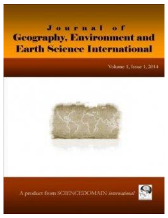

Journal of Geography, Environment and Earth Science International

12(2): 1-16, 2017; Article no.JGEESI.30416
ISSN: 2454-7352

The Southern Benue trough and Anambra Basin, Southeastern Nigeria: A Stratigraphic Review

Onu Frederick Kelechi[1*]

[1]*Department of Geological Sciences, Nnamdi Azikiwe University, Awka, Nigeria.*

Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/JGEESI/2017/30416
Editor(s):
(1) Ioannis K. Oikonomopoulos, Core Laboratories LP., Petroleum Services Division, Houston Texas, USA.
Reviewers:
(1) Aigbedion Isaac, Ambrose Alli University, Nigeria.
(2) Moses Oghenenyoreme Eyankware, Ebonyi State University Abakaliki, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/21395

Original Research Article

Received 8th November 2016
Accepted 1st December 2016
Published 13th October 2017

ABSTRACT

A review of high impact literature on the Southern Benue Trough and Anambra Basin was undertaken to enhance the understanding and definition of the basins in terms of their evolution, area extent, sedimentation history, as well as their litho- bio- and sequence stratigraphy. Early works of [1,2,3,4], and others, which formed the basis for the stratigraphic study of these basins were employed, but were updated by recent reputable works of [5,6,7,8,9,10] and others. The geologic formations encountered in the basins include: the Asu River Group, Eze-Aku Group, Agbani Sandstone/Awgu Shale Formation, Nkporo Group, Mamu, Ajalli, Nsukka, Imo, Ameki and Ogwashi-Asaba Formations. Controversy surrounding the stratigraphy of the Anambra Basin, depositional environments and conditions, and age of geologic formations present in the study basins were considered. The aspect of sequence stratigraphy requires more work for a more accurate definition of stratigraphic surfaces required for the establishment of systems tracts and sequences.

Keywords: Anambra Basin; Eze-Aku; sequence; stratigraphy; Benue trough; depositional environment.

**Corresponding author: E-mail: onufredy@yahoo.co.uk;*

1. INTRODUCTION

A close study of the various basins and sub-basins of the Nigerian continental margin reveals the differences in their stratigraphic evolution, which are attributed to the differences in their structural and tectonic framework. The natural processes that caused these differences in stratigraphic evolution are the main reasons for the different formation types that occur in somewhat close proximity within the studied basins. Therefore, there's a need to outline each of the geologic formations that exist within these basins, with a view to appreciate the process – response mechanism(s) responsible for their deposition within the part(s) of the basin(s) they are found. It is however observed that each major phase of sediments deposition in the studied basins terminates with the deposition of prograding deltaic sands during a regressive phase. It is important to carefully study the basins, especially the stratigraphically complex Anambra Basin, so as to understand its complexity and help clear the controversy arising from the composition and age of the first sedimentary deposit in the basin.

The Cretaceous sedimentary basins and sub-basins of Southeastern Nigerian include the Southern Benue Trough, Anambra Basin, Afikpo Syncline, Calabar Flank and Mamfe Embayment. The sedimentary basins developed on the Basement complex of Nigeria as an 'X' shaped depression oriented in the North East-South West (NE-SW) and North West-South East (NW-SE) (Fig. 1) [11]. The major controls on sedimentation in these basins resulted from eustatic sea level changes, basin tectonics, and local diastrophism. The basins' stratigraphy and paleogeography have been studied and described by various workers, such as [2,3,4,5,7,8,9,10,12,13,14,15,16] amongst others.

Geological work in Southeastern Nigeria dates back to the early 1960's, but most of the published information from these studies relate to general geologic observation and description from fossil localities. In fact, the first stratigraphic study of the Southeastern Nigerian basins was carried out by [2].

Sedimentation is believed to have been initiated after the separation of South America from Africa in the Aptian/Albian, and was controlled by three main tectonic events and epeirogenic movements. These resulted in a series of marine transgressions and regressions [3]. As a result of these tectonic events, the axes of the main basins were displaced, giving rise to three basins such as: the Abakaliki-Benue Trough, the Anambra Basin, and the Afikpo Sub-Basin. Murat also believed that changes in thickness and facies of the sediments throughout these basins inevitably resulted in the creation of a large number of member and formation names. The first of the depositional cycles occurred in the pre-Albian times, and was confined mainly to the Benue-Abakaliki Trough. This was terminated in the Santonian time. The second depositional phase dominated the Anambra basin as well as the narrow Afikpo Synclinorium. This was brought about by the Campanian marine transgression which ended in the Paleocene time. Also the third and final depositional phase started in the Eocene time and coincided with the development of Niger Delta basin, and further continued to the present [13].

1.1 Geologic/Tectonic History of Southern Benue Trough and Anambra Basin

The tectonic history of Southern Benue Trough, Southeastern Nigeria dates back to the Pre-Albian times. According to [17,18], the Abakaliki-Benue Trough originated as a failed arm of the triple junction rift-ridge system, which led to the separation of Africa from South America during the Aptian/Albian. The opening of these arms started in Mid Aptian in the Southern Atlantic by crustal stretching and downwarping, accompanied by the development of coastal evaporites basins. It reached the Gulf of Guinea by Late Albian and extended North East, to form the Benue-Abakaliki Trough. However the North East-South West (NE-SW) trending Benue–Abakaliki Trough is thought to be the result of the Pre-Albian rifting of the African Shield, prior to the opening of the south Atlantic, [19].

[3] identified three main tectonic phases in the Benue Trough which controlled the basin filling. The first phase began during Albian and was characterized by movements along major NE-SW trending Benue–Abakaliki Trough. This led to the emergence of two stable areas on either side of the Benue–Abakaliki Trough, called the Anambra platform on the west and Ikpe Platform on the East (Fig. 1). The NW-SE trending Ikang Trough, Ituk High and the Eket Platform are found on the eastern flank, and all persisted into the Tertiary without Significant changes. [20], made a comparison between Benue Trough and

Calabar Flank tectonic and structural characteristics (Table 1). They outlined the major tectonic phases as well as the significant transgressive and regressive events that occurred.

A second major tectonic event (compressional movements along the established NE-SW trend), caused a generalized folding which affected the Cretaceous sediments in the Benue-Abakaliki Trough [21]. This led to a series of NE-SW trending folds that resulted in the Abakaliki Anticlinorium, and the subsequent downwarping of the Anambra Platform, to form the wide Anambra basin and the narrow Afikpo Synclinorium on the west and east of the Abakaliki Anticlinorium respectively, [13]. The depressions became the main depositional targets from Campanian to Paleocene. The onset of this folding phase in the Late Santonian was accompanied by pronounced igneous activities. These account for the occurrence of massive deposits of intermediate and basic intrusive rocks found at Abakaliki, Ishiagu, Lokpaukwu, Akpoha and some other localities within the region.

The intensity of the folding varies greatly from NE to SW and locally from the axis towards the edges of the basin (Fig. 2). The effects of the Santonian tectonic phase are restricted to the Abakaliki Anticlinorium in the Southern Benue Trough. This second tectonic phase was interpreted as the closing of an embryo Benue Ocean [12], and was as a result of differential movement between two parts of the African plate as a consequence of differences in the rate of spreading and direction between the section of the Mid Atlantic Ridge opposite the bulge of Africa and also south of the Gulf of Guinea. The exposure and subsequent erosion of the Coniacian, Turonian and Albian Formations resulted from the upliftment and folding of the Abakaliki Anticlinorium.

