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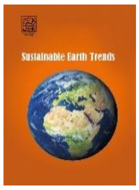

Granulometric and sedimentologic study of the sandstone facies of the Nsukka and Imo formations in parts of the Anambra basin southeastern Nigeria

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ABSTRACT

This study aims to investigate the granulometric and sedimentologic characteristics of the sandstone facies of the Nsukka and Imo Formations to infer their depositional environments. 35 fresh sandstone sediment samples were randomly collected from outcrops in the study area. Sieve analysis of the samples revealed three types of cumulative frequency plots identified as Type-I, II, and III. Type I distribution comprises the bottom traction or creep population, Type II saltation population, and Type III suspension population. The traction population is poorly developed and commonly constitutes less than 10%. The saltation population is well-developed, and its percentage ranges from 70 to 80%. The study showed that samples from the sandstone of the Nsukka Formation are fine to coarse-grained with a dominance of medium-grained sands (0.5-2.27ϕ, mean 1.2±0.42). The values recorded for the kurtosis showed that they are platykurtic to very leptokurtic (0.8-1.8 mean1.1±0.26). They are also well sorted to poorly sorted with a standard deviation value of 0.4-1.6 (mean 0.98±0.33) and nearly symmetrical to fine skewed (-0.01 to 0.26 mean -0.06±0.18). The overall grain size for Imo Formation sandstone shows that they are very fine to coarse-grained with values ranging from 0.07-1.07 (mean 0.69±0.33ϕ), well to poorly sorted with values ranging from 0.48-1.5 (mean 0.89±0.36), and fine skewed with values ranging from 0.17-0.5 (mean 0.33±0.13). The mean grain size of the sediments implies a high-energy-level environment of deposition with intermittent slack in depositional energy. Generally, there is a strong dominance of fluvial origin on the sediments. Results of the multivariate plots show that for the Nsukka Formation, > 90 % and >60% were deposited in a beach/shallow marine environment.

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1. Introduction

Granulometric analysis is a fundamental technique in sedimentology used to infer depositional environments, sediment transport mechanisms, and post-depositional modifications. Granulometric analysis is a fundamental technique in sedimentology used to infer depositional environments, sediment transport mechanisms, and post-depositional modifications. Grain size distribution is a fundamental property of detrital sediments and sedimentary rocks, providing key insights into their transport and depositional history. (Folk and Ward, 1957; Folk, 1974; Friedman and Sanders, 1978; Di Stefano et al., 2010; Brooks et al., 2022). Much can be said from analyzing the size of clastic detrital particles, but also from the overall size distribution, size fraction percentages, textural maturity of the sediment sorting, surface texture attributes of a particle, and sphericity/angularity and shape of a particle (Krumbein and Sloss, 1963; Syvitsky and Ketner, 2008). Several sediment, soil, or material properties are directly influenced by the size of its particles, as well as their shape (form, roundness, and surface texture or the grains) and fabric (grain-to-grain interrelation and grain orientation), such as texture and appearance, density, porosity, and permeability. The size of particles is directly dependent on the type of environmental setting, transporting agent, length and time during transport, and depositional conditions, and hence it possesses significant utility as an environmental proxy (Syvitski and Morehead, 1999; Armstrong et al., 2005; Dürr et al., 2005; Gruzin, 2024).

The late Maatritchian and Paleogene succession in the Anambra and Afikpo Basins has attracted numerous studies. Nwajide and Reijers (1996) and Areguamen et al. (2022) outlined the geology of the Anambra basin and Niger Delta basin and noted that the Nsukka and Imo Formations were post-Santonian formations deposited during the latest Maastrichtian transgressive-regressive episode that ushered in the Niger Delta progradation. Odumodu and Ndicho (2013) evaluated the facies and granulometric characteristics as proxies for the paleo depositional environment of the Imo Formation. Obi et al. (2001) reconstructed the evolution of the Enugu Cuesta while implying a tectonically driven erosional process; Oboh-Ikuenobe et al. (2005), studied the lithofacies, palynofacies, and sequence stratigraphy of Paleogene strata in Southeastern Nigeria; Areguamen et al. (2022) documented a detailed stratigraphic description of the outcropping profiles of late Cretaceous sediments in parts of southeastern Nigeria. Alege et al. (2024) reviewed the lithology, biostratigraphy, and Cretaceous-Neogene paleoenvironment in the BG-1 well, offshore East Dahomey Basin, Nigeria, with implications for future exploration and development efforts. Didi et al. (2025) conducted a reassessment of the stratigraphic, structural, and sedimentary environment of the Kulmani field, Gongola sub-basin, northeastern Nigeria, using outcrop data, trench cutting data, and well logging data for advanced hydrocarbon exploration.

This research, using field data and laboratory analyses, seeks to reconcile previous findings and present a concise sedimentology and depositional environment of the sandstone facies of the Nsukka and Imo formations, which are the transitional facies from the Anambra basin to the Niger Delta in parts of Southeastern Nigeria, incorporating the research findings.

2. Material and methods

The study area covers part of southeastern Nigeria within Longitudes $7^{0}05'$E and $8^{0}05'$E and Latitudes $5^{0}20'$N and $6^{0}20'$N (Fig. 1). Outcrops of sandstones of Nsukka Formation were studied and sampled from Ihube/Okigwe, Umulolo, and Umuasua/Isiukwuato area. Outcrops of Imo Formation sandstones were sampled from Ugwuoba town near Awka and the Bende area near Umuahia (Fig. 1).

