

**SEQUENCE STRATIGRAPHIC INTERPRETATION OF SEDIMENTS IN MEREN
FIELD OFFSHORE NIGER DELTA USING WIRELINE LOG PATTERNS AND
BIOSTRATIGRAPHIC DATA**

BY

NWADIKE CYNTHIA BENEDICTA NKEIRUKA

(B.TECH Geology, FUTO)

20184149178

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CERTIFICATION

This is to certify that this thesis, "SEQUENCE STRATIGRAPHIC INTERPRETATION OF SEDIMENTS IN MEREN FIELD OFFSHORE NIGER DELTA USING WIRELINE LOG PATTERNS AND BIOSTRATIGRAPHIC DATA" was carried out by, NWADIKE CYNTHIA BENEDICTA NKEIRUKA (20184149178) in partial fulfillment of the requirements for the award of the degree of Master of Science (M.Sc) in Sedimentary/Petroleum Geology in the Department of Geology, School of Physical Sciences, Federal University of Technology, Owerri (FUTO), Nigeria.



PROF. S.O. ONYEKURU
(Principal Supervisor)

5/5/2025
DATE



DR. S.I. IBEMEME
(Co-Supervisor)

14/05/2025
DATE



DR. D.O. IKORO
(Head of Department)

14/05/2025
DATE



PROF. MRS. C.E. OGUKWE
(Dean, SOPS)

16-05-25
DATE

PROF. MRS. J.N NWOSU
(Dean Postgraduate School)

DATE



PROF. A.J. UKPONG
(External Examiner)

7/3/2025
DATE

DEDICATION

This work is dedicated to God Almighty the source of my strength. I also dedicate it to the memory of my Late Husband Hon. Chukwuemeka James Odigbo

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I will love to appreciate my supervisor in the person of Prof. S.O Onyekuru for his advice and support throughout the period of my stay in this school from my course work, commencement of my research and completion of it. He has really been like a father to me. He really took time to guide me by assisting with materials that enabled the execution of this work. I will not also forget the special assistance of the co-supervisor, Dr. S.I Ibeneme. I thank him for his inputs and assistance in sourcing some of the data for the research.

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ABSTRACT

Well logs and biostratigraphic data were employed in the reconstruction of sequence stratigraphic framework for Meren 01 and 02 Wells in the Meren Field offshore Niger Delta. A total of one hundred and sixty four (164) core samples were examined for microfossils using standard procedures for foraminifera and palynomorphs analysis. The Palynological Zones (P-Zones) and age determination was achieved using First Downhole Occurrence (FDO), Downhole Increase or Decrease, Quantitative Base (QB), Last Downhole Occurrence (LDO) or Base Occurrence (BO), Top Regular (TR) or Quantitative Top Occurrences (QTO) of age diagnostic palynomorphs as well as known marker species. Additionally, the samples were subjected to detailed description based on their respective lithology. The GR log pattern and microfossil abundance and diversity were used to delineate the sequences to different kinds of system tracts. Accordingly, four depositional sequences were identified comprising of five Sequence Boundaries (SB) dated at 6.30Ma, 5.5 Ma, 3.8 Ma, 3.0 Ma and 2.6 Ma, six Maximum Flooding Surfaces (MFS) dated at 7.00 Ma, 5.80 Ma, 5.00Ma, 3.40 Ma, 2.70 Ma and 2.45 Ma of Middle – Late Miocene age were recognized when significant foraminiferal signatures obtained were integrated with that of palynology. The key stratigraphic surfaces which were identified using index microfossils and higher GR count can be used for basin wide correlation. From the correlation chart, the Maximum Flooding Surfaces are associated with diversity of microfossils and high concentration of radioactive minerals that gave rise to high GR reading at this surface unlike the Sequence Boundary where fewer or no microfossils were identified with low GR readings. The dated stratigraphic surfaces corroborated with established shifts landward and basin ward according to established schemes. Giving the available data from biostratigraphy and GR log, the environment of deposition was inferred to trend from coastal deltaic to marine. The environments over which sediments of Meren-01 and 02 were deposited have been investigated through the integration of sedimentological, palynological and micropaleontological characteristics of these sediments. Based on bathymetric profiles, the shales within the study area are open marine, shelf and floodplain fines, while the sand sequences are most likely due to lobe switching of the river channel and deposition of interdistributary bay. Three reservoirs R4000, R6000 and R8000 were also identified and correlated across the wells. Given their rich sand development, the quality of these reservoirs is generally good and they all possess excellent net-to-gross. Additionally, their facies distribution shows that non reservoir units (shale and silt facies) are in minor amounts

Keywords: *Biostratigraphy, Sequence Stratigraphy, Well Log, Depositional Environment,*

Meren Field, Niger Delta

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The Niger Delta, situated in the Gulf of Guinea, is a prolific petroleum-bearing region with a complex geological history. The sedimentary successions within this region have been shaped by a dynamic interplay of geological processes, including tectonics, eustatic sea-level fluctuations, and sediment supply from the Niger River drainage basin. These sedimentary deposits hold significant implications for hydrocarbon exploration and production in the offshore Meren Field. Understanding the sequence stratigraphy, paleobathymetry, and biostratigraphy of these sediments is paramount for successful reservoir characterization and resource development (Adeleye, Asafa & Adebisi., 2019).

The Niger Delta region has been extensively explored for hydrocarbons, given its substantial oil and gas reserves. However, reservoir quality and distribution vary significantly across the delta, influenced by the complex interplay of geological and environmental factors. Sequence stratigraphy provides a powerful framework for understanding the distribution and architecture of sedimentary successions in response to relative sea-level changes. The identification of sequence boundaries, system tracts, and the associated sedimentary facies allows for a detailed assessment of depositional environments (Posamentier, Allen, James & Tesson., 2007).

In addition to sequence stratigraphy, the integration of paleobathymetry is essential for refining the interpretation of depositional environments. The paleobathymetric analysis aids in discerning the water depths at which sediments were deposited and helps identify potential reservoir facies. Highstand systems tracts typically represent shallow-water environments, while low-stand systems tracts reflect deeper-water conditions (Wright and Marriott, 1993).

Biostratigraphic analysis complements sequence stratigraphy by providing age constraints and paleoenvironmental information. Fossil assemblages and microfossils, such as foraminifera and palynology, serve as valuable tools for dating sediments and correlating horizons across the Niger Delta. The integration of biostratigraphy assists in determining the relative sea-level history and paleoenvironmental conditions during sediment deposition (Galloway, Lohmann & Hansley., 2000).

Understanding the sequence stratigraphy, paleobathymetry, and biostratigraphy of sediments in the Meren Field is not only crucial for academic research but also holds significant economic implications. Successful reservoir characterization and predictive modeling based on these analyses can optimize drilling strategies, well placement, and hydrocarbon recovery, ultimately enhancing the economic viability of the offshore field (Onyekuru, Chiokwe, Nwozor, Njoku, Chikezie & Fagorite, 2024; Onyekuru, Opara, Njoku, Basse & Ukaonu, 2019a; Allen and Allen, 2013).

In summary, the complex sedimentary successions in the Niger Delta region, including the Meren Field, require a multidisciplinary approach. The integration of sequence stratigraphy, paleobathymetry, and biostratigraphy provides a comprehensive framework for understanding the depositional history of these sediments, aiding in reservoir characterization and hydrocarbon exploration.

1.2 Statement of the problem

The Niger Delta, an oil-rich region in West Africa, has attracted substantial attention from the petroleum industry due to its vast hydrocarbon reserves. Within this region, the Meren Field, situated offshore, is of particular interest. However, successful hydrocarbon exploration and production in the Meren Field are challenged by the complex sedimentary deposits that exhibit enmeshed spatial and temporal variations in response to a combination of geological processes, including tectonics, relative sea-level fluctuations, and sediment supply from the Niger River drainage basin (Doust and Omatsola, 1990; Avbovbo, 1978).

The main problem in this context is the need to understand and characterize the sedimentary deposits within the Meren Field. This is crucial because the distribution and quality of reservoir rocks, seals, and potential source rocks are inseparably linked to the sedimentary architecture, lithology, and depositional environments (Ejedawe and Onuoha, 1990). Achieving a detailed understanding of the sedimentary successions is vital for:

1. **Reservoir Characterization:** Identifying potential reservoir rocks and assessing their quality is a fundamental aspect of hydrocarbon exploration. It is essential to determine the thickness, porosity, and permeability of these reservoirs to estimate their production potential (Dott and Bourgeois, 1982).
2. **Depositional History:** Relative sea-level changes and sediment supply patterns have a profound influence on the depositional history. Recognizing sequence stratigraphy and system tracts is vital to decipher the conditions under which sediments were deposited (Vail, Mitchum & Thompson., 1977).
3. **Paleobathymetry:** Understanding the paleobathymetry of the sediments is crucial for determining water depths at the time of deposition. This information assists in identifying potential hydrocarbon reservoirs, as highstand systems tracts are often associated with shallow-water environments suitable for reservoir rocks (Posamentier et al., 2007).
4. **Biostratigraphic Significance:** Accurate dating of sediments and the correlation of horizons across the Meren Field is facilitated through biostratigraphy. Fossil assemblages, such as foraminifera and palynology, provide essential age constraints and paleoenvironmental information (Posamentier and Allen, 1999).
5. **Predictive Modeling:** Developing predictive models for the distribution of sedimentary facies and potential drilling targets requires an in-depth understanding of

the sedimentary successions. These models are vital for optimizing exploration and production strategies (Mitchum & van Wagoner, 1991).

Failure to address these challenges may result in suboptimal exploration and production practices, leading to increased operational costs and potential resource wastage. Moreover, inadequate reservoir characterization may hinder accurate reserve estimations and ultimately impact the economic viability of the Meren Field.

In light of these considerations, the current study aims to comprehensively analyze the sedimentary successions in the Meren Field, incorporating sequence stratigraphy, paleobathymetry, and biostratigraphic data. The overarching objective is to provide a holistic understanding of the sedimentary deposits within the field, facilitating optimized exploration and production strategies while addressing the complex geological dynamics of the Niger Delta.

1.3 Aim and Objectives of the Study

The aim of this study is to conduct Sequence Stratigraphic interpretation of sediments in Meren Field Offshore Niger Delta using wireline log patterns and biostratigraphic data.

The Objectives of the Study are:

- I. To analyze the fauna and flora present in the samples extracted from the wells.
- II. To identify the ancient environment of the well from which the samples originated.
- III. To estimate the age of the sampled well through the examination of its faunal contents.
- IV. To analyse the GR log signatures obtained from the wells

1.4 Scope of the Study

The study aims to conduct a comprehensive paleontological examination of well 01 and 02, situated within Meren Field in the Niger Delta region. The primary focus is on the analysis of fossil assemblages extracted from the well, with the overarching objectives of understanding the faunal composition, reconstructing the ancient environmental conditions in which these fossils were deposited, and estimating the geological age of the sampled well. The scope of the study encompasses the following key aspects:

1.5 Significance of the Study

The study discussed the significance of the findings in terms of understanding the geological history and evolution of the Niger Delta region. It also explored the practical implications for the petroleum industry, such as reservoir characterization and exploration targeting.

The significance of the study lies in its contribution to several important areas, including geology, paleontology, petroleum industry and environmental science. The key significance of the study can be summarized as follows:

1. **Geological Understanding:** The study provides valuable insights into the geological history and evolution of the Niger Delta region. It helps in reconstructing the paleoenvironment and depositional conditions that prevailed during the formation of Meren 01 and 02 wells. By identifying and analyzing fossil assemblages, the study enhances our understanding of past ecosystems, their responses to environmental changes, and the factors that influenced sediment deposition.
2. **Chronostratigraphy and Age Estimation:** The estimation of the geological age of the wells through biostratigraphic analysis contributes to the refinement of the chronostratigraphic framework of the Niger Delta. This information aids in placing the well within the context of regional and global geological timescales.

3. **Petroleum Exploration and Reservoir Characterization:** The study has practical implications for the petroleum industry. Understanding the paleoenvironment and the depositional history of sedimentary successions within the well assists in reservoir characterization. Knowledge of reservoir rocks, their quality, and distribution is essential for optimizing hydrocarbon exploration and production strategies.
4. **Environmental Science:** The paleoecological reconstruction of ancient environments in the Niger Delta region is of interest to environmental scientists. It can provide insights into historical changes in environmental conditions, which can inform modern environmental studies and conservation efforts.
5. **Academic and Scientific Advancement:** The findings of this study contribute to the body of knowledge in paleontology, paleoecology, and biostratigraphy. They can serve as a reference for future research in similar geological contexts and regions.
6. **Industry and Economic Impact:** The petroleum industry in the Niger Delta is a significant economic driver. The study's findings can influence exploration and drilling decisions, potentially leading to cost savings and more efficient resource extraction.
7. **Environmental Impact Assessment:** The study may have implications for environmental impact assessments in the region. Understanding past environmental conditions and changes can inform current and future environmental management and decision-making processes.

CHAPTER TWO

LITERATURE REVIEW

2.1 Niger Delta Region

The Niger Delta, a sprawling and ecologically diverse region in West Africa, occupies a pivotal position in the geological, geographical, and environmental landscape of the continent. It is characterized by its intricate network of river systems, vast wetlands, and a complex geological history. The geological significance of the Niger Delta is underscored by its role as a major hydrocarbon province. The region hosts prolific oil and gas reserves, making it a vital contributor to Nigeria's economy and a significant player in the global energy industry (Olayinka, 2004). The formation of these hydrocarbon reserves is intimately linked to the delta's geological history, marked by sedimentary deposition over millions of years (Nwajide, 2013). Understanding the geological evolution of the Niger Delta is imperative for effective resource exploration and management.

Geographically, the Niger Delta encompasses an extensive area that stretches across Nigeria and into parts of Cameroon, with the Gulf of Guinea to the south (Fig 2.1). It is a deltaic plain formed by the Niger River, Africa's third-largest river, which discharges into the Atlantic Ocean. The region is characterized by a labyrinthine network of creeks, estuaries, and mangrove swamps, providing habitat for diverse flora and fauna (Avbovbo, 1978). The delta's geographical features have a profound influence on its environmental dynamics, biodiversity, and human settlement patterns. From an environmental perspective, the Niger Delta is recognized for its unique and fragile ecosystem. Its vast wetlands, brackish water bodies, and dense mangrove forests are of global ecological importance (Ukoli, 1984). The delta sustains diverse wildlife, including endangered species such as manatees and sea turtles (Anyanwu, Onyene, Rauf., 2018). However, the environmental significance is accompanied by

environmental challenges, as the region faces issues related to pollution, deforestation, and habitat degradation due to anthropogenic activities, particularly those associated with the oil and gas industry (Ezemonye, Okoli & Odunze., 2019).

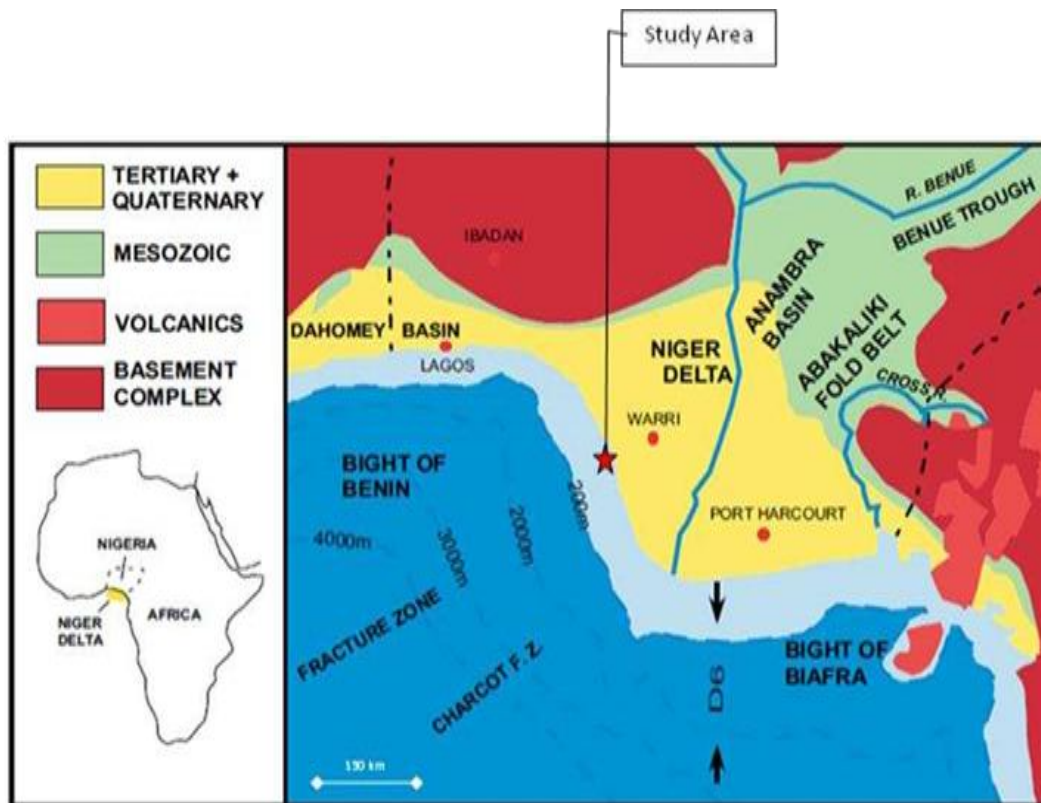


Figure 2.1: Index map of Niger Delta and location of study area (Doust & Omatsola, 1990)

2.1.1 Location of The Study Area

The research site is positioned within the Offshore Niger Delta, spanning Longitudes 3° to 9° E and Latitudes 4°30" to 5°20"N (Fig 2.2).

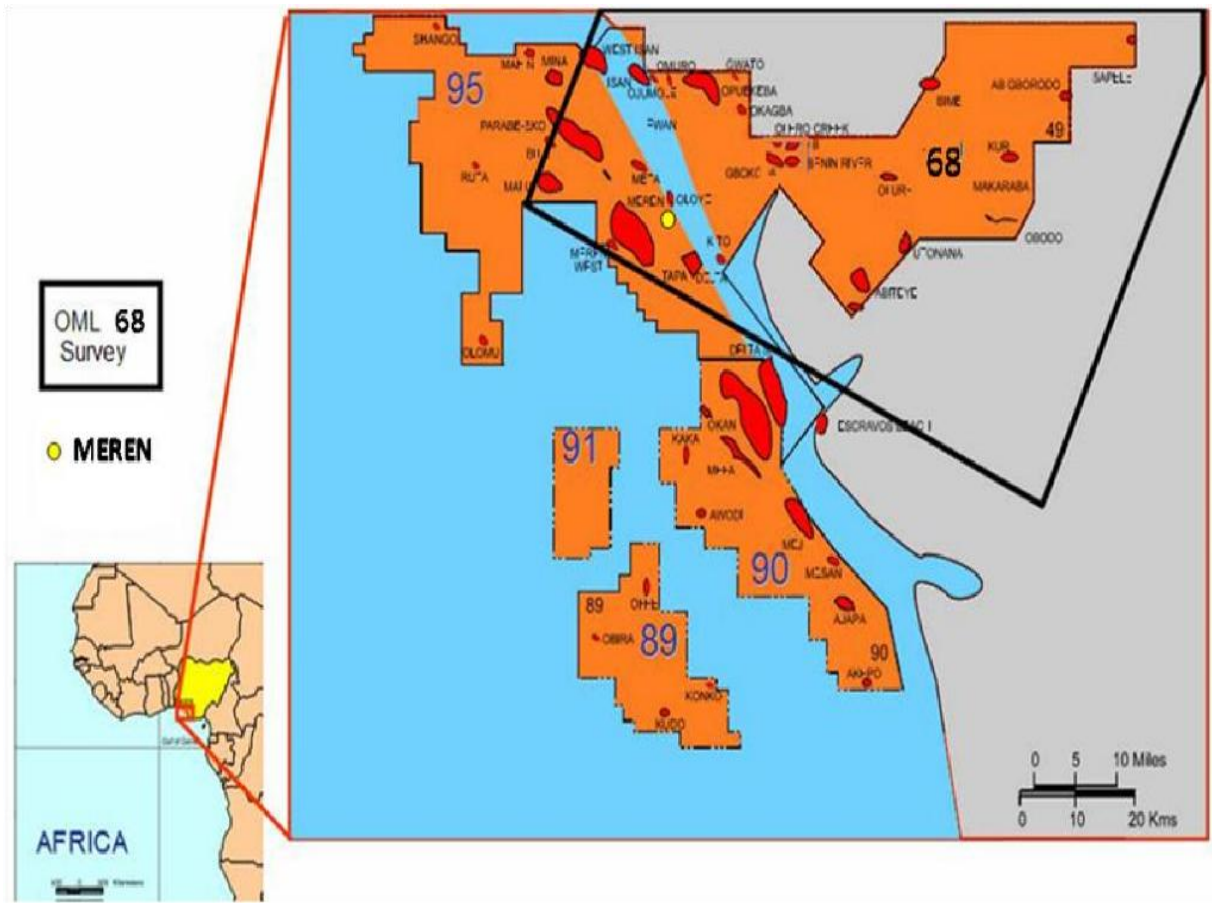


Figure 2.2: Location of Meren Field and adjacent fields in Western Niger Delta mining lease (USGS, 2017)

2.1.1.1 Role in the Petroleum Industry

The Niger Delta region plays a pivotal role in the global petroleum industry, serving as one of the most significant hydrocarbon provinces in the world. This section discusses its role in the petroleum industry, emphasizing the importance of understanding the geological history of the region.

