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RESEARCH ARTICLE

SEDIMENTARY FACIES AND DEPOSITIONAL ENVIRONMENT ANALYSIS OF THE CAMPANIAN-MAASTRICHTIAN DEPOSIT OF THE ANAMBRA BASIN, SOUTHEASTERN NIGERIA

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ABSTRACT

In late Cretaceous, the Benue Trough was subjected to the Santonian tectonism that leads to the formation of the Anambra Basin. A detailed study was carried in the Awgu section of the Anambra Basin were six outcrops were visited across the basin. Lithofacies studies was carried out on the sediments and sedimentary rocks of the various formation in the Anambra Basin. Detailed field mapping exercise was also carried out with respect to logging and identification of sedimentary structures. Six (6) outcrop sections were studied and categories into six lithofacies associations based on their stacking patterns. The Anambra basin is dominated by carbonaceous shales, dark fissile shale, siltstone, heterolithic sandstones, sandstones and conglomerate in some places. The various formations within the basin provides some understanding on the variability of depositional environments and facies succession and association. In the Anambra Basin, studies of the lithofacies, lithofacies association and succession has revealed that the formations in thye basin were deposited in a marginal marine to marine setting and the sub-environments identified are tidal channels to intertidal flat, delta plain to coastal swamp, the subtidal to coastal swamp and the shoreface. The fining upward and coarsening upwards sequences of the lithofacies and their vertical successions shows that the sediments were deposition during the transgressive and regressive phase of the ancient sea.

KEYWORDS

Facies, Sedimentary, Campanian-Masstrichtian, Lithology, Anambra Basin

1. INTRODUCTION

Sedimentary facies is a body of rock or sediments that exhibits a distinct set of characteristics such as lithology, textures, fossil content, geochemical signatures, composition and sedimentary structures that reflects the conditions under which it was deposited in a given setting which can be fluvial, deltaic, Aeolian, glacier and marine (Reading, 1996; Boggs, 2013; Nicolas, 2009). The characterization of clastic sediments was due to the interaction between the physical, chemical and biological processes with respect to weathering, erosion, transportation and deposition and this resulted in the formation of sediments, sedimentary facies and sedimentary environment (Chernicoff and Whitney, 2007; Nichols, 2009).

Evaluation of the different types of basins and sub-basins of the Nigeria continental margin unveils the differences in their stratigraphic evolution, which is suggested to be caused by the difference in their structural and tectonic framework (Agumanu, 2009). The natural processes that caused these differences in stratigraphic evolution are the main reasons for the different Formation types that occur in the proximity within the studied basins. Hence, there is need to outline each of the geologic Formations that exists within these basins, with a view to appreciating mechanism(s) liable for their deposition within the basin they are found (King, 1950). A careful approach should be applied while studying the basins, with respect to the stratigraphically complex Anambra Basin, in order to have a better knowledge on its complexity and proffer a clear understanding on the controversy that arises from the composition and age of the first sedimentary deposit in the basin (Agumanu, 2009). The Anambra Basin is a sedimentary succession formed after the Santonian tectonic event that causes uplift for the Benue Trough thereby creating depositional centres that leads to the formation of the Anambra Basin with successions of the Nkporo Formation, Owelli Sandstones, Enugu Formation, Mamu formation, Ajali Sandstones and the Nsukka Formation (Nwajide, 2013). These successions are lithofacies that is Campanian to Early Palaeocene in age (fig.1). Other notable researchers such as tow the part that the Anambra Basin as part and parcel of the Benue Tough in the ground that it is a consequence of the compressional history of the Trough (Akande and Erdtmann, 1992; Obaje et al., 1999). The study the Anambra Basin is characterized by different lithologic heterogeneity in both lateral and vertical extensions that are gotten from a range of paleoenviornmental settings (Nwajide 2013; Ogala et al., 2009). Several works have been carried out in the Anambra Basin with respect to its sedimentary facies association and succession by several scholars such as but a comprehensive work for proper understanding of the lithofacies has not been fully established because most the works has been on a single formation (Nwajide, 2013; Umeji, 2006; Onugbo et al., 2012; Uzougbu, 2013). Therefore, this work will aid in a better interpretation of sediment deposited across the Basin in a large scale for the purpose of evaluation of the depositional environment of the various formation in the Anambra Basin.

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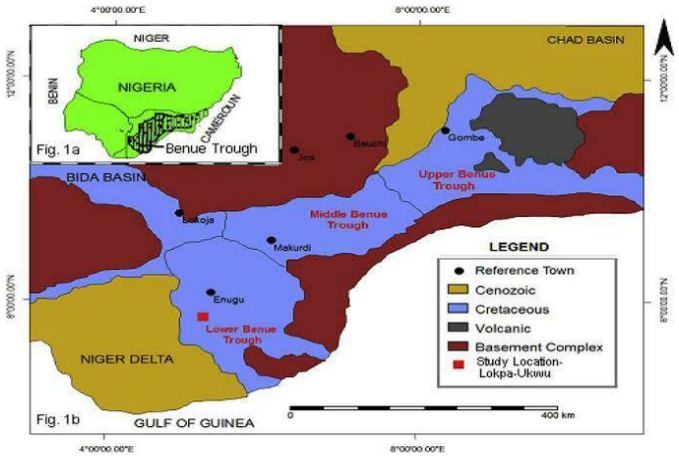

Figure 1: Map showing Geological Units of Benue Trough (Adapted from Short and Staubble, 1967)

2. Location Of Study

The studied area lies within longitudes 7⁰25⁰E and 007035'E and latitudes 6⁰17⁰N and 6⁰02⁰N with an area extent of 513sqkm (fig. 2).The study area covers parts of Enugu, Abia and Imo State Respectively and are eassily accessed by major and minor roads as well as track roads and footpaths that are interconnected.

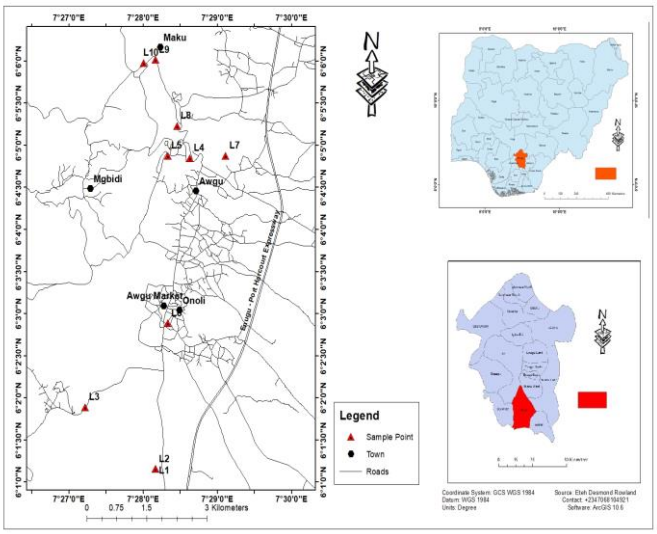

Figure 2: Map showing the study area

3. Materials And Methods

Three systematic stages were initiated in this research work. These stages are: systematic review works done in the past with respect to the study area and reconnaissance survey, then desk study and field studies/mapping, and interpretation of current findings. The adopted method employed in this study was an all-inclusive description of outcrop sections of the exposed out crop on road cuts along Awgu-Archi Road.

