FORAMINIFERAL BIOSTRATIGRAPHY, PALAEOENVIRONMENT AND SEQUENCE STRATIGRAPHY OF WELL-A, NIGER DELTA, NIGERIA

By

EMMANUEL CELESTINE NWAEJIJE

DEPARTMENT OF GEOLOGY

AHMADU BELLO UNIVERSITY, ZARIA

OCTOBER, 2015

FORAMINIFERAL BIOSTRATIGRAPHY, PALAEOENVIRONMENT AND SEQUENCE STRATIGRAPHY OF WELL-A, NIGER DELTA, NIGERIA

By

Emmanuel Celestine NWAEJIJE, BSc (A.B.U.) 2011
MSc/Sci/40962/2012-2013

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES
AHMADU BELLO UNIVERSITY, ZARIA
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A
MASTERDEGREE IN GEOLOGY.

DEPARTMENT OF GEOLOGY
FACULTY OF SCIENCE
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA

OCTOBER, 2015

Declaration

I, declare that the work in this dissertation entitled "Foraminiferal biostratigraphy, Palaeoenvironment and Sequence stratigraphy, of Well-A, Niger Delta, Nigeria" has been carried out in the Department of Geology. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at any other institution.

Emmanuel Celestine NWAEJIJE	________________	_______________
Name of Student	Signature	Date

Certification

This dissertation entitled FORAMINIFERAL BIOSTRATIGRAPHY, PALEOENVIRONMENT AND SEQUENCE STRATIGRAPHY OF WELL – A, NIGER DELTA, NIGERIA by Emmanuel Celestine NWAEJIJE meets the regulations governing the award of the degree of MSc Geology of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Dr. E.O. Obiosio Chairman Supervisory Committee	____________________ Signature	____________________ Date
Dr. I. Hamidu Member Supervisory Committee	____________________ Signature	____________________ Date
Dr. H. Hamza Head of Department	____________________ Signature	____________________ Date
Prof. Kabiru Bala Dean School of Postgraduate Studies	____________________ Signature	____________________ Date

Acknowledgment

First, I thank God Almighty for the opportunity and privilege given to me to carry out this research work, for without God I am nothing.

Special appreciation goes to Dr. E.O. Obiosio who supervised the research, devoting countless hours to reviewing and advising me, even while on sabbatical leave at Gombe State University. His dedication and support made this research possible. Extended gratitude is also given to Dr. I. Hamidu who provided academic critique and research support as a member of the supervisory committee.

My gratitude also extends to Emmanuel Bassey of South Sea Petroleum Port Harcourt and his team for laboratory assistants, providing essential data to this research work.

I also use this opportunity to appreciate my colleagues and classmates at the Department of Geology Ahmadu Bello University, for their valuable academic supports.

Thanks are also extended to the Head of Department, Dr. H. Hamza and the entire academic staff at the Department of Geology, Ahmadu Bello University, for their organization, academic critique and help with critical academic paperwork.

Special appreciation goes to my mother and brothers for their sacrifices, generous supports and understanding through the period of this research work.

Dedication

I dedicate this research work to my loving mother,Mrs. Henrietta Celestine Nwaejije and my family. The love of my family is my inspiration and drive.

Abstract

Sixty seven ditch cutting samples were collected from Well-A (latitudes 5°31'34"N and longitudes 5°42'30"E) in the Niger Delta, Nigeria at depth intervals between 2441m to 3650m for this study. Lithologic description of the samples indicate seven lithofacies comprising shale, siltstone and sandstone corresponding to the Paralic Agbada Formation.Foraminiferal analysis was carried out on these samples, a total of fifty one species were recovered; thirty seven benthonic and fourteen planktonic species. The planktonic index recovered from the well (*Praeorbulina glomerosa, Praeorbulina sicana, Orbulina suturalis* and *Catapsydrax dissimilis*) revealed that the age of the penetrated well is Miocene. Three planktonic foraminiferal zones corresponding to the N6 – N7, N8 –N9 and N9 zones of Blow (1969) are proposed for the well. The planktonic zones are *Catapsydrax dissimilis* Partial-range zone, *Praeorbulina glomerosa* Interval zone, and *Orbulina universa* Taxon – range zone respectively.Sequence stratigraphic analysis of the studied well-A based on foraminiferal biofacies and lithologic characteristics revealed five systems tracts (two TSTs, two HSTs and one LST), two MFS (proposed at 3388m and 3557m - dated 15.9Ma and 17.4Ma respectively) and two sequence boundaries (proposed at 3301m and 3466m dated 15.5Ma and 16.7Ma respectively), as a result, three depositional sequences were established from the well intervals. This also revealed that the well interval was exposed to two local depositional cycles (cycle 6 and 7), two regional cycles (cycles 2.2 and 2.3) within the TB2 super cycles as illustrated in Haq *et al* (1988) chronostratigraphic chart. The sediments of the studied well were considered to be of normal marine depositional environment based on the triangular plot of the foraminiferal test type (arenaceous, porcelaneous and hyaline). The paleobathymetry of

the well rangefrom non-marine to middle neritic setting based on lithologic and foraminiferal distribution.

Table of Content

List of Figures

List of Tables

List of Plates

List of Appendices

List of Abbreviations

1. SPDC – Shell Petroleum Development Company
2. STRATCOM – Stratigraphic Committee of the Niger Delta
3. FAD – First Appearance Datum
4. LAD – Last Appearance Datum
5. FDO – First Down hole Occurrence
6. LDO – Last Down hole Occurrence
7. MFS – Maximum Flooding Surface
8. SB – Sequence Boundary
9. HST – Highstand Systems Tract
10. TST – Transgressive Systems Tract
11. LST – Lowstand Systems Tract
12. FOBC – Foraminifera of Benthonic Calcareous
13. FOBA – Foraminifera of Benthonic Arenaceous

CHAPTER ONE

1.0 INTRODUCTION

The Niger Delta is an oil province of Nigeria located on the West African Continental margin popularly called the Gulf of Guinea. The Niger Delta basin lies between latitude 4°00'00"N and 6°00'00"N and longitude 5°00'00"E and 8°00'00"E. It is bounded to the west and northwest by the Western African shield, which terminates at the Benin hinge line and to the east, by the Calabar hinge line. The Anambra basin and Abakaliki anticlinorium mark its northern limit. To the south, it is bounded by the Gulf of Guinea (Fig. 1.1). The Niger Delta is ranked among the major hydrocarbon provinces in the world, Nigeria has been rated as the sixth largest oil producer and the twelfth giant hydrocarbon province (Okosun *et al.*, 2012). Thousands of wells have been drilled across the delta, penetrating sediments in which petroleum generation, migration and accumulation have occurred (Reijers *et al.*, 1997; Okosun *et al.*, 2012). It is the most important hydrocarbon province in the West African continental margin. The Niger Delta is a large arcuate delta of the destructive, wave-dominated type and is composed of an overall regressive clastic sequence which reaches a maximum thickness of about 12km at the basin centre (Okosun *et al.*, 2012). According to Corredor *et al.*(2005), the shape and internal structure of the Niger Delta are also controlled by fracture zones along the oceanic crust, such as the Charcot fracture zone, Chain fracture zone and the Romanche fracture zones (Fig. 1.1)

The sediments of the Niger Delta show an upward transition from marine pro-delta shales (Akata Formation) through a paralic interval (Agbada Formation) to a continental sequence (Benin Formation). These three formations, extend across the whole Niger Delta and ranges in age from early Tertiary to Recent (Short and Stauble, 1967; Avbovbo, 1978, Yikarebogha *et al*., 2013)

A separate member, the Afam Clay Member, of the Benin Formation is recognized in the eastern part of the delta and is considered as an ancient valley fill formed in Miocene sediments (Corredor *et al.*, 2005).

The three formations are strongly diachronous and cut across the time stratigraphic units which are characteristically S-shaped in cross-section(Murat, 1970; Chukwu *et al.*, 2012). The most economically exploitable hydrocarbon in the delta is believed to be trapped within the Agbada Formation (Bustin, 1988).

The use of foraminiferal biostratigraphy within a sequence stratigraphic context is rapidly emerging as a valuable tool for the recognition of ancient cycles and sequences in the Niger Delta. The application of biostratigraphy to sequence stratigraphy is not a new concept, as both biostratigraphy and sequence stratigraphy have been combined in the study and understanding of depositional environments (e.g. Okosun *et al.*, 2012; Yikarebogha *et al*., 2013; Ozumba, 1995; Armentrout *et al*., 1999).

Biostratigraphy provides valuable tools for the recognition of sequences, system tracts and ancient cycles as well as aid the interpretation of sequence stratigraphy.The use of microfossils to correlate stratigraphic sections, the paleoenvironmental preferences of these microfossils also provide valuable information on the prevailing depositional settings (Emery and Myers, 1997).

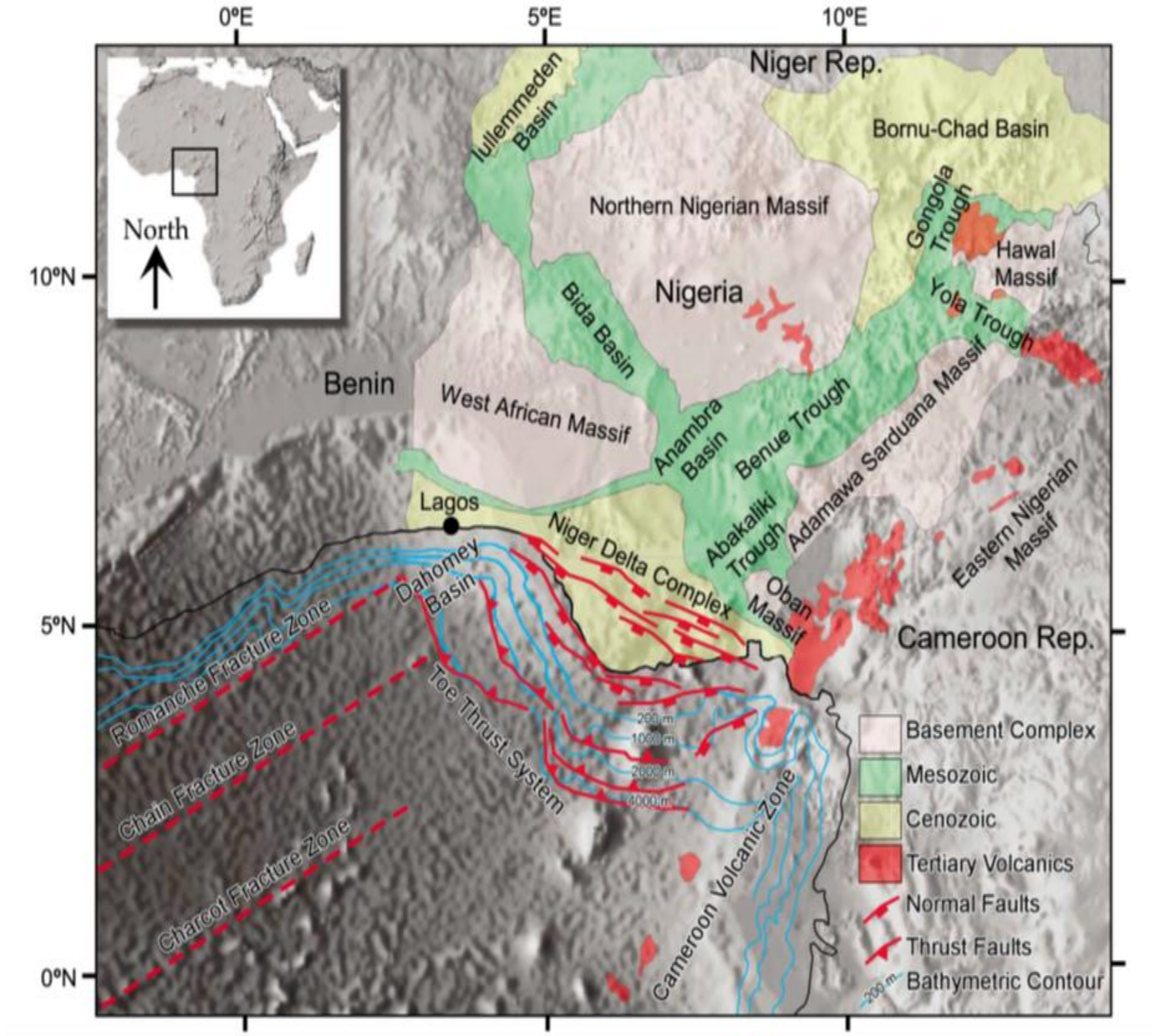


Figure 1.1: Part of West Africa and the Gulf of Guinea Showing Nigeria's Sedimentary Basin and some features controlling Sedimentation in the Niger Delta. In set is a map of Africa showing the Location of the Niger Delta region (Corredor *et al.*, 2005)

The framework of sequence stratigraphy is time, and this is amplified by biostratigraphy because it provides information for the recognition of sequence boundaries and maximum flooding surfaces. The strong link between organisms and changes in relative sea-level provides biostratigraphic data that is used to recognize key stratal surfaces, systems tract and parasequences (Emery and Myers, 1997). This has resulted in the study of relative sea-level changes and its relationship with sediment depositional patterns.

The identification of association of organisms representing a particular depositional environment (biofacies) reveals a valuable amount of information on the control of sedimentary successions and interpretation of depositional environments, the various markers of high and low sea-level phases, such as benthonic foraminifera, seem to provide particularly reliable data as they are very sensitive to any change in the environment. Foraminifera can either be used to characterize systems tracts in a clastic sequence, or to correlate sequence stratigraphic data to relative age values (Emery and Myers, 1997).

1.1 Location of Study Well

The study well pseudo named "Well-A" (Fig. 1.2) is situated in the Greater Ughelli Depo-belt of the Niger Delta on latitudes 5°31'34"N and longitudes 5°42'30"E. It was drilled by Shell Petroleum Development Company (SPDC) in 1962 to total depth of 4500m in Delta State, Nigeria (Fig. 1.3).

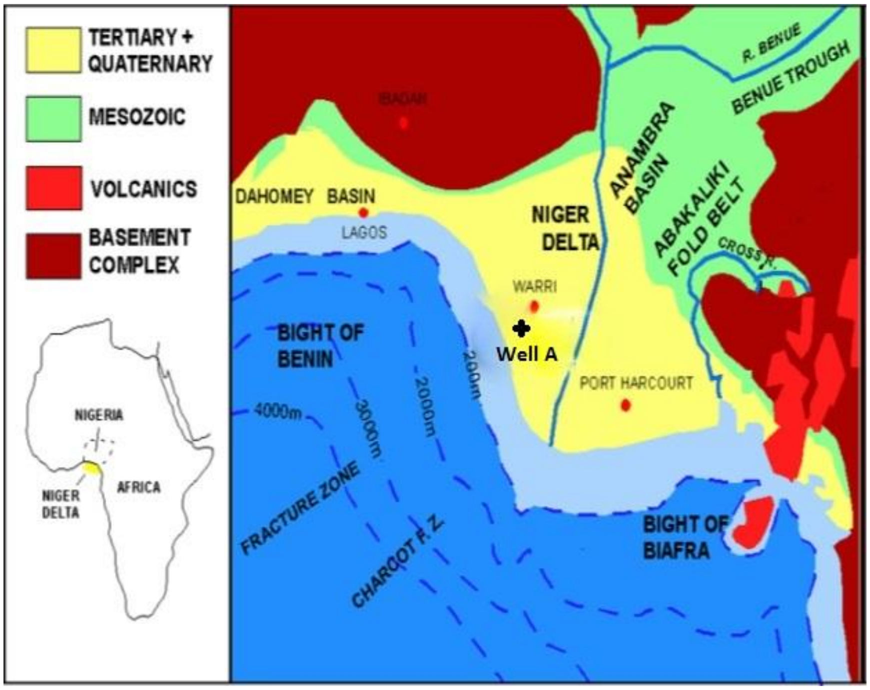


Figure 1.2: Part of West Africa showing the Niger Delta region and the Location Area of Well-A. In set is a map of Africa showing location of Nigeria and Niger Delta (modified after Doust and Omatsola, 1990)

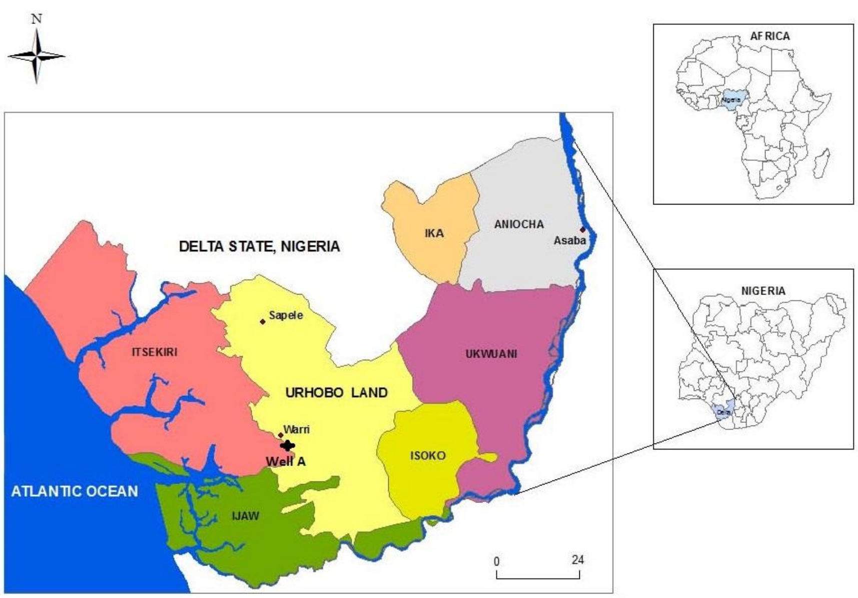


Figure 1.3: Political map of Delta State showing location of Well-A. In set are maps of Africa and Nigeria (Google image of Delta State Nigeria)

1.2 Statement of Research Problem

Petroleum exploration and other related investigations have contributed to stratigraphic and micropaleontologic knowledge for the Niger Delta region, micropaleontologists have gained importance owing to increase in hydrocarbon exploration activities. The petroleum industry in Nigeria have described and adopted informal biostratigraphic zonation which is largely unpublished according to Evamy *et al.*(1978). Although, foraminiferal biostratigraphy of several wells from the Niger Delta have been extensively published (Petters, 1979, 1982, 1983; Adeniran, 1997; Ozumba and Amajor, 1999; Oluwatosin, 2010; Okosun *et al.*, 2012; Obiosio, 2013; Oloto and Promise, 2014), however, the foraminifera biostratigraphy of the present study well has not been documented. The Niger Delta time-stratigraphy is based on biochronological interpretations of fossil spores, foraminifera and calcareous nannoplankton (Reijers *et al.*, 1997). Palynological and foraminiferal biozones have proved to be reliable tools for large-scale correlations between wells.

The delta-wide biostratigraphic framework and alpha-numeric codes used in most work is based on biostratigraphic zonations established by the Shell Petroleum Development Company of Nigeria (SPDC) and calibrated with data from Elf Nigeria (Durand, 1995). The Shell zonation was published by Evamy *et al*. (1978). This zonation allows correlation across all facies types from continental to marine. Attempts to mutually validate and integrate the SPDC framework of Evamy *et al*. (1978) with published and unpublished work of other industry groups is hampered by the use of different alpha-numerical coding systems for the foraminiferal systematics.

There have been concerted efforts, within the scope of the stratigraphic committee of the Niger Delta (STRATCOM), to produce a generally acceptable delta-wide biostratigraphic frame work (Reijers *et al*., 1997) but not much has been accomplished after several data gathering exercise by the committee (Obaje, 2013). This could be due to the facts that most of the biostratigraphic works done in the Niger Delta region (including methods and processes) is not available to the scientific community.

By implication, it is imperative that the scientific community encourage biostratigraphic studies for the Niger Delta region, this will help improve the data gathering process by the STRATCOM and also make resource materials available for future scientific researches in the region.

1.3 Aim

The aim of this work to undertake a stratigraphic study of the well in order to contribute to the data collection of the stratigraphic committee of the Niger Delta (STRATCOM).

1.4 Objectives

The objectives of this work are to:

a. Provide a lithostratigraphic framework of the well.
b. Provide detailed documentation of the foraminiferal assemblage.
c. Propose biozones from recovered foraminifera species.
d. Apply foraminiferal biostratigraphy in the interpretation of sequence stratigraphy of well-A
e. Interpret the environment of deposition.

CHAPTER TWO

2.0 LITERATURE REVIEW

Biostratigraphy uses the chronostratigraphic range of fossil species to correlate stratigraphic sections and their paleoenvironmental preferences to provide information on depositional settings, the most useful fossil groups to use in biostratigraphic studies are those that evolved quickly, with distinct and rapid morphological changes, over a wide area in significant numbers (Emery and Myers, 1997). Both macrofossils and microfossils are useful in biostratigraphic studies with the integration of key marker species from several different fossil groups resulting in more accurate chronostratigraphic interpretation.

Sequence stratigraphy is the study of rock relationships within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or non-deposition, or their correlative conformities (Van Wagoner *et al*., 1988).

The technique is used in the oil industry to correlate rock units and hence predict new hydrocarbon reserves. It is therefore a tool that allows geologists to draw together many different lines of evidence when analyzing the fill of sedimentary basin. The predictive nature of the sequence stratigraphic model can greatly aid in integrating and correlating a range of depositional environments.

2.1 Biostratigraphic Works in the Niger Delta

Several studies have been carried out on the foraminiferal biofacies of the Niger Delta. Adegoke *et al.* (1971) examined thirty six offshore bottom samples dredged by Pillsbury biological expedition (1964 - 1965) from the gulf of Guinea for planktonic foraminifera content. Twenty two planktonic species were recorded, the dominant species in order of relative abundance are *Globigerinoides ruber, Globigerinoides trilobus, Globoquadrina dutertrei and Globorotalia menardii menardii*. They delineated four broad bathymetric biofacies (Shoreline – 25m, 25 – 200m, 200 – 1000m and over 1000m) on the basis of the distribution and abundance of planktonic species. Petters (1982) carried out a detailed benthonic foraminiferal biostratigraphic study and proposed four zones (*Nonion oyae-Uvigerinahourcqi* zone, *Altistoma sclaris-Epistominella pontoni* zone, *Hanzawaia mantaensis-Cibicidoides colombianus* zone, and *Pseudonodosaria paucicostata-Spiroloculina tenuis* zone) from the Early Miocene to the Plioecene.

Adeniran (1997) studied the planktonic foraminifera from the western Niger Delta and defined six zones based on cosmopolitan planktonic foraminifera, he pointed out the lack of a unified foraminiferal zoning scheme for the Niger Delta. Okosun and Liebau (1999), confirmed thescarcity of a zonal scheme for the Niger Delta in their study of five wells in the eastern part of the Niger Delta.A study of four wells in the central and coastal swamps depobelts of the western Niger Delta by Ozumba and Amajor (1999), indicated that foraminifera were moderately rich but poorly preserved.

Frankl and Cordry (1967), Agagu (1981), Petters (1982, 1984), Ozumba (1999), Okosun and Liebau (1999) proposed the Danian age for the sediments of eastern Niger Delta Basin on the basis of *Globorotaliapseudobulloide, Globigerina triloculinoides, Globigerinoides daaubjergensis* assemblages. Chukwu *et al.* (2012) carried out foraminiferal biostratigraphy and depositional environment study of Oloibiri-1 Well, in

Eastern Niger Delta, Nigeria and established two zones namely: *Praeorbulina glomerosa* zone and *Poritextularia panamensis* zone.

Obiosio (2013) studied the *bolivina* biostratigraphy and paleoenvironment of Tonjor-l well of the Niger Delta and documented eighteen *Bolivina* species reported for the first time in the Niger Delta. The stratigraphic diversity variation of the bolivinids allowed the recognition of Late Early Eocene marine transgression which correlates with global timing of Early Eocene transgression. The presence of costae and larger test suggest a deposition in a well oxygenated slope to bathyal environment.

Oloto and Promise (2014) presented a detailed study of the biostratigraphy and paleoenvironmental reconstruction of cores from offshore (South Western) Niger Delta, their biostratigraphic analysis established Early to Middle Miocene based on First Appearance Datum (FAD) and Last Appearance Datum (LAD) of diagnostic faunal markers such as *Globorotalia obesa, Globigerinoides bisphericus*and their suite of Early to Middle benthonic foraminiferal assemblages that include *Bolivina miocenica*. The paleo-depositional environment established was marginal marine to shallow marine (littoral-middle neritic) based on depth sensitive benthonics.

2.2 Sequence Stratigraphic Works in the Niger Delta

Ozumba (1995) used foraminiferal abundance to identify five (5) maximum flooding surfaces (MFS) from penetrated stratigraphic intervals of three (3) wells (EP-1, HB-1 and KC-1) from offshore western Niger Delta. He used FDO and LDO of benthonic and planktonic foraminifers to date MFS and identify systems tracts.

Bassey and Ojesina (1998), carried out sequence stratigraphy of six wells in offshore Western Niger Delta using seismic data, well log and biostratigraphic data, they established that the sediments were Late Miocene to Pleistocene and defined seven depositional sequences.

Armentrout *et al.* (1999), carried out high resolution sequence biostratigraphic study of Oso Field Niger Delta and proposed three sequence stratigraphic models and data were integrated into the interpretation of the producing intervals of the Oso Field:

a. Model based on biostratigraphic data and core sedimentology.
b. Model based on core sedimentology.
c. Model based on regional seismic reflection profile and well log data.

Boboye and Adeleye (2009) recognized four condensed sections based on foraminifera and nanofossil abundance and diversity patterns calibrated with chronostratigraphically important bioevent from deep offshore Niger Delta. These condensed sections were correlated with the Global chart of Haq *et al.* (1987; Appendix A).

