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Sedimentology and Depositional Environments of the Maastrichtian Mamu Formation, Northern Anambra Basin, Nigeria

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ABSTRACT

The Maastrichtian Mamu Formation is an intracratonic formation within the Anambra Basin and is one of the three upper Cretaceous coal measures. An extensive geological field mapping was carried out on well-exposed lithostratigraphic sections. Successions were measured and their peculiar sedimentological features such as textures, physical and biogenic sedimentary structures and used to characterize the facies, facies variations, facies associations and grain size analysis were documented and used to interpret the depositional environments and suggest a paleogeographic model. Eleven lithofacies identified from the formation were grouped into subtidal channel facies and intertidal flat facies based on association The Mamu Formation is made up of bioturbated cross to massive bedded sandstone, siltstone, dark grey to light grey fissile shale, mudstone and milky white claystone which often displays a fining upward trend. The sandstone facies is coarse to fine-grained, poorly to moderately well sorted, leptokurtic and negatively skewed possibly deposited from fluvial source. Tide generated sedimentary structures such as herringbone cross beddings, tidal bundles, reactivation surfaces, clay drapes and clay flasers suggest tidal dominance over wave process. Typical sedimentary structures displayed by the subtidal channel and intertidal flat facies include herringbone cross-bedding, trough cross bedding, tabular cross-bedding, reactivation surfaces, burrows and clay drapes suggest tidal dominance over wave process. Vertical burrows of Ophiomorpha and Skolithos which belongs to Skolithos ichnofacies typifies littoral/intertidal environment suggests show colonization of only suspension feeders typical of high-energy environment. The multivariate scatter plots of the discriminate functions calculated from grain size data indicate deposition of the sandstones in a predominantly shallow marine/subtidal deposit. The fissility of shale the textural study of the siltstone facies suggests deposition in a low energy environment. However, field and textural studies of the sandstone facies suggest that the sediments were deposited in a relatively high-energy environment with tidal influence. The probability curve suggests deposition by rolling to bottom suspension rolling condition**.** *The bimodal oblique paleocurrent pattern obtained shows that the formation was deposited in environment such as shoreline (beach) or fluvio-deltaic where tidal effect is significant. Paleocurrent studies and textural characteristics indicate that the sediments were from more than one source. Probably a regressive model is proposed for the Mamu Formation. Mamu Formation in the study area is deposited in subtidal channel and intertidal flat environments.*

Keywords: Depositional environments, Facies, Subtidal, Intertidal, Paleocurrent.

INTRODUCTION

The study area is in Kogi State, north central Nigeria and lies between latitudes 7° 06' 00"N to 7° 21' 00" N and longitudes 6° 43' 00" E to 6° 58' 00"E, with a total area of seven hundred and seventy square kilometres (770Km²). The area is accessible via foot paths, major and minor roads that link the villages. This study benefited significantly from recently constructed Anyigba-Lokoja road, which provides good and fresh exposures of the shale and clay members of the Mamu Formation hitherto covered by vegetation. Other accessible routes in the study area are Ajegu-Idah road and Ocheche River channels.

The origin of the Anambra Basin is intimately related to the development of the Benue Rift. The Benue Rift was known as the failed arm of a trilate fracture (rift) system, during the breakup of the Gondwana supercontinent and the opening of the southern Atlantic Ocean in the Jurassic [1-6]. The initial synrift sedimentation in the embryonic trough occurred during the Aptian to early Albian and comprised of alluvial fans and lacustrine sediments of the Mamfe Formation in the southern Benue Trough. Two cycles of marine transgressions and regressions from the middle Albian to the Coniacian filled this ancestral trough with mudrocks, sandstones and limestones with an estimated thickness of 3,500 m [7,8]. These sediments belong to the Asu River Group (Albian), the Odukpani Formation (Cenomanian), the Ezeaku Group (Turonian) and the Awgu Shale (Coniacian). During the Santonian, epeirogenic tectonics, these sediments underwent folding and uplifted into the Abakaliki-Benue Anticlinorium [7] with simultaneous subsidence of the Anambra Basin and the Afikpo sub- basins to the northwest and southeast of the folded belt respectively [7,9]. The Abakaliki Anticlinorium later served as a sediment dispersal centre from which sediments were shifted into the Anambra Basin and Afikpo Syncline. The Oban Masif, southwestern Nigeria basement craton and the Cameroon basement complex also served as sources for the sediments of the Anambra Basin [10-13]. After the development of the Anambra Basin following the Santonianepeirogeny, the Campanian-early Maastrichtian transgression deposited the Nkporo Group (i.e., the Enugu Formation, Owelli Sandstone, Nkporo Shale, Afikpo Sandstone, Otobi Sandstone and Lafia Sandstone) as the basal unit of the basin, unconformably overlying the Awgu Formation. This was followed by the Maastrichtian regressive event during which the coal measures (i.e., the Mamu, Ajali and Nsukka Formations) were deposited.

The Mamu Formation in northern Anambra Basin consists of carbonaceous shales, mudstone, clay, coals, interbedded shale and clay, sandstone, and siltstone. The relative abundance of these lithologies changes from east to north across eastern Kogi state: coal and carbonaceous shale become more prevalent to the north. This east to north variation in lithologies suggests that the Mamu Formation formed in several depositional settings. Although marginal marine deposits have long been recognized in the Mamu Formation in Anambra Basin, little or no work has been done on the depositional environments east of the Mamu Formation type section near Ajegu and Idah, Kogi State (Figure 1). Due to paucity of documented interpretation and poor and limited knowledge on Sedimentology and depositional environments of the Maastrichtian Mamu Formation that perhaps may be attributed to lack of detail geological mapping, poor area accessibility, and few available surface sections in the study area.

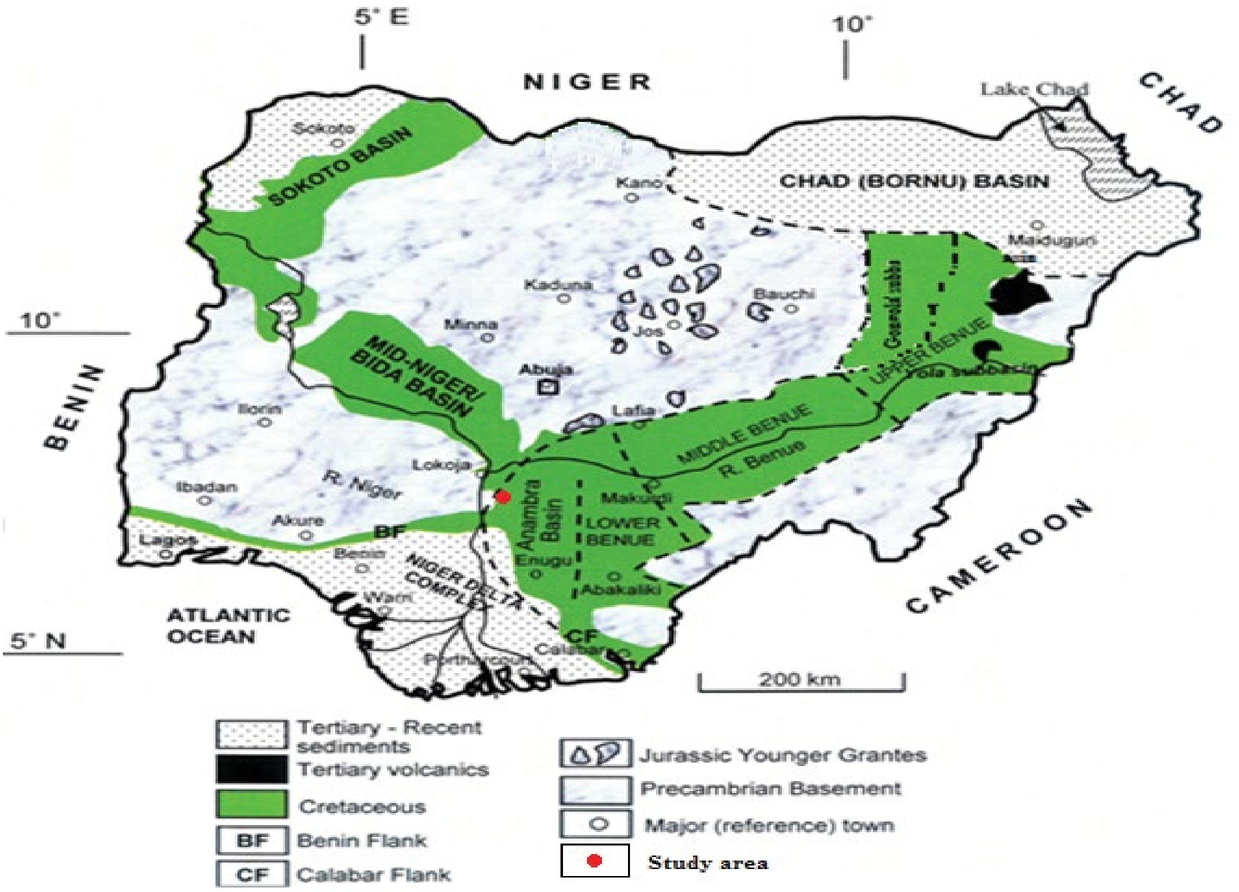

Figure 1: Geological map of Nigeria showing the Northern Anambra basin [14].