The exposed sections of the studied outcrops were described in detailed and were logged from their base to their top with attention given to critical lithofacies definition parameters such as the lithology, texture, sedimentary structures and fossils. Interpretation of depositional environment was achieved through the vertical transition pattern of the lithofacies. Representative outcrop sections of the formation logged were noted. These sections form the basis for definition of the depositional model for the Formation.

4. Results And Discussions

4.1 Data Presentation and Results

This focuses on the presentation of litholog description of outcrops, with respect to their lithologic composition, paleoenvironments and their stratigraphic framework.

4.2 Lithologic Description of Outcrops

Locality: Nkwo-Mbanano Junction, Along Awgu-Mmaku Road

Formation: Nkporo

Rock type: Owelli Sandstone andNkporo Shale

GPS Coordinates: 06⁰ 05/ 47.6//N and 007⁰ 28/ 52.5//E

Elevation: 195m above sea level.

Lithology Description: The basal part of the outcrop is marked by medium to coarse grained sandstone. The brownish to white colour sandstone is characterized by the presence of pebbles that ranges from sub-angular to sub-rounded in shape (indicating that they have not been transported from a long distance) with the presence of Ophioomorpha and Skolithos (bioturbation structures). It is observed that the sandstone in composed predominantly of quartz and feldspathic minerals. Above the basal bed is overlain by a parallel-laminated brownish silt dominant heterolith with clay having a thickness of 0.1m.

Directly above this bed is overlain by another bed composed of fine to medium grained reddish-brown sandstone that is bioturbated with a thickness of 0.2m. This bed is followed by a silt dominant heterolith with clay with a thickness of about 0.3m. This bed is then followed successively by a shale dominant heterolith with silt having thickness of 1m. The bed is succeeded by sand and silt that is matrix supported. The bed unit is bioturbated, having Ophiomorpha Spp with a thickness of about 0.2m. Above this bed in overlain by another bed characterized by brownish fissile shale of 3m thickness. Following this bed, is a very fine-grained well sorted, planar Cross bedded sandstone having a thickness of about 0.7m. Overlying this bed, is another poorly sorted planar cross bedded sandstone bed. The bed is characterized by fine to very coarse grained sandstone, sub- angular to sub-rounded shape of grains and having a thickness of about 1.3m. Above this bed, is overlain by a dark fissile shale having a thickness of about 7.4m. Thus, the sum total of the outcrop section is 12.3m. the described outcrop is shown below in fig. 3, while the lithologic section is shown in fig. 4

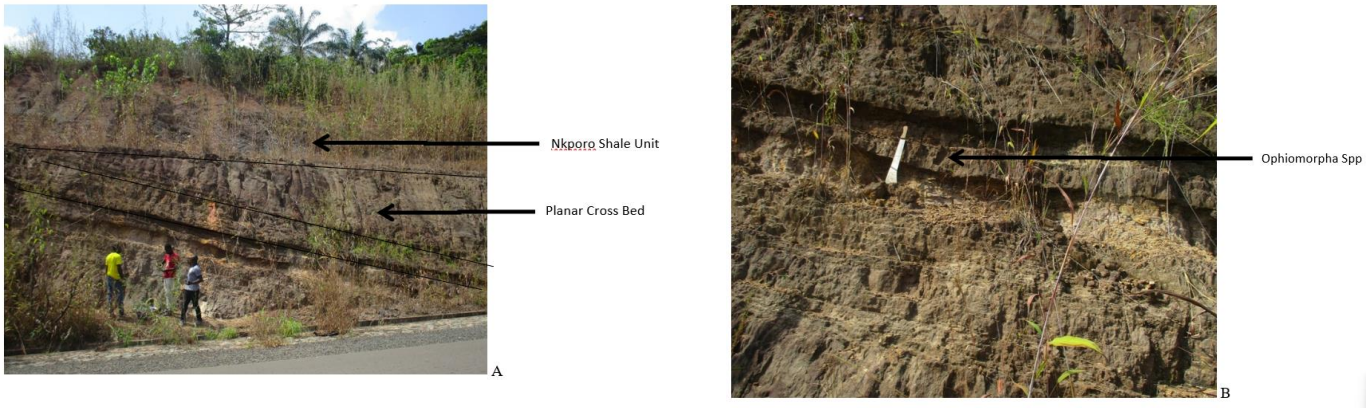

Figure 3: Outcrop Section of Nkporo Formation at Nkwo-Mbanano Junction showing: (A) Lateral view of the Nkpoeo Formation (the human scale is 155cm) (B) Bioturbated section of the outcrop (the matchet scale is 52cm)

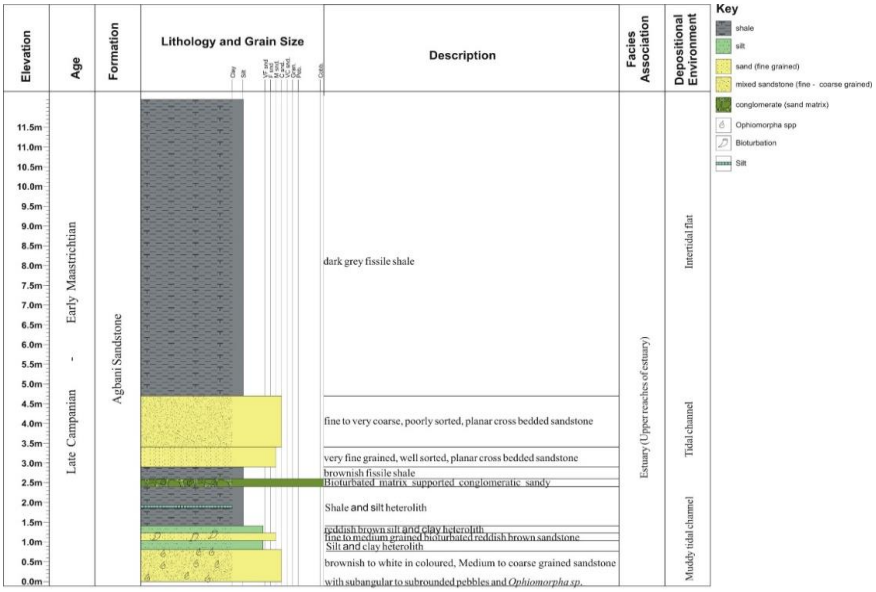

Figure 4: Lithologic Section of Nkporo Formation at Nkwo-Mbanano Junction

Fig. 4.: Lithologic Section of Nkporo Formation at Nkwo-Mbanano Junction

Locality: Mmaku

Rock Type: Shale and Oolitic Ironstone

Formation: Nkporo

GPS Coordinates: 06°11¹013¹¹N and 007°45¹27.2¹¹E

Elevation: 322m

Lithology Description:

The base of this formation comprises of grey coloured shale that are fissile having a thickness of about 0.2m. Above this bed is a dark-grey coloured fissile shale having a thickness of 0.7m. Directly above this bed is a fine to medium grained brownish sandstone, non bioturbated, having planar beds and with a thickness of 1m. Lying above this bed is a dark to grey coloured shale with high fissility, non biortubated, having a thickness of about 0.9m. Above this bed is an oolitic ironstone that are rich in fossils, brownish in colour, having a thickness of 1m. The described outcrop section is shown in fig.5. The total thickness of the bed is approximately 3.8. The outcrop lithologic section is shown below in fig.6.

