Facies Analysis and Depositional Environment of Cretaceous Sediments Exposed Along Enugu–Agbogugu Road, Anambra Basin, Nigeria

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ABSTRACT

This study focuses on facies distribution in Cretaceous outcrops along Enugu-Agbogugu axis of the Anambra Basin, south-eastern Nigeria. It is aimed at unravelling the depositional environments of the sedimentary successions and reconstructing the paleogeographic setting. Six well-exposed outcrops were methodically studied with six lithofacies identified, namely: lateritic claystone, bioturbated sandy heteroliths, carbonaceous shale, coal seam, ironstone beds and cross-bedded sandstones. The lithofacies diagnostic features were flaser and lenticular bedding, herringbone cross-stratification; planar and trough crossbedding and an assemblage of ichnofossils including *Planolites*, *Skolithos*, and *Asterosoma*. The lithofacies were grouped into four genetically correlated facies associations, viz: flood plain, distributary channel, prodelta and open marine or offshore that together defined a deltaic system dominated by fluvial processes and associated tidal overprint. The vertical successions and lateral correlations of lithofacies reveal a stratigraphic architecture indicating a complex history of delta progradation influenced by relative sea-level fluctuations and high sediment supply. The outcrops are generally structurally deformed by joints, fractures, syn-depositional normal faults and folds. The folds are effect of compressive stress believed to be associated with the post-Santonian tectonic events. This outcrop-scale study enhances the understanding of heterogeneity in deltaic reservoir under the strong influence of fluvial and tidal processes, as well as the potential for petroleum stratigraphic and structural traps in Anambra basin and others with similar tectonic and stratigraphic settings.

Keywords: Anambra Basin, Facies Analysis, Fluvial-Deltaic System, Tidal Influence Cretaceous Sedimentology

INTRODUCTION

The Anambra Basin represents a critical post-Santonian depocenter within the complex tectonic framework of the Southern Benue Trough, Nigeria (Figure 1). It was formed as a syncline by the Santonian tectonic inversion of the Abalaliki syncline which resulted in the formation of the fold belt that then moved the major sedimentation point to its location in the west (Murat, 1972; Agagu and Adighije, 1983 & Nwajide, 2013). This marked the beginning deposition of thick successions of Late Cretaceous to Palaeogene sedimentary deposits, that has the basin a major target for stratigraphic analysis and hydrocarbon exploration. Campano-Maastrichtian fill of the basin consist of well-defined paralic to continental successions that include the economically significant Mamu Formation (Lower Coal Measures) and the Ajali Sandstone. See Table (Mbanefo, 2016). Although the regional depositional models fairly developed by Obi *et al.* (2001) and Nwajide (2013) they show that these units document a complicated history of deltaic advancement and river influx, but more elaborate facies corpus at the scales of outcrop still needs to be well documented. Therefore, the main objective of this study is to carry out an intricate facies study of outcrops of the Cretaceous sediments and recreate the Paleo-depositional environments which aims to underscore the local heterogeneities in the formations and the process of deposition that can enhanced their possible application as analogue model for petroleum reservoir and de-risking uncertainty in characteristics prediction. The study outcrop of Cretaceous sediment is along the Enugu-Agbogugu axis of the Port Harcourt-Enugu Expressway, is located in the south-eastern region of the Benue Trough (Figure 2). The outcrop transected by the road gives a continuous exposure of the Enugu Shale and Owelli Sandstone, having a wide range of sedimentary facies and features that give a high-resolution record of paleoenvironmental processes. Analysing such depositional/sedimentary features through facies analysis is the basic key to unlocking knowledge about depositional environments, enabling the reconstruction of paleo-depositional environments and forecasting of geometry and connectivity of reservoir bodies (Obi *et al.*, 2001).

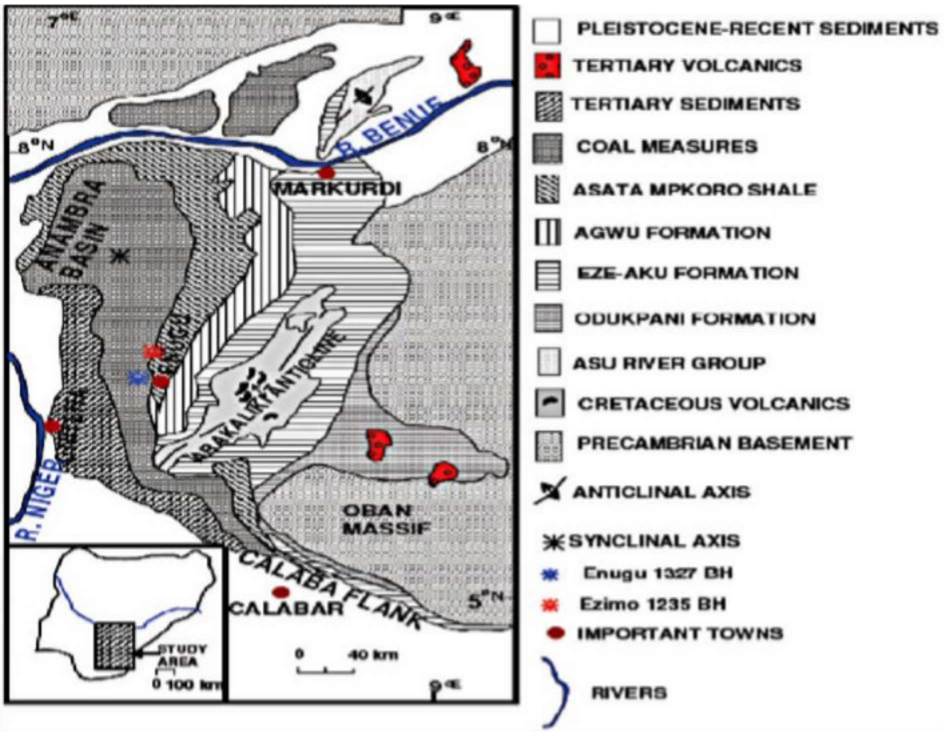

Figure 1: Geological map of South-eastern Nigeria showing the major Cretaceous sedimentary basins and structural elements, highlighting the location of the Anambra Basin (From Onyekuru *et al.*, 2013).