This research describes lithofacies defined based on field descriptions of lithology, grain size, stratification, and sedimentary structures of the Mamu Formation in eastern Kogi, interprets depositional environments associated with these lithofacies, and reconstructs the paleogeography of for the study area for each facies of the Mamu Formation [14].

MATERIALS AND METHODS

Traverses were taken, directional bearing were obtained with the aid of compass and Geographic Positioning System (GPS) along major roads and minor footpaths while sampling of representative rock units was carried out concurrently from exposures. Attention was devoted to locating stratigraphic outcrop sections which are mainly exposed along gullies and road cuts. Fresh samples were carefully collected from each section weathered layers which may give inaccurate results were avoided. Vital information like location, sample number, horizon description such as; lithologies, colours, sedimentary structures from each unit and date of the sampling were clearly indicated on the sample bags and all the relevant data were written in field.

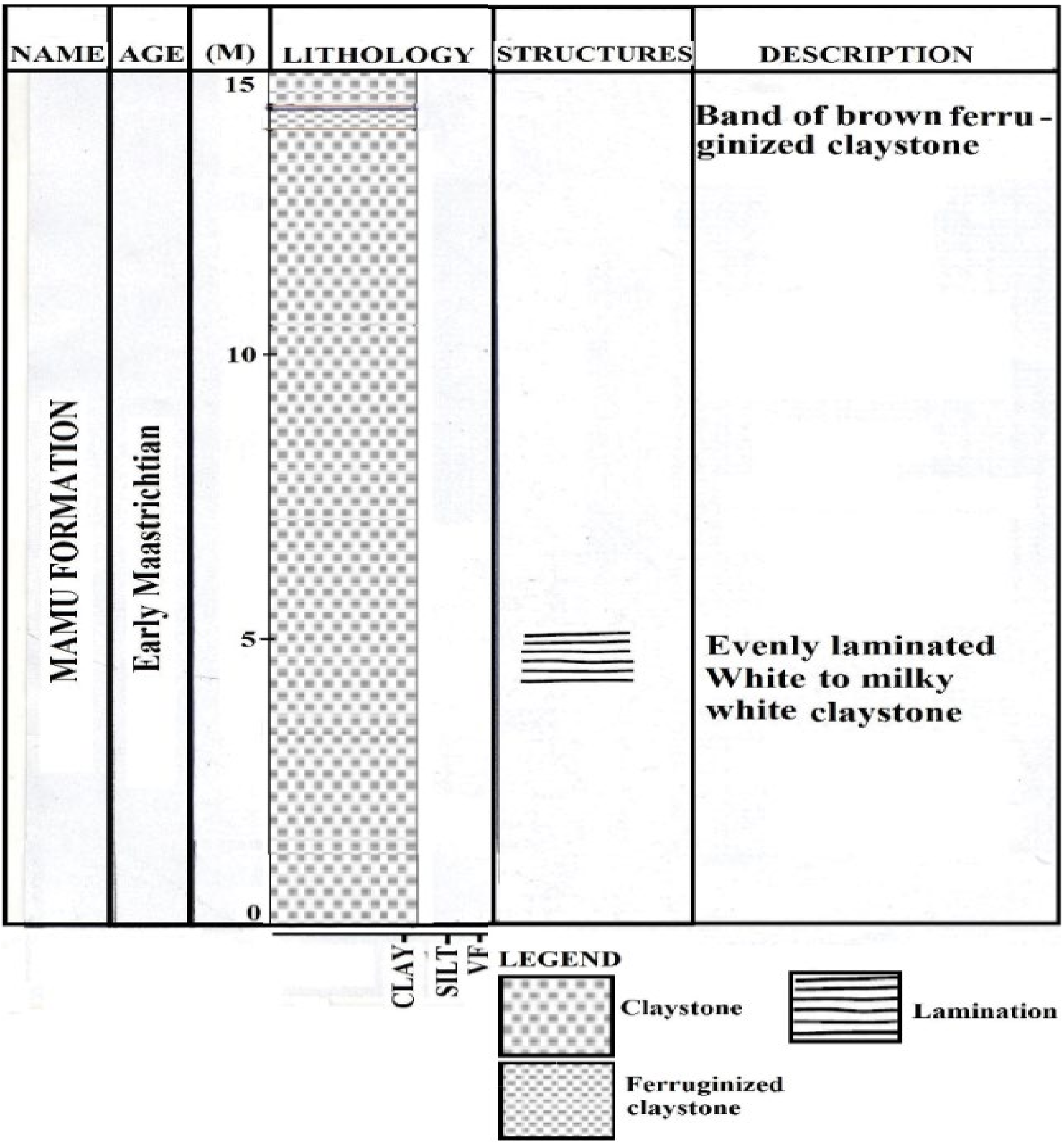

Figure 2: Litho-stratigraphic section of Mamu formation exposed northwest of Ojuwo Omachi town.

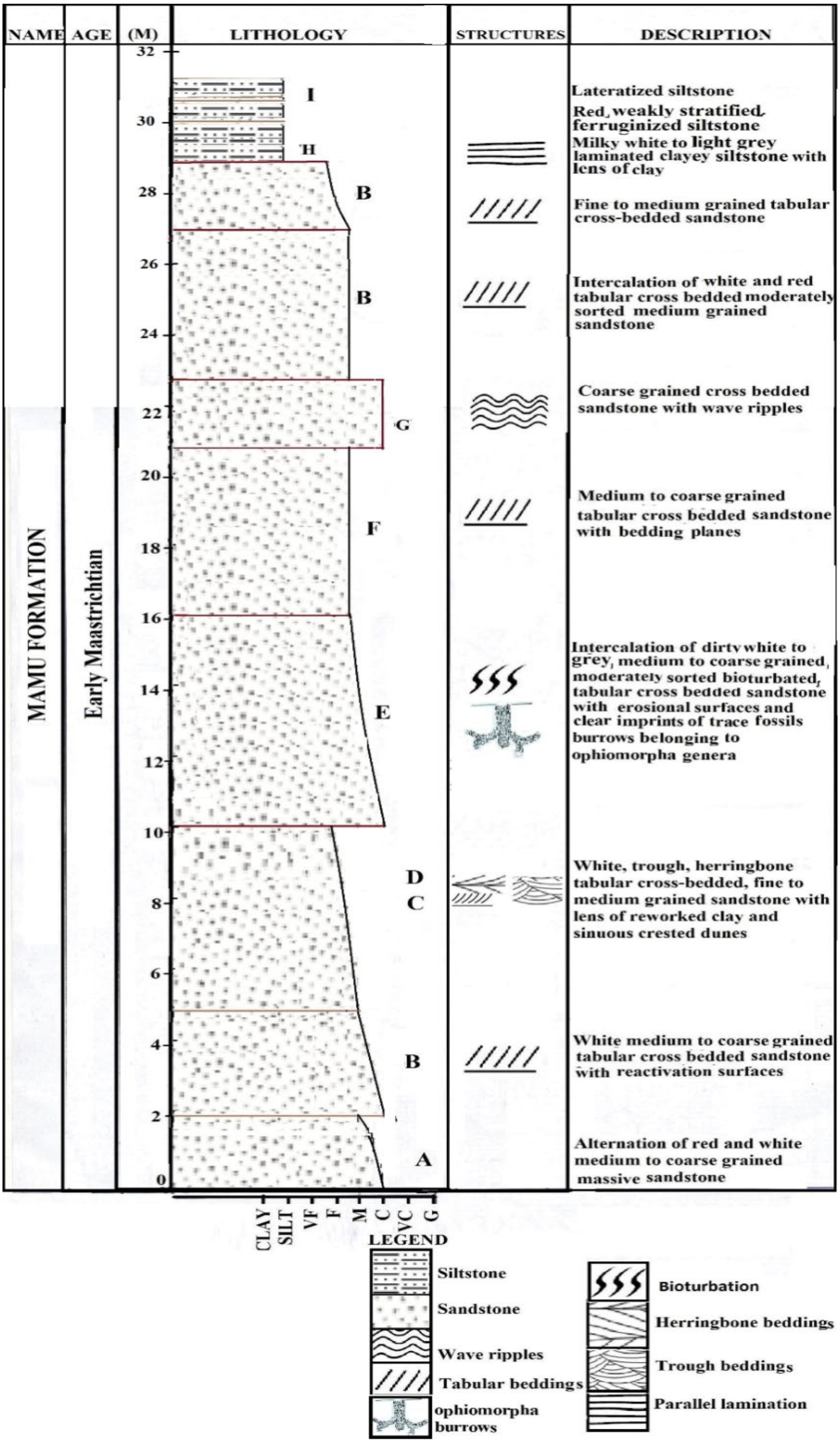

Figure 3: Lithostratigraphic section of sandstones of Mamu Formation exposed near Ocheche River at Idah (07° 07' 27" N, 06° 44' 20.6"

