LATE OLIGOCENE TO EARLY MIDDLE MIOCENE FORAMINIFERAL BIOSTRATIGRAPHY, SEQUENCE STRATIGRAPHY AND PALAEOENVIRONMENT OF WELL – 004 (OML – 34) NIGER DELTA

BY

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DECLARATION

I declare that the work in this dissertation entitled **"Late Oligocene to Early Middle Miocene Foraminiferal Biostratigraphy, Sequence Stratigraphy and Palaeoenvironment of Well - 004 (OML – 34) Niger Delta"** has been carried out by me in the Department of Geology, Faculty of Science, Ahmadu Bello University, Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other Institution.

Abubakar Usman

14/01/2016

Date

CERTIFICATION

This dissertation entitled **Late Oligocene to Early Middle Miocene Biostratigraphy, Sequence Stratigraphy and Palaeoenvironment of Well - 004 (OML - 34) Niger Delta** by Abubakar Usman meets the regulations governing the award of the degree of Master of Science in Geology of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this work to my late father Alhaji Abubakar Hamza and my mother Hajiya Fatima Shehu U.A.T.

ABSTRACT

A total of seventy – two ditch cutting samples from well – 004 were described and analyzed for their foraminiferal content. Lithologic description of the samples shows that the entire sediments belong to the paralic Agbada Formation. A total of sixty three foraminiferal species were recovered out of which fourty – five are benthonics and eighteen are planktonics.

The planktonic foraminifera index species recovered from the well revealed that the sediments penetrated in the well range in age from Late Oligocene to Early Middle Miocene. Five planktonic foraminiferal zones namely *Globigerina ciperoensis* Taxon range zone, *Orbulina bilobata* Interval zone, *Globigerinoides altiaperturus – Catapsydrax dissimilis* Concurrent range zone, *Catapsydrax stainforthi* Interval zone, *Praeorbulina glomerosa* Interval zone were proposed based on First Downhole Occurrences (FDO) and Last Downhole Occurrences (LDO) of the planktonic foraminiferal index forms. Four benthonic foraminiferal zones were also proposed, namely; *Epistominella vitrea* taxon range zone, *Eponides berthelotianus* interval zone, *Ammonia* sp. interval zone and *Miogypsinoides* sp. taxon range zone.

The sediments in the studied well are considered to be of normal marine neritic depositional environment based on the triangular plot of foraminiferal suborders ratio Textulariina (arenaceous), Miliolina (porcelaneous), and Rotaliina (hyaline calcareous) deposited in dysoxic to oxic condition and Palaeobathymetry range from non-marine to outer neritic.

Changes in sea level were inferred base on paleobathymetric data, foraminiferal abundance and coarsening upward nature of the study well section. From the sea level curve it can be deduced that the well sequence is characterized by four episodes of sea level rise and fall during late Oligocene to Early – Middle Miocene.

The sequence stratigraphic analysis based on the available data shows that the well penetrated eight (8) system tracts made up of one (1) Lowstand Systems Tract (LST), four (4) Transgressive System Tract (TST), four (4) Highstand System Tract (HST), three (4) candidates of Maximum Flooding Surfaces (MFS) were proposed at 4,235 m, 3,906 m, 3,760 m and 3,414m. This reveals the existence of four (4) depositional sequence in the study well. The associated SB occur at 4,144 m, 3,851 m and 3,650 m. One transgressive surface (TS) was identified at 4,016 m.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Statement of Research Problem

The importance of Niger Delta Basin (Figs. 1.1 and 1.2) lies in its hydrocarbon resources and is among the world's most prolific petroleum provinces. Nigeria has been rated as the sixth largest oil producer and twelfth giant hydrocarbon province (Reijers*et al.,* 1997). Thousands of wells have been drilled across the delta penetrating sediments, in which petroleum generation, migration and accumulation have occurred (Okosun *et al.,* 2012). Hydrocarbon exploration in the Niger Delta dates back to the 1950's. The oil exploration and other investigations have contributed to the stratigraphic and micropalaeontologic data base of the region. Researches in micropalaeontology has gained importance owing to increase in exploration for hydrocarbons. The petroleum industry in Nigeria have described and adopted informal zonation which is largely unpublished (Evamy *et al.,* 1978). Foraminiferal biostratigraphy of several wells from the Niger Delta Basin have been extensively published (Fayose, 1970; Petters, 1979; Petters, 1982; Petters, 1983; Adeniran, 1997; Okosun and Liebau 1999; Ozumba and Amajor 1999; Okosun, *et al.*2012; Obiosio, 2013), however the foraminiferal biostratigraphy of well – 004 has not been documented.

This research is aimed at carrying out foraminiferal biostratigraphy, sequence stratigraphy and also to determine the environment of deposition of the strata penetrated by well – 004 central swamp of the Niger Delta Basin (Figs. 1.1 and 1.2).

1.2 Objectives of the Present Work

The objectives of the research work are to:

1. Construct lithostratigraphic section of the well and identified distinct lithostratigraphic units from the section;
2. Carry out taxonomic identification of foraminifera species;

3. Construct a range chart of foraminifera species for the well;
4. Attempt zonation of the well using foraminifera species;
5. Deduce palaeoenvironment of deposition of the sediments in the well using foraminiferal assemblages;
6. Attempt to define the key bounding surfaces and depositional systems tracts in the well using foraminiferal abundance and diversity.

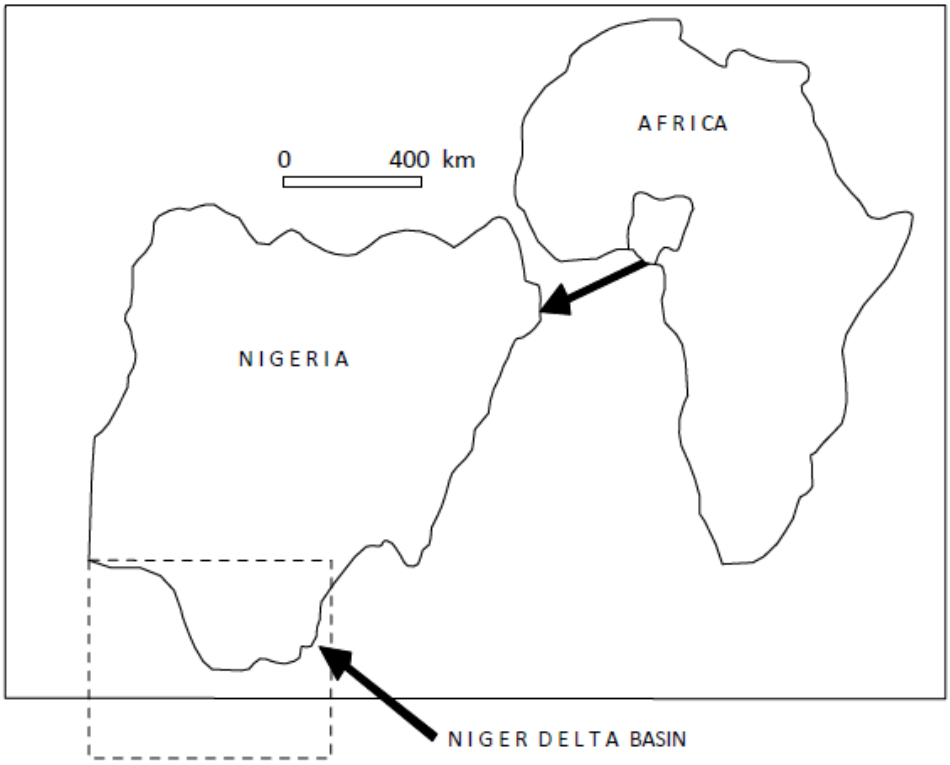


Figure 1.1. Position of Niger Delta Basin in Nigeria and Africa (After Ajibola, 2004)

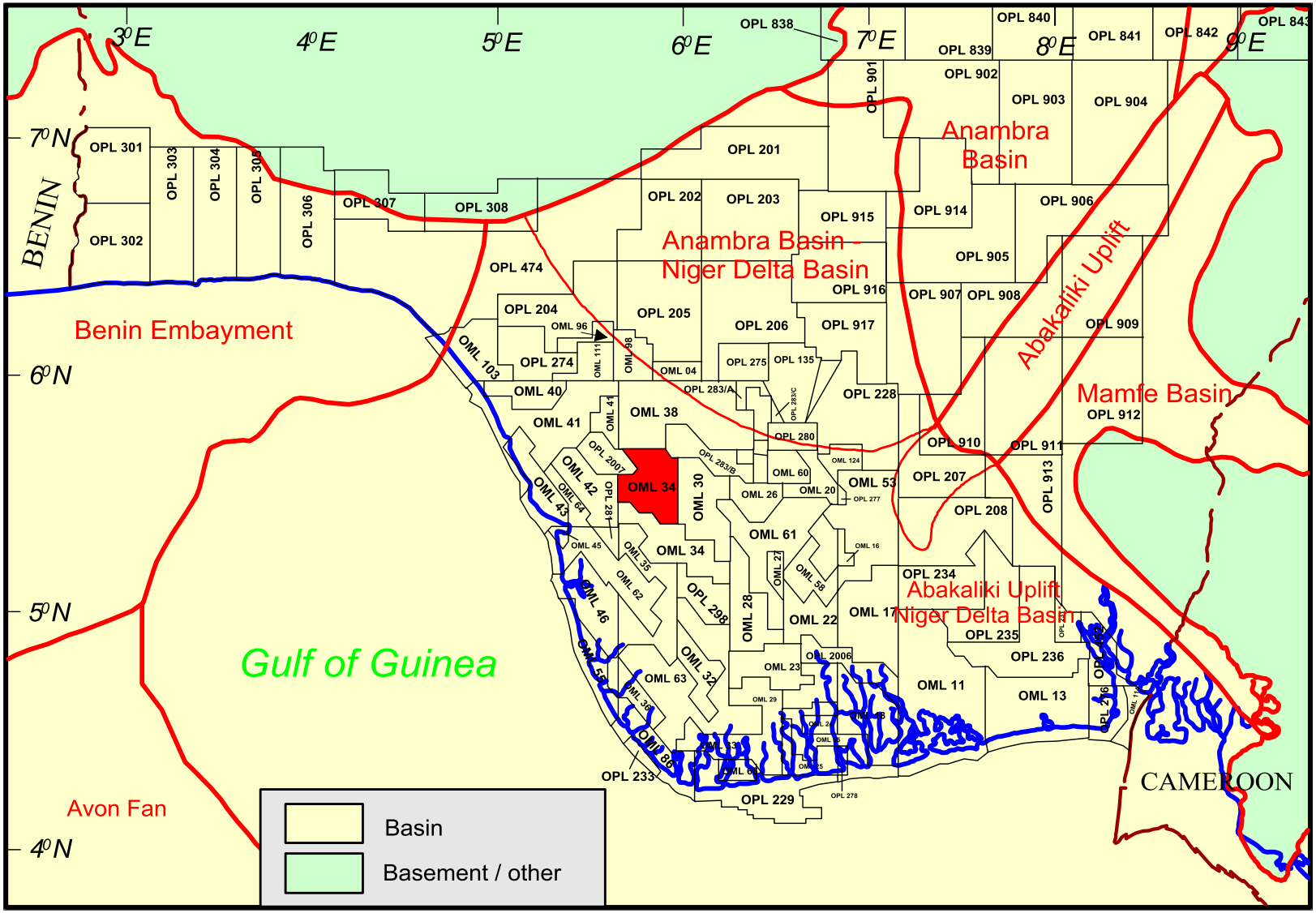


Figure 1.2. Index Map of Onshore Niger Delta Basin Showing Location of OML 34 (Modified after ISH, 2007)

1.3 Location of the study well

Well – 004 (Fig. 1.3) is a Shell Petroleum Development Company of Nigeria (SPDC) well drilled in 1962, to a total depth of 4359m, It is located in central swamp section of the Niger Delta Basin on OML 34 (Fig. 1.2). Its reference geographic co-ordinates are 5° 24□ 26.43□ □N, and 5° 52□ 51□ □E.

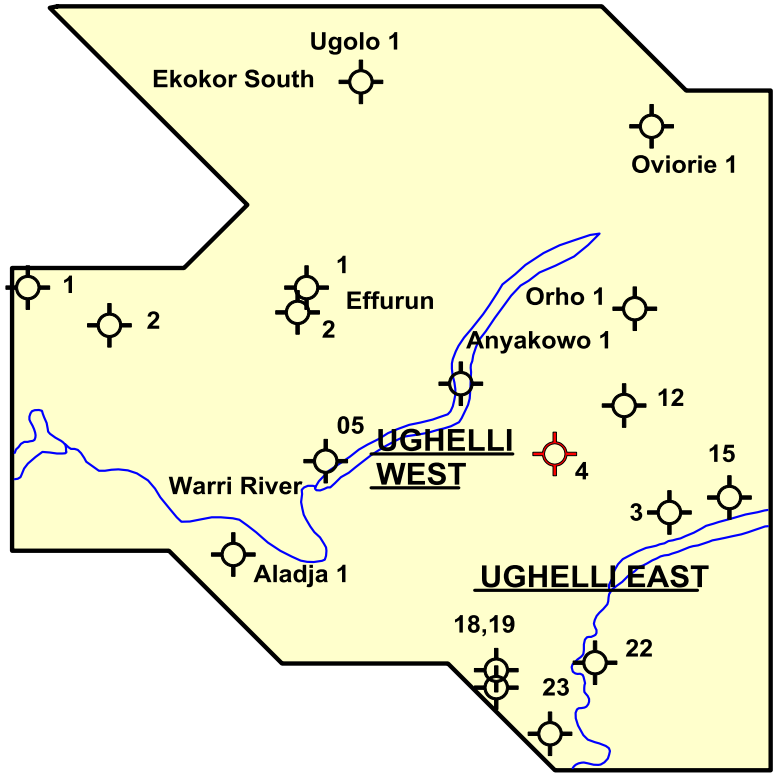


Figure 1.3. Location of the studied well(well –004) in the OML 34 (Modified after ISH, 2007)

1.4 Previous Work

1.4.1 Foraminiferal Biostratigraphy in the Niger Delta Basin

Foraminiferal biostratigraphic studies of the Niger Delta have been carried out by several workers (Reyment, 1965; Adegoke, 1978; Petters, 1982; Seglie *et al.*, 1982; Ozumba, 1995; Adeniran, 1997; Obiosio, 2013).

Fayose (1970) studied the foraminiferal biostratigraphy of Afowa – 1 well in the Dahomey Basin from which he proposed ten biostratigraphic units. Petters (1979) described

three stratigraphic zones in Parabe – 1 well using: *Globorotalia opima nana* and *Globorotalia opima opima* to define late Oligocene.*Globorotalia foshi peripheronda* was used to define early middle Miocene and Pliocene. Petters (1982, 1983) investigated the benthonic and planktonic foraminiferal fauna of the Central West Africa and the Gulf of Guinea respectively of which the Niger Delta Basin sediments were inclusive, he defined nine planktonic and five benthonic foraminiferal zones. Ozumba (1995) studied the foraminiferal biostratigraphy of three wells (EP – 1, HB – 2 and KC – 1) from offshore Niger Delta. He observed that the planktonic foraminifera are scanty and do not reflect any regular distributive pattern, as a result, he defined three biozones for the late Miocene to Pleistocene sediment of the Niger Delta using benthonic foraminiferal species.

Adeniran (1997) defined six zones based on planktonic foraminifera from Oligocene to Pliocene from the western Niger Delta Basin. He noted the scarcity of conventional index species and lack of unified benthonic and planktonic zonal scheme for the Niger Delta. Okosun and Liebau (1999) confirmed the problems pointed out by Adeniran (1997) in their study of five wells (Obirikom – 1, Ebegoro – 1, Afam – 1, Kolcreek – 1, and Akata – 1 wells) from the eastern Niger Delta Basin; and then assigned Danian age to the sediments on the basis of *Globorotalia pseudobulloides, Globigerina triloculinoides, Globigerinoides daaubjergensis* assemblage. Ozumba and Amojor (1999) studied foraminifers of four wells (Kanbo – 5, Egbedicreek – 1, Angalili – 1, and Opunkushi – 5) located in the coastal and central swamp in the western Niger Delta Basin. They defined six foraminiferal zones (assemblages/partial range zones) for the middle to late Miocene Niger Delta namely: *Globigerina sparsicostata zone, Nonion centrosulcatum/Chiloguembelina victoria zone, Eponides eshira zone, Uvigerina sparsicostata zone, Spirosigmoilina oligoceanica zone and Florilus ex. Gr. costiferun zone.*

Okosun *et al.* (2012) carried out foraminiferal biostratigraphic study in the Akata field from Akata-2, Akata-4, Akata-6, and Akata-7 wells in the eastern Niger Delta Basin. They established three planktonic foraminiferal zones (*Globorotalia continuosa*, *Globorotalia obesa/Globorotalia mayeri,* and *Globorotalia peripheroacuta*) and three benthonic zones (*Spirosigmoilina oligocaenica, Uvigerina sparsicostata*, and *Eponides eshira/Brizalina mandorovensis)* in both Akata-2 and Akata-4 wells. They also proposed one planktonic foraminiferal zone of *Praeorbulina glomerosa* for Akata-6 and Akata-7 wells and one benthonic zone of *Brizalina mandorovensis*/*Eponides eshira* and *Poritextularia panamensis* for Akata-6 and Akata-7 wells respectively.

Obiosio (2013) published his work on biostratigraphy and Palaeoenvironment of *Bolivina* fauna from onshore Tonjor-1 well Niger Delta Basin; a total of twenty three species of *Bolivina* were identified, out of which eighteen species were reported for the first time. Using the ranges of the *Bolivina* species recovered from the well, He proposed two biozones; *Bolivina ottaensis*Interval zone and *Bolivina attenuate*Taxon range zone.

1.4.2 Sequence Stratigraphy of the Niger Delta Basin

Sequence stratigraphic study using foraminiferal abundance and diversity in the Niger Delta Basin have been carried out by many authors (Ozumba 1995, 1999; Bassey and Ojesina, 1998; Armentrout *et al.,* 1999). Ozumba (1995) utilized the relative abundance of planktonic, arenaceous, and calcareous foraminifera to identify 5 maximum flooding surfaces (MFS) from penetrated stratigraphic intervals of three wells (EP – 1, HB – 1, and KC – 1) from the offshore western Niger Delta. He used first or last downhole occurrences of planktonic or benthonic foraminiferal species in dating the MFS. In the three wells, three systems track; lowstand systems tract (LST), transgressive systems tract (TST) and highstand systems tract (HST) were well presented. Bassey and Ojesina (1998), carried out sequence stratigraphic studies of six wells located in offshore western Niger Delta using seismic data,

well log and biostratigraphic data. Sediments penetrated were late Miocene – Pleistocene age, they defined seven sequences, one of the sequence have LST, TST, and HST (which is the oldest) while the others have TST and HST. Ozumba (1999) conducted a sequence stratigraphic study of four wells in the central and coastal swamp depobelts in the Niger Delta, and defined three sequences, seven MFS and six sequence boundary (SB) using genetic approach.

Armentrout*et al.* (1999) carried out high-resolution sequence biostratigraphic study of a lowstand deltaic wedge in Oso Field Niger Delta Basin and proposed three sequence stratigraphic models; (1) the first model is based on biostratigraphic data integrated with core sedimentology; (2) a second model was developed using core sedimentology; and (3) a third based on interpreted regional seismic reflection profiles and well-log data. Using the Integration of all the models, they interpreted the lower Oso Field producing interval as a lowstand prograding wedge, and the upper interval as a prograding distaltransgressive or alternatively distal highstand systems tract.

On the basis of foraminifera and nannofossil abundance and diversity patterns calibrated with chronostratigraphically important bioevents from deep offshore Niger Delta Basin, Boboye and Adeleye (2009) recognized four (4) condensed sections and correlated them with the Global Cycle Chart of Haq *et al.* (1988). Okosun *et al.* (2012) defined five third order MFS in Akata-2, Akata-4, Akata-6 and Akata-7 wells from Akata Field eastern Niger Delta Basin based on abundant and diverse planktonic and benthonic foraminifera within the intervals, the wells were also divided into sequences and systems tract.

1.4.3 Palaeoenvironmental interpretation of the subsurface Niger Delta Basin

Depositional environments of the subsurface Niger Delta Basin are recognized based on lithology (basically sandstone – shale ratio), foraminiferal assemblages and mutual juxtaposing (Doust and Omatsola, 1990). The review of Palaeoenvironment of deposition of

the subsurface Niger Delta on the basis of foraminiferal assemblages by different authors is presented below.

Ozumba (1995) used foraminiferal assemblages to delineate outer neritic – upper bathyal environment of deposition of the late Miocene – Pliocene interval of three wells offshore Niger Delta.

Petters (1995) proposed foraminiferal bathymetric zonation for the Niger Delta based on the foraminferal bathymetric range given by Harris (1981) and augmented that of Culver (1988) for the northwestern Gulf of Mexico. He suggested that the bathymetric chart should be used for rapid non-statistical routine identification of marine benthic environments in Niger Delta oil well samples, especially if ditch cuttings were used.Okosun *et al.* (2012) inferred a littoral (deltaic) to marine (outer neritic) environments of deposition for four wells from eastern Niger Delta based largely on the presence of environmentally restricted benthonic foraminifera species.

Chukwu*et al.* (2012) inferred Littoral to marine environments of deposition for sediments of Oloibiri – 1 well on the basis of the occurrence of environmentally restricted benthic foraminifera taxa, some of which belong to the following genera *Quinqueloculina, Hopkinsina, Spiroplectamina, Lenticulina, Heterolepa, Alveolophragmium* and *Textularia*.

In the study of Tonjor-1 well onshore Niger Delta, Obiosio (2013) suggested that the stratigraphic diversity variation of the *Bolivinids* allowed the recognition of late Early Eocene marine transgression which correlates with the global Early Eocene transgression. The presence of strong costae, and larger test suggests deposition in a well oxygenated slope to bathyal environment.

CHAPTER TWO

2.0 GEOLOGICAL SETTING AND STRATIGRAPHY OF THE NIGER DELTA BASIN

2.1 Introduction

The Niger Delta Basin is situated between latitudes 3° and 6° N and longitudes 5° and 8° E in the Gulf of Guinea on the margin of West Africa (Fig. 1.1 and 1.2), and is one of the largest deltaic system in the world (Doust and Omatsola, 1990). The subaerial portion of the delta covers about 75,000 km² and extend more than 300 km from the apex to the distal part. The regressive delta and adjacent margin comprise a wedge of clastic sediments up to 12 km thick formed by the series of off lap cycles (Evamy *et al.*, 1978; Doust and Omatsola, 1990), and is considered a classical shale tectonic province (Wu and Bally, 2002).

2.2 Evolution of Niger Delta Basin

The Niger Delta Basin formed along a failed arm of a triple junction system (aulocogen) that originally developed during the breakup of the South American and African Plates in the late Jurassic (Burke, 1972; Whiteman, 1982). The two arms that followed the southwestern and southeastern coast of Nigeria and Cameroon developed into the passive continental margin of West Africa, whereas the third failed arm formed the Benue Trough. Other depocenters along the African Atlantic coast also contributed to deltaic build-ups (Fig. 2.1). Synrift sediments accumulated during the Cretaceous to Tertiary, with the oldest dated sediments being Aptian age. Thickest successions of syn – rift marine and marginal marine clastics and carbonates were deposited in a series of transgressive and regressive phases (Doust and Omatsola, 1990). Renewed subsidence occurred as the continents separated and the sea transgressed the Benue Trough. The Niger Delta Basin continued to prograde during Middle Cretaceous time into a depocenter located above the collapsed continental margin.

Sediment supply was mainly along drainage systems that followed two failed rift arms, into the Benue Trough and Bida Basins. Sediment progradation was interrupted by episodic transgressions during Late Cretaceous time (Doust and Omatsola, 1990).

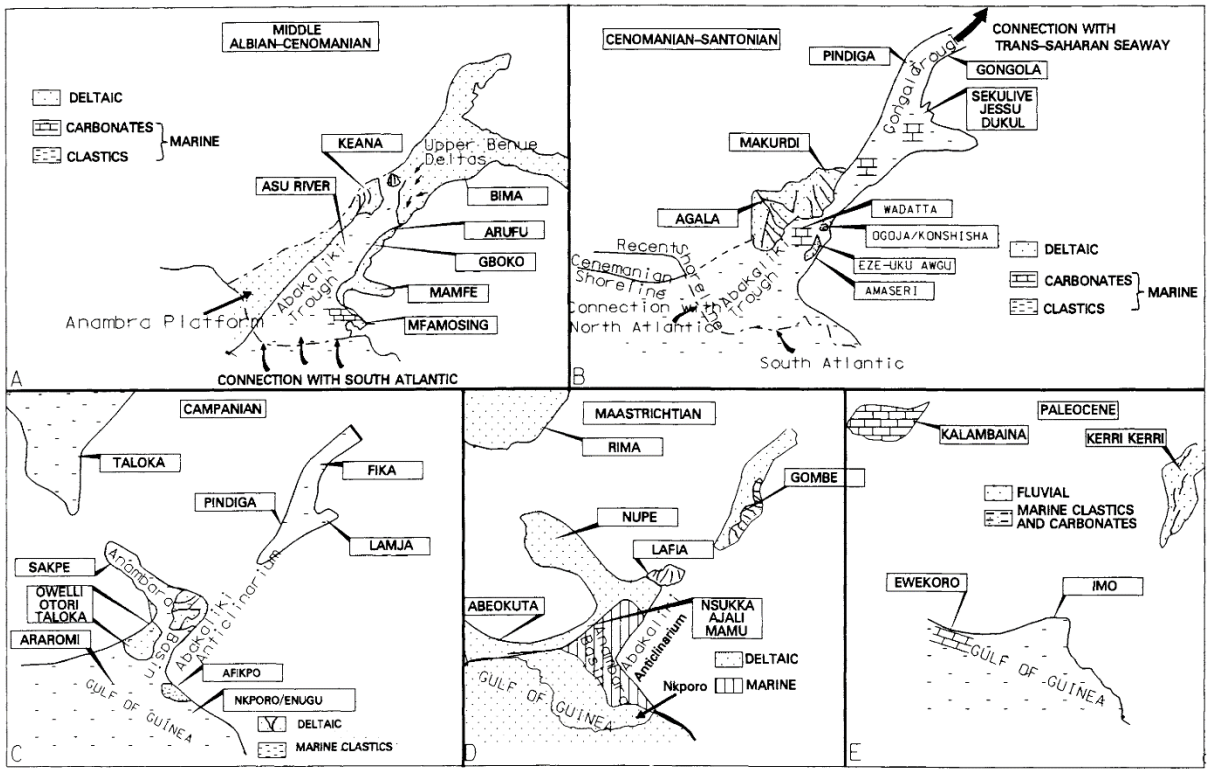


Figure 2.1. Cretaceous to Recent palaeogeographic evolution of Nigerian rift and continental margin deltas (After Petters, 1985).

During the Tertiary, sediment supply was mainly from the north and east through the Niger, Benue and Cross Rivers. Cross and Benue Rivers provided substantial amounts of volcanic detritus from the Cameroon volcanic zone beginning in the Miocene. The Niger Delta Basin prograded into the Gulf of Guinea at a steadily increasing rate in response to the evolution of these drainage areas and continued basement subsidence. Regression rates increased in the Eocene, with an increasing volume of sediments accumulated since the Oligocene (Doust and Omatsola, 1990).

