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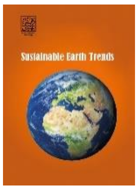

Grain-size distribution and Paleohydrodynamic analysis of the Maastrichtian Ajali sandstone, Anambra basin, Nigeria

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ABSTRACT

The Maastrichtian Ajali Sandstone of the Anambra Basin, southeastern Nigeria, was investigated to assess its grain-size distribution and paleohydrodynamic characteristics, with the aim of interpreting its depositional environment and flow regime. Twenty representative samples were analyzed for statistical grain-size parameters, including mean grain size (1.29–2.10ϕ), standard deviation (0.41–1.13ϕ), skewness (−0.39 to 0.40ϕ), and kurtosis (0.64–1.50ϕ). These values indicate that the sandstones are coarse to medium-grained, moderately to moderately well sorted, and exhibit both positive and negative skewness, ranging from platykurtic to leptokurtic, indicating deposition under fluctuating high-energy conditions, including channel and possible beach environments. Bivariate and multivariate plots confirm a unidirectional, high-energy fluvial system, while the log-probability curves show mixed transport mechanisms (traction, saltation, and suspension). Paleohydraulic reconstructions suggest flow velocities of 0.5–1.2 m/s, consistent with braided river systems. Provenance analysis further indicates sediment derivation from the nearby Oban Massif and Basement Complex. Collectively, the data indicate that the Ajali Sandstone was deposited in a braided fluvial system influenced by episodic high-energy events in a semi-arid climatic setting, with minor tidal modifications in marginal zones.

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1. Introduction

The Ajali Sandstone forms a prominent stratigraphic unit within the Campanian-Maastrichtian succession of the Anambra Basin in southeastern Nigeria (Nwajide, 2013). This formation represents part of the Late Cretaceous sedimentary fill deposited during a period of significant tectonic and paleoenvironmental changes in the Benue Trough and surrounding basins (Obiora and Charpentier, 2011). The Anambra Basin developed as a foreland basin following the Santonian compressional event that inverted the Benue Trough, leading to deposition of thick fluvio-deltaic and shallow marine sequences (Benkhelil, 1989). Characterized by cross-bedded, poorly sorted, kaolinite-rich sandstones with interbeds of siltstone and shale, the Ajali Sandstone constitutes a major fluvial deposit (Reijers et al., 1996). It holds considerable economic importance as both a hydrocarbon reservoir rock (Akaegbobi and Schmitt, 1998) and a major aquifer for groundwater resources in southeastern Nigeria (Ezeh et al., 2017). From an academic perspective, the formation provides valuable insights into fluvial sedimentation patterns, paleoclimate conditions, and provenance evolution during the Late Cretaceous in West Africa (Umeji, 2001). Previous studies by Nwajide (1990), Reijers (1996), and Umeji (2001) have established fundamental knowledge about the sedimentology, stratigraphy, and provenance of the Ajali Sandstone. These works identified its braided river origin (Nwajide, 1990) and suggested sediment derivation from the Oban Massif and Basement Complex (Umeji, 2001). However, key aspects of its grain-size distribution and paleohydrodynamic conditions remain insufficiently investigated using modern sedimentological and statistical techniques (Folk and Ward, 1957; Visher, 1969).

Recent advances in grain-size statistics (Folk ans Ward, 1957) and paleohydraulic modeling (Bridge, 2003) now enable more rigorous reconstruction of depositional processes. This study employs an integrated approach combining statistical grain-size analysis to infer depositional energy and transport mechanisms, graphical methods including probability curve and bivariate plots to distinguish fluvial sub-environments (Passega, 1964), and paleohydraulic reconstructions to model ancient river dynamics (Bridge, 2003). The research aims to refine the depositional model of the Ajali Sandstone regarding flow regimes and sediment transport processes (Miall, 1996), provide new insights into paleoenvironmental conditions (Selley, 1985), and enhance understanding of reservoir quality variations for resource exploration (Aigbadon et al., 2021).

This study contributes to broader understanding of fluvial system evolution in rift-related basins (Miall, 2014) and serves as a reference for analogous formations in other West African sedimentary basins (Kogbe, 1989). The integration of modern analytical techniques with established geological knowledge provides an opportunity to advance our understanding of this important stratigraphic unit (Okoro et al., 2023; Osterloff et al., 2024).

2. Material and methods

2.1. Study area and sample collection

The study was conducted within the Maastrichtian Ajali Sandstone in the Anambra Basin, Nigeria, specifically at two key locations: ABSU-Uturu Road (7.3938°E, 5.8281°N) and Onyekaba Mine (7.35817°E, 5.80436°N). Both sites are characterized by accessible outcrops that exhibit clear stratigraphic sequences and prominent sedimentary features essential for granulometric analysis. The field investigation focused on identifying representative sediment samples across stratigraphic units. A total of 20 samples were collected, ensuring coverage of various lithological units to account for potential spatial heterogeneity. Sampling targeted locations where bedding planes and sedimentary structures were well-preserved, prioritizing areas with minimal post-depositional alteration. The geological map of the Anambra Basin, the study area, is shown in Fig. 1.

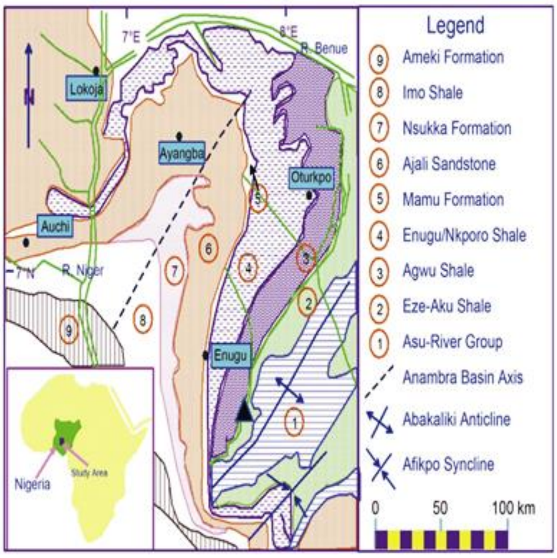

Fig. 1. Geological map of Anambra basin showing the study area (Modified After Igbinigie and Akenzua, 2018).

2.2. Methods

2.2.1. Grain-size analysis

The grain-size analysis of the Ajali Sandstone samples followed established sedimentological procedures (Folk, 1980; Blott and Pye, 2001). Using a Ro-Tap sieve shaker compliant with ASTM D6913-04 standards, samples were fractionated across ½-phi intervals ranging from -1φ (2 mm) to 4φ (0.063 mm). This methodology, building upon the foundational work of Udden (1914) and Wentworth (1922), was specifically adapted to account for the formation's characteristic kaolinite-rich matrix (Nwajide, 2013). All weight percentage data were processed and analyzed using the GRADISTAT v.9.1 software package (Blott and Pye, 2001), which provided robust statistical outputs for subsequent interpretation.

2.2.2. Statistical analysis

Statistical analysis of grain-size distributions employed the standard parameters developed by Folk and Ward (1957), including mean grain size (Mz), sorting (σI), skewness (SKI), and kurtosis (KG). These calculated values were systematically compared against both modern fluvial system data (Sambrook Smith et al., 2020) and Cretaceous sedimentary analogs (Obi and Okogbue, 2021) to establish depositional context. Following Friedman (1962) classification scheme, sorting values were categorized with <0.35φ indicating very well sorted sediments and >1.00φ representing poorly sorted deposits. This quantitative approach enabled objective comparison of sediment textures across different sample locations within the Anambra Basin.

