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LITHOFACIES EVALUATION OF THE MAMU FORMATION, SOUTHEASTERN NIGERIA: IMPLICATIONS FOR DEPOSITIONAL SETTING AND MAASTRICHTIAN SEA REGRESSION

IZUAZU-GERRY, U. M AND ONUIGBO, E. N.

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ABSTRACT

Lithofacies analysis was carried out on the sediments and sedimentary rocks of the Mamu Formation for the purpose of interpretation of the depositional setting and the Maastrichtian Sea history. Both field and laboratory methods were employed in the study. Nine (9) lithofacies were identified and grouped into three lithofacies associations based on their stacking patterns. The three facies' associations include the lagoonal/swamp, tidal flat (dominantly inter-tidal), and the shoreface. Vertical succession indicated deposition in a prograding deltaic system (marginal marine) influenced by both fluvial and marine (tide and wave) processes. The general coarsening upward pattern displayed by the lithofacies association suggests sediment deposition during the regressive phase of the ancient sea.

INTRODUCTION

The Mamu Formation of the Lower Maastrichtian age is the stratigraphic unit forming the Enugu escarpment, the most striking topographic feature crossing the Anambra basin in a sigmoid curve (Nwajide and Reijers, 1996). Nwajide (2013) referred to it as the basal 100 m of the lower part of the Enugu Cuesta (its type locality), consisting of alternations of sandstones, siltstones, mudstones, coal seams, and rare shales. This formation was deposited in the Anambra basin, a north-east and south-west trending syncline of a rough triangular shape with a total sediment of over 900 m in thickness (Nwajide, 2013). The basin is characterized by enormous lithologic heterogeneity in both lateral and vertical extensions derived from a range of paleo-environmental settings (Ogala and Akaegbobi, 2005).

Although work has been done on the depositional environment of the Mamu Formation, there seems to be varying interpretations. The interpreted depositional environments range from complex deltaic (Umeji, 1999; Onyekuru and Iwuagwu, 2010; Akande *et al*., 2012; Nwajide, 2013) to coastal swamp, tidal flats, and shoreface (Onuigbo et al., 2012a &b; Uzoegbu, 2014). Proper understanding of the lithofacies and their stacking patterns (facies association) and succession will aid in better interpretation of sediment depositional settings. Therefore, the lithofacies and lithofacies associations in the Mamu Formation will be identified in this study for the purpose of evaluation of the depositional environments of the formation.

REGIONAL TECTONIC SETTING

Tectonism in the Southern Nigeria started in the Early Creataceous Times with the separation of Africa from South America and the opening of the Atlantic (Burke, Dessauvage, and Whiteman, 1972; Murat, 1972; Nwachukwu, 1972). This separation resulted in the development of the Benue Trough which stretched in a NE-SW direction. It extends from the Gulf of Guinea to the Chad Basin and was formed by the Y-shaped (RRR) triple junction ridge system that initiated the breaking and dispersion of the Afro-Brazilian plates in the Early Cretaceous (Kogbe, 1989). The tectonic map of the Southeastern Nigeria is shown as Figure 1.

Izuazu-Gerry, U. M., Department of Geological Sciences Nnamdi Azikiwe University, Awka
Onuigbo, E. N., Department of Geological Sciences Nnamdi Azikiwe University, Awka

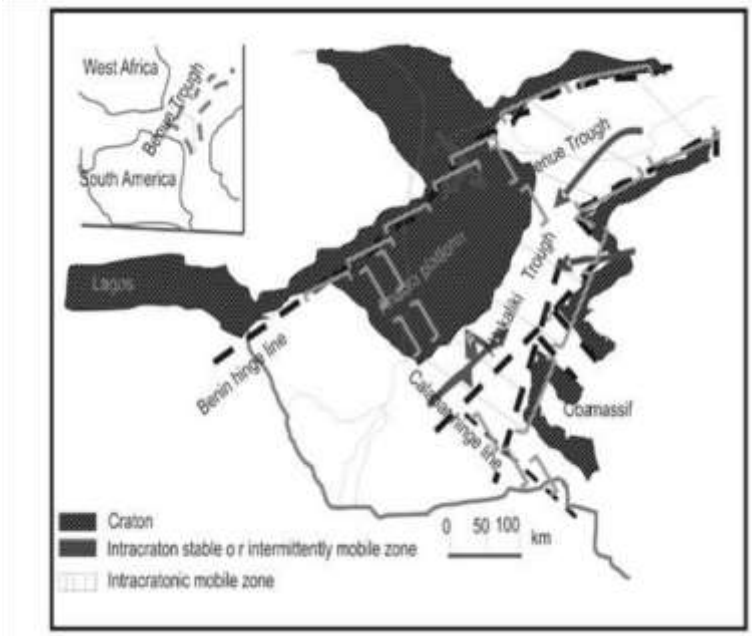


Fig. 1: Tectonic Map of South- Eastern Nigeria (Murat, 1972)

According to Onuigbo, Okoro, Obiadi, and Okoye (2016), the origin of the Anambra Basin is intimately related to the failed arm of a trilate fracture (Benue rift) system, during the breakup of the Gondwana supercontinent and the opening of the southern Atlantic and Indian Oceans in the Jurassic.