Table 1: Generalized stratigraphic column of the Anambra Basin, showing the Campanian to Palaeocene formations, their lithology, and gross depositional environments (modified after Tijani *et al.*, 2010).

Formation	**Age (Epoch)**	**Lithology Description**	**Depositional Environment**
Imo Shale	Palaeocene	Dark grey to black marine shale, mudstone	Shallow marine
Nsukka Formation	Maastrichtian-Palaeocene	Fine-grained sandstone, shale, coal beds	Delta plain to marginal marine
Ajali Sandstone	Maastrichtian	Well-sorted, cross-bedded white sandstone	Fluvial to deltaic
Mamu Formation	Maastrichtian	Alternating sandstone, siltstone, shale, coal seams	Coastal plain, deltaic swamp
Enugu Shale	Campano-Maastrichtian	Dark grey shale, mudstone, sandy shale	Marine (prodelta to shelf)

The Anambra Basin is a post-Santonian depocenter within the Southern Benue Trough of Nigeria, covering approximately 40,000 km^2 (Ogala, 2011; Nton & Bankole, 2013; Haruna 2020 & Omietimi, 2022). Its genesis is inextricably linked to the Santonian tectonic event, a major compressional phase that inverted and uplifted the Abakaliki Anticlinorium. This event created a basin to the west, the Anambra Basin, and the Afikpo Syncline to the southeast (Murat, 1972; Nwajide, 2013; Reijers *et al.*, 1997). This tectonic reorganization established the basin as a significant sediment sink, accumulating a thick (5,000 to 7,000 m) succession of Late Cretaceous to Palaeogene paralic and continental sediments (Agagu * Adhijie, 1983). The development of the basin has been described to be retroarc foreland in nature with flexural loading taking place at the Abakaliki Fold Belt (Aminu & Olorunniwo, 2004). This tectonic domination, along with the eustatic sea-level changes, controlled the space of accommodation and generated the recognizable, cyclical stratigraphy found in the present days (Tijani et al., 2010; Eze et al., 2022). See Table 1. The resulting succession comprises a well-documented suite of formations such as the Enugu Shale, Mamu Formation, Ajali Sandstone and Nsukka Formation that document a complex history of marine transgression and deltaic progradation (Ideozu & Solomon, 2017). See Table 2.