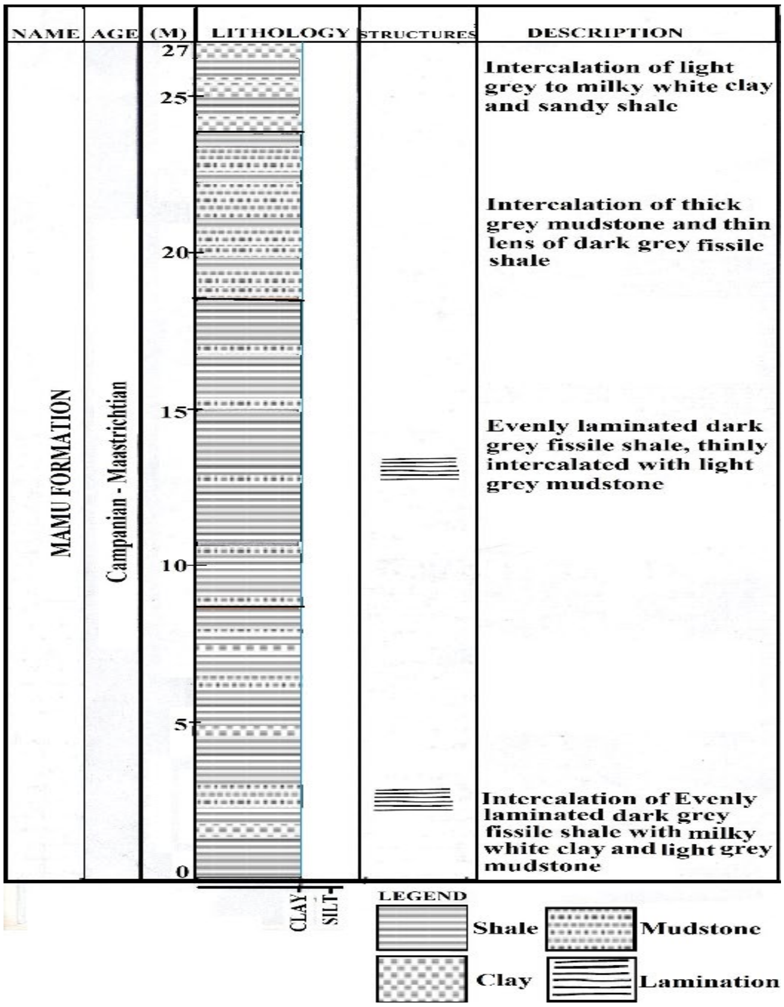

Figure 4: Lithostratigraphic section of the Mamu Formation exposed southwest of Ojodu town (07° 20' 44.9" N, 06° 55' 09.2" E).

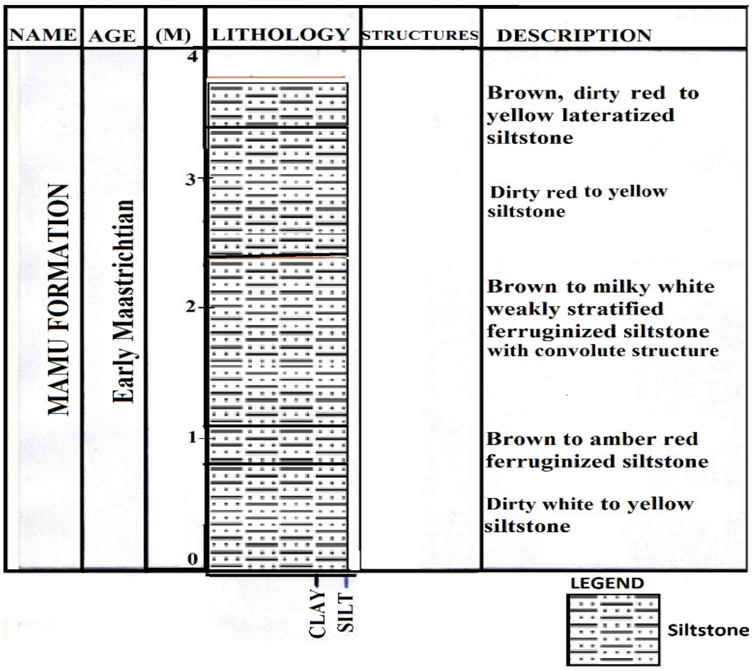

Figure 5: Lithostratigraphic section of Mamu Formation exposed near Aya village (7°14' 59.4" N, 6°48' 02.7" E).

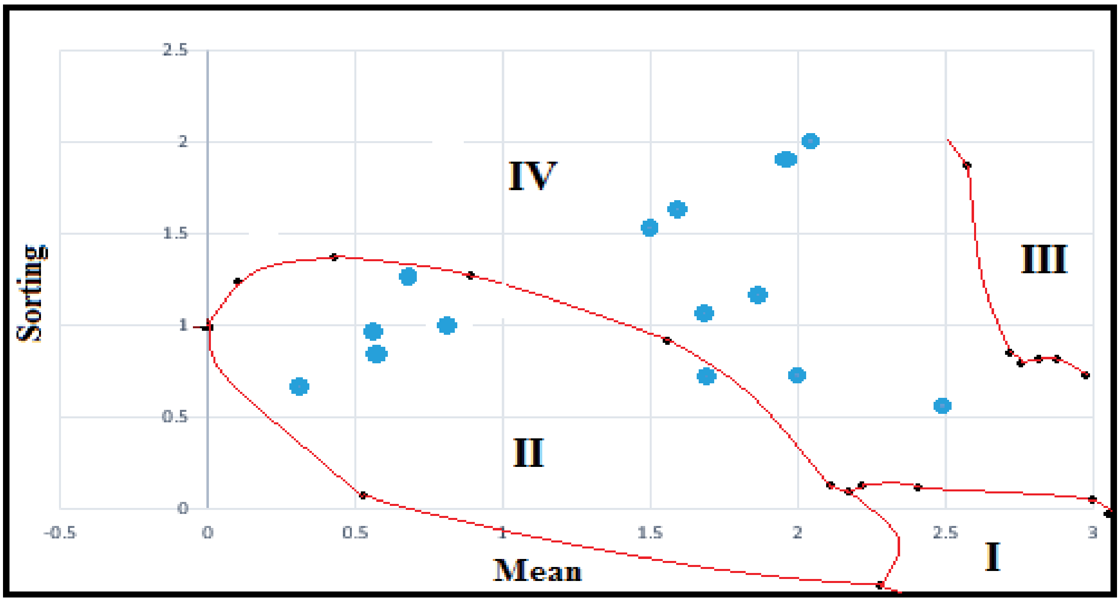

Figure 6: Energy Process diagram (after Stewart, 1958) (I) Beach process; (II) River process; (III) Quiet water; (IV) Inner shelf.

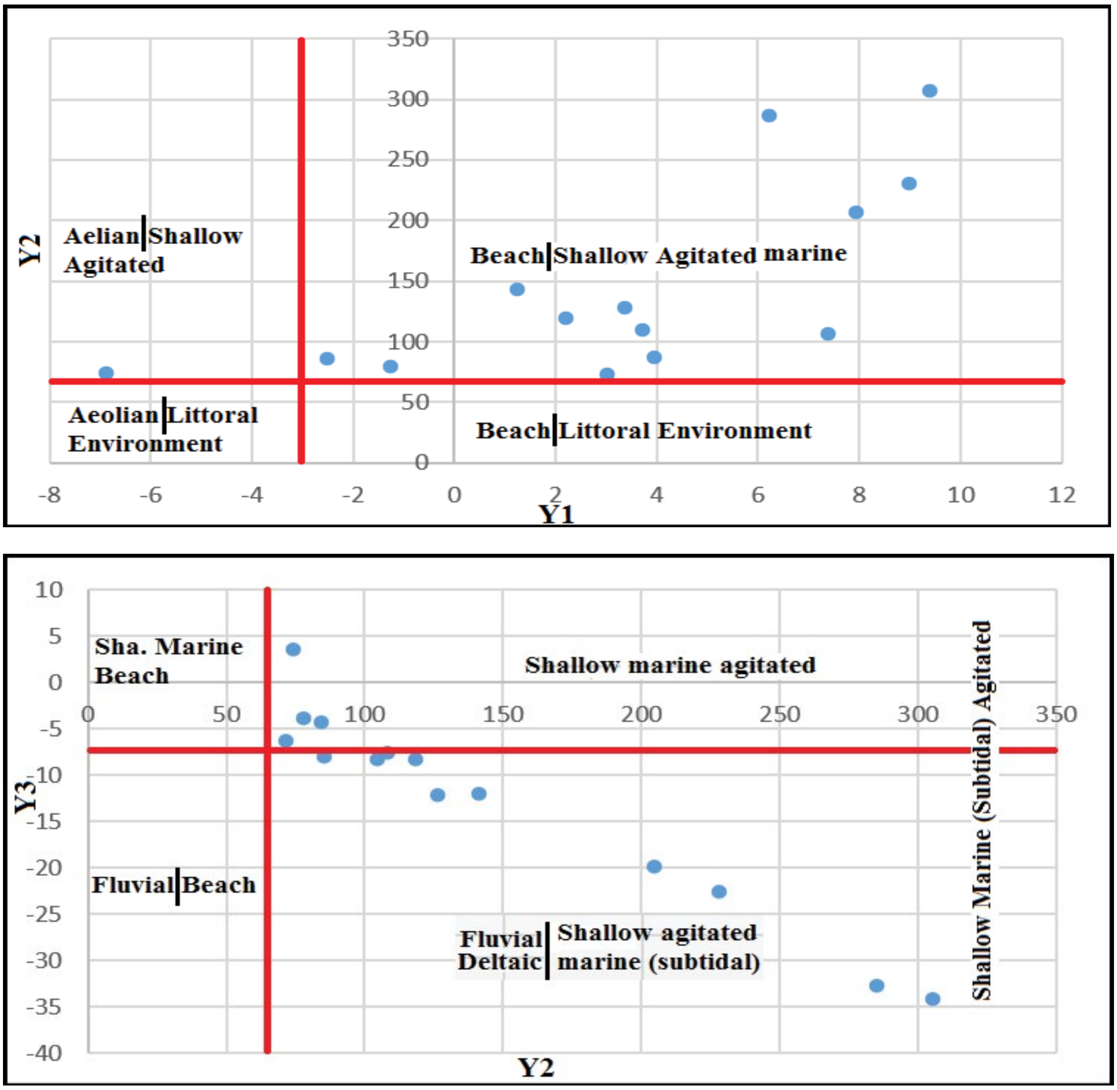

Figure 7: (a and b) Linear Discriminate Function (LDF) scatter plot for the sandstone facies of Mamu Formation in the study area.