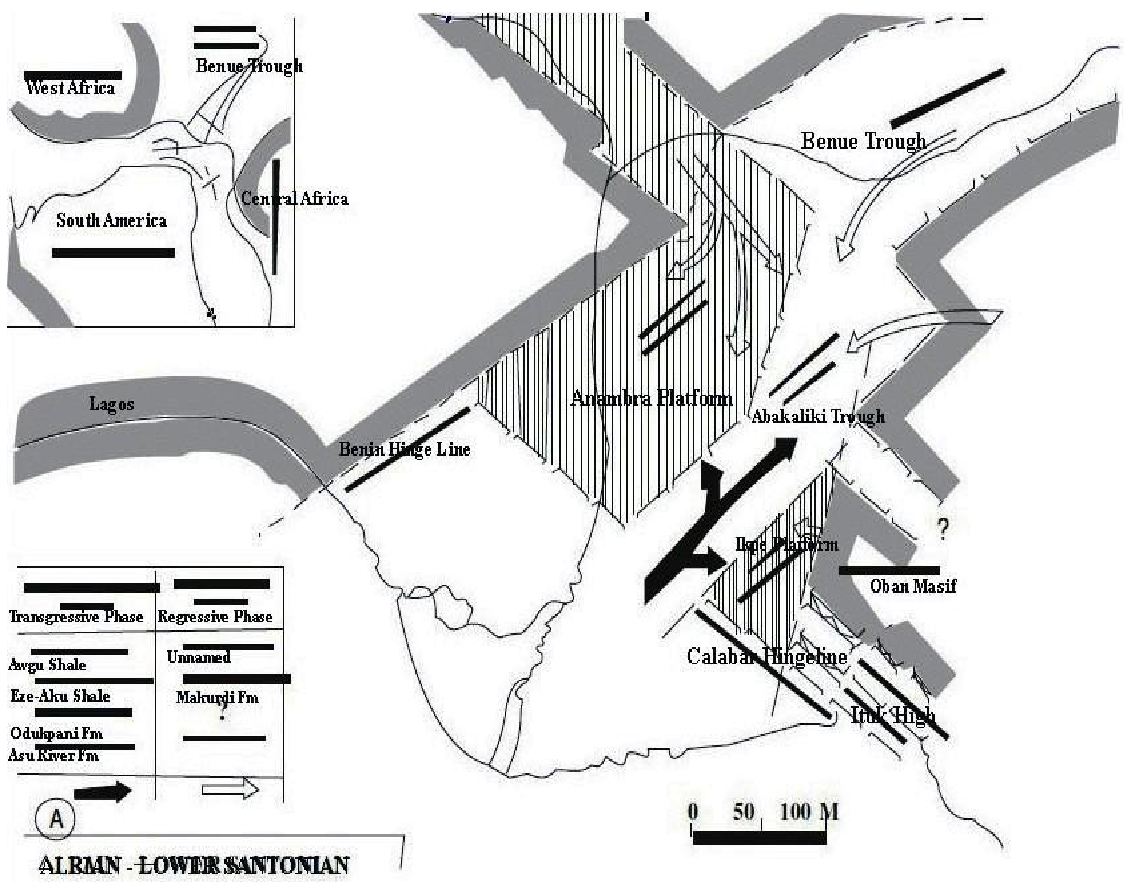

Fig. 1. Tectonic map of southeastern Nigeria during Albian-Tertiary (adapted from [3])

Table 1. Tectonic and structural characteristics of the Benue trough and Calabar Flank (after [20]

	Benue trough	Calabar flank
Structural alignment of the basin.	NE – SW	NW – SE
First major tectonic phase.	Aptian to Early Santonian with possible uplift during Albian to Cenomanian	Aptian to E. Coniacian. Latest with uplifts during Early-Late Albian, Late Cenomanian and Early Coniacian.
Significant transgressions during first tectonic phase.	i. Aptian – Middle Albian ii. Late Albian iii. Cenomanian – E. Turonian iv. Coniacian	i. Middle Albian ii. Cenomanian - Turonian iii. Coniacian
Significant regression during first tectonic phase.	i. Middle Aptian ii .Latest Albian - Cenomanian iii. Late Turonian iv. Early Santonian	i. Late Middle Albian ii. Late Cenomanian iii. Late Turonian
End of the first major tectonic phase.	Characterized by compression movements resulting in folding and uplift of the Abakaliki – Benue folded belt; fold axes was parallel to sub-parallel.	Characterized by simple vertical movements with folding of Cenomanian and older sediments.
Second major tectonic phase	Subsidence of the Anambra platform in the Lower Campanian to Middle Eocene, followed by uplift and subsequent progradation of an Early Tertiary delta.	Rapid subsidence in the Lower Campanian to Maastrichtian followed by rapid uplift with no clear evidence of deposition of Early Tertiary Sediments.

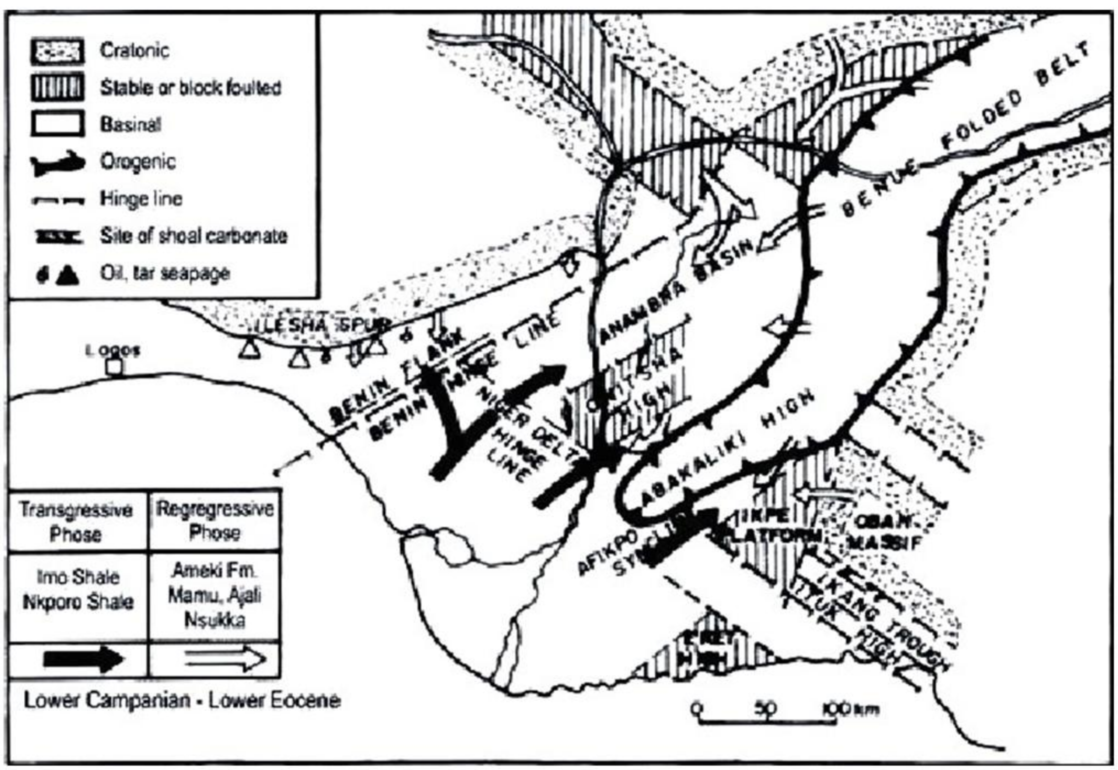

Fig. 2. Tectonic map of southeastern Nigeria during the Campanian-Eocene (adapted from [3])

2. MATERIALS AND METHODS

The materials for this review were obtained from high impact papers of previous researches carried out in the study area. These researches addressed various geologic aspects such as basin evolution and tectonics, biostratigraphy, sedimentology, sequence stratigraphy, economic geology, etc. The papers were studied individually so as to grasp the ideas conveyed by the author(s) in order to pick out points that are relevant for review.

