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Foraminiferal Biostratigraphy, and Paleoenvironmental Interpretations in the Masa-01 Well, Western Offshore, Niger Delta Basin, Nigeria

Mayowa Daniel Ajayi* and Saka Adelayo Opeloye

Department of Applied Geology, The Federal University of Technology, Akure, Ondo State, Nigeria

***Corresponding Author**
Mayowa Daniel Ajayi, Department of Applied Geology, The Federal University of Technology, Akure, Ondo State, Nigeria.

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Abstract

A foraminiferal biostratigraphy and paleoenvironmental studies were carried out on fifty (50) ditch-cut samples retrieved from the MASA-01 well, western offshore region, Niger Delta, Nigeria. The studied intervals ranged from 6810 feet (2076 m) to 8310 feet (2533 m) and were analyzed at intervals of 30 feet (9 m). The samples were subjected to foraminiferal and lithostratigraphy analyses to determine the biozonation and paleoenvironment of deposition. Standard foraminiferal preparation techniques completed with strata-bug software analysis were employed. Lithological studies indicate that the depth intervals belong to the upper paralic Agbada Formation. Seventy-six (76) foraminifera species were retrieved from the well comprising 34 calcareous benthic, 5 agglutinated benthic, and 37 planktic species. Three (3) planktic foraminifera zones, the Sphaeroidinellopsis seminulina/Bulimina marginata Zone, the Globorotalia margaritae/Amphistegina lessonii Zone, and the Globigerina nepenthes/Marginulina costata Zone corresponding to the N20/PL3 and N19/PL2 zones, were identified. The important markers recorded were Globorotalia plesiotumida/merotumida (FDO) and Globorotalia crassaformis crassaformis (LDO) at 7230feet; the lone occurrences of Amphicoryna scalaris caudata at 7470feet; Globorotalia margaritae margaritae (FDO) and Globorotalia margaritae margaritae (LDO) at 7650feet and 8010feet; and Globigerinoides nepenthes (FDO) and depressed Globigerinoides bollii (FDO) at 7920feet and Sphaeroidinellopsis seminulina (FDO) at 8040feet. The well was dated to the early Pliocene (N20/PL3–N19/PL2) based on the occurrence of marker species. The two (2) condensed sections that are associated with maximum flooding surfaces (MFS) were dated to 3.82 Ma at 7230 feet and 4.16 Ma at 7830 feet based on peak faunal abundance and diversity. A hypersaline outer neritic to the upper bathyal environment is deduced from paleoecological indices of bathymetry and planktic/benthic ratio.

Keywords: Foraminifera, Biostratigraphy, Paleoenvironment, Maximum Flooding Surfaces, Pliocene, Biozonation, Lithostratigraphy, Condensed Sections, Bathymetry, Hypersaline, Neritic

1. Introduction

The Niger Delta basin is the West African continental margin's most significant hydrocarbon region. The exploration for additional hydrocarbons requires the identification of terrains suitable for these habitats. Recognition of such habitats entails biostratigraphic studies. The decrease in recoverable hydrocarbons requires that more environments suitable for hydrocarbon habitats be discovered. With this ever-changing economic fortune, it is imperative that more hydrocarbons be discovered. This has led to the evolution of new techniques and approaches for identifying habitats. Using biozonation, correlation, and the age of the sediments, as well as the environment of deposition, studies of these organisms in the Niger Delta province have been shown to be crucial. This has led to the use of planktic and benthic foraminifera in biostratigraphy, which has been demonstrated to play crucial roles in the search for oil and gas. Planktonic foraminifera are among the primary indicators of geological timescales, making their vast range of evolutionary rates a natural advantage for biostratigraphical studies [1]. The crucial importance of these microfossils for any paleoenvironmental or paleobathymetric study is highlighted by the extraordinarily broad range of settings colonized by these microfossils, from the deep sea to the shallow shelf and the oligotrophic surface ocean. The life habits of these plants, which can be directly linked to their substrate, make them a useful group of organisms for inferring the ecological factors controlling their distribution. They are abundant in the sedimentary record due to their high preservation potential. Therefore, these methods have been successfully used to determine the age of sediments and imply paleoenvironmental conditions. [2] went on to state that foraminifera are incredibly reliable and helpful in analyzing, identifying, and comprehending both modern and ancient marine ecosystems. The morphological changes of these microfossils with depth will be useful in determining the variations in environmental pressure on them, especially for bathymetric analysis. Foraminifera are very sensitive to changes in the environment; therefore, a change in environmental parameters (e.g., temperature, salinity) is reflected by a change in the assemblage [3, 4, 5]. Attention needs to be given to offshore regions, as it is more probable that these regions will contain hydrocarbons. In light of the aforementioned reasons, this study on foraminifera biostratigraphy was carried out to identify the foraminiferal assemblages and their biozonation, as encountered in the MASA-01 well.

1.1. Location of the Study Area and Geological Settings

The study well is situated between latitudes 4° and 5°2'N and longitudes 3° to 9°E in the western offshore region of the Niger Delta Basin in Nigeria (Figure 1). The basin is located in the Gulf of Guinea on the west coast of central Africa. It is one of the world's most productive deltaic hydrocarbon areas. The overall regressive clastic sequence that composes the 140,000 km (75,000 km²) sedimentary prism has a maximum thickness of 29,500 feet to 39,400 feet and a stratigraphic thickness of approximately 12 km. The name and exact location of the well-studied and geographical coordinates were not available for this study. 'MASA-01', as the name of the well, is a code adopted to maintain the propriety confidence of the oil company that owns the samples for this research.

On the edge of the West African continent, Nigeria is home to the Niger Delta basin. According to Onyekuru et al. [6, 7], the delta has a depth between 9 and 12 km (29,500 feet to 39,400 feet), a subaerial extension of approximately 75,000 km², a total size of 300,000 km², and a sediment fill of 500,000 km³. It is a high-energy constructive arcuate delta system [8]. Rapid sedimentation occurs in the Niger Delta region, which is significant globally due to its hydrocarbon reserves. The delta is located where a triple junction formed after the split of South America and Africa in the late Jurassic, when the Benue Trough and the South Atlantic Ocean met [9]. The South Atlantic opened up at a rift junction where it was formed in the late Jurassic and continued into the Cretaceous. One of the basins in West Africa, the Niger Delta, was created by basement tectonics associated with crustal translation and divergence during the Cretaceous continental rifting of Gondwanaland. Since the early Tertiary, a thick prism of clastic sediments known as the Niger Delta has prograded into the Gulf of Guinea from the Benue Trough. Cretaceous fracture zones manifested as trenches and ridges in the deep Atlantic are in charge of the tectonic framework of the continental margin along the West Coast of equatorial Africa. The Cretaceous Benue-Abakaliki trough stretches deep beneath the West African shield and further splits the edge into distinct basins. In Nigeria, fracture zones provide the border faults of troughs. The morphology of the Niger Delta changed from an early stage of delta development that spanned the Paleocene to the early Eocene to a later stage in the Miocene epoch. The distribution of deposits was significantly impacted by basement topography and early coastlines bent toward the sea [10].

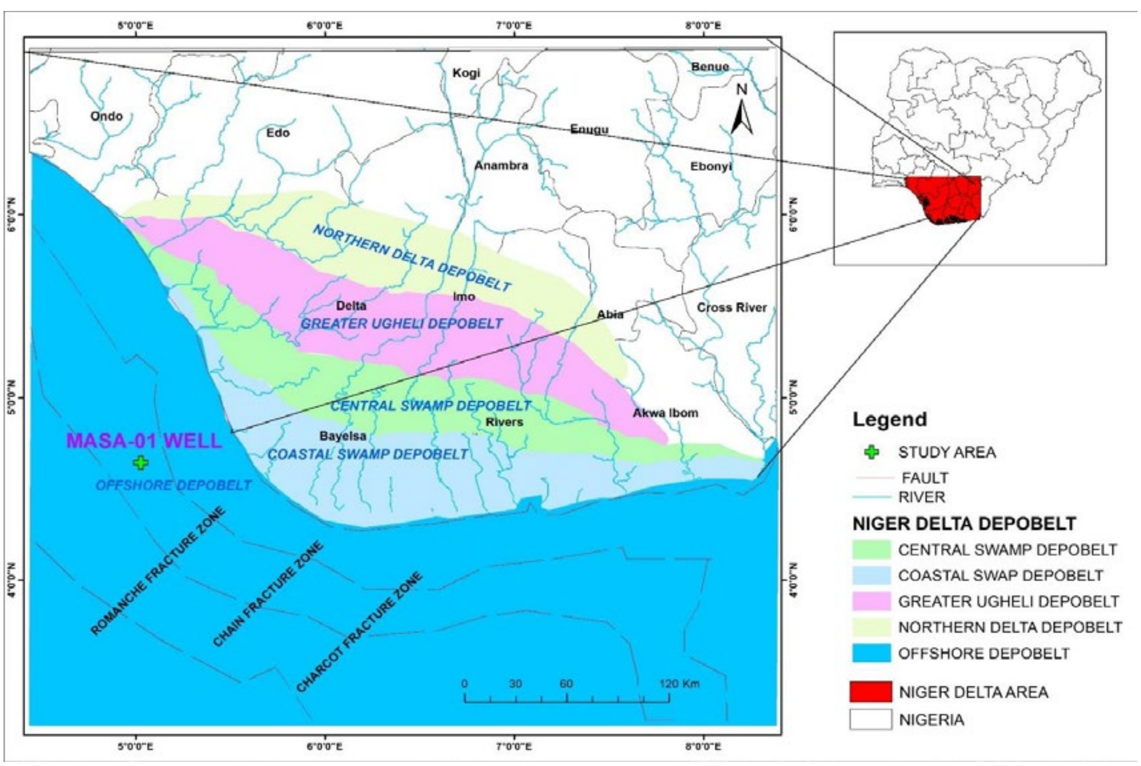

Figure 1: Map of The Study Area (Modified After Stacher, 1995) [11]

1.2. Stratigraphy of the Niger Delta

With sediments ranging from deep-sea mud-sized grains at the bottom to fluvial denser sand-sized grains, the Niger Delta basin has generally regressed over time. The deposits are largely a prograding package of off lapping strata made up of the Akata, Agbada, and Benin Formations, three separate time-transgressive lithologic units (Figure 2). The Akata Formation, a thick marine shale at the base of the package, is often under compacted, over pressed, and mobile. Paralic sands and marine shales alternate in the Agbada Formation, which sits on top of the Akata. The Agbada Formation contains the majority of hydrocarbon deposits in the Niger Delta; the interlacement of sand and shale layers provides fantastic prospects for reservoirs and top-seal formations. The coarse continental sands that make up the uppermost Benin Formation. The stratigraphic framework and intricate Tertiary stratigraphy of the Niger Delta basin are composed of the Akata Formation (Paleocene-Eocene) through a sand-shale paralic sequence. The Miocene-Recent Benin Formation, which, according to the sand-shale ratio, features the prograding depositional facies Short [12, 13]. The Agbada Formation comprises late Eoceneearly Oligocene to continental sands and gravels. These three formations are strongly diachronous according to Obaje (2009) [14], which indicates that they have passed through various geologic periods (Table 1). The three lithostratigraphic units of the Niger Delta show a noticeable coarsening-upward clastic wedge. According to Weber and Daukoru (1975) [15], these formations were primarily deposited in various marine, deltaic, and fluvial environments.

