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Research Article

LITHOFACIES AND DEPOSITIONAL ENVIRONMENT OF THE OUTCROPPING SEDIMENTS OF THE OGWASHI-ASABA FORMATION, NIGER DELTA BASIN

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ABSTRACT

This research is based on in-depth sedimentological studies to assess the lithofacies and depositional environment of outcropping sediments of the Oligocene Ogwashi-Asaba Formation, Niger Delta Basin. These outcrops were exposed at Ibusa Quarrying site and Anwai Campus. To determine depositional conditions and, eventually, minimize geological uncertainty in Paleogene strata, the study tends to integrate methods such as facies heterogeneity and textural features. Based on a detailed field and laboratory investigation the grain texture ranges from medium to coarse-grained sediments, poorly sorted with angular to sub-angular grains. They are leptokurtic in distribution and nearly symmetrically skewed. Prominent sedimentary structures observed include flaser bedding, horizontal planar bedding, planar cross-beds, lenticular bedding, wavy lamination, reactivation surfaces, bioturbation, burrows, liesagang rings, clay drapes and heteroliths. The bivariate plots and structures observed in the outcropping sediments shows that the sandstones were deposited in a range of depositional conditions such as fluvial, tidal and fluvio-estuarine environments and coastal plain setting. The plot of mean grain size against sorting shows that deposition occurs in the fluvial field. The plot of skewness against sorting and simple skewness measure against simple sorting measure shows that deposition was dominant in the fluvial region with a control of tidal invasion in the beach region.

Keywords: Lithofacies, Environment of Deposition, Ogwashi-Asaba, Sedimentology

INTRODUCTION

Lithofacies investigations suffice as a feasible means for rebuilding the environment of deposition of sedimentary successions. It is often the first and most important prerequisite in determining the depositional environment of sedimentary rocks. Facies evaluation is an all-important method for the reconstruction ancient depositional environments likewise for comprehending the subsidence history of sedimentary basins (Catuneanu, 2006). This analysis is inescapable, because it constitutes the most easily accessible and distinctive features of sedimentary rocks. The various sedimentary facies analysis (lithofacies, biofacies, ichnofacies etc.) shows how the sediments were deposited and their provenances. Precise environment of deposition interpretations are paramount, owing to the fact that concentration of valuable minerals form in certain types of environment.

This research work is based on an elaborate lithofacies evaluation of measured subsection of the Ogwashi-Asaba Formation of the Niger Delta Basin. The study tends to reduce uncertainty in the Paleogene strata by employing incorporated tools and concepts which include sedimentology (facies heterogeneity, textural features and reservoir architecture), petrology and mineralogy to deduce the depositional environments.

Aim and Objectives:

The study aims to come up with a detailed sedimentological description of the outcropping sediments to unravel the paleo-environmental condition at the time of deposition.

The objectives include:

- To establish and categorize the lithofacies of the outcropping sediments within the study area.
- To show the various depositional facies of the Ogwashi-Asaba Formation using elaborate sedimentological logging and facies investigation.
- To deduce the facies association and unravel the paleoenvironment of deposition of the sediments.

Scope of Study:

This study centers on an elaborate lithofacies evaluation of subsections of the Ogwashi-Asaba Formation, integrating field and laboratory studies to deduce depositional environments by analyzing vertical and lateral variations in depositional facies, as well as the structures and textural characteristics.

Study Location:

The study area at Anwai lies within latitude N $06^0$14’38.1” and longitude E $006^0$42’00.2” while that of Ibusa lies within N$06^0$11’19.9” and longitude E$006^0$39’33.6” (Figure 1.1). Subsections of the Ogwashi-Asaba Formation such as Anwai Campus and Ibusa quarrying site was used as a framework that may represent regional model for basin-wide forecasts. The Ogwashi-Asaba Formation is identified among the outcropping Niger Delta, with the others being the Ameki Group and the Imo Formation (from distal to proximal delta) (Short and Stauble, 1967; Doust & Omatsola, 1990). These formations are delimited to the North by the Cretaceous Anambra Basin and a gentle gradation to the South into the Niger Delta Basin where they are

commonly referred to as the Akata, Agbada and Benin Formations. The Ogwashi-Asaba Formation was initially referred to as the Lignite Series (Parkinson, 1907). The Formation is seen largely around Benin, Asaba, Onitsha and Owerri.

Stratigraphic Settings of the Basin:

The southern sedimentary basins stratigraphic architecture is characterized in three depositional phases, these are: Aptian to Santonian, Campanian to Early Eocene and Late Eocene to Pliocene (Short and Stauble, 1967; Nwachukwu, 1972; Murat, 1972; Oboh-Ikuenobe, et. al., 2005) [figure 1].

An extensive transgression across the entire southern basin terminated the buildup of the Upper Cretaceous Delta from the modern Niger Delta stratigraphically duirng the Paleocene (Nwajide, 2005) [Figure 2]

Review of Previous Work:

Previous researchers have done justice to aspects of the Paleogene strata which include the petrography, lithofacies, environment of deposition, stratigraphy and micropaleontology.

As a result of the petroleum potential of the Niger Delta sedimentary basin various research ranging from geophysical, biostratigraphic, paleontological, stratigraphic/sedimentological and geology of the petroleum systems have been carried out by several researchers. Some of the works on the particular study location includes:

Oboh-Ikuenobe, et. al., (2005) in their studies on the lithofacies, palynofacies, and sequence stratigraphy of Palaeogene strata in Southeastern Nigeria suggested that the early transgressive systems tract represented in the Ogwashi-Asaba Formation is as a result of the non-marine and coastal aggradational deposits.

Acra, et. al., (2014) from provenance and sedimentological studies suggested that the sediments of the Ogwashi-Asaba Formation were from the basement complex and pre existing sedimentary rocks situated northeast of the study area.

Ekwenye, et al., (2015) studied the sandstone lithofacies of the Paleogene strata of the south-eastern Nigeria. They classified the Ogwashi-Asaba Sandstones as sub-lithic and quartz arenites.