REGIONAL STRATIGRAPHIC SETTING

Sedimentation in the Benue Trough was controlled by three major tectonic phases, giving rise to three successive depocenters (Murat, 1972; Nwachukwu and Odjeba, 2001; Oboh-Ikuenobe, Obi, and Jaranillo, 2005). The First phase (Albian-Santonian) featured the deposition of the Asu River Group, Eze-aku and Awgu Formations within the Abakaliki-Benue Trough which was flanked to the east by the Anambra platform and to the Southwest by the Ikpe platform (Nwachukwu and Odjeba. 2001). The second phase (Campanian-Eocene) was characterized by compressive movement along the NE-SW axis which resulted in the folding and uplift of the trough into an anticlinorium. This forced the Anambra platform to subside and the depocenter to shift South-Westwards to the newly formed Anambra Basin and the Afipko Syncline on the other side of the anticlinorium in the southeast (Nwajide, 2013) and the deposition of the Nkporo Group, Mamu Formation, Ajali Sandstone, and Nsukka Formation followed (Nwachukwu and Odjeba, 2001). Figure 2 is the stratigraphic succession of the Southern Nigerian sedimentary basin.

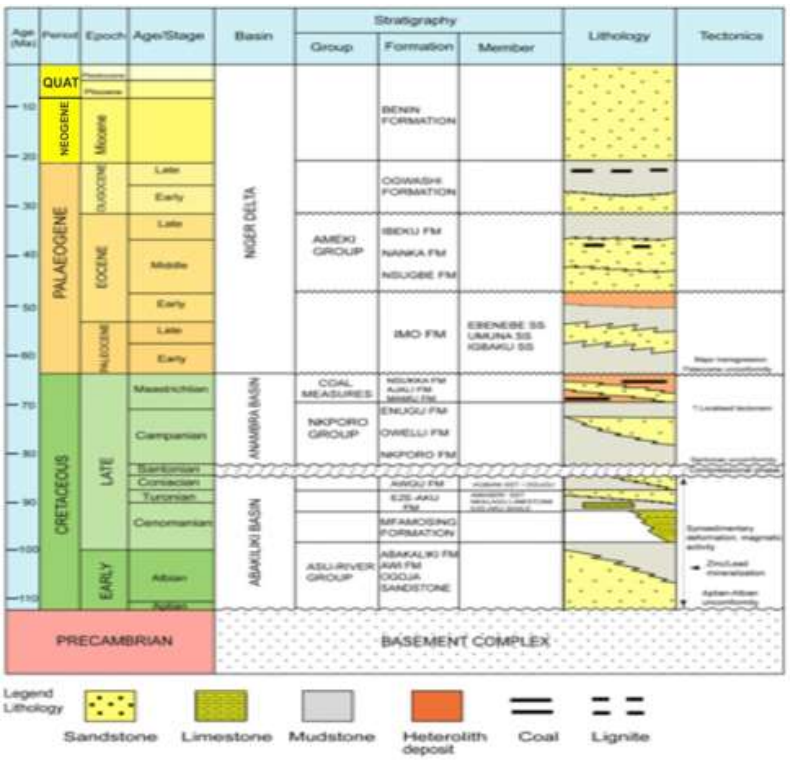


Fig. 2: Stratigraphic Succession of the Southern Nigeria Sedimentary Basin (Modified from Ekwenye, 2017)

The third phase commenced towards the end of Eocene and was characterized by the structural inversion of the Abakaliki region further shifting the depocenter down dip (southwards) to form the Niger Delta basin (Obi, Okogbue, Nwajide, 2001; Nwachukwu and Odjeba, 2001).

METHODOLOGY

Both field work and laboratory methods were employed in this study. Figure 3 shows the workflow chart for the study.

