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Textural Classification of Borehole Sediments of Bonny Island, Coastal Niger Delta, Nigeria: Implication of Depositional environment and geotechnical evaluation

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Abstract

The textural properties of subsurface sediments of three boreholes (BH1, BH 2, BH 3, 0-14 m depth) on Bonny Island, coastal Niger Delta, Rivers State, Nigeria were objectively studied in order to explain depositional conditions and evaluate geotechnical consideration. Standard sieve analysis was applied to thirty samples and the statistical data of the grain-size (mean (Mz), sorting (σ 1), skewness (Sk1) and kurtosis (KG)) were obtained with Folk and Ward (1957) graphical method. The material that serves as the major textural fraction in all boreholes is sand. Mean grain sizes vary between 1.8 - and 3.2 () medium - very fine sand), sorting values 0.6-1.2 -moderately well-sorted to moderately sorted), skewness is largely positive (+0.08 to +0.35), and the kurtosis is meso -leptokurtic (KG = 0.90 -1.40). All boreholes of interest represented by an upward-fining trend indicate successive weakening of energy to the present-day depositional surface. A coarse-sand bed at 911 m in the BH3 that is covered in with coarse sand is seen as a palaeotidal channel or a beach-ridge deposition. The coastal-fluvial facies of the Benin Formation is given a sediment as a part of a barrier-lagoon complex. Geotechnically, the deeper sandy formations have intermediate permeability and sufficient bearing strength worth structural anchorage, but since near-surface silty units have low permeability, ground enhancement is necessary during the structural loading.

Keywords: Grain-size analysis; textural classification; borehole sediments; Bonny Island; Niger Delta; Benin Formation; depositional environment; geotechnical engineering

1. INTRODUCTION

The relative proportions and the distribution of particle size of a particular sediment are diagnostic characteristics of first-order quality in describing the sedimentology and geotechnical studies (Folk and Ward, 1957; Blott and Pye, 2001). Textural properties determine permeability, porosity, compressibility, shear strength, and consolidation behaviour; and at the same time, the hydrodynamic past of the sediment transport

and deposition is encoded in them, which can be used to reconstruct the past environmental conditions in stratigraphic strata (Reineck & Singh, 1980). However, in the coastal area and deltaic environments, where the depositional energy changes quickly along space, time, grain-size analysis is a particularly effective technique to describe the architecture of facies and explain the variability within the subsurface (Pejrup, 1988).

The Niger Delta Nigeria constitutes one of the largest and petroliferous Tertiary deltaic complexes of the world and occupies about 75,000km 2 at the mouth of the River Niger (Short and Stauble, 1967; Evamy et al., 1978). Its geology is characterized by three lithostratigraphic units, namely, the deep-sea Akata Formation, the delta-front Agbada Formation, and the continental-to-nearshore Benin Formation (Avbovbo, 1978; Reijers, 2011). A low-lying formation directly below the shallow subsurface of Bonny Island is Benin Formation that is mostly composed of unconsolidated sands, gravels, and clay lenses that are formed under fluvial and coastal marine environments (Asseez, 1989).

The location of Bonny Island is strategically critical along the southeastern boundary of the Niger Delta whereby the discharge caused by the fluvial of the Niger system, the two-way tidal forcing and the littoral drift interlock to develop a stratigraphy of interbedded sands and muds capturing cycles of high and low energy depositional periods (Nwankwoala, 2019; Akpofure and Akana, 2019). Nigeria has its major Liquefied Natural Gas (LNG) plant as well as extensive petroleum logistic infrastructure in the island, so precise subsurface characterisation is mandatory to the foundation engineering, land recovery, and environment control.

Regardless of the economic significance of Bonny Island and the extensive sedimentological studies conducted in the region over the years, the textural classification of the subsurface sediments of the island, at the high-resolution, and with boreholes, has not been properly developed (Nwankwoala, 2019; Akpokodje, 1987). The majority of current studies would be limited to surface or near-surface levels and not systematic implementation of capabilities of quantitative Folk and Ward (1957) statistical techniques to provide inter-borehole comparison. The current research fills this gap by systematic sieve analysis of sediments in three boreholes, calculation of the entire Folk and Ward textural parameter, and depositional settings and geotechnical implications.

2. GEOLOGICAL SETTING AND STUDY AREA

Niger Delta Basin was formed as a result of passive margin subsidence after the discontinuation of the Gondwana and the opening of the South Atlantic; since the Paleocene period to date the basin has been without cease trying to fill up with sediments (Avbovbo, 1978). The subsurface of the basin is characterised by three lithostratigraphic formations, which are the Akata Formation (Eocene-Recent; marine shale to source rock), Agbada Formation (Eocene-Recent; interbedded sands and shales to hydrocarbon reservoir) and the Benin Formation (Oligocene-Recent; continental-near shore sands and gravels to major freshwater aquifer). The structural features which are notable are growth faults, rollover anticlines, and shale diapirs that are the manifestations that indicate the compaction of terrain and gravitational deformation along the basin base margin (Evamy et al., 1978).