2.3 Morphology of Niger Delta Basin

The morphology of Niger Delta Basin changed from an early stage spanning the Palaeocene to early Eocene to a later stage of delta development in Miocene. The early

coastlines were concave to the sea and the distribution of deposits were strongly influenced by basement topography (Doust and Omatsola, 1990). Delta progradation occurred along two major axes, the first paralleled the Niger River, where sediment supply exceeded subsidence rate. The Second, smaller than the first, became active during Eocene to early Oligocene basinward of the Cross River where shorelines advanced into the Olumbe – 1 area (Short and Stauble, 1967). This axis of deposition was separated from the main Niger Delta deposits by the Ihuo Embayment, which was later rapidly filled by advancing deposits of the Cross River and other local rivers (Short and Stauble, 1967). Late stages of deposition began in the early to middle Miocene, as these separate eastern and western depocenters merged. In the Late Miocene the delta prograded far enough that shorelines became broadly concave into the basin. Accelerated loading by this rapid delta progradation mobilized underlying unstable shales. These shales rose into diapiric walls and swells, deforming overlying strata. The resulting complex deformation structures caused local uplift, which resulted in major erosional events into the leading progradational edge of the Niger Delta. Several deep canyons, now clayfilled, cut into the shelf and are commonly interpreted to have formed during sea level lowstands. The best known are the Afam, Opuama, and Qua Iboe Canyon fills (Short and Stauble, 1967).

Three major depositional cycles have been identified within Tertiary Niger Delta deposits (Short and Stauble, 1967; Doust and Omatsola, 1990). The first two, involving mainly marine deposition, began with a middle Cretaceous marine incursion and ended in a major Palaeocene marine transgression. The second of these two cycles, starting in late Palaeocene to Eocene time, reflects the progradation of a "true" delta, with an arcuate, wave- and tide-dominated coastline. These sediments range in age from Eocene in the north to Quaternary in the south (Doust and Omatsola, 1990). Deposits of the last depositional cycle have been divided into a series of six depobelts (Doust and Omatsola, 1990; also called

depocenters or megasequences) separated by major synsedimentary fault zones. These depobelts formed when paths of sediment supply were restricted by patterns of structural deformation, focusing sediment accumulation into restricted areas on the delta. Such depobelts changed position over time as local accommodation was filled and the focus of deposition shifted basinward (Doust and Omatsola, 1990).

Normal faults triggered by the movement of deep-seated, overpressured, ductile, marine shale have deformed much of the Niger Delta Basin (Doust and Omatsola, 1990). Many of these faults formed during delta progradation and were syndepositional, affecting sediment dispersal. Growth fault was also accompanied by slope instability along the continental margin. Faults flatten with depth onto a master detachment plane near the top of the overpressured marine shales at the base of the Niger Delta succession. Structural complexity in local areas reflects the density and style of faulting. Simple structures, such as flank and crestal folds, occur along individual faults. Hanging-wall rollover anticlines developed because of listric-fault geometry and differential loading of deltaic sediments above ductile shales. More complex structures, cut by swarms of faults with varying amounts of thrown, include collapsed-crest features with domal shape and strongly opposing fault dips at depth (Doust and Omatsola, 1990; Fig. 2.2).

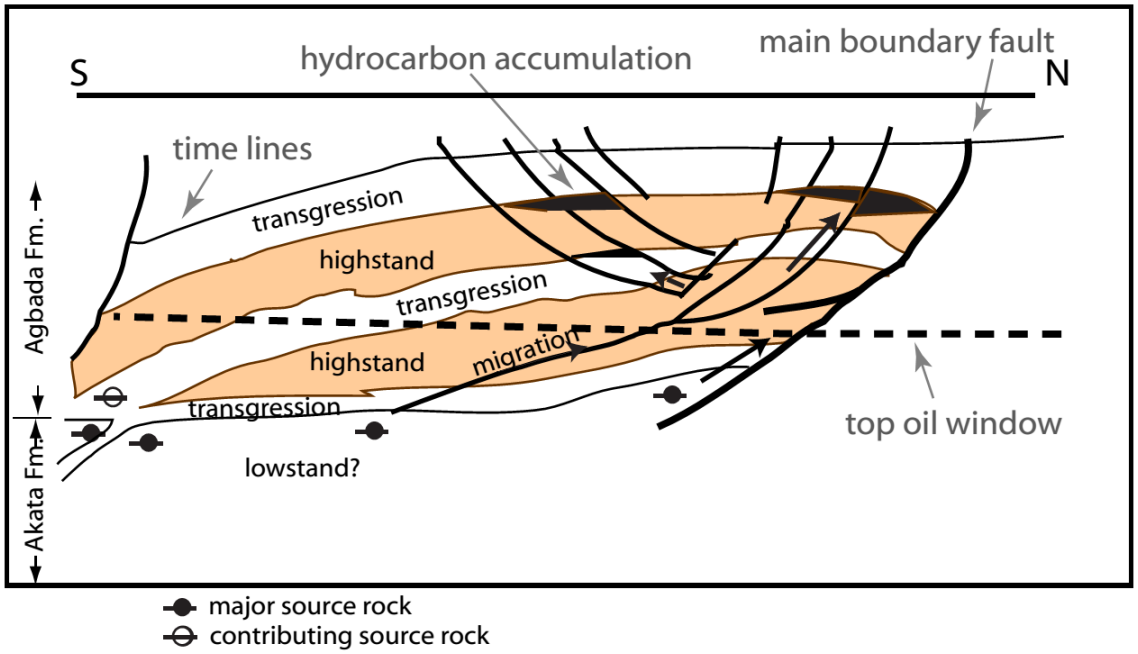


Figure 2.2.Niger Delta oil field structures and associated traps (After Tuttle, et al., 1999)

2.4 Stratigraphy of Niger Delta Basin

Although the stratigraphy of the Niger Delta Basin has been documented during oil exploration and production, most stratigraphic schemes remain proprietary to the major oil companies operating concessions in the Niger Delta Basin. Stratigraphic evolution of the Tertiary Niger Delta and underlying Cretaceous strata was described by Short and Stauble (1967). Petroleum Geology of the Niger Delta was described by Evamy *et al.* (1978); Doust and Omatsola (1990) and Tuttle *et al.* (1999). Stacher (1994) developed a hydrocarbon habitat model for the Niger Delta based on sequence stratigraphic methods. Allen (1965) and Oomkens (1974) described the depositional environments, sedimentation and physiography of the modern Niger Delta.

Three main formations have been recognized in the subsurface of the Niger Delta Basin (Frankl and Cordy 1967; Short and Stauble 1967; Weber and Daukoru 1975; Avbovbo 1978; Knox and Omatsola 1989; Tuttle *et al.*, 1999). These formations are the Akata, Agbada and Benin (Fig. 2.3), decrease in age basinward, reflecting the overall regression of depositional environments within the Niger Delta Basin. Stratigraphic equivalent units to

these three formations are exposed in southern Nigeria (Table 2.1; Short and Stauble, 1967). The formations reflect a gross coarsening-upward progradational clastic wedge (Short and Stauble, 1967), deposited in marine, deltaic, and fluvial environments (Weber and Daukoru, 1975; Weber, 1986).

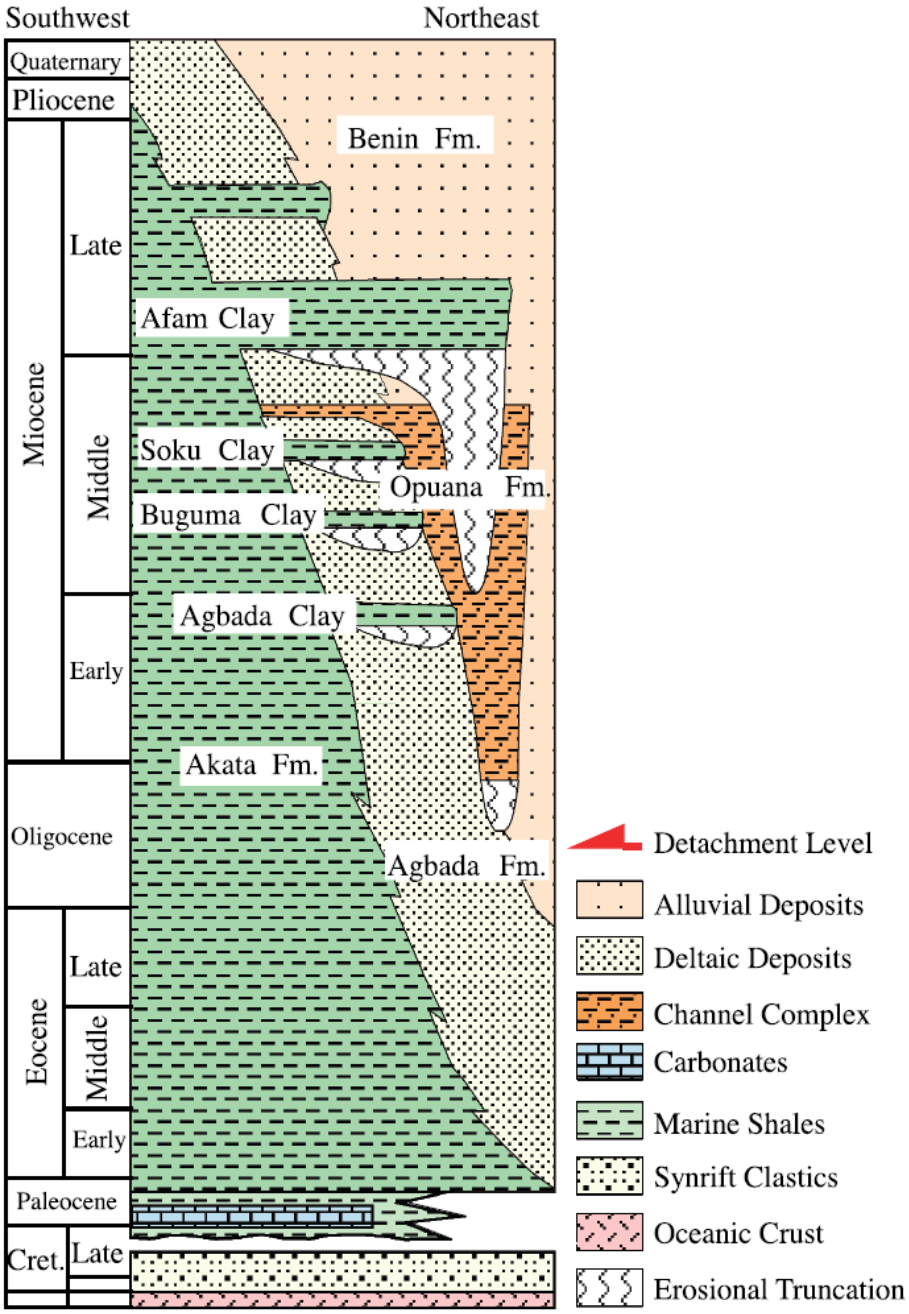


Figure 2.3.Schematic diagram of the regional stratigraphy of the Niger Delta Basin (After Corredor *et al.*, 2005)

Table 2.1. Sedimentary formations in the Niger Delta Basin, Nigeria. (After Short and Stauble, 1967)

Subsurface			Surface Outcrops		
Youngest Known Age		Oldest Known age	Youngest Known Age		Oldest Known Age
Recent	Benin Formation (Afam Clay Member)	Oligocene	Plio/Pleistocene	Benin Formation	
Recent	Agbada Formation	Eocene	Miocene Eocene	Ogwashi Asaba Formation Ameki Formation	Miocene Eocene
Recent	Akata Formation	Eocene	Lower Eocene	Imo Shale Formation	Paleocene
Unknown			Paleocene Maestrichtian Campanian Campanian/Maestrichtian Coniacian/Santonian Turonian Albian	Nsukka Formation Ajali Formation Mamu Formation Nkporo Shale Awgu Shale Eze Aku Shale Asu River Group	Maestrichtian Maestrichtian Campanian Santonian Turonian Turonian Albian

2.4.1 Akata Formation

The type section of the Akata Formation was defined in Akata 1 Well, 80 km east of Port Harcourt (Short and Stauble, 1967). A total depth of 3,680 m was reached in the Akata 1 well without encountering the base of this formation. The top of the formation is defined by the deepest occurrence of deltaic sandstone beds (2,188 m in Akata 1 well). The formation is estimated to be 6,400m thick in the central part of the clastic wedge (Doust and Omatsola, 1989). The lithologies are dark gray shales and silts, with rare streaks of sand of probable

turbidite flow origin (Doust and Omatsola, 1990). Marine planktonic foraminifera make up to 50% of the microfauna assemblage and suggest shallow marine shelf deposition (Doust and Omatsola, 1990). Age of the formation range from Palaeocene to Recent (Doust and Omatsola, 1990). Those shales, formed during the early development stages of Niger Delta progradation. The formation also crops out offshore in diapirs along the continental slope. Where deeply buried, these marine shales are typically overpressured. Akata shales were interpreted to be deep water lowstand deposits by Stacher (1994). The formation grades vertically into the Agbada Formation with abundant plant remains and micas in the transition zone (Doust and Omatsola, 1990).

2.4.2 Agbada Formation

The Agbada Formation is defined in the Agbada 2 well, drilled about 11 km northwest of Port Harcourt (Short and Stauble, 1967). The well reached a total depth of 2896 m without penetrating the base of the formation (the base was defined as the top of the Akata Formation in Akata 1 well). The formation occurs throughout Niger Delta Basin and has a maximum thickness of about 3, 962.4 m. Where it crops out in southern Nigeria (between Ogwashi and Asaba), it is called the Ogwashi – Asaba Formation (Table 2.1) (Doust and Omatsola, 1990). The lithologies consist of alternating sands, silts and shales arranged within ten to hundred meters successions defined by progressive upward changes in grain size and bed thickness. The strata are generally interpreted to have formed in fluvial-deltaic environments. The formation range in age from Eocene to Pleistocene (Doust and Omatsola, 1990).

2.4.3 Benin Formation

The Benin Formation comprises the top part of the Niger Delta Basin, from the Benin-Onitsha area in the north to beyond the present coastline (Short and Stauble, 1967). Its type section is Elele-1 Well, drilled about 38 km north-northwest of Port Harcourt (Short and

Stauble, 1967). The top of the formation is the recent subaerially – exposed delta top surface and its base extends to a depth of 1,402 m. The base is defined by the youngest marine shale. Shallow parts of the formation are composed entirely of non-marine sand deposited in alluvial or upper coastal plain environments during progradation of the delta (Doust and Omatsola, 1990). Although lack of preserved fauna inhibits accurate age dating, the age of the formation is estimated to range from Oligocene to Recent (Short and Stauble, 1967). The formation thins basinward and ends near the shelf edge.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Samples

A total of 72 ditch cutting samples for well – 004 were collected from Shell Petroleum Development Company of Nigeria (SPDC) (available interval 3,024m – 4,359m). The samples were kept in polythene bags. Labelling of each interval was done using marker pen on the masking tape and packaged in the polythene bags. The polythene bags were stapled to prevent the pouring or mixing of the samples.

3.2 Sample Preparation

The ditch cuttings samples were analyzed for their foraminiferal content using standard foraminiferal preparation technique. About 30g of each of the samples was poured into beakers and treated for 10 minute with hydrogen peroxide to disaggregate and dissolve the rock materials to free the fossils. Water was then added to cover the samples.

The samples were then washed under tap water through a 63-µm mesh sieve until clean foraminiferal residues were recovered. The washed samples are dried in an oven at a minimum temperature of 40° C. The samples were then stored in well labelled sample bag ready for picking.

3.3 Foraminiferal Studies

During the picking exercise, dried samples were examined individually on a picking tray under Fisher binocular microscope. The grid lines in the picking tray helped in ensuring that all grid on the tray were examined. Foraminifera were picked with the aid of a sable brush under a binocular microscope. The various foraminifera picked in each sample were grouped and mounted temporarily on micropaleontological slide cavity by the use of a gum. The slides were then covered with micropaleontological cover slips and arranged serially with depths in a slide tray for identification.

The identification of the various foraminiferal taxa (both planktonic and benthonic forms) was done to generic and species level using Taxonomic Scheme of Loeblich and Tappan (1964); Loeblich and Tappan (1988); Petters (1982); and Petters (1983). Digital photomicrographs of the identified foraminifera were taken with a Nikon SMZ 1500 stereomicroscopes.

3.4 Lithologic Description

This was carried out by examining the samples under a hand lens in order to identify the constituents, describe and name the lithology and lithologic log was produced. The ditch cuttings of the interval (3024 m – 4359 m) and GR log that were released for the study by the Shell Petroleum Development Company of Nigeria (SPDC) were used for constructing the lithologic log.

CHAPTER FOUR

4.0 RESULT

4.1 Lithostratigraphy

The lithostratigraphic section of the studywell was produced from ditch cuttings sample description and Gamma ray log (GR). The total thickness of the analyzed sample is 1,326m (i.e. between 3,024 m – 4,359 m intervals. The lithostratigraphic section and cumulative percent of the analyzed sample is presented in Figure 4.1. From the lithostratigraphic section of the study well six coarsening upward (shallowing) sequences were identified. The sequences were characterized by upward increase in the percentage occurrence of sand and upward decreasing in the percentage occurrence of the shale (Fig. 4.1).

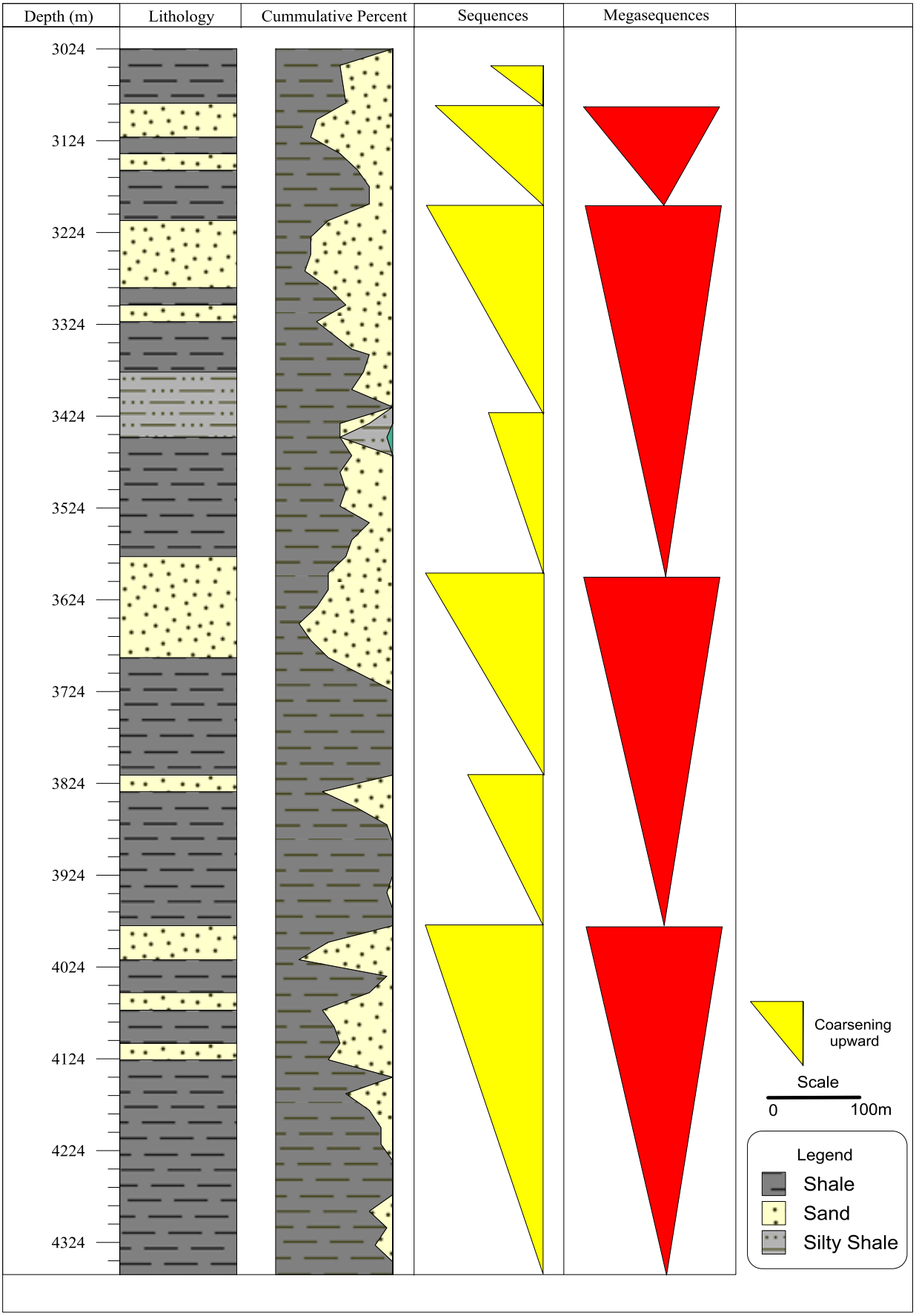


Figure 4.1. Lithostratigraphic Section of the study well

4.2 Foraminiferal Species of the studied well

63foraminiferal species comprising 33 genera from 21 families and 3 suborders were recovered and identified. The species recovered are further classified into Benthonic and planktonic (Fig. 4.2 and 4.3). Of the recovered components benthonic foraminiferal species constitute approximately 71%. Planktonic foraminiferal constitute the remaining 29%. The photomicrographs of some species were taken and shown on Plates 1

4.2.1 Planktonic Foraminifera

Eighteen (18) planktonic foraminiferal speciesbelonging to seven (7) genera and three (3) families were identified. Species abundance is poor (Figs. 4.2 and 4.4). The only exceptionally abundant species are *Praeorbulina glomerosa curva*, and *Praeorbulina glomerosa*. Other important species are *Globigerina ciperoensis*, *Catapsydrax dissimilis*, *Globigerinoides altiaperturus* and *Catapsydrax stainforthi* (Fig. 4.2). The

4.2.2 Benthonic Foraminifera

The benthonic foraminiferal species in the studywell is made up of diverse and abundant foraminiferal species (Figs. 4.3 and 4.4). Faunal preservation is fairly good all through the section (Fig. 4.4). Forty five (45) benthonic foraminiferal species belonging to twenty six (26) generawere identified (Figs. 4.3). Out of this, the calcareous benthonics contributed forty (40) species belonging to twenty four (24) genera (Figs. 4.3) while the arenaceous benthonics contributed five (5) species belonging to two (2) genera (Figs. 4.3).

The calcareous benthonics are dominated by species of *Uvigerina isidroensis*, *Brizalina mandoroveensis*, *Eponides eshira* and *Lenticulina grandis*. The abundance of the remaining species was poor in many instances single occurrences (Fig. 4.3). The arenaceous benthonics foraminifera are dominated by species of *Textularia panamensis*, and *Haplophragmoides* sp. Species of *Textularia panamensis*, *Textularia* sp. have single

occurrences (Fig. 4.3). The photomicrographs of some species were taken and shown on Plates 2, 3 and 4.

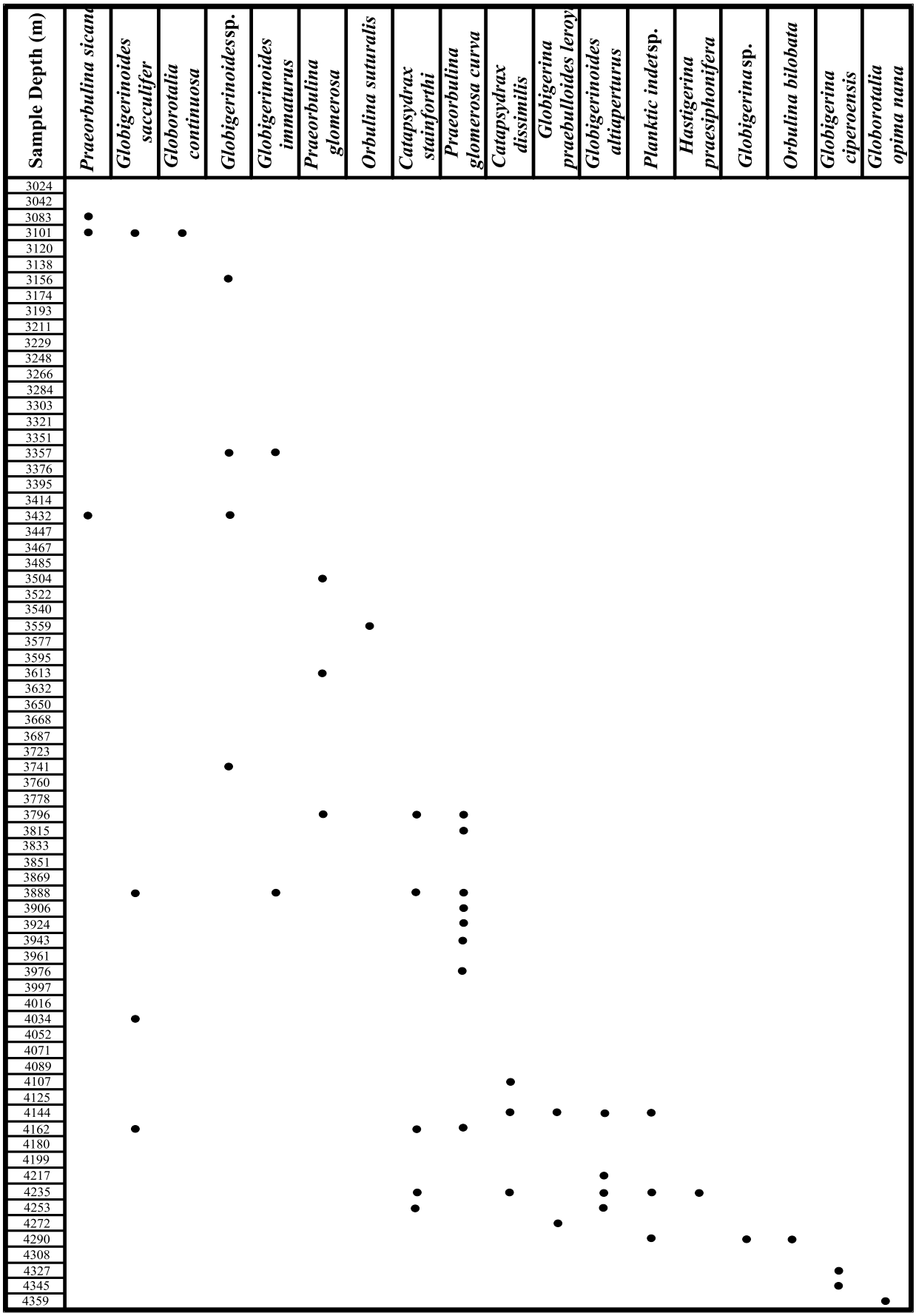


Figure 4.2. Planktonic foraminiferal distribution chart of the studied well.