1. **Abundant Hydrocarbon Reserves:** The Niger Delta is renowned for its vast hydrocarbon reserves, particularly oil and natural gas. Nigeria, which hosts the majority of the delta, is one of the top oil-producing countries globally (Olayinka, 2004). The region's sedimentary basins, characterized by extensive deposition of organic-rich sediments over millions of years, have resulted in the accumulation of substantial hydrocarbons (Nwajide, 2013).
2. **Significance in Global Energy Supply:** The hydrocarbons extracted from the Niger Delta have a profound impact on the global energy supply. Nigeria's oil production contributes significantly to the international energy market, influencing global oil prices and market dynamics. It plays a crucial role in meeting the energy demands of various countries and industries (Nwajide, 2013).
3. **Economic Contribution:** The petroleum industry in the Niger Delta region is a major driver of the Nigerian economy. Oil and gas exports generate a substantial portion of the country's revenue, enabling investments in infrastructure, social programs, and economic development (Olayinka, 2004). The revenue generated from oil exports supports various sectors, contributing to the overall economic well-being of the nation.

2.1.1.2 Importance of Understanding Geological History

Understanding the geological history of the Niger Delta is of paramount importance for various reasons:

1. **Resource Exploration and Reservoir Characterization:** A comprehensive knowledge of the geological history helps in resource exploration and reservoir characterization. It enables geologists and exploration teams to identify potential hydrocarbon-bearing formations, estimate reservoir quality, and make informed decisions about drilling locations (Doust & Omatsola, 1990). This understanding is crucial for optimizing exploration efforts and resource recovery.
2. **Geological Risk Assessment:** The geological history of the delta aids in the assessment of geological risks. It provides insights into the formation of structural traps, fault systems, and salt domes, which can impact drilling operations and reservoir behavior. Understanding these geological features is essential for mitigating exploration and production risks (Nwajide, 2013).
3. **Environmental Management:** A grasp of the geological history also helps in environmental management. It provides context for understanding the natural processes that have shaped the delta's ecosystems and topography. This knowledge is valuable for developing strategies to mitigate the environmental impact of petroleum activities and to protect fragile wetland ecosystems (Ezemonye et al., 2019).
4. **Policy Formulation and Regulation:** For governments and regulatory bodies, an understanding of the geological history informs policy formulation and industry regulation. It helps in setting environmental and safety standards, managing resource allocation, and establishing best practices for the petroleum industry (Nwajide, 2013).

2.2 Paleontological Studies in the Niger Delta

The Niger Delta is a prolific petroleum province with a rich geological history. Paleontological studies have played a significant role in understanding the region's stratigraphy, paleogeography, and paleoclimate. One of the earliest paleontological studies in the Niger Delta was conducted by Reyment (1955), who described the foraminiferal fauna of the Cretaceous section. Since then, numerous other studies have been conducted, focusing on a wide range of microfossils, including foraminifera, ostracods, palynomorphs, and nannofossils. Some of the key methodologies used in paleontological studies in the Niger Delta include:

- i. Surface surveys to collect fossils from exposed rocks.
- ii. Core drilling to collect fossils from subsurface rocks.
- iii. Micropaleontological studies to identify and analyze microscopic fossils.
- iv. Paleoecological studies to reconstruct the past environments in which fossils lived.

A key finding of paleontological studies in the Niger Delta is that the region has undergone multiple cycles of transgression and regression, resulting in the deposition of a variety of sedimentary facies. For example, the Cretaceous section is dominated by marine sediments, while the Tertiary section is characterized by a mix of marine and continental deposits. A study by Petters (1991) used the distribution of fossils to identify different delta lobes in the Niger Delta. The study found that the delta has prograded southwestward over time, with the youngest delta lobes located closest to the coast.

Paleontological studies have also helped to elucidate the paleogeography of the Niger Delta. For example, studies of foraminifera and ostracods have shown that the region was once covered by a shallow sea, which gradually deepened over time. Palynomorphs have also been used to reconstruct the vegetation history of the region, indicating that the Niger Delta was

once covered by tropical rainforest. A study by Adegoke, Fayose & Akande., (2012) identified over 100 species of foraminifera from the Oligocene-Miocene strata of the Niger Delta. The presence of these foraminifera indicates that the region was a marine environment during this time period.

Paleontological studies have also provided insights into the paleoclimate of the Niger Delta. For example, studies of nannofossils have shown that the region experienced a period of global warming during the Eocene epoch. This warming event led to the deposition of carbonate sediments in the Niger Delta, which are now important hydrocarbon reservoirs. A study by Nwajide (2006) used pollen analysis to reconstruct the vegetation history of the Niger Delta. The study found that the region was covered in rainforest during the early Miocene, but that the rainforest gradually transitioned to mangrove swamp by the late Miocene.

2.2.1 Implications for understanding the region's geological history and past environments

Paleontological studies in the Niger Delta have provided valuable insights into the region's geological history and past environments. These studies have helped to:

- i. Elucidate the stratigraphy of the region, enabling geologists to map the distribution of different rock units and identify potential hydrocarbon reservoirs.
- ii. Reconstruct the paleogeography of the region, providing a better understanding of how the region has evolved over time.
- iii. Reconstruct the paleoclimate of the region, providing insights into the factors that have influenced the deposition of different sedimentary facies.

2.2.2 Paleocological Reconstruction

Paleocological reconstruction is the study of ancient environments using fossil assemblages. Fossil assemblages are groups of fossils that occur together in a rock layer. They can provide information about the types of organisms that lived in a particular environment, as well as the interactions between those organisms and their environment.

There are a variety of methods used in paleocological analysis. Some of the most common methods include:

- i. Taphonomy: Taphonomy is the study of how organisms are preserved in the fossil record. Taphonomic analysis can provide information about the environment in which an organism died and the processes that led to its preservation.
- ii. Paleobotany and paleozoology: Paleobotany and paleozoology are the study of fossil plants and animals, respectively. Paleobotanical and paleozoological analysis can provide information about the types of organisms that lived in a particular environment, as well as their morphology, ecology, and evolution.
- iii. Geochemistry: Geochemistry is the study of the chemical composition of rocks and minerals. Geochemical analysis can provide information about the salinity, temperature, and pH of ancient environments.

A study by Smith, Carroll, Singer & Poole., (2001) used fossil assemblages to reconstruct the ancient environment of the Green River Formation in Wyoming. The study found that the Green River Formation was a lake environment that was home to a variety of fish, turtles, and birds. The study also found that the lake environment was highly productive and that it supported a diverse ecosystem. Wing, Blosch & Clydel., (2005) used fossil assemblages to reconstruct the ancient environment of the White River Formation in Colorado. The study found that the White River Formation was a floodplain environment that was home to a

variety of mammals, including horses, rhinos, and camels. The study also found that the floodplain environment was highly seasonal, with alternating periods of wet and dry conditions.

A study by Gastaldo, Feduccia & Rodriguezl., (2019) used fossil assemblages to reconstruct the ancient environment of the Messel Pit in Germany. The study found that the Messel Pit was a lake environment that was home to a variety of mammals, birds, and insects. The study also found that the lake environment was highly eutrophic, meaning that it was rich in nutrients. Retallack (2001) used fossil assemblages to reconstruct the climate of the late Paleozoic ice age. The study found that the ice age was characterized by cold temperatures and dry conditions. Smith, Collinson & Hooker., (2004) used fossil assemblages to reconstruct the vegetation of the early Cretaceous period. The study found that the early Cretaceous vegetation was dominated by ferns and gymnosperms. Brusatte, Benton, Ruta & Lloyd., (2010) used fossil assemblages to reconstruct the food webs of the late Jurassic period. The study found that the food webs were complex and that they included a variety of dinosaurs and other animals.

A study by Williams, Ayliffe & Veron., (2010) used fossil assemblages to reconstruct the paleoecology of the Great Barrier Reef in Australia. The study found that the reef has been inhabited by a diverse community of corals and other marine animals for millions of years.

2.3 Sequence Stratigraphy

Sequence stratigraphy is a fundamental concept in geology and has significant importance in the field of petroleum exploration. Sequence stratigraphy is a framework that emphasizes the vertical and lateral relationships of sedimentary rocks in a stratigraphic sequence, recognizing that sedimentary deposits are not random but are organized into predictable patterns. It is based on the recognition of recurring sequences of strata that represent the response of

sedimentary systems to changes in relative sea level. These sequences are bounded by unconformities or surfaces of erosion and non-deposition, known as sequence boundaries. Within these sequences, various systems tracts are identified, representing different phases of sedimentation and responding to sea-level fluctuations.

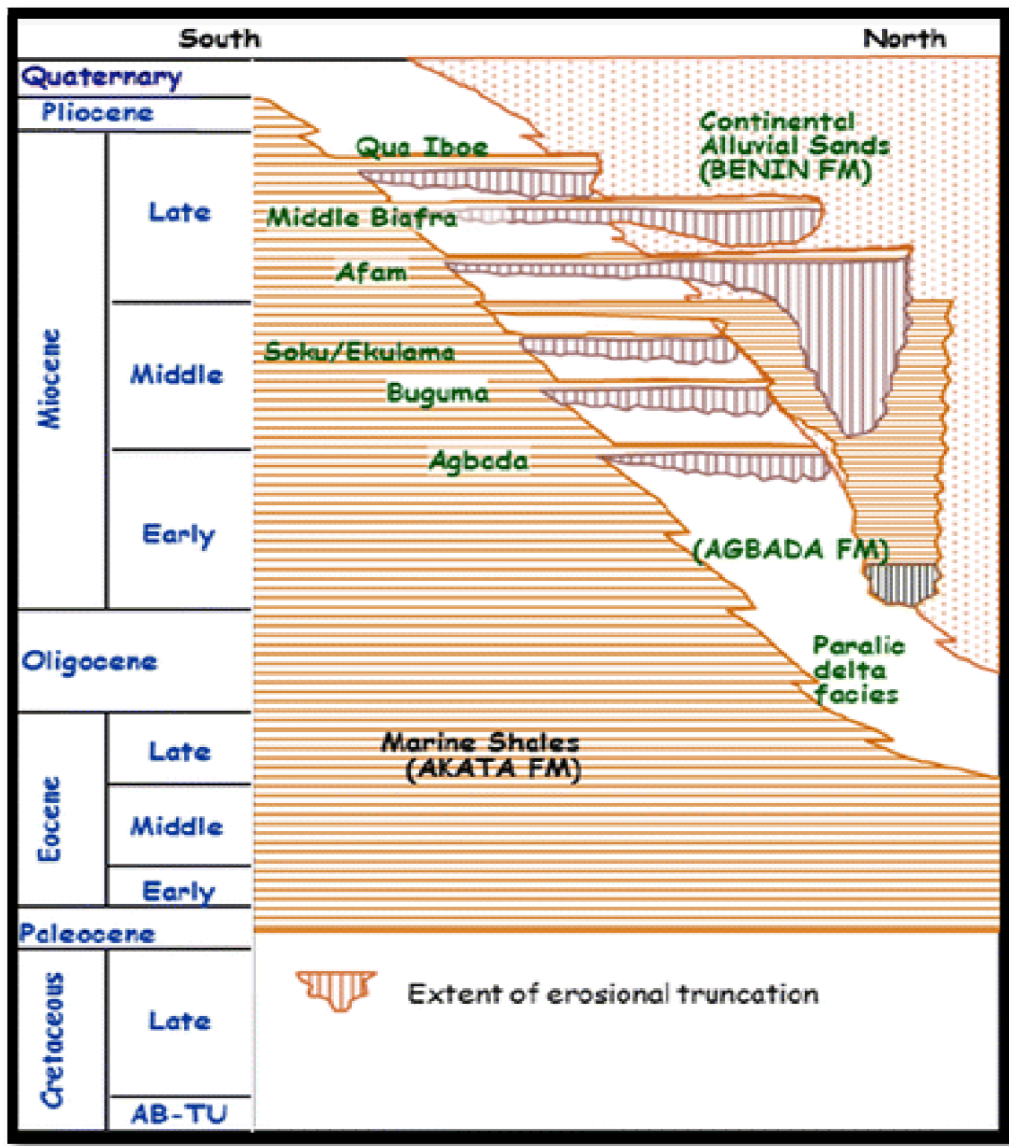


Figure 2.3: Regional stratigraphy of the Niger Delta showing different Formations (Ozumba, 2013)

Table 2.1: Stratigraphic Units of the Niger Delta (Poston, Arungbemi & Olukoga., 2012)

Outcropping units	Subsurface units	Lithology	Depositional environment	facie
Coastal plain sands	Benin Formation	Medium-coarse grained sands, clay and silt	Continental environment	Deltaic plain facie
Ogwash-Asaba/Ammeki	Agbada	Intercalation of sand, silt, and clay	Transitional environment	Deltaic plain facie
Imo Shale	Akata	Clay and Shale	Marine environment	Deltaic front

2.3.1 Importance of Sequence Stratigraphy

Sequence stratigraphy plays a crucial role in petroleum exploration for several reasons:

1. **Facilitating Reservoir Characterization:** Sequence stratigraphy aids in the characterization of reservoir rocks. By identifying sequence boundaries and systems tracts, geologists can delineate reservoir units and understand the distribution of sand bodies, which are critical for hydrocarbon exploration. A study by Carvajal & Steel (2004) used sequence stratigraphy to identify potential reservoir rocks in the Niger Delta. The study found that the best reservoir rocks are located in the upper parts of sequences, where they are associated with falling sea level and forced regression. A study by Mitchum et al., (1977) used sequence stratigraphy to identify potential reservoir rocks in the Gulf of Mexico. The study found that the best reservoir rocks are located in the upper parts of sequences, where they are associated with falling sea level and forced regression. The identification of high-quality reservoir rocks within specific systems tracts is essential for optimizing drilling and production strategies (Posamentier & Allen, 1999).
2. **Predicting Source Rock Distribution:** Understanding sequence stratigraphy helps predict the distribution of source rocks. Organic-rich shales often accumulate during low-stand and transgressive systems tracts when the rate of sediment supply is low relative to the rate of sea-level rise. Recognizing these systems tracts is important for assessing source rock presence and potential hydrocarbon generation (Mitchum & Van Wagoner, 1991).
3. **Identifying Traps and Seal Rocks:** Sequence stratigraphy assists in identifying structural and stratigraphic traps. Specific systems tracts, such as low-stand and high-stand systems tracts, are associated with the deposition of seal rocks and the formation

of traps. Identifying these systems tracts is critical for locating potential hydrocarbon reservoirs (Van Wagoner et al., 1990).

4. **Predicting Depositional Environments:** The concept of sequence stratigraphy provides insights into the depositional environments associated with different systems tracts. This understanding is valuable for interpreting the paleogeography of the basin, predicting sedimentary facies variations, and assessing reservoir quality (Wilgus, Hastings & Posamentier., 1988).
5. **Responding to Sea-Level Changes:** Sequence stratigraphy allows geologists to reconstruct the response of sedimentary systems to sea-level changes. This helps in understanding the sedimentary record and the impact of sea-level fluctuations on the stratigraphic architecture of sedimentary basins (Catuneanu, 2006). A study by Vail et al., (1977) used sequence stratigraphy to develop a global eustatic sea-level curve. This curve can be used to correlate sequence boundaries across different basins.

2.4 Biostratigraphy and Its Role in Age Estimation

Biostratigraphy is a subfield of geology that focuses on the use of fossils, primarily microfossils, as markers for dating sedimentary rocks and establishing chronostratigraphy. Biostratigraphy is a branch of stratigraphy that employs the distribution of fossils in sedimentary rocks to establish a chronological framework for the Earth's history. It relies on the concept that different species of organisms have distinctive temporal ranges and can be used to correlate and date rocks. In biostratigraphy, the focus is often on microfossils, which include microscopic remains of organisms such as foraminifera, diatoms, pollen, and spores. These microfossils are highly abundant, well-preserved, and exhibit rapid evolutionary changes, making them excellent markers for age determination (Gradstein et al., 2004).

2.4.1 Significance in Age Estimation

Biostratigraphy is of paramount importance in the estimation of geological ages for several reasons:

1. **Fossil Zonation:** Biostratigraphy establishes a zonation of fossil assemblages based on their temporal ranges. Different assemblages are indicative of specific time intervals. This zonation allows geologists to compare and correlate rock sequences from different locations and assign them relative ages (Berggren, Kent, Swisher & Aubry, 1995). A study by Gradstein, Ogg & Smith., (2012) used biostratigraphy to develop a global biostratigraphic timescale for the Phanerozoic Eon (the last 541 million years of Earth history). This timescale is used to correlate rock sequences between different continents and to estimate the absolute ages of rocks. Another study by Ogg., Ogg & Gradstein., (2008) used biostratigraphy to correlate the Cretaceous-Paleogene boundary between North America and Europe. This boundary is marked by a mass extinction event that occurred 66 million years ago. The study found that the boundary is located at the same level in both continents, which indicates that the mass extinction event was global.
2. **High Temporal Resolution:** Microfossils, particularly planktonic foraminifera, have short lifespans and rapid evolutionary rates. This high temporal resolution makes them precise markers for dating rocks and for distinguishing relatively small-scale chronological changes within sedimentary sequences (Gradstein et al., 2004).
3. **Establishment of Chronostratigraphy:** Biostratigraphy contributes to the establishment of chronostratigraphic units, which are divisions of geological time based on rock successions with similar fossil assemblages. This framework aids in the correlation of geological events and the creation of a time scale (Gradstein et al., 2004).

4. **Age Determination in Stratigraphy:** Biostratigraphic markers, especially microfossils, are used to determine the ages of stratigraphic units or formations. By identifying specific fossil taxa within rock layers, geologists can confidently assign absolute ages or relative ages within the geological timescale (Gradstein et al., 2004). A study by Lourens, (2005) used biostratigraphy to correlate the Milankovitch cycles between different continents. The Milankovitch cycles are variations in Earth's orbit around the sun that occur on time scales of tens of thousands to hundreds of thousands of years. The study found that the Milankovitch cycles are recorded in the fossil record and that they can be used to correlate rock sequences between different continents.
5. **Integrating with Other Dating Techniques:** Biostratigraphy often complements other dating techniques, such as radiometric dating. It provides a valuable cross-check on the accuracy of age determinations and can refine the dating of rock units (Berggren et al., 1995).

2.5 Paleobathymetry Studies

Paleobathymetry studies involve the reconstruction of ancient water depths in geological history. These studies are crucial for understanding past environmental conditions and depositional settings. Paleobathymetry is the study of ancient water depths and the distribution of marine environments throughout geological time. It aims to reconstruct the bathymetry (seafloor topography) of ancient oceans, seas, and continental margins. Paleobathymetric analysis often involves the examination of sedimentary facies, fossil assemblages, and geochemical proxies within rock sequences to infer water depth (Posamentier & Allen, 1999).

Paleobathymetry studies hold several key significance:

1. **Paleoenvironmental Reconstruction:** Paleobathymetry helps in reconstructing ancient marine environments. By determining past water depths, geologists can infer the proximity of coastlines, the location of continental shelves, and the presence of deep-sea basins. This information aids in understanding the geological history and paleogeography of a region (Posamentier & Allen, 1999).
2. **Facilitating Sequence Stratigraphy:** Paleobathymetry is integral to sequence stratigraphy, helping identify different systems tracts and sequence boundaries. Understanding the changes in water depth through time is essential for defining sedimentary sequences and correlating them across basins (Posamentier & Allen, 1999).
3. **Reservoir Characterization:** In petroleum exploration, paleobathymetry plays a role in reservoir characterization. By reconstructing the paleoenvironment of deposition, geologists can identify potential reservoir rocks and understand their distribution. This information is vital for optimizing drilling and production strategies (Boggs, 2006).
4. **Estimating Relative Sea Level Changes:** Paleobathymetry can provide insights into relative sea level changes throughout geological history. By determining past sea levels, geologists can assess the effects of tectonics, climate, and eustasy on the Earth's surface (Vail et al., 1977).
5. **Sedimentary Facies Analysis:** Paleobathymetry aids in the interpretation of sedimentary facies. Different water depths are associated with distinct sedimentary features and lithologies. Understanding paleobathymetry assists in distinguishing facies associations and their spatial relationships within a stratigraphic sequence (Boggs, 2006).
6. **Ecostratigraphy:** The depth-related distribution of fossil assemblages can be used to infer paleobathymetry. For instance, certain fossils are indicative of specific water

depths, and their presence or absence can help in determining ancient bathymetry (Mullins, Sageman & Arthur., 2003).

2.6 Research Gaps and Limitations

Identifying gaps in existing literature and understanding the limitations of previous studies is crucial for justifying the need for new research and highlighting the unique contributions it can make.