Bonny Island (4N 43OW 7N 15E) is some 40 km south of Port Harcourt in the eastern Niger Delta barrier-lagoon complex. Low-lying topography (below 5 m above mean sea level) defines all the island and tidal creeks and Bonny River distributaries drain it. The rain fall is over 2,500 mm per year and the vegetation comprises mainly of mangrove forests, fresh water swamp forest and coastal scrub. The whole island is covered with the

unconsolidated deltaic sediments of the Benin Formation that dated to the Holocene period that were deposited by the mixed systems of fluvial-tidal-marine (Reijers, 2011).

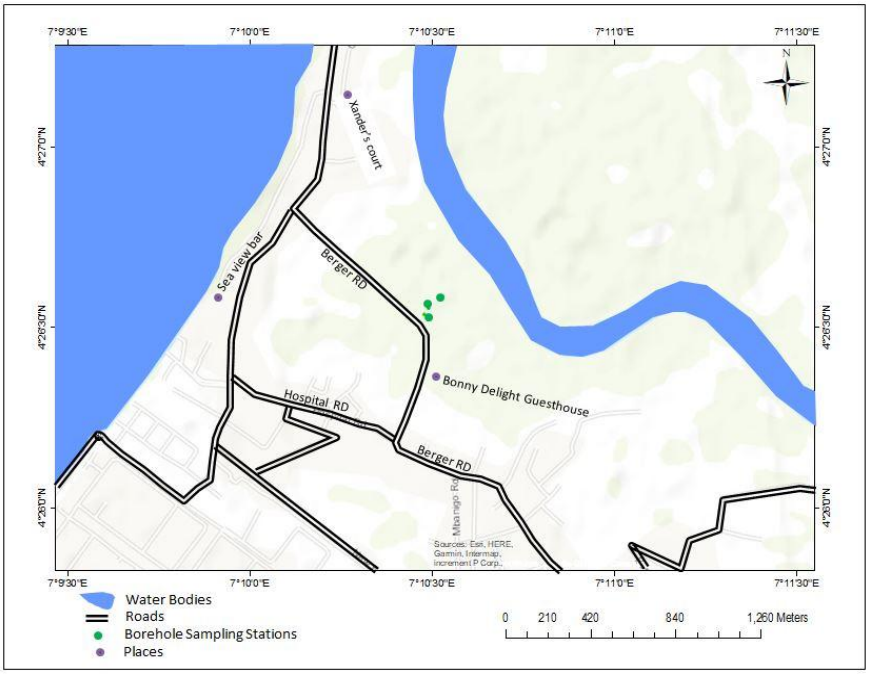


Fig. 1. The location map of Bonny Island in Rivers State, Nigeria, of the three borehole sites (BH1, BH2, BH3) in the framework of the coastal Niger Delta. Inset: the location of the Niger Delta in West Africa.

3. MATERIALS AND METHODS

3.1 Borehole Sampling

The sampled boreholes were 3 boreholes (BH1, BH2, BH3) on the Bonny Island at 1m depth intervals (0-14 m) through a rotary drill rig with a split-spoon sampler (ASTM D1586) so as to avoid excessive disturbance of sediment fabric in place. The samples were put in two polythene bags where they got labelled with borehole identifier and depth before being stored in cool and dry conditions before being laboratory analyzed. There was quality control of the samples by picking duplicates at 10 percent intervals.

3.2 Sample Preparation

The samples were dried at 105 C in the oven to a constant mass after 24h air-drying (BS 1377: Part 2, 1990). The dried samples were disaggregated using a rubber-tipped pestle and mortar gently so as not to fracture the grains. Samples that had a visible organic matter were pre-treated with 10 percent of H 2 O 2, washed in distilled water, and dried. Fragments of shells and plant debris with a size larger than 4 mm were pre-sieved by hand.

3.3 Sieve Analysis

Sub-sample of 100g (ASTM D422; BS 1377) were sieved. An apertured nest of standard wire-mesh sieves (with

2.000, 1.000, 0.500, 0.250, 0.150 and 0.075 mm (-1, 0, 1, 2, 2.7 and 3.7 mm) apertures respectively) were loaded onto a mechanical shaker which was run at a constant amplitude of 10 min. Mass remain sum on each sieve and in the pan were tabulated to the nearest tenth, i.e.0.01 g. Percentage retained, corrected weight retained and cumulative percentage were calculated in that order. In cases where fines (less than 0.075 mm) were found to pass 10 percent by mass, the method of hydrometer (ASTM D422) was also used to describe silt and clay fractions.

3.4 Textural Parameter Computation

Cumulative frequency curves were used and grain-size statistical parameters obtained by use of Folk and Ward (1957) graphical method. The values of percentiles (ϕ 5, 16, 25, 50, 75, 84, 95) were obtained through reading of the curves and the following equations were used:

Mean (Mz): $Mz = (\phi_{16} + \phi_{50} + \phi_{84}) / 3$
Sorting (σ_1): $\sigma_1 = (\phi_{84} - \phi_{16})/4 + (\phi_{95} - \phi_5)/6.6$
Skewness (Sk_1): $Sk_1 = (\phi_{16}+\phi_{84}-2\phi_{50})/[2(\phi_{84}-\phi_{16})] + (\phi_5+\phi_{95}-2\phi_{50})/[2(\phi_{95}-\phi_5)]$
Kurtosis (KG): $KG = (\phi_{95} - \phi_5) / [2.44(\phi_{75} - \phi_{25})]$

Sand–silt–clay proportions were plotted on Folk's (1974) ternary diagram to assign textural classes, and particle fractions were labelled according to the Wentworth (1922) grade scale.