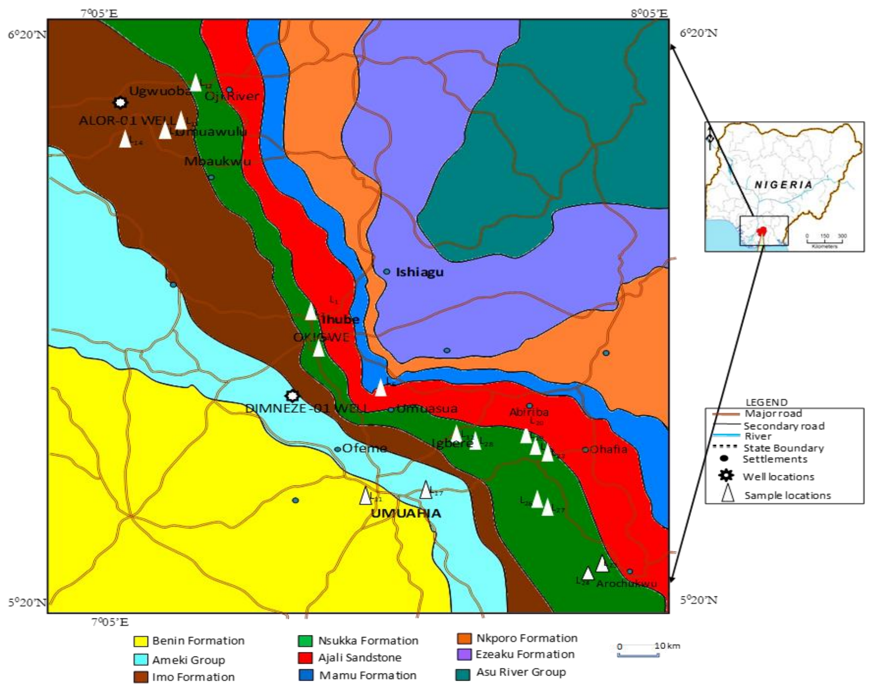

Fig. 1. Location& Geological map of the study area showing samples.

2.1. Geologic and tectonic setting

The Anambra Basin and the Niger Delta Basin are situated on the west and south of the Benue Trough. They are bounded to the west by the Precambrian basement complex rocks of western Nigeria, to the east by the Abakaliki Anticlinorium, and to the south by the northern sector of the Niger Delta basin. The tectonic evolution of the sedimentary basins of southeastern Nigeria started with the break-up and separation of the African and South American plates in the Late Jurassic-Cretaceous, (Burke et al., 1972; Benkhelil, 1982; 1986; Okoro et al., 2020). The Basin fills were controlled by three mega-tectonic cycles, including the displacement of the depositional axis of the main basin, giving rise to three basins, namely, the Abakaliki–Benue Trough, the Anambra Basin, and the Niger Delta Basin (Murat, 1972, Dim et al., 2017). The Santonian compressional folding and uplift of the Benue rift sedimentary fill displaced the depocentre to the Anambra Basin and finally, to the Tertiary, to the Niger Delta (Nwajide and Reijers, 1996).

2.2. Stratigraphic setting

Sedimentation in the Anambra Basin began in the Campanian with a short marine transgression depositing the units of the Nkporo Group (Owelli Formation, Nkporo Formation, Enugu Formation), which consists of carbonaceous shales and sandstone members of deltaic origin (Nwajide and Reijers, 1996; Odunze et al., 2013). This unit was overlain by the coal-bearing Mamu Formation, deposited in the Late Campanian to Early Maastrichtian, at the beginning of a regressive phase. It consists of alternating sandstones, sandy shales, and mudstones, with interbedded sub-bituminous coal seams (Akande and Mucke, 1993). Overlying the Mamu Formation is the Ajali Formation, which comprises predominantly sandstones with minor interbeds of clay laminae, and the Nsukka Formation of mid-to-late Maastrichtian age, consisting of dark shales, sandstones with thin coal seams, marks the beginning of the transgression whose regressive cycle led to the subsidence of the Niger Delta Basin in the early Paleogene (Nwajide and Reijers, 1996). The Imo Formation was deposited during a regressive cycle (relative sea-level fall) (Dim et al., 2018).

2.3. Methodology

2.3.1. Field work

Field studies were carried out to identify outcrops of the Nsukka and Imo Formations and to characterize the different lithofacies units observed in the study area. Representative samples were carefully collected from the unweathered parts of each of the sandstone outcrops. The samples were carefully annotated. Twenty-eight samples were collected from the Nsukka Formation and seven from the Imo Formation to characterize the sediments and interpret their depositional environments.

2.1.2. Granulometric analysis

The samples were sieved to determine the statistical grain size distribution parameters of median, mode, mean, standard deviation, skewness, and kurtosis. Univariate, bivariate, and multivariate measures were used to interpret the possible environments of deposition of the formations. The Average Grain Size (M_z) is computed from the size of particles spread through a range of percentile values. It is much superior to the median because it is based on three points and gives a better overall picture. Sorting is a measure of the range of grain sizes present and the magnitude of the spread or scatter of these sizes around the mean size. The best measurement of this parameter is the Folk (1957) Inclusive Graphic Standard Deviation (σ_I). Skewness reflects sorting in the "tails" of a grain-size population. Populations that have a tail of excess fine particles are said to be positively skewed or fine skewed, i.e., skewed toward positive phi values. Populations with a tail of excess coarse particles are negatively skewed. Kurtosis (K_G) is related to both dispersion and the normality of the distribution. Kurtosis may be leptokurtic when the curve is strongly peaked, in which case it has exceptionally good sorting of the central part of the distribution, and may be platykurtic when the curve is flat, showing poorly sorted sediments or those with a bimodal frequency curve. The formula for calculating kurtosis is given in Table 1.

Sieving was done at the Department of Erosion, Federal University of Technology, Owerri. The equipment used includes a set of sieves, an automatic sieve shaker, and a sensitive beam balance. The samples were sun-dried. 50g of each sample was shaken in a nest of sieves of various sizes with an automatic sieve shaker for 15 minutes. The weight retained in each sieve was recorded in the sieve analysis data sheet, and the cumulative weight and weight percentage were calculated. These are used to plot cumulative graphs. The weight percentages, cumulative frequency graphs, and histograms were plotted. Grain sizes of the 5th, 16th, 25th, 50th, 75th, 84th, and 95th percentiles obtained from the cumulative frequency graph were used to calculate the graphic mean, standard deviation, inclusive graphic skewness, and graphic kurtosis for each sample based on formulae proposed by Folk and Ward (1957).

