

Sequence Stratigraphy and Sea Level changes in Relation to Evolution of Anambra Basin, Southeastern Nigeria

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ABSTRACT

Biostratigraphic sequence stratigraphy technique was used to predict the stacking pattern and geologic events towards understanding sea level changes as precursor for the evolution of Anambra Basin, Nigeria. Palynology analysis data and lithologic description of Nzam-1 well comprising oldest Asu River Group to youngest Ogwashi/Asaba Formation were used. The method involved laboratory preparation of palynology slides and detailed identification of pollen, spores, dinoflagellates, algae, fungal spore, microforaminiferal wall linings and other stratigraphically important forms present. The method entails total abundance and diversity of palynomorphs and cognizance of two types of dinoflagellates such as gonyaulacaceans and peridinaceans. The preponderance of gonyaulacaceans in addition to high abundance and diversity of palynomorphs defines a stratigraphic Condensed Section (CS) within which is Maximum Flooding Surface (MFS), characterizes Highstand Systems Tract (HST). On the other hand, intervals characterized by barren to poor recovery of palynomorphs suggest lowest position of sea level, equivalent to Lowstand Systems Tract (LST) at the base of which is a Sequence Boundary (SB). The rising sea level is the Transgressive Systems Tract (TST) characterized by relative increase in palynomorph abundance, diversity and higher occurrence of peridinacean dinoflagellate cysts compared to LST. Eight transgressive cycles (TCs) and 5 major unconformity surfaces synonymous to regressive surface were identified at different geologic time as a result of eustatic changes in sea levels. The deepest part is characterized by TST/HST suggestive of marine incursion during Albian due to splitting of the Gondwana land; responsible for the deposition of Asu River Group. The second MFS was located at 3125 m, dated Upper Cenomanian, responsible for the accumulation of Eze Aku Formation. A regressive (LST) was responsible for the deposition of Awgu Formation in the Coniacian period. The third transgressive cycle occurred during the Early Campanian, responsible for the deposition of Nkporo Formation; MFS placed at 2411 m, dated Upper Campanian within the formation. The lower part of Mamu Formation was deposited under the influence of LST, dated Lower Maastrichtian; SB placed at 2057 m. The Middle Maastrichtian was marked by the fourth TC; deposited upper Mamu Formation. However, the lower boundary of Nsukka Formation was marked by LST placed at 1234 m, dated Lowermost Upper Maastrichtian within Nsukka Formation. The sixth marine transgression deposited Imo Formation, followed by a regressive phase (LST) in the Upper Late Paleocene. The seventh marine transgression occurred during Middle Eocene, led to deposition of Ameki Formation while the eighth marine transgression was in the Upper Miocene-Pliocene period, responsible for deposition of Ogwashi/Asaba Formation

Keywords: Palynomorph abundance and diversity, Biostratigraphy sequence Stratigraphy, Systems tracts, Maximum Flooding Surface, Sequence Boundary

INTRODUCTION

The study of sequence stratigraphy is no longer new to geologists but it continues to play vital role in understanding stacking pattern of stratigraphic sequence, prediction of geologic events in terms of sequence surface, flooding surfaces, surface of unconformity, sea level fluctuations and climatic conditions. The interpretation of sequence stratigraphy encompasses three major tools which include well-log, seismic and biostratigraphic studies (Ola-Buraimo *et al.*, 2010). The engineering concept of sequence stratigraphy is one whereby the three main aspects are independently studied and interpreted before final synthesis with one another to achieve desired objectives.

Ola-Buraimo *et al.* (2010) posited that the method permits geologists to divide a rock section into series of genetic

units bounded by condensed section and their associated maximum flooding surface using wire line signatures. However, here in the biostratigraphy sequence stratigraphy, it is characterized by bounding condensed sections in which maximum flooding surface present is identified based on maximum occurrence of palynomorphs abundance and diversity.

The sequence bounded by maximum flooding surface (MFS) is sub-divided into smaller sediment packages called systems tracts on the basis of relative abundance and diversity of palynomorphs. However, identification of maximum flooding surface shall as well include appropriate identification of dinoflagellates especially the gonyaulacacean types characterized by short spines; this could serve as starting as starting point for predictive biostratigraphic sequence stratigraphy interpretation.

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Sequence stratigraphy application has been widely used by many workers to solve problem of correlation and understanding the architectural stacking pattern of stratigraphic sequences. Among well documented reports are the works of Vail and Wornardt (1990); Wornardt and Vail (1991); Morley (1992, 1995); Umeji (2007, 2010); Ehinola (2010); Ola-Buraimo and Akaegbobi (2013); Adebayo *et al.* (2015) for the Nkporo Formation in Anambra Basin, Nigeria and Akaegbobi *et al.* (2016) on three wells located in Forcados Yorkri Field, Niger Delta, Nigeria.