3. DISCUSSION

3.1 Stratigraphy of Southern Benue Trough and Anambra Basin

[2] undertook the first detailed study of the stratigraphy of the southern Nigeria sedimentary basins, and he proposed many of the lithostratigraphic units in the region. The stratigraphic history of these basins has been widely described to be characterized by three sedimentary phases [4], as a result of the three tectonic episodes that occurred in the region. Shifts in the basin axis and sedimentation during the periods preceding tectonic activities lead to the three depositional phases - the Abakaliki-Benue phase (Aptian-Santonian), Anambra-Benin phase (Campanian-Mid Eocene), and the Niger Delta phase (Paleocene-Recent). The first two phases (Abakaliki-Benue; and Anambra-Benin phase), are relevant to and form the basis of this study. The Asu River and Eze-Aku Groups, and Awgu Formation where deposited during the first phase of the Abakaliki-Benue basin, the Benue valley and Calabar Flank. The second tectonic phase resulted to the Santonian folding and upliftment of the Abakaliki region and the accompanying shift of the depocenter into the Anambra Basin (formally Anambra platform) and the Afikpo Syncline. This episode saw to the deposition of the Nkporo Group, Mamu, Ajalli, Nsukka, and Imo Formations, and Ameki Group. The Niger Delta basin which started in the Paleocene due to the tectonic movement was a result of the third sedimentary phase development. This tectonism inverted the structure of the Abakaliki region and thus displaced the centre of deposition further towards the south of Anambra Basin [8].

The sedimentary fill in the Southern Benue Trough consists of three major unconformity-bounded depositional successions: Albian-Cenomanian, Turonian-Coniacian and Campanian-Maastrichtian [9]. The Anambra Basin on the other hand is a stratigraphically complex basin, therefore it is important to carefully study it so as to understand its complexity. It appears more likely to assume the age of the first sedimentary deposits in the Anambra Basin to be Post-Santonian, due to the theory behind its evolution. The structural style of the basin, associated with deep faults (graben nature) may be responsible for this blanket erroneous belief that the basin does not contain Pre-Santonian deposits [8]. Studies by [18] and [15], suggested that only the eastern part of the basin (Abakaliki area) should contain Pre-Santonian sediments. Recent study by [7], however shows that the northwestern part of the basin also contain Pre-Santonian facies. Palynological study carried out by them, indicated the presence of diagnostic pollen and spores such as *Afropollis jardinus*, Cretacaeiporate pollen such as *Cretacaeiporates mulleri, C. scabratus, C. polygonalis, Steevesipollenites binodosus, Galeocornea sp,* and *Hexaporoticolpites emelianovi,* which are all Albian to Lower Cenomanian group of forms. [6] indicated that thinner shale successions of Asu River Group, the Eze-Aku and Awgu Formations are reported in oil exploratory wells in the younger Anambra Basin and also in the marginal areas to the Abakaliki Basin.

As earlier asserted, the stratigraphy of the different depositional basins in Nigeria as described by [2] displayed a large number of lithostratigraphic and biostratigraphic divisions. Also, a paleogeographic description of the Cretaceous and Lower Tertiary in Southern Nigeria was presented by [3], based on the major depositional cycles which resulted from three main tectonic episodes that occurred in the area. The sedimentary deposits that make up the stratigraphy of the studied basins, and their paleogeographic descriptions are reviewed below.

3.1.1 The Asu River group

The Abakaliki area contains the oldest sediments in southern Nigeria - “the Asu River Group”, which lies unconformably on the basement complex. The Aptian-Albian alluvial fans and marine shales of the Asu River Group, represents the inception of sedimentation in the southern Benue Trough [22]. This consists of sandstones of the Mamfe Formation [2] and shales, limestones and sandstones of the

Abakaliki Shales in the Southern Benue Trough. The shale is mainly characterized by species of *Mortoniceras* and *Elobiceras*, is deeply weathered and contain radiolaria, echinoids, some pelecypods and gastropods [23]. The sediments are folded in the south of Abakaliki, with a fold axes stretch of NE-SW.

The Asu River Group extended into the Cenomanian as a transgressive deposit within the rest of the Southern Benue Trough (Abakaliki Trough and Afikpo Syncline). The Cenomanian is marked largely by regression in most parts of Nigeria, but at the further southeastern parts of the Southern Benue Trough (towards the Calabar area); the stage is marked by the marine transgressive Cenomanian Odukpani Formation which rests directly on Precambrian basement rocks [23]. [2,24], estimated this deposit to be about 1000 meters thick and deposited under shallow water conditions. The beds at the base are arkosic sandstones, followed by a quartzose sandstone-limestone facies with a predominance of shale in the upper parts. These deposits were described as typical nearshore sediments by [2]. The sediments however are of shallow water origin, and are about 600 meters thick. The Calabar Flank on the south-eastern limit shows a NW-SE trending fault which also controlled sedimentation. According to [2], the type locality of this formation is along the Asu River Southeastern Nigeria.

3.1.2 The Eze-Aku Group

The Turonian marine transgression saw to the termination of the generally regressive conditions that existed during the Cenomanian. In the Southern Benue Trough, the Turonian is represented by the Eze-Aku Group (which consists of hard grey and black calcareous shale, limestone and siltstone of the Eze-Aku Formation) and the inter-fingering regressive sandstones of Agala and Amasiri Formation members (outcrops within the Afikpo Synclinorium on the South East margin of the Abakaliki Anticlinorium) [9]. A shallow water environment for the Eze-Aku Formation was suggested by [2] based on ammonite contents; and [25] based on foraminiferal content. [4] regarded the shales of the Eze-Aku Formation as transgressive deposits in shallow shelf settings. The shales laterally grade into the sandstone of the Amasiri Sandstone, with type locality at Amasiri near Afikpo, and Ezillo Formation. Sandstone outcrops extend from Afikpo through Ugep, and then to Apiampu. The conglomerate facies at Uwakande 1, Obubra south east Nigeria provided significant evidence of fluvial conditions during the deposition of the Eze-Aku Formation in the Turonian, and revealed the type of transporting medium; the mode of sediment deposition; as well as the environment into which the sediments encountered in the study area were deposited [26].

The thickness of the Eze-Aku Formation varies, but may attain about 1000 meters in some places [1]. According to [27], it varies for up to 1200 meters, and is overlain by about 900 meters of bluish-grey, bedded shale with some fine-grained carbonaceous limestone beds (Awgu Shale), which are in some places replaced by sandstone facies (Agbani Sandstones). The lowermost part of the Eze-Aku Formation contains Turonian ammonites while the top is Early Coniacian in the Afikpo Syncline. The Eze-Aku Formation also changes into shaly limestone (in the Nkalagu area), calcareous sandstone and sandy limestone. The type locality of Eze-Aku Formation is at Akaeze South East Nigeria.

Controversy has trailed the depositional model for the Amasiri Sandstone of the Eze-Aku Formation, Southeastern Nigeria. The study of [10], which asserts that the sandstone unit represents the uppermost part of the Eze-Aku Formation on the eastern limb of the Abakaliki Anticlinorium and occurs as parallel ridges trending in a NE-SW direction, is adopted in this paper.

3.1.3 Agbani Sandstone / Awgu Shale

The Southern Benue Trough witnessed the end of regression in the Santonian with the full emergence of the Abakaliki area. The Coniacian-Santonian regression resulted to the deposition of the Agbani Sandstone/Awgu Shale in the Abakaliki-Anambra Basin [23]. The sediments were derived from the now uplifted Abakaliki Anticlinorium and deposited in the downwarped Anambra Basin. There is a marked non-deposition of the Coniacian–Santonian sediments in the Afikpo Syncline; hence the Awgu Shale is missing in the Afikpo Syncline stratigraphy. The Late Santonian is marked by an extensive subaerial unconformity in the Anambra Basin as well as the Abakaliki and Afikpo Synclines. It is however possible that deposit of Awgu Shale must have been eroded away within the entire Afikpo Syncline, hence accounting for its absence.

The Awgu Shale is mainly bluish-grey shale with occasional intercalations of fine-grained sandstone and thin, often mainly shaly limestones. In the Anambra Basin, the shales are well-bedded with a thickness of about 800 meters [8,23]. The beds are rich in ammonites and other molluscs including fish teeth. Palynological study by [8] revealed that the sequence is dominated by angiosperm pollen such as *Monocolpites sp, Tricolpites sp* and *Retimonocolpites sp.* Other diagnostic forms that characterize the formation include *Zlivisporites bianensis, Peromonolites perireculatus and Odontochitina sp*. Therefore, the Awgu Shale is dated Coniacian. New forms of dinoflagellates that appeared in the sediments suggest a transitional environment of deposition.