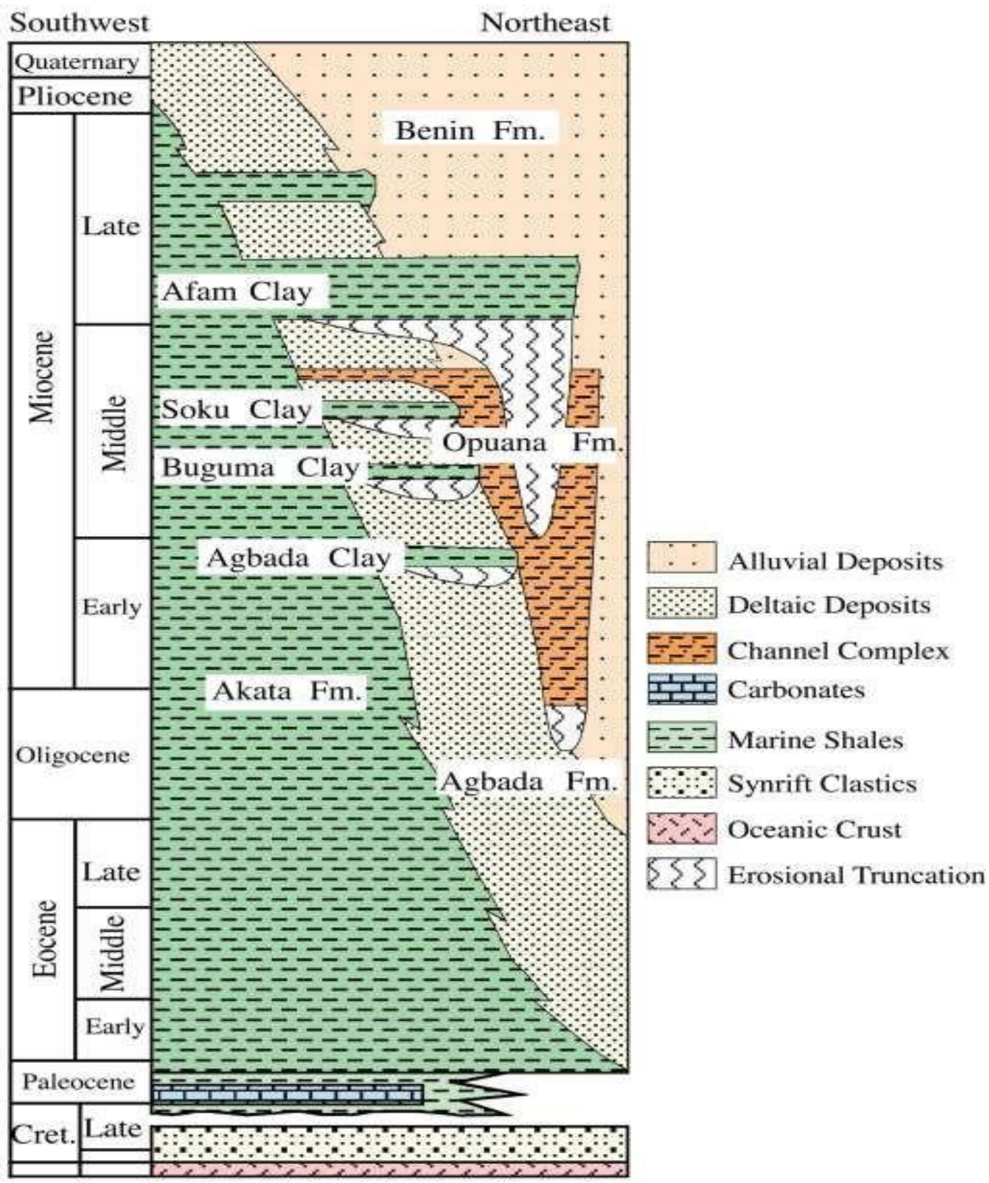

Figure 2: Stratigraphic Column Showing the Three Lithostratigraphic Units of The Niger Delta [16, 17]

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	Oligocene Eocene
Recent	Akata Formation	Eocene	lower Eocene	Imo shale Formation	Paleocene
	Unknown		Paleocene	Nsukka Formation	Maestrichtian
			Maestrichtian	Ajali Formation	Maestrichtian
			Campanian	Mamu Formation	Campanian
			Campanian/Maestrichtian	Nkporo Shale	Santonian
			Coniacian/Santonia	Awgu Shale	Turonian
			Turonian	Eze Aku Shale	Turonian
			Albian	Asu River Group	Albian

Table 1: Stratigraphic Units of the Niger Delta Area, Nigeria. (Modified from Short and Stauble, 1967) [12]

2. Materials and Method

2.1. Materials

Fifty (50) ditch-cut samples collected from the continental shelf of the western offshore Niger Delta Basin were used for the analyses and interpretation of this project. The samples were codenamed MASA-01 well for confidentiality reasons. Sampling intervals ranged from 6810 feet (2076 m) to 8310 feet (2533 m) and were analyzed at intervals of 30 feet (9 m). The samples were provided by Mosunmolu Limited Geological & Environmental Consultants. The study was carried out using the facilities of Mosunmolu Limited and Crystal Age Limited Laboratory, Lagos, Nigeria. The samples were portioned into two (2) parts each for foraminiferal and lithostratigraphic analyses.

2.2. Method

2.2.1. Lithologic Description

The fifty (50) ditch-cut samples were analyzed under an Olympus stereoscopic binocular microscope to determine their lithologic characteristics as well as the accessory minerals present in the sediments. A lithologic description was performed for each sample based on the dominant and secondary rock types, color and texture of the constituent materials, visible fossil content, and other features of the sediment.

2.2.2. Foraminifera Analysis

Preparation and analysis of the samples for foraminifera species followed standard foraminiferal procedures. A standard weight (20 grams of dried sample) was soaked in well-labeled dish pans arranged serially for four (4) hours in kerosene/hydrogen peroxide (organic solvent) to allow proper disaggregation of the samples. The samples were subsequently placed on a hot plate to dry for approximately 40-50 minutes, followed by soaking in soapy water overnight in the fume cupboard. The disaggregated samples were then washed gently under slowly running tap water through a 63-micron mesh sieve. The washed residue was then dried over a hot plate at 40°C and sieved into three fractions (coarse, medium, and fine) in clearly well-labeled sample bags before picking. All the foraminifera species, ostracod shell fragments, and other biota were picked from a gridded picking tray, black-coated with a divided square approximately 5 mm by 5 mm, and counted under a light-reflecting binocular microscope. The specimens were stored on well-labeled slides provided with coverslips for analysis. Identification of foraminifera according to their species and habitats; sorting, naming, and counting of the forams picked from each sample using relevant photomicrographs in published catalogs, atlases, albums, and literature [18] and [19] as a guide. The cascading counting method of Styzen (1997) [20] was used to determine the relative abundance and diversity of the assemblages per sample for quantitative analysis. Absolute care was taken at all stages of sample preparation to avoid contamination.

Strata Bug software (biostratigraphy database software) was used to generate a chart for interpretation purposes on a 1:3,500 scale with depth on the Y-axis and the observed taxa on the X-axis at each depth. The entire set of micropaleontological and statistical data was plotted on a chart.

3. Results and Discussion

3.1. Sedimentology and Lithostratigraphy

The dominant lithofacies consist of sands and shale. The sands consist of fine-grained and, occasionally, medium- to coarse-grained fractions. In addition, the sands within this section are angular/subangular to subrounded and poorly to moderately sorted. The shale varies in color from dark gray to brownish gray and, occasionally, light gray. They are fissile to non-fissile and generally moderately hard. The accessory minerals recorded include a few pyrites (P), carbonaceous matter (CM), ferruginous materials (FMs), and shell fragments (SFs). Detailed lithologic descriptions on a sample-by-sample basis are provided in Appendix 1. The lithologic units of the sequence recognized were deduced from the sedimentological assessment, which suggested the occurrence of predominantly shale and sand (Figure 3). The thickness of the studied section is 457 m, which ranges from 2076 m to 2533 m, and is studied at intervals of 18 m. The studied section is composed of three (3) sands with interbedded shale (shaly sand) units ranging from 2085–2166 m, 2454–2472 m and 2499–2533 m, while the section composed of two (2) shales with interbedded sand (sandy shale) units ranges from 2175–2445 m and 2481–2490 m. According to the samples analyzed, the well is classified as part of the Upper Paralic Agbada Formation, described by Short [12, 13].

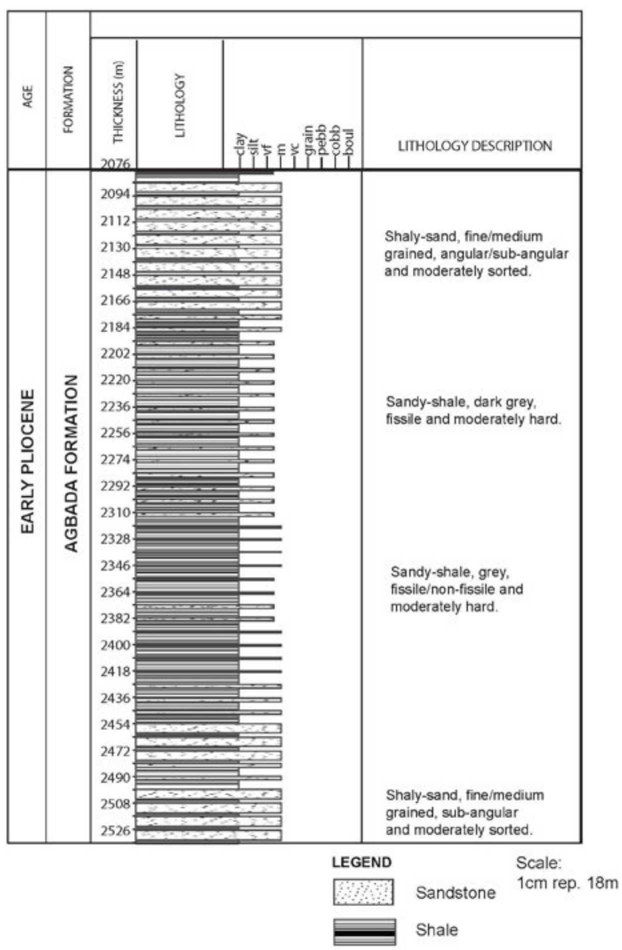

Figure 3: Lithology of The Shale and Sand Sequence of The Studied Section in the 'Masa-01' Well