The application of palynology in interpreting sequence stratigraphy is towards understanding the evolution of Anambra Basin. Identification of maximum flooding surfaces (MFSs) and sequence boundaries (SBs) is

imperative in reconstruction of sea level changes as main contributing factor in deposition of sediments in Anambra Basin. Palynology is the best tool for this purpose because other aspects of biostratigraphy which include study of foraminifera and nannofossil have failed in the hands of many researchers in assessing Anambra Basin chronostratigraphy.

Therefore, Nzam- 1 well was selected for this purpose because it contains records of the oldest sediments in Anambra Basin (Ola-Buraimo and Akaegbobi, 2013c) and complete suits of formations in the basin (Ola-Buraimo, 2019). The Nzam-1 well is the deepest well drilled so far and strategically located away from well studied southern part of the location by previous workers, mostly based on outcrop samples (Fig. 1).

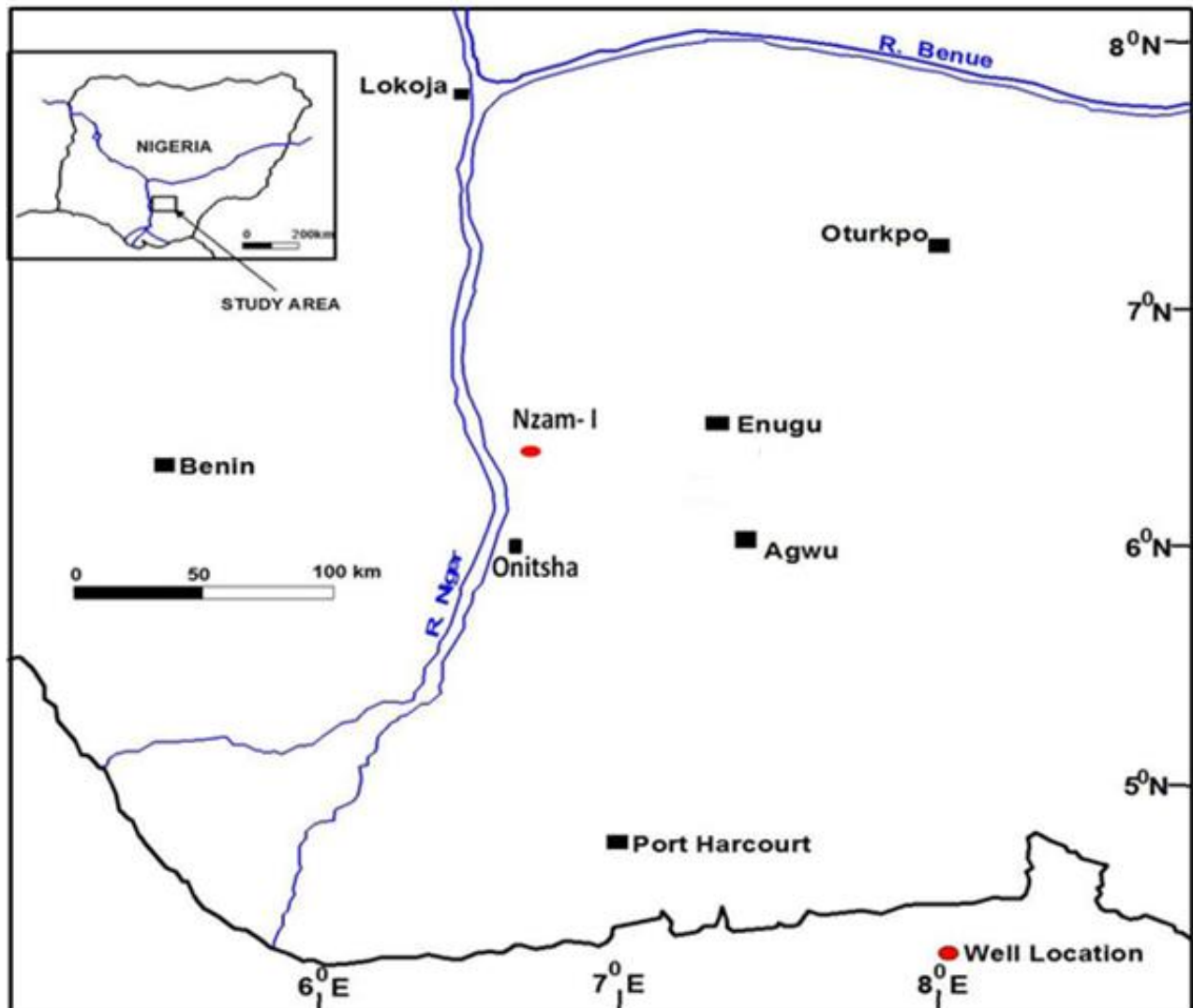


Figure 1.1. Map of Nigeria (inlet) showing map of southern Nigeria with the location of Nzam- 1 well studied and situated in Anambra Basin (After Ola-Buraimo, 2019)

Stratigraphy of Anambra Basin

The stratigraphic sequence of the Anambra Basin was widely discussed by several workers including Reymont (1965), Murat (1972), Dessauvage (1975), Agagu *et al.* (1985), Ladipo (1986), Ehinola (2010), Nton and Bankole (2013). Among notable works was that of Umeji (1985) on the subtidal shelf sedimentation of the Turonian Eze-Aku Formation in the Nkalagu area, southeastern Nigeria. Umeji (1988) also studied the trace fossils present in the Eze-Aku Formation, Anambra Basin, Nigeria. Lawal (1991) dated the Eze-Aku Formation to belong to Late Cenomanian-Turonian based on palynological content. Umeji (1993) studied the hummocky cross-stratification present in the Turonian Eze-Aku Sandstone and related its deposition to tidal effect.