3.1.4 The Nkporo group

Earlier workers such as [15] and [18] took the Nkporo Group as the first oldest sedimentary deposit in the Anambra Basin. But recent works by [7], opened up the possibility of having Pre-Santonian sediments, at least at the northwestern part of the basin, hence helping in clearing the controversies associated with it.

The Nkporo Group forms the basal facies of the Mid to Late Cretaceous sedimentary cycle in the Southern Benue Trough and Anambra Basin, deposited during Late Campanian. It is generally exposed at Leru, 72 kilometer along Enugu-Port Harcourt Expressway, and is described as a coarsening upward deltaic sequence of shales and interbedded sands and shales with occasional thin beds of limestone deposited during a short interval of marine transgression [28]. The thickness is estimated to be 1000 meters maximum [23]. The age assigned to this formation is based on the presence of *Afrobolivina afra* [29].

The Nkporo Group is made up of three members – Afikpo/Owelli Sandstone, Nkporo and Enugu Shales. The arenaceous facies of the Afikpo and Owelli Sandstones are lateral equivalents to the Nkporo Formation in the Afikpo and Anambra Basins respectively [9]. According to [30], the Owelli Sandstone is an elongate shoestring sand body to the northwest defining a meander belt of fluvial channel system and a fluviatile point bar. It is massively bedded, hard and often ferrugenious (in some parts) and friable. It may be prominently cross bedded, medium - coarse grained with pebbles, and sometimes aligned at the base of the cross beds [30]. Body fossils recovered by previous workers include ammonites (represented by *Libycoceras dandense*, and *Sphenodiscus*) which dominate the lower levels [2] and pelecypod (*Inoceramus*) which occur mainly in the sandstone/siltstone lenses at the upper levels [5,31].

The Nkporo Group is essentially marine sediments of deposited by the third transgressive cycle within the Anambra Basin. Its deposition ended in the Early Maastrichtian in both Abakaliki-Anambra and Afikpo Synclines (Fig. 3). The Enugu Shales made up of carbonaceous shales and coals with the upper half deposited in lower floodplain and swampy environments; overlie the Nkporo Formation [28]. It is found north of Awgu and exposed at Milliken Hills at Enugu, restricting the facies to the central and northern parts of the basin [29,32]. The sediments have a poorly developed foreshore and shoreface with extensive coastal swamps, and were assigned Campanian to Lower Maastrichtian (Fig. 3) based on diagenetic species of palynomorphs such as *Cingulatisporites ornatus* and *Tricolpites tienebaensis* [29]. [9] indicated that the deposition of the sediments of the Enugu/Nkporo Formations reflect a funnel-shaped shallow marine setting that graded into channeled low energy marshes.

3.1.5 The Mamu formation

The deposits of the transgressive Nkporo cycle was overlain by the Lower Maastrichtian sandstones, shales, siltstones and mudstones, and the interbedded coal seams of the deltaic Mamu Formation in most parts of the Anambra Basin [6]. The Mamu Formation was deposited as the broad shallow sea that existed at the time of deposition of the Nkporo/Enugu Formations, gradually became shallower. Predominance of regression resulted to the deposition of the continental sequence of Ajalli Formation on top of the Mamu Formation, followed by a return to partially paralic conditions that were responsible to the deposition of Nsukka Formation.

The Mamu Formation is restricted to the Anambra Basin and Afikpo Syncline in southeastern Nigeria [23]. It was previously known as the Lower Coal Measures, and contains marine intercalations composed of ammonitiferous shales [1]. [29], stated that the sediment pile varies across the basin and ranges from 75 to over 1000 meters at different parts of the basin, and were deposited on estuarine floodplain, swamp and tidal flat floodplain.

m.y	AGE	ABAKALIKI – ANAMBRA BASIN	AFIKPO BASIN
30	Oligocene	Ogwashi-Asaba Formation	Ogwashi-Asaba Formation
54.9	Eocene	Ameki/Nanka Formation/ Nsugbe Sandstone (Ameki Group)	Ameki Formation
65	Palaeocene	Imo Formation Nsukka Formation	Imo Formation Nsukka Formation
73	Maastrichtian	Ajali Formation Mamu Formation	Ajali Formation Mamu Formation
	Campanian	Npkoro Oweli Formation/Enugu Shale	Nkporo Shale/ Afikpo Sandstone
83 87.5	Santonian	Agbani Sandstone/Awgu Shale	Non-deposition/erosion
88.5	Coniacian		Eze Aku Group (incl. Amasiri Sandstone)
	Turonian	Eze Aku Group	
93 100	Cenomanian – Albian	Asu River Group	Asu River Group
119	Aptian Barremian Hauterivian	Unnamed Units	
Precambrian		Basement Complex	

Fig. 3. Correlation chart for early Cretaceous-Tertiary strata in southeastern Nigeria (modified from [15])

The formation occurs as narrow strip trending north-south from the Calabar Flank, swinging west around Ankpa Plateau and terminating at Idar near the Niger River [9]. The Mamu Formation is dated Lower to Mid Maastrichtian [15], and is well exposed at the Milliken Hill just on the outskirt of Enugu, along Enugu-Onitsha Road.

3.1.6 The Ajalli sandstone

The Ajalli Formation which is regarded as the "False-Bedded Sandstone" overlies the Mamu Formation [33], with its type locality along the valley of the Ajalli River near Enugu [23]. It is mainly unconsolidated, poorly sorted, coarse-fine grained sandstone, poorly cemented; mudstone and siltstone, and is dated Mid to Late Maastrichtian. The sandstone is typically white in colour but in some cases, iron-stained. Thin bands of white mudstone and shale in the Ajalli Formation occur at intervals and increases in number towards the base. The formation is overlain by a considerable layer of red earth, consisting of red, earthy sands, formed by weathering and ferruginization processes, and exhibits significant thickness variation from less than 300 meters to over 1000 meters at the centre of the basin [15,23,30]. The formation exhibits a dominant cross bedding sedimentary structure. It is associated with reactivation surfaces, mud drapes, tidal bundles, backflow ripple channels cut and fills, lateral accretion surfaces, as well as Skolithos and Ophiomorpha ichnogenera [28]. The Ajalli Sandstone as well as its underlying Mamu Formation accumulated during the epoch of overall regression of the Nkporo cycle. It marks the height of the regression at a time when the coastline was still concave [9].

3.1.7 The Nsukka formation

The diachronous Nsukka Formation (Late Maastrichtian - Early Paleocene) which is also known as the "Upper Coal Measures" conformably overlies the Ajalli Sandstone [2,33]. It is comprised mainly of interbedded shales, siltstones, sands and thin coal seams, which have become laterized in many places where they characteristically form resistant capping on mesas and buttes [32]. The basal bed begins with coarse to medium-grained sandstones and passes upward into well-bedded blue clays, fine-grained sandstones, and carbonaceous shales with thin bands of limestones [2,34].

Sedimentological evidence of [34] suggests that the Nsukka Formation represented a phase of fluvio-deltaic sedimentation that began close to the end of the Maastrichtian and continued during the Paleocene. The depositional environment of the formation has been suggested to be in many ways similar to that of the Mamu Formation (that is transitional/shoreline, mud flat and swamps, deposited during a largely regressive phase).

The Nsukka Formation as well as the overlying Imo Shale marked the onset of another transgression in the Anambra Basin during the Paleocene. Outcrops of the Nsukka Formation can be seen along the Enugu-Onitsha road in the valley of the Nadu River.

3.1.8 The Imo shale formation

The Imo Formation consists of blue-grey clays and shales, and black shales with bands of calcareous sandstone, marl, and limestone [2], with a maximum thickness of about 500 meters. It marks the onset of another transgression in the Anambra Basin during the Paleocene. This Paleocene transgression also deposited its lateral equivalents - the Ewekoro Formation in south western Nigeria. The formation lies conformably on the Maastrichtian Nsukka Formation in the Southeastern portion of the Southern Benue Trough [23].