2.6.1 Research Gaps

1. **Limited Paleobathymetric Studies in the Niger Delta:** Existing literature on paleobathymetry often focuses on well-studied regions, but there is a lack of comprehensive paleobathymetric studies in the Niger Delta. Most studies have concentrated on other aspects of the delta's geology, leaving a gap in our understanding of the region's ancient water depths (Posamentier and Allen, 1999).
2. **Integration of Paleobathymetry with Sequence Stratigraphy:** While sequence stratigraphy is a powerful tool for understanding sedimentary successions, the integration of paleobathymetry with sequence stratigraphy in the Niger Delta has been limited (Boggs, 2006). There is a need for research that effectively combines these approaches to provide a more comprehensive view of the delta's geological history.
3. **Temporal Resolution in Biostratigraphy:** The Niger Delta's complex geological history necessitates high temporal resolution in biostratigraphy. Previous studies in the region often lack the detailed analysis of microfossil assemblages required for precise paleoenvironmental and age reconstructions (Mullins et al., 2003).
4. **Environmental Impact of Oil Exploration:** While there is ample literature on oil exploration and its impact on the Niger Delta's environment, there is a gap in studies that link paleobathymetry with environmental change. Understanding how past water

depth changes may relate to the region's current environmental challenges is an area that needs further exploration (Ezemonye et al., 2019).

2.6.2 Limitations of Previous Studies

1. **Data Availability and Quality:** Many previous studies in the Niger Delta have been limited by the availability and quality of data, especially related to core samples and well logs. This has constrained the accuracy of paleobathymetric and biostratigraphic reconstructions (Posamentier & Allen, 1999).
2. **Assumptions in Sequence Stratigraphy:** Sequence stratigraphy relies on certain assumptions about the nature of sedimentation and the relationship between sea-level changes and sedimentary responses. The accuracy of interpretations can be affected by these assumptions (Vail et al., 1977).
3. **Lack of Geochemical Data:** The absence of comprehensive geochemical data in previous research limits the ability to accurately link paleobathymetry with environmental changes, such as those resulting from oil exploration (Ezemonye et al., 2019).
4. **Interdisciplinary Integration:** Many studies in the Niger Delta have been discipline-specific, focusing solely on geology, paleontology, or environmental science. The limited interdisciplinary integration of these fields has hindered a holistic understanding of the region's history (Boggs, 2006).
5. **Temporal Resolution in Biostratigraphy:** Previous biostratigraphic studies may not have achieved the required temporal resolution to address questions related to detailed chronostratigraphy and high-resolution environmental changes (Mullins et al., 2003).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The research materials utilized in this study encompass a range of items:

1. Well Logs
2. Core samples
3. Picking brush
4. Ceramic mortar and pestle
5. Oven
6. Sodium Bicarbonate or hydrogen peroxide for soaking
7. Sieve (Mesh size of 120 US standard)
8. Paleontological microscope

These tools and equipment are integral to various aspects of the research process, contributing to tasks such as data collection, sample preparation, analysis, and observation within the study's scope.

3.2 Methodology

The sample preparation process included several sequential steps as outlined in Adegoke et al, (2012):

- a. Disaggregation: For both consolidated and mud rock samples, a ceramic mortar and pestle were employed to gently disaggregate the samples using up and down motion. The goal was to release individual grains and microfossils without damaging them.
- b. Soaking: Following disaggregation, the samples were soaked in plastic cups containing hydrogen peroxide and sodium bicarbonate (CALGON) for approximately 24 hours. This step helped to dissolve and disaggregate the samples further, aiding in cleaning and separating individual grains.
- c. Washing: After the 24-hour soaking period, each sample in its plastic cup underwent a washing procedure to eliminate mud and other impurities, leaving a clear residue suitable for

microscopic examination. The washing involved placing the soaked samples onto a sieve (120 mesh sieve size American standard) and letting clean, distilled water flow through the samples. Attention was paid to avoid over-washing that could potentially remove microfossils. Washing was considered complete when the water passing through the sieve appeared clear.

- d. Drying: Post washing, the sediment was spread onto small polythene bags and left in an open-air environment for 48 hours to ensure thorough drying. This drying phase was necessary for effective fossil identification under a microscope.
- e. Bagging: Once dried, each sample was placed in a labeled sample bag, indicating the corresponding sample box and depth for easy identification. These bags were then examined using a microscope.

These meticulous steps were undertaken to ensure that the samples were properly disaggregated, cleaned, and prepared for subsequent microscopic study, thereby contributing to the accuracy and reliability of the research findings.

3.2.1 Microscopic Analysis

Foraminiferal Analysis

Following standard procedures for sample preparation, All representative size fractions are examined individually on a picking tray. The tray is gridded to ensure that the whole rock residual sprayed in the tray are carefully examined. Available microfauna and shell fragments will be picked from the samples with the aid of a picking brush and later sorted according to species and viewed under a binocular microscope. The picked fauna are subjected to species identification and abundance/diversity counts.

Palynological Analysis

A biological microscope was used for the analysis, whereby species were identified by comparison using standard manuals such as Evamy, et al (1978), SHELL photo album, etc. The abundance of the different palynoecological groups were also recorded accordingly.

Biozonation

The Palynological Zones (P-Zones) and age determination was achieved using First Downhole Occurrence (FDO), Downhole Increase or Decrease, Quantitative Base (QB), Last Downhole Occurrence (LDO) or Base Occurrence (BO), Top Regular (TR) or Quantitative Top Occurrences (QTO) of age diagnostic palynomorphs as well as known marker species. Zonation of the study was achieved using the schemes of Evamy et. al, (1978); Germeraad et al., (1968); and Stratcom (2002).

Faunal Analysis:

- ii. Identification of Faunal Assemblages: This phase involves a detailed examination of the fossil specimens recovered from the wells. The study will aim to identify and classify the various taxa present in the samples. This includes the identification of microfossils (such as foraminifera, palynomorphs, and ostracods) and macrofossils, to provide a comprehensive record of the faunal diversity within the well.
- iii. Faunal Abundance and Diversity: A quantitative assessment of the abundance and diversity of the identified fauna will be carried out. This will involve species richness and evenness analyses to provide insights into the ecological and environmental conditions at the time of deposition.

3.2.2 Lithologic and GR/SP Log Description

Lithology identification from well logs is a fundamental task in the field of petroleum geology (Fig 3.1). It involves interpreting the recorded log data to determine the types of rocks encountered while drilling a well. By understanding the lithology, geoscientists can assess reservoir characteristics, such as porosity, permeability, and fluid saturation, which are crucial for reservoir evaluation and hydrocarbon exploration. Accurate lithology identification is vital for various reasons. Firstly, it helps in understanding the geological history of the formation and the depositional environment. This information is crucial for predicting the presence of hydrocarbons and estimating the reservoir's production potential. Additionally, lithology identification aids in

wellbore stability analysis, drilling optimization, and formation evaluation, enabling engineers to make informed decisions during the drilling and production phases. Typical types of well logs for lithology identification include gamma ray, resistivity and neutron logs, among others. Each log provides specific data that can aid in lithology identification.

Biostratigraphic data (especially the planktic/benthic ratios, environmentally diagnostic benthic (paleobathymetry) and palynomorphs taxa) shall be integrated with lithologic and wireline attributes to delineate environment of deposition and settings based on the approach of Rider, 1999 and Allen 1965 & 1970.

Paleoenvironmental analysis and interpretation shall be achieved by:

- i. The integration of foraminiferal biofacies/paleobathymetry, palynofloral assemblages, lithologic description and wireline log data.
- ii. Wireline log data was useful especially in the delineation of the sedimentary sub-environments.

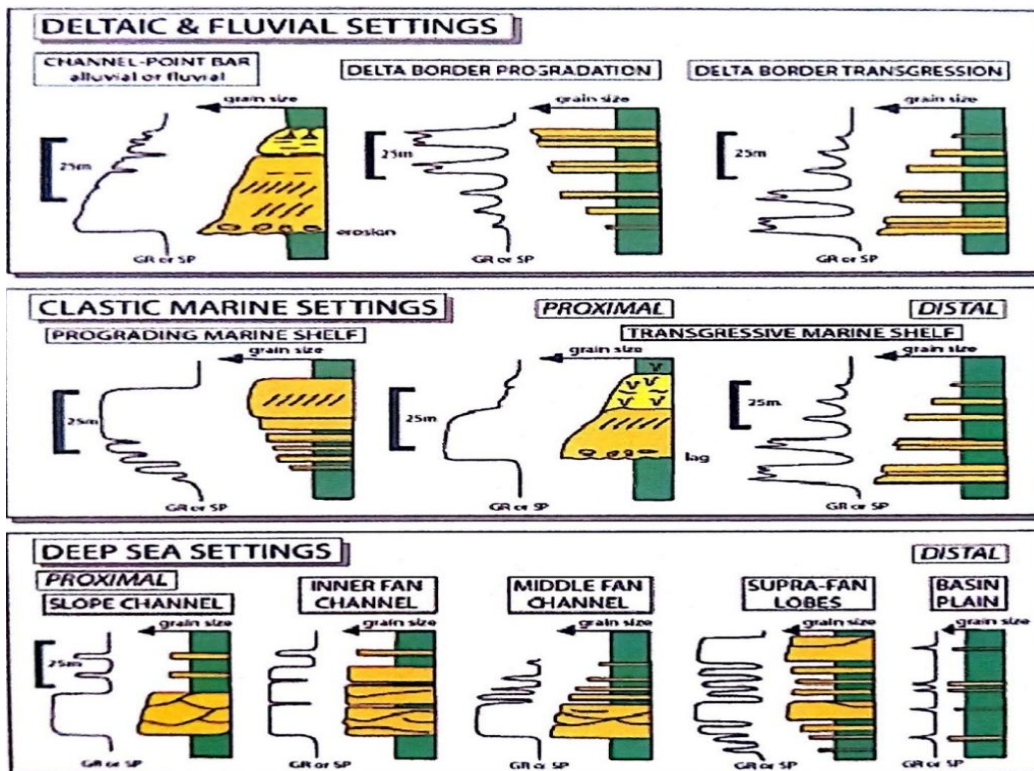


Figure 3.1: Gamma-ray log response and Depositional Settings (Modified after Rider, 1999)

3.2.3 Paleocological Reconstruction:

Paleoenvironmental Indicators: The study will focus on the interpretation of the faunal content as a means to reconstruct the ancient environment. Environmental indicators, such as the presence of specific taxa (e.g., benthic or planktonic foraminifera), ecological preferences of fossil groups, and sedimentological context, will be analyzed to provide insights into water depth, salinity, temperature, and depositional conditions.

3.2.4 Chronostratigraphy:

- i. Biostratigraphic Zonation: The age of the well will be estimated through biostratigraphic analysis. Fossil assemblages will be correlated with established biostratigraphic zones to provide a relative geological age assessment.
- ii. Chronostratigraphic Framework: A chronostratigraphic framework will be established to place the well within the broader geological context of the Niger Delta region.

3.2.5 Sequence Stratigraphic Analysis

The basic parameter of sequence stratigraphy is the unconformity-bounded sequence, which represents deposition in response to a complete cycle of relative sea level (Van Wagoner et al, 1988). This integrates vertical Lithofacies analysis, foraminiferal and palynofacies analysis majorly to identify parasequence, parasequence sets, depositional sequence, accompanying systems tracts and boundaries in the study area. This is used as a model to interpret systems tracts and accompanying key surfaces (Fig. 3.2)

Sequence boundaries are identified at this step based on one or more of the following criteria: clearly defined erosional truncation, direct evidence of subaerial exposure, or abrupt basinward shifts of facies. Likewise, potential condensed sections should be recognized on the basis of unusual burrowed surfaces, abundant diagenetic materials, fossil concentrations, closely spaced bentonite beds, or radioactive shales. Condensed sections may, but do not necessarily, lie along the maximum flooding surface (Walker, 1979).

From the recognition of parasequence sets and potential sequence boundaries and condensed sections, systems tracts and major strata surfaces (sequence boundary, transgressive surface, and maximum flooding surface) can be recognized. It is important to stress that not all of these surfaces or systems tracts may be present within any given sequence in an outcrop.

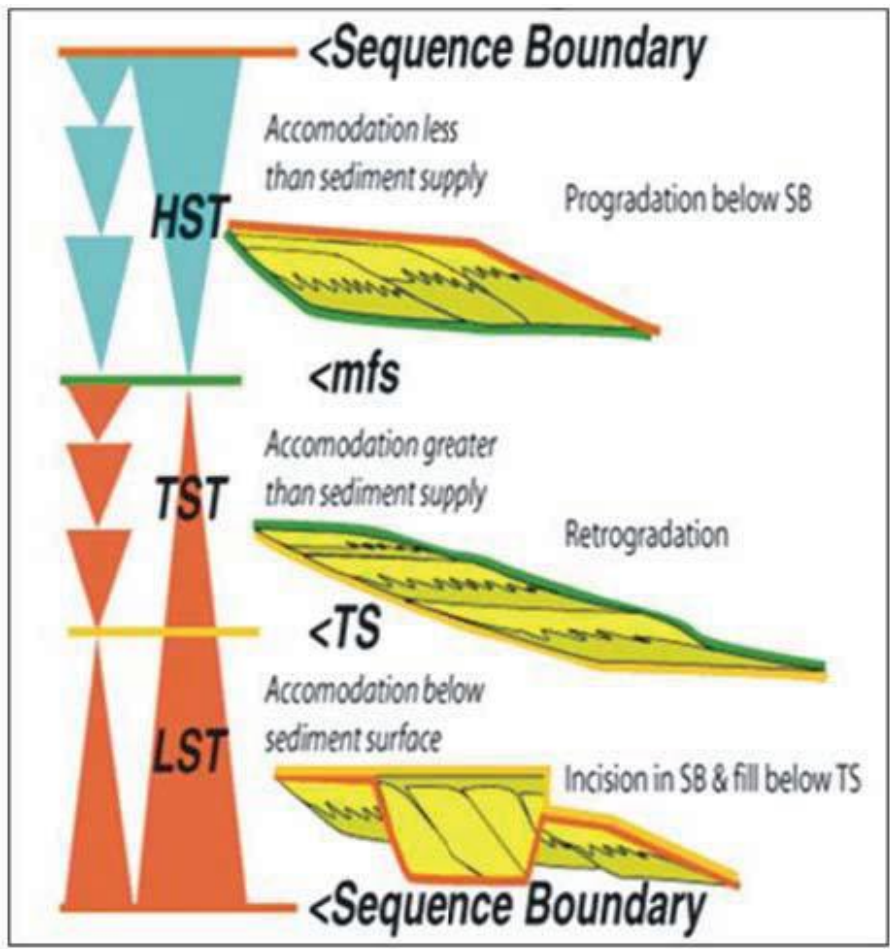


Fig.3.2. Sequence Stratigraphic Model for the Interpretation of Systems Tracts and Accompanying Key Stratigraphic Surfaces (after, Van Wagoner et al., 1990).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Lithologic Description

The description of the samples' lithology was established through a thorough physical examination of the ditch cuttings. The results of this lithologic description are conveniently presented in table 4.1 and 4.2, offering a clear and organized representation of the observed characteristics of the samples' geological composition.

Table 4.1: Lithologic Description of Samples from Meren 01 well

S/N	DEPTH (m)	LITHOLOGY	DESCRIPTION
1	2900-3200	SHALE	Shale (100%): As above. Sand (Traces): As above. Accessory Minerals: Rare glauconite and pyrite.
2	3200-3500	SHALE	Shale (100%): As above. Sand (Traces): As above. Accessory Minerals: Rare carbonaceous detritus and glauconite.
3	3500-3800	SHALE	Shale (100%): As above. Sand (Traces): As above. Accessory Minerals: Rare carbonaceous detritus and glauconite.
4	3800-4100	SHALE	Shale (100%): As above. Sand (Traces): As above. Accessory Minerals: Rare carbonaceous detritus and glauconite.
5	4100-4400	SHALE	Shale (100%): As above. Sand (Traces): As above. Accessory Minerals: Few glauconite, rare carbonaceous detritus.
6	4400-4700	SHALE	Shale (95%): Dark grey, predominantly flaggy to blocky, occasionally platy, predominantly moderately hard, occasionally hard. Sand (5%): Milky white, dominantly coarse to very coarse-grained, occasionally medium to fine-grained, moderately to poorly sorted, sub-rounded. Accessory Minerals: Rare pyrite, glauconite and ferruginous materials.
7	4700-5000	SANDY SHALE	Shale (55%): As above. Sand (45%): As above.

			Accessory Minerals: Rare glauconite, pyrite and ferruginous materials.
8	5000-5300	SANDY SHALE	Shale (60%): As above. Sand (40%): As above. Accessory Minerals: Rare glauconite, rare pyrite and rare ferruginous materials.
9	5300-5600	SANDY SHALE	Shale (60%): As above. Sand (40%): Milky white, predominantly coarse to very coarse-grained, occasionally medium to fine-grained, well sorted, sub-rounded to rounded. Accessory Minerals: Few ferruginous materials, rare shell fragments, rare pyrite.
10	5600-5900	SHALE	Shale (97%): As above. Sand (3%): Milky white to buff, very coarse to coarse-grained, slightly granular, well sorted, sub-rounded. Accessory Minerals: Rare shell fragments, rare pyrite, rare ferruginous materials.
11	5900-6200	SHALE	Shale (98%): As above. Sand (2%): As above. Accessory Minerals: Rare glauconite.
12	6200-6500	SHALE	Shale (97%): As above. Sand (3%): Milky white to buff, very coarse to fine-grained, poorly sorted, sub-angular to sub-round. Accessory Minerals: Few ferruginous materials, rare carbonaceous detritus.
13	6500-6800	SHALE	Shale (97%): Dark grey, predominantly flaggy to blocky, occasionally platy, moderately hard to hard. Sand (3%): Milky white, fine to medium-grained, occasionally coarse-grained, moderately sorted, dominantly sub-angular. Accessory Minerals: Rare ferruginous materials, rare carbonaceous detritus.

14	6800-7100	SANDY SHALE	<p>Shale (90%): As above.</p> <p>Sand (10%): As above</p> <p>Accessory Minerals: Rare carbonaceous detritus.</p>
15	7100-7400	SHALE	<p>Shale (95%): As above.</p> <p>Sand (5%): As above</p> <p>Accessory Minerals: Few carbonaceous detritus</p>
16	7400-8700	SHALE	<p>Shale (95%): As above.</p> <p>Sand (5%): As above</p> <p>Accessory Minerals: Rare carbonaceous detritus</p>
17	8700-9000	SHALE	<p>Shale (95%): As above.</p> <p>Sand (5%): As above.</p> <p>Accessory Minerals: Few carbonaceous detritus, rare pyrite, rare shell fragments, rare ferruginous materials, rare glauconite.</p>
18	9000-9300	SANDY SHALE	<p>Shale (90%): As above.</p> <p>Sand (10%): Milky white, predominantly fine-grained, occasionally medium to coarse-grained, well sorted, sub-angular.</p> <p>Accessory Minerals: Few carbonaceous detritus, rare glauconite.</p>
19	9300-9600	SHALE	<p>Shale (99%): Dark grey, predominantly platy to flaggy occasionally blocky, moderately hard.</p> <p>Sand (1%): As above.</p> <p>Accessory Minerals: Rare carbonaceous detritus, rare glauconite.</p>
20	9600-9900	SHALE	<p>Shale (95%): As above.</p> <p>Sand (5%): As above.</p> <p>Accessory Minerals: Few carbonaceous detritus, rare pyrite, rare glauconite, rare shell fragments.</p>
21	9900-10200	SHALE	<p>Shale (100%): As above.</p> <p>Sand (Traces): As above.</p> <p>Accessory Minerals: rare carbonaceous detritus.</p>

22	10200-10500	SHALE	<p>Shale (100%): As above.</p> <p>Sand (Traces): As above.</p>
23	10500-10800	SHALE	<p>Shale (98%): As above.</p> <p>Sand (2%): Milky white, predominantly coarse to very coarse-grained, occasionally medium to fine-grained, moderately sorted, dominantly sub-rounded.</p> <p>Accessory Minerals: rare carbonaceous detritus.</p>
24	10800-11100	SHALE	<p>Shale (100%): As above.</p> <p>Sand (Traces): As above.</p> <p>Accessory Minerals: Few carbonaceous detritus.</p>
25	11100-11400	SHALE	<p>Shale (98%): As above.</p> <p>Sand (2%): Milky white, dominantly fine-grained, occasionally medium to coarse-grained, moderately sorted, dominantly sub-angular.</p> <p>Accessory Minerals: Rare carbonaceous detritus.</p>

Table 4.2: Showing Lithologic Description of Samples from Meren 02 well

S/N	DEPTH (m)	LITHOLOGY	DESCRIPTION
1	2900-3200	SHALE	Shale (95%): As above. Sand (5%): As above. Accessory Minerals: Few glauconite, rare carbonaceous detritus.
2	3200-3500	SHALE	Shale (95%): As above. Sand (5%): As above. Accessory Minerals: Few Carbonaceous rare Glauconite.
3	3500-3800	SHALE	Shale (95%): As above. Sand (5%): As above. Accessory Minerals: Few carbonaceous detritus few glauconite.
4	3800-4100	SHALE	Shale (98%): As above. Sand (2%): As above. Accessory Minerals: Rare carbonaceous detritus, rare shell fragments.
5	4100-4400	SHALE	Shale (99%): As above. Sand (1%): As above.
6	4400-4700	SHALE	Shale (99%): As above. Sand (1%): As above.
7	4700-5000	SHALE	Shale (99%): As above. Sand (1%): As above. Accessory Minerals: Rare carbonaceous detritus.
8	5000-5300	SHALE	Shale (100%): As above. Sand (Traces): As above.
9	5300-5600	SHALE	Shale (100%): As above. Sand (Traces): As above.
10	5600-5900	SHALE	Shale (100%): As above. Sand (Traces): As above.

