

Topography and Particle Size Gradation Characterization of the Benin Formation in the Lower Niger Delta, Nigeria

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Abstract

The Benin Formation as a significant geologic unit of the Niger delta is well known. However, its importance in engineering geology, as a veritable source of construction material and foundation layer to many civil structures is hardly discussed. This study utilized the records from over 250 geo-referenced boreholes distributed mostly on linear alignments to the east and west of the Niger delta to generate the surface longitudinal profile of the Benin Formation in both the west and the eastern sections of the Niger Delta. In addition, particle size gradation characteristics of the sediments were analyzed to detect possible trends that reflect the predominant mechanisms of transportation. The study shows an initial steep gradient from Agbor to Sapele to the west, followed by a gentler and almost flat profile, with occasional depressions that are infilled with silty clay sediments, that may be linked to buried river channels. To the east, the longitudinal profile mirrors the ground surface, with a gradient approximating 1.91×10^{-4} as a first step in determining the depth to sand in the study area. The particle sizes within the depths of civil engineering significance (0-40m), show a tendency of upward fining. The Uniformity coefficients show some constancy, suggestive of similar environmental and energy conditions of deposition.

Keywords: Benin Formation, Topography, particle size distribution, uniformity coefficient

1 Introduction

The geology of the Niger delta is dominated by a threefold lithostratigraphic sequence comprising an upper sandy Benin formation, an intervening unit of alternating sandstone and shale named the Agbada formation, and a lower shaly Akata formation (Short and

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Stauble 1967). These three units extend across the whole delta and each ranges in age from early Tertiary to Recent.

Sediments originating from the vast and geologically complex hinterland are dispersed through the delta by river, tidal, wave, and currents in the continual evolution of the Niger Delta. According to Allen (1965) Niger Delta growth began during the Late Wisconsin lowstand of the sea when the rivers entrenched the continental shelf to reach mouths above submarine canyons at the shelf edge. He identified the oldest stratigraphical unit of the Late Quaternary deltaic pile as the strand plain sand (Older Sands) representing a marine transgression into the hinterland. Later, in the Holocene, when sea-level became relatively stable, there was a regressive advance across these sands giving rise to the Younger Suite, the uppermost stratigraphical formation in the deltaic lens. The Lithofacies of this suite are said to grade upward from open shelf clays, through pro-delta slope layered clays, silts, and sands, to well-bedded sands formed on the delta-front platform, river mouth bars, and beaches (Allen 1965).

The uppermost part of the Benin Formation has been altered by interglacial transgressions during the Quaternary period (Oomkens, 1974). The upper layers of the Late Quaternary Delta are comprised of inter-bedded layers of sand, silt and clay deposited during changes in sea level (Allen 1970). The most recent post-glacial sea level rise covered the earlier sediments with deposits of Holocene sediments.

The Benin Formation is better known for its hydraulic properties and groundwater yielding potential (Amajor 1991; Ophori 2007 ; Nwankwoala and Ngah 2014) because of the predominantly uniform and granular composition, which allows for reasonably high permeability. Since it pervades across the N/D and it's relatively on the surface, it is encountered by most physical infrastructural developments that entail significant foundation engineering works. This makes the understanding of its geotechnical properties imperative.

Behind the beach ridges and barrier islands is the tidal mangrove swamps in which organic-rich sands and silts are being deposited. Cross-stratified river bar sands are also accumulating in association with top-stratum silts and clays in the delta floodplain environment. This younger suite overlie the Benin Formation and constitute the superficial layer on which many civil structures such as houses and towers, roads and bridges, ancillary structures for the oil and gas sector are built.

The costs and performances of such civil structures usually depend on the thickness and geotechnical properties, including the competence of the layer as well as proximity to the Benin Formation. It is in this context that the topography of the Benin Formation becomes pertinent. The Benin Formation, consisting largely of sandy units, exhibits significantly high intergranular stresses, moderate to high bearing capacity, lower compressibility and consequently settlement, moderate to higher pile axial capacity, attributes that make occurrence of sand on the surface to be profound interest.

Secondly, the sandy unit of the Benin Formation is seen as a source of construction material, for filling in reclamation projects, as road sub-base and in cases where subgrade is to be replaced, for sandcrete, shoreline nourishment and as a constituent of asphalt for road pavements. Where sand is not within economic depth, sourcing of sand either through barging or other means of transportation can disproportionately escalate project cost. Lateral or vertical proximity to sand is therefore of paramount significance.

