INTEGRATED SEDIMENTOLOGICAL AND PALYNOLOGICAL ANALYSIS OF THE AGBADA FORMATION (MIOCENE) IN XY WELL, NIGER DELTA BASIN.

BY

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PSC2208027

A PROJECT WORK SUBMITTED TO THE

DEPARTMENT OF GEOLOGY,

FACULTY OF PHYSICAL SCIENCES

UNIVERSITY OF BENIN,

BENIN CITY

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DEDICATION

This work is dedicated to God Almighty, the source of my strength and inspiration. It is also especially dedicated to my beloved parents for their sacrifices, love, and constant encouragement, and to all who believed in me and supported my academic pursuit.

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ABSTRACT

This study integrates sedimentological, mineralogical, and palynological analyses to evaluate the depositional environments and hydrocarbon potential of the XY Well in the Niger Delta Basin. The well penetrates the Agbada Formation, which forms part of the paralic sequence of the Niger Delta. A total of 190 ditch cutting samples were analyzed using standard sedimentological and palynological procedures to determine their lithological composition, textural characteristics, mineral assemblages, and fossil content. The lithological succession consists predominantly of alternating sandstone, shale, sandy shale, and clayey sand units typical of deltaic successions. Mineralogical studies revealed quartz, pyrite, glauconite, iron oxide, mica, and carbonate minerals, suggesting mixed continental and marine influences, moderate diagenetic alteration, and cyclic depositional energy conditions. The sand units are moderately to well sorted, subrounded to rounded, and interpreted as potential reservoir facies, whereas the shales serve as potential source and seal rocks. Palynological analysis yielded 964 palynomorphs comprising 496 pollen grains, 458 spores, and 10 dinoflagellate cysts. Diagnostic taxa such as *Praedapollis africanus*, *Peregrinipollis nigericus*, and *Retibrevitricolporites obodoensis* enabled the establishment of three biostratigraphic zones (P620, P580, and P560) corresponding to the Miocene age. Thirteen informal palynological zones were also recognized, reflecting alternating terrestrial, marginal marine, and shallow marine environments. Integration of the sedimentological and palynological results indicates a regressive–transgressive depositional cycle characteristic of a prograding delta system comprising delta plain, delta front, and prodelta facies. The study concludes that the Agbada Formation penetrated by the XY Well exhibits favorable reservoir and source rock characteristics, confirming its significance in the hydrocarbon system of the Greater Ughelli Depobelt of the Niger Delta Basin.

CHAPTER ONE

INTRODUCTION

1.0 Introduction

The Niger Delta Basin of southern Nigeria is one of the world's most prolific hydrocarbon provinces, with extensive sedimentary sequences that record the complex interplay between tectonics, sediment supply, and relative sea-level fluctuations. The basin has been a major focus of petroleum exploration and production due to its thick succession of deltaic and marine sediments that host significant oil and gas accumulations.

The **XY Well**, located within the central part of the Niger Delta, penetrates the **Agbada Formation**, a stratigraphic unit that represents the main hydrocarbon-bearing sequence of the delta. The Agbada Formation is characterized by alternations of sandstone, shale, and siltstone facies deposited in paralic to shallow marine environments. Understanding the sedimentological and palynological characteristics of this formation is essential for interpreting depositional environments, identifying reservoir and source intervals, and establishing the stratigraphic framework of the well.

In this study, an integrated sedimentological and palynological approach is applied to the XY Well in order to reconstruct the depositional history and evaluate its hydrocarbon potential. The study involves the detailed description of ditch cutting samples, mineralogical identification, and palynological analysis of microfossil assemblages. The integration of these datasets allows for the identification of lithofacies, interpretation of depositional environments, and establishment of informal palynological zones within the Agbada Formation.

This research provides new insight into the sedimentary architecture and biostratigraphic framework of the XY Well and contributes to the growing body of knowledge on sequence stratigraphy and petroleum system understanding in the Niger Delta Basin.

1.1 Background of the Study

The Niger Delta Basin is one of the most prolific hydrocarbon provinces in the world and remains a focus of intensive geological research due to its complex depositional history and rich stratigraphic record. The basin occupies the coastal margin of southern Nigeria and extends into the Gulf of Guinea (Fig. 1). It covers an area of about 75,000 km^2 onshore, with an additional 200,000 km^2 offshore, and contains sedimentary sequences up to 12 km thick (Short & Stauble, 1967; Avbovbo, 1978; Reijers, 2011). Its formation is closely tied to the break-up of the South American and African plates during the Late Jurassic to Cretaceous, which established the framework for subsequent Tertiary deltaic sedimentation (Doust & Omatsola, 1990).

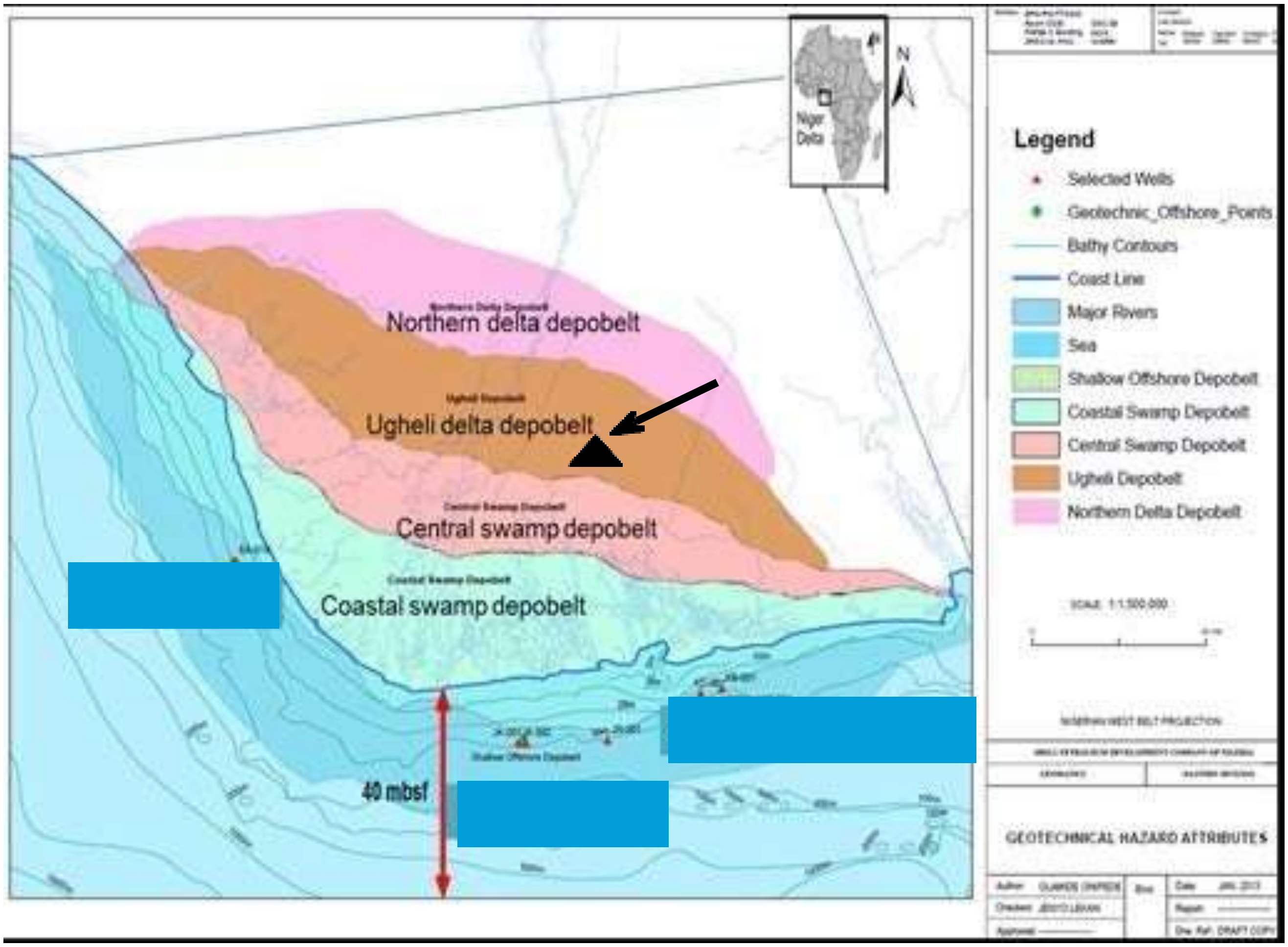


Figure 1: Location map of Niger Delta showing depobelts and position of XY Well (modified from Nwozor, et.al. 2013).

Stratigraphically, the Niger Delta comprises three major lithostratigraphic units: the Benin Formation, composed mainly of continental sand bodies; the Agbada Formation, which represents paralic to delta front sediments; and the Akata Formation, consisting predominantly of pro-delta shales (Fig. 2). These units record a progressive shift from continental to marine deposition and are the primary targets of petroleum exploration and research (Evamy, Haremboure, Kamerling, Knaap, Molloy, & Rowlands, 1978; Kuye, Oboh-Ikuenobe, & Aigbedion, 2023).

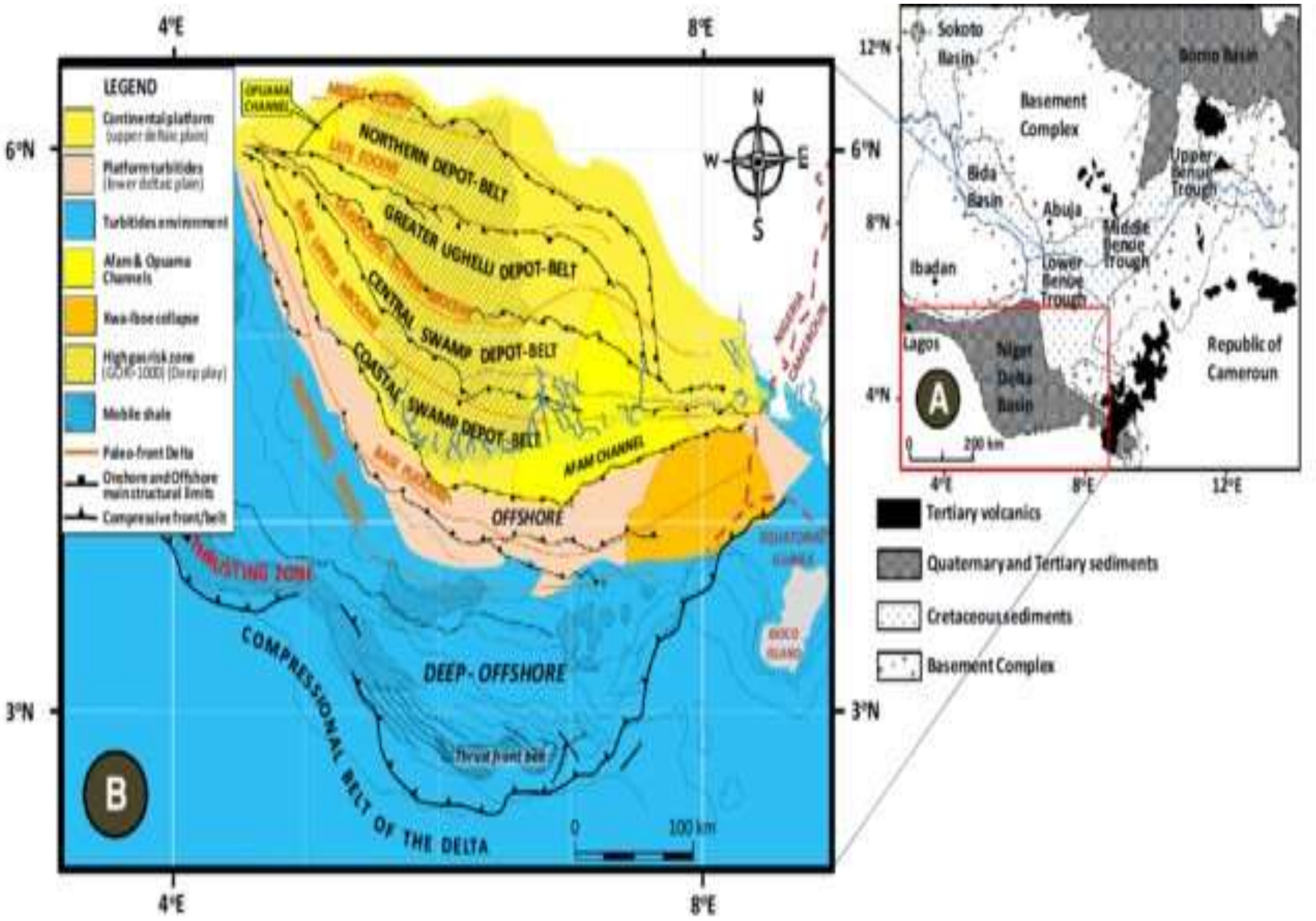


Figure 2: Geologic map of Nigeria showing the location of the Niger Delta Basin (a) (redrawn from Ebong et al. 2017) and sectional map of the Niger Delta depobelts and structural limits (b) (Redrawn from Doust and Omatsola 1990)

Sedimentological and palynological studies are central to reconstructing the depositional environments and chronological framework of the basin. Sedimentology provides insights into grain size distribution, sorting, textural attributes, and facies architecture, which are essential for interpreting depositional settings. Palynology complements this by offering age control through biostratigraphic zonation and by providing information on paleoenvironmental conditions using palynomorph assemblages (Odinaka et al., 2025; Haruna et al., 2025).

The XY Well, located within the depobelts of the Niger Delta, penetrates a thick succession of sand, shale, and associated facies, making it an ideal case for integrated sedimentological and palynological analysis. A total of 190 ditch cutting samples from this well provide data for lithofacies classification, lithozone identification, and biostratigraphic evaluation. Such integration is necessary to improve stratigraphic resolution, refine depositional models, and contribute to reservoir characterization in the basin (Olayiwola et al., 2021; Aigbadon & Igbinigie, 2024).

1.2 Statement of the Problem

Despite decades of research on the Niger Delta Basin, challenges still exist in refining the stratigraphic framework and understanding the depositional environments at well scale. Many earlier studies emphasized regional stratigraphy and petroleum system modeling, but detailed sedimentological and palynological integration at the level of individual wells is still limited (Reijers, 2011; Ocheli, Okosun, Bankole, & Ogunyemi, 2023).

The XY Well provides an opportunity to improve stratigraphic resolution in the study area. However, interpretations are often complicated by the heterogeneity of lithofacies, frequent alternation of sand and shale units, and the difficulty of distinguishing subtle environmental transitions based on lithology alone. Furthermore, palynological zonations of the Niger Delta are well established regionally, but the application of these frameworks to specific wells requires careful analysis of palynomorph distribution and abundance (Odinaka et al., 2025; Haruna et al., 2025).

Another problem is the scarcity of integrated data linking ditch cutting lithology with biostratigraphic evidence. While sedimentology can reveal depositional processes, it cannot independently provide reliable age control. Similarly, palynology offers biostratigraphic markers but requires lithological context for environmental interpretation. The absence of such integration often results in incomplete or generalized interpretations of the basin's stratigraphy (Olayiwola et al., 2021; Aigbadon & Igbinigie, 2024).

This study addresses these issues by combining sedimentological and palynological datasets from XY Well to establish a lithofacies model, identify palynological zones, and reconstruct the depositional environment.

1.3 Aim and Objectives

Aim

The aim of this study is to establish a comprehensive lithofacies and palynological framework for XY Well in the Niger Delta Basin, in order to reconstruct the depositional environment and refine the stratigraphic interpretation of the succession.

Objectives

The specific objectives of the study are to:

Describe and classify lithofacies from ditch cutting samples of XY Well.

Establish lithozones and develop a lithostratigraphic model for the well.

Identify and document associated minerals within the facies.

Analyze palynomorph assemblages and determine stratigraphically significant species.

Recognize and correlate palynological zones (P-zones) within the studied interval.

Integrate sedimentological and palynological data to interpret depositional environments.

Compare results from XY Well with published studies in the Niger Delta and other delta systems.

1.4 Research Questions

This study is guided by the following research questions:

What lithofacies are present in XY Well, and how can they be classified based on grain size, sorting, texture, and associated minerals?

How many lithozones can be identified within the well succession, and what stratigraphic model can be developed from them?

Which stratigraphically significant palynomorphs are recovered from the ditch cutting samples?

What palynological zones (P-zones) can be recognized in XY Well, and what is their biostratigraphic significance?

How can sedimentological and palynological results be integrated to reconstruct the depositional environment?

In what ways do the results from XY Well compare with published sedimentological and palynological studies from other wells in the Niger Delta and globally in similar delta systems?

1.5 Significance of the Study

This study is significant for several reasons. First, it contributes to the growing body of knowledge on the stratigraphy of the Niger Delta Basin by providing a well-based analysis that integrates sedimentology and palynology. The XY Well is located within one of the depobelts of the basin, and its analysis adds detailed information that can improve the resolution of local stratigraphic frameworks.

Second, the integration of lithofacies description with palynological zonation strengthens the interpretation of depositional environments. Sedimentology alone cannot adequately constrain age, while palynology requires a lithological context for meaningful paleoenvironmental reconstruction. This study bridges that gap by combining both datasets to produce a holistic interpretation.

Third, the results have practical implications for petroleum exploration and development in the Niger Delta. Understanding facies distribution, lithozones, and depositional settings improves reservoir characterization and can support exploration models in similar structural settings.

Finally, by comparing the findings from XY Well with results from other published wells in the Niger Delta and globally in analogous delta systems, the study situates local interpretations within a broader geological framework. This enhances its academic value and relevance to future research.

1.6 Scope and Limitations

Scope

This study is restricted to the analysis of ditch cutting samples from XY Well in the Niger Delta Basin. The focus is on sedimentological and palynological characterization of the well succession, with particular attention to lithofacies description, lithozone identification, and palynological zonation. The study integrates these datasets to reconstruct depositional environments and to situate the findings within the broader stratigraphic framework of the Niger Delta.

Limitations

The study is limited by the nature of the available data. Only ditch cutting samples were analyzed, which provide a general but less detailed view compared to core samples or high-resolution geophysical logs. Some fine-scale sedimentary structures and textural features could not be fully resolved. In addition, the absence of gamma ray logs constrained the ability to carry out detailed log-based facies correlation.

Palynological analysis was also affected by preservation quality, as some samples contained poorly preserved or reworked palynomorphs. Despite these limitations, the integration of sedimentological and palynological data yielded meaningful insights into the depositional environments and stratigraphy of the well.

1.7 Organisation of the Project

This project is organized into five chapters.

Chapter One provides the introduction to the study. It covers the background, statement of the problem, aim and objectives, research questions, significance, scope and limitations, and the organisation of the work.

Chapter Two presents the literature review. It discusses the geological setting and stratigraphy of the Niger Delta, highlights relevant sedimentological and palynological studies, and compares findings from similar delta systems worldwide.

Chapter Three outlines the materials and methods used in the study. It describes the ditch cutting samples analyzed, the procedures for sedimentological and palynological analysis, and the analytical workflow adopted.

Chapter Four presents and discusses the results. It includes the lithofacies description, lithostratigraphic framework, palynological results, depositional environment interpretation, and correlation with other Niger Delta studies.

Chapter Five provides the summary, conclusion, and recommendations. It highlights the key findings of the study, draws general conclusions, and suggests areas for future research.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter reviews previous studies and existing knowledge related to the geology, stratigraphy, depositional environments, and hydrocarbon potential of the **Niger Delta Basin** with particular emphasis on the **Agbada Formation**, where the **XY Well** is located. The review provides a scientific foundation for interpreting the sedimentological, mineralogical, and palynological data generated from this study.

The Niger Delta Basin is one of the most extensively studied sedimentary basins in West Africa due to its prolific hydrocarbon reserves and complex depositional architecture. Numerous authors, including **Short and Stauble (1967)**, **Evamy et al. (1978)**, **Doust and Omatsola (1990)**, **Reijers (2011)**, and **Alege (2024)**, have contributed significantly to understanding its geological evolution, lithostratigraphy, and petroleum system.

This review is divided into key thematic areas:

Overview of the Niger Delta Basin - highlighting its tectonic framework, stratigraphic succession, and sedimentary fill.

Lithostratigraphy and Depositional Systems - focusing on the Benin, Agbada, and Akata Formations, their facies characteristics, and depositional environments.

Palynological Studies and Biostratigraphy - examining how microfossil assemblages have been used to establish chronostratigraphic frameworks and environmental reconstructions.

Hydrocarbon Potential and Play Elements - summarizing the regional petroleum system and key reservoir–seal–source relationships within the Agbada Formation.

The purpose of this review is to provide a comprehensive theoretical background that supports the interpretation of results obtained from the XY Well. By synthesizing earlier findings, this chapter helps in correlating field data with existing geological models and enhances the accuracy of depositional and stratigraphic interpretations made in subsequent chapters.

2.1 Geological Setting of the Niger Delta

2.1.1 Regional Setting

The Niger Delta Basin is a large sedimentary province located on the Gulf of Guinea continental margin in southern Nigeria. It lies between latitudes 3°N and 6°N and longitudes 5°E and 8°E, covering about 75,000 km² onshore and extending over 200,000 km² offshore. Sedimentary thicknesses exceed 12 km in parts of the basin (Short & Stauble, 1967; Reijers, 2011). It is bounded to the north by the Benin flank, to the northeast by the Abakaliki anticline and Calabar hinge line, and to the west by the Okitipupa ridge (Avbovbo, 1978). The location of the Niger Delta within Nigeria is shown in **Fig. 2**.

2.1.2 Tectonic and Structural Framework

The evolution of the Niger Delta is linked to the rifting of the African and South American plates during the Late Jurassic to Early Cretaceous. Subsequent opening of the South Atlantic Ocean created accommodation space that was progressively filled with Tertiary sediments (Doust & Omatsola, 1990). Structurally, the basin is characterized by gravity tectonics induced by loading of undercompacted, overpressured Akata shales. This led to growth faulting, shale diapirism, roll-over anticlines, collapsed crest structures, and fault-related traps. These features play critical roles in hydrocarbon entrapment (Whiteman, 1982; Corredor, Shaw, & Bilotti, 2005).

2.1.3 Sediment Supply and Dispersal

Sediment input to the Niger Delta is dominated by the River Niger and its extensive tributary network. During the Tertiary, the system delivered massive volumes of sand, silt, and clay, which were deposited across delta plain, delta front, and pro-delta environments. These sediments were reworked by waves, tides, and relative sea-level fluctuations, creating a complex deltaic architecture (Allen, 1965; Oboh-Ikuenobe, Obi, & Jaramillo, 2005). The interaction of fluvial and marine processes produced the characteristic alternation of sandstone and shale successions.

2.1.4 Depobelts of the Niger Delta

The basin is subdivided into seven depobelts, which represent successive stages of delta progradation and lobe switching: Northern Delta, Greater Ughelli, Central Swamp, Coastal Swamp, Shallow Offshore, Deep Offshore, and Outer Deepwater. Each depobelt records a unique depositional history and structural style. The depobelts are shown in **Fig. 3**, which highlights their distribution across the basin (Doust & Omatsola, 1990; Reijers, 2011).