4. RESULTS

4.1 Grain-Size Distribution Data

The table representations of representative sieve analysis results, of the borehole depth horizons tested in each borehole, are given in Table 1 through Table 3. All the 30 samples have full data, which is in the supplementary data repository. Sand (0.0752.000 mm) is the overriding sediment fraction in all the boreholes and depths, making up > 85 per cent of the mass in the majority of the horizons. The upper samples (012 m) of BH1 and BH2 include high contents of silt and clay (up to 15 percent combined) whereas the deeper in all the boreholes are the materials mostly of sandy nature with less than 5 percent fines.

Table 1. Borehole 1, Depth 0.1–1 m: Representative sieve analysis data.

Sieve Ø (mm)	ϕ	Wt Sieve (g)	Wt Sieve+S (g)	Wt Ret. (g)	Corr. Wt (g)	Cum. Wt (g)	% Ret.	Cum. %
2	-1	529	530.6	1.6	1.63	1.6	0.54	0.54
1	0	474.5	480.2	5.7	5.81	7.3	1.93	2.47
0.5	1	443	463.8	20.8	21.19	28.1	7.04	9.52
0.25	2	463.8	622.1	158.3	161.25	186.4	53.61	63.12
0.15	2.7	459.5	553.8	94.3	96.06	280.7	31.93	95.06
0.075	3.7	469.5	483.3	13.8	14.06	294.5	4.67	99.73
Pan	>3.7	370.3	371.1	0.8	0.81	295.3	0.27	100

Table 2. Borehole 2, Depth 4–5 m: Representative sieve analysis data.

Sieve Ø (mm)	ϕ	Wt Sieve (g)	Wt Sieve+S (g)	Wt Ret. (g)	Corr. Wt (g)	Cum. Wt (g)	% Ret.	Cum. %
2	-1	528.6	538.5	9.9	9.9	9.9	3.46	3.46
1	0	474	485.2	11.2	11.2	21.1	3.91	7.38
0.5	1	442.5	451.6	9.1	9.1	30.2	3.18	10.56
0.25	2	463.1	656.9	193.8	193.73	224	67.74	78.29
0.15	2.7	452.7	510.5	57.8	57.78	281.8	20.2	98.5
0.075	3.7	468.8	473.1	4.3	4.3	286.1	1.5	100
Pan	>3.7	370	370	0	0	286.1	0	100

Table 3. Borehole 3, Depth 9–10 m: Representative sieve analysis data (high-energy unit).

Sieve Ø (mm)	ϕ	Wt Sieve (g)	Wt Sieve+S (g)	Wt Ret. (g)	Corr. Wt (g)	Cum. Wt (g)	% Ret.	Cum. %
2	-1	528.4	568.9	40.5	40.54	40.5	14.36	14.36
1	0	473.9	531.1	57.2	57.26	97.7	20.28	34.63
0.5	1	442.6	493.3	50.7	50.75	148.4	17.97	52.61
0.25	2	463	507.8	44.8	44.85	193.2	15.88	68.49
0.15	2.7	452.6	529.3	76.7	76.78	269.9	27.19	95.68
0.075	3.7	468.8	481	12.2	12.21	282.1	4.32	100
Pan	>3.7	370	370	0	0	282.1	0	100

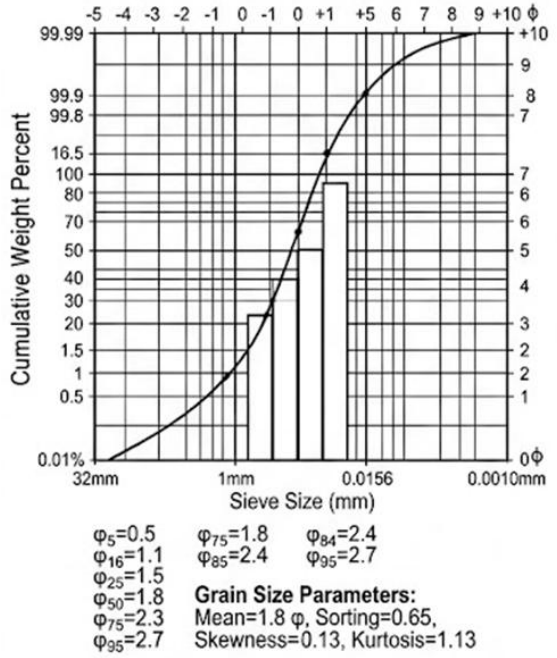


Fig. 2. Grain-size frequency curves of the entire sample of BH1, at each of the depth horizons of the sample. This upward movement fines on the surface (towards the surface) can be observed in the move of curves towards the right at shallow depths.

