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Granulometric and Pebble Morphometric Analyses of Rock Units Within the Uzuakoli-Ahaba Axis and Environs: An Outcome of Geological Mapping and Outcrop Studies

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Abstract

Geological mapping and outcrop studies were carried out around the Uzuakoli-Ahaba axis located in Abia State, Southeastern Nigeria. The aim was to better understand the underlying lithologies and lithostratigraphic units. Detailed sedimentological logging was integrated with granulometric and pebble morphometric analyses in determining the paleodepositional environment of the sediment packages in the study area. Five lithologic units namely sandstone, shale, siltstone, heteroliths, and mudrock were identified within the study area. These lithologic units were exposed within four lithostratigraphic units that underlie the study area namely; the Imo Formation, Ameki Formation, Ajali Formation, and Nsukka Formation. Results from the granulometric analysis of six sandstone samples reveal that the mean size value is indicative of medium-grained to coarse-grained sandstone and suggestive of intermediate to high energy setting. Standard deviation and kurtosis suggest that the sediments are moderately sorted to poorly sorted. Log probability plots, bivariate and multivariate plots reveal fluvial to shallow marine environment. Results from the bivariate plots and Sphericity-Form diagram of pebble morphometry suggest that the pebbles were deposited in a beach dominated environment. Overall, based on the integration of the various plots, it can be concluded that the rock units were deposited in a fluctuating environment ranging from shallow marine to fluvial environment.

Keywords: *Granulometric analysis; Pebble morphometry; Fluvial environment; Outcrop.*

1. Introduction

Detailed geologic mapping with sedimentological logging and analyses have been carried out around the Uzuakoli-Ahaba axis and environs which spans through latitude 5°35' to 5°45'N and longitude 7°28' to 7°37'E of the Greenwich meridian. The study area lies within the western part of the Afikpo Sheet 313 between the Anambra and Niger Delta basins (Fig. 1). Outcrop data incorporated with granulometric and pebble morphometric analyses have been carried out to enhance the understanding of the lithologic, lithostratigraphic units, and paleodepositional environment of the sediment packages. Fig. 2 gives us an insight into the spatial distribution of the outcrops found in the study area, where outcrop data was obtained for this study. The general topographic surface of the study area has been evidently represented in Fig. 3. In this study, due consideration was given to the rock units as studies have revealed that distinct sets of characteristics from rock units such as grain size and primary sedimentary structures are considered necessary to define lithologies and better understand the operational processes during sediment deposition in various environments [1-3].

Notable granulometric and pebble morphometric studies have been carried out within the basins that constitute the study area. The granulometric study of the sand member of Mamu Formation shows characteristic fine to medium-grained, very well sorted sandstone which was deposited in a relatively turbulent well-aerated marine environment, probably above the wave base [4]. According to [5], the granulometric studies of the sands of Nanka Formation show that the sandstones are essentially fine to coarse-grained and moderately to poorly sorted.

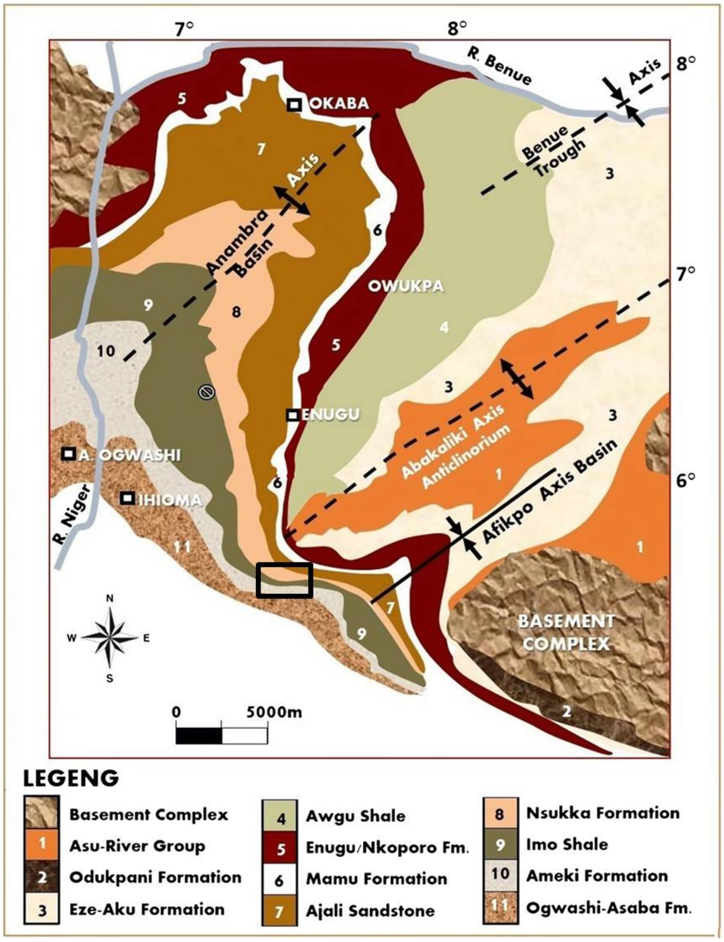

Fig. 1. Generalized geological map of southeastern Nigeria (boxed area of inset) showing the location of the Cretaceous to Tertiary sequences of the Niger Delta Basin (after Akande *et al.* [49])

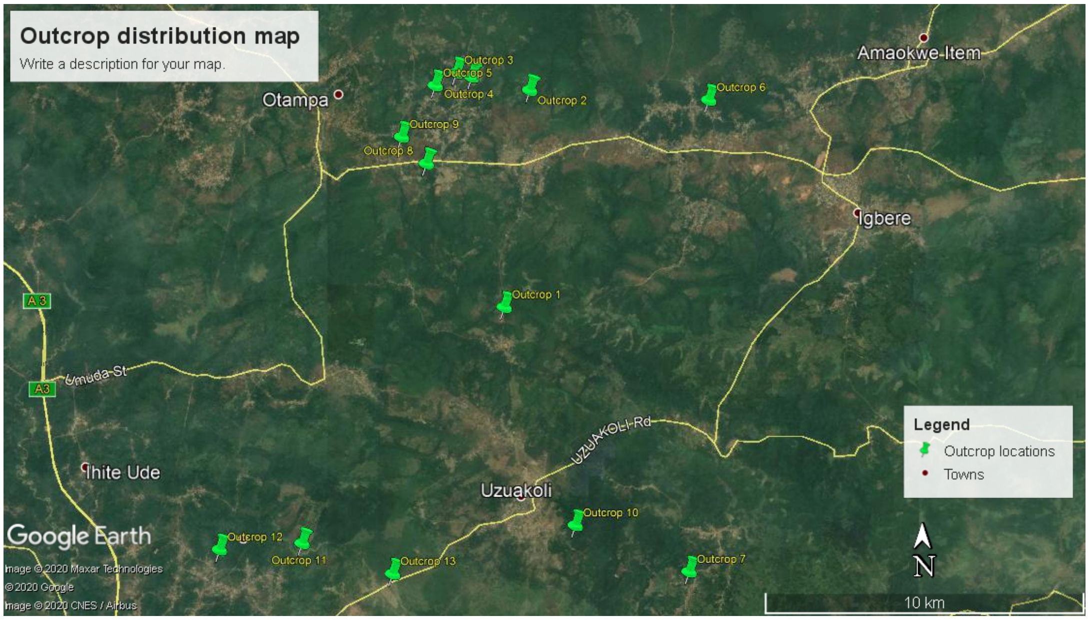

Fig. 2. Satellite imagery map showing the outcrop distribution of the rock exposures in Uzuakoli-Ahaba axis, Southeastern Nigeria (Source: Google Earth™)