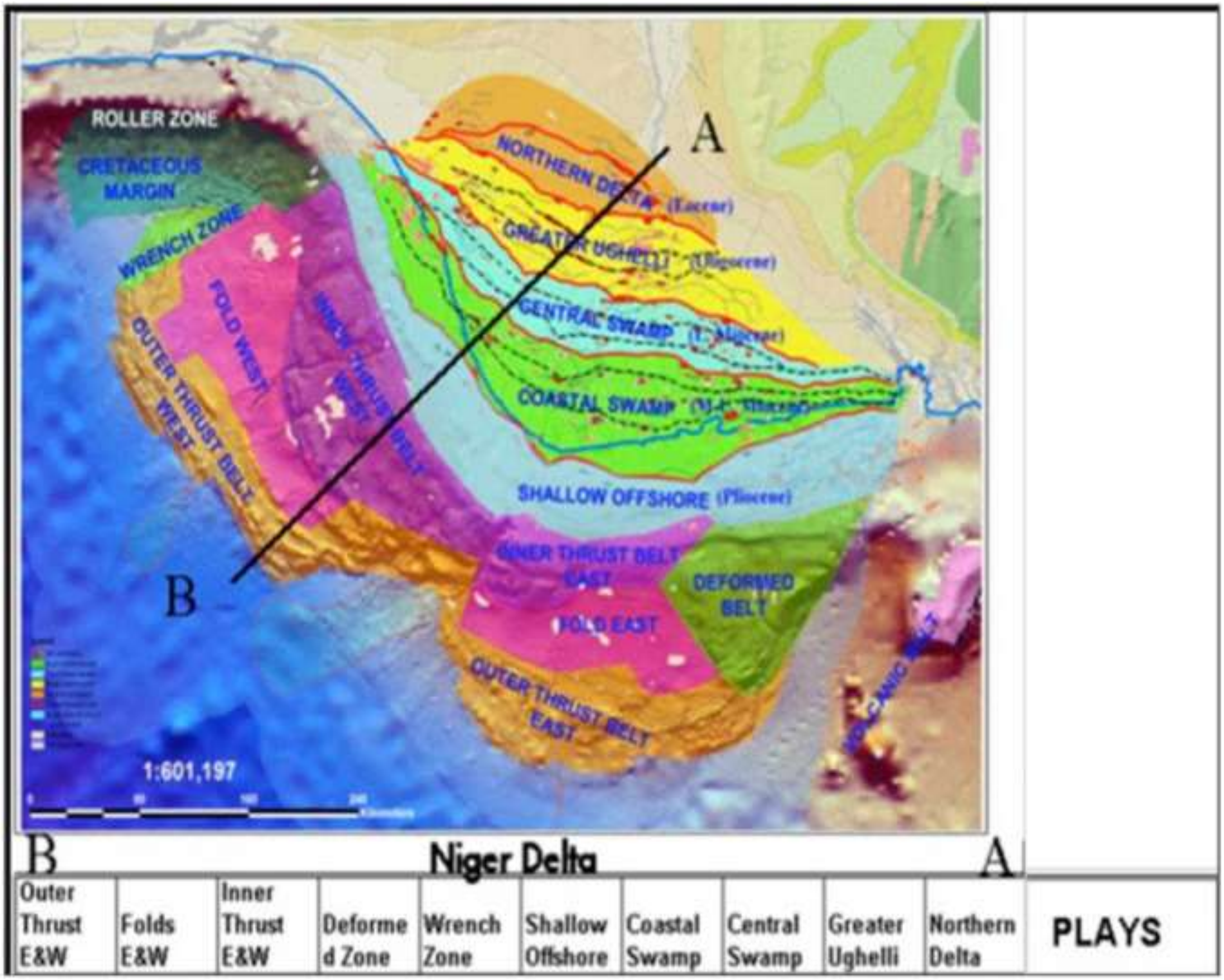


Figure 3: Map of the Niger Delta showing the seven depobelts ((modified from Ejedawe 2012)).

2.1.5 Basin Evolution

Deposition in the Niger Delta began in the Paleocene and has continued into the Recent. Early stages were dominated by alternating continental and shallow marine deposits. During the Oligocene to Miocene, rapid sedimentation and high fluvial discharge led to accelerated delta progradation. From the Pliocene to Recent, sedimentation was influenced by continued progradation, subsidence, and relative sea-level changes (Doust & Omatsola, 1990; Kulke, 1995; Morley, 2022). This long-term evolution produced the thick sedimentary wedge observed today.

2.1.6 Modern Processes and Environmental Setting

The present-day Niger Delta is shaped by the combined influence of fluvial, tidal, and wave processes. Its morphology includes distributary channels, tidal flats, estuaries, mangrove swamps, and shoreface environments. Seasonal variations in fluvial discharge and coastal oceanographic processes continue to control sediment dispersal and deposition. These modern settings serve as analogues for interpreting ancient depositional environments preserved within the stratigraphic record (Bhattacharya et al., 2023).

2.1.7 Significance for Sedimentological and Palynological Studies

Understanding the geological setting of the Niger Delta is essential for studies integrating sedimentology and palynology. The structural complexity of the basin affects facies distribution and preservation, while sediment supply and depositional processes influence palynomorph assemblages. For the XY Well, this context provides the foundation for interpreting the succession of sand, shale, and associated facies, as well as for correlating biostratigraphic zones with regional frameworks.

2.2 Stratigraphic Framework of the Niger Delta

The stratigraphy of the Niger Delta is traditionally divided into three major lithostratigraphic units: the Benin, Agbada, and Akata Formations. These represent continental, transitional, and marine depositional settings respectively, and together form the Tertiary sedimentary wedge of the delta (Short & Stauble, 1967; Avbovbo, 1978). A generalized stratigraphic column is shown in **Fig. 4**.

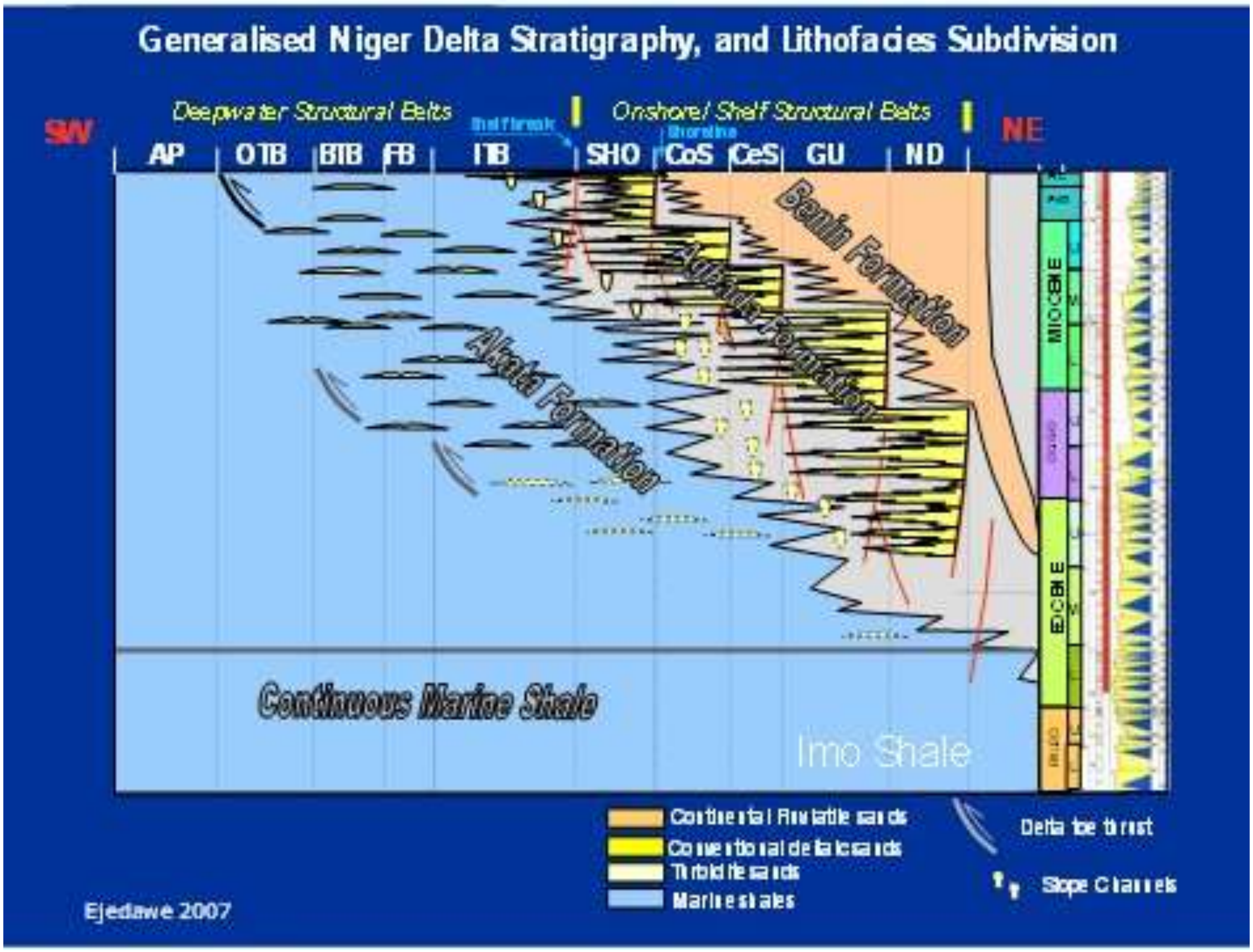


Figure 4: Generalized Niger Delta stratigraphy and Lithofacies subdivision (after Ejedawe, 2007).

The characteristics of these three formations are summarized in **Table 1**, which highlights their thicknesses, lithologies, depositional environments, and petroleum significance.

Table 1: Stratigraphic units of the Niger Delta (Benin, Agbada, Akata Formations) and their characteristics

(compiled from Short & Stauble, 1967; Avbovbo, 1978; Reijers, 2011)

Formation	Age	Thickness	Dominant Lithology	Depositional Environment	Petroleum Significance
Benin Formation	Oligocene-Recent	Up to 2,000 m	Coarse-grained sandstone, minor clay	Continental fluvial and alluvial deposits (upper delta plain)	Serves mainly as aquifer; minor reservoir potential
Agbada Formation	Eocene-Pliocene	3,000–4,500 m	Alternating sandstone and shale	Paralic to delta front (fluvial, distributary channels, mouth bars, shoreface)	Main reservoir rocks with interbedded shale acting as seals
Akata Formation	Paleocene-Recent	2,000–7,000+ m	Dark grey shale, minor turbidite sand	Pro-delta to deep marine	Principal source rocks; also acts as regional seal

2.2.1 Benin Formation

The Benin Formation is the youngest stratigraphic unit of the Niger Delta and is composed predominantly of continental, coarse-grained sandstones. These sediments represent alluvial and upper delta plain deposits formed in fluvial environments. The formation is up to 2,000 m thick in places and is generally devoid of marine fossils (Avbovbo, 1978; Reijers, 2011). Its sands are typically well sorted, with minor clay intercalations, reflecting high-energy fluvial deposition. The Benin Formation overlies the Agbada Formation unconformably in most areas.

2.2.2 Agbada Formation

The Agbada Formation forms the main petroleum-bearing unit of the Niger Delta. It consists of alternating sandstones and shales deposited in paralic to delta front environments. This unit records repeated transgressive-regressive cycles driven by changes in relative sea level and sediment supply (Doust & Omatsola, 1990). The thickness of the Agbada Formation varies from 3,000 to 4,500 m. Sandstones within this formation are the primary hydrocarbon reservoirs, while the interbedded shales act as seals. Palynological assemblages recovered from this unit provide age constraints ranging from Eocene to Pliocene (Evamy, Haremboure, Kamerling, Knaap, Molloy, & Rowlands, 1978; Kuye, Oboh-Ikuenobe, & Aigbedion, 2023).

2.2.3 Akata Formation

The Akata Formation forms the basal unit of the Niger Delta stratigraphy. It is composed mainly of dark grey to black, undercompacted, pro-delta shales with minor interbedded turbiditic sandstones. Thickness estimates range from 2,000 to over 7,000 m in offshore depobelts (Whiteman, 1982). The Akata shales are rich in organic matter and are considered the principal hydrocarbon source rocks of the Niger Delta (Doust & Omatsola, 1990; Corredor, Shaw, & Bilotti, 2005). The ductile nature of these shales has also played a significant role in gravity tectonics and the development of growth faults and diapirs in the basin.

2.2.4 Depositional Significance

The vertical succession of the Benin, Agbada, and Akata Formations reflects the progradation of a regressive delta system. The Benin Formation records continental deposition, the Agbada

Formation represents transitional to shallow marine environments, and the Akata Formation records deep marine deposition. Together, these units form a complete source–reservoir–seal system, making the Niger Delta one of the world’s most important petroleum provinces (Kulke, 1995; Reijers, 2011; Morley, 2022)

2.3 Principles of Sedimentology and Lithofacies Analysis

The sedimentology of the Niger Delta reflects the interplay of fluvial, tidal, and wave processes that controlled the deposition of clastic sediments during the Tertiary and Quaternary. The delta comprises a wide range of facies associations, including fluvial channel sands, delta plain deposits, distributary mouth bar sands, tidal flat deposits, shoreface sands, and pro-delta shales. These facies occur in coarsening- and fining-upward successions that reflect repeated progradational and transgressive episodes (Allen, 1965; Doust & Omatsola, 1990).

2.3.1 Fluvial and Delta Plain Facies

The upper delta plain is dominated by fluvial deposits of the Benin Formation. These consist mainly of coarse, moderately to well-sorted sandstones with cross-bedding, ripple marks, and occasional mud drapes. Channel migration and avulsion processes produced stacked sandstone bodies interbedded with thin floodplain clays and lignite horizons (Reijers, 2011). These deposits represent high-energy environments characterized by unidirectional currents.

2.3.2 Delta Front and Shoreface Facies

The delta front, represented largely within the Agbada Formation, consists of alternating sandstone and shale successions. Sandstones occur as mouth bar and distributary channel deposits, commonly showing coarsening-upward trends. Shales within this interval represent pro-delta and interdistributary bay deposits (Doust & Omatsola, 1990). Shoreface environments are represented by hummocky cross-stratified sandstones and bioturbated shales, reflecting storm- and wave-dominated conditions (Bhattacharya et al., 2023).

2.3.3 Pro-Delta Facies

The pro-delta environment is dominated by the fine-grained shales of the Akata Formation. These sediments were deposited in low-energy, offshore settings below storm wave base. They often contain turbidite sand interbeds, representing episodic gravity flows triggered by delta slope instability (Whiteman, 1982). These shales are rich in organic matter, making them excellent hydrocarbon source rocks (Corredor, Shaw, & Bilotti, 2005).

2.3.4 Facies Associations and Depositional Cycles

The alternation of sandstones and shales in the Agbada Formation reflects cyclic delta progradation, abandonment, and marine transgression. This produced repetitive coarsening-upward parasequences, typically 10-100 m thick, capped by marine flooding surfaces. These stacking patterns are consistent with a regressive deltaic system strongly influenced by eustatic sea-level fluctuations (Doust & Omatsola, 1990; Morley, 2022).

2.3.5 Depositional Model

The depositional model of the Niger Delta (Fig. 5) illustrates the distribution of facies from fluvial channels in the upper delta plain through distributary mouth bars, delta front, and shallow marine deposits to pro-delta shales. This model provides the sedimentological framework for interpreting lithofacies observed in individual wells such as XY.

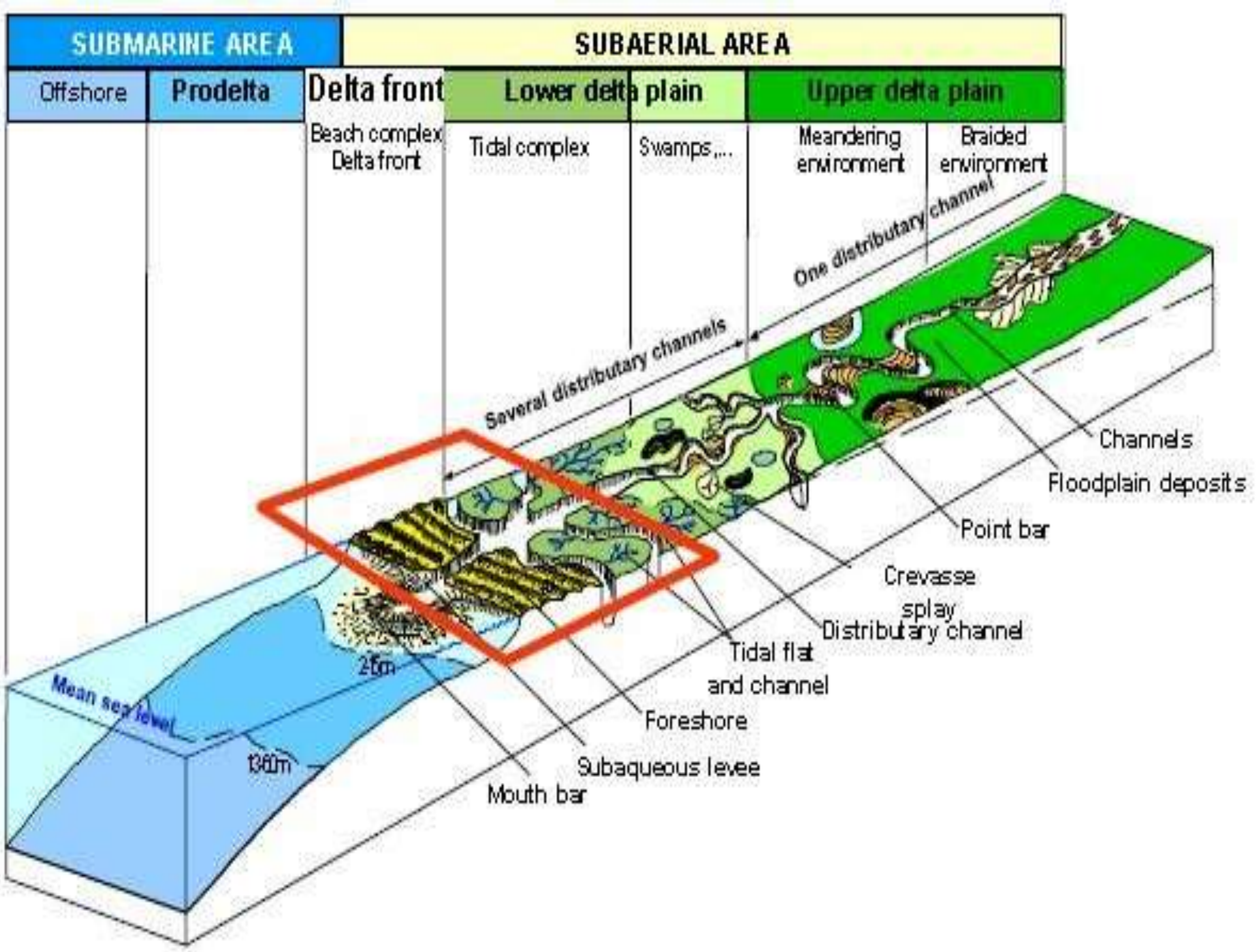


Figure 5: Niger Delta depositional environments and facies distributions (after TotalEnergies, 2021)

2.4 Depositional Environments in Deltaic Systems

Deltas represent the transition between terrestrial and marine depositional systems. Their environments are controlled by the interaction of fluvial input, wave action, tidal processes, sediment supply, and relative sea-level fluctuations. The resulting facies associations and stacking patterns vary according to the dominant processes in each delta (Bhattacharya et al., 2023; Morley, 2022).

2.4.1 Fluvial-Dominated Deltas

Fluvial-dominated deltas are controlled mainly by river discharge, with limited modification by marine processes. They are characterized by elongate delta lobes, distributary channels, and mouth bar deposits. Sedimentary successions typically display thick, channelized sand bodies with fining-upward trends. The Mississippi Delta in the Gulf of Mexico is a classic example, where repeated lobe switching produces a complex stratigraphic architecture (Coleman, 1981; Wang et al., 2024).

2.4.2 Wave-Dominated Deltas

Wave-dominated deltas form where wave action is strong enough to rework fluvial sediments along the coastline. These systems are characterized by well-developed shoreface sands, beach ridges, and barrier islands. Facies successions often show coarsening-upward trends capped by marine reworking surfaces. The Niger Delta exhibits significant wave influence, especially along its shoreline, where longshore drift redistributes sediments deposited by distributary channels (Doust & Omatsola, 1990; Bhattacharya et al., 2023).

2.4.3 Tide-Dominated Deltas

Tide-dominated deltas are shaped by strong tidal currents, which produce sand-dominated tidal bars, tidal flats, and mud drapes within distributary channels. The Mahakam Delta of Indonesia exemplifies a tide-dominated system, with tidal sand ridges and heterolithic facies recording bidirectional current activity (Allen & Chambers, 1998; Morley, 2022).

2.4.4 Mixed-Process Deltas

Many deltas, including the Niger Delta, are influenced by a combination of fluvial, wave, and tidal processes. In such settings, facies distribution is complex, reflecting shifts in the dominance of individual processes over time. The alternation of sand and shale successions in the Agbada Formation illustrates the interaction of riverine sediment supply with tidal and wave reworking (Reijers, 2011).

2.4.5 Comparative Depositional Models

A comparison of global deltas highlights the range of depositional environments that can develop within deltaic systems. The Mississippi Delta represents a fluvial-dominated system, the Mahakam Delta is tide-dominated, while the Orinoco and Amazon deltas show mixed-process influences. The Niger Delta fits into this spectrum as a mixed fluvial–wave–tidal delta, where process interactions vary across time and space (Coleman, 1981; Santos, Almeida, & Nogueira, 2023; Wang et al., 2024). The distribution of facies across these deltas is illustrated in Fig. 6, which compares their dominant processes and depositional patterns.

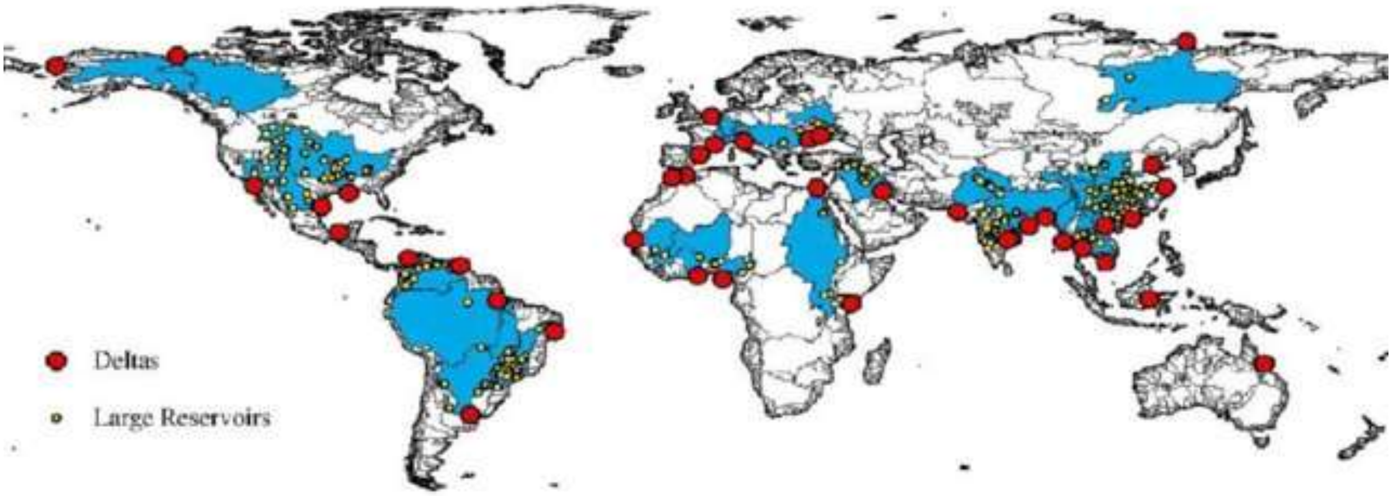


Figure 6: Global distribution of 40 large delta systems (Ericson et al., 2006)

The depositional characteristics of these deltas are summarized in **Table 2**, which compares their dominant processes, facies types, and depositional geometries.