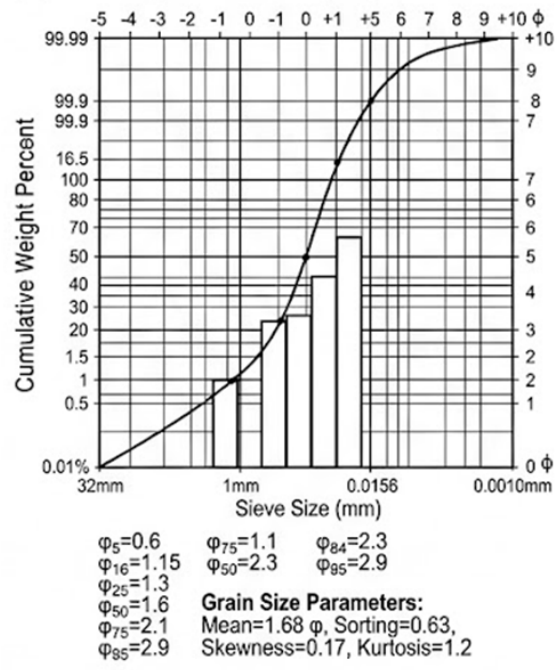


Fig. 3. Grain-size frequency curves Cumulative grain-size curves of BH2. In most of the intervals, moderate sorting is observed in the shape of curves which is in a form of the sigma.

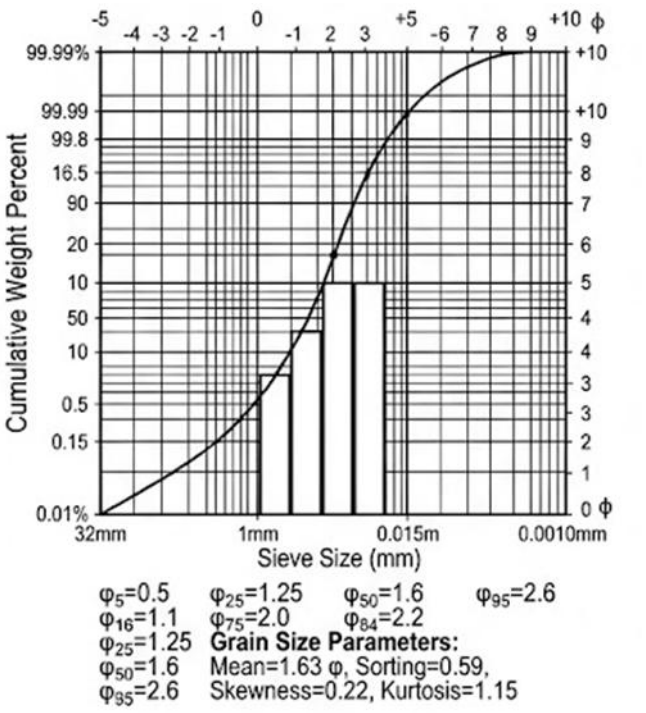
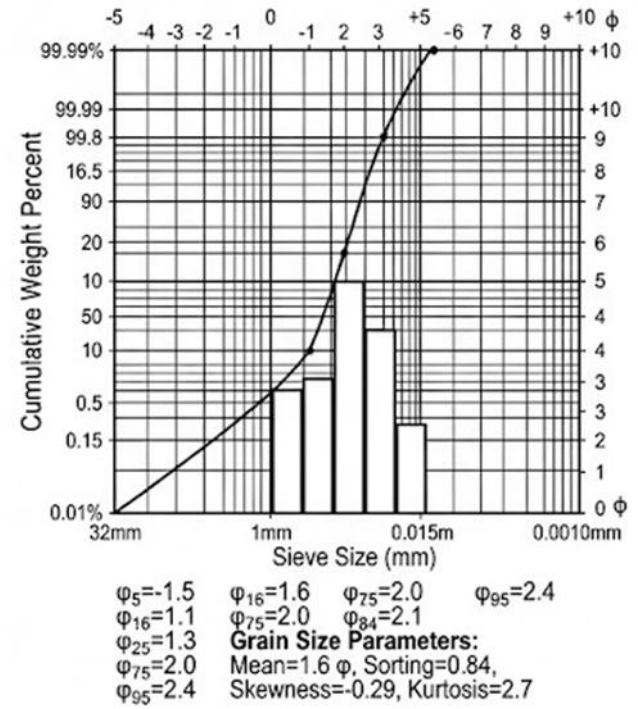


Fig. 4. cumulative frequency curves of grain-size of BH3. The even more steep and skewed (z) curves at 9-11m depth (emphasized) are associated with the buried high-energy sand unit.