2 Methodology

Boreholes through three transects running from cawthorne channel near Bonny to Obrikom (190km), Agbor through Sapele to Omadino and further south to Escravos (188km) and from Brass through Ubeta to Obrikom were correlated. A total of 250 borehole records were utilized, broken down as follows; 183 for cawthorne channel to Obrikom and 66 for the Agbor to Escravos section. The elevations of boring locations and the first occurrences of significant sand units were measured. The topographies of both ground surface and top of major sand units along these transects/ alignments were generated to reveal the surface expression of the “Benin Formation”.

Soil samples retrieved from borings at different locations on the alignment were subjected to particle size gradation analysis using sieves in order to reveal possible vertical trends in particle sizes and uniformity coefficients.

3 Results and Discussion

The topography of the Western section of the Benin Formation (Agbor to Escravos) in comparison to the ground surface is presented in Fig. 1. This section is characterized by a fairly elevated upstream part with some significant gradient up to the Sapele end, where changes in ground surface elevation become gradual. The topography of the Benin Formation (Agbor-Sapele) somewhat reflects the significant slope of the ground surface and to a large extent almost coincides with the topography of the ground surface, but for some overburden sediments comprising silty and sandy clay. The thickness of this overburden is at a minimum at the points of inflexion in the gradient of the ground surface. The exposure of this section of the Benin Formation to interglacial transgressions during the Quaternary period (Oomkens, 1974) may be responsible in part to its alteration and current erosional status.

Changes in elevation of the Benin Formation underlying the coastal estuaries and mangrove swamps shown in (Fig. 2) and amplified in Fig. (3) are generally within 30m, the deepest sections usually suspected to be abandoned or buried old river channels.

In some areas, for example, the Abitiye Canal segment, sandy layers “supposed Benin Formation” are exposed on the surface in the form of a coastal Island, and provide a ready source suitable construction aggregates.

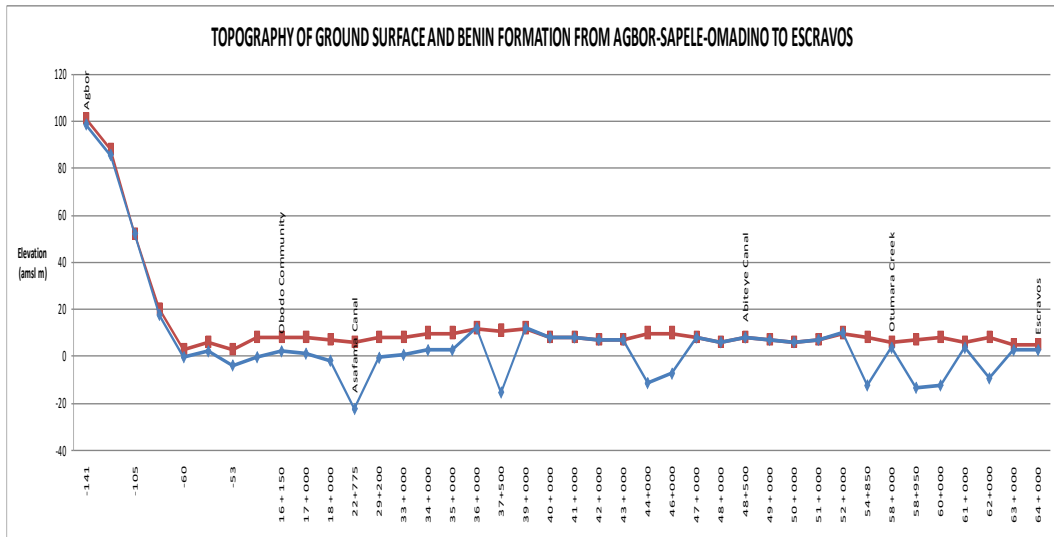


Figure 2: Topography of Benin Formation in comparison to the ground surface in the Western Niger delta