Table 1. Grain size distribution parameters and formulas (Folk and Ward, 1957).

Parameter	Formula
Average Grain Size (M_z)	$Mz = \frac{\Phi16 + \Phi50 + \Phi84}{3}$
Standard Deviation	$SD = \frac{\Phi84 - \Phi16}{4} + \frac{\Phi95 - \Phi5}{6.6}$
Skewness	$Sk = \frac{\Phi84 + \Phi16 + 2\Phi50}{2(\Phi84 - \Phi16)} + \frac{\Phi95 + \Phi5 + 2\Phi50}{2(\Phi95 - \Phi5)}$
Kurtosis	$K_G = \frac{\Phi95 - \Phi5}{2.44\,(\Phi0.75 - \Phi25)}$

3. Results and discussion

3.1. Graphic logs and Inclusive graphic measures

Figs 2 and 3 present representative graphic logs for the studied samples, which illustrate the different grain size distributions and their respective populations. Three types of curves were identified. Type-I distribution comprises four populations, which include the traction or creep population, saltation population, and suspension population. The bottom traction population is poorly developed in most samples and commonly less than 10% of the total grain population.

The Type II distribution comprises two populations: saltation and suspension. This is the dominant curve type in the samples. The saltation population is well developed, and its percentage ranges from 70 to 80% and exhibits a 60^0-70^0 slope inclination. The suspension population is mostly poorly developed. The percentage of the population generally ranges from 5 to 15%.

At its coarser end, the saltation population is truncated at 1Φ. Friedman and Sanders (1978) identified these types and characterized them as environmental indicators.

The Histogram plots of the individual weight per cent against the phi scale showed that the sandstones from the Nsukka Formation vary from unimodal to polymodal, while the Imo Formation is dominantly unimodal with modal class clustering around 0.2Φ to 2Φ.

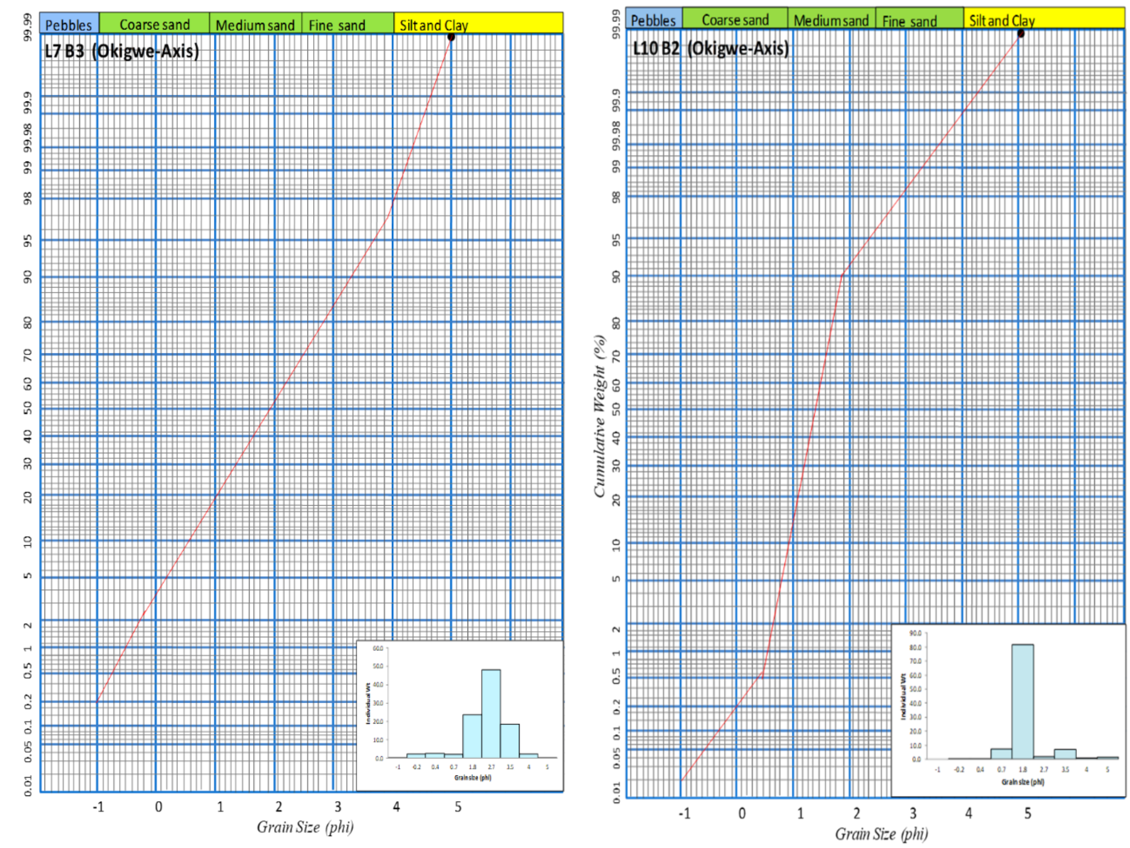

Fig. 2. Representative cumulative frequency graph for sandstones of the Nsukka Formation.