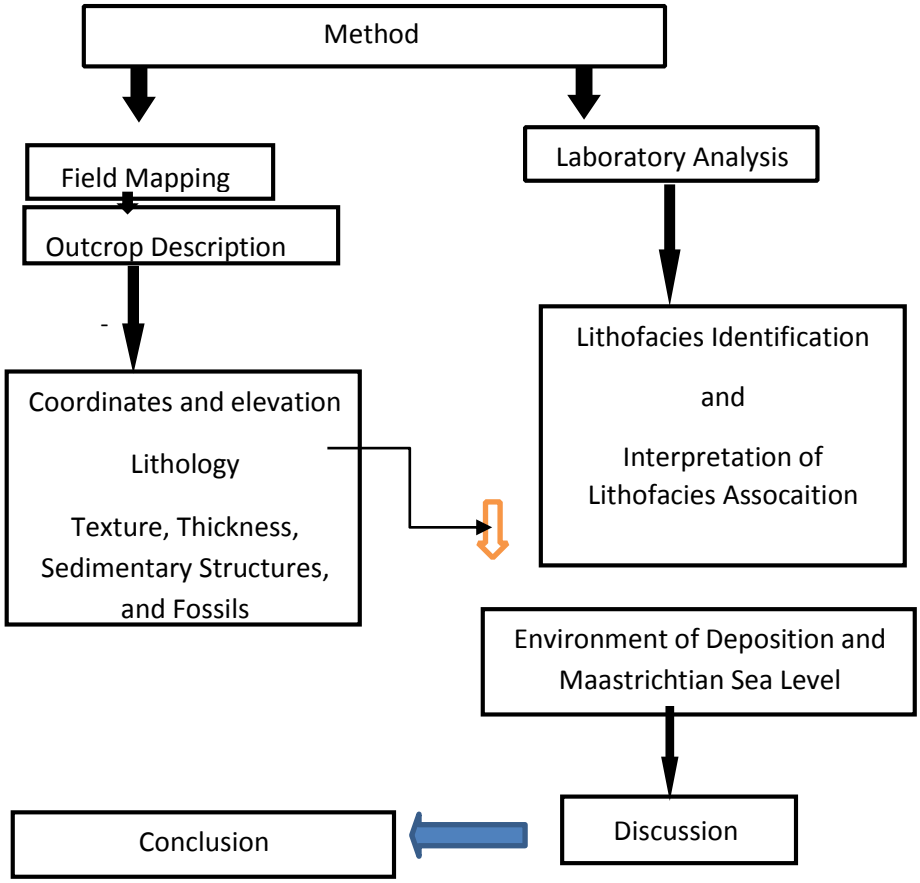


Fig.3: Workflow for the study

The selected outcrops within the study area were logged from the base to the top and the lithologic sections of each of the exposures were produced. The lithofacies were identified based on the lithologic type, texture, and sedimentary structures. Colour was very useful for mudrocks such as shale. The lithofacies association and environment of deposition were evaluated based on the lithologic stacking pattern.

RESULTS

Outcrop Description

Locality: Ekulu River
Coordinate: Latitude N06° 27' 47"
Longitude E07° 27' 42"
Elevation: 183 m

Outcrops consists of basal dark shale (0.4 m thick) which is overlain by cross bedded fine-grained sandstone (0.6m thick) succeeded upward by mudstone as shown in Fig.5. The sandstone is planar cross bedded, well sorted with sub-angular to sub-rounded quartz grains. The strike and dip of the bed recorded 140^0 azimuth and 8^0 SW respectively. Figs. 4A and 4B shows the exposure at the Ekulu River.

Locality: Living Faith Church (Iva Valley)
Coordinate: Latitude N06° 27' 39"
Longitude E07° 27' 38"
Elevation: 209.2 m

The exposure is shown in Fig. 4C, and it is about 2.0 m thick. The base consists of alternation or inter-bedded greyish shale and siltstone which is overlain by sandy shale. This is succeeded upward by cross-bedded fine-grained sandstone, then the mudstone. The topmost part of the outcrop has been weathered. The sandstone is consolidated, well sorted with sub-angular to sub-rounded quartz grains. Strike and dip measured from the bedding plane recorded 150^0 azimuth and 14^0 SW respectively. Sedimentary structures include flaser and lenticular beddings, clay drape, flame structure, and Skolithos isp burrows on the fine-grained sandstone.

Locality: Old Enugu-Onitsha Express Way, Trans Ekulu
Coordinate: Latitude N06° 28' 11"
Longitude E07° 27' 22"
Elevation: 219.5 m

The exposure is about 2.6 m thick. It consists of the basal coal unit of about 0.5 m thick overlain by dark shale of 0.2 m thick which is followed upward by wavy, and ripple laminated, very fine to fine grained sandstone of 0.8 m thick, and the overlying mudstone (Fig. 7). The sandstone is well sorted with few burrows of Skolithos isp and has a sharp contact with the underlying dark shale. Strike and dip of bed recorded 100^0 azimuth and 14^0 SW respectively. The exposure is shown in Fig. 4 D.

Locality: Trade More Zion Hill Estate, Enugu
Coordinate: Latitude N06° 28' 7"
Longitude E07° 27' 28"
Elevation: 183.3 m
The exposure is about 3.5 m thick. The base consists of coal unit of about 1 m in thick which is overlain by the dark shale of 0.6 m The shale is vertically succeeded by fine to medium grained consolidated sandstone of about 1 m thickness. The topmost part of the outcrop has been weathered (Figs. 4E and 8). The strike recorded 120^0 azimuth and the dip 6^0SW.

Locality: New Enugu-Onitsha Express Way I
Coordinate: Latitude N06° 28' 4"
Longitude E07° 25' 59"
Elevation: 302.9 m
The exposure is located 100 m away from the express way as shown in Fig.4F. It consists of 0.8 m thick of fine to medium grained and friable whitish sandstone which is overlain by coarse grained sandstone. Sedimentary structures include convolute laminations and clay drape. The strike and dip measured recorded 170^0 azimuth and 12^0 SW respectively. Fig. 9 shows a 2.0 m thick litholog of this section (shale is 0.4 m thick and sandstone is 0.8 m thick). Convolute laminations occur in the sandstone possibly due to internal shear (Miall, 1999).

