© MAY 2022 | IRE Journals | Volume 5 Issue 11 | ISSN: 2456-8880

Lithofacies, Granulometric and Pebble Morphometric Studies: Outcome of Geologic Mapping of Enugwu-Agidi Area and Its Environs, Southeast Nigeria

OFFIAUKWU K. C
University of Nigeria, Nsukka.

Abstract- This paper presents findings from the geologic mapping of Enugwu-Agidi and its environs. The Early to Middle Paleogene sedimentary succession in Enugwu-Agidi and its environs of Southeastern Nigeria comprises shales of the Imo Formation at the northern portion and the Nanka Formation at the southern portion of the study area which outcrops within the Niger Delta Basin. The aim of the work was to better understand the distribution of lithofacies, identification of various sedimentation processes from their deposits, characteristics of rock units, transport mechanisms and also to establish the Paleo-depositional environments of outcropping units by carrying out detailed geologic mapping of the study area. Based on the field mapping on 12 outcrops and Laboratory analyses which comprised granulometric and pebble morphometry studies on samples collected from the outcrops, the occurrence of 9 lithofacies, which were interpreted to infer deposits of fluvial through marine environments was observed. Paleo-current analysis was also carried out on cross beds of the rocks. The results from granulometric analyses indicate that the sandstones are fine to coarse grained, with mean size that ranges between 0.48 and 2.54. The estimated values for sorting of the grains ranges between 0.86 and 1.14, indicating that the sandstones are moderately to poorly sorted. The probability-log plots show three-segment curve types corresponding to traction, saltation and suspension which may suggest shallow marine environment and two-segment curve types corresponding to traction and saltation which are dominant, relating to deposition in fluvial environment. Studies based on the bivariate and multivariate sieve parameters show a fluvial to shallow marine environment. The three axes: the long (L), the intermediate (I) and the short (S) were measured for 100 pebbles collected from Agwu-Eke and Independent Pebble form indices such as Maximum Projection Sphericity (MPS), Coefficient of flatness (FR %), Elongation ratio (ER) and Oblate-prolate index (OPI) were calculated from these measurements with values of 0.715, 0.102, 52.29 and 0.552 respectively. Based on results from pebble morphometric analysis, the bivariate plots of MPS against OPI and FI against MPS, indicates that the pebbles have been reworked by mainly fluvial processes. The form indices diagram plot indicates that the pebbles are Bladed, Compact Bladed and platy which is diagnostic of river action. The direction of the paleo-current in the study area is NE-SW and based on palaeocurrent patterns classification, the unimodal local current vector pattern indicates fluvial, braided or meandering depositional environment.

Indexed Terms- Geomorphological features 3, Granulometric analysis 4, Lithostratigraphic Units 2, Stacking Pattern 2, Tidal flat 3.

I. INTRODUCTION

The main focus of this work is the detailed geological mapping of the Enugwu- Agidi and its environs in Anambra state which covers an area of approximately 191 km^2. The study area consists of strata of the Imo Formation which is the lowest stratigraphic unit of the Niger Delta Basin and the Nanka Formation of the Ameki group.

Emphasis is laid on Granulometric, Facies, Pebble and Paleocurrent analysis in order to interpret the Depositional environment and Stacking pattern. Equipment used in the field and in the laboratory analysis includes; sunto compass, hand lens, geologic hammer, sieve machine, weighing balance and vernier caliper with software applications such as Arc-Gis, GeoRose and SedLog.

- GEOLOGIC SETTING OF THE STUDY AREA - The stratigraphic sequence of the Niger Delta comprises three broad lithostratigraphic units which includes; a continental shallow massive sand sequence (Benin Formation), a coastal marine sequence of alternating sands and shales (Agbada Formation) and a basal marine shale unit (Akata Formation) (Weber, 1972, Ejedawe, 1989).

The basal outcropping unit of the Niger Delta Basin is the Imo Formation consisting of a series of exposures along Imo River, near Okigwe-Umuahia road with lithologies such as blue-grey shales with sand lenses, marl and fossiliferous limestones, sandstone members which are the Ebenebe, Umuna and Igbaku sandstones and shales with foraminifera and ostracods (Ekwenye, et al., 2014).

The Ameki Group consists of three different laterally equivalent formations which are the Nsugbe Formation, Nanka Formation and Ameki Formation (Nwajide, 1982). Facies of the Ameki Group conformably overlie the Imo Formation with its environment of deposition interpreted as tide-dominated estuarine system.

The Nanka Formation refers to loose sand facies of the Ameki Group with a type locality of gully exposures along Nanka and Agulu. Its lithofacies includes cross beds, flaser beds, fine to medium grains and few mudrock breaks with an environment of deposition interpreted as tidal sand bar and tidal flat (Ekwenye, 2014).