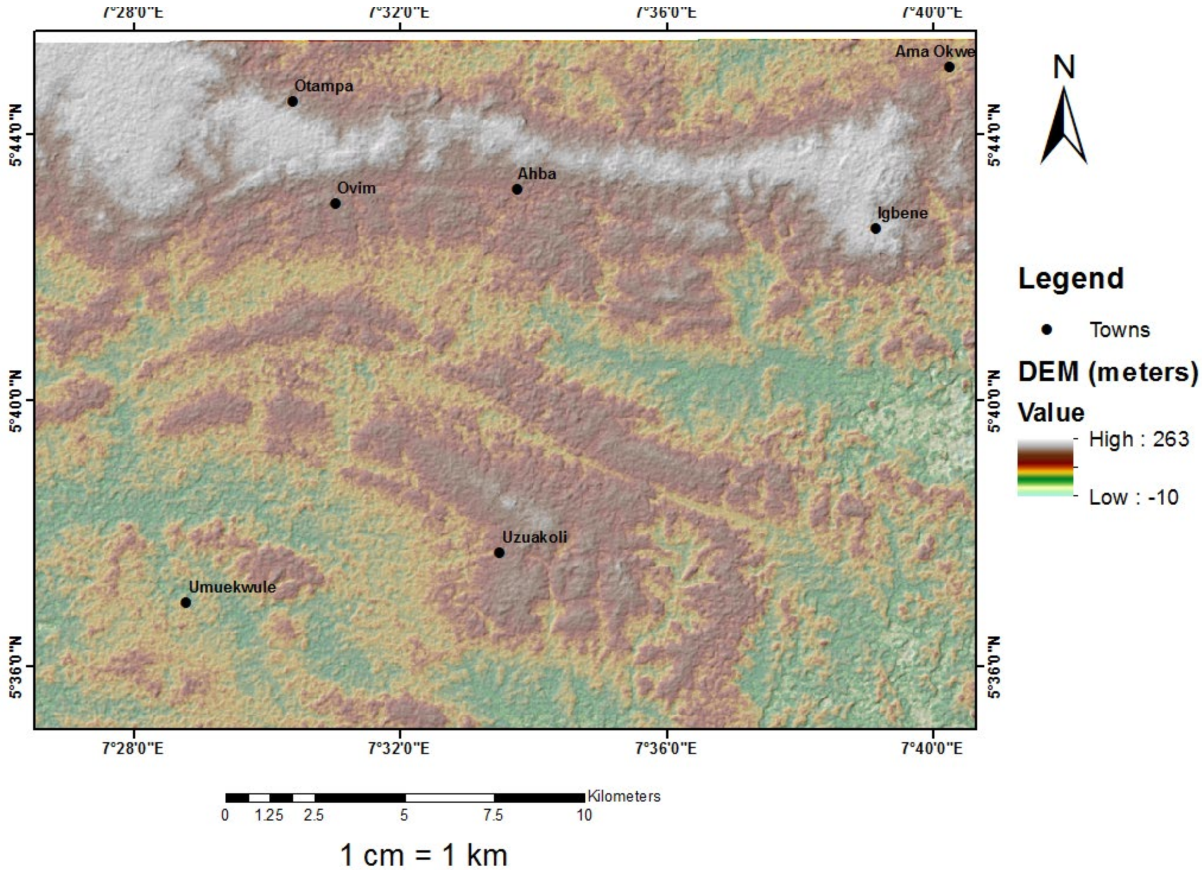

Fig. 3. 2D Digital Elevation Map (DEM) of the study area (Note: DEM is in meters)

The study of the Maastrichtian siliciclastic sedimentary unit of the Ajali Formation by [6] revealed that the grain size analysis shows medium to coarse-grained sand particles, suggestive of moderate to high energy environment of deposition. Studies of Nsugbe Sands exposed along Onitsha-Otocha-Omor-Nsukka road and the Onitsha-Enugu expressway, show that the sands are medium to coarse-grained and mainly moderately sorted [7]. Moreso, [8] studied the sandstone deposits of Ameki Formation, exposed in the northeastern part of Akwa Ibom State, and discovered from the granulometric analysis, that the deposits are moderate to poorly sorted, suggestive of fluvial origin. A paleogeographic model for the sandstone member of the Imo Shale was developed by [9], which portrayed the sands to be texturally mature, fine to coarse-grained with characteristic large-scale cross-stratification. Grain size and textural analysis of sandstone packages of Benin Formation, exposed along Atamiri River showed that the sandstones were deposited in a fluvial depositional environment [10]. Pebble morphometric studies of Nanka Formation by [5] showed that the bivariate plots are indicative of reworked pebbles deposited by fluvial processes, and the form indices diagram which connotes bladed, compact-bladed, and platy, is diagnostic of river action. Also, [6] showed that pebble morphometric studies of Ajali Formation showed that its environment of deposition is a fluviatile depositional environment. Pebble morphometric studies of Ogwashi-Asaba Formation revealed that the bivariate plots and the form indices are suggestive of fluvial sedimentation [11]. Studies from the pebble morphometric analyses of the pebbly sandstone of Ameki Formation by [8] showed that they were deposited in a fluvial environment. A pebble form studies of the pebbles from Benin Formation, exposed along Atamiri River by [10], revealed that they were deposited in a fluvial environment. This present study is aimed at carrying out a detailed outcrop mapping and integrating the data obtained from granulometric and pebble morphometric analyses to better delineate the lithologic units and understand the paleodepositional environment that resulted in the deposition of the sediment packages.

2. Regional geologic setting

The Anambra Basin is about 40,000km² in size [12] and is bounded to the west by the Okitipupa Ridge, in the east by the Abakiliki Basin, and in the south by the Niger Delta Basin [13]. Provenance areas for texturally mature sediments in the Anambra Basin include the crystalline basement areas of the Oban Massif, southwestern Nigeria craton, and Cameroon basement granites which had undergone prolonged chemical weathering as established by [14-16]. The tectonic evolution of the Anambra Basin may be traced back to the Late Jurassic due to the break-up of the Gondwana Supercontinent [16]. The Anambra Basin is a multicycle basin whose initiation began in the Late Jurassic to Early Cretaceous associated with the opening of the Gulf of Guinea and South Atlantic Ocean consequent upon the separation of the African and South American plates [17]. In southern Nigeria, which constitutes the location of the study area, the Anambra Basin is inserted between the Benue Trough and the Niger Delta Basin [18]. The Anambra Basin has an apparently simple structural configuration, being a broad syncline and plunging gently south of southwest to beneath the Niger Delta [19] as shown in Fig. 4. The Niger Delta Basin, as a separate basin, is located at the southern extremity of the elongated intra-continental Benue Trough [20]. The Lower Benue Trough, the Anambra Basin, and the Niger Delta Basin are vertically stacked (Fig. 4; 5) and hence constitute separate stratigraphic entities, as illustrated by [21]. The three basins are clearly separated by unconformities which are essentially erosional features or substantial time gaps [22]. The Anambra Basin and the Niger Delta Basin are demarcated by a discontinuity (Paleocene discontinuity) (Fig. 5) which is due to the cessation of the progradation of the "Nsukka Delta" as a result of the onset of large-scale transgression [18]. [18].

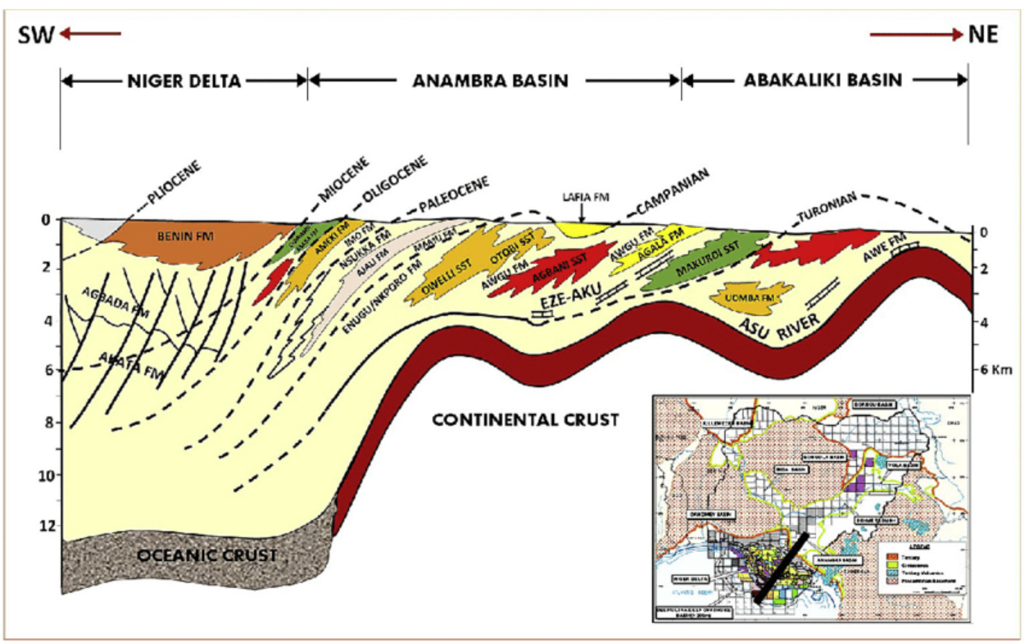

Fig. 4. Cross-section showing the lithostratigraphic units of Abakiliki, Anambra and Niger Delta basins (after [17, 50])

The structural evolution of the Niger Delta has been controlled by basement tectonics as related to crustal divergence and translation during the Late Jurassic to Cretaceous continental rifting. The Niger Delta has been rapidly subsiding because of sediment accumulation, flexural loading, and thermal contraction of the lithosphere [23-24]. According to [25], throughout the geological history of the delta, its structure and stratigraphy, have been controlled by the interplay between rates of sediment supply and subsidence. The fault type common in the Niger Delta to include structure building faults, crestal faults, flank faults, and counter regional growth faults as well as antithetic faults [26]. These growth faults were triggered by the movement of the deep-seated, over-pressured, ductile marine shales, and aided by slope instability [25]. A growth fault is defined as a fault that offsets an active surface of deposition [27]. The study area, which is found within the Anambra Basin and Niger Delta Basin (Fig. 5), consists of Upper Cretaceous (Campanian-Maastrichtian) and Paleogene clastic sediments, specially situated on the southwestern flank of the Lower Benue Trough (Fig. 1).