A total of 22 samples from Mamu Formation were selected from different locations for sieve analysis at Sedimentology Laboratory, Department of Geology, Ahmadu Bello University Zaria and Sedimentology Laboratory, Department of Earth Sciences, Kogi State University, Anyigba. Granulometric analysis (sieve analysis) was carried out on the samples with primary aim of determining particles size distribution and other grain size parameters like sorting, skewness, mean and kurtosis. The statistical parameters of the grain size frequency distribution were obtained and computed using method used by Folk and Ward [15]. These were used as an independent function or combined in multivariate analysis such as the Linear Discriminate Function (LDF) and Coarse Median (CM) pattern to interpret the depositional environments and processes. For the CM pattern, parameter C (one percentile of the grain size

Sample ID	Mean (mm)	Sorting (Φ)	Skewness (Φ)	Kurtosis
MI1	1.280 Medium sand	1.030 Poorly sorted	-0.240 Negatively skewed	1.250 Leptokurtic
MI2	0.570 Coarse sand	0.850 Moderately sorted	0.040 Near symmetrical	0.800 Platykurtic
MI3	0.570 Coarse sand	0.980 Moderately sorted	-0.020 Near symmetrical	0.770 Platykurtic
MI4	1.600 Medium sand	1.610 Poorly sorted	0.100 Positively skewed	1.710 V. Leptokurtic
MI5	1.500 Medium sand	1.520 Poorly sorted	0.060 Near symmetrical	1.560 V. Leptokurtic
MO1	1.200 Medium sand	1.220 Poorly sorted	0.070Near symmetrical	0.640 V. Leptokurtic
MO2	1.700 Medium sand	0.720 Moderately sorted	0.0083 Near symmetrical	0.940 Mesokurtic
MO3	2.513 Fine sand	0.578 Moderately sorted	0.2523 Positively skewed	1.082 Mesokurtic
MO4	1.681 Medium sand	1.050 Poorly sorted	-0.170 Negatively skewed	1.220 V. Leptokurtic
MO5	2.050 Fine sand	1.985 Poorly sorted	0.0588 Near symmetrical	0.7319 Platykurtic
MO6	2.000 Medium sand	0.720 Moderately sorted	0.090 Near symmetrical	0.940 Mesokurtic
MO7	1.960 Medium sand	1.908 Poorly sorted	0.1195 Positively skewed	0.7295 Platykurtic
MO8	0.310 Coarse sand	0.660 Moderately sorted	0.990 Strongly fine skewed	2.870 V. Leptokurtic
MO9	1.870 Medium sand	1.150 Poorly sorted	0.250 Positively skewed	1.150 Leptokurtic
MO10	1.280 Medium sand	1.030 Poorly sorted	-0.240 Negatively skewed	1.250 Leptokurtic
MO11	1.280 Medium sand	1.030 Poorly sorted	-0.240 Negatively skewed	1.250 Leptokurtic
MO12	1.200 Medium sand	1.220 Poorly sorted	0.070Near symmetrical	0.640 V. Leptokurtic
MO13	0.570 Coarse sand	0.850 Moderately sorted	0.040 Near symmetrical	0.800 Platykurtic
MO14	0.570 Coarse sand	0.980 Moderately sorted	-0.020 Near symmetrical	0.770 Platykurtic
MOI5	1.500 Medium sand	1.520 Poorly sorted	0.060 Near symmetrical	1.560 V. Leptokurtic
MO16	1.200 Medium sand	1.220 Poorly sorted	0.070Near symmetrical	0.640 V. Leptokurtic
MO17	2.513 Fine sand	0.578 Moderately sorted	0.2523 Positively skewed	1.082 Mesokurtic

Table 1: Grain size distribution and quantitative parameters of samples of the sandstone facies of Mamu formation in the study area.

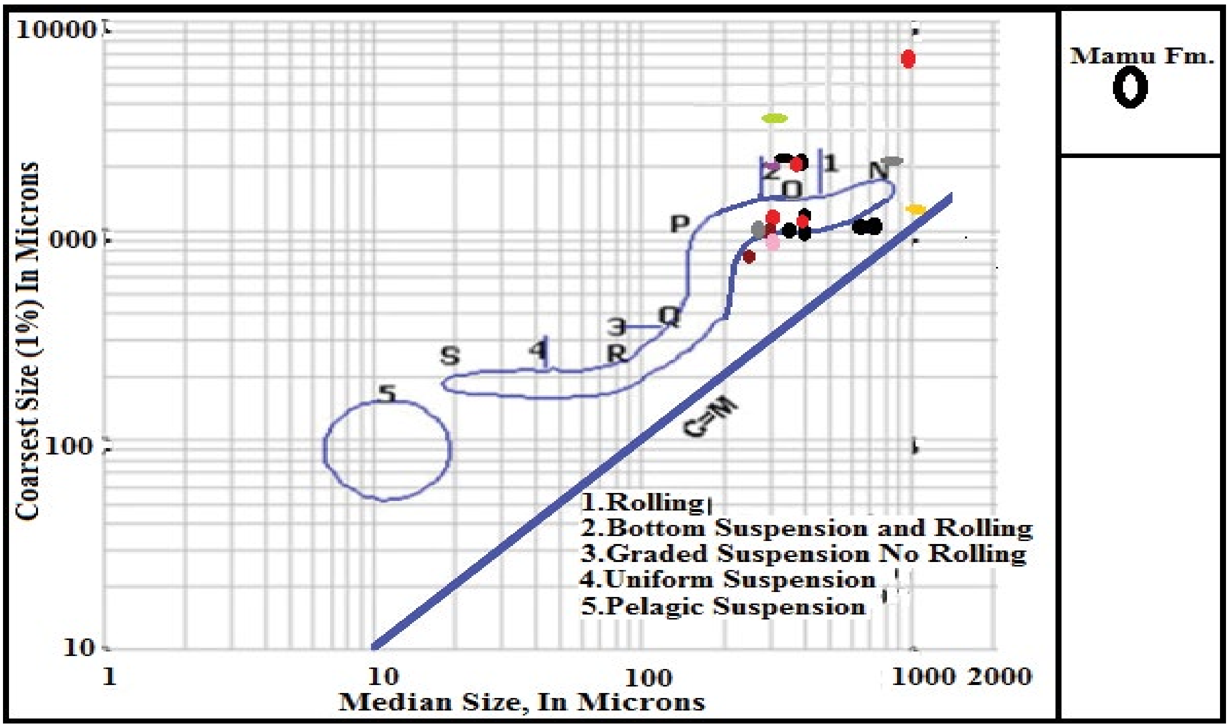

Figure 8: CM diagram for sandstone facies samples in the study area [30,31].