Oluwatosin (2010) developed sequence stratigraphic model for Ningning Field in the Niger Delta based on the interpretations carried out on five different wells that penetrated the various subsurface lithologies. Thisenabled the field-wide reconstruction of a chronostratigraphically constrained biostratigraphy of subsurface lithological sequences.

Okosun *et al.* (2012) carried out foraminiferal biostratigraphy and sequence stratigraphic analyses of Akata Field in Eastern Niger Delta using four wells and established Miocene ages for the studied wells, the depositional environments inferred range from littoral (deltaic) to marine (outer neritic) based on restricted benthonic foraminiferal species. Third order maximum flooding surfaces were recognized in the studied wells.

Soronnadi *et al.* (2013) undertook a palaeoenvironmental and sequence stratigraphic study of the D7000 sand 'Erne' Field of the Niger Delta using integrated core samples, biostratigraphic data and wireline logs analyses of the D7000 sand. The environments of deposition were established as marine to estuarine settings which revealed that a period of regression was followed by a transgressive phase. Core analysis revealed the existence of tenlithofacies, which were grouped into facies association in a vertical sequence with genetic significance using primary structures and shape of wireline logs.

2.3 Paleoenvironmental Interpretation in the Niger Delta

According to Doust and Omatsola (1990), the deposiotional environments of the subsurface Niger Delta are recognized by lithology, foraminiferal assemblages and mutual juxtaposition of the lithofacies and foraminiferal assemblages. Ozumba (1995) used foraminiferal assemblages to interpret outer neritic to upper bathyal environment of deposition from three wells in offshore Niger Delta.

Petters (1995) proposed foraminiferal bathymetric zonation for the Niger Delta based on the foraminiferal bathymetric ranges given by Harris (1981) and augmented that of Culver (1988) for Northwestern Gulf of Mexico. He proposed that the bathymetric chart should be used for rapid non-statistical routine identification of marine benthonic environments in the Niger Delta oil well samples especially when ditch cutting samples are used.

Chukwu *et al*. (2012), studied the paleoenvironment of depositions of the Oloibiri-1 well in the eastern Niger Delta and inferred littoral (deltaic) to marine environments on the basis of the occurrence of environmentally restricted taxa, some of which belong to the following genera: *Quinqueloculina, Hopkinsina, Spiroleptamina, Lenticulina, Heterolepa, Alveolophragmium* and *Textularia*.

2.4 Geology of the Niger Delta

Short and Stauble (1967) presented a detailed stratigraphy of the subsurface Niger Delta, while Asseez (1976) reviewed the stratigraphy, sedimentation and structures of the Niger Delta. The structural geology of the Tertiary Niger Delta have been described by Hospers(1971); Merki (1972); Weber and Daukoru (1975).

The Niger Delta is one of the prolific oil province in the world, located in Gulf of Guinea within the West African subcontinent where it host numerous oil fields both onshore and offshore. Hydrocarbon exploration in the Niger Delta dates back to the 1950s from rocks of Eocene to Pliocene ages gradually shifting to both the offshore (Pliocene – Pleistocene sections) and the flanks of the delta where Cretaceous prospects are expected (Ozumba and Amajor, 1999). Petroleum exploration and other investigations have contributed to documented stratigraphic and micropaleontologic data base for the region (Obiosio, 2013).

2.5.1 Origin and geomorphology of the Niger Delta

The history of the Niger Delta is closely related with the breaking up of the African continent from South America in the Santonian. This led to the formation of the Benue Trough folded belt and subsequent accumulation of Tertiary deltaic sediments formed at the southern extremity of the Benue Trough. (Yikarebogha *et al.*, 2013).The main regression and the formation of the present Niger Delta began in middle Eocene with the deposition of the Ameki Formation, west and east of the Niger River. Sediment supply was derived from two drainage systems, the Niger-Benue system through the Anambra Basin north of Onitsha, and the less important Cross River system through the Afikpo syncline (Short and Stauble, 1967; Yikarebogha *et al.*, 2013). In Eocene to Oligocene time, the two systems appear to have been separated from each other by the Abakaliki anticlinorium and its southwestern extension. The Cross River system did not supply much sediment during all of middle and late Eocene time. The delta built up mainly in the Bende-Ameki area, although the increasing amount of sand toward the top of the Ameki Formation indicates a possible movement of the coast line toward the south. At the same time the Niger Delta advanced very rapidly over the shallow Anambra shelf (Short and Stauble, 1967).

During the middle Eocene, it straddled the Onitsha-Benin area and advanced further toward the Kwale area (Ogume-1, Ethiope-l, Benin West-l). It reached the Aboh area in late Eocene time (Fig.2.1). Because of the slow movement of the Cross River Delta System, a marine interdeltaic area named the Ihuo embayment formed between the two deltas, extending beyond the Orlu area (Fig.2.1). This rapid advance of the Niger Delta continued in post - Eocene time, In the Oligocene the delta front reached the Ubie-1 area east of the Niger River and extended westward across the river to the Warri area, in late Oligocene to Early Miocene time, it had advanced in a line extending from Elele-1, east of the Niger River, to Kumbowei-1 and Ubefan-1 on the west (Short and Stauble, 1967).

In late Eocene - early Oligocene, sedimentation in the Cross River Delta area became more active and a small but important and rapidly advancing delta developed in the Olumbe-1 area (Short and Stauble, 1967).

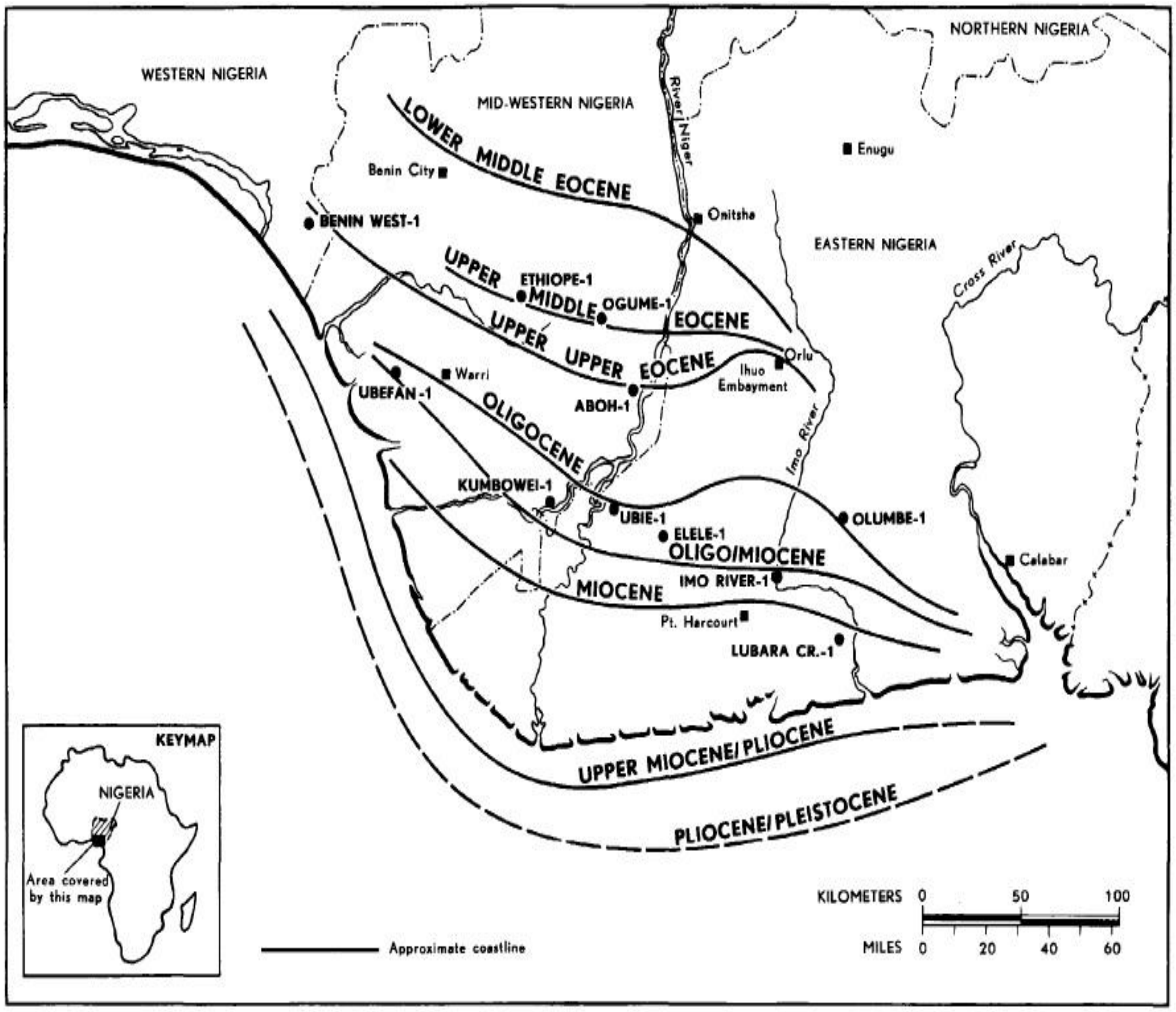


Figure 2.1: Map of Niger Delta Region showing Stages of Niger Delta growth
In set is a map of Africa showing Nigeria and the Niger Delta region
(Short and Stauble, 1967).

At this stage it was separated from the main Niger Delta by the Ihuo embayment which, being a fairly shallow bay, was filled rapidly by the advancing Cross River Delta and probably by local rivers. In late Oligoccne to Early Miocene, the sediments of the Cross River merged with those of the Niger Delta. Henceforth, extensive mixing of sediments by long shore and tidal currents makes the distinction of the two deltas difficult. However, the later growth of the Cross River Delta can be traced southward from the Imo River field area to the Lubara Creek area (Short and Stauble, 1967; Fig. 2.1).

Little is known either of the movement of the Cross River Delta in Miocene to Pliocene or of its shift from the Lubara Creek area to its present northwest - southeast course, reaching the sea southeast of Calabar(Short and Stauble, 1967).

In late Miocene the sub aerial Niger Delta reached a position beyond the present coast line. In Pliocene-Pleistocene it advanced further seaward and reached its maximum extent very probably at approximately the edge of the present continental shelf. Coarse channel sands of fluviatile origin and shallow marine to estuarine - lagoon faunas have been obtained from sea-floor samples taken from various localities up to 40 miles offshore (Allen, l965).

2.5.2 Tectonic setting of the Niger Delta

The tectonic framework of the continental margin along the West Coast of equatorial Africa is controlled by Cretaceous fracture zones expressed as trenches and ridges in the deep Atlantic. The fracture zone ridges subdivide the margin into individual basins, and, in Nigeria, form the boundary faults of the Cretaceous Benue-Abakaliki Trough, which cuts far into the West African shield (Michelle *et al.*, 1999).

The trough represents a failed arm of a rift triple junction associated with the opening of the South Atlantic. In this region, rifting started in the Late Jurassic and persisted into the Middle Cretaceous (Lehner and De Ruiter, 1977). In the region of the Niger Delta, rifting diminished altogether in the Late Cretaceous. Figures2.2 and 2.3 shows the gross paleogeography of the region as well as the relative position of the African and South American Plates since rifting began.

After rifting ceased, gravity tectonism became the primary deformational process. Shale mobility induced internal deformation and occurred in response to two processes (Kulke, 1995).

a. First, shale diapirs formed from loading of poorly compacted, over-pressured, prodelta and delta-slope clays (Akata Formation) by the higher density delta-front sands (Agbada Formation).
b. Second, slope instability occurred due to a lack of lateral, basinward support for the under-compacted delta-slope clays (Akata Formation).

For any given depobelt, gravity tectonics were completed before deposition of the Benin Formation and are expressed in complex structures, including shale diapirs, roll-over anticlines, collapsed growth fault crests, back-to-back features, and steeply dipping, closely spaced flank faults (Evamy *et al.*, 1978). These faults mostly offset different parts of the Agbada Formation and flatten out into detachment planes near the top of the Akata Formation.

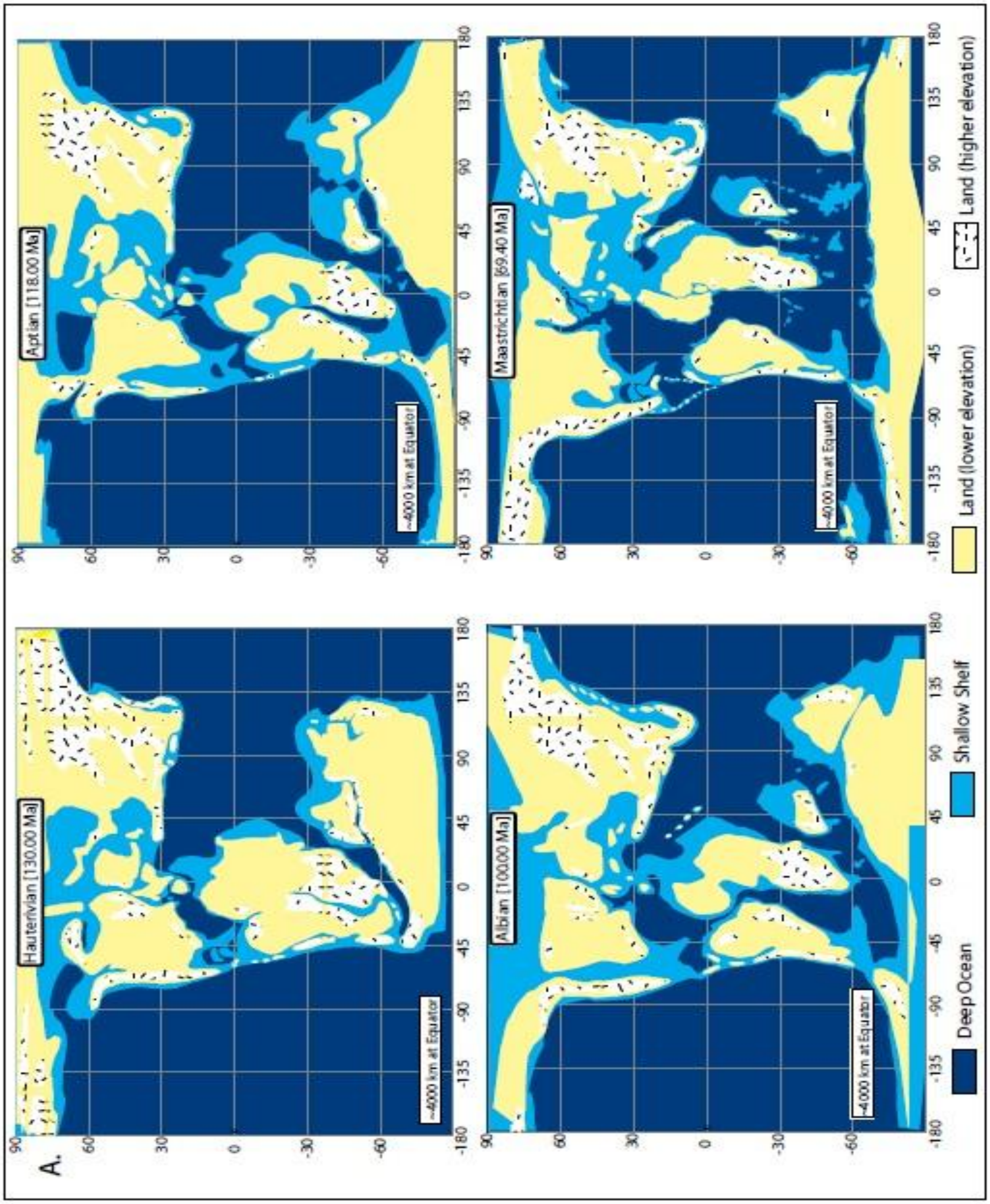


Figure 2.2: Cretaceous Paleogeography showing the opening of the South Atlantic, and development of the region around Niger Delta (Michelle *et al.*,1999).

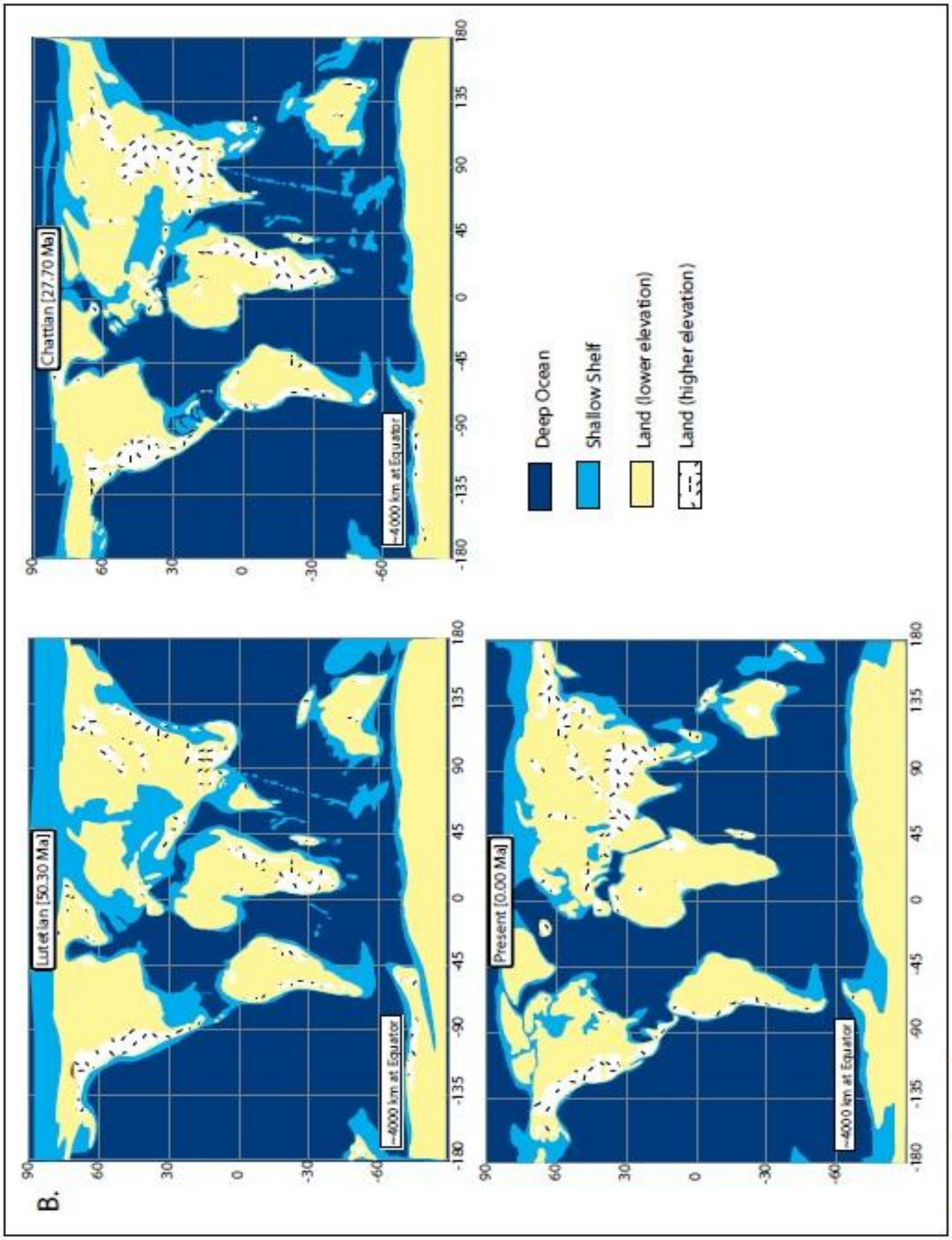


Figure 2.3: Cenozoic Paleogeography showing the opening of the South Atlantic, and development of the region around Niger Delta (Michelle *et al.*, 1999).

2.5.3 Depobelts of the Niger Delta

Deposition of the three formations occurred in each of the five offlapping siliciclastic sedimentation cycles that comprise the Niger Delta. These cycles (depobelts) are 30-60 kilometers wide, prograde southwestward 250 kilometers over oceanic crust into the Gulf of Guinea (Stacher, 1995), and are defined by synsedimentary faulting that occurred in response to variable rates of subsidence and sediment supply (Doust and Omatsola, 1990). The interplay of subsidence and supply rates resulted in deposition of discrete depobelts, when further crustal subsidence of the basin could no longer be accommodated, the focus of sediment deposition shifted seaward, forming a new depobelt (Doust and Omatsola, 1990). Each depobelt is a separate unit that corresponds to a break in regional dip of the delta and is bounded landward by growth faults and seaward by large counter-regional faults or the growth fault of the next seaward belt (Evamy *et al.*, 1978, Doust and Omatsola, 1990). Five major depobelts are generally recognized by Doust and Omatsola(1990), each with its own sedimentation, deformation, and petroleum history (Fig.2.4). They described three depobelt provinces based on structure. The northern delta province, which overlies relatively shallow basement, has the oldest growth faults that are generally rotational, evenly spaced, and increase their steepness seaward. The central delta province has depobelts with well-defined structures such as successively deeper rollover crests that shift seaward for any given growth fault. Last, the distal delta province is the most structurally complex due to internal gravity tectonics on the modern continental slope.

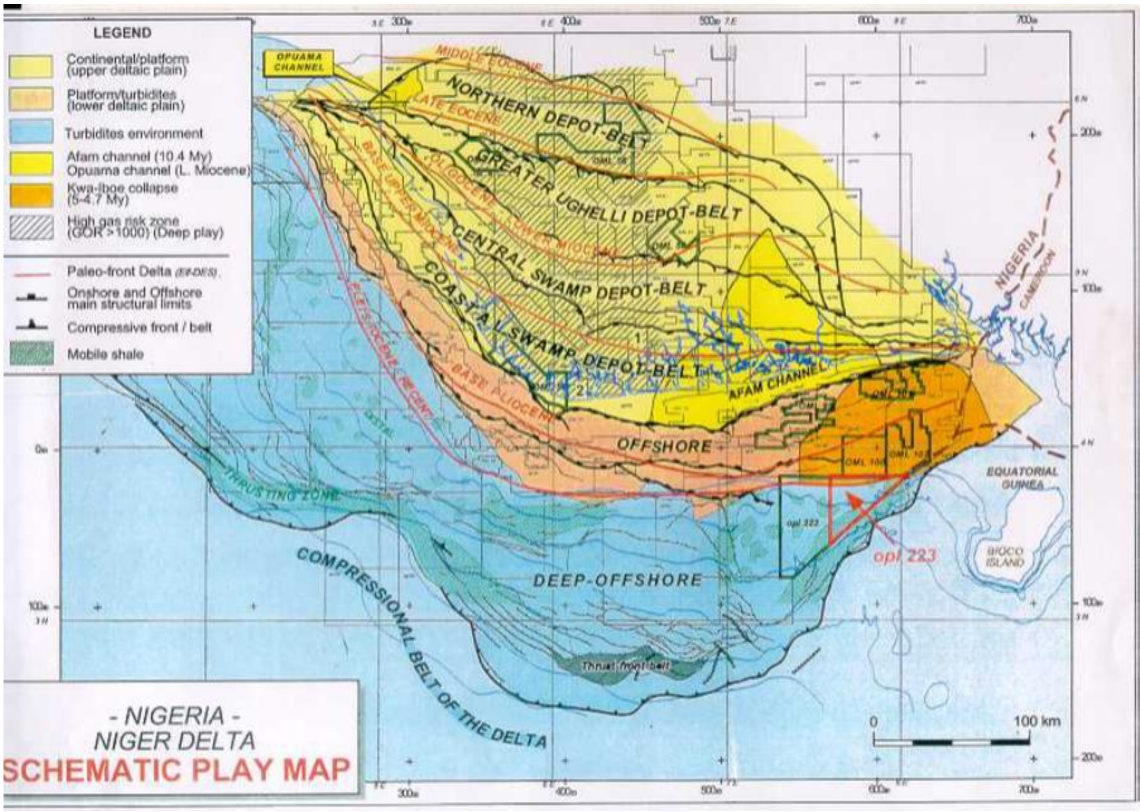


Figure 2.4: Schematic Play Map of Niger Delta Showing Depo-belts, Sedimentation, Deformation, and Petroleum history (Google Image)

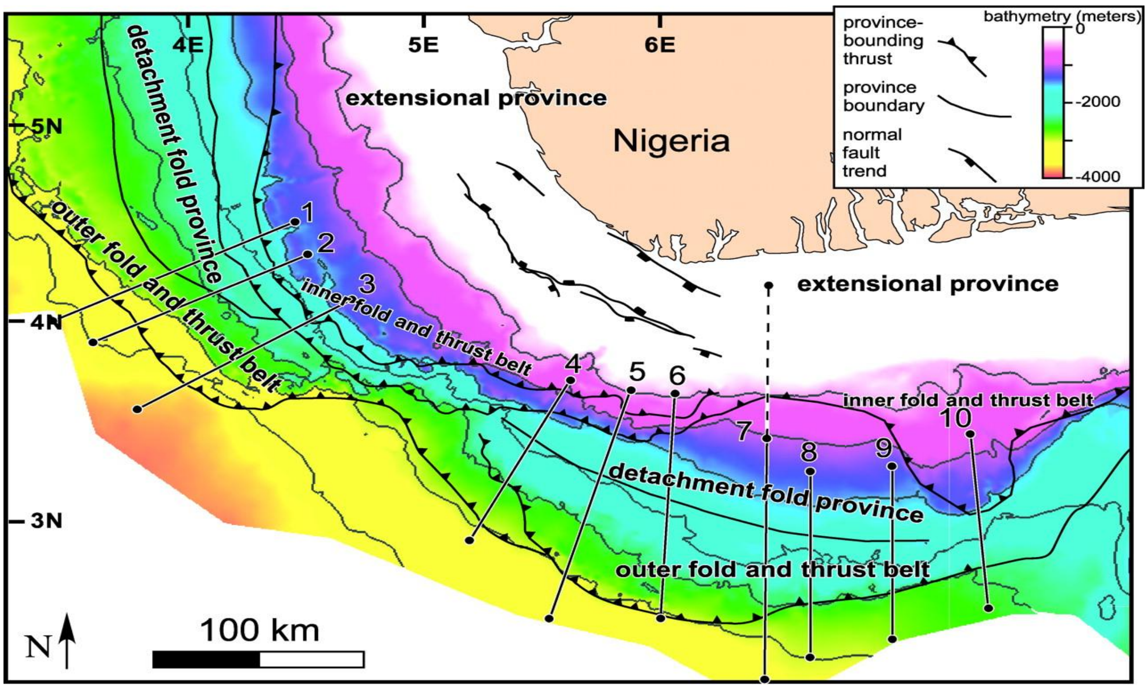


Figure 2.5: Structural provinces or zones in high resolution bathymetry of Offshore Niger Delta (Lehner and De Ruiter, 1977).