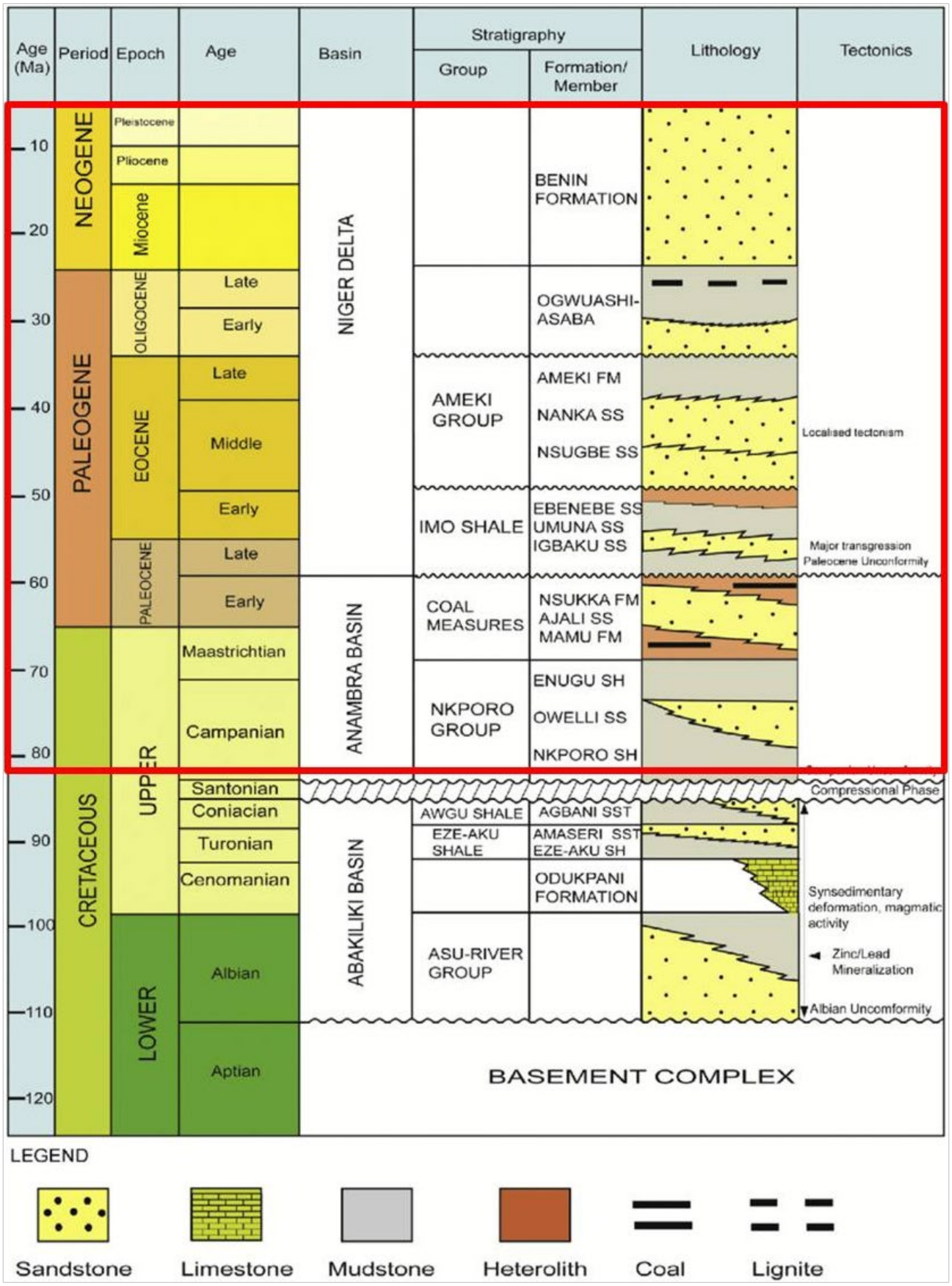

Fig. 5. Stratigraphic succession in the Anambra Basin and Niger Delta basins (after [9.48, 51])

The Anambra Basin underlies the Niger Delta Basin [22], and detailed extensive studies have been carried out by numerous scholars aimed at highlighting the lithologic, lithostratigraphic, and paleodepositional reconstruction of the environment of deposition of these basins. Uzuakoli - Ahaba axis and environs are underlain by lithologies belonging to four lithostratigraphic units, namely: the Ajali Formation and Nsukka Formation (Coal Measures), the Imo Formation, and the Ameki Formation. The Coal Measures characterize an extensive Maastrichtian interval and document a period of non-marine alternating with shallow marine sedimentation in the Anambra Basin as identified by [18]. The Ajali Sandstone consists of unconsolidated, fine to coarse-grained, poorly cemented sandstone with little siltstone and drapes of claystone extending as stacks of sheet-like bodies, according to [28-31]. The fluvio-deltaic Nsukka Formation consists of a variety of sandstones which passes upward into well-bedded blue clays, fine-grained sandstones, and carbonaceous shales with thin bands of limestone [32-33]. The Imo Formation, which is part of the outcropping units of the Niger Delta basin, is essentially made up of mudrock units consisting mainly of dark grey to bluish-grey shale, with occasional mixtures of clay, ironstone, thin sandstone bands, and limestone intercalations [18]. On the other hand, the Ameki Formation which is one of the laterally equivalent units of the Ameki Group is predominantly alternating shale and sandy shale, clayey sandstone, and fine-grained fossiliferous sandstone with thin limestone bands [34-35]. Efforts at carrying out detailed outcrop studies across these areas have been limited due to the dearth of good rock exposures.

3. Materials and methods

Exposed outcrop sections, specifically quarries, roads, streams, rivers, and springs were mapped, logged, and sampled. Selected rock samples were subjected to granulometric and pebble morphometry analyses, to provide data for a better understanding of the depositional environment of the study area and hence reconstruct the paleoenvironment. Lithologic units delineation was carried out based on attributes such as textural features (bedding type, texture, grain-size and shape, fossils, and primary sedimentary structures). Primary sedimentary structures were also studied and used in determining the hydrodynamic processes that were prevalent during sediment deposition and also infer potential depositional environment. Sedimentologic logs (that were generated using data obtained from outcrop locations) were built using modified SedLog 2.1.4™. Graphical plots of cumulative retained sieve weight percentage against the phi scale were made on an arithmetic-log probability sheet using the method according to [36]. Univariate statistical parameters (skewness, sorting, mean size, kurtosis) according to [37], bivariate plots of [38] and [39] from the granulometric analysis were used to obtain a certain range of values which may indicate a distinct depositional environment out of a range of adjacent environments. Univariate parameters of form, mean roundness, form indices; bivariate plots of [40] and [41] and sphericity-form diagram of [42] form the pebble morphometric analysis were used for the discrimination of depositional environment of the pebbles found in the study area.

4. Results and discussion

4.1. Rock Units description across various outcrop locations

Various rock units were studied across several outcrop locations as typically shown in Fig. 2. The outcrop locations were well logged and detailed measured sedimentological logs of most of the outcrops encountered within the study area were produced (Fig. 10). Some of the outcrop units include sandstone unit, shale unit, heterolithic unit, siltstone unit, and mudstone unit.

4.1.1. Sandstone unit

The sandstone units were encountered mainly at road-cuts, quarry sites, and caves. The sandstone unit at Outcrop 1 (about 10m thick of sediment, with a lateral extent of about 50m) encountered at a quarry site, about 1500m from Amafor Community, Akoli Imenyi is creamy white, friable, medium to coarse-grained, poorly sorted and pebbly (Fig. 6c). It is strongly bioturbated and dominated by *Ophiomorpha nodosa* with a distinct planar crossbedding with tangential contact whose foresets are mud-draped (Fig. 6b; 6d). The lower section of Outcrop 2 (about 20m thick of sediment, with a lateral extent of about 70m), well exposed at Uhuchukwu cave (Fig. 8a), about 4000m from Amaja Ukwu, Amiyi, Ahaba Amenyi is basically white, medium to coarse-grained, friable, poorly sorted, pebbly and highly fractured with wavy ripples. The trend of a representative fracture is 02°NNE-182°SSW.