Table 2: Comparative depositional environments of major world deltas

(compiled from Coleman, 1981; Doust & Omatsola, 1990; Morley, 2022; Bhattacharya et al., 2023; Santos, Almeida, & Nogueira, 2023)

Delta	Dominant Processes	Characteristic Facies	Depositional Geometry
Niger Delta	Fluvial, wave, and tidal (mixed influence)	Sand–shale alternations, distributary channels, mouth bars, tidal flats	Lobate delta with successive depobelts
Mississippi Delta (USA)	Fluvial-dominated	Thick channel sands, mouth bar sands, mud-draped floodplains	Bird-foot, elongate lobes
Mahakam Delta (Indonesia)	Tide-dominated	Heterolithic tidal sands, tidal bars, mudflats	Tidal sand ridges, funnel-shaped estuaries
Amazon Delta (Brazil)	Mixed fluvial–tidal	Silty clays, reworked sands, estuarine deposits	Large-scale estuarine mouth with tidal channels
Nile Delta (Egypt)	Wave-dominated	Shoreface sands, beach ridges, lagoonal muds	Smooth arcuate shoreline with beach ridges

2.5 Previous Sedimentological Studies in the Niger Delta

The sedimentology of the Niger Delta has been studied extensively over the last six decades, owing to the basin's petroleum significance and its complex depositional history. Research has ranged from regional stratigraphic frameworks to detailed well-based facies analyses, depositional environment reconstructions, and reservoir quality assessments. This section reviews major contributions from both classical and recent works, with emphasis on studies relevant to lithofacies characterization such as that undertaken in XY Well.

2.5.1 Classical Stratigraphic and Sedimentological Works

The earliest comprehensive work on the Niger Delta stratigraphy was by Short and Stauble (1967), who divided the subsurface sequence into three lithostratigraphic units: the Akata, Agbada, and Benin Formations. The Akata Formation was described as dominantly marine shales deposited in prodelta environments, the Agbada Formation as alternating sands and shales of delta-front and delta-plain origin, and the Benin Formation as continental sands deposited in fluvial to alluvial plain settings. Their study established the tripartite stratigraphic framework still used in modern research.

Whiteman (1982) interpreted the Niger Delta as a failed arm of a rift triple junction formed during the separation of Africa and South America in the Late Jurassic to Cretaceous. He emphasized tectonic control on sedimentation, noting how faulting, subsidence, and sediment supply governed the evolution of deltaic depobelts. Evamy et al. (1978) focused on the hydrocarbon habitat of the delta, highlighting how alternating sand and shale successions in the Agbada Formation created reservoirs and seals, while the organic-rich Akata shales served as the source rock.

Weber and Daukoru (1975) examined sedimentary and structural aspects of the delta, emphasizing the role of syn-sedimentary growth faults in creating accommodation space and petroleum traps. Their sedimentological descriptions revealed the heterogeneity of sand-shale alternations and the importance of depositional cycles in controlling reservoir quality. Reyment (1959) and Germeraad et al. (1968) provided early micropaleontological studies that refined biozonations, further supporting the stratigraphic framework and depositional models of the delta.

2.5.2 Sedimentology, Lithofacies, and Depositional Environments

The Niger Delta has been described as a classic example of a tide- and wave-influenced delta (Doust & Omatsola, 1990; Reijers, 2011). Detailed sedimentological studies show that lithofacies associations include channel sands, mouth bars, shoreface sands, tidal heteroliths, and prodelta muds. Weber and Daukoru (1975) emphasized how distributary channel migration and lobe switching controlled facies stacking patterns.

Facies analysis in well studies often highlights sand, shale, shaly sand, and siltstone units. For example, Oboh (1992) reconstructed Middle Miocene paleoenvironmental conditions using palynology, revealing cyclic alternations of marine flooding and regressive phases. Fadiya (1999) combined foraminiferal and calcareous nannofossil data with log analysis to establish sequence stratigraphy in Opolo wells, showing how maximum flooding surfaces and sequence boundaries controlled facies architecture. These findings resonate with XY Well data where sands, shales, and shaly sands alternate vertically (see Table 2 in this document), reflecting repeated changes in depositional energy and accommodation.

2.5.3 Geochemical and Provenance Studies

Lithofacies characterization is often complemented by geochemical analysis. Bhatia (1983) proposed tectonic discrimination diagrams for sandstones, while Roser and Korsch (1986) developed discriminant function analyses that use major oxides to distinguish provenance types (mafic, felsic, quartzose sedimentary). Herron (1988) provided a geochemical classification for sands and shales that has since been widely applied in Niger Delta studies. In XY Well, sediments plotted as Fe-shale, Fe-sand, sublitharenite, and quartz arenite (Fig. 15 in this document), consistent with other Agbada Formation successions.

Nesbitt and Young (1982) introduced the Chemical Index of Alteration (CIA), while Harnois (1988) proposed the Chemical Index of Weathering (CIW). These indices have been used to infer weathering intensity in source areas of Niger Delta sediments. In XY Well, CIA values range between 48.6 and 94.9% and CIW values between 60.6 and 96.7% (Table 23 in this document), indicating moderate to high weathering at the source, consistent with humid tropical climatic conditions reported by McLennan et al. (1993).

2.5.4 Reservoir Quality and Diagenesis

Reservoir characterization in the Niger Delta has also focused on how sedimentological facies relate to reservoir quality. Diagenetic studies (Overare et al., 2024) demonstrate that porosity reduction occurs due to cementation, compaction, and mineral overgrowths, especially in Agbada sands. Aigbadon et al. (2024) identified facies-dependent porosity in Usani reservoirs, with bioturbated sandstones averaging 14-28% porosity and permeability values up to 455 mD. Similarly, Arochukwu et al. (2023) in the Central Swamp depobelt showed that shoreface and distributary mouth bar sands have significantly higher reservoir quality than interdistributary bay or heterolithic facies.

2.5.5 Sequence Stratigraphy and High-Resolution Studies

Modern sedimentological work integrates sequence stratigraphy to link facies to basin-scale processes. Catuneanu (2006) emphasized the significance of maximum flooding surfaces (MFS) and sequence boundaries (SB) in reconstructing depositional cycles. Ocheli et al. (2023) applied high-resolution palynostratigraphy and sedimentology in KW Field wells to identify depositional sequences and cyclic stratigraphy. Oluwadare et al. (2024) used 3-D seismic data offshore Niger Delta to map sequences and depositional breaks, demonstrating the role of sequence stratigraphy in predicting reservoir architecture.

2.5.6 Summary

Collectively, these studies show that while the regional stratigraphy and depositional models of the Niger Delta are well established, detailed well-specific sedimentological characterization remains critical. Facies heterogeneity, diagenetic modification, and sequence stratigraphic complexity continue to challenge reservoir prediction. The XY Well study contributes to this body of work by constructing a dedicated lithofacies model, refining depositional environment interpretations, and linking facies characteristics to reservoir quality.

2.6 Sedimentological and Lithofacies Studies in Other Basins (Comparative Works)

Sedimentological and lithofacies studies in basins worldwide provide valuable comparative frameworks for understanding depositional processes and reservoir characteristics. These studies highlight how basin tectonics, sediment supply, and marine processes influence lithofacies architecture, and they offer analogues that can be applied to the Niger Delta.

2.6.1 Mississippi Delta, USA

The Mississippi Delta has been extensively studied as a classic fluvial-dominated delta system. Coleman (1981) and Bhattacharya and Giosan (2003) described its lobate geometry, distributary channels, and mouth bar successions. Lithofacies studies reveal thick, channelized sand bodies with fining-upward trends, reflecting repeated lobe switching. More recent work by Gani and Gani (2024) has emphasized high-resolution sequence stratigraphy, showing that fluvial processes dominate sediment dispersal, but storm and tidal modifications are also evident.

2.6.2 Mahakam Delta, Indonesia

The Mahakam Delta is a tide-dominated delta characterized by heterolithic facies. Allen and Chambers (1998) and Storms, Hoitink, and Kroonenberg (2008) documented tidal sand ridges, funnel-shaped estuaries, and heterolithic successions with mud drapes that indicate bidirectional current activity. Lithofacies models from the Mahakam provide analogues for interpreting heterolithic sequences in the Niger Delta, particularly where tidal influence is significant.

2.6.3 Orinoco and Amazon Deltas, South America

The Orinoco and Amazon deltas are large mixed-process systems influenced by fluvial discharge, tides, and waves. Santos, Almeida, and Nogueira (2023) noted that the Amazon Delta exhibits massive fine-grained sedimentation, with tidal channels and estuarine deposits dominating the coastal zone. Lithofacies associations include silty clays and reworked sands, which differ markedly from the sand-rich Niger Delta but highlight the variability of mixed-process deltas.

2.6.4 Nile Delta, Egypt

The Nile Delta represents a wave-dominated system. Stanley and Warne (1998) documented arcuate shorelines, beach ridges, and reworked coastal sands as the dominant lithofacies. These deposits differ from fluvial-dominated deltas but provide an analogue for wave-modified shoreface successions in the Niger Delta.

2.6.5 Other Clastic Basins

Sedimentological studies outside deltaic systems also offer insights into lithofacies models. In the North Sea Basin, Steel and Milliken (2013) described shoreface and barrier island successions with complex diagenetic overprints affecting reservoir quality. In the Gulf of Mexico, Posamentier and Kolla (2003) emphasized the role of slope processes and turbidite deposition in deep-water settings, which provide useful analogues for the deep-water depobelts of the Niger Delta.

2.6.6 Relevance to the Niger Delta

These comparative studies highlight that lithofacies successions vary depending on the dominant processes in each basin. While the Niger Delta is a mixed-process delta, it shares attributes with fluvial-dominated deltas (Mississippi), tide-dominated deltas (Mahakam), and wave-dominated deltas (Nile). Lessons from these global systems improve the interpretation of depositional environments in the XY Well by providing analogues for facies successions and depositional processes.

2.7 Palynology and Biostratigraphy of the Niger Delta

Palynology has played a central role in establishing the chronostratigraphy and depositional framework of the Niger Delta. Since the 1970s, palynological zonation has provided a reliable tool for age dating, correlation, and environmental reconstruction. Early studies by Evamy, Haremboure, Kamerling, Knaap, Molloy, and Rowlands (1978) and Jan du Chêne, Onyike, and Sowunmi (1978) defined the first comprehensive palynological zonation for the basin. Later works (Oboh-Ikuenobe, Obi, & Jaramillo, 2005; Odinaka et al., 2025; Haruna et al., 2025) refined this framework and demonstrated its value in integrated petroleum exploration.

2.7.1 Role of Palynology in the Niger Delta

Palynomorphs are abundant in Niger Delta sediments and provide both stratigraphic and paleoenvironmental information. Taxa such as *Zonocostites ramonae* are diagnostic of mangrove swamp environments, while *Monoporites annulatus* reflects freshwater swamp and delta plain settings. Marine dinoflagellates such as *Spiniferites* indicate open marine influence. Their stratigraphic ranges make them excellent biostratigraphic markers, while their ecological preferences help reconstruct depositional environments (Oboh-Ikuenobe et al., 2005).

2.7.2 Palynological Zonation (P-Zones)

The Niger Delta palynological framework spans the Paleocene to Recent. Zones are defined by the first and last occurrences of key marker taxa, and they have been widely used in exploration and academic studies. This standard zonation is illustrated in Fig. 7 and summarized in Table 3.

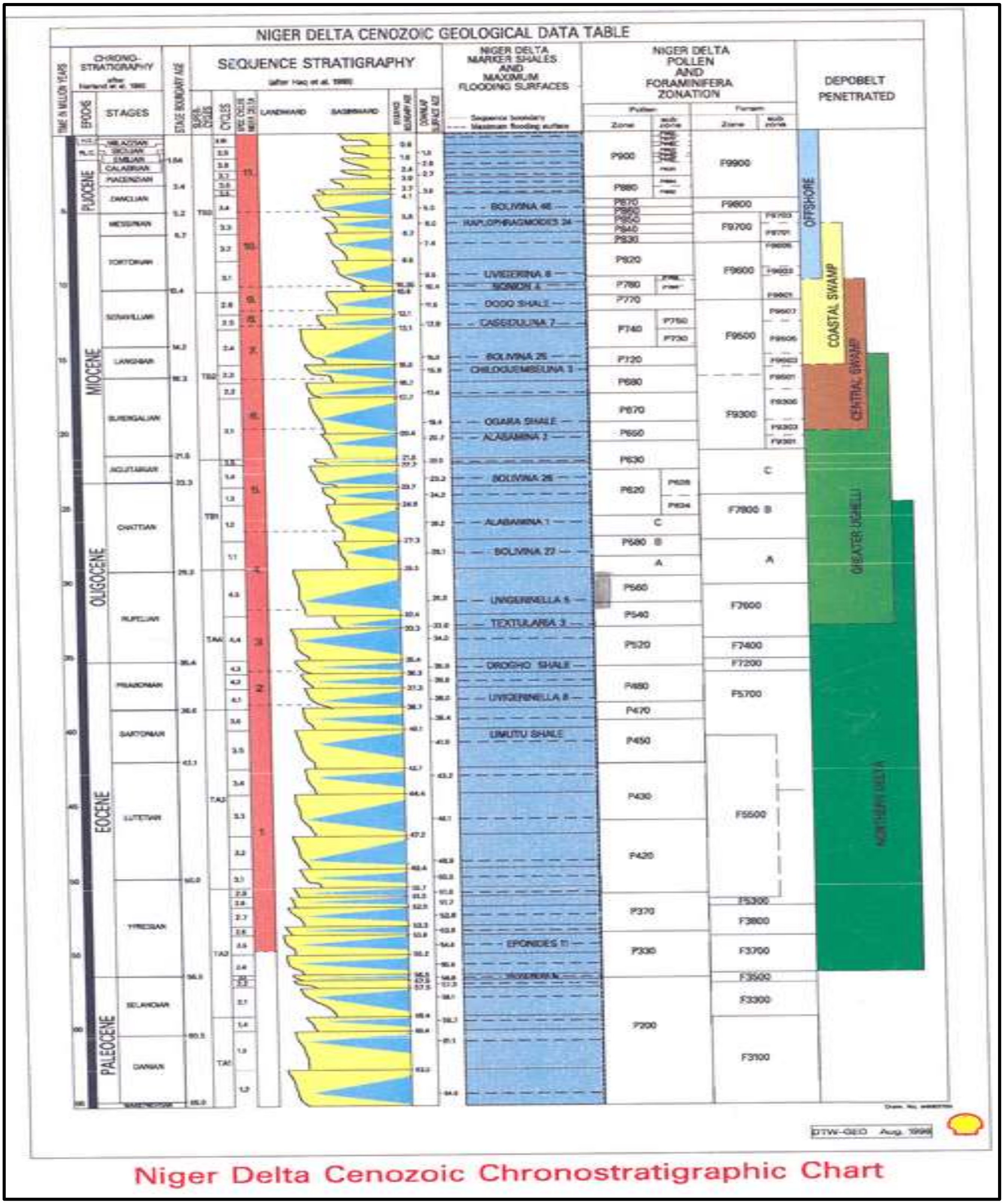


Figure 7: Niger Delta Cenozoic Chronostratigraphic Chart (SPDC)

Table 3: Palynological zonations of the Niger Delta and corresponding marker taxa (Evamy et al., 1978; Jan du Chêne et al., 1978; updated Odinaka et al., 2025; Haruna et al., 2025).

Zone (P-Zone)	Age	Key Marker Taxa	Significance
P860-P850	Paleocene	*Spinizonocolpites baculatus*	Marks base of deltaic sedimentation
P720	Eocene	*Psilatricolporites crassus*, *Monocolpopollenites sphaeroidites*	Early delta progradation
P660	Oligocene	*Retidiporites magdalenensis*	Records marine flooding surface
P620/P580	Early–Middle Miocene	*Praedapollis africanus*, *Peregrinipollis nigericus*	Key for Miocene correlation
P560	Middle Miocene	*Retibrevitricolporites obodoensis*	Refines Miocene stratigraphy
P480-Recent	Pliocene–Recent	*Zonocostites ramonae* (mangrove), *Monoporites annulatus* (freshwater)	Coastal swamp and fluvial indicators

2.7.3 Stratigraphically Significant Palynomorphs

Among the many palynomorphs recovered from Niger Delta sediments, several are of particular stratigraphic importance. In the XY Well, three diagnostic taxa were identified:

Praedapollis africanus - characteristic of the Early to Middle Miocene (P620/P580 zones).

Peregrinipollis nigericus - a key marker for Miocene correlation.

Retibrevitricolporites obodoensis – important for defining the Middle Miocene P560 zone.

Other significant taxa include *Zonocostites ramonae* (Pliocene-Recent, mangrove indicator) and *Monoporites annulatus* (Miocene–Recent, freshwater indicator). Their stratigraphic ranges are shown in Table 4.

Table 4: Stratigraphically significant palynomorphs identified in the Niger Delta and their known stratigraphic ranges (compiled from Evamy et al., 1978; Adeonipekun et al., 2023; Odinaka et al., 2025).

Palynomorph	Stratigraphic Range	Age Significance
Praedapollis africanus	Early-Middle Miocene	Defines Miocene P620/P580 zones
Peregrinipollis nigericus	Early-Middle Miocene	Regional marker in Miocene succession
Retibrevitricolporites obodoensis	Middle Miocene	Marker for P560 zone
Zonocostites ramonae	Pliocene-Recent	Coastal swamp/mangrove indicator
Monoporites annulatus	Miocene-Recent	Freshwater swamp/delta plain indicator

2.7.4 Applications in Biostratigraphy and Paleoenvironmental Studies

Palynological data have been integrated with sedimentology to refine depositional models and improve well correlations. For example, the abundance of *Zonocostites ramonae* indicates coastal swamp deposition, while increased frequencies of *Monoporites annulatus* suggest fluvial influence. The presence of marine dinoflagellates provides evidence for marine incursions. This multi-proxy approach has been successfully applied in both exploration and academic studies (Oboh-Ikuenobe et al., 2005; Haruna et al., 2025). In the XY Well, the recovered palynomorphs help constrain Miocene depositional environments and provide critical support for facies interpretations.

2.8 Summary and Identified Gaps

The literature reviewed shows that the Niger Delta has been extensively studied in terms of its geology, stratigraphy, and petroleum system elements. Foundational works (Allen, 1965; Short & Stauble, 1967; Avbovbo, 1978) established the stratigraphic and sedimentological framework, while subsequent studies (Doust & Omatsola, 1990; Reijers, 2011) advanced understanding of depositional processes, sequence stratigraphy, and facies models. More recent works (Oboh-Ikuenobe et al., 2005; Odinaka et al., 2025; Haruna et al., 2025) have emphasized integrated sedimentological, palynological, and geochemical approaches. Comparative studies from other deltas, such as the Mississippi, Mahakam, and Amazon, provide useful global analogues.

Despite this progress, certain research gaps remain:

Well-specific lithofacies characterization: While regional sedimentological models exist, fewer studies provide detailed facies analysis from individual wells using ditch cuttings.

Integration of sedimentology and palynology: Many works treat sedimentology and palynology separately. Integrated studies that link facies to palynological assemblages for environmental reconstruction are still limited.

High-resolution biostratigraphy: Although palynological zonations are well established, more recent high-resolution refinements have not been consistently applied across all wells.

Reservoir heterogeneity and facies variability: Comparative studies indicate variability in facies architecture across depobelts, but well-scale heterogeneity remains underexplored in several parts of the delta.

Application to the XY Well: No published work has yet documented the detailed lithofacies description, palynological assemblages, and depositional environment interpretation for this specific well.

This study addresses these gaps by carrying out a combined sedimentological and palynological analysis of ditch cuttings from the XY Well. The results will provide new insights into facies variability, depositional processes, and biostratigraphic control within the Niger Delta Basin.

CHAPTER THREE

MATERIALS AND METHODS

3.0 Introduction

This chapter presents the materials and methods employed in the study of the **XY Well** in the Niger Delta Basin. The study integrates sedimentological, mineralogical, and palynological analyses to characterize the lithostratigraphic succession, interpret depositional environments, and assess the hydrocarbon potential of the penetrated formations.

The materials used in this study include ditch cutting samples obtained from the XY Well and various laboratory instruments for microscopic and palynological analyses. A total of **190 ditch cutting samples** were collected at consistent depth intervals ranging from **20 ft to 11,820 ft**, covering the entire stratigraphic succession penetrated by the well. These samples were subjected to detailed macroscopic and microscopic descriptions to determine grain size, sorting, texture, color, mineral composition, and fossil content.

The methods adopted include sedimentological logging, mineral identification, and palynological processing. Each analytical step was guided by standard geological and micropaleontological procedures as described by **Tucker (2003)**, **Reijers (2011)**, and **Traverse (2007)**. The workflow involves:

Sedimentological Description - to classify lithofacies and identify potential reservoir and source intervals.

Mineralogical Assessment - to determine the compositional variations and diagenetic signatures.

Palynological Analysis - to identify age-diagnostic palynomorphs and reconstruct depositional environments.

Integration of Results - to establish the sequence stratigraphic framework of the XY Well and interpret its depositional model within the Agbada Formation.

The analytical framework adopted for this research ensures that both the **lithologic characteristics** and **palynological data** are adequately integrated to produce a comprehensive geologic interpretation of the studied interval.

3.1 Data Source

The primary dataset for this study was obtained from the XY Well located in the Niger Delta Basin (Fig. 2). A total of one hundred and ninety (190) ditch cutting samples were recovered at regular depth intervals from the well. These samples represent the entire stratigraphic succession penetrated, thereby providing continuous lithological coverage for sedimentological description.

Two lithostratigraphic units were identified in the well: the Benin Formation, dominated by continental fluvial sandstones, and the Agbada Formation, characterized by alternating sandstones and shales. Detailed examination of the ditch cuttings resulted in the recognition of forty-nine (49) lithofacies zones, which formed the basis for lithological and facies analysis.

In addition, palynological data were generated from selected samples within the succession. This involved microscopic analysis of palynomorphs for biostratigraphic zonation and paleoenvironmental reconstruction. Together, the sedimentological and palynological datasets form the foundation of this study.