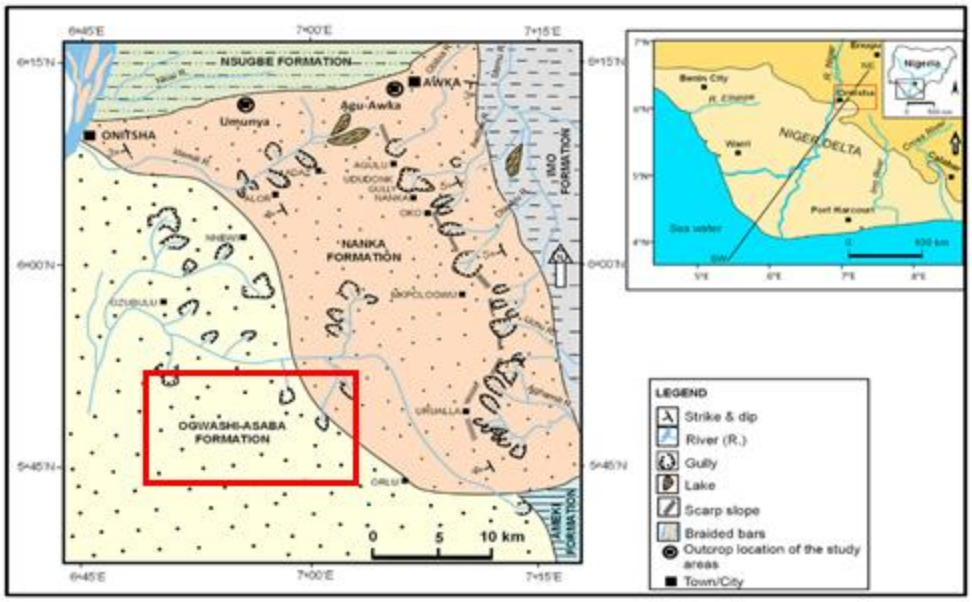


Figure 1: A Geologic map of Ogwashi-Asaba Formation and other outcropping sediments of the Niger Delta Basin. After (Ogbe & Osokpor, 2021).

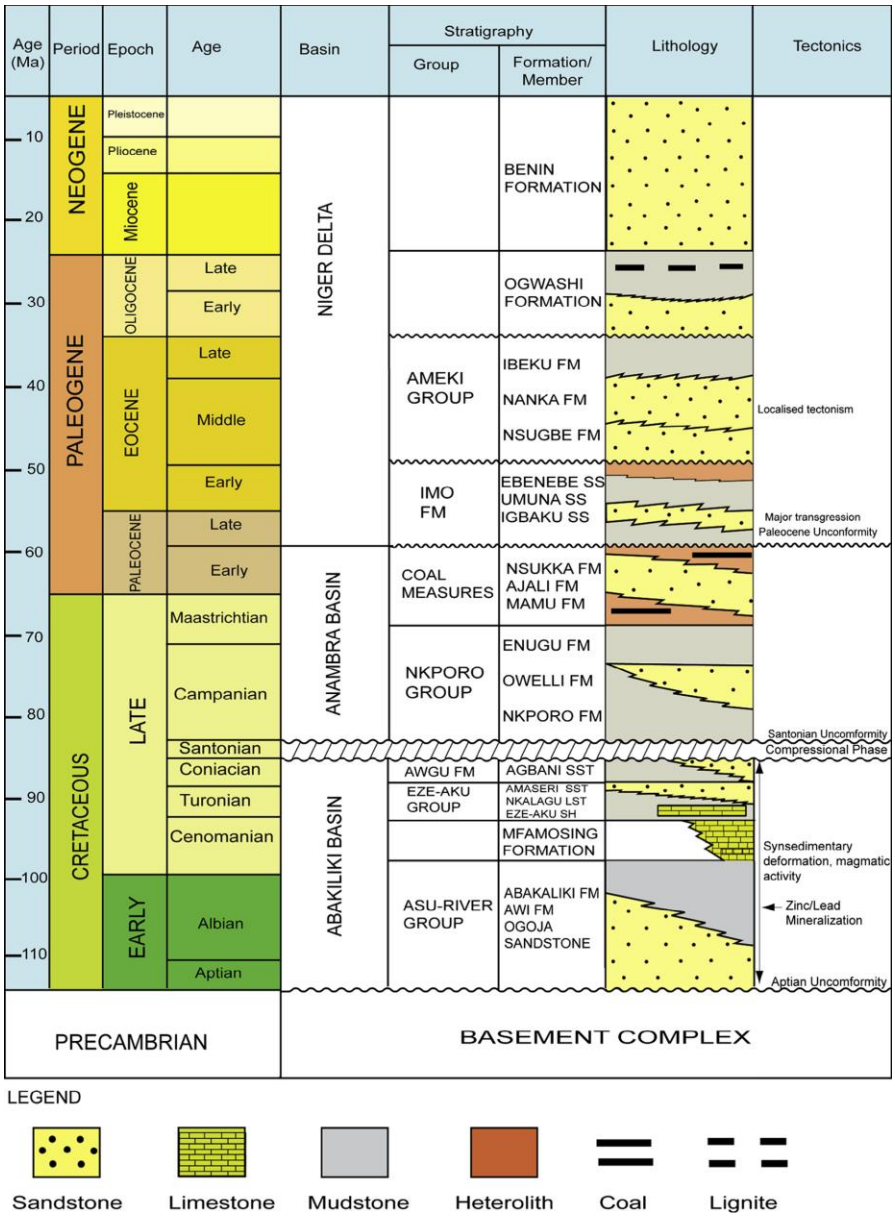


Figure 2: Stratigraphic successions of the Anambra Basin and outcropping Niger Delta modified after (Short and Stauble, 1967; Ekwenye, 2014; Nwajide, 2013).

Methodology:

The investigation procedure was executed in three (3) phases:

a) Field mapping

b) Laboratory investigation

c) Data incorporation and interpretation

Twenty (20) samples were obtained from the two outcrops studied. A detailed sedimentological evaluation was carried out which involves lithology recognition and description (the visible formation of

rocks types and mineralogical framework).

The above sedimentological field investigations were used to:

- ❖ Decipher the facies collection and lithofacies units.
- ❖ Interpret the environment of deposition.
- ❖ Reconstruct the ancient geography of the study area.