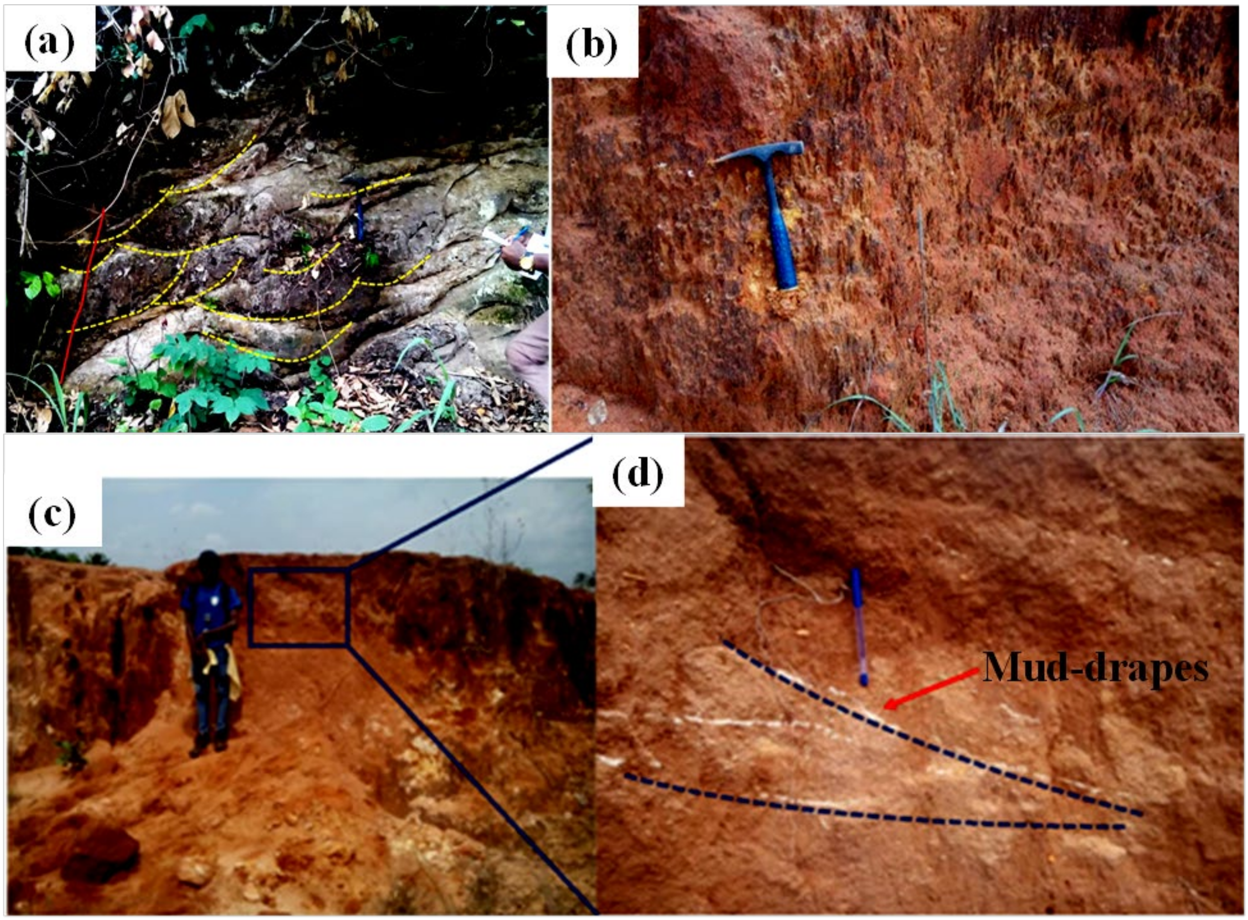

Fig. 6. (a) Pebbly sandstone showing trough cross-bedding and fractures encountered at lower section of Outcrop 4; (b) Upper section of Outcrop 1 showing *Ophiomorpha* burrows as shown by the circular patches; (c) Upper section of the sandstone encountered at Outcrop 1; (d) Closed up section of the blue-boxed area shown in (c), showing planar cross-bedding with tangential contact and mud-drapes in the upper section of Outcrop 1

The sandstone unit at Outcrop 3 (about 7m thick of sediment, with a lateral extent of about 60m) found along Ahaba-Ovim road, about 150m from Ovim Community School, Ovim is essentially made up of white, medium to coarse-grained, friable, poorly sorted, fractured and pebbly sandstone with a characteristic parallel lamination and wavy laminations. The trend of a representative fracture measured is 38°NNW-218°SSW. The strike of one of the beds is 09°NNE-189°SSW, the dip direction is 81°ENE, and the dip amount is 10°. The sandstone unit encountered at Outcrop 4 (about 5m thick, with a lateral extent of about 50m) shown along Ovim road, about 170m from New Layout Avenue, Amune, Ovim is white, fine to medium-grained, poorly sorted, and shows characteristic trough cross-bedding, parallel lamination, and wavy laminations (Fig. 6a). The trend of a representative fracture measured is 302°WNW-102°ESE; the strike of one of the beds is 2°NNE-182°SSW, the dip direction is 92°WSW whereas the dip amount is 18°. Sandstone unit of Outcrop 5 (about 5m thick of sediment, with a lateral extent of about 50m) found along Amune road, about 20m from No.12 New Layout Avenue, Amune, Ovim is essentially made up of white, fine to medium-grained, poorly sorted sandstone which shows parallel lamination and wavy laminations. The strike of one of the beds is 347°NNW-167°SSE, the dip direction is 257°WSW and the dip amount is 12°.

4.1.2. Shale unit

Shale units were exposed at springs, streams, and roads. The middle section of Outcrop 6 (about 3m of sediment thick, with a lateral extent of about 120m) exposed at a spring, about 1500m from Alayi Junction, Amaeke, Alayi comprises dark grey, carbonaceous shale which is overlain by a few meters thick sediments of white, friable, poorly sorted sandstone. It is important to note that the shale was overlain by a sandstone unit which gave rise to a contact spring that serves as a source of water for the inhabitants (Fig. 9a). The shale bed has a strike of 02°NNE-182°SSW, dip direction of 92°ESE, and a dip amount of 8°. The basal section of Outcrop 7 (about 2m of sediment thick, with a lateral extent of about 20m) found along Ibeku road at Ishi Iyi, Ubani Ibeku consists dominantly of dark grey, fissile shale with pelecypod imprints and overlain by about 1m thick sandstone with characteristic planar crossbedding (Fig. 7d ; 9c).

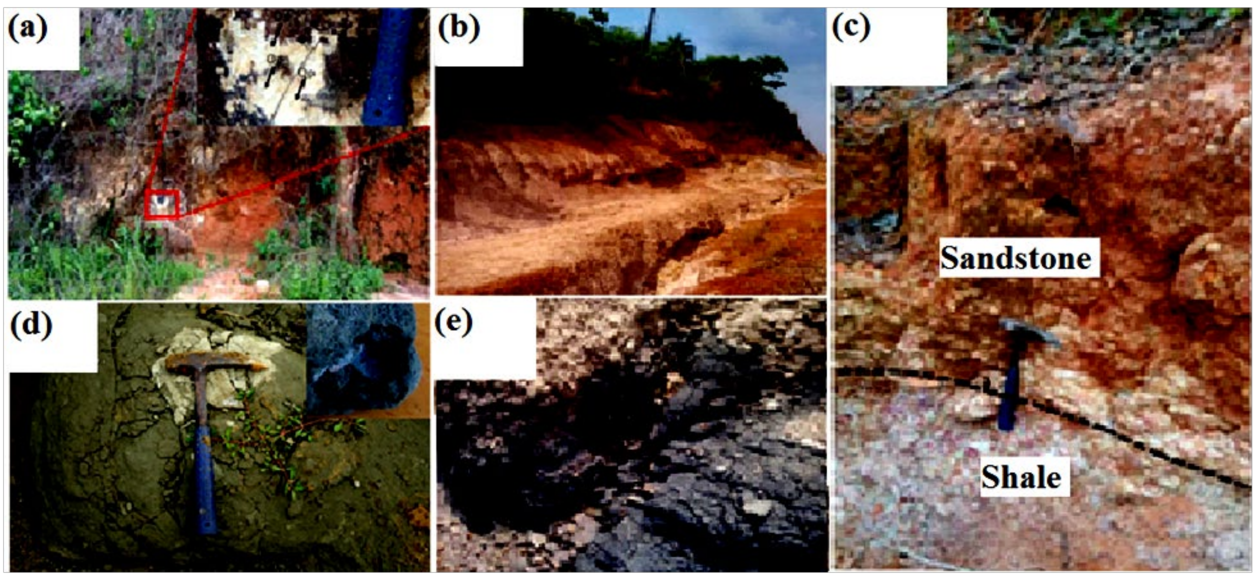

Fig. 7. (a) The middle section of Outcrop 8 showing the sandstone bed which is bioturbated with *Ophiomorpha* (Op) burrows as shown in the red-boxed area; (b) A panoramic view of Outcrop 9, showing iron-dominated shale beds; (c) Outcrop section of Outcrop 8 showing the contact of the iron-dominated weathered shale bed with the overlying sandstone bed; (d) Calcareous mudstone encountered at Outcrop 12, showing the cast of pelecypod occurrence; (e) Outcrop section of Outcrop 9 showing mud cracks on the shale

4.1.3. Heterolithic unit

Heterolithic units were mainly encountered at road-cuts. The heterolithic unit at Outcrop 8 (about 5m thick of sediment, with a lateral extent of about 50m) seen along Ovim road, about 100m from Nigeria Police Station, Ovim comprises 2m thick intensely weathered iron-dominated shale (Fig. 7c), which is overlain by 3m thick white, friable, fine to medium-grained, moderately sorted sandstone which is bioturbated with *Ophiomorpha* burrows and has mud drapes (Fig. 7a). The strike of the shale bed is 30°NNE-210°SSW; the dip direction is 120°ENE and its dip amount is 12°. The middle section of Outcrop 9 (Fig. 7b) (about 9m thick of sediment, with a lateral extent of about 70m) exposed along Ovim road, about 300m from Amaba Health Centre, Amaba, Ovim comprises 0.5m thick pebbly, friable, well-sorted, coarse-grained sandstone, which is overlain by another sandstone bed that is white, medium to coarse-grained, friable, and moderately sorted and about 2.5m thick with characteristic planar cross-bedding and mud drapes. Overlying this sandstone bed is an intensely weathered iron-dominated, fissile, laminated shale bed that is about 1m thick with evident mud cracks (Fig. 7e). It has an erosional contact with an overlying bed of sandstone, about 1.5m thick. The next bed, which is about 0.5m, comprises intensely weathered iron-dominated, fissile shale and has erosional contact with a 0.2m thick sandstone bed. Overlying the sandstone bed is a 1m thick bed of weathered iron-dominated shale capped by 0.5m thick lateritic overburden. The strike of one of the beds is 28°NNE-208°SSW; its dip direction is 298°WSW and the dip amount is 20°.

