40	23	Arkosic arenites
12	16B	Okuni	70	36	106	28	14	42	11	-	8	-	6	-	68	27	5	Arkosic arenites
13	17A	Ikom	61	25	86	20	15	35	2	-	20	-	12	-	61	25	14	Arkosic arenites
14	13C	Nde	51	16	67	22	10	32	22	16	-	-	8	4	53	25	22	Arkosic arenites

Explanation: MQ - monocrystalline quartz, PQ - polycrystalline quartz, TQ - total quartz, TF - total feldspar, M - microcline, P - plagioclase, MC - mica, BI-biotite, RF-rock fragment

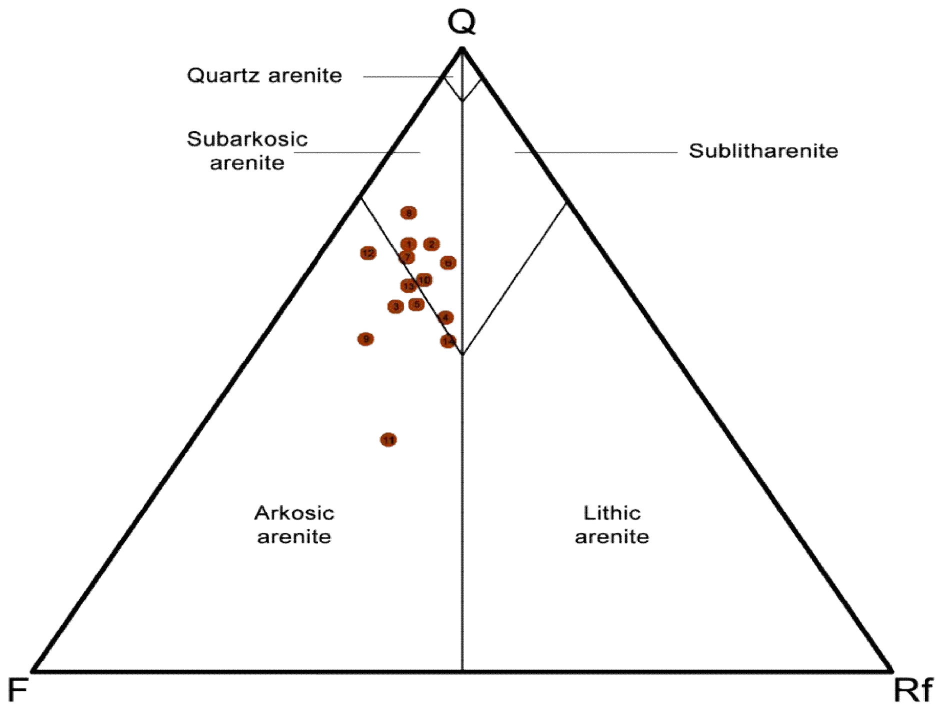

Fig. 8. QFR mineralogical classification for the sandstones of the Mamfe Formation (after Pettijohn [15])

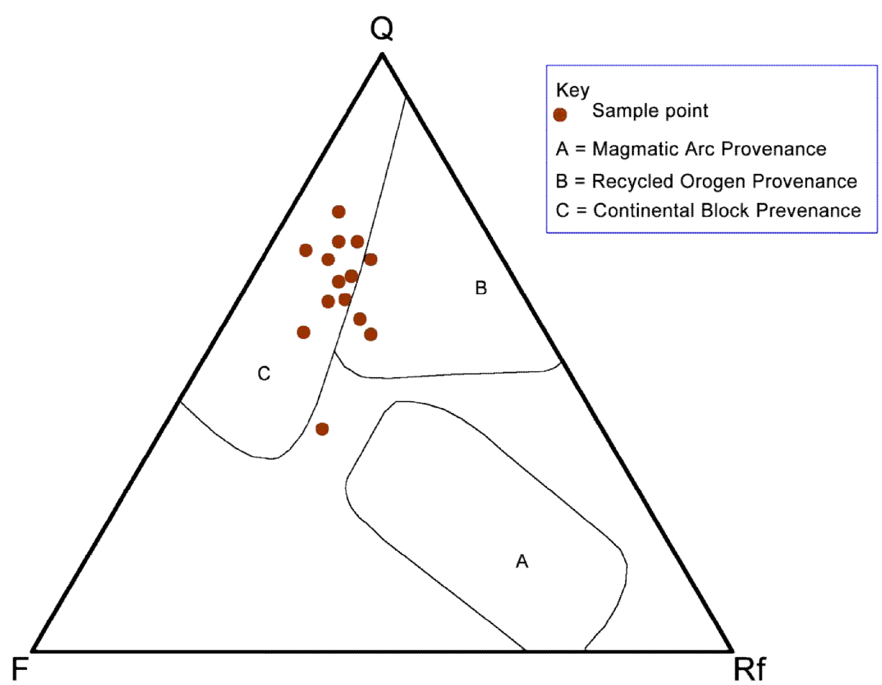

Fig. 9. QRF Ternary plot for provenance setting for sandstone of the Mamfe Formation (modified after Dickinson, 1982)