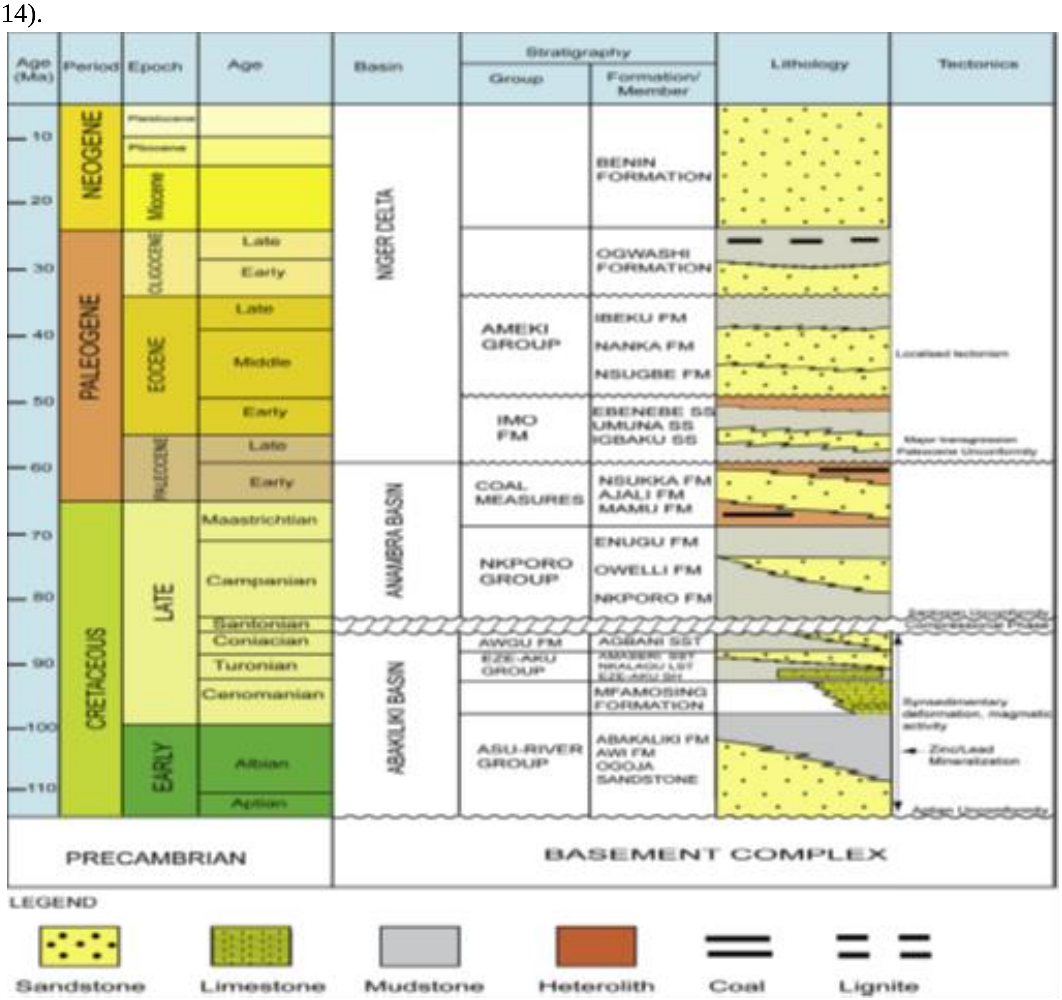

Figure 1: Stratigraphic succession in the Anambra Basin and outcropping Paleogene Niger Delta (Modified after Short and Stauble, 1967, Ekwenye, 2014 and Nwajide, 2013).

II. METHODOLOGY

Fieldwork was carried out in the study area in order to describe the lithologies and establish their stratigraphic relationships. Geologic mapping involved location of outcrops, description of lithologies and taking note of salient features such as texture and structures. The tools used in the process for a successful mapping includes Global Positioning System (GPS) for navigation; Sunto compass was used to measure attitude of beds and trends of joints and rivers; Geologic hammer was used to break off rocks samples for detailed study and sample collection, a digital camera was used to take images of specific features on rock exposures and other geological and geomorphological features; sample bags and masking tapes were used to collect and label representative samples respectively; All geologic information obtained in the field were recorded in the field note book while a topographic map was used as a field guide and for plotting outcrops. The total area of the study area is 191 km^2. Arc-Gis is a geographic information system (GIS) used for working with maps and geographic information. It is used for creating using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications and managing geographic information in a database.

The following analyses were carried out on samples collected from the field. These includes; Facies analysis, Granulometric analysis and Pebble morphometry.

- Facies analysis: It is an analysis which involves description and classification of sedimentary units followed by interpretation of depositional processes and environment setting (Lindholm, 1987). This analysis was carried out on all the samples collected from the field. It is based on physical description of rock features such as type of rock, colour, grain size, sorting, structures, etc.
- Granulometric analysis: It is the identification of various sedimentation processes from their deposits. This is based on identification of mineral composition, grain size, sorting, grain shape etc. Materials used for this analysis include; sieve machine and weighing balance.
- Pebble morphometry: It is an analysis on pebbles which relies on various independent and dependent functions such as the coefficient of flatness ratio, elongation ratio, oblate- prolate index, etc.

This was done to determine the depositional environments of the rocks and reconstructing the paleo-environment.

III. AIMS AND OBJECTIVES OF THE STUDY

The studies is aimed at carrying out a detailed geologic mapping of Enugwu-Agidi, understanding the distribution of lithofacies, characteristics of rock units and establish the Paleo-depositional setting of outcropping units in the Niger Delta Basin.

The objectives include:

- Accurate location and description of outcrops, lithologies and their characteristics, contacts (if exposed) and geologic features.
- Lithofacies identification.
- Integration of granulometric, pebble morphometry and paleocurrent analysis in order to infer environments of deposition.

IV. RESULTS

OUTCROP DESCRIPTION

Outcrop sections logged across the study area are as follows:

i. Agwu-eke section (outcrop 1) which comprises predominantly of grey shale with a coarse grained lateritic sandstone overlying it opposite Awka Tipper park off Onitsha express road (Fig. 2A);
ii. Agwu-eke section—(outcrop 2) comprising predominantly of bioturbated sandstone conformably overlying the shale units of the Agwu-eke shale section and is well exposed at three sections opposite Awka Tipper park off Onitsha express road (Fig. 2B);
iii. Umudioka section (outcrop 3) comprising predominantly of sandstone at a quarry section at Umudioka, Akwa off Nibo road (Fig. 2C);
iv. Umuanunu section (outcrop 4) comprising predominantly of structureless sandstone occurring at a quarry section at Umuanunu, off Nibo- Amawbia road (Fig. 2D);

v. Ugwu-akpi section (outcrop 5) comprising predominantly of sandstone at a quarry section at Ugwu- akpi, Enugwu- Ukwu off Enugu- Onitsha Express road (Fig. 2E);

vi. Ukpo section (outcrop 6) is exposed at a quarry section opposite Ceepharm along Enugu- Onitsha Express road, Ukpo (Fig. 2F);

vii. Agwu-eke road section (outcrop 7) comprising sandstone with pebble imbrication and is exposed along Enugu Onitsha Express Road, Agwu- Eke (Fig. 2G).

viii. Abagana road section (outcrop 8) comprising predominantly of sandstone and shale interbeds and is exposed along Enugu Onitsha Express Road, Abagana (Fig. 2H).

ix. Nawfia gully section (outcrop 9) comprising predominantly of structureless siltstone along Enugu Onitsha Express Road, Nawfia (Fig. 2I).

x. Umuokpu road section (outcrop 10 - 11) exposed along Enugu Onitsha Express Road, Umuokpu (Fig. 2J, 2K).

xi. Amawbia section (outcrop 12) comprising interlamination of sandstone and mudstone along Enugu Onitsha Express Road, Amawbia (Fig. 2L).

Bed thicknesses ranges from 0.1 to 3 m. Lithologies include fine, medium and coarse-grained sandstone, pebbly conglomeritic sandstone, siltstone, shale, mudstone units. Primary sedimentary structures such as parallel laminations, ripple marks, planar cross-beddings with tangential contacts, reactivation surfaces, herringbone structures also characterize some of the sandstone units (Fig. 3A- 3E). Presence of mud drapes and desiccation cracks also characterize some units. Visible on some of the lithologic units are also joint structures and flexuring which are evidence of sediment deformation. Evidence of bioturbation are also present as complex network of vertical burrows (Ophiomorpha) are observed in some of the mudstone and sandstone units