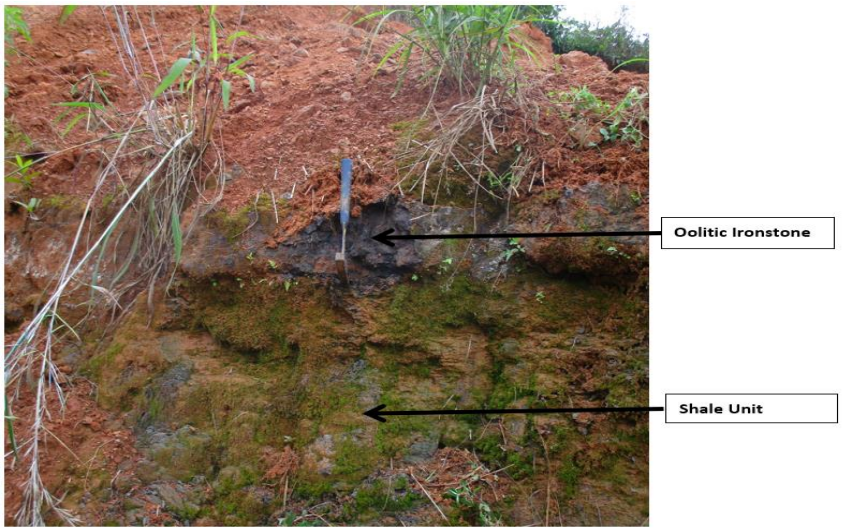

Figure 5: Nkporo Formation outcrop section at Community Secondary School, Mmaku showing Lateral view of the formation where the hoeizontal planar lamination, the sandstone unit and the shale unit of the formation (the human scale is 256cm)

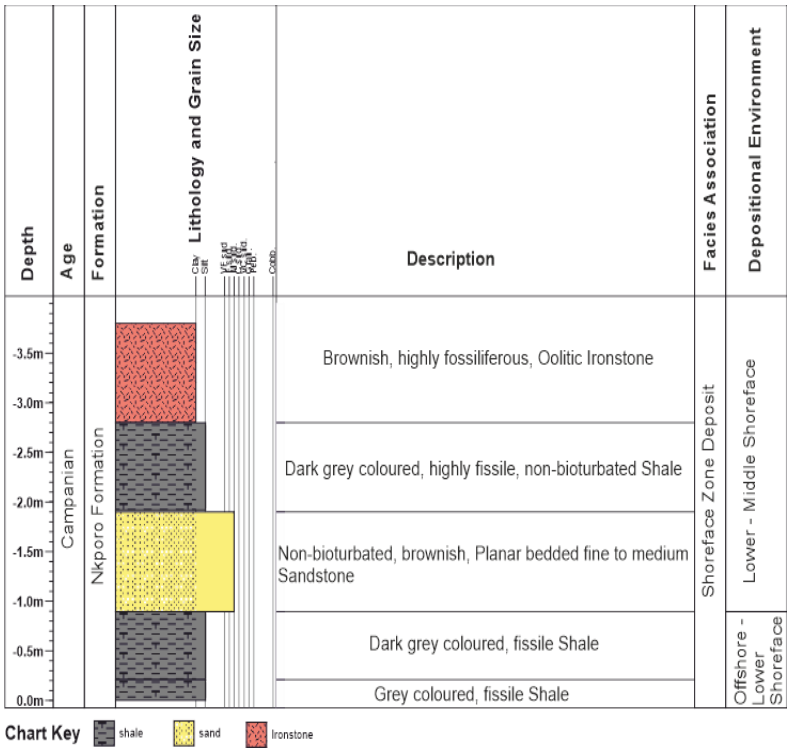

Figure 6: Lithologic Section of Nkporo Formation at Community Secondary School, Mmaku

Locality: Ugwueme Town

Rock Type: Shale

Formation: Nkporo

GPS Coordinates: $06^{0}01^{///}$ 48.6N and $007^{0}27^{/}$ 06.5$^{//}$E

Elevation: 247m above sea level

Lithology Description: The base of the outcropping section is marked with dark to grey coloured shale having a thickness of 0.17m. Above this bed is a fine grained sandstone ranges from grey to brownish in colour with clay presence having a thickness of about 0.23m, with striking values of $270^{o}/320^{o}$ and dip angle of 4^{o}. Directly above this bed is a dark to grey coloured shale of about 0.26m thick. Succeeding this layer is a fine grained parallel laminated clayey sandstone that is reddish to brown in colour with thickness of about 0.15m. Above this bed is a fine grained clayey sandstone with siltstone that are parallel laminated. This bed is a sandstone dominated heterolith with siltstone of about 0.35m. Above this bed is cover section of about 1.20m. Directly above this bed is a coarse-grained bioturbated sandstone that are characterized by planar cross beds. There is presence of Ophiomorphas. The bed is succeeded by a conglomeratic bed that are trough cross-bedded of about 3.5m thick. The topmost layer of the formation is conglomeratic with athickness of about 2.0m thick. It serves as a very good reservoir due to the presence of high porosity. The described outcrop section is shown in fig.7. The outcrop lithologic section is shown below in fig.8

Figure 7: Outcrop Section of Nkporo Formation at Ugwueme Town showing (A) The upper section of the outcrop composed of very course grained sandstone (the biro scale is 20cm) (B) The basal part of the outcrop composed of shale rock

