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Characterization of Upper Cretaceous Sediments in Parts of Afikpo Area, Afikpo Syncline, Southeastern Nigeria

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Abstract
Lithostratigraphic study in parts of Afikpo area, was undertaken to reappraise and characterize sedimentary packages of the Upper Campanian – Maastrichtian periods using descriptive lithostratigraphic, sedimentologic, petrographic and paleontologic methods. The study was undertaken to give insights into the petroleum prospectivity of the area by reconstructing the paleogeographic conditions of the Afikpo sedimentary basin. Six lithofacies were analyzed to establish dominant depositional processes. The sediments of the Nkporo Group in the area, with dominant coarsening up and aggradational patterns were deposited in shallow shelf environments of deposition (EODs). The sediments of Mamu Formation have heterolithic carbonaceous mudstone and sandstone intervals suggesting brackish backshore marsh EOD. The identified gastropod (Turritella) in the sediments of Nkporo Formation indicated shallow marine conditions of about 22 m paleobathymetry where Turritella was able to burrow spires downwards into muddy sediments. The foraminiferal assemblage in the studied sediments was mainly coarsely agglutinated benthonic taxa suggesting deposition in estuarine-nearshore shallow marine EOD. Palynofacies recovered in the studied sediments are indicative of swampy conditions within a predominantly fluvial setting. The age range of the studied sediments diagnosed using palynofacies indicated Late Campanian to Late Maastrichtian age. Petrographic examination of sandstone samples showed a mineralogy dominated by quartz with minor feldspars and rock fragments and a Maturity Index in the range of 5-16, which is indicative of mineralogically mature sandstones. Provenance of the sandstones indicated sources from recycled orogen. A 3-D depositional model for the study area showed pro-delta to delta front deposits for the Nkporo Group as the sediments were deposited in shallow marine conditions during the waning periods of the Late Campanian transgression and became increasingly arenaceous and shallower during the deposition of Afikpo Sandstone deposits. An estuarine tidal delta to shallow marine conditions with intermittent paludal paleodepositional model was proposed for the Mamu Formation. The lithostratigraphic units in the study area thus have petroleum system elements deposited under conditions that could favor generation and accumulation of hydrocarbons.

Keywords: Characterization, Environment, Lithostratigraphy, Depositional, Petroleum, System, Model

INTRODUCTION

The Upper Cretaceous strata in the southeastern Nigerian sedimentary basins are being investigated as prospective targets for stratigraphic and structural traps for possible petroleum development. This consideration has arisen due to the urgent need to increase petroleum reserves to meet increasing demands in Nigeria. The spatial differentiation of the various lithostratigraphic units in the sedimentary basins has not been substantially achieved, but somewhat tricky as a result of widely spaced outcrop and insufficient subcrop data (Nwajide and Reijers, 1996; Obaje et al., 2004; Onyekuru and Iwuagwu, 2010). Several works have predicted the existence of oil and gas in the Campanian to Maastrichtian strata of the Anambra and Afikpo Basins. The basins are, however, still considered frontier basins due to the challenges associated with the interpretation of stratigraphy and structure arising from non-availability of subsurface data.

The insufficient data on stratigraphy, structure, and distribution in time and space of the sedimentary fills in the Afikpo Basin have culminated in the poor understanding of the petroleum systems' elements and processes thus hindering exploration activity in the basin. As part of an ongoing review of the stratigraphy of the Afikpo Basin, this study utilizes surface data obtained from various outcrop sections in furthering the understanding of the key play elements of the petroleum systems and proffering better

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exploration guide within the frontier basins of Nigeria. Thus the integrated sedimentological study of the outcropping profiles of the Upper Cretaceous sediments in the study area employed in this study, will not only give insights into basin evolution, dispersal patterns and stratigraphy, but will also lead to the display in 3-D model the paleogeography of the study area for better understanding of the conditions prevailing at the time of deposition of the sediments. This procedure remains the first and very important appraisal conducted in a sedimentary basin for petroleum exploration.

The use of geologic models in environmental interpretation has played a big role, especially in the exploration industries as they provide predictive tools for making inferences. Development of 2-D and 3-D depositional models from facies analysis in the present study provides a template for environmental interpretation and valuable insight into basin evolution and possible re-assessment of play elements of the basin's petroleum systems.

The study area is located between Longitudes 7°43′and 7°53′E and Latitudes 5 °40′and 5 °54′N (Fig. 1), enclosing Ebuwana, Ndibe, Mgbom and Edda all in Afikpo and Amaesiri axis, Afikpo Syncline.

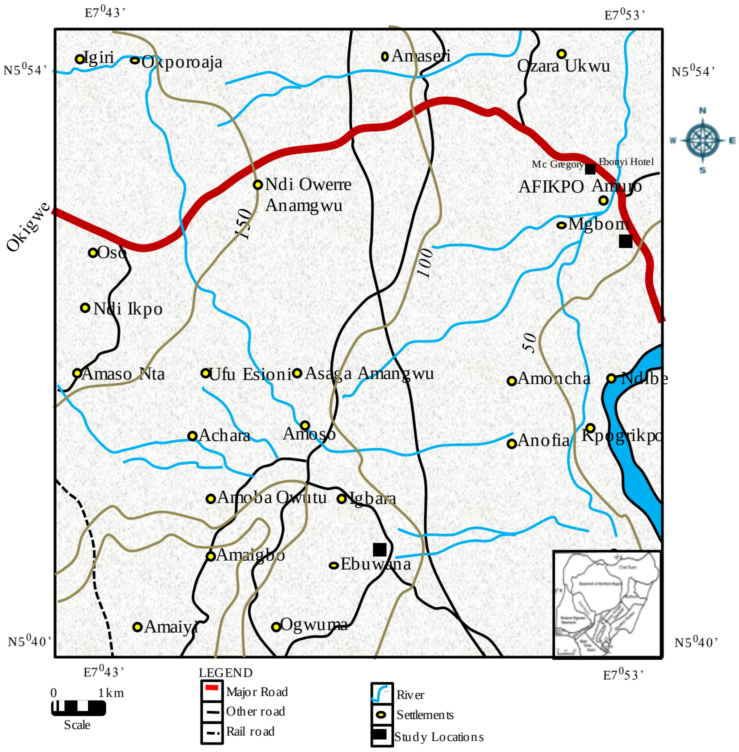


Fig 1: Location and topographic map of the study area

The Afikpo Sub-basin resulted from Santonian tectonism during the thermo-compressional event which uplifted the Abakaliki domain and formed the Abakaliki Anticlinorium, resulting in two main depocenters – the Anambra Basin and the Afikpo Sub-basin (commonly referred to as the Afikpo Syncline) (Murat, 1972; Benkhelil, 1989). The down-faulting of the Anambra Platform to the west of the Abakaliki Benue Trough formed the Anambra Basin (Umeji, 2007). Down-warping led to the formation of the Afikpo Sub-basin On the eastern side of the trough (Fig. 2). Nwajide (2013) has opined that since both the Anambra and Afikpo Basins resulted from the same Santonian thermotectonic event in the southern Benue Trough with no physical separation or barrier between the two areas, therefore, there should be no justification for according to the status of Afikpo Basin distinct from the Anambra Basin. The geologic histories of both the Afikpo and Anambra Basins are thus related.