2.5.4 Structure of the Niger Delta

The Niger Delta has a geosynclinals structure which continues offshore into the continental shelf and is characterized by features such as growth faults, rollover anticlines and shale diapirs. The Offshore Niger Delta was originally divided into three structural zones (Damuth, 1994; Mascle *et al.*, 1973): an extensional zone I beneath the outer continental shelf and upper slope; an intermediate translational zone II beneath the continental slope; and a compressional zone III beneath the lower continental slope and uppermost rise.

Connors *et al*. (1998), further subdivide the offshore Niger Delta into five major structural provinces or zones based on structural styles image in seismic data and high resolution bathymetry (Fig. 2.5).

These structural zones (Fig. 2.5) include:

a. An extensional province beneath the continental shelf that is characterized by both basinward-dipping (Roho-type) and counter regional growth normal faults and associated rollovers and depocenters;
b. A muddiapir zone located beneath the upper continental slope, which is characterized by passive, active, and reactive mud diapirs (Morley andGuerin, 1996), including shale ridges and massifs, shale overhangs, vertical mud diapirs that form mud volcanoes at the seafloor (Graue, 2000), and inter-diapir depocenters;

c. The inner fold and thrust belt, which is characterized by basinward verging thrust faults (typically imbricated) and associated folds, including some detachment folds;
d. A transitional detachment fold zone beneath the lower continental slope that is characterized by large areas of little or no deformation interspersed with large, broad detachment folds above structurally thickened Akata Formation; and
e. The outer fold and thrust belt characterized by both basinward and hinterland-verging thrust faults and associated folds.

Deformation across these structural provinces is active today, resulting in pronounced bathymetry expressions of structures that are not buried by recent sediments. The inner and outer fold and thrust belts are most evident in the bathymetry, where ridges represent the crests of fault-related folds, and low regions correspond to piggyback basins formed above the back limbs of fault imbricates (Corredor *et al.*, 2005).

The inner fold and thrust belt extends in an arcuate path across the center of the offshore delta, whereas the outer fold and thrust belt consists of northern and southern sections that define two outboard lobes of the delta. These two lobes, and their associated fold belts, are separated by a major rise in the basement topography that corresponds to the northern culmination of the Charcot fracture zone (Fig 1.1). The break between the northern and southern sections of the outer fold and thrust belt results from thrust sheets being stacked in a narrow zone above and behind this major basement uplift (Connors *et al.*, 1998; Wu and Bally, 2000).

2.5.5 Stratigraphy of the Niger Delta

The stratigraphy of the Niger Delta is closely related to its structure. The development of each being dependent on interplay between sediment supply and subsidence rate.

Short and Stauble (1967) recognized three subsurface stratigraphic units in the modern Niger Delta. The delta sequence is mainly a succession of marine clays (Akata Formation) overlain by paralic sediments (Agbada Formation) which were finally capped by continental sands (Benin Formation).

2.5.5.1 Benin Formation**:** The formation comprising over 90% sandstone with shale intercalations extends from the west across the entire Niger Delta area and southward beyond the present coast line. The thickness though variable is estimated at about 1829m. It is coarse grained, gravelly, poorly sorted, sub-angular to well-rounded and bears lignite streaks and wood fragment. The formation is characterized by structural units such as channel fills, point bars, which indicate variability of the shallow water depositional medium. The Benin Formation with very little hydrocarbon accumulation ranges in age from Oligocene to Recent (Short and Stauble, 1967).

2.5.5.2 Agbada Formation: The formation is a sequence of sandstones and shales with sandstone dominant in the upper unit and thick shales in the lower unit. It is very rich in microfauna at the base decreasing upwards suggesting an increase in the rate of deposition at the delta front. The sandstone is coarse and poorly sorted indicating a fluvatile origin. The Agbada Formation covers the entire subsurface of the delta and may be continuous with the Ogwashi-Asaba and Ameki Formations of Eocene to Oligocene age. The formation is over 3048m thick and are the major hydrocarbon bearing unit in the delta (Short and Stauble, 1967).

2.5.5.3 Akata Formation: The formation underlies the entire delta and forms the lower most unit. It is a uniform shale development consisting of dark grey sandy, silty shale with plantremains at the top. The Akata Formation is typically over pressured and believed to have formed during low stands when terrestrial organic matter and clays were transported to deep water areas characterized by low energy conditions and oxygen deficiency (Statcher, 1995). It is over 1219m thick and ranges in age from Eocene to Recent and is believed to have been deposited in front of the advancing delta (Short and Stauble, 1967). According to Reijers (1996), the age of the Akata Formation ranges from Paleocene in the proximal parts of the delta to Recent in the distal offshore; the oldest deposits of the Agbada Formation are of Eocene in the north and are presently being deposited in the near shore shelf domain, while the Benin Formation first occurs in Oligocene times in the northern delta sector (Fig. 2.6).

Along the northern perimeter of the Niger Delta, where the proximal parts of these lithostratigraphic units are exposed and partly grade into the lithofacies of the Anambra Basin, the same formations have been termed Imo Shale (Akata), Ameki (Agbada) and Ogwashi-Asaba (upper Agbada facies). The stratigraphic sequence and age relations of the Niger Delta is shown in Table 2.1

2.5.6 Depositional Environment of the Niger Delta Basin

The Niger Delta area may be divided into three main sedimentary environments, the continental environment, the transitional environment, and the marine environment (Short and Stauble, 1967).

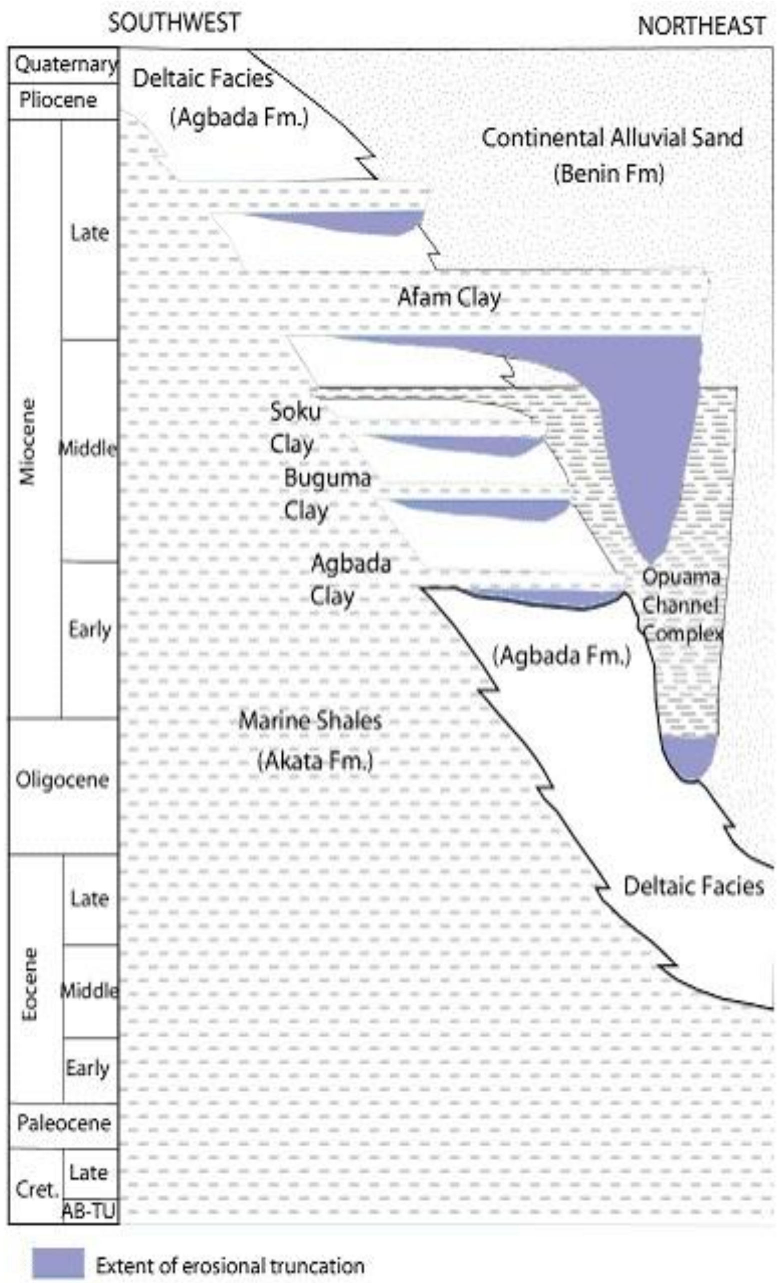


Figure 2.6: Schematic diagram of Regional Stratigraphy of the Niger Delta (Shannon and Naylor, 1989 and Doust and Omatsola, 1990).

Table 2.1: Stratigraphic Sequence of the Niger Delta (Short and Stauble, 1967)

<table>
<tr><th>Age</th><th colspan="2">Surface Information</th><th>Sub-Surface Equivalent</th><th>Megadepositional Environment</th></tr>
<tr><td>Pliocene-Recent</td><td colspan="2">Coastal Plain Sand</td><td rowspan="2">Benin Formation Afam
and
Qua Iboe
Clay Member</td><td rowspan="2">Continental</td></tr>
<tr><td>Miocene-Recent</td><td>Ogwashi-Asaba Formation</td><td>Ijebu Fm</td></tr>
<tr><td>Eocene-Recent</td><td>Ameki Fm</td><td>Ilaro Fm
Oshoshun Fm</td><td>Agbada Formation</td><td>Paralic</td></tr>
<tr><td>Paleocene</td><td colspan="2">Imo Formation</td><td>Akata Formation</td><td>Marine</td></tr>
</table>

The Continental environment comprises the alluvial environment, including the braided-stream and meander-belt system of the upper deltaic plain (Fig. 2.7). The sediments deposited in this zone are predominantly sands. Feldspar grains are fairly common and sand grains commonly are limonite coated. Finer-grained sediments (silt and clay) are deposited in the adjacent fresh-water back swamps and oxbows, together with large quantities of plant remains

The Transitional environment comprises the brackish-water lower deltaic plain (mangrove swamps, flood-plain basin, and marsh) and the coastal area with its beaches, barrier bars, and lagoons (Fig. 2.7). The sediments in this environment are distinctly fine-grained than in the continental environment. Feldspar is scarce and brackish-water faunas may occur.

The Marine environment includes the submarine part of the delta, the delta fringe with its fine sand, silt, and clay, and the associated marine faunas (Fig. 2.7). This environment grades laterally into the holomarine environment which is not affected by deltaic activity.

The succession of the Niger Delta is characterized by an overall coarsening upward regressive sequence from open marine and pro-delta shales of the Akata Formation, through the paralic sediments of the Agbada Formation, to the delta-front and lower-delta plain deposits of the Benin Formation. TheNiger Delta sequence has been described as a wave and tide dominated delta characterized by barrier island, tidal channels, and tidal deltas. (Allen, 1965; Weber, 1971).

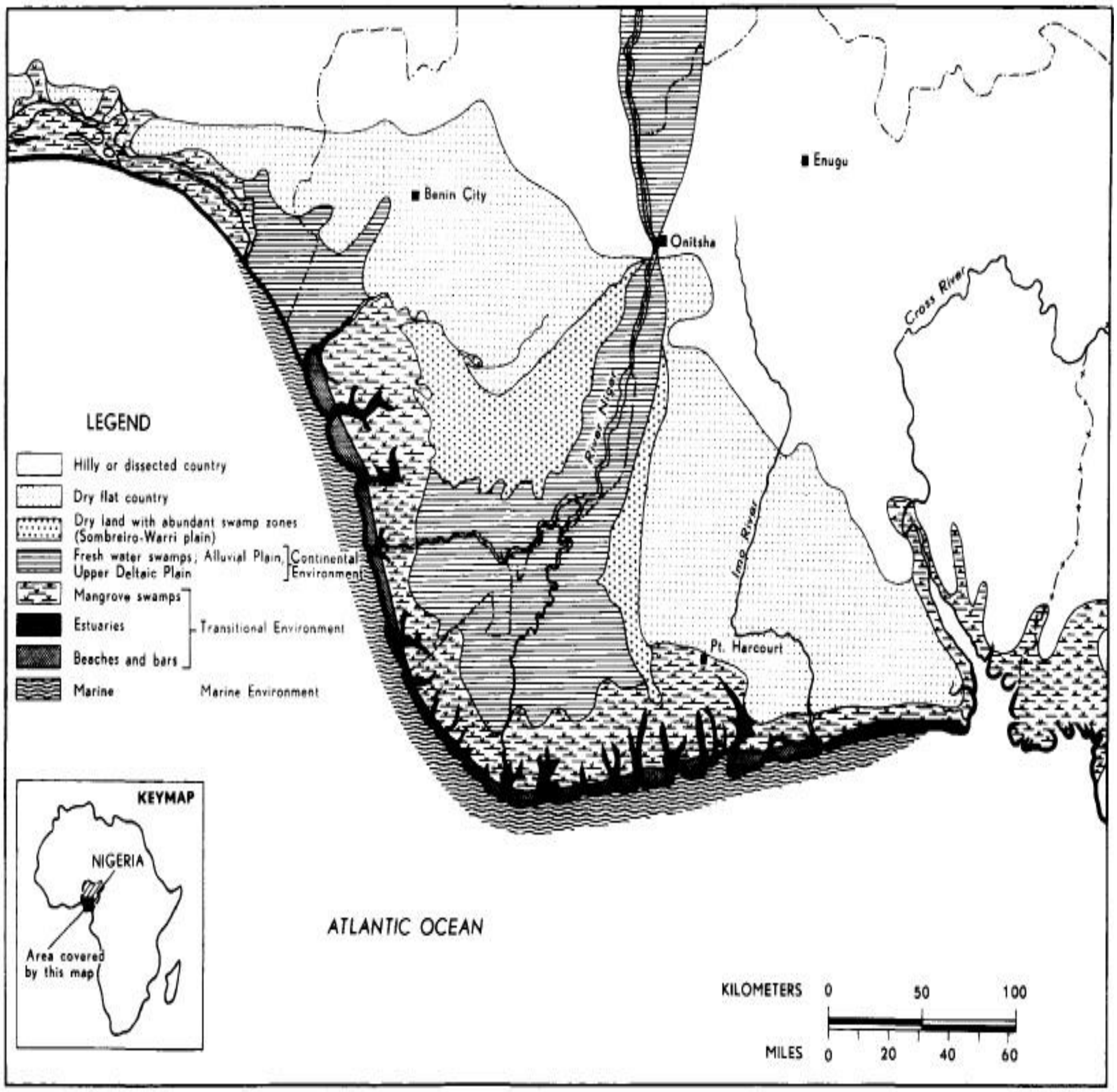


Figure 2.7: Map of Niger Delta showing Sedimentary Environment
In set is a map of Africa showing Nigeria and Niger Delta region
(Short and Stauble, 1967).

Weber (1971) distinguished five physiographic provinces in the Niger Delta Basin as:

1. Holomarine zone**:** Predominantly of clay deposition and ranges in depth from the outer shelf to 33m.
2. Transition zone: Barrier foot or fluvio-marine sedimentation composed typically of laminate clays, silts and fine sands in water 3-33m deep.
3. Barrier bars: These occurs along the coastal belt and consist of fine to medium grained sands. At certain depths, the bars may inter-finger with barrier foot sediments.
4. Tidal coastal plain: Includes tidal swamps and flats and extends behind barrier bars. The sediments vary from medium to coarse grained sands in channel fills, fine clayey sands in natural levees to clayey and peaty deposits in swamps and lagoons.
5. Flood plains: Deposits of those sedimentary environment consist of medium to coarse grained point-bar sands and clayey back swamp deposits.

The Cenozoic Niger Delta displays concentric arrangements of terrestrial and transitional depositional environments. These environments can be broadly categorized into three (3) distinct facies belts; Continental delta top facies, Paralic delta front facies belt, and Pro-delta facies (Short and Stauble, 1967). Fluvial processes control sedimentation in the lower flood plain of the delta top environment while tidal influence prevails in the mangrove swamps coastward.

2.5.7 Oil and Gas Occurrence

Almost all hydrocarbon accumulations in the Niger Delta occurs in the sandstones of the Agbada Formation, mostly trapped in rollover anticlines fronting growth faults (Fig. 2.8).

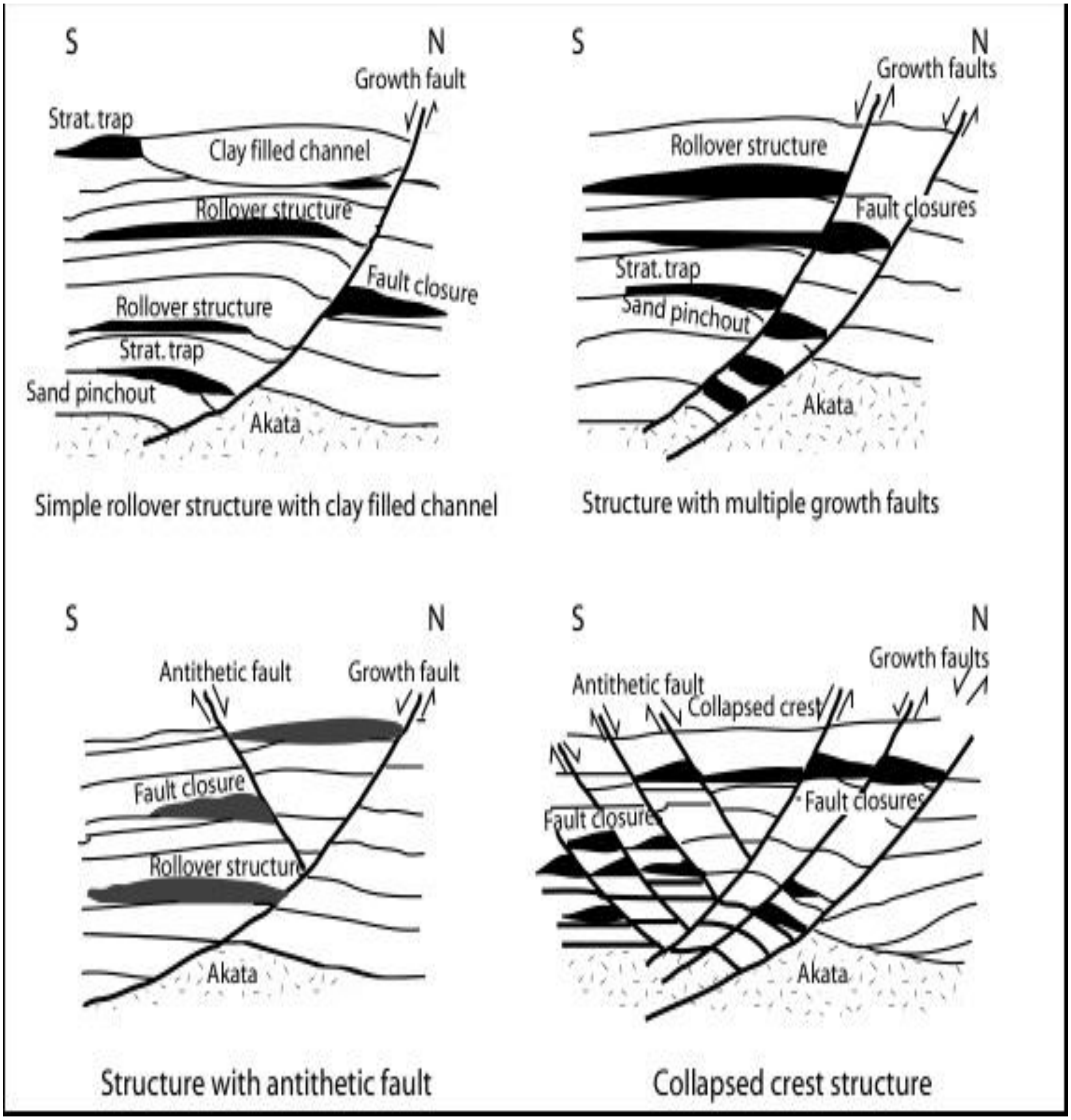


Figure 2.8: Oil field structures and associated traps in the Niger Delta (Doust and Omatsola, 1990 and Stacher, 1995).

The extent of the accumulation may or may not be restricted by subsidiary growth faults or antithetic faults cutting the anticline. This restriction becomes more evident on the larger anticlines, which, because of the size and extent of their crestal area, tend to form a less efficient focus for migration. In addition to these anticlinal traps, hydrocarbons have also been found in fault traps that are not closed on all sides by dip. Fields, particularly those in the rollover anticlines, are normally of the multi-reservoir type. However, few, if any of the reservoirs found are full to the structural spill-point and many contain no hydrocarbons at all (Short and Stauble, 1967).

The reservoirs of the Agbada Formation are typically channel and barrier sandstone bodies similar to those of the recent delta. The large variation in the hydrocarbon content of Niger Delta Fields, and the discontinuous nature of the sandstone reservoirs evidenced by the difficulties of inter-field correlation, argue strongly against any long-range migration of oil. The most obvious source rocks are the shales of the Agbada Formation itself and of the upper part of the Akata Formation, which lie close to the sandstone reservoirs. The oil would then migrate a relatively short distance up dip into the nearest trap available at the time the oil migrated (Short and Stauble, 1967).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

Ditch cuttings for this study were available from 2438m – 4039m from well-A drilled by Shell Petroleum Development Company (SPDC) in the Niger Delta. Other materials used include: charts, microscope and camera, and computer software (Stratabug, Corel draw, Surfer and Microsoft Excel).

3.2 Methods

The methods employed in this work include: Sample preparation, description, picking and analysis.

3.2.1 Sample preparation

Ditch cuttings from the well were prepared forlithostratigraphic description and micropaleontologicanalysis at 18m (60ft) intervals. The procedures adopted for the microfossil extraction is in line with standard micropaleontological sample preparation technique (Pessagno, 1967; Zingular, 1968; Brasier, 1979). The procedure is outlined below.

a. Prepared sample list,
b. Washed samples free from drilling mud and allowed to dry,
c. Treated a quantity (200g) with one teaspoonful of anhydrous sodium carbonate for thorough disintegration,
d. Added enough water to cover the samples and allow to stand for few hours,

e. Washed the soaked sample using a 63µ (230-mesh), sieve,

f. Dried the washed sample at a minimum temperature of 20°C,

g. Decanted the dried sample into coarse, medium and fine fractions,

h. Stored samples in well labelled sample bags.

In carrying out the detailed procedure outlined above, care was taken to avoid contaminationwith other samples.

3.2.2 Picking

All size fractions were examined individually on a picking tray, the grid lines in the tray helped to ensure that all parts of the tray was well observed. Foraminifera was picked with the aid of a sable brush 000 under a trinocular microscope.

The various foraminifera taxa encountered in each sample during the picking exercise were grouped and mounted temporarily with gum on a micropaleontological slide cavity and covered with a cover slip. These slides were arranged serially for identification. The identification of the various foraminifera was done largely by comparison with forms that have been previously described by Sellier de Civrieux (1976), Petters (1982), Loeblich and Tappan (1987), Bolli and Saunders (1985) and Jones (1994).

3.2.3 Description of lithology and recovered foraminifera

Foraminiferal descriptions (Appendix B) were done using previously published catalogues asillustrated in published literatures listed above.

Sedimentologic analysis was carried out on the samples by visual inspection. Physical characteristics such as colour,texture, hardness, fissility, rock type etc. were noted taking into consideration published lithofacies description of the Niger Delta as well as lithofacies models of Webber and Daukoru (1975) and Whiteman (1982).The sedimentology data and wire line logs were used to generate the lithostratigraphic chart of the well.

Biostratigraphic data yielded biofacies information for paleoenvironment and bathymetry. Graphic charts were generated using the STRATABUGS software.Dating of the key surfaces where possible was achieved by their calibration to the third order cycles of Haq *et al*. (1988).

3.2.4 Photomicrographs

Photomicrographs (Plates I, II, III) of foraminifera recovered from the studied well was taken using a Sony 12mp camera, mounted on a trinocular microscope.

CHAPTER FOUR

4.0 RESULTS

4.1 Lithostratigraphic Units

The lithostratigraphic section of the wellis based on ditch cutting samples described and information gathered from wire line log. The thickness of analyzed interval is 1209m (2441m - 3650minterval). The lithologies are mainly sandstone, shale and siltstone.

a. Sandstone**:** Smokey white to orange colour, fine to coarse grained, sub-angular to sub-rounded, well sorted, occasionally ferruginized, sometimes containing woody materials, muscovite flakes and some carbonaceous fragments.

b. Shale: Brown to grey, sometimes black, fissile, moderately hard and occasionally carbonaceous.

c. Siltstone: White, fine grained, micromicaceous and carbonaceous, and traces of woody materials.(Appendix C)

The lithostratigraphic section revealed seven distinct lithofacies(Fig. 4.1) as follows:

Unit 1 (2450m - 2620m): Intercalation of sandstone, siltstone and shale.