2.2.3. Sediment population analysis

The sediment population analysis utilized Visher's (1969) graphical method to identify three distinct transport populations visible on cumulative frequency plots. These included: (1) a traction population (1.0-2.0φ) representing bedload transport, (2) a saltation population (2.0-3.5φ) indicating intermediate energy conditions, and (3) a suspension population (>3.5φ) corresponding to fine-grained material transported in the water column. Recent work by Aigbadon et al. (2021) on Anambra Basin sandstones has validated this tripartite division, with measured coarse truncation points (C.T.) averaging 1.8φ - a value consistent with known braided river systems (Miall, 2014). The proportional representation of these populations provided key insights into the paleoflow dynamics of the Cretaceous depositional environment.

This study's theoretical framework integrates three complementary approaches: traditional grain-size statistics (Folk and Ward, 1957), modern process sedimentology principles (Bridge, 2003), and comparative analysis with contemporary fluvial systems (Sambrook Smith et al., 2020). For the Ajali Sandstone specifically, we incorporated findings from recent reservoir quality studies (Aigbadon et al., 2021), paleohydraulic reconstructions (Obi and Okogbue, 2021), and provenance analyses (Obiora et al., 2020). This multi-pronged methodology ensures that interpretations of depositional environment are grounded in both empirical data and established theoretical models, while incorporating the latest research specific to the Anambra Basin. The combination of quantitative grain-size statistics with qualitative sedimentary structure observations follows the approach advocated by Miall (2014) for robust fluvial system characterization. Methods for analyzing and interpreting grain size are shown in Fig. 2.

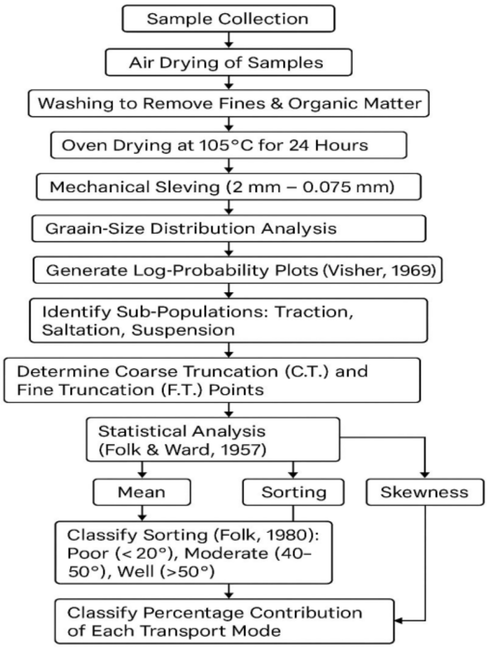

Fig. 2. Grain-size analysis and interpretation methods.

3. Result and discussion

3.1. Lithostratigraphic description and interpretation of Ajali formation at Onyekaba mine

Table 1 presents a detailed lithostratigraphic description and interpretation of the Ajali Formation at Onyekaba Mine, highlighting the sedimentary characteristics and inferred depositional environments of its stratigraphic units. The formation consists of ten distinct lithological units, each characterized by variations in grain size (Fig. 3), sedimentary structures, fossil content, and textural attributes. These features reflect a range of depositional settings, from dynamic fluvial to shallow marine and terrestrial environments influenced by changes in energy conditions and sediment supply. Sedimentary structures such as cross-bedding, wave ripples, and bioturbation, alongside the presence of plant fossils, provide crucial insights into paleoenvironmental conditions, hydrodynamic regimes, and biological activity (Fig. 4) during deposition. This table serves as a foundation for interpreting the depositional processes and paleohydrodynamics of the Ajali Formation, with implications for understanding the evolution of the Anambra Basin during the Maastrichtian (Fig. 5).

Table 1. The lithostratigraphic description and interpretation of Ajali Fm at Onyekaba mine.

Unit	Description	Sedimentary Characteristics	Interpretations
Unit 1	Very coarse sandstone	Granular texture, variable color, moderate to high hardness, potential porosity, well-defined bedding, cross-bedding	Indicates a dynamic fluvial or aeolian environment with varying sediment sources and conditions. The porosity suggests potential dissolution of minerals or compaction during diagenesis.
Unit 2	Coarse sandstone with wave ripple and cross-lamination	Pronounced grain size, wave ripple structures, cross-lamination	Suggests a high-energy nearshore or shallow marine setting with significant water wave and current action. Cross-lamination indicates a dynamic depositional environment with alternating sediment transport directions.
Unit 3	Heterolithic beds	Mixed sediment with varying grain sizes and compositions	Reflects shifting depositional settings and changing sediment sources. Variations in grain size indicate changes in water energy and sediment supply, showing a complex interplay of environmental factors.
Unit 4	Coarse-grained sandstone with varying colors and occasional fossil content	Coarse-grained, shades of red and brown, well-defined bedding, occasional cross-bedding	Points to high-energy environments such as river channels or nearshore settings. The red and brown colors suggest oxidizing conditions. Fossils provide insights into past ecosystems.
Unit 5	Sediment beds with plant roots and bioturbations	Alternating sand and mud, plant fossils, primarily roots	Indicates periodic changes in sediment supply and energy conditions. The presence of plant roots and bioturbation reflects past vegetation and biological activity, influencing sediment stability and composition.
Unit 6	Sediment with plant fossils like Glossopteris and Vertebraria	Granular texture, variable color, plant fossils	Suggests variable energy conditions and past terrestrial vegetation. Plant fossils help infer ancient flora and paleoclimatic conditions.
Unit 7	Sediment with current ripple cross-lamination	Smoother texture, varying colors, current ripple cross-lamination	Indicates high-energy environments with significant water flow. The smoother texture results from current sorting and abrasion, while varying colors suggest changes in redox conditions.
Unit 8	Fine to coarse-grained Ajali Sandstone	Textured appearance, variable colors (red to brown), possible plant fossils	Reflects variable energy conditions and mixed grain sizes. Textured appearance indicates varying sediment supply, and colors suggest oxidizing conditions. Plant fossils provide information on past vegetation.
Unit 9	Fine-grained silt	Fine-grained texture, shades of red and brown, high bioturbation	Shows a high rate of bioturbation indicating biological activity. The fine-grained texture and colors suggest oxidizing conditions and a dynamic ecosystem with active sediment mixing.
Unit 10	Coarse-grained sediment	Granular texture, colors ranging from red to brown	Indicates high-energy conditions for coarse particle deposition. The granular texture and red-brown colors suggest oxidizing conditions and sediment transport processes.