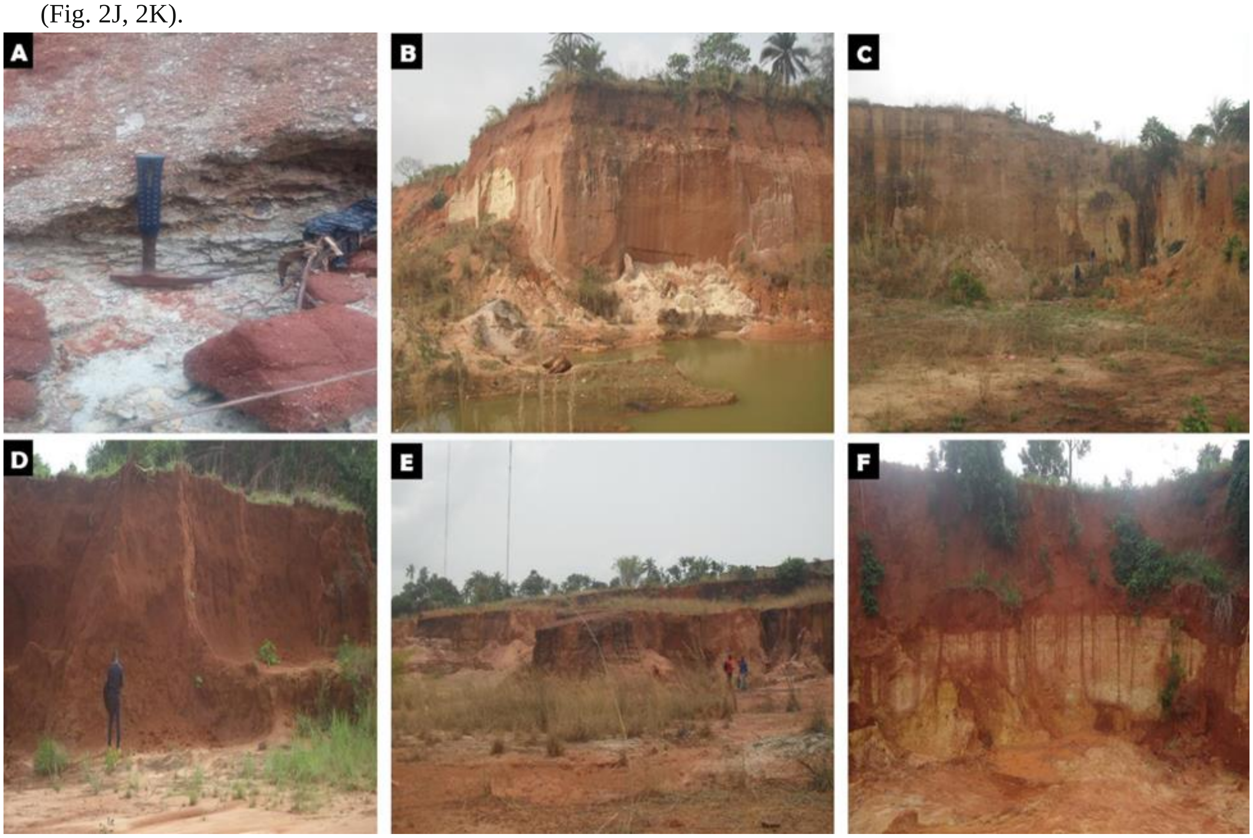

Figure 2: Photographs showing outcrop sections logged along the study area. A. Grey shale, B. Bioturbated sandstone, C. Quarry section Sandstone, Umudioka, D. Structureless Sandstone, E. Quarry section Sandstone, Ugwu Akpi, F. Quarry section Sandstone, Ukpo, G. Pebble imbrication, H. Alternating Shale and Sandstone, I. Gully section Sandstone, Nawfia, J. Road section sandstone, Umuokpu, K. Road section Sandstone, Umuokpu, L. Inerlamination of Mudstone and Sandstone.

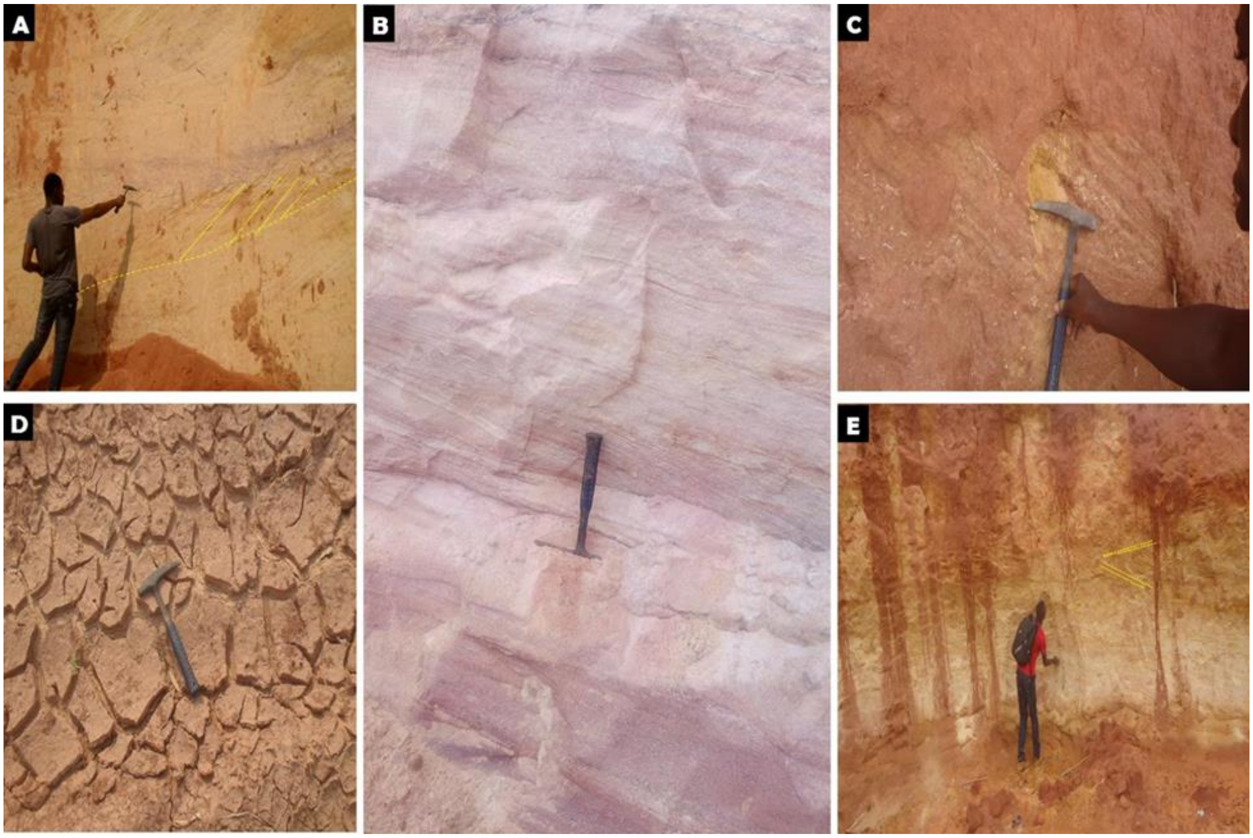

Figure 3: Photographs showing outcrop sections logged along the study area. A. Reactivation surfaces, B. Large scale cross bedded Sandstone, C. Cross bedded Sandstone, D. Mudcracks, E. Herringbone structures.

V. FACIES SUCCESSION

Facies analysis reveals the occurrence of nine lithofacies which are Bioturbated planar cross-bedded sandstone facies, Fine grained inter-bedded sandstone and shale facies, Structureless sandstone facies, Heterolith facies, Shale facies, Pebbly sandstone, Ripple cross bedded sandstone, Inter-bedded sandstone and mudstone, Siltstone facies.