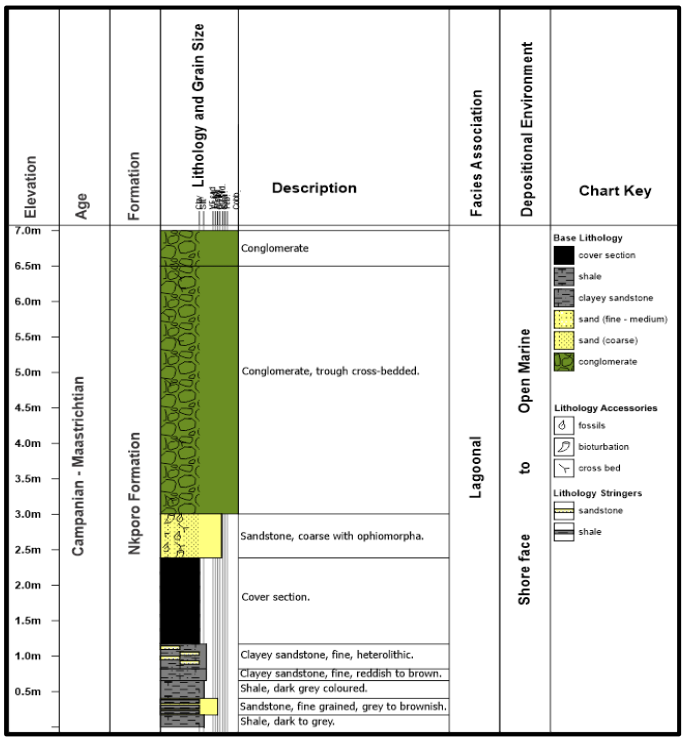

Figure 8: Lithologic Section of Nkporo Formation at Ugwueme Town

Locality: Ozuola Junction

Rock Type: Shale

Formation: Enugu Shale

GPS Coordinates: 06°31′81.9″N and 007°47′85.2″E

Elevation: 210m

Lithology Description:

The basal section of the outcrop section is made up of predominantly shales that are very dark in colour, with less fissility, having a thickness of 1.0m. Directly above this bed is a dark to grey coloured shales that are highly fissile with a thickness of 3m.

Above this bed is a dark to grey coloured carbonated shale, having fissile with a thickness of 2.5m. Lying directly above this bed is a fine to coarse grained pebbly clayey sandstone, brownish in colour, non bioturbated with a thickness of 1.6m. Thus bring the total thickness of the outcrop section 8.1m.

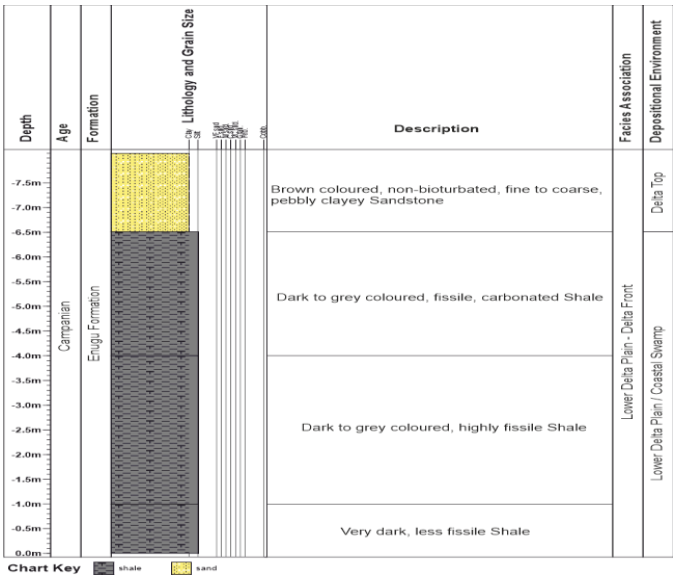

Figure 9: Lithologic Section of Enugu Formation at Ozuola, Enugu State

Locality: Obeagu Town

Formation: Mamu

Rock Type: Shale

GPS Coordinates: 06°09’ 21.9” N and 007°25’41.3”

Elevation: 326m above sea level

Lithology Description: The bsasl part of the outcrop is marked by coarse-grained moderately sorted well rounded, not bioturbated, clayey sandstone that are whitish to pinkish in colour comprises of feldspars and quartz minerals. The clayey sandstone bed strikes 326° and dip direction of 6° – 8°. The thickness of this bed is 0.2m. Overlying this bed is a cover section of about 0.23 m thick. Lying directly above the cover section is a coarse-grained, moderately sorted sandstone bed. The sandstone bed is not bioturbated, the grains are sub-angular to rounded in shape. The sandstone is whitish in colour and has a thickness of 0.52m. This bed is overlain by brownish to grey coloured indurated fine to medium grained sandstone bed, having a thickness of 0.65m. the sandstone are moderately sorted having a rounded shape. This bed is however succeeded by a fine-grained brownish sandstone that are parallel laminated with a thickness of 0.1. Above this bed is a thin layer of siltstone, yellowish in colour having a thickness of approximately 0.07m striking 278°. This bed is overlain by a siltstone bed that are parallel laminated with a thickness of 0.16m. Just

directly above this bed is a ferrogenise sandstone bed. The sandstones coalesce to form ironstone and is brownish in colour, striking 312^0, dip direction 68^o and dip angle 8^o with a thickness of 0.11m. above this bed is a grey coloured fossiliferous shale that looks carbonated having a thickness of 1.46m. Lying directly above this bed is another grey coloured shale bed with a thickness of 0.4m. The shale is not fossiliferous like the overlying layer. This bed is then successively overlain by a grey coloured overturned shale bed. The bed is greatly disturbed. This is believed to be caused by tectonism which confirms that the Santonian tectonic event continued up to Maastrichtian. It has a thickness of about 1.55m. This bed is succeeded by an overturned shale that is very dark in colour, having a thickness of 1.30m. Lying above this bed is also an overturned grey to dark coloured shale about 0.6m thick. Above this bed is a horizontal bedded shale of about 3.0m thick. The shale is highly fissile but darker in colour.

Figure 10: Outcrop Section of Mamu Formation in Obeagu Town Showing tectonic effect caused by the Santonian Tectonism (A) Faulting of te sandstone unit of the outcrop (the hammer scale is 20cm) (B). Showing the overturned nature of the shale unit (the hammer scale is 20cm)