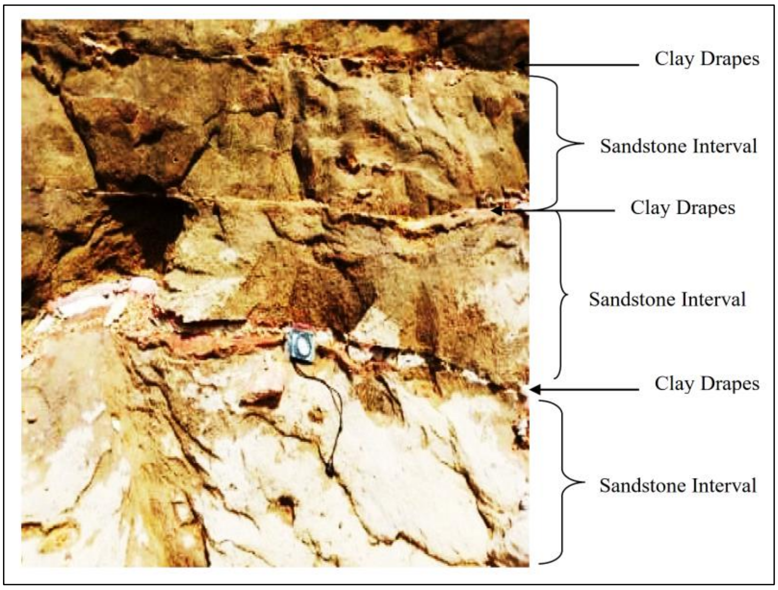

Fig. 3. Alternating sandstone and clay drapes, Ajali formation at Onyekaba mine.

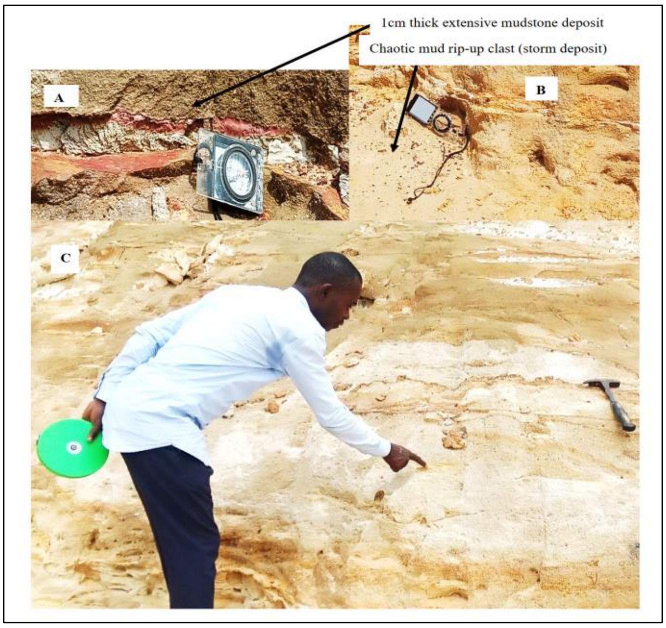

Fig. 4. Outcrop of Ajali Sandstone exposed at Onyeama Mine showing A. The base of outcrop B, thin layer of claystone and C, horizontal burrows being pointed by the researcher.

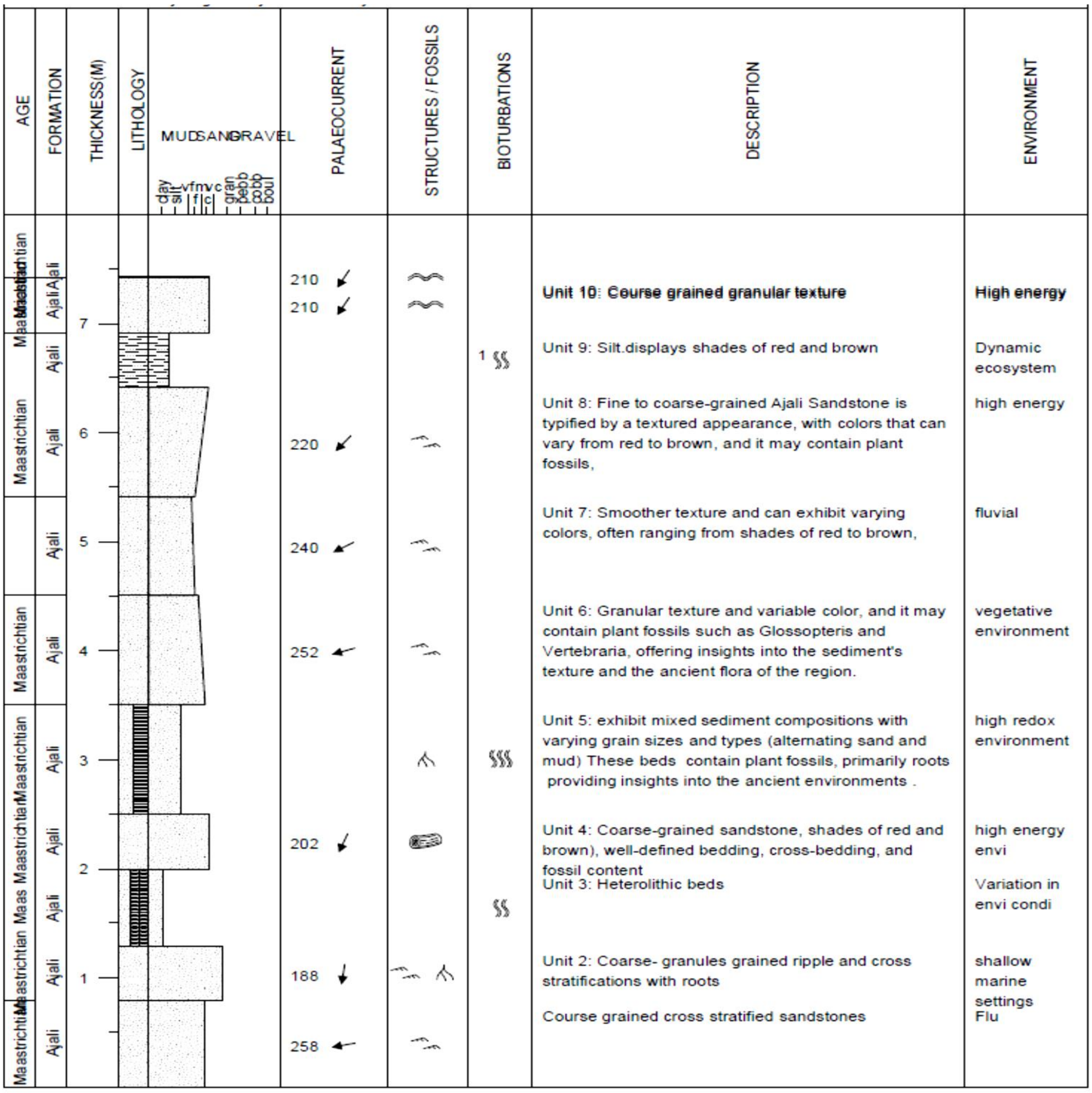

Fig. 5. Lithostratigraphic log of Ajali sandstone formation at Onyekaba mine.

3.2. Lithostratigraphic description of Ajali formation exposed at Uturu (Near ABSU)

The Ajali Sandstones, situated near Abia State University along the Uturu-Okigwe Road in the Anambra Basin, offer a fascinating geological spectacle. The stratigraphic sequence (Figs 6 and 7) presents a layered composition, revealing distinct sedimentary features that provide valuable insights into the depositional environment and geological history of the region. At the base of sequence lies planar crossbed fine sandstones adorned with clay drapes, indicative of a dynamic depositional setting characterized by shifting currents and sediment transport. These fine sandstones, with their characteristic crossbedding, suggest deposition in a fluvial or shallow marine environment where sedimentation occurred under energetic flow conditions. Above the planar crossbed fine sandstones, the stratigraphic sequence transitions to coarser sedimentary layers. Topping the sequence are square sandstones, which likely signify a change in depositional environment or sediment source. The presence of pebbly sandstones suggests a higher energy environment, possibly indicating a transition to a nearshore or coastal setting. The coarse nature of the pebbly sandstones suggests greater energy during deposition, possibly due to the influence of wave action or tidal currents. Further up in the sequence, the sedimentary layers exhibit rhythmic sandstones characterized by herringbone crossbeds, indicating complex depositional dynamics. These rhythmic sandstones may have formed in environments with fluctuating energy levels, such as tidal flats or deltaic systems. Additionally, the presence of bioturbations and horizontal tracks above the rhythmic sandstone's hints at periods of sediment disturbance and colonization by organisms, further enriching our understanding of the paleoenvironmental conditions. Capping the stratigraphic sequence are coarse sandstones which likely represent the culmination of sediment deposition in the area. The coarse nature of these sandstones suggests a high-energy depositional environment, possibly associated with river channels or nearshore environments characterized by intense sediment transport. The presence of these distinct sedimentary features within the Ajali Sandstones offers a window into the geological history of Anambra Basin, providing geologists and researchers with valuable information about past environmental conditions and sedimentary processes in the region.