4. SUMMARY AND CONCLUSION

The grain size parameters show that the Mamfe Formation sandstones range from fine to coarse grain, poorly sorted and largely positively skewed suggesting a varied energy fluvial setting alternating between low to high energy regimes. The textural characteristics suggest a predominance of river-dominated sediments. On the basis of the pebble morphometric parameters eg form, sphericity, OP index for the Mamfe Formation, it is believed that the pebbles were shaped in a fluvial environmental setting. Mean roundness estimates also indicates a fluvial depositional environment with short transportation history. Petrographic analysis reveals that quartz is the most dominant framework grain with feldspar, rock fragment and few accessory minerals taking the subordinate composition. The Mamfe Formation shows textural and mineralogical immaturity. From the QFR plot, the sandstone belongs to the subarkosic - arkosic arenites and sourced from a relatively nearby uplifted continental basement rocks with few admix of recycled orogeny contribution to the sediment source.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Hell JV, Ngako V, Bea JB, Olinga M, Eyong JT. Report des travaux sur petude du basin sedimentaire de Mamfe: 1 IRGM – SNH. Rapport Non Publie. 2000;55.
2. Ndougsa M, Manguelle DE, Bisso D, Njingti N. Geophysical evaluation based on gravity data of the Mamfe basin, South Western Cameroun. SEGMITE International. A Journal of Resource, Industrial and Environmental Geology. 2004;1(1):15–2.
3. Fairhead JD, Okereke CS, Nnange JM. Crustal structure of the Mamfe basin, West Africa, based on gravity data. Tectonophysics. 1991;186:351-358.
4. Petters SW, Okereke CS, Nwajide CS. Geology of Mamfe Rift, S. E. Nigeria. Extended Abstract, 14th Colloquim on African Geology, Berlin West. Current Research in African Earth Sciences. (ed. G. Matheis and H. Schandeimeir) 1987;299-302.
5. Friedman HM. Differences in size distributions of population of particles among sands of various origins: Presidential address. Sedimentology. 1979;26:3-32.
6. Folks RL. Petrology of sedimentary rocks. 2nd Edition. Hemphill Publication Company, Austin Texas. 1980;184.
7. Folk RL, Ward WC. Brazos River bar: A study in the significance of grain size parameters. Journal of Sedimentary Petrology. 1957;27:3–26.
8. Folk RL. The distribution between size and mineral composition in sedimentary rock nomenclature. Journal of Geology. 1954; 62:344–351.
9. Friedman HM. Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands. Journal of Sedimentary Petrology. 1967;37:327-354.
10. Krumbein WC. Measurement and geological significance of shape and roundness of sedimentary particles. Journal of Sedimentary Petrology. 1941;11:64–72.
11. Powers M. A new roundness scale for sedimentary particles. Journal of Sedimentary Petrology. 1953;23:117–119.
12. Lutig G. The shape of pebbles in the continental, fluviatile and marine facies. International Association of Scientific Hydrology, Publication No. 59. 1962;235-258.
13. Sneed ED, Folks RL. Pebbles in the lower Colorado River, Texas, a study in particle morphogenesis. Journal of Geology. 1958;66:114-150.
14. Dobkins JE, Folk RL. Shape and development on Tahiti-Nui. Journal of Sedimentary Petrology. 1970;40:1167-1203.
15. Pettijohn FJ. Sedimentary rocks. Harper and Row, Publication Company, New York. 1975;628.
16. Friedman GM. Comparison of moment measures for sieving and thin section data in sedimentary petrologic studies. Journal of Sedimentary Petrology. 1962;32:15-25.
17. Friedman GM. The distinction between dune, beach and river sands from their textural characteristics. Journal of Sedimentary Petrology. 1961;31:514–529.
18. Sames CW. Morphometric data of some recent Pebble associations and their application to ancient deposits. Journal of Sedimentary Petrology. 1966;36:126-142.

19. Blatt H, Middleton G, Murray R. Origin of sedimentary rocks, 2nd edn. Prentice-Hall, Englewood Cliffs, NJ; 1980.
20. Folks RL. Petrology of sedimentary rocks. 1st edition. Hemphill Publication Company, Austin Texas. 1974;182.
21. Dickinson WR. Composition of sandstones in circum-pacific subduction complexes and fore-arc basins. American Association of Petroleum Geologists Bulletin. 1982;66: 121–137.
22. Dickinson WR, Suczek CA. Pate tectonic and sandstone composition. American Association of Petroleum Geologist Bulletin. 1979;63:2164-2182.

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