Unit 2 (2620m - 2710m): Sandstone and siltstone intercalation.

Unit 3 (2710m - 3120m): Sandstone and shale intercalation.

Unit 4 (3120m - 3180m): Mainly siltstone with traces of sandstone.

Unit 5 (3180m - 3380m): Sandstone and shale intercalation.

Unit 6 (3380m - 3540m): Siltstone and shale intercalation.

Unit 7 (3540m - 3650m): Sandstone and shale intercalation.

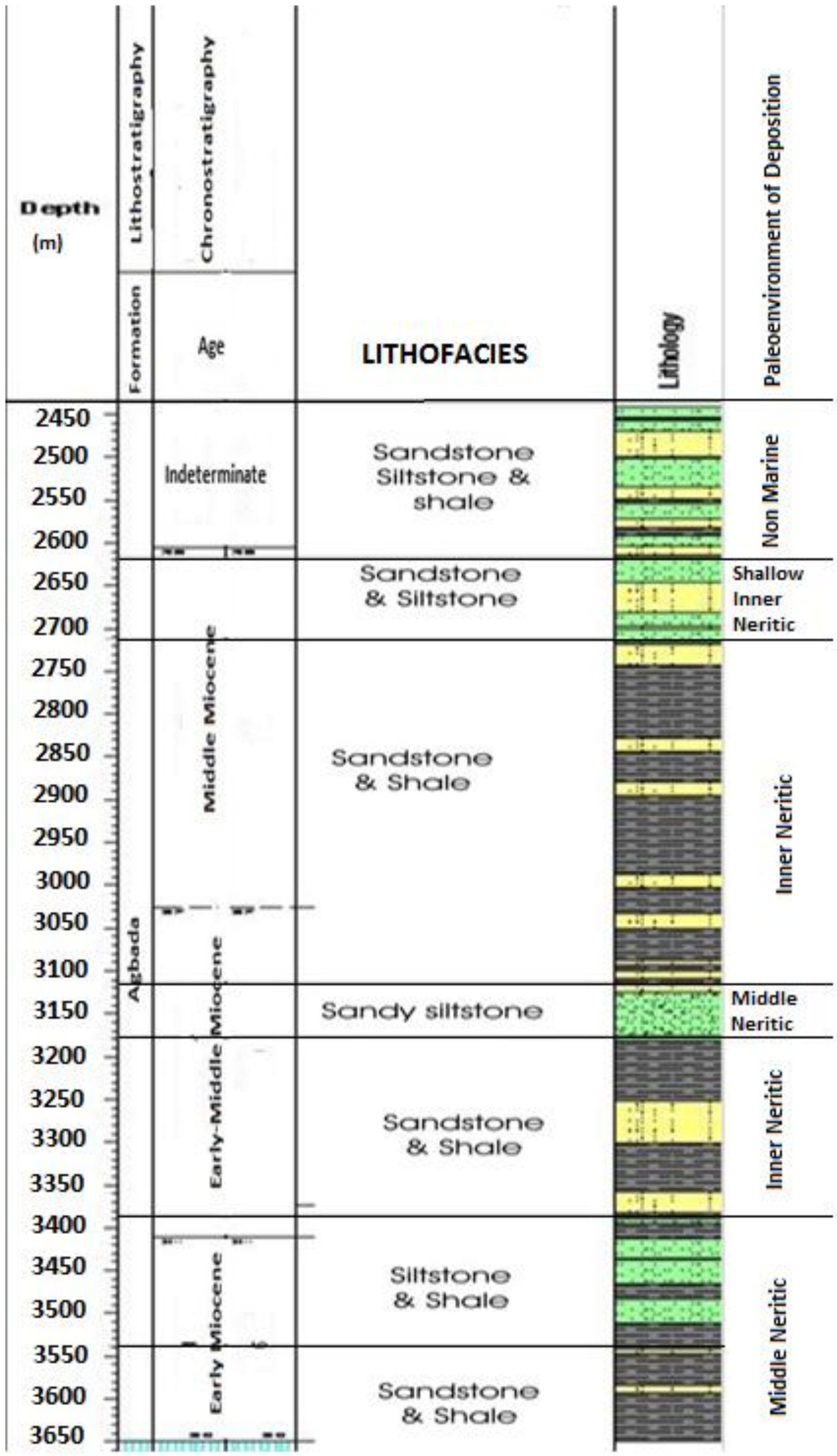


Figure 4.1: Paleoenvironment of Deposition and Lithostratigraphic section of well-A based on the Alternation of Sandstone, Shale and Siltstone

4.2 Foraminifera Micro Fauna

Foraminiferal analysis was carried out on sixty seven samples obtained from the well (interval 2441m - 3650m). The foraminifera recovered was fair, the diversity, however, was high. The forms encountered include planktonic foraminifera, benthonic calcareous foraminifera and also benthonic arenaceous foraminifera. Some forms are long ranging in terms of stratigraphic distributions while others had restricted distributions.

4.2.1 Benthonic foraminifera

The benthonic foraminiferal species in the well are made up of diverse and rich to occasionally abundant species. Preservation is fairly good all through the section. A total of Thirty seven different species were recovered from the studied interval, accounting for about seventy two percent (72%) of foraminiferal count (Fig. 4.2), six of which make up the benthonic arenaceous species (Table 4.1), and thirty-one calcareous species (Table 4.2). The benthonic foraminifera are dominated bythe following species: *Uvigerina isidroensis, Brizalina mandoroveensis, Lenticulina grandis, Hopkinsina bononiensis, Hanzawaia stratonii, Ammonia beccarii, Heterolepafloridana, Cibicorbis inflata, Uvigerina* sp. *Valvulineria gasparensis, Haptophragmoides* sp. *and Spiroplectammina* sp. Some of the other species have poor occurrences to single occurrences as in the case of *Textularia laminata, Ammobaculites* sp. *Bolivina spinata*.

4.2.2 Planktonic foraminifera

Fourteen planktonic foraminiferaspecies (Table 4.3) which constitutes about twenty eight percent (28%)of foraminiferal count (Fig. 4.2). Poor to fairly rich occurrences were recovered in the well interval. The planktonic foraminifera are dominated bythe following species: *Globigerina* sp. *Orbulina suturalis, Praeorbulina glomerosa, Globorotalia continuosa, and Planktic indet* sp. Other important planktonic foraminifera species recovered include *Catapsydrax dissimilis, and Praeorbulina sicana.*

Table 4.1: Benthonic Calcareous Foraminiferal Total count

Calcareous Assemblage (FOBC)	Total Count
Ammonia beccarii	14
Hanzawaia stratonii	21
Lenticulina grandis	36
Uvigerina isidroensis	97
Brizelina interjuncta	8
Heterolepa floridana	18
Quinqueloculina sp.	6
Uvigerina sp.	13
Valvulineria gasparensis	10
Eponides eshira	8
Hopkinsina bononiensis	33
Lenticulina inornata	3
Quinqueloculina lamarckiana	1
Myogypsinoides sp.	5
Quinqueloculina microcostata	2
Uvigerina sparsicostata	8
Bolivina sp.	2
Bulimina sp.	2
Hanzawaia concentrica	1
Heterolepa pseudoungeriana	5
Bolivina dilatata	1
Epistominella vitrea	2
Uvigerina topilensis	3
Cibicorbis inflata	14
Eponides ornatus	2
Gavelinella aff. *beninensis*	1
Quinqueloculina seminulum	1
Bolivina spinata	1
Brizalina mandoroveensis	59
Epistominella potoni	7
Florilus atlanticus	2
Total	386

Table 4.2: Benthonic Arenaceous Foraminiferal Total count

Arenaceous Assemblage (FOBA)	Total Count
Ammobaculites sp.	1
Spiroplectammina sp.	2
Haplophragmoides sp.	3
Textularia laminata	1
Textularia panamensis	1
Spiroplectammina wrightii	1
Total	9

Table 4.3: Planktonic foraminiferal Total count.

Foraminifera Assemblage	Total count
Globigerina sp.	5
Globigerina venezuelana	2
Orbulina universa	2
Planktic indet sp.	3
Globorotalia continuosa	3
Praeorbulina glomerosa	3
Praeorbulina sicana	2
Orbulina saturalis	4
Globigerinoides immaturus	2
Globigerinoides sacculifer	1
Globigerinoides trilobus	2
Globigerinoides quadrilobatus	1
Catapsydrax dissimilis	1
Globigerinoides sp	1
Total	32

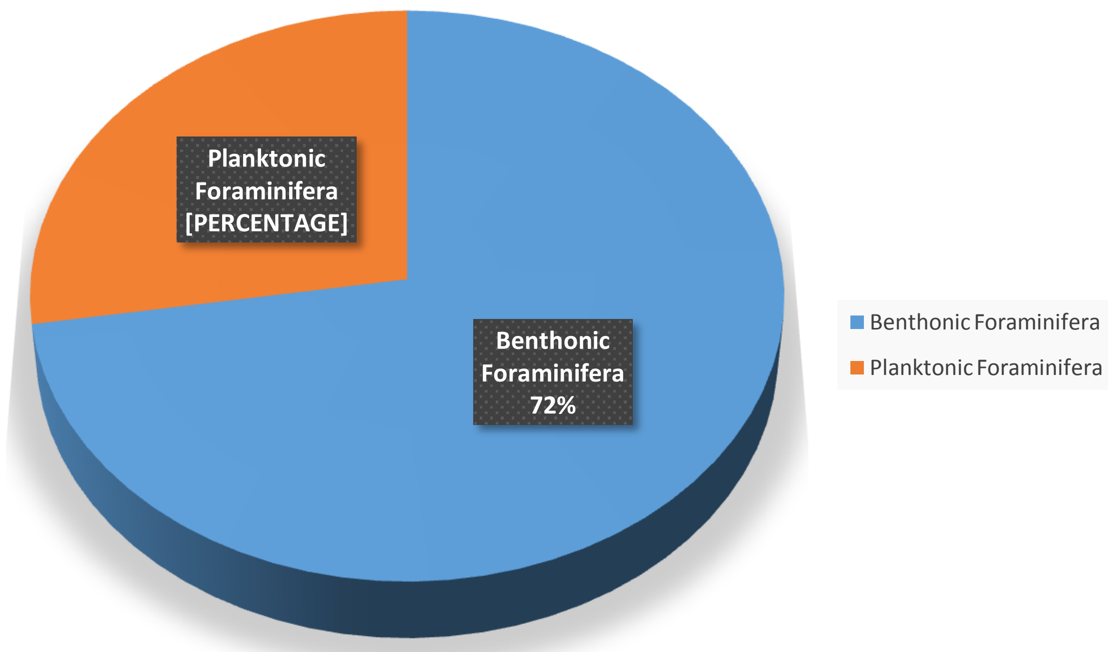


Figure 4.2: Planktonic and benthonic (calcareous and arenaceous) foraminiferal count percent

4.3 Sequence Stratigraphic Units

Sequence stratigraphic analysis of the well is based on lithostratigraphic data and biostratigraphy of the well. From the analysis, five systems tracts as well as associated key surfaces were delineated. The delineated data were correlated to Haq *et al*. (1988) chart. Delineated systems tracts include:

1.	Transgressive systems tract TST	3648m - 3566m
2.	Highstands systems tract HST	3548m - 3475m
3.	Transgressive systems tract TST	3457m-3347m
4.	Highstands systems tract HST	3329m-3310m
5.	Lowstand systems tract LST	3292m-2441m

Associated Key surfaces and their correlated ages:

1.	Maximum flooding surface MFS	3557m	17.4Ma
2.	Sequence boundary SB	3466m	16.7Ma
3.	Maximum flooding surface MFS	3338m	15.9Ma
4.	Sequence boundary SB	3301m	15.5Ma

CHAPTER FIVE

5.0 DISCUSSION

5.1 Lithostratigraphy

From the graphic log seen in Figure 4.1 and the detailed lithostratigraphic description, the lithology show siltstone layers with the alternation of sandstone and shale, the shale is brown to grey in colour (occasionally black to brown,), fissile, moderately hard. The sand is smokey white to orange, fine-grained (occasionally coarse-grained), sub-angular to sub-rounded, well sorted and occasionally ferruginized. According to Short and Stauble (1967), the Agbada Formation is characterized by the alternation of sandstone and sand bodies with shale layers. The sandstone is fine to coarse grained, predominantly unconsolidated. The alternations of sandstone, and shale are the result of differential subsidence, variation in the sediment supply, and shifts of the delta depositional axes which cause local transgressions and regressions (Short and Stauble, 1967). The alternations of the sandstone, and shale in the studied well interval (2441m – 3650m) reveals that it penetrated the Agbada Formation of the Niger Delta.In general, the upper part of the formation has a higher sandstone percentage than the lower part, this demonstrates the progressive, seaward advancement of the Niger Delta through geological time despite the numerous, transgressive sequences found in the Agbada Formation, the Agbada Formation generally is marine (Short and Stauble, 1967). The percentage of each lithologic type is presented in the Appendix-A section of this study.

5.2 Age Determination

Planktonic foraminifera represent a major calcareous microfossil group widely used for biostratigraphic subdivisions and correlation of deep sea cores (Bolli and Saunders, 1985). The value of the planktonic foraminifera as index fossils has become increasingly recognized, their abundance in marine sediments combined with the short life span of many species makes the planktonic foraminifera in this respect often superior to benthonic foraminifera and other micro and macro organisms for stratigraphic correlations. It is their wide geographical distribution combined with additional dispersal by ocean currents that make the planktonic Foraminifera such valuable index fossils for world-wide stratigraphic correlation (Bolli and Saunders, 1985).

The Miocene Epoch (23.2 – 5.2 Ma) is a crucial period of the Cenozoic Era, as it witnessed major changes in ocean circulations and global climates affecting strongly biogeographic patterns and evolution of planktonic foraminifera. The beginning of the Miocene was marked by the evolutionary radiations of planktonic foraminifera leading to the developments of various lineages (Arun and Verma, 2014).

The following planktonic index forms were identified from the studied well interval: *Praeorbulina glomerosa, Praeorbulina sicana, Orbulina suturalis* and *Catapsydrax dissimilis.* Based on the presence of these index forms, as defined by Bolli and Saunders (1985) and Petters (1983), the age of the studied well is proposed to belong to Early Miocene to Middle Miocene (Fig. 5.1)

Age	Zones	Datum Marker
Indeterminate	Undiagnostic	
Middle Miocene	N9	*Orbulina universa* (LDO) @ 3027m
Early-Middle Miocene	N8-N9	*Orbulina sutualis* (LDO) @ 3374m
Early Miocene	N6-N7	*Praeorbulina glomerosa* (LDO) @ 3411m *Catapstdrax dissimili* (FDO) @3648m

Figure 5.1: Identified Datum Markers for Well-A

5.2.1. Early Miocene

The upper limit of the Early Miocene in the studied well interval is marked at 3411m based on the Last down hole occurrence (LDO) of *Praeorbulina glomerosa* and the lower limit is marked at 3648m based on the first down hole (FDO) occurrence of *Catapsydrax dissimili* (Fig. 5.1). This interval is characterized by the presence of other typical Early Miocene planktonics, including *Globigerinoides quadrilobatus.*Most members of the early Miocene assemblage are non-diagnostic taxa such as those of *Catapsydrax*, *Globigerina*, *Globigerinoides*, primitive *Globorotalia*, and *Globoquadrina* (Chengjie *et al.*, 1997)

5.2.2 Early – Middle Miocene

The upper limit is marked at 3027m based on the last down hole occurrence (LDO) of *Orbulina universa* and the lower limit is marked at 3374m based on the last down hole occurrence (LDO) of both *Orbulina saturalis* and *Praeorbulina glomerosa.*(Fig. 5.1). Other planktonic forms present include *Globigerinoides trilobus*, *Globigerinoides quadrilobatus* and *Globigerinoides sacculifer*.

5.2.3 Middle Miocene

The upper limit of the Middle Miocene is indeterminate in the sequence studied because of the absence of marker species, the lower limit, however, is marked at 3027m based on the last down hole occurrence (LDO) of *Orbulina universa* (Fig. 5.1). Other planktonic forms present here include *Praeorbulina sicana*, *Globigerina* sp. *Globigerina venezuelana*, *Globorotalia continuosa.*

5.3 Biozonation

Three zonehave been proposed in this study (based on the International stratigraphic guide of Hedberg (1976) and the observation of the ranges of planktonic foraminifera in Fig. 5.2) as follows: *Catapsydrax dissimilis* partial-range zone, *Praeorbulina glomerosa* interval zone and *Orbulina universa* taxon-range zone.

5.3.1 *Catapsydrax dissimilis* partial-range zone

Stratigraphic interval: 3648m – 3411m

The zone is defined by the First Down Hole Occurrence (FDO) of *Catapsydrax dissimilis* and *Globigerinoides* sp at the base and the Last Down Hole Occurrence (LDO) of *Praeorbulina glomerosa* at the top (Fig. 5.2). Other planktonic forms occurring within the zone are *Globigerinoides* sp., *Globigerinoides quadrilobatus, Planktic idet* sp., and *Globorotalia continuosa.* This zone is equivalent to N6 – N7 zone of Blow (1969). The extinction of *Catapsydrax dissimilis* marks the N6/N7 boundary of Blow (1969). *Catapsydrax dissimilis* is continuously present in the Early Miocene. The age of this zone is Early Miocene based on the presence of planktonic index forms (*Praeorbulina glomerosa, Praeorbulina sicana, Orbulina suturalis* and *Catapsydrax dissimilis*).

5.3.2 *Praeorbulina glomerosa* interval zone

Stratigraphic interval: 3411m – 3027m

The zone is defined by the LDO of *Praeorbulina glomerosa* at the base and the LDOs of*Praeorbulina sicana* and *Orbulina universa* at the top (Fig. 5.2).

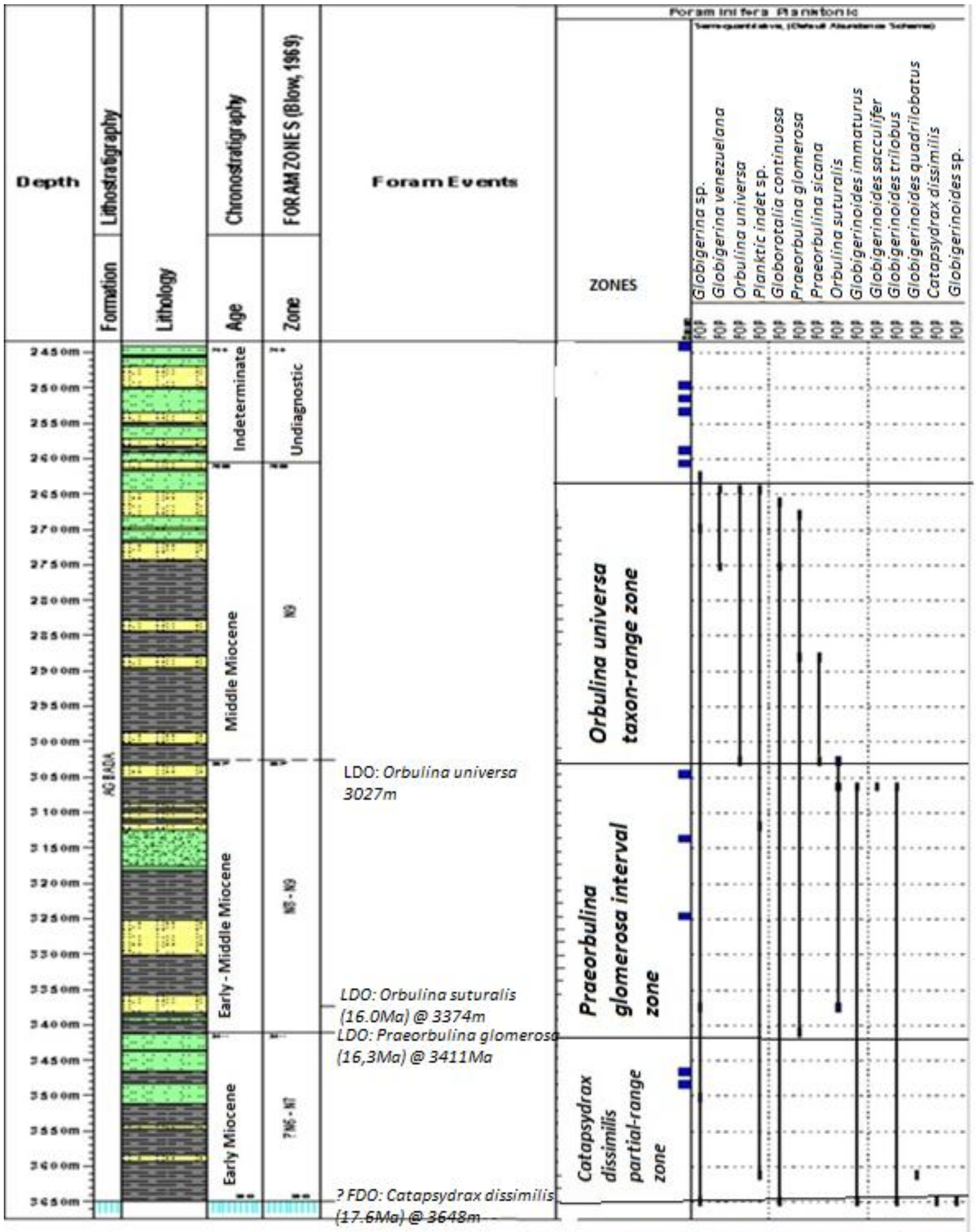


Figure 5.2: Range of Planktonic Foraminifera showing proposed Biozones for the studied well interval.

Other planktonic forms occurring in this zone are *Globigerinoides immaturus, Globigerinoides sacculifer,Globigerinoides trilobus* and *Orbulina suturalis.*

This zone is equivalent to the N8 –N9 zone of Blow (1969). The age of the zone is Early to Middle Miocene, based on the presence of planktonic index forms.

5.3.3 *Orbulina universa* taxon – range zone

Stratigraphic interval: 3027m – 2760m

This zone is defined by the entire occurrence of *Orbulina universa.* The base of the zone is marked by the LDO of *Orbulina universa,* and *Praeorbulina sicana,* while the top is marked by the FDO of *Orbulina universa, Globigerina venezuelana* and *Planktic indet* sp. (Fig. 5.2). Other planktonic forms occurring in the zone are *Globigerina* sp., *Globigerina venezuelana, Globorotalia continuosa, Praeorbulina glomerosa* and *Praeorbulina sicana.* The zone is equivalent to the N9 zone of Blow (1969). The age of the zone is Middle Miocene based on the presence of planktonic index forms.

The planktonic foraminiferal preservation in the upper intervals of the well is poor. Stratigraphically important taxa (planktonic index forms) were not identifiable,therefore the undiagnosed stratigraphic interval above the *Orbulina universa* taxon – range zone is assumed to be N9/N10 zone of Blow (1969), because of the stratigraphic position above the positively analyzed zone (*Orbulina universa* taxon – range zone). The age is also assumed to be Middle Miocene for the same reason.

5.4 Sequence Stratigraphy

Sequence stratigraphy is the study of rock relationships within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or non-deposition, or their correlative conformities (Van Wagoner *et al.*,1988). Sequence is a relatively conformable succession of genetically related strata bounded by unconformities and their correlative conformities. Sequences are the basic strata units used to construct a sequence-stratigraphic framework (Mitchum, 1977).

Sequences can be divided into system tracts which are a linkage of contemporaneous depositional systems. The term system tracts is used to designate three subdivisions within each sequence:

Lowstand Systems Tract (LST), Transgressive Systems Tract (TST), and Highstand Systems Tract (LST), exhibiting periods of transgression and regression(Brown and Fishers, 1980).

Sedimentary sections are subdivided by a variety of surfaces that envelope and enclose discrete geometric bodies of sediment. The commonest boundaries and surfaces used in this characterization are:

The Sequence Boundary (SB): is an unconformity formed during relative lowering of sea level, and during lowstand of sea level (Van Wagoner *et al.*, 1988). The Sequence Boundary may be marked by a decrease in both fossil abundance and diversity due to rapid accumulation of sediments or destruction of shell materials in shallow water, high energy environments associated with the erosional unconformity (Armentrout, 1991).

Transgressive Surface (TS) of a sequence: this is the first significant marine-flooding surface across the shelf within the sequence and separates older strata from younger strata across which there is evidence of an abrupt increase in paleowater depth (Van Wagoner *et al.,* 1988). This surface represents the landward stepping onlap of deposition related to relative sea level rise (Van Wagoner *et al.,* 1988). The Transgressive Surface Separates the Lowstand Systems Tract (LST) and Transgressive Systems Tract (TST), and is recognized by regionally correlative flooding surfaces above prograding coarse-grained sediments. Biofacies tend to be shallow below, and deepening above the Transgressive Surface (Armentrout, 1996).

Maximum Flooding Surface (MFS): This surface separates the Transgressive Systems Tract (TST) from the Highstand Systems Tract (HST), and represents the landward extent of marine conditions (Emery and Myers, 1997). This surface is often represented by significant increases in fossil abundance and diversity, by the deepest water biofacies of the transgressive – regressive cycle and also by the abundance of authigenic materials (Armentrout, 1987, 1991; Loutit *et al.,* 1988). Sequence stratigraphic analysis of the studied well-A based on foraminiferal biofacies and lithologic descriptions revealed five systems tracts (two TSTs, two HSTs and one LST), two MFS (proposed at 3388m and 3557m, dated 15.9Ma and 17.4Ma respectively) and two sequence boundaries proposed at 3301m (15.5Ma) and 3466m (16.7Ma), as a result, three depositional sequences were established from the well intervals. This also revealed that the well interval was exposed to two local depositional cycles (cycle 6 and 7), two regional cycles (cycles 2.2 and 2.3) within the TB2 super cycles as illustrated in Haq *et al.* (1988) chronostratigraphic chart (Fig. 5.3).