The Late Cretaceous stratigraphic succession in the basins began with the Campanian - Maastrichtian Nkporo Shale and its lateral equivalent: the Enugu Shale and Owelli Sandstone. These basal units are overlain successively by the Early-Middle Maastrichtian Mamu Formation (Lower Coal Measures), the Middle Maastrichtian Ajali Sandstone and the Nsukka Formation (Upper Coal Measures) which was deposited from the Late Maastrichtian into the Danian (Murat, 1972; Obi et al., 2001).

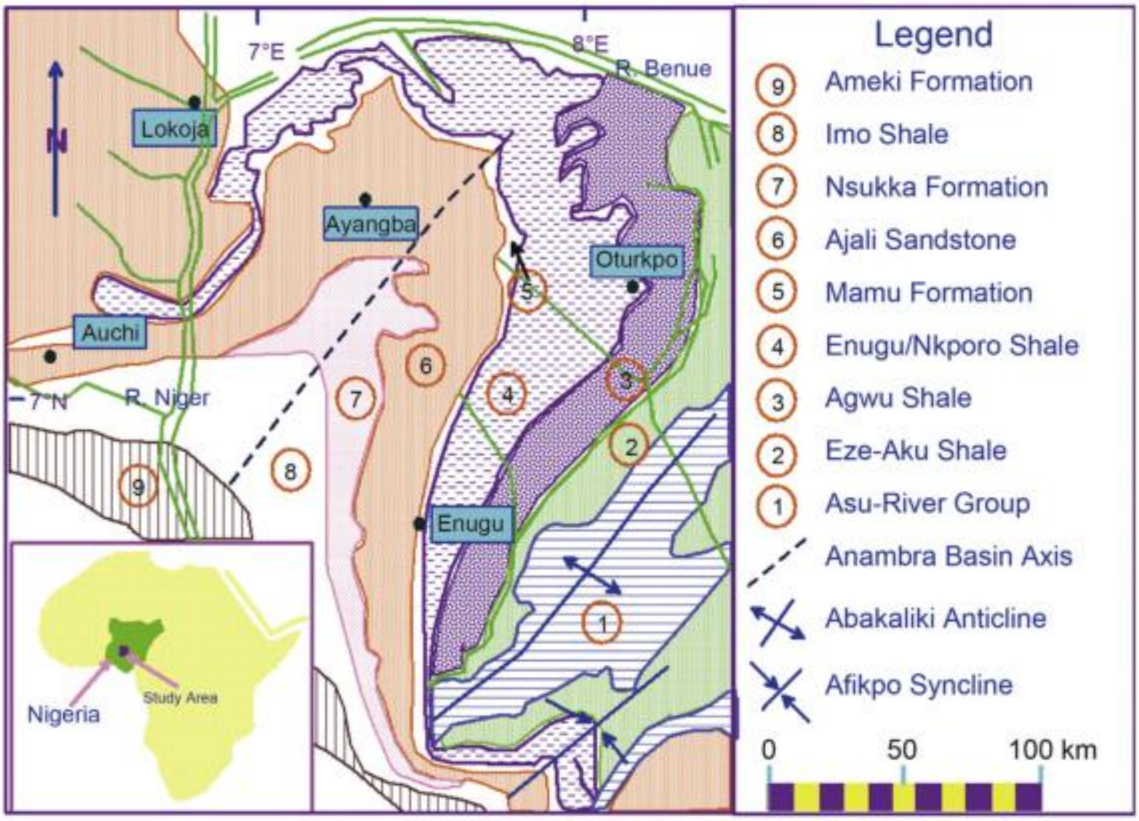


Fig 2: Generalized map of southeastern Nigeria showing the Afikpo Basin (after Nton and Bankole, 2013)

METHODOLOGY

Field Study

A detailed field investigation was carried out around Mgbom, Ndibe, and Ebuwana. Sedimentological logging of four major outcrops was carried out using standard procedures. Fresh samples were collected for laboratory analysis.

Grain size Analysis

Grain size analysis was carried out following standard procedures. Graphic mean, standard deviation, inclusive graphic skewness and graphic kurtosis for each sample was calculated using formulas proposed by Folk (1974).

Statistical Analysis

Identified facies were subjected to the Markov Chain statistical analysis. Selley (1970) described three models of structuring lithofacies states observed in the field for finite Markov analysis.

i. The regular Markov Matrix
ii. The embedded Markov Matrix and
iii. The multi-story Markov Matrix

The Embedded Markov Matrix utilized in the present study involved the following as described by Krumbien and Darcy (1969):

i. Erection of transition count matrix (a two-dimensional way of all possible vertical lithologic transitions) for each section.
ii. Tabulation of the transition probability matrix,
iii. Tabulation of independent trial probability matrix,
iv. Erection of difference matrix,
v. A test of significance of resulting difference matrix (Selley, 1970; Walker, 1979).

The analytical technique helps to condense stratigraphic section into a manageable size. It brings out the essentials of the section, detects cyclicity, if present and allow comparison of the section, with established facies models. Three matrices (observed transition probability, random probability and difference probability) were calculated respectively from the transition count matrix using the following formulae:

Three matrices (observed transition probability, random probability and difference probability) were calculated respectively from the transition count matrix using the following formulae:

- Pij = Fij/Rt,

Where Pij has observed transition probability of i being followed by j; Fij is the number of transitions of i to j; Rt is the row total (Miall, 1973).

- Rij = nj/N – ni,

Where rij is the random probability of transition from facies i to facies j, ni and nj are the number of occurrences of facies i and j respectively; and N is the total number of occurrences of all facies (Walker, 1979).

– Dij = Pij – rij,
Where dij is the difference between the observed probability (Pij) and the random probability (rij)

Paleontological Study

Samples from each unit were pulverized and 10 g weighed into enamel container. The samples were mixed with water and treated with 2 g of Sodium Bicarbonate (Na_2CO_3) and boiled at about 200 ◦C for some minutes. Samples were thereafter turned into plastic containers and allowed to cool.