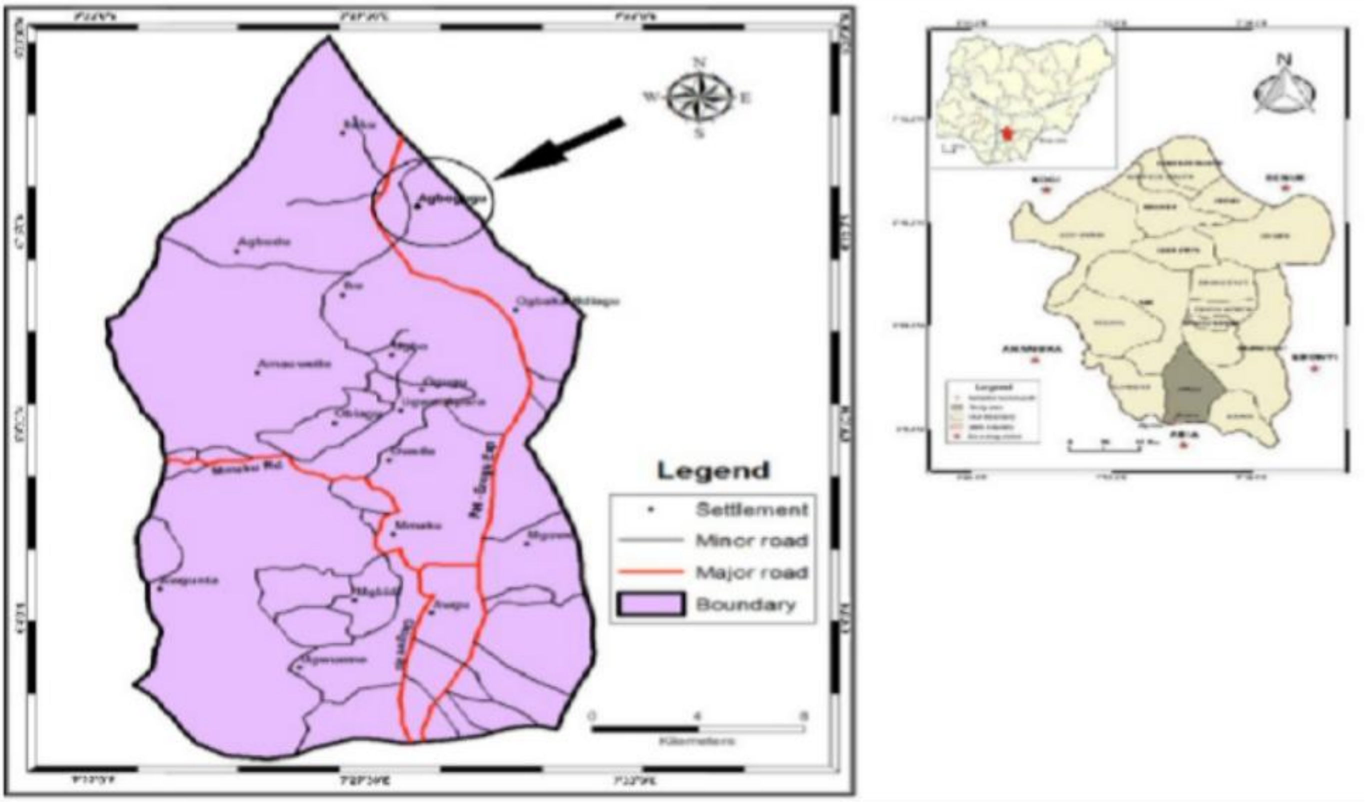

Figure 2. Detailed map of the Enugu–Agbogugu study axis along the Port Harcourt–Enugu Expressway, showing the approximate positions of the logged outcrop locations.

Table 2: Major Lithostratigraphic Units of the Anambra Basin (Modified after Reijers et al. 1997; Obi et al. 2001; Nwajide 2013).

Formation	Age (Epoch)	Lithology Description	Depositional Environment
Imo Shale	Palaeocene	Dark grey to black marine shale, mudstone	Shallow marine
Nsukka Formation	Maastrichtian-Palaeocene	Fine-grained sandstone, shale, coal beds	Delta plain to marginal marine
Ajali Sandstone	Maastrichtian	Well-sorted, cross-bedded white sandstone	Fluvial to deltaic
Mamu Formation	Maastrichtian	Alternating sandstone, siltstone, shale, coal seams	Coastal plain, deltaic swamp
Nkporo Formation	Campano-Maastrichtian	Dark grey shale, mudstone, sandy shale	Marine (prodelta to shelf)

Review of Depositional Systems and Previous Facies Studies

The Campano-Maastrichtian sediments of the Anambra Basin can be regarded as a classic, southward, upward, fluvio-deltaic system showing a heavy tidal impact. The basal marine unit is the Enugu Shale which depicts the prodelta to shelf conditions (Simpson, 1954). The superimposing Mamu Formation (Lower Coal Measures) denotes delta-plain and coastal-swamp settings, which are represented by heterolithic facies, coal seams, and fluvio-tidal channels (Ladipo, 1988 & Odedede, 2013). Ajali Sandstone is a texturally mature and cross-bedded rock that is often construed as a fluvial-dominated, braided river, and delta-frontal deposit (Ladipo, 1983; Onuigbo et al., 2016 Ilevbare and Omodolor, 2020: Oyanyan et al., 2021 and Ogbonna et al., 2023). Capping Nsukka Formation marks going back to the marginal marine and lagoons (Seifullah, 2023; Okeke et al., 2024). The analysis of facies has played a crucial role in solving this complicated depositional history. They have been used in defining the regional stratigraphic and paleogeographic framework by early works (Murat, 1972; Petters, 1982) and later literature elaborated on the processes. The wave and tidal influences were reported by Ladipo (1988), and Obi et al. (2001) emphasized the importance of tectonics in determining the pattern of sediment dispersal. Recent studies keep on improving these models. An example is that Adamu et al. (2022) that applied integrated litho-biofacies of well cuttings to outline marine boundaries in the Mamu Formation and Omoniyi & Imagbe (2025) described fluvial bodies in detail to improve prediction of the reservoirs on a larger scale. In spite of this highly developed regional work, there is a critical gap in the outcrop-ground basin analysis of the facilities of high resolution in the Enugu to Agbogugu axis. Although some general discussions have been made on the basin, the architecture of the facies, the lateral continuity of sandstones which are likely to form reservoirs and the exact interactive process of fluvial and tidal processes in this particular corridor are not well constrained. The observed here complex lithofacies assemblages as bioturbated heteroliths, bioturbated carbonaceous shales with coal seams, lateritic palaeosoils, and soft-sediment deformation structures require a systematic analysis to address the local heterogeneities that prove invaluable in refining the exploration models (Reijers, 2011; Odumoso et al., 2013; Onuigbo et al., 2017; Adamu et al., 2020). The Anambra Basin hosts a working petroleum system. The Campanian-Maastrichtian Nkporo Shale and the Palaeocene Imo Shale are the known source rocks, which contain oil- and gas-prone Type II/III kerogen (Ekweozor and Gormly, 1983; Obaje et al., 2004). The Ajali Sandstone is porous and friable and is believed to be the main reservoir, but the Mamu and Nsukka formations are used as secondary potential (Uzoegbu et al., 2015 and Adamu et al., 2025). Imo Shale and intra-formational shales offer regional seals and trapping styles include both structural (anticlines, fault blocks) and stratigraphic (channel pinch-outs) (Reijers et al., 1997; Nwajide, 2013). The existence of commercial gas at Ihube and Nnewi proves the viability of the basin, and the successful exploration and exploitation of petroleum deposit will be determined by enhanced visualized traps. This work is part of this effort as it gives detailed analogues of reservoir allocations, successions and heterogeneities of a typical deltaic environment