Other palynological studies include the works of Umeji (2003, 2004, and 2005); Umeji and Nwajide (2007); Umeji and Edet (2008); Umeji (2011) and Ogala *et al.*, (2009). Umeji (2013) classified the sedimentary succession in Benue Trough, grouped them into Asu-River Group and dated it Neocomian-Cenomanian age. The date given to Asu River Group is in contrary to the work of Ola-Buraimo and Akaegbobi (2013b) who assigned Albian to Early Cenomanian age based on palynological contents such as *Forma PO 304 Lawal, Afropollis jadinus, Cretacaeiporites* pollen, *Steevesipollenites binodosus, Galeacornia* sp. and *Hexaporotricolporites emelianovi* deposited in marginal marine, continental and open marine systems. Ola-Buraimo (2013a) dated the Eze-Aku Formation to be Upper Cenomanian to Turonian age based on the occurrence of diagnostic palynological marker forms. The Awgu Formation that overlies the Eze-Aku Formation was dated Coniacian age in the Nzam-1 well on the basis of palynomorph contents (Ola-Buraimo, 2013b).

Umeji (2010) studied the sequence Stratigraphy of Nkporo Shale, showed that both the Nkporo Shale and Afikpo Sandstone were deposited under marine and near shore environment with a late highstand systems tract (HST). Umeji (2011) also studied the palynofacies and palaeodepositional environment of the Campano-Maastrichtian Nkporo sediments exposed around Leru in Anambra Basin, Nigeria. However, Chiaghanam *et al.*, (2012) assigned Late Campanian age to Nkporo Shale at Leru and Early to Middle Maastrichtian to Mamu Formation at Uturu while Nsukka Formation at Ihube was dated Late Maastrichtian age. Ola-Buraimo and Akaegbobi (2013a) studied the Nkporo Shale which overlies the Awgu Shale stratigraphically to be Campanian to Lowermost Maastrichtian age based on palynological contents. Igwe (2015) dated Nkporo Shale to be Late Campanian to Maastrichtian age, while the environment of deposition was described to be open marine to estuarine. In the work of Adebayo *et al.* (2015), Nkporo shale located at Orekepe-Imiegba area was dated Early-Late Campanian age while sequence stratigraphy study classified the sequence into TST which suggested inundation of the marine responsible for deposition of Nkporo shale in the Early Campanian. A more detailed study was carried out on a section of Ubiaja-I well whereby the section was delineated into Eze-Aku dated Turonian; Awgu Formation, dated Coniacian to Santonian and Nkporo Shale dated Early Campanian;

deposited in marginal marine environment (Ola-Buraimo *et al.*, 2016).

Bankole and Ola-Buraimo (2017) dated the Nsukka Formation to be Late Maastrichtian based on the occurrence of *Spinizonocolpites baculatus*, *S. echinatus*, *Construcitipollenites ineffectus*, *Periretisyncolpites* sp., *P. giganteus*, *Foveotriletes margaritae*, *Syncolporites marginatus*, *Anacolocidites luidonensis*, *Mauritiidites crassibaculatus*, *Retistephanocolpites williamsi*, *Proteacidites dehaani*, *Echitriporites trianguliformis*, *Proxaperites cursus*, *Retidiporites magdalenensis*, *Retitricolpites gigeoneti*, and *Araucariacites* sp.; while the paleoenvironments of deposition vary alternately from marginal marine to continental setting based on the presence of land-derived miospores and dinoflagellates. Imo Formation overlies the Nsukka Formation; it was dated to belong to Selandinian to Aquitanian based on abundant occurrence of dinoflagellates (Umeji, 2016).

Umeji (2012) used the presence of *Podocarpus millanjanus* to date Ogwashi-Asaba Formation to be Pliocene age. However, the same Ogwashi-Asaba Formation was dated to be of Late Miocene to Pliocene age based on dinoflagellate constituents such as *Selenopemphix nephroides*, *Multispinula quanta*, *Tuberculodinium vancampoae*, *Polysphaeridium zoharyi* and *Impagidinium* spp.; accompanied with diagnostic pollen forms such as *Nymphae lotus*, *Elaeis guineensis*, *Cypracaepallis* sp., *Podocarpus mullanjanus*, *Retistephanocolpites gracilis*, *Arecipites* sp. and *Echitricolporites spinosus* (Ola-Buraimo and Akaegbobi, 2012).