The cooled samples were successively washed with a jet of water using a set of sieves with diameters of 90, 75 and 53µm. Residues from each sieve were collected and dried. The dried samples were examined using paleontological microscopes at varying magnifications. The fossils were variously picked and morphological examinations were then carried out on the species with nomenclatural aid schemes. Identified species were differentiated, counted and recorded to know diversity and abundance.

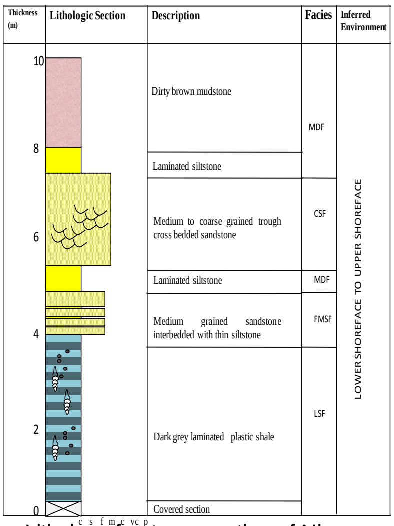
Petrographic Study

Samples were impregnated with resin before cutting. Thereafter, the samples were each mounted using the polished side on a glass slide with Araldite and Canada balsam followed by grinding. Modal analysis was performed by counting more than 300 points per thin section while the slides were examined under the flat stage of a petrological microscope and classified based on Folk (1974).

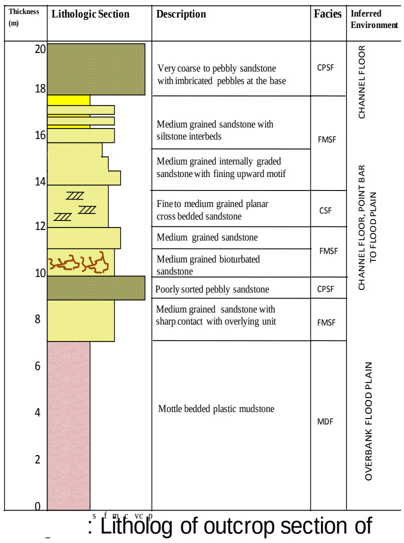
RESULTS

Description of outcrop sections

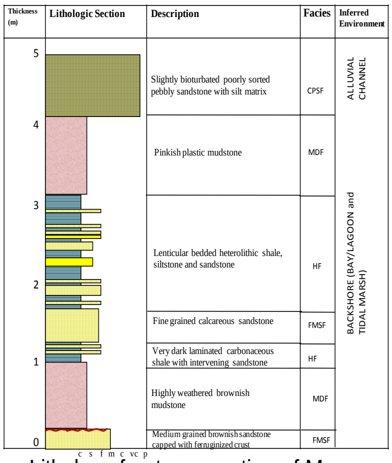
Four outcrop locations belonging to Nkporo Group and Mamu Formation were studied (Fig 3).



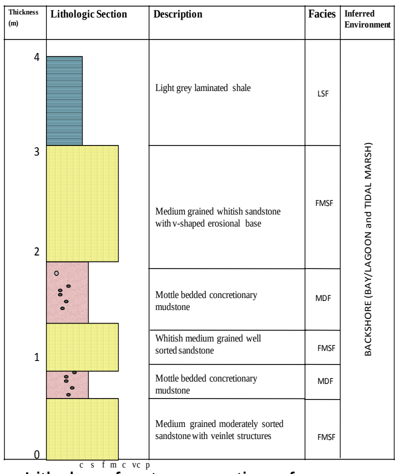
Litholog of outcrop section of Nkporo Formation along Ndibe Beach road



: Litholog of outcrop section of Afikpo Sandstone at Ebonyi Hotel junction



Litholog of outcrop section of Mamu Formation at Ebuwana I



Litholog of outcrop section of mamu Formation at Ebuwana II

Fig. 3. Lithosections of representative outcrops

RESULTS OF LITHOFACIES ANALYSIS

The outcrop locations were subdivided into lithofacies following the standard facies practices such as that proposed by Miall (1973). They lithofacies are briefly described below:

Laminated Shale Facies (LSF)

This facies is composed of dark to light grey shale. At Ebuwana I, the shale is hard, very fissile, highly cleaved and carbonaceous, with lots of post-depositional joints. At Mgbom, the shale facies is very dark, plastic and highly fossiliferous with abundant body fossils belonging to Turritella species. It is also pyritic, evidenced by the concretions and display of yellowish colorations of exposed surfaces as the pyrite is oxidized. Considerable thickness was attained in the sections.

Mudrock Facies (MDF)

These facies comprise light grey to brown mudstone often mottled with several bright color streaks and whitish to yellowish laminated siltstone. The facies attained considerable thicknesses at the exposed sections at Ebonyi hotel junction where it spanned up to 7 m thick at the Why Worry stream. At Ebuwana, it is sandy and carbonaceous with comminuted plant remains. This facies is in all probability a suspension deposit.

Heterolithic Facies (HF)

This facies is comprised of a succession of siltstone-sand-shale interbeds with sharp contacts. These facies is characterized by flaser to lenticular bedding structures. At Ebuwana, this feature is stood out as pronounced competent sand units jutting out and interbedded with withdrawn/eroded less competent shale and silt units.

Fine to Medium grained Sandstone Facies (FMSF)

This facies is the most abundant in the study area having occurred in all the sections. In some units, they are massive bedded (i.e. deposits lacking in any form of visible sedimentary structures, probably due to high rates of sedimentation or intense bioturbation) while in others, the facies are slightly or intensely bioturbated. The section exposed at Ebonyi hotel junction showed straight and branched forms of *Rhizocorallium and Ophiomorpha nodosa species, respectively*. The average thickness ranges from 0.2 to 2 m and generally fairly moderately well sorted.

Cross bedded Sandstone Facies (CSF)

In general, this lithofacies comprises planar to trough cross-bedded sandstone. Planar cross-stratified sandstone facies is characterized by sets of planar-tabular cross-beds that occur as a single set or co-sets. Height of the planar cross-strata varies from 0.10 to 0.80 m. The grain size varies from fine to coarse grained. The trough cross-bedded facies consists of distinct sets of cross-beds with troughs. Reactivation surfaces commonly mud-draped were observed in this facies.

Coarse to Pebbly Sandstone facies (CPSF)

This facies comprises of very coarse-grained to pebbly sandstone. It was observed at Ebuwana II and Ebonyi hotel junction. At Ebuwana, the facies is slightly bioturbated, matrix-supported and poorly sorted. At Ebonyi hotel junction, the facies ranges from very coarse to pebbly sandstone. The pebbles are often imbricated typical of channel deposits in a steady current flow.