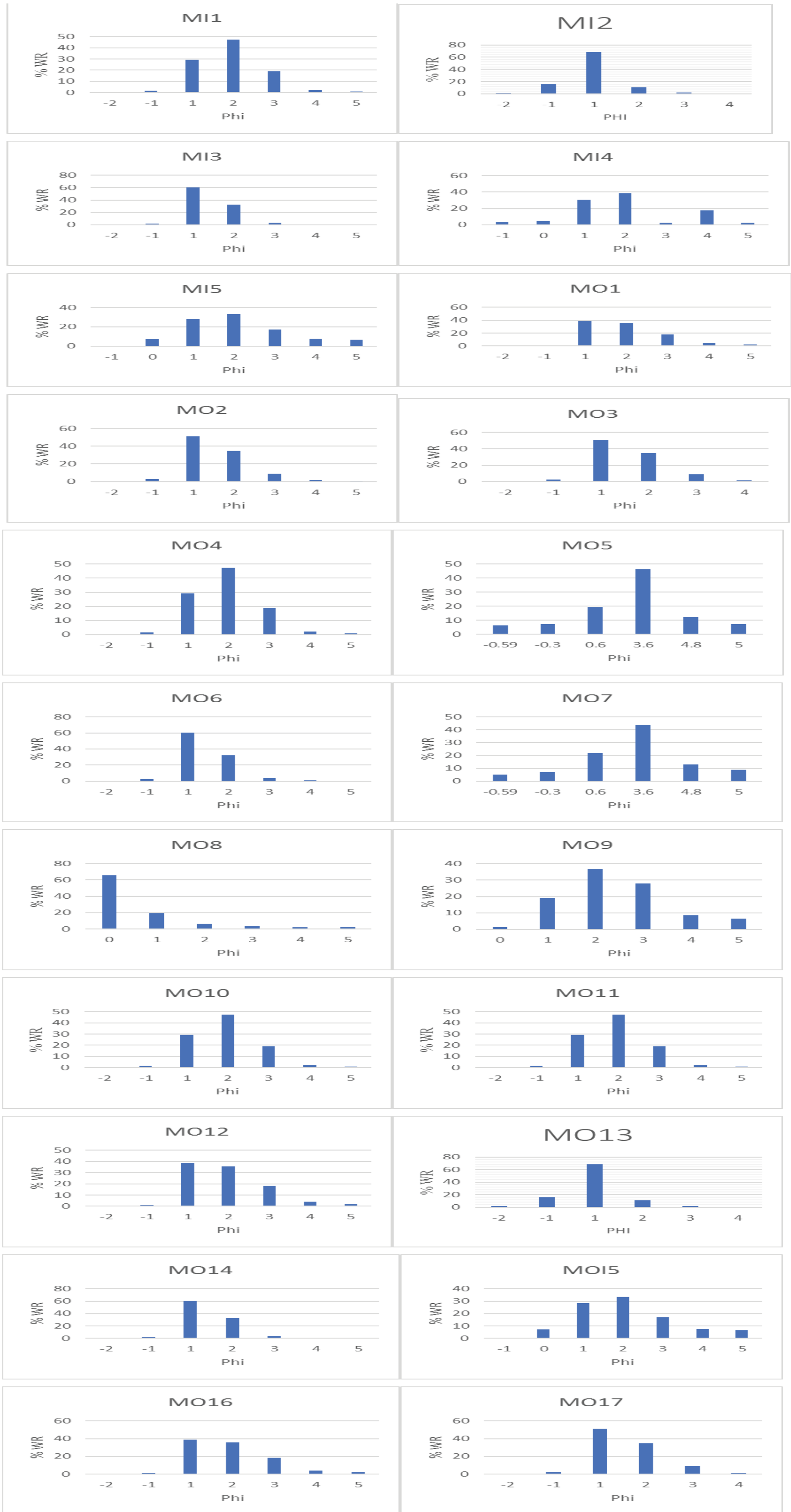

Figure 9: Histogram plots of sandstone facies of the Mamu formation that underlie the study area.

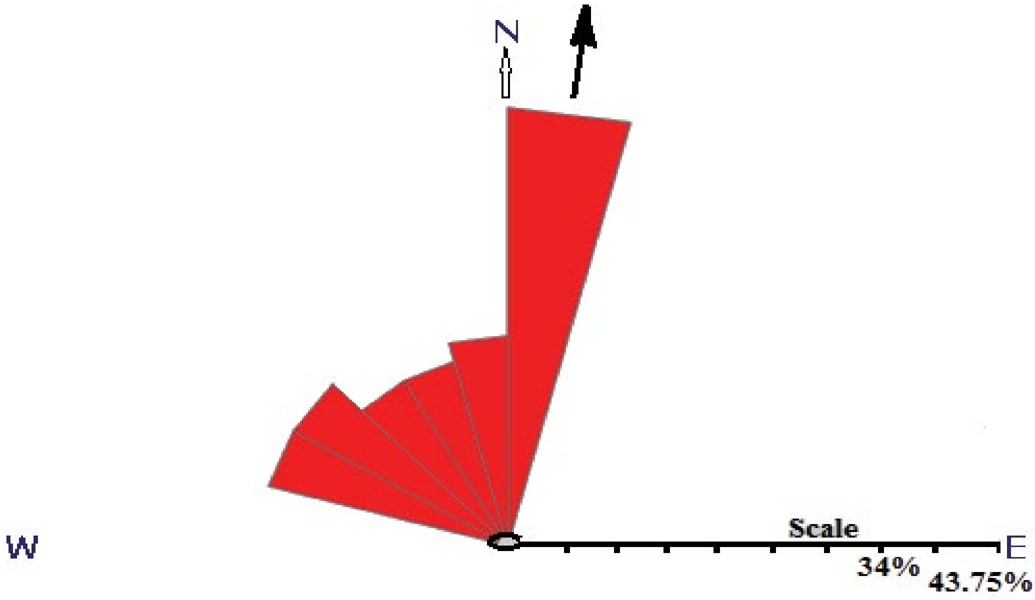

Figure 10: Paleocurrent pattern from cross bed azimuths in the Sandstone beds of the Mamu formation showing a bimodal pattern in the NW and NE direction in tidal environment.

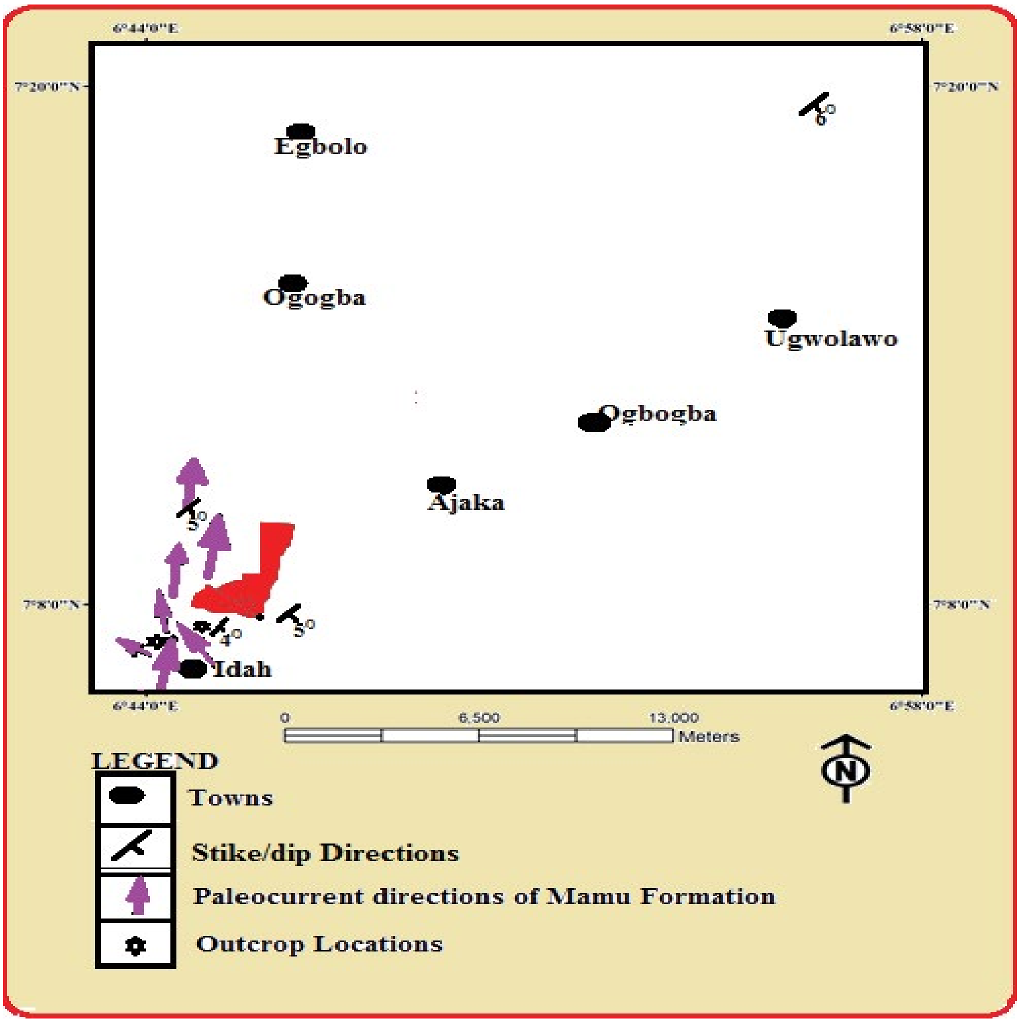

Figure 11: Paleocurrent map of the Campanian to Maastrichtian Mamu formation in the study area.