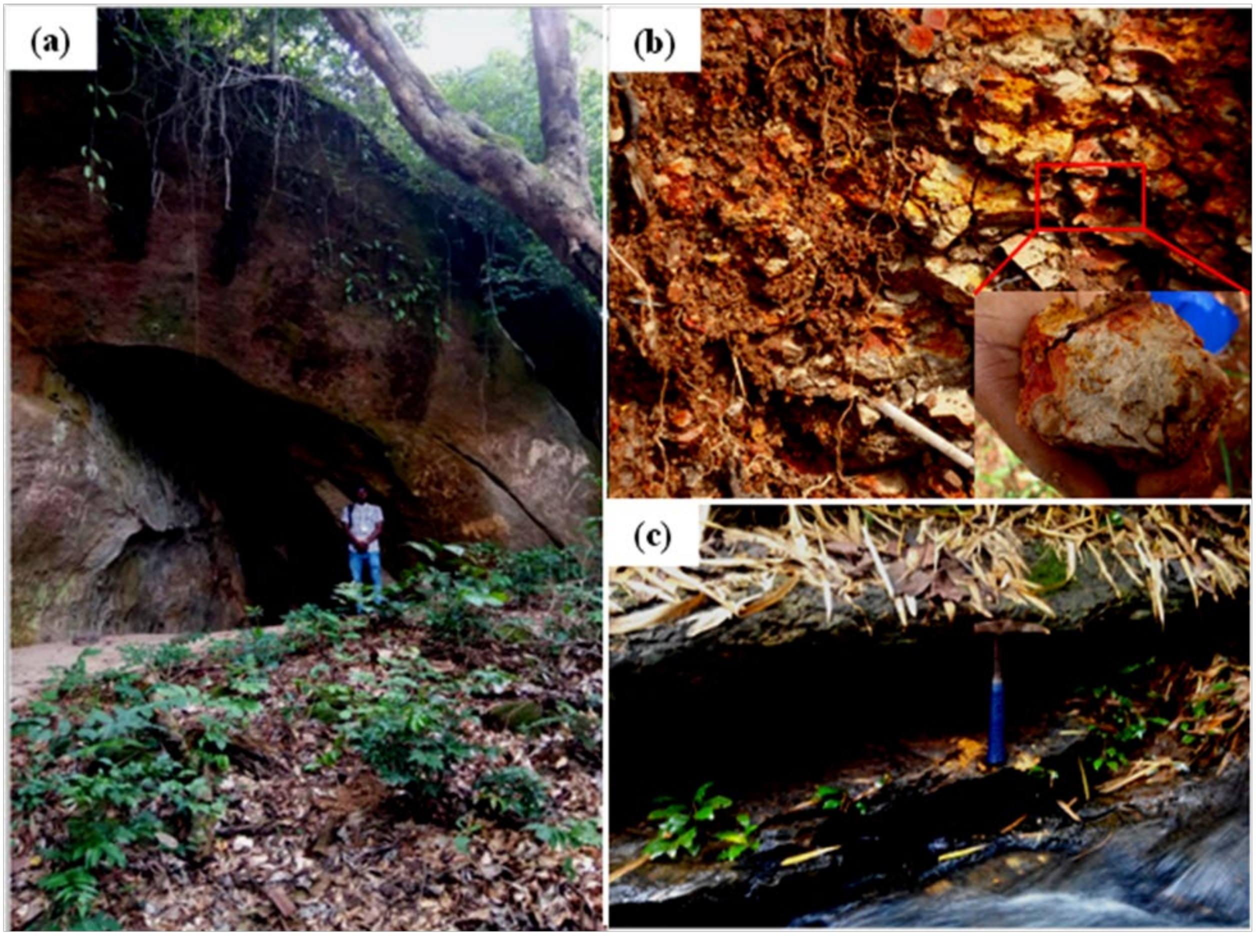

Fig. 8. (a) Pebbly sandstone encountered at Uhuchukwu cave (Outcrop 2); (b) Close-up section of the mudstone encountered at Outcrop 12, showing the occurrence of pelecypod, as shown in the red-boxed area; (c) Lower section of Outcrop 10, showing siltstone unit

4.1.4. Siltstone unit

Rock exposure of the siltstone unit was found in a stream section, along the Ilo River in Uzuakoli. The basal section of Outcrop 10 (about 3m thick of sediment, with a lateral extent of about 40m) comprises light brown, fine-grained, gritty, indurated, poorly sorted, micaceous siltstone with a characteristic planar cross-stratification Fig. 8c). The strike of the siltstone bed is 348°NNW-168°SSE; the dip direction is 258°WSW, while the dip amount is 4°.

4.1.5. Mudstone unit

Outcrop exposures of the mudstone units were mainly found in rivers, streams, and roads. The basal section of Outcrop 11 (about 1m thick of sediment, with a lateral extent of about 20m) exposed at Umuokoroala River in Ohuhu, is made up of reddish grey, laminated mudstone. The strike of a representative bed is 332°NNW-152°SSE; the dip direction is 242°WSW, while its dip amount is 3°. The upper section of Outcrop 12 (about 1m thick of sediment, with a lateral extent of about 30m) encountered at Umule Stream in Ohuhu comprises reddish-brown, highly fossiliferous mudstone with a characteristic presence of pelecypods (Fig. 7d; 8b). The strike of a representative bed is 350°NNW-170°SSE; the dip direction is 260°WSW, and its dip amount is 2°. The middle section of Outcrop 13 (about 2m thick sediment, with a lateral extent of about 25m) found along Umuahia-Uzuakoli road, about 15m from Umuahia-Uzuakoli boundary, Ubani Ibeku, is made up of brown weathered laminated shale and dark calcareous mudstone, which is highly fossilized by pelecypod imprints. Moreover, the basal section of Outcrop 13 is basically composed of weathered laminated shale (Fig. 9b). The strike of a representative bed is 342°NNW-162°SSE; the dip direction is 252°WSW, and the dip amount is 3°.

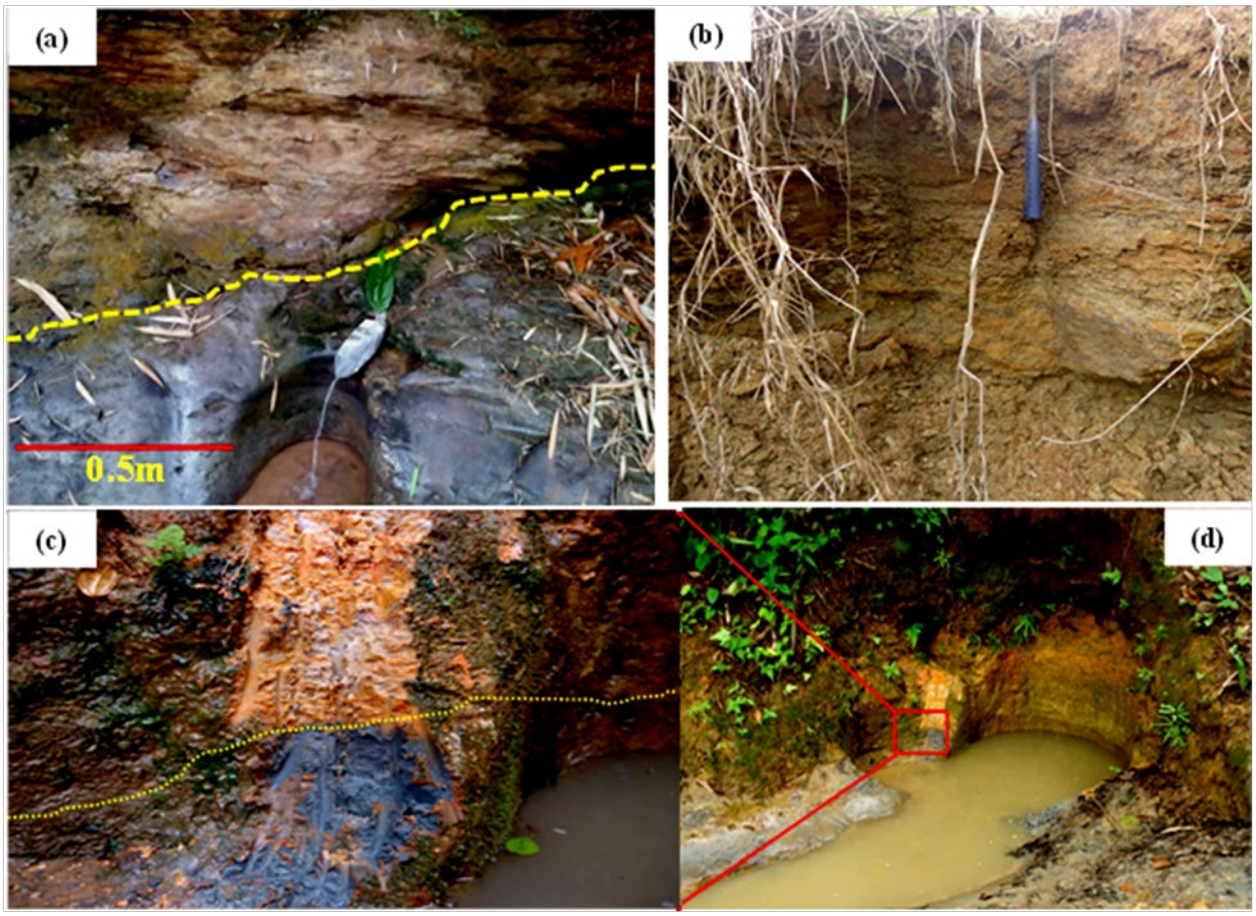

Fig. 9. (a) Outcrop section showing dark carbonaceous shale and a contact spring, formed due to the contact between shale and sandstone at Outcrop 6; (b) Basal section of Outcrop 13 showing brown weathered laminated shale; (c) Close-up section of Outcrop 7, showing the contact between the shale and sandstone, as shown in the red-boxed area in Fig 7d; (d) Outcrop view of Outcrop 7