3.2. Foraminifera Biostratigraphy

3.2.1. Foraminifera Distribution

The MASA-01 well was studied for foraminifera analysis and paleoenvironmental interpretations in which fifty (50) ditch-cutting samples at 30 feet intervals within the ranges of 6810 feet (2076 m) – 8310 feet (2533 m) were prepared and analyzed for preserved fauna and accessories. Eleven (11) samples were completely barren, while the remaining samples recorded were moderately abundant and contained benthic and planktic species and only a few foraminifera species micro accessories (Figure 4). A total of seventy-six (76) foraminifera species were identified, comprising 39 benthic species (34 calcareous benthic species and 5 agglutinated benthic species) and 37 planktic species. Photomicrographs of several identified forms are shown for Plate 1. Several important index species were used for biozonation and interpretation of the well, such as *Oridorsalis umbonatus, Cibicidoides pseudoungerianus, Sphaeroidinellopsis seminulina, Hoeglundina elegans, Cibicidoides pachyderma, Globorotalia margaritae margaritae, and Globigerinoides bollii. Other species include Globigerina nepenthes, Amphicoryna scalaris caudata, Globorotalia crassaformis crassaformis, Bulimina inflata, Heterolepa bellincionii, Ceratobulimina pacifica, and Globorotalia plesiotumida/merotumida.*

In terms of the total abundance of the foraminifera species recovered, the calcareous benthic foraminifera accounted for 44.73%, while the agglutinated benthic foraminifera accounted for 6.57%; the remaining 48.68% was accounted for by the planktic microfauna (Figure 5).

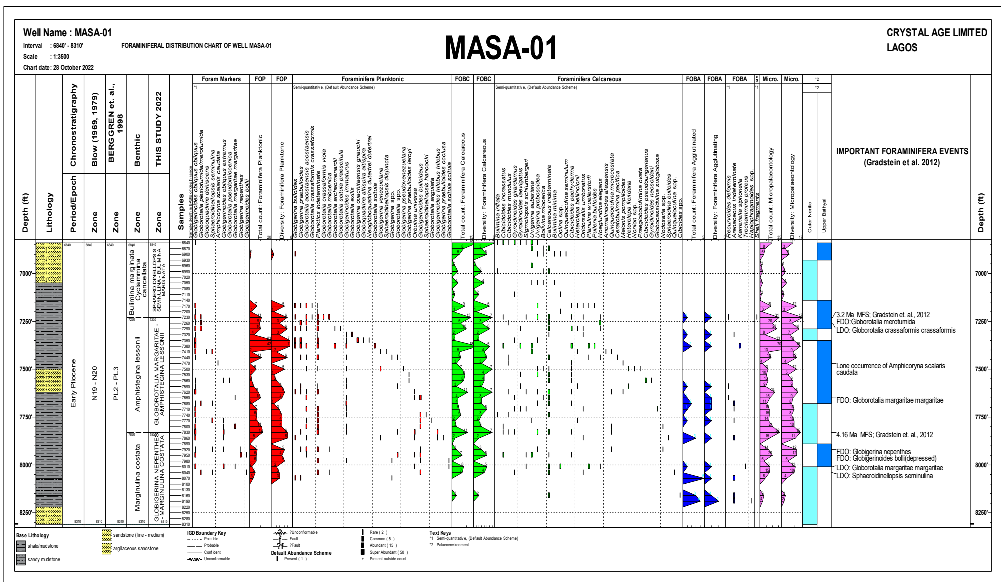

Figure 4: Stratigraphic Distribution of Foraminiferal Assemblages Recorded in the 'Masa-01' Well

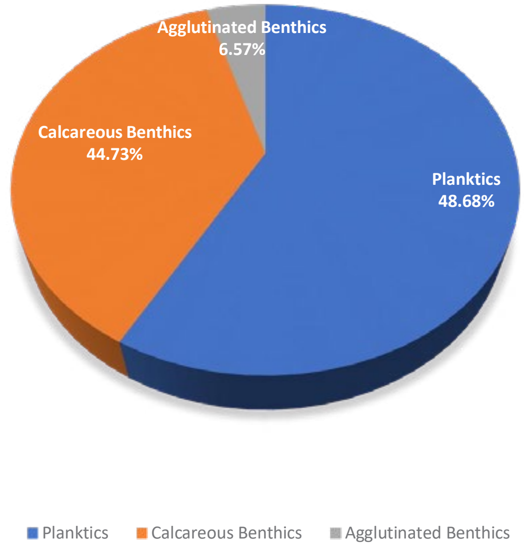

Figure 5: Pie Chart Showing the Percentage Abundance Distribution of The Major Foraminifera Groups Identified in the 'Masa-01' Well

In terms of abundance, the moderately abundant calcareous benthic species are *Uvigerina proboscidea, Uvigerina auberiana, Cibicidoides pachyderma,* and *Cibicidoides incrassatus* (Figure 6), and the fairly abundant arenaceous benthic species are Recurvoides deformis (Figure 7), while the moderately abundant planktic species are *Globigerinoides obliquus obliquus, Globorotalia acostaensis acostainoides, Globigerina praebulloides, Globigerinoides immaturus, Globigerinoides bulloideus, Globigerina bulloides,* and *Globorotalia plesiotumida merotumida* (Figure 8).

In terms of diversity, the most important calcareous benthic families are Cibicididae, Hauerinidae, Buliminidae, and Uvigerinidae, which have species diversities of 7, 4, 3, and 2, respectively; the most important arenaceous benthic families are Ammosphaeroidinidae, Eggerellidae, Trochamminidae, and Haplophragmoididae, which have species diversities of 1, 1, 1 and 1, respectively; and the important planktic families are Globigerinidae and Globorotaliidae, which have species diversities of 19 and 15, respectively. The foraminifera assemblages recovered were categorized according to their suborder, superfamily, family, and genus (Table 2) using Loeblich and Tappan's Foraminiferal genera and their classification (1988).

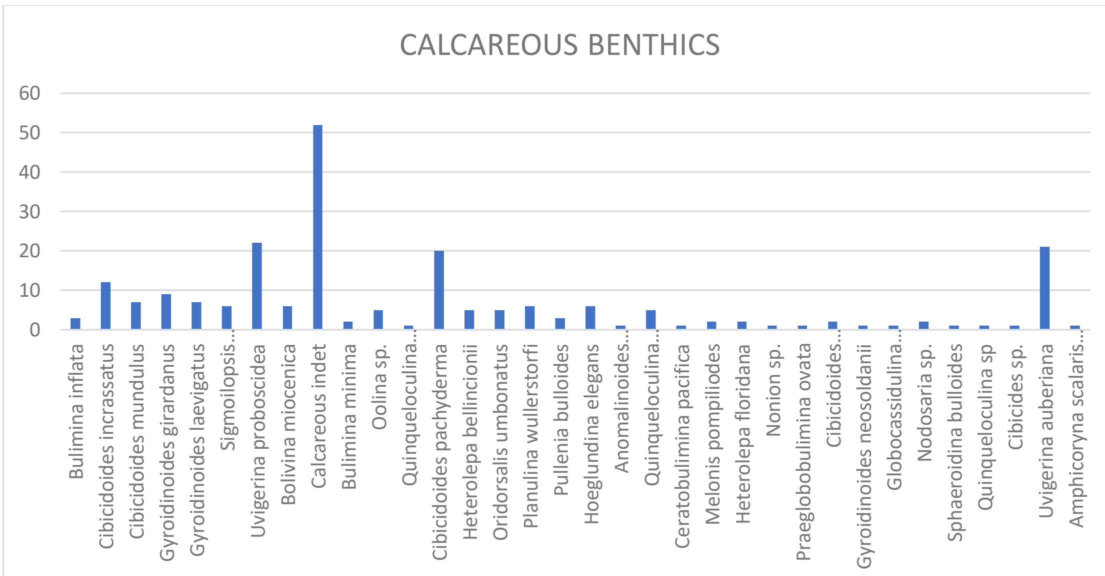

Figure 6: Bar Chart Showing the Abundance of Calcareous Benthic Foraminifera Recorded in The Masa-01' Well.

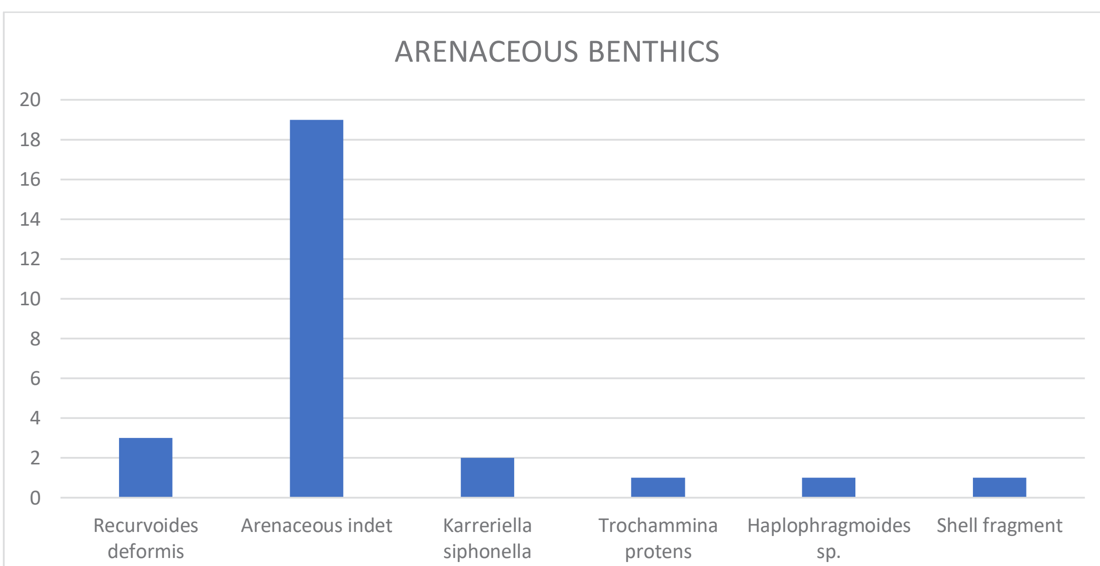

Figure 7: Bar Chart Showing the Abundance of Arenaceous Benthic Foraminifera Recorded in The 'Masa-01' Well.