Laminated shale Facies (LSF)

Heterolithic Facies (HF)

Coarse to Pebbly Sandstone facies (CPSF)

Mottle coloured mudstone Facies (MDF)

Fig.4 Representative Facies in the study area

Facies Associations

Identified lithofacies were grouped into three (3) genetically related facies associations (comprising dominant and subordinate lithofacies) to aid paleo-depositional environmental interpretation. This grouping was based on observed vertical facies succession, lateral facies transition, nature and geometry of bedding contacts, sedimentary structures and gross mineralogical composition.

Channel-Fill Facies Association

This is the dominant facies in the Afikpo Sandstone. It is comprised of coarse-pebbly sandstone, Cross-bedded sandstone and claystone facies. The pebbly and cross-bedded sandstone facies represent deposition from sand-rich, high concentration turbulent flow. Channel fill facies consisting of an abundant pebble that underlies the massive and cross-bedded sandstone is common and accounts for ≅25% of the channel-fill area. The planar cross-bedded sandstone facies suggest a product of traction current probably resulting from the preservation of the straight crested dunes and sand waves and transverse bars (Walker, 1979; Boggs, 2006).

Shore faces Facies Association

These facies association consists of lowermost fine-grained, ripple laminated upper shoreface sandstone facies and interbeds of fine-grained sandstone, mudstone and laminated shale units, interpreted as the lower shoreface deposits. The occurrence of wave-ripple laminated sandstone and siltstone suggests deposition/reworking by oscillatory wave processes or wave reworking of traction current ripples that dominate in the upper shoreface environment, above fair-weather wave base (Nichols, 2009), while observed coarsening and thickening-upward trend suggest increasing energy level during progradation/shoaling (Adeigbe and Salufu, 2007).

Estuarine/Coastal Swamp Facies Association

The heterolithic facies with occasional coaly intervals as recorded at Ebuwana is interpreted as a lagoonal and coastal swamp deposit. At Ebuwana, this facies grades into calcareous sandstone, suggesting an intermittent marine influence as the area was periodically inundated (Oboh-Ikuenobe et al., 2005). Estuarine bay and fill delta is suggested by the fine to medium-grained sandstone facies. This facies is well sorted, bioturbated and ripple laminated. The lenticular clay and low diversity burrow types attest to low energy settings such that exist in a tidally-influenced estuary (Allen, 1963, Oboh-Ikuenobe et al., 2005). The alternation of thin mudstone and sandstone/siltstone units containing wave ripple laminations reflect frequent energy fluctuations consistent with subtidal and intertidal settings (Onyekuru et al., 2013., Prothero and Schwab, 1996).

Facies Associations and Models

The various sections studied in the field were erected based on observed facies transitions. The composite facies relationship diagrams for the formations were constructed by combining their respective individual FRDs (Fig. 5), which were used to generate a 2D model of Facies succession spatially (Fig. 6).

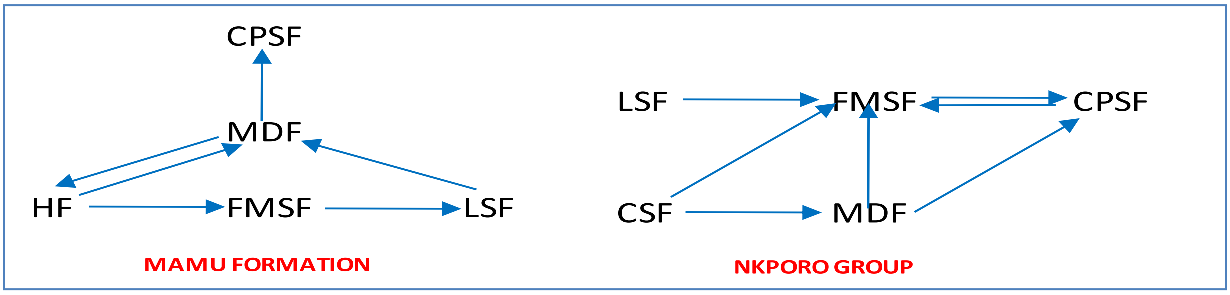


Fig 5: Composite FRD for the sections in the study area

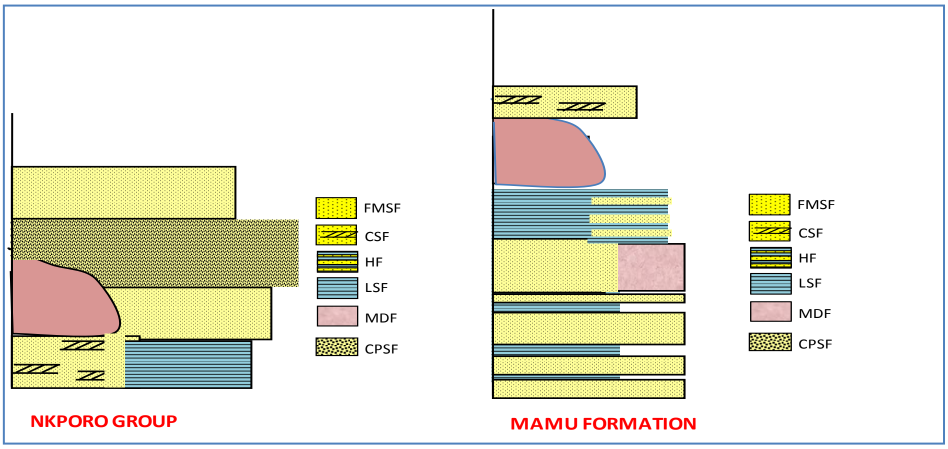


Fig 6: 2 D Depositional facies model of the 2 lithostratigraphic units in the study area

FMSF-Fine to medium grained sandstone facies, CSF – Cross bedded sandstone facies, HF – Heterolithic facies, LSF – Laminated shale facies, MDF – Mudrock facies, CPSF – Coarse to pebbly sandstone facies

Result of Paleontology

Macropaleontology

The black shale unit of the Ndibe road location was very rich in macro fossils. The macrofossil contents of this unit are enumerated below and illustrated in Fig 7.

