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Calcareous Nannofossil Biostratigraphy Studies of IZA-1 Well, Offshore Depobelt, Niger Delta

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Abstract
Calcareous nannofossil biostratigraphic analysis was conducted on 20 ditch cutting samples from the IZA-1 well, located in the offshore deep-water area of the Niger Delta. The study employed the pipette strew preparation method to establish nannofossil biozonation and determine the age of the study intervals. Lithologically, the examined sequences consist of grey shales, siltstones, and mudstones, with intercalations of thin-bedded sandstones. The analysis revealed a moderately diverse assemblage of calcareous nannofossils. Nannofossil zones were identified based on the first and last occurrences of easily recognizable marker species and their relative abundances. These zones facilitated the age determination of the sequences, which range from the Early Miocene to the Middle Miocene. Key marker species and diagnostic assemblages, including *Sphenolithus abies*, *Sphenolithus heteromorphus* and *Discoaster drugii*, were used to assign ages from NN5 to NN3, according to the classic zonation scheme of Martini (1971).

Keywords
Zonation, nannofossil, calcareous, biostratigraphic, chronostratigraphic

1. Introduction

Calcareous nannofossils are the remains of minute, golden-brown, unicellular, autotrophic, planktonic marine algae that inhabit the oceans. Typically measuring less than 30 microns in diameter, and usually between 5 and 10 microns for coccoliths, they contribute significantly to deposits of marine carbonate-rich rocks. These organisms can be found in various habitats, including the open ocean, pelagic environments, nearshore littoral zones, and inshore lagoon environments, and they exist as free floaters (plankton).

Calcareous nannofossils have been present since the Late Triassic period and continue to the present day. This group encompasses all forms of coccolithophores and associated non-coccolithophore nannoliths, such as the Discoasters from the Paleogene and Neogene periods, which are particularly valuable due to their high diversity and significant biostratigraphic importance. Coccolithophores secrete circular to elliptical calcite plates known as coccoliths, which together form a coccosphere. These structures may be preserved intact or disaggregated before being buried in sediments. The calcite plates that remain are of particular interest to paleontologists. Calcareous nannoplankton are restricted to marine environments, ranging from open oceans to neritic (shelf) zones, as well as nearshore and littoral habitats. Their widespread distribution can be attributed to their planktonic nature, high tolerance for saline waters up to 32-37 ppt (Baumann et al., 2005), resilience against predation by zooplankton, and their ability to thrive in conditions that are inhospitable to other microorganisms. Their evolutionary history, characterized by great diversity, makes calcareous nannofossils invaluable tools for biostratigraphy, as well as for applications in paleoclimatic, paleoceanographic, paleoenvironmental, and paleoecological studies. The biozone, or zone, is a fundamental aspect of biostratigraphy, focused on differentiating rock units based on the distinctive fossil taxa they contain.

Changes in fossil assemblages across stratigraphic rock units play a crucial role in determining the age of rocks, characterizing biostratigraphic units, and enabling correlation between different geological formations. The concept of zonation, outlined by Oppel and Darwin in 1856, explained these changes in fossil assemblages through the theory of evolution. Darwin drew upon data from extinct fossil organisms, attributing the evolution of species to the principle of "survival of the fittest" (natural selection). He proposed that this process occurs as organisms adapt to changing environments and compete for survival, leading to the emergence of new species. Darwin's ideas were further illuminated by the genetic theory put forth by Mendel (1865), which explained how genetic mutations are transferred from parent organisms to their offspring. Evolution in organisms can occur gradually or in a more abrupt, punctuated manner. In the case of calcareous nannoplankton, two evolutionary trends have been proposed: (1) phyletic changes in morphology over time from ancestral to descendant species, and (2) changes in taxonomic frequencies during evolution.

Calcareous nannoplankton first appeared during the Late Triassic (Rhaetic-Lias), with relatively low species diversity. The first significant diversification of these organisms occurred during the Late Jurassic (Oxfordian), followed by another major diversification in the Cretaceous (Maastrichtian). However, a near-complete extinction event at the end of the Maastrichtian drastically reduced the ocean's calcareous nannoplankton, with only about 4-5 species surviving into the Earliest Tertiary (Danian). From this small genetic pool, new taxa gradually evolved, with the pace of evolution initially slow but accelerating during the Late Paleocene and Early Eocene. This period marked the highest diversity of calcareous nannoplankton in the Cenozoic era, partly due to the appearance and rapid diversification of discoasters in the Late Paleocene and their continued evolution through the Early and Middle Eocene. Following this peak, species diversity gradually decreased throughout the remainder of the Eocene and more sharply during the Early and Late Oligocene. A second, less pronounced diversification of taxa occurred during the Middle Miocene. After this period, a trend of decreasing diversity persisted until the Pleistocene. These evolutionary patterns highlight the dynamic nature of calcareous nannoplankton and their response to changing environmental conditions over geological time.