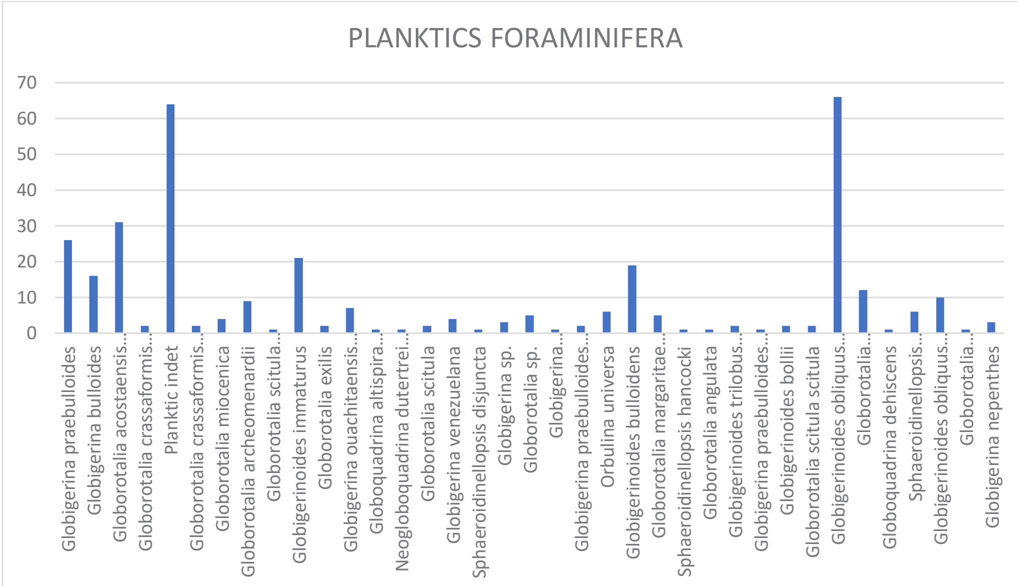

Figure 8: Bar Chart Showing the Abundance of Planktonic Foraminifera Recorded in the 'Masa-01' Well.

	Suborder	**Superfamily**	**Family**	**Genus**	**Species diversity**
BENTHICS	Textulariina	Recurvoidoidea	Ammosphaeroidinidae	Recurvoides	1
		Eggerelloidea	Eggerellidae	Karreriella	1
		Trochamminoidea	Trochamminidae	Trochammina	1
		Lituoloidea	Haplophragmoididae	Haplophragmoides	1
	Miliolina	Miliolidea	Hauerinidae	Quinqueloculina	3
				Sigmoilopsis	1
	Rotaliina	Buliminoidea	Buliminidae	Bulimina	2
				Praeglobobulimina	1
		Cassidulinoidea	Uvigerinidae	Uvigerina	2
			Cassidulinidae	Globocassidulina	1
			Sphaeroidinidae	Sphaeroidina	1
			Bolivinitidae	Bolivina	1
		Planorbulinoidea	Cibicididae Planulinidae	Cibicidoides	4
				Heterolepa	2
				Cibicides	1
				Planulina	1
		Polymorphinoidea	Ellipsolagenidae	Oolina	1
		Chilostomelloidea	Alabaminidae	Oridorsalis	1
			Anomalinidae	Anomalinoides	1
		Nonionoidea	Pulleniidae	Pullenia	1
			Melonidae	Melonis	1
			Nonionidae	Nonion	1
		Ceretobuliminoidea	Epistominidae	Hoeglundina	1
			Ceratobuliminidae	Ceratobulimina	1
		Nodosarioidea	Nodosariidae	Nodosaria	1
		Vaginulinidea	Vaginulinidae	Amphicoryna	1

PLANKTICS	Rotaliina	Globigerinoidea	Globigerinidae	Globigerina	9
				Globigerinoides	6
				Sphaeroidinellopsis	3
				Orbulina	1
		Globorotalioidea	Globorotaliidae	Globorotalia	14
				Neoglobooquadrina	1
			Catapsydracidae	Globoquadrina	2

Table 2: Suborders, Superfamilies, Families, Genera, and Species Diversity of Each Foraminifera Family Identified from The Masa-01 Well in The Niger Delta.

3.2.2. Foraminifera Zonation

The establishment of the biozones in the MASA-01 well was based on the zonation scheme of Blow (1969, 1979) and Berggren et al. (1998) [21,22]. The first down occurrence (FDO) and last downhole occurrence (LDO) of chronostratigraphically significant planktic foraminifera species formed the basis of biozonation. Three (3) planktic foraminifera zones corresponding to the N20/PL3 and N19/PL2 zones were delineated (Figure 9). The three (3) foraminiferal zones suggested early Pliocene ages dated 3.82 Ma at 7230 feet and 4.16 Ma at the 7830 feet maximum flooding surface (MFS) according to the chronostratigraphic scheme adopted by Gradstein et al. (2012) [1].

3.2.3 Sphaeroidinellopsis Seminulina/Bulimina Marginata Zone

Stratigraphic Interval: 6810 feet–7230 feet.
Equivalent Planktonic Foraminifera Zone: N20/PL3
Age: Piacenzian/Zanclean
Diagnosis: The upper boundary of this zone is tentatively marked by the depth of the first sample at 6810 feet, and the lower boundary of this zone is placed at 7230 feet, which marks the maximum flooding surface (MFS) and was dated to 3.82 Ma (MFS; Gradstein et al., 2012) [1] based on peak faunal abundance and species diversity. This zone is correlated with the N20/PL3 Planktic foraminifera zone of Blow (1979) [21] and Berggren et al. (1998) [22]. The age is suggested to be early Pliocene.

Remarks: The interval is also characterized by the co-occurrence of *Globigerinoides obliquus obliquus obliquus, Globorotalia plesiotumida/merotumida, Globigerina bulloides, Globigerina praebulloides, Globorotalia acostaensis acostaensis, Globorotalia crassaformis crassaformis, Bulimina inflata, Bulimina minima, Uvigerina auberiana, Uvigerina proboscidea, Gyroidinoides girardanus, Gyroidinoides laevigatus, Heterolepa bellincionii, Hoeglundina elegans, Planulina wullerstorfi, and Oridorsalis umbonatus.*

3.2.4 Globorotalia Margaritae/Amphistegina Lessonii Zone

Stratigraphic Interval: 7230 feet–7830 feet.
Equivalent Planktonic Foraminifera Zone: N20/PL3
Age: Zanclean (Early Pliocene)
Diagnosis: The upper boundary of this zone is marked by the first downhole occurrence (FDO) of *Globorotalia plesiotumida/merotumida* and the last downhole occurrence of *Globorotalia crassaformis crassaformis* at 7230 feet. The upper and lower boundaries of this zone, which mark the maximum flooding surface (MFS), are dated to 3.82 Ma and 4.16 Ma, respectively, according to Gradstein et al. (2012) [1], at 7230 feet and 7830 feet, respectively. The first downhole occurrence (FDO) of *Globorotalia margaritae* margaritae was marked at 7650 feet, and the lone occurrence of Amphicoryna scalaris caudata was at 7470 feet.

Remarks: The interval is also characterized by important planktic foraminiferal species recorded, which include *Globigerinoides obliquus obliquus, Globigerinoides obliquus extremus, Globigerinoides immaturus, Globigerinoides bollii, Globigerinoides bulloides, Orbulina universa, Globorotalia plesiotumida/merotumida, Globigerina bulloides, Globigerina praebulloides, Globorotalia acostaensis acostaensis, Globorotalia margaritae margaritae Sphaeroidinellopsis seminulina, Cibicidoides incrassatus, Cibicidoides mundulus, Cibicidoides pachyderma, Bulimina inflata, Bulimina minima, Uvigerina auberiana, Uvigerina proboscidea, Gyroxin, Girardanus, Gyroinoides laevigatus, Heterolepa bellincionii, Hoeglundina elegans, Planulina wullerstorfi, and Oridorsalis umbonatus.*

3.2.5 Globigerina Nepenthes/Marginulina Costata Zone

Stratigraphic Interval: 7830 feet–8310 feet.
Equivalent Planktonic Foraminifera Zone: N19/PL2
Age: Zanclean (Early Pliocene)
Diagnosis: The first downhole occurrence (FDO) of Globigerina nepenthes is marked at 7920 feet and the last downhole occurrence of *Globorotalia margaritae margaritae* and *Sphaeroidinellopsis seminulina* is marked at 8010 feet and 8040 feet, respectively. The upper boundary of this zone, which marks the maximum flooding surface (MFS), is dated to 4.16 Ma by MFS Gradstein et al. (2012) [1] at 7830 feet. The lower boundary of this zone is tentatively placed at 8310 feet, the depth of the last analyzed sample.

Remarks: The interval is also characterized by important planktic foraminiferal species recorded, which include *Globigerinoides obliquus obliquus, Globigerinoides obliquus extremus, Globigerinoides immaturus, Globigerinoides bollii, Globigerinoides bulloides, Orbulina universa, Globorotalia plesiotumida/merotumida, Globigerina bulloides, Globigerina praebulloides, Globorotalia acostaensis acostaensis, Globorotalia margaritae margaritae Sphaeroidinellopsis seminulina, Cibicidoides incrassatus, Cibicidoides pachyderma, Sigmoilopsis schlumbergeri, Uvigerina auberiana, Uvigerina proboscidea, Gyroidinoides girardanus, Hoeglundina elegans, Planulina wullerstorfi, Oridorsalis umbonatus and Sphaeroidina bulloides.*