11	5900-6200	SHALE	<p>Shale (95%): Dark grey predominantly platy to flaggy, occasionally blocky, moderately hard.</p> <p>Sand (5%): Milky white, dominantly fine-grained. Occasionally medium to very coarse-grained, moderately to poorly sorted, subangular to sub-rounded.</p> <p>Accessory Minerals: Rare carbonaceous detritus.</p>
12	6200-6500	SHALE	<p>Shale (95%): As above.</p> <p>Sand (5%): buff, consolidated, fine-grained well Sorted, sub-angular.</p> <p>Accessory Minerals: Rare carbonaceous detritus.</p>
13	6500-6800	SHALE	<p>Shale (95%): As above.</p> <p>Sand (5%): As above.</p> <p>Accessory Minerals: Rare carbonaceous detritus.</p>
14	6800-7100	SHALE	<p>Shale (100%): As above.</p> <p>Sand (Traces).</p> <p>Accessory Minerals: Rare carbonaceous detritus.</p>
15	7100-7400	SHALE	<p>Shale (100%): As above.</p> <p>Sand (Traces).</p>
16	7400-8700	SHALE	<p>Shale (98%): As above.</p> <p>Sand (2%): Milky white, dominantly to very coarse-grained, occasionally medium to fine-grained, moderately sorted, sub-rounded.</p>
17	8700-9000	SHALE	<p>Shale (100%): Dark grey, predominantly platy to flaggy, occasionally blocky, moderately hard.</p> <p>Sand (Traces): Fine-grained.</p> <p>Accessory Minerals: Rare glauconite.</p>

18	9000-9300	SHALE	<p>Shale (97%): As above.</p> <p>Sand (3%): Milky white, predominantly fine-grained, occasionally medium to very coarse-grained, well sorted, dominantly sub-angular.</p> <p>Accessory Minerals: Rare carbonaceous detritus and pyrite.</p>
19	9300-9600	SHALE	<p>Shale (98%): As above.</p> <p>Sand (2%): As above.</p>
20	9600-9900	SHALE	<p>Shale (99%): As above.</p> <p>Sand (1%): As above. Accessory Mineral: Rare glauconite.</p>

4.1.2 Biostratigraphy of wells

In the analysis conducted on Meren 01 and 02 wells, a total of one hundred and sixty four (164) samples were examined for microfossils. Additionally, the samples were subjected to detailed description based on their respective lithology. This comprehensive approach to analysis provides a robust understanding of the microfossil content and the lithological characteristics of the samples obtained from the wells.

4.1.2.1 Calcareous Nannofossil Biostratigraphy

The result of the Calcareous nannofossil analysis of ditch cutting samples between 2892 – 11405ft of the Meren 01 and 02 well are presented below.

The samples analyzed, yielded very rich and diverse calcareous nannofossil assemblages especially at stratigraphic intervals 7000-8000 ft and 9000-10000ft in well 1 and 2 respectively. These intervals represent major marine flooding events and have been dated based on calcareous nannofossil marker species. The remaining intervals were virtually barren.

Important age diagnostic nanofossils recorded include *Catinaster coalitus*, *Catinaster mexicanus*, *Sphenolithus abies*, *Discoaster berggrenii*, *Discoaster quinquerramus*, *Amaurolithus primus* and *Discoaster bollii*.

4.1.2.2 Foraminiferal Biostratigraphy of Meren 01 and 02 Wells

Fifty nine (59) ditch cutting samples were processed and analysed for foraminifera and accessory microfauna contents. The samples yielded highly abundant and diverse foraminiferal species. A total of one hundred and sixty-four (164) foraminiferal species were recovered. Forty-three species (26%) are planktics, eighty-five (52%) are calcareous benthics while the remaining thirty-six species (22%) are arenaceous/agglutinating species. Accessory microfauna present are shell fragments, echinoid remains, ostrapods, sponges, pelecypods and scaphopods.

The following bioevents are significant in the studied interval

- i. First and Last Downhole Occurrences (FDO and LDO) of chronostratigraphically important planktic foraminiferal species.
- ii. First and Last Downhole Occurrences (FDO and LDO) of significant benthic foraminiferal species whose ranges are known and have been correlated with diagnostic planktic foraminiferal species in the Niger Delta.
- iii. The acme abundance zone

The zones recognized are discussed below and are based on standard planktic foraminiferal zones of Blow (1969, 1979) and Bolli and Saunders (1988). These zones are discussed below:

Stratigraphic Interval : 2892-4000ft., late Miocene (N18)

Top of N18 zone probably lies shallower than the top of the analysed section

Last Downhole Occurrence (LDO) of *Globorotalia margaritae prnitiva* is used to define the base of N18 zone. High abundance and diversity of planktics characterize this zone.

Planktics present include *Globigerinoides extremus*, *Globorotalia scitula*, *Globorotalia pseudomiocenica* and *Neogloboquadrina dutertrei dutertrei*.

Stratigraphic Interval : 4000 – 5000ft., late Miocene (N17)

The Last Downhole Occurrence (LDO) of *Globorotalia margaritae primitiva* at 4400ft defines top of the N17 zone. Base of the zone is approximately at 4950ft, the LDO of interval *Globorotalia merotumida*. The LDOs of N17 marker species, *Globorotalia pseudomiocenica*, *Sphaeridinellopsis seminulina* and *Globorotalia pseudopima* support the zonal assignment to the interval.

Stratigraphic Interval : 5000 – 7000 ft., late Miocene (N16)

Top of the N16 zone is approximated at 5360ft., the LDO of *Globorotalia merotumida*. The Last Downhole Occurrence (LDO) of *Globorotalia acostaensis* at 6020ft defines zonal base. The zone is characterised by paucity of planktics. Few planktics present include *Globigerinoides trilobus*, *Globigerina quinqueloba* and species of *Globigerina*.

Stratigraphic Interval : 7000 – 10,200ft., middle – late Miocene (N15)

The LDO of *Globorotalia acostaensis* at 8020 is used to define the zonal top. The zonal base is placed at 9190ft, the FDO of *Globorotalia mayeri*. Low abundance and diversity of planktics characterize this interval. *Globorotalia obesa* is a middle Miocene form recorded within the interval.

Stratigraphic Interval : 10980 – 11250ft., middle Miocene (N14)

The interval was only penetrated by Meren Well 01. Zonal top is defined by the FDO of *Globorotalia mayeri* at 10180ft. The zonal base is placed at TD, last sample studied. Fair to low abundance and diversity of planktics characterize this interval. Planktics recorded include *Globorotalia obesa*, *Globigerina praebulloides*, *Globigerinoides trilobus* and *Orbulina universa*.

4.1.2.2 Palynostratigraphy of Meren 01 and 02 Wells

Seventy-four (74) composite samples were processed and logged to provide data for palynostratigraphic interpretations. Study section penetrated by Meren 01 and 02 wells

revealed fairly diverse, abundant and well preserved miospore suites. *Zonocostites ramonae*, *Corypollis avelana*, *Monoporites annulatus*, species of *Sapotaceaeoidapollenites*. *Laevigatosporites* and *Verrucosporites* dominate the microfloral assemblage of the analysed interval. Marine microplankton remains and accessories were rare within the studied section. The stratigraphic distributions and relative abundance of age diagnostic miospores enabled the identification of two (2) major P800 and P700 zones together with seven (7) associated P860, combined P840 – P850, P830, P820, P780 and P770 subzones of Evamy *et al.*, (1978). The zones represent the age equivalent of the middle part of the broad *Echitricolporites spinosus* Pan-tropical zone of Germeraad *et al.*, (1968). It also correlates with the J2, H – J1, G and F zones of Legoux (1978) in floral content and age. The studied section is assigned middle to late Miocene age.

The defined zones/subzones are described as follows:

Stratigraphic Interval : 2892-4000ft., late Miocene (P860 subzones)

Quantitative base occurrence of *Nymphaepollis clarus* at 3810ft defines the subzonal lower boundary. The interval is characterized by high abundance of *Zonocostites ramonae*; moderately rich recovery of *Monoporites annulatus*, *Retibrevitricolporites protrudens*, species of *Sapotaceaeoidapollenites*, *Laevigatosporites* and *Verrucosporites*. Rare occurrence of *Retistephanocolites gracilis* is also diagnostic.

Stratigraphic Interval : 4000 – 5000ft., late Miocene (P840 – P850 subzones)

Subzonal top is defined by quantitative base occurrence of *Nymphaepollis clarus* at 4160ft. Subzonal base is marked by quantitative base occurrence of *Cyperaceapollis* spp. at 4780ft. *Zonocostites ramonae*, species of *Sapotaceaeoidapollenites*, *Laevigatosporites* and *Verrucosporites* dominate the microfloral assemblage within this interval. • Moderately rich recoveries of *Monoporites annulatus* and *Retibrevitricolporites protrudens*; common species of *Stereisporites* and *Cyperaceapollis* are other characteristic features of this interval.

Stratigraphic Interval : 5000 – 7000 ft., late Miocene (P830 subzone)

Subzonal top is defined by quantitative base occurrence of *Cyperaceapollis* spp at 5100ft. The lower subzonal boundary is marked by quantitative base occurrence of *Stereisporites* spp at 6910ft. Base abundance of *Monoporites annulatus*, appreciable recovery of *Corypollis avelana*, *Sapotaceaeoidapollenites*, *Laevigatosporites* and *Verrucatosporites* are other observable features of this subzone.

Stratigraphic Interval : 7000 – 10,200ft., middle – late Miocene (P820)

Subzonal top is defined by quantitative base occurrence of *Stereisporites* spp at 7210ft. Quantitative top occurrence of *Racemonocolpites hians* at 9540ft. marks the subzonal lower boundary. High abundance of *Zonocostites ramonae* with rare to common recoveries of *Psilatricolporites crassus*, *Monoporites annulatus* and *Stereisporites* spp characterize this interval.

Stratigraphic Interval : 10980 – 11250ft., middle Miocene (P780)

Top of P780 subzone is marked by quantitative top occurrence of *Racemonocolpites hians* at 10,998ft. Top rich recovery of *Verrutricolporites rotundiporus* at 11150ft. defines the lower boundary of the subzone. *Zonocostites ramonae* exhibits moderately rich recovery with percentage count not as high as in the overlying P800 subzones. Fairly rich to common recoveries of *Psilatricolporites crassus*, *Verrutricolporites rotundiporus*, *Racemonocolpites hians* and *Crassoretitriletes vanraadshoveni* are other characteristic features of this interval.

4.2 Discussion

4.2.1 Sequence Stratigraphy of Meren 01 and 02 Wells

Figure 4.1 shows MEREN-01 and 02 well with calibration of key sequence stratigraphic surfaces and third-order sequence stratigraphic systems tract for the Meren Field. A total of four (4) depositional sequences bounded on the top and base by sequence boundaries were

identified and correlated in Meren 01 and 02 wells. Sequence-1 is the oldest depositional unit, while Sequence-4 is the youngest depositional unit. The sand content in each of the depositional sequences decreased with depth, while the shale content increased. This indicates the depositional influence of sea-level fluctuation as one moves deeper into the ocean basin. The increasing sand content from Sequence-1 to Sequence-4 replicates the coarsening upward sequences in the Niger Delta Basin

Depositional Sequence 1

The sequence occur at 7000 - 8000 ft in Meren01 well and at 9200 – 10,000 ft. in Meren 02 well. It consists of Transgressive Systems Tract (TST) just after the previous Sequence boundary atop the Low Systems Tract (LST). It is characyerised by increasing-upward foraminiferal and nannofossil abundances/diversities. Fining-upward profile. Terminating in a condensed section corresponding to the Maximum Flooding Surface (MFS 5.80Ma) at 4230ft and 4280ft in wells 01 and 02 respectively. The Highstand Systems Tract above the TST is made up of shale prograding to argillaceous siltstone at 7200ft. The HST is terminated at the top by a sequence boundary (SB: 5.50Ma) at 7150 ft. In Meren-02 well, the entire HST was probably eroded off during the sea level fall. At this point there was abrupt change in lithology from shale to coarse sand with rare or no microfossil. This obvious change in lithology indicated an erosional truncation that defined the aforementioned sequence boundary as boundaries of lithostratigraphic units are placed at positions of lithologic change (Stains, 1985). They are usually designated at sharp lithologic contacts, but also may be placed arbitrarily within zones of lithologic gradation. They should be drawn to express most usefully lithostratigraphic development. Boundaries of lithostratigraphic units commonly cut across time horizons, across the limits of fossil ranges and across the' boundaries of any other kind of stratigraphic unit. The HST is deposited during and shortly after the peak of relative regression cycle, and is usually the youngest and uppermost system

tract of a sequence. The sediments accumulate during a time of decelerating rate of relative sea level rise, enabling the rate of sediment supply to exceed the rate of accommodation. The microfossils that make up this sequence include calcareous benthics (*Bolivina sp.*, *Bolivina miocenica* *Epistominella vitrea*). The agglutinating foraminifera include *Textularia panamensis*, *Eggerella sp.*, *Valvulina flexis*, *Ammobaculites stratheamensis* and few shell fragments.

Depositional Sequence 11

The sequence occur at 5850 - 7000 ft in Meren01 well and at 5920 – 9,000 ft. in Meren 02 well. It is bounded at the base by SB-5.50 Ma and capped at the top by SB-3.80Ma (Fig 4.3), indicating that the depositional cycle was completed in 1.7 Myr. The LST deposits that begin the sequence contain channel sands capped by a shale layer which was the first occurrence of more distal facies. As accommodation space was created, and base level increased it was not met with sufficient sediment influx, causing the TST to be mud rich, with minor amounts of heteroliths and sandstones that appear to be deposited within a lower shoreface environment. It thinned into a condensed section (MFS: 5.00Ma) indicated by abundance peak of First Down Hole occurrence (FDO) of *Globorotalia continuosa* and *Globorotalia Mayeri* at 5820 ft and 6510ft respectively for wells 01 and 02. The condensed section was identified as shale prone, organic rich interval with elevated gamma – ray counts (Fig 4.2).

The MFS constitute diversity of microfossils. The calcareous benthics observed at this depth include calcareous indet, *Epstomella vitrea*, *Hanzawaia Strattoni*, *Lenticulina inonata*, *Noniella auris*, *Quinquiloculina sp.*, *Bolivina miocenica*, *Uvigerina Sp.*, *Heterolepa detonensis* *Brizalina beyrichi*, *Bullimina apiculate*, *Praeglobobulimina ovata*,.The agllunatingforams here include *Kerreriella siphonella*, *Textularia panamensis*, *Valvulina flexis*, *Ammobalites sp*, *Ammobaculites stratheamensis*, *Eggrella scrabba* and shell fragments. The overlying HST is made up of aggradational stacking

pattern of units of shale and siltstone. A Sequence Boundary capped the HST where the shaly siltstone changed from aggradational to retrogradational stacking pattern. The HST also contains few microfossils like planktic in det, *Globorotalia bulloides* and some few calcareous benthics.

Sequence III

The sequence occur at 4400 - 5000 ft in. is bounded at the top and base by SBs 3.00 Ma and 3.80 Ma respectively. All deposits within this sequence were emplaced in a period of about 0.8Myr. The LST channel sand is also thicker also points to a high sediment flux of continental sands following the fall in sea level, possibly via incised valleys. The overlying TST is made up of shale interbedded with thinly bedded siltstone, and coarse sand. The sand units are aggradational with fining upward stacking pattern towards the Maximum Flooding Surface (MFS: 3.40Ma) at 4560 ft and 4890ft depths in 0Meren01 and 02 wells where there happens to be diversity of microfossils including planktic forams (*Globigerina sp.*, *Globigerina bulloides*, *Globorotalia continuosa*), calcareous benthics (*Ammonia baccari*, *Amphistegena lesson*, *Bolivina sp.*, *Epistomella vitrea*, *Flrilus atlaticus*, *Hanzawaia strattoni*, *Heterlepa detonensis*, *Heterilepa pseudoungerina*, *Lenticulina inornata*, *Noniella auris*, *Quinquiloculina seminulum*, *Heterolepa crebbisi*, *Amphicoryna sp*, *Maginulina sp.*, *Cibicides sp.*, *Pseudoglandilunila sp*, *Quinquiloculina lata*, *Uvigerina superigena*) and shell fragments. The HST is made up of shale interbedded with silty sand. At the top of the HST is the Sequence Boundary. The wireline signature (Fig 4.3) at this depth (4300 ft and 4700ft) signifies an erosional truncation that defined the SB. Very few microfossils were observed at this depth.

Sequence 1V

This is the youngest depositional sequence and it is defined by SBs 3.0 Ma and 2.6 Ma, respectively. The depositional cycle lasted for 0.4 Myr, beginning with the deposition of a channel sand within the LST when the sea level was at its lowest. This sand overlies the shoreface sediments of the underlying HST. As the sea level increased, there was creation of accommodation space accompanied by a high influx of sediments, prompting the deposition of a set of tidally influenced channel sands with individual fining upward profiles and an overall aggradational succession (Fig. 4.5). These represent the main deposits within the TST. The MFS was identified at 4230ft, which marked the beginning of the fall in sea level characterized by maximum diversity of microfossils were observed including planktics (*Globigerina sp.*, *Globigerina bulloides*, *Globigerina venezuelena*, *Globigerina bulloideus*, *Globorotali sp.*), planktic indets and benthics (*Bulliminella sp.*, *Ammonia baccarii*, *Amphistegina lessonii*, *Bolivina sp.*, *Epistominala vitrea*, *Florilus atlanticus*, *Hanzawaia strattoni*, *Heterlepa detonensis*, *Heterilepa pseudoungerina*, *Lenticulina inornata*, *Noniella auris*, *Quinquiloculina seminulum*, *Quinquiloculina sp.*, *Bolivina miocenica*, *Uvigerina sp.*, *Planularia animinensis*, *Pseudonodosaria sp.*, *Valvulinaria bradyana*, *Florilus ex gr.costiferum*), very few agglutinating forams (*Textularia sp.*, *Textularia panamensis*) and shell fragments.. The HST in this sequence is thicker, with a higher sand-to-shale ratio than the preceding sequence III, which implies much more influx of continental sands with time and minor marine input. The highstand paleoenvironments of deposition are mainly distributary channels and delta front with minor shelf deposits.