Data Requirements

The basic tools needed for biostratigraphic sequence stratigraphy interpretation are prepared palynology slides of a well sequence or stratigraphic interval of interest, analyzed under the microscope by identifying the pollen, spores, dinoflagellates, algae, fungal spores, microforaminifera wall linings and other macerals that are stratigraphically important as a data set and ditch cutting samples or fresh outcrop samples necessary for lithologic description. The combination of these suits of data would be appropriate for the exercise.

METHODOLOGY

The technology of biostratigraphy sequence stratigraphy is based on the assumption that sea level changes are the predominant control on stratigraphic architecture geometries and facies, but recognizes that the rate of sedimentation, tectonic, subsidence, isotasy and compaction contribute to creating space for sediment accommodation (Vail, *et al.*, 1977). In addition to these factors are climate, salinity, pH, temperature, nutrient and other ecological factors contribute to the understanding of biostratigraphy sequence stratigraphy concept. Sequence stratigraphy was described as a hierarchical system in which genetic units and elements are usually placed in a resolution framework of time line (Ola-Buraimo *et al.*, 2010).

Therefore, in this study Nzam-1 well located in Anambra Basin, southeastern Nigeria was used by generating data on palynomorph abundance and diversity in order to deduce

systems tracts. Palynological systems tracts delineated are Lowstand Systems Tract (LST), Transgressive Systems Tract (TST) and Highstand Systems Tract (HST). Other sections and surfaces that permitted identification of the systems tracts are the condensed section (CS), maximum Flooding Surface (MFS) and Sequence Boundary (SB). Definitions of the terms used are given below according to Morley (1995).

Sequence stratigraphy: It is the study of relationship within a chronostratigraphic framework wherein the succession of rocks is cyclic and composed of genetically related strata unit.

Lowstand systems tract: These are sediments deposited during the lowest sea levels following a type 1 sequence boundary. The geometry of its constituent parts differs according to whether deposition occurred in a basin with a shelf break or ramp margin.

Transgressive systems tract: It is the middle systems tract in both type 1 and type 2 sequences. It is characterized by one or more retrogradational parasequence sets. The base of the transgressive systems tract is the transgressive surface at the top of the lowstand or shelf margin systems tracts.

Highstand systems tract: Deposited during the highest sea levels during either type 1 or type 2 sequence, widespread on the shelf and may be characterized by one or more aggradational parasequence sets that are succeeded by one or more progradational parasequence sets with prograding clinof orm geometries.

Sequence: A relatively conformable succession of genetically related strata bounded by unconformity and their correlative conformities. It is composed of a succession of systems tract and is interpreted to be deposited between eustatic fall inflection points.

Systems tract: It is the linkage of contemporaneous depositional systems, each defined objectively by strata geometries at boundary surfaces position within a sequence and internal parasequence stacking patterns.

In a nut shell biostratigraphy sequence stratigraphy study entails total abundance and diversity of palynomorphs and cognizance of two types of dinoflagellates such as gonyaulacaceans and peridinaceans. The preponderance of gonyaulacaceans in addition to high abundance and diversity of palynomorphs defines a stratigraphic condensed section (CS) within which is maximum flooding surface (MFS), characterizes highstand systems tract (HST). On the other hand, intervals characterized by barren to poor recovery of palynomorphs, little or no recovery of dinoflagellate cyst, suggest decrease in sea level, equivalent to lowstand systems tract (LST) at the base of which is a sequence boundary (SB). The rising sea level is the transgressive systems tract (TST) characterized by increase in palynomorph abundance, diversity and higher

occurrence of peridinacean dinoflagellate cysts compared to HST.

RESULT AND DISCUSSION

The interpretation of the sequence stratigraphy of the Nzam-1 well was established through the integration of lithology and palynology data. The ages of the formations in Anambra Basin given are adapted from the work of Ola-Buraimo (2018). The result shows that there are six sequences of events of deposition from the Middle Cretaceous to the Pliocene time (Table 1). The lowest part of the section dated Albian is characterized by transgressive/highstand systems tract which suggest the incursion of the marine water due to splitting of the Gondwana landmass. It was the period at which Anambra Basin evolved, resulted to deposition of shallow marine sediments equivalent to Asu River Group. This observation is similar to the Latest Albian transgression noted by Ramanathan and Fayose (1990) on the Calabar Flank, southeast Nigeria; also in consonant with the work of Ehinola (2010) on oil shale deposit in the Abakaliki fold belt. The marine transgression was responsible for the contemporaneous sedimentation of Asu River Group in Anambra Basin as noted in this study, Abakaliki Anticlinorium as indicated by Ehinola (2010) and its facies equivalent in the Benue Trough, Nigeria (Reyment and Morner, 1977) and Calabar Flank, Nigeria (Ramanathan and Fayose, 1990) (Fig. 4). Eight maximum flooding surfaces were delineated in the Anambra Basin compared to four transgressions reported by Ramanathan and Fayose (1990) for Calabar Flank and Benue Trough (Reyment and Morner (1977). The maximum flooding surfaces (MFS) established were located within the condensed section (CS) (Table 1).