Sample ID	Y1	Remark	Y2	Remark	Y3	Remark
MI1	3.75	Beach	108.53	Shallow Agitated marine (Subtidal)	-7.69	Fluvial deltaic
MI2	3.05	Beach	71.93	Shallow Agitated marine (Subtidal)	-6.32	Sha. marine
MI3	3.96	Beach	85.92	Shallow Agitated marine (Subtidal)	-8.12	Fluvial deltaic
MI4	9.00	Beach	228.83	Shallow Agitated marine (Subtidal)	-22.66	Fluvial deltaic
MI5	7.93	Beach	205.25	Shallow Agitated marine (Subtidal)	-20.03	Fluvial deltaic
MO1	3.37	Beach	127.16	Shallow Agitated marine (Subtidal)	-12.32	Fluvial deltaic
MO2	-1.24	Beach	78.22	Shallow Agitated marine (Subtidal)	-4.05	Sha. marine
MO3	-6.85	Aeolian	74.23	Shallow Agitated marine (Subtidal)	3.42	Fluvial deltaic
MO4	2.23	Beach	118.26	Shallow Agitated marine (Subtidal)	-8.29	Fluvial deltaic
MO5	9.42	Beach	306.06	Shallow Agitated marine (Subtidal)	34.17	Fluvial deltaic
MO6	-2.47	Beach	84.39	Shallow Agitated marine (Subtidal)	-4.37	Sha. marine
MO7	6.24	Beach	285.63	Shallow Agitated marine (Subtidal)	-32.87	Fluvial deltaic
MO8	7.39	Beach	104.51	Shallow Agitated marine (Subtidal)	-8.43	Fluvial deltaic
MO9	1.28	Beach	141.98	Shallow Agitated marine (Subtidal)	-12.22	Fluvial deltaic
MO10	3.75	Beach	108.53	Shallow Agitated marine (Subtidal)	-7.69	Fluvial deltaic
MO11	3.75	Beach	108.53	Shallow Agitated marine (Subtidal)	-7.69	Fluvial deltaic
MO12	3.37	Beach	127.16	Shallow Agitated marine (Subtidal)	-12.32	Fluvial deltaic
MO13	3.05	Beach	71.93	Shallow Agitated marine (Subtidal)	-6.32	Sha. marine
MO14	3.96	Beach	85.92	Shallow Agitated marine (Subtidal)	-8.12	Fluvial deltaic
MO15	7.93	Beach	205.25	Shallow Agitated marine (Subtidal)	-20.03	Fluvial deltaic
MO16	3.37	Beach	127.16	Shallow Agitated marine (Subtidal)	-12.32	Fluvial deltaic
MO17	-6.85	Aeolian	74.23	Shallow Agitated marine (Subtidal)	3.42	Fluvial deltaic
		B=92.86% A=7.14%		100%		Fd=78.57% Sm=21.43%

Table 2: Linear discriminate function of sandstone facies of Mamu formation in the study area.

S/N	Location of Cross-bed	Number of measurements	Mean Azimuthal reading	Standard deviation	Average forest dip
1	Ocheche 1 (07° 10' 02.2" N, 06° 50' 12.8" E)	25	299.6	4.6	17
2	Ocheche 2a (07° 10' 02.2" N, 06° 50' 12.8" E)	10	192.1	1.3	19
3	Ocheche 2b (07° 10' 02.2" N, 06° 50' 12.8" E)	11	352.5	1.6	18
4	Ocheche 3 (07° 10' 02.2" N, 06° 50' 12.8" E)	14	9	1.8	22
5	Ocheche 4 (07° 10' 02.2" N, 06° 50' 12.8" E)	20	329.2	6.8	17

Table 3: Azimuthal readings and statistical values for the sandstone facies of Mamu formation in the study area.

distribution) and M (the median) were plotted with phi values of the C and M obtained from cumulative curves in phi and converted to microns using the standard formula $\mu m = 2^{-\phi} \times 1000$. In addition, the azimuthal readings of the dip directions of all types of cross-stratification generated by the flow within the limits of preservation were measured in the field for paleocurrent studies. A total of 80 readings of cross-strata azimuthal dip directions were taken from beds of the Mamu Formation. Current roses were plotted, and standard deviations computed from the measured data.

RESULTS AND DISCUSSION

Detailed descriptions of measured outcrop sections indicate that the Mamu Formation was deposited in a wide range of environments. The suite of depositional environments recognized include subtidal and intertidal to mixed flats. Sedimentary facies corresponding to fluvial channels was also recorded.

Lithofacies descriptions

The lithofacies described in this report are defined based on field descriptions of lithology, sedimentary structures, grain size, and stratification. The Mamu Formation in the study area consists of sandstone facies, siltstone facies and mudstone facies (Figures 2-5 and Plates I to VII in Appendix).

Sandstone facies comprises of the following subfaces

(a) Massive sandstone A: They are made up of alternation of red and white, medium-grained, poorly to moderately well sorted, near symmetrical, platykurtic to very platykurtic, massive sandstone commonly seen at the base of the section (Figure 3). These features suggest deposition in upper flow regime. Massive sandstone associated with medium-grained sandstone may have been formed as a result of partial fluidization [16] and/or like high density turbidity flows in distal shelf [17].

(b) Tabular cross-bedded sandstone with reactivation surfaces B: Consists of intercalation of white and red, medium to coarse grained, poorly sorted, negatively, positively skewed, leptokurtic to very leptokurtic sandstone with reactivation surfaces and bedding planes (Plate III). The presence of tabular cross-stratification reflects river deposition by migrating sand waves. The facies features suggest a river sands.

(c) Trough cross-bedded sandstone surfaces C: Consists of white, fine to medium grained, moderately well sorted to poorly sorted, negatively to positively skewed, mesokurtic to leptokurtic, trough bedded sandstone with lens of reworked clay and sinuous crested dunes (Plate VII). The presence of trough cross beddings is sometimes indicative of tidal influence.

(d) Herringbone cross-bedded sandstone surfaces D: Consists of white fine to medium grained, moderately to poorly sorted, near symmetrical, mesokurtic to platykurtic, trough, tabular and herringbone cross-bedded sandstone with reactivation surfaces and lens of reworked clay and sinuous crested dunes (Plate VIII). Herringbone cross-bedding indicates deposition by tidal currents. The feature is the typical expression of alternating tidal currents in high energy subtidal settings.

(e) Sandstone with *Ophiomorpha* burrows surfaces E: Consists of dirty white to grey, medium to coarse-grained, poorly to moderately well sorted, positively to strongly fine skewed, very leptokurtic to platykurtic, tabular cross-bedded sandstone with reactivation surfaces, erosional surfaces and clear imprints of trace fossils burrows belonging to *Ophiomorpha* genera. *Ophiomorpha* burrows belong to the *Skolithos* ichnofacies. The interpretation of *Ophiomorpha* ichnofacies are indication of intertidal flats and marginal marine settings (Plate VI).

(f) Well bedded, tabular cross-bedded sandstone surfaces F: Consists of intercalation of white and red, medium grained, poorly sorted, positively skewed, leptokurtic sandstone with bedding planes (Plate V). The presence of tabular cross-stratification reflects river deposition by migrating sand waves.

(g) Cross-bedded sandstone with wave ripples surfaces G: Consist of white medium to coarse grained, moderately sorted (Table 1), cross-bedded sandstone wave ripple and reactivation surfaces which passes upward into intercalation of white and red, high angled tabular cross-bedded fine to medium grained, moderately sorted sandstone overlain by a tabular cross-bedded, fine to medium grained sandstone terminating the whole sandstone section. The facies features suggest a transverse bar, upper flow regime.

Siltstone facies comprises of the following sub-facies:

(h) Laminated clayey siltstone surfaces H: Consists of milky white to light grey, parallel laminated clayey siltstone with lens of clay. These facies are interpreted as a floodplain deposits resulting from deposition out of suspension in overbank sub environment during upper flow regime.

(i) Ferruginized siltstone surfaces I: This consists of white to dirty yellow siltstone, which passes upward into brown to amber red ferruginized siltstone, brown to milky white weakly stratified concretional siltstone with convolute structure and dirty red to yellow siltstone, which graded into a bed of brown, red to dirty yellow lateritized siltstone terminating the section (Plate II). The facies features suggest a floodplain deposits resulting from deposition out of suspension in overbank sub environment.

Mudstone facies consists of the following subfacies:

(a) Shale surfaces J: Consists of evenly laminated dark grey fissile shale thinly intercalated with light grey mudstone overlain by intercalation of thick grey mudstone and a thin lens of dark grey fissile shale which is in turn overlain by intercalation of light grey to milky white silt and sandy shale (Plate I and Figure 4). These features suggest deposition unaffected by wave or tidal process, that is, a stable zone where mud is deposited from suspension to form well-(evenly) laminated sediments reflecting fluctuations in river sediment carried in buoyant plumes where bottom waters are anoxic.

(b) Claystone surfaces K: This consists of evenly laminated light grey to milky white claystone with erosional surfaces and a thin (0.2 m) thick band of light grey to brownish ferruginized claystone due to subarea exposure terminating the section (Plate VI and Figure 2). The characteristics of this facies may represent low energy depositional environment. Absence of marine fossils suggests prevalence of freshwater in this low-energy environment probably a lower delta plain.

Facie association in Mamu formation

Facies association is a group of facies that is used to define a sedimentary environment [17,18]. From the description and interpretation of the facies, two facies associations were recognized; the FA-1 (subtidal channel) and the FA-2 (Intertidal flat).

FA-1 (Subtidal channel)

These facies composed of **A** (massive sandstone subfacies), **B** (Tabular cross-bedded sandstone subfacies), **C** (Trough cross-bedded sandstone), **D** (Herringbone Cross-bedded sandstone subfacies), **G** (Cross-bedded sandstone with wave ripples subfacies), **H** (Clayey siltstone subfacies) and **I** (Ferruginized siltstone subfacies).

