The International Journal of Engineering and Science (IJES)
|| Volume || 12 || Issue || 6 || June || Pages || PP 25-37 || 2023 ||
ISSN (e): 2319-1813 ISSN (p): 20-24-1805

Sedimentary Facies Analysis of Sandstone Member of the Imo Formation in Northeastern Part of the Niger Delta Basin, Nigeria

UDO, ITORO GABRIEL[1], UDOFIA, PAUL ALEXANDER[2], ETUKUDO, NSIKAK JACKSON[3], IBANGA, IFIOK MFON[4]

[1, 2, 3, 4] *Department of Geology, Akwa Ibom State University, Nigeria*

ABSTRACT

Sandstone member of the Imo Formation occur in northeastern part of the Niger Delta Basin. Lithofacies analysis was carried out in order to ascertain the depositional environment of the sandstone deposit. Seven lithofacies were delineated and grouped into two facies associations: facies association 1 comprising black shale (Bss), interstratified sand, mud and clay (Smc}, cross stratified sandstone (Css) and bioturbated siltstone (Bst); facies association 2 comprising paraconglomerate (Pcg), cross stratified sandstone (Cst) and brownish mudstone (Bms). Facies association 1 was deposited in a tidal flat environment because of the presence of presence of Ophiomorpha, Skolithos and Thalassinoides ichnofossils, herringbone cross-strata and bimodal-bipolar paleocurrent pattern, reactivation surfaces, suspension deposits on foreset laminae, alternating fine- and coarse-grained forest laminae, flaser bedding, lenticular bedding and sand, mud and clay heteroliths. Facies association 2 represents a sequence of channel to over bank deposit of a typical meandering river due to the existence of lag deposits, lateral accretion surfaces, small scale trough cross stratification overlain by large scale planar cross stratification up to 1m in thickness, and brownish mudstone. The environmental setting of the sandstone Member of the Imo Formation in northeastern part of the Niger Delta Basin is therefore interpreted as an intertidal flat with tidal channels and this grade landward into continental deposits.

Keywords: *Sandstone, tidal, fluvial, facies, environment*

Date of Submission: 01-06-2023 Date of Acceptance: 10-06-2023

I. Introduction

The study area lies within the northeastern part of the Niger Delta Basin. The Imo Formation is considered as the basal unit of the Tertiary Niger Delta Basin which overlies the Nsukka Formation of the Anambra Basin and its subsurface equivalent is the protodelta Akata shale (Short and Stauble, 1967; Kogbe, 1976; Avbovbo, 1978; Petters, 1991). Imo Formation has been described as consisting essentially of mud rock mainly dark grey to bluish grey shale with occasional admixture of clay, ironstone, sandstone and limestone intercalations. The macro and micro fossils recovered from the basal limestone unit indicates a Paleocene age for the formation (Reyment, 1965; Adegoke et al., 1980).

Sandstone Member of the Imo Formation outcrop extensively in northeastern part of the Niger Delta Basin where they are mined for construction purposes. There is no previous work in the area probably due to the fact that the formation was not exposed because of inadequate access roads and thick overburden. Now, with extensive road construction and quarrying, the formation is well exposed and accessible. Hence, the need for a thorough research work to be carried out in the area in order to characterize the deposits. The aim of this research work is to undertake a detailed lithofacies analysis of sandstone deposits in order to reconstruct the depositional milieu.