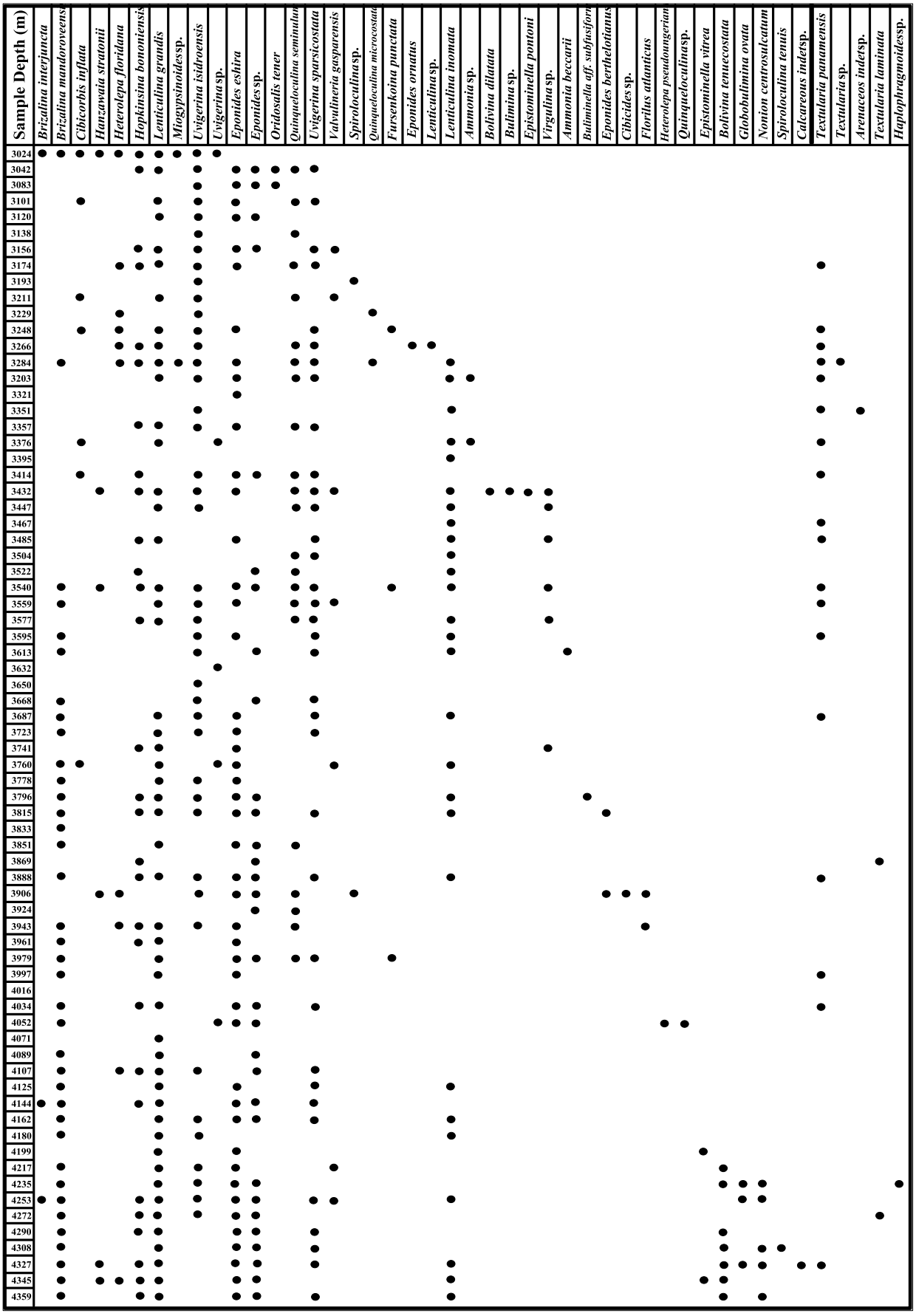


Figure 4.3. Benthonic foraminiferal distribution chart of the studied well.

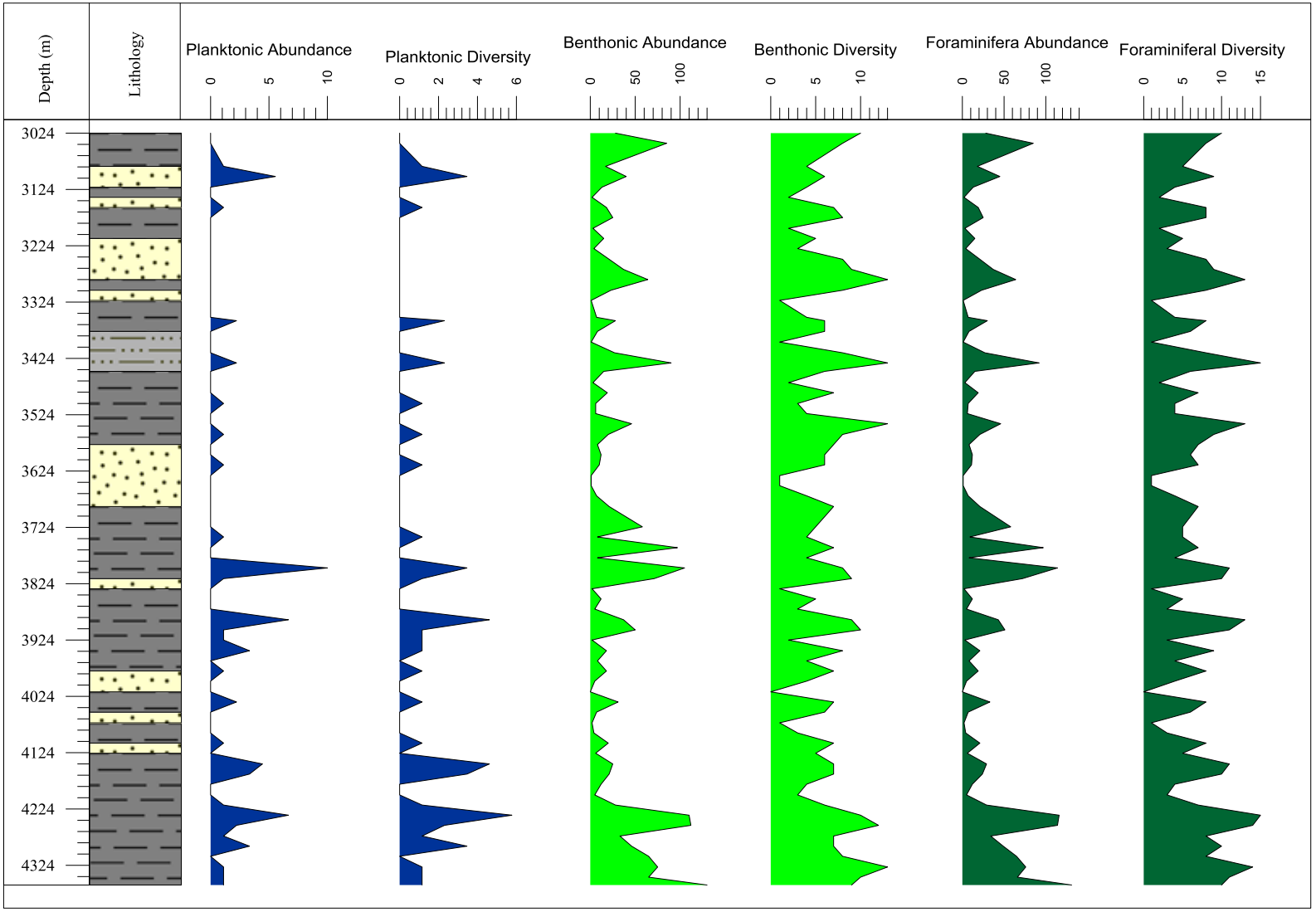


Figure 4.4. Abundance and diversity of benthonic, planktonic and total foraminiferal species recovered from the study well

4.2.3 Range charts

Range charts for both benthonicand planktonicforaminiferal species were generated and these show great differences in the ranges of the fauna found in the samples of the study well. The range charts form the basis for the biostratigraphic zonation. The planktonic foraminiferal range chart (Fig. 5.3)shows that most of the species have short stratigraphic ranges and are also restricted to a particular interval, a criterion that make them good index species. The only exceptional species among the planktonic foraminifera are *Globorotalia sacculifer* and *Globigerinoides immaturus*which have long stratigraphic range. For the benthonic foraminiferal species some species ranged throughout the well section (e.g. *Brizalina mandoroveensis*, *Lenticulina grandis*) while others (e.g. *Miogypsinoides* sp., *Oridorsalis tener*, *Eponides vitrea* and *Eponides berthelotianus*) are restricted to a particular depth range (Fig. 5.5).

4.2.4 Distribution of the foraminiferal suborders

Thegeneralcompositionofthe foraminiferal species in terms of wall structure of well – 004 isshown in figure 4.5.Overallthecalcareous hyaline componentisthemostabundant with 96 %, while Porcelaneous and Arenaceous with 2.3 % and 2.1 % respectively.Amoredetaileddivisionoftheassemblagecanbeexamined ifthenumberoffamilies, genera and species belonging to each suborder is known.These resultsareshowninTable 4.1. Familiespercentages arebased on number ofindividualsrecorded. The relative abundance and percentage of the suborders at each sample depth is shown in figures 4.6 and 4.7 respectively.

In this study the assemblages comprises a total of 21 families, consisting 32 genera and 61 species. The Uvigerinidae, Eponididae, Bolivinitidae and Nodosariidae are the most diverse families among the Rotaliina (Calcareous hyaline) (Table 4.1). The Textulariina (Arenaceous) is represented by Textulariidae and Lituolidae. The Miliolidae is the dominant family of the Miliolina (Porcelaneous) and contain the most dominant and abundant species.

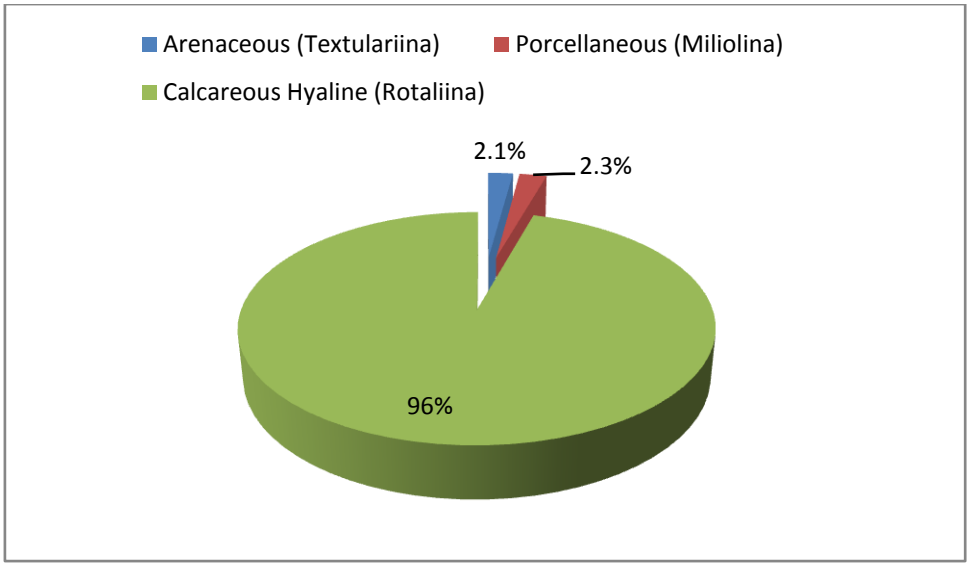


Figure 4.5. A pie chart showing percentages ofthe foraminiferal assemblages based on wall composition

Table 4.1.Thegeneric, specific and families abundanceofall Suborders.

Suborder	Family	Number of Genera	Number of Species	Abundance of Taxa %
Textulariina	Lituolidae	1	1	0.05
	Textulariidae	1	3	2.05
Miliolina	Nubeculariidae	1	2	0.14
	Miliolidae	1	3	2.19
Rotaliina	Nodosariidae	1	3	14.50
	Turrilinidae	1	1	0.19
	Bolivinitidae	2	4	20.18
	Buliminidae	2	2	0.38
	Uvigerinidae	2	4	30.39
	Discorbidae	2	4	1.00
	Rotaliidae	1	2	0.14
	Miogypsinidae	1	1	0.14
	Eponididae	2	5	21.47
	Cibicididae	1	1	0.05
	Caucasinidae	2	2	0.91
	Nonionidae	2	2	0.57
	Alabaminidae	1	1	0.10
	Anomalinidae	2	3	2.53
	Hantkeninidae	1	1	0.05
	Globorotaliidae	1	2	0.10
	Globigerinidae	4	14	2.86

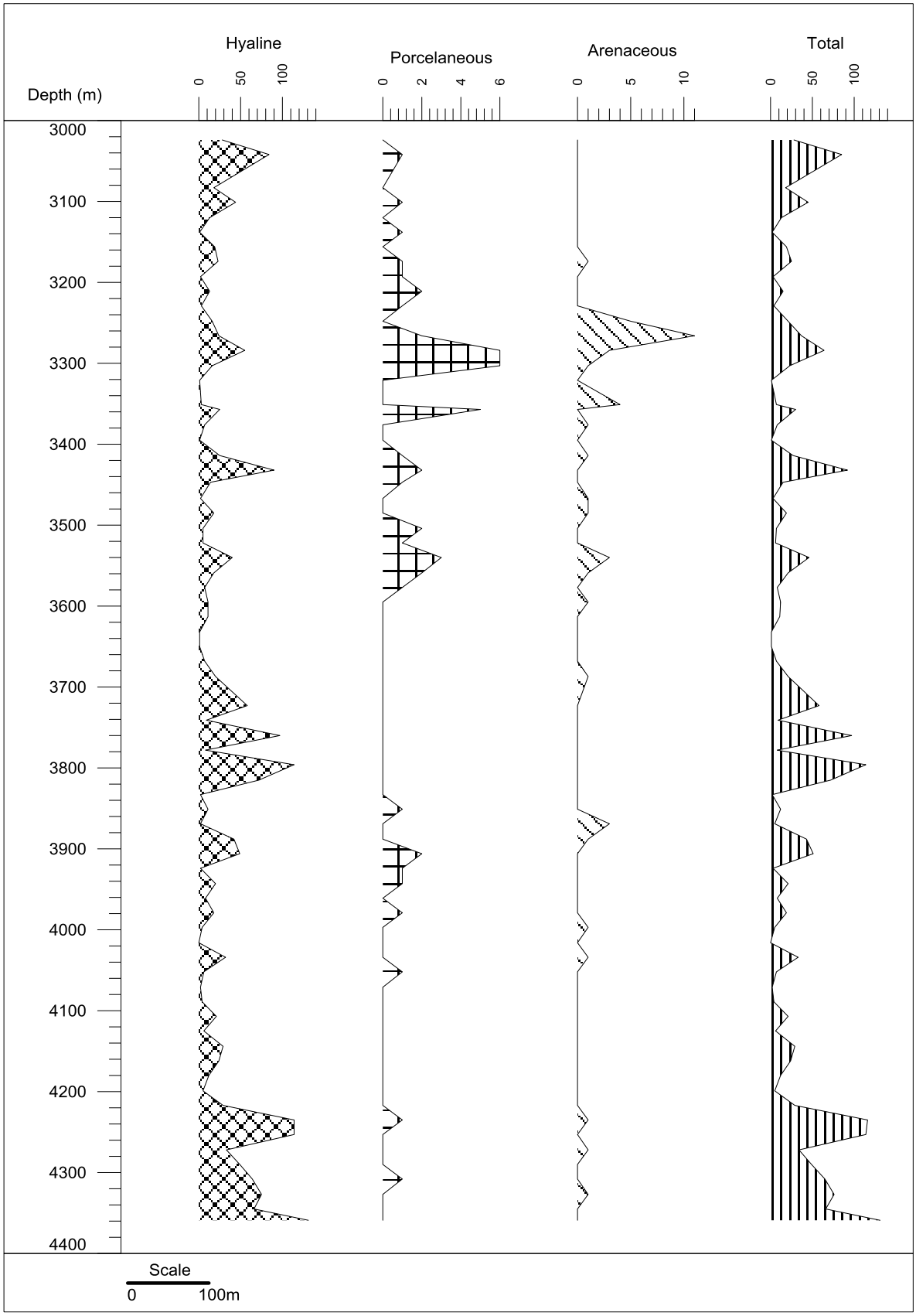


Figure 4.6. Relative abundances of the three foraminiferal wall compositiontypes at each depth

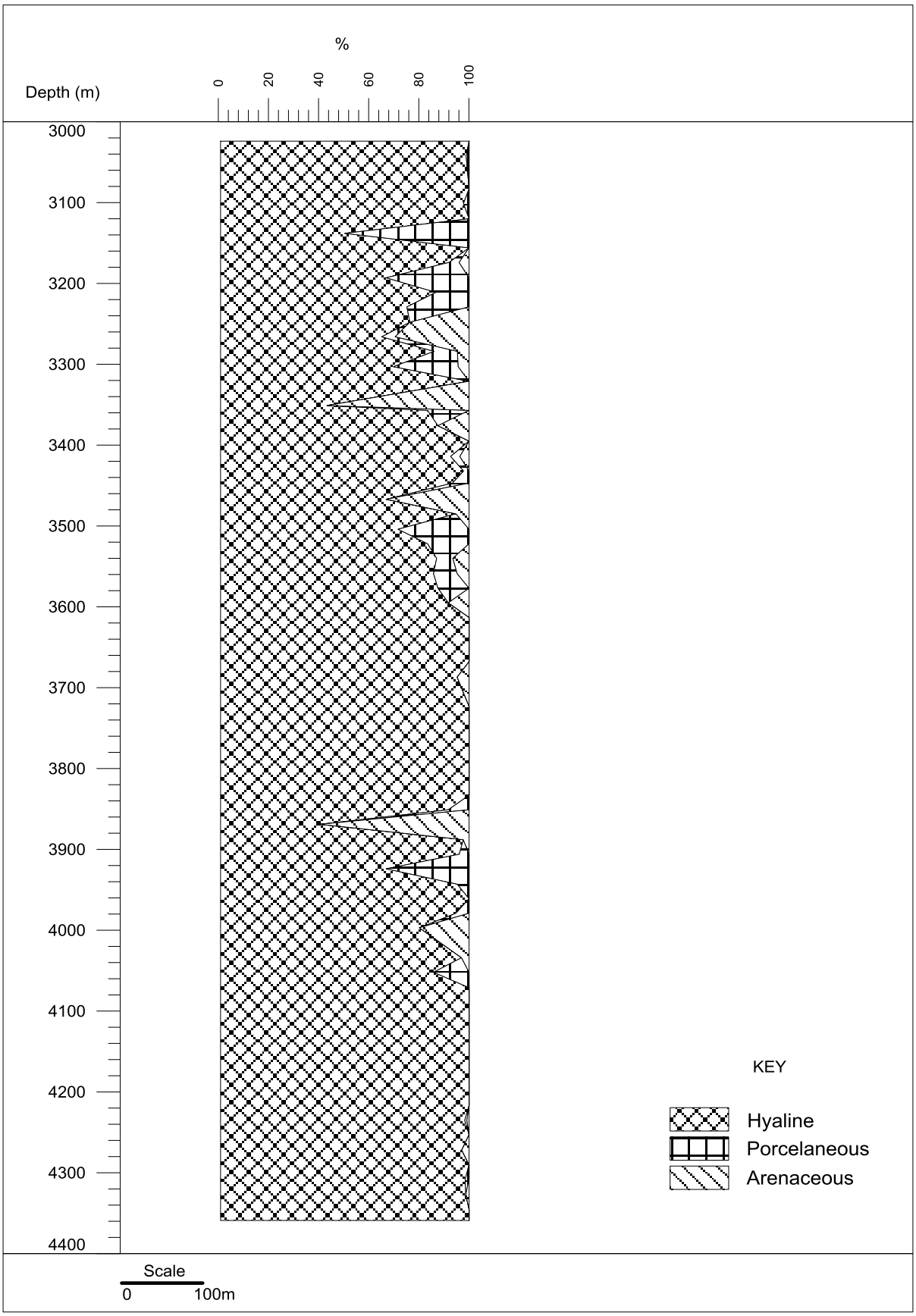


Figure 4.7. Relative Percentages of the three foraminiferal wall composition types at each depth

CHAPTER FIVE

5.0 DISCUSSION

5.1 Lithostratigraphy

The lithostratigraphic units of the analyzed interval (3,024 m – 4,359 m) is interpreted as the Paralic sequence of Agbada Formation (Fig. 4.1) base on the alternation of sandstone and shale and the coarsening upward nature of the study well section. Previous authors (e.g. Avbovbo, 1978) interpreted the alternation of sandstones and shales of Agbada Formation as delta-front, distributary-channel, and deltaic-plain origin. The alternating sequence of sandstones and shales of the Agbada Formation has been shown by Weber (1971) to be cyclic sequences of marine and fluvial deposits.

5.2 Age Determination of the Study Well

From the planktonic foraminifers that were recovered during the study, the following index forms were identified (Fig. 5.1):

Praeorbulina glomerosa, *Praeorbulina sicana*, *Globigerina ciperoensis*, *Catapsydrax dissimilis*, *Globigerinoides altiaperturus*and *Catapsydrax stainforthi*

Using the index forms as defined by Postuma (1971); Bolli and Saunders (1985) and Petters (1983), the age of the studied section of the study well (Well – 004) has been interpreted to belong to Late – Oligocene to Early – Middle Miocene (Figs. 5.1, 5.2).

5.2.1 Late Oligocene

The presence of *Globigerina ciperoensis*, *Globorotalia opima nana*and the absence of *Globigerinoides* spp. is indicative of Late – Oligocene age and occurs between intervals 4,359m – 4,327m**.** According to Postuma(1971); Bolli and Saunders (1985) and Petters (1983), these planktonic foraminifers are both valuable index species for Late - Oligocene.Petters (1979) used *Globorotalia opima nana* to define late Oligocene age in Parable – 1 well in the Niger Delta Basin. Hewaidy *et al*. (2014) used the presence of *Globigerina ciperoensis* in

addition to the absence of *Globigerinoides* spp. to defined Late – Oligocene age in west Central Sinai, Egypt. In this study, the boundary of Oligocene and Miocene was picked at 4,327 m based on the first downhole occurrence (FDO) of Oligocene species *Globigerina ciperoensis* and occurrence of *Globigerinoides* ssp. above the FDO of the Late – Oligocene index species. The occurrence of *Globigerinoides* has widely been accepted as the datum for the Oligocene/Miocene boundary (Bolli, 1966; Bolli and Saunders, 1985). The base of Late – Oligocene was not penetrated by the study well (Figs. 5.1, 5.2).

5.2.2 Early Miocene

The lower limit of Early – Miocene in the studied samples is marked at 4327 m by the FDO of *Globigerina ciperoensis*. The upper limit is marked at 3796m based on last downhole occurrence (LDO) of *Praeorbulina glomerosa* and FDO of *Catapsydrax stainforthi*. This interval is also characterized by the presence of other Early – Miocene index species which include *Catapsydrax dissimilis*, *Globigerinoides altiaperturus* (Figs. 5.1, 5.2).

5.2.3 Early – Middle Miocene

The lower limit of Early – Middle Miocene is marked at 3,796 m by (LDO) of *Praeorbulina glomerosa* and FDO of *Catapsydrax stainforthi*. The upper limit of Early – Middle Miocene is not within the interval studied (Figs. 5.1, 5.2).

5.3 Foraminiferal Biostratigraphy of the Study Well

Biostratigraphy uses the chronostratigraphic range of fossil species to correlate stratigraphic sections and their palaeoenvironmental preferences to provide information on depositional settings (Emery and Myers, 1996). The most useful fossil groups in biostratigraphic studies are those that evolved rapidly, with distinct morphologicalchanges that spread over a wide area in significant numbers (Emery and Myers, 1996). 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 interpretations.

5.3.1 Planktonic Foraminifera Biozonation

In this study, the schemes proposed by Bolli and Saunders (1985) for the Oligocene – Holocene was used. The N – Zone of Blow (1969) as amended by Kennett and Srinivasan (1983) for the Late – Middle Eocene to recent were also considered. In this study only cutting samples were available; therefore, the first evolutionary appearance of index species which was the principal criterion used by these investigators (Blow, 1969;Kennett and Srinivasan, 1983; Bolli and Saunders, 1985) for defining their zonal boundaries could not be defined. For this reason, extinctions (or first downhole occurrences) and evolving (or last downhole occurrence) of selected microfossils were used. The same method of defining biohorizons have been applied in the Niger Delta Basin (Petters, 1983; Ozumba, 1995; Ozumba and Amayor, 1999). Medina (2001) used the same method in the biozonation of Tertiary Campeche Basin Mexico.

In this study, five planktonic foraminiferal zones and two subzones were proposed: one zone for the Late Oligocene; *Globigerina ciperoensis* Taxon range zone (P22/N3). Three for the Early Miocene; *Orbulina bilobata* Interval zone (N4), *Globigerinoides altiaperturus* – *Catapsydrax dissimilis* Concurrent range zone (N5 – N6) and *Catapsydrax stainforthi* Interval zone (N7). One for the Early – Middle Miocene; *Praeorbulina glomerosa* Interval zone (N8 – N9). Identifieddatum markersand zones in the study well are presented in figures. 5.1 and 5.2respectively. A comparison of the zones proposed in this study with the zonal schemes described by Bolli and Saunders (1985), Stainforth *et al.* (1975) and Medina (2001) is shown in figure. 5.3.