Association of the coarse sandstones with herringbone cross bedding and reactivation surfaces is suggestive of tidal process. Herringbone cross bedding is a product of tidal cyclicity characterized by two vertically adjacent cross-beds with opposing foresets dip directions. Tidal currents tend to be channelized into largely bidirectional currents in nearshore areas. Such bi-directional currents always show some degree of asymmetry during tidal cycle. This is interpreted as reflecting ebb- flood tidal current flow in a single ebb- flood cycle. Planar and trough cross bedding has been interpreted as the product of large flow- transverse bedforms (sandwave or medium to very large subaqueous dunes) [19] and these forms one of the best-known ancient subtidal sandstone facies [20]. Reactivation surfaces and herringbone cross stratification in the unit are suggestive of tidal dominance. The presence of reactivation surfaces suggests a tidal environment as a result of lee-face modification of the bedforms by subordinate tidal currents [21]. Boggs [22] attributed them to tidal reversal during an asymmetrical tidal cycle under which the ripple crests can be eroded and redeposited during the next tidal cycle thereby giving rise to reactivation surfaces. The reactivation surfaces may occur in tidal sands deposits through tidal current reversals in fluvial sediments through change in river stages suggesting a moderately upper flow regime (relatively high energy), tranverse bars deposit. Nwajide [23] attributed the mode of origin of reactivation surfaces to the overriding of one sandwave by another. It is among the characteristics of strongly asymmetric tidal flow with abundant supply of medium to coarse grained sand. Tidal bundles separated by erosional reactivation surfaces is suggestive of subtidal environment [24]. The fine to medium grained lithofacies is interpreted as products of moderate energy in subtidal channel setting. The association of the low angle cross beds and laminations with herringbone cross beds suggests subtidal channel fill deposited in shallow marine.

This Association ranges in thickness between 0.5 to 3 m. Due to its fining upward sequence, presence of bedform and structures above it is usually associated with moderately to high-energy environment and characterized by high current velocity therefore, interpreted as subtidal channel environment [25,26].

FA-2 (Intertidal flat)

These facies is composed of **B** (Tabular cross-bedded sandstone with reactivation subfacies), **C** (Trough cross-bedded sandstone subfacies), **E** (Sandstone with *Ophiomorpha* burrows subfacies), **F** (Tabular cross-bedded sandstone with bedding planes subfacies), **H** (Siltstone/clay subfacies), **I** (Ferruginized siltstone subfacies), **J** (Shale subfacies) and **K** (Laminated claystone subfacies). These facies are characterized by fining upward succession reflecting decrease in energy from the lower to the upper part of the intertidal flats as recorded by texture, sedimentary structure. The presence of trough bedded sandstone with lens of reworked clay and sinuous crested dunes (Plate VII) is indicative of tidal influence, it is formed through migration of sinuous and lunate dune bedforms. In many situations there are changes of flow velocity or depth during bedform migration so that the dunes are modified and eroded. When deposition resumes an erosional surface will be formed like what we have here. The presence of reactivation surfaces suggests a tidal environment because of lee-face modification of the bedforms by subordinate tidal currents [21]. The presence of tabular cross-stratification reflects river deposition by migrating sand waves [27]. The identified forms of trace fossils are cylindrical vertical burrow of length 7 cm and diameters between 2 and 3 cm. Some of them are identified as *Ophiomorpha* (Plate VI). *Ophiomorpha* burrows belong to the *Skolithos* ichnofacies. *Skolithos* ichnofacies are indication of intertidal flats and marginal marine settings [25]. The presence of Sediments predominantly of fine to medium sand which may also include scattered coarse to very coarse and gravel lenses in association with parallel laminae, formed during swash-backwash flow, that dip gently seaward suggests a foreshore, intertidal flat deposits. The presence of thin, lenticular sets of low-angle, landward-dipping laminae, possibly formed by antidune migration during backwash are suggestive of intertidal flat environment. These features suggest an intertidal or mixed flats environment [22].

Grain size distribution and paleo-environmental implications

In this study, representative sandstone samples from the sandstone facies were selected for grain size analysis to reinforce the earlier inferences drawn from lithofacies association and sedimentary structures in the sections studied. Sandstone samples of the subtidal facies association in the study area are predominantly fine, medium to coarse-grained, poorly to moderately well sorted, and negatively, positively skewed to near symmetrical. Okoro [28] reported that negative skewness gives indication of marine reworking in the continental shelf settings. In the study area, samples of the fluvial channel sandstones are coarse grained, moderately sorted, and near symmetrical. The prevalence of poorly sorted sandstones and unimodal grain size variation suggest low energy unidirectional fluvial system of deposition. Energy Process diagram suggest 45% river Process and 55% deposition in inner shelf. These observations lend credence to the paleoenvironmental deductions based on lithesome characters and sedimentary structures presented in Table 1 and Figure 6.

Linear discriminate function

With reference to the Y1, Y2 and Y3 values from the Linear Discriminate Plots of Y2 versus Y1 indicate that all the sandstone samples of the Mamu Formation in the study area fall within Beach/Shallow marine environment (subtidal) [29] as adopted), Y3 versus Y2 indicate that 100% of the sandstone samples fall within Shallow marine agitated with 71.43% plotted within Fluvial/deltaic field and 28.57% in Turbidity field suggesting that the sandstone of Mamu Formation in the study area was deposited under shallow marine environment (Figures 7a, 7b and Table 2).

CM pattern

The probability curve (CM pattern) for the samples from the studied area show that the sandstone units of Mamu Formation (MI1, MI2, MI3, MI4, MI5, MO1, MO2, MO3, MO4, MO5, MO6, MO7, MO8, MO9, MO10, MO11, MO12, MO13, MO14, MO15, MO16 and MO17) were deposited by rolling to bottom suspension rolling condition (Figures 8 and 9).

Histogram

The histogram plots of the cumulative weight percentage against phi scale and energy process diagram (Figures 7-9) show that the sandstone facies of Mamu Formation in the study area are unimodal (Figure 10). This indicates samples support mixing of populations as indicated by kurtosis values (Table 1).

Paleocurrent studies

The paleocurrent of the sandstone facies of Mamu Formation was determined using paleocurrent analysis. Current rose diagrams plotted were used and `studied to identify the paleocurrent directions (Figures 10 and 11).

The rose diagram reflects bimodal high variability paleocurrent pattern for the Sandstone facies of Mamu Formation (Figure 10). These paleocurrent patterns (bimodal) suggest sediments deposited in an environment where tidal currents were prevalent with net long-shore marine transport [30-32]. The direction of provenace indicated that the sediments of the sandstone facies of Mamu Formation in the study area were sourced from more than one source which is like the observation made by Akaegbobi and Boboye [33] and Adeigbe and Salufu [34] (Table 3).

Paleogeography

The depositional processes suggested by the assemblage of sedimentary structures present in the lithofacies association of the Mamu Formation range from regressive (fluvial) to transgressive (marine) processes. The sandstone facies association characterized by trough cross bedding, herringbone cross bedding, planar cross bedding, reactivation surfaces, and clay drapes in the study area provide evidence of tidal currents and deposition by oscillatory flow conditions in tide and wave dominated shoreline environments [35-37]. Other notable features of the tidal channel and shoreface facies include wave ripple, cross lamination and *Ophiomorpha* burrows, which further support the fluctuating shallow marine environments [38]. The above scenario closely compares with the Maastrichtian shallow marine conditions that largely influenced the sedimentation of the well-known Patti Formation in the adjacent Southern Bida basin, northcentral Nigeria. Several authors [39,40] have advanced shallow marine intertidal depositional environments for the Mamu Formation, based on similar sedimentary features identified in the present study area.

Low energy, shallow marine depositional environments are also well-represented in the study area by the tidal marsh to coastal swamp facies association. This facies consists of shales, claystone and siltstones, which have been differentiated and classified as the mudstone facies of the Mamu Formation. This lithofacies assemblage is similar in part also to the Patti Formation in the adjacent Southern Bida basin, north central Nigeria. Bio stratigraphic studies by the authors Ojo and Akande [41,42] have revealed the occurrence of shallow marine dinoflagellate cysts like assemblages described by Salami [43] from the Mamu Formation. This further support the idea of regional correlation, that part of the Maastrichtian Mamu Formation was deposited in marginal marine to brackish water conditions like the depositional environment of the Patti Formation. The above inferences point to the fact that perhaps there was at least marginal marine connection between the Anambra and Bida Basins during Maastrichtian time and this could be the link between the Tran Saharan Sea and the Gulf of Guinea in the Late Cretaceous. The offshore to landward transition in the study area is indicated by the presence of fluvial facies associations, such as the fluvial channel sandstones and overbank claystones in the study area. Based on the detailed facies analysis, we confirm the influence of fluvial processes in the sedimentation of parts of the Mamu Formation.

CONCLUSION

The MaastrichtianMamu Formation in the northern Anambra Basin consists of sandstone, siltstone and mudstone facies deposited in a wide range of environments ranging from fluvial to marine. The Mamu Formation in the study area comprises of fine, medium to coarse-grained, poorly to moderately sorted, near symmetrical, platykurtic to very leptokurtic, parallel laminated, tabular cross-bedded, herringbone, trough cross-bedded sandstones with wave ripples, siltstone, mudstone, fissile shale and claystone and contain no fossils. Reactivation surfaces and trace fossils (*Ophiamorpha)* burrows were observed in the sandstones. These sedimentary structures observed in the sandstone suggests subtidal to intertidal environments.

Two sedimentary depositional facies association comprising of subtidal and intertidal to coastal swamp are recognized in the study area. Freshwater sedimentary depositional facies such as fluvial channel, swamp, and overbank were also documented. Bimodal direction of the rose diagram suggests deposition in a tidal environment and sediments sourced from more than one source. The ferruginous and weakly stratified siltstone suggest a floodplain deposit. The presence of mudstone, shales and claystone indicate deposition in quiet water palaeo environment. Where shales show fissility it indicates that burrowing organisms were absent in the depositional environment. Generally, the fluvial channel sandstones are characterized by poor sorting and unidirectional cross bedding. The overbank claystone's, which are kaolinitic, are very prominent in the study area.