MATERIALS AND METHODS

This study was carried out based on a comprehensive dataset of field measurements and observations from six main outcrop located along the Enugu-Agbogugu transect of the Anambra Basin. To achieve the aim and objective of the study, the method of study includes: (1) definition and description of the constituent lithofacies based on bed-by-bed lithologic descriptions and thickness measurements; (2) determination of the stratigraphic relationships, and lateral continuity of these lithofacies based on strike and dip measurements and descriptions of structural features and well-log style correlating resulting in the production; of graphic lithologic logs for all measured sections documenting sedimentary structures and facies relationships (3) determination of the depositional environments through facies association and sedimentological indicators and (4) evaluation of the effects of syn- and post-deposition structure on the sedimentary record. This study employed a standardized facies analysis approach to interpret depositional environments. Stratigraphic logging was carried out to record vertical and lateral changes in facies. Actual bed thicknesses were recorded, and lithology was detailed out in each section. These involved identifying colour (with Munsell soil colour chart), grain size, sorting, sedimentary structures (e.g., cross bedding, ripple lamination, flaser bedding and slump folds), bioturbation intensity, ichnofossils types and fossil content. Bedding contacts and key stratigraphic surfaces were determined and noted. The identification and classification of the facies were based on accepted schemes (Miall, 1996; Reineck & Singh, 2012). Lithofacies were categorized through a lithology, sedimentary structure, and biogenic components, and each facies had a standard code (i.e. Sh for shale, Sm for massive sandstone). Facies associations were then formed through the association of genetically related lithofacies which are found in vertical and lateral recurrent successions. There was a grouping, which depended on stacking patterns (e.g., coarsening-upward, fining-upward), correlation panel lateral relationships, and genetic relationships. This methodology enabled the interpretation of certain sub environments, including distributary channels, tidal flats and delta plains. A hierarchical method was employed to interpret depositional environments, which combined lithofacies features, ichnofacies, and vertical stacking. Calibration of the resulting interpretations was done using the models of established facies and the geologic framework of the Anambra Basin. Lithologic logs and laterally persistent marker beds such as ironstone layers and coal seams were used to calculate stratigraphic correlation to build correlation panels. This method made it possible to evaluate the lateral facies continuity and variability across the study region, which allowed consistency of the depositional model of outcrop and regional levels.

RESULTS AND DISCUSSIONS

Lithofacies Analysis and Depositional Interpretation

Six outcrop sections located along the Enugu-Agbogugu highway of the Port Harcourt-Enugu expressway thoroughly investigated with special attention paid to the Enugu Shale and Owelli Sandstone. The analysis which had been carried out rigorously resulted in the identification of six main lithofacies which are lateritic claystones, bioturbated sandy heteroliths, carbonaceous shales, coal bed, ironstone bed and sandstones. The dimensions of outcrops, lithofacies and deformation structural features distributions in the various outcrop's locations are summarized in Table 3. The following provides a description and interpretation of each lithofacies, with their characteristics summarized in Table 4.

Table 3: Summary of facies and structural features across the Study Area

Outcrops Locations	Nearest landmark	Dimension	Strike of beds	Dip of Beds	Facies	Structural Features
1	Enugu township bye-pass near the Flyover	Thickness: 30m. Length: 320m	24° NE/206° SW	6°–8°	Lateritic claystone, bioturbated sandy heteroliths, shale units, and intercalated lateritic ironstone beds.	-
2	Umuatubo village	Thickness: 10.6m Length: 400 m	40° NE/220°	4–12°	Lateritic claystone, shale, bioturbated sandy and muddy heteroliths and ironstone beds	Two normal faults with throws of 1.2 to 1.52 m
3	Agbani roundabout, Port Harcourt–Enugu expressway	Thickness: 8.7m Length: 240m	40° NE/200° SW	6–10°	Lateritic claystone, bioturbated sandy heteroliths with shale interbedded, shale facies and ironstone beds	Folding, joints fractures and normal fault with a throw of about 4.6 m
4	Ituku Secondary School	Thickness: 6.9 m. Length: 180 m	340° NW/160 °	4–10°.	Lateritic claystone, shale, sandy heteroliths, and ironstone beds	-
5	Allied Block Moulding Industry, Port Harcourt–Enugu expressway	Thickness: 8.0m Length: 240m	70° NE/250° SW	4–6°.	Carbonaceous shale, ironstone, coal streaks, claystone and sandy heterolith	-
6	Agbogugu main gate, Port Harcourt-Enugu Road	Length: 255 m	40° NE/220° SW	4–15°	Lateritic claystone, shale, mudstone, bioturbated sandy heteroliths, ironstone beds, coal seams, and sandstone	Folding

Facies Mm: Lateritic Claystone

This lithofacies comprises massive, structureless claystone with a distinctive reddish to cream colouration and pervasive ferruginous mottling. It is characterised by ironstone concretions and a general lack of primary sedimentary structures. It occurs in all locations and commonly found as a thick 3-7 m, laterally continuous unit on top of the sedimentary successions (Table 3; Figures 3A, 4 and 5). It is weakly bioturbated with small horizontal burrows and has sharp to gradational bedding contacts with underlying facies.

Interpretation: Its occurrence on top of sedimentary succession and very fine-grained texture suggests channel abandonment. Reddish colouration indicates deposition and preservation in a highly oxidizing environment, while the ferruginous mottling suggests periodic inundation (Oyanyan et al., 2021). Typical environment of deposition is flood plain.