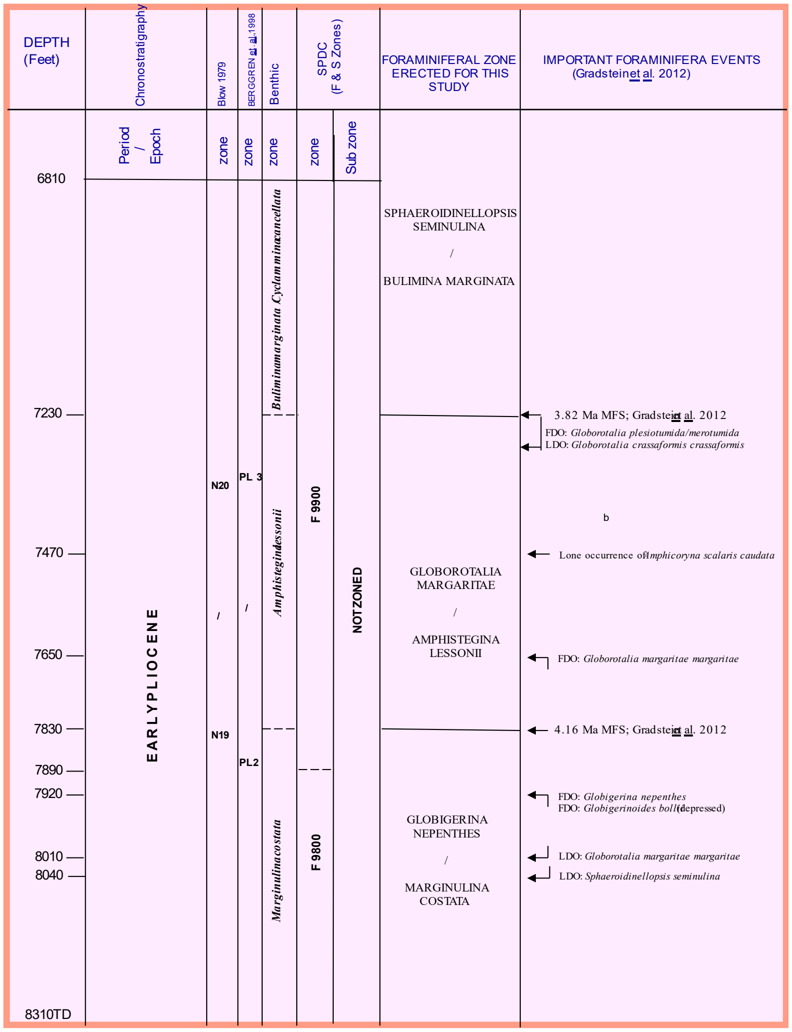

Figure 9: Foraminiferal Zones Recognized in the 'Masa-01' Well

3.3. Paleoenvironmental Deduction

The technique of employing foraminiferal assemblages for paleoenvironmental reconstruction is fairly reliable for well-preserved faunal assemblages that have not been significantly impacted by selective dissolution of foraminiferal tests during and after sedimentation Berger, (1968) [23]; Parker and Berger, (1971) [24]. Based on the integration of paleobathymetric deductions from the planktic to benthic ratio and paleosalinity, the paleoenvironmental interpretation of the examined section of the MASA-01 well was deduced. Because foraminifera diversity and abundance are influenced by a variety of variables, including temperature, light intensity, prey or nutrient availability, among others, these variables can be used as proxies for the establishment of paleoenvironments, according to BouDagher-Fade (2013) [25]. Several studies have used the planktic/benthic ratio (P:B ratio) to determine the depth of deposition; higher planktonic ratios suggest deep marine habitats, and vice versa [26].

3.3.1. Paleobathymetry

The use of test morphology as a paleobathymetric tool has been widely employed; for example, Douglas and Savin (1973) and Odebode (1982) [27, 28]. Douglas recognized three general habitat characteristics of the density stratified portion of Mesozoic and Cenozoic tropical oceans, viz., shallow, intermediate, and deep-water habitats. Benthic foraminifera are crucial resources for determining the depositional history of sedimentary basins. Due to their vast range of habitats, which extend from the shallow marine environment to the deep marine environment, these species are frequently utilized for paleobathymetric interpretation. They primarily live on the bottom, which helps scientists understand the environmental conditions that prevailed at the time the sediment was deposited [7]. [29] Proposed that species with similar morphologies (i.e., forms and structures) respond in similar ways under similar environmental conditions. This idea has been supported by data on environmentally restricted benthonic foraminifera obtained by Phleger (1960) [30]. The occurrence of similar species with globular chambers and umbilical apertures (i.e., Globigerina-like forms) indicates a shallow marine environment, while the presence of planktic foraminifera with complex morphologies (keeled species), which usually dwell in deep marine environments (i.e., Globorotaliids-like forms), infers the upper bathyal environment. The bathymetric analysis of this well was performed based on the correlation of the percentage of planktic/benthic foraminifera ratio (Table 3). Because the quantity of planktonic foraminifera increases with distance from the shore, the P/B ratio is a reasonable proxy for estimating the ocean depth [26]. The variation in the P/B ratio with depth suggested sporadic sea level changes (sea level rise and fall). The planktic/benthic ratio was calculated as follows:

P/(P + B) *100 (equation 1) where P = Planktic diversity B = Benthic diversity

Using the Van der Zwaan et al. (1990) [31] formula, the water depth was determined: $D = e^{(3.58718 + (0.03534 \times \%P))}$ (equation 2) where ^{e} = constant or natural exponent (2.71828) %P = Planktic percentage

The calculated water depths (Table 3) for the MASA-01 well samples, compared with the paleobathymetry chart of Allen (1965) [32], correspond to the outer neritic environment to the upper bathyal environment (Figure 10).

DEPTH (feet)	PLANKTICS DIVERSITY	BENTHICS DIVERSITY	PLANKTICS PERCENTAGE	WATER DEPTH(m) Van der Zwaan et al., (1990)
6810 – 6840	1	8	11	53
6840 – 6870	0	3	0	36
6870 – 6900	1	5	17	66
6900 – 6930	0	0	0	36
6930 – 6960	0	1	0	36
6960 – 6990	0	3	0	36
6990 – 7020	0	0	0	36
7020 – 7050	0	4	0	36
7050 – 7080	0	0	0	36
7080 – 7110	0	2	0	36
7110 – 7140	0	0	0	36
7140 – 7170	6	6	50	211
7170 – 7200	2	1	67	386
7200 – 7230	8	8	50	211
7230 – 7260	5	3	63	335
7260 – 7290	8	6	57	271
7290 – 7320	4	3	57	271
7320 – 7350	8	2	80	611

DEPTH (feet)	PLANKTICS DIVERSITY	BENTHICS DIVERSITY	PLANKTICS PERCENTAGE	WATER DEPTH(m) Van der Zwaan et al., (1990)
7350 - 7380	8	7	53	235
7380 – 7410	5	4	56	261
7410 – 7440	7	5	58	281
7440 – 7470	0	4	0	36
7470 – 7500	5	7	42	159
7500 – 7530	1	4	20	73
7530 – 7560	5	4	56	261
7560 – 7590	5	4	56	261
7590 – 7620	6	7	46	184
7620 – 7650	5	4	56	261
7650 – 7680	4	5	44	171
7680 – 7710	4	5	44	171
7710 – 7740	5	3	63	335

7740 – 7770	8	3	73	477
7770 – 7800	7	3	70	429
7800 – 7830	9	7	56	261
7830 – 7860	8	3	73	477
7860 – 7890	0	0	0	36
7890 – 7920	9	3	75	512
DEPTH (feet)	**PLANKTICS DIVERSITY**	**BENTHICS DIVERSITY**	**PLANKTICS PERCENTAGE**	**WATER DEPTH(m) Van der Zwaan et al., (1990)**
7920 - 7950	7	5	58	281
7950 – 7980	5	0	100	1238
7980 – 8010	5	6	45	177
8010 – 8040	6	4	60	301
8040 – 8070	3	1	75	512
8070 – 8100	0	0	0	36
8100 – 8130	0	0	0	36
8130 – 8160	0	3	0	36
8160 – 8190	0	0	0	36
8190 – 8220	0	2	0	36
8220 – 8250	0	0	0	36
8250 – 8280	0	0	0	36
8280 – 8310	0	0	0	36

Table 3: Statistical Distribution of The Planktonic Diversity, Benthic Diversity, Planktonic Percentage and Water Depth of The Foraminiferal Taxa at Each Depth.

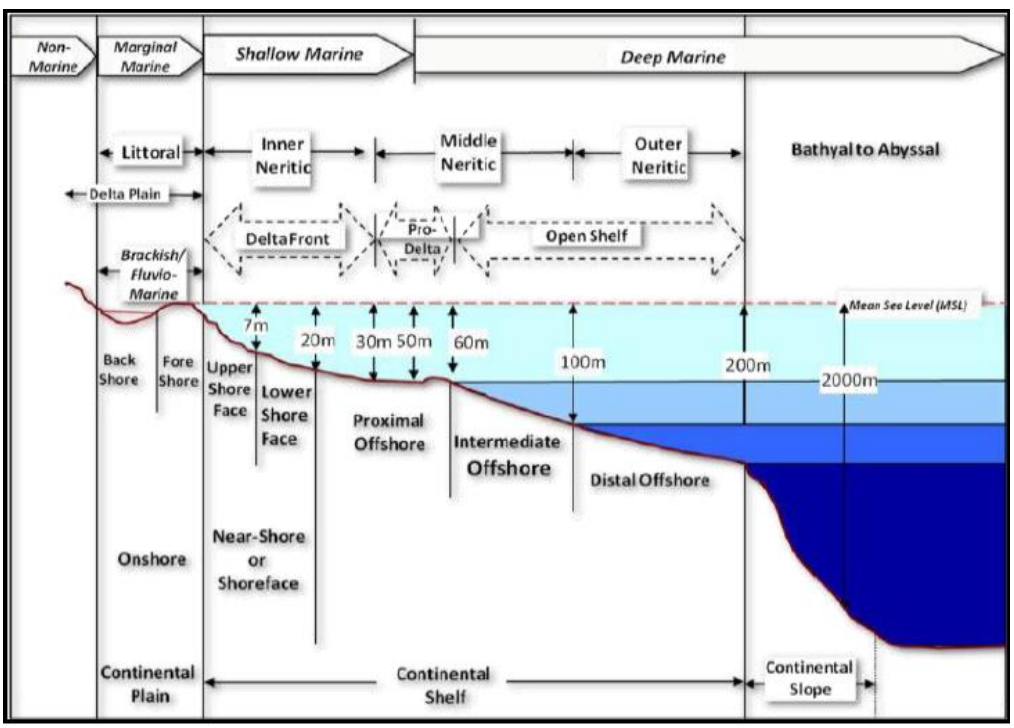

Figure 10: Paleobathymetry (After Allen, 1965) [32].

The paleoenvironmental interpretation of the MASA-01 well presented below is based on a qualitative assessment of chosen environmentally relevant benthic foraminifera bathymetric ranges. The depositional environment of the well fluctuated between the outer neritic and upper bathyal layers. Details of the depositional environments are presented on an interval basis below.

3.3.2 Between 6810 Feet and 7230 Feet Depth

The interval is characterized by moderately rich foraminifera assemblages and encounters with deep-water foraminifera, such as *Bulimina inflata, Cibicidoides incrassatus, Cibicidoides pachyderma, Cibicidoides mundulus, Uvigerina proboscidea, Uvigerina auberiana, Heterolepa bellincionii, Gyroidinoides laevigatus, Gyroidinoides girardanus, Planulina wullerstorfi, Oridorsalis umbonatus, Hoeglundina elegans, Sigmoilopsis schlumbergeri,* and *Recurvoides deformis*. The above foraminifera species abundance and diversity indicate a depositional environment that ranged from outer neritic to upper bathyal Phleger (1960)[30] and Bandy (1967)[33].