The macrofossil assemblage identified in the dark grey, basal shale unit cropping out in the Ndibe beach road section is the ***Turritella sp*** of the gastropod family**.**

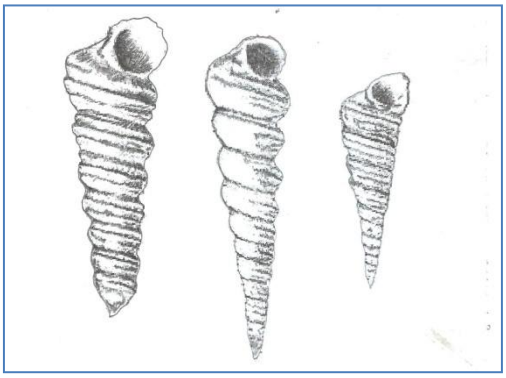


Fig 7. Sketch of identified Turritella fossils in the Ndibe Beach road Section

Result of Foraminiferal Analysis

A total of eleven (11) forams were also recovered from the Ndibe Beach Road section and described. The forams include: *Ammobaculites amabiensis, Ammobaculites amabiensis, Ammobaculites talokaensis, Amobaculites saheliensis, Ammobaculites coprolithiformis, Haplophragmoides, sp., Spiroloculina excavate, Spiroloculina canaliculata, Miliammina telemaquensis and Miliammina pindigensis.* The dominant species however include *Ammobaculites amabiensis, Ammobaculites talokaensis, Bolivina jacksonensis and Haplophragmoides sp.* (Figs. 8 and 9)

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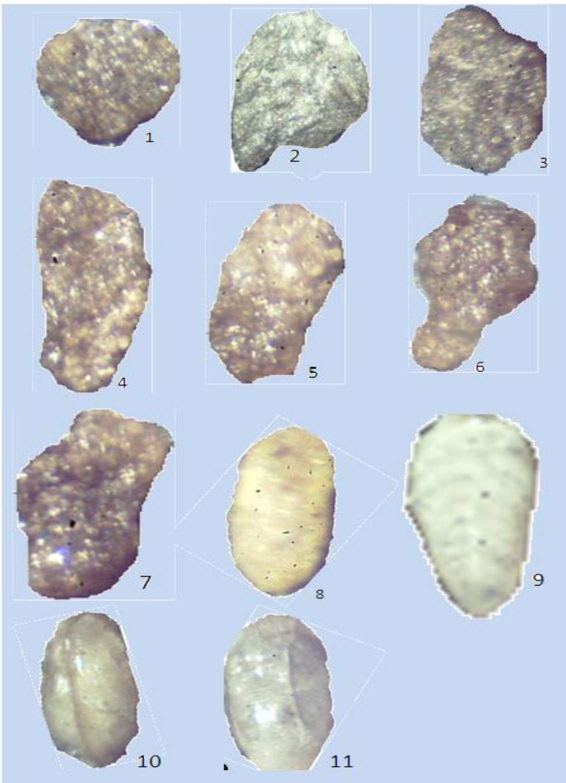

Fig 8: Photomicrographs of identified foraminifera in the section off Ndibe Beach Road (Nkporo Formation)

1 Ammobaculites amabiensis 2. Ammobaculites talokaensis 3. Ammobaculites saheliensis.4, 5, 6, 7Ammobaculites coprolithiformis 8. Haplophragmoides sp 9. . Bolivina jacksonensis 10. Spiroculina excavate 11. Spiroculina canaliculata

Fig.9: Photomicrographs of identified foraminiferas in the sections at Ebuwana (Mamu Formation)

1,2Haplophragmoides sp 3, 4 Ammobaculites talokaensis 5. Spiroculina excavata

6. Spiroculina canaliculata 7 Miliammina pindigensis 8. Miliammina telemaquensis

RESULTS OF PALYNOLOGICAL ANALYSIS

Eight types of dispersed organic matter and palynomorphs were identified. These include spores and pollens, fungal remains, freshwater algae, microforaminiferal inner linings, structured phytoclasts (wood, cuticles and parenchyma), unstructured phytoclasts (comminuted and degraded fragments).

Sporomorphs identified the samples include *Levigatosporites discordatus, Longapertites maginatus, Foveotriletes margaritae, Cycadopites sp., Ephedripites regularis, Gleicherudites senonicus, Foveodrites margaritae, Leiotrites adriennis, Retidiporites sp, Cingulattisporite ornatus, Psilatricolpites sp and Ariadnaesporites spinus.* Fresh water species include *Azollacretacea* and Dinoflagellate *indeterminate.* Marine dinoflagellates include *Spiniferites sp and Gonyaula cystacassidata* (Fig. 10).