Comparing the results of the Linear Discriminate Function with the overall results from the sedimentary structures, sieve analysis, micropaleontological studies, CM pattern and paleocurrent analysis shows that the variations in the energy and fluidity factors have excellent correlation with the different processes and the environment of deposition. This conforms to the work of [29]. Therefore, this method of discrimination should be considered as a supporting technique to enhance good paleoenvironmental studies.

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REFERENCES

[1] Burke KC, Dessauvagie TFJ, Whiteman AJ. Geological history of the Benue valley and adjacent areas. In *J African Geology*, **1972**, 187-206. *Ibadan. Uni. Ibadan*.

[2] Olade MA. Evolution of Nigeria's Benue Trough (aulacogens): a tectonic model. *Geo Mag*, **1975**, 112: 575-583.

[3] Benkhelil J. Benue trough and Benue chain. *Geo Magazine* **1982**, 119: 155-168.

[4] Benkhelil, J. The origin and evolution of the cretaceous Benue trough. Nigeria. *Jour of Afr Eth Sci,* **1989,** 8: 251-282.

[5] Hoque M, Nwajide CS. Tectono-sedimentological evolution of an elongate Intracratonic basin (Aulacogen): the case of the Benue Trough of Nigeria. *Nig Jour of Min Geo,* **1984**, 21: 19-26.

[6] Fairhead JD. Mesozoic plate tectonic reconstruction of the central south Atlantic Ocean: the role of the West and Central African Rift Systems. *Tectonophysics*, **1988,** 155: 181-191.

[7] Murat RC. Stratigraphy and palaeogeography of the Cretaceous and Lower Tertiary in southern Nigeria. In: Dessauvagie, T. F. J., Whiteman, AJ, (eds). African Geology. Nigeria*: University of Ibadan Press*, **1972**, 251-266.

[8] Hoque M. Petrographic differentiation of tectonically controlled Cretaceous sedimentary cycles, southeastern Nigeria. *Sed Geo,* **1977**, 17: 235-245.

[9] Mode AW, Onuoha KM. Organic matter evaluation of the Nkporo Shale, Anambra Basin, from wireline logs", *Glob Jour of App Sci,* **2001**, 7: 103-107.

[10] Hoque M, Ezepue CM. Petrology and paleogeography of the Ajali Sandstone. *Journal of Nig Min & Geosci Soc,* **1977**, 14: 16-22.

[11] Amajor LC. Paleocurrent, petrography and provenance analyses of the Ajalli Sandstone (Upper Cretaceous), Southeastern Benue Trough, Nigeria. *Sedi Geo*, **1987**, 54: 47-60.

[12] Nwajide CS, Reijers TJA. Geology of the Southern Anambra Basin. In: Reijers, T.J.A. (Ed.), Selected Chapters on Geology. *SPDC, Warri*, **1996a**, 133-148.

[13] Nwajide CS, Reijers TJA. Sequence architecture in outcrops: examples from the Anambra Basin. *Nig Assoc of Petroleum Exploration Bulletin*, **1996b**, 11: 23-32.

[14] Obaje NG. Geology and mineral resources of Nigeria. *Lecture notes in Earth Science*, *Springer-Verlag Berlin Heidelberg*. **2009,** 58-62.

[15] Folk RL, Ward WC. Brazos River bar: A study in the significance of grain size parameters. *Jour of Sedi Pet,* **1957**, 27: 3-26.

[16] Romos E, Margo M, De Gibert J, Tawengi KS, Khoja AA, et al. Stratigraphy and sedimentology of the middle Ordovician Hawaz Formation (Murzuq Basin, Libya). *American Association of Petroleum Geologists Bulletin*,**2006**, 9: 1309-1336.

[17] Nichols GJ. Sedimentology and Stratigraphy. *John Wiley and Sons*, New York, USA. **2009**, 452.

[18] Anderton R. Clastic facies models and facies analysis. Sedimentology, recent developments and applied aspects. *Blackwell Scientific Publications.* Oxford, **1985**, 31-47.

[19] Ashley GM, *Jour of Sedi Petro*, **1990**, 60: 160-172.

[20] Surlyk F, Noe-Nygard N. *Geo Croa*, **1991**, 56: 69-81.

[21] Ladipo KO. Tidal shelf depositional model for the Ajali Sandstone, Anambra Basin, Southern Nigeria. *Journal of African Earth Sciences*, **1986**, 5: 177-185.

[22] Boggs S. Principles of sedimentology and stratigraphy. *Prentice Hall, Englewood Cliffs, New Jersey*, **1995**, 79-93.

[23] Nwajide CS. Geology of Nigeria's sedimentary basins. *CSS Bookshop Ltd*, Lagos, Nigeria. **2013**, 311- 326.

[24] Reineck HE, Singh, IB. Depositional sedimentary environments with reference to terrigenous clastics. 2nd edn., *Springer- Verlag*, New York, **1980**, 549.

[25] Pemberton SG, MacEachern JA, Frey RW. Trace fossil facies models: Environmental and all stratigraphic significance. In: Facies Models: Response to Sea Level Change (R. G. Walker and N. James, eds.), St. John's, Newfoundland, *Geo Associ of Can*. **1992**, 47-72.

[26] Dalrymple RW. Tidal depositional systems. Facies Models 4. *Geologist Association of Canada, St. John's, Geotext*, **2010**, 201-231.

[27] Harms JC, Southard JB, Spearing DR, Walker RG. Stratification produced by migrating bedforms: In: Depositional Environments as Interpreted from Primary Sedimentary Structures and Stratification Sequences. S.E.P.M. Short Course, **1975**, 2:120.

[28] Okoro AU. Petrology and depositional history of the sandstone facies of the Nkporo Formation (Campanian-Maastrichtian) in Leru area, southeastern, Nigeria. *Jour of Min & Geo,* **1995**, 31: 105-112.

[29] Sahu BK. Depositional mechanisms from the size analysis of clasticsediments. *Jour of Sedi Plogy,* **1964**, 34: 73- 83.

[30] Passega R. Texture and characteristic of clastic deposition. *American Association of Petroleum Geologists Bulletin*. **1957**, 41: 1952-1984.

[31] Passega R. Grain size representation by CM patterns as a geological tool. *Journal of Sedimentary Petrology,* **1964**, 34: 830-847.

[32] Selley RC. Paleocurrent and sediment Transport in near Shore Sediment of Sincte Basin. *Libya Journal of Geology.***1966**, 75: 215-222.

[33] Akaegbobi IM, Boboye OA. Textural, structural features and microfossil assemblage relationship as delineating criteria for the stratigraphic boundary between Mamu Formation and Nkporo Shale within the Anambra Basin, Nigeria. *Nig Assoc of Petro Exp Bull,* **1999**, 193-206.

[34] Adeigbe OC, Salufu AE. Geology and depositional environment of Campano-Maastrichtian sediments in the Anambra Basin, southeastern Nigeria: Evidence from field relationship and sedimentological study, *Eth Sci Res Jour*, **2009**, 13: 2.

[35] DeCelles PG. Variable preservation of middle Tertiary coarse-grained, nearshore to outershelf storm deposits in southern California. *Jour of Sedi Plogy,* **1987,** 57, 250-264.

[36] DeCelles PG, Cavazza W. Constraints on the formation of Pliocene hummocky cross-stratification in Calabria (southern Italy) from consideration of hydraulic and dispersive, equivalence, grain-flow theory and suspended-load fallout rate. *Geo Soc of Amer Bull,* **1992**, 93: 663-680.

[37] Colguhoun GP. Siliciclastic sedimentation on a storm and tide- influenced shelf and shoreline: The Early Devonian Roxbourgh formation, NE Lacthan fold belt; Southeastern Australia. *Sed Geo,* **1995,** 97: 69-98.

[38] Howard JD. Trace fossils as criteria for recognizing shorelines in stratigraphic record. Recognition of Ancient Sedimentary Environments *S.E P.M. Special Publication*, **1972**, 161: 215-225.

[39] Ladipo KO. Paleogeography, sedimentation and tectonics of the upper cretaceous Anambra Basin, south-eastern Nigeria. *Jour of Afr Eth Sci,* **1988,** 7: 865-871.

[40] Reijers TJA. Selected chapters in geology and sequence stratigraphy in Nigeria and Three Case Studies and a Field Guide. *Shell Petroleum Development Company of Nigeria, Corp Repro Serv, Warri*, **1996,** 197.

[41] Ojo OJ, Akande SO. Sedimentological and palynological studies of the Patti Formation, southeastern Bida Basin, Nigeria: implication for Paleoenvironments and paleogeography. *Nig Assoc of Petro Exp Bull*, **2006**, 19: 61-77.

[42] Ojo OJ, Akande SO. Sedimentological and depositional environments of the Maastrichtian Patti Formation, southeastern Bida Basin, Nigeria. *Elsevier,* **2009**, 30: 1415-1425.

[43] Salami MB. Palynomorph taxa from the Lower Coal Measures deposits (Campanian-Maastrichtian) of Anambra Trough, southeastern Nigeria. *Jour of Afr. Eth Sci,* **1990**, 11: 135-150.