Procedure:

Because most of the samples were friable the sieve analysis was mainly used to deduct the textural parameters. A total of fourteen (14) unconsolidated and six (6) indurated samples were obtained from the outcrops logged. Standard sieve analysis procedure proposed by Friedman (1979) was utilized for dry sieving the samples. At the end of the procedure the results were analyzed; comparing the starting sample weight with the finished retained sample weight after the experiment. Using the Folk & Ward, (1957) statistical formula, textural parameters were obtained such as graphic mean size, standard deviation (sorting), skewness, kurtosis, simple skewness measure, simple sorting measure and mineralogical maturity index. These variables are paramount for in order to establish scattered plots required for the elucidation of depositional environments since size frequency distribution amid sands often match up with their different origins and terminating depositional environment (Nwajide & Reijers, 1997).

RESULTS AND DISCUSSION

Outcrop exposures that constitute the broad Ogwashi-Asaba stratigraphic successions were examined at different areas to represent a regional framework for the formation. The outcropping sections sampled are in quarrying site at Anwai Campus and Ibusa respectively [figure 1].

Location 1:

Locality name: Anwai Campus

Grid: Lat. $06^0$15’38.1” and Long. $006^0$42’00.2” **Elevation:** 103m

The section is about 9m thick. The lenticular bedded fissile shales forms the base of the outcrop which is about 1m thick and shows a sharp contact with the overlying heterolithic sequence. The 2m thick sequence comprise a lower unit of shaly heterolith characterized by lenticular bedding and an upper sandy heterolith unit characterized by flaser beddings. The sand in both units ranges from very fine to silty and the entire heterolith shows a mottle color. Overlying this sequence is a very fine to medium grained, highly bioturbated clayey sand of about 2m characterized by relics planar beds with an off-white color followed by a shaly heterolith of about 2.5m containing ripples with an erosional base. The top portion of the outcrop is a moderately bioturbated fine to medium grained sand with a creamy color having a thickness of about 1.5m [figure 3a & 3b].

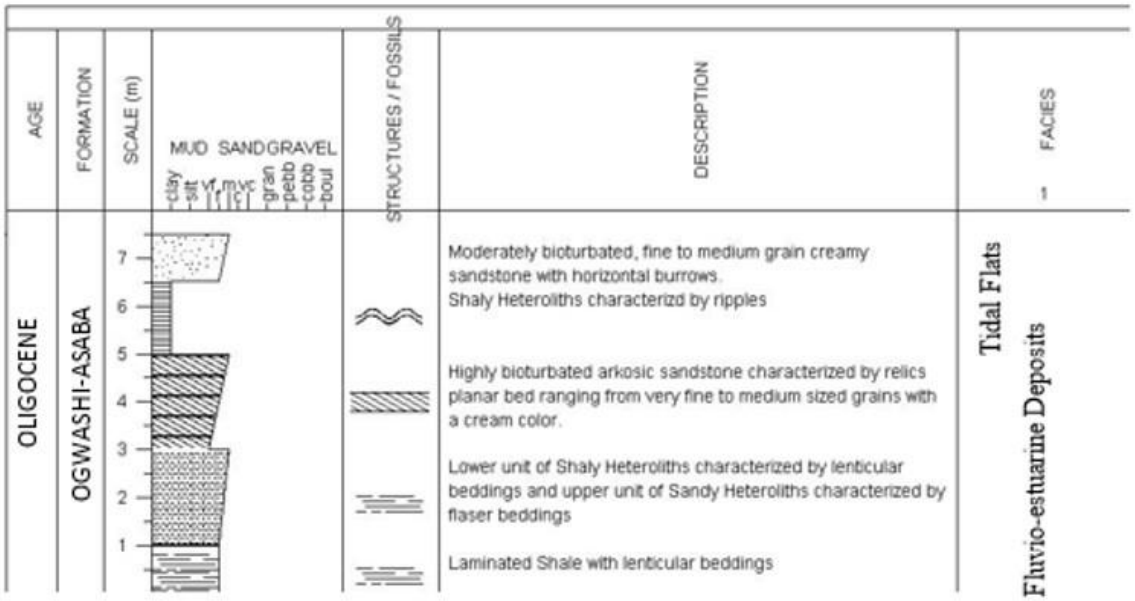


Figure 3a: Litholog of the outcrop section

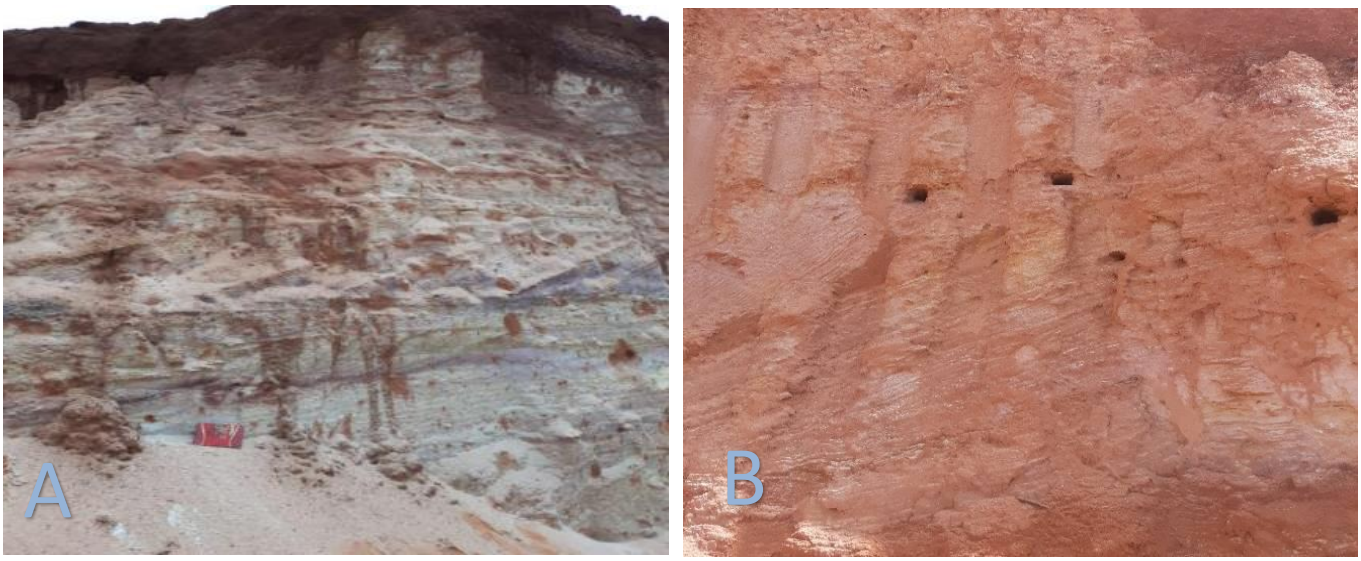


Figure 3b: section of the outcrop, Anwai 1

Location 2:

This exposure is about 6m thick. The basal part comprises of a flaser and cross bessed sandstone with angular to sub angular, medium to coarse moderately sorted grains showing a yellowish colour. With the overlying medium grain cross bedded sandstone its shows a gradual contact. Overlying this is a 0.5m clay

with lenticular bedding followed by a highly ferruginous, coarse to very coarse grain sandstone with subangular grains. They are poorly sorted. This was followed by a 2m thick medium grain sandstone. It is highly bioturbated relics with planar beds [figure 4a-4c]

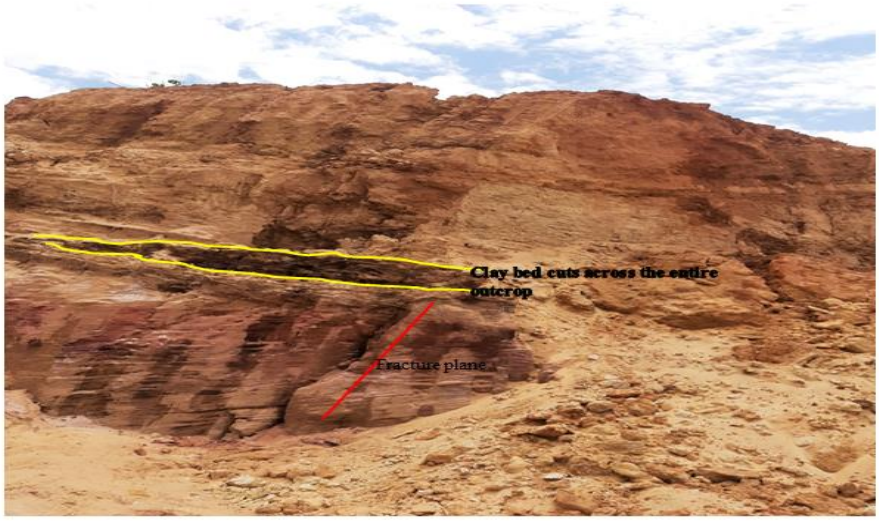


Figure 4a: showing laminated crossbed, fracture plane and clay bed

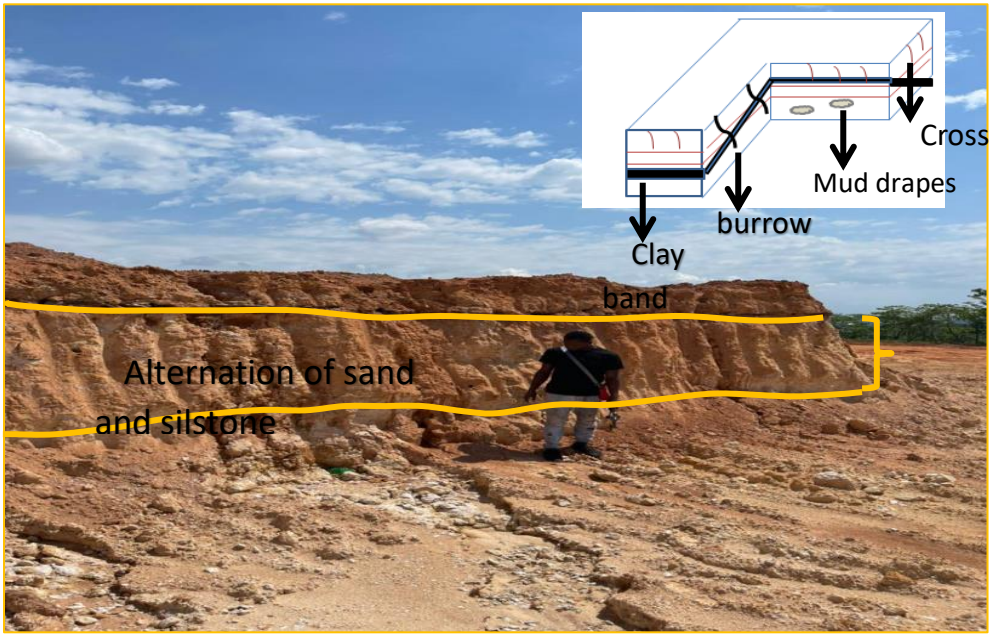


Figure 4b: showing the clay bed that cuts across the exposure

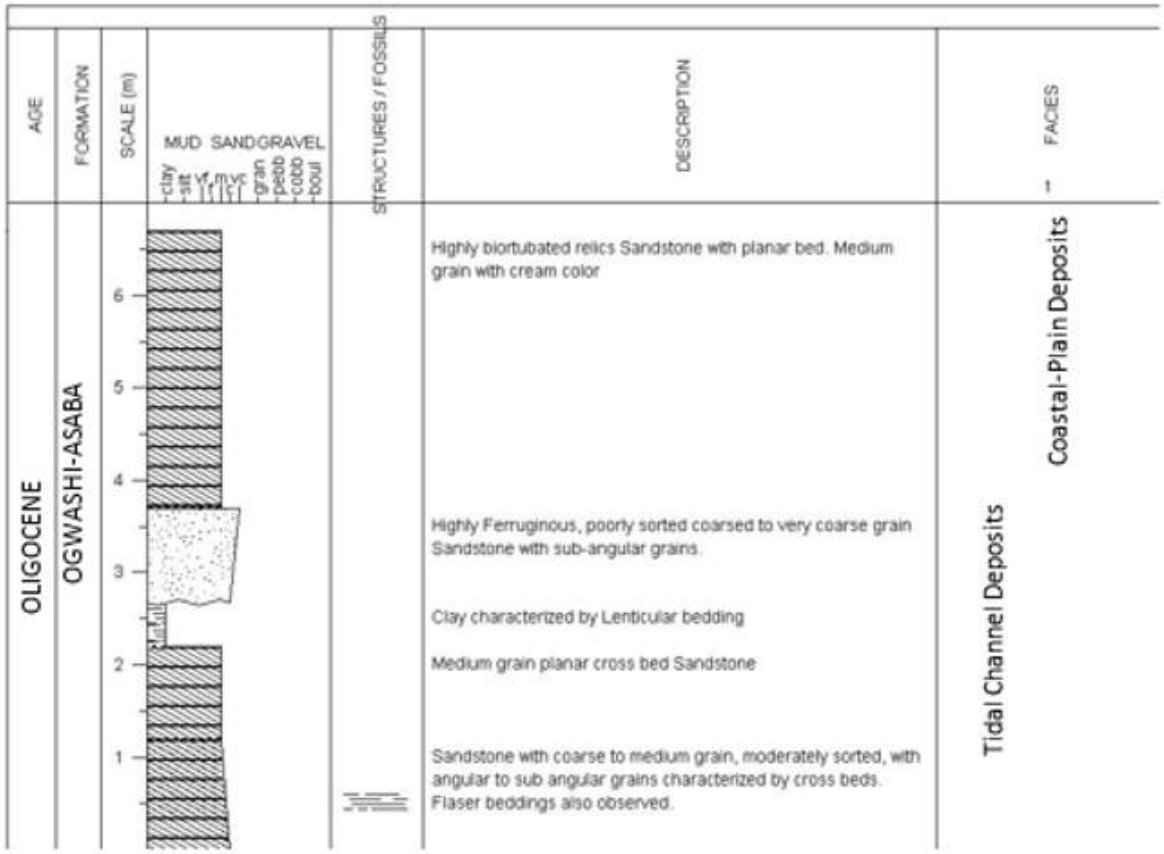


Figure 4c: Litholog and description of Anwai 2

Location 3:

This exposure shows the rear of the outcrop. The basal part is a coarse grained moderately sorted sandstone with cross beds and yellowish in colour. It grades into a medium to coarse grained trough bedded sandstone of about 2m thick characterized by clay drapes. A fine grain planar clayey sandstone that shows a sharp contact overlies this unit followed by another planar clayey sandstone ranging from fine to coarse grain. This is bounded at the base by an unconformity and at the top by a visible sub aerial exposure of iron concretion. Overlying the iron concretion is a parallel laminated shale with lenticular bedding of about 0.5m thick followed by a 3m sandy to sandy-silty heterolith [figure 5a]. The topmost portion consist of shales of more than 2.5m thick with lenticular beddings.

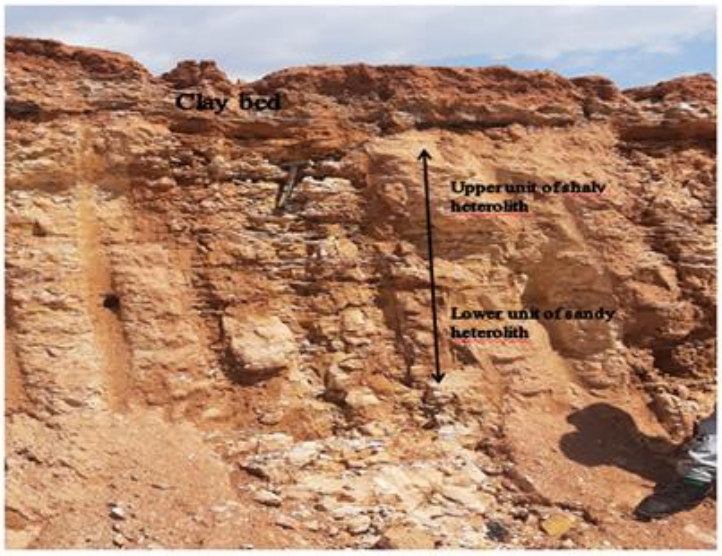


Figure 5a: Anwai 3 Heteroliths in tidally influenced deposit consisting of thinly interbedded sandstone and mudrock. Streaky laminae of very fine mudrock in sandstone.