4.2 Textural Classification

The grain composition of sand, silt, and clay graphed onto a ternary diagram by Folk (1974) indicate that most of the samples collected in BH1 and BH2 are Sand to Silt and a few samples in the near surface are classified within the "Sandy Silt" region (Fig. 5). BH3 distribution is more widely spread: deeper (9-11 m) samples are concentrated towards the upper part (Sand and Gravelly Sand), and shallower samples are concentrated in the intermediate span zone between the Silty Sand and Sandy Silt ranges. Based on the Wentworth (1922) grade scale, the prevailing textural class is that of fine sand (0.1250250 mm; 1030 -1) and the medium sand (0.250500 mm; 0-20 -1) was found at a depth in all three boreholes.



D *Fig. 5. All 30 boreholes of the Bonny Island sand silts and clay samples are in sand-silt-clay ternary diagram by Folk (1974). BH1 triangle and BH2 and BH3 circles and squares respectively.*

4.3 Statistical Textural Parameters

4.3.1 Mean Grain Size (Mz)

The mean grain sizes vary between 1.8 to 3.2 ph in all the sampled horizons with a modal range between 2.0-2.5 ph (fine to medium sand). In all boreholes, the means (1.8 2.2) characterise the length of the mid-to-lower parts and the mean (2.8 3.2) is common in the near-surface experiences of the boreholes, with all three boreholes showing consistent upward-fining trends (Fig. 7).

4.3.2 Sorting (σ_1)

The coefficient ranges of sorting take values between 0.6-1.2phi which described a moderately well sorted to moderately sorted folks and wards (1957). The better sorted horizons (1 = 0.60 0.75 2) can be attributed simply to the deeper sandy units, and are themselves interpreted to be a result of sustained tidal rework. The weakly sorted shallow subsurface (σn = 1.012) layers are an indicator of reduced sorting efficiency in the reduction of estuarine or lagoonal flow.

4.3.3 Skewness (Sk_1)

The values of skewness are strictly positive in all the boreholes and range between +0.08 and +0.35, which indicates that the resources are of the type of a fine-skewed to strongly fine-skewed (Folk and Ward, 1957). Positive skew denotes a fine-grained tail of a grain-size, a feature which is diagnostic of the admixture of fines

suspended and thus settling into a traction-moved sandy population- a feature typical in tidal flats and estuaries (Pejrup, 1989 or Allen, 1965). A limited grouping of deep BH3 samples yields near-symmetrical values (Sk 1 = +0.08 to +0.12) which is equal to a higher-energy environment with negligible fine-tail contributions.

4.3.4 Kurtosis (KG)

The kurtosis is between 0.90 and 1.40 with values that lie in the range of mesokurtic (0.90 to 1.11) and leptokurtic distributions (greater than 1.11). The data is dominated by mesokurtic samples, which is evidence that there is equal energy influx due to the combined action of the wave and tidal power. Leptokurtic values are clustered within deeper and well-sorted basins, and they signify long reworking done under unidirectional or oscillatory tidal currents and hence concentrate the grain sizes within a small modal range (Reineck and Singh, 1980).

Table 4. Summary of Folk and Ward (1957) textural parameters for representative borehole horizons, Bonny Island.

BH	Depth (m)	Mz (ϕ)	σ_1 (Sorting)	Sk_1 (Skewness)	KG (Kurtosis)	Textural Class
BH1	0.1–1	2.22	0.71 (Mod. Well)	+0.18 (Fine-sk)	1.05 (Meso)	Fine Sand
BH1	2–3	2.30	0.68 (Mod. Well)	+0.12 (Fine-sk)	1.00 (Meso)	Fine Sand
BH1	7–8	1.95	0.82 (Moderate)	+0.28 (Fine-sk)	1.22 (Lepto)	Medium Sand
BH1	12–13	2.55	1.10 (Moderate)	+0.30 (Fine-sk)	0.98 (Meso)	Silty Sand
BH2	0–1	2.18	0.72 (Mod. Well)	+0.20 (Fine-sk)	1.03 (Meso)	Fine Sand
BH2	4–5	2.10	0.75 (Mod. Well)	+0.15 (Fine-sk)	1.01 (Meso)	Fine Sand
BH2	9–10	1.82	0.88 (Moderate)	+0.22 (Fine-sk)	1.18 (Lepto)	Med–Fine Sand
BH3	1–2	2.35	0.74 (Mod. Well)	+0.19 (Fine-sk)	1.06 (Meso)	Fine Sand
BH3	9–10	1.65	0.92 (Moderate)	+0.08 (Symm)	1.35 (Lepto)	Medium Sand
BH3	10–11	1.70	0.95 (Moderate)	+0.10 (Symm)	1.38 (Lepto)	Medium Sand

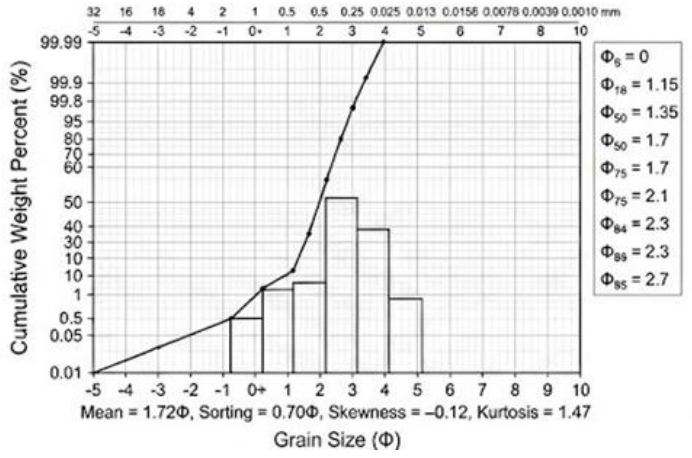


Fig. 6. Mz 2 (2) vs. 0 1 (2) biplot of all the samples in Bonny Island boreholes. The dominant grouping of Mz = 2.0 -2.5 -phi, -1 = 0.6 -0.9 -phi agrees that the well-sorted fine sands are of tidal-estuarine in origin.