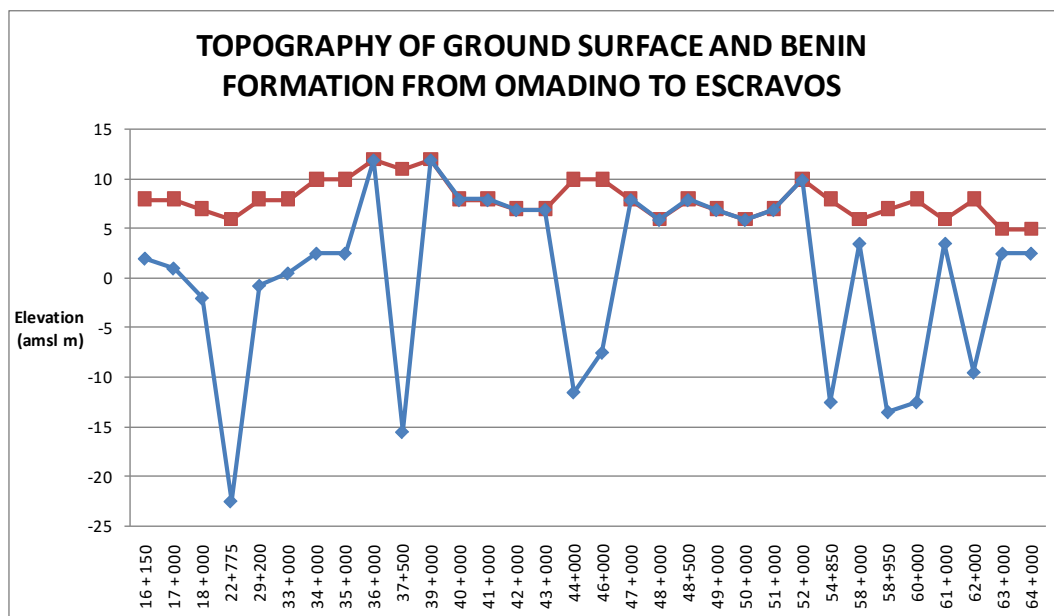


Figure 3: Amplified section of Topography of Benin Formation within the Estuaries and Mangrove swamps Western Niger delta

The depth to the Benin Formation in sections of the Eastern Niger Delta (Cawthorne Channel to Obrikom) closely mirrors the surface topography (Fig. 4). As in the western section, thicker silty and sandy clay overburdens occur in the marine sections of the alignment between Cawthorne Channel and Okochiri. These are areas that are still experiencing sedimentation and are at different stages of consolidation. Unlike in the western section, the surface of the Benin Formation in the eastern marine section in spite of some undulations generally dips towards the sea with a slope of about 1.91×10^{-4} .

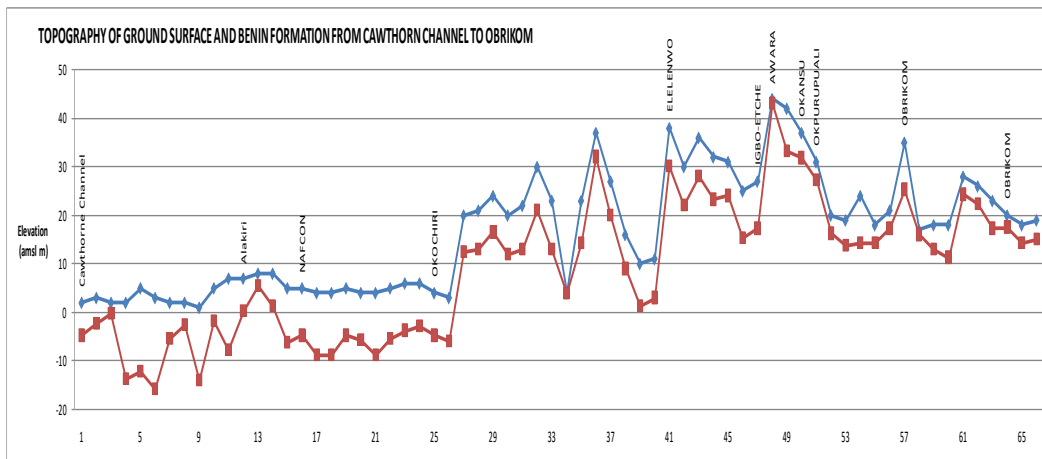


Figure 4: Topography of Benin Formation in comparison to the ground surface in the Eastern Niger delta

The sand particle gradation for soil samples from different sections are presented in figs. 5 to 7. Particle size distribution curves for borings in the marine segment between Omadino and Escravos (Fig. 5) show that the sand sizes are mostly fine-medium. As expected, towards the upstream, between Agbaloke and Agbor, the average sand sizes increase to medium to coarse classes, with Effective (D_{10}) and Mean (D_{50}) sizes in the neighbourhood of 0.25mm and 0.8mm respectively and with Uniformity coefficients varying from 3 to 5. As shown in Fig. 6 to 8, there is a tendency for upward fining, but there are occasional departures from this trend. This is understandable particularly in this case, where there may be multiple mechanisms of transport.