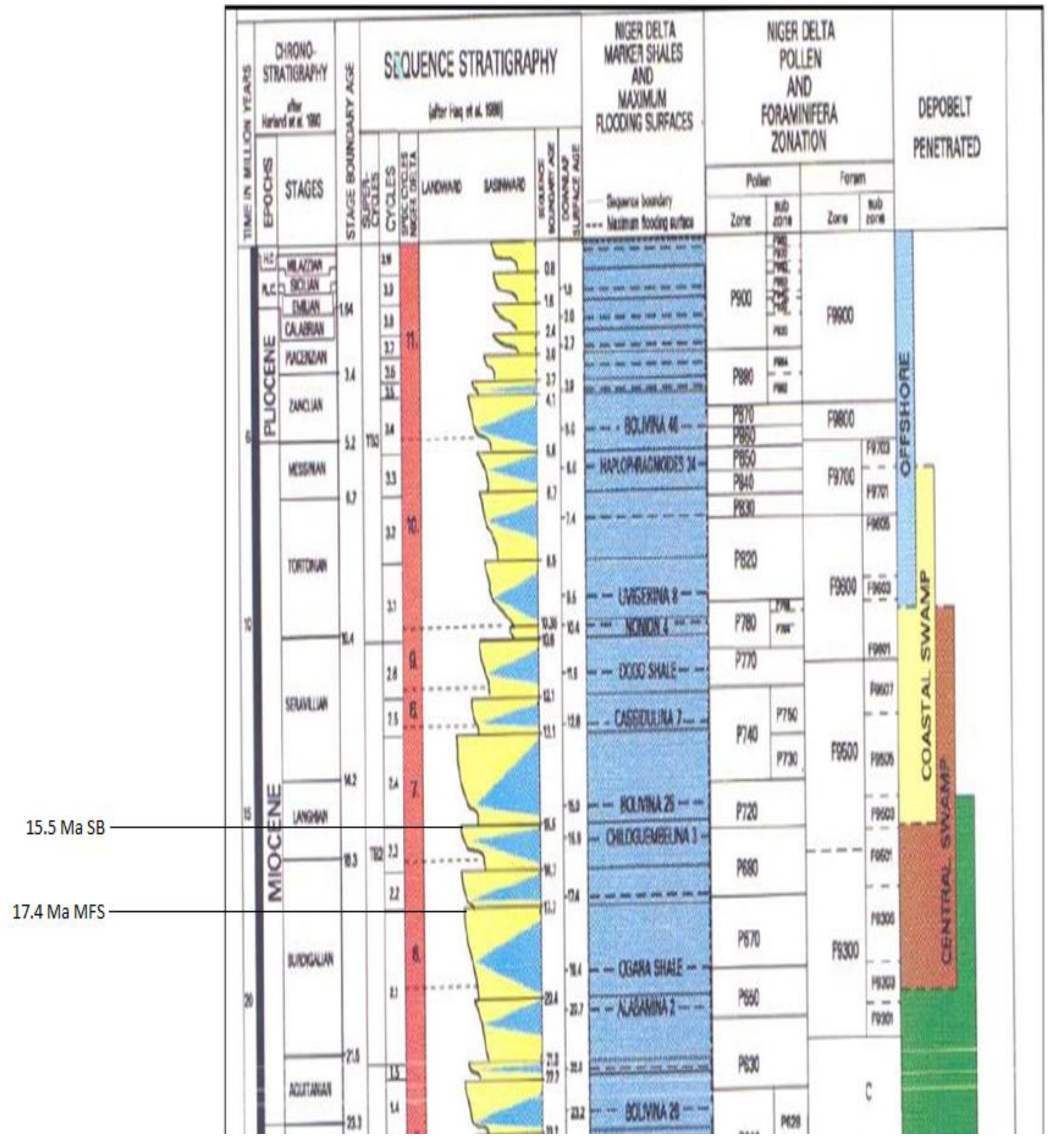


Figure 5.3: Haq *et al.* (1988) chronostratigraphic chart showing SB and MFS, as well as the Sedimentary Cycles for studied well interval

The sequence stratigraphic analysis also employed similar approaches by Armentrout (1987), Armentrout and Clement (1990), Pacht *et al*. (1990), and Vail and Wornardt (1990), Armentrout *et al*. (1990), Armentrout (1996),Armentout *et al*. (1999). These authors used microfossil abundance and diversity pattern to locate flooding surfaces and sequence boundaries as follows:

a. The introduction of diverse forms and increase in planktonic forms suggest transgressions.
b. The reduction in abundance and diversity of foraminifera as well as the increase in benthonic forms suggest regressions.

5.4.1 Sequences of the study well

5.4.1.1 Transgressive systems tract (TST)

This system tract develops as a result of an increase in the rate of sea-level rise which has an overall deepening upward bathymetric signature (Posamentier and Vail, 1988). It is a period of increasing rate of relative sea level that is characterized by an overall fining upward sequence,the TST is composed of retrogradational parasequence sets, in a vertical succession, the biofacies pass upward from terrestrial through brackish to shallow marine and finally deep marine assemblages(Armentrout, 1987).

The TST in the well at an interval of 3648m - 3566m is defined based on its fining upward sequence, and marked at the top by MFS at 3557m with increased number of faunal assemblage (from 1 -7).The lower section of this interval is predominantly shale, the mid-section shows sandstone and shale intercalation, while a predominance of shale caps the top section of the interval (Fig. 5.4).

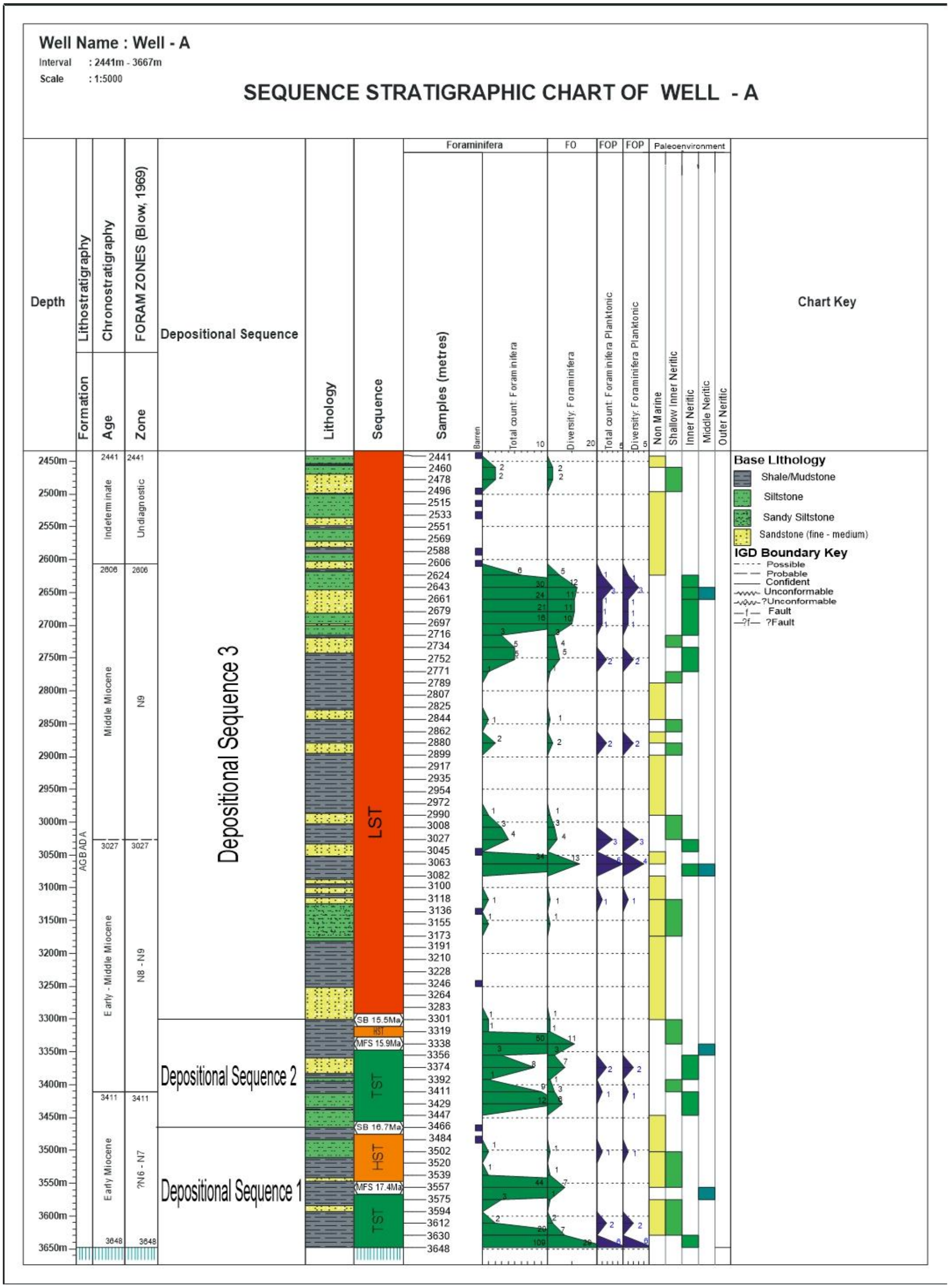


Figure 5.4: Sequence stratigraphy Chart showing Depositional Sequence and Systems Tracts of the studied well

At an interval of 3457m - 3347m, the renewed TST in this interval is characterized by intercalation of shale and siltstone in the lower section, and siltstone, shale and sandstone in the upper section, with the shale percentage increasing towards the top of the section reflecting an overall fining upward sequence. Also reflected here is the increasing faunal diversity that culminates at the MFS at 3338m.

5.4.1.2 Highstand systems tract (HST)

During this stage, the sea-level rise decreases and they are characterized by initially aggradational deep sea shale that grade into intervals of shallowing upwards. This system tract is first defined at an interval of 3548m - 3475m, (Fig. 5.4) based on the presence of the MFS (at 3557m) below the HST and the SB (at 3466m) marking the top of the interval. This progradational sequence is characterized by shale, silt and sand lithofacies, with gradual decrease in the percentage occurrence of shale. This suggest an overall coarsening (shallowing upward) sequence. The biostratigraphic data reveal the relative appearance and diversity of slope benthonic forms (shallow inner neritic formse.g. *Ammobaculites* sp., *Valvullineria gasparensis and Globigerina* sp.). This is consistent with the views of Armentrout (1987).

Also at an interval of 3329m - 3310m, (Fig. 5.4) this short lived regression is characterized by shale deposited in the shallow inner neritics at its base on the MFS at 3338m and marked at the top by the SB at 3301m.

5.4.1.3 Lowstand systems tract (LST)

The LST is a period defined by very low rate of relative sea level rise or standstill and comprising progradational to aggradational parasequence sets. It was deposited during intervals characterized by relative sea level fall followed by subsequent low relative sea level rise (Posamentier and Vail, 1988). LST comprises two main components; the lowstand fan and the lowstand wedge (Emery and Myers, 1997).

The LST in well-A is defined at an interval of 3292m - 2441m (Fig. 5.4), This interval shows interbedding of shale and sandstone at the lower section, and siltstone, shale and sandstone interbedded at the top, though the siltstone and shale beds thin upwards while the sandstone becomes relatively thick. The upper part of the LST is no longer erosional as the sea-level starts to rise (2771m – 2624m), the geometry starts becoming aggradational and moving seawards, thenit becomes stationary, this shows reworked foraminifera assemblages when compared to adjacent shale, it also exhibits a coarsening upward sequence, suggesting incised valley fill deposits.

There is decrease in foraminiferal abundance from about eight to zero (barren) at 2606m – 2496m interval suggesting a Lowstand Prograding Wedge (LPW). The biofacies associated with the lowstand wedge usually show a shallowing from inner neritic to non-marine environments, each prograding complex is characterized by a regular alternation of thin sandstone and shale bands (incised valley fills deposits) in which the sandstone become relatively thicker and respectively more prominent up section(Emery and Myers, 1997).

5.4.2 Associated key surfaces

The Maximum Flooding Surfaces and sequence boundaries derived from foraminiferal peaks, abundance and diversities is identified basically on the inflection from overall progradation to overall retrogradation of parasequences. The relative thickness of the systems tracts reveal changes in sediment accumulation rate as a result of varying local conditions which may include the effect of gravity, tectonics, availability of accommodation space, and eustatic sea level changes.

5.4.2.1 Maximum flooding surface (MFS)

Stratigraphic interval: at 3388m (15.9Ma) and 3557m (17.4Ma)

These are the periods between maximum relative sea level rise and maximum relative sea level characterized by abundant and diverse fauna (especially benthonic foraminiferal assemblages). The dates of the MFS have been correlated to the Haq *et al.* (1988) chronostratigraphic chart (Fig. 5.3).The ages are dated because of their stratigraphic positions above the positively identified TSTs.

5.4.2.2 Sequence boundaries

Stratigraphic interval: at 3301m (15.5Ma) and 3466m (16.7Ma)

Identified basically on the inflection from overall progradation to overall retrogradation of parasequences in the shallowing sand units. The relative thickness of the systems tracts suggest changes in sediment accumulation rate as a result of varying local conditions which may include the effect of gravity, tectonics, availability of accommodation space, and eustatic sea level changes. This period is characterized by biostratigraphic gaps suggesting periods of non-preservation of fossils, as seen in SB of 16.7Ma (Fig. 5.4). The dates of the SB have been correlated to Haq *et al.* (1988) chronostratigraphic chart (Fig. 5.3). The ages have been dated based on their stratigraphic positions above the positively identified HSTs.

5.4.3 Depositional sequence

Generally, a depositional sequence consists of LST, TST and HST. It is a stratigraphic unit composed of a relatively conformable succession of genetically related strata bounded at its top and base by unconformities or their correlative conformities, known as sequence boundaries (Reijers, 1996). On the above premise, two depositional sequence and one incomplete depositional sequence was recognized in the penetrated interval of well-A with their environment of deposition ranging from Non marine to Middle neritic (Fig. 5.4).

5.4.3.1 Depositional sequence 1

This sequence is topped with the 16.7Ma sequence boundary, though the base was not penetrated. The TST in this interval is capped by the 17.4Ma MFS.

5.4.3.2 Depositional sequence 2

This sequence starts with the 16.7Ma sequence boundary at the base and ends with the 15.5Ma sequence boundary at the top. It is made up of TST and HST, characterized by progradational, retrogradational and aggradational parasequence sets. The TST is capped by the 15.9Ma MFS.

5.4.3.3 Depositional sequence 3

An incomplete depositional sequence that starts with the 15.5Ma sequence boundary and consist of only the LST containing reworked foraminifera assemblages.

5.4.4 Sedimentary cycle interpretation

A sedimentary cycle represents a direct link between geological concept, sedimentary process and the formation of stratigraphic sequences. The study of cyclic depositional patterns in the geologic record produced by climatic and tectonic process called Cyclostratigraphy consists of series of stacked coarsening upward or fining upward sequences representing regressive or transgressive events within a basin. The causes of this can be attributed to eustatic sea level, orbital climatic or tectonic effects, time span, volume of supplied sediments and accommodation space, which affect sedimentary sequences and sedimentary cycle. Therefore, a relationship exists between sedimentary cycle concept and sequence stratigraphy. Eleven discrete cycles represented by figures in ascending order had been erected in Niger Delta and they are defined by shale markers which are assigned definite ages. Using the ages of the two MFS correlated to Haq *et al.* (1988) chronostratigraphic chart:

a. MFS at 3388m (15.9Ma) corresponds to the TB2 super cycle, 2.3 Regional cycle and cycle 7 of the SPDC cycle for Niger Delta (Local cycle). These cycles are correlated to Middle Miocene.
b. MFS at 3557m (17.4Ma) corresponds to the TB2 super cycle, 2.2 Regional cycle and cycle 6 of the SPDC cycle for Niger Delta (Local cycle). These cycles are correlated to Early to Middle Miocene.

This reveals that the studied well interval went through two cycles of deposition:
Early to Middle Miocene (Cycle 6), and Middle Miocene (Cycle 7).

5.5 Paleoenvironment

The paleodepositional environments of the studied well was interpreted based on the biofacies information obtained from the evaluation of the benthonic foraminiferal assemblages. This has been integrated with the lithologic description of the well and the planktonic/benthonic foraminifera ratio. It is on these bases, that the sequences of the wells are interpreted to have fluctuated from non-marine to coastal deltaic to marine (i.e. non-marine to shallow inner neritic, to inner neritic to middle neritic).

Foraminiferal data (benthonic foraminifera) was most useful in paleobathymetric estimation, this involved utilizing relative abundance and diversity of encountered benthonic foraminifera (Boersma, 1978). Benthonic foraminifera have evolved to exist in a range of environments, from marginal marine to deep ocean. In deep water environments, the physical properties of the stratified water masses, such as nutrients, oxygen, salinity and temperature, control benthonic distribution, whereas in shelf seas, current energy, substrate type, salinity, temperature and photic intensity are important. There is therefore a general relationship between benthonic organisms and water depth.Furthermore, the percentage ratio of calcareous benthonic to arenaceous benthonic foraminifera (FOBC/FOBA ratio) provides useful paleoenvironmental guide, the higher the percentage FOBC ratio, the shallower the paleodepths, conversely, the higher the percentage FOBA, the deeper the paleodepths (Boersma, 1978).

The ratio of planktonic to benthonic foraminifera (P/B ratio) also provides useful paleoenvironmental guide, the higher the percentages of planktonic foraminifera, the deeper the paleodepth of deposition (Bandy, 1964; Funnel, 1967; Boersma, 1978; Brasier, 1979).

The ratios between Textulariina, Miliolina and Rotaliina plotted in a foraminiferal shell-type ratio (morphogroup) triangular cross-plot and foraminiferal abundance/diversity enabled the discrimination of a range of paleosalinity of deposition (Murray, 1971, 1973; Murray and Wright, 1974). Planktonic foraminifera are depth-stratified because they are very sensitive to certain environmental factors such as salinity, turbidity, temperature, etc. (Bandy, 1964;Brasier, 1979). Thus, their thanatocoenoses (death assemblages) have higher diversity in deeper marine environment than in shallower water environment.

Boersma (1978) outlined the following criteria for paleoenvironmental analysis:

a. The marshes and lagoon environments are characterized by lower numbers or absence of calcareous genera in relation to the population of the agglutinated/arenaceous forms.
b. The shallow shelf is characterized by a numerically small fauna dominated by a few species, very few of which are agglutinated/arenaceous and none of which are pelagic. The agglutinated/arenaceous tests have simple interior.
c. The inner shelf is characterized by coarse-grained, clear, well sorted sands containing abundant rounded shell fragments. The fauna are usually highly dominated by a few species. Tests are small and not strongly ornamented. A few pelagic species, usually of the genus *Globigerina* may be present.
d. The deeper inner neritic/shelf contains fine - medium grained sand, silt, clay, with common glauconite and micro-mollusc and echinoid remains. Pelagic types are more numerous and the agglutinated/arenaceous foraminifera increase in abundance, but still have simple interior.
e. The middle neritic/shelf are composed of clay, silt, poorly sorted sands and abundant glauconite. The species are often highly ornamented, large and robust. The pelagic planktonic foraminifera make up 15-30% of the micro-fauna populations. The arenaceous forms have more complex interior structures.

f. The outer neritic/shelf is characterized by fine-grained sediments such as clay and some glauconite. Species number is high and ornamentation is strong. The planktonics constitute approximately 50% of the faunas.

g. The upper continental slope/bathyal strongly resembles the outer neritic. Smooth slope to submarine canyons are common with varying amounts of allogenic or transported materials. The planktonic foraminiferas populations range from 50-85% of the fauna.

h. The lower slope/bathyal is like the abyssal plain in its fine-grained calcareous marls and clays. The number of benthic species is large on the abyssal plain. Though there is a dilution effect from dead planktonic tests. The planktonic foraminifera range 75-90% of the micro-fauna. The agglutinated forms have very complex labyrinth interior structures.

Benthonic foraminifera of the Niger Delta contain paleobathymetric indicators of varying environments of sediment deposition from coastal to bathyal depths (Okosun, 2003). The indicator foraminiferal assemblages and individual specimens (Bandy, 1964; Stehli and Creath, 1964; Funnel, 1967; Kafesioglu, 1971; Murray, 1971, 1973; Boersma, 1978; Brasier, 1979; Morkhoven *et al.*, 1986; Okosun, 2003) were used to characterize the paleobathymetric environments. Parts of the well's interval show occurrence of early Miocene forms characteristic of deep water arenaceous benthonics such as *Ammobaculites* sp. *Spiroplectammina* sp. *Haplophragmoides* sp.amongst others which are probably products of deep water canyon fills in the Middle Miocene, consistent with the views of Petters (1982).

5.5.1 Paleobathymetry

Foraminifera data was most useful in the estimation of paleobathymetry, it involved the use of relative abundance and diversity of the foraminifera encountered as well as the occurrence of environmentally significant taxa.It is on these bases that the sediments of the well were interpreted to have fluctuated from non-marine to middle neritic as follows:

a. Middle Neritic Environment
b. Inner Neritic Environment
c. Shallow Inner Neritic Environment
d. Non marine Environment

The well interval possessed characteristics that are exhibited by the above environments

5.5.1.1 Non marine environment

The intervals ranges from 3502m - 3447m, 3301m - 3173m, 3118m - 3082m, 3063m - 3045m, 2990m - 2899m, 2880m - 2862m, 2844m - 2789m, 2624m - 2496m and 2461m - 2441m (Fig. 5.5). This inference is based on the following reasons:

1. The intervals are characterized by fine to medium through coarse grained sandstone (smoky white to orange, sub-angular to sub-rounded, well-sorted and occasionally ferruginized), siltstone (white, fine-grained, micromicaceous and carbonaceous plus traces of woody materials) and shale (brown to grey, fissile, moderately hard, micromicaceous and occasionally carbonaceous). The presence of coarse sandstone, ferruginousmaterials and carbonaceous detritus in these intervals suggests deposition inhigh energy, occasional oxidized conditions, probably near-shore settings, The presence of woody fragments suggest a landlocked body of watersystem typical of non-marine swamp environments. This

condition is evidentShallow marine and brackishenvironments reflects a marine transgression (Oboh-Ikuenobe *et al*., 2005).

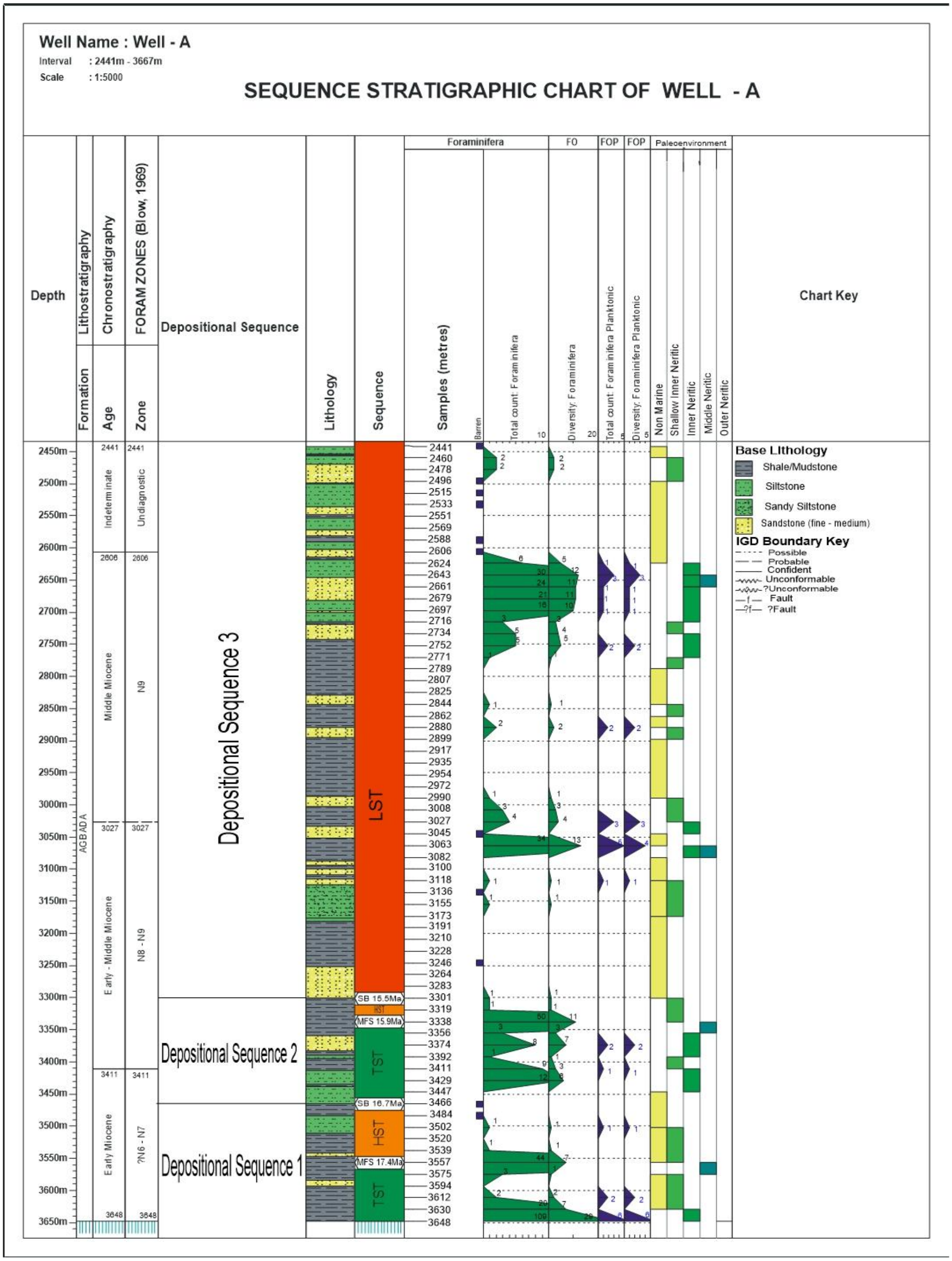


Figure 5.5: Sequence Stratigraphy Chart showing Paleoenvironment of Deposition of studied well.