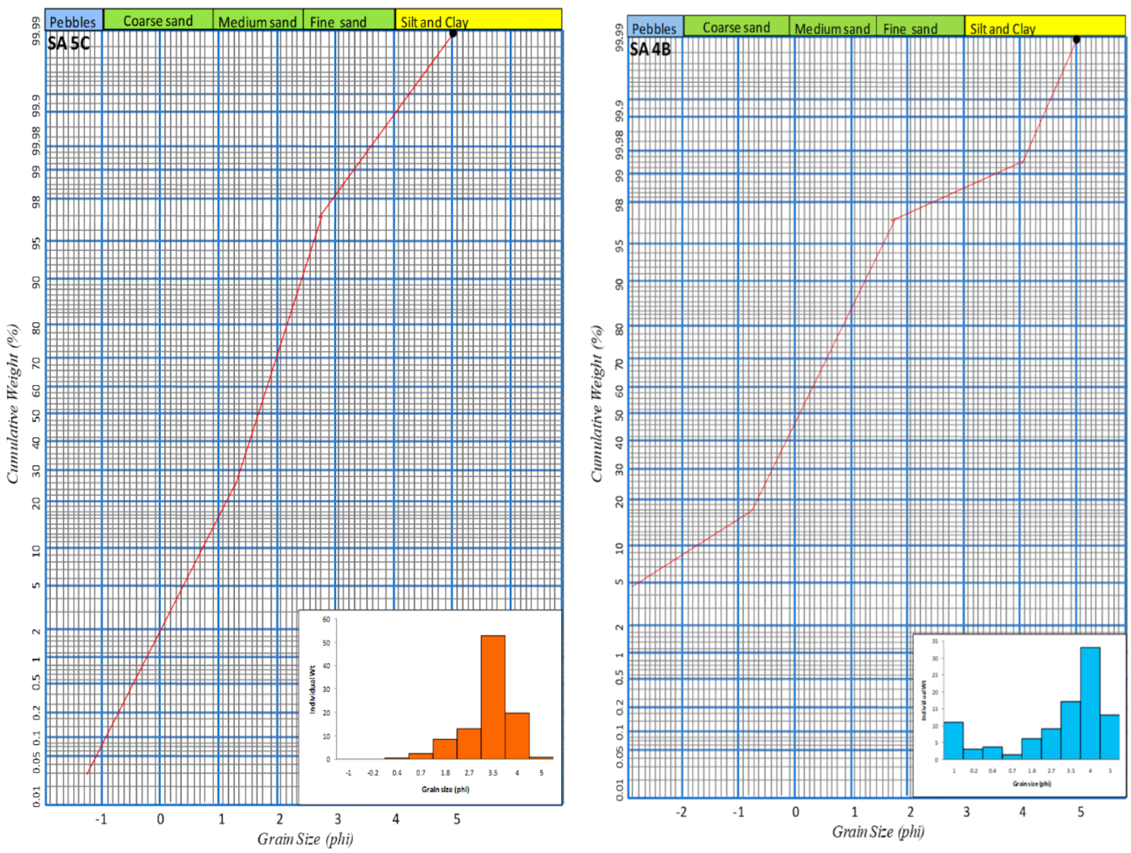

Fig. 3. Representative cumulative frequency graph for sandstones of Imo Formation.

3.2. Univariate Analysis

The percentiles (Tables 1 and 2) obtained from the cumulative frequency curves were input into established formulas proposed by Folks (1975) to calculate the grain size parameters such as mean grain size, skewness, sorting, and kurtosis (Tables 3 and 4).

Table 1. Percentile values for sandstones of the Nsukka Formation.

Sample ID	Φ5	Φ16	Φ25	Φ50	Φ75	Φ84	Φ95
L1B5	-1.80	0.50	1.00	2.80	3.20	3.50	4.00
L1B6	1.20	1.50	1.90	2.30	2.70	3.00	3.50
L1B5	-0.20	0.40	0.60	1.30	2.20	2.50	3.30
L3B2	-0.80	0.20	0.60	1.50	2.30	2.90	3.50
L3B3	-0.50	0.30	0.70	1.50	2.50	3.00	3.80
L6B9	-0.90	0.10	1.00	2.00	3.00	3.30	3.80
L6B14	-0.90	-0.20	0.40	1.50	2.40	2.70	3.50
L6B16	-0.70	0.70	1.10	1.80	2.60	3.00	3.60
L6B18	-0.90	0.20	0.70	1.20	1.80	2.40	3.00
L7B1	1.00	1.80	2.00	2.80	3.20	3.40	3.50
L7B2	-0.20	0.70	1.10	1.80	2.70	3.00	3.20
L7B3	0.45	1.10	1.40	2.00	2.90	3.00	3.20
L7B4	-0.50	0.40	1.00	2.00	3.00	3.20	3.30
L7B5	0.50	1.30	1.90	2.80	3.20	3.30	3.60
L7B6	0.40	1.20	1.50	2.20	3.00	3.10	3.30
L7B7	0.60	1.30	1.80	2.40	3.00	3.10	3.30
L7B8	0.60	1.20	1.50	1.90	2.40	2.70	3.20
L10B1	0.80	1.00	1.10	1.30	1.50	1.70	2.00
L10B2	0.90	1.00	1.20	1.40	1.80	1.90	3.20
L10B3	0.80	0.90	1.00	1.20	1.60	1.80	2.70
L10B4	0.70	0.90	1.00	1.30	1.60	1.70	2.70
L1S4A	0.10	0.50	0.80	1.10	1.40	1.60	1.90
L1S4B	-0.90	0.80	0.80	1.20	1.60	1.80	2.70
L1S4C	0.80	1.00	1.10	1.40	1.80	2.00	2.60
L1S4D	-0.90	0.70	0.90	1.30	2.00	2.60	3.30
L1S5C	0.50	1.00	1.20	1.80	2.60	3.00	3.20
L1S5D	0.30	1.00	1.10	1.50	2.00	2.40	2.70
L1S5E	-1.20	-0.50	-0.10	1.00	2.00	3.00	3.30
Average	-0.03	0.64	0.79	0.83	1.17	1.33	1.86

Table 2. Percentile values for sandstone samples of the Imo Formation.