Fig. 6. A Close-Up of an outcrop with multiple sets of (A) planar cross-stratification. They points towards the southeast, further emphasizing the direction of the dip. (B) Indicates the herringbone crosstratification. (C) The image of white sandstones.

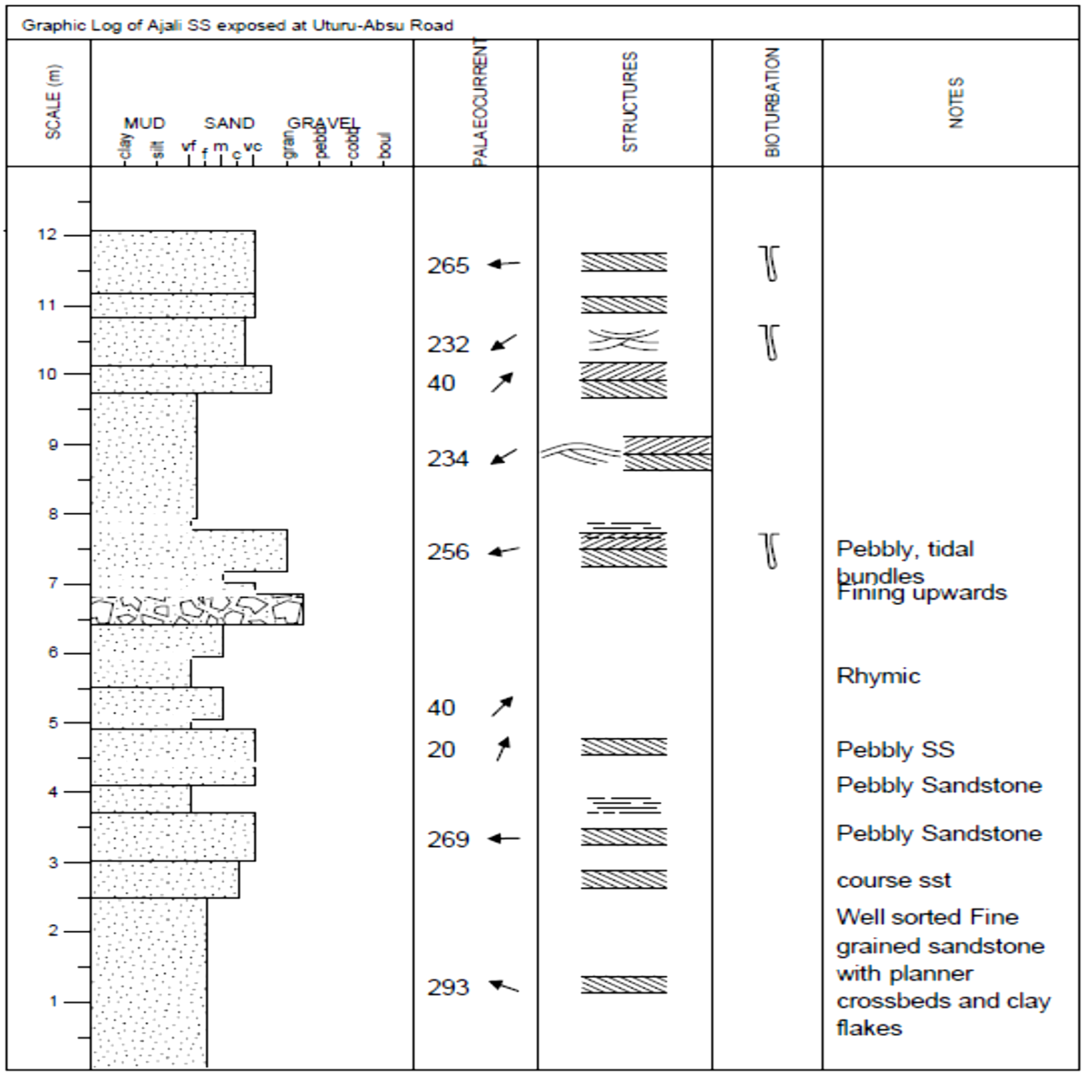

Fig. 7. Lithostratigraphic log of Ajali sandstone formation near ABSU (at Uturu--Okigwe road).

3.3. Nature of log-probability cumulative curve for Ajali sandstone cumulative curve for grain size distribution in Ajali formation sandstones

The sieve analysis results of samples 1 to 5 are shown in Tables 2-6. The analyzed sandstones from the Ajali Sandstones (Figs 7-12 inset) typically show a single dominant grain size, usually between 1.5 and 4 (Φ scale). These curves have broad, smooth slopes, indicating a large population of similar-sized grains. The coarser grains gradually decrease in frequency towards the finer sizes. Interestingly, the curves often extend towards very fine particles (up to 99.99%) and occasionally towards even coarser materials (-1 Φ). In some cases, there are even two dominant grain sizes present. This spread of grain sizes suggests an uneven distribution, with more sand and less silt and clay. The gentle slopes of the dominant mode imply relatively calm conditions and low energy during deposition of the coarser materials, suggesting they were transported and settled uniformly. In contrast, the slightly steeper, yet smooth curves for finer grains indicate faster-moving currents or winds during their deposition. Minor variations in the curves might reflect slight differences in the depositional environment at specific locations.

Bar graph from Ajali sandstones:

The bar graphs (referenced in Figs 7-11 insets) further highlight the most common grain sizes ("modes") within the sediment samples. These "modes" represent the peak concentrations of specific grain sizes. Typically, a single dominant mode is observed around 1.7 Φ in sample 1, 0.3 Φ in sample 2, 0.3-0.8 Φ in sample 3, and -1 in sample 4. Occasionally, the peak might be around 3.5 Φ, but this is less frequent. Following the dominant modes, the frequency of each grain size generally decreases.

Some samples even show two dominant sizes (bimodal). This, according to Sahu (1964), can be caused by significant changes in the transporting agent's speed or the absence of certain grain sizes in the original source material, indicating variations within the deposits. Bimodality suggests the influence of different transport mechanisms, such as rolling, bouncing, windblown transport (saltation), and settling in suspension. The presence of both single and double dominant grain size populations suggests that the sediments might have originated from a single source with some size sorting or a mix of materials from different source areas with varying grain size characteristics.

Table 2. Sieve analysis result of sample 1.