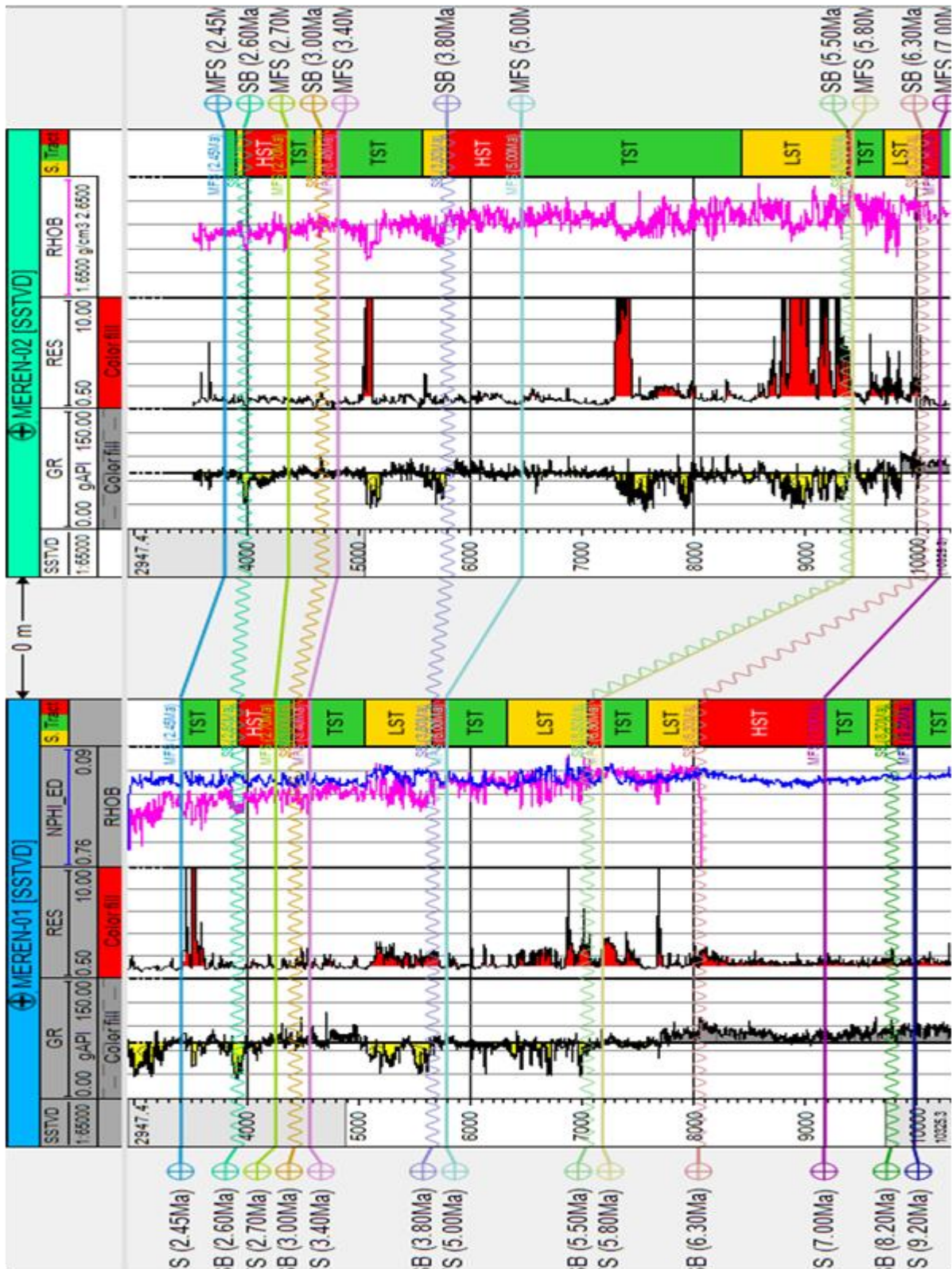


Fig 4.1a. Log correlation panel with the systems tract in Meren 01 and 02 wells

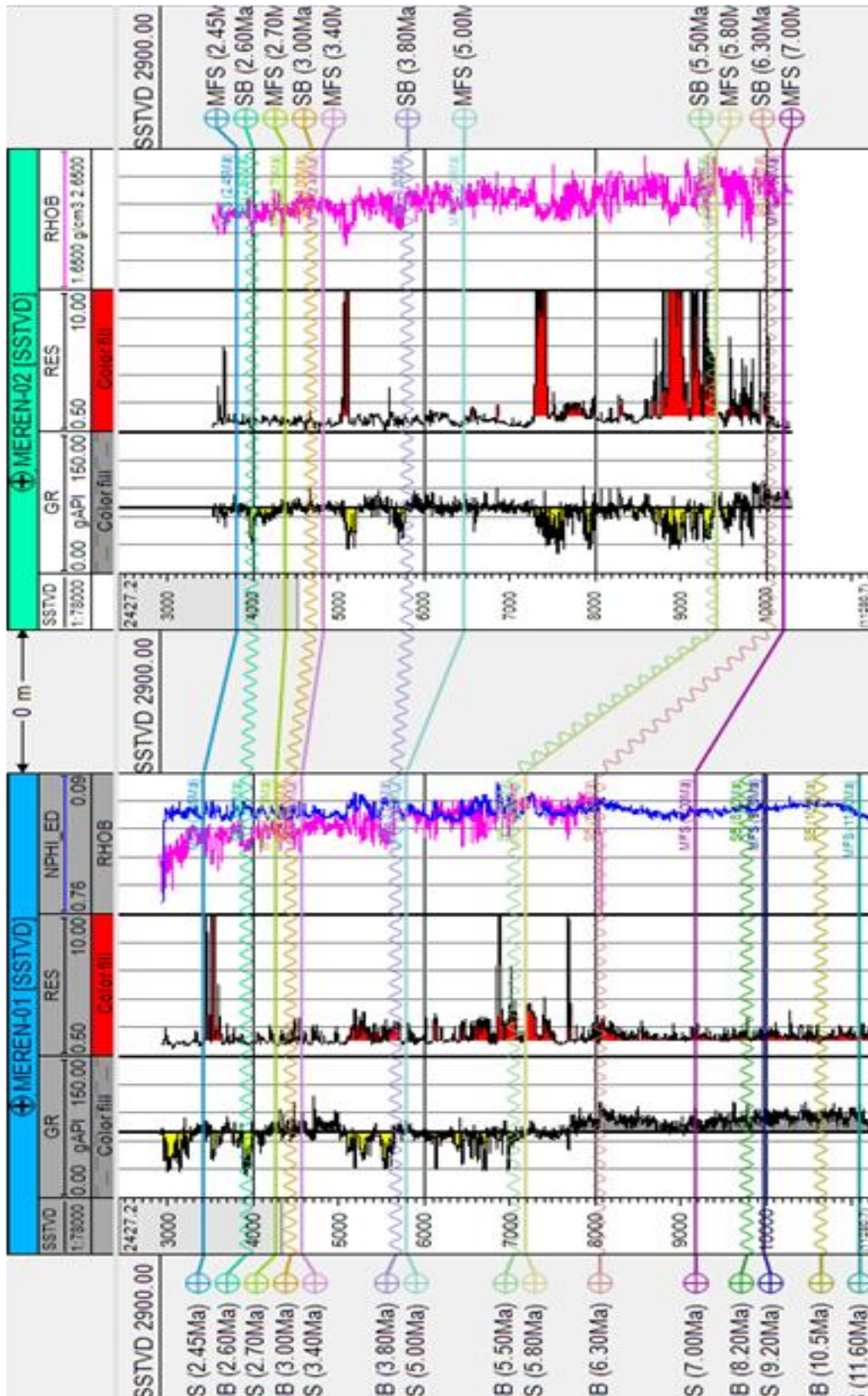


Fig 4.1b. Chronostratigraphic correlation of Meren 01 and 02 wells

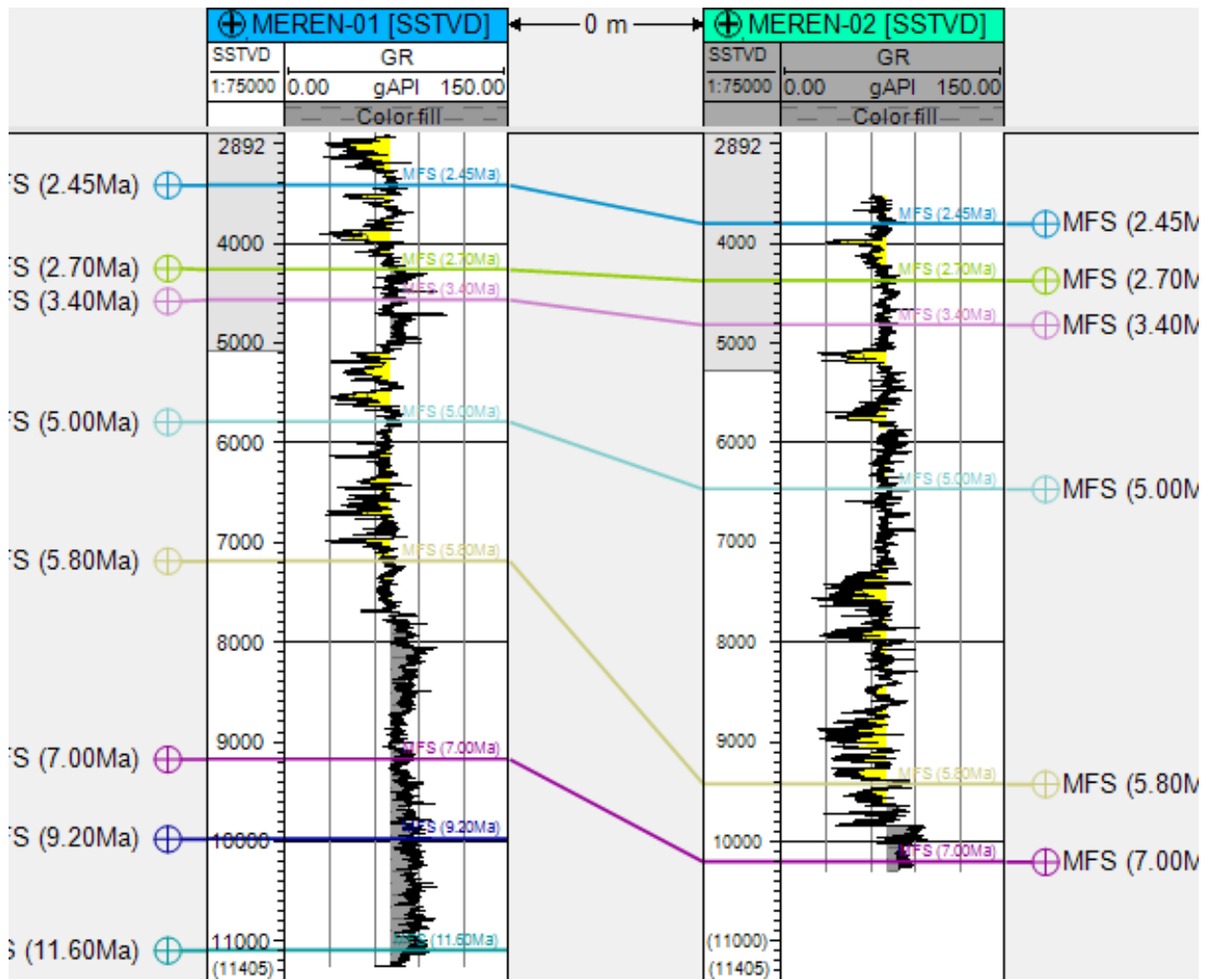


Fig 4.2 Log correlation panel for the maximum flooding surfaces (MFS) across the two wells.

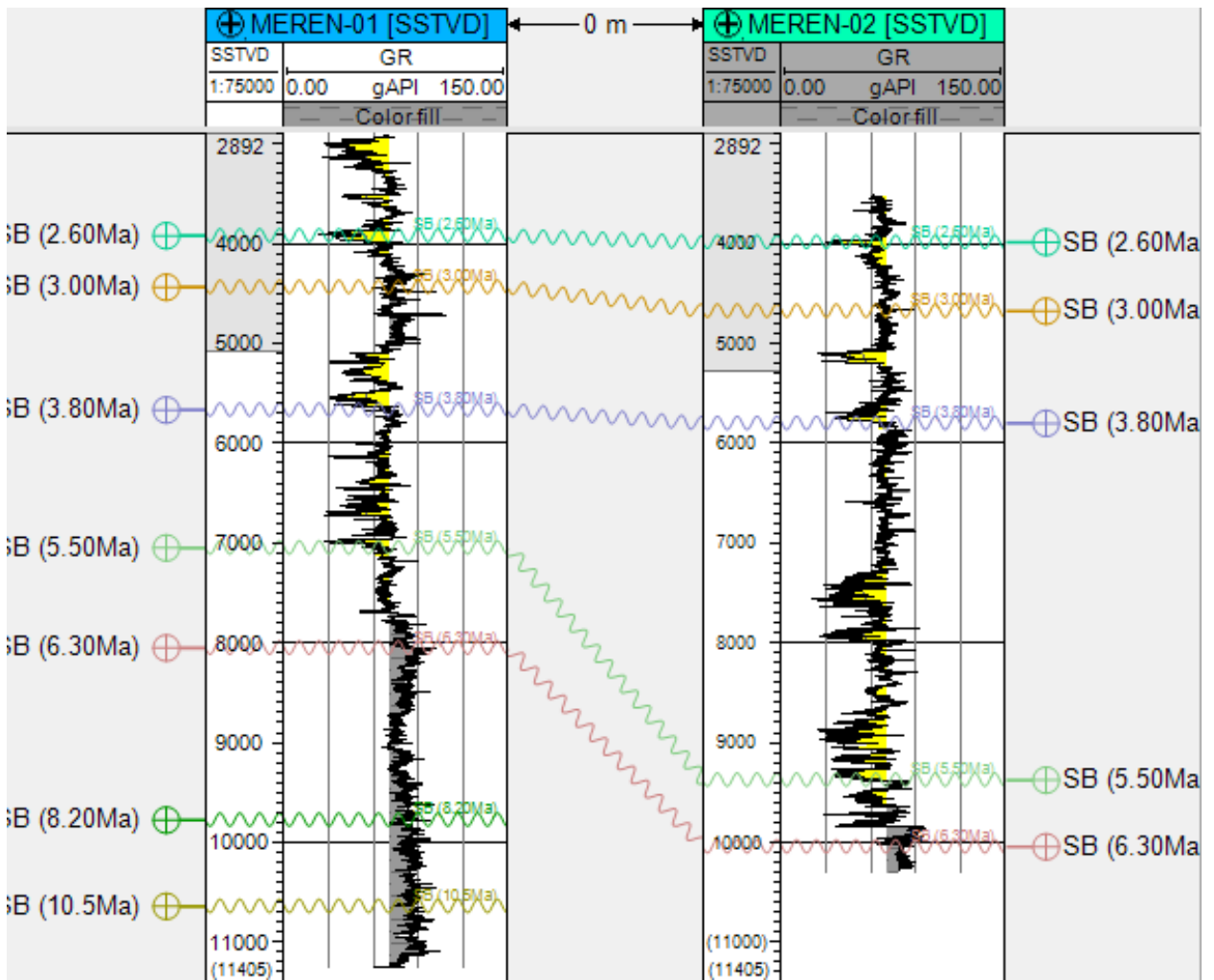


Fig 4.3. Log correlation panel for the sequence boundaries (SB).

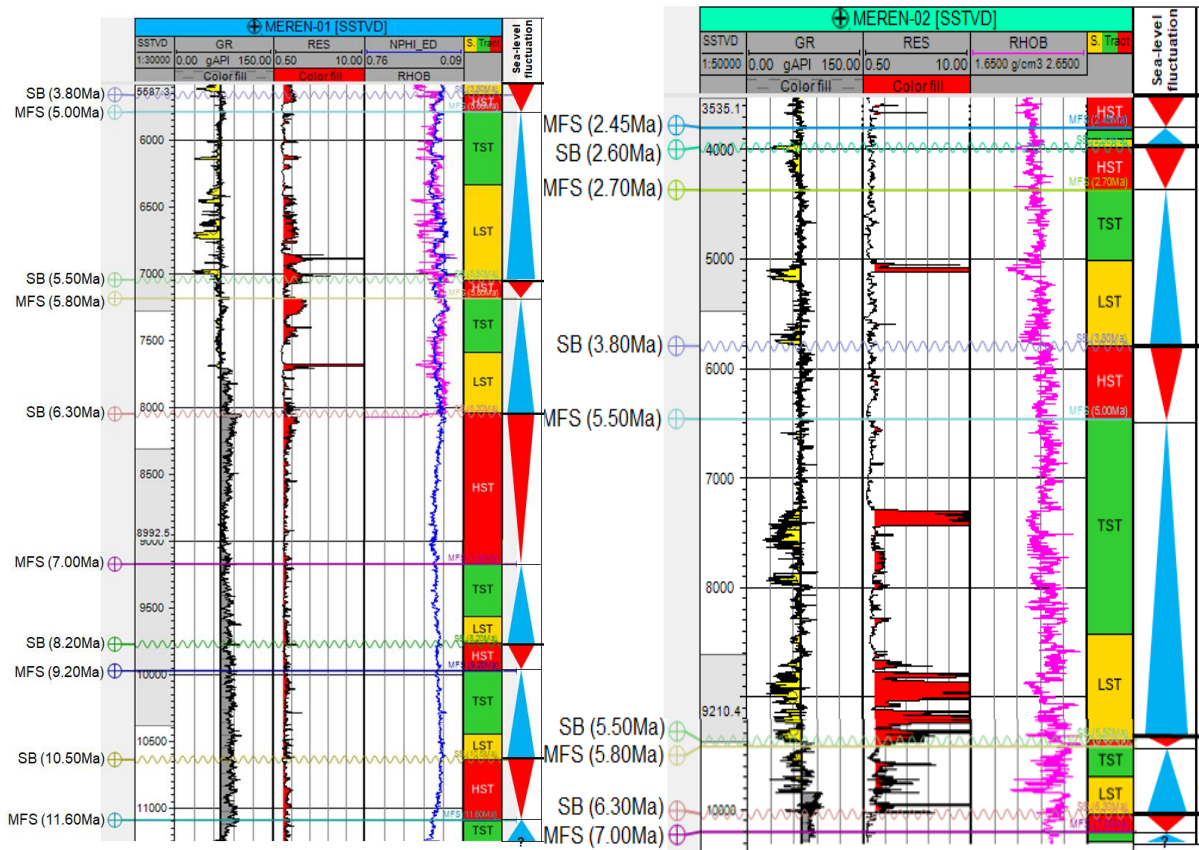


Fig 4.4. Log correlation panel with the system tracts in each of the wells

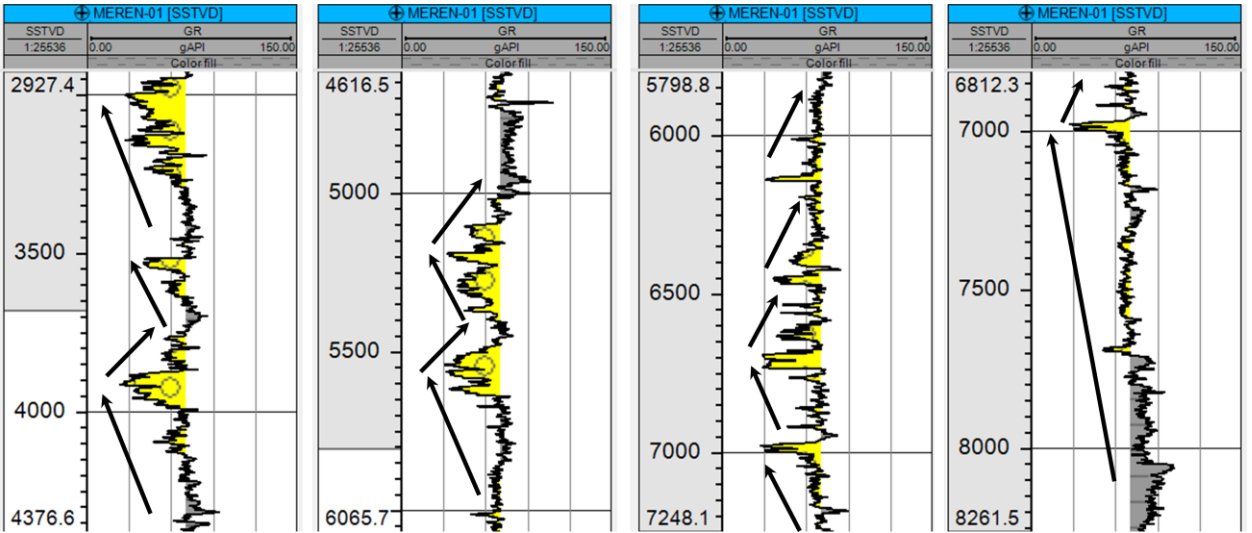


Fig 4.5a Stacking patterns of Meren 01 well parasequences on the GR log

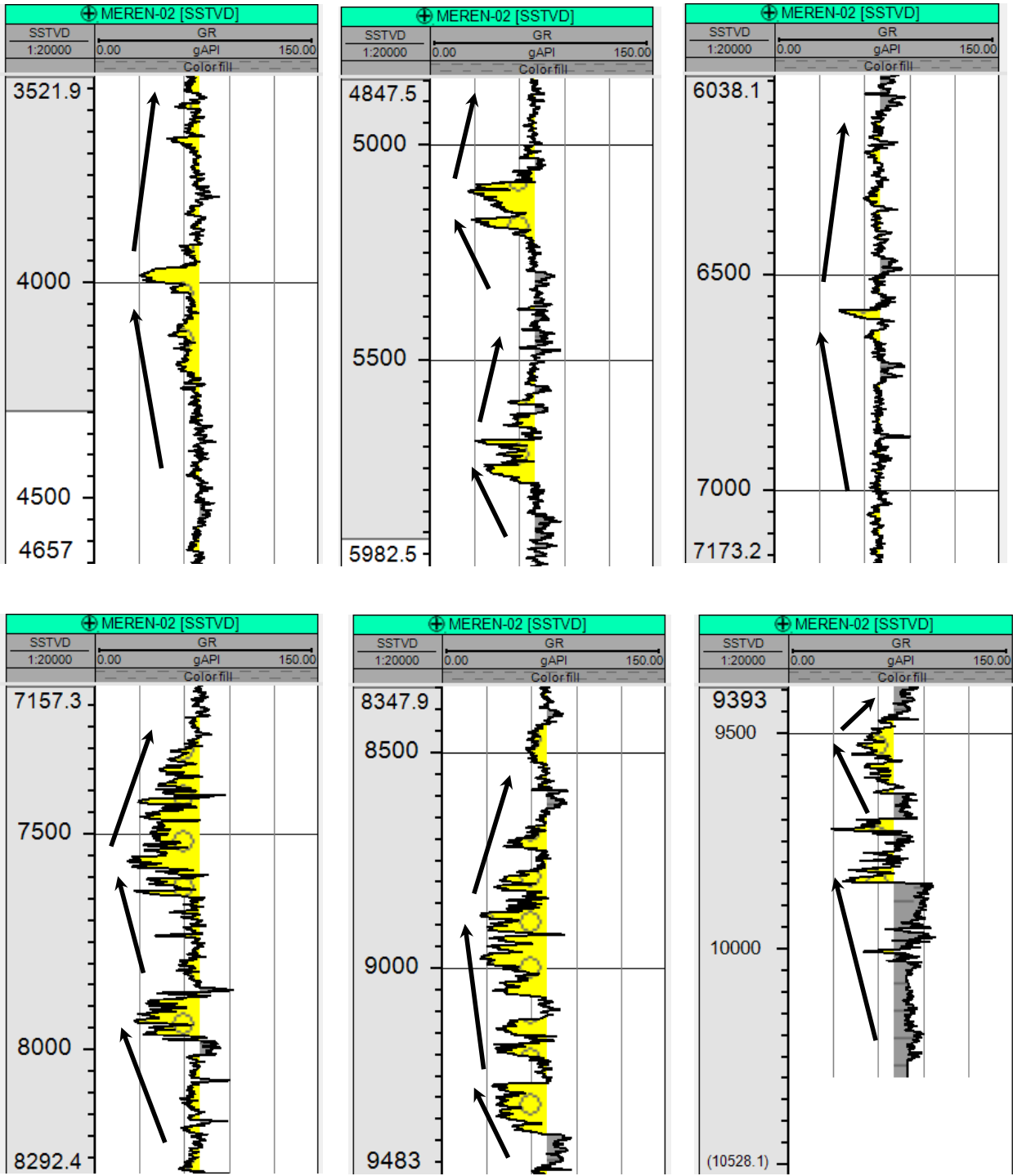


Fig 4.5b Stacking patterns of Meren 02 well parasequences on the GR log

4.2.2 Depositional Environments

The environments over which sediments of Meren-01 and 02 were deposited have been investigated through the integration of sedimentological, palynological and micropaleontological characteristics of these sediments.