This upward fining tendency is also manifest in the eastern segment of the Niger delta although not as pronounced as indicated in a depth profile plot of the effective and mean particle sizes for borings from Cawthorne channel, Obigbo and Obrikom (Fig. 7 and 8). The variations in the effective particle size with depth are within narrower margins (0.2 to 0.3 for D_{10}) in comparison to the Escravos – Agbor segment. The mean particle size (D_{50}) on the other hand increases upstream (Fig. 8) as expected, reflecting the predominant fluvial transport mechanism. The slightly lower D_{50} and particle size distribution at the Obrikom end in comparison to Obigbo, which is a more elevated ground, reflects the influence of the Niger River flood plain. A plot of depth profile for Uniformity coefficient (Fig. 9) shows a narrow margin of variation around 2, indicating a somewhat similar energy condition of deposition for the sediments.

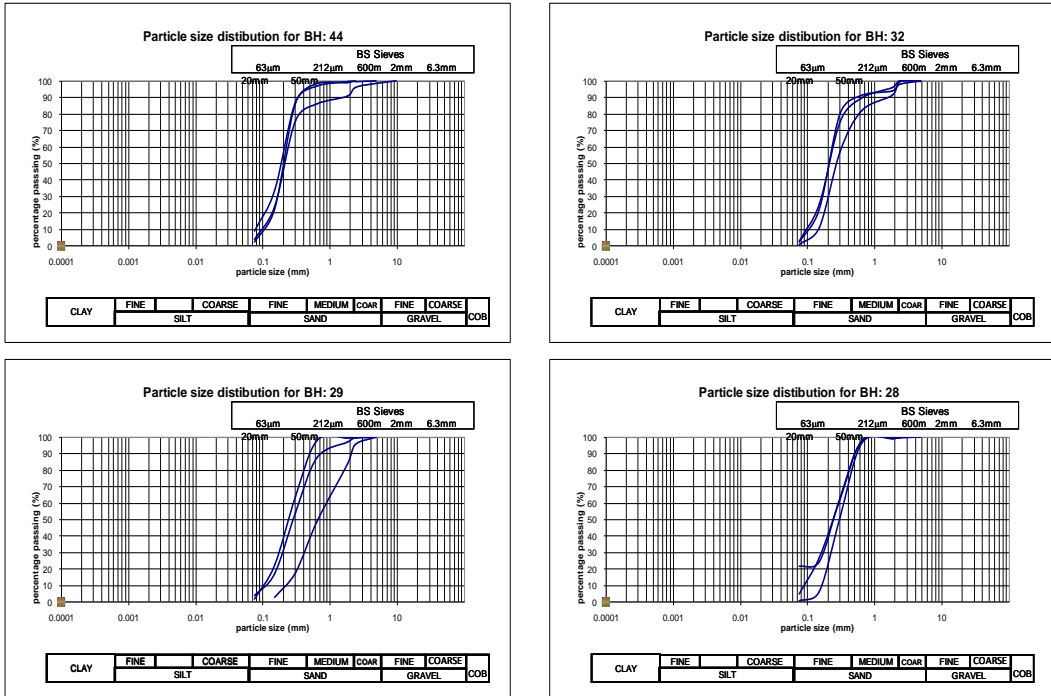


Figure 5: Comparison of particle size distribution in selected locations

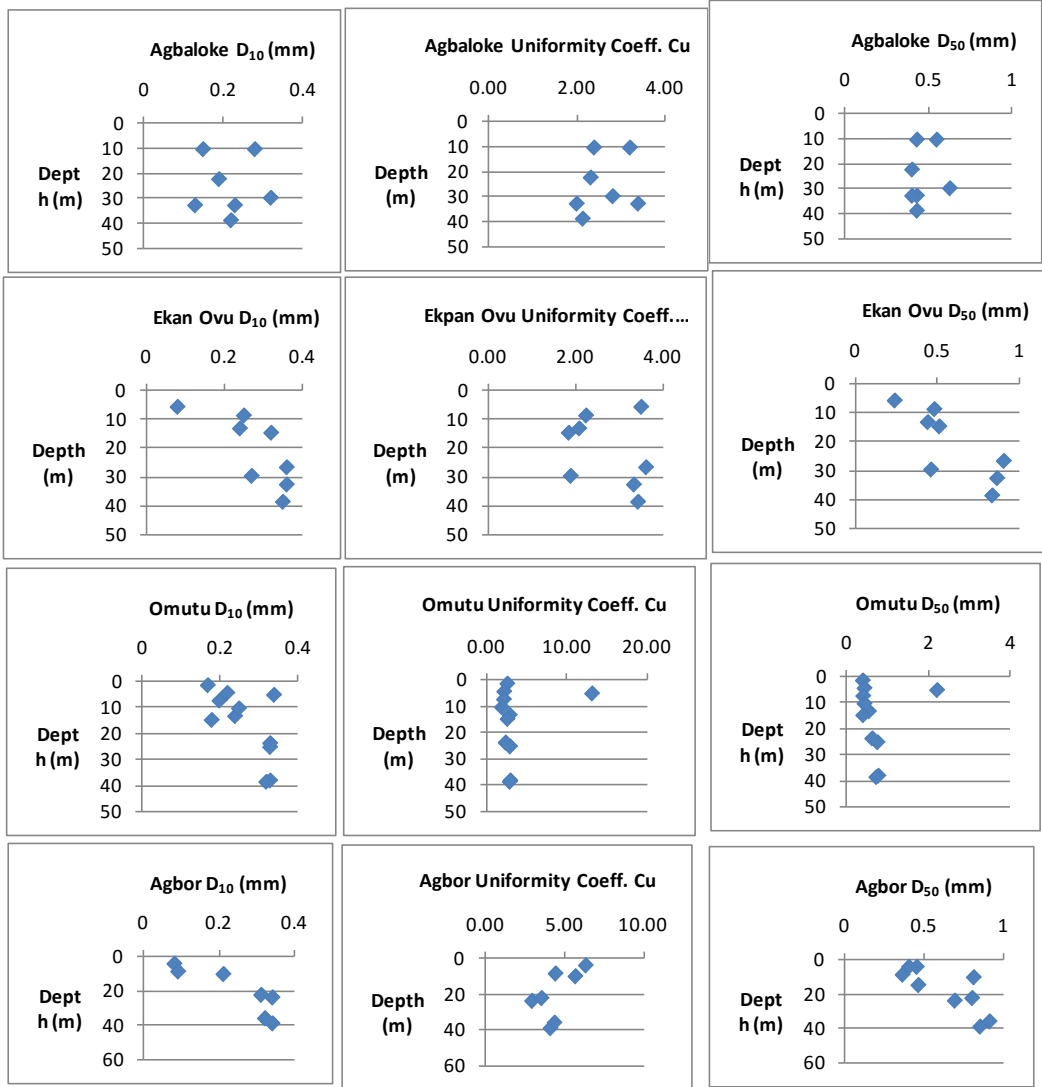


Figure 6: Variation of effective and mean sizes and Uniformity coefficients with depth at the upstream sections of Benin Formation

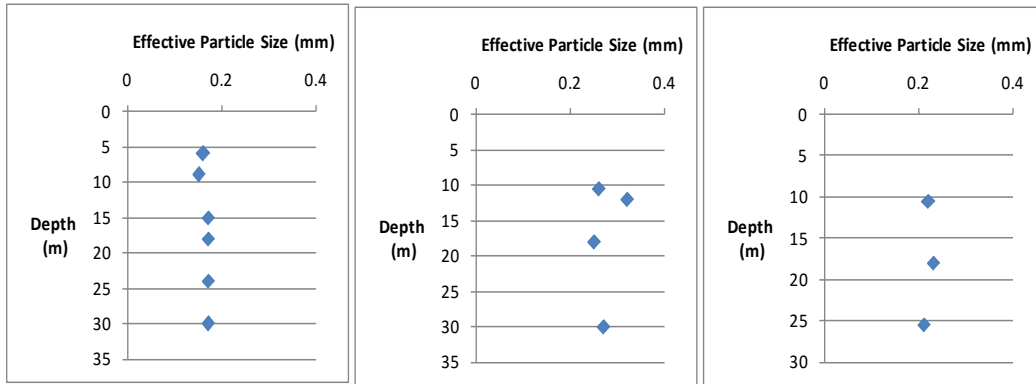


Figure 7: Variation of effective size with depth at Cawthorne Channel, Obigbo and Obrikom respectively