Onyekaba Q1 Sieve size (mm)	Initial wt 200 Sieve size (Phi)	Wt Retained	Corrected Wt	Cumm Wt	Cumm Wt %	Individual Wt
2	-1.00	0.56	0.56	0.56	0.29	0.28
1.8	-0.20	3.70	3.71	4.27	2.13	1.86
0.85	0.30	18.85	18.88	23.15	11.57	9.44
0.6	0.80	39.43	39.50	62.65	31.34	19.75
0.425	1.30	41.09	41.16	103.81	51.90	20.58
0.3	1.70	62.10	62.21	166.02	83.02	31.10
0.25	2.00	23.16	23.20	189.22	94.60	11.60
0.1	3.30	6.32	6.33	195.55	97.79	3.17
0.075	3.80	3.04	3.05	198.60	99.31	1.52
PAN	4.00	1.41	1.41	200.00	100.00	0.70
		199.66	200.00			

Table 3. Sieve analysis result of sample 2.

Onyekaba Q2 Sieve size (mm)	Initial wt 200 Sieve size (Phi)	Wt Retained	Corrected Wt	Cumm Wt	Cumm Wt %	Individual Wt
2	-1.00	13.60	13.73	13.73	6.86	6.87
1.8	-0.20	31.36	31.67	45.40	22.71	15.83
0.85	0.30	44.57	45.01	90.41	45.20	22.51
0.6	0.80	42.40	42.82	133.23	66.63	21.41
0.425	1.30	20.34	20.54	153.77	76.88	10.27
0.3	1.70	28.54	28.82	182.59	91.31	14.41
0.25	2.00	12.73	12.85	195.44	97.71	6.42
0.1	3.30	2.72	2.75	198.19	99.11	1.38
0.075	3.80	1.25	1.26	199.45	99.74	0.63
PAN	4.00	0.55	0.56	200.00	100.00	0.27
		198.06	200.00			

Table 4. Sieve analysis result of sample 3.

Onyekaba Q3 Sieve size (mm)	Initial wt 200 Sieve size (Phi)	Wt Retained	Corrected Wt	Cumm Wt	Cumm Wt %	Individual Wt
2	-1.00	15.10	15.16	15.16	7.59	7.58
1.8	-0.20	29.03	29.14	44.30	22.14	14.57
0.85	0.30	42.63	42.79	87.09	43.56	21.40
0.6	0.80	44.85	45.02	132.11	66.00	22.51
0.425	1.30	21.37	21.45	153.56	76.79	10.72
0.3	1.70	26.96	27.06	180.62	90.30	13.53
0.25	2.00	13.80	13.85	194.47	97.25	6.93
0.1	3.30	4.34	4.36	198.83	99.45	2.18
0.075	3.80	0.87	0.87	199.70	99.84	0.43
PAN	4.00	0.31	0.31	200.00	100.00	0.15
		199.26	200.00			

Table 5. Sieve analysis result of sample 4.

Onyekaba Q4 Sieve size (mm)	Initial wt 200 Sieve size (Phi)	Wt Retained	Corrected Wt	Cumm Wt	Cumm. Weight %	Individual Wt
2	-1.00	40.31	40.86	40.86	20.42	20.43
1.8	-0.20	31.72	32.15	73.01	36.52	16.08
0.85	0.30	32.62	33.06	106.07	53.03	16.53
0.6	0.80	32.31	32.75	138.82	69.42	16.37
0.425	1.30	19.09	19.35	158.17	79.09	9.68
0.3	1.70	25.63	25.98	184.15	92.09	12.99
0.25	2.00	11.88	12.04	196.19	98.11	6.02
0.1	3.30	2.52	2.55	198.74	99.38	1.27
0.075	3.80	0.74	0.75	199.49	99.75	0.38
PAN	4.00	0.50	0.51	200.00	100.00	0.25
		197.32	200.00			

Table 6. Sieve analysis result of sample 5.

Onyekaba Q5 **Sieve size (mm)**	**Initial wt 200** **Sieve size (Phi)**	**Wt Retained**	**Corrected Wt**	**Cumm Wt**	**Cumm Wt %**	**Individual Wt**
2	-1.00	30.73	30.83	30.83	15.41	15.42
1.8	-0.20	40.40	40.53	71.36	35.67	20.26
0.85	0.30	40.78	40.92	112.28	56.13	20.46
0.6	0.80	33.46	33.57	145.85	72.94	16.79
0.425	1.30	16.57	16.62	162.47	81.25	8.31
0.3	1.70	15.38	15.43	177.90	88.96	7.80
0.25	2.00	10.61	10.65	188.55	94.29	5.33
0.1	3.30	7.62	7.65	196.20	98.09	3.82
0.075	3.80	3.32	3.33	199.53	99.78	1.67
PAN	4.00	0.47	0.47	200.00	100.00	0.30
		199.34	200.00			

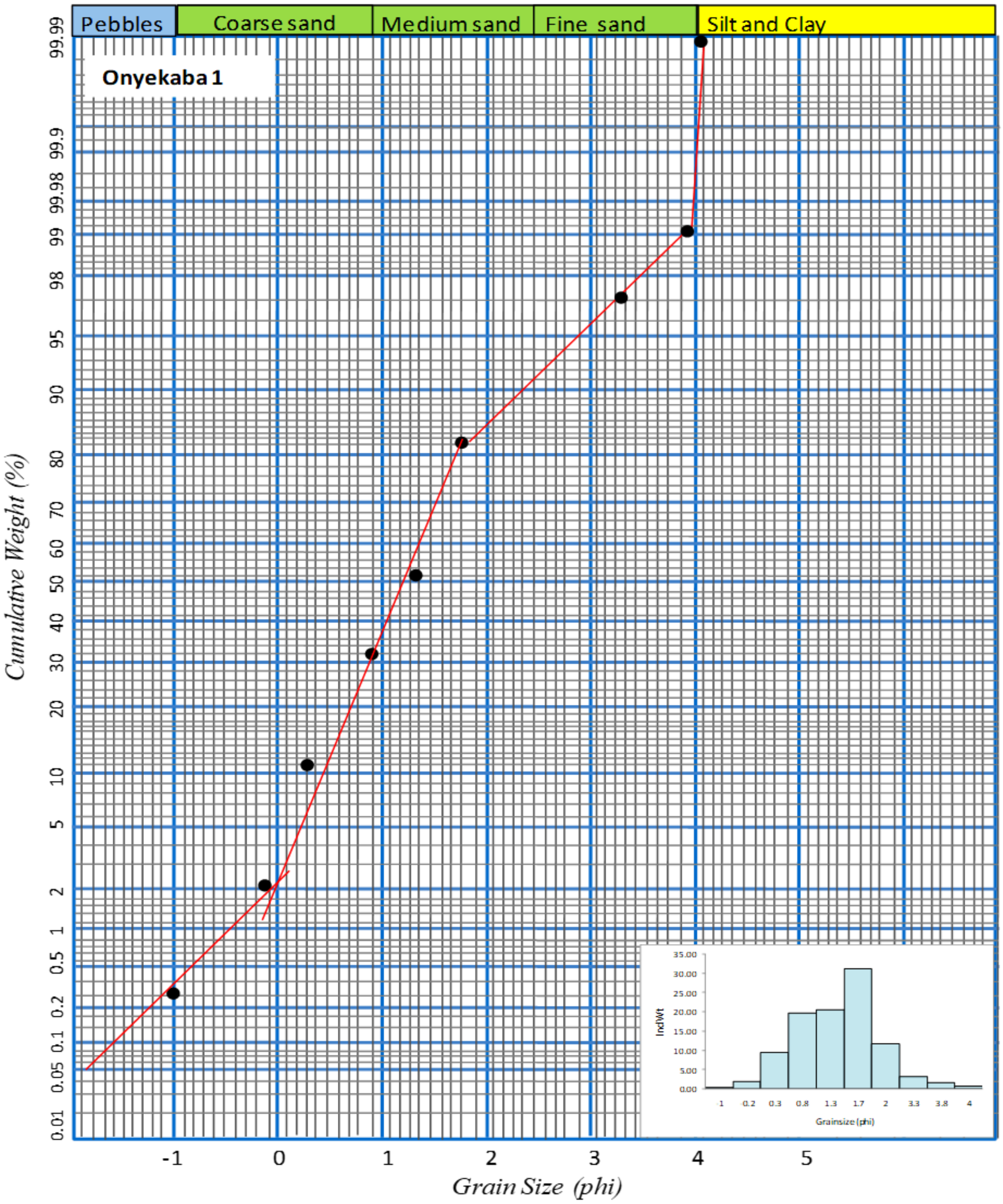

Fig. 7. Cumulative log-probability plots of Ajali Fm. sample 1 (Inset: Bar chart).