3.2 Methods of Sedimentological Analysis

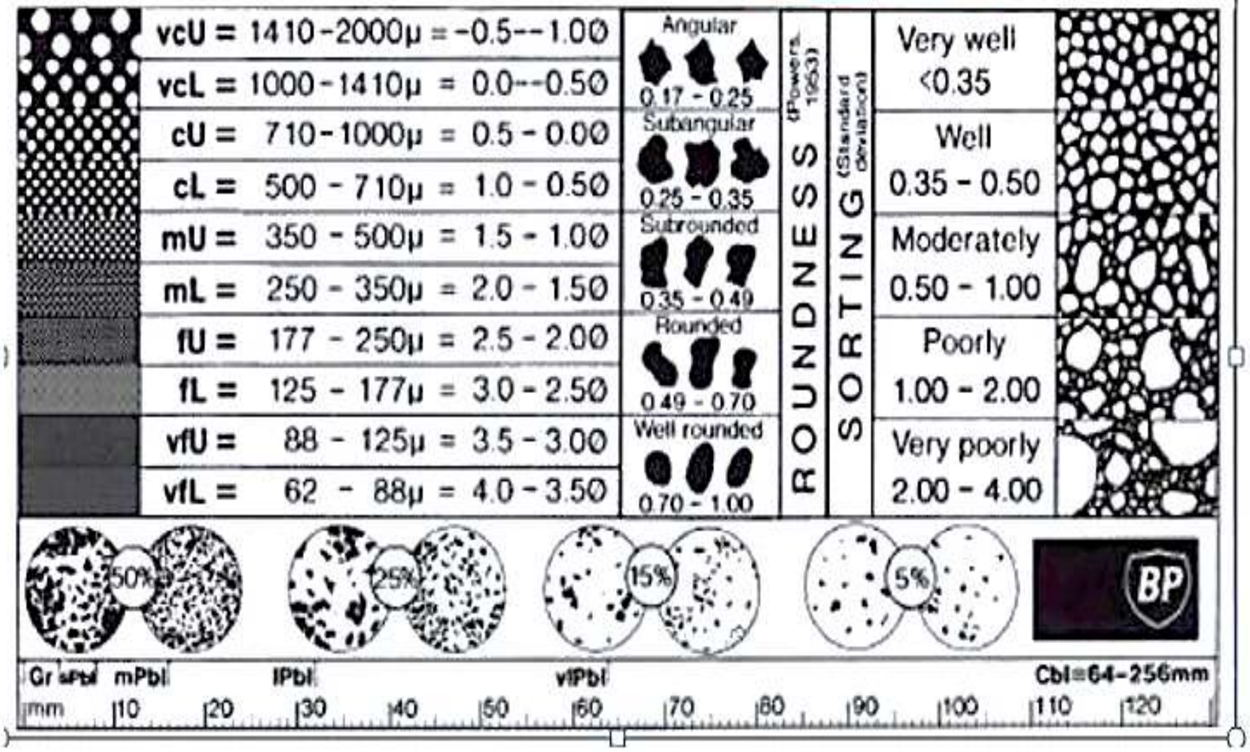
Sedimentological analysis of the XY Well ditch cuttings was carried out to establish lithological variations and identify distinct facies successions. Standard descriptive methods outlined by Folk (1980), Tucker (2003), and Reijers (2011) were followed.

3.2.1 Sample Handling and Labeling

A total of one hundred and ninety (190) ditch cutting samples were received from the XY Well. Each sample was carefully labeled according to its depth interval to ensure proper stratigraphic positioning. The samples were stored in sealed polythene bags to prevent contamination and were arranged sequentially for description.

3.2.2 Grain Size Analysis

Grain size was estimated visually under a binocular microscope and hand lens. Textural classes such as clay, silt, fine sand, medium sand, and coarse sand were distinguished using the Udden–Wentworth grain-size scale (Folk, 1980). Vertical grain-size trends were documented to recognize coarsening- or fining-upward successions. A generalized grain-size classification chart is presented in **Fig. 8**.



vcU = 1410-2000µ = -0.5--1.00
vcL = 1000-1410µ = 0.0--0.50
cU = 710-1000µ = 0.5 - 0.00
cL = 500 - 710µ = 1.0 - 0.50
mU = 350 - 500µ = 1.5 - 1.00
mL = 250 - 350µ = 2.0 - 1.50
fU = 177 - 250µ = 2.5 - 2.00
fL = 125 - 177µ = 3.0 - 2.50
vfU = 88 - 125µ = 3.5 - 3.00
vfL = 62 - 88µ = 4.0 - 3.50

Figure 8: Grain size classification chart adapted from Folk (1980).

3.2.3 Sorting and Grain Shape

Sorting was described qualitatively as well sorted, moderately sorted, or poorly sorted, depending on grain-size uniformity. Grain shape was assessed using standard comparative charts of roundness and sphericity, which provide information on transport history and depositional energy (Tucker, 2003; Reijers, 2011).

3.2.4 Lithofacies Identification

Facies were identified based on a combination of textural properties, color, mineral composition, and observable sedimentary features in the cuttings. The main facies include sand, shale, sandy shale, shaly sand, sandy silt, silt, and clayey sand. Facies distribution was logged, and changes were used to define lithozones. The overall workflow followed in facies analysis is shown in **Fig. 9**.

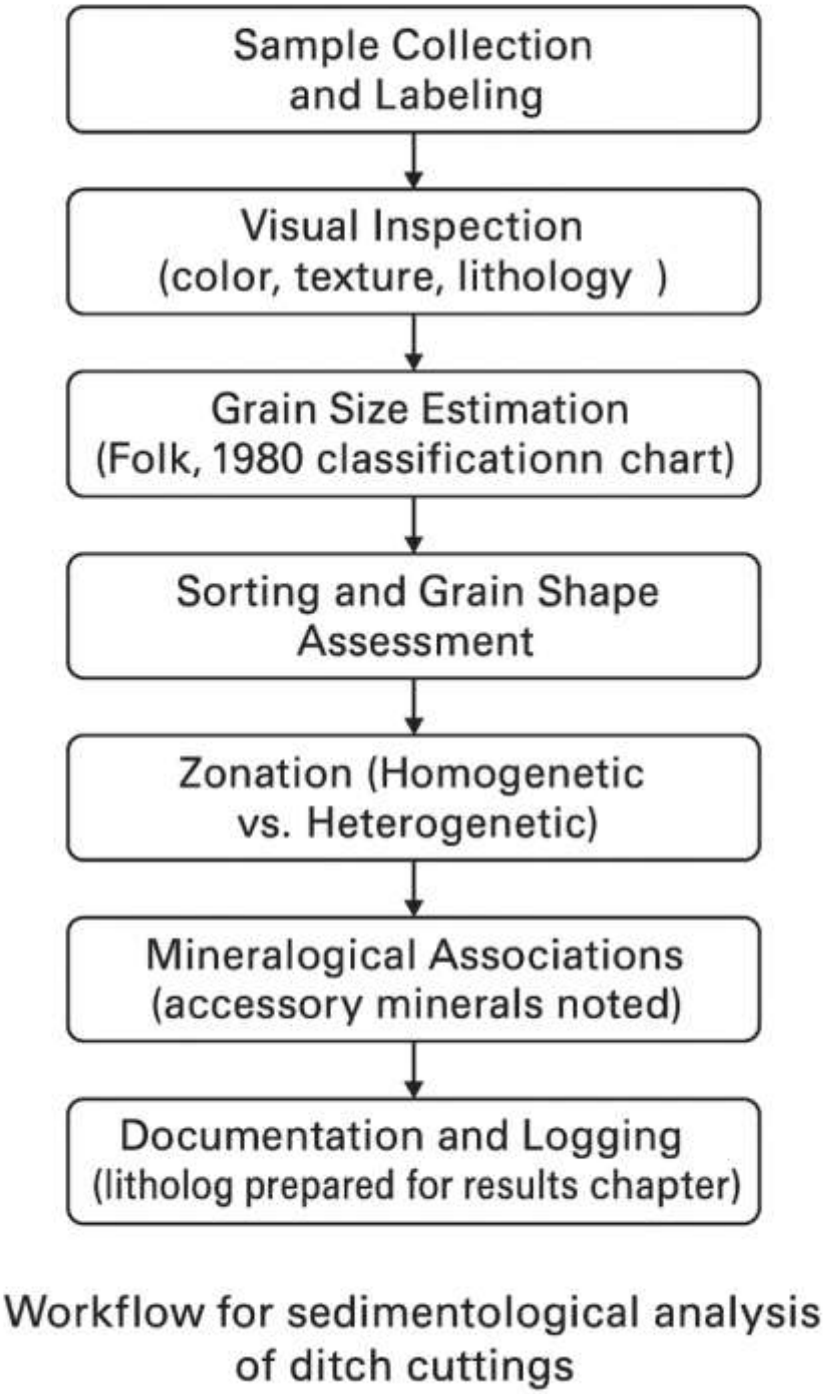


Figure 9: Workflow for sedimentological analysis of ditch cuttings

3.2.5 Homogenetic and Heterogenetic Zones

The well succession was further subdivided into homogenetic zones (dominated by a single facies type, e.g., thick sandstone or shale intervals) and heterogenetic zones (alternating facies such as sand–shale successions). This classification, commonly used in Niger Delta studies (Doust & Omatsola, 1990; Reijers, 2011), helps distinguish intervals of relative environmental stability from those influenced by changing depositional conditions.

3.2.6 Mineralogical Associations

Mineralogical observations were made using a binocular microscope. Accessory minerals such as feldspars, micas, iron oxides, and pyrite inclusions were recorded. Their presence provides insights into provenance (e.g., feldspars indicating granitic source rocks), diagenesis (e.g., iron oxides reflecting oxidation), and redox conditions (e.g., pyrite indicating reducing environments) (Tucker, 2003; Wilson, 2014).

3.3 Methods of Palynological Analysis

Palynological analysis was carried out on selected ditch cutting samples from the XY Well to establish biostratigraphic zonation and reconstruct depositional environments. Standard laboratory methods for the recovery of acid-resistant organic microfossils were employed, following procedures described by Traverse (2007), Oboh-Ikuenobe et al. (2005), and Alege (2024).

3.3.1 Sample Selection and Labeling

Representative ditch cutting samples were chosen at regular depth intervals across the stratigraphic succession. Each sample was labeled with its corresponding depth to ensure accurate stratigraphic positioning (Fig. 10).

3.3.2 Chemical Treatment

Samples were subjected to a series of acid treatments to remove unwanted mineral matter:

Carbonates removal: 10% hydrochloric acid (HCl).

Silicates removal: 40% hydrofluoric acid (HF).

Neutralization: multiple washes with distilled water until neutral pH was attained. These steps ensured preservation of organic-walled microfossils (Traverse, 2007).

3.3.3 Sieving and Concentration

Residues were sieved through a 10 µm mesh to concentrate palynomorphs. Light oxidation using nitric acid (HNO_3) was applied selectively to remove excess organic matter. In some cases, safranin stain was used to enhance visibility of palynomorphs under the microscope.

3.3.4 Slide Preparation and Microscopy

Concentrated residues were mounted on glass slides using glycerin jelly. Each slide was examined under a transmitted light microscope at magnifications of ×400 and ×1000. Palynomorphs were identified to species level using standard taxonomic keys and published reference collections (Evamy et al., 1978; Jan du Chêne et al., 1978; Adeonipekun et al., 2023).

3.3.5 Palynomorph Identification and Counting

Counts of individual palynomorphs were made to determine relative abundance and vertical distribution. Both pollen/spores and dinoflagellate cysts were recorded. The data were compiled into distribution charts that allowed correlation with established Niger Delta palynological zonations (Evamy et al., 1978; Odinaka et al., 2025).

3.3.6 Biostratigraphic and Paleoenvironmental Interpretation

Identified palynomorph assemblages were interpreted in terms of their stratigraphic significance and environmental preferences, following the workflow illustrated in Figure 10. The integration of palynological data with sedimentological observations provided a consistent framework for biostratigraphic and paleoenvironmental interpretation.

For instance:

- Praedapollis africanus, Peregrinipollis nigericus, and Retibrevitricolporites obodoensis were used for Miocene zonal assignments.
- Zonocostites ramonae was taken as an indicator of mangrove swamp environments.
- Monoporites annulatus was interpreted as representing freshwater swamp or delta-plain settings.
- Marine dinoflagellates such as Spiniferites indicated periodic marine incursions.

These interpretations were integrated with lithological results to reconstruct depositional environments in the XY Well succession, as outlined in the analytical sequence (Fig. 10).

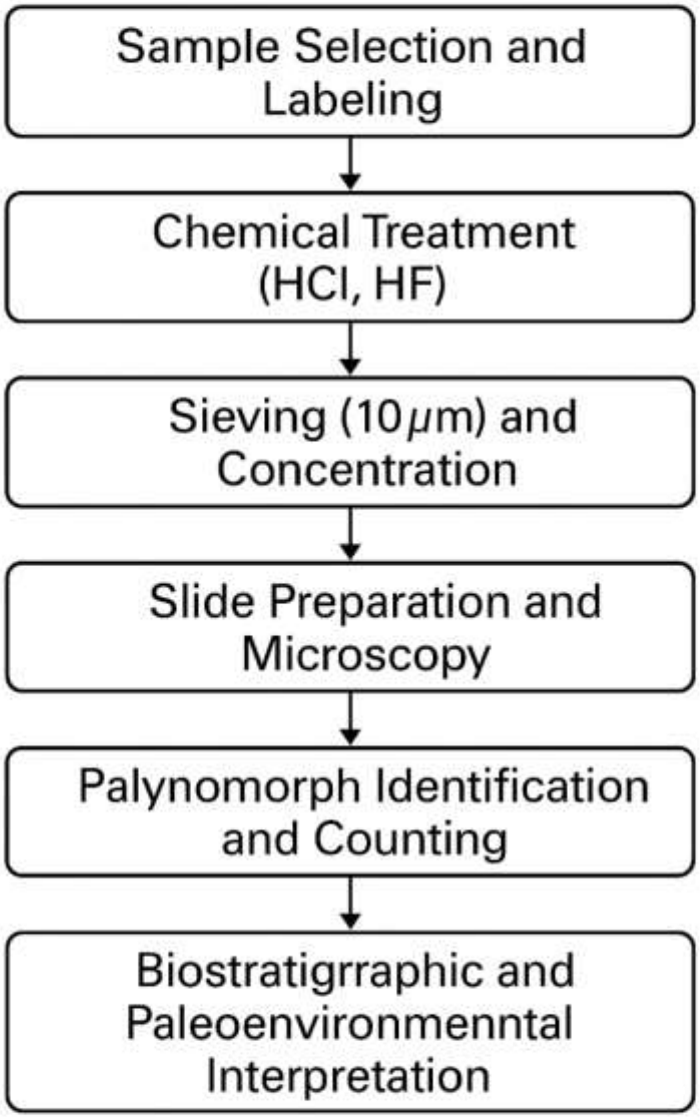


Figure 10: Workflow for palynological analysis of ditch-cutting samples (modified after Reijers 2011; Oboh-Ikuenobe et al., 2005).

3.4 Analytical Workflow

The analytical workflow adopted in this study integrated sedimentological and palynological methods to provide a comprehensive understanding of the XY Well succession. The steps are summarized as follows:

Data Collection

Recovery of 190 ditch cutting samples from the XY Well.

Depth labeling and sequential arrangement for analysis.

Sedimentological Description

Grain size estimation, sorting, and grain shape assessment using comparative charts (Folk, 1980; Tucker, 2003).

Identification of lithofacies (sand, shale, silt, and mixed facies).

Subdivision of the succession into homogenetic and heterogenetic zones.

Mineralogical assessment of accessory minerals such as quartz, feldspar, mica, and pyrite.

Palynological Analysis

Chemical treatment of samples to remove carbonates and silicates (Traverse, 2007).

Concentration and sieving to isolate organic residues.

Preparation of slides and microscopic examination at ×400 and ×1000 magnifications.

Identification of stratigraphically significant palynomorphs (*Praedapollis africanus*, *Peregrinipollis nigericus*, *Retibrevitricolporites obodoensis*).

Quantitative counts and preparation of palynomorph distribution charts.

Integration of Results

Correlation of lithofacies trends with palynomorph assemblages.

Application of palynological zonation schemes (Evamy et al., 1978; Jan du Chêne et al., 1978; Odinaka et al., 2025) to refine stratigraphic interpretation.

Reconstruction of depositional environments based on combined lithological and palynological evidence.

This integrated workflow (Fig. 11) ensured that both lithological characteristics and microfossil assemblages were systematically analyzed, allowing for robust interpretation of depositional environments and biostratigraphic control in the XY Well.

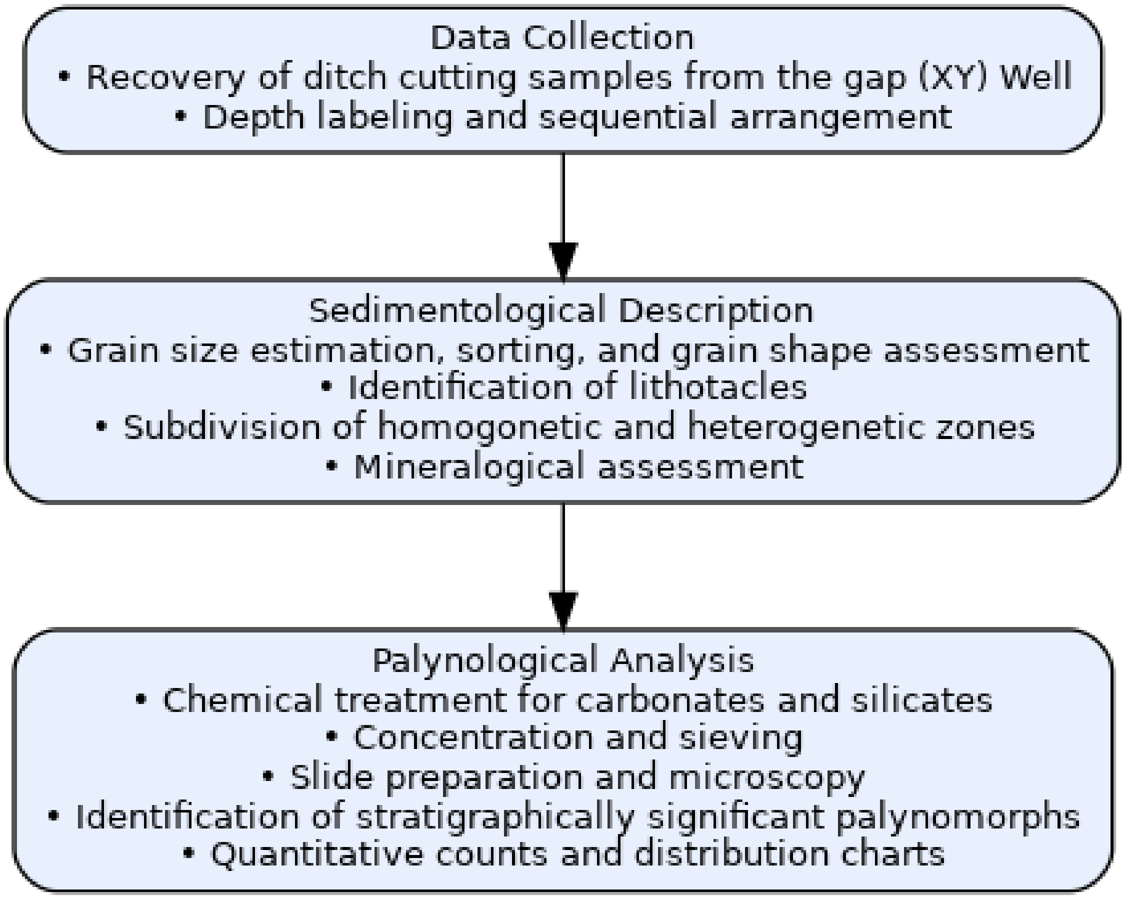


Figure 11: Integrated analytical workflow combining sedimentological and palynological methods used in this study (modified from Reijers, 2011; Oboh-Ikuenobe et al., 2005).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents the results obtained from the sedimentological, mineralogical, and palynological analyses conducted on samples from the **XY Well** in the Niger Delta Basin. The interpretation integrates field data, laboratory descriptions, and analytical results to reconstruct the depositional environments and evaluate the hydrocarbon potential of the studied interval.

A total of 190 ditch cutting samples from the XY Well were analyzed to determine their lithological composition, texture, and microfossil content. The integration of sedimentological and palynological data provides a detailed understanding of the stratigraphic framework and the paleoenvironmental conditions that prevailed during deposition.

The results are presented in sequential subsections beginning with sedimentological observations, followed by the identification of hydrocarbon play elements, mineralogical composition, palynological interpretations, and sequence stratigraphic implications. Each subsection discusses the findings in relation to established studies within the Niger Delta Basin and other comparable deltaic systems.

Overall, the integration of these datasets enhances the understanding of reservoir quality, source rock potential, and depositional architecture within the Agbada Formation penetrated by the (XY Well.

4.1 Sedimentological Analysis of XY Well

A total of one hundred and ninety (190) ditch-cutting samples were obtained from the **XY Well** at regular depth intervals. Each sample was examined lithologically under a reflected-light microscope to determine **texture, sorting, colour, grain shape and roundness, mineral**

composition, and post-depositional diagenetic features. These parameters formed the basis for identifying and classifying the various **lithofacies** encountered within the well.

Lithofacies analysis groups sedimentary deposits that exhibit comparable textural and compositional attributes, thereby revealing variations of genetic and environmental significance. The sedimentological description of the XY Well therefore aimed at recognizing distinctive facies units and interpreting the depositional processes that governed their formation.

A **geological model** incorporating lithofacies, associated minerals, and **homogenetic and heterogenetic zones** was established for the XY Well succession. The homogenetic zones represent relatively uniform intervals dominated by a single facies type, typically thick sandstone or shale beds, indicating stable depositional conditions. In contrast, the heterogenetic zones consist of alternating sand-shale successions, signifying fluctuating energy levels and variable sediment supply.

The **XY Well** penetrated two major **lithostratigraphic units** of the Niger Delta Basin: the **Benin Formation** at the top and the **Agbada Formation** below. The Benin Formation consists predominantly of loose to moderately consolidated sands that reflect continental to upper delta-plain environments. The underlying Agbada Formation is characterized by alternating sand, clayey sand, shale, shaly sand, and sandy-shale facies deposited in fluvio-deltaic to shallow-marine settings.

The principal **lithofacies types** recognized in the XY Well include:

Sand facies - fine- to coarse-grained, well-sorted quartzose sands deposited under high-energy conditions in distributary-channel or fluvial settings.

Clayey sand facies - moderately sorted sands with clay admixtures, representing transitional sub-environments such as lower delta plain or interdistributary channels.

Shale facies - dark-grey to brown, fissile, clay-rich intervals that represent low-energy prodelta and delta-plain swamp environments.

Shaly-sand facies - thinly interbedded sand and shale laminations that record alternating depositional energy typical of tidal-flat or lower-shoreface conditions.

Sandy-shale facies - shale-dominated units with minor sand streaks, indicating distal delta-front or bay-fill environments.

Vertically, these facies alternate repeatedly, producing a **cyclic succession** that mirrors the regressive–transgressive nature of Agbada Formation deposition. The upward transition from shale-rich intervals to sand-dominated units records an overall **progradational trend** from marine to continental influence within the stratigraphic column.

A comprehensive sedimentological model illustrating the **lithofacies distribution, associated minerals, and homogenetic/heterogenetic zonation** in the XY Well is presented in **Figure 12**. This model highlights the vertical variability of facies and the interplay of depositional and diagenetic controls that shaped the sedimentary architecture of the well.