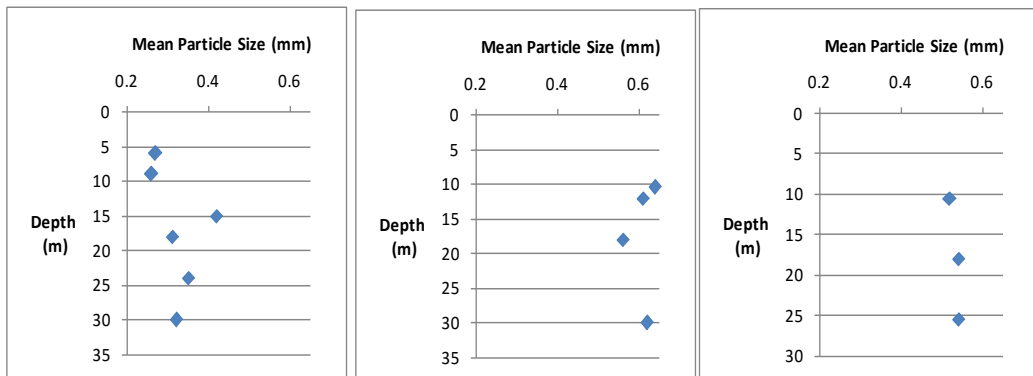


Figure 8: Variation of Mean size with depth at Cawthorne Channel, Obigbo and Obrikom respectively

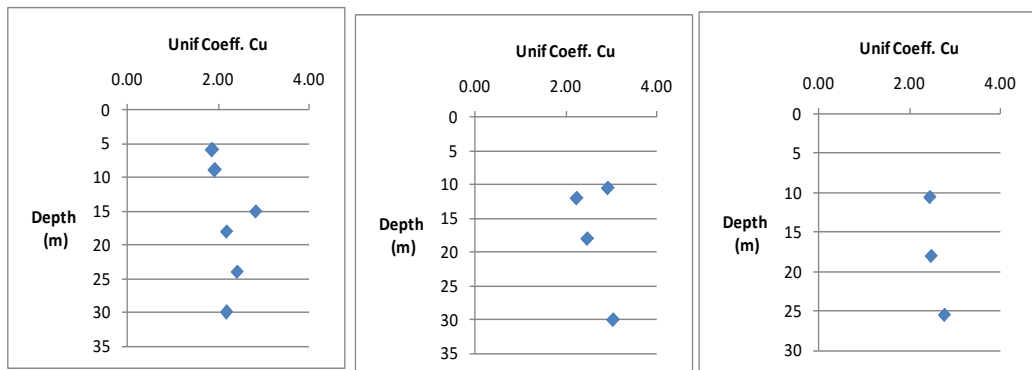


Figure 9: Variation of Uniformity Coefficient with depth at Cawthorne Channel, Obigbo and Obrikom respectively

The sediments which form the delta also vary with distance from sediment source. The more proximal deposition zones, such as the shoreline, are dominated by tidal channel and coastal barrier sands overlaying earlier (Holocene) marine clays. The delta slope deposition zone, in water depths of approximately 15m, is characterized by marine sands. As distance from shore and water depth increase, more distal sediments such as clay are

deposited in these deeper shelf margin conditions. This association of sediments represents a typical progradational sequence of delta development.

The Benin Formation is significant for different reasons for oil and gas, hydrogeological exploration and for geotechnical as well as a veritable source of construction material.

4 Conclusions

Knowledge of the topography of the Benin Formation is important in exploring for sand as a construction material in an area with limited exposures. The upper sections of the Benin Formation (Agbor to Sapele) have limited top soil cover consisting of silty and sandy clay, and are exposed to erosion, accounting for the comparatively steep gradient. The Benin Formation underlying the estuaries and mangrove swamps has a gentler and almost flat profile, with occasional depressions that are infilled with silty clay sediments, that may be linked to buried river channels. In the east, the longitudinal profile of the Benin Formation has a gradient of approximately 1.91×10^{-4} . The particle sizes within the depths of civil engineering significance (0-40m), show a tendency of upward fining. The Uniformity coefficients show some constancy, suggestive of similar energy conditions of deposition.

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