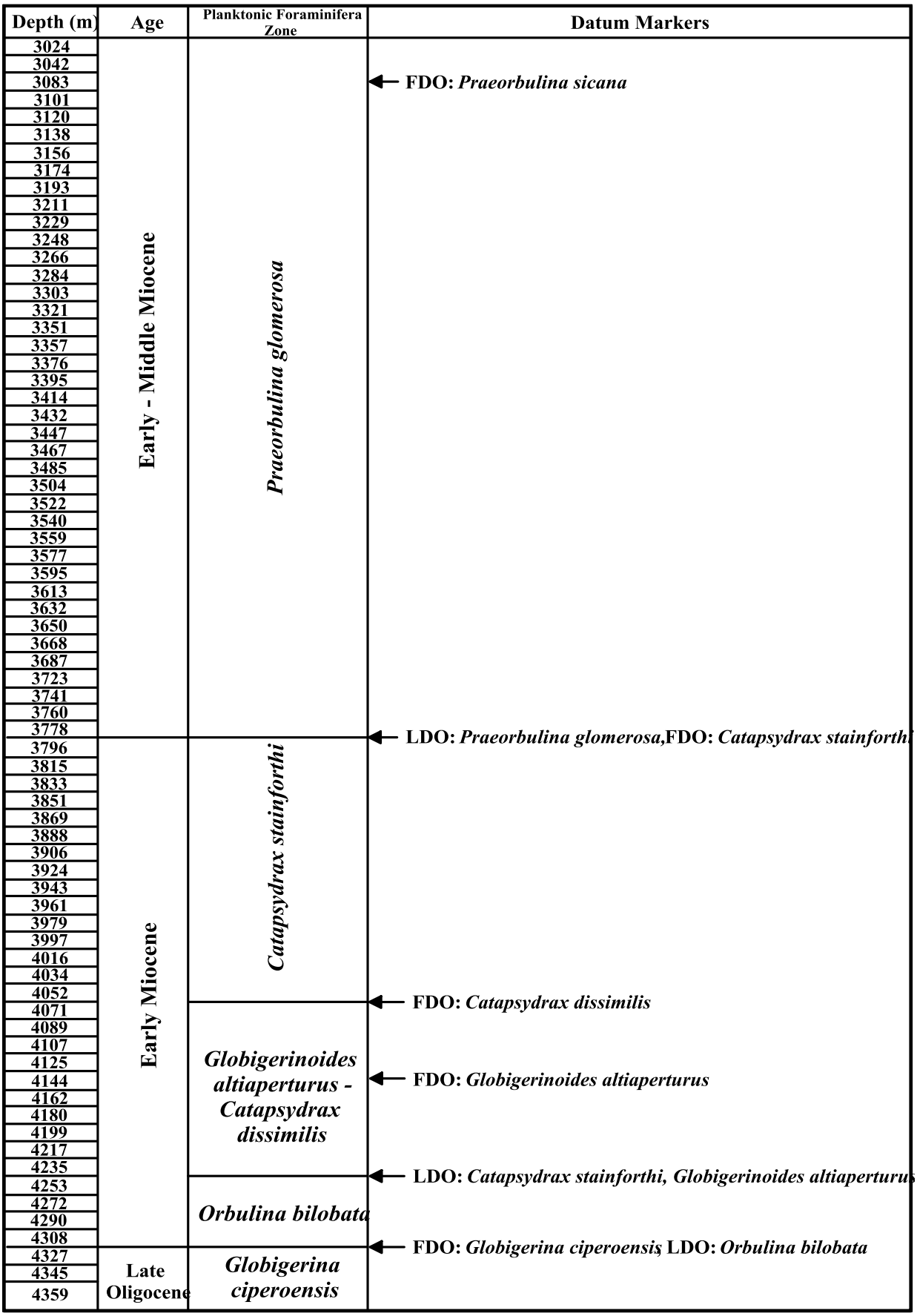

Depth (m)
Age
Planktonic Foraminifera Zone
Datum Markers
3024
3042
3083
3101
3120
3138
3156
3174
3193
3211
3229
3248
3266
3284
3303
3321
3351
3357
3376
3395
3414
3432
3447
3467
3485
3504
3522
3540
3559
3577
3595
3613
3632
3650
3668
3687
3723
3741
3760
3778
3796
3815
3833
3851
3869
3888
3906
3924
3943
3961
3979
3997
4016
4034
4052
4071
4089
4107
4125
4144
4162
4180
4199
4217
4235
4253
4272
4290
4308
4327
4345
4359
Early - Middle Miocene
Early Miocene
Late Oligocene
Praeorbulina glomerosa
Catapsydrax stainforthi
Globigerinoides altiaperturus - Catapsydrax dissimilis
Orbulina bilobata
Globigerina ciperoensis
FDO: Praeorbulina sicana
LDO: Praeorbulina glomerosa,FDO: Catapsydrax stainforthi
FDO: Catapsydrax dissimilis
FDO: Globigerinoides altiaperturus
LDO: Catapsydrax stainforthi, Globigerinoides altiaperturus
FDO: Globigerina ciperoensis, LDO: Orbulina bilobata

Figure 5.1. Proposed Planktonic foraminifera zones and Datum Marker in the study well

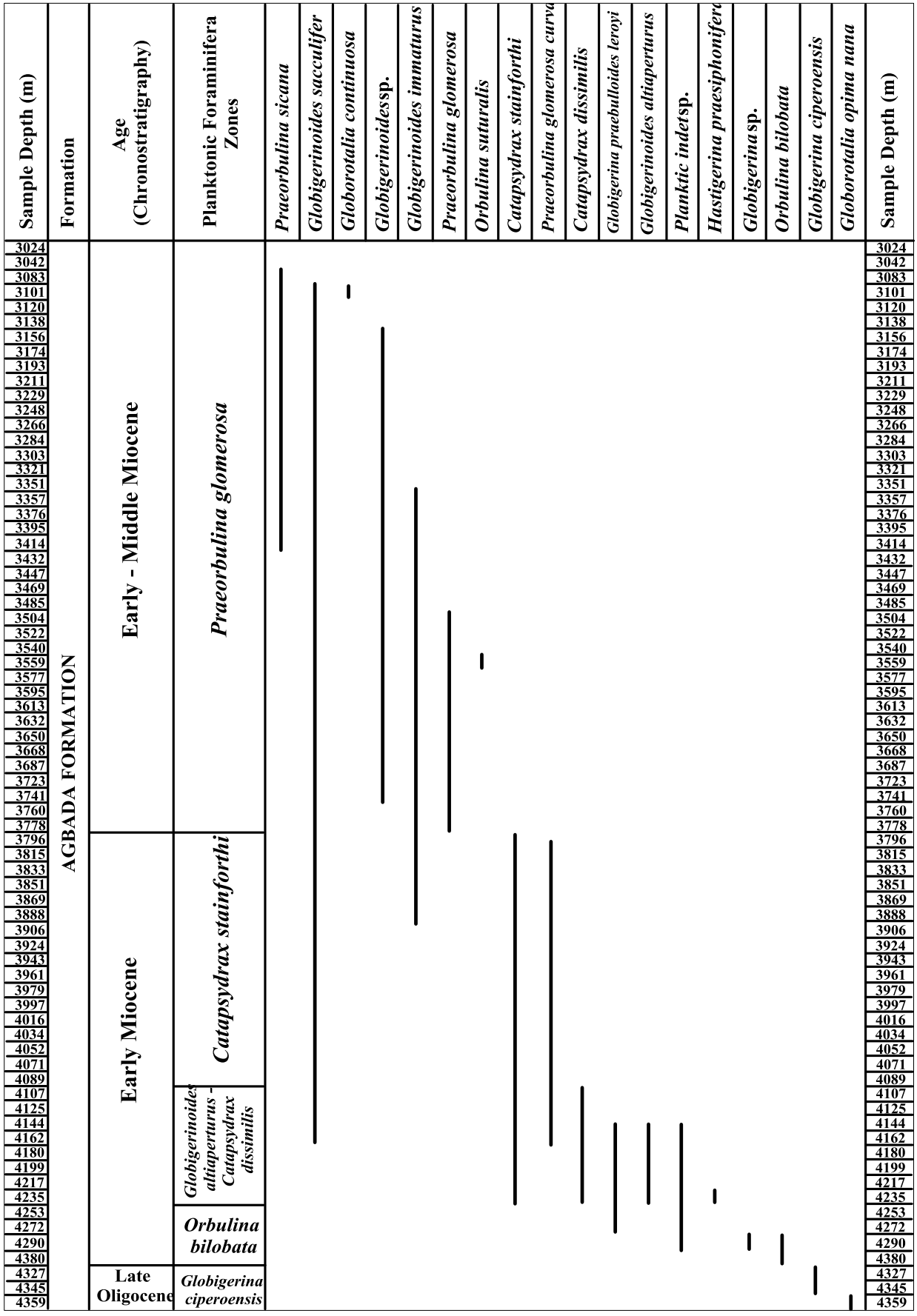


Figure 5.2. Range chart and proposedPlanktonic foraminifera zones of the study well

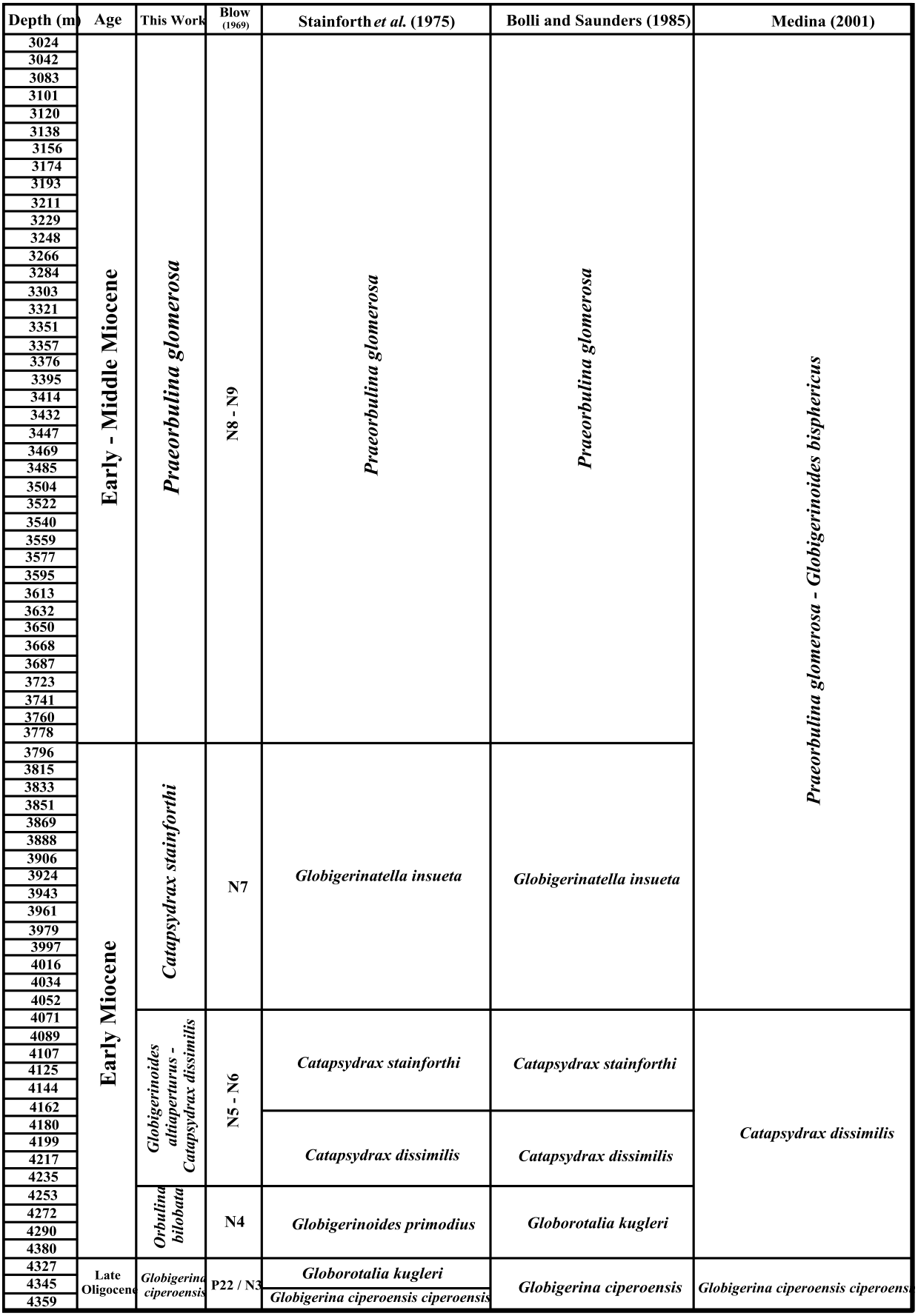


Figure 5.3. Comparison of the Zones identified in this study with other Zonal Scheme

5.3.1.1 *Globigerina ciperoensis* Taxon range zone (P22/N3)

Age: Late Oligocene

Definition: This zone is defined by FDO of *Globigerina ciperoensis* (top), the lower boundary of this zone is indeterminate (Figs. 5.1 and 5.2).

Occurrence: The top of the zone is marked at 4,327 m. species restricted to this zone are *Globorotalia opima nana* and *Globigerina ciperoensis*. The presence of the mentioned index species suggest Late Oligocene age for this zone (Figs. 5.1 and 5.2).

Remark:*Globigerina ciperoensis* zone correlates with zone P22/N3 of Blow (1969) and can be compared with *Globigerina ciperoensis* zone of Stainforth *et al.* (1975) and *Globigerina ciperoensis ciperoensis*zoneof Medina (2001). Bolli and Saunders (1985) subdivide this zone into *Globigerina ciperoensis ciperoensis*zoneand *Globigerina kugleri* zone (Fig. 5.3).

5.3.1.2 *Orbulina bilobata* Interval zone (N4)

Age: Early Miocene

Definition: The base of this zone is defined by LDO of *Orbulina bilobata*. The top is marked by LDO of *Globigerinoides altiaperturus* (Figs. 5.1 and 5.2).

Characteristics: This zone is recognized between depths of 4,253 m and 4,327 m. The LDO of *Orbulina bilobata* coincide with FDO of *Globigerina ciperoensis* while the LDO of *Globigerinoides altiaperturus* coincide with LDO of *Catapsydrax stainforthi*. Species restricted to this zone are *Orbulina bilobata* and *Globigerina* sp. species of *Globigerinoides praebulloides leroyi*ranged beyond this zone (Figs. 5.1 and 5.2).

Remark: *Orbulina bilobata* zoneas identified in this study correlates with zone N4 of Blow (1969) and may be compare with *Globorotalia kugleri* of Stainforth *et al.*(1975) and *Globorotalia primordius* of Bolli and Saunders(1985) (Fig. 5.3).

5.3.1.3 *Globigerinoides altiaperturus – Catapsydrax dissimilis* Concurrent range zone (N5 – N6)

Age: Early – Miocene

Definition: The base of this zone is recognized by the LDO of *Catapsydrax stainforthi* and*Globigerinoides altiaperturus*. The top coincides with the FDO of *Catapsydrax dissimilis* (Figs. 5.1 and 5.2).

Characteristics: This zone is recognized at the depth of 4,107m – 4,253 m. Species that are restricted to this zone are *Hastigerina praesiphonifera*, *Globigerinoides altiaperturus*, and *Catapsydrax dissimilis* (Figs. 5.1 and 5.2).

Remark:*Globigerinoides altiaperturus – Catapsydrax dissimilis*zonecorrelates with zone N5 – N6 of Blow (1969).Stainforth *et al.*(1975) and Bolli and Saunders (1985) defined boundary between zone N5 and N6 of Blow (1969) by the LDO of *Giobigerinatella insueta*an event that could not be determined in this study. This zone may be correlated with *Catapsydrax dissimilis* zone (N5) – *Catapsydrax stainforthi* zone (N6) of Stainforth *et al.*(1975); Bolli and Saunders (1985). Medina,(2001) called zone N4, N5 and N6 *Catapsydrax dissimilis* zone because of the absence of index species that separate the zones (Fig. 5.3).

5.3.1.4 *Catapsydrax stainforthi* Interval zone (N7)

Age: Early Miocene

Definition: The base of this zone is marked by the FDO of *Catapsydrax dissimilis*. The top is recognized byFDO of *Catapsydrax stainforthi* (Figs. 5.1 and 5.2).

Characteristics: This zone is marked at 3,796 m – 4,107m. The FDO of *Catapsydrax dissimilis* (top of this zone)coincide with the LDO of *Praeorbulina glomerosa*and FDO of *Praeorbulina glomerosa curva*. *Globigerinoides immaturus*ranged beyond this zone.

Remark: *Catapsydrax stainforthi* zone correlates with zone N7 of Blow (1969)andmaybe correlated with *Globigerinatella insueta* zone of Stainforth *et al.* (1975); Bolli and Saunders (1985) (Fig. 5.3).

5.3.1.5 *Praeorbulina glomerosa* Interval zone (N8 – N9)

Age: Early – Middle Miocene

Definition: The base of this zone is defined by the LDO of *Praeorbulina glomerosa* and the top is defined by the FDO of *Praeorbulina sicana*(Figs. 5.1 and 5.2).

Characteristics: This zone is recognized at the depth of 3,083 to 3,432 m. Species that are restricted to this zone are *Praeorbulina glomerosa, Praeorbulina sicana*, *Orbulina suturalis, Globorotalia continuosa*and *Globigerinoides*sp. *Globigerinoides sacculifer* and *Globigerinoides immaturus* are inherited from the previous zone (Figs. 5.1 and 5.2).

Remark:*Praeorbulina glomerosa* Interval zone correlates with zone N8 – N9 of Blow (1969). In this study the index species that separate zone N8 – N9 is absent. *Praeorbulina glomerosa* Interval zone may be correlated to *Praeorbulina glomerosa* of Stainforth *et al.*(1975) and Bolli and Saunders(1985) (Fig. 5.3).

5.3.2 Benthonic Foraminifera Biozonation

In this study, four benthonic foraminiferal biozones have been proposed with the aid of Petters (1982) benthonic foraminiferal zonation of the Niger Delta Basin. The proposed zones are; *Epistominella vitrea* Taxon range zone, *Eponides berthelotianus* Interval zone, *Ammonia* sp. Interval zone and *Miogypsinoides* sp. Taxon range zone (Fig. 5.4). The dating of the well using planktonic foraminifera was used for the dating of the proposed benthonic biozones. The biozones were correlated with Niger Delta benthonic foraminiferal biozones of Petters (1982), standard planktonic foraminiferal biozones and proposed planktonic foraminiferal biozone of this study (Table 5.1).

5.3.2.1 *Epistominella vitrea* Taxon Range Zone

Age: Late Oligocene to Early Miocene

Definition: The zone is defined by the total stratigraphic range of *Epistominella vitrea*(Fig. 5.4).

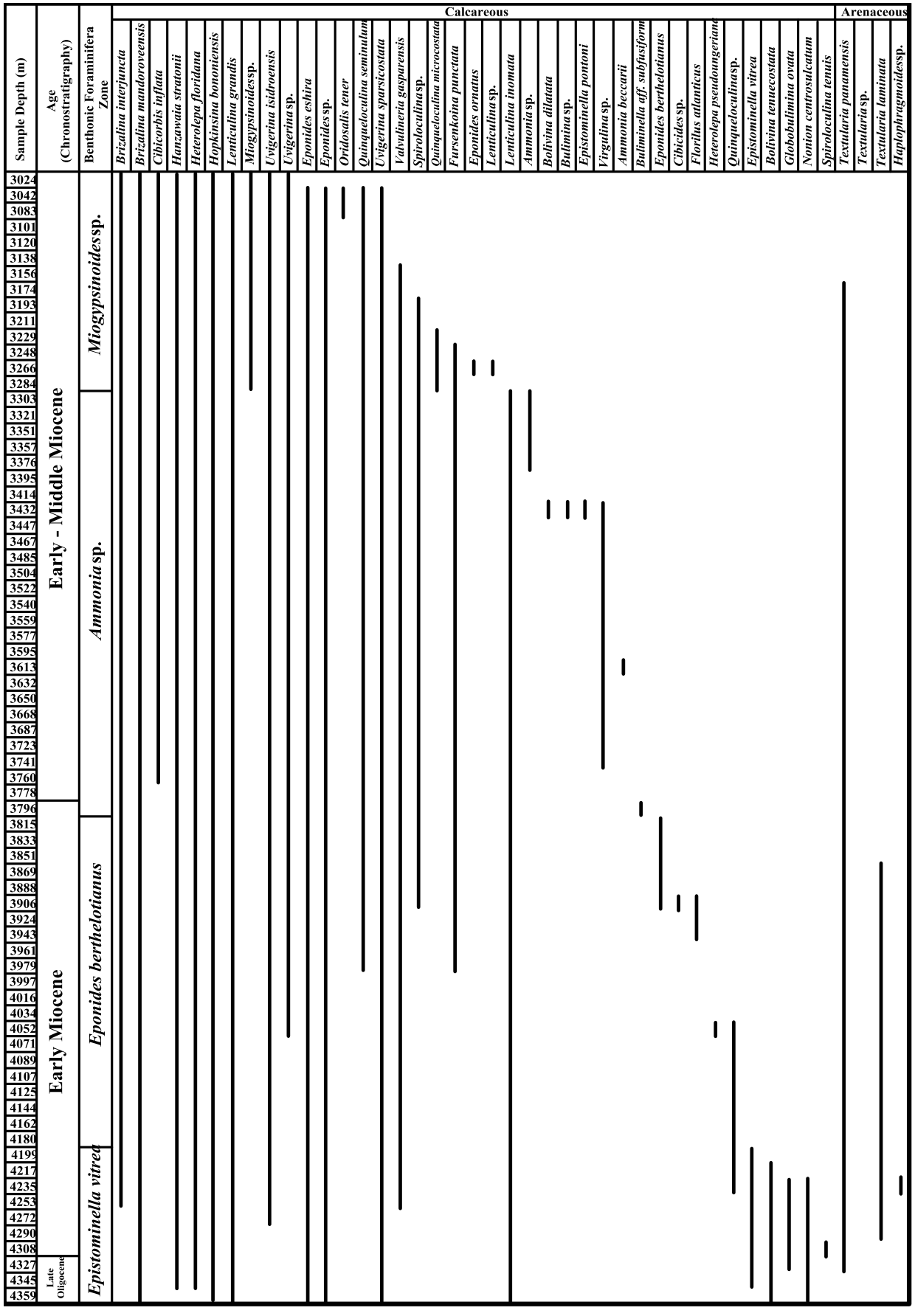


Figure 5.4. Range chart and proposed benthonic foraminifera zones of the study well

Table 5.1. Correlation of proposed planktonic and benthonic foraminiferal zone with global planktonic foraminiferal zone and Niger Delta benthonic foraminifera zone

AGE	STANDARD GLOBAL PLANKTONIC FORAMINIFERAL ZONE (Blow, 1969; Stainforthi,*et al.*, 1975; Petters, 1983; Bolli and Saunders, 1983; Medina 2001)	PLANKTONIC FORAMINIFERAL ZONE (This Study)	NIGER DELTA BENTHONIC FORAMINIFERAL ZONE (Petters, 1982)	BENTHONIC FORAMINIFERAL ZONE (This Study)
EARLY - MIDDLE MIOCENE	*Globorotalia fohsi peripheroronda* *Praeorbulina glomerosa*	*Praeorbulina glomerosa*	*Hanzawaia mantaensis - Cibicidoides colombianus*	*Miogypsinoides* sp.
				Ammonia sp.
EARLY MIOCENE	*Globigerinatella insueta*	*Catapsydrax stainforthi*	*Altistoma scalaris - Epistominella pontoni*	*Eponides bertheloti anus*
	Catapsydrax stainforthi	*Globigerinoides altiaperturus - Catapsydrax dissimilis*		
	Catapsydrax dissimilis			*Epistominella vitrea*
	Globorotalia kugleri	*Orbulina bilobata*		
LATE OLIGOCENE	*Globigerina ciperoensis*	*Globigerina ciperoensis*		

Characteristics: This zone is characterized by *Epistominella vitrea* in association with *Bolivina tenuicostata, Globobulimina ovata, Nonion centrosulcatum, Spiroloculina tenuis,* and *Haplophragmoides* sp. The zone occur between the depths of 4,199 m to 4,359 m (Fig. 5.4).

Remark: *Epistominella vitrea* zone may be correlated with lower*Altistoma scalaris – Epistominella pontoni* benthonic foraminiferal zone of Petters (1982). The zone also correlates with *Globigerina ciperoensis, Orbulina bilobata* and *Globigerinoides altiaperturus – Catapsydrax dissimilis*planktonic foraminiferal zones of this study (Table 5.1).

5.3.2.2 *Eponides berthelotianus* Interval zone

Age: Early Miocene

Definition: The base of this zone is defined by the FDO of *Epistominella vitrea* which coincide with the top of *Epistominella vitrea* Taxon Range Zone. The top is marked by the FDO of *Eponides berthelotianus* which coincide with the LDO of *Buliminella aff. Subfusiformis*(Fig. 5.5).

Characteristics: Species restricted to this zone are*Eponides berthelotianus,Cibicides* sp., *Florilus atlanticus,* and *Heterolepa pseudoungeriana*. The LDO of *Uvigerina* sp., *Quinqueloculina seminulum, Spiroloculina* sp., *Fursenkoina punctata* occur in this zone and ranged into *Ammonia* sp. interval zone. The remaining species of this zone ranged from *epistominella vitrea*Taxon range zone and ranged into *Ammonia* sp. zone. *Eponidesberthelotianus* Interval zone occurs between the depths of 3,815 m – 4,199 m (Fig. 5.4).

Remark:*Eponides berthelotianus* zone correlates with upper *Altistoma scalaris – Epistominella pontoni* benthonic foraminiferal zone of Petters (1982) and *Catapsydrax stainforthi*planktonic zone of this study (Table 5.1).

5.3.2.3 *Ammonia* sp. Interval Zone

Age: Early Miocene – Early Middle Miocene

Definition: The base of this zone is defined by the FDO of *Eponides berthelotianus* which coincide with the top of *Eponidesberthelotianus* Interval zone and the bioevents LDO of *Buliminella aff. Subfusiformis.* The top of the zone is marked by the FDO of *Ammonia* sp.which coincide with FDO of *Lenticulina inomata*(Fig. 5.4).

Characteristics: Species that are restricted to this zone are;*Ammonia*sp**.,***Bolivina dilatata*, *Bulimina* sp., *Epistominella pontoni*, *Virgulina* sp., and *Ammonia beccarii*. The LDO bioevents of *Cibicorbis inflata* occur in this zone and range into *Miogypsinoides* sp.taxon range zone. Other species that occur within zone range from *Eponidesberthelotianus* Interval zone into *Miogypsinoides* sp. Taxon range zone.*Ammonia* sp. Interval Zone occur between the depths of 3,303m to 3,815m (Fig. 5.4).

Remark:*Ammonia* sp. zone correlates with lower *Hanzawaia mantaensis – Cibicidoidis columbianus* benthonic foraminiferal zone of Petters (1982) and *Praeorbulina glomerosa* planktonic zone of this study (Table 5.1).

5.3.2.4 *Miogypsinoides* sp. Taxon Range Zone

Age: Early Middle Miocene

Definition:*Miogypsinoides* sp. Taxon range zone is defined by the total stratigraphic range of *Miogypsinoides* sp. (Fig. 5.4).

Characteristics:*Miogypsinoides* sp. occurs in association with *Oridorsalis tener*, *Quinqueloculina microcostata*, *Eponides ornatus*, *Lenticulina* sp., and *Textularia* sp. (Fig. 5.4).

Remark:*Miogypsinoides* sp. zone correlates with upper *Hanzawaia mantaensis* – *Cibicidoidis columbianus* benthonic foraminiferal zone of Petters (1982) and *Praeorbulina glomerosa* planktonic zone of this study (Table 5.1).

5.4 Palaeoenvironment

There are diverse documented approaches since early sixties on foraminiferal palaeoenvironmental interpretation. Some of the approaches are:

1. Species and general specimen abundance based on the theory that species number and specimen abundance increase with increasing depth of water and greater distance from shore (Bandy, 1953; Parker, 1954; Bandy and Anal, 1960).
2. Genera assemblages (biofacies).
3. Relative percentage (%) of Miliolina, Textulariina and Rotaliina suborders (triangular plot of Murray, 1973).
4. Relative percentage of planktics [planktonic/benthonic (P/B) ratios] amongst many others.

The methods used in this study include:

1. Foraminiferal species assemblages (biofacies) and bathymetric ranges of the dominance genera and species.
2. Miliolina – Textularia – Rotaliina triangular plot (Murray, 1973).
3. Relative planktonic percentages (P/B ratio)

5.4.1 Bathymetry

Palaeobathymetry is the paleoenvironmental interpretation most widely used in petroleum exploration because of its value in determining the depositional history of a basin. Benthonic foraminifera are usually used for this purpose. As bottom dwellers, they provide information about conditions at the sea floor (Fleisher and Lane, 1999). The approach adopted by Petters (1982, 1995), where various biofacies were styled after bathymetric

features was used in this study. This approach was based on previous studies by Harris (1981) and Culver (1988), from which the bathymetric zonation for the offshore Niger Delta was derived. This interpretation took into consideration the total foraminiferal assemblages characteristics and the presence of particular foraminiferal genera and species in the samples. Depositional environment and bathymetric ranges of Allen (1965) were also considered (Appendix II). The palaeobathymetric ranges of some genera and species used in this study are presented in Table 5.2.

In the studied interval the Paleobathymetry ranged from non-marine, shallow inner neritic, inner neritic, inner – middle neritic, middle neritic, middle – outer neritic and outer neritic environment (Fig. 5.5).