Sample ID	Φ5	Φ16	Φ25	Φ50	Φ75	Φ84	Φ95
SA 4A	-0.20	0.30	0.70	1.30	1.50	1.60	2.00
SA 4B	-2.70	-2.00	-0.20	0.80	1.20	1.40	1.60
SA 4C	0.30	0.80	1.00	1.30	1.60	1.70	2.00
SA 4D	-0.30	0.30	0.60	1.20	1.50	1.70	3.00
SA 5C	0.40	1.00	1.30	1.50	1.80	2.00	2.50
SA 5D	0.10	-0.60	0.85	1.40	1.60	1.80	2.00
SA 5E	-1.20	-0.30	0.30	1.20	1.80	2.40	3.20
Average	-0.51	-0.07	0.65	1.24	1.57	1.80	2.33

Table 3. Grain size variables for sandstones of the Nsukka Formation.

Sample ID	Mean (ϕ)	Kurtosis	Standard Deviation	Skewness
L1B5	2.27	1.10	1.60	-0.56
L1B6	2.27	1.20	0.70	-0.01
L1B4	0.84	0.90	1.10	0.14
L3B2	0.89	1.00	1.30	-0.02
L3B3	0.93	1.00	1.30	0.09
L6B9	1.07	1.00	1.50	-0.21
L6B14	0.73	0.90	1.40	-0.13
L6B16	1.29	1.20	1.20	-0.06
L6B18	0.73	1.50	1.10	0.01
L7B1	1.91	0.90	0.80	-0.35
L7B2	1.17	0.90	1.10	-0.07
L7B3	1.37	0.80	0.90	-0.04
L7B4	1.16	0.80	1.30	-0.11
L7B5	1.73	1.00	1.00	-0.49
L7B6	1.48	0.80	0.90	0.09
L7B7	1.58	0.90	0.90	0.06
L7B8	1.33	1.20	0.80	0.03
L10B1	0.96	1.20	0.40	-0.08
L10B2	1.01	1.60	0.60	-0.23
L10B3	0.90	1.30	0.50	-0.12
L10B4	0.92	1.40	0.50	-0.20
L1S4A	1.07	1.20	0.80	-0.10
L1S4B	1.27	1.80	0.50	0.02

L1S4C	1.02	1.10	1.10	0.26
L1S4D	0.96	1.60	0.90	0.16
L1S5C	1.27	0.80	0.70	0.12
L1S5D	1.10	1.10	1.60	0.14
L1S5E	0.50	0.90	0.80	0.08
Mean	0.18±0.42	0.07±0.26	0.11±0.33	0.03±0.18

Table 4. Grain size variables for Imo Formation sandstone samples.

Sample ID	Mean (ϕ)	Kurtosis	Standard Deviation	Skewness
SA 4A	1.07	1.13	0.66	0.23
SA 4B	0.07	1.26	1.50	0.18
SA 4C	0.89	1.16	0.48	0.44
SA 4D	0.69	1.50	0.85	0.36
SA 5C	1.06	1.72	0.57	0.50
SA 5D	0.47	1.04	0.89	0.17
SA 5E	0.57	1.20	1.34	0.44
Mean	0.69±0.33	1.29±0.22	0.89±0.36	033±0.13

3.3. Bivariate and multivariate analysis

Friedman's (1967) and Moiola and Weiser (1968) discrimination plots of Skewness versus Sorting and Mean versus Sorting, respectively, were used for different sediments of Beach and Fluvial (River) origin for the sandstone samples of Nsukka and Imo Formations (Figs 4 and 5).

Also, plots were made using the linear discriminant functions of Sahu (1964) (Figs 6 and 7). The linear discriminant functions (Sahu, 1964), values of linear discrimination functions for sandstone of the Nsukka formation, and values of linear discrimination functions for sandstone of the Imo formation in Tables 5, 6, and 7 are shown, respectively.

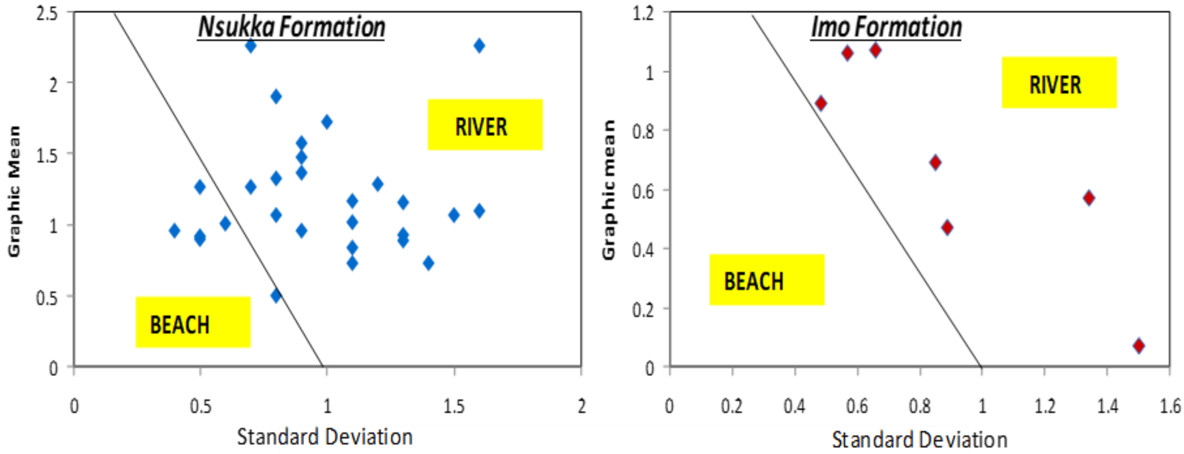

Fig. 4. Bivariate plots graphic mean against sorting for sandstone samples of Nsukka and Imo Formations (After Friedman, 1967).