Sedimentological deductions based on logs motifs, textural and lithological characteristics permitted the assignment of the entire studied section (2892 – 11405ft) of Meren 01 and 02 wells to the Agbada Formation.

Palynological deductions of the prevailing depositional environment were based on the relative percentage abundance of the flora assemblage with emphasis on the occurrences of both marine and freshwater species. Paleobathymetric interpretations were guided by micropaleontological criteria such as: species diversity and abundance, planktic/benthic ratio and environmentally diagnostic benthic species (Adegoke, Fayose & Akande., 2012; Van Morkhoven, 1986; Murray, 1991). In addition, the type and nature of the accessory microfauna recorded within the intervals were also used in interpretations.

The field's stratigraphy is predominantly characterized by an assortment of clastic deposits in varying depositional environments within different bathymetric zones. As eustacy, sediment supply and accommodation space changed through the Early to Middle Miocene, these factors influenced the depositional styles and thus facies architecture of the packages within the field.

There is a noticeable overall progradation of the facies, which is apparent from the increase in the ratio of sand to shale through geologic time (Fig. 4.6). The shoaling-upward profile shows an increasingly dominant fluvial supply responsible for the building out of the Delta. Two distinct episodes of high sediment influx coupled with low accommodation space produced thick sand packages associated with sea-level falls at 5.50Ma, 3.8Ma, 3.0Ma and 2.6Ma

which were likely incised valley fills (Anyiam, Eradiri, Mode, Okeugo, Okwara, & Ibemesi, 2019; Reijers, 2011).

Tidal and wave influence on sedimentation styles is also apparent across the field, it is established by the occurrence of tidally influenced sandstones and shoreface deposits which formed as delta front sediments were reworked by longshore drift currents (Fig. 4.7).

These processes caused the reservoirs to be mainly found as fluvial and tidal channel sands, and shoreface packages, an observation which is common within the Agbada Formation of the Niger Delta and supports the works of Osinowo, Ayorinde, Nwankwo, Ekeng, & Taiwo (2018); Akaerue, Nnakuba, Urang, Ebong, Eradiri, & Ubgaja , (2022).

Based on bathymetric profiles, the shales within the study area are open marine, shelf and floodplain fines, while the mud and silt were deposited within a swamp in a delta plain setting during a period of marine transgression (Fig. 4.7). Sand sequences are most likely due to lobe switching of the river channel and deposition of interdistributary bay facies. (Evamy, Haremboure , Kamerling , Knaap, Molloy, Rowlands, 1978).

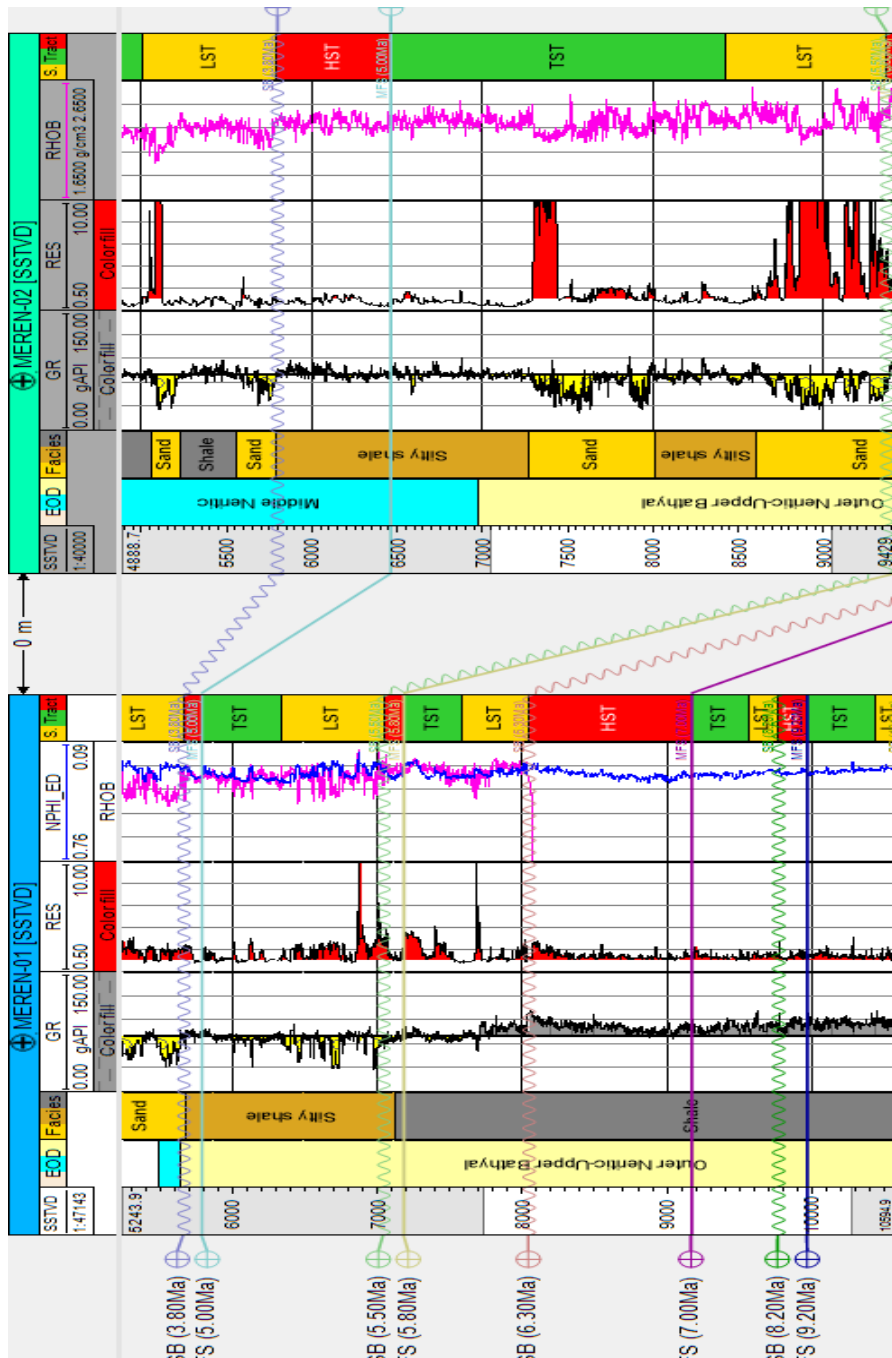
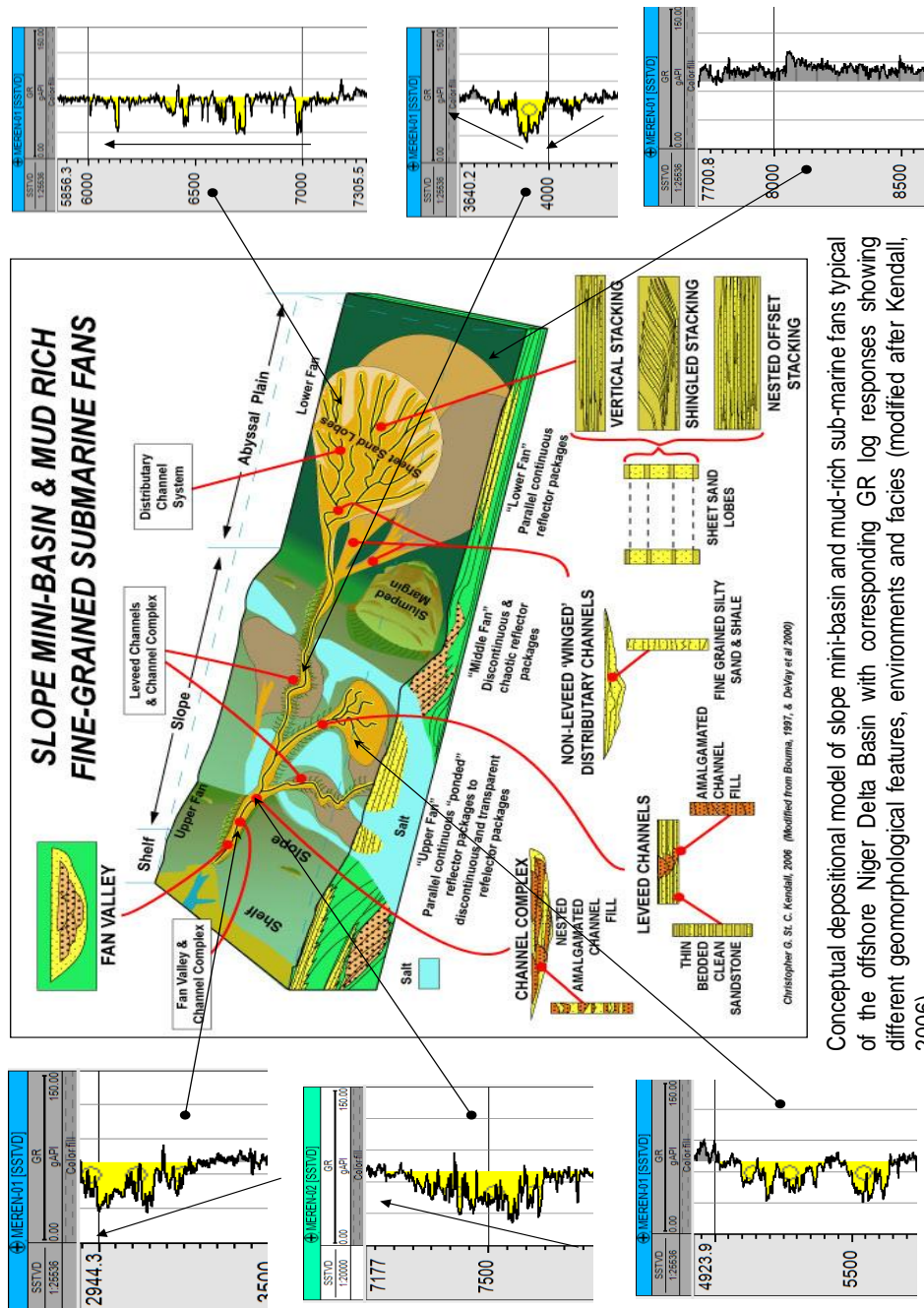


Fig 4.6 Meren 01 and 02 Wells with calibration of EOD, Facies, systems tract, and key stratal surfaces.



Conceptual depositional model of slope mini-basin and mud-rich sub-marine fans typical of the offshore Niger Delta Basin with corresponding GR log responses showing different geomorphological features, environments and facies (modified after Kendall, 2006).

Fig 4.7. Conceptual depositional model of slope mini-basin and mud-rich sub-marine fans typical of the offshore Niger Delta Basin with corresponding GR log responses showing different geomorphological features, environments and facies (modified after Kendall, 2006).

4.2.3. Facies architecture and reservoir behaviour

All the studied reservoirs are sand-rich; however, minor associated shale units and coaly facies are also present in them, making up non-reservoir facies. Generally, coastal deltaic and shallow inner-neritic sandstones tend to have good reservoir quality. However, the heterogeneities of these sandstones can hamper producibility (Shepherd, 2009). The proportion of reservoir to non-reservoir facies is high within the delineated packages, with sand and shaly sand composition at about 86%, 96% and 85% for reservoirs R4000, R6000 and R8000 respectively (Fig. 4.8).

Regarding the delineated reservoirs, they were deposited during a lowstand (R6000 and R8000) and in a subsequent rise (R4000), accompanied by a relatively higher (compared to previous transgressive cycles) sediment flux into the basin. This gave rise to shoreface sands capped by fluvial channel deposits influenced occasionally by tides.

Given their rich sand development, the quality of these reservoirs is generally good and they all possess excellent net-to-gross. Additionally, their facies distribution shows that non-reservoir units (shale and silt facies) are in minor amounts (Fig. 4.8).

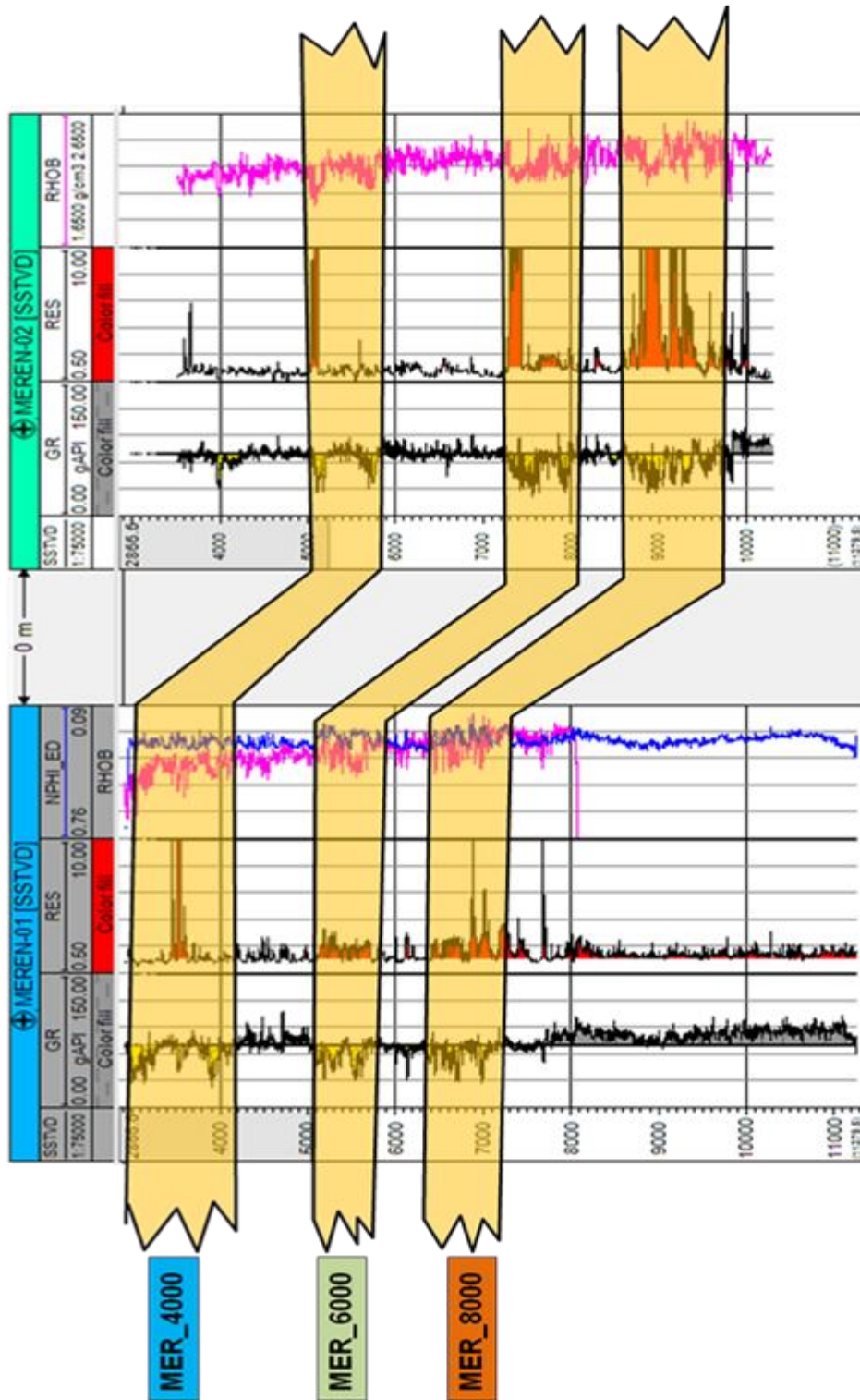


Fig 4.8. Log panel showing lithological correlation of the reservoir sand units

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

GR log pattern and biostratigraphic data were employed in the reconstruction of sequence stratigraphic framework for Meren 01 and 02 Wells. The GR log pattern and microfossil abundance and diversity were used to delineate the sequences to different kinds of system tracts. Four depositional sequences were identified comprising of five Sequence Boundaries (SB) dated at 6.30Ma, 5.5 Ma, 3.8 Ma, 3.0 Ma and 2.6 Ma, six Maximum Flooding Surfaces (MFS) dated at 7.00 Ma, 5.80 Ma, 5.00Ma, 3.40 Ma, 2.70 Ma and 2.45 Ma of Middle – Late Miocene age were recognized when significant foraminiferal signatures obtained were integrated with that of palynology. The key stratigraphic surfaces which were identified using index microfossils and higher GR count can be used for basin wide correlation. From the correlation chart, the Maximum Flooding Surfaces are associated with diversity of microfossils and high concentration of radioactive minerals that gave rise to high GR reading at this surface unlike the Sequence Boundary where fewer or no microfossils were identified with low GR readings. The dated stratigraphic surfaces corroborated with established shifts landward and basin ward according to the scheme of Haq *et al.*, 1988, indicating that the main factor which controlled sequence development in the well field was eustacy. The dated surface (MFSs and SBs) also corroborated established dating scheme. Giving the available data from biostratigraphy and GR log, the environment of deposition was inferred to trend from coastal deltaic to marine. The environments over which sediments of Meren-01 and 02 were deposited have been investigated through the integration of sedimentological, palynological and micropaleontological characteristics of these sediments. Based on bathymetric

profiles, the shales within the study area are open marine, shelf and floodplain fines, while the sand sequences are most likely due to lobe switching of the river channel and deposition of interdistributary bay.

Three reservoirs rR4000, R6000 and R8000 were also identified and correlated across the wells. Given their rich sand development, the quality of these reservoirs is generally good and they all possess excellent net-to-gross. Additionally, their facies distribution shows that non reservoir units (shale and silt facies) are in minor amounts

5.2 Recommendations

1. Meren –01 and 02 wells should be correlated with other wells in the Meren Field of the offshore Niger Delta to fine tune further most aspects of the study.
2. More work should be carried out on the samples to ascertain its hydrocarbon generating potential.

5.3 Contributions to knowledge

1. This study has utilized microfossils to identify key stratigraphic surfaces (Maximum Flooding Surfaces and Sequence Boundaries) which can be used for basin wide correlation where play elements can be identified.
2. The lithostratigraphic section drilled in the well was systematically dated using fossils which corroborated established dating scheme.