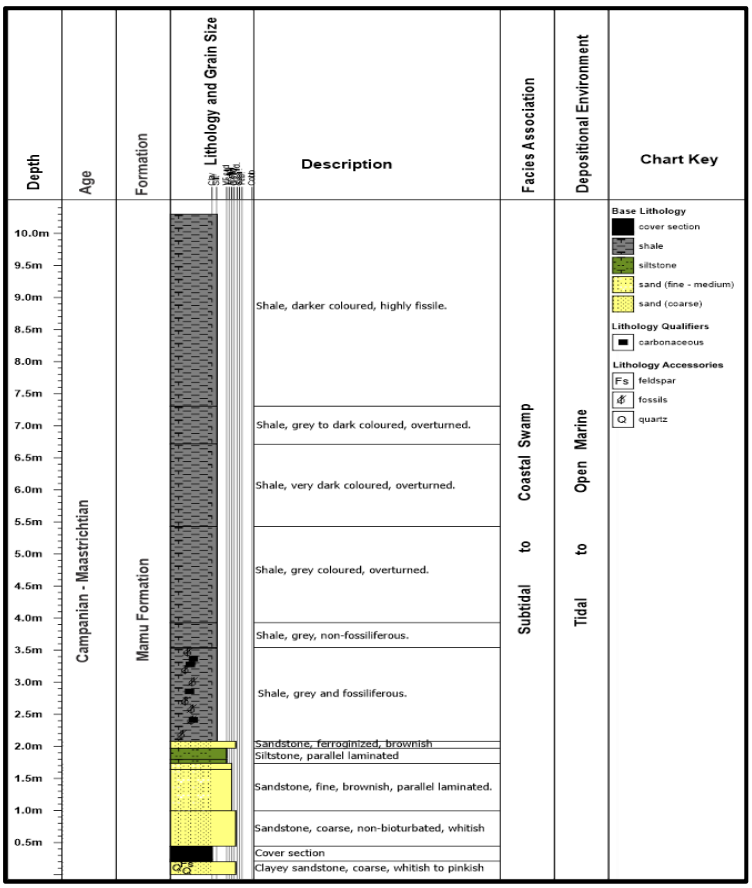

Figure 11: Lithologic Section of Mamu at Obeagu Town

Locality: Isuochi

Formation: Ajali

Rock Type: Sandstone

GPS Coordinates: 06^{o}00'47.7" N and 007^{o}25'02.9" E

Elevation: 350m above sea level

Lithology Description: The basal part of the outcrop is marked by medium to coarse grained sandstones that are poorly sorted, pale to pinkish in colours, having deactivated surfaces with a thickness of 0.23m.

This bad is overlain by well sorted, fine-grained sandstones that ranges from pale to yellowish in colour having a thickness of 0.17m. the bed is however, succeeded by a pale to brownish medium to coarse grained sandstone that are poorly sorted. The bed is characterized by planar-cross bed having strike values of 212^o/208^o/ and dip direction of 98^o. The bed has a thickness of 0.20m. Directly above this bed is a medium to coarse grained bed. The grains are moderately sorted, having colours ranging from light brown to dark brown and is characterized by trough cross-beds with a thickness of 0.06m. This bed is then overlain by coarse-grained sandstone, brownish in colour with a lot of inter-fingering cross-beds, having strikes values in the range of 220/210/208. The thickness of the bed is 0.17m. Above this bed is medium grained parallel laminated sandstone having multi-colours ranging from yellow to pink to pale. The thickness of the bed is 0.30m. Succeeding this bed is a fine-grained clayey sandstone, light brown to pinkish in colour, having planar cross-beds with a thickness of 0.16m. Thin bed is overlain by fine-grained clayey sandstone, characterized by herringbone cross-bed structures with thickness of 2m. Above this bed is a cover section with a thickness of 4m.

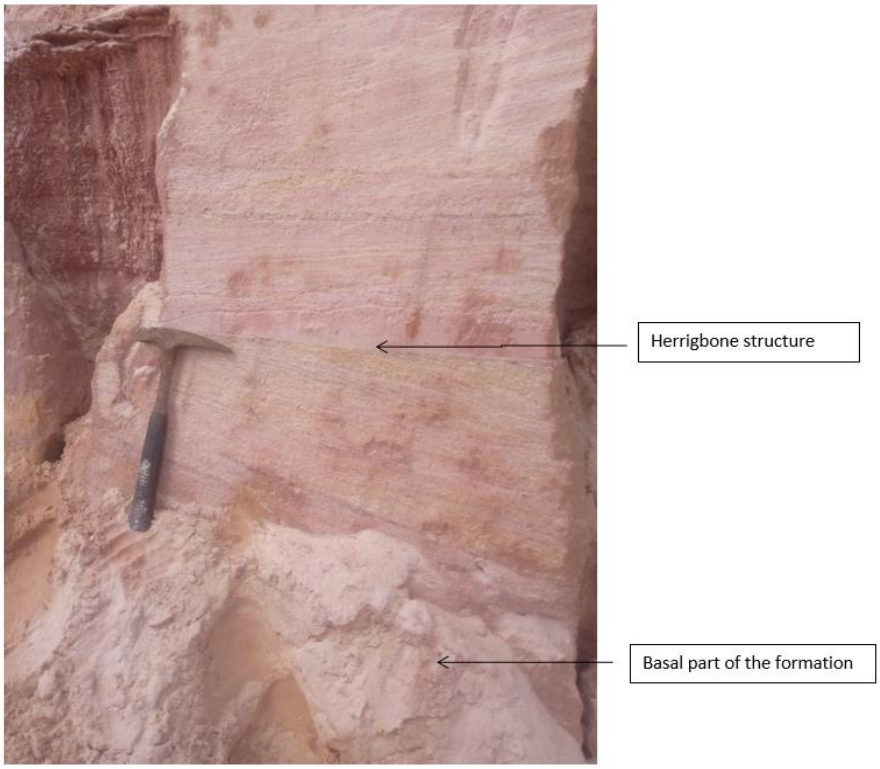

Figure 12: Outcrop Section of Ajali Sandstone at Isuochi showing the herringbone structure and the basal part of the formation (the hammer scale is 20cm)

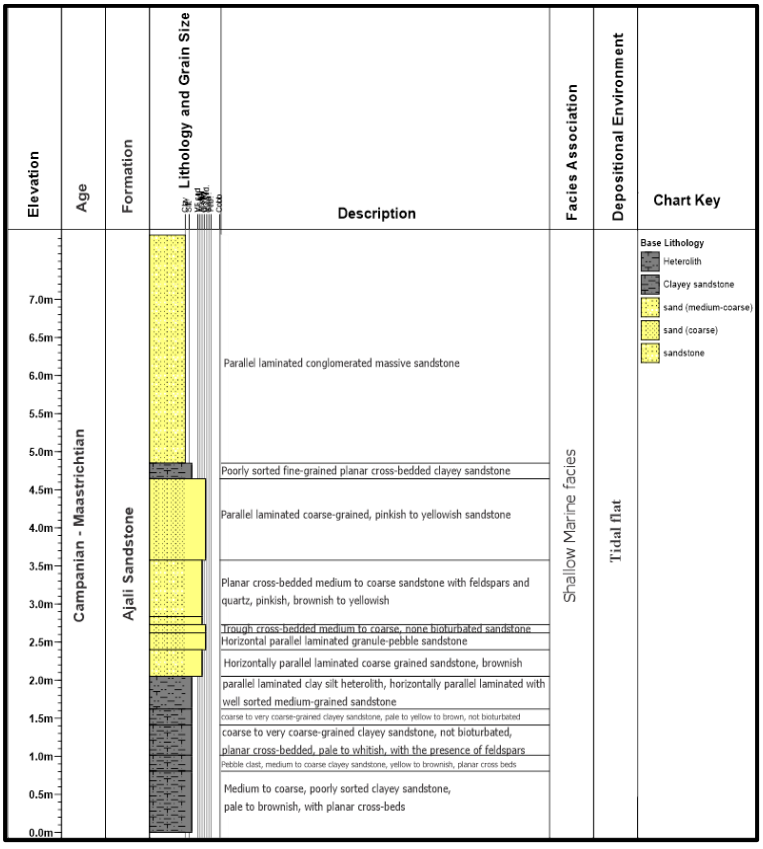

Figure 13: Lithologic Section of the Friable Ajali Sandstone at Isuochi

Locality: Ihube

Rock Type: Shale and Sandstone

Formation: Nsukka Formation

GPS Coordinates: 06°81¹80.00¹¹N and 007°47¹42.6E

Elevation: 198m

Lithology Description:

The base of the outcrop is composed of very dark coloured shale that are fissile, having a thickness of 1m. Above this bed is an ironstone forming capping with a lot of fossils under the bed, having a thickness of 0.2m. Directly above this bed is a fine to medium grained clayey sandstone, brownish in colour, non bioturbated with a thickness of 0.8m.