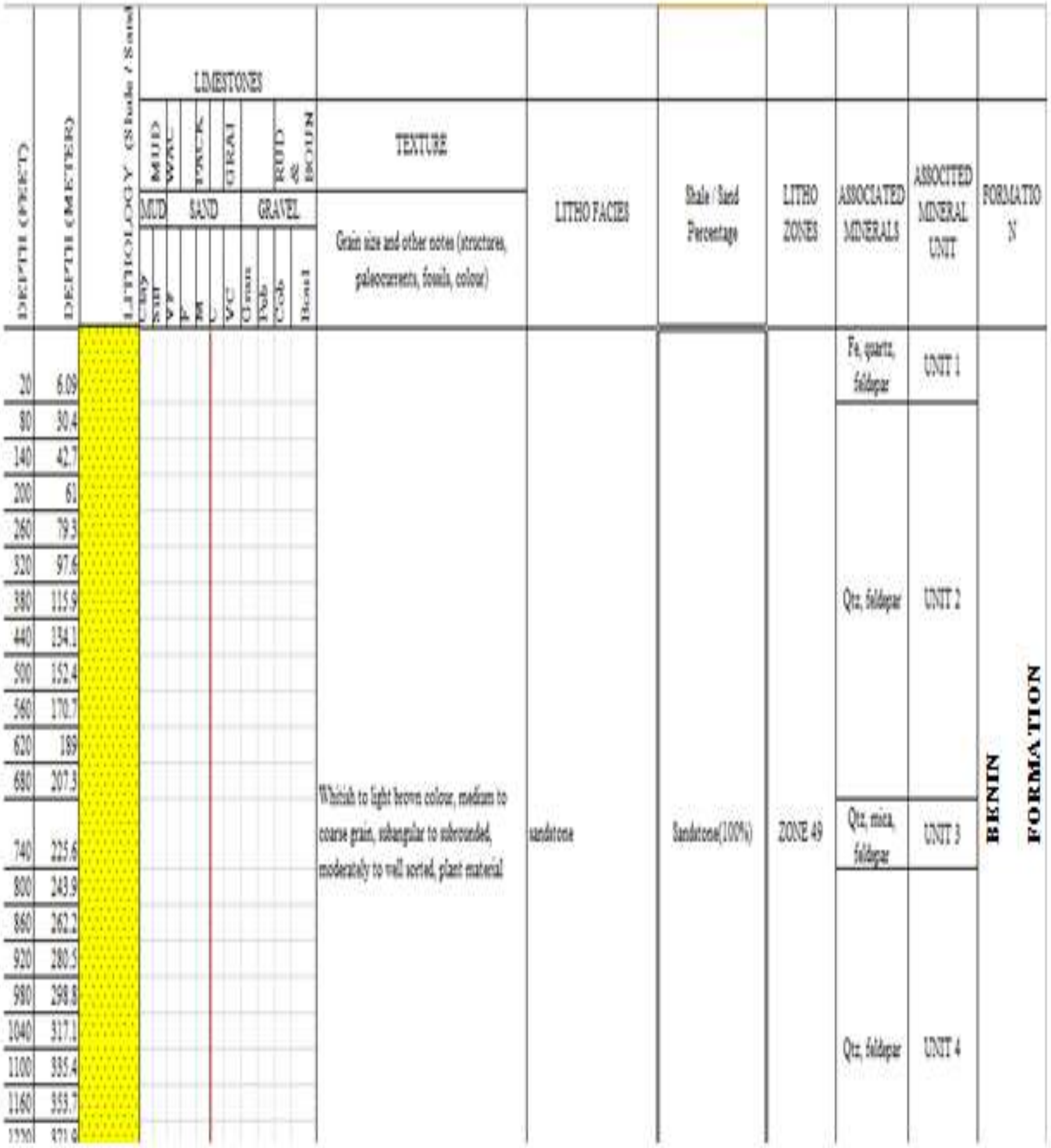


Figure 12: Lithofacies and sedimentological model of XY Well showing vertical facies variations, homogenetic and heterogenetic zones, and associated minerals.

4.1.1 Lithofacies Units

The concept of lithofacies in sedimentary geology provides a systematic means of classifying and grouping sedimentary deposits in order to emphasize differences that have genetic and environmental significance. In the **XY Well**, a total of thirty lithofacies zones were identified and described in detail. These lithofacies include **sandstone, shale, sandy clay, clayey sand, sandy shale, and shaly sand**. Each facies was defined through detailed visual and microscopic examination of ditch-cutting samples using a reflected-light microscope.

The analyses focused on parameters such as grain size, sorting, roundness, mineral composition, color, and diagenetic features. Textural and mineralogical properties were then correlated with depositional energy and processes. This allowed the classification of the sediments into genetically related facies that reflect environmental variations within the **Agbada Formation** of the Niger Delta Basin.

From bottom to top, the succession in the well displays cyclic alternations of sand-rich and shale-rich intervals. This pattern indicates shifts between high-energy depositional environments such as distributary channels and mouth bars and low-energy settings such as delta plains, prodelta mudflats, and interdistributary bays. These cycles correspond to transgressive and regressive phases associated with delta progradation and marine incursions.

The sand facies in the XY Well are typically milky to translucent, medium to coarse grained, and quartz rich. Most are subrounded to rounded and moderately to well sorted. Such features suggest deposition by moderately strong to high currents within distributary channels, shorefaces, or tidal bars. The frequent presence of lignite streaks and cuticular materials also points to proximity to vegetated delta-plain environments.

The shale facies are light to dark grey, fissile, and fine grained. They contain abundant organic matter, lignite streaks, and plant debris. These shales were deposited under quiet-water conditions that favored organic matter accumulation. The occurrence of calcareous shales within Zones 7 and 8 implies marine incursions that brought carbonate material and temporarily increased water salinity.

Mineralogical studies indicate that the sands are dominantly quartzose, containing more than 80 percent quartz with minor feldspar, mica, and iron oxide. Feldspar alteration to kaolinite and the presence of iron-oxide coatings reveal early diagenetic modifications under slightly oxidizing conditions. The shale units contain illite, kaolinite, smectite, and sporadic pyrite nodules, which reflect reducing depositional conditions.

The individual lithofacies zones vary in thickness from 18 meters to more than 290 meters. The sandstone intervals such as Zones 2, 4, 9, 13, 15, 19, 23, 25, 27, and 30 represent potential reservoir horizons, while the shale units such as Zones 1, 3, 5, 7, 10, 12, 14, 18, 20, 22, 24, and 26 are considered potential source and seal beds. The repetition of these facies produces a vertical stacking pattern typical of the **Agbada Formation**, which is characterized by alternating paralic sand and shale sequences.

The vertical arrangement of the lithofacies shows that the deeper parts of the well are dominated by shale and sandy shale, reflecting distal prodelta and marine shelf environments. The upper sections contain more sand, shaly sand, and clayey sand facies, representing delta-front and fluvial channel deposits. This upward increase in sand proportion confirms a **progradational trend**, indicating progressive shallowing and delta advancement toward the continent.

Overall, the textural, compositional, and mineralogical attributes of these facies reveal a dynamic depositional history controlled by relative sea-level changes, sediment supply, and deltaic processes. The **Agbada Formation** thus records the interplay of marine transgression and deltaic regression that produced the cyclic architecture observed in the well.

4.1.2 Hydrocarbon Play Elements of XY Well

Hydrocarbon play elements refer to the fundamental geological components that control the generation, migration, and accumulation of hydrocarbons. These include reservoir rocks, source rocks, traps, seals, and migration pathways. In the **XY Well**, all these elements are developed within the **Agbada Formation**, which forms the main petroleum-bearing unit of the Niger Delta.

Reservoir Rocks

Eleven probable reservoir intervals were recognized in **Lithofacies Zones 2, 4, 9, 11, 13, 15, 17, 19, 21, 23, and 25**. These are composed mainly of sandstone facies characterized by clean, quartzose grains that are medium to coarse, moderately to well sorted, and subrounded to rounded. The sands are mostly non-calcareous and rich in quartz, with minor feldspar, mica, and iron oxide. The high degree of sorting and grain roundness suggests deposition in high-energy environments such as distributary channels, shorefaces, and mouth bars.

These sand units exhibit excellent reservoir quality. Their original porosity is estimated to range between 20 and 30 percent, with permeability enhanced by limited cementation and good intergranular connectivity. The presence of lignite fragments and organic cuticles suggests deposition under delta-plain influence, which may enhance hydrocarbon enrichment through organic association.

Source Rocks

Twelve potential source rock intervals were identified in **Lithofacies Zones 1, 3, 5, 7, 10, 12, 14, 18, 20, 22, 24, and 26**. These are light-grey to dark-grey fissile shales rich in lignite streaks, plant remains, and other organic materials. Their fine grain size and laminated structure suggest low depositional energy typical of prodelta and delta-plain swamps where anoxic conditions prevailed.

The organic matter contained within these shales provides the material necessary for hydrocarbon generation. With increasing burial and thermal maturity, these units could generate both oil and gas, depending on the kerogen type and maturity level. The non-calcareous nature of most of these shales further supports a dominantly terrestrial organic input with limited marine dilution.

Seal and Trap Elements

The shale intervals in the Agbada Formation also act as effective cap rocks or seals. They prevent the upward escape of hydrocarbons from underlying reservoirs. The alternating sand–shale sequence creates a natural **layered seal–reservoir couplet**. In addition, the Niger Delta is structurally controlled by growth faults, which have produced rollover anticlines and fault-bounded closures. These structural features, combined with facies pinch-outs, provide both **structural and stratigraphic traps** that are ideal for hydrocarbon accumulation.

Migration Pathways

Hydrocarbon migration within the XYsequence occurs through both vertical and lateral pathways. Vertical migration takes place through permeable sand laminae and along fault planes that cut across shale barriers, while lateral migration follows the continuity of interconnected sand channels. The close association of source and reservoir intervals ensures efficient migration with minimal loss of hydrocarbons during movement.

Homogenetic and Heterogenetic Zones

Textural and compositional variations in the analyzed intervals allow the identification of **homogenetic** and **heterogenetic** zones.

Homogenetic Zones: Twenty-five intervals consisting predominantly of either sand or shale. The sand-dominated homogenetic zones represent stable depositional regimes of consistent energy, such as well-developed channel systems. The shale-dominated zones represent extended low-energy periods in quiet-water conditions that favor organic matter accumulation.

Heterogenetic Zones: Five intervals that contain alternations of **sandy clay, clayey sand, shaly sand, and sandy shale**. These facies reflect unstable depositional conditions where energy levels fluctuated due to shifting delta lobes, tidal reworking, or storm influences. The heterogenetic zones act as transitional beds that link reservoir and sealing facies, and they may influence hydrocarbon flow patterns.

Summary of Hydrocarbon Play

The integration of these elements shows that the Agbada Formation within the XY Well has all the necessary geological components for hydrocarbon generation, migration, and accumulation.

Organic-rich shales serve as effective source rocks.

Clean, well-sorted sandstones provide high-quality reservoirs.

Interbedded shale units act as seals and barriers to migration.

Faults and facies variations form structural and stratigraphic traps.

Alternating homogenetic and heterogenetic zones ensure the presence of both continuous reservoirs and sealing intervals.

This configuration represents a typical **Agbada paralic sequence** where alternating cycles of progradation and retrogradation create multiple stacked petroleum systems. The spatial relationship between source, reservoir, and seal intervals confirms that the **XY Well** has a well-developed hydrocarbon play potential within the Niger Delta Basin (Figure 13).

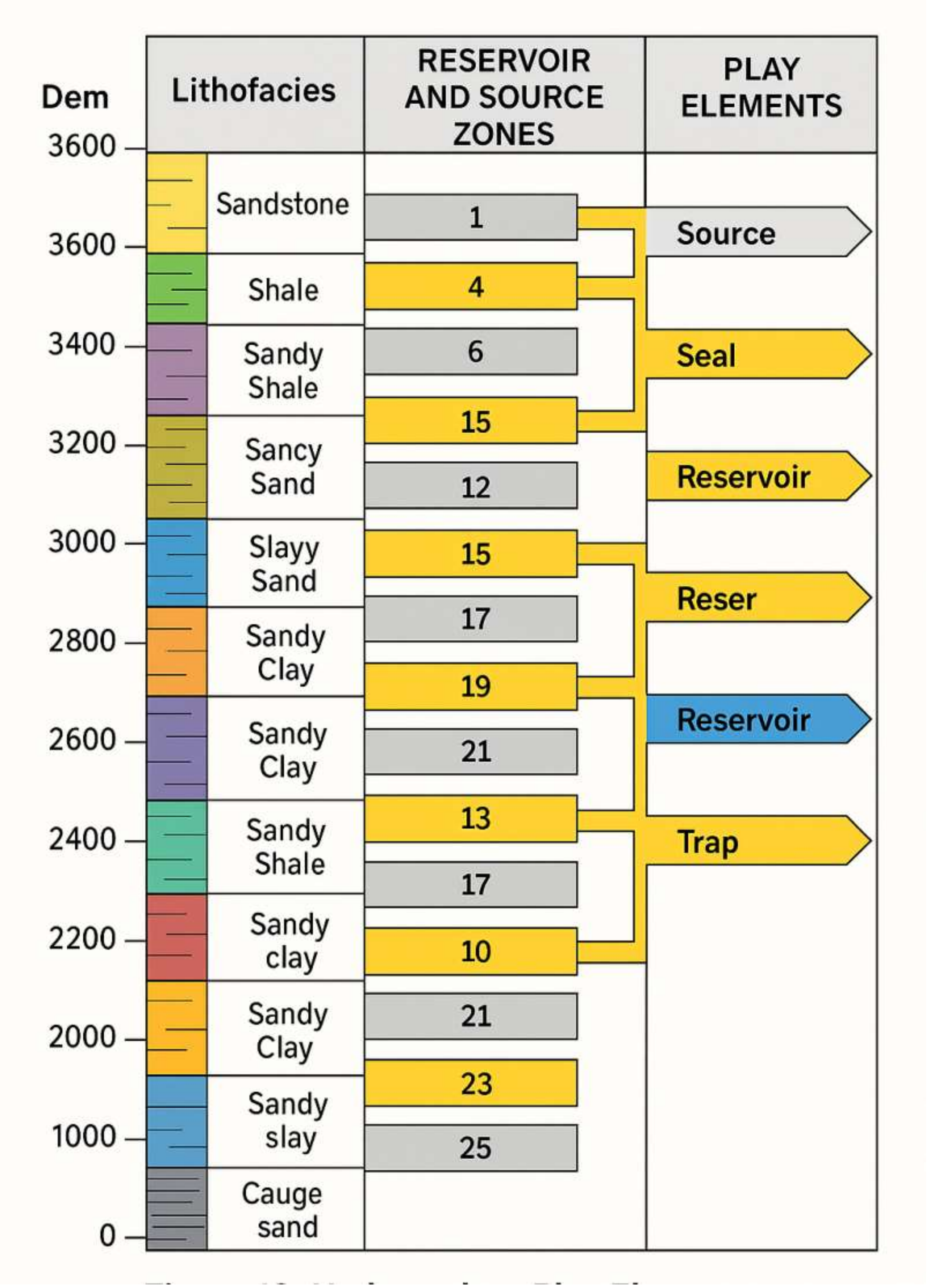


Figure 13: Hydrocarbon play elements and lithofacies relationship within the Agbada Formation, XY Well.

4.2 Mineralogical and Chemical Composition of XY Well

Mineralogical and chemical analyses of selected samples from the **XY Well** revealed the presence of **quartz, iron oxide, pyrite, glauconite, carbonate minerals, and mica**. These minerals occur in varying proportions within the sandstone and shale intervals of the **Agbada Formation**. Their distribution, textural characteristics, and alteration features provide valuable insights into provenance, depositional processes, diagenesis, and reservoir quality (Figure 14).

4.2.1 Quartz

Quartz is the most dominant mineral identified in the samples. It is a silicate mineral composed of silicon dioxide (SiO_2) and occurs in a hexagonal crystal system. The grains are generally **milky to translucent**, fine to coarse, subrounded to rounded, and show conchoidal fracture with vitreous luster. Quartz is highly resistant to chemical and mechanical weathering, and its persistence throughout the succession indicates **derivation from stable continental or cratonic sources**.

The abundance of quartz suggests that the sediments were derived from **weathered igneous and metamorphic basement rocks**, reworked and transported by long-distance fluvial systems before deposition in a deltaic to shallow-marine environment. The well-developed roundness and sorting of grains imply **high depositional energy** and continuous reworking within distributary channels and shoreface environments.

Quartz plays a key role in determining reservoir quality. Its chemical stability limits compaction and dissolution, maintaining intergranular porosity. Quartz cementation, however, can occur during burial diagenesis, reducing permeability. The identified quartz composition supports the interpretation of the **Agbada Formation** as a quartz arenite-rich sequence (Doust and Omatsola, 1990; Reijers, 2011).

Table 5 presents the physical and chemical properties of quartz observed in the XY Well samples.

Table 5: Physical Properties of Quartz

Property	Description
Chemical Classification	Silicate
Chemical Formula	SiO_2
Color	Clear, white, gray, purple, yellow, brown, black, pink, green, red
Streak	Colorless (harder than the streak plate)
Luster	Vitreous
Diaphaneity	Transparent to translucent
Cleavage	None; conchoidal fracture
Mohs Hardness	7
Specific Gravity	2.6-2.7
Diagnostic Properties	Conchoidal fracture, glassy luster, hardness
Crystal System	Hexagonal
Common Uses	Glass manufacture, foundry sand, abrasive materials, hydraulic fracturing, gemstone production

Quartz is also widely utilized in the petroleum industry during **hydraulic fracturing operations**, where durable quartz grains serve as proppants that keep fractures open, enhancing the flow of oil and gas toward the wellbore (Schieber et al., 2010).

4.2.2 Iron Oxide

Iron oxides occur as secondary minerals within the sandstones, often as reddish-brown coatings on grain surfaces or as cement. They include **hematite (Fe_2O_3)** and **magnetite (Fe_3O_4)**, which are typical weathering products of ferromagnesian minerals from the source area. These oxides are important indicators of **oxidizing depositional and diagenetic environments**.

The presence of iron oxide coatings suggests periods of **subaerial exposure or shallow oxygenated water conditions** during sediment deposition. Hematite imparts reddish hues to the sediments, while magnetite may indicate association with mafic or ultramafic rock sources. Iron oxides are also linked to **early diagenetic cementation** and can reduce porosity by filling pore spaces (Ekweozor and Daukoru, 1994).

In industrial contexts, iron oxides serve as catalysts, pigments, and feedstock for iron production, while in sedimentary analysis, they are used as environmental redox indicators (Wilson, 2014).

4.2.3 Pyrite

Pyrite (FeS_2) was identified as fine-grained disseminations and nodular crystals within shale units. It is an iron sulfide mineral commonly known as **fool's gold** because of its metallic luster and brass-yellow color. Pyrite formation occurs in **reducing environments** where sulfate ions are reduced by organic matter and microbial activity.

The occurrence of pyrite in the XY Well shales indicates deposition under **anoxic conditions** within prodelta or swamp settings. Its presence provides evidence of organic matter enrichment and potential hydrocarbon generation. During early diagenesis, iron reacts with biogenic hydrogen sulfide produced by bacterial sulfate reduction to form pyrite.

Pyrite is also a significant indicator of paleoenvironmental conditions. In marine-dominated settings, pyrite commonly forms framboidal aggregates, while in non-marine sequences it occurs as irregular disseminations. Its abundance supports the interpretation that portions of the Agbada Formation were deposited in **reducing, organic-rich, and poorly oxygenated environments**.

Commercially, pyrite is used in the production of **sulfur dioxide and sulfuric acid**, and it serves as a source of sulfur for industrial processes (Obaje, 2009).

4.2.4 Glauconite

Glauconite is a greenish, iron-potassium silicate mineral that occurs as small, rounded pellets in some shale and sandstone intervals. It forms primarily in **marine shelf environments** under slow sedimentation rates and slightly reducing conditions.

Its presence in the XY Well signifies intermittent **marine transgressions** and low sediment influx during the deposition of the Agbada Formation. Glauconite typically develops through the **alteration of clay minerals** such as illite and biotite in seawater or through the modification of fecal pellets of bottom-dwelling organisms (Reijers, 2011).

The occurrence of glauconite in the studied interval supports a **paralic depositional environment** with alternating marine and deltaic influence. It also provides evidence for pauses in sedimentation, allowing mineral alteration and maturation.

4.2.5 Carbonate Minerals

Carbonate minerals, mainly **calcite and dolomite**, were identified as cementing materials within the sandstone facies and as discrete beds within the shale sequences. These carbonates occur both as skeletal remains of marine organisms and as chemical precipitates.

In the XY Well, carbonates are most prominent within Zones 7, 8, and 9, indicating **periodic marine influence** during transgressive episodes. In shallow marine environments, carbonate formation results from the disintegration of shells and skeletal fragments of foraminifera, mollusks, and algae.

Carbonate cementation affects reservoir quality by **reducing porosity and permeability**. However, partial dissolution during late diagenesis can create **secondary porosity**, enhancing reservoir potential. The alternation of carbonate-rich and quartz-rich beds reflects the cyclic variation between siliciclastic and carbonate deposition controlled by relative sea-level changes.

4.2.6 Mica

Mica occurs as fine flakes and plate-like inclusions within both sandstone and shale intervals. Muscovite and biotite are the most common species identified. These minerals are typically derived from **granitic and metamorphic sources**, transported as detrital particles.

The occurrence of mica indicates **moderate hydraulic energy conditions** and a short transport distance from the source area. Muscovite, being stable under sedimentary conditions, contributes to the fine fraction of the sands, while biotite and chlorite often undergo alteration to clay minerals during burial diagenesis.

Micas influence sediment compaction and clay content. Their platy morphology promotes alignment during burial, contributing to rock anisotropy. In petroleum reservoirs, high mica content can increase clay matrix and affect permeability, though their presence also confirms a **continental provenance**.

4.2.7 Implications for Provenance and Diagenesis

The combined mineralogical and chemical data indicate that the sediments of the XY Well were derived mainly from **cratonic and metamorphic terranes**, dominated by quartz, feldspar, and mica, with minor contributions from mafic sources represented by iron oxide and glauconite.

The dominance of quartz and subordinate feldspar suggests a **mature siliciclastic provenance**, consistent with the recycled or stable continental crust sources that feed the Niger Delta. The presence of iron oxides and pyrite demonstrates alternating **oxidizing and reducing environments**, a reflection of deltaic cyclicity and fluctuating water chemistry.

Carbonate occurrences reflect marine incursions during transgressive phases, while glauconite confirms intervals of marine influence and slow sedimentation. These minerals collectively reveal that the Agbada Formation in the XY Well underwent early cementation, compaction, and minor dissolution, typical of burial diagenesis in the Niger Delta Basin (Evamy et al., 1978; Reijers, 2011; Odinaka et al., 2025).

Figure 14 illustrates the distribution of these key minerals within the well succession and their environmental significance.