Vertical log section at the various outcrops indicates the occurrence of two facies successions. These include the following:

i. Fining-upwards succession that contains coarser grained facies near the base and progressively fines upwards.
ii. Coarsening-upward facies successions that show overall finer grained facies near the base which progressively becomes coarser grained towards the top with variable thickness of sediment package from few centimeters to meters. A majority of study area shows a dominance of fining upwards facies successions. These successions are made up of sediment packages that belong to various lithofacies.

The bioturbated planar cross bedded sandstone facies (SB) consists of basically horizontal bedded fine to coarse grained sandstone units. The fresh sandstone layer is yellowish brown with well sorted fine, medium, very coarse-grained sandstone and mudstone units. The large-scale cross-beds have mud-drapes on the corsets (Fig. 3B). Reactivation surfaces are also visible on the outcrops (Fig. 3A). SB facies are found within a fining upwards facies succession and litthofacies thickness varies from 0.15 to 1.5 m.

The fine grained inter-bedded sandstone and shale facies (Sf) comprises well sorted, fine- grained sandstone of centimetre scale and shale of centimetre scale at Abagana. The sandstones vary from yellow to brown while shale is dark grey in colour, with a black weathered surface. Average bed thickness is about 0.45 m and has sharp basal and planar top contact. It is characterized by flaggy shale intercalations in beds 2, 4 and 6. Sf facies are found within a fining upwards facies succession.

The Structureless sandstone facies (Ss) comprises sandstone facies that are structureless. Ss is characterized by very coarse- medium grained, poorly sorted sandstone. The sandstone is yellowish and average bed thickness ranges from 0.15 to 2.2 m. The facies is devoid of internal sedimentary structures having a tabular geometry.

The Heterolithic facies (Sh) denotes medium- fine grained, centimetre to metre thick sandstone and mudstone (Fig: 2L). Sandstone colour varies from red white to pinkish red, while mudstone colour is whitish. At Sh, heteroliths of sandstone and mudstone of about 2 m with mottled mud forming the top of the outcrop. The Shale facies (SH) facies is characterized by dark grey shale with a light grey weathered surface that consists of characterized by desiccation cracks. The shale unit has gradational top contacts with overlying beds. The thickness of the shale bed is 100 cm (slabby) with lateral extent of about 40 m.

The Siltstone facies (Si) comprises light brown siltstone. Bed thickness is about 3 m (blocky) with an exposed interval with aerial extent of 150 m observed at a gully exposure in location 9. Si facies consists of numerous joints which form conduits for water passage.

The Pebbly sandstone (Sp) facies is exposed on a road-side exposure. It exhibits 4.2 m of total relief over a lateral distance of approximately 150 m surrounded by very heavy vegetation. The pebbly sandstone facie is characterized parallel pebble imbrication (Fig: 2G) at the top while the middle part of this section of the outcrop is predominantly parallel laminated, medium grained sandstone with a brown colour and about 0.2 m thick with minor folding. The Conglomeritic Arkosic Sandstone consists of predominantly white, micaceous, coarse to pebbly sandstone. The sandstones are well consolidated. Mineralogically, the sandstones consists mainly of quartz and feldspar. The sandstones are non-fossiliferous.

The Ripple cross bedded sandstone (Sr) is exposed at a local quarry sites. It exhibits 6 m of total relief over a lateral distance of approximately 40 m surrounded by very sparse vegetation due to quarry activities. It is characterized by large-scale planar and trough cross-beds with paleocurrent data of the planar cross-beddings with dip direction of 244°, ripple marks on the mud drapes. The fresh sandstone layer is yellowish brown with well sorted fine, medium, very coarse-grained sandstone and mudstone units.

The Inter-bedded sandstone and mudstone (SM) facies denotes a well sorted, medium grained, centimetre to metre thick sandstone and mudstone. Sandstone and mudstone colour varies from reddish brown to brown with a red weathered surface. It is characterized by low angle (0º-180º) parallel sequences of sandstone and mudstone.

VI. GRANULOMETRIC ANALYSIS

Figure 4 and 5 displays the probability-log plots for the Sandstone samples. The probability-log plots show two-segment curve types corresponding to traction and saltation. This is with exception of probability-log plots for beds LOC 3/ Umudioka where three-segment curve types corresponding to traction, saltation and suspension are dominant. The sandstone samples are medium-grained, poorly-sorted, negatively skewed and platykurtic for LOC 2, medium- grained, moderately sorted, negatively skewed and mesokurtic for LOC 3, coarse- grained, moderately-sorted, positively skewed and leptokurtic for LOC 4, medium-grained, moderately sorted, positively skewed and platykurtic for LOC 5, coarse- grained, moderately to poorly sorted, positively skewed and mesokurtic for LOC 6 and fine- grained, poorly sorted, negative skewed and leptokurtic for LOC 10.

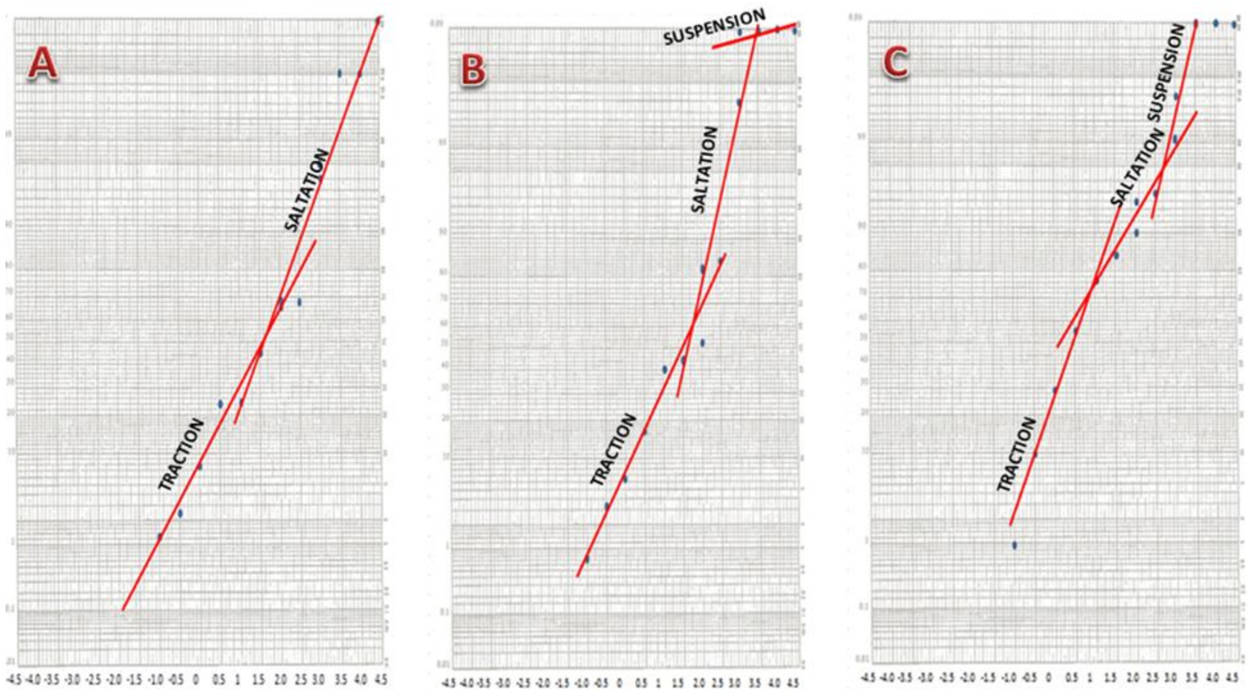

Figure 4: (A) Log probability plot for samples from LOC 2/ Agwu- Eke (B) Log probability plot for samples from LOC 3/ Umudioka (A) Log probability plot for samples from LOC 4/ Umuanunu (after Visher, 1969).