Locality: New Enugu-Onitsha Express Way II
Coordinate: Latitude N06° 28' 2"
Longitude E07° 26' 0"
Elevation: 313.8 m
The outcrop is situated 150 m away from the expressway as shown in Fig.4G. The exposure is about 2 m thick and consists of planar cross bedded whitish to greyish fine-grained sandstone of about 0.6 m thick and shale of 0.4 m thick. The strike of the bed is 110^0 azimuth whereas the dip recorded 10^0SW. Figure 11 shows a composite litholog of the sandstone units of the exposures in New Enugu-Onitsha Express Way.

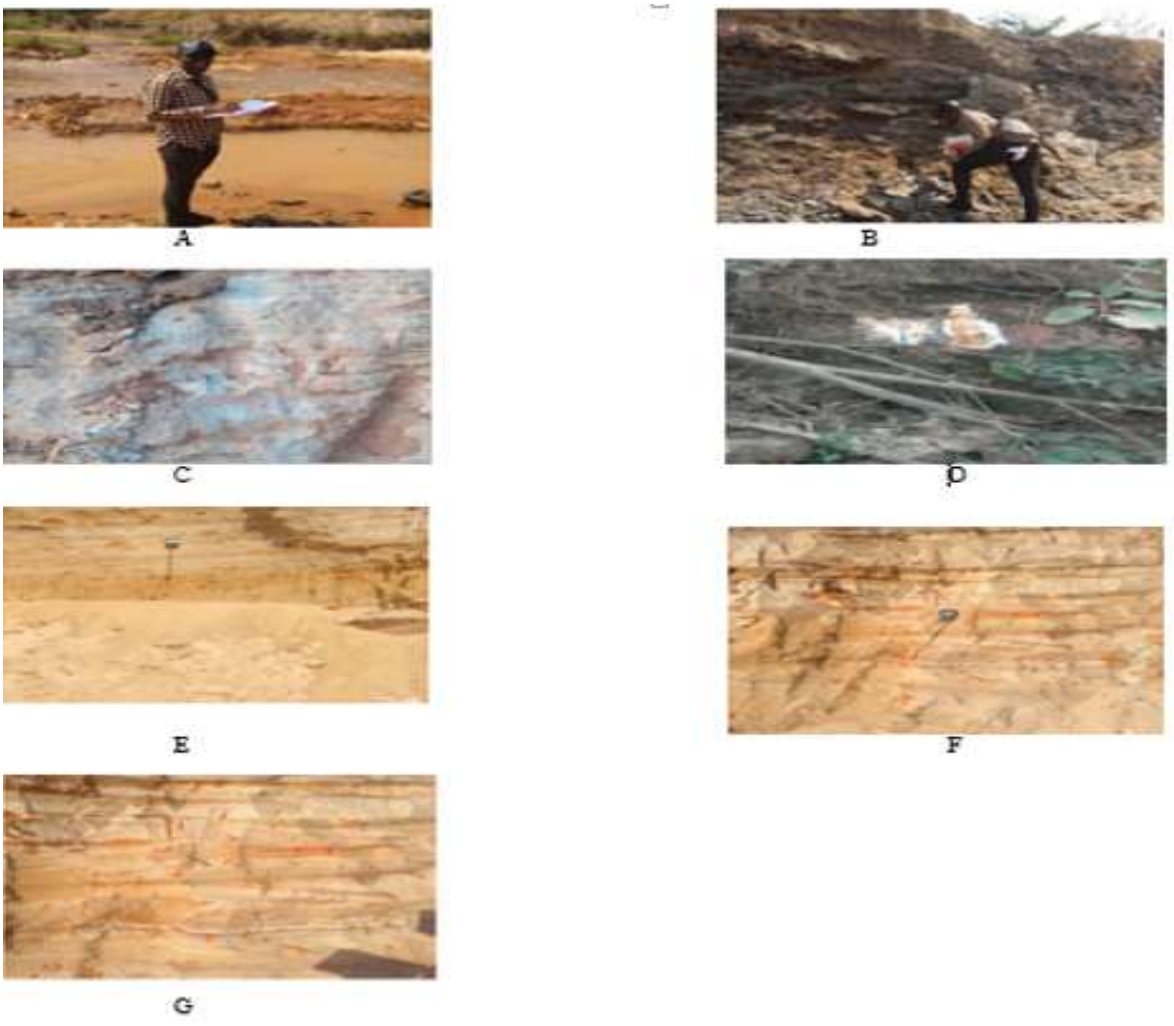


Figure. 4: Lithological Plates of the Mamu Formation at the Enugu Area

A: Mamu Formation exposed at the Ekulu River. B: Mamu Formation Exposed at the Bank of the Ekulu River. C: Mamu Formation exposed at Living Faith Church (Iva Valley). D: Mamu Formation exposed at Old-Enugu Expressway, Trans-Ekulu. E: Outcrop of Mamu Formation Exposed at Trade More Zion Hill Estate. F:Exposure of Mamu Formation at 100m away from New Enugu-Onitsha Expressway I. G: Exposure of Mamu Formation at 150m away from New Enugu-Onitsha Expressway II