Facies Fm: Ironstone beds

Ironstone beds occur at distinct stratigraphic intervals, conformable with bedding and serving as marker horizons that divide the shale into units or as discontinuous beds (4–42 cm thick) with conchoidal fracture and shiny ferruginous surfaces within the sandy heteroliths. It massive or structureless and in most cases to fractured. It occurs at distinct stratigraphic intervals, conformable with bedding and serving as marker horizons that divide the shale into units. It occurs in all outcrop locations except location 4 (Table 3; Figures 4 and 5).

Interpretation: This assemblage is interpreted as a palaeosoil (fossil soil) representing prolonged periods of subaerial exposure and pedogenesis on a coastal plain (Retallack, 2001). The ferrigization results from intense chemical weathering under oxidizing conditions in a tropical climate. This facies marks significant stratigraphic hiatuses, forming a key regional marker that signifies episodes of regression or sediment starvation. Typical environment of deposition is coastal plain in tropical zone.

Facies SH: Carbonaceous Shale

The shale facies are grey to dark grey, fissile and carbonaceous with abundant plant debris, wood imprints and carbonaceous leaf imprints, and occasional thin coal streaks. Ironstone concretions and occur within the shales and as bed serve as marker horizons across the outcrop. It occurs in all locations (Figures 3 and 4). In location 2, it is found to have black carbonaceous leaf imprints, plant remains, and load casts at boundaries with sandstone facies described below (Plate 1- 3C, 3 and 4). In location 4 the facies are completely devoid of ironstone bed and ferruginous concretions (Figure 4). Bioturbation is generally low to moderate.

Interpretation: The lithology is attributed to suspension load deposition during quiet or slack water characterised by low energy (Nichols, 2009). The iron concretions indicate post-depositional lateralisation in tropical environment. The dark grey colour is attributed to organic richness and oxygen-deficient settings (Oyanyan & Oti, 2015). Typical depositional environments for the units with ironstone beds are lagoon, bay, floodplain lake or pond and offshore, while the one devoid of ironstone or ferruginous concretions suggest open marine or offshore deposition.

Facies Bh: Bioturbated sandy heterolith

This facies consists of a rhythmic, millimetre- to centimetre-scale alternation of very fine-grained sandstone and siltstone/mudstone. Sedimentary structures include ripple lamination, flaser and lenticular bedding and slump features as well as micro-faults and micro-folds in some locations (Plates 3B, C, D and E). The heterolithic facies consist of very fine-grained sandstone interlaminated with shale in cyclic successions, with average thicknesses of 1–2 m separated by thin ironstone beds (commonly 7–10 cm thick). Specifically, in location 2 and 3, a normal fault with a throw that ranged from 1.2 to 4.6 m cuts through the facies and the underlying facies. In location 2, you have a fault plane infilled by large hexagonal crystals of calcite (Figure 3F). The units are rare to moderately bioturbated, with ichnofossils including *Planolites, Skolithos, Asterosoma, Teichichnus*, *Tigillites,* and *Arenicolites*. Carbonaceous leaf imprints, coal streaks, and load casts occur at some bed contacts in location 2. In most of the locations, the shale units are strongly modified by bioturbation and foreignization. The facies architecture indicates upward-thickening of sand units and downward-thickening of shale units.

Table 4: Summary of Lithofacies Identified in the Enugu-Agbogugu Succession.

Facies Code	**Lithofacies**	**Lithology & Description**	**Sedimentary Structures**	**Fossil Content**	**Interpretation**
Mm	Lateritic claystone	Claystone, reddish to cream.	Massive, gradational contacts; ironstone concretions.	Rare *Planolite s*, *Skolithos*.	Palaeosoil; reddish coloration indicates ferruginsation associated with prolonged subaerial exposure and pedogenesis on a coastal plain.
Bh	Bioturbated Sandy heterolith	Bioturbated very fine-grained sandstone interlaminated with shale indicating flaser and heterolithic bedding.	Ripple lamination, flaser and lenticular bedding, slump structures.	Diverse ichnofossils (*Planolites*, *Skolithos*, *Asterosoma*, *Diplocraterion*); plant debris.	Tidal flat; rhythmic sedimentation controlled by tidal currents in a brackish- water setting.
Sh	Carbonaceous Shale	Shale; grey to black, fissile to platy.	Parallel to wavy laminae; fissile partings.	Abundant plant debris, leaf/wood imprints; thin coal seams; faecal pellets.	Inter-distributary Bay/Prodelta; low- energy, oxygen- deficient conditions in a vegetated swamp or prodelta setting.
Sm/S h	Sandstone	Sandstone; fine to coarse-grained, channelized.	Trough and planar crossbedding, ripple lamination, pebble lags, clay clasts.	Rare macrofossils. Unbioturbated	Distributary Channel; high-energy fluvial- tidal channels within the delta plain and front.
Cm Fm	Coal seam Ironstone bed	Coal Ironstone	27 – 30 cm thick continuous bed. Hard and brittle. Vitreous luster on fresh surface Discontinuous beds (4–42 cm thick). Conchoidal fracture and shiny ferruginous surfaces.	No fossil and unbioturbated	Coastal swamp Coastal plain

Interpretation: Alternation of beds of sand and shale records deposition under fluctuating energy conditions, typical of tidal setting in a marginal marine–deltaic setting (Reineck and Singh, 2012). Micro-faults are syn-sedimentary faults attributed to high rate of sedimentation over compaction while micro-fold is attributed to local or regional tectonics. The occurrence of calcite crystals on a major fault plane suggests mobilization and precipitation of calcite leached from formation. Load cast is an evidence of soft sediment deposition caused by variation in density values between sand and clay as the former is rapidly deposited on the under-compacted latter (Nichols, 2009). The trace fossil assemblage is Skolithos–Cruziana ichnofacies indicating sediment deposition under brackish-water stressed by salinity fluctuations and high rate of sedimentation (Buatois & Mangano, 2011). The upward-thickening of sand units and downward-thickening of shale units indicate sediment progradation in a marginal marine environment (Oyanyan & Oti, 2015). Typical environment of deposition is prodelta.