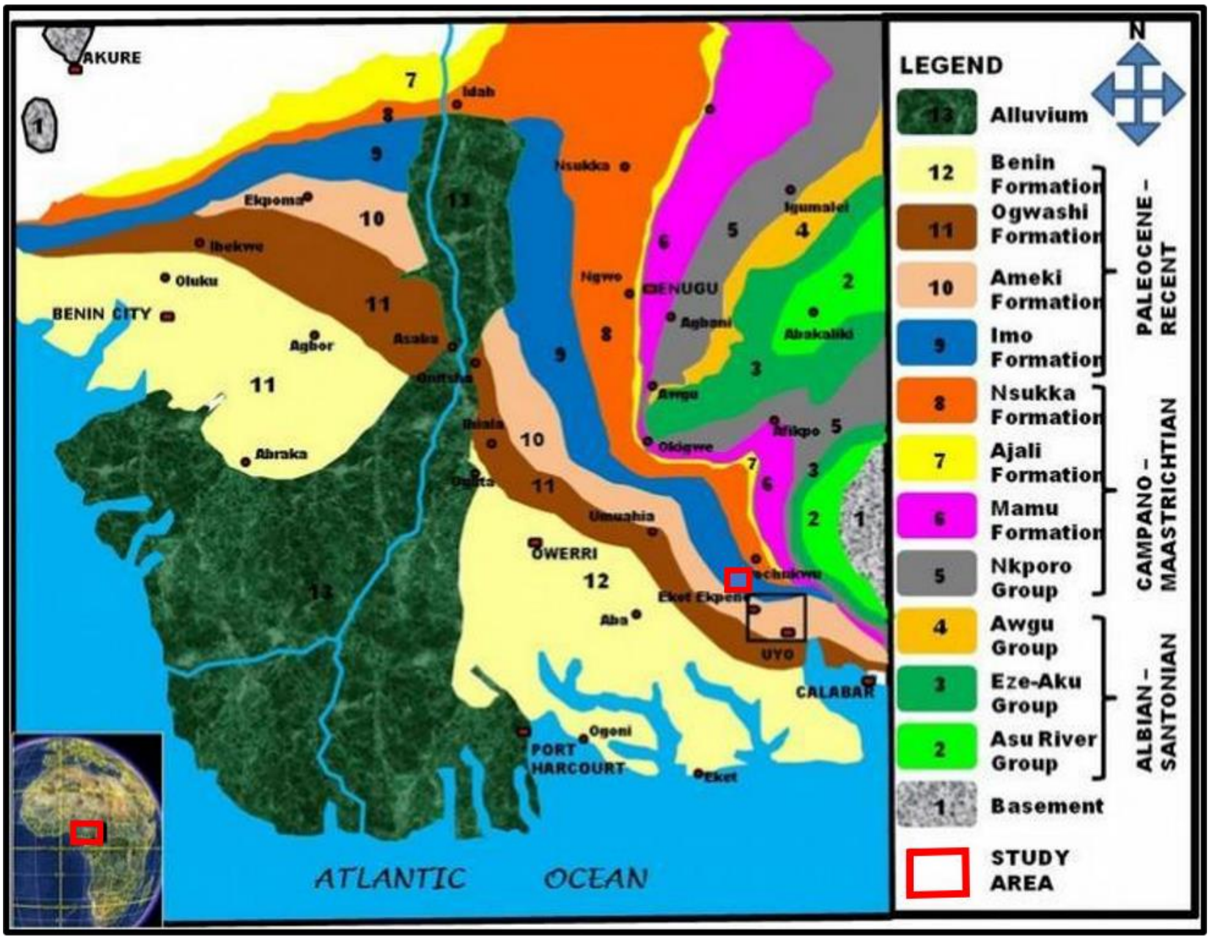

Fig. 1: Geological map showing the study area.

II. Geology of the study area

The origin of the southern Nigeria sedimentary basins is linked to the evolution of the Benue Trough. The Benue Trough is a continental scale intraplate tectonic megastructure which constitutes part of the Mid-African Rift system (Malauski et al., 1995). The tectonics of the Benue is controlled by transcurrent faulting - sinistral wrenging (Benkhelil, 1989). Genik, 1993 suggested that the Benue Trough is part of the west and central African Rift System that opened as a sinistral wrench complex. The Benue Trough is the failed arm of a Y-shaped triple junction that initiated the opening of the south Atlantic Ocean and is thus regarded as an aulacogen (Hoffman et al., 1974; Olade, 1975; Hoque and Nwajide, 1984). The Benue Trough occurs as a NE-SW trending linear depression with about 4500m thick Cretaceous sediments (Olade, 1975). Hoque, 1984 and Benkhelil, 1989 sugested magmatic activity during the opening and closing of the Benue Trough which led to the deposition of Abakaliki pyroclastics. Contact metamorphism occured around the intrusive bodies while low grade metamorphism affected most deformed areas in Abakaliki (Benkhelil, 1989). The Niger Delta complex is a regressive off lap sequence which prograded across the southern Benue Trough and spread out onto cooling and subsiding oceanic crust which was formed as Africa and south America separated.

Three depositional cycles took place in southern Nigeria basins. The first began with a marine incursion in the Middle Cretaceous and was terminated by a mild folding phase in the Santonian time. The second included the growth of a proto-Niger Delta during the Late Cretaceous and ended in a major Paleocene marine transgression. The third cycle from Eocene to Recent, marked the continuous growth of the main Niger Delta (Short and Stauble, 1967).