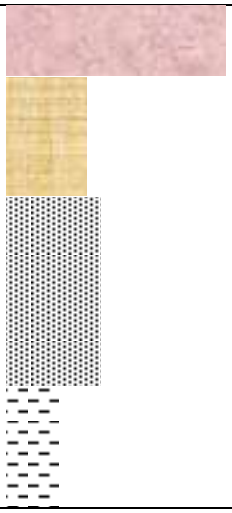
Thickness Scale (m)	Lithology CL SI FS MS CS PB	Description	Environment of Interpretation
2 1 0		Red earth/ top weathered material Mud stone Fine grained cross-bedded whitish sandstone Dark Shale	 Tidal Flat (Intertidal) Coastal Swamp/Lagoonal

Figure 5: Litholog of top section of the Bank of the Ekulu River

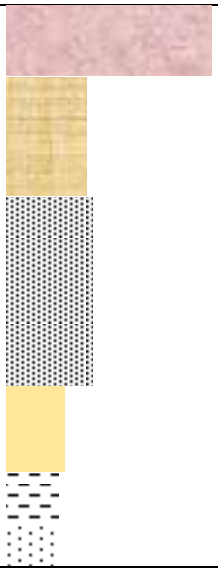
Thickness Scale (m)	Lithology CL SI FS MS CS PB	Description	Environment of Interpretation
2 1 0		Red earth/ top weathered material Mud stone Fine grained cross-bedded whitish sandstone Light brown sandy shale Alternation of grey shale and siltstone	 Tidal Flat (Intertidal) Coastal Swamp/Lagoonal

Figure 6: Litholog of Outcrop at Living Faith Church (Iva Valley)

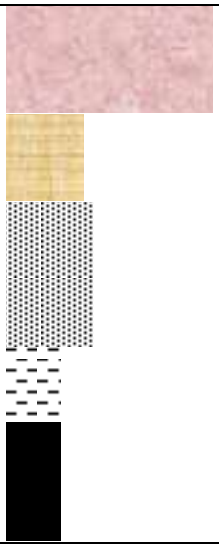
Thickness Scale (m)	Lithology CL SI FS MS CS PB	Description	Environment of Interpretation
2 1 0		Red earth/ top weathered material Mud stone Very fine- fine wavy and ripple laminated sandstone with sharp basal contact Dark shale Coal	 Shoreface/Littoral Swamp

Figure 7: Litholog of Trans-Ekulu Exposure

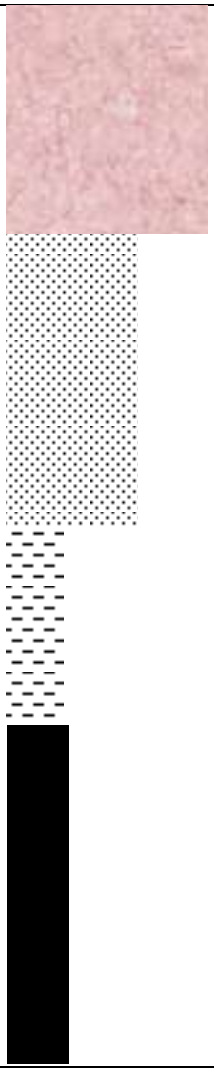
Thickness Scale (m)	Lithology CL SI FS MS CS PB	Description	Environment of Interpretation
3 2 1 0		Red earth/ top weathered material Fine to medium grained consolidated sandstone with distinct bedding plane Dark shale Coal	 Inter distributary bay Swamp/marsh

Figure 8: Lithology of the Exposure at Trade More Zion Hill Estate

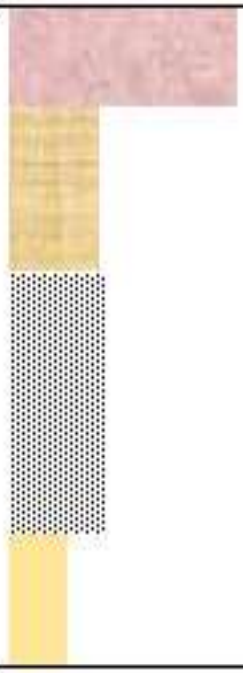
Thickness Scale (m)	Lithology CL SI FS MS CS PB	Description	Environment of Interpretation
2		Red earth/ top weathered material Mud stone	
1		Fine grained cross-bedded whitish sandstone	Tidal Flat (Intertidal)
0		Light brown sandy shale	Coastal Swamp/Lagoonal

Fig. 9: Litholog of the Mamu Formation Exposure along New Enugu-Onitsha Road I

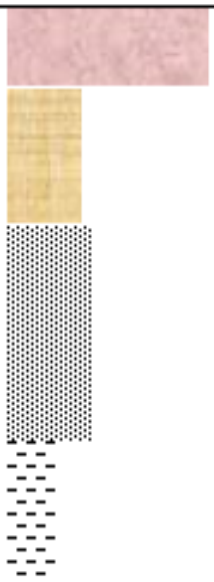
Thickness Scale (m)	Lithology CL SI FS MS CS PB	Description	Environment of Interpretation
2		Red earth/ top weathered material Mud stone	
1		Fine grained cross-bedded whitish sandstone	Tidal Flat (Intertidal)
0		Dark Shale	Coastal Swamp/Lagoonal