Laying above this bed is a medium to coarse grained sandstone, non bioturbated, brownish to whitish in colour, with a thickness of 1.2m. This bed is followed by a fine to medium grained sandstone, brownish in colour, having a thickness of 0.8m. This bed is also followed by a fine grained clayey sandstone, brownish in colour, slightly friable, with a thickness of 0.6m. Lying above this bed

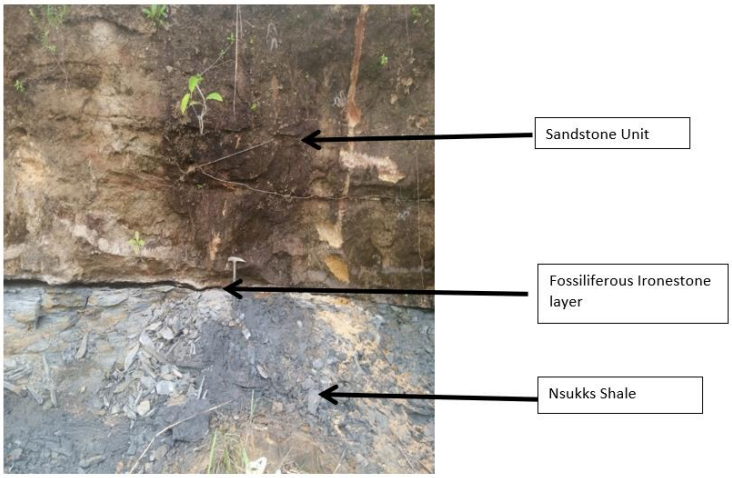

Figure 14: Outcrop Section of the Nsukka Formation at Ihube showing the Shale unit, Ironstone Cap and the Sandstone unit (the hammer scale is 20cm)

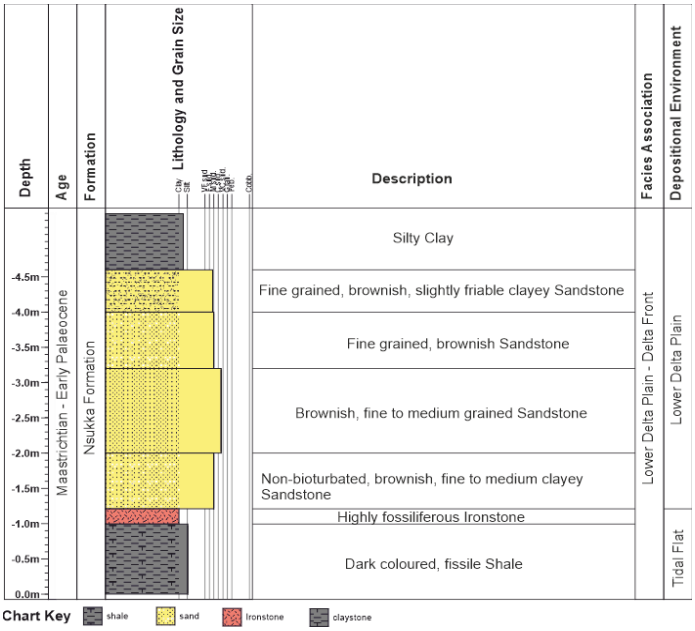

Figure 15: Lithologic Section of the Nsukka Formation at Ihube

4.3 Sedimentological Description of Lithofacies in the Studied Sections

In geology, facies are body of rock with specific characterization, which can be any observable attribute of rock such as their overall appearance, composition or condition of formation and the change that may occur in those attributes over a geographical area (Reading 1996). This implies that the rock should be distinctive formed under conditions of sedimentation, reflecting a particular process, set of conditions or environment. However, some of those outcrop scale characteristics are not unique to one depositional environment, therefore, other rock features such as sedimentary structures, fossils, association and form are needed to provide richer context.Facies repetition throughout a succession is pattern by an idea and this emphasizes the similarity between sequence. The identification of cycles formed the basis for the analysis of the outcrop section in these studies.

Six (6) lithofacies were interpreted and they are

- Heterolithic siltstone and claystone facies
- Heterolithic Shale, sandstone and Oolitic Facies
- Horizontal and Cross-stratified Sandstone Fcies
- Interstratified calcareous Oolitic ironstone and shale
- Coarse grained sandstone lithofacies:
- Stratified Sandstone Facies

Heterolithic Siltstone and Claystone Facies: This lithofacies are characterized of Owelli sandstones, composed of fine to very fine-grained greyish to reddish brown siltstones. The siltstones are mostly fine-grained, friable and weakly cemented. The grains are well sorted and are sub-angular to rounded in shape. Facies assemblages exhibit generally a fining upward sequence. The sedimentary structures identified are parallel lamination. Fossil assemblages identified are the Ophiomorpha, Skolithos and rootlets. Heterolithic Shale, sandstone and Oolitic Facies: This lithology exhibit sands dominated interbeds of mudstone, shale and Oolitic ironstone.

The shales are dark grey with yellowish sandstone concretion. The sandstones are mostly fine to very fine-grained sometimes grading into silt texture. They show horizontal to parallel laminated structures and are bioturbated. They are characterized by sharp bases, calcareous and fossiliferous indurated oolitic ironstone. The sharp bases are as a result of grain size and colour variations. The facies generally show a coarsing upward sequence in the manner of increase in the sand content and sand layer thickness upward. Thin facie association is of the Nkporo formation in Mmaku Community Secondary School.Horizontal and Cross-stratified Sandstone Facies: They are characterized of Nkporo Group and Mamu Formation, Ajali and the Nsukka Formation section comprises of medium to coarse-grained and occasionally fine-grained sandstone. The sandstone is poorly sorted and friable to weakly cemented. The poorly sorted grains are sub-angular to sub-rounded in shape. The facies assemblage displays a general fining upward sequence.

The main sedimentary structure identified are horizontal to planar trough cross beds with intervening mud drapes. The fossil assemblage in this flow facies are Skolithos and Ophiomorpha Spp.Interstratified calcareous Oolitic ironstone and shale Facies: This lithofacie unit consist of grey to dark ferruginous fissile shales and calcareous Oolitic ironstone. The beds are parallel laminated and lenticular, they are highly fossiliferous and have large assemblages of palynomorphs. The calcareous Oolitic ironstone are grey to reddish and are indurated.

Coarse grained sandstone lithofacies: This is poorly sorted and characterized by subangular to subrounded quartz grains. Bed thickness is 0.5 m that occurs in the Ajali Sandstones. Stratified Sandstone Facies: This lithofacies consist of fine-medium g rained sandstone with scattered pebbles and admixture of clay clast and characterized by well-developed structured of district stratification. They exhibit clay drapes at some point. The lithofacie occur in the Ajali sandstone section.