Facies Sm/Sh: Sandstone

Sandstone bodies show channel geometries with sharp basal contact, basal pebble lags, clay clasts and finning upward of grains. Generally, it is silty very fine- to coarse-grained, though with basal pebbly lag consisting rounded clay clast. Sedimentary structures are dominated by large-scale trough and planar crossbedding, and herringbone cross-stratification. There is buckling and folding of sandstone units. It occurs as stacked finning upward units with sharp basal contact mainly at location 6 (Table 3, Plate 1 and Figure 4). The upper units are mainly silty very fine-grained sandstone grading upward to silty shale/shale typically stacked vertically, creating multi-storey channel complexes. Bioturbation is rare to absent.

Interpretation: The sharp/erosive base indicates channel that is a primary path for sediment delivery and also suggest an unconformity surface truncating underlying bed. Fining-upward trends, and crossbedding are classic indicators of unidirectional flow and associated channel migration and bar accretion. The herringbone cross-stratification provides direct and unambiguous evidence for tidal current reversal and therefore indicates tidal influence during deposition (Dalrymple, 1992). The buckling and folding of sandstone units reflect significant tectonic influence during the post Santonian tectonic event. The stacking of sandstone units is an indication of variable discharge or current energy during channel filling. The rare to absent of bioturbation reflects high rate of sedimentation. Typical environment of deposition is high-energy distributary channels within the fluvio-deltaic system.

Facies Cm: Coal Seam

Coal seams with thickness that ranges from to 27 – 30 cm thick occurs only in location 6 where it interstratified with shale (Figure 4). It is hard and brittle; and black in colour. It characterised by vitreous luster and smooth feeling texture on fresh surface and sharp contact with overlying and underlying facies. Interpretation: The black colour can be attributed to high organic residue of plant and anoxic condition as a result of long period of submergence (Wagner, 2020). The smooth feeling texture can be attributed to high clay content. Typical environments of deposition are lagoon, coastal swamp and tidal flat (Raju et al. 2015).

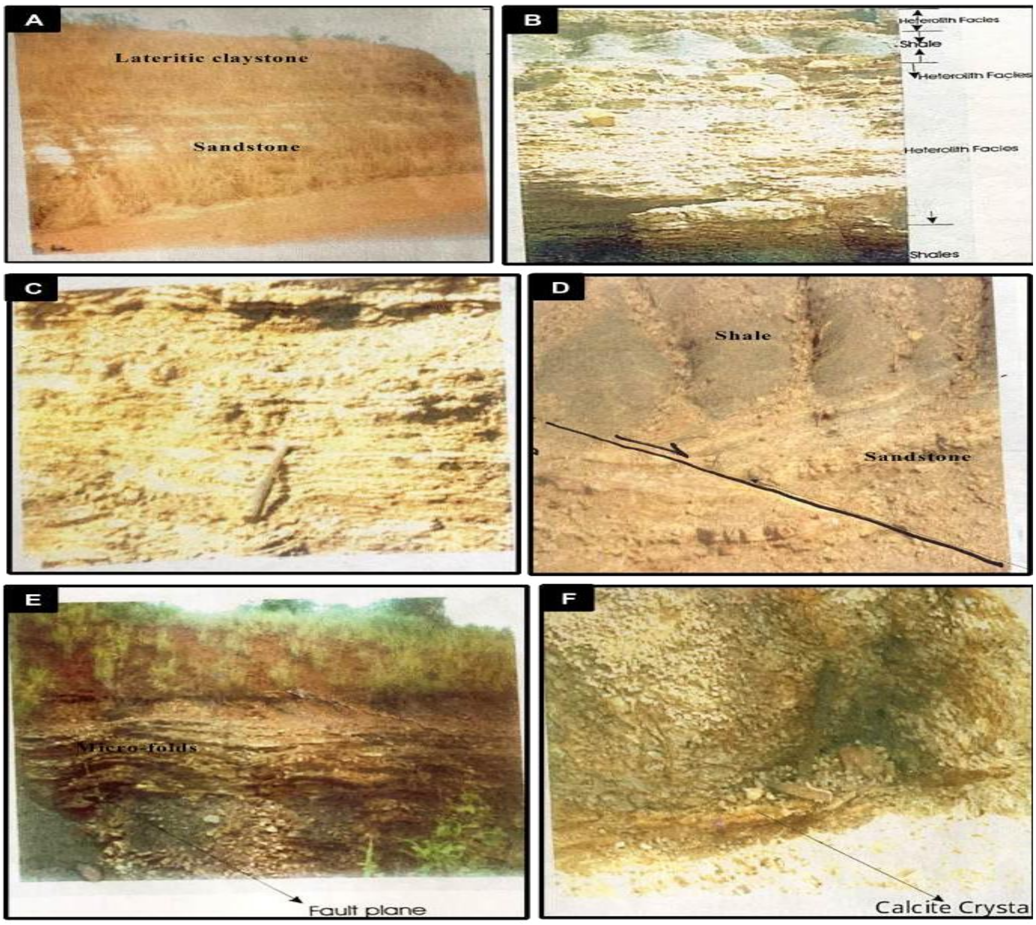

Plate 1: Pictures of lithofacies. (A). Lateritic claystone and sandstone facies at location 6, (B) Bioturbated sandy heterolith interbedded with shale, (C) Sandy Heterolith, (D) Sandstone grading upward to shale and a layers displacement indicatin reverse fault, (E) Micro-folds and micro-fault in sandy heterolith, (F) Calcite crystals along a major fault plane in location 2.