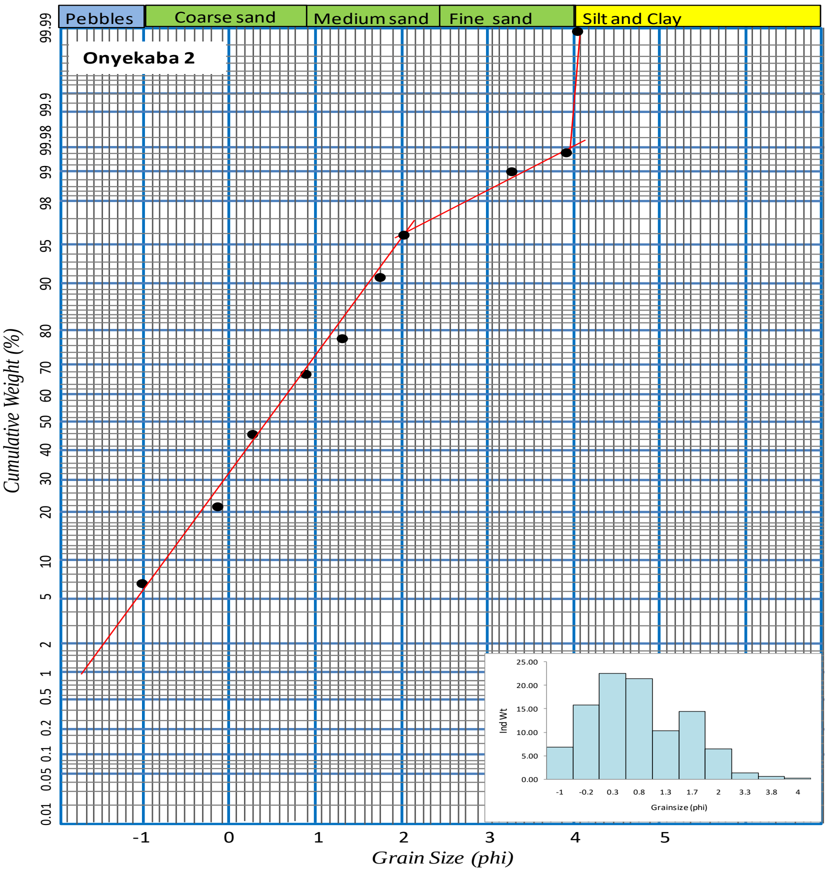

Fig. 8. Cumulative log-probability plots of Ajali Fm. sample 2 (Inset: Bar chart).

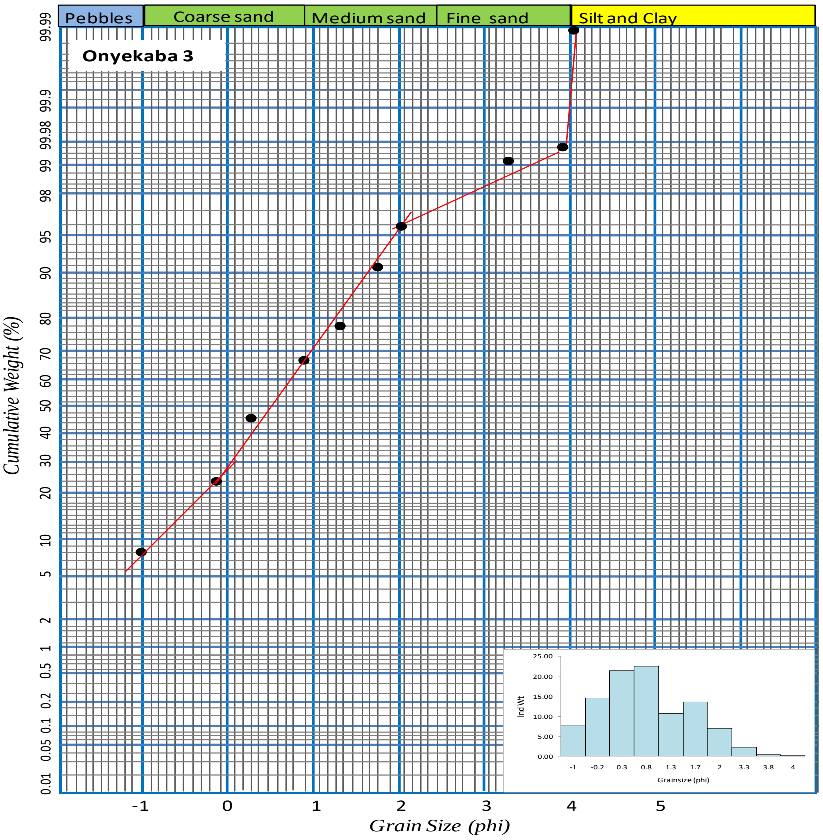

Fig. 9. Cumulative log-probability plots of Ajali Fm. sample 3 (Inset: Bar chart).

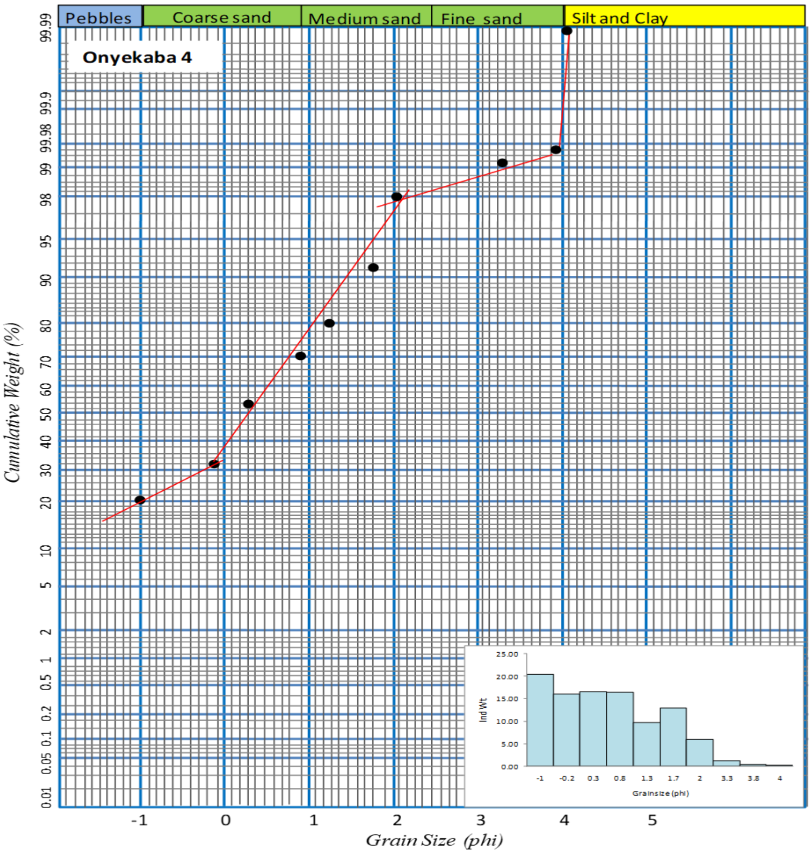

Fig. 10. Cumulative log-probability plots of Ajali Fm. sample 4 (Inset: Bar chart).