3.3.3 Between 7230 Feet and 7830 Feet Depth

The interval is characterized by rich foraminifera assemblages and encounters with deep-water foraminifera, such as *Bulimina inflata, Cibicidoides incrassatus, Cibicidoides pachyderma, Cibicidoides mundulus, Cibicidoides pseudoungerianus, Uvigerina proboscidea, Uvigerina auberiana, Heterolepa bellincionii, Heterolepa floridana, Gyroidinoides laevigatus, Gyroidinoides girardanus, Melonis pompiliodes, Praeglobobulimina ovata, Ceratobulimina pacifica, Globocassidulina subglobosa, Planulina wullerstorfi, Oridorsalis umbonatus, Hoeglundina elegans, Sigmoilopsis schlumbergeri, Recurvoides deformis,* and *Karreriella siphonella.* The above foraminifera species abundance and diversity indicate a depositional environment that ranged from outer neritic to upper bathyal Phleger (1960) [30] and Bandy (1967) [33].

3.3.4 Between 7830 Feet and 8310 Feet Depth

The interval is characterized by moderately rich foraminifera assemblages and encounters with deep-water foraminifera, such as *Bulimina inflata, Gyroidinoides girardanus, Sigmoilopsis schlumbergeri, Uvigerina proboscidea, Uvigerina auberiana, Cibicidoides pachyderma, Planulina wullerstorfi, Globorotalia margaritae margaritae, Oridorsalis umbonatus, Hoeglundina elegans*, and *Sphaeroidina bulloides*. *Trochammina protens,* and *Haplophragmoides* sp. The above foraminifera species abundance and diversity indicate a depositional environment that ranged from outer neritic to upper bathyal Phleger (1960) [30] and Bandy (1967)[33].

3.3.5. Paleosalinity

Most foraminifera species are adapted to typical marine salinities, and specific marine environments have diverse assemblages. The brackish lagoons and marshes favor agglutinated foraminiferal assemblages with low diversity. To measure paleosalinity, triangular plots of the relative proportions of Textulariina, Miliolina, and hyaline forms have been successfully generated. According to Murray (1991) [26], samples from particular ecosystems typically plot within designated fields. Based on the ratio of shell type (hyaline, agglutinated, and porcelaneous) to triangle plot (Figure 11), the paleosalinity of the wells was interpreted. The predominance of a hypersaline lagoon environment is suggested by the presence of a hyaline calcareous shell. A deep marine habitat is also suggested by the dominance of calcareous benthic (FOBC) habitats, with 87.17% of which form over arenaceous benthic (FOBA) habitats (12.82%).

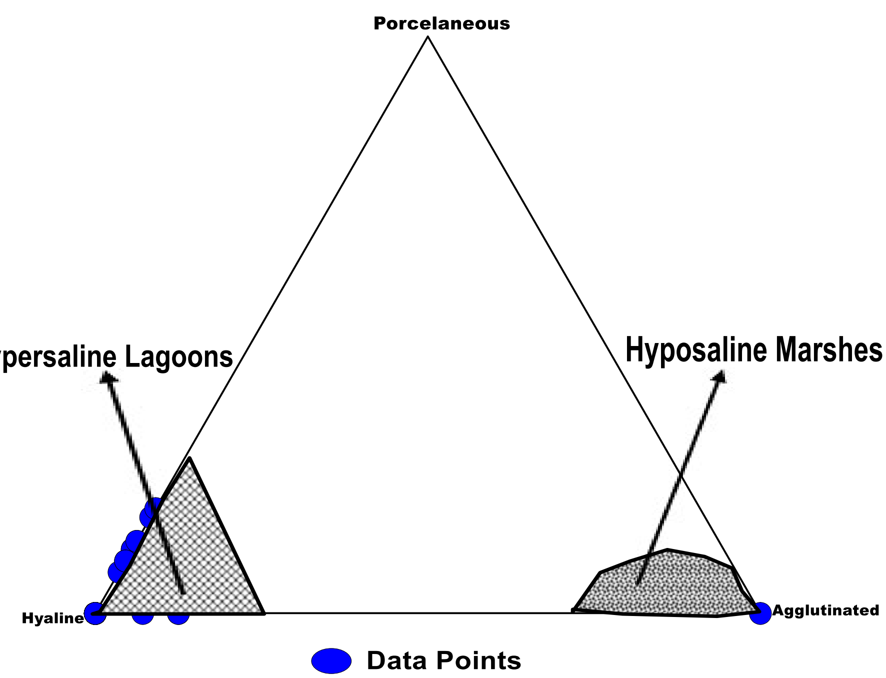

Figure 11: Shell-Type Ratio Triangular Plot of Samples from the 'Masa-01' Well (modified from Murray 1991) [26].

3.4. Systematic (Foraminifera)

The description and classification of identified foraminifera in this study were based on a set of criteria outlined by Loeblich and Tappan (1964) [34].

These are, in the hierarchical order of their importance:

1) Wall composition and microstructure
2) Chamber arrangement and septal addition;
3) Apertural characters and modifications;
4) Chamber form;
5) Geologic ranges.

In this study, all the recovered and identified foraminifera species were arranged according to the classification of Loeblich and Tappan (1964) [34]. This is because Loeblich and Tappan's classification system is the most up-to-date system adopted by most foraminiferal workers. A detailed systematic presentation of the foraminiferal taxa recovered from the studied samples as well as species morphology and occurrences are presented in Appendix 2.

4. Conclusion

Fifty (50) ditch-cut samples within the interval 6810 feet (2076 m) - 8310 feet (2533 m) of the MASA-01 well situated in the western offshore region of the Niger Delta, Nigeria, were analyzed for foraminiferal biostratigraphic, lithostratigraphic and paleoenvironmental studies. Lithological analysis of the well and deduction from the sedimentological assessment reveal that the bulk of the lithofacies is dominated by dark grayish shale with intercalations of fine- to medium-grained sandstones. The studied section is composed of three (3) sands with interbedded shale (shaly sand) units ranging from (2085 m–2166 m), (2454 m–2472 m) and (2499 m–2533 m), while the section is composed of two (2) shales with interbedded sand (sandy shale) units ranging from (2175 m–2445 m) to (2481 m–2490 m). The samples studied indicate that the well belongs to the Upper Paralic Agbada Formation. A total of seventy-six (76) foraminifera species were identified from the ditch cuttings; these included 34 calcareous benthic species, 5 agglutinated benthic species, and 37 planktic species. Three (3) planktic foraminifera zones corresponding to the N20/PL3 and N19/PL2 zones were identified. The foraminifera analysis identified the *Sphaeroidinellopsis seminulina/Bulimina marginata zone*, which is the Zanclean/Piacenzian (N20/PL3) foraminiferal zone; the *Globorotalia margaritae/Amphistegina lessonii zone*, which is the Zanclean (N20/PL3) foraminiferal zone; and the *Globigerina nepenthes/Marginulina costata zone*, which is the Zanclean (N19/PL2) foraminiferal zone. The important markers recorded were *Globorotalia plesiotumida/merotumida* (FDO) and *Globorotalia crassaformis crassaformis* (LDO) at 7230 feet; the lone occurrences of *Amphicoryna scalaris caudata* at 7470 feet; *Globorotalia margaritae margaritae* (FDO) and *Globorotalia margaritae margaritae* (LDO) at 7650 feet and 8010 feet; Globigerina nepenthes (FDO) and depressed *Globigerinoides bollii* (FDO) at 7920 feet; and *Sphaeroidinellopsis seminulina* (FDO) at 8040 feet. The well was dated to the early Pliocene (N20/PL3–N19/PL2) based on the occurrence of marker species. Based on peak faunal abundance and diversity, the two (2) condensed portions that are linked to maximum flooding surfaces (MFS) were dated at 3.82 Ma at 7230 feet and 4.16 Ma at 7830 feet.

The foraminiferal shell type triangular plot based on the ratios between *Textulariina, Miliolina* and *Rotaliina* indicated a deep marine paleoenvironment. The occurrence of predominantly hyaline foraminifera assemblages in the investigated sections of the MASA-01 well suggested a hypersaline environment of deposition. The results of Planktic percentage (%P) analysis of foraminiferal assemblages show that the paleobathymetry spans from outer neritic to upper bathyal settings. Additionally, the paleowater depth of the outer neritic to upper bathyal habitats of deposition was supported by the planktic percentage (%P). Furthermore, a deep marine paleoenvironment was indicated by a FOBC/FOBA ratio of 87.17%/12.82% between calcareous benthic and arenaceous benthic foraminifera. The presence of paleowater depth indicator fossils such as *Globorotalia margaritae margaritae, Globorotalia plesiotumida/merotumida, Oridorsalis umbonatus, Haplophragmoides* sp., and *Bulimina inflata* also confirmed the presence of outer neritics in the upper bathyal environment during deposition. The assessed lithofacies and important foraminifera species also established the paleowater depth of the outer neritic to the upper bathyal environment of deposition. Paleoenvironmental interpretation is a valuable and cost-effective contribution to petroleum exploration and development for identifying habitats for hydrocarbon generation.

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Competing Interests

The contact author has declared that none of the authors has any competing interests.

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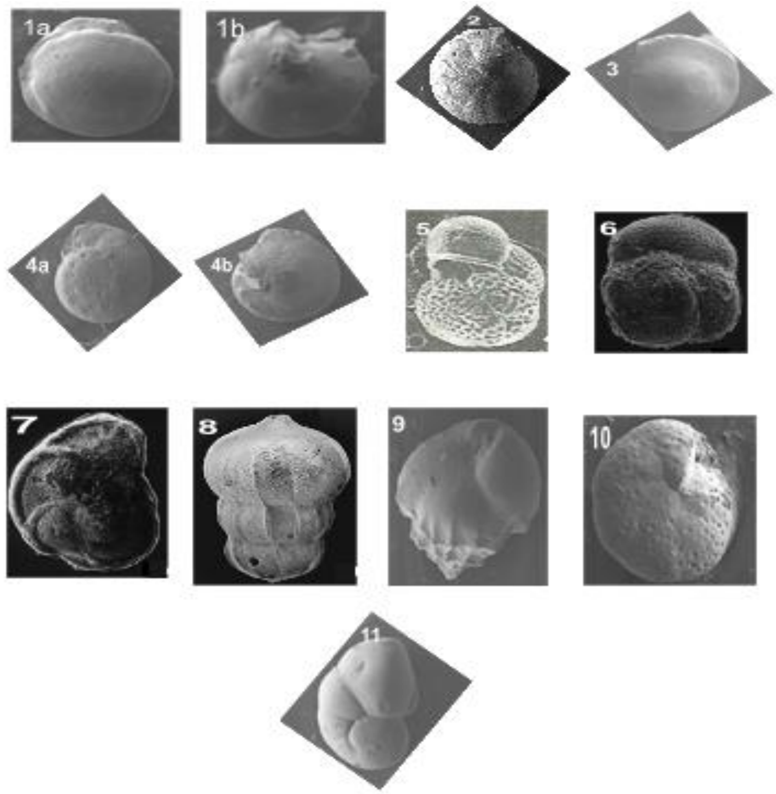

PLATE 1

Photomicrographs of Some Foraminifera Recovered from The 'MASA-01' Well

1a. *The oridorsalis umbonatus* (spiral view, Mag. X100); 1b. *Oridorsalis umbonatus* (umbilical view, Mag. X100); 2. *Cibicidoides pseudoungerianus* (umbilical view, Mag. X150); 3. *Hoeglundina elegans* (spiral view, Mag. X100); 4a. *Cibicidoides pachyderma* (spiral view, Mag. X100); 4b. *Cibicidoides pachyderma* (umbilical view, Mag. X100); 5. *Globigerina nepenthes* (umbilical view, X100); 6. *Globorotalia crassaformis* (spiral view, Mag. X250); 7. *Globorotalia merotumida* (spiral view, Mag. X150); 8. *Amphicoryna scalaris* caudata (side view, Mag. X200); 9. *Bulimina inflata* (apertural view, Mag. X100); 10. *Heterolepa bellincionii* (umbilical view, Mag. X100); 11. *Ceratobulimina pacifica* (spiral view, Mag. X200).