The periods of maximum flooding surface is equivalent to the time of increase in sea level resulting to retrogradation and deposition of fine materials such as shale (Wornardt and Vail, 1991). The process of deposition of fine grained materials in the marine environment is otherwise described as sediment starvation. The sequence boundary was located at 3378 m. The SB was characterized by no recovery of palynomorphs, barren of stratigraphically important forms. The non-recovery of palynomorphs within the clay deposit might be as a result of progradation of oxygenated sediments into the environment. The second maximum flooding surface is located at 3125 m; characterized by high abundance and high diversity of palynomorphs relatively rich in gonyaulacacean form of dinoflagellates and recovery of scolecodont in the Upper Cenomanian marking the transition from the Asu-River Group to Eze Aku Formation; here a conformable relationship exists (Table 1). The second MFS that marks on-set deposition of Eze Aku Formation was also reported in the work of Ehinola (2010) characterized by highest abundance recovery of microfaraminifera. This is a type 2 sequence (Morley, 1995).

Table 1. Sequence Stratigraphy of the Nzam- well, Anambra Basin, Nigeria

| Depth (m) | Palynomorph Abundance | Palynomorph Diversity | Systems Tracts | Lithology | Formation | Age (Ma) |
|-----------|-----------------------|-----------------------|------------------------------|---------------------|---------------|---------------------------|
| 113 | 11 | 9 | Condensed section TST/HST | [Lithology symbols] | OGWASHI-ASABA | Upper Miocene To Pliocene |
| 128 | 66 | 25 | | | | |
| 151 | 38 | 19 | | | | |
| 232 | 79 | 31 | | | | |
| 256 | 66 | 35 | | | | |
| 287 | 53 | 23 | | | | |
| 311 | 36 | 14 | | | | |
| 355 | 22 | 13 | | | | |
| 366 | 56 | 28 | | | | |
| 390 | 26 | 15 | | | | |
| 412 | 29 | 14 | | | | |
| 445 | 25 | 17 | | | | |
| 469 | 38 | 19 | | | | |
| 494 | 37 | 17 | | | | |
| 518 | 47 | 20 | | | | |
| 543 | 27 | 14 | LST | [Lithology symbols] | AMEKI | Middle Eocene |
| 567 | 8 | 7 | | | | |
| 591 | 12 | 11 | | | | |
| 628 | 10 | 8 | | | | |
| 658 | 27 | 15 | | | | |
| 689 | 8 | 6 | TST/HST | [Lithology symbols] | IMO | Early Paleocene |
| 713 | 30 | 13 | | | | |
| 738 | 41 | 23 | | | | |
| 762 | 36 | 15 | | | | |
| 792 | 97 | 31 | | | | |
| 817 | 116 | 25 | | | | |
| 847 | 182 | 63 | | | | |
| 872 | 66 | 38 | | | | |
| 896 | 75 | 46 | | | | |
| 924 | 5 | 5 | | | | |
| 951 | 2 | 2 | | | | |
| 975 | 1 | 1 | | | | |
| 1009 | 1 | 1 | | | | |
| 1036 | 1 | 1 | | | | |
| 1064 | 0 | 0 | | | | |
| 1088 | 1 | 1 | | | | |
| 1106 | 6 | 6 | | | | |
| 1131 | 4 | 4 | | | | |
| 1158 | 2 | 2 | | | | |
| 1180 | 18 | 9 | | | | |
| 1207 | 10 | 9 | | | | |

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| 1234 | 27 | 13 | | | | |
| 1237 | 16 | 10 | TST/HST | | NSUKKA | Upper Maastrichtian |
| 1271 | 12 | 8 | | | | |
| 1256 | 1 | 1 | → SB | | | |
| 1292 | 5 | 4 | LST | | | |
| 1320 | 5 | 5 | | | | |
| 1372 | 48 | 30 | HST | | MAMU | |
| 1423 | 28 | 17 | | | | |
| 1430 | 60 | 26 | | | | |
| 1445 | 3 | 3 | | | | |
| 1457 | 42 | 28 | | | | |
| 1511 | 46 | 26 | | | | |
| 1640 | 2 | 2 | | | | |
| 1743 | 12 | 9 | | | | |
| 1786 | 3 | 3 | | | | |
| 1817 | 108 | 34 | → MFS | | | |
| 1844 | 13 | 8 | TST | | | |
| 1871 | 23 | 10 | | | | |
| 1899 | 10 | 6 | | | | |
| 1926 | 12 | 10 | | | | |
| 1954 | 33 | 19 | | | | |