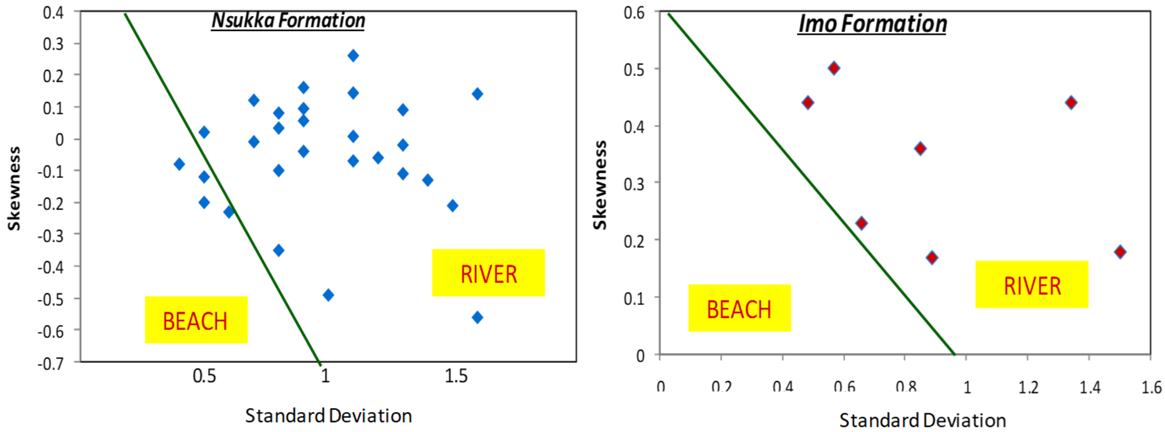

Fig. 5. Bivariate plot of skewness versus sorting for sandstone samples of Nsukka and Imo Formations (After Miola and Weiser, 1968).

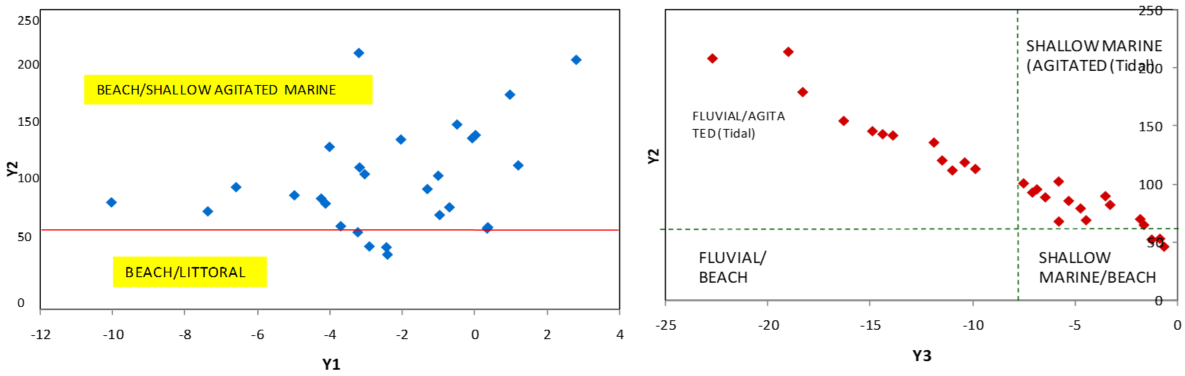

Fig. 6. Function plots of sandstone samples for Nsukka Formation (After Sahu, 1964).

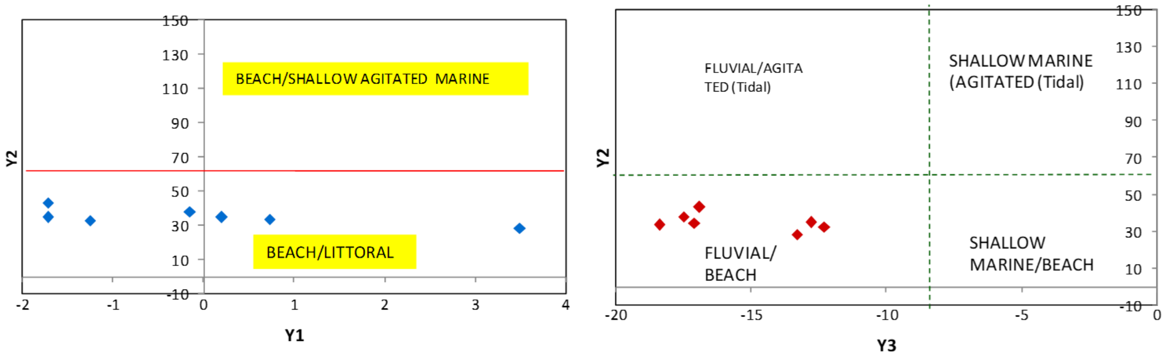

Fig. 7. Function plots of sandstone samples for Imo Formation (After Sahu, 1964).

Table 5. Linear Discriminant Functions (Sahu, 1964).

Y1 Function	Y2 Function	Y 3 function
Y1 = -3.5688 MZ + 3.7016 δ1 - 2.0766 SK1 + 3.1135 KG Y1 < -2.7411 = Aeolian Y1>-2.7411 = Beach	Y2 = 15.6534 MZ + 65.7091ϸ + 18.1071 SK1 + 18.5043 KG Y2 < 65.3650 beach Y2 > 65.3650 = shallow agitated marine environment	Y3 = 0.2852 MZ - 8.7604ϸ - 4.8932 SK1 + 0.0482 KG Y3 < -7.419 = Fluvial (deltaic) Y3 > -7.419 = Shallow marine

Table 6. Values of linear discrimination functions for sandstone of the Nsukka Formation.