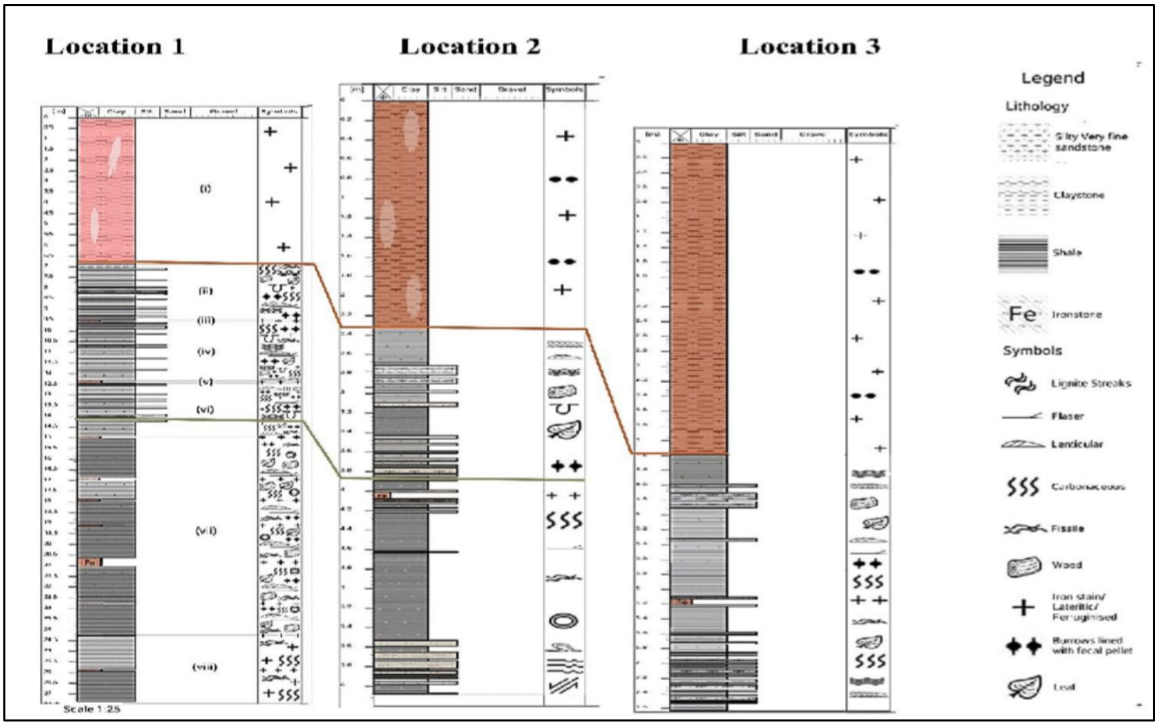

Figure 3: Sedimentary log of outrops at location 1, 2 and 3. It shows the correlation of lateritic claystone across the three locations (Modified after Ideozu, 2002).

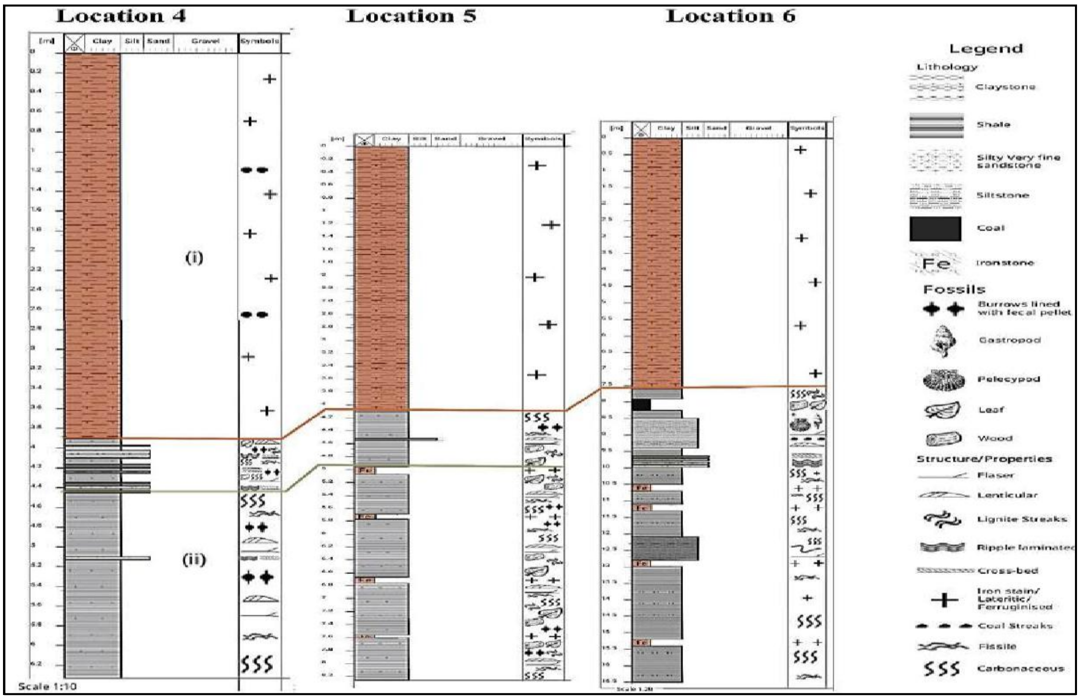

Figure 4: Sedimentary logs of outcrops at location 4, 5 and 6. It shows the correlation of lateritic clay across the locations, devoid of irostone bed at location 4 and the occurrence of coal seam only at location 6 (Modified after Ideozu, 2002).