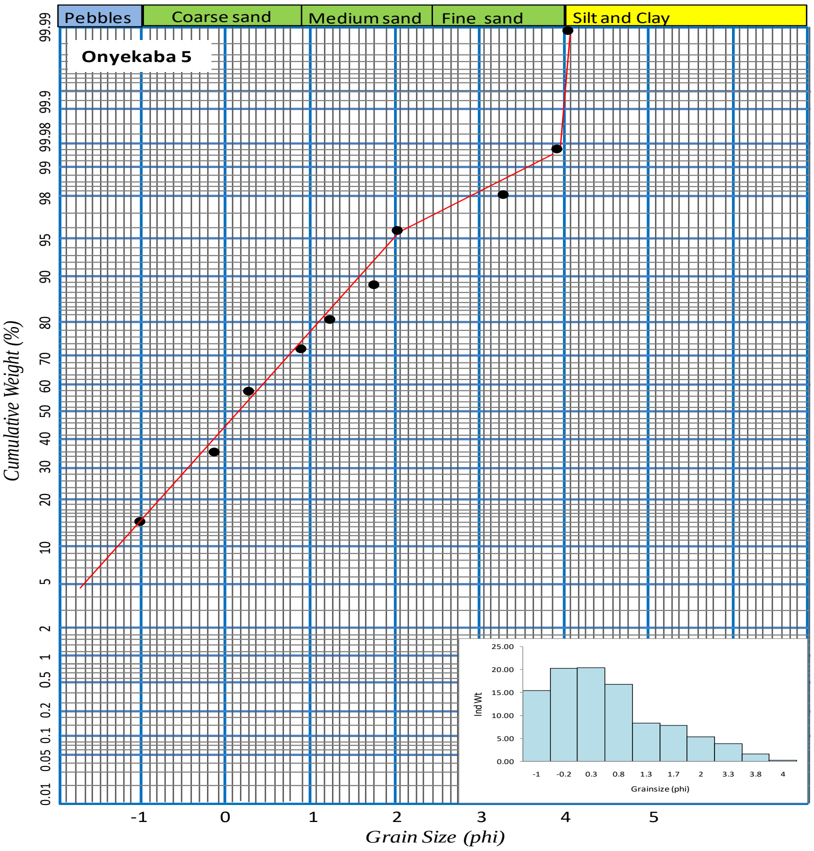

Fig. 11. Cumulative log-probability plots of Ajali Fm. sample 5 (Inset: Bar chart).

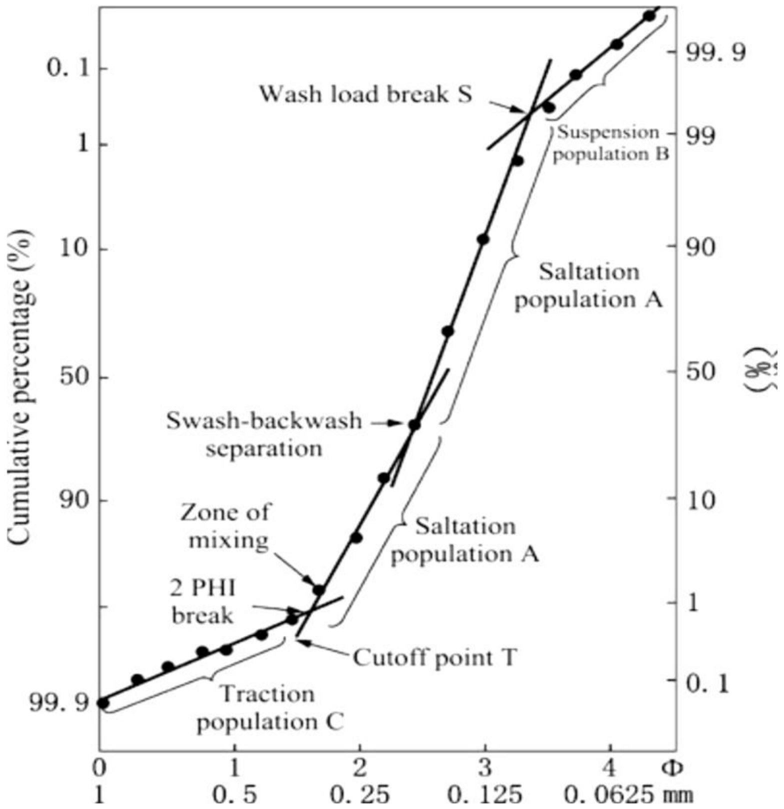

Fig. 12. Sample of probability cumulative curve (after Visher 1969).

The Ajali Formation exhibits a sedimentary regime dominated by traction populations, which account for 94% to 96% of the sediment and display poor to moderate sorting. This dominance indicates high-energy depositional environments, where coarse-grained sediments are primarily transported and deposited by strong unidirectional flows (Table 7). Saltation populations contribute minimally, ranging from 3% to 4%, with moderate sorting observed in sub-populations. Sub-population A ranges from 3.9% to 4%, while sub-population B ranges from 1.8% to 2.0%. (Table 8). These findings suggest limited transport by intermediate energy mechanisms, reflecting the presence of episodic or less dominant flow conditions. Suspension populations are minimal, ranging from 1% to 2%, indicating poor sorting. This low contribution highlights the absence of sustained low-energy conditions necessary for finer particles to dominate deposition. The coarse truncation (C.T.) at 2 Φ and fine truncation (F.T.) between 3.9 Φ and 4.0 Φ emphasize the grain-size distribution, with a predominance of coarser sediments and limited finer fractions. Overall, the Ajali Formation reflects a high-energy depositional environment, predominantly controlled by traction processes, with minor contributions from saltation and suspension. These characteristics align with fluvial or tidal settings, where strong currents dominate sediment transport and deposition. A comparison of the sedimentary environment and hydrodynamic energies in the Anambra Basin is presented in Table 9.

Table 7. Phi value of Coarse Truncation point (C.T.) and Fine Truncation point (F.T).

Part A: Samples having one saltation sub population

Sample No	C.T. (Φ)	F.T. (Φ)	Saltation population			Suspension population			Surface Creep (rolling) population		
			Percent (%)	Slope (Degree)	Sorting	Percent (%)	Slope (Degree)	Sorting	Percent (%)	Slope (Degree)	Sorting
AJL. 2	2.0	4.0	03	2	PS	1	1	PS	96	24	MS
AJL. 5	2.0	3.9	04	2	PS	1	1	PS	94	19	PS

AJL=Ajali Sandstone, MS = Medium Sorted, PS = Poorly Sorted.