The Imo Formation is said to be of Paleocene age as indicated by its ostracode and foraminiferal biostratigraphy [2], and microfauna recovered from the basal limestone unit [35,36]. The type of rock and trace fossils of the basal sandstone unit reflect foreshore and shoreface [37] or delta front sedimentation [38]. The type locality/area of the Imo Formation is along the Imo River between Umuahia and Okigwe Southeastern Nigeria. At the type area, the formation has a thickness of about 500 meters [39]. [11], placed the outcropping Imo Shale at Paleocene to Early Eocene. [15,40,41] placed the Imo Formation at Early to Late Paleocene. The formation varies laterally into sandstones in some parts of southeastern Nigeria. These lateral equivalents are the Igbabu, Ebenebe and Umuna Sandstones [2].

3.1.9 The Ameki group

This is the regressive sandstone succession that overly the Imo Formation. The Eocene witnessed regression due to the uplift and erosion of folded sediment as a result of the post Maastrichtian folding movement that affected different parts of the country. Regression continued throughout the Eocene [2]. In the Abakaliki/Anambra basin areas (Fig. 3), the Ameki Group is made up of the Ameki Formation, Nanka and Nsugbe Sandstone members which are lateral equivalents, whereas in the Afikpo Syncline, it has only one member (the Ameki Formation) [15,42]. The formation consists of a series of highly fossiliferous greyish-green sandy clay with calcareous concretions and white clayey sandstones [23], and may attain a thickness of about 1400 meters in some parts. A thickness of about 1900 meters was suggested by [39] in the area of Ameki and Mile 73 and half, on the eastern railway. The type locality of the Ameki Formation is between Miles 73 to 87 along the eastern railway, near the Ameki station [23]. The formation shows rapid lateral changes in facies in Southeastern Nigeria, and may locally show shale development or inclusions of white and mottled claystone and sandstone. Carbonaceous plant remains are rare but lignified wood may be present.

The Nanka Sands in the Anambra Basin has its type locality at Nanka. It consists of fine to coarse sandstones with abundant calcareous shale and thin shaly limestone intercalations below and unconsolidated cross bedded white or yellow sandstone, with bands of fine-grained sandstone and sandy clay above [23]. The Eocene Nanka Sand marks the return to regressive conditions with well exposed sand waves suggesting the predominance of flood-tidal currents over weak ebb-reverse currents (only suggested by the bundling of lamina separated from each other by mud drapes reflecting neap tides) [9]. A good outcrop of the Nanka Formation is at Umunya section, 18km from the Niger Bridge at Onitsha on the Enugu-Onitsha Expressway [43].

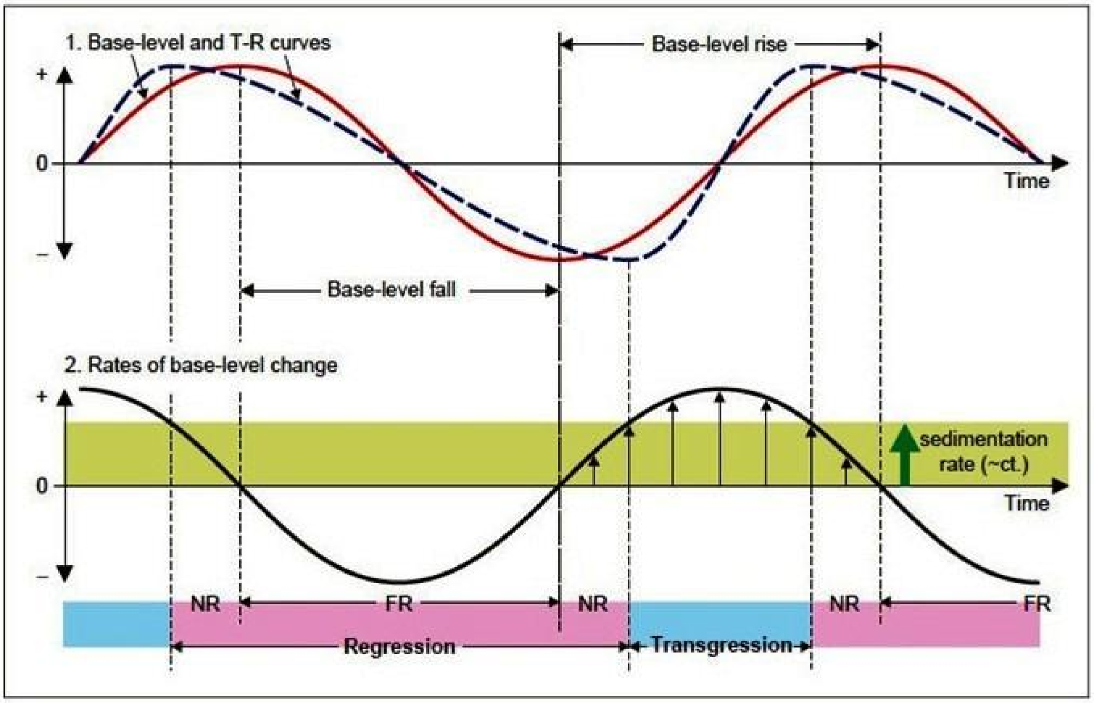

Fig. 4. Base-level and transgressive–regressive (T–R) curves. FR = forced regression; NR = normal regression [49]

Environments that ranged from nearshore (barrier ridge-lagoonal complex) to intertidal and subtidal zones of the shelf environments were suggested for the Ameki Formation by [42] and [44]. [45] suggested that the sediments were deposited in shallow marine environments, where water depths range between 10 to 100 meters. However, [46], interpreted the depositional environment of the Ameki Group as estuarine, lagoonal, and open marine, based on the faunal content. The Ameki Formation shows steeper dips than the overlying Ogwashi-Asaba Formation, indicative of an unconformable relationship. Its age has been considered to be either Early Eocene [2] or Early-Mid Eocene [47].

3.1.10 The Ogwashi-Asaba formation

This represents the last sedimentary deposit within the Anambra and Afikpo Synclines. It lies unconformably on the Ameki Group. The Ogwashi-Asaba Formation comprises of alternating coarse grained sandstone, lignite seams, and light coloured clays of continental origin [13]. The age of the formation was suggested by [2,6,15], to be of Oligocene-Miocene, although palynological study by [48] yielded a Mid Eocene age for the basal part. The Ameki Group and the overlying Ogwashi-Asaba Formation in the Southern Benue Trough and Anambra Basin are correlative with the Agbada Formation in the Niger Delta.

3.2 Sequence Stratigraphy of the Southern Benue trough and Anambra Basin

The sequence stratigraphic interpretation employed in this study is based on the shifts in the shoreline trajectories (Transgression-Regression, T-R cycles) brought about by the global fluctuations in sea level (base-level) and tectonics. [29] identified about five transgressive episodes in the Benue Trough; four out of these are wholly or partly linked to global sea-level changes. [32] also recorded at least five major transgressive episodes from the stratigraphic succession of the Anambra Basin from the Late Cretaceous to Eocene, which were correlatable to the global eustatic sea level chart. The Turonian marked the most widespread transgression, although it is not clear whether this transgression was caused by a link between the Benue Trough and the Tethys Ocean in the North [13,25].

In defining a sequence stratigraphic model for the basins, it is vital to identify surfaces of sequence stratigraphic significance that can serve, at least in part, as systems tract or sequence boundaries [49]. These surfaces are defined relative to two curves; one describing the base-level changes at the shoreline, and the other describing the associated shoreline shifts (Fig. 4).

Sequence stratigraphic surfaces, and systems tracts, are all defined relative to these curves in Fig. 5. The transgressive–regressive curve describing the shoreline shifts is the result of the interplay between sedimentation and base-level changes at the shoreline. The first transgression which occurred as the sea incursed over the basement rocks in the Late Aptian/Albian following the opening up of the South Atlantic. The failed arm of the triple rift-ridge system opened up the Benue Trough, thereby creating the accommodation space where the Albian Asu River Group sediments were deposited. This marine transgressive episode which was triggered by sea level rise persisted throughout the Albian. In the Abakaliki-Anambra and Afikpo Synclines, the base of Asu River Group (top of Basement Complex) serves as the first sequence boundary. The Maximum Flooding Surface is hung on the Albian-Cenomanian boundary, indicating the end of marine transgression. Regressive conditions started during the Late Albian period in most parts of Nigeria.