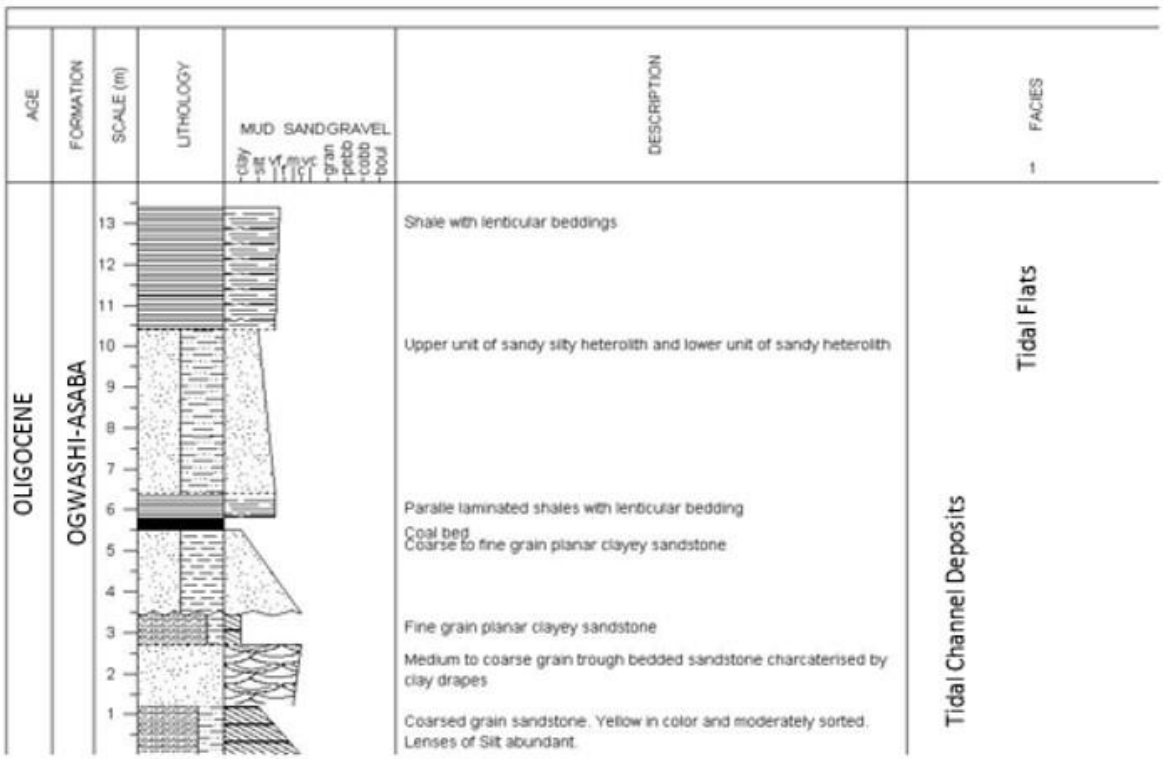


Figure 5b: Litholog and description of Anwai 3

Grain Size Evaluation:

Graphic Mean:

The sediments of the Ogwashi-Asaba Formation (Anwai Campus and Ibusa) has a mean value ranging from 1.4Φ – 2.1Φ with average of 1.8Φ indicating medium grained sand. Thus, the environment of deposition hinted here is a low energy depositional environment.

Graphic Standard Deviation:

The result shows that sediments of the Anwai Campus have a sorting value ranging from 1.3 through 1.8 to 2.0 with an average of 1.7 suggesting poorly sorted sediments. While those of Ibusa have values ranging from 1.1 to 1.5 with an average of 1.4 also suggesting poorly sorted.

Graphic Skewness:

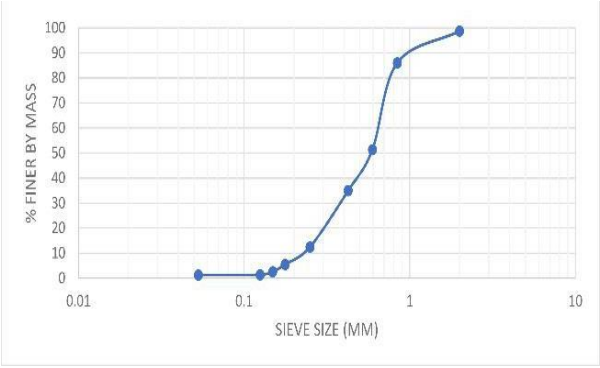
The graphic skewness of the sediments of the Ogwashi-Asaba Formation (Anwai Campus) ranges from -0.1 to 0.4 with average of -0.02 indicating nearly symmetrical. Those of Ibusa also have an average of -0.02, indicating nearly symmetrical.

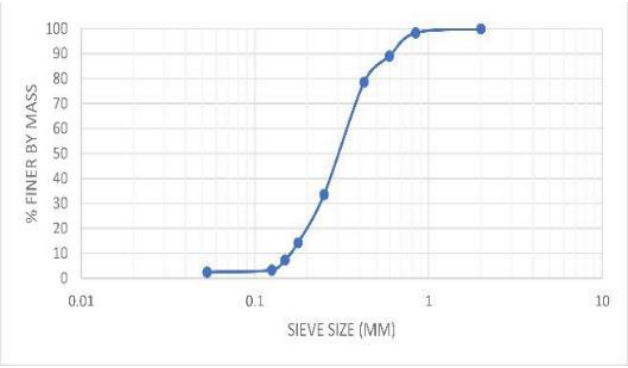
Size Parameter	Average value	Interpretation
Median	1.8	-
Mean	1.8	Medium grain
Sorting	1.6	Poorly Sorted
Skewness	-0.5	Nearly symmetrical
Kurtosis	1.2	Leptokurtic

Table 4.1: Ogwashi-Asaba Formation graphic measures summary (after on Folk & Ward, 1957)

Graphic Kurtosis:

The sediment values of the Anwai Campus ranges from 0.8 to 1.5 with average of 1.2 while those of Ibusa ranges from 1.1 through 1.9 with an average of 1.4. The values above are indicative of lepto-kurtic kurtosis. Figure 6 shows a graphical representation from the sieve analysis.





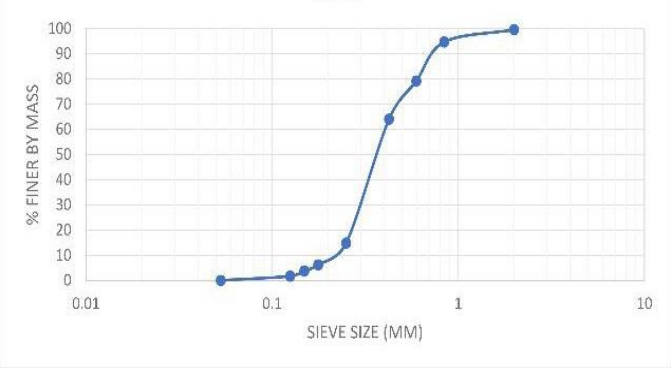


Figure 6: Graphical representation of samples collected for sieve analysis

Facies Association:

Based on the textures of the grains, sedimentary structures, geometries and bedding contacts four facies associations were tacked together from the outcrops visited.

Facies Association 1 – Tidal flats:

The facies association 1 comprises of bioturbated sandstones (Sb), laminated current rippled sandstone facies (Scr) and a good proportion of sandy heteroliths (Sh) facies characterized by yellow to pinkish fine grained sands and clays forming lenticular, flaser and wavy beddings [figure 7]. The burrows observed in the unit are moderate to strong and Ekwenye, (2015) described the heterolith facies as intertidal flat.

This facies is dominated by heterolithic strata. This strata constitute of interbedded sandstone and shales deposited in intervals. Noticeable facies within this assemblage include bioturbated sandstone, horizontally laminated, cross laminated sandstone, massive sandstone, trough cross bed, planar tabular cross bedded sandstone, convolute lamination (following rapid deposition), lenticular beddings, flaser beddings, wavy and streaky beddings. Beddings are also inclined to an angle from the original horizontal layer. Also abundant were drapes of muds, burrows, traces and borings.