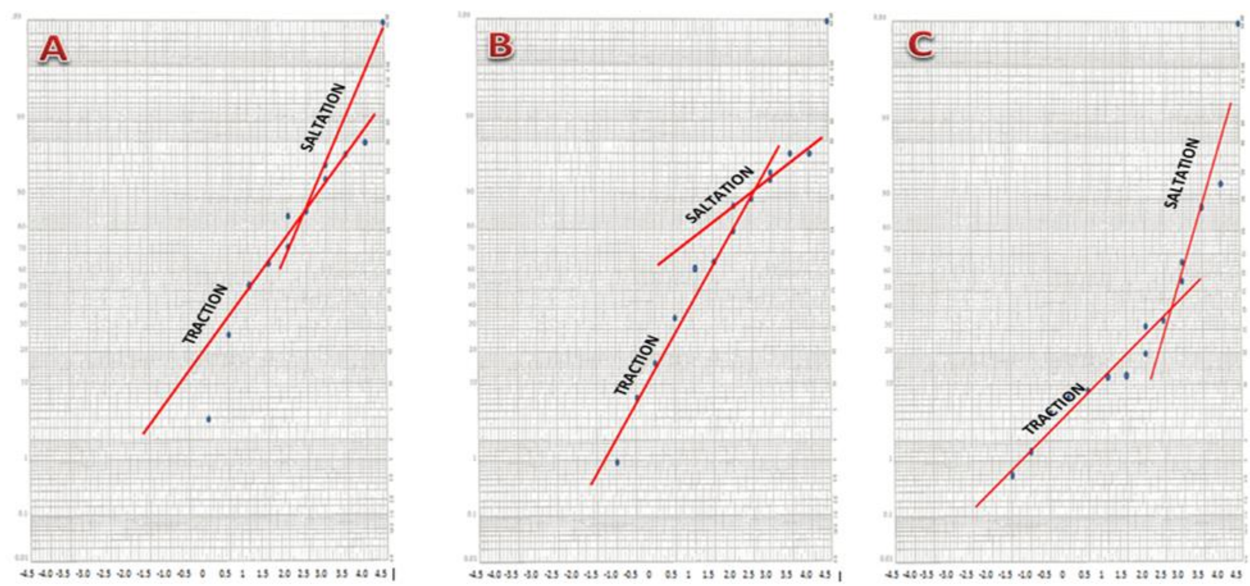

Figure 5: (A) Log probability plot for samples from LOC 5/ Ugwu- Akpi (B) Log probability plot for samples from LOC 6/ Ukpo (A) Log probability plot for samples from LOC 10/ Umuokpu (after Visher, 1969).

VII. PEBBLE MORPHOMETRY

Only unbroken pebbles, whose three axes could be determined unambiguously and accurately, were used for the study. The long (L), intermediate (I) and the short (S) axes of hundred pebbles were measured using vernier calipers Figs 48, 49 and 50 shows the FI against MPS plot, MPS against OPI plot and Sphericity form diagram of the pebbles respectively.

VIII. PALAEOCURRENT ANALYSIS

The dip (dip amount) and azimuth (dip direction) of foreset planes of planar cross-beds were measured on the cross-bedded sandstone unit. A total of 16 measurements were taken. The measurements were grouped and then plotted as rose diagram.

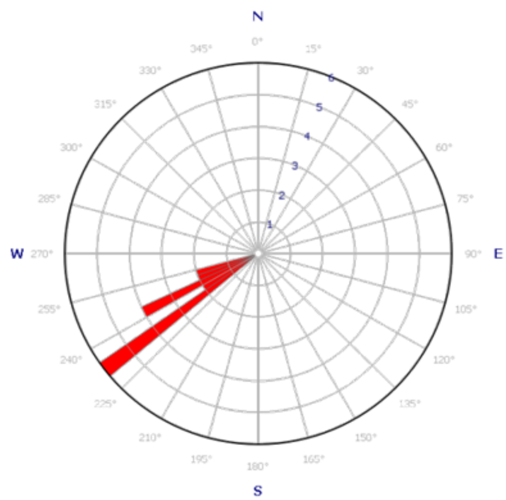

Figure 6: Rose diagram showing paleocurrent flow of cross bed in the study area.

IX. INTERPRETATION FACIES ANALYSIS

Large-scale cross-beds are formed by avalanching of sediments along the slip-face of dunes (Nio and Yang, 1991). Mud drapes on cross beds foresets in Sb are deposited during slack water conditions in response to semi-diurnal tidal fluctuation (Shanley et al., 1992). Presence of mud drapes and trace fossils may portray periods of quieter current regimes. Ophiomorpha is formed by suspension-feeder dwelling burrows that reflect high-energy environments typical of shallow sub- tidal to intertidal deposits (Howard and Frey, 1984; Dam, 1990).

The centimetre- metre scale sand and mud layers could result from repetitive autocyclic changes which involves changes in current velocities, changes in sedimentary inputs and the shifting of channels and shoals (Rebatah et al., 2006). Intercalation of centimetre-metre scale sandstone and mudstone denote cyclic accumulation of vertically and laterally accreted sediment, referred to as tidal rhythmites (Kvale, 2006).

Massive sandstone is suggested to originate from gradual aggradation of sediments beneath steady or near-steady flows (Johansson et al., 1998). Massive sandstone can also occur as a result of rapid deposition, through deceleration of a heavily sediment-laden current (Collinson et al., 2006).

Intercalation of centimetre-metre scale sandstone and mudstone denote cyclic accumulation of vertically and laterally accreted sediment, referred to as tidal rhythmites (Kvale, 2006). Differences in the thickness of centimetre thick sand and mudstone couplets are due to the neap-spring variations in tidal current speed (Shi, 1991; Dalrymple, 1992).

The dark grey to black colour of the shale is caused by high organic content of the shales. The presence of brownish black plant matters suggests subaerial or supratidal conditions. The presence of dessication cracks in SH indicates subaerial exposure during sedimentation (Thomas et. al., 2002; Mazumder and Sarkar, 2004 and Bridge, 2006).

Siltstone is interpreted to represent the deposits of waning stage flood deposition, chiefly in overbank areas (Hjellbakk, 1997).