Table 5.2. Palaeobathymetric ranges of selected benthonic foraminiferal genera and species in the studied well

SPECIES	Fluvio - Marine	Inner Neritc	Middle Neritic	Outer Neritic	Upper Bathyal	Middle Bathyal	Lower Bathyal	Abyssal
Ammonia								
Quinqueloculina								
Textularia								
Bulimina								
Bolivina								
Brizalina								
Globobulimina								
Hanzawaia								
Hopkinsina								
Heterolepa								
Uvigerina								
Eponides eshira								
Eponides bertholetianus								
Epistominella pontoni								
Epistominella vitrea								
Fusenkoina punctata								
Lenticulina inormata								
Nonion centrosulcatum								
Oridosalis tener								
Spiroloculina tenuies								

5.4.1.1 Non – Marine

Non marine palaeobathymetry is observed between 4,016 m to 4,034 m (Fig. 5.6). This interpretation is based on absence (barren) of foraminiferal species (Figs. 4.2 and 4.3) and high percentage occurrence of sand usually 80% to 95% and 20% to 5% shale.

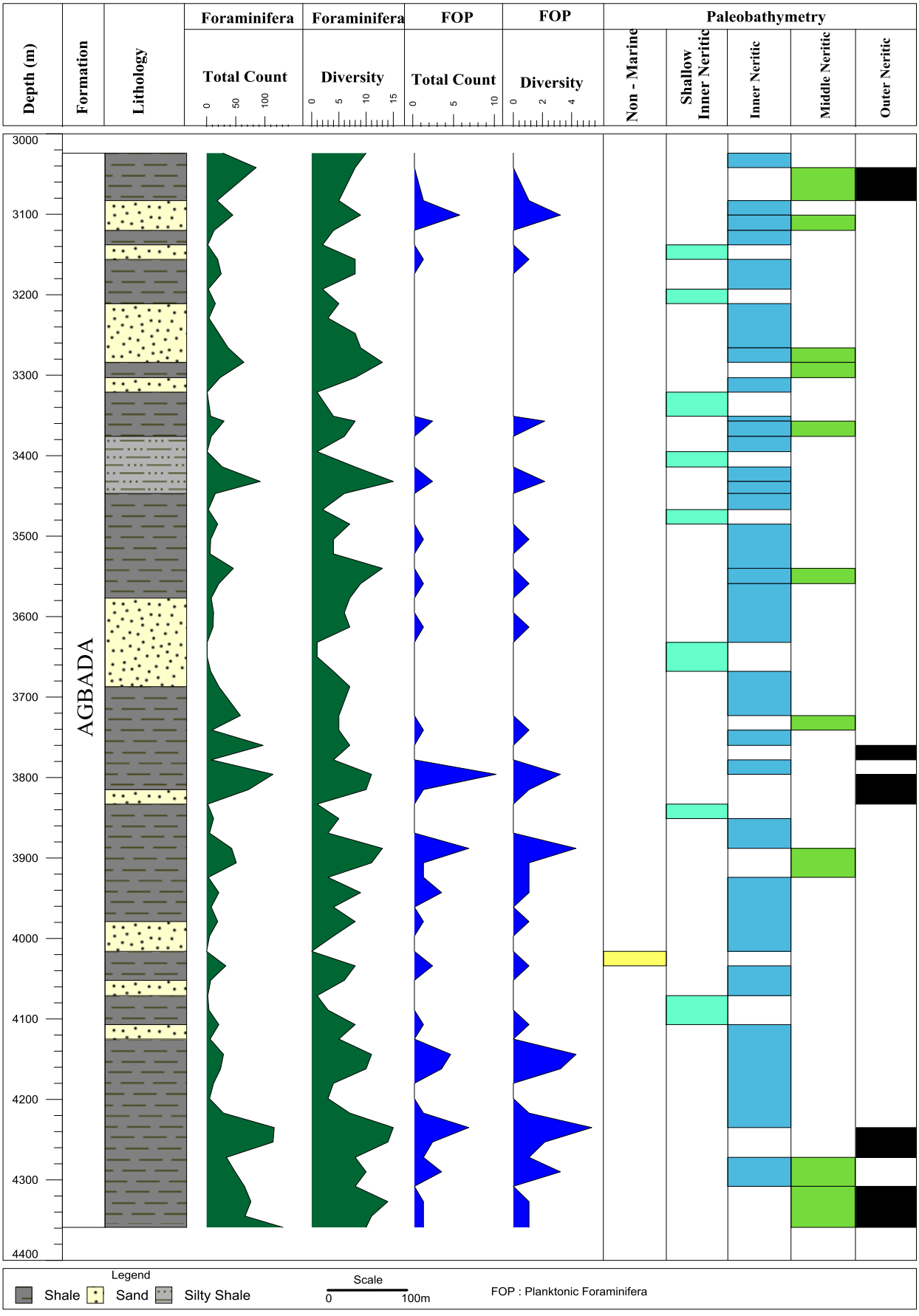


Figure 5.5. Palaeobathymetric interpretation of the study well

5.4.1.2 Shallow Inner Neritic

Boersma, (1978) included shallow inner neritic in subdivision of the neritic environment. The shallow inner neritic is characterized by a numerically small fauna dominated by a few species, very few of which are agglutinated and none of which are pelagic. The agglutinated species construct tests with simple interiors (Boersma, 1978).

In this study, the interval inferred to be shallow inner neritic ranges from the following depths; 4,107 m – 4,071m, 3,851 m – 3,833m, 3,668 m – 3,632m, 3,485 m – 3,467m, 3,414 m – 3,395m, 3,351 m – 3,321m, 3,266 m – 3,211m, 3,156 m – 3,138m (Fig. 5.5) . The intervals are characterized by fine to medium grained sand, contain very few shallow water benthonic foraminifera species e.g. *Textularia panamensis*, *Quinqueloculina seminulum*, *Eponides eshira*, *Eponides* sp. (Fig. 4.3 and Table 5.2)

5.4.1.3 Inner Neritic

This is a subdivision of marine environment that lies within 0 – 20m on the continental shelf (Allen, 1965). According to Boersma, (1978) the inner neritic is usually characterized by coarse-grained, clean sand containing abundant rounded shell fragments; A few species usually dominate the benthic faunas; Tests are small and weakly ornamented. Agglutinated species with simple wall structure are common foraminifera. Common taxa are arenaceous forms (e.g. *Textularia*sp.),*miliolids* (e.g. *Quinqueloculina*), *Nonion* sp., and *Ammonia beccarii*.

The ranges of intervals inferred to be inner neritic environment are 4,235 m – 4,107m, 4,016 m – 3,924m, 3,888 m – 3,851m, 3,796 m – 3,778m, 3,760 m – 3,741m, 3,741 m – 3,668m, 3,632 m – 3,559m, 3,540 m – 3,485m, 3,467 m – 3,447m, 3,421 m – 3,414m, 3,395 m – 3,376m, 3,357 m – 3,351m, 3,321 m – 3,303m, 3,321 m – 3,303m, 3,266 m – 3,211m, 3,211 m – 3,156m, 3,138 m – 3,120m, 3,101 m – 3,083m, 3,042 m – 3,024m (Fig. 5.5).

Deposits in the inner neritic environment of the above intervals are characterized by the following;

1. Low species abundance and diversity of both planktonic and benthonic foraminifera
2. Presence of exclusively inner neritic benthonic foraminiferal species; *Quinqueloculina seminulum*, *Textularia panamensis*, *Textularia laminata*, *Ammonia beccarii* and *Ammonia* sp. (Bandy and Anal 1957; Bandy and Anal, 1960; Haywick and Henderson, 1999; Petters, 1995). The occurrence of the above mentioned species was also used by Bassey and Alalade, (2005) and Chukwu *et al*., (2012) to infer inner neritic environment of deposition in the Niger DeltaBasin.
3. The occurrence of *Eponides eshira*, *Eponides* sp., *Epistominella vitrea*, *Fursenkoina punctata*which are considered to be fluvio marine to middle neritic species by Petters (1995).
4. *Lenticulina grandis* and *Lenticulina inomata*are considered to be characteristics of Inner neritic environment but they ranged up to outer neritic environment (Petters, 1995, Murray 2006).Okosun*et al*., (2012) used the presence of *Lenticulina grandis*, *Lenticulina inomata* andinferred inner neritic environment for sediments of Niger Delta Basin.

5.4.1.4 Inner Neritic – Middle Neritic

The environment of deposition here fluctuated from inner neritic to middle neritic. Benthonics foraminifera occurring within this environment include *Textularia* sp., *Ammonia beccarii*, *miliolids*, *Lenticulina* sp., *Eponides*sp. and *nodosariids*(Boersma, 1978). Lithologically, it is composed of fine to medium grained sand, clays silts and some shale intervals (Chukwu, 2012).

Depth intervals of the study well that are inferred to belong to this environment are; 4,308 m – 4,272m, 3,559 m – 3,540m, 3,376 m – 3,357m, 3,284 m – 3,266m, 3,120 m –

3,101m (Fig. 5.5). Deposition in the Inner – middle neritic environment of the above intervals is suggested based on the occurrence of typical forms from inner and middle neritic environment. The inner neritic forms includes; *Textularia laminata, Quinqueloculina seminulum, Textularia panamensis* (Bandy and Anal 1957; Bandy and Anal, 1960; Haywick and Henderson, 1999; Petters, 1995) while *Eponides eshira, Eponides ornatus, Eponides* sp., *Fursenkoina punctata*, *Hanzawaia strattoni,* occurs in both inner and middle neritic environments (Petters 1995;Okosun*et al*., 2012). There is increase in the foraminifera species abundance and diversity when compared with inner neritic intervals. *Bolivina tenuicostata* is considered as inner neritic to upper bathyal species (Murray, 2006).

5.4.1.5 Middle Neritic

This environment lies between 20 – 100m in the marine environment within the continental shelf (Allen 1965; Boersma1978). Lithologically, it is composed of clay, silt, poorly sorted sands, and abundant glauconite. Large and robust species that are often highly ornamented are present. Species dominance is low and the number of species (diversity) is high. The planktic types constitute from 15 – 30% of the total fauna (Boersma, 1978). In well – 004 the %planktonics of the intervals inferred to be middle neritic ranges from 0 to 11.11. Common taxa are *Bolivina* sp., *Lenticulina* sp., *Uvigerina* sp., *Eponides* sp., *Nodosariids*and *Cibicides* sp.

This environment is recognized in the study well from the following intervals 3926 – 3888m, 3,741 m – 3,723m, 3,303 m – 3,284m (Fig. 5.5). The criteria used for recognition of the middle neritic environment are the presence of *Brizalina mandoroveensis, Spiroloculina* sp.,*Lenticulina grandis, Lenticulina inomata, Hopkinsina bononiensis* and *Eponides berthelotianus*. Petters (1995) consider *Brizalina mandoroveensis, Spiroloculina* sp. as middle neritic to upper bathyal species while*Lenticulina grandis*, and*Lenticulina inomata*range in terms of depth from inner neritic to outer neritic environment but dominate

in the middle neritic environment. The presence of *Eponides eshira*, *Eponides* sp. *Hanzawaia strattoni* also suggest middle neritic environment (Petters, 1995) as they are not found beyond middle neritic environment. Chukwu *et al*., (2012) used the occurrence of *Hopkinsina bononiensis,Lenticulina inomata,*and *Spiroloculina* sp. to suggest middle neritic environment while Okosun *et al*., (2012) suggested the same environment based on the association of *Brizalina mandoroveensis, Uvigerina isidroensis, Uvigerina sparsicostata, Eponides* sp.and *Hopkinsina bononiensis*.

5.4.1.6 Middle Neritic – Outer Neritic

Theintervals inferred to be middle neritic – outer neritic environment are 4,359 m – 4,308m, 3,083 m – 3,043m (Fig. 5.5). Deposition in middle neritic – outer neritic water depth is suggested based on high abundance (65 to 131 individual per sample) of the foraminiferal species, presence of deep water benthonic foraminiferal species such as; *Bolivina tenuicostata, Brizalina mandoroveensis, Globobulimina ovata,Nonion centrosulcatum, Spiroloculina tenuis, Uvigerina sparsicostata* and *Heterolepa floridana*. The deep water benthonic foraminiferal species occur in association with inner to middle neritic species (i.e. they do not occur beyond middle neritic); *Eponides eshira, Eponides* sp., *Hanzawaia strattoni,Epistominella vitrea*and inner to outer neritic species (i.e. they do not occur beyond outer neritic);*Hopkinsina bononiensis,Lenticulina inomata* and*Lenticulina grandis*. Bandy and Anal (1960) reported the occurrence of *Hanzawaia*, *Epistominella* in the middle to outer shelf/neritic.

5.4.2.7 Outer neritic

This environment lies between 20m– 200m in the marine environment within the continental shelf (Allen 1965; Boersma1978). The outer shelf is characterized by finegrained sediments such as clays and some glauconite. The abundance of the foraminiferal species is high and ornamentation is strong. Planktonics constitute approximately 50% of the faunas

(Boersma,1978). In this study P/B ratio is not used as proxy for palaeobathymetry because of poor abundance of the planktonic foraminiferal species in well – 004.

Sediments deposited in the outer neriticenvironment were observed from the following intervals 3,833 m – 3,796m, 3,778 m – 3,760 m and 3,447 m – 3,432 m (Fig. 5.5).Deposition in the outer neritic environments is suggested by the following: high abundance of the foraminiferal species (65 to 114 individual per sample); presence of planktonic foraminifera such as *Globigerinoides* sp. *Praeorbulina glomerosa*, *Catapsydrax stainforthi*; presence of deep water benthonic foraminifera species including *Uvigerina sparsicostata*, *Uvigerina isidroensis*, *Uvigerina* sp., *Brizalina mandoroveensis*; the presence of *Lenticulina grandis*, *Lenticulina inormata*, *Eponides berthelotianus* and *Hopkinsina bononiensis*, which are considered to be characteristics of Inner to outer neritic environment (Petters, 1995) and would appear to limit the intervals to no greater than outer neritic environment. Petters, (1995) reported the occurrences of *Hopkinsina bononiensis*, *Eponides berthelotianus*, *Uvigerina sparsicostata*, *Eponides berthelotianus* in outer neritic environment of the Nigerian rift and continental margin deltas.

Bassey and Aladede (2005) used the presence of the above benthonic foraminifera species coupled with high P/B ratio and high foraminiferal species abundance to infer outer neritic environment. Gibson (2007) suggested outer neritic environment using *Uvigerina* and *Lenticulina*. Bandy and Anal (1957) reported the occurrence of *Uvigerina* in outer shelf/neritic water depth off the coast of Central America.

5.4.2 Salinity

The relative abundances of the foraminiferal suborders Textulariina (arenaceous), Miliolina (porcelaneous), and Rotaliina (hyaline calcareous) were plotted on triangular diagrams on which the composition or fields for recent marine environment (Murray 1973; Murray, 2006) are shown. The triangular plot (Murray 1973; Murray, 2006) is widely used

for paleoenvironmental reconstruction (Petters, 1982). This is however only applicable for distinguishing brackish from hypersaline and normal marine environments.

The foraminiferal suborders ratio Textulariina (arenaceous), Miliolina (porcelaneous calcareous), and Rotaliina (hyaline calcareous) (Fig. 5.6) reveals a dominance of hyaline calcareous. Comparison with modern microfauna suggests a normal marine neritic environment (Murray, 1973, Murray, 2006).

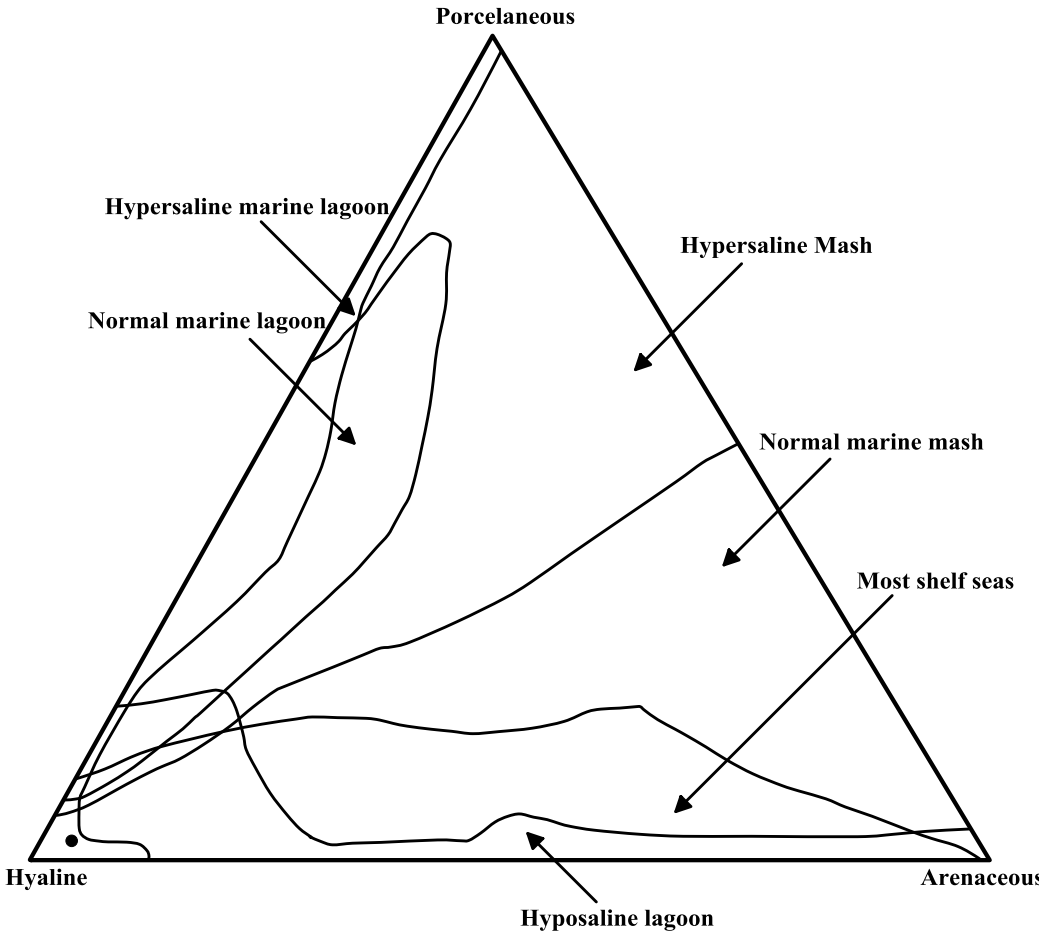


Figure 5.6.Triangular plot of the ratio of the three suborders showing dominance of calcareous hyaline.

5.4.3 Oxygen

After the review of all the palaeoenvironmental, palaeoecological and palaeobathymetric concepts widely employed as tools for marine palaeoenvironmental reconstruction, Van der Zwaan *et al.* (1999) concluded, after Van der Zwaan *et al.* (1990),

that it would be preferable to use planktonic/benthonic (P/B) ratios, or the percentage planktons in a total foraminiferal assemblages, as quantitative markers of depth. Earlier Bandy and Arnal (1960) assigned an outer shelf to upper bathyal zone to the southern end of the San Joaquin Basin, California based on the occurrence of >50% planktics (0.5 P/B ratio). However, the most sensitive applicability of the P/B ratio is the identification of oxygen deficiency (Van der Zwaan, *et al.,* 1999; Van Hinsbergen, *et al.,* 2005; Lowery *et al.,* 2014). Anoxic condition can be identified by the absence of the benthic foraminifera (particularly calcareous benthics) and the high occurrence of planktics (high P/B ratios) (Echer and Worstell, 1970; Kaiho, 1994; Van der Zwaan *et al.,* 1999). Van Hinsbergen, *et al.,* (2005) suggested that P/B ratio can only be used as proxy for bottom water oxygenation in environment prone to dysoxia.

Planktonic foraminifera have been recovered from the study well with poor abundance (0 – 6 count per sample) and diversity (0 – 5 species per sample) (Fig. 4.4). In this study P/B ratios, i.e. the percentages of planktonic foraminifera in the total foraminiferal assemblages was calculated using $\%P = P/(P + B) * 100$. The result (Appendix III) shows that the P/B ratio ranges from 0% to 33.33% with most frequent values of 0 to 14%.

Based on low P/B ratio (0% – 33.33%) and dominance of foraminiferal taxa that are prone to dysoxia (e.g. *Bolivina*, *Bulimina*, *Brizalina*, *Globobulimina*, *Lenticulina*, *Uvigerina*, and *Hopkinsina*) well – 004 sequence was interpreted as deposited in dysoxic to oxic condition (Fig. 5.7). Abubakar, (2006) interpreted low P/B ratio (10% – 30%), as dysoxic to oxic in the Pindiga Formation Upper Benue Trough. The high abundance and diversity of benthonic foraminifera as compared to planktonic is another evidence that the well sequence is not deposited in anoxic condition but rather dysoxic to oxic conditions (Fig. 5.7) because sediments that were deposited in anoxic condition are characterized by the absence of benthonic foraminifera and abundance of dwarf planktonic foraminifera (Petters, 1982).

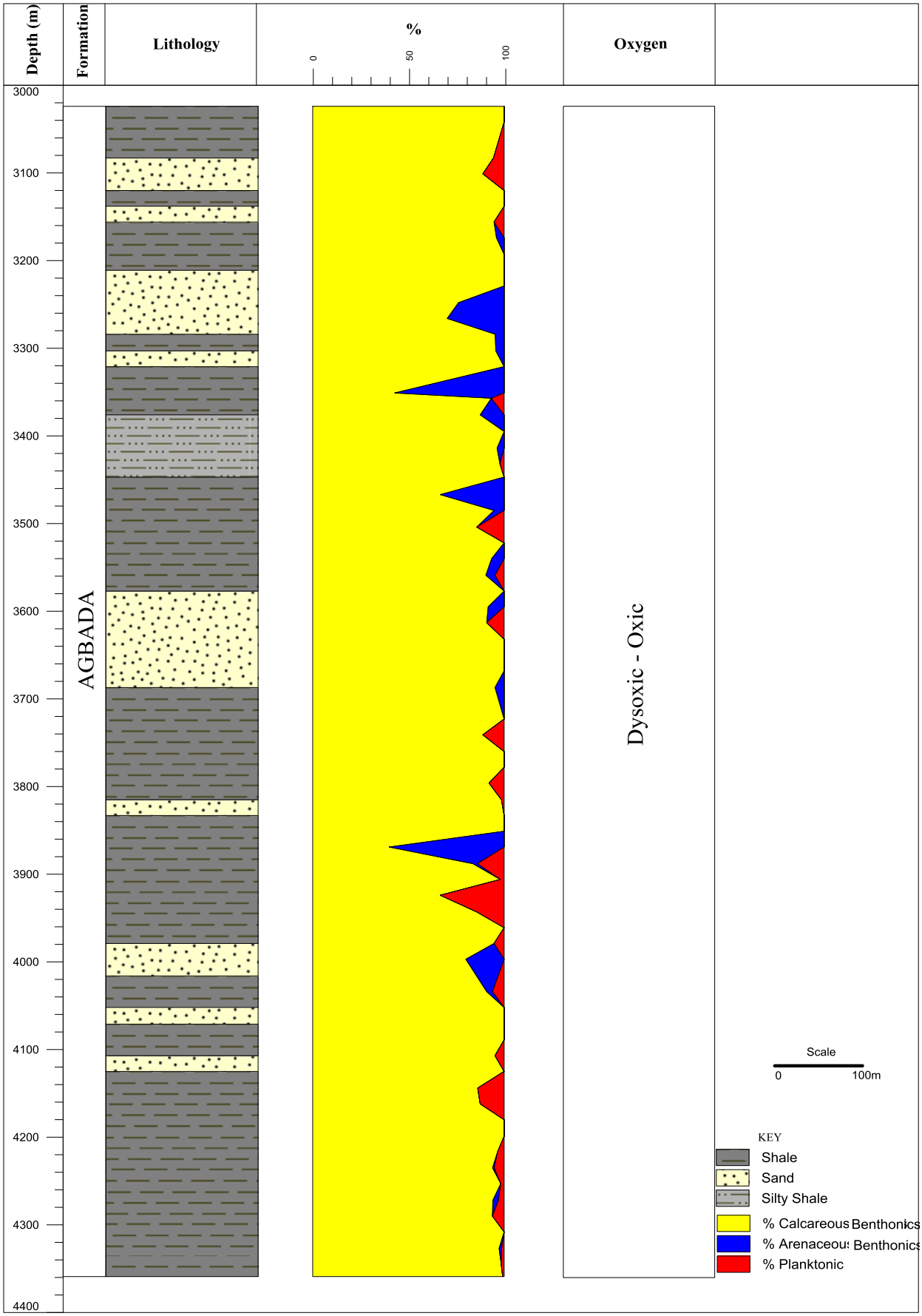


Figure 5.7. Planktonic/Benthonic ratios and Oxygen deficiency horizons in the study well

5.5 Sea level and Palaeobathymetry

The cornerstone of most sequence stratigraphic models, is the concept of accommodation, defined as the space available for sedimentation generated by relative sea – level changes (eustasy and subsidence) (e.g. Vail, 1987; Van Wagoner *et al*., 1988; Posamentier *et al*., 1988). Accommodation changes during a cycle of relative sea level are considered to be the primary control on the architecture of the resulting stratigraphic record. However, the relationship between accommodation/relative sea – level change and bathymetry is not always clear (Naish and Kamp, 1997). This is because palaeobathymetry, while broadly controlled by the generation and loss of accommodation, also responds to changes in the rate of sedimentation. Under conditions of high sedimentation rates the magnitude of bathymetric change may be substantially less than the magnitude of relative sea – level change (Naish and Kamp, 1997). Maximum palaeowater - depth approximates the magnitude of the relative sea-level rise while minimum paleowater depth approximate sea level fall. The clues about the sea level can also be obtained from foraminiferal abundance. It is assumed that a regular pattern of up-section changes in foraminiferal abundance corresponds to environmental changes associated with sea – level rise and fall. The rise in sea levels is always associated with increase in foraminiferal abundance while decrease in the abundance of the foraminifera indicates fall in sea level.

From the paleobathymetric data (Fig. 5.5) and foraminiferal abundance (Fig. 4.4) coupled with the coarsening upward sequences (Fig. 4.1) of the study well section, a possible sea level curve was proposed and presented in figure 5.8. The greatest magnitude of sea-level rise is probably recorded at 4,235 m, 3,906 m 3,760 m and 3,020 m indicating a maximum palaeodepth which is associated with maximum foraminifera abundance and high shale content (Fig. 5.8). The high shale content occurs in the lower portion of the coarsening upward sequences above which there is change in lithology to high sand content (Fig. 5.8).