Across the exposure the heterolithic units are dominated by sandstones or a range of sandstone – mudrock dominated. The predominant sandstone heterolith generally comprises of parallel laminated sandstone, trough cross beds with thin mud drapes. Portions of this interval are highly bioturbated. The sandstone-mudrock dominated heterolith contains about 40-95 percent mudrock. Sandstone beds are about 1m thick while some bioturbated portions are about 3m thick. Observed structures here include lenticular, flaser and wavy beddings. Wavy, flaser, streaky and lenticular beddings are normally formed in a coarsening-upward sequence (Hettinger, 1995)

Interpretation:

Heteroliths contain attributes that are indicative of a subaqueous depositional environment subjected to the influence of tidal currents. Within a tidal zone sub-environments include estuaries, lagoon and tidal creeks. In contrast the lenticular, flaser, wavy and streaky bedding are results of mixed or

alternating energy within the environment e.g. churning water occurrence related to intertidal and subtidal activities (Reineck & Singh, 1980)

Occasionally, mud drapes are deposited above dunes during sandwaves that comprise extensive reactivation and erosion surfaces within tidally controlled rivers (Hettinger, 1995).

Sandstones and mudrock beds that are tilted are explained as inclined heteroliths. Inclined heterolithic layers with steady and continuous drapes of mud have been described in contemporary lateral accumulation of point bars in tidally influenced rivers (Smith, 1987; 1988); these have been used as a standard to differientiate past tidally influenced point bars (Thomas , et, al., 1987).

Figure 7: Heteroliths in tidally influenced deposit consisting of thinly interbedded sandstone and mudrock. Streaky laminae of very fine mudrock in sandstone

Facies Association 2 – Tidal channel deposits:

This facie association comprises of laminated current rippled sandstone (Scr), sandstones defined by low angle planar cross beddings (Sp), sandstones characterized by trough cross beddings (St) trending south-east, and bioturbated sandstone (Sb) facies. The unit largely constitute of very coarse grained sandstones although the base is characterized by pebble-sized ranges. Also commonly observed in this unit were extensive lenses of clays, pockets of mud drapes with planar bedding, reactivation surfaces (Sr) with wavy beddings formed by thick mud bands and ripped-up clasts [figure 8]

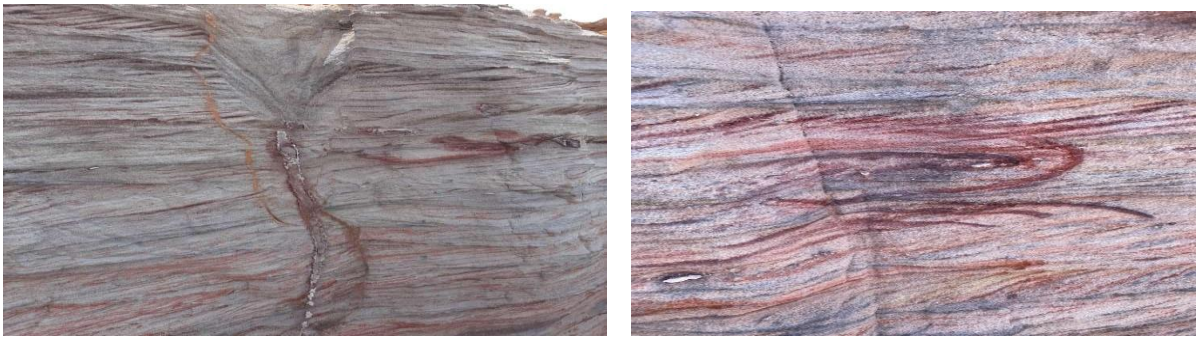


Figure 8: The sandstone is cross-bedded, contains reactivation surfaces, ripped up clasts and burrows

Facies Association 3 – Fluvio-estuarine deposits:

The facies association herein contains laminated cross rippled sandstone (Scr), trough cross beds (St), planar cross beds (Sp), bioturbated sandstone (Sb) facies and cross stratified herringbone sandstone (Scsh). The trough cross bedded sandstones lies in alternating manner with planar cross bedded sandstones, plane parallel laminated sandstone beds, and the low angle cross bedded sandstones. The sand size ranges from medium to coarse grains and a fining upward trend was generally observed.

According to Pearson, et. al., (2012) the tidal influence observed in this setting accompanied by high energy regime during the deposition of sediments are buttressed by the coarse grained sizes, cross-bedded sandstones, lenses of muds, drapes of mud foresets and mud clasts.

The distinctive feature of the fluvial channel deposits from the tidal deposits are the absence of trace fossils and mud. The fluvial channel deposits are believed to have been deposited in a zone extending landward from the tidal zone (a coastal plain setting) (McCabe & Shanley, 1992)

Tidally influenced fluvial deposits that accumulate in the transition zone between the tidal and fluvial channel are explained as sandstones accomodating scanty mud, borings, and shell fragments.

Facies association 4 – Coastal plain deposit:

The massive fine grained sandstones and mudrocks (siltstone and clays) suggests a coastal plain deposit. The coastal plain deposits are further subdivided into sand-filled or mud-filled channelized deposits which occur as multistorey or isolated deposits, and the non channelized deposits which are seen as floodplain deposits and cross-stratified sandy successions.

On the basis of facies analysis, elaborate description of outcrops encountered and the petrographic analysis, the Ogwashi-Asaba Formation can be interpreted as **tidally influenced deposits.**

Depositional Environment:

Prevailing depositional condition at the time when sediments are deposited and preserved can be established from lithofacies intepretation. The ranges of grain sizes from fine through medium to coarse grain with associated cross beds with occasional drapes of clays is an indication of mixed energy regime during

deposition. These environments inlcude tidal settings, fluvial settings and fluvio-estuarine deposits. The depositional characteristics that suggests a tidal setting include flaser beddings, planar structures of unidirection, drapes of clay, wavy laminations and reactivation surfaces. The reactivation surfaces indicates a prevailing high energy system.