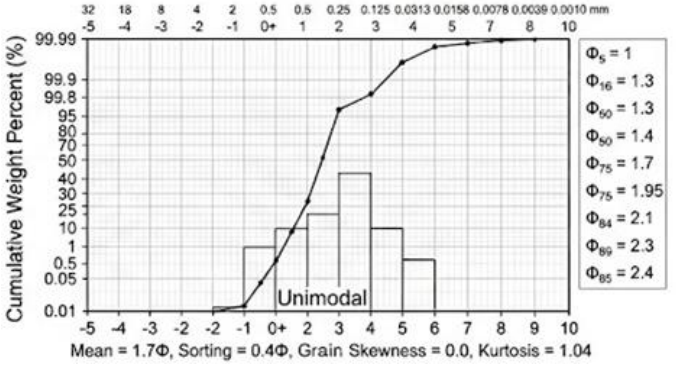


Fig. 7. Profiles of depth vs. mean grain size (foi), BH 1, BH 2, and BH 3. Every borehole has an upward-fining tendency; BH3 leaves the hole at 911 m whereby there is a coarser buried unit retained.

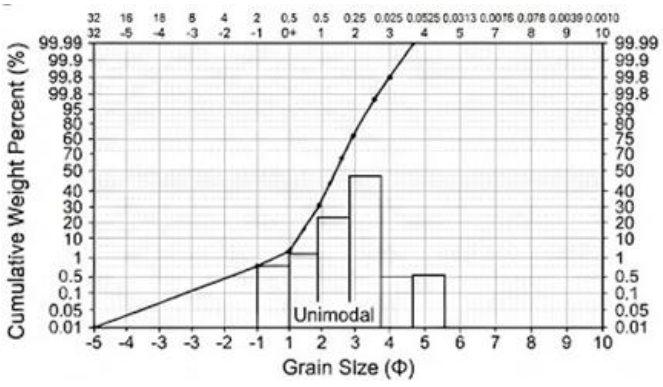


Fig. 8. Mz (ϕ) vs. Sk_1 crossplot. The skewness is predominantly positive with all the grain sizes, which is a confirmation of the presence of the fine-tail enrichment by settling by suspension, which is a diagnostic of an estuarine tidal flat environment.

5. DISCUSSION

5.1 Depositional Environment Interpretation

Moderately well-sorted fine sands (Mz = 1.826 2 with constant positive skewness (Sk 1 = +0.150.35) and mesokurtic-to-leptokurtic kurtosis (KG = 0.901.35) in most of the sampled horizons are all characteristic of a tidal flat to estuarine channel environment, with bidirectional tidal flows cyclically reworking the sandy sediment and loading it with fine-grained suspense loads at the time of Such explanation agrees with the geomorphology of Bonny Island located in the eastern Niger Delta barrier-lagoon complex, reported by Nwankwoala (2019) and Akpofure and Akana (2019).

In the BH1 and BH2 (02m) near-surface silty horizons, which are experiencing poor sorting (S 1) larger than 1.0 2) and are dominated by high fines, deposition takes place in lagoonal or back-barrier, low-energy, mudflat environments. The trend can be compared with that of Daka et al. (2007) in the upper Bonny Estuary, and with that of Adekunle and Enu (2015) in various localities of the Niger Delta coast where authors bibliographically observed poorly sorted, silty shallow layers above, and better sorted sandy deeper layers below. The coarse-sand unit (911m of M). 9 11 m unit in BH3 was identified to be a buried coarse-sand fill or beach-ridge deposit, indicating a more high-energy episode that had been deposited, subsequently covered by later lagoonal and tidal flat sedimentation. This interpretation is supported by what Akpan et al. (2022) determined as analogous high-energy stratigraphic horizons in cores with radionuclide datings collected at the upper of Bonny Estuary.

The uniform upward-fining pattern in all three boreholes is a pattern of interest as in the Benin Formation regionally (Reijers 2011) of diminishing fluvial competence and increasing relative sea level during the course of the Holocene, the energetic fluvial-tidal channel sedimentation gave way to the subdued lagoonal and estuarine flat accumulation. The general framework of the textural architecture of the subsurface of the Bonny Island as a whole indicates a vertical facies succession as the depth to the high-energy tidal channel/beach-ridge deposits to the top of the low-energy tidal flat and lagoonal sediments.