The oldest sediment found in southern Nigeria are non-fossiliferous, arkosic, gravelly and in general, ill-sorted, commonly crossbedded sand and quartzitic sandstone. These form the weathering products of the nearby and underlying crystalline and metamorphic basement complex. The first marine incursion from the Gulf of Guinea in Aptian time covered southern Nigeria and reach the Middle Benue Trough depositing Asu River Group in the Albian, Odukpani Formation in Cenomanian, Eze-Aku shale in Turonian and Awgwu shale in the Coniacian Time. The third sedimentary phase, which initiated the formation of the petroliferous Niger Delta, commenced in the Late Eocene as a result of a major earth movement that further structurally inverted the Abakaliki region and displaced the depositional axis further to the south of the Anambra Basin (Obi et al., 2001). This ended with the onset of a phase of folding, faulting and uplift in early Santonian, resulting in erosion of Coniacian, Turonian, Cenomanian and even Albian deposits of the uplifted Abakaliki Anticlinorium and simultaneous subsidence of Anambra Platform to form Anambra Basin and Ikpe Platform to form the Afikpo Sub Basin (Nwachukwu, 1972; Whiteman, 1982; Nwajide, 2005). The subsidence initiated a new marine transgression in the Campanian time resulting in the deposition of the Nkporo shale of Campanian-Maastrichtian age and its lateral equivalent, the Owelli sandstone and the Enugu shale. West of the River Niger, the Marine Nkporo shale ranges in age from Campanian-Maastrichtian. In the east, the Maastrichtian is represented by deltaic deposits (regressive phase) – the Mamu Formation, the Ajali Formation and the Nsukka Formation. This regressive phase with the formation of a proto-Niger Delta, continued throughout the end of the Cretaceous and ended in a major Paleocene marine transgression. The Paeocene transgression also referred to as the Sokoto transgression resulted in the deposition of the Imo shale and its eqivalent, Akata shale. The Imo shale ranges into Early Eocene (Stolk, 1963) and is overlain by the sandy Ameki Formation (fig. 2) which marks the onset of a regression and the formation of the modern Niger Delta. East of the Niger, the Ameki Formation is very heterogeneous, consisting of alternating sandstone and shale, sandy or calcareous shale, marl, and a few fossiliferous shale and limestone beds. These abrupt, irregular alternations indicate deposition in a shallow marine environment with sediment supply from the nearby coast. During the Middle and Late Eocene, the sedimentary rocks became increasingly sandy, marking the onset of a general regression and of deltaic deposition.

In the Middle Eocene, major depocenters initiated in the Paleocene to Eocene in the Anambra basin, Afikpo syncline, and the Ikang Trough were the sites of deltaic outbuilding with the Niger-Benue and the Cross River drainage systems accounting for the bulk of the sediment supply. Both drainage systems merged at the end of the Oligocene and formed the present-day Niger delta. Simple growth faults were initiated in the Oligocene (Whiteman,1982).

During the Miocene, uplift of the Cameroon mountains provided a new and dorminant sediment supply through the Cross River, thus constructing the Cross River Delta. The shoreline progressively migrated seaward during deltaic progradation. This was greatly accelerated in Miocene to Pliocene times with attendant increase in growth faulting and large-scale diapiric movement of the Akata Shale. Deltaic growth declined in the Late Pliocene to Pleistocene during a major drop in sea level, with sediments by- passing into deep sea fans. A Late Pleistocene transgression flooded the Plio-Pleistocene upper and lower deltaic plains. As sea level stabilized, a new regressive sequence developed.

Surface evidence of Oligicene and Miocene deposits is limited and much of the evidence for the age determination is inferred. The main rock-stratigraphic unit is the continental Ogwashi-Asaba Formation and its equivalent, the Ijebu Formation in the Lagos area, which contains some sparse marine faunas. Both Formations are predominantly sandy, the sand alternating with lignite seams and a few beds of clay in the Ogwashi-Asaba Formation, or with a few thin clay beds with scarce marine faunas as in the Ijebu Formation (Reyment, 1965).

The youngest rock stratigraphic unit is the Benin Formation of possible Miocene to Recent age. The unit consists predominantly of yellow and white continental sand, alternating with pebbly layers and a few clay beds (Reyment, 1965).