| | | | | | | |
|------|----|----|---|-----|--------|-------------------------------|
| 1981 | 12 | 12 | | | | |
| 2003 | 11 | 10 | | LST | | |
| 2030 | 5 | 5 | | | | |
| 2057 | 2 | 2 | → | | | |
| 2084 | 32 | 23 | | SR | | |
| 2112 | 53 | 30 | | | | Lower To Middle Maastrichtian |
| 2135 | 6 | 6 | | | | |
| 2140 | 50 | 30 | | | | |
| 2164 | 11 | 9 | | | | |
| 2189 | 15 | 9 | | | | |
| 2216 | 35 | 28 | | HST | | |
| 2271 | 33 | 22 | | | | |
| 2303 | 3 | 3 | | | | |
| 2304 | 12 | 10 | | | | |
| 2335 | 6 | 6 | | | | |
| 2356 | 3 | 3 | | | | |
| 2384 | 13 | 9 | | | | |
| 2411 | 38 | 20 | ↔ | | | |
| 2438 | 28 | 15 | | | | |
| 2463 | 2 | 2 | | | | |
| 2493 | 8 | 6 | | | | |
| 2521 | 17 | 12 | | | | |
| | | | | MFS | | |
| | | | | | NKPORO | Campanian |

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|------|----|----|---------|-----|---------|------------------------------|
| | | | | | | |
| 2548 | 10 | 9 | TST | | NKPORO | Campanian |
| 2576 | 2 | 2 | | | | |
| 2603 | 29 | 21 | | | | |
| 2630 | 1 | 1 | LST | | AWGU | ?Santonian To Coniacian |
| 2658 | 4 | 4 | | | | |
| 2688 | 3 | 3 | | | | |
| 2716 | 9 | 8 | | | | |
| 2744 | 5 | 4 | | | | |
| 2771 | 6 | 5 | | | | |
| 2799 | 2 | 2 | | | | |
| 2823 | 4 | 4 | | | | |
| 2851 | 2 | 2 | | | | |
| 2878 | 3 | 3 | | | | |
| 2906 | 17 | 12 | HST | | EZE-AKU | Upper Cenomanian To Turonian |
| 2933 | 20 | 15 | | | | |
| 2960 | 4 | 4 | | | | |
| 2988 | 5 | 4 | | | | |
| 3012 | 9 | 6 | | | | |
| 3043 | 9 | 9 | | | | |
| 3070 | 4 | 4 | | | | |
| 3098 | 2 | 2 | | | | |
| 3125 | 29 | 19 | | | | |
| 3156 | 12 | 10 | | MFS | | |
| 3183 | 21 | 16 | TST | | | |
| 3210 | 14 | 11 | | | | |
| 3256 | 2 | 2 | | | | |
| 3265 | 8 | 7 | | | | |
| 3293 | 5 | 4 | | | | |
| 3320 | 4 | 4 | | | | |
| 3351 | 2 | 2 | LST | | | |
| 3378 | 0 | 0 | | | | |
| 3402 | 2 | 2 | | | | |
| 3430 | 3 | 3 | | SB | | |
| 3457 | 8 | 6 | | | | |
| 3482 | 1 | 1 | | | | |
| 3500 | 2 | 2 | TST/HST | | | |
| 3524 | 21 | 13 | | | | |
| 3543 | 4 | 4 | | | | |
| 3558 | 3 | 3 | | | | |
| 3585 | 11 | 10 | | | | |
| 3616 | 5 | 5 | | | | |

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|------|----|---|--|--|--|
| 3643 | 12 | 9 | | | |
| 3672 | 0 | 0 | | | |

However, the third transgressive cycle noted by Ramanathan and Fayose (1990) for the Turonian seems not to be present. Only one transgressive phase was responsible for the deposition of Cenomanian-Turonian sediments

(Eze-Aku Formation) unlike two phases suggested by Ramanathan and Fayose (1990) (Table 1). The two transgressions mentioned by them were flooding surfaces rather than maximum flooding surface which was supposed

to be the shaliest facies formed as a result of highest increase in sea level (Table 2).

The regressive phase represented by lowstand systems tract (LST) was responsible for the deposition of the Awgu Formation in the Coniacian time. A comparison of the transgressions noted in the Cretaceous sediments of this study to that of Reyment and Morner (1977) show some correlations except their third cycle (Awgu cycle) that differs, in that, this study shows that Awgu Formation was deposited under lowstand systems tract (regressive phase) which is in contrast to transgressive phase suggested by them (Tables 2 and 3). In the work of Ehinola (2010) similar transgression cycle was noted in the Abakaliki Anticlinorium which suggests that the eastern flank of Anambra Basin experienced favourable ecological factors, where sediments were deposited under anoxic condition. In the contrary, Anambra Basin witnessed poor ecological factors at the time and the sediments were deposited under oxic condition. These are suggested to account for lowstand

systems tract interpreted in this study and highstand systems tract suggested by other workers.