Fig. 10: Litholog of the Mamu Formation Exposure along New Enugu-Onitsha Road II

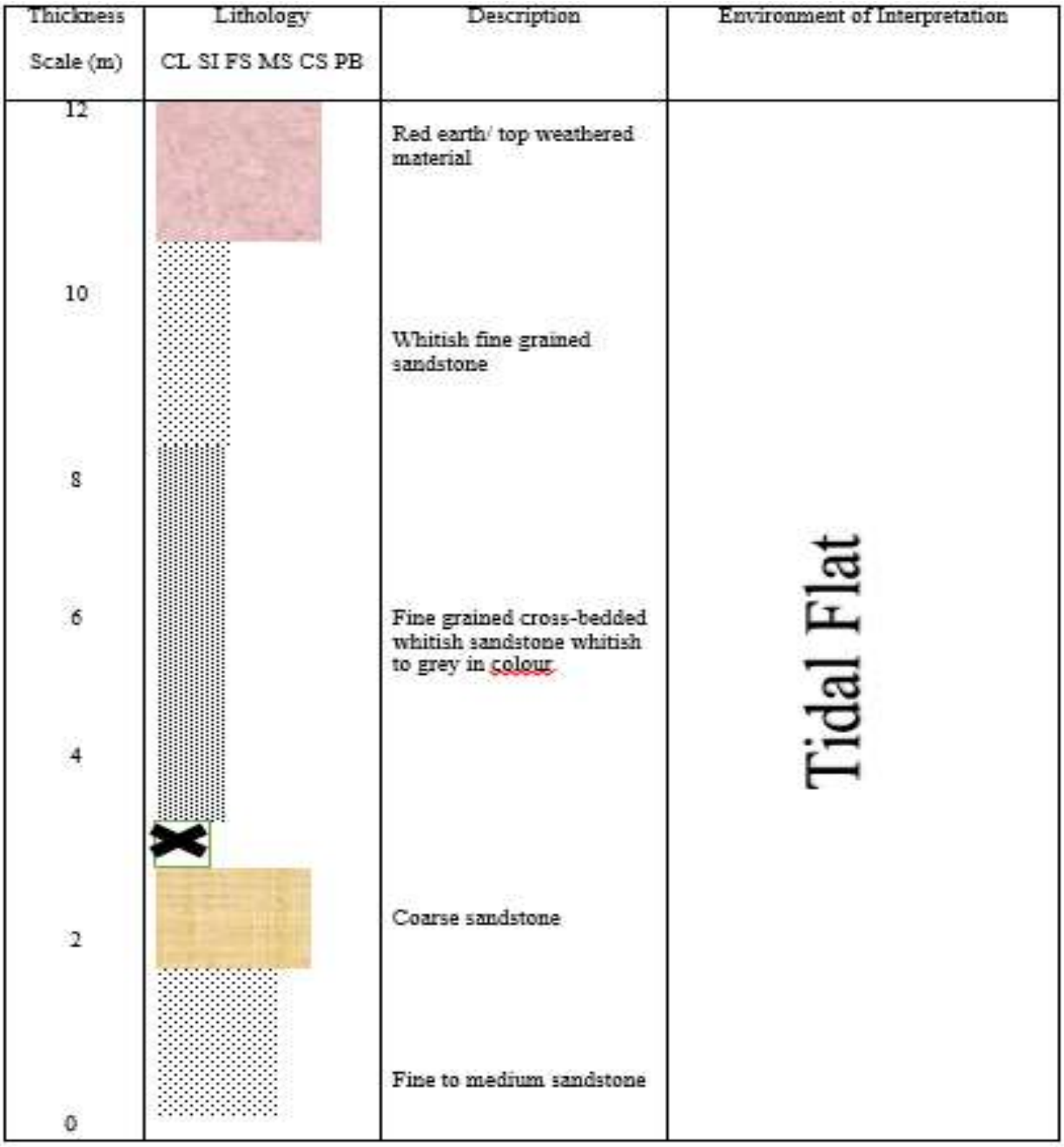


Figure 11: Composite Log of Exposures at the New Road Enugu-Onitsha Expressway I & II

Sedimentary Structures

The sedimentary structures in the Mamu Formation can be grouped into three classes as shown in Table 1. Fig. shows some of these sedimentary structures.

Table 1: Classification of Sedimentary Structures from the Mamu Formation

Physical	Biogenic	Chemical
Bedding and Laminations	Skolithos	Concretions
Cross Bedding	Sub-vertical to Horizontal burrows made by unidentifiable organisms	
Flaser Bedding		
Wavy Laminations		
Ripple Laminations		
Soft Sediment Deformation e.g Flame Structures Convolute Laminations		

Sedimentary structures such as clay drape and flaser bedding are indication of tidal environment. Wavy laminations suggest environment affected by wave action. A trend from vertical burrows of Skolithos isp to

subvertical and horizontal burrows suggest energy fluctuation from high to lower energy condition (Boggs, 2006).