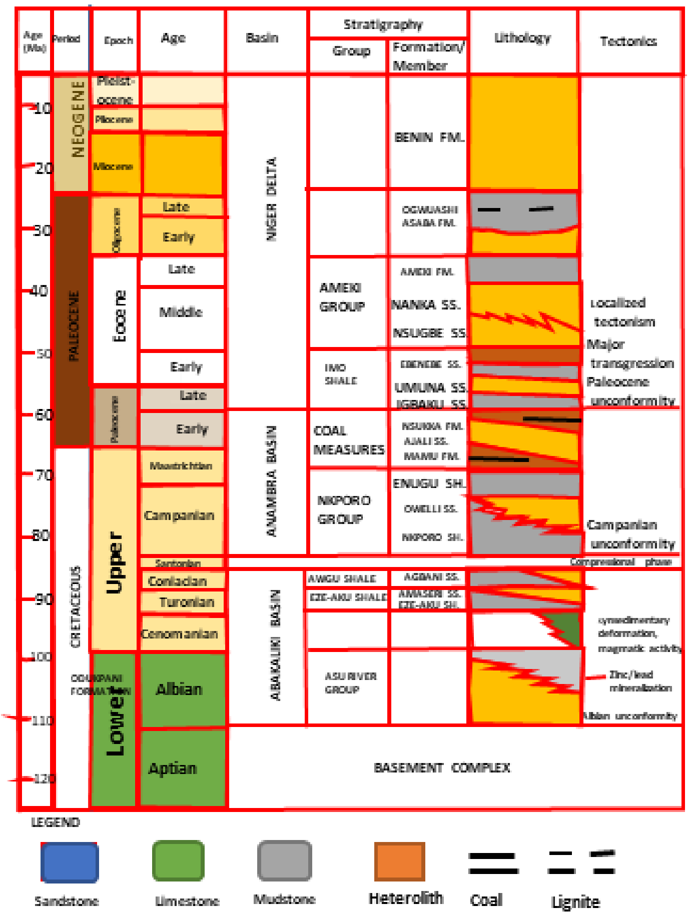

Fig. 2: The stratigraphic succession in the Anambra Basin and outcropping Paleogene Niger Delta Basin (modified after Ekwaenye *et al*., 2014)

Table 1: Stratigraphic correlation of Tertiary Formation in the Niger Delta (modified after Reyment, 1965)

Age	Surface Formation	Subsurface Eqivalent	Broad Depositional Environment
Pliocene-Recent	Coastal Plain Sands	Benin Formation, Afam and Qua Iboe Clay Member	Continental
Miocene-Recent	Ogwashi-Asaba Formation	-	-
Eocene-Recent	Ameki Formation	Agbada Formation	Paralic
Paleocene-Recent	Imo Formation	Akata Formation	Marine

III. Methodology

Detailed field work was undertaken in northeastern part of the Niger Delta Basin using a topographic map. Outcrops were accessed through road cuts and quarries. All rock exposure within the mapped area were sedimentologically logged and described. Attitude of the beds and azimuth of crosssbeds were measured using a compass clinometer. The studied lithologic sections were systematically sampled, and important features photographed. The field observations were used to ascertain the lithofacies units and facies assemblage which gave information on the depositional environment.

IV. Result

The sandstone deposit in northeastern part of the Niger Delta consists of seven sedimentary facies, defined on the basis of textural attributes, lithology and sedimentary structures. These facies were further subdivided into two facies associations.

Facies association 1 (Tidal flat deposit)

Facies A: Black shale (Bsh)

This facies consists of black non-calcareous shale rich in ostracode, brachiopods, foraminifera and palynomorphs (fig.3). The shale was dated Late Paleocene age – Early Eocene age based on the recovered palynomorphs assemblage. They included *Proxapertites operculatus* overwhelming in most of the samples. Other species are *Spinizonocolpites baculatus, Psilatriporites rotundus, Scabratriporites simpliformis, Mauritidiites crassibaculatus, Retidiporites magdalenensis,* and *Momipites sp***.** Marine species (Dinocysts assemblage) include *Apectodinium homomorphum* overwhelming, *Homotryblium tenuispinosum*, *Operculodinium centrocarpum*, *Cyclonephelium deckonincki*, *Deflanfrea* sp., *Adnatosphaeridium* sp and *Spiniferites* sp. This facies underlies the sandstone facies.

Fig. 3: Black shale facies

Facies B; Interstratified sand, mud and clay (Smc)

This facies (fig. 4, 5) consists of beds and laminae of mottled, fine to medium grained, poorly to moderately well sorted, micaceous, quartz sandstone alternating with laminae of mottled clay and mudstone. Maximum thickness of the sandstone bed is 4cm. The thicker sandstone appears massive while some of the thinner layers are ripple cross laminated. Lenses of sandstone and mud/clay occur in places. Leaf imprints occur in the mudstones and bioturbation is mild. This facies ranges in thickness from 0.7cm to 2.8cm and overly facies A. Generally, the sand to mud/clay ratio increases upward.

Fig. 4: Interstratified sand, mud and clay facies

Fig. 5: Interstratified sand, mud and clay facies

Facies C: Cross stratified sandstone (Css)

This facies (fig. 6) is made up of medium to coarse grained, moderately sorted, subangular to subrounded cross stratified sandstone. Medium scale herringbone, planar and trough cross stratification are the outstanding sedimentary structures. Reactivation surfaces occur in places. Bed thicknesses range from 0.3 to 1m. Thickness of the cross strata range between 0.9cm to 2cm. Paleocurrent analysis suggests a bimodal pattern with the dorminant mode to the southwest. Alternating cross and fine laminae and forests draped by clays abound.