This same view was shared and reported in the work of Umeji (2007) that lowstand systems tract was responsible for the deposition of Awgu Shale but the Awgu Shale was not recorded (missing) in some parts of Anambra Basin, Nigeria such as in Umuna-1 well (Ola-Buraimo, 2019 unpublished thesis) and at an outcrop at Leru in Anambra Basin (Umeji, 2006). The absence of the Awgu Shale may as well be due to thinning out of the facies. The adverse drop in marine water level (regression) in conjunction with tectonic activity were responsible for the removal of deposited sediments or non deposition of sediments during the Santonian period. There is no scientific and biostratigraphic facts that support the idea of re-deposition of sediments deposited during pre-Santonian period, eroded during Santonian and re-deposited during the Campanian period.

Table 2. Comparison of sea level cycles in Anambra Basin with Benue Trough (Reyment and Moraner, 1977) and Calabar Flank (Ramanathan and Fayose, 1990) Nigeria

| Stages/Epoch | | Benue Trough | | Calabar Flank | | Anambra Basin | | | | | | | | | |
|---------------|---|----------------------------------|--------------|-------------------------------------|------------|-----------------|---------------------|-----------------|-------------|-----------------|---------------|-----------------|---------------|-----------------|-----------------|
| | | After Reyment and Morner, (1977) | | After Ramanathan and Fayose, (1990) | | Present Study | | | | | | | | | |
| | | Transgression | Name | Transgression | Name | Transgression | Name | | | | | | | | |
| Pliocene | | NO DATA | NO DATA | NO DATA | NO DATA | 7 TH | Ogwashi/Asaba Cycle | | | | | | | | |
| Maastrichtian | U | | | | | HIATUS | HIATUS | | | | | | | | |
| | M | | | | | | | | | | | | | | |
| | L | | | | | | | | | | | | | | |
| Oligocene | | | | | | | | | | | | | | | |
| Eocene | U | | | | | | | 6 TH | Ameki Cycle | | | | | | |
| | M | | | | | | | | | | | | | | |
| | L | | | | | | | | | | | | | | |
| Paleocene | U | | | | | | | | | HIATUS | HIATUS | | | | |
| | M | | | | | | | | | | | | | | |
| | L | | | | | | | | | | | | | | |
| Maastrichtian | U | | | | | | | | | | | 5 TH | Imo Cycle | | |
| | M | | | | | | | | | | | | | | |
| | L | | | | | | | | | | | | | | |
| Campanian | U | 4 TH | Nkporo Cycle | | | | | | | | | | | | |
| | L | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Santonian | U | | | 3 RD | Regression | | | | | | | | | | |
| | L | | | | | | | | | | | | | | |
| Turonian | | | | | | 2 ND | Nkporo Cycle | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Cenomanian | U | | | | | | | HIATUS | HIATUS | | | | | | |
| | L | | | | | | | | | | | | | | |
| Albian | | | | | | | | | | 1 ST | Eze Aku Cycle | | | | |
| | | | | | | | | | | | | | | | |
| Cenomanian | U | | | | | | | | | | | 2 ND | Eze Aku Cycle | | |
| | L | | | | | | | | | | | | | | |
| Albian | | | | | | | | | | | | | | 1 ST | Asu River Cycle |
| | | | | | | | | | | | | | | | |
| | | NO DATA | NO DATA | | | | | | | | | | | | |

The lowest part of the Nkporo Formation was formed during the Earliest Campanian under the influence of

marine retrogradation and major parts of the Nkporo Formation was under the influence of marine incursion.

Maximum flooding surface was placed at 2411 m within the Nkporo Formation; dated Upper Campanian. The stratigraphic horizon is defined by high abundance and diversity of palynomorphs, relative abundance of dinoflagellates. Lithologically, the shale facies is dark grey in colour with strong effervescence on acid test.

Similar phenomenon was reported by Umeji (2010), Odunze and Obi (2013) on the Nkporo Formation outcrop at Leru in Anambra Basin, Nigeria. The position of the third transgressive phase is similar to the observation of Reymont and Morner (1977), Ramanathan and Fayose (1990) for Benue Trough and Calabar Flank respectively (Table 2).

Table 3. Transgressive and regressive cycles in Nzam- 1 well (Present study)

| STAGE | EPOCH | TRANSGRESSION | NAME | CYCLE |
|-------------------|-------|---------------|-----------------------|-------|
| Piocne Miocene | U | 7TH | Owashi/Asaba Cycle | |
| | M | HIATUS | HIATUS | |
| | L | | | |
| Oligocene | | | | |
| Eocene | U | 6TH | Ameki | |
| | M | | HIATUS | |
| | L | | | |
| Paleocene | U | 5TH | Imo Cycle | |
| | M | | HIATUS | |
| | L | | | |
| Maastrichtian | U | 4TH | Nsukka Cycle | |
| | M | 3RD | Mamu Transgression | |
| | L | | Regression | |
| Campanian | U | 2ND | Nkporo Cycle | |
| | L | | | |
| Santonian | U | | HIATUS | |
| | L | | | |
| Coniacian | | | Awgu Regression | |
| Turonian | | 1ST | Eze Aku Cycle | |
| Cenomanian | U | | Asu River | |
| | L | | | |