Lithofacies Analysis

Nine lithofacies identified include:

1. Cross bedded fine-grained sandstone lithofacies: This lithofacies consists of planar cross bedded, well sorted fine grained sandstone with sub-angular to sub-rounded quartz grains. The cross bed foresets are draped by clay. Other sedimentary structures are flaser bedding and Skolithos isp. The bed thickness varies from 0.5 m to 0.8 m.
2. Wave ripple laminated, fine grained sandstone lithofacies: The lithofacies is about 0.7 m in thick, moderately to well-sorted with sub-angular to sub-rounded quartz grains. Wavy, ripple laminations are common on the sandstone.
3. Fine to medium grained sandstone lithofacies: The sandstone is moderately sorted with sub-angular to sub-rounded quartz grains and partly consolidated. Convolute laminations and clay drapes occur in the sandstone.
4. Coarse grained sandstone lithofacies: This is poorly sorted and characterized by subangular to subrounded quartz grains. Bed thickness is 0.5 m.
5. Coal lithofacies: Has thickness ranges from 0.5 m to 1 m where found.
6. The mudstone lithofacies: This has thickness that varies from 0.5 m to 1 m. The lithofacies recorded few subvertical to horizontal burrows of organisms. The mudstone is brown in colour.
7. The greyish shale lithofacies: Has thickness of 0.2 m and it alternates with siltstone.
8. The dark shale lithofacies: Has a general thickness ranging from 0.3 m -0.5 m
9. The siltstone lithofacies: Alternated with grey shale with thickness 0.3 m

Lithofacies Association (FA)

Three litho facies association were recognized in the study area; coastal swamp/lagoonal, tidal flat, and, shorefore/littoral.

FA1: Coastal Swamp/Lagoonal

The hetrolithic units consisting of inter bedded greyish shale and siltstone (Figs. 5, 6, 7, 8, 9, 10), sandy shale as well as coal overlain by the dark shale lithofacies are inferred to be deposit of swamp/lagoonal environments.

FA2: Tidal Flat

The cross bedded fine-grained sandstone with tidal signatures such as clay drape and flaser beddings, together with the vertical tubes of Skolithos isp and the overlying mudstone lithofacies is interpreted as tidal flat environment (possibly intertidal). This is shown in Figs. 5, 6, 7, 8, 9, 10.

FA3: Shoreface/Littoral

The wave ripple laminated fine grained sandstone with a shale base and the overlying mudstone lithofacies (Fig. 7) is inferred to be a shoreface/littoral deposit.

DISCUSSION

Depositional Environment and Maastrichtian Sea Regression

The three lithofacies associations identified in this study suggest the deposition of the Mamu Formation in a transitional/marginal marine setting. The various sub-environments of the formation include the coastal swamp/lagoonal, the tidal flat (dominantly inter-tidal), and the shoreface. This agrees with the previous workers (e.g., Onuigbo et al., 2012 a& b; Uzoegbu, 2014; Dim et al., 2019).

However, the vertical succession of the facies association as shown in the lithologic sections (Figs. 5-11) generally indicated a coarsening upwards sequence which is typical of a prograding delta. The deltaic system was influenced by both fluvial and marine (tide and wave) processes thereby producing deposits of a range of environments that varied from the swamp/lagoonal to tidal flat and shoreface. This interpretation supported the complex deltaic system which has been assigned to the formation by Umeji (1999), Onyekuru and Iwuagwu (2010), Akande et al. (2012), and Nwajide (2013).

The coarsening upward stacking pattern displayed by the sediments of the Mamu Formation in which lagoonal/swamp deposits are overlain by the tidal flat (inter-tidal) deposits depicts a falling sea level (Walter's Law of facies succession). This suggests deposition of Mamu Formation during the regressive phase of the ancient sea.

CONCLUSION

Evaluation of the lithofacies, lithofacies association and successions in the Mamu Formation have shown that the formation was deposited in a marginal marine setting (deltaic) and the three sub-environments identified include the lagoonal/swamp, the tidal flat (inter-tidal), and the shoreface. The coarsening upwards of the lithofacies and their vertical successions indicated sediment deposition during the regressive phase of the ancient sea.

REFERENCES

Allen R. L. J., 2009. Current Ripples. Their relation to patterns of water and sediment motion. North Holland Publishing Company, Amsterdam. Geological Mag0azine 106(06):614. DOI:10.1017/S001675680005946X. Retrieved November 09, 2021.

Akande S. O., Egenhoff S., Obaje N. G., Ojo O. J. Adekeye O., and Erdtmann B. D., 2012. Hydrocarbon potential of Cretaceous sediments in the Lower and Middle Benue Trough, Nigeria: Insights from new source rock facies evaluation. Journal of African Earth Sciences 64, 34–47 DOI: 10.1016/j.jafrearsci.2011.11.008

Boggs S. Jr., 2012. Principles of Sedimentology and Stratigraphy (5th Ed). Pearson: University of Oregon. pp. 45-56.