The coarse to very coarse grained nature of the sandstones, the absence of fossils and trace fossils are suggestive of deposition in a fluvial channel bar, while the clays and sandy clays indicate floodplain deposits of a braided fluvial system (Odumodu, C.F.R. and Ephraim, B.E., 2008).

Mud drapes on cross-laminations in Sr are deposited during slack water conditions in response to semi-diurnal tidal fluctuation (Shanley et al., 1992). The wave ripples are asymmetrical produced as a combination of oscillatory waves and unidirectional currents. The ripples become asymmetrical when there is an asymmetry in the orbital current due to the combination with unidirectional current as proved by (Collinson et al., 2006).

In summary, lithofacies were interpreted to infer the strata deposited in fluvial to marine envirnments, suggesting that the sediments were deposited within the continental, transitional and shallow marine environments.

Table ii: Showing the summary of the outcrops, characteristics and their locations.

S/N	FACIES	CHARACTERISTICS	OUTCROPPING LOCATIONS
1	Bioturbated planar cross-bedded sandstone facies (Sb)	Fine to coarse grained sandstone units. The fresh sandstone layer is yellowish brown with well sorted fine, medium, very coarse-grained sandstone and mudstone units.	Agwu-eke
2	Fine grained inter-bedded sandstone and shale facies (Sf)	Well sorted, fine- grained sandstone of centimetre scale and shale of centimetre scale at Abagana. The sandstones vary from yellow to brown while shale is dark grey in colour.	Abagana
3	Structureless sandstone facies (Ss)	Structureless sandstone characterized by very coarse-medium grained, poorly sorted sandstone.	Umuokpu Umuanunu Ugwu Akpi
4	Heterolith facies (H)	Medium- fine grained, centimetre to metre thick sandstone and mudstone.	Umuokpu
5	Shale facies (SH)	Dark grey shale with a light grey weathered surface that consists of characterized by desiccation cracks.	Agwu- Eke
6	Pebbly sandstone (Sp)	Parallel pebble imbrication at the top while the middle part of this section of the outcrop is predominantly parallel laminated, medium grained sandstone.	Agwu- Eke
7	Ripple cross bedded sandstone (Sr)	Yellowish brown with well sorted fine, medium, very coarse-grained sandstone and mudstone units.	Ukpo
8	Inter-bedded sandstone and mudstone (SM)	Well sorted, medium grained, centimetre to metre thick sandstone and mudstone. Sandstone and mudstone colour varies from reddish brown to brown with a red weathered surface.	Amawbia
9	Siltstone (Si)	Light brown siltstone.	Nawfia

X. GRANULOMETRIC ANALYSIS INTERPRETATION

The probability-log plots show three-segment curve types corresponding to traction, saltation and suspension which may suggest shallow marine environment and two-segment curve types corresponding to traction and saltation which are dominant, relating to deposition in fluvial environment. The sandstones are predominately moderately sorted to poorly showing moderate energy conditions. The sandstones are predominantly platykurtic, mesokurtic and leptokurtic.

Negative (coarse) skewness may indicate that the velocity of the depositing agent operated at a level higher than normal for a long period of time (littoral, beach and tidal inlet environment) while positive (fine) skewness may indicate that the energy level was low for most of the time (rivers, deep water environment). This fits in with a fluvially dissected shallow marine environment. From the univariate, bivariate and multivariate parameters indicate that the sand samples are mainly fluvial marine sediments.

XI. PEBBLE MORPHOMETRY

The bivariate plots of MPS against OPI (Dobkins and Folk, 1970) and FI against MPS (Stratten, 1974), indicates that the pebbles have been reworked by mainly fluvial processes. From the plot on the form indices diagram after Sneed and Folk (1958) indicates that the pebbles are Bladed, Compact Bladed and platy which is diagnostic of river action.

In summary, the study of form indices has shown that pebbles from the Agwu- Eke sandstone unit of were shaped in a fluvial environment.

XII. PALEOCURRENT INTERPRETATION

The rose diagram which had a unimodal pattern, with the trend of flow or direction of deposition in the SSW direction, the MVA is (58.05°) which gives the mean direction of the depositional agent which is used to infer the regional slope and source direction. Based on classification of palaeocurrent patterns after Selley (1985) the unimodal local current vector pattern indicates fluvial, braided or meandering depositional environment.

Also, variance (34618.06) and vector strength (0.992) indicates that the depositional environment is shallow marine environments. (Potter and Pettijohn, 1977), with high dispersion ability of the depositional agent of the sediment respectively. (Collinson and Thompson).

CONCLUSION

The field and research work were carried out within the study area in order to reconstruct the geologic history and depositional environment of the study area. A total of twelve outcrops were mapped these rocks belonged to the Nanka and Imo Formation. Facies analysis reveals the occurrence of nine lithofacies which are Bioturbated planar cross-bedded sandstone facies, Fine grained inter-bedded sandstone and shale facies, Structureless sandstone facies, Heterolith facies, Shale facies, Pebbly sandstone, Ripple cross bedded sandstone, Inter-bedded sandstone and mudstone, Siltstone facies. Lithologies mapped are predominantly sands and shales and these lithologies determined the topography of the study area with the shales forming the lowlands and the sandstone forming the highlands.

The results from granulometric analyses indicate that the sandstones are fine to coarse grained, with mean size that ranges between 0.48 and 2.54. The estimated values for sorting of the grains ranges between 0.86 and 1.14, indicating that the sandstones are moderately to poorly sorted. The probability-log plots show three-segment curve types corresponding to traction, saltation and suspension which may suggest shallow marine environment and two-segment curve types corresponding to traction and saltation which are dominant, relating to deposition in fluvial environment. Studies based on the bivariate and multivariate sieve parameters show a fluvial to shallow marine environment. Based on results from pebble morphometric analysis, the bivariate plots of MPS against OPI (Dobkins and Folk, 1970) and FI against MPS (Stratten, 1974), indicates that the pebbles have been reworked by mainly fluvial processes. From the plot on the form indices diagram after Sneed and Folk (1958) indicates that the pebbles are Bladed, Compact Bladed and platy which is diagnostic of river action. Based on classification of palaeocurrent patterns after Selley (1985) the unimodal local current vector pattern indicates fluvial, braided or meandering depositional environment.

ACKNOWLEDGEMENT

Sincere gratitude goes to our lecturers and colleagues. We thank the District Heads and the people of the Enugwu- Agidi and Awka axes for their cooperation and help during the course of the fieldwork. To the entire staff of the Department of Geology, University of Nigeria, Nsukka, Thank you.

REFERENCES

[1] Adegoke, O.S., 1969. The Eocene stratigraphy of southern Nigeria. Bull Bur Econ Geol Mineral vol. 6, pp. 23–28.

[2] Adesida, A. A., Reijers, T. J., and Nwajide, C. S., 1997. Sequence stratigraphic framework of the Niger Delta. Paper presented at the AAPG international conference and exhibition, Vienna, Austria.

[3] Anyanwu, N. P. C., and Arua, I., 1990. Ichnofossils from the Imo Formation and their palaeoenvironmnental significance. Journal of Mining and Geology vol. 26, pp. 1–4.