Table 5. Depositional environment interpretation by borehole and depth interval.

BH	Depth (m)	Mz (ϕ)	σ_1 (ϕ)	Textural Class	Interpreted Environment
BH1	0–2	2.2–2.5	0.9–1.1	Silty Fine Sand	Lagoonal / Tidal Flat
BH1	2–7	2.0–2.3	0.7–0.9	Fine Sand	Estuarine Channel
BH1	7–13	1.9–2.6	0.7–1.1	Fine–Medium Sand	Tidal Channel / Beach Ridge
BH2	0–1	2.1–2.2	0.7–0.8	Fine Sand	Tidal Flat / Estuarine
BH2	1–10	2.0–2.2	0.7–0.9	Fine Sand	Estuarine Channel
BH2	10–14	1.8–2.1	0.7–0.9	Fine–Medium Sand	Tidal Channel
BH3	1–8	2.2–2.4	0.7–0.9	Fine Sand	Estuarine / Tidal Flat
BH3	9–11	1.6–1.7	0.9–1.0	Medium Sand	Buried Palaeotidal Channel / Beach Ridge
BH3	12–14	2.0–2.2	0.7–0.9	Fine Sand	Tidal Channel Fill

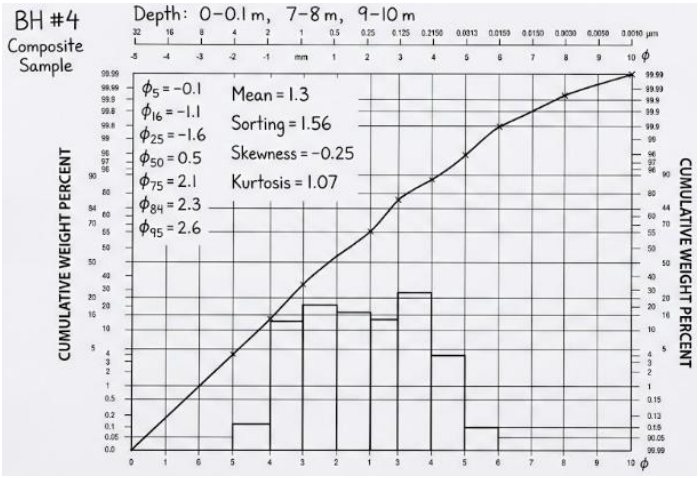


Fig. 9. BH3 interpreted vertical sediment log which breaks into high-energy (medium sand, tidal channel), low-energy (fine sand to silt, tidal flat) units. The more pronounced coarser unit at 9 -11 m is mishandled as an overlaying palaeotidal channel deposit.

5.2 Comparison with Published Niger Delta Studies

The set of textual parameters reported in this paper is consistent with the existing studies in similar Niger Delta settings. According to Akpokodje (1987), fine sands with moderate sorting were found in Niger deltaic soils and the correlation between textural classes and engineering properties was linear which has also been validated in this dataset. Oomkens (1974) defined that vertical variations of grain-size in the sequences of the Late Quaternary Niger delta can be attributed to episodic alterations in the flow of fluvia and marine power; the upward-fining characteristic observed in the three boreholes in Bonny Island is entirely in line with the trends observed in the region. These nearshore sandy deposits shifted to clayey deposits in mangrove-rich lower-energy areas along Port Harcourt which were reported by Olorunfemi and Okhue (2015) in a spatial analogue of stratigraphic shift along the vertically examined borehole profiles of the Bonny Island.

This work is an expansion of the current database of Bonny Island in terms of depth-resolved grain-size statistics to 14 m in depth compared to the near-surface geotechnical studies of Nwankwoala (2019) and records the buried high-energy unit located at 911 m deep in BH3, which is not noted in the published literature on this site.

5.3 Geotechnical Implications

Sediment texture has the major control on geotechnical properties of the subsurface of Bonny Island. The well-sorted, low-fines, sandy horizons that are present below 35 m and below 35 m in depth are moderately well-sorted, well-bearing of moderately high to high bearing capacity, the horizons are of high permeability (estimated k > 10m 4 ms clean sands) and low compressibility. These attributes can be equated with geotechnical characterisation of the same Benin Formation sands by Akpokodje (1987) and Nwankwoala (2019).

On the other hand, the near-surface silty to sandy silt series (02 m, BH1 and BH2) has much greater capacity to consolidate and much less bearing capacity, and understructure would be susceptible to differential

settlement and inefficiency of infiltration. Lambe and Whitman (1979) measured that fine-grained silty units that had typical void ratios in deltaic deposits could experience primary consolidation settlements of centimetres with applied stresses that were standard, which is also a major concern in the current development of infrastructure of Bonny Island. Examples of ground improvement measures are pre-loading, dynamic compaction, column-supported embankments; that are justified to such zones before any heavy structural development.