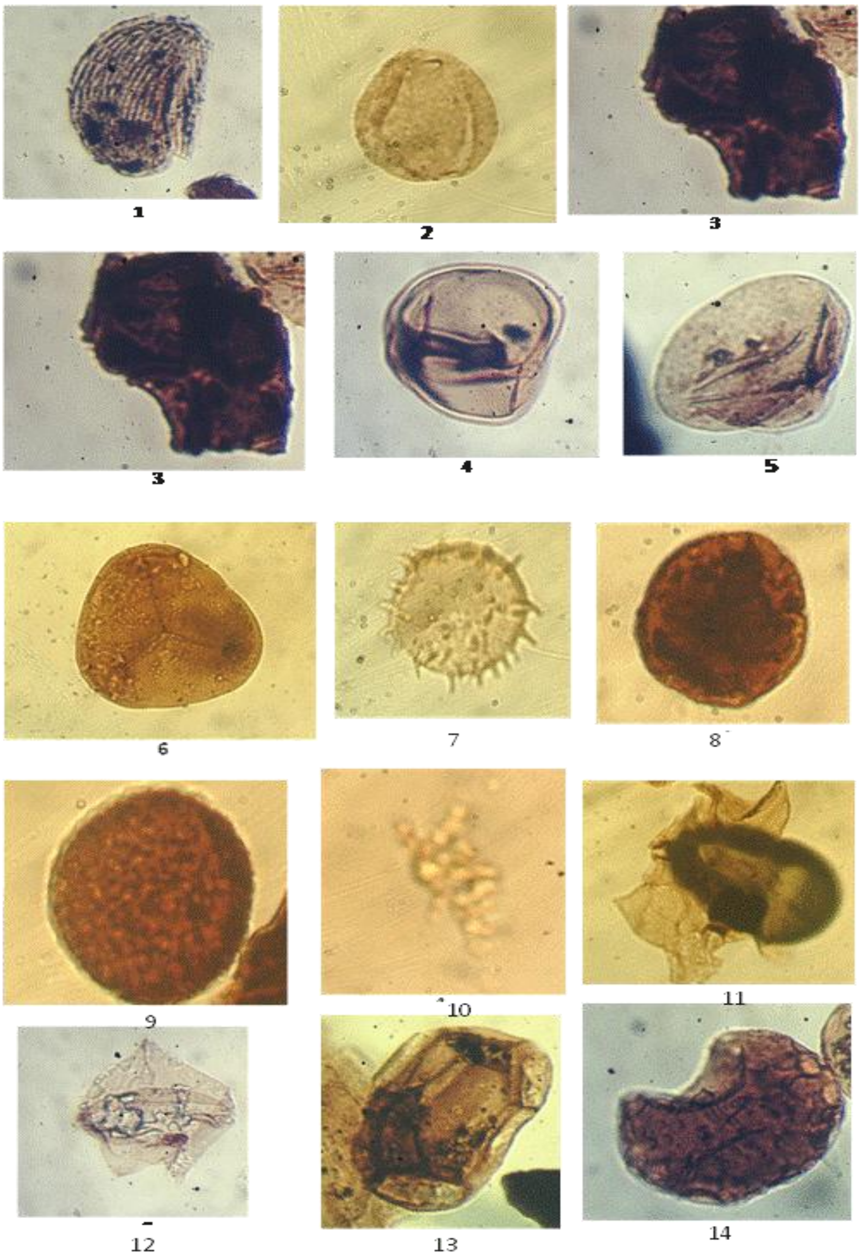

Fig. 10: Photomicrographs of palynomorphs in the study area
1, 2 Cicatricosisporite 3. Lygodiosporites perverrucatus 4, 5. Glaeicheniidites senonicus 6. Tricolporopollenites sp 7. Spiniferites sp 8, 9. Monocolpopollenites sphaeroidites 10, 11. Inner chitinous linings 12. Gonyaula cystacassidata 13, 14. Buttiniaandreevi

RESULT OF THIN SECTION PETROGRAPHY

Thin Section Petrography of representative sandstone samples from the study area are shown in Figs. 11 and 12, the modal composition is presented in Table 1, while the petrographic description is shown in table 1.

Table 1: Modal composition of representative Sandstone Samples in the Study Area.

Sample	**Quartz %**	**Feldspar %**	**Rock Fragments %**	**Matrix**	**Cement (Calcite + Clay)**	**Opaque**
MA1	70	2	10	11	5	2
AFK1	78	1	4	15	2	0
MA2	71	4	3	8	12	2

The modal analysis of the studied samples exhibits a comparatively simple mineralogy dominated by quartz. Feldspar and rock fragments were present in small amounts. Petrographic examination of the sandstones reveals the dominance of sub-angular to sub-rounded quartz. They occur as colourless to faint colored grains under cross polarized and plane polarized light (CPL and PPL) respectively. Matrix is made up of kaolinitic clay and silt. Cement is composed of calcite. The individual grains displayed a point to floating point contact. This is consistent with the friable to loosely consolidated nature of the sandstone.
The studied sandstones are designated as sub-litharenite (Fig.13), based on the classification scheme of Pettijohn (1975). The tectonic setting of the depositional environment is assumed to influence sedimentation, diagenesis and composition of sediments (Odigi, 2002). Using the typical quartz-feldspar-lithic fragment (Qt-F-Rf) Ternary diagram, adapted from Dickinson and Suczec (1979) the provenance of the sandstone was attempted (Fig 14).

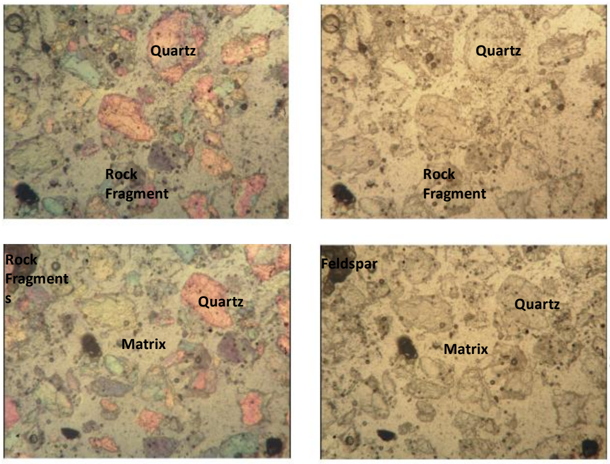

Fig 11: Photomicrograph of sandstone (MA1)

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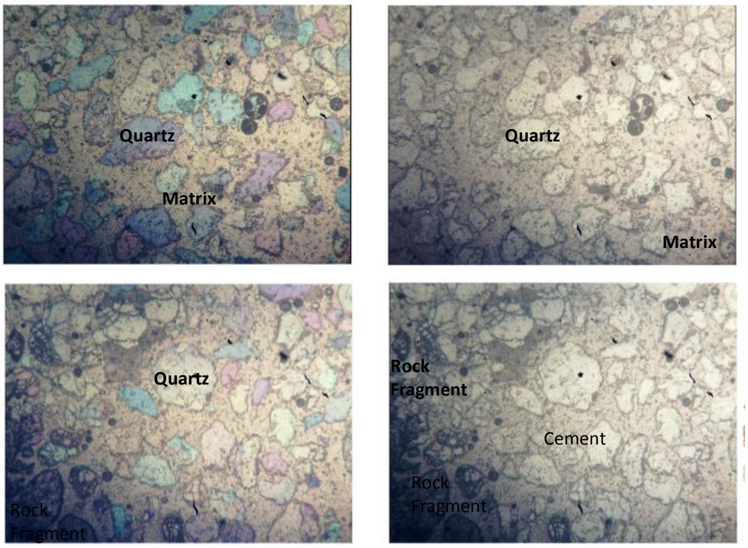

Fig 12: Photomicrograph of sandstone (AFK 1)

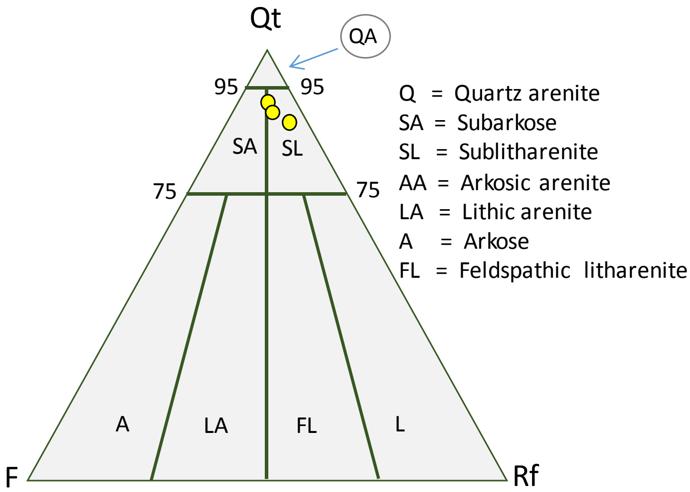

Fig 13: Triangular diagrams for the classification of the studied sandstones (after Folk, 1974)