The Cenomanian witnessed a return of shallow water conditions as sea level began to fall (Fig. 6). The overall regressive event ended in the end of the Cenomanian. The Asu River Group deposition continued into the Cenomanian as a transgressive deposit within the rest of the Southern Benue Trough (Abakaliki and Afikpo Synclines), although most parts of Nigeria witnessed regressive events during this era. The Odukpani Formation which lies unconformably on the basement within Calabar area was also deposited by marine transgressive Cenomanian events [23].

The second transgressive event started in the Turonian as sea level began to rise again, leading to the deposition of the Eze-Aku Formation in the Southern Benue Trough, as well as thin deposit in the northern part of Anambra

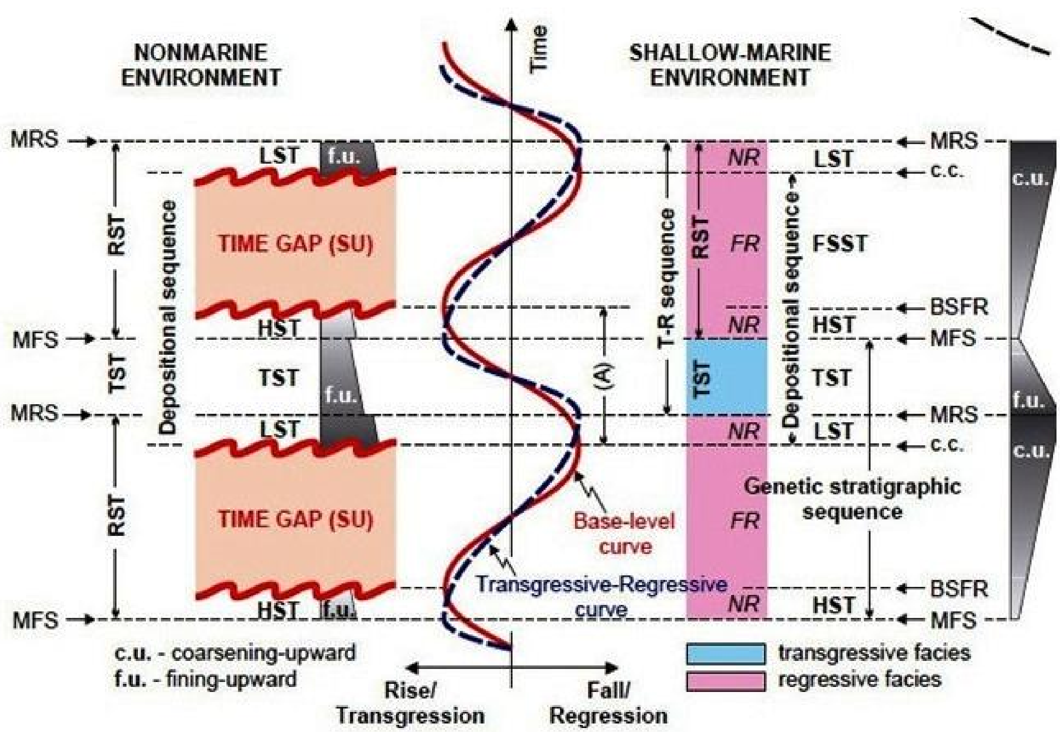

Fig. 5. Sequences, systems tracts, and stratigraphic surfaces defined in relation to the base-level and the transgressive–regressive curves [49]

Basin close to the Abakaliki area. This transgressive episode ended the generally regressive conditions that existed during the Cenomanian. In the Afikpo Syncline, the interfingering regressive Amasiri Sandstone was deposited as a lateral equivalent of the Eze-Aku Shale. The Turonian transgression persisted into the Early Coniacian. The maximum flooding surface is roughly taken to be around Early Coniacian, marking the end of transgression. The Turonian to Early Coniacian is interpreted to represent transgressive systems tract deposits.

Regression commenced during Mid Coniacian when the sea-level once again began to fall, leading to the deposition of the Agbani Sandstone and Awgu Shale in the Southern Benue Trough and Anambra Basin. This regression continued till Early Santonian. However, deposits of Agbani Sandstone/Awgu Shale Formations are not found in the Afikpo Syncline, probably due to a time of non-deposition of sediment or erosion. In the Anambra Basin, the sediments were deposited as highstand systems tract, being derived from the uplifted Abakaliki Anticlinorium and deposited in the Anambra Basin. The Late Santonian is marked by an extensive subaerial unconformity in the Anambra Basin as well as the rest of the Southern Benue Trough (Fig. 6). The Awgu Shale beds are rich in ammonites and other molluscs including fish teeth, and the sequence is dominated by angiosperm pollen such as *Monocolpites sp, Tricolpites sp*, and other diagnostic forms such as *Zlivisporites bianensis and Odontochitina sp* [8,23].

The Nkporo Group consisting of Owelli Sandstone, and Nkporo and Enugu Shale members in the Abakaliki/Anambra Basin as well as Nkporo and Afikpo Sandstone in the Afikpo Syncline was deposited as sedimentation resumed during the third transgressive cycle in these basins during the Late Campanian [6]. It was laid on the top of the third sequence boundary (SB3) (Fig. 6). Ammonites *(Libycoceras dandense and Sphenodiscus)* dominate the base, while pelecypod *(Inoceramus)* occurs at the upper levels [2,5,31]. Deposits of Nkporo Group represent the transgressive systems tract which indicate landward shift in the shoreline during Late Campanian to Early Maastrichtian in both Anambra and Afikpo Synclines (Fig. 3).

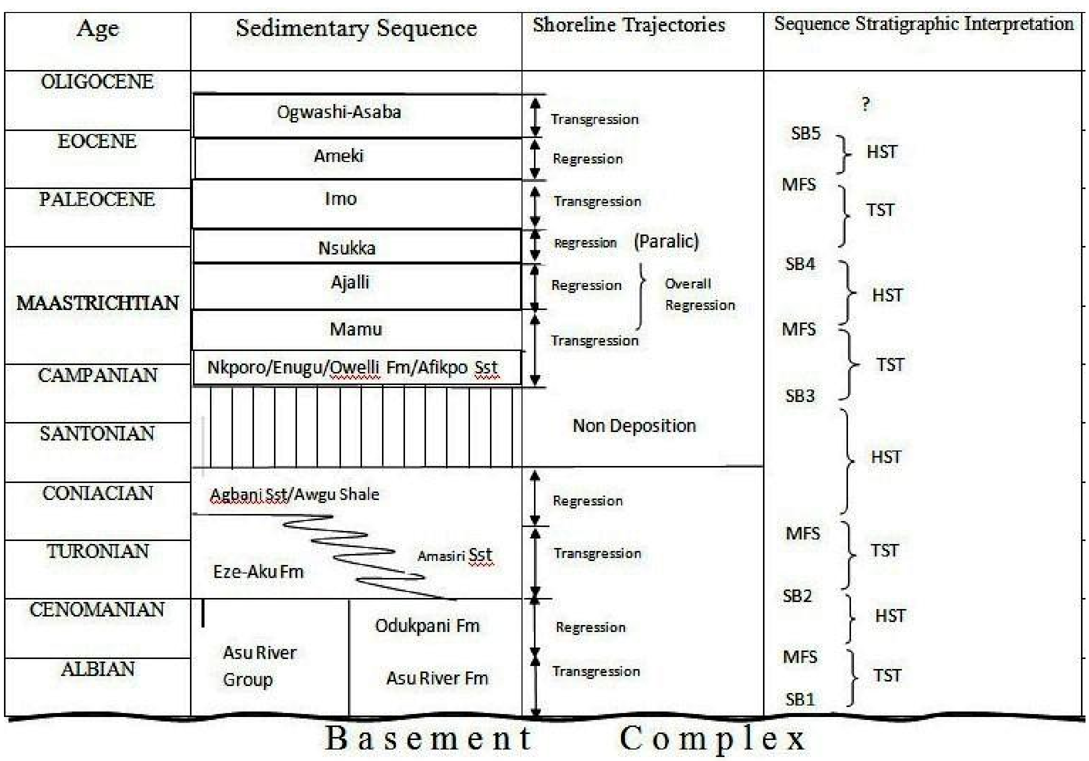

Fig. 6. Sequence stratigraphic model of Southern Benue trough and Anambra Basin using the Transgressive-regressive curve

Later part of the third transgressive cycle that deposited the Nkporo Group was also responsible for the deposition of the Mamu Formation. This formation was probably deposited during the period between sea-level stillstand and end of sea-level rise (during base-level rise at the shoreline. This marked a change in the direction of shoreline shift from transgression to subsequent regression as the broad shallow sea that existed at the time of deposition of the Nkporo/Enugu Formation gradually became shallower. The transgressive phase ended in the Mid Maastrichtian and also signified the end of deposition of Mamu Formation.