Appendix 1

Summary of lithological descriptions of the MASA-01 Well

Depth (Feet)	Code	Description	P	CM	FM
6810-6840	Sand 5%	Fine-grained, subangular, and well sorted			
	Shale 95%	Brownish/dark gray, soft/moderately hard and fissile/nonfissile			
6840-6870	Sand 75%	Fine/medium grained, angular/subangular and moderately sorted		5	15
	Shale 25%	Dark gray, moderately hard and fissile/nonfissile.			
6870-6900	Sand 75%	Fine/medium grained, angular/subangular and moderately sorted		4	13
	Shale 25%	Dark gray, moderately hard and fissile/nonfissile.			

6900-6930	Sand 75%	Dark gray, moderately hard and fissile/ nonfissile.		5	20
	Shale 25%	Fine/medium grained, angular/subangular and moderately sorted			
6930-6960	Sand 75%	Dark gray, moderately hard and fissile/ nonfissile.		5	15
	Shale 25%	Fine/medium grained, angular/subangular and moderately sorted			
6960-6990	Sand 75%	Dark gray, moderately hard and fissile/ nonfissile.		1	10
	Shale 25%	Fine/medium grained, angular/subangular and moderately sorted			
6990-7020	Sand 75%	Dark gray, moderately hard and fissile/ nonfissile.		5	25
	Shale 25%	Fine/medium grained, angular/subangular and moderately sorted			
7020-7050	Sand 75%	Dark gray, moderately hard and fissile/ nonfissile.		7	20
	Shale 25%	Fine/medium grained, angular/subangular and moderately sorted			
7050-7080	Sand 75%	Dark gray, moderately hard and fissile/ nonfissile.		5	10
	Shale 25%	Fine/medium grained, angular/subangular and moderately sorted			
7080-7110	Sand 75%	Dark gray, moderately hard and fissile/ nonfissile.			25
	Shale 25%	Fine/coarse-grained, pebbly, subrounded and poorly sorted.			

Depth (Feet)	Code	Description	P	CM	FM
7110-7140	Sand 65%	Fine/coarse-grained, pebbly, subrounded and poorly sorted.			15
	Shale 35%	Dark gray, moderately hard and fissile/ nonfissile			
7140-7170	Sand 35%	Fine/coarse-grained, pebbly, subrounded and poorly sorted.			28
	Shale 65%	Dark gray, moderately hard and fissile/ nonfissile			
7170-7200	Sand 35%	Fine/coarse-grained, pebbly, subrounded and poorly sorted.			
	Shale 65%	Dark gray, moderately hard and fissile/ nonfissile			
7200-7230	Sand 30%	Fine-grained, subangular and well sorted			20
	Shale 70%	Brown/gray, soft and fissile/nonfissile.			
7230-7260	Sand 30%	Fine-grained, subangular and well sorted		14	24
	Shale 70%	Brown/gray, soft and fissile/nonfissile.			
7260-7290	Sand 20%	Fine-grained, subangular and well sorted		10	12
	Shale 80%	Dark gray, soft/moderately hard and fissile			

7290-7320	Sand 20%	Fine-grained, subangular and well sorted		15	18
	Shale 80%	Dark gray, soft/moderately hard and fissile			
7320-7350	Sand 20%	Fine-grained, subangular and well sorted		14	15
	Shale 80%	Dark gray, soft/moderately hard and fissile			
7350-7380	Sand 20%	Fine-grained, subangular and well sorted		10	8
	Shale 80%	Dark gray, soft/moderately hard and fissile			
7380-7410	Sand 20%	Fine-grained, subangular and well sorted		15	10
	Shale 80%	Dark gray, soft/moderately hard and fissile			
7410-7440	Sand 20%	Fine-grained, subangular and well sorted		8	5
	Shale 80%	Dark gray, soft/moderately hard and fissile			
7440-7470	Sand 20%	Fine-grained, subangular and well sorted		12	15
	Shale 80%	Dark gray, soft/moderately hard and fissile			
7470-7500	Sand 20%	Fine-grained, subangular and well sorted		10	18
	Shale 80%	Dark gray, soft/moderately hard and fissile			

Depth (Feet)	**Code**	**Description**	**P**	**CM**	**FM**
7500-7530	Sand 35%	Fine-grained, subangular and well sorted			
	Mudstone 65%	Dark gray, soft/moderately hard and fissile			
7530-7560	Sand 35%	Fine-grained, subangular and well sorted			
	Mudstone 65%	Dark gray, soft/moderately hard and fissile			
7560-7590	Sand 35%	Fine-grained, subangular and well sorted			
	Mudstone 65%	Dark gray, soft/moderately hard and fissile			
7590-7620	Sand 35%	Fine-grained, subangular and well sorted			
	Mudstone 65%	Dark gray, soft/moderately hard and fissile			
7620-7650	Sand 10%	Fine/medium grained occasionally coarse, pebbly, subangular/subrounded and poorly sorted	5	30	25
	Shale 90%	Dark gray, soft/moderately hard and fissile			
7650-7680	Sand 10%	Fine/medium grained occasionally coarse, pebbly, subangular/subrounded and poorly sorted	5	28	30
	Shale 90%	Dark gray, soft/moderately hard and fissile			
7680-7710	Sand 3%	Fine/medium grained, subangular/subrounded and moderately sorted.			
	Shale 97%	Dark gray, soft/moderately hard and fissile			
7710-7740	Sand 3%	Fine/medium-grained, subangular/subrounded and moderately sorted.			
	Shale 97%	Dark gray, soft/moderately hard and fissile			
7740-7770	Sand 10%	Fine-grained occasionally medium-grained, subangular and moderately sorted		20	20
	Shale 97%	Dark gray, soft/moderately hard and fissile			

Depth (Feet)	Code	Description	P	CM	FM
7770-7800	Sand 10%	Fine-grained occasionally medium-grained, subangular and moderately sorted		15	25
	Shale 90%	Gray, moderately hard and fissile			
7800-7830	Sand 25%	Fine-grained occasionally medium-grained, subangular and moderately sorted			
	Shale75%	Gray, moderately hard and fissile			
7830-7860	Sand 25%	Fine-grained occasionally medium-grained, subangular and moderately sorted			
	Shale 75%	Gray, moderately hard and fissile			
7860-7890	Sand 10%	Fine/medium grained, subangular and moderately sorted	1	10	5
	Shale 90%	Dark gray, moderately hard and fissile			
7890-7920	Sand 10%	Fine/medium grained, subangular and moderately sorted	5	12	8
	Shale 90%	Dark gray, moderately hard and fissile			
7920-7950	Sand 10%	Fine/medium grained, subangular and moderately sorted	4	15	11
	Shale 90%	Dark gray, moderately hard and fissile			
7950-7980	Sand 10%	Fine/medium grained, subangular and moderately sorted	3	20	15
	Shale 90%	Dark gray, moderately hard and fissile			
7980-8010	Sand 25%	Fine/medium grained, subangular and moderately sorted			
	Shale 75%	Dark gray, moderately hard and fissile			
8010-8040	Sand 25%	Fine/medium grained, subangular and moderately sorted			
	Shale 75%	Dark gray, moderately hard and fissile			
8040-8070	Sand 25%	Fine/medium grained, subangular and moderately sorted			
	Shale 75%	Dark gray, moderately hard and fissile			
Depth (Feet)	**Code**	**Description**	**P**	**CM**	**FM**
8070-8100	Sand 75%	Fine/medium grained, subangular and moderately sorted			
	Shale 25%	Dark gray, moderately hard and fissile			
8100-8130	Sand 75%	Fine/medium grained, subangular and moderately sorted			
	Shale 25%	Dark gray, moderately hard and fissile			
8130-8160	Sand 75%	Fine/medium grained, subangular and moderately sorted			
	Shale 25%	Dark gray, moderately hard and fissile			
8160-8190	Sand 20%	Fine/medium grained, subangular and moderately sorted		10	5
	Shale 80%	Dark gray, moderately hard and fissile			
8190-8220	Sand 20%	Fine/medium grained, subangular and moderately sorted		5	5
	Shale 80%	Dark gray, moderately hard and fissile			

8220-8250	Sand 80%	Fine/medium grained, subangular and moderately sorted	10		
	Shale 20%	Dark gray, moderately hard and fissile			
8250-8280	Sand 80%	Fine/medium grained, subangular and moderately sorted	5		
	Shale 20%	Dark gray, moderately hard and fissile			
8280-8310	Sand 80%	Fine/medium grained, subangular and moderately sorted	5		
	Shale 20%	Dark gray, moderately hard and fissile			

Keys

P – Pyrites
CM – Carbonaceous matter
FM – Ferruginous Materials

Appendix 2

Systematic Description of Microfossils
Kingdom: Protista
Phylum: Protozoa
Class: Sarcodina
Subclasses: Rhizopoda Von Siebold (1845)
Order: Foraminiferida Erchwald, (1830)
Superfamily: Globigerinacea Carpenter, Parker and Jones, 1862
Family: GLOBIGERINIDAE Carpenter, Parker and Jones, 1862
Subfamily: Globigerininae
Genus: *Globigerina d'Orbigny,* 1826
Species: *Globigerina bulloides* (d'Orbigny, 1826, p.277)
Description: The test is performed on a trochoid throughout the umbilicate. Chambers, such as Discorbis, are usually smooth, and the wall is thin; later, chambers are globular; wall, calcareous, and thickly cancellated; and coated with long slender spines coming from the angles of the cancellated surface areas, the base of such areas with the pores of the wall; and the aperture is large, opening into the umbilicus.
Locations: 6870-6900 feet, 7140-7170 feet, 7200-7230 feet, 7260-7290 feet, 7320-7380 feet,
7590-7620 feet, 7830-7860 feet, and 8040-8070 feet.
Remarks: Fairly well preserved. Rare in distribution.
Age: Eocene to Recent.