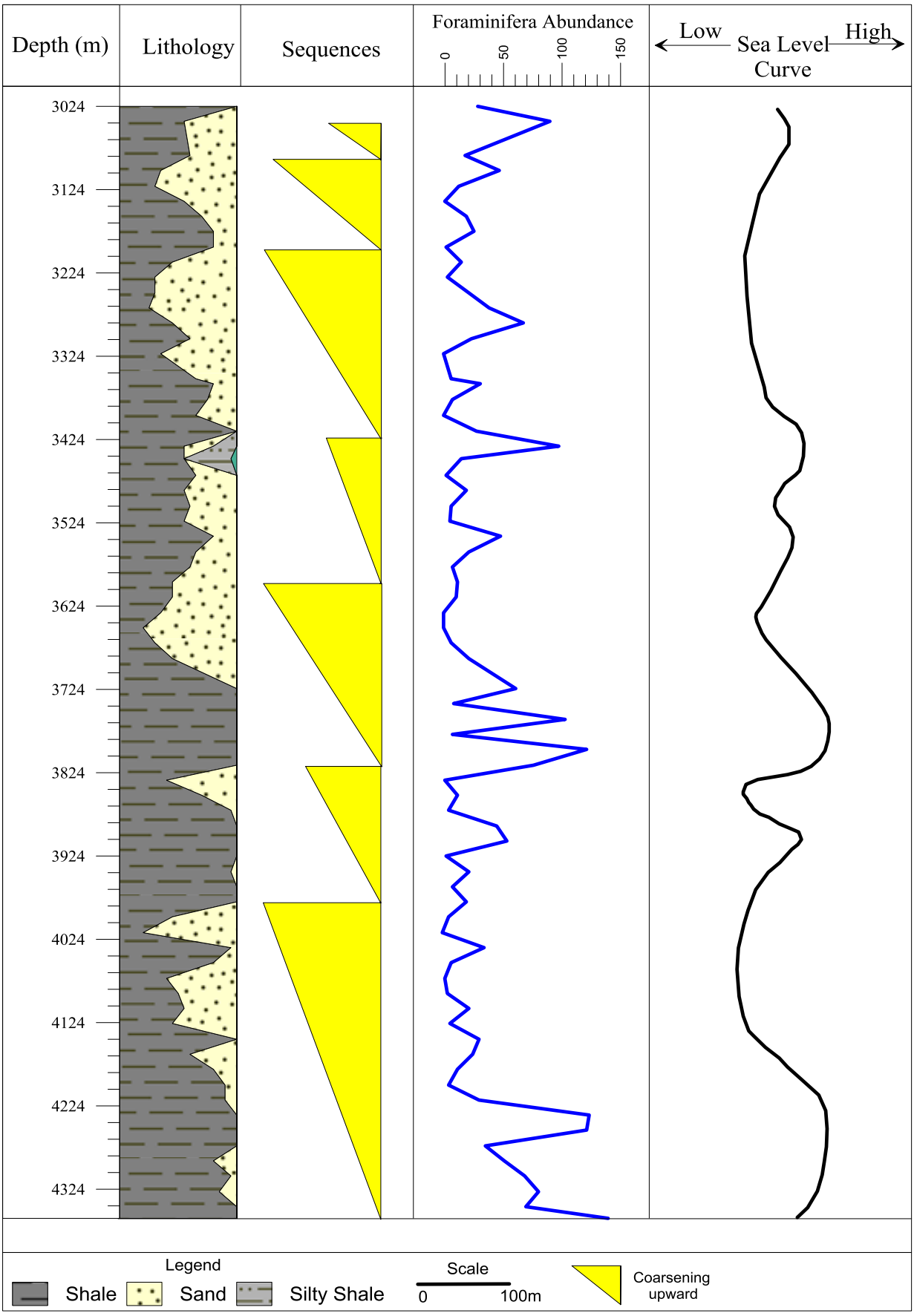


Figure 5.8. Proposed sea level curve of the study well

It can be deduced that the well sequence is characterized by four episodes of sea level rise and fall during late Oligocene to Early – Middle Miocene. The sea level rise is always associated with upward deepening of palaeobathymetry, upward increase in foraminiferal abundance and upward increase in shale content (deepening) while the sea level fall is associated with upward shallowing of palaeobathymetry, decrease in foraminiferal abundance and upward increase in sand content (shallowing)(Fig. 5.8).

5.6 Sequence Stratigraphy

The study of sea-level changes and the relationship with sediment accumulation patterns, has received a great deal of attention in the last two decades as a result of the development of sequence stratigraphy. The concept of sequence stratigraphy dates back to the early work ofSuess (1906), who discussed the concept of eustacy and attributed the patterns of onlap and offlap of sediments to global sea level changes (Emery and Myers, 1996). Although there was a general lack of support for the ideas of Suess (1906), a number of American geologists began to develop concepts of global controls on unconformity development (Chamberlin, 1898, 1909; Wheeler, 1958; Sloss, 1962, 1963). It was not until the 1960s and 1970s when the development of digitally recorded seismic data became available that a major breakthrough in sequence stratigraphy took place (Emery and Myers, 1996). Seismic stratigraphy was developed within the Carter Oil Company and subsequently at the Exxon Production Research Corporation (Vail and Wilbur, 1966; Mitchum *et al.*, 1976). This led to the development of more detailed modem sequence stratigraphic concepts (Wilgus *et al.,* 1988) and the application of sequence stratigraphy to outcrops, wells and seismic sections (Van Wagoner *et al.,* 1990).

Today, three main models have been developed for the prediction of sediment accumulation patterns; the Exxon Production Research Model(EPRM), the Einsele (1985) Model and Galloway (1989) Model. This thesis will use the EPRM model of sequence

stratigraphy and will attempt to constrain the model using micropaleontology (Foraminiferal abundance).

The principal hypothesis of the EPRM is that sediments are divided into packages that are separated by several types of bounding surface such as sequence boundaries (SB), maximum flooding surfaces (MFS) and ravinementsurfaces. The model recognizes that different scales of sediment packages are present within sequences and introduced the concept of parasequences and systems tracts. Parasequences are the smallest unit, consisting of coarsening – upward packages bounded by marine flooding surfaces, which are the commonest type of bounding surface (Wignall, 1991). Systems tracts are built of parasequences, with three main systems tracts recognized; the Lowstand Systems Tract (LST), the Transgressive Systems Tract (TST) and the Highstand Systems Tract (HST). The LST is deposited during intervals characterized by relative sea – level fall followed by subsequent slow relative sea – levelrise (Posamentier and Vail, 1988). The TST is deposited in the phase of the sea – levelfall/rise cycle when accommodation space is increasing faster than sediment accumulation/supply (Emery and Myers, 1996). The HST is deposited during the eustatic highstand of the sea-levelfall/rise cycle when the rate of accumulation of accommodation space is less than the rate of sediment supply (Emery and Myers, 1996).

In this study, the vertical distribution of the foraminiferal abundance is integrated with lithology and palaeobathymetric data for the sequence stratigraphic study. The study employed the approach of Armentrout (1987), Armentrout (1996), Armentrout and Clement (1990), Armentrout *et al.* (1990); Armentrout *et al.* (1999); Pacht *et al.* (1990) and Vail and Wornardt, (1990). These authors used microfossils abundance patterns for locating condense sections (MFS) and sequence boundaries (SB) and for constraining the interpretation of depositional systems tract. Foraminiferal abundance peaks and high shale content are used to locate condense interval (MFS) and minimum foraminiferal abundance, and high sand/low

shale content are used to locate sequence boundaries (SB) in the sequence stratigraphic study. Additionally, variations in both abundance patterns and specific fossil content are used to characterize depositional systems tract. Dating of the key surfaces (MFS and SB) where possible was achieved by their calibration to the third cycles of Haq*et al.* (1988), which is incorporated in the Niger Delta chronostratigraphic chart of Stacher (1994).

5.6.1 Bounding Surfaces of Sequence Stratigraphy

The primary horizons used in sequence stratigraphic analysis are the sequence boundary, transgressive surface and maximum flooding surface which occur within the condensed section in areas of low sediment accumulation rates (Armentrout, 1996). These regionally correlative surfaces can be identified from checklists of foraminiferal abundance(Armentrout, 1996). The framework of some of these surfaces or boundaries is used to define sequences and systems tracts(Armentrout, 1996). The surfaces identified in this work are three sequence boundaries (SB), one transgressive surface (TS), and three maximum flooding surfaces (MFS) (Fig. 5.9; Table 5.4).

5.6.1.1 Sequence Boundary

The sequence boundary is an unconformity formed during relative lowering 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 sediment or destruction of shell material in shallow water, high-energy environments associated with the erosional unconformity (Armentrout, 1991).

In the study well the minimum abundance of foraminiferal species at 4,144 m, 3,851 m and 3,650 m (Fig. 5.9) are interpreted as sequence boundaries. SB at 4,144 m separate the LST below and HST above. SB at 3,851 m and 3,650 m separate HST below and TST above (Fig. 5.9). The proposed SB occur as sea level begins to fall (Fig. 5.8) and occur within the

intervals of minimum abundance of foraminifera, high percentage occurrence of sand and shallow

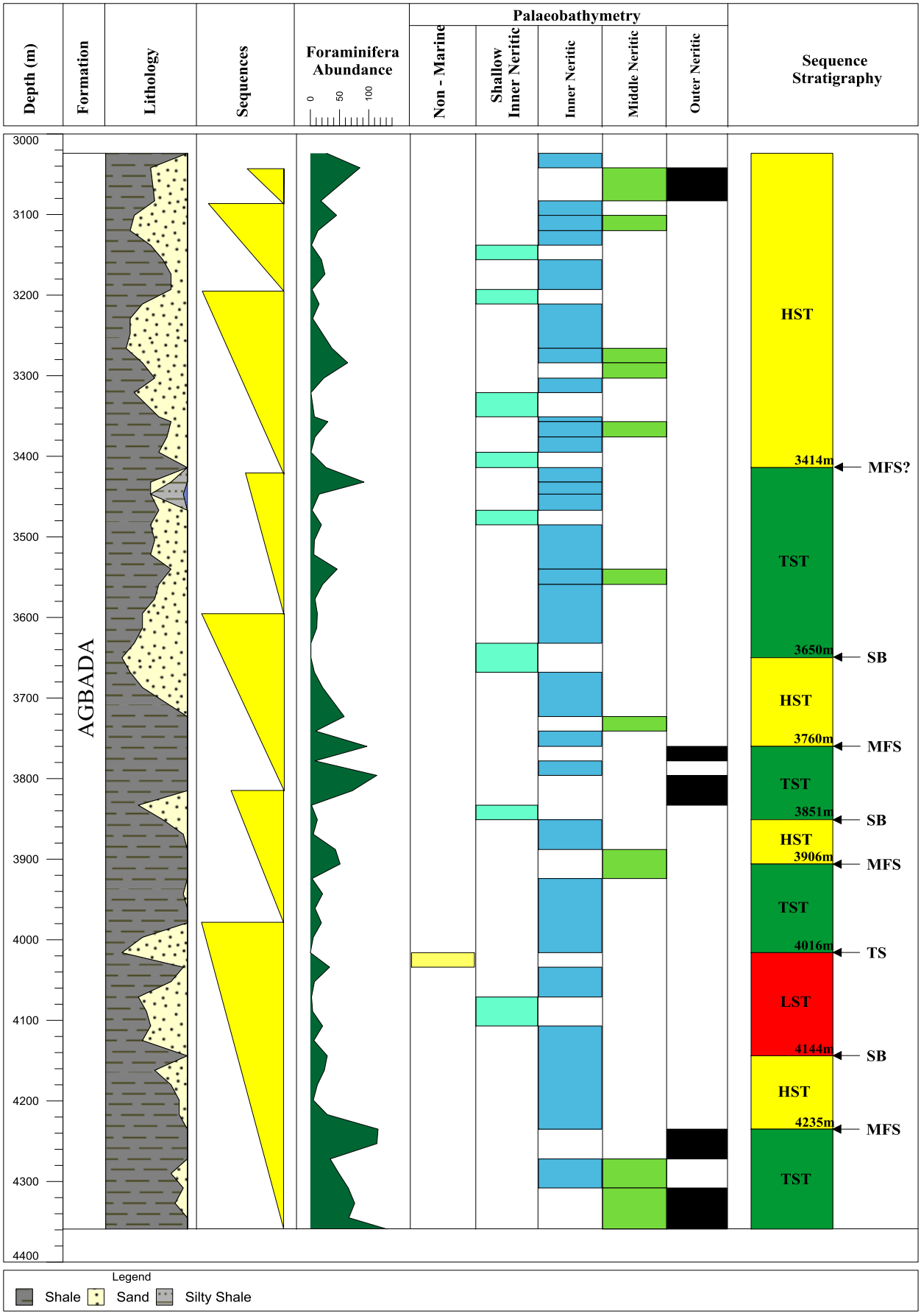


Figure 5.9. Sequence stratigraphic interpretation of the study well

Palaeobathymetry.The SB at 4,144 m, 3,851 m and 3,650 m are deposited in inner neritic, shallow inner neritic, and inner neritic palaeobathymetryrespectively (Fig. 5.9).

5.6.1.2 Transgressive Surface (TS)

The TS is a surface that separates older strata from younger strata, across which there is evidence of an abrupt increase in Palaeobathymetry (Van Wagoner *et al.,* 1988). This surface represents the landward stepping onlap of deposition related to relative rise in sea – level(Van Wagoner et *al.* 1988). Transgressive surface separate the lowstand and transgressive systems tracts. This surface 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).

In the studied well, transgressive surface (TS) was observed at 4,016m based on high percentage occurrence of sand and absence of foraminiferal speciesbellow the TS (Fig. 5.9). The palaeobathymetry below the TS range from inner neritic to shallow inner neritic and then non-marine (shallowing), while there is sudden deepening of the palaeobathymetry above the TS from the non-marine to inner neritic and terminated at middle neritic (MFS at 3,906 m; Fig. 5.9).

5.6.1.3 Maximum flooding surface (MFS)

The MFS separates the transgressive systems tract (TST) from the highstand systems tract (HST), and represent the landward extent of marine conditions (Emery and Myers, 1996). Away from the locus of major input of sediment this surface is a clay-rich condensed section formed by slow accumulation of sediment. This interval is often represented by significant increase in fossil abundance and diversity, by the deepest water biofacies assemblage of the transgressive-regressive cycle, and by the abundance of authigenic minerals such as phosphate and glauconite (Armentrout, 1987, 1991; Loutit *et al.*, 1988).

In the study well, the maximum sea level rise at 4,235m, 3,906m and 3,760mand 3,414 m were observed as MFS (Figs. 5.9 and 5.10). The maximum sea level rise is associated with maximum abundance of foraminfera, high percentage occurrence of shale and deepest biofacies assemblages. MFS at 4,235m (Fig. 5.9) is characterized by outer neritic benthonic foraminiferal assemblages (Fig. 5.9) which include *Eponides eshira, Eponides* sp.*Lenticulina grandis* and *Uvigerina isidroensis* associated with planktonic foraminifers. MFS at 3,906 m, species of *Heterolepa floridana* dominate the foraminiferal assemblages of this MFS and is associated with *Uvigerina isidroensis*, *Eponides eshira.* The foraminiferal assemblages suggest deposition in middle neritic Palaeobathymetry (Fig. 5.9). MFS at 3,760m, is characterized by maximum abundance of *Brizalina mandoroveensis, Cibicorbis inflata, Lenticulina grandis and Valvulineria gasparensis* in association with other foraminferal species. The foraminiferal assemblages suggest outer neritic Palaeobathymetry depth (Figs. 5.9). MFS at 3414 is characterized by abundance of *Cibicorbis inflata, Eponides eshira*and *Uvigerina isidroensis*. The foraminifer's assemblages suggest inner neritic palaeobathymetry.

5.6.2 The Sequences

Four (4) sequences (Fig. 5.10) were delineated in the well study comprising of eight (9) systems tract made up of one (1) Lowstand Systems Tract (LST), four (4) Transgressive Systems Tract (TST), three (4) Highstand Systems Tract (HST), three (3) candidates of Sequence Boundaries (SB), three (4) candidates of Maximum Flooding Surfaces (MFS) and one Transgressive surface (TS) (Figs. 5.10).

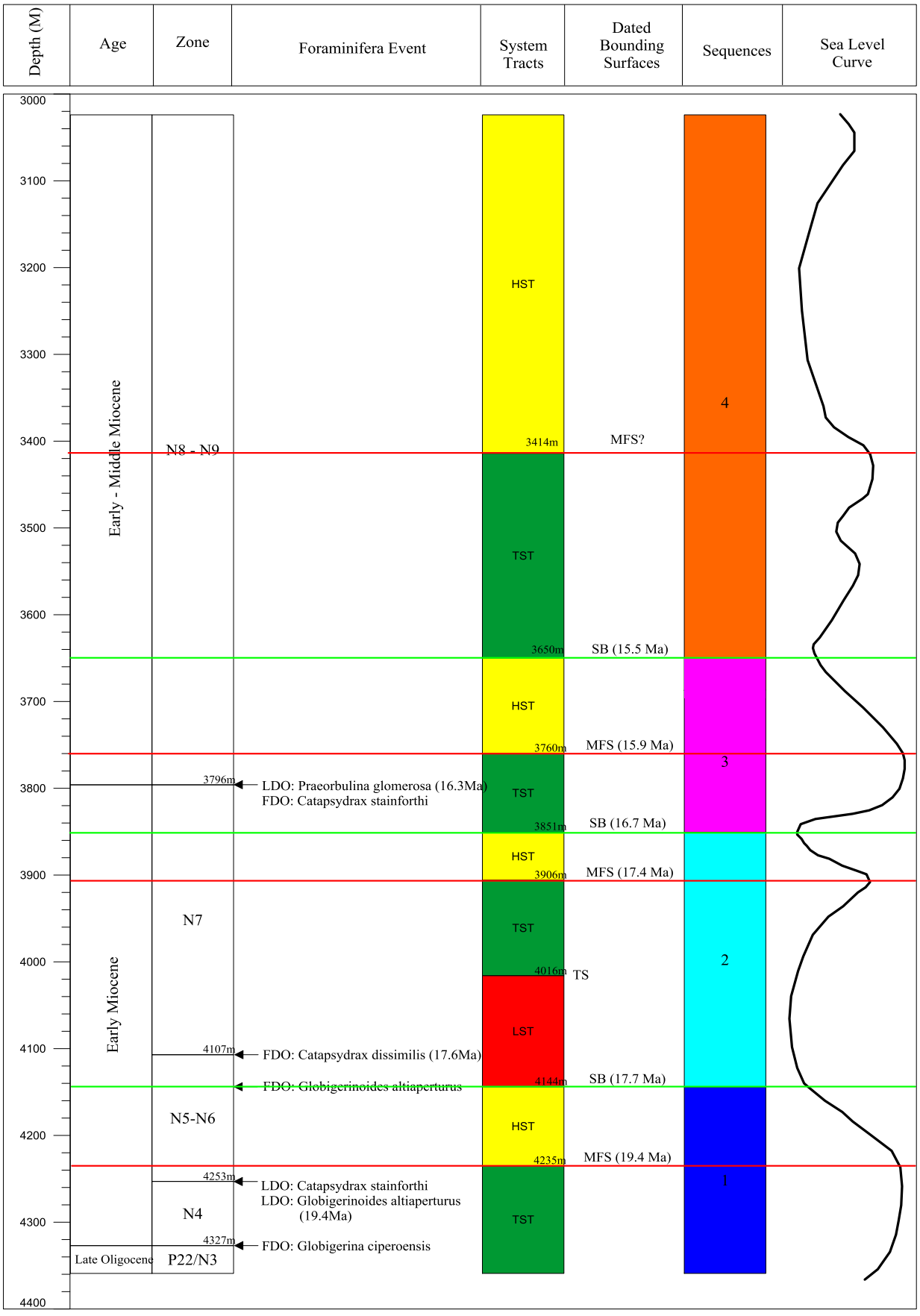


Figure 5.10. Showing sequences and sequence boundaries dating

5.6.2.1 Lowstand System Tract

The LST is deposited during intervals characterized by relative sea-level fall followed by subsequent low relative sea-level rise (Posamentier and Vail, 1988). LST comprises two components; the lowstand fan and the lowstand wedge (Emery and Myers, 1996).

Lowstand wedge is initiated as sea – levelbegin to rise following a rapid fall. Lowstand wedge deposit comprises of progradational to aggradational parasequences, and contain indigenous fossils with proximal to distal biofacies gradient. In a vertical succession through a prograding wedge, the fossils assemblages indicate a shallowing up signature from deeper marine, shallow marine through marginal marine to non-marine biofacies. Aggradation wedge will not show such a pronounced shallowing-up succession rather a thick accumulation of similar biofacies (Emery and Myers, 1996).

In the study well lowstand prograding wedge (LPW) was observed between 4,144m – 4,016m and is present only in sequence two (Fig. 5.9). The fall of sea level at 4,144 m was picked as the base of the LPW and the pronounced increase in sea level at 4,016 m (TS) was picked as the top of the LPW. This interval (4,144m – 4,016m)shows a rapid upward increase in sand percentage occurrence (coarsening/shallowing upward) (Fig. 5.10), upward decrease in foraminiferal abundance and shallowing palaeobathymetry pattern (Figs. 5.10 and 5.11).

5.6.2.2 Transgressive Systems Tract (TST)

The TST is the middle systems tract deposited in that part of the sea-level fall / rise cycle when accommodation is increasing faster than sediment accumulation/sediment supply rate (Emery and Myers, 1996). The base is the TS, which represents the first significant flooding event within the sequence (Posamentier and Vail, 1988) and the upper boundary defined the MFS (condensed sections characterized by foraminferal abundance peak). The transgressive systems tract comprises a backstepping, transgressive depositional facies

(retrogradation) with upward increasing fossils abundance and diversity and reach their maximum at MFS (Armentrout, 1996).

Four TST were identified in the study well from the following intervals 4,359 m – 4,235 m, 4,016 m – 3,906 m, 3,851 m – 3,760 m, and 3,650 m– 3,414 m as presented in Figure 5.9. All the TST were interpreted to result from sea level rise (Fig. 5.10) with the maximum of the sea level rise picked as MFSs of the TSTs. The sea level rise of the TST is associated with upward increasing abundance of foraminiferal species with maximum abundance of the species at MFS (Fig. 5.9), upward increase in percentage occurrence of shale (fining upward/deepening) from SB (in case of sequence 1, 3, and 4) and TS (in case of sequence 2), and upward deepening of Palaeobathymetry (Figs. 5.9 and 5.10).

5.6.2.3 Highstand Systems Tract (HST)

The highstand systems tract are recognized by occurring above MFS and below SB. In the study well, as sea level start to fall there is upward decreasing in foraminiferal abundance, shallowing of palaeobathymetry and upward increase in percentage occurrence of sand (coarsening upward/shallowing). The above mentioned characteristics was interpreted as HST which occur above interpreted TST with upward increasing foraminiferaabundance and palaeobathymetry (Figs. 5.9 and 5.10).

Four HST were identified in the study well in the following intervals 4,235 m – 4,144 m in sequence 1, 3,906 m – 3,851 m in sequence 2, 3,760 m – 3,687 m in sequence 3 and 3,414 m – 3020 m in sequence 4 as presented in Fig. 5.10.

5.6.3 Age assessment and Correlation

The key bounding surfaces identified in this study were dated based on the ages of the FDO and LDO of some planktonic foraminiferal index forms (Fig. 10). The ages proposed by Berggren et al., (1995) was used (Fig. 10). The bounding surfaces were also correlate with the proposed zones of this study and the Haq et al., (1988) global chronostratigraphic chart

which is incorporated in to the Niger Delta chronostratigraphic chart (Fig. 11) by Stacher (1994).

In this study MFS were proposed at 4,235 m, 3,906 m, 3,760 m and 3,414 m. MFS at 4,235 m occur in zone N5 – N6 of this study above LDO of *Catapsydrax stainforthi* (19.4 Ma) (Fig. 10). Based on that it may be dated 19.4 Ma MFS of Haq et al., 1988. MFS at 3906 occur in zone N7 above FDO of *Catapsydrax dissimilis* (17.6 Ma) (Fig. 10). Based on that it may be dated 17.4 Ma when compare with Haq et al., (1988) (Fig. 11). MFS at 3760 may be dated 15.9 Ma when compare with Haq et al., (1988) (Fig. 11) as it occur in zone N8 – N9 above LDO of *Praeorbulina glomerosa* (16.3 Ma) (Fig. 10). MFS at 3414 Ma is not correlated with any of the Haq et al., 1988 MFS.

SB at 4,144m may be dated 17.7 Ma based on it occurrence in top of zone N5 – N6 below FDO of *Catapsydrax dissimilis*(17.6 Ma). SB at 3851 occur in zone N7 below LDO of LDO of *Praeorbulina glomerosa* (16.3 Ma) when compare with Haq et al., (1988) it may be dated 16.7 Ma. SB at 3650 Ma is dated 15.5 Ma based on it occurrence above LDO of *Praeorbulina glomerosa* (16.3 Ma) in zone N8 – N9.

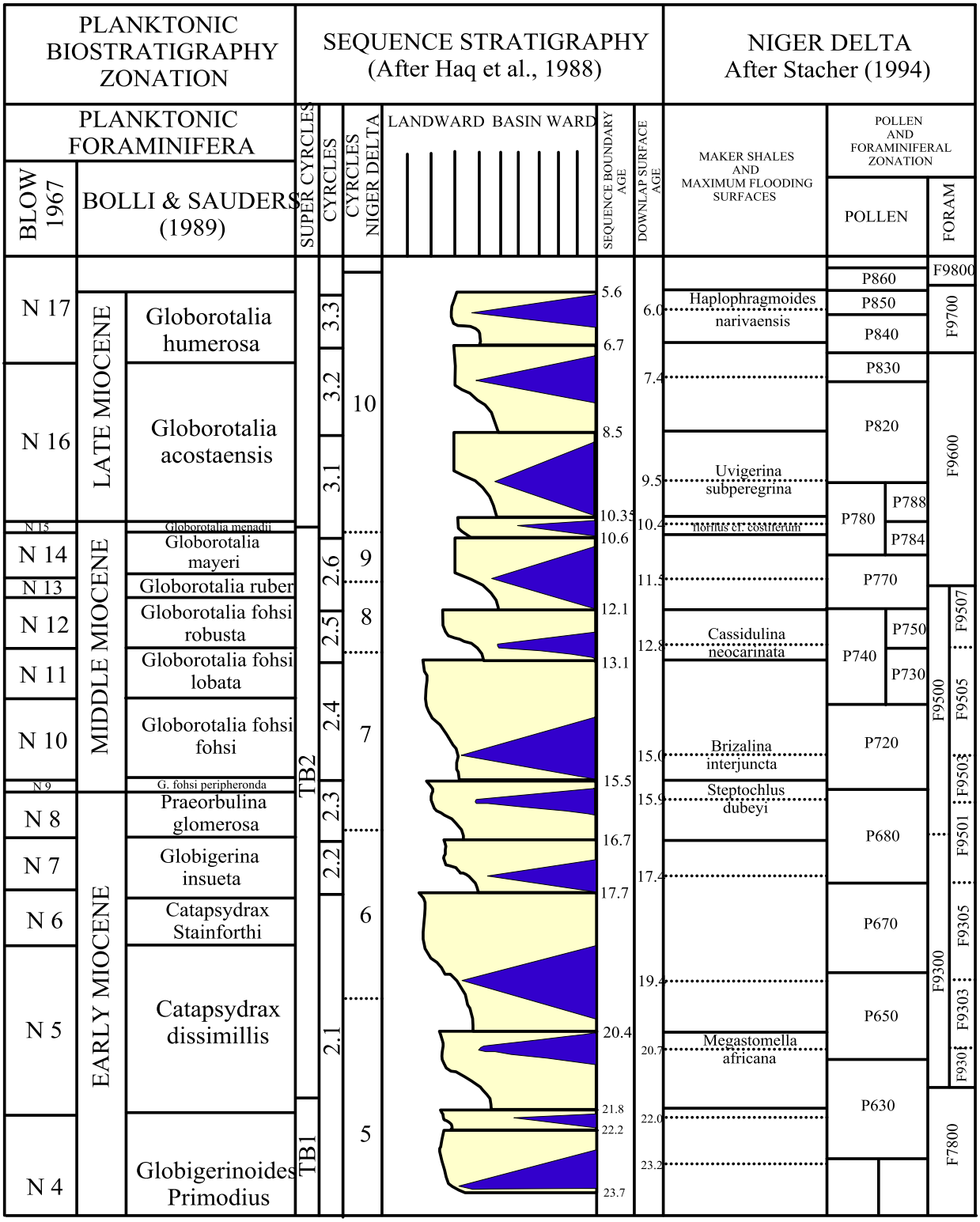


Figure 5.11. Correlation of bounding surfaces identified in this study with Haq *et al.* 1988 Chronostratigraphic chart.