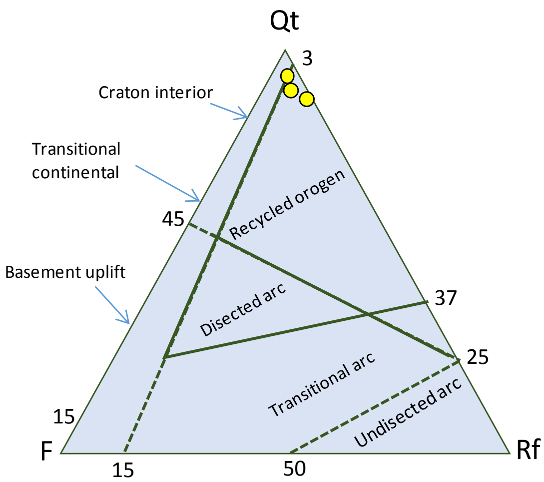

Fig. 14: Qt-F-Rf Triangular Diagram for the Sandstones of the Study Area Showing Provenance Fields (after Dickinson and Suczek, 1979)

3-D Depositional Environments and Models

The depositional environments for the different depositional units within the Afikpo Basin were interpreted by integrating results of lithofacies analysis, granulometric analysis, sedimentary structures interpretation, petrographic and biostratigraphic analyses.

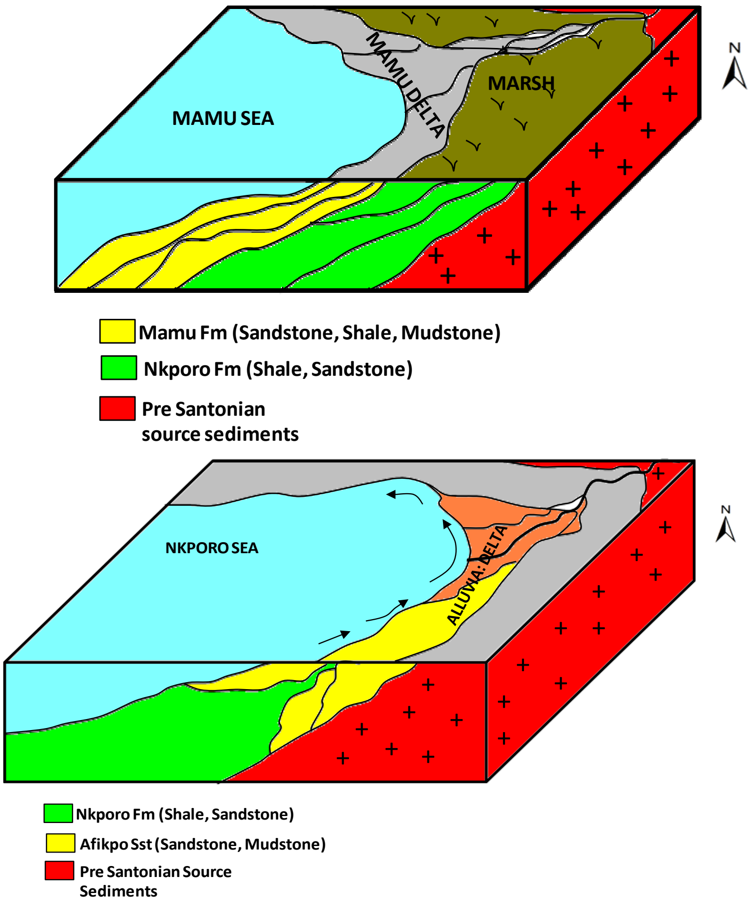

Fig 15. 3-D depositional model for Mamu and Nkporo Formations

DISCUSSION

Environment of Deposition

Evidence from calculated sieve parameters indicate a fluvial to nearshore environment. Cumulative frequency curve shows that the grain size population was dominated by traction and saltation population. Discriminatory plots of sorting versus mean size and sorting versus skewness suggest fluvial dominated influence (Friedman, 1967, Miola and Weiser, 1968).

Three facies association distilled from lithofacies include the Channel-Fill Facies, Shoreface Facies and Estuarine/Coastal Swamp Facies Association. The channel facies comprised of coarse-pebbly sandstone, Cross-bedded sandstone and claystone facies. The planar cross-bedded sandstone facies suggest product of traction current probably resulting from the preservation of the straight crested dunes and sand waves and transverse bars. (Nichols, 1999; Walker, 1992, Allen, 1967).

The shore face facies consist of lowermost fine-grained ripple laminated upper shore face sandstone facies, an interbeds of fine-grained sandstone, mudstone and laminated shale suggesting deposition/reworking by oscillatory wave processes or wave reworking of traction current ripples that dominate in the upper shore face environment, above fair-weather wave base (Dalrymple., 1992). The heterolithic estuarine facies with occasional coaly interval as recorded at Ebuwana is interpreted as a lagoonal and coastal swamp deposit. At Ebuwana, this facies grades into calcareous sandstone, suggesting intermittent marine influence as the area was periodically inundated (Oboh-Ikuenobe e al., 2005). Markov chain analysis indicates that the transition pattern in the studies sections has genetic links between the lithofacies, and consequently the environments of deposition. This is because the product of facies depicts the environment.

The facies model shows a characteristic coarsening up to aggradational pattern typical of a regressive shoreline deltaic environment. Dark grey laminated shale and fine-grained sandstone facies at the base of the Nkporo Group depositional model attest to shallow shelf inner neritic environment characterized by agglutinated/arenaceous forms. Shallowing up of the sea is indicated by the mudrock and crossbedded sandstone facies. Depositional model for Mamu Formation is dominated by the heterolithic facies with coaly intervals suggesting backshore lagoonal and marsh environment. Based on these, a pro-delta to delta front is proposed for the Nkporo Group. The Nkporo shale was laid down in a marine environment during the Late Campanian transgression. The Nkporo shale becomes increasingly arenaceous and eventually pass into sandstones such as the Afikpo Sandstone. The Afikpo Sandstone, therefore, represent fluvial point bars, ebb-and-flow tidal delta sandstones and tidal flat facies in a submerged/drowned river valley system (Okoro and Igwe, 2018).

On the other hand, an estuarine tidal delta to shallow marine with the intermittent paludal paleodepositional model has been proposed for the Mamu Formation. The sediments are parallel because of alternating marine and continental conditions culminating in shale sandstone interlayer. A species of gastropod (Turritella) was identified in the shale at the Ndibe Beach road cut location. Studies have shown that Turritella community is found in shallow marine water, about 22 m deep where it burrows spires downwards in muddy gravel (Rhona, 1972).