4.2. Granulometric analysis

Six (6) sandstone samples have been collected from Outcrop 1, Outcrop 2, Outcrop 3, Outcrop 4, Outcrop 8, and Outcrop 9, and were used to carry out sieve analysis. The log-probability plots of the different samples were produced as shown in Figures 12 and 13. The log-probability plots of samples 1 (Fig. 12), 2 (Fig. 12), and 4 (Fig. 13) is a three-segment plot, deposited by traction, saltation, and suspension processes, which is suggestive of a shallow marine environment. The mean size result shows that the samples are medium to coarse-grained, indicative of intermediate to high energy depositional setting while the standard deviation shows that the sandstone is poorly sorted, which is a pointer to variable energy setting.

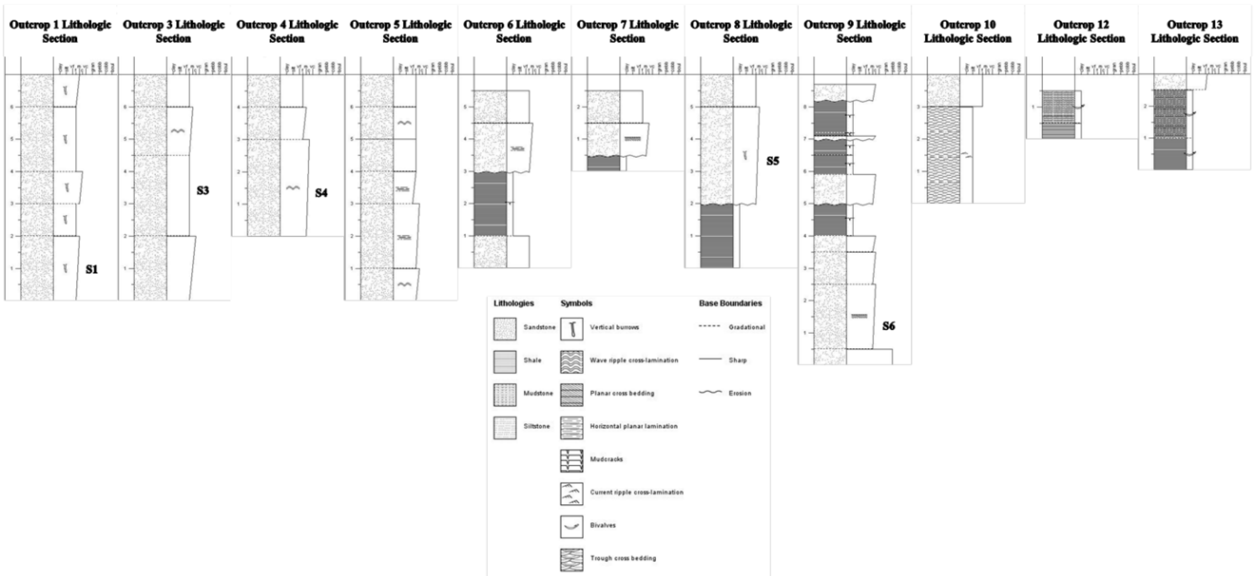

Fig. 10. Detailed measured sedimentological logs of most of the outcrops encountered within the Uzuakoli-Ahaba axis, southeastern Nigeria. (Note: Thickness is in meters)