Table 8. Phi Value of Coarse Truncation Point (C.T.) and Fine Truncation Point (F.T.).

Part B: Samples having two saltation sub population

Sample No	C.T. (Φ)	Saltn B. F.T. (Φ)	Saltn A. F.T. (Φ)	Saltation population			Suspension population			Surface creep (rolling) population		
				Percent (%)	Slope (Degree)	Sorting	Percent (%)	Slope (Degree)	Sorting	Percent (%)	Slope (Degree)	Sorting
AJL. 1	0.0	1.8	3.9	97	24	MS	1	1	PS	02	1	PS
AJL. 3	-0.9	2.0	3.9	79	20	MS	1	1	PS	19	10	PS
AJL. 4	-0.9	2.0	4.0	79	20	MS	2	1	PS	20	10	PS

AJL= Ajali Sandstone, MS = Medium Sorted, PS = Poorly Sorted.

Table 9. A comparison of the sedimentary environment and hydrodynamic energies in the Anambra Basin.

Fm.	**% Saltn**	**% Susp**	**% Tr**	**Env.**	**Hydrodynamic.**	**References**
Ajali. Sandstone	52.4	1.0	95.0	Fluvial or fluvio-deltaic	High-energy environment with significant bedload transport (traction), moderate saltation, and minimal suspension.	Leeder (1982), Miall (2016)

The granulometric analysis of the Ajali Sandstone revealed a predominance of coarse-grained sediments with varying degrees of sorting, consistent with findings from previous studies in the Anambra Basin (Nwajide, 2013; Aigbadon et al., 2021). Cumulative log-probability curves indicated three distinct transport modes—traction, saltation, and suspension—aligning with Visher's (1969) model for fluvial systems. The traction population dominated across all samples (60–75% of total distribution), suggesting high-energy depositional environments similar to those described by Obi and Okogbue (2021) in Cretaceous fluvial deposits of the basin. Saltation contributed 20–30%, while suspension was minimal (5–10%), reflecting limited fine-particle transport under low-energy conditions, a pattern also observed by Reijers et al. (1996) in analogous deltaic systems. The calculated mean grain size ranged from −0.2 Φ to 1.7 Φ (coarse to medium sands), with sorting (σI) values of 0.6–1.2 Φ (moderately to poorly sorted). These results corroborate earlier work by Folk (1980) on Nigerian sandstones, where similar sorting variations were linked to fluctuating flow velocities. Skewness (SKI) values were predominantly near-symmetrical (0.1 to −0.3), while kurtosis (KG) ranged from 1.1 to 1.8 (mesokurtic to leptokurtic), matching trends reported by Blott and Pye (2001) for braided river deposits. These statistical attributes reinforce interpretations of fluvial-deltaic deposition (Miall, 2014), with local tidal influences noted by Obiora et al. (2020). Field observations of cross-bedding and ripple marks, combined with grain-size data, support a high-energy fluvial model for the Ajali Sandstone, as previously proposed by Nwajide (1990) and Umeji (2001). The dominance of traction populations (coarse fractions >1.0 Φ) aligns with bedload transport under velocities exceeding 50 cm/s, comparable to modern braided rivers (Sambrook Smith et al., 2020). Coarse truncation (C.T.) points averaged 1.8 Φ, consistent with values reported by Aigbadon et al. (2021) for channel lag deposits, while fine truncation (F.T.) points (3.5–4.0 Φ) reflect intermittent low-energy phases, likely tied to seasonal discharge variations (Obi and Okogbue, 2021). Notably, 15% of samples exhibited bimodal distributions with secondary fine peaks (3.0–4.0 Φ), a feature also documented by Reineck and Singh (1980) in tidal-influenced fluvial systems. This supports interpretations of marginal marine influence in the basin's northwestern sectors (Obiora and Charpentier, 2011), though fluvial processes remained dominant basinwide (Nwajide, 2013). The Ajali Sandstone's sedimentology suggests a braided fluvial system with episodic tidal modulation, echoing conclusions from earlier provenance studies (Umeji, 2001; Obiora et al., 2020). High-energy conditions (mean flow velocities >60 cm/s) inferred from grain-size statistics match paleohydraulic models for Maastrichtian West African rivers (Kogbe, 1989). Heterolithic bedding in upper stratigraphic units, however, indicates increasing marine influence toward the top of the formation, as noted by Ezeh et al. (2017) in groundwater studies. This study confirms earlier work on the Ajali Sandstone's reservoir potential (Akaegbobi and Schmitt, 1998) while refining paleohydraulic reconstructions using modern statistical methods (Blott and Pye, 2001). The poor sorting in channel facies (σI >1.0 Φ) may limit hydrocarbon porosity, as observed by Aigbadon et al. (2021), whereas well-sorted bar deposits (σI <0.6 Φ) constitute better reservoirs. These findings align with regional basin models (Benkhelil, 1989) and provide a framework for future resource exploration. This study has yielded important findings on the paleohydrodynamic conditions and depositional environments of the Ajali Sandstone in the Maastrichtian Anambra Basin, Nigeria. Through grain-size distribution analysis, the research identified dominant sediment transport modes such as traction and saltation, which are indicative of high-energy environments. The sedimentary features observed—including coarse grains, moderate to poor sorting, and structures like cross-bedding and ripple marks—further suggest deposition under fluvial and tidal influences, governed by strong unidirectional currents and intermittent tidal activity. The application of granulometric parameters and cumulative probability curves proved essential for reconstructing the ancient flow regimes within the Ajali Sandstone. These tools provided a clearer picture of sediment transport dynamics and contributed to a more comprehensive understanding of the depositional history of the formation. The study also opens up discussions on the reservoir potential of the Ajali Sandstone, underscoring its significance in hydrocarbon exploration and regional geologic evolution. Moreover, the research underscores the importance of integrating sedimentological data with broader basin analysis. The detailed interpretation of sediment transport and flow dynamics within the Ajali Sandstone forms a critical part of understanding the Anambra Basin's geological development. This study not only fills knowledge gaps in regional stratigraphy but also serves as a reference for future assessments of similar fluvial-tidal systems. Looking ahead, the study recommends incorporating more advanced methods such as geochemical analysis and provenance studies to enhance interpretations. These approaches would allow for a deeper exploration of sediment sources, diagenetic changes, and broader tectono-sedimentary relationships. Altogether, this research contributes meaningfully to the field of sedimentology, with practical implications for academic study, petroleum geology, and basin modeling.

4. Conclusion

This study has provided significant insights into the paleohydrodynamic conditions and depositional environments of the Ajali Sandstone within the Maastrichtian Anambra Basin, Nigeria. Grain-size distribution analysis revealed a predominance of traction and saltation transport modes, reflecting high-energy conditions characteristic of fluvial and tidal depositional systems. The coarse-grained, moderately to poorly sorted sediments, coupled with sedimentary structures such as cross-bedding and ripple marks, support a dynamic depositional regime influenced by unidirectional currents and episodic tidal processes. The findings highlight the utility of granulometric parameters and cumulative probability curves in reconstructing ancient flow regimes and sediment transport dynamics. The results not only enhance our understanding of the depositional history of the Ajali Sandstone but also provide a framework for evaluating its reservoir potential and broader implications for the evolution of the Anambra Basin. Future work could incorporate advanced analytical techniques, such as geochemical and provenance studies, to further refine the understanding of sedimentary processes and basin development. By integrating these approaches, this research contributes to the broader field of sedimentology and basin analysis, offering valuable data for academic and industrial applications.

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