The highstand systems tract that was responsible for the deposition of Nkporo Shale did not continued and was not responsible for deposition of lower Mamu Formation (Tables 1 and 3). The lower part of Mamu Formation was deposited under the influence of lowstand systems tract (regression), dated Lower Maastrichtian. A sequence boundary was placed at 2057 m and a conformable facies relationship exists between the Campo/Maastrichtian. The fourth maximum flooding surface (MFS) represents maximum landward movement of the shoreline as result of increase in sea water level during Middle Maastrichtian time. The wet favourable climatic condition was responsible for the maximum development of *Longapertites marginatus*. The upper boundary of the Mamu Formation is marked by the top of HST, while the lower boundary of Nsukka Formation is marked by lowstand systems tract (regression), characterised by paucity of palynomorph abundance and diversity. Sequence boundary (SB) was placed at 1256 m, while a short transgressive phase followed. Fifth maximum flooding surface was placed at 1234 m, tentatively dated Lowermost

sediments (Table 1). The Middle Maastrichtian was marked by the fourth cycle in this study but was not identified by Reymont and Morner (1972); partially identified by Ramanathan and Fayose (1990) (Table 2). Mamu Formation was categorized into lower and upper Mamu Formation (Table 3). The upper Mamu is characterised by the fourth transgressive cycle of Middle Maastrichtian age.

Upper Maastrichtian age located within the Nsukka Formation (Table 1).

The uppermost part of the Nsukka Formation is characterised by very high recovery of palynomorph abundance and diversity depicting of a condensed section (Table 1); within this is the location of MFS at 847 m. The sixth major marine transgression commenced deposition of the Imo Formation. Thereby, a conformable facies relationship exists between the Imo Formation and the underlying Nsukka Formation.

A regressive phase during Upper Late Paleocene followed the marine transgression during the Early Paleocene and the effect of the lowstand systems tract of type 1 unconformity resulted and responsible for the removal or starvation of

sediments till seventh marine transgression occurred during the Middle Eocene. This was responsible for the deposition of Ameki Formation (Table 1). An unconformity exists between the Ameki Formation (Middle Eocene) and the younger Ogwashi/Asaba Formation (Upper Miocene-Pliocene). The eighth maximum flooding surface was placed at 232 m within the Ogwashi-Asaba Formation and

that marks the last stratigraphically documented maximum flooding surface in Anambra Basin, Nigeria. Palynology data from Nzam- 1 well in Anambra Basin has provided insight into the sea level changes that resulted into various flooding surfaces and sequence boundaries used in predicting the systems tracks and architectural arrangement of the formations and the dating of such events in geologic time.

| Stages Epoch | | Transgression | Name |
|---------------------|---|---|---|
| Pliocene Miocene | U | 8 TH | Ogwashi + Asaba Cycle |
| | M | | |
| | L | | |
| Oligocene | | HIATUS | HIATUS |
| Eocene | U | 7 TH | Ameki |
| | M | | |
| Paleocene | L | HIATUS | HIATUS |
| | U | | |
| | M | | |
| Maastrich- tian | L | 6 TH 5 TH 4 TH | Imo Cycle Nsukka Cycle MANU Transgression |
| | U | | |
| | M | | |
| Campanian | L | 3 RD | NKporo Cycle |
| | U | | |
| Santonian | U | | HIATUS |
| | L | | |
| Coniacian | | | Awgu (Regression) |
| Turonian | | 2 ND | Eze Aku Cycle |
| Cenomanian | U | | |
| | | L | |
| Albian | | 1 ST | Asu River Cycle |

Conclusion

Eight transgressive cycles (TCs) and 5 major unconformity surfaces were identified. The deepest part is characterized by TST/HST suggestive of marine incursion during Albian responsible for the deposition of Asu River Group. The second MFS was responsible for deposition of Eze Aku Formation, located at 3125 m, dated Upper Cenomanian. A LST was responsible for the deposition of Awgu Formation in the Coniacian period. The third transgressive cycle in the Earliest Campanian for deposition of Nkporo Formation. The lower part of Mamu Formation was deposited by LST, dated Lower Maastrichtian; SB placed at 2057 m. The Middle Maastrichtian was marked by the fourth TC; deposited upper Mamu Formation. Nsukka Formation was marked by LST placed at 1234 m, dated Lowermost Upper Maastrichtian within Nsukka Formation. The sixth marine transgression deposited Imo Formation, followed by a regressive phase (LST) in the Upper Late Paleocene. The seventh marine transgression was in Middle Eocene, led to deposition of Ameki Formation and the eighth marine transgression was in the Upper Miocene-Pliocene period, responsible for deposition of Ogwashi/Asaba Formation.

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