5.6.4 Depositional Sequences

The depositional sequence is a relatively conformable succession of genetically related strata bounded by unconformities, or their correlative conformities. A sequence is interpreted to have been deposited during a complete cycle of sea-level change(Van Wagoner, *et al.*, 1988). A complete cycle of sea-level change includes two relative falls of sea level and extends from the inflection point of the maximum rate of sea-level fall to the subsequent rise, followed by the next fall. A complete cycle of sea-level change is interpreted to be represented in the rock record by a depositional sequence (Haq et al., 1988).Generally, a depositional sequence consists of LST, TST and HST.

In the study well four 4 cycles for sea level changes were identified which resulted in the deposition of four sequences (Fig. 5.10). The depth summary of the depositional sequences is presented in Table 5.3. Four depositional sequences are recognized and are described briefly in turn below:

Table 5.3. Depth summary of sequence present in the study well.

Sequence	Depth Range (m)	Age
Sequence 1	4359 – 4144	Late Oligocene – Early Miocene
Sequence 2	4144 – 3851	Early Miocene
Sequence 3	3851 – 3650	Early Miocene to Early Middle Miocene
Sequence 4	3867 -	Early Middle Miocene

Depositional Sequence 1

This depositional sequence, is recognized between 4,359m and 4,144m. The sequence has Transgressive Systems Tract (TST) and Highstand Systems Tracts (HST). The sequence is marked at the top by 17.7Ma SB and the TST is marked at the top by the MFS which is dated 19.4Ma. The base of the sequence was not penetrated. The sequence is correlated with 2.1 cycle of Haq *et al.*(1988) and 5 – 6 Niger Delta Cycles of Stacher (1994) which fall in TB1 – TB2 super cycle of Haq *et al.* (1988) (Fig. 5.10 and 5.11).

Depositional Sequence 2

Depositional sequence 2 is the only complete sequence with all the system tracts and was identified between 4,144m and 3,851m starting with the 17.7Ma SB and ends with the 16.7Ma SB. It is made up of LST (lowstand prograding wedge), TST and HST and they are characterized by retrogradational and progradational parasequence sets respectively. The 17.4Ma MFS marked the top of the TST. This sequence is correlated with 2.2 cycle of Haq *et al.*,(1988) and Circle 6 of Niger Delta (Stacher 1994) which fall in TB2 super cycle of Haq *et al.*(1988) (Figs. 5.10 and 5.11).

Depositional Sequence 3

This sequence was identified between 3,851m and 3,687m and starts with the 16.7Ma SB and ends with the 15.5MaSB. The sequence has two systems tract – TST and HST. The TST is marked at the top by the 15.9Ma MFS. This sequence is correlated with 2.3 cycle of Haq *et al.*(1988) and Circle 6 - 7 of Niger Delta of Stacher (1994) which fall in TB2 super cycle of Haq *et al.* (1988) (Figs. 5.10 and 5.11)

Depositional Sequence 4

This is identified between 3,650 m – 3,024m. The sequence have two System Tract TST and HST. 15.5Ma SB marked the beginning of the sequence while the top is beyond the studied interval. MFS was identified but it was not dated and correlated with Haq *et al.*(1988). This sequence is correlated with 2.4 cycle of Haq *et al.*(1988) and Circle 7 of Niger Delta of Stacher (1994) which fall in TB2 super cycle of Haq *et al.* (1988) (Figs. 5.10 and 5.11).

5.6.5 Sea Level Changes and Depositional History

During the Late – Oligocene to Early – Miocene there is sea level rise and fall cycle between 4,359 m and 4,144 m that leads to the deposition of depositional sequence one. The rise in the sea level attain maximum at 4,235 m which is interpreted as MFS. Below the MFS

is marine deposit mainly shale (TST). From the MFS there is gradual fall in sea level with it minimum at 4,144 m (SB). The sediments that were deposited during the sea level fall are interpreted as HST and are characterized by coarsening and shallowing upward pattern. Within the Early – Miocene, there is continuous fall in the sea level from 4,144 m (SB) which lead to the increase in sand content. Significant rise in sea level start at 4,016 m, below that depth is shallowing upward deposit which is interpreted as LST and above it shows deepening pattern which is interpreted as TST. At the top of the TST the sea level rise marked it maximum at 3,906 m (MFS of the TST), from the MFS at 3,906 m there is gradual fall in the sea level with it minimum at 3,851 m and is associated with coarsening/shallowing pattern which is interpreted HST. The rise and fall of the sea level within the Early – Miocene lead to the deposition of depositional sequence 2.

In the Early Miocene to Early – Middle Miocene there is cycle of sea level rise and fall which lead to the deposition of depositional sequence three. From the fall in sea level at 3,851 m there is prominent rise with it peak at 3,760 m. form 3,760 m there is gradual fall of the sea level with it minimum at 3,650 m. The rise in the sea level lead to the deposition of TST while the fall of the sea level lead to the deposition of HST. MFS and SB was placed at 3,760 m and 3,650 m respectively. The Early – Middle Miocene is characterized by slight rise and fall in the sea level. The peak in sea level is at 3,414 m. Above that peak is interpreted as HST and below is interpreted as LST.

5.6 Micro – Systematic Palaeontology

The foraminiferal species identification was done using Loeblich and Tappan, (1964, 1988), Petters, (1982) and Petters (1983). A total of 61foraminiferal species were recovered and identified, comprising 32 genera from 21 families and 3 suborders. The species recovered are further divided into benthonic and planktonic.

The classification given here adopted the one contained in Loeblich and Tappan (1964, 1988). Dates of proposals are given with authors names for formal taxa. Specimens that could not be matched with published illustrations were placed in open taxonomy. Only few photomicrographs of some species were presented in Plates 1, 2, 3, and 4. For the descriptions and the photomicrographs of the species recovered that are not presented in this study see Petters (1982; 1983).

5.6.1 Systematic Palaeontology

Kingdom PROTOZA

Phylum SARCODINA

Class RHIZOPODA

Order FORAMINIFERIDA

Suborder TEXTULARIINA Delage & Herouard, 1896

Super family Lituolacea De Brainville, 1825

Family Lituolidae De Brainville, 1825

Subfamily Haplophragmoidinae Maync, 1952

Genus *Haplophragmoides* Cushman, 1910

Haplophragmoides sp.

Haplophragmoides sp.

Occurrence: The species occurs in Early Miocene (4235m).

Material: One specimen.

Family Texulariidae Ehrenberg, 1838

Subfamily Textulariinae Ehrenberg, 1838

Genus *Textularia* Defrance in De Brainville, 1824

Textularia laminata Cushman, 1918

1918 *Textularia laminata* Cushman

Occurrence: Petters (1982) reported the occurrence of this species in the Middle Oligocene – Early Miocene Opuama Submarine Canyon Fill in the western Niger Delta (Meren-1, 1368m). In this study the species occur within the Early Miocene (3869m – 4272m).

Material: Four specimens.

Textularia panamensis Cushman, 1918

1918 *Textularia panamensis* Cushman

Occurrence: Original forms were from the Oligocene of Panama. Rare in the Middle Oligocene – Early Miocene Opuama Submarine Canyon Fill (Opuama-1, 1985m) (Petters 1982). In this study, the species occurs in Early Miocene – Early Middle Miocene (3174 – 4327m).

Material: 37 specimens.

Textularia sp.Cushman & Renz 1946

Textularia sp.Cushman & Renz 1946

Occurrence: Poorly preserved. Early Middle Miocene (3284m)

Material: One specimen.

Suborder MILIOLINA Delage & Herouard 1896

Superfamily Miliolacea Ehrenberg 1839

Family Nubeculariidae Jones 1895

Subfamily Spiroloculininae Wiesner 1920

Genus *Spiroloculina* D'Orbigny 1826

Spiroloculina tenuis Czjzek 1848

1848 *Spiroloculina tenuis* Czjzek

Occurrence: Typical specimens are common in the Oligocene – Miocene of the Niger Delta, especially in the Opuama Submarine Canyon Fill; (Sonam-09, 702-720; Bita-9. 111m) (Petters, 1982). In this study the species occur in the Early – Miocene part of the study well (4308m)

Material: One specimen.

Spiroloculina sp.

Spiroloculina sp.

Occurrences: The species is rare in Early Miocene – Early Middle Miocene (3193m – 2906m).

Material: Two specimens.

Family Miliolidae Ehrenberg 1839

Subfamily QuinqueloculininaeCushman1917

Genus *Quinqueloculina* D'Orbigny 1826

Quinqueloculina seminulum Linne 1758

1758 *Quinqueloculina seminulum* Linne

Occurrence: Typical forms are common in the Late Miocene – Pliocene of the Niger Delta (Bita – 9, 111m, Sonam-9 702-720m) (Petters, 1982). In this study the species is reported from the Early Miocene – Early Middle Miocene (3042m – 3979m).

Material: 42 specimens.

*Quinqueloculina microcostata*Natland 1938

1938*Quinqueloculina microcostata*Natland

Occurrence: Poorly preserved. Occurs at the Early – Middle Miocene of the well (3229m – 3266m)

Material: Two specimens.

Quinqueloculina sp.

Quinqueloculina sp.

Occurrence: Poorly preserved, occurs in Early Miocene (4052m – 4235m)

Material: Two specimens.

Suborder ROTALIINA Delage & Hérouard, 1896

Superfamily Nodosariacea Ehrenberg, 1838

Family Nodosariidae Ehrenberg, 1838

Subfamily Nodosariinae Ehrenberg, 1838

Genus *Lenticulina* Lamarck, 1804

*Lenticulina grandis*Cushman 1921

(Plate 3, Fig. 1)

1921 *Lenticulina grandis* Cushman

Occurrence: The species is well preserved and range throughout the well from Late Oligocene – Early Middle Miocene (3024m – 4359m). This species make up 11% of the total foraminiferal species recovered from the well sequence.

Material: 223 specimens

Lenticulina inormata D'Orbigny 1846

(Plate 3, Fig. 2)

1846 *Lenticulina inormata*D'Orbigny

Occurrence: The species is fairly preserved when compared with *Lenticulina grandis*. The species are found at the Late – Oligocene to Early Middle Miocene of the well.

Material: 80 specimens

Lenticulina sp.

Lenticulina sp.

Occurrence: Poorly preserved and occur in Early - Middle Miocene (3266m)

Material: One specimen

Superfamily Buliminacea Jones, 1895

Family Turrilinidae Cushman, 1927

Subfamily Turrilininae Cushman, 1927

Genus *Buliminella* Cushman 1911

Buliminella aff. Subfusiformis Cushman, 1926

(Plate 1, Fig. 9)

1926*Buliminella aff. Subfusiformis*Cushman

Occurrence: occurs at the boundary between Late Miocene and Early – Middle Miocene (3797m).

Material: Four specimens.

Family Bolivinitidae Cushman, 1927

Genus *Bolivina* Cushman, 1839

Bolivina tenuicostata De Klasz, Le Calvex & Rérat, 1964

1964 *Bolivina tenuicostata* De Klasz, Le Calvex & Rérat

Occurrence: This distinctive, inflated, and sparingly costate bolivinid is common in the Middle Oligocene – Early Miocene of the Niger Delta especially in the Opuama Submarine

Canyon Fill (Opuekeba-1, 2200m – 2238m); originally described from the Early Miocene of Gabon (Petters, 1982). In the studied well, the species was preserved between the Late Oligocene to Early Miocene (range from zone P22/N3 to zone N5 – N6) (4359m – 4217m) part of the well. Is the most abundant (37%) among the species that were recovered within late Oligocene interval.

Material: 134 specimens

Bolivina dilatata Reuss 1850

(Plate 2, Fig.7)

1850*Bolivina dilatata*Reuss

Occurrence: Poorly preserved and occur within the Early – Middle Miocene (Zone N8 – N9) part of the well.

Material: One specimen.

Genus *Brizalina* Costa, 1856

Brizalina interjuncta Graham, De Klasz and Rerat, 1965

(Plate 2, Fig. 8)

1965 *Brizalina interjuncta* Graham, De Klasz and Rerat

Occurrence: Poorly distributed from zone N5 – N6 (4253m) of Early Miocene to zone N8 – N9 (3024m) of Early – Middle Miocene.

Specimen: Three specimens.

Brizilina mandoroveensis Graham, De Klasz and Rerat, 1965

(Plate 3, Fig. 3)

1965 *Brizilina mandoroveensis*Graham, De Klasz and Rerat

Occurrence: Very abundant and occur throughout in the study well. The species constitute 14% of the total foraminifera species recovered from the well.

Specimens: 285 specimens.

Family Buliminidae Jones, 1895

Subfamily Bulimininae Jones, 1895

Genus *Bulimina* D'Orbigny, 1826

Bulimina sp.

Bulimina sp.

Occurrence: Poorly preserved and occurs in Zone N8 – N9 of Early – Middle Miocene in the well.

Material: One specimen

Genus *Globobulimina* Cushman,1927

Globobulimina ovata D'Orbigny 1826

(Plate 2, Fig. 12)

1826 *Globobulimina ovata* D'Orbigny

Occurrence: Rare in the Middle Miocene of the Niger Delta (Meta-1, 2295 – 2313 m); this species was recorded by Harris (1981) from the recent Niger Delta. In the study well *Globobulimina ovata* mark the beginning of Early Miocene. The species is restricted to Early Miocene and rage from zone N4 to zone N5 – N6.

Material: Seven specimens

Family Uvigerinidae Haekel, 1894

Genus *Hopkinsina* Howe & Wallace, 1932

Hopkinsina bononiensis Fornasini, 1888

(Plate 3, Fig. 6)

1888 *Hopkinsina bononiensis* Fornasini

Occurrence: This highly variable form is very abundant in the Middle Oligocene – Middle Miocene of the Niger Delta (Opuekeba – 1, 2526 m; Delta South – 1, 3069m – 3087m) (Petters 1982); it is a common Miocene – Pliocene species in Egypt and Europe (Macfadyen, 1930; Marks 1951; Thomas 1980). In this study the species occur throughout in the well form Late Oligocene to Early Middle Miocene.

Material: 75 specimens

Genus *Uvigerina* D'Orbigny, 1826

Uvigerina sparsicostata Cushman & Laiming, 1931

(Plate 3, Fig. 4)

1931 *Uvigerina sparsicostata* Cushman & Laiming

Occurrence: Very abundant in the Middle Oligocene – Early Middle Miocene of the Niger Delta especially in the Opuama Submarine Canyon Fill (Opuekeba-1, 2292 – 2310 m) and in other part of the delta (Etelebou-1, 2715 m; Obuzo-1, 2993 m) (Petters, 1982) originally described from the Miocene of California, this species is a middle Oligocene zonal index form in Venezuela (Renz, 1948). In this study is very abundant and range from Late Oligocene to Early Middle Miocene (4359m – 3042m). This species constitute 6.5% of the total foraminiferal species recovered from the study well.

Material: 145 specimens

Uvigerina isidroensis Cushman & Renz, 1941

(Plate 3, Fig. 5)

1941*Uvigerina isidroensis* Cushman & Renz

Occurrence: The most abundant of all the foraminiferal species recovered from the study well making 20% of the total assemblages. Range from zone N4 of Early Miocene to the end of zone N8 – N9 (4272m – 3024m).

Material: 411 specimens

Uvigerina sp. Petters 1982

1982 *Uvigerina* sp. Petters

Occurrence: Common in the Palaeocene of the Niger Delta (Baba – 1, 2655m – 2673m) (Petters, 1982). In this study the species is poorly preserved. Range from zone N7 of Early Miocene to zone N8 – N9 of Early – Middle Miocene (4052m – 3376m).

Material: Five specimens

Superfamily Discorbacea Ehrenberg, 1838

Family Discorbidae Ehrenberg, 1838

Subfamily Discorbidinae Ehrenberg, 1838

Genus *Epistominella* Husezima & Maruhasi, 1944

Epistominella pontoni Cushman, 1930

1930 *Epistominella pontoni* Cushman

Occurrence: Very abundant in the Middle Oligocene – Early Miocene of the Niger Delta (Meta-1, 3138-3156 m), widely recorded in the Miocene of the U.S. Atlantic Coastal Plain (Petters, 1982). In this study the species has low abundance and occurs at zone N8 – N9 of Early Middle Miocene.

Material: One specimen

Epistominella vitrea Parker in Parker, Phleger and Peirson, 1953

1983 *Epistominella vitrea* Parker in Parker, Phleger and Peirson

Occurrence: Very abundant in the Middle Miocene – Pliocene of the Niger Delta (Sonam-9, 594-612 m) (Petters, 1982); this is reported in Palaeocene to Recent strata (Haynes, 1956). In

the Gulf of Mexico this species is associated with the area of deltaic discharge (Culver and Buzas, 1982). In this study the species occurs in association with *Epistominella pontoni* at zone N8 – N9 of Early Middle Miocene.

Material: One specimen

Subfamily Baggininae Cushman, 1927

Genus *Valvulineria* Cushman, 1926

Valvulineria gasparensis Bermudez, 1949

(Plate 2, Figs. 3, 4)

1949 *Valvulineria gasparensis* Bermudez

Occurrence: The species is fairly abundant and ranged from zone N4 (4253m) of Early Miocene to N8 – N9 (3156m) of Early – Middle Miocene.

Material: 18 specimens

Superfamily Rotaliacea Ehrenberg, 1839

Family Rotaliidae Ehrenberg, 1839

Subfamily Rotaliinae Ehrenberg, 1839

Genus *Ammonia* Brunnich, 1772

Ammonia beccarii Linné 1758

(Plate 1, Figs. 1, 2)

1758 *Ammonia beccarii* Linné

Occurrence: Abundant in the Miocene – Pliocene of the Niger Delta (Delta South-1, 486-504 m). This is a cosmopolitan species in recent hyposaline lagoons and estuaries, and also on the continental shelf (Petters, 1982). Rare in zone N8 – N9 (3613m) of Early – Middle Miocene of the study well.

Material: One specimen

Ammonia sp.Petters, 1982

1982 *Ammonia* sp.Petters

Occurrence: Rare in the Miocene-Pliocene of the Niger Delta where it co-occurs with *A. beccarii.* This species occurs within zone N8 – N9 (3378 – 3303m) of the Early – Middle Miocene of the study well.

Material: Two specimens

Family Miogypsinidae Vaughan, 1928

Genus *Miogypsinoides* Yabe and Hanzawa, 1928

Miogypsinoides sp. Yabe and Hanzawa, 1928

1928 *Miogypsinoides* sp. Yabe and Hanzawa

Occurrence: Rare in the zone N8 – N9 (3024 – 3284) of Early – Middle Miocene.

Material: Three specimens

Superfamily Orbitoidacea Schwager, 1876

Family Eponididae Hofker, 1951

Genus *Eponides* De Montfort, 1808

Eponides eshira De Klasz and Rérat, 1962

(Plate 1, Figs. 7, 8)

1962 *Eponides eshira* De Klasz and Rérat

Occurrence: Abundant in the Middle Oligocene-Middle Miocene of the Niger Delta (Meta-1, 3138-3156 m; Parabe-1, 2373 m); originally described from the Lower Miocene of Gabon. In this study the species is very abundant and range from zone P22/N3 (Late – Oligocene)

(3042m) to N8 – N9 (Early – Middle Miocene) (4359). This species consist of 13% of the total foraminiferal assemblages recovered from the well.

Material: 264 specimens

Eponides sp.

Eponides sp.

Occurrence: Very abundance and range from zone P22/N3 (Late – Oligocene) (3042m) to N8 – N9 (Early – Middle Miocene) (4359).

Material: 156 specimens

Eponides ornatus Galloway & Heminway 1941

1941 *Eponides ornatus*Galloway & Heminway

Occurrence: Rare abundance. Occurs in zone N8 – N9 (3266m) of the Early Middle Miocene.

Material: One specimen

Eponides berthelotianus D'Orbigny 1839

(Plate 1, Fig. 5, 6)

1839*Eponides berthelotianus* D'Orbigny

Occurrence: Rare abundance. Occurs in zone N7 (3266m) of the Early Miocene.

Material: Two specimens

Genus *Cibicorbis* Hadley, 1934

*Cibicorbis inflata*Galloway & Wissler 1927

(Plate 1, Fig. 3, 4)

1927 *Cibicorbis inflata*Galloway & Wissler

Occurrence: Rare abundance. Occurs in zone N7 (3024m – 3760m) of the Early Miocene.

Material: 27 specimens

Family Cibicididae Cushman, 1927

Subfamily Cibicidinae Cushman, 1927

Genus *Cibicides* De Montfort, 1808

Cibicides sp.

Cibicides sp.

Occurrence: Rare abundance. Occurs in N7 (3906m) of the Early Miocene.

Material: One specimen.

Superfamily Cassidulinacea D'Orbigny, 1839

Family Caucasinidae Bykova in Rauzer-Chernousova and Furenko, 1959

Subfamily Fursenkoininae Loeblich and Tappan, 1961

Genus *Fursenkoina* Loeblich and Tappan, 1961

*Fursenkoina punctata*D'Orbigny 1839

1839*Fursenkoina punctata* D'Orbigny

Occurrence: rare abundant. Range from zone N7 (3970m) of Early Miocene to zone N8 – N9 (3248) of Early Middle Miocene.

Material: Three specimens.

Genus *Virgulina*

Virgulina sp.

Virgulina sp.

Occurrence: This species range through zone N8 – N9 (3741m – 3432m) of Early – Middle Miocene.

Material: 16 specimens

Family Nonionidae Schultze 1854

Subfamily Nonioninae Schultze 1854

Genus *Nonion*De Montfort, 1808

*Nonion centrosulcatum*Klasz, Le Calves & Rerat 1964

(Plate 2, Figs. 10, 11)

1964 *Nonion centrosulcatum*Klasz, Le Calves & Rerat

Occurrence: rare abundance and range from zone P22/N3 (4235m) of Late Oligocene through zone N4 to zone N5 – N6 of Early Miocene.

Material: Nine specimens.

Genus *Florilus* De Montfort, 1808

*Florilus atlantucus*Cushman 1936

1936 *Florilus atlantucus*Cushman

Occurrence: Occurs within Zone N7 (3943m – 3906m) of Early Miocene.

Material: Three specimens.

Family Alabaminidae Hafker, 1951

Genus *Oridorsalis* Anderson, 1961

Oridorsalis tener Brady 1884

Oridorsalis tener Brady 1884

Occurrence: Restricted to upper part of zone N8 – N9 of Early - Middle Miocene

Material: Two specimens

Family Anomalinidae Cushman 1927

Subfamily Anomalininea Cushman 1927

Genus *Hanzawaia* Asano, 1944

*Hanzawaia strattoni*Applin,1925

(Plate 2, Figs. 1, 2, 5, 6)

1758 *Hanzawaia strattoni* Applin

Occurrence: Fairly distributed throughout the well. Range from zone P22/N3 (4345m) of Late Oligocene to zone N8 – N9 (3024m) of Early – Middle Miocene.

Material: 10 specimens.

Genus *Heterolepa* Franzenau 1884

*Heterolepa floridana*Cushman 1922

(Plate 2, Fig. 9)

1984 *Heterolepa floridana*Cushman 1922

Occurrence: Fairly distributed throughout the well. Range from zone P22/N3 (4345m) of Late Oligocene to zone N8 – N9 (3024m) of Early – Middle Miocene.

Material: 41 specimens.

Superfamily Globigerinacea Carpenter, Parker and Jones, 1862

Family Hantkeninidae Cushman, 1927

Subfamily Hastigerininae Bolli, Loeblich and Tappan, 1957

Genus *Hastigerina*Murray, 1876

Hastigerina praesiphonifera Blow, 1969

1969 *Hastigerina praesiphonifera* Blow

Occurrence: Restricted only to zone N7 (4235m) of Early Miocene.

Material: One specimen.

Family Globorotaliidae Cushman, 1927

Subfamily Globorotaliinae Cushman, 1927

Genus *Globorotalia* Cushman, 1927

Globorotalia continuosa Blow 1959

1959 *Globorotalia continuosa* Blow

Occurrence: Late Early Miocene- Middle Miocene; common in the Niger Delta (Ireti-9, 1,638-1,863 m; Sonam-9, 140-142 m) (Petters, 1983). In this study, it is restricted to upper part of zone N8 – N9 (3101) of Early – Middle Miocene.

Material: One specimen.

Globorotalia opima nana Bolli, 1957

1957 *Globorotalia opima nana* Bolli

Occurrence: Middle Eocene - late Oligocene; common in the Niger Delta (Petters, 1983). In the study well is restricted to zone P22/N3 (4359m) of Late Oligocene.

Material: One specimen.

Family Globigerinidae Carpenter, Parker and Jones, 1862

Subfamily Globigerininae Carpenter, Parker and Jones, 1862

Genus *Globigerina* D'Orbigny, 1826

Globigerina praebulloides leroyi Blow and Banner, 1962

1962 *Globigerina praebulloides leroyi* Blow and Banner

Occurrence: Restricted to Early – Miocene and range from zone N4 (4272m) to zone N5 – N6 (4144m).

Material: Two specimens.

Globigerina ciperoensis Bolli, 1957

(Plate 4, Figs. 13, 14)

1954 *Globigerina ciperoensis* Bolli

Occurrence: Oligocene - Earliest Miocene; common in the Niger Delta (Petters 1983). The FOD of this species was used to mark the boundary between Late – Oligocene and Early – Miocene (4327m). Is restricted to P22/N3 zone (4327m – 4395m) of Late – Oligocene.

Material: Two specimens.

Globigerina sp.

Globigerina sp.

Occurrence: Early Miocene (this study). Restricted to zone N4 (4290m).

Material: One specimen.

Genus *Globigerinoides* Cushman 1927

Globigerinoides sacculifer Brady, 1877

1877 *Globigerinoides sacculifer* Brady

Occurrence: Miocene-Recent; common in the Niger Delta (Petters, 1983). Early Miocene – Early – Middle Miocene (in this study) and range from zone N5 – N6 (4162m) through zone N7 to zone N8 – N9 (4301m).

Material: Six specimens.

Globigerinoides immaturus Leroy, 1939

1939 *Globigerinoides immaturus* Leroy

Occurrence: Early Miocene – Early Middle Miocene (this study). Range from zone N7 (3888m) to zone N8 – N9 (3357m).

Material: Two specimens.

Globigerinoides altiaperturus Bolli, 1957

(Plate 4, Figs. 1, 2)

1957 *Globigerinoides altiaperturus* Bolli

Occurrence: Early – Miocene (this study). Restricted to Zone N5 – N6 (4144m – 4253m). The LOD of this species together with LDO of *Catapsydrax stainforthi* are used to mark the lower boundary of zone N5 – N6 and the upper boundary of N4 (4253m).

Material: Four specimens.

Globigerinoides sp.

Globigerinoides sp.

Occurrence: Early – Middle Miocene. Restricted to zone N8 – N9 (3741m – 3156m).

Material: Four specimens.

Subfamily Orbulininae Schultze, 1854

Genus *Orbulina* D'Orbigny 1839

Orbulina bilobata D'Orbigny, 1846

1846 *Orbulina bilobata* D'Orbigny

Occurrence: Early Miocene (this study). Restricted to zone N4 (4290m).

Material: One specimen.

Orbulina suturalis Bronnimann, 1951

(Plate 4, Fig.6)

1951 *Orbulina suturalis* Bronnimann

Occurrence: Early – Middle Miocene (this study). Restricted to zone N8 – N9 (3559m).