Sample ID	Y1	Y2	Y3
L1B5	-3.21	214	-19
L1B6	-10.04	89.75	-3.54
L1B??	-1.02	111.9	-11
L3B2	-0.08	143.1	-14.4
L3B3	0.01	145.7	-14.9
L6B9	0.96	179.3	-18.3
L6B14	-0.50	154.5	-16.3
L6B16	-4.02	135.9	-11.9
L6B18	-3.19	118.8	-10.4
L7B1	-7.38	82.27	-3.31
L7B2	-3.05	113.2	-9.88
L7B3	-4.13	88.75	-6.47
L7B4	-2.05	142	-13.9
L7B5	-6.60	102.4	-5.82
L7B6	-4.25	92.9	-7.1
L7B7	-4.99	95.62	-6.88
L7B8	-0.71	85.67	-5.33
L10B1	-2.42	46.3	-0.68
L10B2	-3.24	64.91	-1.66
L10B3	-2.45	52.4	-1.28
L10B4	-2.92	53.11	-0.88
L1B5	-0.98	79.2	-4.75
L1B6	-3.71	69.98	-1.84
L1B??	1.19	120.5	-11.5
L3B2	-1.32	100.8	-7.53
L3B3	0.35	69.05	-4.48
L6B9	2.79	208.3	-22.7
L6B14	0.33	67.98	-5.81
Mean	-2.38	108.15	-8.63

Table 7. Values of linear discrimination functions for sandstone of the Imo Formation.

Sample ID	Y1	Y2	Y3
SA 4A	-1.72	34.91	-12.8
SA 4B	0.73	33.61	-18.4
SA 4C	-1.26	32.82	-12.3
SA 4D	0.20	34.85	-17.1
SA 5C	-0.15	38.13	-17.5
SA 5D	3.49	28.58	-13.3
SA 5E	-1.72	43.35	-16.9
Mean	**-0.06**	**35.18**	**-15.47**

The study showed that sandstones of the Nsukka formation are fine to coarse-grained with a dominance of medium-grained sands with a range of values of 0.5-2.27ϕ, (mean 1.2±0.42), well sorted to poorly sorted with a standard deviation value of 0.40-1.60 (mean 0.98±0.33), and nearly symmetrical to fine skewed with range value of -0.01 to 0.26 (mean -0.06±0.18).

The overall grain size for Imo Formation sandstone is very fine to coarse-grained with values ranging from 0.07-1.07 (mean 0.69±0.33ϕ), well to poorly sorted with values ranging from 0.48-1.50, (mean 0.89±0.36), fine skewed with values ranging from 0.17-0.5 (mean 0.33±0.13)

The mean grain size of the sediments implies a high-energy-level environment of deposition (Allen, 1965) with intermittent slack in depositional energy (Nichols, 2009). There is a direct correlation between sediment sorting and the degree of reworking; well-sorted sands have generally been subjected to high degrees of reworking (Nichols, 2009). For any given flow velocity, there is a maximum grain size that can be moved across a sediment surface; smaller or lighter grains will move across the bed (or in suspension), and coarser or heavier grains will not move. Thus, sediment is sorted according to size and mass; lighter or smaller grains are separated or winnowed from coarser-heavier grains. The more frequently this process occurs, the greater the degree of grain sorting.

Discriminatory bivariate plots suggest a fluvial origin for the sediments. Enyioko et al. (2022) conducted a sedimentological and petrographic study of the Ajali sandstone outcrops in Okigwe, Otoro and Isiokwato, Anambra Basin, southeastern Nigeria. The study suggests that the sandstones must have undergone a significant amount of reworking, which resulted in the removal of ferromagnesian and feldspar minerals common in the recycled sediments. Using the multivariate plot of linear discriminant functions of Sahu (1964), the Nsukka Formation may have been deposited in a beach/shallow marine setting. However, for the Imo Formation, the plots are suggestive of variable environments, indicating fluvial and shallow marine settings for Y2 vs Y3 and Y1 vs Y2 functions. Overall, however, the discriminant functions strongly suggest deposition in a continental fluvial setting for the Imo sandstone. This result corroborates the findings of Ekwenye et al. (2014), who interpreted the Umunna sandstone (a member of the Imo Formation) as a product of the continental coastal plain environment.

4. Conclusion

The study used granulometric analysis to evaluate the paleoenvironments of deposition of the sandy facies of Nsukka and Imo Formations (Ebenebe sandstone and Umunna sandstone) outcropping in some parts of southeastern Nigeria. Four inclusive graphic measures, mean grain size, standard deviation, skewness, and kurtosis, were used as univariable, bivariate, and multivariate evaluations to infer the hydrodynamic energies and paleodepositional setting of the sandstone facies. The results closely aligned with previous studies by various authors, with the Nsukkka Formation sandstone facies possibly deposited in shallow marine/beach settings, while the Ebenebe and Umunna sandstone members of the Imo Formation may be deposited in fluvial and marginal marine regimes.

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References

Allen, J.R.L., 1965. Late Quaternary Niger delta, and adjacent areas: sedimentary environments and lithofacies. *AAPG Bulletin*, 49(5), 547-600.

Alege, T. S., Tella, T.O. & Aigbadon, G.O., 2024. Lithofacies, bio-sequence stratigraphy and paleoenvironment of the Cretaceous-Neogene at the BG-1 well, offshore Eastern Dahomey Basin, Nigeria: implications for future exploration and development efforts. *Carbonates and Evaporites*, 39(2), 49.

Armstrong, R., Raup, B., Khalsa, S.J.S., Barry, R., Kargel, J., Helm, C. & Kieffer, H., 2005. GLIMS glacier database. National Snow and Ice Data Center, Boulder, Colorado, USA digital media.

Akande, S.O. and Mucke, A. 1993. depositional environment and diagenesis of carbonates at Mamu/Nkporo shale within the Anambra basin, Nigeria. *Journal of African Earth Sciences*, 17, 445-456.

Benkhelil, J., 1982. Benue trough and Benue chain. *Geological Magazine*, 119(2), 155-168.