Fig. 6: Herringbone structure in cross stratified sandstone facies

Facies D: Bioturbated siltstone (Bst)

This facies (fig. 7) consists of white siltstone and mudstone with intense bioturbation. Horizontal burrows of Thalassinoides and u-shaped burrows of Skolithos and Ophiomorpha are ubiquitous. This facies overlies facies 1 gradationally and ranges in thickness from 0.7 to 3m.

Fig 7: Bioturbated siltstone facies

Facies association 2 (Meandering fluvial channel and over bank deposits)

Facies A: Paraconglomerate (Pcg)

This facies (fig. 8) consists of poorly sorted matrix supported conglomerate that ranges in thickness from 0.2m to 0.9m. The clasts which include mudstone clasts, siltstone clasts and other lithic fragments are generally subangular to subrounded and ranges in size from 2 to 61mm. The matrix is made up of poorly sorted medium to coarse grained sand and clay. This facies overlies facies D of facies association 1 with a sharp and erosional contact.

Fig. 8: Paraconglomerate facies

Facies B: Cross stratified sandstone (Cst)

This facies (fig. 9, 10) consists of fine to medium grained, poorly sorted cross stratified sandstone. The basal part is medium grained and trough cross laminated. Set thickness ranges up to 0.3m while the forests are generally below 1.3cm in thickness. The trough cross laminated unit is succeeded by planar cross stratified which is up to 1m in thickness and finer grained. Forsets are up to 2.5cm in thickness while set thickness ranges from 0.4 to 1.2m. The paleocurrent pattern is unimodal. This facies overlies the basal conglomerate facies, facies A.

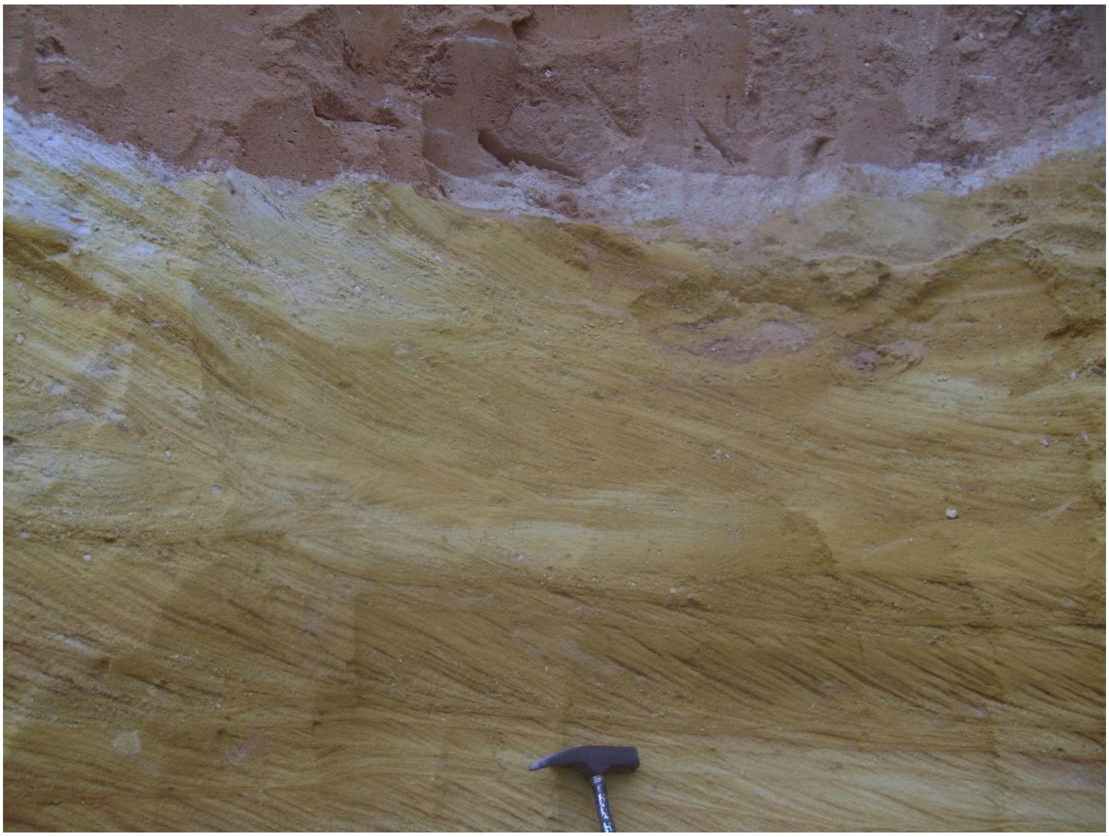

Fig. 9: Cross stratified sandstone facies

Fig. 10: Cross stratified sandstone facies

Facies C: Brownish mudstone (Bms)
This facies (fig. 11) consists of brownish massive sandy mudstone that ranges in thickness from 0.3m to 0.6m. Red siltstone beds, rootlets and carbonaceous materials occur in places. This facies overlies facies B. This facies is similar to facies M of Udo, 2013 and facies Ct of Udo, 2020.