Material: One specimen.

Genus *Praeorbulina* Olsson, 1964

Praeorbulina glomerosa Blow, 1956

(Plate 3, Fig. 5)

1956 *Praeorbulina glomerosa* Blow

Occurrence: Early – Middle Miocene (this study). Restricted to zone N8 – N9 (3796m - 3504m). The LOD of this species is used to mark the lower boundary of N8 – N9 (3796m).

Material: Nine specimens.

Praeorbulina sicana Cushman & Stainforth, 1945

(Plate 3, Figs. 7, 8)

1945*Globigerinoides sicana* Cushman & Stainforth

Occurrence: Early – Middle Miocene (this study). Restricted to zone N8 – N9 (3432m – 3083m).

Material: Four specimens.

Praeorbulina glomerosa curva Blow, 1956

(Plate 4, Figs. 3, 4)

1956 *Praeorbulina glomerosa curva* Blow

Occurrence: Late Early Miocene, common in the Niger Delta (Petters, 1983). Early Miocene (this study), restricted to zone N5 – N6 (4162m – 3796m).

Material: 12 specimens.

Subfamily Catapsydracinae Bolli, Loeblich and Tappan, 1957

Genus *Catapsydrax* Bolli, Loeblich and Tappan, 1957

Catapsydrax stainforthi Bolli, Loeblich and Tappan, 1957

(Plate 4, Figs. 11, 12)

1957 *Catapsydrax stainforthi* Bolli, Loeblich and Tappan

Occurrence: Early Miocene (this study). Range from base of zone N5 – N6 (4253m) to the top zone N7 (3796m).

Material: Six specimens.

Catapsydrax dissimilis Cushman and Bermudez, 1937

(Plate 4, Figs. 9, 10)

1937 *Catapsydrax dissimilis* Cushman and Bermudez

Occurrence: Middle Eocene-early Miocene; common in the Niger Delta (Petters 1983). Early Miocene (this study). Range throughout zone N5 – N6 (4107m – 4235m).

Material: Threespecimens.

CHAPTER SIX

6.0 SUMMARY AND CONCLUSION

The lithostratigraphic unit of the analyzed interval (3,024 m – 4,350 m) is interpreted as the Paralic sequence of Agbada Formation. A total of 63 foraminiferal species were identified from the study well (3,024 m – 4,350 m) out of which 18 species are planktonics and represent 29% of the total foraminiferal assemblage. The remaining 45 species are benthonics out of which 40 are calcareous and 5 are arenaceous representing 63% and 8% of the total foraminiferal assemblages respectively.

The entire deposition took place during Late – Oligocene to Early – Middle Miocene time. The boundary between Late – Oligocene and Early – Miocene was identified at 4327 m based on the FDO of Late – Oligocene species *Globigerina ciperoensis* (Postuma, 1971 and Petters, 1983). The boundary between Early – Miocene and Early Middle Miocene was identified at 3796m based on LDO of *Praeorbulina glomerosa* and FDO of *Catapsydrax stainforthi* (Postuma, 1971 and Petters, 1983). In this study five planktonic foraminiferal zones were proposed: *Globigerina ciperoensis* Taxon range zone (P22/N3), *Orbulina bilobata* Interval zone (N4), *Globigerinoides altiaperturus – Catapsydrax dissimilis* Concurrent range zone (N5 – N6), *Catapsydrax stainforthi* Interval zone (N7), *Praeorbulina glomerosa* Interval zone (N8 – N9). The identification of the zone was based on FDO or LDO of identified index foraminiferal species in the well and which conform to the earlier works of Bolli (1957), Bolli and Saunders (1985) and Stainforth *et al.* (1975). Based on the

work of Petters (1983) and the proposed planktonic foraminiferal zones of this study, four benthonic foraminiferal zones were proposed; *Epistominella vitrea* Taxon Range Zone, *Eponides berthelotianus* Interval Zone, *Ammonia* sp. Interval Zone and *Miogypsinoides* sp. Taxon Range Zone.

The sediments in the study well may be considered to be of normal marine neritic depositional environment based on Murray (1973, 2006) triangular plot of foraminiferal suborders ratio of Textulariina (arenaceous), Miliolina (porcelaneous), and Rotaliina (hyaline calcareous). The Paleobathymetry ranged from non-marine, shallow inner neritic, inner neritic, inner – middle neritic, middle neritic, middle – outer neritic and outer neritic environment. Based on the P/B ratio, it is concluded that the sediments in the well were deposited in dysoxic – oxic conditions.

Changes in sea level were inferred base on paleobathymetric data, foraminiferal abundance and coarsening upward nature of the study well section. From the sea level curve it can be deduced that the well sequence is characterized by four episodes of sea level rise and fall during late Oligocene to Early – Middle Miocene.

The sequence stratigraphic analysis based on the available data shows that the well penetrated eight (8) system tracts made up of one (1) Lowstand Systems Tract (LST), four (4) Transgressive System Tract (TST), three (4) Highstand System Tract (HST), three (4) candidates of Maximum Flooding Surfaces (MFS) were proposed at 4,235 m, 3,906 m, 3,760 m and 3,414m. This reveals the existence of four (4) depositional sequence in the study well. The associated SB occur at 4,144 m, 3,851 m and 3650 m. One transgressive surface (TS) was identified at 4016 m.

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APPENDIXI

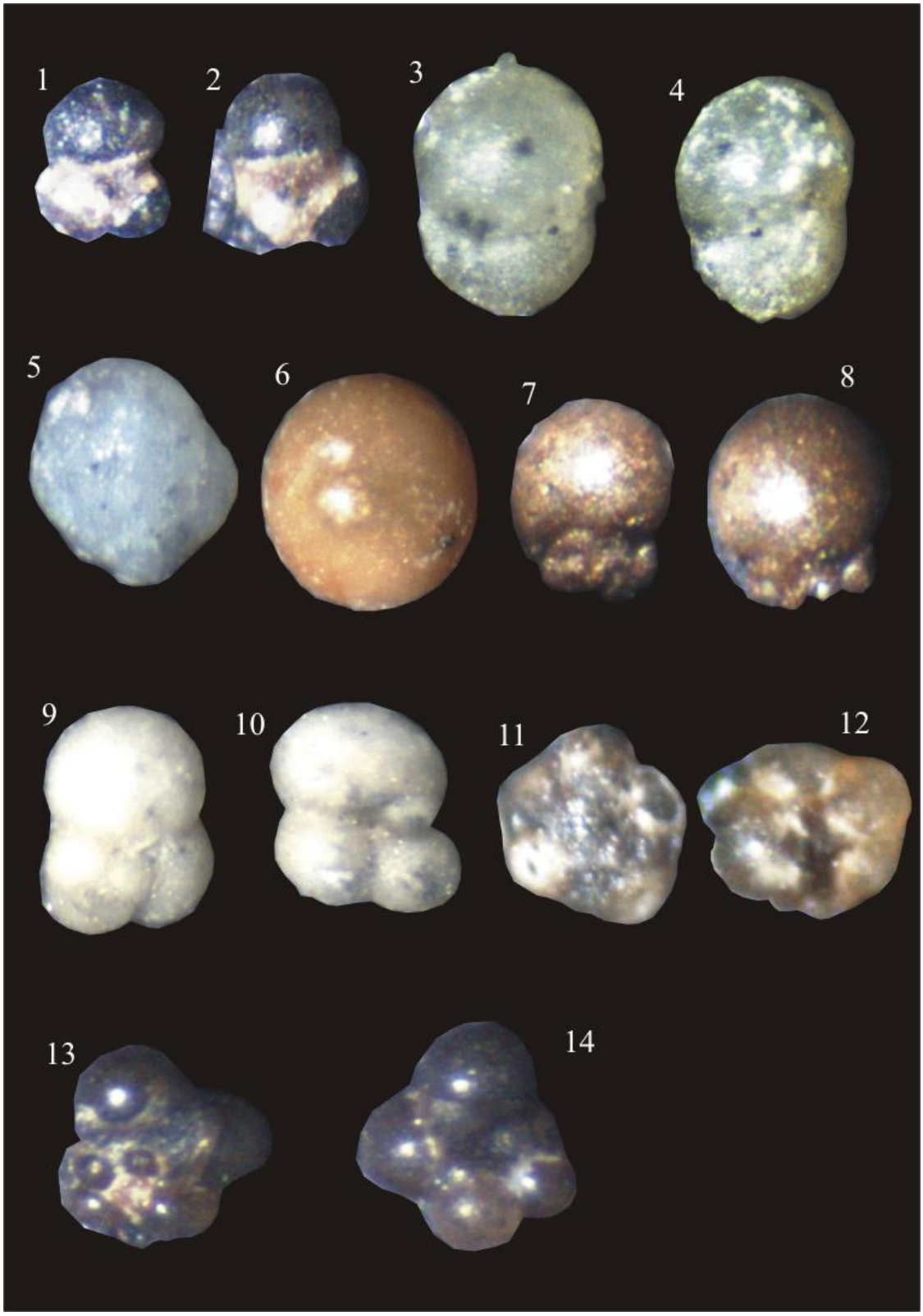


Plate 1:Fig.1, 2. *Globigerinoides altiaperturus* (X500); Fig.3, 4.*Praeorbulina glomerosa* (X300);Fig.5. *Praeorbulina glomerosa* (X300);Fig.6. *Orbulina suturalis* (X300)Fig.7.8. *Praeorbulina sicana* (X300); Fig.9, 10.*Catapsydrax dissimilis* (X400); Fig.11, 12. *Catapsydrax stainforthi* (X500), Fig. 13, 14 *Globigerina ciperoensis* (X500).

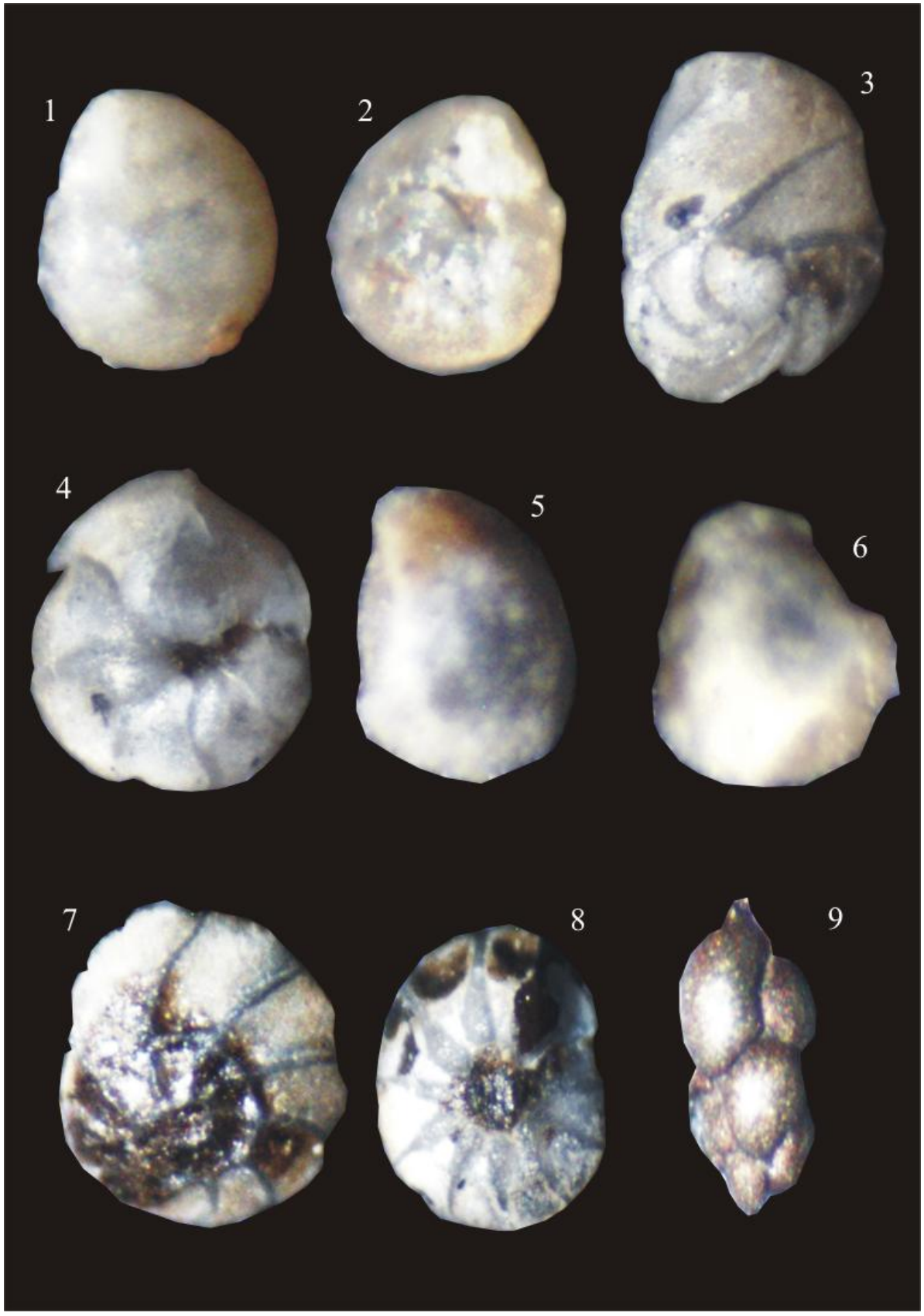


Plate 1: Fig. 1, 2 *Ammonia beccarii*(X500); Fig. 3, 4 *Cibicorbis inflata* (X500); Fig. 5, 6 *Eponides berthelotianus* (X500); Fig. 7, 8. *Eponides eshira* (X500); Fig. 9*Buliminella aff. Subfusiformis* (X350).

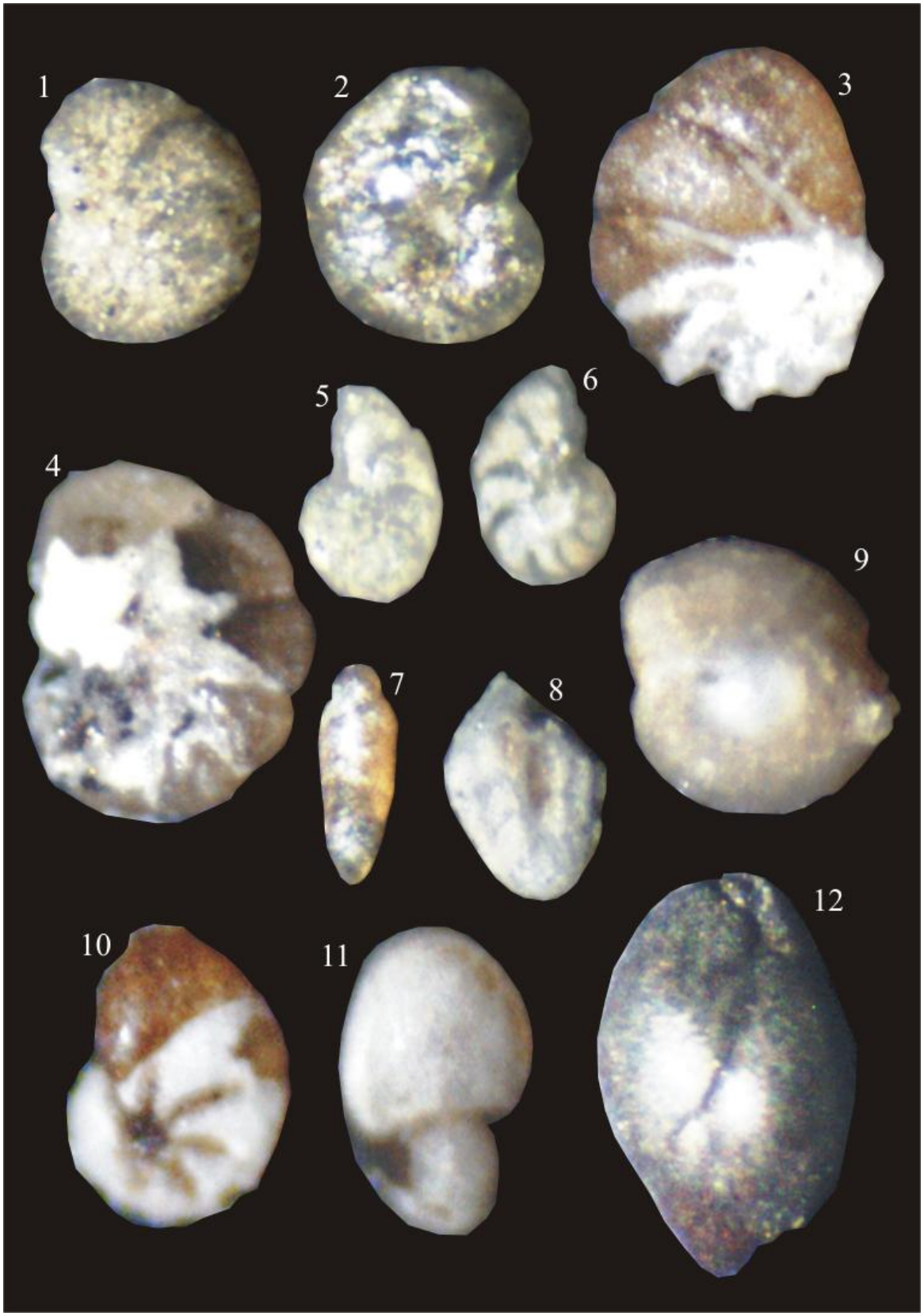


Plate 2: Fig.1, 2, 5, 6.*Hanzawaia stratonii* (X500);Fig. 3, 4.*Valvulineria gasparensis* (X500);Fig.7. *Bolivina dilatata* (X500);Fig. 8. *Brizalina interjuncta* (X500)Fig.9. *Heterolepa floridana* (X500);Fig.10, 11.*Nonion centrosulcatum* (X500);Fig.12. Globobulimina ovata(X300).

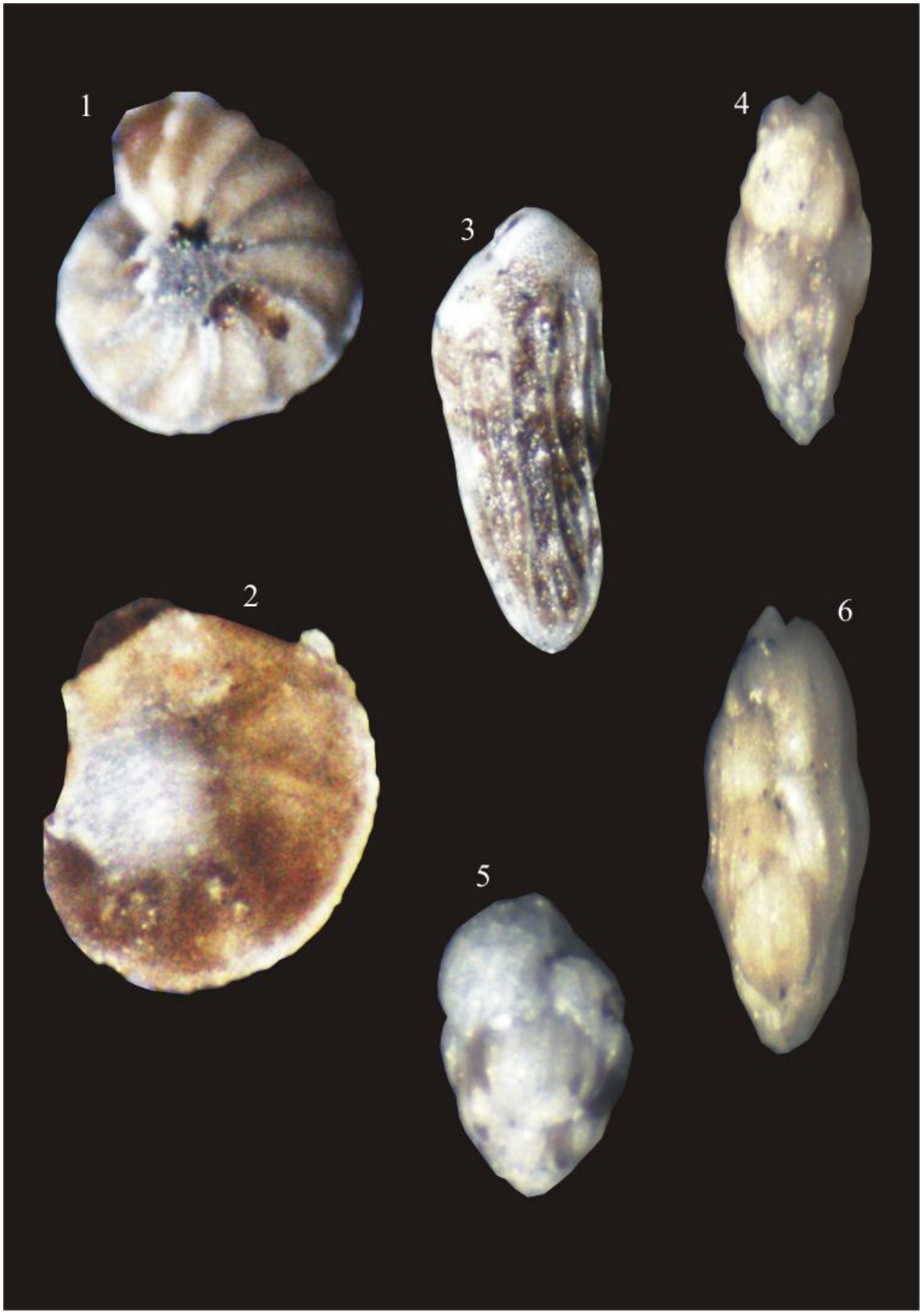
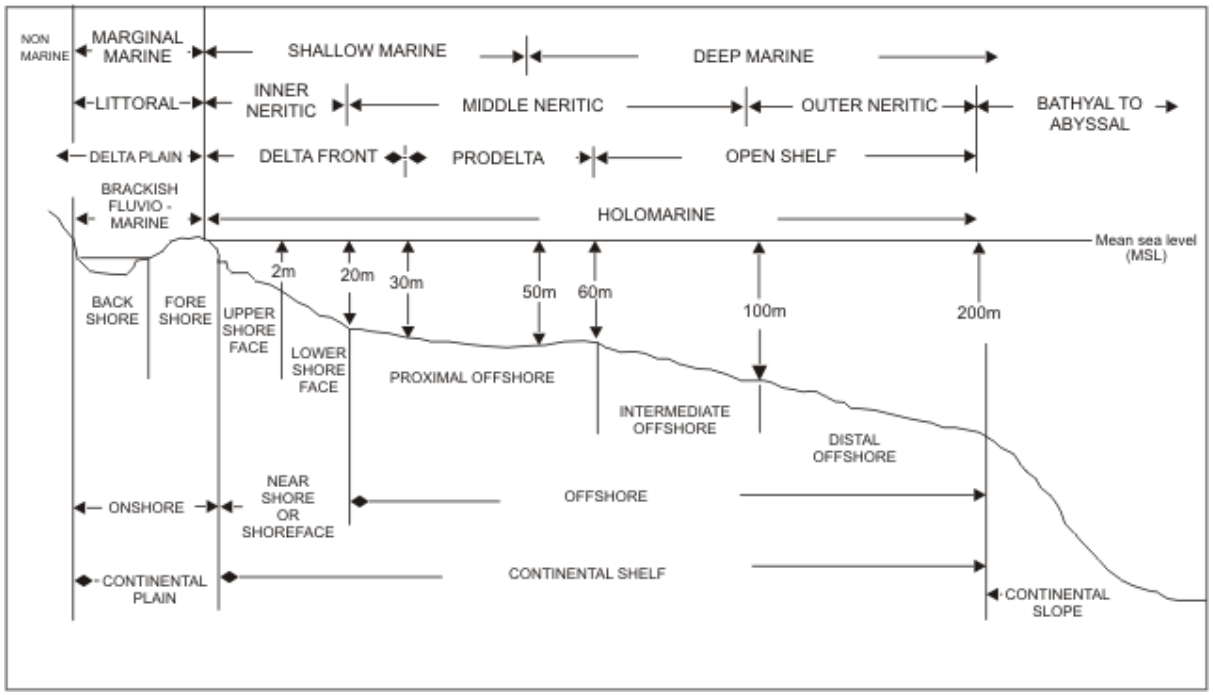


Plate 3: Fig.1, 2*Lenticulina grandis* (X300); Fig.3. *Brizalina mandoroveensis* (X300); Fig.4. *Uvigerina sparsicostata*;Fig.5. *Uvigerina isidroensis*;Fig.6. *Hopkinsina bononiensis* (X350).

APPENDIX II: Depositional environments and bathymetric ranges used for palaeoenvironmental interpretation (After Allen 1965)



APPENDIX III: Planktonic/Benthonic Ratio in the study well

Depth (m)	% Calcareous Benthonics	% Arenaceous Benthonics	% Planktonic
3024	100.00	0.00	0.00
3042	100.00	0.00	0.00
3083	94.44	0.00	5.56
3101	88.89	0.00	11.11
3120	100.00	0.00	0.00
3138	100.00	0.00	0.00
3156	94.74	0.00	5.26
3174	96.00	4.00	0.00
3193	100.00	0.00	0.00
3211	100.00	0.00	0.00
3229	100.00	0.00	0.00
3248	76.19	23.81	0.00
3266	70.27	29.73	0.00
3284	95.31	4.69	0.00
3303	95.65	4.35	0.00
3321	100.00	0.00	0.00
3351	42.86	57.14	0.00
3357	93.33	0.00	6.67
3376	87.50	12.50	0.00
3395	100.00	0.00	0.00
3414	96.30	3.70	0.00
3432	97.83	0.00	2.17
3447	100.00	0.00	0.00
3467	66.67	33.33	0.00
3485	94.74	5.26	0.00
3504	85.71	0.00	14.29
3522	100.00	0.00	0.00
3540	93.48	6.52	0.00
3559	90.48	4.76	4.76
3577	100.00	0.00	0.00
3595	91.67	8.33	0.00
3613	90.91	0.00	9.09

Depth (m)	% Calcareous Benthonics	% Arenaceous Benthonics	% Planktonic
3632	100.00	0.00	0.00
3650	100.00	0.00	0.00
3668	100.00	0.00	0.00
3687	95.24	4.76	0.00
3723	100.00	0.00	0.00
3741	88.89	0.00	11.11
3760	100.00	0.00	0.00
3778	100.00	0.00	0.00
3796	92.11	0.00	7.89
3815	98.61	0.00	1.39
3833	100.00	0.00	0.00
3851	100.00	0.00	0.00
3869	40.00	60.00	0.00
3888	83.72	2.33	13.95
3906	98.04	0.00	1.96
3924	66.67	0.00	33.33
3943	85.71	0.00	14.29
3961	100.00	0.00	0.00
3979	94.74	0.00	5.26
3997	80.00	20.00	0.00
4016	0.00	0.00	0.00
4034	90.91	3.03	6.06
4052	100.00	0.00	0.00
4071	100.00	0.00	0.00
4089	100.00	0.00	0.00
4107	95.24	0.00	4.76
4125	100.00	0.00	0.00
4144	86.21	0.00	13.79
4162	87.50	0.00	12.50
4180	100.00	0.00	0.00
4199	100.00	0.00	0.00
4217	96.55	0.00	3.45
4235	93.97	0.86	5.17
4253	98.25	0.00	1.75
4272	94.12	2.94	2.94
4290	93.88	0.00	6.12
c4308	100.00	0.00	0.00

4327	97.37	1.32	1.32
4345	98.48	0.00	1.52
4359	99.24	0.00	0.76