2. The intervals are completely barren of foraminifera. The complete absence of fauna in this interval suggest a littoral (shore or coastal) settings.

5.5.1.2 Shallow inner neritic environment

The intervals inferred to be shallow inner neritic environment ranges from 3411m - 3392m, 3338m - 3301m, 3027m - 2990m, 2899m - 2880m, 2862m - 2844m, 2789m - 2771m, 2734m - 2716, and 2496m - 2460m (Fig. 5.5).

This inference is based on the following reasons:

1. The intervals are predominantly characterized by fine to medium grained sand (smoky white to orange, sub-angular to sub-rounded, well-sorted and occasionally ferruginized), suggesting deposition during progradational phase, and thin shale beds (brown to grey, fissile, moderately hard, micromicaceous and occasionally carbonaceous). The presence of coarse sandstone, ferruginous materials and carbonaceous detritus in these intervals indicates deposition in high energy, probably near-shore settings
2. The intervals contain very few benthonic and planktonic foraminifera eg. *Ammobaculites* sp.,*Valvullineria gasparensis and Globigerina* sp.Species dominance is low and the number of species (diversity) is high. The planktonic types constitute from 15-30% of the total fauna, (Boersma, 1978).

5.5.1.3 Inner neritic environment:

The intervals inferred to be inner neritic environment ranges from 3648m - 3630m, 3447m -3411m, 3392m -3356m, 3045m - 3027m, 2771m - 2734m, 2716m - 2661m, and 2643m - 2624m (Fig. 5.5).This inference is based on the following criteria:

1. The micro fauna found here suggest inner neritic environmental settings with middle neritic influence, these include: *Quinqueloculina* sp. *Lenticulina grandis, Uvigerina* sp. *Miogypsinoides* sp. *Cubicubis inflata, Briziana mandoreveensis, Spiroplectammina wrightii, Uvigerina isidroensis and Uvigerina sparsicostata*. The diversity range from 0-9 species.
2. The lithology of the intervals is composed of medium to coarse grained sand (smoky white to orange, sub-angular to sub-rounded, well-sorted and occasionally ferruginized), siltstone (white, fine-grained, micromicaceous and carbonaceous plus traces of woody materials) and shale (brown to grey, fissile, moderately hard, micromicaceous and occasionally carbonaceous).

5.5.1.4 Inner to middle neritic environment

Depth intervals of the studied well that are inferred to this environment are from 3082m-3063m, and 2661m - 2643m (Fig. 5.5).

The criteria for this inference are based on the following:

1. The occurrence of the typical forms from inner and middle neritic environments, including: *Uvigerina* sp. *Heterolepa floridana, Valvulineria gasparensis, Cibicorbis inflata, Orbulina suturalis, Hanzawaia stratonii, Globigerinoides immaturus, Globigerinoides sacculifer, Globigerinoides trilobus, Hanzawaia concentrica, Hopkinsina bononiensis and Spiroplectammina wrightii.*There is an increase in the population of the planktonics and increase in species diversity (ranging from 0-20 species).
2. The lithology is composed of sand (smoky white to orange, sub-angular to sub-rounded, well-sorted and occasionally ferruginized), siltstone (white, fine-grained, micromicaceous and carbonaceous plus traces of woody materials) and shale (brown to grey, fissile, moderately hard, micromicaceous and occasionally carbonaceous).

According to Okosun *et al.*(2012), the inner to middle neritic environment is characterized by the occurrence of the typical forms from inner, middle and outer neritic environments like *Uvigerina* sp, *Spiroplectamina wrightii*, and *Hanzawaia strattoni*,

5.5.1.5 Middle neritic environment

This environment is marked at the following intervals 3575m - 3557m, and 3356m - 3338m (Fig. 5.5), based on the following characteristics:

1. The presence of indicator fauna like: *Lenticulina inornata, Heterolepa pseudoungeriana, Lenticulina grandis, Uvigerina isidroensis, Brizalina mandoroveensis, Valvullineria gasparensis, Globigerina* sp., *Globigerina*

venezuelana, Orbulina universa, Globorotalia continuosa, Panktic indet sp. *and Praeorbulina glomerosa.*Increase in the number of planktonic specimens. The average planktonic/benthonic ratio is high, the simple species diversity also increased, ranging from 0-23 species.

2. The lithology is composed of siltstone (white, fine-grained, micromicaceous and carbonaceous plus traces of woody materials) and shale (brown to grey, fissile, moderately hard, micromicaceous and occasionally carbonaceous).

This environment is recognized by the presence of indicator fauna like, *Lenticulina inornata,*and *Heterolepa pseudougerina.* Increase in the number of planktonic specimens. The average planktonic/benthonic ratio is high, the sample species diversity is also increased and the lithology of the middle neritic environment is composed of shale and silt (Okosun *et al.*, 2012).

The occurrence of shell fragments, ostracods, gastropods, along with the occurence of *Textularina* sp.suggest a shallow marine origin, the presence of *Textularina laminata* (Cushman), *Textularina panamensis* (Cushman), and *Ammobaculites* sp. suggest inner shelf environment of deposition (Nton and Esan, 2010).

Based on the paleoenvironmental interpretation provided above, it can be inferred that the paleobathymetry of the study well ranges from shallow to inner shelf environment.

5.5.2 Paleosalinity

Foraminifera live in all marine environments from the deepest ocean floor to the intertidal salt marshes found behind barrier islands or around the margins of estuaries.

Paleoesalinity interpretations for the studied well was made based on Shell-type (morphogroup) ratio triangular plot (Fig. 5.6, Appendix D). The proportion of the three shell type (agglutinated, hyaline and porcelaneous) of foraminifera in a sample can be used to characterize a particular environment in seas and oceans.

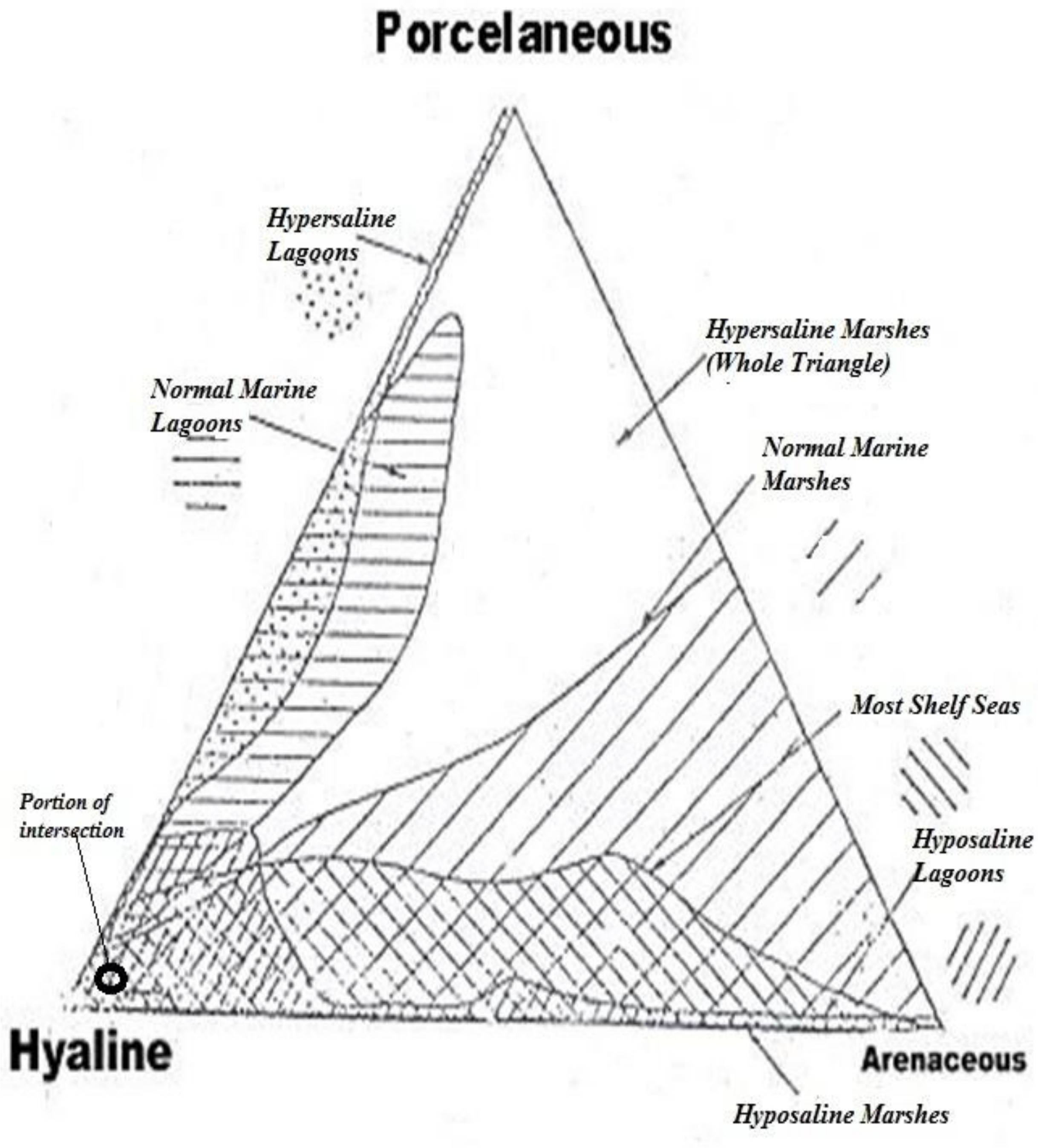


Figure 5.6: Triangular plot of shell-type ratio, showing portion of intersection as normal marine shelf sea environment

The triangular plot above reveals the dominance of the hyaline calcareous shell type suggesting a normal marine shelf sea environment. Comparison with modern micro fauna suggest a normal marine neritic environment (Murray, 1973, 1991).

The dominance of the calcareous benthonics (FOBC) with over 60% of total forms present (Appendix- E) suggest an open marine condition (Nagy *et al*, 1988).

According to Murray (1991) and Sen Gupta (1999), the high diversity and dominance of calcareous taxa suggest transition from brackish marginal marine habitats to open neritic conditions.

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 Summary

This study was carried out on ditch cutting samples from well – Adrilled by the Shell Petroleum Development Company (SPDC) in the central Niger Delta region of Nigeria.sssThe studied depth interval ranges from 2441m – 3650m.

The lithology of well is composed of grey shale and siltstone beds with intercalation of sand/sandstone beds, revealing seven lithostratigraphic units characteristic of the Agbada Formation in the Niger delta.

Foraminiferal biostratigraphic characteristics of the well was analyzed. Based on the foraminifera content of the studied well interval and following the international stratigraphic guide (Hedberg, 1976), three planktonic foraminiferal zones equivalent to the N6–N7, N8 –N9 and N9 zones of Blow, (1969) was proposed for the well, as follows: *Catapsydrax dissimilis* Partial-range zone, *Praeorbulina glomerosa* Interval zone, and *Orbulina universa* Taxon – range zone respectively. The Maximum Flooding Surfaces and sequence boundaries derived from foraminiferal peaks, abundance and diversities together enabled the subdivision of the well into sequences and systems tracts. HST, TST and LST are the recognized systems tracts in the well,the relative thickness of the systems tracts reveal changes in sediment accumulation rate as a result of varying local conditions which may include the effect of gravity, tectonics, availability of accommodation space, and eustatic sea level changes.

The observed foramniferal assemblages especially the benthonics together with other associated microfauna indicate that the sediments of the well were deposited in a range of environment viz: non-marine to inner neritic, inner to middle neritic, middle neritic environments.

Based on foraminiferal and lithostratigraphic analyses, it is inferred that the intervals penetrated by the well correspond to Agbada Formation, and also dated as Miocene. The alternation of sandstone and shales/mudstones within the sequence provides the combination of source, reservoir and cap rocks essential for hydrocarbon generation, accumulation and trapping.

6.2 Conclusion

Based on lithologic and foraminiferal analysis, this study has established that the well interval penetrated the Agbada Formation with deposition occurring during the Miocene (Early and Middle Miocene), similar to the findings of Okosun *et al* (2012) and Chukwu *et al.* (2012).

Five systems tracts, two Maximum Flooding Surfaces and two Sequence Boundaries were recognized, along with the establishment of three depositional sequences in the well interval. Depositional environments and paleobathymetric interpretations from the well revealed a transitional to deep shelf depositional settings (shallow to inner shelf.).

6.3 Recommendation

It is hoped that the three biozones proposed in this study will contribute to the findings of the stratigraphic committee of the Niger Delta (STRATCOM), to produce a generally acceptable delta-wide biostratigraphic frame work. The *Praeorbulina glomerosa* zone in this work correlates to N8-N9 of Blow (1969) and can be found in the works of Okosun *et al* (2012) on the Akata field, Niger Delta, as well as in the works of Chukwu *et al* (2012) on Oloibiri-1 well, eastern Niger Delta.

Further studies of data sets from adjoining wells in the region will help in proper correlation of the zones, boundaries and depositional environments in the study area.

REFERENCES

Adegoke, O.S., Dessauvagie, T.F.J., and Kogbe, C.A., (1971). Planktonic Foraminifera in the Gulf of Guinea sediments. *Micropaleontology*. **17**: 197-213

Adeniran, B.V., (1997). Quantitative Neogene planktic foraminiferal biostratigraphy of Western Niger Delta, Nigeria. *Nigerian Association of Petroleum Explorationists Bulletin*. **12**: (10) 54-59

Agagu, O.K (1981): Effect of overpressure in petroleum accumulation in the Niger subsurface. *American Association of Petroleum Geologists Bulletin*, **70**: 50-75.

Allen, J.R.L. (1965), Late Quaternary Niger Delta, and adjacent areas-sedimentary environments and lithofacies: *American Association of Petroleum Geologists Bulletin*, **49**: 547-600.

Asano, K., (1944). Hanzawaia a new genus of foraminifera from the Pliocene of Japan. Geological Society, Japan Journal. **51** (606): 97 – 98

Armentrout, J. M. (1987). Integration of biostratigraphy and seismic stratigraphy: Pliocene-Pleistocene, Gulf of Mexico. In: *Gulf Coast Section, Society of Economic Paleontologist and Mineralogists*. Eighth Annual Research Conference: 1 -6

Armentout, J.M. and Clement, J.F., (1990). Biostratigraphic correlation of depositional cycles: A case study in High Island-Galveston-East break areas, offshore Texas. In: *Gulf coast section, Society of economic paleontoloist and mineralogists*, Eleventh annual research conference, Huston: 21-51

Armentrout, J.M., (1996). High Resolution Sequence Biostratigraphy: Example from the Gulf of Mexico, Plio -Pleistocene. In: Howel, J.A., and Aitken, J.F., (eds.) High resolution sequence stratigraphy: Innovations and Applications. *Geological society special publication*: 65-86

Armentrout, J.M., Echols, R.H and Lee, T.D. (1990). Patterns of foraminiferal abundance and diversity: implications of sequence stratigraphic analysis. In: Armentrout, J.M. and Perkins, B.F (eds) *Sequence Stratigraphy as an Exploration Tool: concepts and practices in the gulf coast*. Gulf coast section SEMP foundation eleventh annual research conference program and abstracts: 53 - 58

Armentrout, J.M., Feam, B., Rodgers, K., Root, S., Lyle, W.D., Hedrick, D.C., Bloch, R.B., Snedden, J.W. and Nwankwo, B. (1999). High resolution sequence biostratigraphy of a lowstand prograding deltaic wedge: Oso field (Late Miocene), Nigeria. In: Jones, R.W., and Simmons, M.D., (eds.) Biostratigraphy in production and development geology. *Geological society, London, Special Bulletin*. **152**: 259-290

Arun D. S., And Verma, K.(2014).Miocene Planktic Foraminifera from the Northern Indian Ocean. *Special Publication of the Paleontological Society of India*. **5** 199 - 212

Asseez, L.O (1976): Review of stratigraphic sedimentation and structure of the Niger DeltaIn Kogbe, C.A., (ed.) Geology of Nigeria Rock in View: 311-324.

Avbovbo, A.A (1978): Tertiary lithostratigraphy of Niger delta. *American Association of Petroleum Geologists Bulletin*. **62** (2): 295-300.

Bassey, C.E. and Ojesina, O.A. (1998) Sequence stratigraphic interpretation of E – Block in western offshore Niger Delta, Nigeria. *Global Journal of Pure and Applied Sciences*.**5**: 227 - 233

Bandy, O.L., (1964). General correlation of foraminiferal structure with environment, in: Imbrie, J. and Newell, N. D. (eds.), *Approaches to paleoecology*, John Wiley, New York: 75–90.

Bandy O.L. and Arnal R. E., (1957). Distribution of Recent Foraminifera off the West Coast of Central *America. American Association of Petroleum Geologists Bulletin*, **41**: 2037 – 2052.

Bandy O.L. and Arnal R. E., (1960). Concept in Foraminiferal Biostratigraphy. *American Association of Petroleum Geologists Bulletin*, **44**: 1921 – 1932.

Bermúdez P. J., (1952). Estudio sistemático de los foraminiferos rotaliformis. *Boletín de Geología*(Caracas), **2**: 1-230.

Blow, W. H. (1969). Late Middle Eocene to Recent Planktonic Foraminiferal Biostratigraphy. Proc. First International Conf. Planktonic Microfossils: 199–422.

Boboye, E.A. and Adeleye, A.M. (2009). High resolution biostratigraphy of Early Pliocene to Late Miocene calcareous Nannoplankton and foraminifera, deep offshore, Niger Delta, Nigeria.*European Journal of Scientific Research*, **34**: 308 - 325

Boersma, A., (1978). Foraminifera, Introduction to Marine Micropaleontology, B. U. Haq and A. Boersma, (eds). Elsevier North Holland Inc.: 50- 69.

Bolli, H. M., and J. B. Saunders, (1985). Oligocene to Holocene low latitude planktic foraminifera, in H. M. Bolli, J. B. Saunders and K. Perch-Nielsen, (eds)., *Plankton stratigraphy*. New York, Cambridge University Press, **1**: 155-257.

Brasier, M. D., (1979). Microfossils. Univ. Hull Press, Kingston-upon-Hull, UK: 193

Brown, L.F. and Fisher, W.L. (1980). Principles of seismic stratigraphic interpretation, *American Association of Petroleum Geologists* continuing education course note series, No. 16

Bronnimann, P. (1953). Arenaceous foraminifera from the Oligocene-Miocene of Trinidad. *Cushman Foundation Foraminifera Research*. **4**: 87 - 100

Brunnich, M.T., (1772). Zoologiae fundamenta. Grunde I Dyreloeren (Hafniae et Lipsiae), 253

Bustin, R. M., 1988, Sedimentology and characteristics of dispersed organic matter in Tertiary Niger delta: Origin of source rocks in a deltaic environment: *American Association of Petroleum Geologists Bulletin*, **72**: 277-298.

Carpenter, W.P., Parker, W.K., and Jones, T.R., (1862). Introduction to the study of the Foraminifera.The Ray Society by R. Hardwicke in London: 1–319.

Chengjie L., James V. B., Kenneth G. M., and Richard K. O., (1997). Paleocene Benthic Foraminiferal Biofacies and Sequence Stratigraphy,Island Beach Borehole, New Jersey, in: Miller, K.G., and Snyder, S.W. (Eds.), Proceedings of the Ocean Drilling Program, *Scientific Results*. 150: 267

Chukwu, J.N., Okosun, E.A., and Alkali, Y.B. (2012). Foraminiferal Biostratigraphy and Depositional Environment of Oloibiri-1 Well, Eastern Niger Delta, *Nigeria Journal of Geography and Geology*; **4** (4): 114 - 122

Cifelli, R., (1990). Part I. Foraminiferal classification from d'Orbigny to Galloway. In: Cifelli, R. (Ed.), A History of the Classification of Foraminifera (1826–1933): Cushman Foundation for Foraminiferal Research, Special Publication, **27**: 1–88.

Connors, C. D., Denson, D. B., Kristiansen, G. and Angstadt, D. M. (1998). Compressive anticlines of the mid-outer slope, central Niger Delta (abs.): *American Association Petroleum Geologist Bulletin*. **82**: 1903.

Corredor, F., John, H.S., and Frank, B., (2005). Structural Styles in the deep-water fold and thrust belts of the Niger Delta: *American Association of Petroleum Geologists Bulletin*, **89** (6): 753 – 780

Costa, O.G., (1856). Paleontologia del regnodi Napoli. *Atti. Accad. Pont.*,**7** (2): 113 - 378

Culver, S.J. 1988. New foraminiferal depth zonation of the Northwestern Gulf of Mexico. Palaios, **3**: 69-86.

Cushman, J.A., (1918). Foraminifera of the Atlantic Ocean. Part 1. Astrohizidae. *USA National Museum Bulletin.* **104**: 1 -39.

Cushman, J.A. (1926). Some fossils Bolivinas from Mexico. *Cushman laboratory for foraminiferal Research, Contribution.* **1**: 81 - 85

Cushman, J.A., (1927). Some Characteristic Mexican Fossils Foraminifera. *Journal of paleontology*, **1**: 147 - 172

Cushman, J.A., and Laiming, B. (1931). Miocene foraminifera from Los Sauce Creek, Ventura County, California. *Journal of Paleontology*. **5** (2): 79 - 120

Cushman, J.A. and Renz, H.H. (1941). New Oligocene Miocene foraminifera from Venezuela. *Cushman laboratory for foraminiferal Research, Contribution.* **17**: 1 - 27

Cushman, J.A., and Stainforth, R.M., (1945). The Foraminifera of the Cipero Marl Formation of Trinidad, British West Indies. *Cushman laboratory for foraminiferal Research, Contribution.* **14**: 3 - 75

d'Orbigny, A.D., (1826). Tableau methodique de la classe des Céphalopodes. *Annales des Sciences Naturelles* **7**: 245–314.

Damuth, J. E., (1994) Neogene gravity tectonics and depositional processes on the deep Niger Delta continental margin: Marine and Petroleum Geology, **11**: 320– 346.

De Klasz, I., and Rerat, D., (1961). Quelques nouveaux foraminiferes du Cretace et du Tertiaire du Gabon (Afrique equitoriale). *Rev Micropal*., **4** (4): 175 – 189.

Delage, Y. and Herouard, E., (1896). Traite de Zoologie concrete. Tome I la cellule et les Protozoaires. Paris. 584

De Montfort P. D., (1808). Conchyliologie systématique et classification méthodique des coquilles, t. 1.Paris, France, F. de Schoell ed.: 1-410.

Doust, H. and Omatsola, E., (1990). Niger Delta, in Edwards, J.D and Santogrossi, P.A. (eds), Divergent/passive margin basins, *American Association of Petroleum Geologists Memoir***48**: 201-239.

Durand, J., (1995). High resolution sequence stratigraphy (genetic-stratigraphy) in reservoir sedimentology: examples from the Niger Delta. *Nigerian Association of Petroleum Explorationists Bulletin***10**: 65-73.

Ehrenberg C. G., (1839). Über die Bildung der Kreidefelsen und des Kreidemergels durch unsichtbare Organismen. *Physikalisch abhandlungen der königlichen Akademie der Wissenschaften zu Berlin*: 59-147.

Emery, D. and Myers, K.J. (1997).Sequence Stratigraphy. Blackwell, Oxford, UK: 297

Evamy, D.D.J., Haremboure, P., Kamerling, W.A., Knaap, F.Molloy, A. & Rowlands, M.H., (1978). Hydrocarbon habitat of the Tertiary Niger Delta. *American Association of Petroleum Geologists Bulletin***62**: 1-39.

Fornasini C., (1896). Ottavo Contributo alla conoscenza della microfanna terziarii. Italiana - *Memorie dell'Accademia della Scienze dell'Istituto di Bologna***5/6**: 1-6.

Frankl, E. J., and Cordry, E. A. (1967). The Niger Delta oil province: Recent development onshore and offshore. *In seventh world petroleum congress proceedings, Mexico*, **2**: 195-209.

Franzenau, A., (1888). Adat Budapest altalajanak ismeretehez. *Foldtani Kozlony*. Budapest. **18**(3 -4): 87 -106

Funnel, B.M., (1967). *Foraminifera and radiolarian as depth indicators in the marine environment*, Mar. Geol., **5**: 333 – 347.

Graham, J.J., De Klasz, I., and Rerat, D. (1965). Quelques importants foraminiferes du Tertiaire du Gabon (Afrique Equatoriale). *Rev. Micropal*., **8** (2): 71 - 84

Graue, K., (2000). Mud volcanoes in deepwater Nigeria: *Marine and Petroleum Geology*, **17**: 959– 974.

Haeckel, E. (1894). Systematische phylogenie. Entwuf eines naturlichen Systems der Organismen auf Grund Ihrer Stemmesgeschichte. Theil 1, Systematische Phylogenie der Protisten and Pflanzen. Georg Reimer, Berlin. 400

Harris, D.K., (1981). Paleoenvironmental interpretation and foraminifera biostratigraphy of cores offshore from the Niger Delta (Unpublished dissertation). University College Swansea.