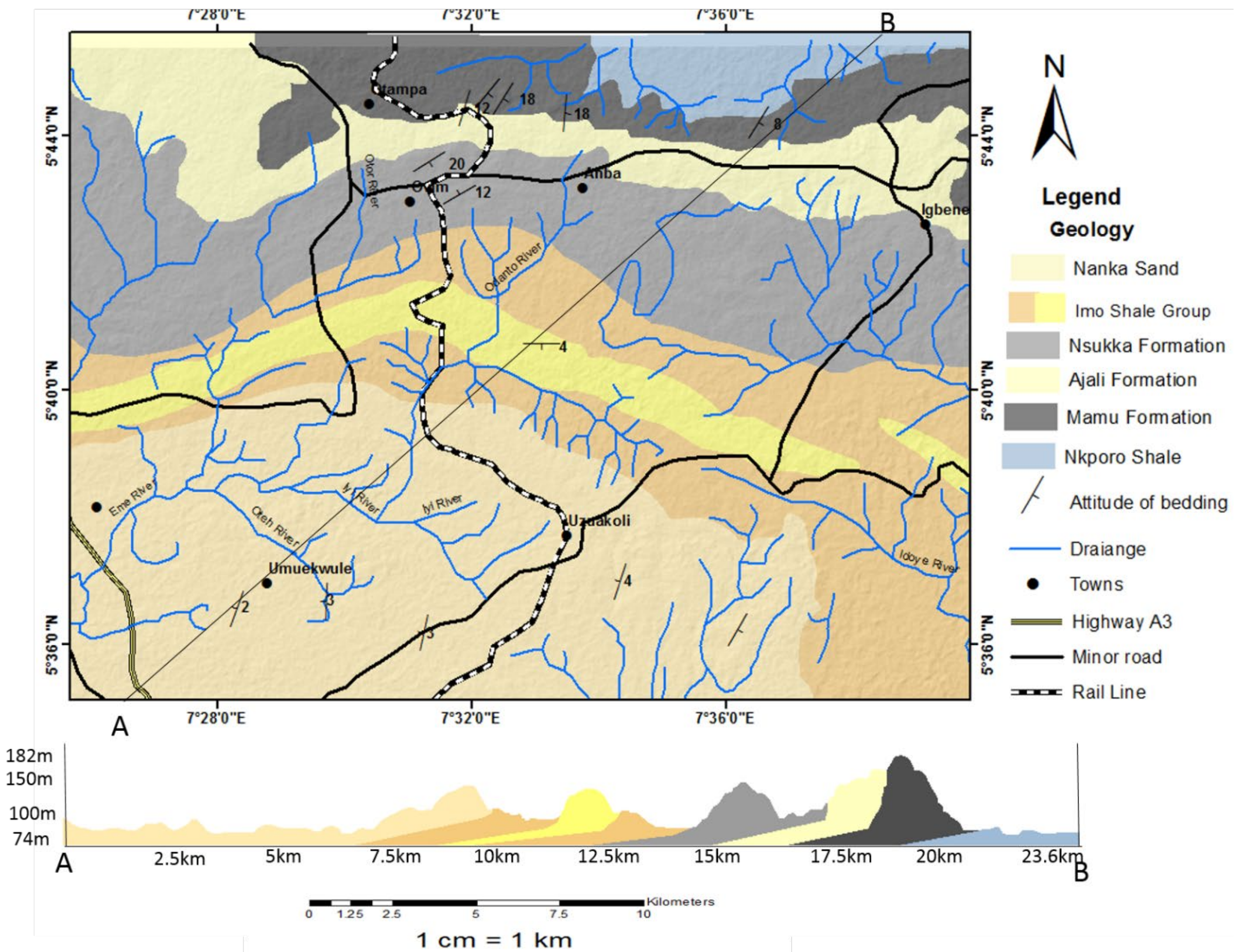

Fig. 11. Geologic map and geologic cross-section (A-B) across the study area

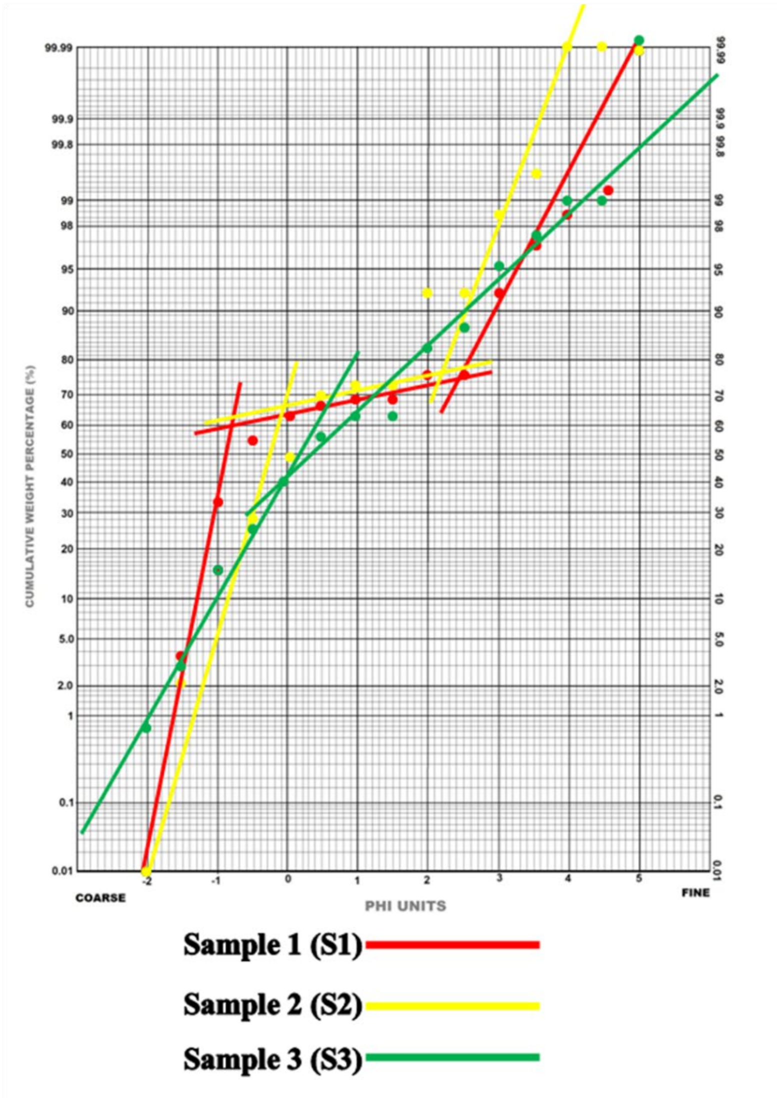

Fig. 12. Log-probability plots showing the trends of traction, saltation and suspension population of samples 1-3 (after Visher [36])

The dominant positive (fine) skewness of the sandstone connotes that the energy was low for most of the time, whereas the kurtosis indicates that the sandstone is essentially very platykurtic, relating to poor sorting. However, the log-probability plots of samples 3 (Fig. 12), 5 (Fig. 13), and 6 (Fig. 13) is a two-segment plot, deposited by traction and suspension, indicating deposition in a fluvial environment. The mean size result shows that the samples are medium-grained to coarse-grained, suggestive of intermediate to high energy setting while the standard deviation indicates that the sandstones are moderately sorted to poorly sorted. The positive (fine) skewness of sample 5 indicates that the energy was low for most of the time whereas the symmetrical skewness of samples 3 and 4 indicate that the velocity of the depositing agent operated at a normal level. Also, the kurtosis of these samples which range from mesokurtic to platykurtic shows that they are moderate to poorly sorted. The bivariate plots of skewness versus sorting (Fig. 14) by [38] and mean size versus sorting (Fig. 15) by [39] indicate that the majority of the sandstone samples were deposited in a fluvial-dominated environment with few of the sediments being deposited in a beach-dominated environment.

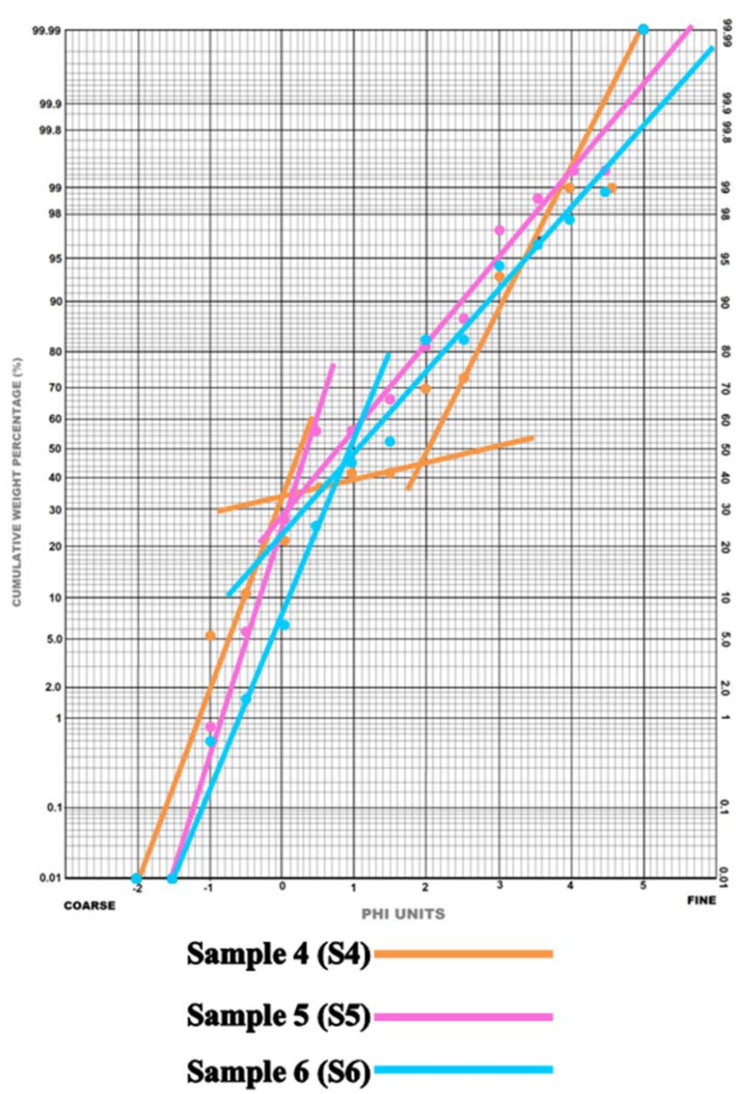

Fig. 13. Log-probability plots showing the trends of traction, saltation and suspension population of samples 4-6 (after Visher [36])

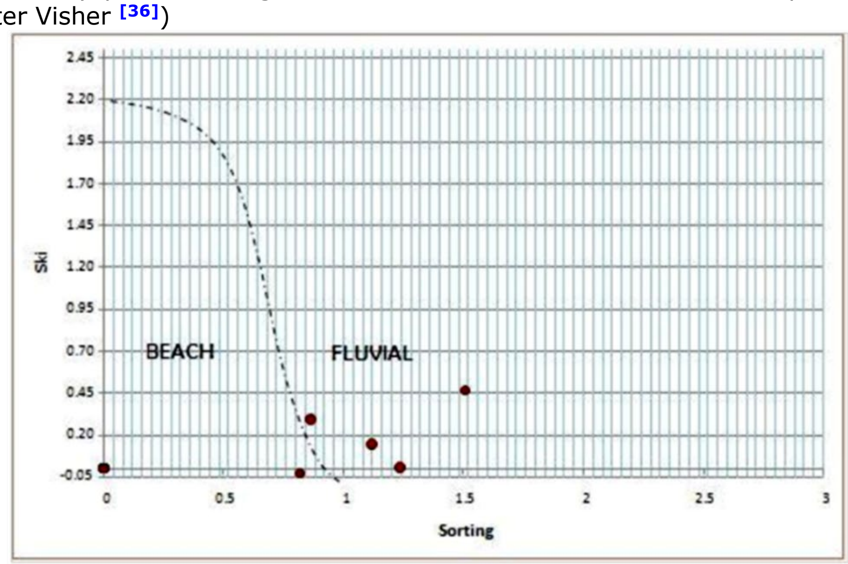

Fig. 14. Bivariate plot of skewness versus sorting for the six outcrops (after Friedman [38])

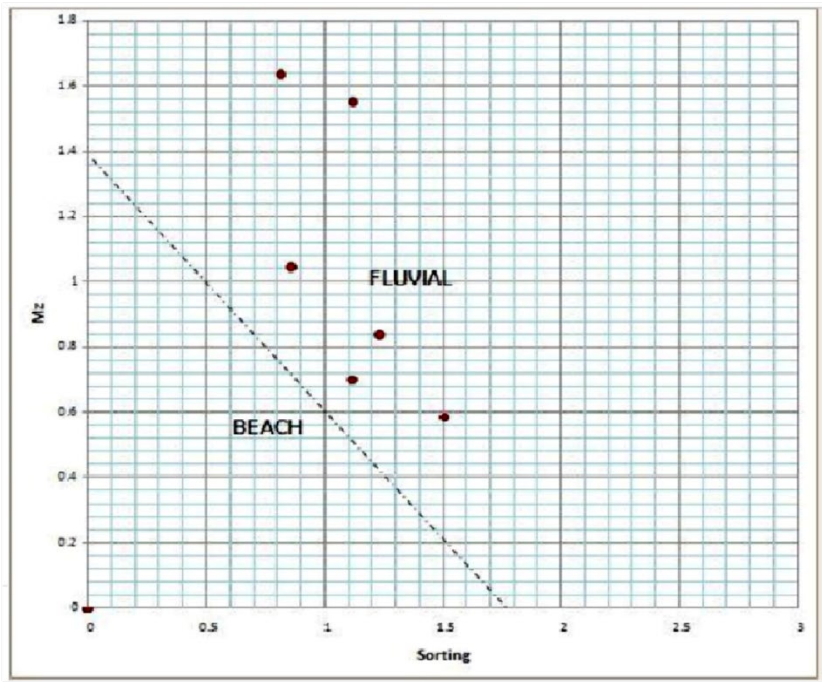

Fig. 15. Bivariate plot of mean size versus sorting for the six outcrops (after Moiola and Weiser [39])

4.3. Pebble morphometry

A total number of 100 pebbles were obtained from the sandstone sediment in Outcrop 1, which was used for the pebble morphometry. Various univariate parameters such as form, mean roundness, form indices, oblate-prolate index (OPI), maximum projection sphericity (MPS), and flatness index (FI) have been measured, calculated, and used to infer the depositional setting of the pebbles. Bivariate plots of MPS versus OPI [40] and FI versus MPS [41] were also plotted to further delineate the depositional environment as well. Also, [42] classification was used to classify the pebbles into a compact, platy, bladed, and elongated. Results from the bivariate plots of MPS versus OPI (Fig. 16) shows that 51% of the plots fall in the beach portion of the graph and the remaining 49% in the fluvial portion of the graph. The high percentage of the plots in the beach portion of the graph indicates that the environment was beach dominated.