From the associated tidal and fluvial processes the outcropping sediments of the Ogwashi-Asaba Formation is thus interpreted as a **tidally influenced coastal plain fluvial channel** [figure 9a & 9b]**.** According to Ekwenye, (2015) the outcropping sediments of the Ogwashi-Asaba Formation are coastal plain deposits that may have been tectonically and eustatically controlled. As a result of relative sea level changes the depositional sequence depicts a condition from marine to non marine [figure 10].

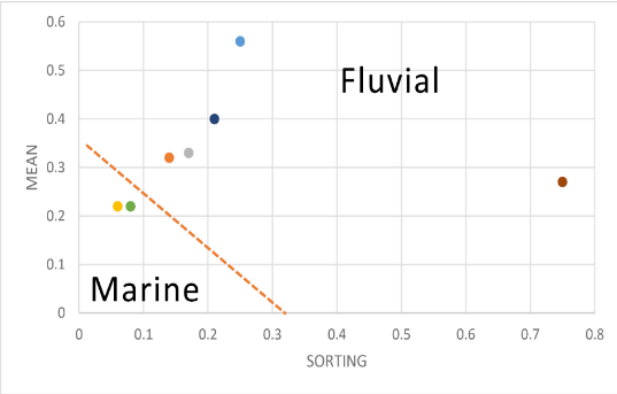


Figure 9a: Bivariate plot of graphic mean versus sorting show deposition in fluvial setting (Modified after Friedman, 1967)

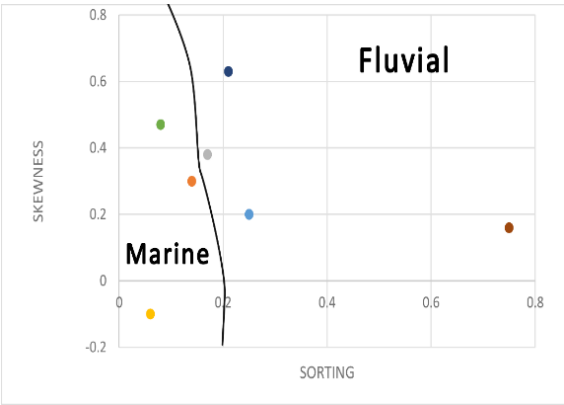


Figure 9b: Bivariate Plot of Skewness Versus Sorting suggest deposition in fluvial setting (Modified after Friedman,1967)

Deposits of isolated channels are most common in the fluvio-estuarine depositional environments with a lower bounding and scoured surface. Also associated with the fluvio-estuaine, coastal plain and tidal channel environments respectively are the multistorey channel deposits. They are made up of several channels that are incised and stacked into each other with a lower bounding, scoured erosive surface (Miall, 1985). Continuous erosion and infilling according Komatsubara, (2004) may be an hint of erosional surfaces

within the multistorey channel deposits. Mud-fill channels maybe due to rapid channel abandonment while sand in-fill may be product of progressive channel abandonment (Hopkins, 1985).

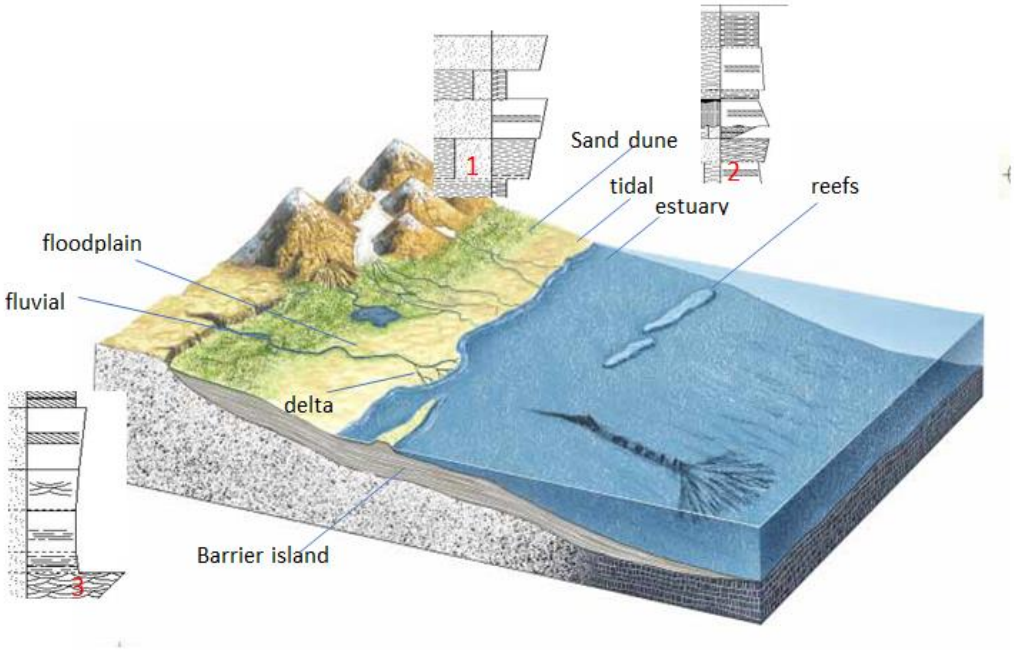


Figure 10: A conceptual model modified after (Thompson & Turk, 1997) showing the facies and the environment of deposition in which the sediments of the Ogwashi-Asaba Formation accumulated. Log 1 shows deposition in a coastal plain setting. Log 2 indicates a tidal flat deposit. Log 3 shows an fluvio-estuarine environment respectively.

CONCLUSION

The outcropping sediments of the Oligocene Ogwashi-Asaba Formation of the Niger Delta Basin shows a **tidally influenced coastal plain fluvial channel** deposits that may have been tectonically and eustatically controlled. The depositional sequence depicts a condition from marine to non marine resulting from relative sea level changes.

Facies architecture in the coastal plain and fluvial deposit implies a predominance of channelized deposits that shows various isolated and multistorey channel deposits that were formed during the intermittent shoreline transgression. In a nutshell, the stratigraphic sequence of the Ogwashi-Asaba Formation may have resulted from relative sea level changes, sediments availability from pre-existing rocks, accomodation space and geomorphology of the area.

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