Turritella communis occurs locally and abundantly in gravelly muddy, more or less buried, in shallow water sediments up to 200 m (Graham 1988). T. *communis*, who have a highly specialized mud-burrowing habit, maintains contact with the water, from which the gill filters suspended particles (Baltzer et al., 2015; Yonge, 1946) — based identified forams, dominated by coarsely agglutinated benthonic taxa the studied samples indicate deposition in an estuarine-nearshore shallow marine environment because the assemblage fauna consists of dominantly of agglutinated forms attributed to the brackish environment or to stagnant conditions (Nagy et al., 1988). This is typified by their small thin shell, unornamented calcareous, or agglutinated assemblage (Zarborski, 1983., Brison, 1980).

Bolivina fauna was recovered only from the Nkporo Formation. Fadiya (1999), however, noted that Bolivina fauna found in slope environments generally show large test size compared to those of the inner neritic zone. With regards to oxygen level concentration, in the bottom waters, Petters and Edet, (1996) observed that high oxygen levels are associated with the secretion of more surface sculpture, more costae or large keels, whereas very low oxygen concentration results in marked reduction or absence of many kinds of surface sculpture. Umeji (2007) reported significant variations in palynofacies abundance in different depositional environments. Cuticles, spores and pollen are most common in shoreface and overbank deposits, whereas opaque structureless organic matter is most abundant in barrier/beach and offshore sands. In the strata of all ages, structured woody material is most abundant in prodelta deposits and upper delta-plain channel sands.

Results of the analysis showed that the assemblage indicates dominance of sporomorphs over marine diniflagellate cyst. The vascular tissue sporomorphs are suggestive of proximal prodelta and nearshore shallow shelf environments (Ojo and Akande, 2008). This denotes the influx of terrigenous organic matter in response to deltaic progradation on the shallow shelf (Habib, 1970). The co-existence of the structured organic palynomorphs debris in the units as shown in palynological data suggests swampy conditions within a predominantly fluvial setting (Okoro and Igwe, 2018). Laevigatosporites sp suggest swampy freshwater influx (Oloto, 1994).

Provenance and maturity of sandstone
The tectonic setting of the depositional environment is assumed to influence sedimentation, diagenesis and composition of sediments (Petijohn 1975; Odigi, 2002). Several studies have used the detrital composition of sandstones to infer provenance and tectonic settings (Dickinson, 1985; Tijani et al., 2012). Using the typical quartz-feldspar-lithic fragment (Qt-F-Rf) ternary diagram, adapted from Dickinson and Suczec (1979). The plot revealed high quartz content, low feldspar and relatively moderate amounts of lithic grains which are indicative of recycled orogen provenance. This implies sandstones derived mainly from exposed shield /platform or uplifted areas and deposited in stable sites (Tijani et al., 2012).

Age Determination
Assignment of age to the sediments from the study area was based on the selected key age diagnostic taxa of *Ammobaculites amabiensis, Ammobaculites stalokaensis, Amobaculites saheliensis, Ammobaculites coprolithiformis, Ammotium sp., Haplophragmoides, sp* based on the stratigraphic chart of Petters (1982) (Table 4.12), and the recognized palynomorphs taxa that connote Campanian age, according to Umeji (2011) includes *Cingulatisporite ornatus, Gleicheniidites senonicus, Leiotritites adrennis, Laevigatosporite sp, Cyathidites australis.*
Based on the sporomorph assemblage of *Foeveotriletes magaritae, Zivisporites blanesis, Longapertites marginatus, Retridiporites magdeliensis and Monocolpites marginatus* typical of the Late Cretaceous of West Africa-South America phytogeographic province (Herngreen and Chlonova, 1981) and the assemblage of Umeji (2011) mentioned above which are typical of the study area, the sediments were thus dated Late Campanian to Late Maastrichtian.

Petroleum System Elements
The reservoirs in the Basin of study are clastic sandstones, which comprise mainly of interbedded sandstone bodies of Nkporo and Mamu Formations that have adequate hydrocarbon reservoir quality evidenced from petrographic and grain size study. Traps within the basin were formed possibly due to south-westward stacking of sediment which created differential subsidence basinward (Nwajide and Reijers, 1996., Ladipo et al., 1992)
This could have caused the development of syndepositional growth faults during the Campanian renewed thermal subsidence in the Anambra and Afikpo Basin. The presence of the growth faults and associated rollover anticlinal structures offer possible traps

for hydrocarbon accumulation (Dim et al., 2018). Stratigraphic pinch outs and facies changes can provide additional stratigraphic traps.
The seal packages are mainly the interbedded shale of Nkporo, Mamu and overlying Nsukka Formation. As noted by Dim et al. (2018), the overlying Imo Formation (Paleogene) of the Niger Delta Basin, which has not undergone any deformation can provide a regional seal.

Table 4.12: Distribution of Stratigraphically important Cretaceous arenaceous Benthic Foraminifera in the study area (Modified from Petters 1982)

AGE / *FORAMINEFERA*	*CAMPANIAN*	*MAASTRICHTIAN*	*PALEOCENE*
Ammobaculites coprolithiformis	——	——	
Haplophragmoides sahariense	——	——	
Ammobaculites amabensis	——	——	
Haplophragmoides talokaense	——	——	
Ammobaculites texanus	——	——	
Haplophragmoides hausa	——	——	
Haplophragmoides saheliense	——	——	
Ammobaculites sp	——	——	
Arenaceous indet sp		——	——
Ostracoda		——	——
Anomalinoides midwayensis		——	——
Trochamina dutsuna		——	——

CONCLUSION

The study involved lithofacies analysis and interpretations of environments of deposition (EOD) of Upper Cretaceous sediments in parts of Afikpo area Southeastern Nigeria. The study was based on field and laboratory studies, including sedimentological, thin section petrographic and paleontological analyses. Environmental interpretation from lithofacies studies suggested shoreline environments with occasional fluvial influences as depicted in the generated depositional models. The foraminiferal assemblages of the sediments are mainly coarsely agglutinated benthonic taxa: typical of estuarine-nearshore shallow depositional environment. Palynofacies recovered in the sediments suggested swampy conditions within a predominantly fluvial setting. Assignment of age to the sediments from the study area was based on the selected key age diagnostic taxa indicating Late Campanian to Late Maastrichtian. The shale of Nkporo Group and the coals of Mamu Formations could serve as good source rocks, whereas the sandstone of the Mamu Formation could serve as potential reservoir rocks. The juxtaposed fault blocks due to structural deformation and facies changes could serve as possible entrapment mechanisms, whereas the joints in shale could provide possible migration pathways for hydrocarbons. Generally, detailed outcrop studies in the study area have enabled the understanding of the petroleum system elements that could be utilized in hydrocarbon exploration in the southeastern part of the Afikpo Basin of Nigeria.

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