Benkhelil, J., 1986. Structure and geodynamic evolution of the intracontinental Benue Trough (Nigeria) (Doctoral dissertation, Elf Nigeria Limited).

Brooks, H.L., Steel, E. & Moore, M., 2022. Grain-size analysis of ancient deep-marine sediments using laser diffraction. *Frontiers in Earth Science*, 10, 820866.

Burke, K.C., Dessauvagie, T.F.J. & Whiteman, A.J., 1972. Geological history of the Benue valley and adjacent areas. *African Geology*, 1(8), 7-2.

Dim, C.I.P., Mode, A.W. & Okwara, I.C., 2019. Signatures of key petroleum system elements: outcrop examples from the Anambra Basin, Southeastern Nigeria. *Journal of Petroleum Exploration and Production Technology*, 9(3), 1615-1631.

Dim, C.I.P., Onuoha, K.M., Okeugo, C.G. & Ozumba, B.M., 2017. Petroleum system elements within the Late Cretaceous and Early Paleogene sediments of Nigeria's inland basins: An integrated sequence stratigraphic approach. *Journal of African Earth Sciences*, 130, 76-86.

Di Stefano, C., Ferro, V., & Mirabile, S. (2010). Comparison between grain-size analyses using laser diffraction and sedimentation methods. Biosystems engineering, 106(2), 205-215.

Dürr, H.H., Meybeck, M, & Dürr, S.H., 2005. Lithologic composition of the Earth's continental surfaces derived from a new digital map emphasizing riverine material transfer. *Global Biogeochemical Cycles*, 19(4).

Didi, C.N., Osinowo, O.O., Akpunonu, O.E. & Usman, M.B., 2025. Re-evaluation of the stratigraphy, structural, and depositional environment of Kolmani field, Gongola sub-basin, northeast Nigeria using outcrop data, ditch cutting data, and well log data for enhanced hydrocarbon exploration. *Discover Geoscience*, 3(1), 95.

Ekwenye, O.C., Nichols, G.J., Collinson, M., Nwajide, C.S. & Obi, G.C., 2014. A paleogeographic model for the sandstone members of the Imo Shale, south-eastern Nigeria. *Journal of African Earth Sciences*, 96, 190-211.

Enyioko, N. D., Onyekuru, S. O., Ikoro, D. O., & Ogbonna, T. L. (2022). Sedimentologic and Petrographic Study of Outcrops of Ajali Sandstone in Okigwe, Uturu and Isiukwuato, Anambra Basin Southeastern Nigeria. Earth Sciences and Human Constructions, 2, 111-120.

Folk, R.L. & Ward, W.C., 1957. Brazos River bar [Texas]; a study in the significance of grain size parameters. *Journal of Sedimentary Research*, 27(1), 3-26.

Folk, R.L., 1974. Petrology of Sedimentary Rocks. Hemphill Publication Co, Austin, Texas, USA.

Friedman, G.M., 1967. Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands. *Journal of Sedimentary Research*, 37(2), 327-354.

Friedman, G.M. & Sanders, J.E., 1978. Principles of Sedimentology. Wiley, New York.

Gruzin, A.V., 2024. Soil information model for prediction the soil properties characteristics. *Magazine of Civil Engineering*, 17(5), 2.

Krumbein, W. & Sloss, L., 1963. Stratigraphy and Sedimentation. W.H. Freeman and Co., San Francisco, 660 p.

Moiola, R.J. & Weiser, D.A.N.I.E.L., 1968. Textural parameters; an evaluation. *Journal of Sedimentary Research*, 38(1), 45-53.

Areguamen, D.O., Critchlow, K., Dereshwisky, M. & Muhammad, B., 2022. Strategies for enhancing Nigeria’s procurement procedures. *American Journal of Industrial and Business Management*, 12(3), 331-364.

Nwajide, C.S & Reijers, T.J.A., 1996. Anambra Basin Excursion Guide. *In*Reijers, T.J.A. Ed., *Selected Chapters on Geology*, 149-197.

Obi, G.C., Okogbue, C.O. & Nwajide, C.S., 2001. Evolution of the Enugu Cuesta: a tectonically driven erosional process. *Global Journal of Pure and Applied Sciences*, 7(2), 321-330.

Oboh-Ikuenobe, F.E., Obi, C.G. & Jaramillo, C.A., 2005. Lithofacies, palynofacies, and sequence stratigraphy of Palaeogene strata in Southeastern Nigeria. *Journal of African Earth Sciences*, 41(1-2), 79-101.

Odumodu, C. & Ndicho, B., 2013. Facies and granulometric analysis as proxies for the paleodepositional environment of the Imo Formation, southeastern Nigeria. *Journal of Environment and Earth Science*, 3(14), 55-70.

Odunze, S.O., Obi, G.C., Yuan, W. & Min, L., 2013. Sedimentology and sequence stratigraphy of the Nkporo Group (Campanian–Maastrichtian), Anambra Basin, Nigeria. *Journal of Palaeogeography*, 2(2), 192-208.

Okoro, A.U., Igwe, E.O. & Umo, I.A., 2020. Sedimentary facies, paleoenvironments and reservoir potential of the Afikpo Sandstone on Macgregor Hill area in the Afikpo Sub-basin, southeastern Nigeria. *SN Applied Sciences*, 2(11), 1862.

Sahu, B.K., 1964. Depositional Mechanisms from the Size Analysis of Clastic Sediments. *Journal of Sedimentary Research*, 34, 1107-2821

Syvitski, J.P. & Morehead, M.D., 1999. Estimating river-sediment discharge to the ocean: application to the Eel Margin, northern California. *Marine Geology* 154, 13–28.

Syvitski, P.M. & Kettner, A.J., 2008. Sediment Dynamics in Changing Environments Proceedings of a symposium held in Christchurch, New Zealand, December 2008. IAHS Publ. 325, 2008.