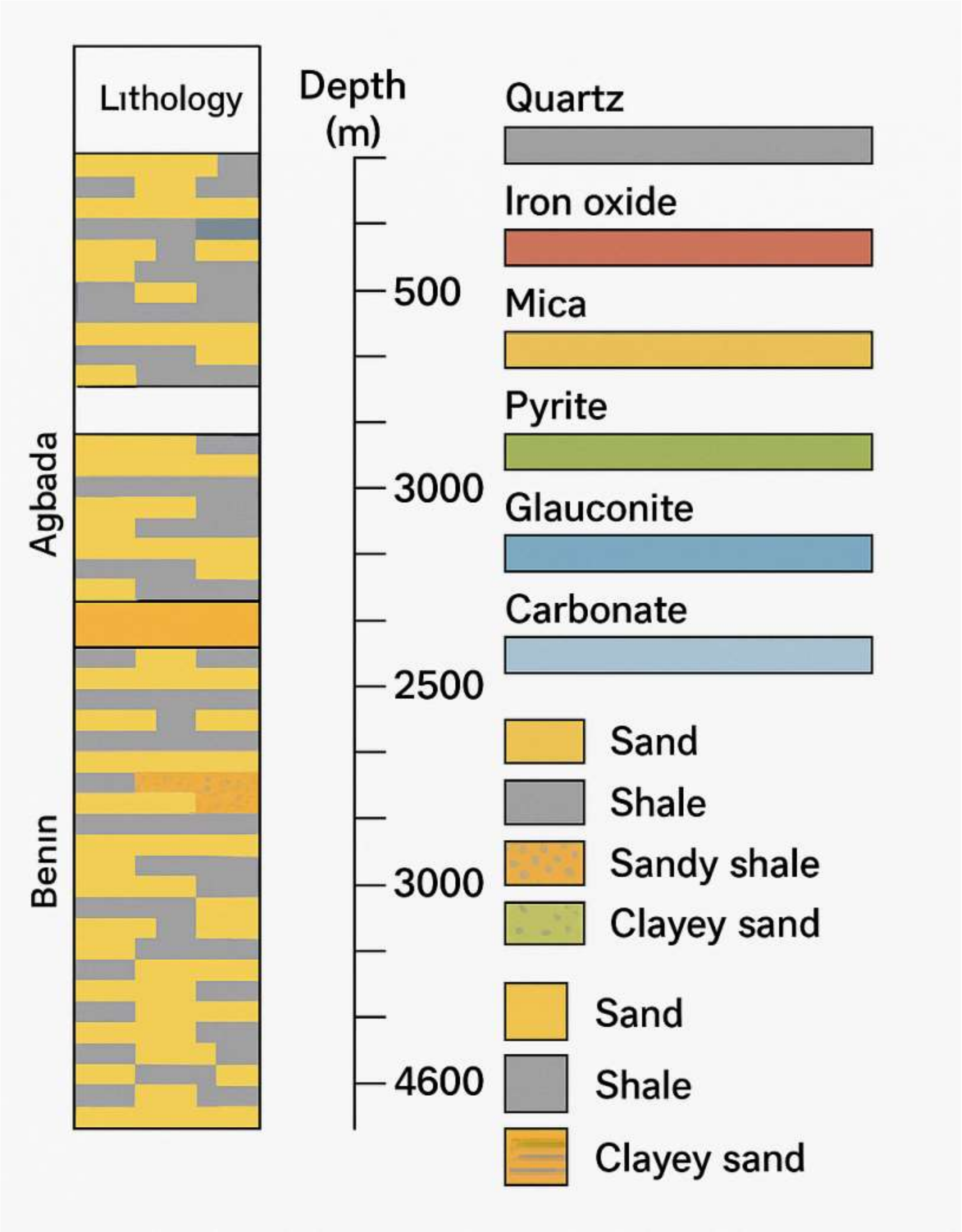


Figure 14: Identified minerals and their distribution within the Agbada Formation of XY Well showing quartz, iron oxide, pyrite, glauconite, carbonate, and mica associations.

4.3 Palynological Results and Interpretation

Palynological analyses were carried out on ditch-cutting samples from the XY Well to establish the palynostratigraphy, age, and depositional environment of the sediments. The identified palynomorphs were counted and arranged in stratigraphic order from the base to the top of the well. Stratigraphically significant and environmentally diagnostic taxa were selected to define the P-zones of the Greater Ughelli Depobelt. The procedures followed the guidelines of Fregene and Luca (2024) as shown in Figure 15. The established P-zones were later correlated with the Niger Delta chronostratigraphic framework to interpret maximum flooding surfaces (MFS), sequence boundaries (SB), and the relative ages of the sediments (Figures 16 and 17).

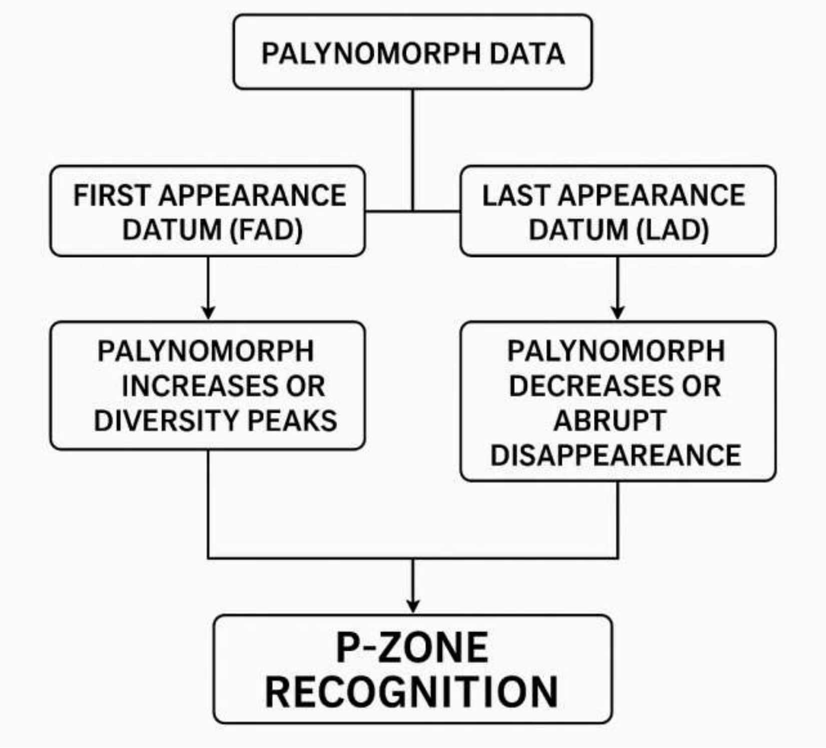


Figure 15: Guidelines for Characterizing P-Zones in the Greater Ughelli Depobelt

(Modified after Fregene T.J. and Luca F.A., 2024.)

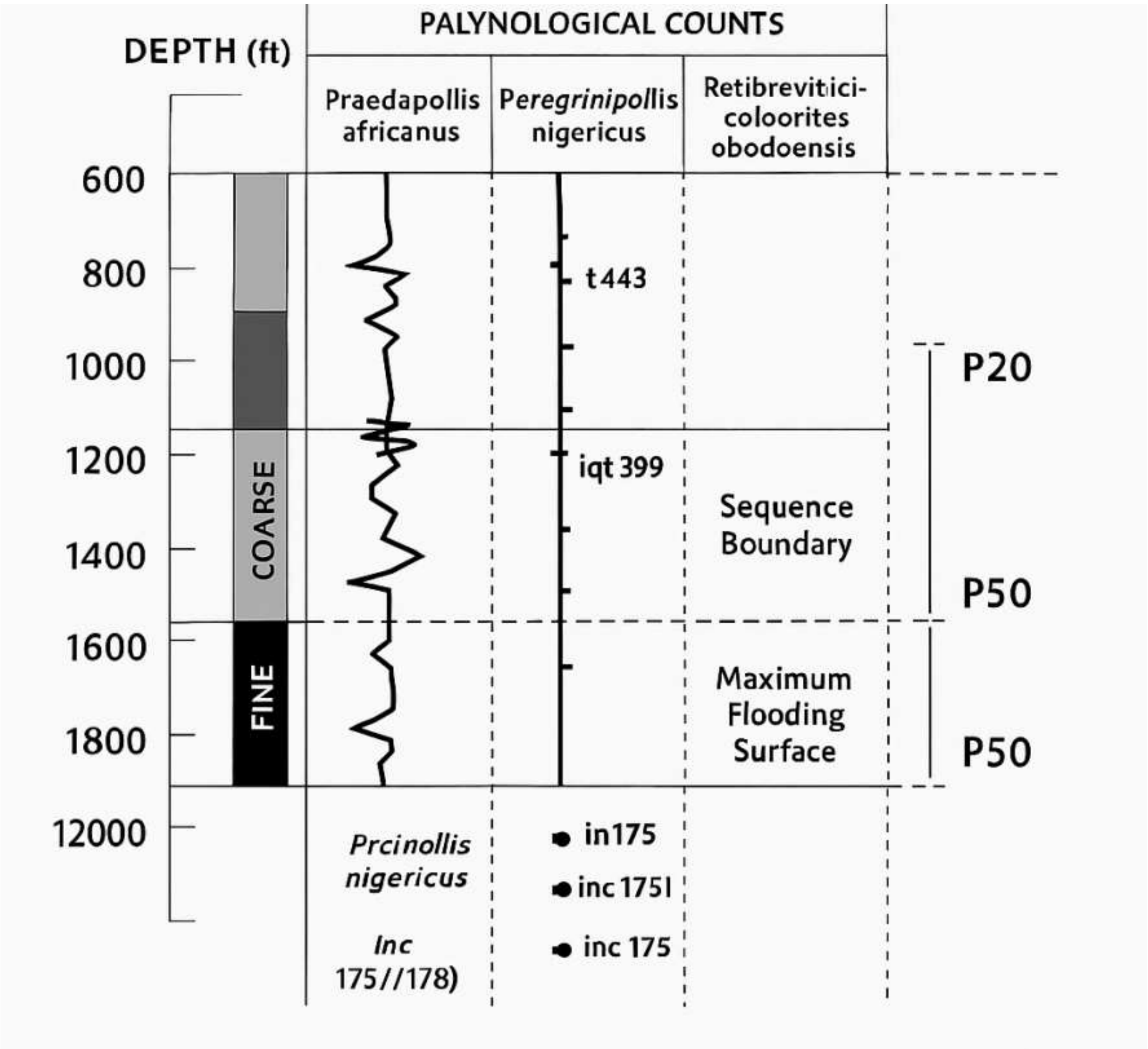


Figure 16: Established P-Zones (P620, P580, P560) in the XY Well Showing Correlation with Maximum Flooding Surfaces and Sequence Boundaries ***(After Evamy et al., 1978; Reijers, 2011; Odinaka et al., 2025.)***

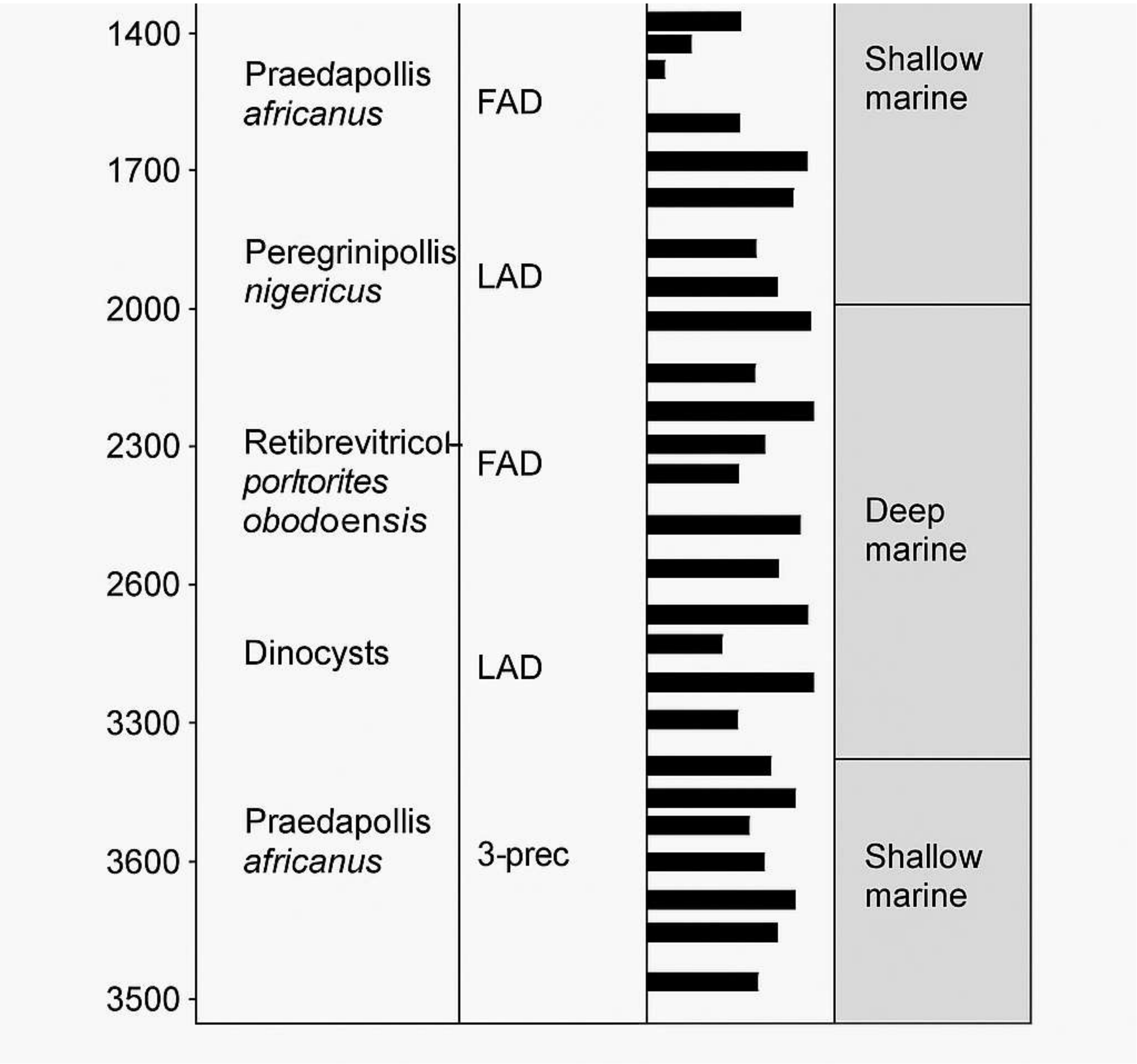


Figure 17: Palynomorph Distribution Chart of the XY Well

(Illustrating FADs, LADs, relative abundance of diagnostic taxa, and interpreted environments.)

4.3.1 Quantitative Analysis of Palynomorphs

A total of 964 palynomorphs were recovered from the analyzed interval (20 - 11 820 ft). These consist of 496 pollen grains, 458 spores, and 10 dinocysts (Table 6). The assemblage is moderately abundant and diverse, containing both terrestrial and marine elements that point to a paralic depositional setting.

Prominent pollen species include *Praedapollis africanus*, *Peregrinipollis nigericus*, *Retibrevitricolporites obodoensis*, *Zonocostites ramonae*, *Monoporites annulatus*, and *Echiperiporites estelae*. Spores such as *Polypediaceisporites*, *Verrucatosporites*, *Dictyophidiles*, and *Stereisporites* are also well represented. The occurrence of a few dinocysts (*Spiniferites* and *Pediastrum*) reveals short-lived marine incursions.

The dominance of *Zonocostites ramonae* indicates a mangrove-swamp environment, whereas *Monoporites annulatus* and *Psilatricolporites crassus* suggest freshwater or delta-plain conditions. The coexistence of these species reflects alternating terrestrial and marine influence typical of the Agbada Formation.

Table 6: Quantitative Occurrence and Distribution of Palynomorphs in XY Well

S/N	Depth (ft)	Depth (m)	Pollen	Spores	Miospores	Dinocysts	Total
1	1640	500	0	8	8	2	10
2	1760	536	2	0	2	0	2
3	1940	591	0	5	5	3	8
4	4500	1372	7	5	12	3	15
…	…	…	…	…	…	…	…
42	11 760	3584	6	11	16	0	16
Total	—	—	496	458	954	10	964

4.3.2 Palynomorph Distribution and Zonation

The identified palynomorphs were arranged according to their **first appearance datum (FAD)** and **last appearance datum (LAD)** to determine the evolutionary and stratigraphic succession within the studied interval. Three diagnostic taxa, *Praedapollis africanus*, *Peregrinipollis nigericus*, and *Retibrevitricolporites obodoensis*, were used to establish the **P-zones** for the well. The distribution of these key species and their depth occurrences are summarized in **Table 7**, while **Figure 16** illustrates the palynomorph distribution chart for the entire well section.

Table 7: Diagnostic Palynomorphs and Depth Occurrence Used in Zonation

Taxon	FAD (m)	LAD (m)	P-Zone	Inferred Age	Environmental Setting
Praedapollis africanus	3531	1427	P620–P580	Late Miocene	Shallow-marine to delta-front
Peregrinipollis nigericus	2323	1738	P580	Late Miocene	Delta-plain to shoreface
Retibrevitricolporites obodoensis	3531	1372	P560	Middle Miocene	Prodelta to shallow-marine

4.3.3 Interpretation of P-Zones

P620–P580 Composite Zone

This composite zone extends for about **2940 ft**, defined by the **top occurrence of** *Praedapollis africanus* (4680 ft) and the **quantitative base of** *Peregrinipollis nigericus* (7620 ft). The dominance of *Praedapollis africanus*, *Peregrinipollis nigericus*, and *Zonocostites ramonae* reflects deposition in a **delta-front to shallow-marine environment** during the **Late Miocene**. The missing *Gemmatriporites* top is likely due to minor thermal alteration of the samples.

P560 Zone

This zone spans approximately **3960 ft**, bounded by the **quantitative base of** *Peregrinipollis nigericus* (7620 ft) and the **increase of** *Retibrevitricolporites obodoensis* (11 580 ft). It corresponds to the **Middle Miocene** and represents **prodeltaic to near-shore marine deposition** influenced by periodic fluvial input.

The combination of these zones correlates well with regional Niger Delta palynozones (Evamy et al., 1978; Jan du Chêne et al., 1978; Odinaka et al., 2025), confirming that the studied interval belongs to the **Agbada Formation**.

4.3.4 Environmental and Sequence-Stratigraphic Interpretation

Variation in palynomorph composition from base to top indicates repeated changes between **fluvio-deltaic, swamp, and shallow-marine settings**. High proportions of *Zonocostites ramonae* and *Psilatricolporites crassus* correspond to mangrove and delta-plain vegetation, while marine dinocysts such as *Spiniferites* signal marine flooding episodes.

Integration of the palynological record with lithofacies data allowed identification of **maximum flooding surfaces (MFS)** where marine taxa peak, and **sequence boundaries (SB)** where terrestrial pollen dominate. These surfaces correlate with the Niger Delta chronostratigraphic framework, revealing multiple regressive–transgressive cycles during the Miocene.

4.3.5 Informal Palynomorph Zones for X) Well

Thirteen informal palynological zones were established for the XY Well using first-appearance datum and last-appearance datum picks taken consistently from top to bottom of the succession. Boundaries were tied to first down-hole occurrence, quantitative base, or last down-hole occurrence of key taxa. The narrative descriptions below follow your field data exactly and are supported by the summary in Table 8, which compiles thickness, boundary criteria, diagnostic taxa, and brief environmental notes for rapid reference (Table 8).

Biozone 1: Polypediaceisporites Zone

Thickness ≈ 92 m.

The top is defined by the first down-hole occurrence or last appearance datum of Polypediaceisporites (38) cf (33) at 500 m. The base is defined by continuous Echiperiporites estelae (200) at 592 m. Other recorded palynomorphs include Verrucatosporites usmensis (5), Dictyphidiles harassi (11), Crototricolpites crotonoisculptus (364), and smooth trilate spores cf Acrostichum aureum.

Biozone 2: Sapotaceae pollenites Zone

Thickness ≈ 817 m.

The top is marked by the base-continuous Echiperiporites estelae (200) at 592 m. The base is defined by the first down-hole occurrence of Sapotaceae pollenites (303) at 1409 m. Associated forms include Polypediaceisporites (38) cf (33), Verrucatosporites usmensis (5), Dictyphidiles harassi (11), Crototricolpites crotonoisculptus (364), smooth trilate spores, Laevigatosporites smooth monolete spores, Proxapertites operculatus (272), Praedapollis flexibilis (420), Psilatricolporites crassus (535) cf (533), Sapotaceae pollenites (303), and Retibrevitricolporites obodoensis (178).

Biozone 3: Stereisporites Zone

Thickness ≈ 128 m.

The top is defined by the first down-hole occurrence of Sapotaceae pollenites (303) at 1409 m; the base by the first down-hole occurrence of Stereisporites (45) at 1537 m. Common taxa include Polypediaceisporites (38) cf (33), Verrucatosporites usmensis (5), Dictyphidiles harassi (11), smooth trilate spores, Laevigatosporites smooth monolete spores, Sapotaceae pollenites (303), Retibrevitricolporites obodoensis (178), Praedapollis africanus (443), Pachydemites diederixi (317), Psilamonocolpites marginatus (237), Arecipites exilimuratus (280), Numulipollis neogenicus (139), Striatomonocolpites rectostriatus (252), Striatricolpites catatumbus (445), Monoporites annulatus (125), Echitricolporites spinosus (455), and Verrucatosporites usmensis (3).

Biozone 4: Racemonocolpites hians Zone

Thickness ≈ 109 m.

The top is defined by the first down-hole occurrence of Stereisporites (45) at 1537 m; the base by the first down-hole occurrence of Racemonocolpites hians (250) at 1646 m. Associated forms include Polypediaceisporites (38) cf (33), Verrucatosporites usmensis (5), Dictyphidiles harassi (11), smooth trilate spores, Laevigatosporites smooth monolete spores, Sapotaceae pollenites (303), Retibrevitricolporites obodoensis (178), Praedapollis africanus (443), Pachydemites diederixi (317), Psilamonocolpites marginatus (237), Arecipites exilimuratus (280), Numulipollis neogenicus (139), Striatomonocolpites rectostriatus (252), Striatricolpites catatumbus (445), Monoporites annulatus (125), Echitricolporites spinosus (455), Verrucatosporites usmensis (3), Zonocostites ramonae (531), Spirosyncolporites brunnii (412), Polygalaceae (312), Echiperiporites minor, and Cinctiperiporites mulleri (190).

Biozone 5: Peregrinipollis nigericus Zone

Thickness ≈ 92 m.

The top is fixed at the first down-hole occurrence of Racemonocolpites hians (250) at 1646 m; the base at the first down-hole occurrence of Peregrinipollis nigericus (399) at 1738 m. Co-occurring taxa include Polypediaceisporites (38) cf (33), Verrucatosporites usmensis (5), Dictyphidiles harassi (11), smooth trilate spores, Laevigatosporites smooth monolete spores, Sapotaceae pollenites (303), Retibrevitricolporites obodoensis (178), Praedapollis africanus (443), Pachydemites diederixi (317), Psilamonocolpites marginatus (237), Arecipites exilimuratus (280), Numulipollis neogenicus (139), Striatomonocolpites rectostriatus (252), Striatricolpites catatumbus (445), Monoporites annulatus (125), Echitricolporites spinosus (455), Verrucatosporites usmensis (3), Zonocostites ramonae (531), Spirosyncolporites brunnii (412), Polygalaceae (312), Echiperiporites minor, Cinctiperiporites mulleri (190), Grimsdalea baculatus (112), and Magnastriatites (14).

Biozone 6: Proxapertites operculatus Zone

Thickness ≈ 122 m.

The top is placed at the first down-hole occurrence of Peregrinipollis nigericus (399) at 1738 m; the base at the first appearance or last down-hole occurrence of Proxapertites operculatus (272) at 1860 m. Other taxa include Polypediaceisporites (38), Verrucatosporites usmensis (5), smooth trilate spores, Retibrevitricolporites obodoensis (178), Laevigatosporites smooth monolete spores, Retitricolporites irregularis (511), Proxapertites operculatus (272), Sapotaceae pollenites (303), Praedapollis africanus (443), Pachydemites diederixi (317), Psilamonocolpites marginatus (237), Arecipites exilimuratus (280), Striatricolpites catatumbus (445), Echitricolporites spinosus (455), and Zonocostites ramonae (531).

Biozone 7: Magnastriatites hawardi Zone

Thickness ≈ 91 m.