Burke, K. C., Dessauvagie, T. F. J., and Whiteman, A. J. (Eds). 1972. African Geology. University of Ibadan Press, pp187- 205.

Dim C. I. P., Onuoha, K. M., Okwara, I. C., Okonkwo, I. A., and Ibemesi, P., 2019. Facies analysis and depositional environment of the Campano – Maastrichtian coal-bearing Mamu Formation in the Anambra Basin, Nigeria. Journal of African Earth Sciences 152:69-83 DOI:10.1016/j.jafrearsci.2019.01.011.

Ekwenye, C. O., Nichols, G. J., Okogbue, C. O., Dim, C. I. P., Onyemesili, O. C., 2017. Facies Architecture and Reservoir Potential of a Macrotidal Estuarine System: Eocene Ameki Group, South-Eastern Nigeria. Advances in Petroelum Geoscience Research in Nigeria. SN - 978-1-4276-5590-5. Pp 371

Kogbe, C. A., 1989. Geology of Nigeria. Nigeria: Rockview. Pp 325- 333.

Maju-Oyovwikowhe, G. E and Imasuen, I. O., 2019. Reservoir Potential, Environment of Deposition, Tectonic Setting, and Provenance of Rock Units in the Anambra Basin, Southeastern Nigeria. Journal of Geosciences and Geomatics 7(4):172-183. doi: 10.12691/jgg-7-4-2.

Murat, R. C., 1972. Stratigraphy and paleogeography of Cretaceous and Lower Tertiany in Southern–Nigeria. In T. F. J. Dessauvagie and A. J. Whiteman (Eds.), African Geology pp. 251–266. Ibadan: University press

Nwachukwu, S. O., 1972. The tectonic evolution of the Southern portion of the Benue Trough, Nigeria. Geology Magazine 109: 411-419

Nwachukwu, J. I. and Odjeba, E. T., 2001. Compaction in reservoir Sandstones of the Niger Delta, Nigeria. Journal of Mining and Geology 32 (2), pp.113-120.

Nwajide, C. S., Reijers, T. J. A., 1996. Geology of the Southern Anambra Basin. In T. J. A., Reijers (Ed.), Selected chapters on Geology: sedimentary Geology and sequence stratigraphy of the Anambra Basin (pp. 133-148). Warri, Nigeria: SPDC Corporate Reproghraphic Services.

Nwajide, C. S., 2013. Geology of Nigeria's Sedimentary Basins. Lagos: CSS Bookshop Ltd.

Obi, G. C., Okogbue, C. O., and Nwajide, C. S., 2001. Evolution of the Enugu Cuesta: A tectonically driven erosional process. Global Journal Pure Applied Sciences 7 (2), pp. 321-330.

Oboh-Ikuenob,e F. E., Obi, C. G., and Jaramillo, C. A., 2005. Lithofacies, palynofacies, and sequence stratigraphy of Palaeogene strata in Southeastern Nigeria. Journal of African Earth Sciences 41, pp. 79-101.

Ogala, J. E., Akaegbobi, I. M. and Adaikpoh, E. O., 2005. Sedimentary characteristics of the Maastrichtian fluvial marine sedimentary facies of Anambra Basin. African Scientist 6, 17-28.

Onyekuru, S. O. and Iwuagwu C. J., 2010. Depositional environments and sequence stratigraphic interpretation of the Campano-Maastrichtian Nkporo Shale Group and Mamu Formation exposures at Leru-Okigwe Axis, Anambra Basin, Southeastern Nigeria. Journal of Basic and Applied Sciences 4(12) Australia: INSInet Publication Australian. 6623-6640, 2010ISSN 1991-8178

Onuigbo, E. N., Etu-Efeotor, J. O., and Okoro A. U., 2012a. Palynology, Paleoenvironment, and Sequence Stratigraphy of the Campanian-Maastrichtian deposits in the Anambra Basin, Southeastern Nigeria. Europen Journal of Scientific Research 78(3): 333-348

Onuigbo, E. N., Okoro A. U., and Etu-Efeotor, J. O., 2012b. Lithofacies, palynology, and facies association: Keys to paleogeographical interpretation of the Enugu and the Mamu Formations of the southeastern Nigeria. Journal of Environment and Earth Science 2 (5): 1.

Onuigbo, E. N., Okoro, A. U., Obiadi, I. I., and Okoye, E. I., 2016. Sedimentary facies characterisation and depositional setting of the Ajali Sandstone, Anambra Basin, Southeastern Nigeria. Archives of Applied Science Research 8(10): 10-25

Umeji, A. C., 1999. The evolution of the Abakaliki/Anambra basins, SE Nigeria. Report submitted to The Shell Petroleum Development Co. Ltd, Lagos. Pp.1-126.

Uzoegbu, M. U., 2014. Petrographic and structural implications on petroleum system in Igumale-Nsukka Area in relation to Anambra Graben, Nigeria. International Journal of Advanced Engineering Research and Science (IJAERS) 1(5), pp. 6-22