The predominance of regression at the later stage resulted in the deposition of the Ajalli Sandstone Formation on top of Mamu Formation. The Ajalli Formation is dated Mid to Late Maastrichtian. The formation is associated with reactivation surfaces, mud drapes, tidal bundles, backflow ripple channels cut and fill, lateral accretion surfaces, as well as Skolithos and Ophiomorpha ichnogenera [28]. The end of regression during the Upper Maastrichtian is marked by subaerial unconformity identified as sequence boundary 4 (SB4). The Ajalli Formation and the Upper part of Mamu Formation are deposits of highstand systems tract (Fig. 6). Interplay of alternating marine and continental conditions resulted in the deposition of the paralic Late Maastrichtian to Early Paleocene Nsukka Formation. This signified the return of marine influence over the former overall regressive conditions that gave rise to the deposition of the Mamu and Ajalli Formations. It forms part of the transgressive systems tract deposits in the Southern Benue Trough and Anambra Basin.

Predominance of transgression during the Paleocene resulted in the deposition of the Imo Shale. The Imo Shale was deposited between the period of sea-level rise and end of sea-level rise, leading to a landward shift in shoreline [49]. This formed the last and bulk of the transgressive systems tract deposits in the basins under study. The maximum flooding surface of the sequence is placed at the boundary between the Paleocene Imo Shale and the Eocene regressive Ameki Group. As the sea-level begins to fall once again within the vicinity of the Southern Benue Trough and Anambra Basin, the shoreline shifted basinward resulting in the deposition of the Ameki Formation. This Eocene regressive succession was deposited due to the uplift and erosion of folded sediment as a result of the Post Maastrichtian folding movement that affected different parts of Nigeria [2,23]. The Ameki Group is made up of the Ameki Formation, and Nanka and Nsugbe Sandstone members that are lateral equivalents in the Abakaliki/Anambra Basins; whereas in the Afikpo Syncline, it is made up of only one deposit - the Ameki Formation [42]. The end of the Eocene regression is marked by the sequence boundary 5 (SB5), and the deposits represents that of a highstand systems tract - the last observed in the Anambra, and Afikpo Synclines, and the rest of the Southern Benue Trough.

The Ameki Group was succeeded by the Ogwashi-Asaba Formation. This formation unconformably overlies the Ameki Group. It is a transgressive deposit, laid as marine influence was renewed during the Late Eocene to Late Oligocene. The formation as well as the underlying Ameki Formation is correlatable with the Agbada Formation in the Niger Delta basin.

4. CONCLUSION

The Southern Benue Trough and Anambra Basin have been studied extensively by various scholars, who helped to form and define their stratigraphy. Tectonic activities that created these basins also caused the upliftment of areas flanking them, which formed source areas for sediment supply depending on the direction and duration of shoreline shift. These tectonic activities also caused the axis of deposition to shift, especially during the second tectonic phase when the Anambra Basin emerged from being a platform, and the Afikpo Sub-Basin was as well formed.

Various episodes of shoreline shifts which occurred from the Cretaceous to the Tertiary resulted in the formation of the formation types discussed in this study. At least three transgressive cycles were recorded in the basins studied (Fig. 6). Previous workers took time to define the age relationships, environments of deposition, and prevailing conditions at the time of deposition, as well as litho- and bio- facies characteristics of these formations thereby giving us a basis for further studies / validation and criticism of their works.

Southern Benue Trough which is erroneously termed ‘Lower’ Benue Trough by some authors covers a large area where the Albian Asu River Group; Turonian Eze-Aku Formation; Coniacian

Awgu Formation; Campano-Maastrichtian Nkporo Group; Maastrichtian Mamu, Ajalli and Nsukka Formations; Paleocene Imo Shale; Eocene Ameki Formation; and the Late Eocene Ogwashi-Asaba Formation were deposited in succession. The Anambra Basin also contains the same number of formation types. Earlier workers assumed the age of the first sedimentary deposits in the Anambra Basin to be Post-Santonian. But the eastern and northwestern parts of the basin have been proven to contain Pre-Santonian deposits [6,7,8,15].

The bulk of the available sequence stratigraphic studies for the basins were obtained from limited outcrops, cores and well logs. Therefore, an integration of seismic, well logs, cores, outcrop data and global analogue studies is required for an accurate and workable sequence stratigraphic model to be defined in these basins. The application of 3-D seismic data would be necessary to define the lateral extent and equivalent of lithofacies that make up the members of the various formation groups. However lack of high resolution seismic and well logs may be attributed to the little interest in hydrocarbon exploration within the basins, as well as the high cost associated with seismic acquisition by independent researchers. Future studies in this area should focus on the creation of a chronostratigraphic chart for the basins using the pollen and spores and forams population and diversity found in the area. This will help is establishing the stratigraphic surfaces needed for the definition of the systems tracts and sequences to a high degree of accuracy.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Reyment RA. Review of Nigerian cretaceous - Cenozoic stratigraphy. Journal of Nigerian Mining, Geology and Metallurgical Society. 1964;1:61-80.
2. Reyment RA. Aspect of the geology of Nigeria. University of Ibadan Press, Ibadan, Nigeria. 1965;145.
3. Murat RC. Stratigraphy and paleogeography of the cretaceous and lower tertiary in Southern Nigeria. In Dessauvagie, T.T.J. and Whiteman, A.J. (eds.) African Geology. University of Ibadan Press, Ibadan, Nigeria. 1970;251-256.
4. Murat RC. Stratigraphy and paleogeography of the cretaceous and lower tertiary in Southern Nigeria. In Dessauvagie, T.T.J. and Whiteman, A.J. (eds.) African Geology. University of Ibadan Press, Ibadan, Nigeria. 1972;251-266.
5. Okoro AU. Petrology and depositional history of the sandstone facie of the Nkporo formation (Campano-Maastrichtian) in Leru Area, Southeastern Nigeria. Nigeria Journal of Mining Geology. 1995;105-112.
6. Akande SO, Ojo OJ, Adekeye OA, Egenhoff SO, Obaje NG, Erdtmann BD. Stratigraphic evolution and petroleum potential of middle cretaceous sediments in the lower and middle Benue trough, Nigeria: Insights from new source rock facies evaluation. Petroleum Technology Development Journal. 2011;1:74-106.
7. Ola-Buraimo AO, Akaegbobi IM. Neogene dinoflagellate cysts assemblages of the Late Miocene-Pliocene Ogwashi/Asaba sediments in Umuna-1 well, Anambra Basin, Southeastern Nigeria. Journal of Petroleum and Gas Exploration Research. 2012;2(6):115-124.
8. Ola-Buraimo AO. Biostratigraphy and paleoenvironment of the coniacian awgu formation in Nzam-1 well, Anambra Basin, Southeastern Nigeria. International Journal of Scientific and Technology Research. 2013;2(3):112-122.
9. Okeke HC, Orajaka IP, Okoro I, Onuigbo EN. Biomarker evaluation of the oil generative potential of organic matter, in the upper Maastrichtian strata, Anambra Basin, Southeastern Nigeria. Journal of Scientific Research. 2014;2(1):16-25.
10. Okoro AU, Igwe EO. Lithofacies and depositional environment of the Amasiri sandstone, southern Benue Trough, Nigeria. Journal of African Earth Sciences, Elsevier. 2014;100:179-190.
11. Short KC, Staubble AJ. Outline of geology of Niger delta. American Association of Petroleum Geologists Bulletin. 1967;51: 761–779.
12. Burke KC, Dessauvagie TFJ, Whiteman AJ. The opening of the Gulf of Guinea and the geological history of the Benue depression and Niger delta. Nature Physical Science. 1971;233:51–55.