[4] Avbovbo, A. A., Ayoola, E. O., and Osahon, G. A., 1986. Depositional and structural styles in the Chad Basin of northeastern Nigeria. AAPG vol. 70, pp. 1787–1798.

[5] Bouma, A. H., 1962. Sedimentology of Some Flysch Deposits: A Graphic approach to Facies Interpretation. Elsevier; 168pp.

[6] Bridge, J. S., 2006. Fluvial facies models: recent developments. *In:* Posamentier, H., Walker, R. G., (Eds.), Facies Models Revisited: Society of Economic Palynologists and Mineralogists Special Publication, vol. 84, pp. 85 - 170.

[7] Cant, D. J., and Walker, R. G., 1976. Development of a braided fluvial facies model for the Devonian Battery Point Sandstone, Quebec. Canadian Journal of Earth Sciences, vol. 13, (1), pp. 102 - 119.

[8] Capuzzo, N., and Wetzel, A., 2004. Facies and basin architecture of the Late Carboniferous Salvan-Dorénaz continental basin (Western Alps Switzerland/France). *Sedimentology*, vol. 51, (4), pp. 675 - 697.

[9] Casshyap, S. M., 1970. Sedimentary cycles and environment of deposition of the Barakar coal measures of Lower Gondwana, India. Journal of Sedimentary Petrology, vol 40, (4), pp. 1302 - 1317.

[10] Collinson, J., Mountney, N., and Thompson, D., 2006. Sedimentary Structures. Hertfordshire, England, Terra Publishing; 292p.

[11] Dalrymple, R.W., 1992. Tidal depositional systems, in Walker, R.G., and James, N.P. eds., Facies Models: Response to Sea Level Change: Geological Association of Canada, pp. 195-218.

[12] Dam, G., 1990. Palaeoenvironmental significance of trace fossils from the shallow marine Lower Jurassic Neill Klinter Formation, East Greenland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 79, (3), pp. 221 - 248.

[13] Doust, H., and Omatsola, E., 1989. Niger Delta. AAPG Memoir vol. 48, pp. 201–238

[14] Durand, J., 1995. High-resolution sequence stratigraphy (genetic stratigraphy) reservoir sedimentology: examples from the Niger Delta. Niger Assoc Pet Explor Bull vol. 10, pp. 65–73

[15] Dobkins, J. E., and Folk, R. L., 1970. Shape development on Tahiti: Journal of sedimentary petrology, vol. 40.

[16] Ejedawe, J. E., 1989. The Eastern Niger Delta: geological evolution and hydrocarbon occurrences. SPDC Internal Report, Exploration Note 89.

[17] Evamy, B. D., Haremboure, J., Kameling, P., Knaap, W. A., Molloy, F. A., and Rowlands, P. H., 1978. Hydrocarbon habitat of tertiary Niger Delta. AAPG Bull vol. 62, pp. 1–39

[18] Ekwenye, O. C., 2014. Facies Architecture, Sedimentary Environment and Paleogeographic Evolution of the Paleogene Stratigraphy, South-eastern Nigeria. Unpublished Ph.D thesis. Royal Holloway, University of London, England; 544p

[19] Ekwenye, O. C., Nichols, G. J., Collinson, M., Nwajide, S. C., and Obi, G. C., 2014. A paleogeographic model for the sandstone members of the Imo Shale, Southeastern Nigeria. J Afr Earth Sci vol. 96, pp. 190–211.

[20] Friedman, G. M., 1961. Distinction between Dune, Beach and River sands from their Textural Characteristics. Journal of Sedimentary Petrology, vol. 31, pp. 514 - 529.

[21] Folk, R. L., and Ward, W. C., 1957. Brazon River Bar: a study of the significance of gram size parameters. Journal of Sedimentary Petrology, vol. 27, (1), pp. 3 - 26.

[22] Galloway, W. E., 1989. Genetic stratigraphic sequences in basin analysis: architecture and genesis of flooding-surface bounded depositional units. AAPG Bull vol. 73, pp. 125–142.

[23] Gibson, J. W., and Hickin, E. J., 1997. Inter- and supratidal sedimentology of a fjord-head estuary, south-western British Columbia. *Sedimentology*, vol. 44, (6), pp. 1031 – 1051.

[24] Howard, J. D., and Frey, R. W., 1984. Characteristic trace fossils in nearshore to offshore sequences, Upper Cretaceous of east-central Utah. Canadian Journal of Earth Sciences, vol. 21, (2), pp. 200 - 219.

[25] Hjellbakk, A., 1997. Facies and fluvial architecture of a high-energy braided river: The Upper Proterozoic Seglodden Member, Varanger Peninsula, northern Norway. *Sedimentary Geology*, vol. 114, pp. 131 - 161.

[26] Igbokwe, J. I., 2004. Gully erosion monitoring in parts of south eastern Nigeria. Research paper delivered to the department of Surveying and geo-informatics, Nnamdi Azikiwe University, Awka. Anambra State.

[27] Johansson, M., Braakenburg, N. E., Stow, D. A., and Faugeres, J. C., 1998. Deep-water massive sands: facies, processes and channel geometry in the Numidian Flysch, Sicily. *Sedimentary Geology*, vol. 115, (1), pp. 233 - 265.

[28] Kendall, G. S. C., 2005. Introduction to sedimentary facies, elements, hierarchy and architecture: a key to determining depositional setting. *Sequence Stratigraphy*. University of South Carolina.

[29] Kneller, B., and Branney, M. J., 1995. Sustained high-density turbidity currents and the deposition of thick massive sands. *Sedimentology,* vol. 42, pp. 607 - 616.

[30] Knox, G., and Omatsola, M. E., 1989. Development of the Cenozoic Niger delta in terms of the escalator regression model. Proceedings, Coastal Lowlands and Geomorphology, Kon. Nederl. Geol. Mijnb. Genootschap, pp. 181–202.

[31] Kvale, E. P., 2006. The origin of neap–spring tidal cycles. *Marine Geology*, vol. 235, (1), pp. 5 - 18.

[32] Lindholm, R. C, 1987. A Practical Approach to Sedimentology. *Allen and Unwin LTD*, London. 257pp.

[33] Lowe, D. R., 1982. Sedimentary gravity flows: II. Depositional models with special reference to the deposits of high-density turbidity currents. Journal of Sedimentary Research, vol. 52, pp. 279 - 297.

[34] Mazumder, R., and Sarkar, S., 2004. Sedimentary history of the Palaeoproterozoic Dhanjori Formation, Singhbhum, eastern India. *Precambrian Research*, pp. 267 - 287.

[35] Miall, A. D., 1996. The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis, and Petroleum Geology. Springer-Verlag, New York; 582p.

[36] Miall, A. D., 2000. Principles of sedimentary basin analysis, 3rd edition.: Springer–Verlag Berlin Heidelberg, 616 p.

[37] Mitchum, R. M., Sangree, J. B., Vail, P. R., and Womardt, W. W., 1994. Recognizing sequences and systems tracts from well logs, seismic data and biostratigraphy: examples from the Late Cenozoic of the Gulf of Mexico. AAPG Memoir vol. 58, pp. 163–197.