The top is defined by the first appearance or last down-hole occurrence of Proxapertites operculatus (272) at 1860 m; the base by the first down-hole occurrence of Magnastriatites hawardi (9) cf (14) at 1951 m. Companion taxa include Polypediaceisporites (38) cf (33), Verrucatosporites usmensis (5), Dictyphidiles harassi (11), smooth trilate spores, Retibrevitricolporites obodoensis (178), Laevigatosporites smooth monolete spores, Retitricolporites irregularis (511), Proxapertites operculatus (272), Praedapollis flexibilis (420), Psilatricolporites crassus (535) cf (533), Praedapollis africanus (443), Pachydemites diederixi (317), Psilamonocolpites marginatus (237), Arecipites exilimuratus (280), Verrucatosporites usmensis (3), Stereisporites (45), and Zonocostites ramonae (531).

Biozone 8: Verrucatosporites usmensis Zone

Thickness ≈ 92 m.

The top is the first down-hole occurrence of Magnastriatites hawardi (9) cf (14) at 1951 m; the base is the increase of Verrucatosporites usmensis (3) at 2043 m. Other taxa include Polypediaceisporites (38) cf (33), Verrucatosporites usmensis (5), Dictyphidiles harassi (11), smooth trilate spores, Retibrevitricolporites obodoensis (178), Laevigatosporites smooth monolete spores, Retitricolporites irregularis (511), Psilatricolporites crassus (535) cf (533), Sapotaceae pollenites (303), Psilamonocolpites marginatus (237), Arecipites exilimuratus (280), Zonocostites ramonae (531), and Racemonocolpites hians (250).

Biozone 9: Arecipites exilimuratus Zone

Thickness ≈ 225 m.

The top is the increase of Verrucatosporites usmensis (3) at 2043 m; the base is the increase of Arecipites exilimuratus (280) at 2268 m. Co-occurring taxa include Polypediaceisporites (38) cf (33), Verrucatosporites usmensis (5), Echiperiporites estelae (200), smooth trilate spores, Retibrevitricolporites obodoensis (178), Laevigatosporites smooth monolete spores, Proxapertites operculatus (272), Praedapollis flexibilis (420), Praedapollis africanus (443), Pachydemites diederixi (317), Psilamonocolpites marginatus (237), Striatomonocolpites rectostriatus (252), Striatricolpites catatumbus (445), Monoporites annulatus (125), Zonocostites ramonae (531), Racemonocolpites hians (250), Retimonocolpites obaensis (265), Magnastriatites hawardi (9) cf (14), Racemonocolpites rarispinosus (249), Psilaheterecolpites (215), and Pediastrum.

Biozone 10: Retimonocolpites obaensis Zone

Thickness ≈ 128 m.

The top is the increase of Arecipites exilimuratus (280) at 2268 m; the base is the first appearance datum of Retimonocolpites obaensis (265) at 2396 m. Accompanying taxa include Polypediaceisporites (38), Verrucatosporites usmensis (5), Dictyphidiles harassi (11), Echiperiporites estelae (200), smooth trilate spores, Retibrevitricolporites obodoensis (178), Laevigatosporites smooth monolete spores, Retitricolporites irregularis (511), Praedapollis flexibilis (420), Sapotaceae pollenites (303), Praedapollis africanus (443), Pachydemites diederixi (317), Psilamonocolpites marginatus (237), Arecipites exilimuratus (280), Striatomonocolpites rectostriatus (252), Striatricolpites catatumbus (445), Monoporites annulatus (125), Verrucatosporites usmensis (3), Stereisporites (45), Zonocostites ramonae (531), Spirosyncolporites brunnii (412), Cinctiperiporites mulleri (190), Racemonocolpites hians (250), Grimsdalea baculatus (112), Magnastriatites (14), Peregrinipollis nigericus (399), Cyperoceapollis sp. (118), Retimonocolpites obaensis (265), Magnastriatites hawardi (9) cf (14), Racemonocolpites rarispinosus (249), and Pediastrum.

Biozone 11: Striatricolpites catatumbus Zone

Thickness ≈ 970 m.

The top is at the first appearance datum of Retimonocolpites obaensis (265) at 2396 m; the base is the first appearance datum of Striatricolpites catatumbus (445) at 3366 m. Assemblages include Polypediaceisporites (38) cf (33), Verrucatosporites usmensis (5), Dictyphidiles harassi (11), smooth trilate spores, Laevigatosporites smooth monolete spores, Retitricolporites irregularis (511), Praedapollis flexibilis (420), Praedapollis africanus (443), Pachydemites diederixi (317), Psilamonocolpites marginatus (237), Arecipites exilimuratus (280), Striatomonocolpites rectostriatus (252), Echitricolporites spinosus (455), Stereisporites (45), Zonocostites ramonae (531), Spirosyncolporites brunnii (412), Cinctiperiporites mulleri (190), Racemonocolpites hians (250), and Pediastrum.

Biozone 12: Bombacacidites Zone

Thickness ≈ 110 m.

The top is the first appearance datum of Striatricolpites catatumbus (445) at 3366 m; the base is the first appearance datum of Bombacacidites (400) at 3476 m. Other forms include Polypediaceisporites (38) cf (33), Verrucatosporites usmensis (5), Dictyphidiles harassi (11), smooth trilate spores, Retibrevitricolporites obodoensis (178), Laevigatosporites smooth monolete spores, Praedapollis flexibilis (420), Praedapollis africanus (443), Pachydemites diederixi (317), Psilamonocolpites marginatus (237), Arecipites exilimuratus (280), Striatomonocolpites rectostriatus (252), Echitricolporites spinosus (455), Verrucatosporites usmensis (3), Zonocostites ramonae (531), Spirosyncolporites brunnii (412), Racemonocolpites hians (250), Belskipollis elegans (320), and Polyadopollenites vancampori (204).

Biozone 13: Praedapollis flexibilis Zone

Thickness ≈ 109 m.

The top is the first appearance datum of Bombacacidites (400) at 3476 m; the base is the first appearance datum of Praedapollis flexibilis (420) at 3585 m. Additional taxa include Polypediaceisporites (38), Verrucatosporites usmensis (5), Dictyphidiles harassi (11), smooth trilate spores, Retibrevitricolporites obodoensis (178), Laevigatosporites smooth monolete spores, Retitricolporites irregularis (511), Praedapollis flexibilis (420), Praedapollis africanus (443), Pachydemites diederixi (317), Psilamonocolpites marginatus (237), Arecipites exilimuratus (280), Striatomonocolpites rectostriatus (252), Striatricolpites catatumbus (445), Monoporites annulatus (125), Verrucatosporites usmensis (3), Cinctiperiporites mulleri (190), and Racemonocolpites hians (250).

Table 8: Informal palynological zones for XY Well summarizing thickness, boundary picks, key taxa, and brief environmental notes.)

Biozone	Thickness (m)	Top & Base Boundary Definition	Key Palynomorphs	Environmental Interpretation
1. Polypediaceisporites Zone	92	Top: FDO/LAD *Polypediaceisporites* (38) cf (33) at 500 m; Base: Continuous *Echiperiporites estelae* (200) at 592 m	*Polypediaceisporites, Verrucatosporites usmensis, Crototricolpites crotonoisculptus, Smooth trilate spores*	Marginal marine to lower delta plain; nearshore swampy setting
2. Sapotaceaepollenites Zone	817	Top: *Echiperiporites estelae* (200) at 592 m; Base: FDO *Sapotaceaepollenites* (303) at 1409 m	*Sapotaceaepollenites, Praedapollis flexibilis, Retibrevitricolporites obodoensis*	Delta front–delta plain transitional zone
3. Stereisporites Zone	128	Top: FDO *Sapotaceaepollenites* (303) at 1409 m; Base: FDO *Stereisporites* (45) at 1537 m	*Stereisporites, Pradapollis africanus, Arecipites exilimuratus*	Freshwater swamp to lower delta plain
4. Racemonocolpites hians Zone	109	Top: FDO *Stereisporites* (45) at 1537 m; Base: FDO *Racemonocolpites hians* (250) at 1646 m	*Racemonocolpites hians, Polygalaceae, Zonocostites ramonae*	Mixed brackish to marginal marine delta front
5. Peregrinipollis nigericus Zone	92	Top: FDO *Racemonocolpites hians* (250) at 1646 m; Base: FDO *Peregrinipollis nigericus* (399) at 1738 m	*Peregrinipollis nigericus, Praedapollis africanus, Zonocostites ramonae*	Lower delta front–prodelta; marine influence
6. Proxapertites operculatus Zone	122	Top: FDO *Peregrinipollis nigericus* (399) at 1738 m; Base: FAD/LDO	*Proxapertites operculatus, Retibrevitricolporites obodoensis, Sapotaceaepollenites*	Prodelta to shallow marine setting

Biozone	Thickness (m)	Top & Base Boundary Definition	Key Palynomorphs	Environmental Interpretation
		Proxapertites operculatus (272) at 1860 m		
7. Magnastriatites hawardi Zone	91	Top: FAD/LDO *Proxapertites operculatus* (272) at 1860 m; Base: FDO *Magnastriatites hawardi* (9) cf (14) at 1951 m	*Magnastriatites hawardi*, *Psilatricolporites crassus*, *Zonocostites ramonae*	Brackish marginal marine environment
8. Verrucatosporites usmensis Zone	92	Top: FDO *Magnastriatites hawardi* (9) cf (14) at 1951 m; Base: Increase *Verrucatosporites usmensis* (3) at 2043 m	*Verrucatosporites usmensis*, *Racemonocolpites hians*, *Arecipites exilimuratus*	Lower delta plain under fluctuating salinity
9. Arecipites exilimuratus Zone	225	Top: Increase *Verrucatosporites usmensis* (3) at 2043 m; Base: Increase *Arecipites exilimuratus* (280) at 2268 m	*Arecipites exilimuratus*, *Praedapollis flexibilis*, *Racemonocolpites rarispinosus*	Delta front to prodelta; transgressive episode
10. Retimonocolpites obaensis Zone	128	Top: Increase *Arecipites exilimuratus* (280) at 2268 m; Base: FAD *Retimonocolpites obaensis* (265) at 2396 m	*Retimonocolpites obaensis*, *Peregrinipollis nigericus*, *Spirosincoporites brunnii*	Marine shelf to inner neritic condition
11. Striatricolpites catatumbus Zone	970	Top: FAD *Retimonocolpites obaensis* (265) at 2396 m; Base: FAD *Striatricolpites*	*Striatricolpites catatumbus*, *Monoporites annulatus*, *Zonocostites ramonae*	Delta front–prodelta transition; transgressive–regressive

Biozone	Thickness (m)	Top & Base Boundary Definition	Key Palynomorphs	Environmental Interpretation
		catatumbus (445) at 3366 m		cycle
12. Bombacacidites Zone	110	Top: FAD *Striatricolpites catatumbus* (445) at 3366 m; Base: FAD *Bombacacidites* (400) at 3476 m	*Bombacacidites*, *Belskipollis elegans*, *Polyadopollenites vancampori*	Delta plain, humid tropical swamp vegetation
13. Praedapollis flexibilis Zone	109	Top: FAD *Bombacacidites* (400) at 3476 m; Base: FAD *Praedapollis flexibilis* (420) at 3585 m	*Praedapollis flexibilis*, *Retibrevitricolporites obodoensis*, *Cinctiperiporites mulleri*	Prodelta to shallow marine; deeper water influence

Biozone	Key Taxa	Depositional Environment
1	*Polypodiaceispor-Ites* Zone	Swamp
2	*Sapotaceapollenites* Zone	Delta plain
3	*Stereisporites* Zone	Delta plain
4	*Racemonocolpites hlans* Zone	Inner shelf
5	*Peregrinipollis nigericas*	Prodelta
6	*Proxapertites operculatus* Zone	Prodelta
7	*Magnastriatites hawardli cf* Magnas-triatites	Increase Verrucatosprites usmensis
8	*Verrucasiritites* usmensis Zone Magnastriatites	Increase Arecipites cr eximuratus
9	*Arecipites exilimuratus* Zone Retimonocolpites obaensis Zone	Inner shelf
11	*Striatricolpites catatumbus* Zone	Delta plain
12	*Bombacacidites* Bombacacidites	Delta plain
13	*Praedopollis flexibilis Zone*	Delta plain

Figure 18: Informal Palynological Zonation Chart of the XY Well

4.3.6 Sequence Stratigraphic Interpretation of the XY Well

The integration of lithofacies, palynological zones, and bioevents from the XY Well enabled the establishment of a detailed sequence stratigraphic framework for the studied interval. The identification of key sequence stratigraphic surfaces such as **Maximum Flooding Surfaces (MFS)** and **Sequence Boundaries (SB)** was achieved through the correlation of informal palynological zones, foraminiferal abundance trends, and lithologic variations.

Palynological data, particularly the first and last down-hole occurrences of diagnostic taxa such as *Praedapollis africanus*, *Peregrinipollis nigericus*, and *Retibrevitricolporites obodoensis*, served as biostratigraphic markers constraining the chronostratigraphic positions of the surfaces. The sequence framework is further supported by changes in facies composition and depositional environments reflected in the alternation of shale- and sand-dominated intervals.

Three main depositional sequences were recognized, corresponding to **P620, P580, and P560 Zones** (Fig. 19).

P620/P580 Sequence (Depth 4680-7620 ft)

This interval represents a composite sequence characterized by the appearance of *Praedapollis africanus* (Top t443) and *Peregrinipollis nigericus* (qb399). The lower part of the sequence shows a dominance of fluvio-deltaic sand facies, interpreted as a **Lowstand Systems Tract (LST)**, overlain by marine shales indicating a **Transgressive Systems Tract (TST)**. The upper portion, marked by increased marine palynomorphs and dinocysts, corresponds to a **Highstand Systems Tract (HST)**. The associated **MFS** is placed at approximately 6,000 ft within the Agbada Formation.

P560 Sequence (Depth 7620-11,580 ft)

This sequence is defined by the quantitative base of *Peregrinipollis nigericus* (qb399) and the increased occurrence of *Retibrevitricolporites obodoensis* (inc 175/178). The interval is characterized by a significant upward coarsening trend with alternation of sand–shale facies, typical of regressive cycles. The MFS is located near 9,800 ft, above which a progradational stacking pattern suggests a **Highstand Systems Tract (HST)** capped by an erosional **Sequence Boundary (SB)**.

Upper Composite Sequence (Depth 20-4,680 ft)

This upper sequence is dominated by terrestrial palynomorphs such as *Zonocostites ramonae* and *Monoporites annulatus*, indicating a delta plain to marginal marine environment. The transition from lignite-bearing shale to fine-grained sandstone represents a regressive sequence that correlates with the upper Agbada Formation, showing shallow marine to deltaic influences.

Overall, the established sequence stratigraphic framework reflects repetitive regressive-transgressive cycles consistent with the sedimentary evolution of the Niger Delta Basin, controlled primarily by relative sea-level fluctuations and sediment supply.

The stratigraphic architecture showing the vertical stacking of depositional sequences, identified systems tracts, and correlated MFS and SB markers is illustrated in **Figure 19**.

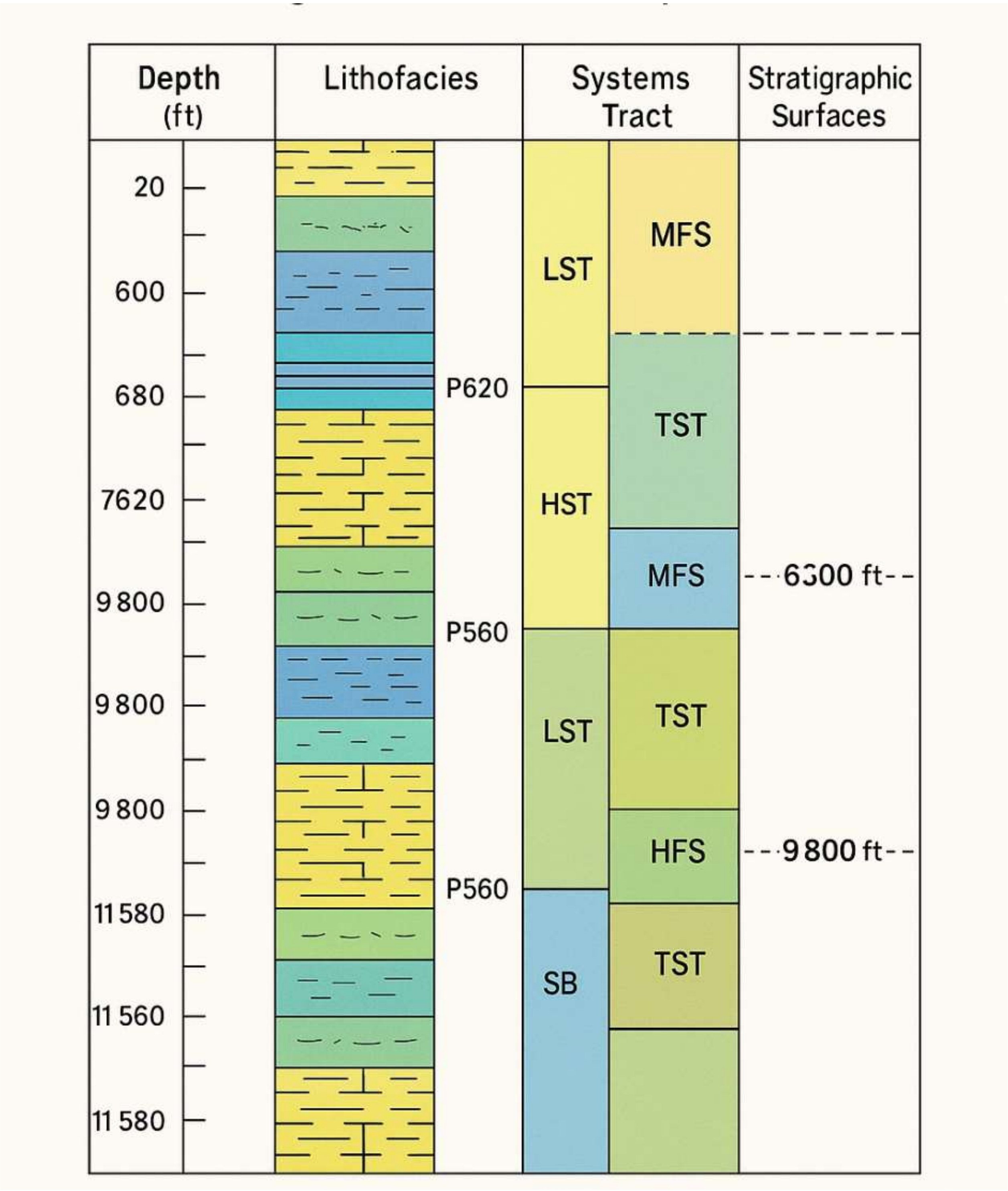


Figure 19: *Sequence Stratigraphic Framework of the XY Well Showing Recognized Systems Tracts, Maximum Flooding Surfaces (MFS), and Sequence Boundaries (SB) within P620, P580, and P560 Zones.*

4.4 Depositional Environment Interpretation of the XY Well

The depositional environment of the XY Well was interpreted by integrating sedimentological, mineralogical, and palynological evidence. Observations from lithofacies composition, mineral assemblages, palynomorph distribution, and sequence stratigraphic trends indicate that the analyzed interval represents a complex **fluvio-deltaic to shallow marine depositional system**, typical of the **Agbada Formation** of the Niger Delta Basin.

4.4.1 Evidence from Lithofacies Characteristics

The well section consists predominantly of alternating sandstones, shales, shaly sands, and sandy shales. The sandstones are fine- to medium-grained, moderately to well sorted, and display subrounded to rounded grains, suggesting deposition in moderate- to high-energy environments such as **fluvial channels, distributary mouth bars, and shoreface settings**. The interbedded shale and sandy shale facies, characterized by fissility and the presence of lignite streaks, plant remains, and cuticles, point to **low-energy environments** including **delta plain swamps, tidal flats, and prodelta regions**.

Vertically, coarsening-upward successions dominate, consistent with progradational deltaic cycles resulting from regression and sediment build-up. These stacking patterns confirm deposition under **fluctuating energy conditions** controlled by both sediment influx and relative sea-level changes.

4.4.2 Evidence from Palynological Assemblages

Palynological data support the sedimentological interpretation. The occurrence of **Zonocostites ramonae** (mangrove pollen) and **Monoporites annulatus** (freshwater swamp indicator) in the upper intervals indicates deposition in **coastal to delta plain environments** influenced by freshwater and tidal conditions.

Marine and brackish indicators such as **Spiniferites**, **Praedapollis africanus**, **Retibrevitricolporites obodoensis**, and **Peregrinipollis nigericus** in the deeper sections reveal **prodeltaic to shallow marine settings**.

The co-existence of terrestrial and marine palynomorphs across certain zones suggests **delta front to marginal marine transitions**, typical of the **Agbada Formation's paralic sequences**.

4.4.3 Evidence from Mineralogical Composition

Mineralogical analysis identified **quartz, pyrite, iron oxides, mica, glauconite, and carbonates**. The dominance of quartz and feldspar reflects a **continental (cratonic) source**, while the presence of glauconite and pyrite points to **marine reducing conditions** at intervals of lower energy.

Iron oxides indicate periods of oxidation associated with subaerial exposure or deltaic topset environments. Collectively, these mineralogical patterns reinforce the alternating terrestrial–marine character of deposition, influenced by regressive–transgressive cycles.

4.4.4 Integrated Depositional Model

The integration of lithological, mineralogical, and palynological datasets supports a **coastal deltaic depositional model** comprising three principal sub-environments (Fig. 20):

Delta Plain (Upper Agbada Unit): Dominated by sandstones and shaly sands containing *Zonocostites ramonae* and *Monoporites annulatus*. These represent freshwater and mangrove swamp deposits laid down under high sediment supply and occasional flooding.

Delta Front (Middle Agbada Unit): Characterized by alternations of sand and shale with abundant *Praedapollis africanus* and *Peregrinipollis nigericus*. This reflects distributary mouth bar and shoreface deposits influenced by tidal and wave reworking.

Prodelta to Shallow Marine (Lower Agbada Unit): Composed mainly of shales with marine palynomorphs such as *Spiniferites* and *Retibrevitricolporites obodoensis*. These indicate deposition in a lower-energy, offshore environment beyond the main delta front.

The observed facies succession, mineral associations, and microfossil assemblages collectively reveal a **progradational delta system**, with deposition proceeding from marine to continental environments in response to repeated fluctuations in sea level and sediment supply.