Table 1: Showing the description of lithofacies in the studied outcrop sections

Formations	Identified Lithofacies	General Characteristics
Owelli Sandstone	Heterolithic Siltstone and Claystone Facies	Consist of siltstones and a fining upward sequence
Nkporo and Enugu Formation	Heterolithic Shale, Sandstone and Oolitic Fcaies	Oolitic ironstone, carbonated shale, sandstone and a coarsening upward sequence
Mamu Formation	Shale and Sandstone facies	Consist of parallel laminated and lenticular beds, carbonated shale sandstone member and a coarsening upward sequence
Ajali Sandstone	Coarse-grained sandstone facies	Consist of coarse-fine grained sandstone with well-developed sedimentary structures
Nsukka Formation	Heterolithic shale	Comprises of shale layers, calcareous ironstone thin bed and coarse to fine grained sandstone and exhibit a coarsening upward sequence

4.4 Facies Association

Analysis of sedimentary facies of outcropping sections studied within the Awgu area allow the identification and interpretation of lithofacies with respect to the sedimentary attributes such as geometry (thickness and extend), continuity and shape of lithologic units, rock types, sedimentary structures and fauna. The sediments are mainly siliciclastics that can be presented in variable proportion, interpreted to represent a wide range of depositional conditions and environment

4.4.1 Nkporo Formation (Along Awgu Road) Facies Association

Lithofacies studies shows that the Nkporo Formation consists of three main facies associations which includes fluvio deltaic facies, estuarine and shallow shelf facies and estuarine channel fill faciesA. Estuarine Facies Association (Upper Reaches of an Estuary): This facies association comprises of fine to coarse grained sandstone. They include lenticular and tabular units that usually exhibit large-scale inclined strata with dipping angle of less than 15° (Schwarz et al.,2015). These facies association consists of trough cross-bedded strata that pass upwards into ripple cross laminated beds. This formation exhibits a well-defined upward fining sequence that grades upwards into tabular deposits. Above the sandstone facies, grey coloured shale is lying uncomformably parallel to the inclined surface and these surface is draped by mudstone. The tabular unit is composed of few centimeter-scale heterloith intervals, planar laminated sandstone bed separated by mud drapes. The presence of bioturbation was observed in the outcropping section.The absence of macrofossils in the studied outcrop section suggested a common tidal flat environment.

B. Estuarine Facies Association (Lower Reaches of Estuary)

This facies association is composed of various forms of lithologies from sandstone to mudstone, poorly sorted sandstones and shales. The units comprise of a sectional coarsening upward succession. It consists of shale intervals with scarce marine ostracods. The shale intervals in this facies association indicate a muddy and low energy setting, with a marine connection according which interpretes the depositional environment as lagoon, bay or central estuary to (Yoshida, 2000).

C. Shoreface Facies Association (Upper to Middle)

This facies association comprises of cross-stratified beds. It consists of deposit that contain few to abundant vertical burrows of skolithos (they are ichnofacies). This formation consists of sandstone, siltstone shale and mudstone deposits. This facies association tends to represents lower-middle shoreface depositional environment which is subtidal. Tidal influence can be observed in the deposit due to the presence of mud drapes, thick-thin sandstones bundles.

D. Lower Shoreface Facies Association (Nkporo Formation at Ugwueme)

This facies association include very fine to fine grained sandstones and oolithic calcareous sandstones. Some units of thin facies association displays a high proportion of ripple cross-stratification. In ripple-dominated units of this formation, bed sets are less than 2cm thick and have flat undulatory basal surfaces. A good number of trace fossils were observed in this facies association, although there is a high density of trace fossils, belonging more of the skolithos lnchnofacies, With Ophiomorphas also common. The units in this formation shows an upwards thickening trend and coarsening upward sequence.

4.4.2 Enugu Formation (Ozuola Junction) Facies Association

Lithofacies studies shows that the Enugu Formation comprises of two main facies associations which lower delta plain and Delta front facies association

A. Lower Delta Plain Facies Association

The facies association is comprises of heterolithic rythmites of fine sand to silt to mud alternations, carbonaceous mudstones of thin coal seams and distributary sandstones. The various units have an average thickness of 4m and above and shows an upwards coarsening trends. There is the presence of mixed fluvial-tidal influences of minor marine flooding and periodic channel avulsion and overbank deposits. This facie association represent a low-energy, brackish water coastal plain, a transitional between the marine influenced delta front and swampy upper delta plain

B. Delta Front Facies Association

This is made up primarily of sandstone-siltstone- shale succession forming a coarsening upward sequence. The facies association is composed predominantly of fine to coarse grained sandstone with interbedded siltstones and mudstones. Sedimentary structures identified were hummocky cross stratification that are storm influenced, wave and current ripples and cross beddings. Sediments were believed to have been deposited through distributary channels reworked by wave, storms and tide processes. This faciesassociation represent a transition from shallow marine to active delta building environments indicating moderate to high energy.

4.4.3 Lagoon Facies Association (Mamu Formation at Ugwe-Ise Road)

This facies association is composed mainly by dark-gray, carbon shales and siltstones with minor very fine to medium grained sandstones. The various units have an average thickness of 6m and above and shows an upwards fining trends. The shale and siltstones are weakly bioturbated. The sandstone units are thin and have horizontal-wavy lamination, with oscillation ripples. They lack fauna but contain rare horizontal borrows. Sediments from this facies association are believed to have settled from suspension in a very low energy environment. The abundance of plants fragments, a scarcity of bioturbation and low diversity probably with brackish water suggest a marginal marine environment (Pemberton et al., 1992). In this setting, it believes that wavy energy was low and biogenic retworking was minimal.

4.4.4 Offshore Transitional Facies Association (Mamu Formation at Obeagu)

This facies association include mostly of very fine grained sandstones, shale and muddy sandstones, with a subordinate amount of sandy mudstones. This facies association also composed of normally graded sandstones bed, which can be traced for some meters. In these sandstones beds, bioturbational is typically low and decreases downwards from their tops. Ophiomorphas and skolithos are noticed. Diversity and intensity of bioturbation probably suggest moderate energy conditions, normal marine salinity and low sedimentation rate (Morris et al., 2006) which are optimal conditions for colorization in fauna. The preservation of few sandstone beds is probably related to intense reworking by bioturbation, which homogenized fair weather muds and sandy-storm beds.