13. Kogbe CA. Paleogeographic history of Nigeria from Albian times. In Kogbe, C.A. (ed). Geology of Nigeria. Elizabethan Publishers, Lagos. 1976;237-252.
14. Petters SW, Ekweozor CM. Petroleum geology of Benue trough and southeastern Chad Basin, Nigeria. Bulletin of America Association of Petroleum Geologists. 1982;66:1141-1149.
15. Nwajide CS. Cretaceous sedimentation and paleogeography of the central Benue trough. In: The Benue Trough structure and evolution (Ed. C. O. Ofoegbu). Braunschweig and Wiesbaden, Germany, Virweg and Sohne Verlag. 1990;19-38.
16. Nwajide CS, Reijers TJA. Sequence architecture of the campanian Nkporo and the Eocene Nanka formations of the Anambra Basin, Nigeria. Nigerian Association of Petroleum Explorationists Bulletin. 1997;12(1):75-87.
17. Burke KC, Dessauvagie RFJ, Whiteman AW. Geological history of the Benue valley and adjacent areas. In: African Geology, University of Ibadan Press. 1972;187-206.
18. Nwachukwu SO. The tectonic evolution of the southern portion of the Benue trough. Geological Magazine. 1972;109(5):411-419.
19. Uzuakpunwa AB. The Abakaliki Pyroclastics Eastern Nigeria: New age and tectonic implications. Geological Magazine. 1974;1111:65-70.
20. Petters SW, Ekwueme BN, Eyo EN. Geological Excursion Guidebook to Oban Massif, Calabar Flank and Mamfe Embayment. 2004;27-33.
21. Benkhelil J. Caracteristiques structurales et evolution geodynamique du basin intracontinentale de la Benoue (Nigeria). Thesis d etat, Nice. 1986;275.
22. Ojoh KA. The southern part of the Benue trough (Nigeria): Cretaceous stratigraphy, basin analysis, paleo-oceanography and geodynamic evolution in the equatorial domain of the south Atlantic. Bulletin of Nigerian Association of Petroleum Explorationists. 1992;7(2):131-152.
23. Kogbe CA. The cretaceous and paleogene sediments of southern Nigeria. In Kogbe, C.A. (ed). Geology of Nigeria. 2nd Edition. Rockview Nigeria Limited, Jos. 1989;273-286.
24. Dessauvagie TTJ. Biostratigraphy of the Odukpani (Cretaceous) type section, Nigeria. In: African Geology, University of Ibadan Press, Ibadan, Nigeria. 1970;207-218.
25. Petters SW. Mid-cretaceous paleoenvironments and biostratigraphy of the Benue trough, Nigeria. Bulletin Geological Society of America. 1978;151-155.
26. Onu FK, Ikoro DO, Emeruem UC, Inyang DO. Discrimination of depositional environment using statistical parameters of conglomeratic outcrop sections, Obubra Southeastern Nigeria. British Journal of Applied Science and Technology. 2015;6(1):24-33.
27. Dessauvagie TTJ. Geological map of Nigeria, 1:1,000,000 with explanatory notes. Journal of Mining and Geology. 1975;9:1-12.
28. Ladipo KO, Nwajide CS, Akande SO. Cretaceous and paleogene sequences in the Abakaliki and Anambra Basins, Southeastern Nigeria. International Symposium on Geology of Deltas, Port Harcourt. 1992;39.
29. Reyment RA, Morner NA. Cretaceous transgressions and regressions exemplified by the South Atlantic. Special Paper of the Paleontological Society of Japan. 1977;21:247-260.
30. Odumoso SE, Oloto IN, Omoboriowo AO. Sedimentological and depositional environment of the mid-Maastrichtian Ajalli sandstone, Anambra Basin, Southern Nigeria. International Journal of Science and Technology. 2013;3(1):26-33.
31. Arua I. Episodic sedimentation. An example from the Nkporo shale (Campano - Maastrichtian) Nigeria. Journal of African Earth Sciences. 1988;7(8):759-762.
32. Uzoegbu UM, Uchebo UA, Okafor I. Lithostratigraphy of the Maastrichtian Nsukka formation in the Anambra Basin, S.E Nigeria. Journal of Environmental Science, Toxicology and Food Technology. 2013;5(5):96-102.
33. Obi GC. Depositional model for the Campanian-Maastrichtian Anambra Basin, Southern Nigeria. Ph.D. Thesis, University of Nigeria, Nsukka. 2000;291.
34. Obi GC, Okogbue CO, Nwajide CS. Evolution of the Enugu Cuesta: A tectonically driven erosional process. Global Journal of Pure Applied Sciences. 2001;7:321–330.
35. Adegoke OS, Arua I, Oyegoke O. Two new nautiloids from the Imo Shale, (Paleocene)

and Ameki Formation (Middle Eocene), Anambra State, Nigeria. Journal of Mining and Geology. 1980;17:85–89.
36. Arua I. Paleocene macrofossils from the Imo Shale in Anambra Basin. Journal of Mining Geology. 1980;17:81-84.
37. Reijers TJA, Petters SW, Nwajide CS. The Niger Delta Basin. In: African Basins (Ed. R.C. Selley), Elsevier, Amsterdam. 1997;151–172.
38. Anyanwu NPC, Arua I. Ichnofossils from the Imo formation and their paleoenvironmental significance. Journal of Mining and Geology. 1990;26(1):1-4.
39. Simpson A. The Nigeria coalfield. The geology of parts of Onitsha, Owerri and Benue Provinces. Bulletin Geological Survey Nigeria. 1954;24:1-85.
40. Ladipo KO. Paleogeography, sedimentation and tectonics of the upper cretaceous Anambra Basin, Southeastern Nigeria. Journal of African Earth Sciences. 1988;7:865-871.
41. Akande SO, Hoffknecht A, Erdtmann BD. Upper cretaceous and tertiary coals from Southern Nigeria: Composition, rank, depositional environments and their technological properties. Bulletin Nigerian Association of Petroleum Explorationists. 1992;7:26-38.
42. Nwajide CS. A lithostratigraphic analysis of the Nanka sands, Southeastern Nigeria. Journal of Mining and Geology. 1979;16:103–109.
43. Obaje NG. Geology and mineral resources of Nigeria. Springer-Verlag Berlin Heidelberg. 2009;57-65.
44. Arua I. Paleoenvironment of Eocene deposits in the Afikpo syncline, southern Nigeria. Journal of African Earth Sciences. 1986;5:279–284.
45. Fayose EA, Ola PS. Radiolarian occurrences in the Ameki type section, eastern Nigeria. Journal of Mining and Geology. 1990;26:75–80.
46. Oboh-Ikuenobe FE, Obi CG, Jaramillo CA. Lithofacies, palynofacies, and sequence stratigraphy of Paleogene strata in Southeastern Nigeria. Journal of African Earth Sciences. 2005;41:79–101.
47. Adegoke OS. The Eocene stratigraphy of southern Nigeria. Bulletin Bureau Economic Geologic Mineral Memoir. 1969;6:23–28.
48. Jan Du CheˆNe R, Onyike MS, Sowumi MA. Some new Eocene pollen of the Ogwashi-Asaba formation, Southeastern Nigeria. Revista de Espanol Micropaleontologie. 1978;10:285–322.
49. Catuneanu O. Principles of sequence stratigraphy. Elsevier. 2006;73-155.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/21395