[38] Monanu, P. C., 1975. Temperature and Sunshine. In G. E. K. Ofomata (ED) Nigeria in Maps.Eastern states Benin city. Ethiope Publishers. pp. 16- 18.

[39] Mutti, E., 1992. Turbidite Sandstones. Agip, San Donato Milanese; 275p.

[40] Nio, S. D., and Yang, C. S., 1991. Diagnostic attributes of clastic tidal deposits: A review. *In:* Clastic Tidal Sedimentology (Eds.), by Smith, D. G., Reinson, G. E., Zaitlin, B. A., and Rahamani, R. A, pp. 3 - 28.

[41] Nwajide, C.S., 1982. *Petrology and Paleogeography of the Makurdi Formation, Benue Trough.* Unpub. Ph.D. thesis, Univ. Nigeria, Nsukka, Nigeria

[42] Nwajide, C. S., 2013. *Geology of Nigeria's Sedimentary Basins*. Lagos: CSS Press.

[43] Obaje, N. G., 2005. Fairways and reservoir potential of Pliocene – Recent sands in the shallow offshore Niger Delta. J Mining Geol vol. 40, pp. 25–38.

[44] Obaje, N. G., 2009. *Geology and Mineral Resources of Nigeria*. Springer.

[45] Obaje, N. G., Lar, U. A., Nzegbuna, A. I., Moumouni, A., Chaanda, M. S., and Goki, N. G., 2006. Geology and Mineral Resources of Nasarawa State: an Investors's Guide. Nasara

Scientifique (A publication of the Nasarawa State University) vol. 2, pp. 1–34.

[46] Obi, G. C., 2000. Depositional Model for the Campanian-Maastrichtian Anambra Basin, Southern Nigeria. Unpublished Ph.D. Thesis, University of Nigeria, Nsukka, 291p.

[47] Odumodu, C.F.R., and Ephraim, B.E., 2008. Pebble Morphometry as an indicator of the depositional environment of the Ajali Sandstone. Natural and Applied Sciences Journal. vol. 8, (2), pp. 132 – 143.

[48] Oti, M. N., and Postma, G., 1995. Causes of architectural variation in Delta. *In:* Postma, G., (Ed.), Geology of Deltas, Rotterdam, Netherlands, Balkema, A. A, pp. 3 - 16.

[49] Potter, P. E., Pettijohn, F. J., 1977. Methods of Study. *In:* Paleocurrents and Basin Analysis. Springer Berlin Heidelberg: pp. 364 - 389.

[50] Ramanathan, R. M., and Fayose, E. A., 1990. Cretaceous trangressions and regressions in Calabar Flank, SE Nigeria. In: Ofoegbu CO (ed) The Benue Trough, pp. 60–75.

[51] Reading, H. G., 1996. Sedimentary Environments: Processes, Facies and Stratigraphy, 3rd edition. Blackwell Publishing, Oxford; 688p.

[52] Rebata-H, L. A., Gingras, M. K., Rasanen, M. E., and Barberi, M., 2006. Tidal-channel deposits on a delta plain from the Upper Miocene Nauta Formation, Maranon Foreland Sub-basin, Peru. *Sedimentology*, vol. 53, pp. 971 - 1013.

[53] Reijers, T. J. A., Nwajide, C. S., and Adesida, A. A., 1997. Sedimentology and Lithostratigraphy of the Niger Delta. Abstract, 15th International Conference of the Nigerian Association of Petroleum Explorationist (NAPE), Lagos, Nigeria

[54] Reyment, R. A., 1965. *Aspects of the geology of Nigeria*: University of Ibadan press, Nigeria.

[55] Sahu, K. B., 1964. Depositional mechanisms for Size Analysis of Clastic Sediments. Journal of Sedimentary Petrology, vol. 34, pp. 73 - 83.

[56] Selley, R. C., 1985. Elements of Petroleum Geology. Freeman, W. H., and Company, New York; 449p.

[57] Shanley, K. W., McCabe, P. J., and Hettinger, R. D., 1992. Tidal influence in Cretaceous fluvial strata from Utah, USA: a key to sequence stratigraphic interpretation. *Sedimentology,* vol. 39, (5), pp. 905 - 930.

[58] Shi, Z., 1991. Tidal bedding and tidal cyclicities within the intertidal sediments of a microtidal estuary, Dyfi River Estuary, West Wales, United Kingdom. *Sedimentary Geology,* vol. 73, (1 – 2), pp. 43 - 58.

[59] Short, K. C., and Stauble, J., 1967. Outline geology of the Niger Delta. AAPG Bull vol. 5, pp. 761–779.

[60] Sneed, E.D., and Folk, R.L., 1970. *Pebbles in the Lower Colorado river, Texas: A study in particle morphogenesis*. Journal of Geology, vol. 66, pp. 144-150.

[61] Stratten, T.,1974. *Notes on the application of shape parameters to differentiate between beach and river deposits in southern Africa.* Transactions Geological Society, South Africa, vol. 77, pp. 59-64.

[62] Stride, A. H., 1982. Offshore tidal sands; processes and deposits. New York, Chapman and Hall, 222p.

[63] Talling, P. J., Masson, D. G., Summer, E. J., and Malgesini, G., 2012. Subaqueous sediment density flows: depositional processes and deposit types. *Sedimentology,* vol. 59, pp. 1937 - 2003.

[64] Thomas, J. V., Parkash, B., and Mohindra, R., 2002. Lithofacies and palaeosol analysis of the Middle and Upper Siwalik Group (Plio-Pleistocene), Haripur-Kolar section, Himachal Pradesh, India. *Sedimentary Geology*, vol. 150, pp. 343 - 366.

[65] Vail, P. R., 1987. Seismic stratigraphy interpretation, using sequence stratigraphy. Part 1: Seismic Stratigraphic Procedure. In: Balley AW (ed) Atlas of Seismic Stratigraphy. AAPG Stud Geol vol. 27, pp. 1–10.

[66] Visher, G. S., 1969. Grain Size Distribution and Depositional Processes. Journal of *Sedimentary Petrology*, vol. 39, pp. 1074 - 1106.

[67] Weber, K. J., 1972. Sedimentological aspects of oil fields in the Niger Delta. Geologe en Mijnbouw vol. 50, pp. 559–576

[68] Weber, K. J., 1986. Hydrocarbon distribution patterns in Nigerian growth fault structures controlled by structural style and stratigraphy. AAPG Bull vol. 70, pp. 661–662.

[69] Whiteman, A., 1982. Nigeria: its petroleum geology, resources and potential. Graham and Trotman, London, 381pp.

[70] Zaghloul, M. N., Critelli, S., Perri, F., Mongelli, G., Perrone, V., Sonnino, M., Tucker, M., Aiello, M., and Ventimiglia. C., 2010. Depositional systems, composition and geochemistry of Triassic rifted-continental margin red-beds of the Internal Rif Chain, Morocco. *Sedimentology,* vol. 57, (2), pp. 312 - 350.