4.4.5 Tidal Flat Facies Association of Ajali Sandstone

This facies association comprises of trough cross-bedded medium to coarse grained massive sandstone unit with parallel laminated clay beds (mud drapes) with thickness of about 0.3m. The facies association occurs as planar and continuous heterolithic beds. It consists mainly of wavy bedded sandstone heterolith with thin current-rippled sandstones occasionally showing drawing ripples that are thin, having laterally discontinuous fine to coarse-grained cross-stratified sandstone beds with abundant mud drapes. This facies exhibits a coarsening upward signature consisting of moderately sorted sandstone with the trough, planar and herringbone cross-bedding reactivation surfaces. The beds have an average inclined angle (dip angle) of 18°. Bioturbation is generally of low intensity and diversity, with bioturbation index ranging from 0 – 1. The sandstone content ranges in an average of 70%. The facies are deposited in a shallow marine environment dominated by a tidal flat facies association (Okoro et al., 2020; Nwajide, 2022)

4.4.6 Facies Association of Nsukka Formation at Ihube

The Nsukka Formation at Ihube comprises of stacked sandstone to siltstone to shale intervals showing strong deltaic influence. These facies are best grouped into two major deltaic environments: Lower delta plain and Delta front facies aasociation

A. Lower Delta Plain Facies Association

This consist of Sandstone, laminated Sandstone, trough cross bedded sandstone. Also present in the succession, is an interbedded with bioturbated sandstones. The laminations point toward relatively lower-energy deposition (e.g., tidal, intertidal, or shallow subtidal settings). The rough cross-bedded sandstones are interpreted as channel deposits, possibly influenced by tidal or fluvial processes. Medium to coarse grained sandstones, cross-bedding, trough cross-bedding and mud drapes and occasional tidal bundles were also noticed

B. Delta Front Facies Association

The Delta Front lies seaward from the delta plain and is dominated by marine processes—waves, tides, and storm reworking. This facies association is composed of Shale and Mudstone Facies that formed the basal parts of the Nsukka Formation. These shales are often dark-grey, laminated, and pyritic (low-oxygen bottom conditions). It has an abundance of Foraminiferal assemblages (benthic) that support deposition in shallow to marginal marine settings. The facies are Fine-grained, laminated shales and siltstones with a distal delta-front, alternating with traction and suspension deposition that are strongly tidal influence

Table 2: Summary of Description and interpretation of Facies Association Recognized in the study

Formation	General Characteristics	Lithology and Sedimenary structures	Bedset, thickness and internal organization	Fossils and true fossils	Interpretation
Nkporo Formation (Owelli Sandstone)	Lenticular and tabular unit	Clay, siltstone, fine to coarse grained sandstones, matrix supported silt and sand shale heterolith.	Form cm-m. planar cross-beds sets, parallel laminated and exhibiting a fusing upward sequence.	Presence of tree fossils Ophiomorphas.	Estuarine-upper reach of an estuary.
Nkporo Formation (Owelli Sandstone)	Lenticular and tabular units	Clay, siltstone shale and sandstone.	From cm-m thickness sets. Weakly erosive base with coarsening upward trends. Parallel laminated planar beds, flaser beds, having symmetrical ripples.	Rootlets	Lower reaches estuary facies
Nkporo Formation (Mmaku)	Lenticular and tabular unit	Clay, siltstone, oolitic ironstone and sandstone.	Ranging from cm-m in thickness – horizontal planar lamination.	Rich in fossils and presence of trace fossils	Upper to middle shoreface facies.
Nkporo Formation (Ugwueme)	Lenticular units and tabular units.	Clay, siltstone, shale coarse-grained sandstones and conglomerates	Thickness of the beds are in the range of cm-m. Weakly erosive base, planar to trough cross-bred sets and horizontal planar lamination	Rich in micro fossils no presence of trace fossils.	
Enugu Formation (Ozuola Junction)	Lenticular units and tabular units. Generally coarsening upward sequence	Clay, Siltstone, shale, coal, siltstone and fine-medium grained sandstones.	Thickness of bed sets ranges from cm-m. horizontal planar lamination.	Rich in fossils. Presence of trace fossils	Lower delta plain/Coastal Swamp
Mamu Formation (Igwu-Ise-Achi Road)	Lenticular and tabular units.	Clay, shale, coal, siltstone and fine-medium grained sandstones.	Thickness of bed sets ranges from cm-m. horizontal planar lamination.	Rich in fossils. Presence of trace fossils	Lagoonal facies (shore free to open marine)
Mamu Formation (Obeagu Town)	Lenticular and tabular units.	Clay, shales, siltstone and sandstone.	Thickness ranges from cm-m overturned bed due to gadlvonism planar laminated bed sets.	Rich in fossils. Few trace fossils turd.	Offshore-traditional facies.
Ajali Sandstone Achi Road	General upward coarsening sequence, tabular unit at bottom and middle; lenticular units at the top.	Planar to trough cross-bedded sandstone units, laminated clay units nomarl grading herringbone structures, rane assymmictric ripple marks. Massive planar to tangential cross-stratified beds separated by mud drapes.	Thickness are in the range of cm-m seal with sharp bases. Individual upwards-coarsening and thickening packages sets with erosive bases.	Abundant plant debris, no bioclasts.	Tidal flat shallow marine facies deposit.
Nsukka Formation (Ihube Town)	Lenticular units and tabular units. Generally coarsening upward sequence	Planar to trough cross-bedded sandstone units, laminated clay, siltstone, massive fine to medium grained sandstone	Thickness are in the range of cm-m seal with sharp bases, with an ironstone capping layer. upwards-coarsening and thickening packages sets	Rich in fossils. Presence of trace fossils. Mega fossils were seen at ironstone capping layer	Tidal flat shallow marine facies deposit.

5. Conclusion

The study examined the lithofacies, paleo-depositional environment and facies succession interpretation of the Campanian-Maastrichtian sedimentary deposits of the Anambra Basin in Awgu and its environment. This work aimed to provide a regional lithostratigraphic framework for a better understanding and interpretation of the facies, depositional system and mapping of the area.From the study carried out, lithofaces units were identified and interpreted. The Nkporo Formation consists of a tidally influenced estuarine deposited facies association with the lower Owelli

Sandstone being deposited in environment ranging from tidal channels to intertidal flat. The Enugu Formation comprises of two main facies associations which are lower delta plain and Delta front associated with delta plain and coastal swamp environment The Mamu Formation comprises of two sedimentary depositional facies association, the lagoonal facies and the subtidal to coastal swamp facies association were recognized in the study with depositional environment ranging from tidal to shoe face open marine depositional environment. The Ajali Formation consist of shallow marine depositional facies occurring in a tidal flat depositional environment, while in the Nsukka Formation, tidal flat and lower delta plain were recognized as the depositional environments.

The section is made up of coarse-grained, moderately sorted, well rounded sandstones that are whitish to pinkish in colour that has a mineralogical composition of feldspar and quartz minerals and shales that are carbonated and highly fissile. The various formations within the basin gives an insight about the variability of depositional environments and facies succession and association.

Evaluation of the lithofacies, lithofacies association and successions in the Anambra Basin, have shown that the formation was deposited in a marginal marine to marine setting and the sub-environments identified are tidal channels to intertidal flat, delta plain to coastal swamp, the subtidal to coastal swamp, tidal flat (inter-tidal), and the shoreface. The fining upward and coarsening upwards of the lithofacies and their vertical successions indicated sediment deposition during the transgressive and regressive phase of the ancient sea.

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