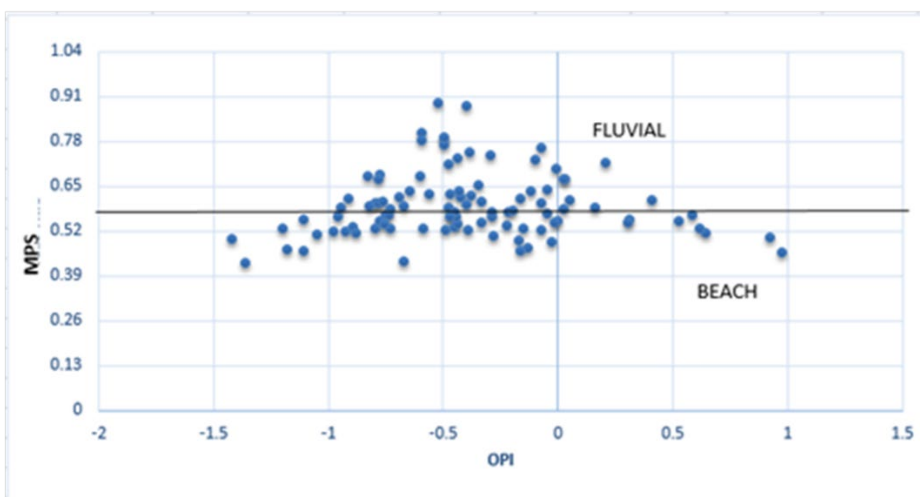

Fig. 16. Bivariate plots of MPS versus OPI of pebbles obtained at Outcrop 1 (after Dobkins and Folk [40])

Also, the bivariate plot of FI versus MPS (Fig. 17) shows that 53% of the plots fall in the beach portion of the graph, 38% in the fluvial portion, 7% of the plots in the lower part of the non-diagnostic portion of the graph while 2% plotted in the upper part of the non-diagnostic portion of the graph. The high percentage of plots in the beach portion of the graph indicates that the environment was beach dominated. The plots on the Sphericity-Form Diagram (Fig. 18) of [42] shows that 43% of the pebble fall into the bladed portion of the plot, 23% on the platy portion, 10% on the elongated portion, 9% on the very bladed portion, 4% on the compact-elongated portion, 2% on the very elongated portion, and also 2% on the compact portion of the plot. The high percentage of the plots in the bladed portion of the plot implies that the environment is beach dominated.

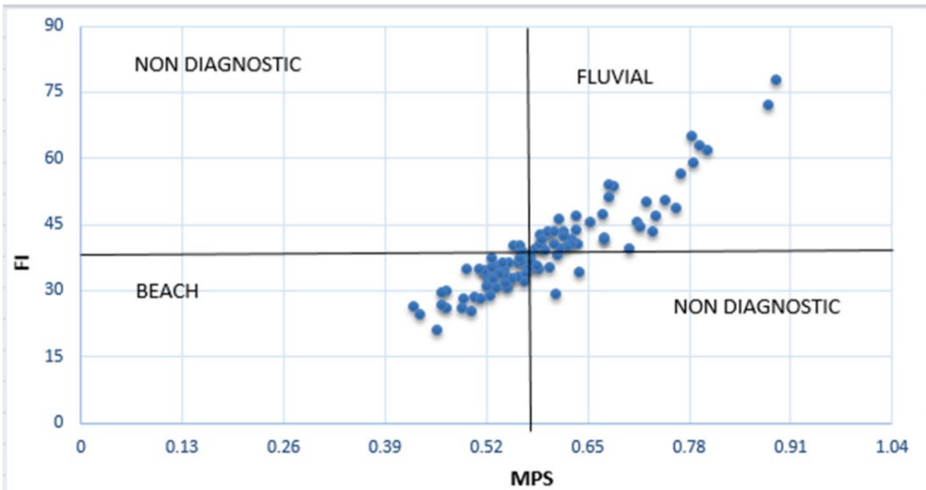

Fig. 17. Bivariate plots of FI versus OPI of pebble obtained from Outcrop 1 (after Stratten [41])

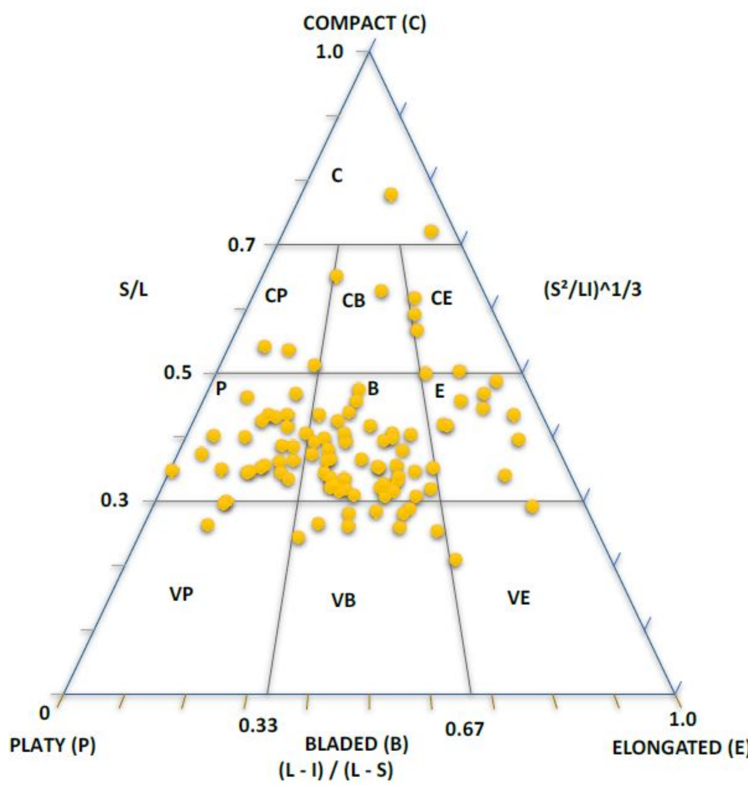

Fig. 18. Sphericity-Form Diagram of pebbles obtained from Outcrop 1 (after Sneed and Folk [42])

4.4. Implications on the depositional environment

The prevalence of pebbly sandstones which are typically medium to coarse-grained and indicate moderate to high energy environment of deposition implies that the sediment influx in the study area may be attributed to the action of the wave. The mud-drapes found on the cross bedded foresets (Fig. 6d) reflect the fallout of suspended sediments at slack water periods [43]. The presence of Ophiomorpha burrows (Fig. 6b) connotes suspension-feeder dwelling burrows that reflect high energy environments, typically shallow sub-tidal to intertidal deposits [44-45]. The occurrence of planar crossbedding with depositional contact suggests the onset of high energy depositional influx. The existence of heterolithic units in the study area indicates high-frequency oscillation of the sea level. The presence of mudcracks (Fig. 7e) portrays subaerial exposure during deposition [46-47]. The occurrence of carbonaceous shale suggests a shallow marine environment and the presence of organic matter under reducing conditions. Pelecypod imprints found in the study area are indicative of a high energy setting. The depositional setting of siltstone and mudstone mapped in the study area implies a very low to low energy environment. Also, a low to high energy depositional setting is observed from the rock unit analysis.

5. Conclusions

Detailed geologic mapping of various rock units encountered at Uzuakoli-Ahaba axis and generated sedimentologic logs integrated with granulometric and pebble morphometric analyses have provided useful data for interpreting processes that were established during sediment packages and their depositional environment. The study area is characterized by the presence of mainly pebbly sandstone towards the northern axis and shales and mudstones towards the southern part. Integration of field information and various plots from granulometric and pebble morphometric analyses helped in determining the depositional environment of the study area. From the integration of these analyses, the depositional environment of the Uzuakoli-Ahaba axis spans from shallow marine to fluvial environment. Finally, a geologic map of the Uzuakoli-Ahaba axis, with its cross-section, has been produced after integrating field data and results from granulometric and pebble morphometric analyses.

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