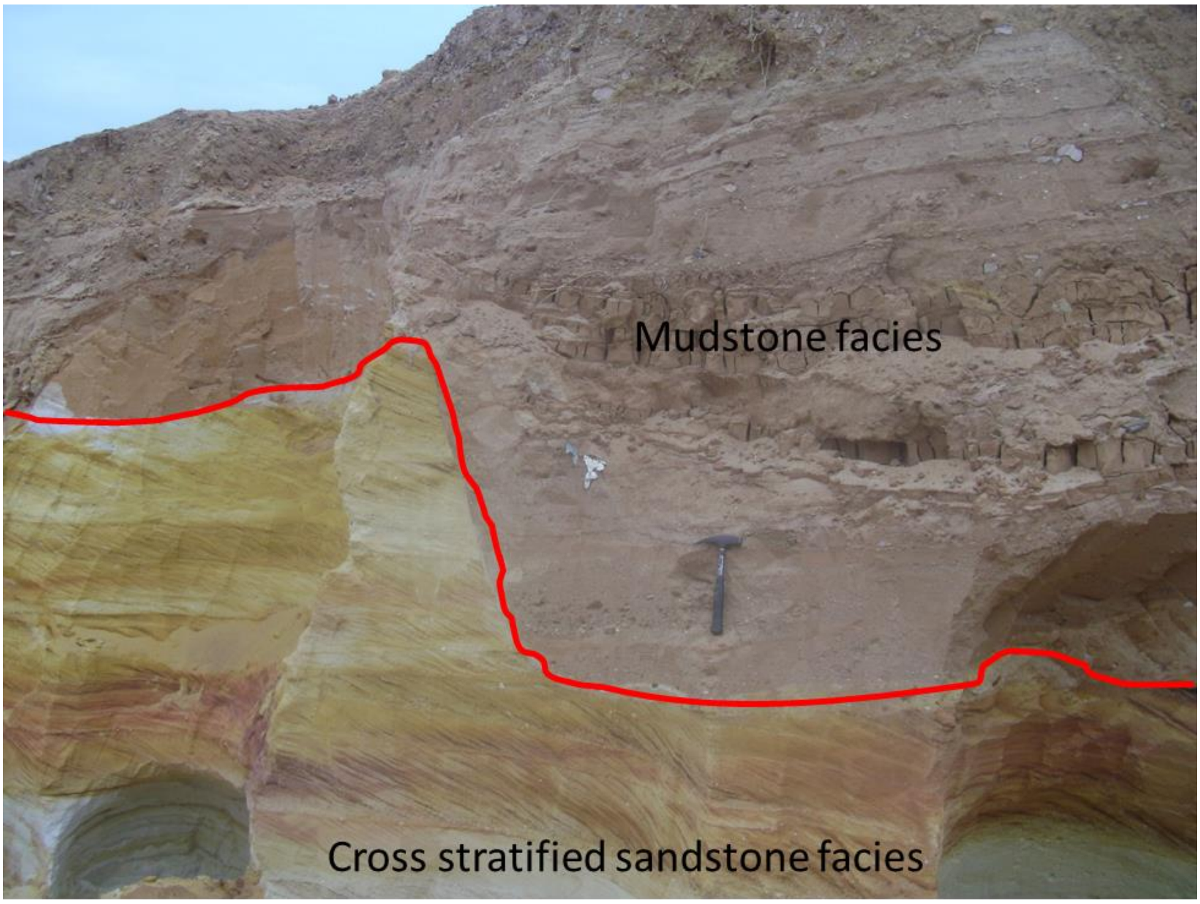

Fig. 11: Mudstone facies underlain by cross stratified sandstone facies

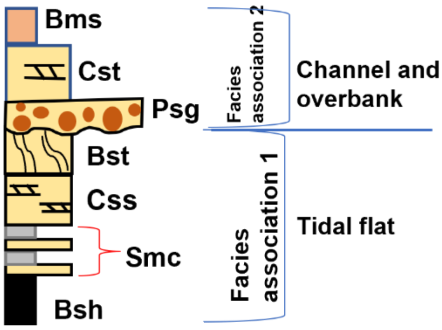

Fig. 12: Vertical sedimentary facies model

Table 2: Summary of the description and interpretation of the lithofacies

Facies Association	Facies	Characteristics	Processes	Depositional Environment
Facies Association 2	Brownish mudstone (Bms)	Brown sandy mudstone and red siltstone, massive, rootlets, carbonaceous materials	Poorly drained paleosol in overbank area.	Channel and overbank
	Cross stratified sandstone (Cst)	Fine to medium grained, poorly sorted, trough cross stratification overlain by large scale planar cross bedding	Lateral accretion of point bars	
	Paraconglomerate (Psg)	Matrix supported, mud and quartz clasts	Channel lag deposit due to channel scouring and re-suspension by currents	
Facies Association 1	Bioturbated siltstone (Bst)	Burrowed siltstone and mudstone, Thalasinoides, Skolithos and Ophiomorpha	Disruption of sediment by the activities of organisms during slack water transition period	Tidal flat
	Cross stratified sandstone facies (Css)	Medium to coarse grained, moderately sorted, medium scale herringbone, planar and trough cross stratification, alternating fine and coarse laminae, clay draped forests	Migration of sandwaves and dunes by tidal currents, Tidal currents reversal, alternation of traction transport with suspension settling of sediment	
	Intersratified sand, mud and clay (Smc)	Intercalationos sand, mud and clay, flaser and lenticular bedding, leaf imprints	Tidal activity	
	Black shale (Bsh)	Fine grained, fissile, rich in Paleocene palynomorphs	Sediment fallout in low energy environment	

V. Discussion

The underlying shale is marginal marine in origin and Paleocene in age due to the presence of diagnostic palynomorphs assemblage. It occurred as a result of sediment fallout in low energy environment. The interstratified sandstone, mud and clay suggest deposition in tidal flat milieu. During high tide, bedload deposition takes place whereas mud and clay deposition occurs during slack water periods. This process would produce the observed interstratified lithology, ripple lamination, flaser and lenticular bedding. Leaf deposition and bioturbation may have occurred during the low tide exposure periods. The cross stratified sandstone facies of facies association 1 is thought to have been fashioned into sandwaves and dunes by tidal currents whose reversing flow characteristics are reflected in the bimodal-bipolar paleocurrent pattern and reactivation surfaces. The alternation of bedload transport with suspension settling of fine-grained sediments suggests that deposition of the fine sediments occurred during the slack water periods. Klein, 1977 suggested that the deposition of fine sediments occurred during slack water periods in a tidal cycle.