Species: Globigerina praebulloides (Blow, 1959-Plate 3, Fig. 18)
Description: Test trochospiral, chambers inflated with the round axial periphery. Four chambers in the whorl, sutures of the spiral and umbilical sides depressed, radial to slightly curved; aperture low arched, interiomarginal umbilical, wall calcareous perforate.
Locations: 7140-7170 feet, 7230-7290 feet, 7320-7380 feet, 7410-7440 feet, 7560-7620 feet, 7800-7830 feet, 7890-7920 feet, 8040-8070 feet.
Remarks: Fairly well preserved. The distribution was moderate.
Age: Eocene to Recent.

Species: Globigerina nepenthes (Todd 1957)
Description: Test small, compactly coiled except for the last formed protruding chamber; the height of the spire ranges between three-quarters and equal to the diameter of the spire. Chambers indistinct and slightly inflated; four chambers constituting the last whorl, with a fifth elongated chamber extending downward and at an angle to the axis of coiling. The sutures are indistinct, except for the last few, which are indented. The wall is thin, calcareous, perforate, and ornamented by a rather coarse cancellation. The aperture is large, semicircular or broad and arched at the umbilical edge of the protruding chamber, bordered by a thickened and slightly upturned lip of clear shell material.
Locations: 7890-7950 feet.
Remarks: Fairly well preserved. Very rare in distribution.
Age: Miocene to recent.

Genus: Sphaeroidinellopsis
Species: Sphaeroidinellopsis seminulina (Schwager 1866)
Description: Test low trochospiral, compact, equatorial periphery broadly ovate to slightly trilobulate; 3 subglobular chambers in the final whorl; sutures obscured by heavy cortex; surface coarsely perforate, covered by secondary layer of shell material (cortex) reducing the pore openings and providing a smooth, polished, and glossy appearance to the test (PI). 51, Fig. 1).
Umbilicus open; aperture an elongate umbilical opening bordered by thickened crenulate margin.
Locations: 7380-7410 feet, 7650-7680 feet, 7740-7770 feet, 7890-7920 feet, and 8010-8040 feet. Remarks: Fairly well preserved. Rare in distribution.
Age: Miocene to recent.

Genus: Globigerinoides Cushman 1927
Species: Globigerinoides immaturus (Leroy, 1939-Plate 3; Fig. 1)
Description: Test is trochospiral, unequally biconvex, equatorial periphery lobate with axial periphery broad rounded, wall perforate with pitted surface; chambers spherically arranged in three and half whorls with the last three chambers increasing in size; primary aperture interiomarginal; umbilical low arched with lip, secondary apertures sutural with one of the directly adjacent primary apertures.
Locations: 7290-7380 feet, 7410-7440 feet, 7470-7500 feet, 7530-7560 feet, 7620-7830 feet, and
7950-7980 feet.
Remarks: Fairly well preserved. Rare in distribution.
Age: Miocene to recent.

Family: Glodorism Database (Cushman, 1927)
Subfamily: Globorotaliinae
Genus: Globorotalia (Cushman, 1927)

Species: Globorotalia crassaformis (Galloway & Wissler, 1927)
Description: Test low trochospiral, spiral side almost flat, umbilical side strongly convex, equatorial periphery slightly lobulate, subquadrate; axial periphery planoconvex, subacute to subrounded; chambers compressed, 4 in the final whorl, increasing rapidly in size; sutures on spiral side curved, depressed; on the umbilical side almost radial, depressed; surface finely perforate, pustulate on umbilical as well as spiral side; umbilicus narrow, deep; aperture interiomarginal, extraumbilical, a low-arched slit bordered by a lip.
Locations: 7140-7170 feet, 7200-7230 feet
Remarks: Fairly well preserved. Very rare in distribution
Age: Miocene to recent.

Species: Globorotalia acostaensis (Blow, 1959)
Description: Test low trochospiral; spire opening regularly but fairly rapidly, with 11-13 chambers composing the spire, usually with 5-6 chambers in the last whorl. The equatorial periphery is strongly lobate, with the test appearing subcircular in the equatorial profile; the axial periphery is rounded, with the test appearing thick and parallel-sided in side view; chambers ovate or subspherical, generally inflated but not well separated; often, the last chamber is much reduced in size compared with its predecessor, and it also occasionally becomes somewhat displaced toward the umbilical side. The spiral side is slightly convex, almost flat, or occasionally slightly concave due to the inflated nature of the chambers of the last whorl. The umbilical side is generally slightly convex, with a small but usually deep umbilicus; the sutures on the spiral and umbilical sides are radial and depressed; and the aperture is interiomarginal, umbilical-extraumbilical, and arched, with a distinctive lip.
Locations: 7140-7170 feet, 7200-7290 feet, 7350-7380 feet, 7410-7440 feet, 7470-7500 feet, 7590-7650 feet, 7680-7710 feet, 7740-7800 feet, 7830-7860 feet, and 7890-7950 feet.
Remarks: Fairly well preserved. The distribution was moderate.
Age: Miocene to recent.

Species: Globorotalia miocenica (Palmer, 1945)
Description: Very low trochospiral, spiral side flat, umbilical side strongly convex, equatorial periphery almost circular, axial periphery planoconvex with a pronounced keel; 6 to 7 chambers in the final whorl; spiral sutures curved, limbate, merging into keel, on umbilical side sinuous to radial, depressed; surface smooth, densely perforate; umbilicus small, fairly deep; aperture interiomarginal, extraumbilical-umbilical, a fairly low-arched slit with a thin lip.
Locations: 7200-7230 feet, 7890-7920 feet, and 8010-8040 feet
Remarks: Fairly well preserved. Very rare in distribution
Age: Miocene to recent

Species: Globorotalia margaritae (Bolli & Bermudez 1965)
Description: Test low trochospiral, compressed, spiral side convex, umbilical side concave to almost flat, equatorial periphery slightly lobulate, axial periphery acute with a thin keel; chambers strongly compressed, 5 in the final whorl, increasing rapidly in size; sutures on spiral side strongly curved, limbate, slightly raised, on umbilical side gently curved, depressed; surface coarsely and densely perforate, early chambers slightly pustulose, later chambers smooth. Umbilicus narrow; aperture a low slit bordered by a pronounced lip, interiomarginal, extraumbilical-umbilical.
Locations: 7620-7650 feet, 7770-7800 feet, 7980-8010 feet
Remarks: Fairly well preserved. Very rare in distribution
Age: Miocene to recent

Species: Globorotalia plesiotumida (Banner & Blow 1965)
Description: Lenticular trochospire, biconvex, equatorial periphery ovate, slight lobulate; axial periphery acute with a distinct keel; generally, 6 chambers in the final whorl, increasing regularly in size as added, final chamber noticeably projecting; sutures on spiral side limbate, slightly raised, oblique to curved, merging into keel; on umbilical side radial, depressed; surface smooth, densely perforate, pustulate on umbilical shoulders; umbilicus narrow, aperture a low arch, bordered by a lip, interiomarginal, umbilical-extraumbilical.
Locations: 7200-7290 feet, 7650-7680 feet, and 8010-8040 feet
Remarks: Fairly well preserved. Moderate in distribution
Age: Miocene to recent

Superfamily: Chilostomelloidea
Family: ALABAMINIDAE
Subfamily: Alabamininae
Genus: Oridorsalis Andersen, 1961
Species: Oridorsalis umbonatus (Reuss, 1851)
Description: The wall material is hyaline with a coiled spiral appearance. The test was trochospiral. The chamber form is triangular to trapezoid. The apertures are slit, lip and basal. The sutures are curved and thickened.
Locations: 7140-7170 feet, 7260-7320 feet, 7830-7860 feet, and 8010-8040 feet.
Remarks: Fairly well preserved. Rare in distribution.
Age: Oligocene to Recent.

Superfamily: Planorbulinoidea
Family: CIBICIDIDAE
Subfamily: Cibicidinae
Genus: Cibicidoides Thalmann, 1939
Species: Cibicidoides pseudoungerianus (Cushman, 1922)
Description: The wall is calcareous and densely and coarsely perforated on the spiral side. The abscess was imperforate and loosely coarsely perforated on the umbilical side. The test is slightly biconvex and subcarinate in peripheral view. The sutures are distinct, thickened, radial, and curved on the spiral side. The sutures are oblique on the umbilical side except for the final chambers, where the sutures are depressed. The aperture is an interiomarginal, extraumbilical arch that extends along the base of the last few chambers on the spiral side and is bordered by a lip. The test surface is smooth.
Locations: 7530-7560 feet
Remarks: Very rare in distribution and well preserved.
Age: Eocene to Recent.

Superfamily: Buliminoidea
Family: BULIMINIDAE
Subfamily: Bulimininae
Genus: Bulimina d'Orbigny, 1826
Species: Bulimina inflata (Seguenza, 1862)
Description: The test elongates, biserial and strongly compressed with a sharp carinate margin; the spiral suture oblique, depressed, and distinct; chambers about four in a whorl; wall smooth hyaline, finely perforate; aperture elongate, loop-shaped, and very slightly twisted.
Locations: 6810-6840 feet, 6960-6990 feet, 7530-7560 feet
Remarks: Rare in distribution, well preserved.
Age: Eocene to Recent.

Superfamily: Vaginulinidea
Family: VAGINULINIDAE
Subfamily: Marginulininae
Genus: Amphicoryna Schlumberger in Mine-Edwards, 1881
Species: Amphicoryna scalaris (Batsch, 1791)
Description: The wall material is hyaline with an elongated appearance. The test was performed on a coiled uniserial plate. The chamber form is pyriform. The aperture radiates to the neck and terminal position. The sutures are depressed and straight and have striate ornamentation.
Locations: 7440-7470 feet
Remarks: Rare in distribution, well preserved.
Age: Miocene to recent.

Suborder: Textulariina
Superfamily: Eggerelloidea
Family: EGGERELLIDAE
Subfamily: Eggerellinae
Genus: Karreriella Cushman, 1933
Species: Karreriella siphonella (Reuss, 1851)
Description: The wall material is agglutinated with an elongated overall appearance. The test involved coiled biserial plates. The chamber was constructed of brick. The aperture is round, oval, and reniform, with no tooth, neck, or lip. The sutures were depressed and straight.
Locations: 7350-7380 feet
Remarks: Rare in distribution, well preserved.
Age: Oligocene to Recent.