Hadley W. H. Jr, (1934). Some Tertiary Foraminifera from the North Coast of Cuba. *Bulletin of American Paleontology*, **20** (70): 1-40.

Haq, B. U., Hardenbol, J. and Vail, P.R. (1987). Chronology of Fluctuating Sea Levels since the Triassic. Journal of Science. **235**: 1156-1167.

Haq, B.U., Hardenbol, J., and Vail, P.R., (1988). Mesozoic and Cenozoic Chronostratigraphy and Cycles, in: C.K., Wilgus, B.S., Hastings, H., Posamentier, J., Van Wagoner, C.A., Ross and C.G., st. C. Kendall (eds.); Sea Level Changes: An Integrated Approach.*SEMP Special Publication*. **42**: 71 -108.

Hedberg, H.D. (1976). International Stratigraphic Guide – A guide to stratigraphic classification, terminology, and procedure. John Wiley and Sons, New York. 200

Hofker J., (1951). The foraminifera of the Siboga Expedition; Part 3. *Siboga Expeditie, Monographie IVb*. Leiden. E. J. Brill: 1-513.

Hohenegger, J. and Piller,W., (1975).Wandstrukturen und Grossgliederung der Foraminiferen.Sitzungsbericht der österreichischen Akademie derWissenschaften. *Mathematisch naturwissenschaftliche Klasse*, Abtlg **1** (184): 67–96.

Hospers, J (1971). The Geology of the Niger delta area.*Great Britain Institute of Geological science report*, **70** (16): 121 -142.

Howe, H.V., and Wallace, W.E. (1932). Foraminifera of the Jackson Eocene at Danville Landing on the Ouachita, Catahoula Parish, Louisiana. *Louisiana Department Conservative Geology Bulletin*. **2**: 1-118

Husezima, R., and Maruhasi, M. (1944). A new genus and thirteen new species of foraminifera from the core samples of Kasiwazaki oil-field Nigata-ken: *Singenkagaku Kenkyusyo Journal*. B **1** (3): 391 -400

Kafesioglu, I.A., (1971). Specific diversity of planktonic foraminifera on the continental shelves as a paleobathymetric tool, *Micropaleontologists*. **17**: 455 –470.

Kaminski M., (2005). The year 2000 classification of the agglutinated foraminifera. In Bubík M., Kaminski M. A. (eds): *Proceedings of the Sixth International Workshop on Agglutinated Foraminifera*. Grzybowski Foundation Special Publication, **8**: 237-255.

Kulke, H., (1995). Nigeria, in H. Kulke, ed., *Regional petroleum geology of the world. Part II: Africa, America, Australia and Antarctica*: Berlin, Gebruder Bornteaeger: 143-172.

Jones T. R., (1895). The Crag Foraminifera. Part 2. *Monograph of the Palaeontographical Society London*, **230** (49): 73-210.

Lamarck J. B., 1804 – Suite des mémoires sur les fossils des environs de Paris. *Annales du Muséum national d'histoire naturelle*, **5**: 349-357.

Lehner, P., and De Ruiter, P. A. C. (1977) Structural history of Atlantic margin of Africa: *American Association of Petroleum Geologists Bulletin*, **61**: 961– 981.

Linne, C., (1758). Systema naturae per regna tria naturae, secumdum classes, ordines, genera, species, cum characteribus, differentiis, synoymis, locis, Engelman, Lipsiae, **10** (1): 1 -824

Loeblich A.R., Jr. and Tappan,H., (1964). *Sarcodina Chiefly Thecamoebians and Foraminiferida",Treatise on Invertebrate Paleontology, part C, Protista*, 1 and 2, R.C. Moore, (ed.), U.S.A., Geological Society of American and University of Kansas Press: C1 –C900.

Loeblich, A. R., Jr. and Tappan, H. (1987).Foraminifera and their Classification. Van Nostrand Reinhold Company, New York: 970

Loeblich, A.R., Jr. and Tappan, H., (1988). Foraminiferal evolution, diversification, and extinction. *Journal of Paleontology* **62**: 695–714.

Loutit, TS, Bradsaw, WB and Kingsley, KO (1988). Condensed sections: Key to age determination of continental margin sequences. In: Wilgus C.K. et al. (eds.) Sea-level changes: An integrated approach. *Special Publications. American Association Petroleum Geologist* **42**: 183-213

Mascle, J. R., B. D. Bornhold, and V. Renard, (1973). Diapiric structures off Niger delta: *American Association of Petroleum Geologists Bulletin.*, **57**: 1672-1678.

Merki, PJ (1972): Structural Geology of the Cenozoic Niger delta. In: Dessauvagie, T.F.J and Whiteman, A.J(eds). *African Geology*, University of Ibadan press: 635-646.

Michele L. W. T., Ronald R. C., and Michael E.B. (1999). The Niger Delta Petroleum System: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa. *United State Geological Survey*. Denver Colorado: 4 - 70

Mikhalevich, V.I., (2004). On the heterogeneity of the former Textulariina (Foraminifera). In: Bubik, M. and Kaminski, M.A. (Eds.), *Proceedings of the Sixth International Workshop on Agglutinated Foraminifera*: Grzybowski Foundation Special Publication, **8**: 317-349.

Mitchum Jr., R.M., (1977). Seismic stratigraphy and global changes of sea level. Part 11: glossary of terms used in seismic stratigraphy, In: Payton, C.E. (Ed.), Seismic Stratigraphy Applications to Hydrocarbon Exploration.*American Association of Petroleum Geologists Memoir*. **26**: 205–212.

Morkhoven, F.P.C.M. Van, Berggren, W.A. and Edwards, A.S., (1986). Cenozoic cosmopolitan deep-water benthic foraminifera. *BulletinCentr. Rech. Expl. Prod., Elf-Aquitaine*, **11**: 421.

Morley, C. K., and Guerin, G. (1996). Comparison of gravity-driven deformation styles and behavior associated with mobile shales and salt: *Tectonics*, **15**: 1154–1170.

Murat, R.C., (1970). Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria, in: T.F.J., Dessauvagie and A.J., Whiteman (eds)., *African-geology*: Ibadan, Nigeria, Ibadan University press: 251 - 266

Murray,J.W.,(1971). Ecology and Paleoecology of Benthic Foraminifera. New York, John Wille and Sons Inc.: .5-397.

Murray, J.W., (1973). Distribution and ecology of living benthic foraminiferids. Crane, Russak & Co., New York, 274

Murray, J.W., and Wright, C.A., (1974). Paleogene Foraminiferida andpaleoecology, Hampshire and Paris Basins and the English Channnel. *Paleontology Association London, Special Papers Paleontology*, **14**: 1 - 129

Nagy, J., Lofadli, M., and Backstrom, S.A., (1988).Aspects of Fofaminiferal Distribution and Depositional Conditions in Middle Jurassic to Early Cretaceous Shales in Eastern Spitsbergen, *Proc. 2nd Int. Workshop on Agglutinated Foraminifera*: 287-300

Nton, M.E. and Esan, T.B., (2010). Sequence Stratigraphy of EMI Field, Offshore Eastern Niger Delta, Nigeria. European Journal of Scientific Research **44**(1): 115-132

Obaje, S.O., (2013). Sequence Stratigraphic Interpretation of Kafe-1 Field, Offshore Western Niger Delta, Nigeria. *International Journal of Engineering Science Invention***2** (11): 20-30

Obiosio, E.O., (2013). Biostratigraphy and Paleoenvironment of Bolivina fauna from the Niger Delta, *Nigeria. Earth Science Research*. **2** (2): 80 - 90

Oboh-Ikuenobe, F.E., Obi, C.G. and Jaramillo, C.A. (2005). Lithofacies, Palynofacies and Sequence Stratigraphy of Palaeogene Strata in Southeastern Nigeria. *Journal of African Earth Sciences*,**41**: 79-101.

Okosun, E.A. and Liebau, A., (1999). Foraminiferal Biostratigraphy of Eastern Niger Delta, Nigeria. *Nigerian Association of Petroleum Explorationist Bulletin*. **13** (2): 136 - 156

Okosun, E.A., (2003). Taxonomic review of SPDC Niger Delta benthic foraminiferal type collection. *Unpublished. Shell Petroleum Development Company Records*: 62

Okosun, E.A., Chukwu, J.N., Ajayi, E.G., and Olatunji, O.A., (2012). Biostratigraphy, Depositional Environment and Sequence Stratigraphy of Akata Field (Akata 2, 4, 6 and 7 Wells), Eastern Niger Delta, *Nigeria. International Journal of Scientific & Engineering Research***3** (7): 1 - 27

Oloto, I.N., and Promise, W., (2014). Biostratigraphic Study and Paleoenvironmental Reconstruction of Cores from offshore (South Western) Niger Delta, *Nigeria. International Journal of Scientific & Technology Research*. **3**: 21 - 35

Olsson, R.K., (1960). Foraminifera of latest Cretaceous and earliest Tertiary age in the New Jersey Coastal Plain. *Journal of Paleontology*.**34** (1): 1 - 58

Oluwatosin, J.R., (2010). Sequence stratigraphy study within a chronostratigraphic framework of'Ningning field', Niger Delta. RMZ - *Materials and Geoenvironment*. **57**: 475 - 500

Ozumba, M.B. (1995). Late Miocene-Pliocene Biostratgraphy Offshore Niger Delta. *Nigerian Association of Petroleum Explorationist*, **10**: 40-48

Ozumba, M.B. (1999). Middle to Late Miocene sequence stratigraphy of the Western Niger Delta, Nigeria. *Nigerian Association of Petroleum Explorationist Bulletin*. **14** (2): 176 – 192

Ozumba, M.B. and Amajor, L.C., (1999). Evolutionary Relationships in some benthonic foraminifera of the Middle to Late Miocene, Niger Delta. *Nigerian Association of Petroleum Explorationist Bulletin*. **14** (2): 157-167

Pacht. J.A., Bowen, B.E., Beard, J.H., and Shaffer. B.L., (1990). Sequence stratigraphy of Plio-Peistocene depositional facies in the offshore Louisiana south addition. *Gulf coast association of geological society*. **40**: 1-18

Parker F. L., (1952). Foraminifera species off Portsmouth, New Hampshire. *Bulletin of the Museum of Comparative Zoology at Harvard College*, **106**: 391-423.

Pessagno, E. A. Jr. (1967) Upper Cretaceous Stratigraphy of the western Gulf Coastal Plain. Palaeontogr. *Americana*, **5** (37): 245 – 445

Petters, S. W. (1979). Nigerian Paleocene benthonic foraminiferal biostratigraphy, paleoecology and paleobiologeography. *Marine Micropaleontology*, Netherlands, **4**(1): 85-99.

Petters, S.W., (1982). *Central West African Cretaceous-Tertiary benthic foraminifera and stratigraphy*: Palaeontographia A **179**: 1-104.

Petters, S.W. (1983). Gulf of Guinea planktonic foraminiferal biochronology and geological history of the South Atlantic. *Journal of Foraminiferal Research*. **13**: 32-59

Petters, S.W., (1984). An ancient submarine canyon in the Oligocene-Miocene of the western Niger Delta. *Sedimentology* **2**: 805-810.

Petters, S.W., (1995). Foraminiferal biofacies in Nigeria rift and continental margin deltas, in: M.N., Oti and G., Postma (eds.); *Geology of Deltas*. A. A., Balkema, Rotterdam: 219-235

Pokorny, V., (1963).Principles of Zoological Micropaleontology. Pergamon Press, N.Y: 1–652.

Reijers, T.J.A., (1996). Selected chapters in geology: sedimentary geology and sequence stratigraphy in Nigeria and three case studies and field guide, Shell Petroleum Development Company, Nigeria: 197

Reijers, T.J.A., Petters, S.W. & Nwajide, C.S., (1997). The Niger Delta Basin. [In:] R.C. Selley (Ed.): *African basins. Sedimentary Basins of the World* (Elsevier, Amsterdam) **3**: 145-168.

Reuss, A.E., (1851). Uber die fossilen Foraminiferen und Entomostraceen der Septarienthone der Umgegend von Berlin. *Z.Deutsch. Geol. Gessel.***3**: 49 -91

Sellier de Crivrieux, J.M. (1976). Estudio sistematico y ecologico de las Bolivinitidae recientes de Venezuelea. *Cuadernos Oceanografico*, **5**: 3 - 43

Sen Gupta, B.K., (1999). Systematics of modern Foraminifera. In: Sen Gupta, B.K. (Ed.), *Modern Foraminifera*. Kluwer Academic Publishers: 7–36.

Schultze, M., (1854). *Ueber den Organismus der Polythalamien (Foraminiferen)*, nebst Bemerkungen über die Rhizopoden im Allgemeinen. Wilhelm Engelmann, Leipzig.

Schwager C., (1866). Fossile Foraminiferen von Kar Nikobar, Reise der Österreichischen Fregatte Novara um die Erde in den Jahren 1857, 1858, 1859 unter den Befehlen des Commodore B. Vo Wüllerstorf-Urbair. Geologischer Theil 2 (1); Geologische Beobachtungen 2; Paläontologische Mittheilungen: 187-268.

Shannon, P. M., and Naylor N., (1989).*Petroleum Basin Studies*: London, Graham and Trotman Limited: 153-169

Short, K.C. and Stauble, A.J., (1967). Outline geology of the Niger Delta. *American Association of Petroleum Geologists Bulletin***51**: 761-779.

Soronnadi-Ononiwu, G.C., Omoboriowo, A.O., Yikareboga, Y., and Madu, V.C., (2013). Paleoenvironmental and sequence stratigraphic studies of the D7000 sand, 'Erne' field, Niger Delta, *Nigeria. Greener Journal of Physical Sciences*. **3**: 6 -18.

Stacher, P.,(1995), Present understanding of the Niger delta hydrocarbon habitat, in Oti, M. N. and Postma, G., (eds).*Geology of deltas*: Rotterdam, A.A. Balkema: 257-267.

Stehli, F.G. and Creath, W.B., (1964). Foraminifera ratios and regional environments, *American Association Petroleum Geologists Bulletin*. **48**: 1810 – 1827.

Vail, E.R., and Wornardt, W.W., (1990). Well-log seismic stratigraphy: an integrated tool for the 1990's. In: Sequence Stratigraphy as an exploration tool: concepts and practices in the Gulf coast. *Gulf coast section of the Society of Economic Paleontologists and Mineralogists*. Eleventh annual research conference: 379-397

Van Wagoner, J.C., Posamentier,H.W., Mitchum, R.M.Jr., Vail, P.R., Sarg, J.F., Loutit, T.S. and Hardenbol, J. (1988) An Overview of Sequence Stratigraphy and Definitions, Sea level changes, an integrated approach, in: C. K. Wilgus, B. S. Hastings, H.M. Posamentier, J.C. Van Wagoner, C.A. Ross, and C. G. Kendall, (eds.)*Society of Economic Paleontologist and Mineralogist Special Publications*,**42**: 39 – 45

Weber, K.J., and Daukoru, E., (1975). Petroleum geology of the Niger Delta: *Ninth World Petroleum congress Tokyo proceedings*. (Geology), **2**: 209 - 221

Whiteman, A., (1982). Nigeria; Its Petroleum geology, resources and potentials, 1 & 2: London, Graham and Trotman Ltd: 176-238.

Wu, S., and Bally, A.W. (2000). Slope tectonics— Comparisons and contrasts of structural styles of salt and shale tectonics of the northern Gulf of Mexico with shale tectonics of offshore Nigeria in Gulf of Guinea, in: W. Mohriak and M. Talwani, (eds.), Atlantic rifts and continental margins: Washington, D.C., *American Geophysical Union*: 151– 172.

Yikarebogha, Y., Chighanam, O.I., Soronnadi, O.G.C., Omoboriowo, A.O., and Okengwu, K.C., (2013). Paleontological studies of an X-well, offshore, Niger Delta, Nigeria. *International Journal of Science Innovations and Discoveries*. **3** (5): 504 – 511

Zingula, R. P. (1968). A new breakthrough in sample washing. *Journal of Paleontology*. **42**(4): 1092.

PLATE I

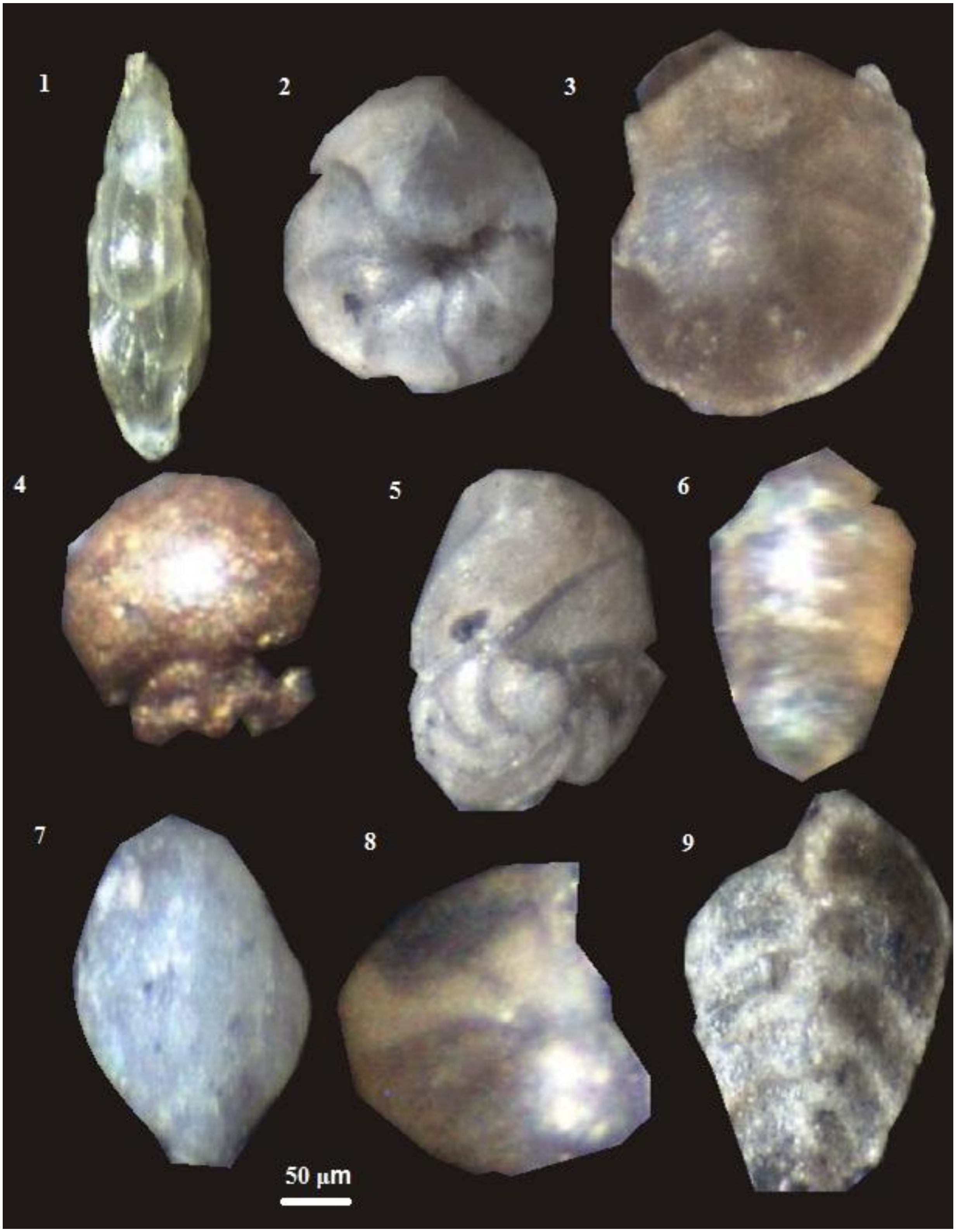


Plate I Explanation

All the foraminifera species illustrated in Plate I above were collected from Well-A, Niger Delta, below is the species name, corresponding depth of occurrence and magnification.

1. *Uvigerina sparsicostata* (Cushman & Laiming, 1931), (2650m – 3650m) X 300
2. *Cibicorbis inflata*(d'Orbigny,), (3000m – 3650m) umbilical view(X 500)
3. *Lenticulina inornata* (Cushman), (2650m) umbilical view (X 300)
4. *Praeorbulina sicana* (Cushman & Stainforth, 1945), (2800m –3050m),spiral view (X 300)
5. *Cibicorbis inflata*(d'Orbigny,), (3000m – 3650m) spiral view (X 500)
6. *Bolivina dilatata* (Reuss, 1851), (2700m), side view (X 500)
7. *Praeorbulina glomerosa* (Blow, 1956), (2650m – 3400m), side view (X 300)
8. *Epistominella vitrea* (Parker, 1957), (2700m – 2750m), spiral view (X 500)
9. *Textularia laminata* (Cushman, 1918), (3650m), appertural view (X 300)

PLATE II

Plate II Explanation

All the foraminifera species illustrated in Plate II above were collected from Well-A, Niger Delta, below is the species name, corresponding depth of occurrence and magnification.

1. *Orbulina suturalis* (Bronnimann, 1953), (3000m – 3400m), spiral view (X 300)
2. *Brizalina mandoroveensis* (Graham), (3350m – 3650m), umbilical view (X 300)
3. *Brizalina interjuncta* (Graham, De Klasz & Rerat, 1965), (2650m – 2700m), side view (X 500)
4. *Hopkinsina bononiensis* (Fornasini, 1888), (2650m – 3650m), side view (X 350)
5. *Eponides eshira*(De Klasz & Rerat,1961), (2650m – 3650m), spiral view (X 500)
6. *Ammonia beccarii* spiral view (Linne, 1758)
7. *Praeorbulina sicana* (Cushman & Stainforth, 1945), (2800m – 3050m), umbilical view (X 300)
8. *Epistominella vitrea* (Parker, 1957), (2700m – 2750m), umbilical view (X 500)
9. *Ammonia beccarii* (Linne. 1758), (2600m – 2750m) umbilical view (X 500)

PLATE III

Plate III Explanation

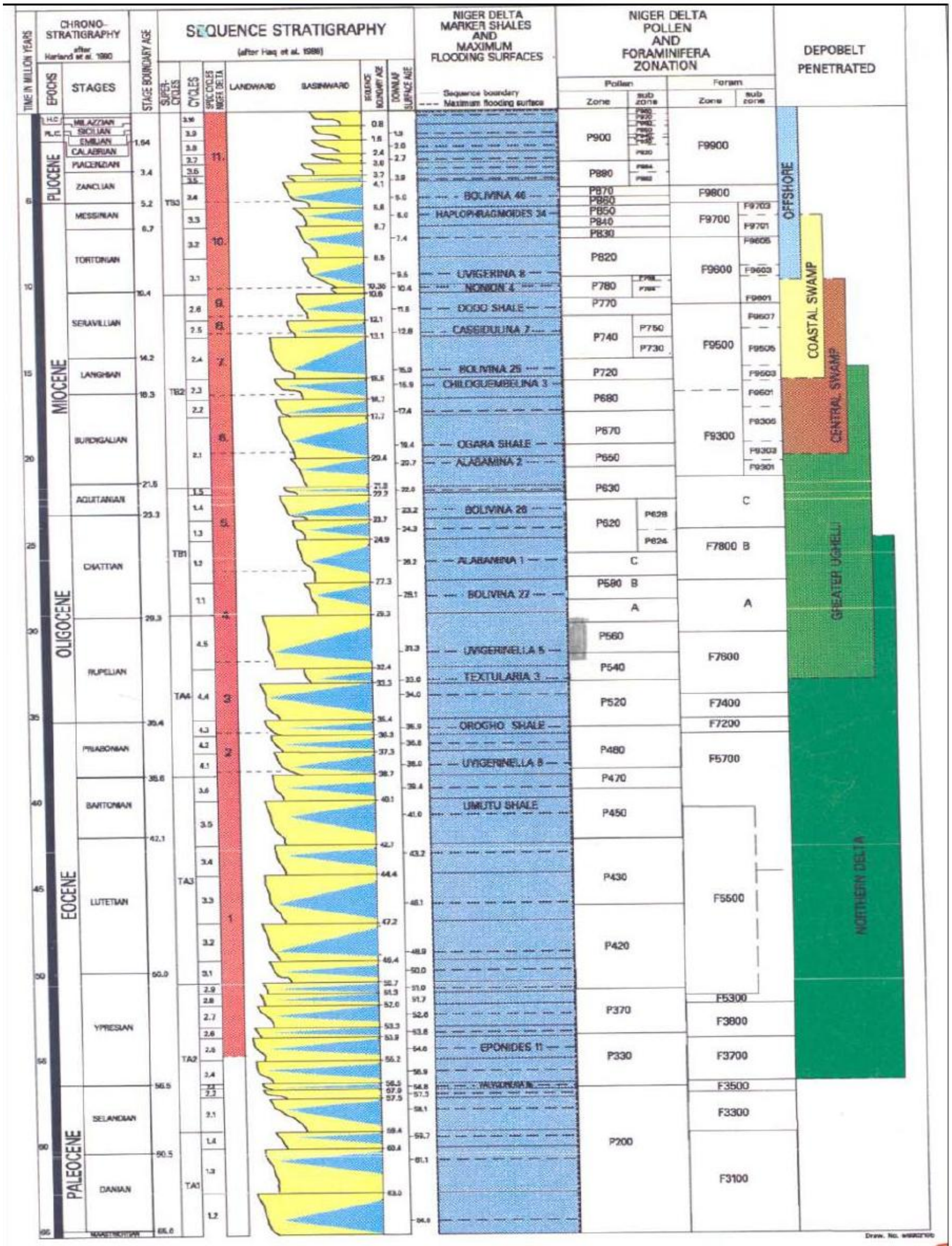
All the foraminifera species illustrated in Plate III above were collected from Well-A, Niger Delta, below is the species name, corresponding depth of occurrence and magnification.