The intense bioturbation and ichnofossils of the siltstone facies coupled with its stratigraphic position suggest deposition during the slack water transition period between high tide and low tide. At the time of high tide and low tide, there is usually a short period when there is no flow. During this period some of the suspended loads are deposited. Klein, 1971 stated that the high tidal flat is the zone of suspension deposition and bioturbation.

The paraconglomerate facies of facies association 2 indicates deposition as a channel lag due to channel scouring and re-suspension by currents.

The large scale planar cross stratified sandstone facies of facies association 2 represents lateral migration of point bars on the inner bank of a meandering stream (Jackson, 1976a).

The facies characteristics and stratigraphic position of the brownish mudstone facies of facies association 2 indicates deposition on the overbank setting typical of non-marine regressive fluvial channel. The sedimentary characteristics of this facies are similar to those of fluvial channels described by Allen (1965).

The general characteristics of facies association 1: presence of Ophiomorpha, Skolithos and Thalassinoides ichnofossils in the burrowed siltstone facies, herringbone cross-strata, bimodal-bipolar paleocurrent pattern and reactivation surfaces in the cross stratified sandstone facies, suspension deposits on foreset laminae, alternating fine- and coarse-grained forest laminae, flaser bedding, lenticular bedding and sand, mud and clay heteroliths suggest deposition in tidal flat environment. The attributes of facies association 2: lag deposits, lateral accretion surfaces, small scale trough cross stratification overlain by large scale planar cross stratification up to 1m in thickness, and brownish mudstone facies indicates deposition in meandering channels and overbank areas respectively. The lateral migration of the channel deposits on the tidal flat produce the fining upward succession of facies association 2.

VI. Conclusion

The environmental setting of the sandstone Member of the Imo Formation in northeastern part of the Niger Delta Basin is therefore interpreted as an intertidal flat with tidal channels and this grade landward into continental deposits.

REFERENCES

[1]. Adegoke, O. S., Arua, I., Oyegoke, O., 1980. Two new nautiloids from the Imo shale (Paleocene) and Ameki Formation (Middle Eocene), Anambra Basin, Nigeria. Journal of Mining and Geology, v. 17, p. 85-89.