Facies Associations and Depositional Environments

The above mentioned six lithofacies described the outcrops along Enugu-Agbogugu axis of the Anambra basin. These lithofacies form the basic building block of the paleo-depositional system. The grouping of the lithofacies into genetically related associations resulted in the following sub-depositional environments:

1. Floodplain Association: This association consist of three lithofacies: Lateritic Claystone Facies (Mm) defined as palaeosoils, Carbonaceous Shale Facies (Sh) that contain plant debris; ironstone beds (Fm) and the

coal seam (Cm). The upward gradation from shale interstratified with ironstone beds and in rare location with coal seam to lateritic claystone represents flood plain deposition. The coal seam represents deposition in floodplain lake or pond. The iron beds and concretions are ferruginous units that capture long durations of subaerial exposure. Carbonaceous shale is a deposition in low-energy anoxic environments that may span offshore environment down to sheltered inter-distributary bays and swampy delta plain environments. But the occurrence of iron concretions and interstratification with iron bed differentiate the environment of deposition of shale as anoxic zones in the flood plain that periodically become oxidized.

2. Prodelta: Bioturbated Sandy Heterolithic Facies (Bh) characterised by upward-thickening of sand units and downward-thickening of shale units as well as inter-stratification with ironstone beds represents deposition in prodelta environment. The basal part characterised by increasing shale thickness indicate distal prodelta while the upper part with increasing sand thickness represents proximal prodelta in a deltaic progradation setting (Oyanyan and Oti, 2015). The iron beds represent iron mineralisation during subaerial exposure associated with regression. This facies association with diagnostic flaser, lenticular, and wavy bedding, alongside a diverse ichnofossils suite, are indicative of tidally modulated deposition on prodelta deposition (Ideozu, 2002; MacEachern *et al*., 2005; Dalrymple, 1992).

3. Distributary Channel: A finning upward sandstone facies (Sm/Sh) with erosive basal contact strewed in most units by ironstone indicates channel fill deposition. These channelized units of sand bodies with erosional base, pebble lag infill and herringbone cross-stratification are considered the fills of high-energy and tidally influenced fluvial distributary channels (Ideozu, 2002; Gingras et al., 2012).

4. Open marine: The shale facies (Sh) devoid of ironstone beds, characterised by rare to no bioturbation and truncated erosively by channel fill sandstone facies (Sm/Sh) represent open marine or offshore deposition. The overlying channel fill is fluvial facies shifting toward and overlying marine facies in open marine regression setting.

The above listed sub-environments described by the lithofacies show that the deposition and preservation of the outcrops' sediments was control by fluvial and tidal processes as well as relative sea level changes or shoreline migration direction. Seaward movement (regression) of the shoreline or fall in relative sea level resulted in the deposition and preservation of the prodelta and distributary channel facies while landward migration (transgression) of the shoreline or relative sea level fall resulted in the deposition and preservation of open marine and floodplain facies.

Deformation Structural Features

Deformation structures that include faults, folds, fractures and joints were identified in locations 2, 3 and 6 (Table 3; Plates 3D, E and F). The ironstone bed was used as a reference or stratigraphic marker in determining the throw of the faults. The faults are mainly normal faults with throw that ranged from 1.2 to 4.6m. The faults are described as syn-depositional faults caused by high rate of sand deposition over under-compacted shale. The high rate of sand deposition was also established with the local occurrences of load cast a (soft sediment deformation structure). The folds are effect of compressive stress on rocks. Therefore, the folding can be taken as post-depositional structures attributed to post-Santonian tectonic events (Ideozu, 2002; Amogu et al., 2010).

CONCLUSION

This study achieved its aim of carrying out a facies analysis to interpret the depositional environments of the Cretaceous sediments around the Enugu–Agbogugu area. The integration of field study, lithofacies analysis, and stratigraphic correlation suggests that the Cretaceous succession records a genetically linked suite of facies deposited in a fluvial-dominated and tidally influenced deltaic system. The depositional environments were between a continuum of continental to transitional and eventually to marine. The lithofacies analysis indicated a progradational setting driven by sediment supply, punctuated by periods of fluctuations in relative sea-level or shoreline position. Seaward movement (regression) of the shoreline or relative sea level fall resulted in the deposition and preservation of prodelta and distributary channel facies while landward migration (transgression) of the shoreline or relative sea level rise resulted in the deposition and preservation of open marine and floodplain facies. The sediments of these sub-depositional environments have been structurally deformed by joints, fractures, faults and folds. The faults are mainly normal faults and are described as syn-depositional faults caused by high rate of sand deposition over under-compacted shale while the folds are effect of compressive stress associated with the post-Santonian tectonic events. The facies distribution and deformation structures has further underscored the potential for petroleum stratigraphic and structural traps in Anambra basin

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