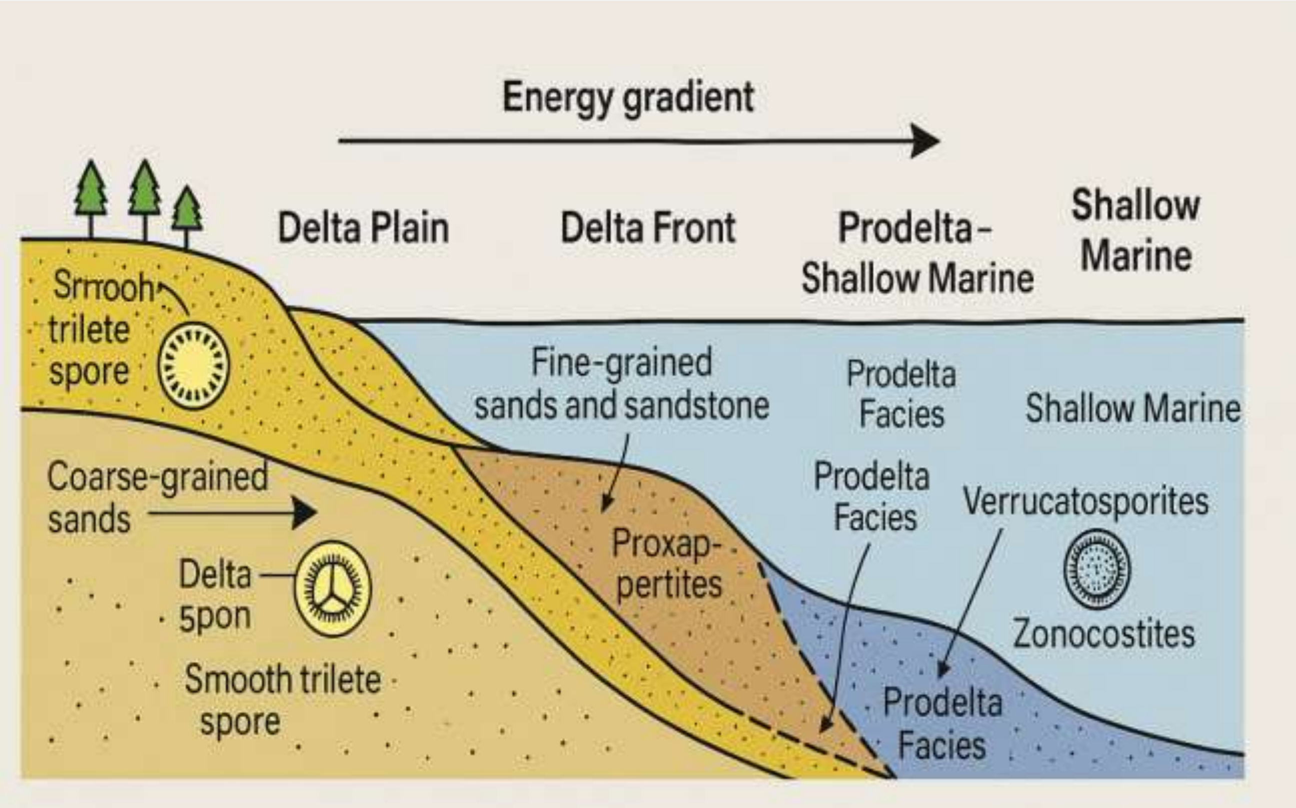


Figure 20: *Interpreted Depositional Model of the XY Well Showing Delta Plain, Delta Front, and Prodelta–Shallow Marine Environments within the Agbada Formation.*

4.4.5 Integrated Sedimentological and Palynological Interpretation

The integration of sedimentological, mineralogical, and palynological data from the XY Well provides a clear understanding of the depositional history, environmental evolution, and sequence stratigraphic framework of the penetrated section within the Agbada Formation of the Niger Delta Basin. The data collectively reveal a coarsening-upward succession typical of **prograding deltaic systems**, characterized by alternating sand, shaly sand, and shale intervals representing repeated cycles of deposition and marine influence.

Sedimentological Evidence

The sedimentological analysis (Figure 13) revealed thirty (30) distinct lithofacies zones comprising sand, shale, sandy shale, shaly sand, clayey sand, and sandy clay. The dominance of fine- to medium-grained, moderately to well-sorted quartzose sands interbedded with fissile shales reflects deposition in a high-energy, near-shore setting transitioning to lower-energy marine environments.

Upward-coarsening sequences identified in Zones 1-9 and 13-23 indicate **progradational episodes**, representing distributary-mouth bar and delta-front deposits. In contrast, fining-upward cycles such as Zones 10, 12, and 18 signify **retrogradational phases**, corresponding to transgressive or flooding events during marine incursions. The repeated alternation of these facies types demonstrates active interplay between sediment supply and relative sea-level fluctuations.

Palynological Support

Palynological analysis corroborates the sedimentological interpretation (Figures 15-19). The occurrence of *Zonocostites ramonae* and *Monoporites annulatus* throughout the middle to upper parts of the succession points to a **mangrove-to-freshwater swamp environment** typical of delta plains. The presence of marine palynomorphs such as *Spiniferites* and *Praedapollis africanus* within deeper shale intervals suggests **marine incursions** and deposition in delta-front to prodelta settings.

Furthermore, the diagnostic palynomorphs *Praedapollis africanus*, *Peregrinipollis nigericus*, and *Retibrevitricolporites obodoensis* define the P620–P560 zones, providing a Miocene age constraint and confirming deposition during active deltaic progradation and subsidence within the Greater Ughelli Depobelt.

Sequence Stratigraphic Synthesis

The integration of palynological and lithological data delineates distinct **sequence boundaries (SB)** and **maximum flooding surfaces (MFS)** that record alternating transgressive and regressive episodes. The identified **SB1** (around 3,500 m) marks a major regression represented by thick, coarsening-upward sand units deposited under delta-plain conditions. Two major **MFSs** (at approximately 2,000 m and 1,400 m) correspond to intervals of high marine influence, evidenced by increased shale content and marine palynomorph abundance.

These MFSs coincide with the transition from delta-front to prodelta facies and represent periods of peak transgression, while the intervening sand-dominated successions reflect regression and renewed deltaic advance (see Figure 20).

Depositional Environments

The combined data suggest that the XY Well succession records deposition in **three major depositional belts**:

Delta Plain: Dominated by sands containing *Monoporites annulatus* and *Zonocostites ramonae*, representing channel and swamp deposits.

Delta Front: Characterized by alternating sand and shale units with *Praedapollis africanus* and *Peregrinipollis nigericus*, deposited under fluctuating energy conditions.

Prodelta–Shallow Marine: Represented by dark grey, calcareous shales with *Spiniferites* and *Retibrevitricolporites obodoensis*, reflecting low-energy marine conditions during transgression.

Summary of Integration.

Overall, the integrated interpretation shows that sedimentation within the XY Well was strongly influenced by **relative sea-level changes, sediment influx, and delta lobe switching** within the Agbada Formation. The consistent alternation between sand- and shale-rich intervals confirms a **cyclic depositional pattern**, while the palynological zonation refines the chronostratigraphic framework and supports a **Middle–Late Miocene age** for the studied interval.

The depositional history reflects the classic deltaic progression of the Niger Delta, from **prodelta marine shales at the base**, through **delta-front sand-shale alternations**, to **continental delta-plain sands near the top** (Figure 20).

4.5 Summary of Results

The integrated sedimentological, mineralogical, and palynological analyses carried out on samples from the XY Well provided a coherent understanding of the lithologic characteristics, facies associations, palynostratigraphic framework, and depositional environments within the Agbada Formation of the Niger Delta Basin.

A total of one hundred and ninety (190) ditch-cutting samples were analyzed from depths of 3603.7 m to 6.09 m. Thirty (30) distinct lithofacies zones were identified based on grain size, texture, mineral composition, color, and sorting. These zones consist mainly of sandstones, shales, sandy shales, shaly sands, clayey sands, and sandy clays. The alternation of sand and shale intervals revealed cyclic coarsening and fining upward successions typical of a prograding deltaic sequence.

Sedimentological observations showed that the sandstones are generally fine to medium grained, subrounded to rounded, and moderately to well sorted. They are predominantly quartzose with accessory minerals such as feldspars, micas, pyrite, glauconite, carbonates, and iron oxides. The shales are light to dark grey, fissile, and locally calcareous, containing organic matter, lignite, and cuticles. These features reflect deposition under alternating high and low energy conditions, ranging from delta plain channels to prodelta marine settings.

Mineralogical assessment confirmed the dominance of quartz, indicating a stable continental source; the presence of pyrite and glauconite, suggesting reducing marine conditions; iron oxides reflecting oxidation and diagenetic alteration; and mica signifying sediment input from crystalline terrains. Carbonate minerals occur mainly in calcareous shales, implying brief periods of low clastic influx and marine transgression.

Palynological studies revealed a total of 964 palynomorphs, consisting of 496 pollen, 458 spores, and 10 dinoflagellate cysts. Diagnostic species such as *Praedapollis africanus, Peregrinipollis nigericus*, and *Retibrevitricolporites obodoensis* defined the P620 to P560 palynozones, assigning a Middle to Late Miocene age to the succession. The occurrence of *Zonocostites ramonae* and *Monoporites annulatus* indicates mangrove and freshwater swamp conditions, whereas the presence of marine dinocysts confirms short-lived marine incursions.

Sequence stratigraphic analysis integrated from facies patterns and palynomorph distribution recognized one major sequence boundary (SB1) at about 3500 m and two maximum flooding surfaces (MFS1 and MFS2) at approximately 2000 m and 1400 m respectively. These surfaces mark alternating phases of regression and transgression within the depositional history of the Agbada Formation in the study area.

Overall, the data demonstrate that deposition in the XY Well occurred within a coastal deltaic system evolving through prodelta, delta front, and delta plain environments. The coarsening upward sequences correspond to progradational episodes of sediment supply, while the shale-rich intervals record marine transgressions and maximum flooding events.

Hence, the XY Well succession represents a typical paralic sequence of the Agbada Formation, a product of alternating fluvial and marine influences controlled by relative sea level fluctuations, sediment influx, and periodic delta lobe switching within the Greater Ughelli Depobelt of the Niger Delta.

CHAPTER FIVE

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

5.0 Introduction

This chapter summarizes the findings obtained from the integrated sedimentological, mineralogical, and palynological analyses of the **XY Well** in the Niger Delta Basin. The study aimed to characterize the lithostratigraphic succession, interpret depositional environments, and evaluate the hydrocarbon potential of the penetrated formations. The results from the various analyses are synthesized here to draw conclusions and propose recommendations for future research and exploration within the study area.

5.1 Summary

This study integrated sedimentological, mineralogical, and palynological analyses to characterize the lithologic succession, depositional environments, and hydrocarbon potential of the XY Well within the Agbada Formation of the Niger Delta Basin. A total of one hundred and ninety (190) ditch cutting samples were examined from depths of 3603.7 m to 6.09 m. The analyses involved macroscopic and microscopic lithologic description, mineral identification, and palynological evaluation to establish biostratigraphic zonation and depositional setting.

Thirty (30) lithofacies zones were identified, comprising alternating beds of sand, shale, sandy shale, shaly sand, sandy clay, and clayey sand. The sandstones are fine to medium grained, subrounded to rounded, and moderately to well sorted, suggesting deposition under moderately high energy conditions. The shales are fissile, grey to dark brown, and contain lignite and plant materials, representing lower energy environments. These alternating facies reflect repeated changes in depositional energy, which are characteristic of deltaic successions influenced by fluctuating sea levels.

Mineralogical analyses identified quartz, pyrite, iron oxide, glauconite, carbonate, and mica as the dominant minerals. Quartz occurs as the most abundant component, reflecting a stable continental provenance. Pyrite and glauconite indicate reducing and marine conditions, while iron oxide reflects oxidation and post depositional alteration. The presence of carbonate suggests temporary marine transgressions.

Palynological analysis yielded 964 palynomorphs consisting of 496 pollen, 458 spores, and 10 dinoflagellate cysts. The identified key species, *Praedapollis africanus*, *Peregrinipollis nigericus*, and *Retibrevitricolporites obodoensis*, were used to establish the P620 to P560 palynozones, which correspond to the Middle to Late Miocene age. The distribution of palynomorphs such as *Zonocostites ramonae* and *Monoporites annulatus* indicates delta plain and swampy environments, while *Spiniferites* and other dinocysts signify marine incursions.

Integration of sedimentological and palynological data delineated one major sequence boundary and two maximum flooding surfaces. These surfaces define alternating phases of regression and transgression that controlled sediment deposition. The overall pattern represents a prograding deltaic sequence that evolved through prodelta, delta front, and delta plain environments.

5.2 Conclusion

The XY Well penetrated the Agbada Formation, which consists of alternating sandstone and shale units typical of paralic depositional environments in the Niger Delta Basin. The sedimentological evidence, supported by mineralogical and palynological data, indicates that sedimentation occurred in a coastal deltaic system influenced by both fluvial and marine processes.

The palynological assemblages confirmed a Middle to Late Miocene age and revealed cyclic environmental changes linked to deltaic progradation and marine transgression. The occurrence of lignite streaks, plant cuticles, and calcareous shales, together with marine and terrestrial palynomorphs, suggests periodic shifts between continental and shallow marine conditions.

The recognized sequence boundary at about 3500 m and the two maximum flooding surfaces at approximately 2000 m and 1400 m mark key stratigraphic surfaces representing major depositional events in the well. The depositional model demonstrates a coarsening upward sequence that reflects progressive shallowing from prodelta through delta front to delta plain settings.

This study concludes that the XY Well records a dynamic depositional history controlled by relative sea level fluctuations, sediment supply, and delta lobe switching within the Agbada Formation. These findings improve the understanding of the stratigraphic architecture and depositional evolution of the Niger Delta Basin.

5.3 Recommendations

Further Geochemical Analysis:

Additional geochemical studies such as Total Organic Carbon (TOC) and Rock-Eval pyrolysis should be conducted to confirm the hydrocarbon generation potential of the identified source rock intervals.

Integration with Wireline Logs:

Future work should integrate the lithofacies and palynological data with wireline log interpretation to refine the correlation of reservoir and seal units.

Core Sampling and Petrographic Studies:

Where possible, core samples should be collected for detailed petrographic and grain size analyses to validate depositional interpretations made from ditch cutting samples.

Expanded Palynological Correlation:

Comparative palynological studies across neighboring wells in the Greater Ughelli Depobelt should be carried out to establish regional chronostratigraphic correlations.

Hydrocarbon Exploration Implications:

The identified reservoirs and seals should be further evaluated for their structural and stratigraphic trapping potential to enhance hydrocarbon exploration within the area.

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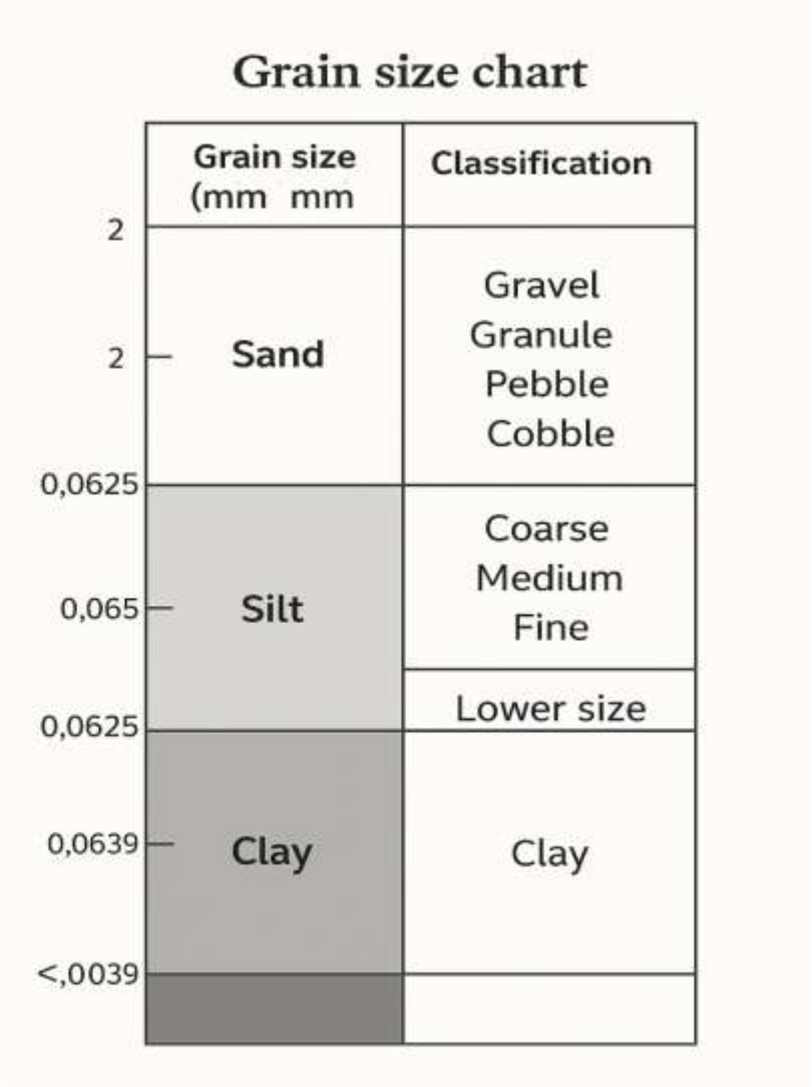
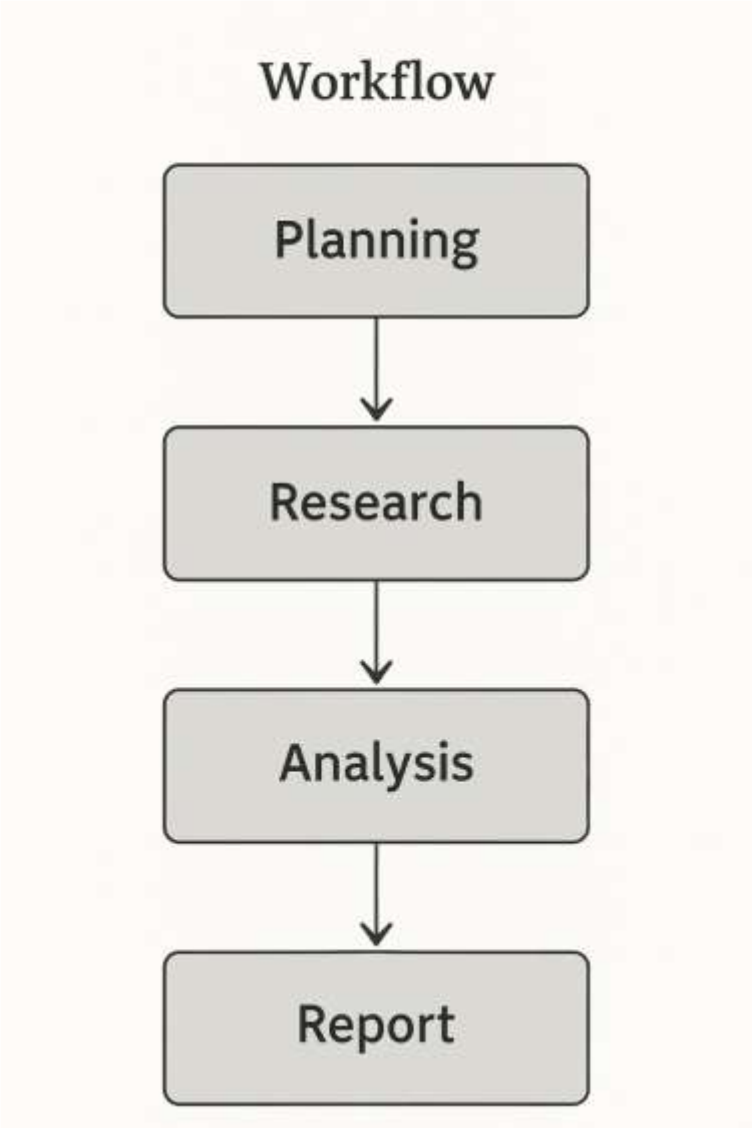
APPENDIXES



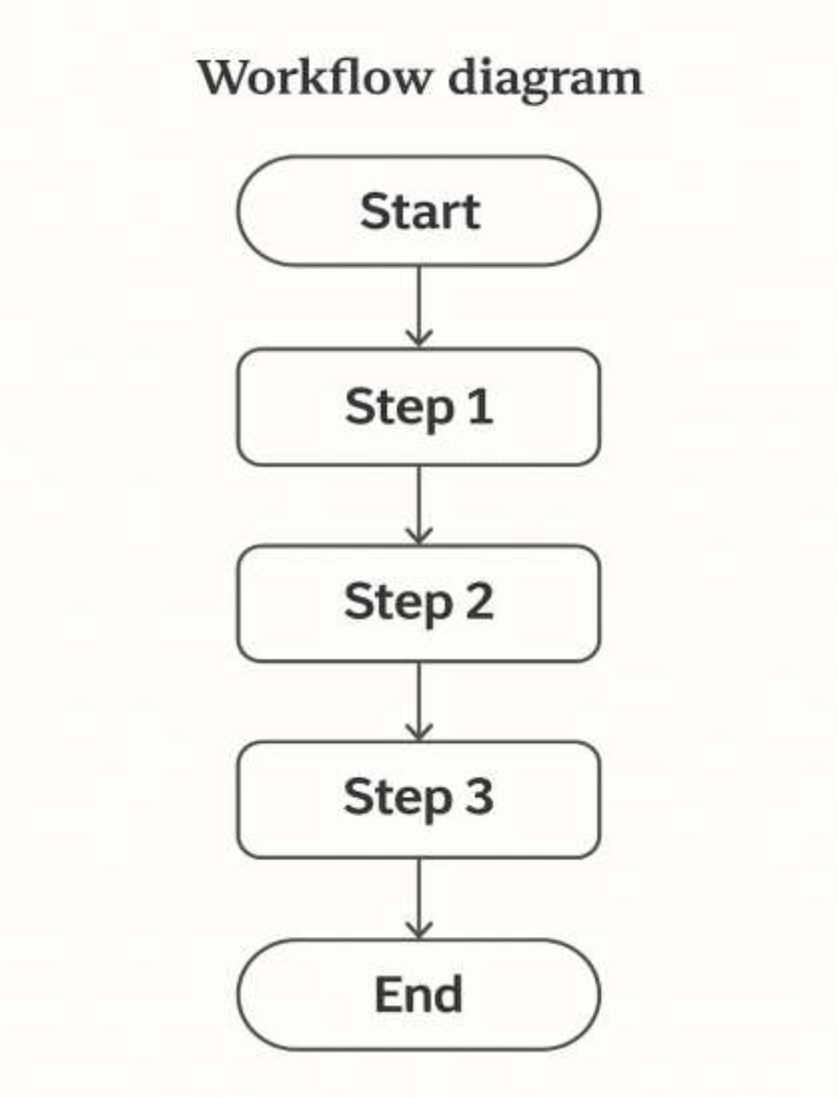
Appendix Figure A1: Grain Size Classification Chart

This figure presents a standard grain size classification chart used in sedimentological studies. It illustrates the textural categories of gravel, sand, silt, and clay, along with their corresponding grain size ranges. The chart supports the lithofacies descriptions in the Materials and Methods chapter by providing a visual guide for identifying grain size, sorting patterns, and sediment textures encountered in the XY Well. It also helps demonstrate how grain size influences energy conditions during deposition within the Agbada Formation.



Appendix Figure A2: Sedimentological Workflow Diagram

This workflow diagram outlines the sequence of sedimentological procedures applied to the ditch cutting samples. It includes the stages of planning, sample handling, descriptive logging, classification, and interpretation. The diagram serves as a visual summary of the analytical steps described in the methodology. It enhances clarity and helps readers understand how the lithofacies zones, homogenetic units, and heterogenetic units were identified from the 190 cutting samples.



Appendix Figure A3: Integrated Analytical Workflow for Sedimentology and Palynology

This diagram illustrates the integrated approach used in this study by combining sedimentological analysis with palynological evaluation. It summarises the stepwise process from initial sample selection to environmental reconstruction. The workflow highlights the connection between lithofacies interpretation, mineral identification, palynomorph recovery, biostratigraphic zonation, and the final depositional environment model. This appendix figure strengthens the methodological transparency of the research and provides a visual reference for readers who want to follow the analytical sequence adopted in this study.