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APPENDICES

Appendix 1

Analyses sheet 1: Shows the taxon name and count of palynomorphs retrieved from each depth of the well.		
Depth (ft)	Taxon name	Count
2840	Fungal spore	2
	Psilatricolporites sp	4
	Psilatricolpites spp.	1
	Verrucatosporites tenellis	62
	Pachydermites diderixi	70
	Psilatricolporites crassus	7
	Aletesporites sp.	3
	Botryococcus braunii	4
	Brevitricolporites guinetii	2
	Cranwellipollis sp	1
	Crassoretitriletes vanraadshooveni	7
	Ctenolophonidites costatus	12
	Dinocysts indeterminate	2
	Echiperiporites estelae	1
	Echitricolporites spinosus	1
	Gemmamonoporites sp.	1
	Ipomaea digitate	1

	<i>Monoporites annulatus</i>	1
	<i>Multiareolites formosus</i>	2
	<i>Nymphaeapollenites clarus</i>	5
	<i>Polypodiaceoisorites retirugatus</i>	3
	<i>Psilaperiporites minimus</i>	1
	<i>Psilastephanocolpites</i> spp.	1
	<i>Psilastephanocolporites grandis</i>	1
	<i>Psilastephanocolporites laevigatus</i>	13
	<i>Psilatriporites</i> spp.	3
	<i>Retibrevitricolporites obodoensis</i>	14
	<i>Retitriporites heterobrochatti</i>	1
	Smoth monolete spore	40
	Smoth trilete spore	40
	<i>Spirosyncolpites bruni</i>	1
	<i>Stereisorites</i> sp	9
	<i>Striatricolpites catatumbus</i>	2
	<i>Thomsonipollis magnificus</i>	1
	<i>Verrucatosporites farvus</i>	1
	<i>Zonocostites ramonae</i>	182
	<i>Retitricolporites irregularis</i>	38
	<i>Echistephanoporites echinatus</i>	2
	<i>Magnastriatites howardi</i>	44
	<i>Retitricolporites amazoensis</i>	1
2930	<i>Leiosphaeridia</i> spp.	1
	Fungal spore	11
	<i>Verrucatosporites tenellis</i>	36
	<i>Pachydermites diderixi</i>	62
	<i>Psilatricolporites crassus</i>	16
	<i>Alchornea cordifolia</i>	3
	<i>Botryococcus braunii</i>	5
	<i>Brevitricolporites guinetii</i>	1
	<i>Crassoretitriletes vanraadshooveni</i>	6

	<i>Ctenolophonidites costatus</i>	7
	Dinocysts indeterminate	2
	<i>Echiperiporites estelae</i>	3
	<i>Lycopodiumsporites</i> sp	1
	<i>Margocolporites raувolfii</i>	1
	<i>Monoporites annulatus</i>	4
	<i>Multiareolites formosus</i>	3
	<i>Polypodiaceoisporites retirugatus</i>	2
	<i>Proteacidites cooksonii</i>	1
	<i>Psilamonocolpites</i> spp.	1
	<i>Psilastephanocolporites laevigatus</i>	7
	<i>Psilatricolporites annuliporis</i>	1
	<i>Pterospermella</i> sp	1
	<i>Retibrevitricolporites obodoensis</i>	7
	Smoth monolete spore	40
	Smoth trilete spore	12
	<i>Stereisporites</i> sp	1
	<i>Striatricolpites catatumbus</i>	2
	<i>Verrucatosporites farvus</i>	1
	<i>Zonocostites ramonae</i>	328
	<i>Retitricolporites irregularis</i>	12
	<i>Echistephanoporites echinatus</i>	1
	<i>Magnastriatites howardi</i>	3
3020	Fungal spore	1
	<i>Verrucatosporites tenellis</i>	15
	<i>Pachydermites diderixi</i>	78
	<i>Psilatricolporites crassus</i>	4
	<i>Botryococcus braunii</i>	2
	<i>Brevitricolporites guinetii</i>	3
	<i>Cranwellipollis</i> sp	1
	<i>Crassoretitriletes vanraadshooveni</i>	9
	<i>Ctenolophonidites costatus</i>	9

	<i>Echiperiporites estelae</i>	7
	<i>Echitricolporites spinosus</i>	1
	<i>Lycopodium</i> sp	1
	<i>Nymphaeapolli clarus</i>	1
	<i>Peregrinipollis nigericus</i>	1
	<i>Polypodiaceoisorites retirugatus</i>	1
	<i>Proteacidites cooksonii</i>	1
	<i>Psilastephanocolporites laevigatus</i>	7
	<i>Retibrevitricolporites obodoensis</i>	2
	<i>Rugulatisporites caperatus</i>	18
	Smoth monolete spore	8
	Smoth trilete spore	8
	<i>Stereisorites</i> sp	1
	<i>Verrucatosporites farvus</i>	1
	<i>Zonocostites ramonae</i>	129
	<i>Retitricolporites irregularis</i>	18
	<i>Magnastriatites howardi</i>	1
	<i>Retitricolporites amazoensis</i>	2
3110	<i>Leiosphaeridia</i> spp.	1
	<i>Psilatricolporites</i> sp	1
	<i>Echiperiporites</i> sp.	8
	<i>Verrucatosporites tenellis</i>	30
	<i>Pachydermites diderixi</i>	172
	<i>Psilatricolporites crassus</i>	8
	<i>Alchornea cordifolia</i>	2
	<i>Botryococcus braunii</i>	4
	<i>Brevitricolporites guinetii</i>	2
	<i>Crassoretitriletes vanraadshooveni</i>	4
	<i>Ctenolophonidites costatus</i>	16
	Dinocysts indeterminate	1
	<i>Echiperiporites estelae</i>	22

	<i>Echitricolporites spinosus</i>	1
	<i>Gemmamonoporites</i> sp.	1
	<i>Lycopodiumsporites</i> sp	1
	<i>Monoporites annulatus</i>	2
	<i>Nymphaeapolli clarus</i>	3
	<i>Polypodiaceosporites retirugatus</i>	1
	<i>Psilastephanocolporites laevigatus</i>	11
	<i>Retibrevitricolporites obodoensis</i>	16
	Smoth monolete spore	31
	Smoth trilete spore	23
	<i>Striatricolpites catatumbus</i>	1
	<i>Verrucatosporites farvus</i>	1
	<i>Zonocostites ramonae</i>	200
	<i>Retitricolporites irregularis</i>	48
	<i>Echistephanoporites echinatus</i>	3
	<i>Magnastriatites howardi</i>	3
	<i>Retitricolporites amazoensis</i>	3
3200	Fungal spore	2
	<i>Echiperiporites</i> sp.	3
	<i>Verrucatosporites tenellis</i>	21
	<i>Pachydermites diderixi</i>	200
	<i>Psilatricolporites crassus</i>	15
	<i>Alchornea cordifolia</i>	5
	<i>Botryococcus braunii</i>	8
	<i>Crassoretitriletes vanraadshooveni</i>	11
	<i>Ctenolophonidites costatus</i>	21
	<i>Echiperiporites estelae</i>	15
	<i>Echitricolporites spinosus</i>	2
	<i>Ipomaea digitate</i>	1
	<i>Lycopodiumsporites</i> sp	2
	<i>Monoporites annulatus</i>	6
	<i>Multiareolites formosus</i>	1

	<i>Peregrinipollis nigericus</i>	2
	<i>Psilastephanocolporites laevigatus</i>	9
	<i>Psilastephanocolporites</i> spp.	1
	<i>Psilatroporites</i> spp.	1
	<i>Pterospermella</i> sp	1
	<i>Retibrevitricolporites obodoensis</i>	8
	Smoth monolete spore	40
	Smoth trilete spore	46
	<i>Verrucatosporites farvus</i>	4
	<i>Zonocostites ramonae</i>	220
	<i>Retitricolporites irregularis</i>	42
	<i>Echistephanoporites echinatus</i>	3
	<i>Magnastriatites howardi</i>	6
	<i>Retitricolporites amazoensis</i>	3
3290	Fungal spore	3
	<i>Echiperiporites</i> sp.	1
	<i>Verrucatosporites tenellis</i>	14
	<i>Pachydermites diderixi</i>	86
	<i>Psilatricolporites crassus</i>	6
	<i>Botryococcus braunii</i>	1
	<i>Crassoretitriletes vanraadshooveni</i>	1
	<i>Ctenolophonidites costatus</i>	3
	<i>Echiperiporites estelae</i>	8
	<i>Peregrinipollis nigericus</i>	2
	<i>Polypodiaceosporites retirugatus</i>	1
	<i>Proteacidites cooksonii</i>	1
	<i>Psilastephanocolporites laevigatus</i>	4
	<i>Retibrevitricolporites obodoensis</i>	3
	Smoth monolete spore	4
	Smoth trilete spore	7
	<i>Striatricolpites catatumbus</i>	1
	<i>Thomsonipollis magnificus</i>	1

	<i>Zonocostites ramonae</i>	60
	<i>Retitricolporites irregularis</i>	23
3380	<i>Leiosphaeridia</i> spp.	1
	Fungal spore	5
	<i>Retitricolporites</i> spp.	1
	<i>Verrucatosporites tenellis</i>	50
	<i>Pachydermites diederixi</i>	80
	<i>Psilatricolporites crassus</i>	1
	<i>Alchornea cordifolia</i>	1
	<i>Botryococcus braunii</i>	6
	<i>Crassoretitriletes vanraadshooveni</i>	1
	<i>Ctenolophonidites costatus</i>	1
	Dinocysts indeterminate	1
	<i>Monoporites annulatus</i>	4
	<i>Nymphaeapolli clarus</i>	1
	<i>Peregrinipollis nigericus</i>	6
	<i>Polypodiaceoisporites retirugatus</i>	7
	<i>Psilastephanocolporites laevigatus</i>	26
	<i>Retibrevitricolporites obodoensis</i>	5
	Smoth monolete spore	32
	Smoth trilete spore	10
	<i>Striatricolpites catatumbus</i>	2
	<i>Triporetetradites letouzeyi</i>	1
	<i>Verrucatosporites farvus</i>	1
	<i>Zonocostites ramonae</i>	402
	<i>Retitricolporites irregularis</i>	12
	<i>Echistephanoporites echinatus</i>	1
	<i>Magnastriatites howardi</i>	2
	<i>Retitricolporites amazoensis</i>	2
3470	Fungal spore	5
	<i>Verrucatosporites tenellis</i>	15

	<i>Pachydermites diderixi</i>	62
	<i>Psilatricolporites crassus</i>	6
	<i>Alchornea cordifolia</i>	1
	<i>Crassoretitriletes vanraadshooveni</i>	3
	<i>Ctenolophonidites costatus</i>	2
	<i>Echitricolporites spinosus</i>	1
	<i>Lycopodiumsporites</i> sp	1
	<i>Monoporites annulatus</i>	1
	<i>Nummulipollis neogenicus</i>	1
	<i>Polypodiaceoisorites retirugatus</i>	5
	<i>Psilastephanocolporites boureaw</i>	1
	<i>Psilastephanocolporites grandis</i>	1
	<i>Psilastephanocolporites laevigatus</i>	4
	<i>Pterospermella</i> sp	1
	<i>Racemonocolpites hians</i>	1
	Smoth monolete spore	8
	Smoth trilete spore	14
	<i>Striatricolpites catatumbus</i>	1
	<i>Zonocostites ramonae</i>	14
	<i>Retitricolporites irregularis</i>	5
	<i>Retitricolporites amazoensis</i>	1
3560	<i>Leiosphaeridia</i> spp.	1
	Fungal spore	5
	<i>Verrucatosporites tenellis</i>	43
	<i>Pachydermites diderixi</i>	38
	<i>Psilatricolporites crassus</i>	5
	<i>Alchornea cordifolia</i>	3
	<i>Botryococcus braunii</i>	10
	<i>Brevitricolporites guinetii</i>	3
	<i>Cinctiperiporites mulleri</i>	1
	<i>Crassoretitriletes vanraadshooveni</i>	3
	<i>Ctenolophonidites costatus</i>	5

	<i>Echiperiporites estelae</i>	5
	<i>Echitriporites</i> sp	1
	<i>Lycopodiumsporites</i> sp	4
	<i>Monoporites annulatus</i>	3
	<i>Multiareolites formosus</i>	1
	<i>Peregrinipollis nigericus</i>	4
	<i>Polyadopollenites vancampori</i>	1
	<i>Polypodiaceoisporites retirugatus</i>	4
	<i>Psilastephanocolporites laevigatus</i>	7
	<i>Racemonocolpites hians</i>	1
	<i>Retibrevitricolporites obodoensis</i>	3
	<i>Rugulatisporites caperatus</i>	1
	Smoth monolete spore	30
	Smoth trilete spore	22
	<i>Stereisporites</i> sp	1
	<i>Striatricolpites catatumbus</i>	1
	<i>Zonocostites ramonae</i>	96
	<i>Retitricolporites irregularis</i>	17
	<i>Echistephanoporites echinatus</i>	1
	<i>Magnastriatites howardi</i>	1
	<i>Retitricolporites amazoensis</i>	1
3650	<i>Leiosphaeridia</i> spp.	1
	Fungal spore	4
	<i>Echiperiporites</i> sp.	1
	<i>Verrucatosporites tenellis</i>	88
	<i>Pachydermites diderixi</i>	90
	<i>Botryococcus braunii</i>	9
	<i>Brevitricolporites guinetii</i>	1
	<i>Cinctiperiporites mulleri</i>	1
	<i>Crassoretitriletes vanraadshooveni</i>	4
	<i>Ctenolophonidites costatus</i>	6
	Dinocysts indeterminate	1

	Echiperiporites estelae	2
	Lycopodiumsporites sp	7
	Margocolporites rauvolfii	1
	Monoporites annulatus	4
	Multiareolites formosus	1
	Nymphaeapolli clarus	3
	Peregrinipollis nigericus	2
	Polyadopollenites vancampori	1
	Polypodiaceoisporites retirugatus	5
	Psilastephanocolporites laevigatus	12
	Racemonocolpites hians	1
	Retibrevitricolporites obodoensis	9
	Smoth monolete spore	19
	Smoth trilete spore	13
	Stereisporites sp	1
	Striatricolpites catatumbus	2
	Verrucatosporites farvus	2
	Zonocostites ramonae	162
	Retitricolporites irregularis	21
	Echistephanoporites echinatus	3
	Magnastriatites howardi	4
	Retitricolporites amazoensis	1
	Corsinipollenites jussiaensis	1
3740	Fungal spore	11
	Psilatricolporites sp	1
	Echiperiporites sp.	4
	Psilatricolpites spp.	1
	Retitricolporites spp.	1
	Verrucatosporites tenellis	120
	Pachydermites diderixi	190
	Psilatricolporites crassus	5
	Foram lining	3

	<i>Alchornea cordifolia</i>	5
	<i>Aletesporites</i> sp.	1
	<i>Crassoretitriletes vanraadshooveni</i>	14
	<i>Ctenolophonidites costatus</i>	1
	<i>Echiperiporites estelae</i>	3
	<i>Echitricolporites spinosus</i>	1
	<i>Ipomaea digitate</i>	1
	<i>Lycopodium neogenicus</i>	2
	<i>Lycopodium</i> sp	3
	<i>Marginipollis concinnus</i>	1
	<i>Monoporites annulatus</i>	7
	<i>Multiareolites formosus</i>	11
	<i>Peregrinipollis nigericus</i>	1
	<i>Polyadopollenites vancampori</i>	1
	<i>Polypodiaceoisporites retirugatus</i>	18
	<i>Psilastephanocolporites grandis</i>	2
	<i>Psilastephanocolporites laevigatus</i>	14
	<i>Psilatriporites</i> spp.	3
	<i>Retibrevitricolporites obodoensis</i>	9
	<i>Retitriporites heterobrochatti</i>	1
	<i>Rugulatisporites</i> sp	1
	Smoth monolete spore	8
	Smoth trilete spore	17
	<i>Stereisporites</i> sp	1
	<i>Zonocostites ramonae</i>	325
	<i>Retitricolporites irregularis</i>	30
	<i>Echistephanoporites echinatus</i>	3
	<i>Magnastriatites howardi</i>	1
	<i>Crototricolpites crotonoisculptus</i>	2
3920	<i>Leiosphaeridia</i> spp.	1
	Fungal spore	2
	<i>Verrucatosporites tenellis</i>	9

	<i>Pachydermites diderixi</i>	16
	<i>Psilatricolporites crassus</i>	5
	<i>Botryococcus braunii</i>	1
	<i>Brevitricolporites guinetii</i>	1
	Dinocysts indeterminate	2
	<i>Echitricolporites spinosus</i>	1
	<i>Monoporites annulatus</i>	1
	<i>Polypodiaceoisporites retirugatus</i>	4
	<i>Psilaperiporites minimus</i>	1
	<i>Psilastephanocolporites laevigatus</i>	7
	<i>Retibrevitricolporites obodoensis</i>	2
	Smoth monolete spore	10
	Smoth trilete spore	8
	<i>Stereisporites</i> sp	1
	<i>Striatricolpites catatumbus</i>	2
	<i>Zonocostites ramonae</i>	38
	<i>Retitricolporites irregularis</i>	6
	<i>Retitricolporites amazoensis</i>	2
	<i>Crototricolpites crotonoisculptus</i>	1
	<i>Verrutricolporites</i> cf. <i>rotundiporus</i>	1
4010	Fungal spore	1
	<i>Selaginella myosurus</i>	2
	<i>Echiperiporites</i> sp.	1
	<i>Verrucatosporites tenellis</i>	5
	<i>Pachydermites diderixi</i>	11
	<i>Psilatricolporites crassus</i>	14
	<i>Margocolporites rauvolfii</i>	1
	<i>Monoporites annulatus</i>	4
	<i>Multiareolites formosus</i>	1
	<i>Polypodiaceoisporites retirugatus</i>	2
	<i>Psilastephanocolporites laevigatus</i>	2
	<i>Retibrevitricolporites obodoensis</i>	1

	Smoth monolete spore	3
	Smoth trilete spore	7
	Zonocostites ramonae	74
	Retitricolporites irregularis	1
4100	Fungal spore	1
	Verrucatosporites tenellis	8
	Pachydermites diderixi	9
	Psilatricolporites crassus	4
	Alchornea cordifolia	1
	Crassoretitriletes vanraadshooveni	1
	Diatom spp.	1
	Polypodiaceosporites retirugatus	3
	Psilatropites spp.	2
	Racemonocolpites hians	1
	Smoth monolete spore	2
	Smoth trilete spore	11
	Zonocostites ramonae	13
	Granulatisporites spp	1
4280	Fungal spore	2
	Psilatricolporites sp	5
	Verrucatosporites tenellis	2
	Pachydermites diderixi	4
	Psilatricolporites crassus	3
	Foram lining	1
	Aletesporites sp.	2
	Crassoretitriletes vanraadshooveni	1
	Dinocysts indeterminate	1
	Marginipollis concinnus	1
	Monoporites annulatus	8
	Polypodiaceosporites retirugatus	4
	Proteacidites cooksonii	1

	<i>Psilastephanocolporites grandis</i>	1
	<i>Psilastephanocolporites laevigatus</i>	3
	<i>Psilatриporites</i> spp.	4
	<i>Retibrevitricolporites obodoensis</i>	3
	Smoth trilete spore	2
	<i>Zonocostites ramonae</i>	30
	<i>Magnastriatites howardi</i>	3
4370	Fungal spore	2
	<i>Psilatricolporites</i> sp	3
	<i>Psilatricolpites</i> spp.	1
	<i>Retitricolporites</i> spp.	1
	<i>Verrucatosporites tenellis</i>	3
	<i>Pachydermites diderixi</i>	6
	<i>Psilatricolporites crassus</i>	8
	<i>Alchornea cordifolia</i>	1
	<i>Crassoretitriletes vanraadshooveni</i>	2
	<i>Monoporites annulatus</i>	2
	<i>Peregrinipollis nigericus</i>	1
	<i>Polypodiaceoisporites retirugatus</i>	2
	<i>Proteacidites cooksonii</i>	1
	<i>Psilastephanocolporites grandis</i>	1
	<i>Psilastephanocolporites laevigatus</i>	4
	<i>Retibrevitricolporites obodoensis</i>	1
	Smoth monolete spore	2
	Smoth trilete spore	11
	<i>Zonocostites ramonae</i>	20
	<i>Magnastriatites howardi</i>	1
	<i>Granulatisporites</i> spp	1
4460	Fungal spore	2
	<i>Psilatricolpites</i> spp.	2
	<i>Verrucatosporites tenellis</i>	2

	<i>Pachydermites diderixi</i>	29
	<i>Psilatricolporites crassus</i>	20
	<i>Aletesporites</i> sp.	1
	<i>Crassoretitriletes vanraadshooveni</i>	2
	<i>Ctenolophonidites costatus</i>	1
	<i>Lycopodium</i> sp	1
	<i>Monoporites annulatus</i>	4
	<i>Polypodiaceoisporites retirugatus</i>	5
	<i>Psilastephanocolporites</i> spp.	1
	<i>Retibrevitricolporites obodoensis</i>	2
	Smoth monolete spore	4
	Smoth trilete spore	20
	<i>Zonocostites ramonae</i>	53
	<i>Magnastriatites howardi</i>	1
	<i>Granulatisporites</i> spp	5
4640	Fungal spore	1
	<i>Psilatricolporites</i> sp	1
	<i>Psilatricolpites</i> spp.	1
	<i>Verrucatosporites tenellis</i>	5
	<i>Pachydermites diderixi</i>	6
	<i>Psilatricolporites crassus</i>	6
	<i>Alchornea cordifolia</i>	1
	<i>Monoporites annulatus</i>	1
	<i>Polypodiaceoisporites retirugatus</i>	1
	<i>Psilastephanocolporites laevigatus</i>	3
	<i>Retitriporites heterobrochatti</i>	1
	Smoth monolete spore	1
	Smoth trilete spore	6
	<i>Zonocostites ramonae</i>	16
4730	<i>Selaginella myosurus</i>	1
	<i>Verrucatosporites tenellis</i>	2

	<i>Pachydermites diderixi</i>	2
	<i>Psilatricolporites crassus</i>	3
	<i>Crassoretitriletes vanraadshooveni</i>	1
	<i>Monoporites annulatus</i>	1
	Smoth trilete spore	1
	<i>Zonocostites ramonae</i>	2
4820	Fungal spore	2
	<i>Verrucatosporites tenellis</i>	1
	<i>Pachydermites diderixi</i>	5
	<i>Psilatricolporites crassus</i>	3
	<i>Monoporites annulatus</i>	1
	<i>Retibrevitricolporites obodoensis</i>	1
	Smoth trilete spore	5
	<i>Zonocostites ramonae</i>	6
	<i>Magnastriatites howardi</i>	1
4910	<i>Verrucatosporites tenellis</i>	1
	<i>Pachydermites diderixi</i>	1
	<i>Psilatricolporites crassus</i>	4
	Diatom spp.	1
	Dinocysts indeterminate	2
	<i>Elaeis guineensis</i>	1
	<i>Monoporites annulatus</i>	9
	<i>Psilatricolporites annuliporis</i>	1
	<i>Psilatriporites</i> spp.	6
	<i>Retibrevitricolporites obodoensis</i>	2
	Smoth monolete spore	3
	Smoth trilete spore	2
	<i>Zonocostites ramonae</i>	25
5000	Fungal spore	1
	<i>Psilatricolporites</i> sp	3

	Psilatricolporites crassus	2
	Botryococcus braunii	1
	Monoporites annulatus	1
	Polypodiaceoisporites retirugatus	1
	Psilastephanocolporites laevigatus	1
	Psilatриporites spp.	1
	Retibrevitricolporites obodoensis	1
	Smoth monolete spore	2
	Smoth trilete spore	2
	Striatricolpites catatumbus	1
	Zonocostites ramonae	22
5090	Leiosphaeridia spp.	1
	Fungal spore	2
	Pachydermites diderixi	1
	Psilatricolporites crassus	3
	Dinocysts indeterminate	2
	Monoporites annulatus	2
	Psilatриporites spp.	1
	Smoth monolete spore	2
	Smoth trilete spore	2
	Zonocostites ramonae	4
5180	Fungal spore	7
	Psilatricolporites sp	2
	Psilatricolpites spp.	1
	Verrucatosporites tenellis	4
	Pachydermites diderixi	10
	Psilatricolporites crassus	8
	Foram lining	1
	Crassoretitriletes vanraadshooveni	2
	Dinocysts indeterminate	2
	Elaeis guineensis	1