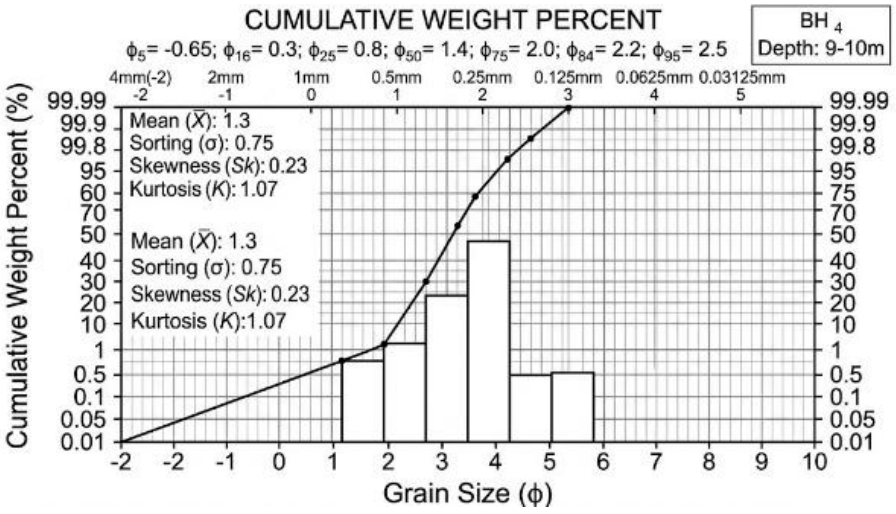


Fig. 10. Laboratory sieve analysis- mechanical shaker where it is used in BH1 sample analysis at the University of Port Sediementology Laboratory.

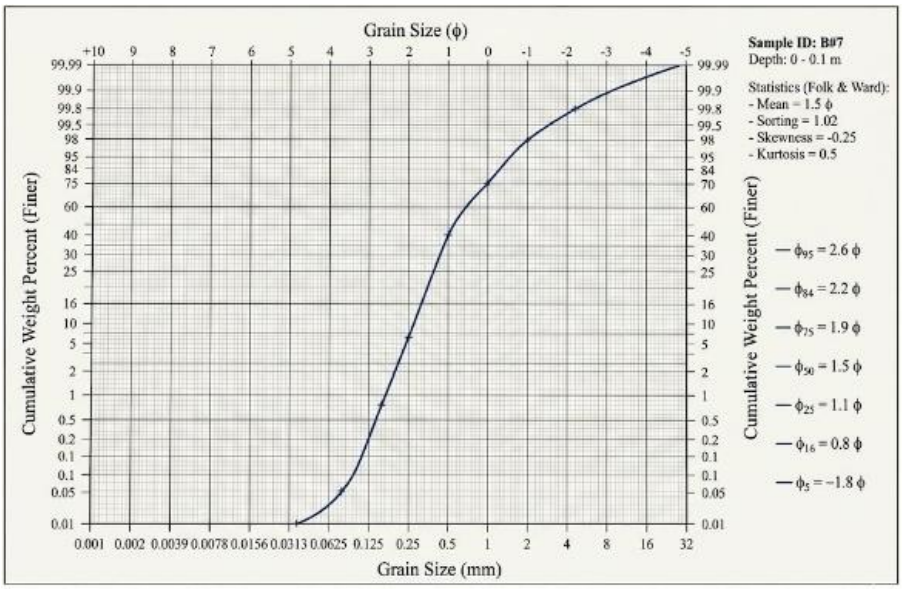


Fig. 11. Separated sieves on BH3, depth 9 -10 m, showing the rather coarser size of grain-population of the buried population of high-energy at this horizon.

6. CONCLUSIONS

Sieve analysis of 30 folklore boreholes between 30 and 14 m of depth between three boreholes on the Bonny Island coastal of the Niger Delta and coupled by Folk and Ward (1957), statistical calculation of the parameters of Folk (1974) ternary diagram were used to provide a systematic approach in the textural classification of the borehole sediments. The main conclusions are the following:

(1) The principal class of sediment is fine to medium sand (Mz = 1.832 ph). Most of the sampled horizons are characterised by moderately well-sorted or moderately sorted populations (σ 1 = 0.61.2 0) with positive skew (Sk 1 = +0.08 +0.35), and mesokurtic-to-leptokurtic kurtosis (KG = 0.901.40).
(2) It is texturally similar to deposition in a tidal flat-estuarine channel space of eastern Niger Delta barrier-lagoon system.
(3) All three borehole profiles have a steady upward-fining profile of successively less energy since the Holocene to the present in spite of the overall stratigraphic development of the Benin Formation across the region (Reijers, 2011).
(4) An undescribed high-energy depositional horizon 911 m in the BH3 medium-sand unit is a depositional event that has not been previously described, a palaeotidal channel or beach-ridge deposit which has implications of great significance to both local stratigraphy and foundation design.
(5) Foundation anchorage should be successful in geotechnically deeper sandy horizons (more than 35 m), but ground improvement is required where silty units are located near the surface. The analyses will provide a fundamental textural foundation as a basis of the engineering design, ground water evaluation, and environmental management on the Island of Bonny.

7. DECLARATIONS

Conflict of interest: None declared

Data availability: Complete datasets of sieve analysis of all 30 samples is available upon a reasonable request.

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