1. *Orbulina universa* (d'Orbigny, 1839), (2600m 3050m), spiral view (X 300)
2. *Heterolepa floridana* (Cushman,), (2650m – 3650m), umbilical view (X 500)
3. *Valvulineria gasparensis* (Bermudez,1949), (2650m – 2700m), spiral view (X 500)
4. *Eponides eshira*(De Klasz & Rerat,1961), (2650m – 3650m), umbilical view (X 500)
5. *Hanzawaia strattonii* (Applin,1758), (2600m – 2800m), spiral view (X 500)
6. *Lenticulina grandis* (Cushman), (2600m – 3650m), umbilical view (X 300)
7. *Hanzawaia strattonii* (Applin,1758), (2600m – 2800m), umbilical view (X 500)
8. *Valvulineria gasparensis* (Bermudez,1949), (2650m – 2700m), Umbilical view (X 500)
9. *Uvigerina isidroensis* (Cushman & Renz, 1941), (2600m – 3650m).

APPENDICES

Appendix A

Haq *et al.,* Niger Delta Chronostratigraphic Chart



Haq *et al.*, Niger Delta Chronostratigraphic Chart

Appendix B

Systematic Paleontology

Kingdom Protozoa

Phylum Sarcodina

Class Rhizopoda

Order Foraminiferida

Uvigerina sparsicostata Cushman & Laiming, 1931

PlateI, Fig. 1

Description: Test elongate, about 2 times as long as broad, widest in the middle, ends rounded; chambers inflated, distinct; sutures depressed; wall ornamented with longitudinal costae, about 10 on a full-grown chamber, high and very thin and sharp, toward the base and apertural ends of the test becoming broken up into spinose or irregular short portions; aperture circular at the end of a distinct cylindrical neck, often spinose and with a lip.

Genus *Cibicorbis* Hadley, 1934

Cibicorbis inflata d'Orbigny 1839

Plate I, Fig. 2

Description: Test trochospiral, plano-convex; spiral side flattened and partially involute, umbilical side involute with closed umbilicus, chambers broad, increasing rapidly in breadth so that whorls are flaring; chambers triangular in section, inflated and with sharply angled apertural face; margin of the spiral side carinate, sutures thickened, curved, slightly elevated in early stages wall distinctly perforate, surface smooth.

Lenticulina inornata Cushman 1927

Plate I, Fig. 3

Description: Test close-coiled, entirely involute, biconvex, broadly rounded; 6-7 chambers in the last-formed coil; apertural face small, rounded; sutures flush, curved; wall smooth; aperture at the peripheral angle of the test, radiate with a series of radiating slits at the periphery, but with a tendency to become cribrate, due to irregularly settled slits in the center. **Superfamily Discorbacea** Ehrenberg, 1839

Praeorbulina sicana Cushman & Stainforth, 1945

PlateI, Fig. 4

Description: Test trochospiral, spherical to subspherical. The last three chambers of the final whorl increase rapidly in size; the ultimate chamber embraces up to about 40% of the penultimate and earlier chambers. Wall cancellate, spinose. Sutures slightly depressed. Two to four irregular slit-like, often elongate apertures at the suture between the last and earlier chambers.

Superfamily Bolivinacea Glassner, 1937

Family Bolivinidae Glassner, 1937

Genus*Bolivina* d' Orbigny, 1839

Bolivina dilatata Reuss, 1851

PlateI, Fig. 6

Description: Test elongate, slender, compressed tapering; chambers biserially arranged, higher than broad; periphery rounded; sutures depressed, strongly oblique; wall distinctly perforated, surface ornamented by longitudinal striations 'occupying about the entire length of the test, except the last chamber; aperture elliptical, extending from the base of the aperturalface, with narrow rim and tooth plate.

Genus*Praeorbulina* Olsson, 1960

Praeorbulina glomerosa Blow, 1969

PlateI, Fig. 7

Description: Test subglobular to subspherical, periphery quite circular. Chambers spherical to subspherical arranged in about four whorls; last chambers increasing rapidly in size. Final chamber much inflated and embracing the earlier chambers up to more than 40 percent. Sutures curved depressed, primary aperture of the early portion is covered by the final chamber. Several small, sutural, slit-like secondary apertures along the basal suture.

Family Discorbidae Ehrenberg, 1839

Subfamily Discorbidinae Ehrenberg, 1839

Genus *Epistominella* Husezima and Maruhasi, 1944

Epistominella vitrea Parker, 1952

PlateI, Fig. 8

Description: Test free, trochospiral, biconvex periphery, rounded and slightly tabulated; calcareous wall, hyaline, smooth, finely perforate, spiral side with all 3 whorls and chambers visible and sutures straight, depressed and oblique, only final 6 chambers visible on umbilical side with sutures radial and depressed; aperture narrow slit oriented slightly oblique to peripheral margin.

Suborder Textulariina Delage & Herouard, 1896

Family Textulariaiidae Ehrenberg, 1839

Subfamily Textulariaiinae Ehrenberg, 1839

Genus*Textularia* Defrance, 1824

Textularia laminata Cushman, 1918

PlateI, Fig. 9

Description: Test elongate, tapering, very little compressed, periphery rounded; chambers inflated, increasing in width and height toward the apertural end rather uniformly; sutures indistinct in the early portion, deeply incised in the later portion, about right angles to the long axis of the test; wall coarsely agglutinated, surface rough; aperture a slit in a well-marked depression of the inner margin of the last-formed chamber.

Orbulina suturalis Bronnimann, 1953

PlateII, Fig. 1

Description: Test almost spherical, early globigerine stage trochospiral. The spherical ultimate chamber not completely enveloping the initial globigerine stage. Tests show gradations from partly enveloped initial globigerine stage to an almost completely enveloped one. Wall cancellate-spinose.

Brizalina mandoroveensis Graham, 1965

PlateII, Fig. 2

Description: The small laterally compressed test tapers from a broad apertural end towards an acutely rounded initial end. Biserially arranged chambers are subrectangular and increase in size gradually. The distinct arcuate sutures are slightly limbate and depressed. The thin translucent calcareous wall is finely perforate and ornamented with numerous longitudinal striations that are restricted to most of the test from the initial end. The narrow elongate aperture extends from the base of the ultimate chamber to a terminal position.

Superfamily Buliminacea Jones, 1895

Family Turrilinidae Cushman, 1927

Genus*Brizalina*Costa, 1856

Brizalina interjuncta Graham, De Klasz & Rerat, 1965

PlateII, Fig. 3

Description: The small compressed test tapers from a broad apertural end towards an acutely rounded initial end. Biserially arranged chambers are sub rectangular and increase in size gradually. The distinct arcuate sutures are slightly limbate and depressed. The thin translucent calcareous wall is finely perforate and ornamented with numerous longitudinal striations that are restricted to about 3/4th of the test from the initial end.

Genus*Hopkinsina* Howe & Wallace, 1932

Hopkinsina bononiensis Fornasini, 1896

PlateII, Fig. 4

Superfamily Rotaliacea Ehrenberg, 1839

Family Rotaliidae Ehrenberg, 1839

Subfamily Rotaliinae Ehrenberg, 1839

Genus *Ammonia* Brunnich, 1772

Ammonia beccarii Linne, 1758

PlateII, Fig 6 & 9

Description: The test is large, almost rounded, trochoid with a more convex ventral side. Dorsally, about 3 whorls are visible, whereas only the last-formed whorl is visible on the ventral side. The chambers on the dorsal side are slightly higher than broad and gradually increase in size, while on ventral side, the externally visible 11-13 chambers are subtriangular. Dorsally, distinct arcuate sutures are limbate and slightly raised, whereas ventrally, they are deeply depressed and radial. The umblical area is covered with solid plugs of shell material. The thin calcareous translucent wall is finely perforate. The periphery is subacute.

Occurrence: A cosmopolitan species in recent hyposaline lagoons and estuaries, and also on the continental shelf. Abundant in the Miocene – Pliocene of the Niger Delta. (Petters, 1982)

Superfamily Globigerinaceae Carpenter, Parker & Jones, 1862

Family Globigerinidae Carpenter, Parker & Jones, 1862

GenusOrbulina d'Orbigny, 1839

Orbulina universa d'Orbigny, 1839

PlateIII, Fig. 1

Description: Test bilobate, large two spherical chambers, the penultimate one partly to completely enveloping the initial globigerine stage, which is trochspiral with spherical chambers. Wall distinctly perforate, spinose.

Genus *Heterolepa* Franzenau, 1888

Heterolepa floridana Cushman 1927

PlateIII, Fig. 2

Description: Test trochospiral; spiral side evolute, flat; umbilical side involute, highly convex, with lateral margins almost straight; peripheral edge sharply angled, subcarinate, not lobulate; about 6 chambers in the last whorl; sutures flush, except between the last chamber; walls conspicuously perforated on the spiral side, only rows of large pores along the margins of the last two chambers on the umbilical side.

Subfamily Bagginінae Cushman, 1927

GenusValvulineria Cushman, 1926

Valvulineria gasparensis Bermudez, 1952

PlateIII, Fig. 3

Description: Test low-trochospiral, composed of 2 - 3 coils, the last-formed coil composed of about 6 chambers, rapidly increasing in size, inflated, the last-formed chamber often somewhat deformed; periphery lobulate, rounded; sutures curved backwards, depressed on both sides, except in the early portion of the test; deep umbilicus partly covered by small flaps; wall transparent, distinctly perforate on both sides, except in the early chambers on the spiral side; aperture a narrow, arched slit at the base of the last-formed chamber with a lip.

Superfamily ORBITOIDICAE Schwager, 1866

Family EPONIDIDAE Hofker, 1951

Genus*Eponoides* De Montfort, 1808

Eponides eshira De Klasz & Rerat, 1961

Plate III, Fig. 4

Description: Test low trochospiral, biconvex, more convex on the umbilical side; umbilicus closed; periphery angular to carinate; 2-3 whorls with about 5-7 chambers per whorl; sutures curved and limbate on the spiral side, continuing into the peripheral keel, nearly radial on the umbilical side, wall finely perforate, sutures and keel imperforate.

Occurrence: Abundant in Middle Oligocene – Middle Miocene of the Niger Delta. Originally described from the Lower Miocene of Gabon.

Family Anomalinidae Cushman, 1927

Subfamily Anomalininea Cushman, 1927

Genus*Hanzawaia* Asano, 1944

Hanzawaia strattonii Applin 1758

PlateIII, Fig. 5 & 7

Description: Test low trochospiral, planoconvex, periphery subangular; whorls enlarging rapidly, chambers numerous; sutures thickened, depressed, and curved back at the periphery; umbilical side involute, convex with clear central boss; spiral side flattened, partially evolute with apertural flapfrom each chamber extending centrally over earlier whorls; wall coarsely perforate.

Suborder Rotaliina Delage & Herouard, 1896

Superfamily Nodosariacae Ehrenberg, 1839

Family Nodosariidae Ehrenberg, 1839

Subfamily Nodosariinae Ehrenberg, 1839

Genus *Lenticulina* Lamarck, 1804

Lenticulina grandis Cushman 1927

PlateIII, Fig. 6

Description: Test close-coiled, involute, lenticular, biumbonate; chambers curved, increasing slightly in size as added; sutures and umbo flush, giving a very smooth surface to the test; peripheral margin acutely rounded; apertural face small, rounded; wall very finely perforate; aperture radiate, transformed into an elongated double row of lateral slits that converge towards an axial wall, itself with a central opening; apertural face partially divided by an elongate equatorial slit somewhat radiating at its base.

Family Uvigerinidae Haeckel, 1894

Subfamily Uvigerininae Haeckel, 1894

Genus*Uvigerina* d' Orbigny, 1826

Uvigerina isidroensis Cushman & Renz, 1941

PlateIII, Fig. 9

Description: Test compact, rather bulbous, triserial with about 3-4 whorls visible; periphery smoothly rounded, lobulate; chambers somewhat angular in the early stage, later inflated;sutures depressed; wall thick finely perforate, generally smooth though some specimens show faint longitudinal striations; aperture terminal, at the end of a short neck; neck, in a depression near the indented margin of the last chamber, with a distinct lip.

Appendix C

Lithologic Descriptions and Percentage Composition of Lithology from Studied Well Interval

Lithologic Description:

Siltstone: White, very fine-grained, micromicaceous and carbonaceous plus traces of sandand shale plus woody materials in some samples coalfragments woody materials and muscovite flakes are present.

Shale: Brown to grey, fissile, moderately hard, micromicaceous and occasionally carbonaceous.

Sandstone: Smoky white to orange, fine-grained, sub-angular to sub-rounded, well-sorted and occasionally ferruginized.

Depth (m)	**Percentage Composition per Sample**
2441	Siltstone 100%
2460	Siltstone 90% Shale 5% Sandstone 5%
2478	Siltstone 10% Shale 20% Sandstone 70%
2496	Siltstone 35% Shale 10% Sandstone 55%
2515	Siltstone 25% Shale 10% Sandstone 65%
2533	Siltstone 10% Shale 10% Sandstone 80%
2551	Siltstone 20% Shale 10%

	Sandstone 70%
2569	Shale 10% Sandstone 90%
2588	Shale 5% Sandstone 95%
2606	Shale 10% Sandstone 90%
2624	Siltstone 30% Sandstone 70%
2643	Siltstone 45% Sandstone 55%
2661	Siltstone 40% Shale 10% Sandstone 50%
2679	Siltstone 45% Shale 5% Sandstone 55%
2697	Siltstone 30% Shale 15% Sandstone 55%
2716	Siltstone 40% Shale 10% Sandstone 50%
2734	Siltstone 10% Sandstone 90%
2752	Siltstone 5% Shale 10% Sandstone 85%

2771	Siltstone 5% Shale 10% Sandstone 85%
2789	Siltstone 30% Shale 60% Sandstone 10%
2807	Siltstone 35% Shale 50% Sandstone 15%
2825	Siltstone 45% Shale 45% Sandstone 10%
2844	Siltstone 40% Shale 45% Sandstone 15%
2862	Siltstone 35% Shale 65%
2880	Siltstone 45% Shale 55%
2899	Siltstone 50% Shale 45% Sandstone 5%
2917	Siltstone 35% Shale 60% Sandstone 5%
2935	Siltstone 15% Shale 65% Sandstone 20%
2954	Shale 90% Sandstone 10%

2972	Shale 85% Sandstone 15%
2990	Shale 75% Sandstone 25%
3008	Shale 65% Sandstone 35%
3027	Siltstone 20% Shale 30% Sandstone 50%
3045	Siltstone 85% Shale 15%
3063	Siltstone 75% Shale 20% Sandstone 5%
3082	Siltstone 65% Shale 25% Sandstone 10%
3100	Siltstone 40% Shale 30% Sandstone 30%
3118	Siltstone 50% Shale 5% Sandstone 45%
3136	Siltstone 10% Shale 5% Sandstone 85%
3155	Siltstone 55% Shale 45%
3173	Siltstone 65% Shale 35%

3191	Siltstone 40% Shale 60%
3210	Siltstone 45% Shale55%
3228	Siltstone 35% Shale 55% Sandstone 10%
3246	Siltstone 30% Shale 45% Sandstone 25%
3264	Siltstone 25% Shale 45% Sandstone 30%
3283	Siltstone 50% Shale 10% Sandstone 40%
3301	Siltstone 45% Shale 25% Sandstone 35%
3319	Siltstone 35% Shale 40% Sandstone 25%
3338	Siltstone 5% Shale 95%
3356	Siltstone 90% Shale 10%
3374	Siltstone 15% Shale 10% Sandstone 75%
3392	Siltstone 10%

	Shale 15% Sandstone 75%
3411	Siltstone 45% Shale 55%
3429	Siltstone 35% Shale 55% Sandstone 10%
3447	Siltstone 60% Shale 20% Sandstone 20%
3466	Siltstone 60% Shale 25% Sandstone 15%
3484	Siltstone 30% Shale 45% Sandstone 25%
3502	Siltstone 80% Shale 15% Sandstone 5%
3520	Siltstone 80% Shale 15% Sandstone 5%
3539	Siltstone 35% Shale 50% Sandstone 15%
3557	Siltstone 30% Shale 60% Sandstone 10%
3575	Siltstone 60% Shale 35%

	Sandstone 5%
3594	Siltstone 55% Shale 35% Sandstone 10%
3612	Siltstone 30% Shale 55% Sandstone 15%
3630	Siltstone 25% Shale 70% Sandstone 5%
3648	Siltstone 5% Shale 90% Sandstone 5%

Appendix D

Shell-type Ratio Determination for study well interval

Total Hyaline shell-type foraminiferas present	=	408
Total Porcelaneous shell-type foraminiferas present	=	10
Total Agglutinated shell-type foraminiferas present	=	9
Total foraminifera count	=	427

Hyaline shell ratio

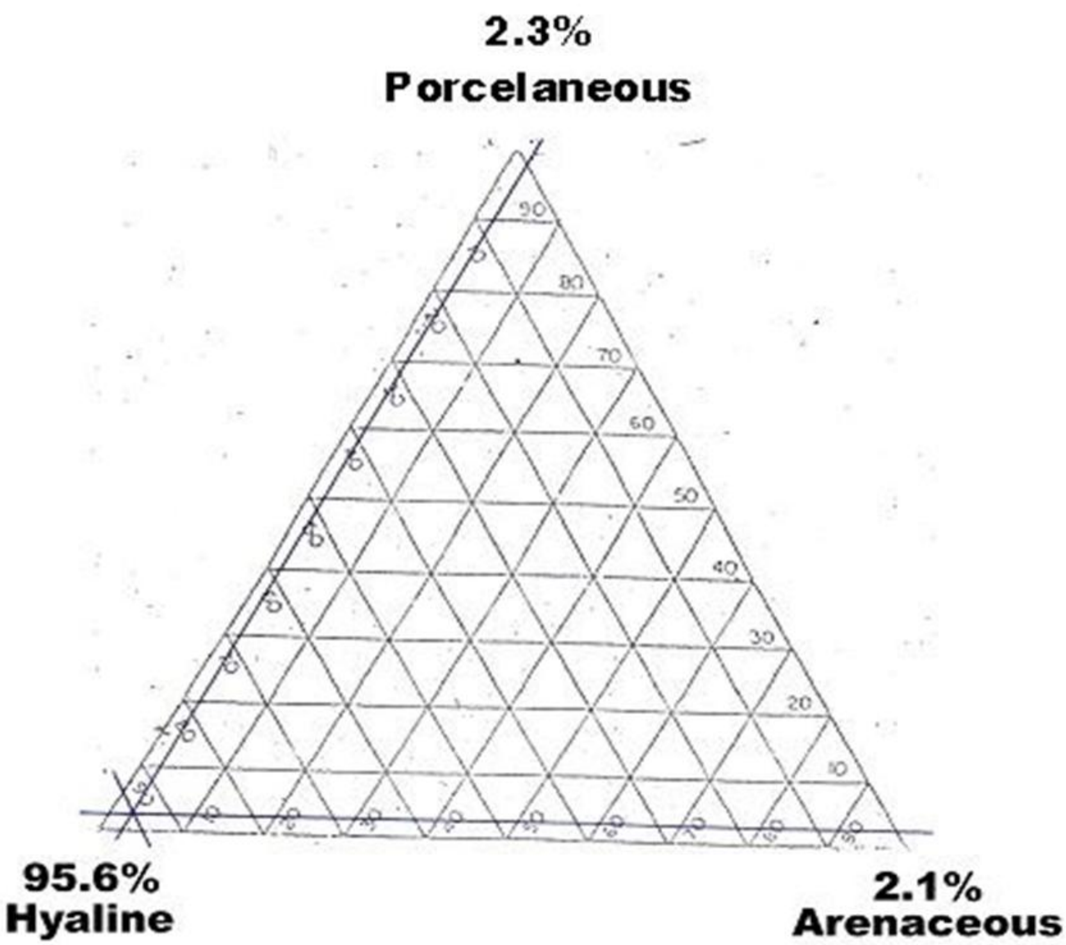
408/427 x 100% = 95.6%

Porcelaneous shell ratio

10/427 x 100% = 2.3%

Agglutinated shell ratio

9/427 x 100% = 2.1%



Appendix E

Ratios of Foraminifera Present in Study Well

Planktic/Benthic (P/B) ratio:

Total Planktic forms	=	32
Total Benthic forms	=	395
Total Foram count	=	427
P/B ratio	=	7.5: 92.5

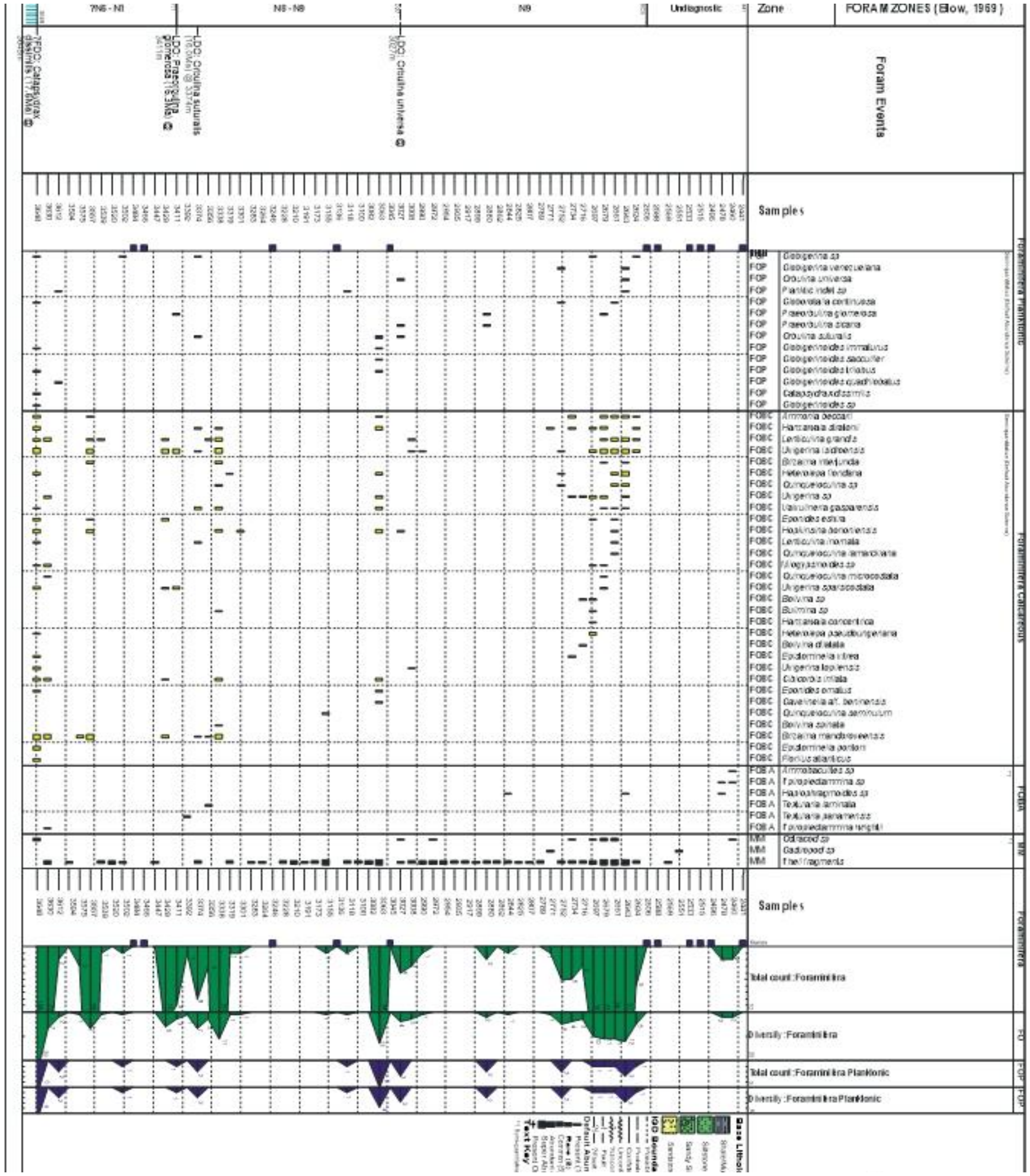
FOBA/FOBC ratio:

Total Arenaceous forms	=	9
Total Calcareous forms	=	386
Total Benthic forms	=	395
Ratio	=	2.3 : 97.7

Appendix F

Systematic Classification of Foraminifera

Loeblich and Tappan (1988)	Sen Gupta (1999)	Mikhalevich (2004)	Kaminski (2005)
Order	*Order*	*Order*	*Order*
Foraminiferida	Foraminifera	Foraminifera	Foraminifera
Suborders	*Orders*	*Classes*	*Orders*
Allogromiina	Allogromiida	Astrorhizata	Allogromiina
Textulariina	Astrorhizida	Lagynana	Astrorhizida
Fusulinina	Lituolida	Astrorhizana	Lituolida
Involutinina	Trochamminida	Spirillinnata	Loftusiida
Spirillinina	Textulariida	Ammodiscana	Textulariida
Carterinina	Fusulinida	Spirillinana	Fusulinida
Miliolina	Miliolida	Miliolata	Miliolida
Silicoloculinina	Carterinida	Miliamminana	Silicoloculinida
Lagenina	Spirillinida	Miliolana	Involutinida
Robertinina	Lagenida	Nodosariata	Robertinida
Globigerinina	Rotaliida	Hormosinana	Favusellida
Rotaliina	Buliminida	Nodosariana	Spirillinida
	Globigerinida	Rotaliata	Lagenida
	Involutinida	Textulariana	Buliminida
	Robertinida	Rotaliana	Rotaliida
	Silicoloculinida	Globigerinana	Globigerinida



Foraminifera Distribution Chart for Well-A