	Gemmamonocolpites sp	1
	Monoporites annulatus	8
	Peregrinipollis nigericus	2
	Polypodiaceoisorites retirugatus	1
	Psilastephanocolporites laevigatus	1
	Psilatroporites spp.	4
	Pterospermella sp	1
	Racemonocolpites hians	1
	Smoth monolete spore	6
	Smoth trilete spore	7
	Stereisorites sp	1
	Verrutricolporites rotundiporus	1
	Zonocostites ramonae	62
	Retitricolporites irregularis	1
	Magnastriatites howardi	1
5270	Fungal spore	1
	Verrucatosporites tenellis	1
	Pachydermites diderixi	2
	Psilatricolporites crassus	7
	Crassoretitriletes vanraadshooveni	1
	Dinocysts indeterminate	1
	Monoporites annulatus	2
	Polypodiaceoisorites retirugatus	2
	Smoth monolete spore	1
	Smoth trilete spore	1
	Striatricolpites catatumbus	3
	Zonocostites ramonae	29
	Retitricolporites irregularis	4
5360	Leiosphaeridia spp.	1
	Fungal spore	1
	Psilatricolporites crassus	3

	Polypodiaceoisorites retirugatus	1
	Smoth monolete spore	1
	Smoth trilete spore	6
	Zonocostites ramonae	1
	Magnastriatites howardi	1
5450	Fungal spore	3
	Verrucosisorites sp	3
	Verrucosisorites tenellis	3
	Pachydermites diderixi	1
	Psilatricolporites crassus	2
	Monoporites annulatus	8
	Polypodiaceoisorites retirugatus	1
	Psilastephanocolporites laevigatus	1
	Smoth monolete spore	3
	Smoth trilete spore	8
	Zonocostites ramonae	9
5540	Fungal spore	3
	Verrucosisorites tenellis	2
	Pachydermites diderixi	4
	Psilatricolporites crassus	5
	Monoporites annulatus	4
	Polypodiaceoisorites retirugatus	1
	Psilatirporites spp.	1
	Smoth monolete spore	1
	Smoth trilete spore	5
	Zonocostites ramonae	13
5630	Leiosphaeridia spp.	1
	Fungal spore	2
	Verrucosisorites sp	1
	Verrucosisorites tenellis	4

	Pachydermites diderixi	13
	Psilatricolporites crassus	10
	Foram lining	1
	Botryococcus braunii	1
	Monoporites annulatus	11
	Perfotricolpites digitatus	1
	Podocarpidites sp	1
	Polypodiaceoisorites retirugatus	4
	Psilastephanocolporites laevigatus	2
	Psilatirporites spp.	4
	Smoth monolete spore	7
	Smoth trilete spore	20
	Zonocostites ramonae	28
5720	Fungal spore	2
	Verrucatosporites tenellis	1
	Pachydermites diderixi	2
	Psilatricolporites crassus	2
	Dinocysts indeterminate	2
	Monoporites annulatus	12
	Psilatirporites spp.	2
	Smoth monolete spore	1
	Smoth trilete spore	5
	Zonocostites ramonae	3
5810	Pachydermites diderixi	1
	Foram lining	1
	Crassoretitriletes vanraadshooveni	1
	Monoporites annulatus	3
	Smoth trilete spore	2
	Zonocostites ramonae	1
5900	Fungal spore	1

	<i>Pachydermites diderixi</i>	4
	<i>Psilatricolporites crassus</i>	1
	<i>Crassoretitriletes vanraadshooveni</i>	1
	Dinocysts indeterminate	2
	<i>Monoporites annulatus</i>	19
	<i>Psilatroporites</i> spp.	1
	Smoth trilete spore	4
	<i>Verrutricolporites rotundiporus</i>	1
	<i>Zonocostites ramonae</i>	8
6530	Fungal spore	1
	<i>Verrucatosporites tenellis</i>	5
	<i>Pachydermites diderixi</i>	1
	<i>Psilatricolporites crassus</i>	2
	Foram lining	1
	<i>Ctenolophonidites costatus</i>	1
	Dinocysts indeterminate	1
	<i>Lycopodiumsporites</i> sp	1
	<i>Margocolporites rauvolfii</i>	1
	<i>Monoporites annulatus</i>	3
	<i>Perfotricolpites digitatus</i>	1
	<i>Polypodiaceoisporites retirugatus</i>	3
	<i>Psilatricolporites annuliporis</i>	1
	<i>Psilatroporites</i> spp.	1
	Smoth monolete spore	1
	Smoth trilete spore	1
	<i>Striatricolpites catatumbus</i>	2
	<i>Verrutricolporites rotundiporus</i>	1
	<i>Zonocostites ramonae</i>	7
	<i>Magnastriatites howardi</i>	2
6620	Fungal spore	1
	<i>Psilatricolporites</i> sp	1

	<i>Pachydermites diederixi</i>	1
	<i>Psilatricolporites crassus</i>	1
	Foram lining	1
	Dinocysts indeterminate	1
	<i>Lycopodium neogenicus</i>	1
	<i>Monoporites annulatus</i>	1
	<i>Peregrinipollis nigericus</i>	1
	<i>Polypodiaceoisorites retirugatus</i>	2
	<i>Psilatroporites</i> spp.	3
	<i>Pterospermella</i> sp	1
	<i>Retibrevitricolporites obodoensis</i>	1
	Smoth monolete spore	1
	Smoth trilete spore	3
	<i>Zonocostites ramonae</i>	7
6710	<i>Psilatricolporites</i> sp	1
	<i>Verrucatosporites tenellis</i>	3
	<i>Pachydermites diederixi</i>	1
	<i>Psilatricolporites crassus</i>	1
	Foram lining	1
	<i>Belskipollis elegans</i>	1
	<i>Monoporites annulatus</i>	22
	<i>Peregrinipollis nigericus</i>	1
	<i>Proteacidites cooksonii</i>	1
	<i>Psilatroporites</i> spp.	2
	<i>Retibrevitricolporites obodoensis</i>	1
	Smoth monolete spore	3
	<i>Striatricolpites catatumbus</i>	1
	<i>Magnastriatites howardi</i>	1
6800	Foram lining	3
	<i>Monoporites annulatus</i>	4
	<i>Striatricolpites catatumbus</i>	1

6890	Fungal spore	1
	Psilatricolporites sp	1
	Verrucatosporites tenellis	2
	Pachydermites diederixi	1
	Psilatricolporites crassus	2
	Elaeis guineensis	1
	Monoporites annulatus	1
	Polypodiaceosporites retirugatus	1
	Psilatroporites spp.	1
	Smoth monolete spore	4
	Smoth trilete spore	1
6980	Psilatricolpites spp.	1
	Verrucatosporites tenellis	3
	Pachydermites diederixi	1
	Monoporites annulatus	70
	Nymphaeapolleni clarus	1
	Polypodiaceosporites retirugatus	2
	Proteacidites cooksonii	1
	Psilastephanocolporites laevigatus	1
	Zonocostites ramonae	15
	Granulatisporites spp	1
7070	Fungal spore	1
	Foram lining	1
	Monoporites annulatus	2
	Nummulipollis neogenicus	1
	Polypodiaceosporites retirugatus	2
	Proteacidites cooksonii	1
	Psilatroporites spp.	1
	Verrutricolporites rotundiporus	1
	Zonocostites ramonae	1

	Magnastriatites howardi	1
7160	Verrucatosporites tenellis	1
	Psilatricolporites crassus	4
	Belskipollis elegans	1
	Lycopodium sp	1
	Monoporites annulatus	12
	Polypodiaceosporites retirugatus	3
	Psilastephanocolporites grandis	2
	Psilastephanocolporites laevigatus	2
	Smoth monolete spore	1
	Smoth trilete spore	3
	Zonocostites ramonae	11
	Granulatisporites spp	1
7250	Leiosphaeridia spp.	1
	Fungal spore	1
	Psilatricolporites sp	1
	Pachydermites diderixi	1
	Psilatricolporites crassus	4
	Foram lining	1
	Polypodiaceosporites retirugatus	1
	Smoth monolete spore	2
	Smoth trilete spore	5
	Zonocostites ramonae	7
7340	Selaginella myosurus	1
	Psilatricolpites spp.	2
	Verrucatosporites tenellis	7
	Psilatricolporites crassus	1
	Monoporites annulatus	1
	Smoth trilete spore	1
	Zonocostites ramonae	2

7430	Verrucatosporites tenellis	1
	Psilatricolporites crassus	1
	Monoporites annulatus	6
	Magnastriatites howardi	1
7520	Verrucatosporites tenellis	1
	Pachydermites diderixi	1
	Psilatricolporites crassus	5
	Crassoretitriletes vanraadshooveni	1
	Lycopodium sp	1
	Monoporites annulatus	1
	Polypodiaceoisporites retirugatus	1
	Psilastephanocolporites laevigatus	2
	Smoth trilete spore	2
	Zonocostites ramonae	2
	Magnastriatites howardi	1
7610	Pachydermites diderixi	1
	Striatricolpites catatumbus	2
	Magnastriatites howardi	1
7700	Monoporites annulatus	4
7810	Psilatricolporites crassus	1
	Monoporites annulatus	1
7900	Lycopodium sp	1
7990	Verrucatosporites tenellis	2
	Smoth monolete spore	1
	Smoth trilete spore	2
	Zonocostites ramonae	3
	Magnastriatites howardi	1

8080	<i>Psilatricolporites crassus</i>	2
	<i>Retitriporites heterobrochatti</i>	1
8170	<i>Verrucatosporites tenellis</i>	1
	<i>Polypodiaceoisporites retirugatus</i>	1
	Smoth trilete spore	5
	<i>Magnastriatites howardi</i>	1
8260	<i>Verrucatosporites tenellis</i>	2
	<i>Psilatricolporites crassus</i>	2
	<i>Belskipollis elegans</i>	1
	<i>Monoporites annulatus</i>	1
	<i>Psilastephanocolporites laevigatus</i>	1
	Smoth monolete spore	1
	Smoth trilete spore	3
	<i>Zonocostites ramonae</i>	1
	<i>Retitricolporites irregularis</i>	1
	<i>Granulatisporites</i> spp	1
8330	<i>Pachydermites diderixi</i>	1
	<i>Psilatricolporites crassus</i>	3
	Foram lining	19
	<i>Crassoretitriletes vanraadshooveni</i>	1
	<i>Podocarpidites</i> sp	1
	<i>Polypodiaceoisporites retirugatus</i>	1
	Smoth trilete spore	1
	<i>Zonocostites ramonae</i>	1
	<i>Granulatisporites</i> spp	1
8670	Fungal spore	1
	<i>Verrucatosporites tenellis</i>	5
	<i>Pachydermites diderixi</i>	1
	<i>Psilatricolporites crassus</i>	2

	Foram lining	1
	Ctenolophonidites costatus	1
	Dinocysts indeterminate	1
	Lycopodiumsporites sp	1
	Margocolporites rauvolfii	1
	Monoporites annulatus	3
	Perfotricolpites digitatus	1
	Polypodiaceoisporites retirugatus	3
9201	Psilatricolporites annuliporis	1
	Psilatirporites spp.	1
	Smoth monolete spore	1
	Smoth trilete spore	1
	Striatricolpites catatumbus	2
	Verrutricolporites rotundiporus	1
	Zonocostites ramonae	7
	Magnastriatites howardi	2
10230	Fungal spore	1
	Psilatricolporites sp	1
	Pachydermites diderixi	1
	Psilatricolporites crassus	1
	Foram lining	1
	Dinocysts indeterminate	1
	Lycopodium neogenicus	1
	Monoporites annulatus	1
	Peregrinipollis nigericus	1
	Polypodiaceoisporites retirugatus	2
	Psilatirporites spp.	3
	Pterospermella sp	1
	Retibrevitricolporites obodoensis	1
	Smoth monolete spore	1
	Smoth trilete spore	3
	Zonocostites ramonae	7

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Appendix 2

Analysis sheet show Taxon name and count of foraminifers and shell fragments recovered.		
Depth (ft)	Taxon name	Foraminifera Count
2840	Shell fragments	2
	Buliminella sp	1
2930	Globigerinoides bulloideus	1
	Globigerina bulloides	9
	Globigerina venezuelana	2
	Amphistegina lessonii	4
	Shell fragments	16
	Ammonia beccarii	8
	Epistominella vitrea	12
	Florilus atlanticus	10
	Globigerina sp	3

	Hanzawaia strattoni	21
	Lenticulina inornata	1
	Nonionella auris	2
	Quinqueloculina seminulum	4
	Quinqueloculina sp	2
	Heterolepa pseudoungerina	30
	Bolivina sp	1
	Hanzawaia mantaensis	6
	Heterolepa detonensis	8
3020	Karriella siphonella	1
	Globigerina venezuelana	3
	Shell fragments	10
	Ammonia beccarii	2
	Epistominella vitrea	4
	Globigerina sp	4
	Heterolepa pseudoungerina	5
	Bolivina miocenica	2
	Globorotalia sp	4

3110	Shell fragments	8
	Epistominella vitrea	1
	Buliminella sp	1
	Heterolepa detonensis	1
3200	Shell fragments	3
	Calcareous indet	1
	Heterolepa pseudoungerina	1
	Uvigerina sp	1
3290	Globigerina bulloides	2
	Valvulineria bradyana	1
	Shell fragments	14
	Epistominella vitrea	14
	Globigerina sp	2
	Hanzawaia strattoni	2
	Textularia panamensis	1
	Pseudonodosaria sp	2
	Gastropoda sp	3
	Planularia ariminensis	1
	Textularia sp	1
3470	Amphistegina	2

	lessonii	
	Shell fragments	4
	Epistominella vitrea	9
	Florilus atlanticus	1
	Globorotalia acostaensis.	2
	Globigerina sp	1
	Hanzawaia strattoni	3
	Lenticulina inornata	1
	Nonionella auris	1
	Quinqueloculina seminulum	1
	Quinqueloculina sp	1
	Heterolepa pseudoungerina	18
	Nodosaria sp	1
	Gastropoda sp	2
3560	Globigerina bulloides	4
	Globigerina venezuelana	2
	Amphistegina lessonii	2
	Arenaceous indet	2
	Epistominella vitrea	36

	Florilus atlanticus	5
	Globigerina sp	1
	Hanzawaia strattoni	3
	Nonionella auris	4
	Heterolepa pseudoungerina	12
	Bolivina miocenica	1
	Globorotalia sp	3
	Hanzawaia mantaensis	1
	Gastropoda sp	3
3650	Globigerina bulloides	1
	Globigerina venezuelana	1
	Shell fragments	1
	Epistominella vitrea	10
	Florilus atlanticus	1
	Nonionella auris	1
	Heterolepa pseudoungerina	6
	Bolivina miocenica	3
	Globorotalia sp	3
	Heterolepa crebbi	8
	Lenticulina sp.	2

	Gastropoda sp	1
3740	Shell fragments	1
	Ammonia beccarii	1
	Heterolepa pseudoungerina	5
	Trifarina reussi	1
	Heterolepa crebbsi	2
3830	Globigerina bulloides	2
	Epistominella vitrea	2
	Hanzawaia strattoni	4
	Lenticulina inornata	2
	Quinqueloculina microcostata	1
	Quinqueloculina seminulum	2
	Quinqueloculina sp	1
	Heterolepa pseudoungerina	9
	Heterolepa crebbsi	2
	Gastropoda sp	2
3920	Amphistegina lessonii	1
	Planktic indet	1

	Shell fragments	6
	Nonionella auris	2
	Heterolepa pseudoungerina	6
	Trifarina reussi	1
	Uvigerina sp	1
	Gastropoda sp	1
4010	Shell fragments	4
	Epistominella vitrea	1
	Heterolepa detonensis	1
4100	Shell fragments	1
	Calcareous indet	2
	Eggerella sp	1
4190	Globigerina bulloides	1
	Shell fragments	2
	Hanzawaia strattoni	2
	Quinqueloculina seminulum	1
	Marginulina sp	1
	Amphicoryna sp	2
	Textularia sp	1
4370	Shell fragments	2

	Gastropoda sp	2
4460	Shell fragments	4
	Quinqueloculina seminulum	1
	Heterolepa pseudoungerina	2
	Bolivina miocenica	1
	Shell fragments	1
4730	Amphistegina lessonii	1
	Shell fragments	7
	Marginulina sp	1
	Pelecypoda sp	2
	Gastropoda sp	1
4820	Shell fragments	17
	Florilus atlanticus	1
	Hanzawaia strattoni	1
	Gastropoda sp	1
4910	Shell fragments	2
	Heterolepa pseudoungerina	3
5000	Shell fragments	7

	Nonionella auris	1
5090	Uvigerina subperegrina	1
	Globigerina bulloides	2
	Amphistegina lessonii	1
	Shell fragments	18
	Ammonia beccarii	1
	Florilus atlanticus	3
	Globigerina sp	1
	Hanzawaia strattoni	4
	Nonionella auris	1
	Quinqueloculina microcostata	5
	Quinqueloculina seminulum	1
	Heterolepa pseudoungerina	9
	Quinqueloculina lata	1
	Cibicides sp	2
	Pseudoglandulina sp	1
	Gastropoda sp	6
5180	Bolivina sp	1

5270	Shell fragments	11
	Epistominella vitrea	1
	Nonionella auris	1
	Heterolepa pseudoungerina	3
	Globorotalia continua	1
5360	Shell fragments	10
	Cibicorbis inflata	2
	Hanzawaia strattoni	9
	Nonionella auris	1
	Quinqueloculina microcostata	2
	Heterolepa pseudoungerina	7
	Marginulina sp	1
	Heterolepa crebbi	2
	Lenticulina costata	2
5540	Shell fragments	8
	Pelecypoda sp	1
5630	Lenticulina inornata	2
5720	Shell fragments	9

	Calcareous indet	1
	Pseudoglandulina sp	1
6530	Globigerina bulloides	1
	Planktic indet	1
	Calcareous indet	1
	Nonionella auris	1
	Bolivina miocenica	1
	Cibicides sp	1
6550	Globigerina bulloides	1
	Planktic indet	1
	Calcareous indet	1
	Nonionella auris	1
	Bolivina miocenica	1
	Cibicides sp	1
6640	Calcareous indet	5
6730	Valvulina flexilis	6
6820	Ammobaculites sp	1
6820	Arenaceous indet	1
6820	Textularia panamensis	5

	Ammobaculites strathearnensis	1
	Valvulina flexilis	6
6910	Karriella siphonella	78
	Globigerina bulloides	3
	Globorotalia mayeri	1
	Praeglobobulimina ovate	1
	Shell fragments	8
	Ammobaculites sp	7
	Arenaceous indet	6
	Calcareous indet	2
	Epistominella vitrea	18
	Hanzawaia strattoni	13
	Lenticulina inornata	3
	Nonionella auris	3
	Quinqueloculina seminulum	1
	Quinqueloculina sp	1
	Ammobaculites strathearnensis	6
	Eggerella scabra	8
	Heterolepa pseudoungerina	68

	<i>Bolivina miocenica</i>	2
	<i>Heterolepa crebbi</i>	13
	<i>Uvigerina</i> sp	3
	<i>Valvulina flexilis</i>	1
	<i>Brizalina beyrichi</i>	1
	<i>Buliminella apiculate</i>	1
7000	<i>Karreriella siphonella</i>	20
	<i>Ammobaculites</i> sp	4
	<i>Eggerella scabra</i>	2
7450	<i>Karreriella siphonella</i>	9
	<i>Ammobaculites</i> <i>strathearnensis</i>	3
	<i>Eggerella scabra</i>	1
	<i>Marginulina</i> sp	1
7540	<i>Karreriella siphonella</i>	1
	<i>Epistominella vitrea</i>	1
	<i>Eggerella scabra</i>	2
7630	<i>Karreriella siphonella</i>	14
	<i>Ammobaculites</i> sp	4
	<i>Reophax</i> sp.	1
	<i>Ammobaculites</i> <i>strathearnensis</i>	2

7720	Karriella siphonella	20
	Ammobaculites strathearnensis	2
	Eggerella scabra	2
7900	Karriella siphonella	3
	Lenticulina inornata	1
	Spiroplectammina wrightii	1
	Textularia panamensis	1
8080	Karriella siphonella	4
	Nonionella auris	1
	Valvulina flexilis	2
8170	Karriella siphonella	6
	Arenaceous indet	5
	Ammobaculites strathearnensis	2
	Eggerella scabra	3
8350	Karriella siphonella	4
	Planktic indet	1
	Epistominella vitrea	6
	Ammobaculites	2

	strathearnensis	
	Bolivina miocenica	78
	Bolivina sp	2
	Cassidulina spp.	1
	Globorotalia continua	1
8910	Shell fragments	2
	Heterolepa pseudoungerina	3
9100	Shell fragments	7
	Nonionella auris	1
9890	Uvigerina subperegrina	1
	Globigerina bulloides	2
	Amphistegina lessonii	1