[2]. Avbovbo, A. A., 1978. Tertiary lithosratigraphy of the Niger Delta. American Association of Petroleum Geologists Bulletin, v. 62, p. 295 – 306.

[3]. Benkhelil, J., 1989. The origin and evolution of the Cretaceous Benue Trough, Nigeria. Journal of African Earth Sciences, v. 8, p. 251 – 282.

[4]. Ekwenye, O. C., Nichols, G. J., Collinson, M., Nwajide, C. S., 2014. A paleogeographic model for the sandstone member of the Imo shale, southeastern Nigeria. Jour, Afric. Earth Sci., v. 96, p. 191.

[5]. Genik, G. J., 1993. Petroleum geology of Cretaceous Tertiary rift basins in Niger, Chad and Central African Republic. AAPG Bull., v. 77, p. 1405 – 1434.

[6]. Hoffman, P., Dewey, J. F., and Burke, K. C., 1974. Aulacogens and their genetic relations to geosynclines with Proterozoic example from Great Slave Lake, Canada. In: Dot, R. H. Jr. and Shaver, R. H., editors. Modern and ancient geosynclinals sedimentation. SEPM spec. Publ., v. 19, p. 38 -58.

[7]. Hoque, M., and Nwajide, C. S., 1984. Tectono-sedimentological evolution of an elongate intracratonic basin (aulacogen): the case of the Benue Trough of Nigeria. Nigeria Journal of Mining Geol., v. 21, p. 19 – 26.

[8]. Hoque, M., 1984. Pyroclasts from the Lower Benue Trough of Nigeria and their tectonic implications. Jour. Afric. Earth Sc., v. 2, p. 351- 358.

[9]. Kogbe, C.A., 1975. The Cretaceous and Paleogene sediments of Southern Nigeria. Geology of Nigeria. Elizabethan publishing company, Lagos,pp 273-282

[10]. Malauski, H., Coulon, C., Popoff, M., Boudin, P., 1995. ^{40}/Ar/^{39}Ar chronology, petrology and geodynamic setting of Mesozoic to Early Cenozoic magmatism from the Benue Trough, Nigeria. Jour. Geol. Soc. Lond., v.152, p. 322 – 326.

[11]. Nwachukwu, S. O., 1972. The tectonic evolution of southern portion of the Benue Trough, NIigeria. Geological Magazine, v. 109, p. 411 – 419.

[12]. Nwajide, C.S. and M. Hoque 1982. Pebble Morphometry as an Aid in Environmental Diagnosis: An example from the Middle Benue Trough. Nig. Jour. Min. Geol., Vol. 19(1), pp. 114-120.

[13]. Olade, M. A., 1975. Evolution of Nigeria Benue Trough (aulacogen): a tectonic model. Geol. Mag., v.112, p. 575 – 583.

[14]. Obi, G. C., Okogbue, C. O. Nwajide, C. S., 1984. Evolution of the Enugu cuester: A tectonically driven erosional process. Global Journal of Pure and Applied Sciences, v. 7, P. 321 – 330.

[15]. Reyment, R.A., 1965. Aspects of the Geology of Nigeria, Ibadan University Press, Ibadan, 143pp.

[16]. Short, K. C. and A. J. Stauble, 1967. Outline of Geology of Niger Delta. Am. Asso. Petrol. Geol. Bull. 51, pp. 761-781.

[17]. Stolk, J., 1963. Contribution à l'ètude des corrèlations microfauniques du Tertiare infèrièur de la Nigeria mèridionale: Colloque Internatl. De Micropalèontologie, pp. 247-275.

[18]. Udo, I. G. and Mode, A. W., 2013. Sedimentary facies analysis of conglomerate deposits in northeastern part of Akwa Ibom State, Niger Delta Basin, Nigeria. The International Journal of Engineering and Science, V. 2, P. 79 -90.

[19]. Udo, I. G., Etukudo, N. J., Abia, U. B. and Ibangha, I. M., 2020. Facies analysis and depositional environment of conglomeritic deposits in the northeastern part of the Niger Delta Basin, Nigeria. IOSR Journal of Applied Geology and Geophysics, v. 8, p. 11 - 30.

[20]. Whiteman, A. J., 1982. Nigeria: Its petroleum geology, resources and potentials. Graham and Trotman, London, vol. 1, 166pp.

UDO, ITORO GABRIEL, et. al. "Sedimentary Facies Analysis of Sandstone Member of the Imo Formation in Northeastern Part of the Niger Delta Basin, Nigeria." *The International Journal of Engineering and Science (IJES)*, 12(6), (2023): pp. 25-37.