The relative abundance and short stratigraphic ranges of nannofossils make them ideal group for the biostratigraphic subdivision of Mesozoic and Cenozoic strata. Their planktonic nature facilitates rapid dispersal over large areas, enhancing their utility as tools for inter-regional correlation. Many species are widespread in both tropical and temperate regions, allowing for relatively refined biostratigraphic zonations in these areas. However, in higher latitudes, species diversity is limited, typically dominated by hardier, long-ranging forms. Several biostratigraphic zonation schemes have been proposed for various sections of the Cenozoic, resulting in fairly high-resolution zonations for the entire era. Notable contributions include zonations by Hay and Mohler (1967) for the Paleocene-Eocene interval, as well as Bramlette and Wilcoxon (1967) and Roth et al. (1970) for the Oligocene. Theodoridis (1984) provided a zonation for the Miocene, while Gartner (1967) and Hay et al. (1967) addressed the Neogene and Quaternary. Bukry (1971) presented a comprehensive zonation for the entire Cenozoic of the Pacific Ocean. Martini's (1971) zonation is particularly relevant for nearshore and shelf areas in tropical to temperate regions, relying heavily on hemi-pelagic species that are not typically found in the open ocean. For oceanic sections, the zonation schemes proposed by Bukry (1971, 1973) are more appropriate. In the context of the Paleogene zonation in relatively higher latitudes, Edwards's (1971) zonation is applicable to New Zealand and adjacent Southern Ocean regions. In contrast to the relatively rapid evolutionary rates observed during the Cenozoic, nannoplankton evolutionary rates were slower throughout much of the Mesozoic, resulting in less refined zonations for that era. Notable zonations for the early Jurassic were suggested by Prins (1969), while Bown and Cooper (1998) synthesized mid-latitude and boreal Jurassic zonations. Additional contributions include Thierstein (1973), Mutterlose (1992), and Bown and Young (1998) for the Early Cretaceous, as well as Cepek and Hay (1969), Manivit (1971), Sissingh (1977) and Burnett (1998) for the Late Cretaceous.

A comprehensive summary of Mesozoic nannofossil zonation is documented in works by Thierstein (1976), Verbeek (1976, 1977) and Roth (1978). Ajayi and Okosun (2013) conducted calcareous nannofossil biostratigraphic studies on Wells A, B, C, and D, located offshore in the Niger Delta, Nigeria. Their study aimed to document the biostratigraphic distribution, establish biozonation, and achieve stratigraphic correlation within these wells. They identified a total of forty-two nannofossil species across the four wells, leading to the recognition of five zones and two subzones based on diagnostic marker species and significant nannofossil events. These biozones were suggested to be valuable for subdividing and correlating the deep offshore Neogene sequence in the Niger Delta. Alkali et al. (2014) performed a calcareous nannofossil biostratigraphic study on the strata penetrated by Well 02 in the shallow offshore area of the Niger Delta. Their research aimed to determine the age and biozonations of the well. They identified forty calcareous nannofossil species, which helped establish the biozonations and date the sequence. The study identified three nannofossil zones: *Helicosphaera ampliaperta* (NN4), *Sphenolithus heteromorphus* (NN5), and *Catinaster coalitus* (NN8), corresponding to the Early Miocene to Late Miocene. These zones were established following standard zonation schemes based on the first and last occurrences of marker species. Nannofossil abundance and diversity patterns, calibrated with chronostratigraphic bioevents, revealed four condensed sections when correlated with the Global Cycle Chart.

Okewale and Omoboriowo (2017) also conducted biostratigraphic studies on ditch cutting samples from wells X-1 and X-2, located offshore in the deep-water Niger Delta. Their objective was to establish nannofossil biozonation, determine the age, and perform correlation across the wells. The study revealed fairly diverse nannofossil assemblages, leading to the establishment of calcareous nannofossil zones based on the first and last occurrences of identifiable marker species and their relative abundances. These zones facilitated the age determination of the studied sections, spanning from the Early Pliocene to the Middle Miocene. The current research aims to perform calcareous nannofossil biostratigraphic studies on the IZA-1 well, located offshore, 120 km southwest of the Niger Delta, Nigeria. The study area covers approximately 60 km², with an average water depth of 1,000 meters (3,300 feet). The field produces both petroleum and natural gas as shown in Fig. 1.

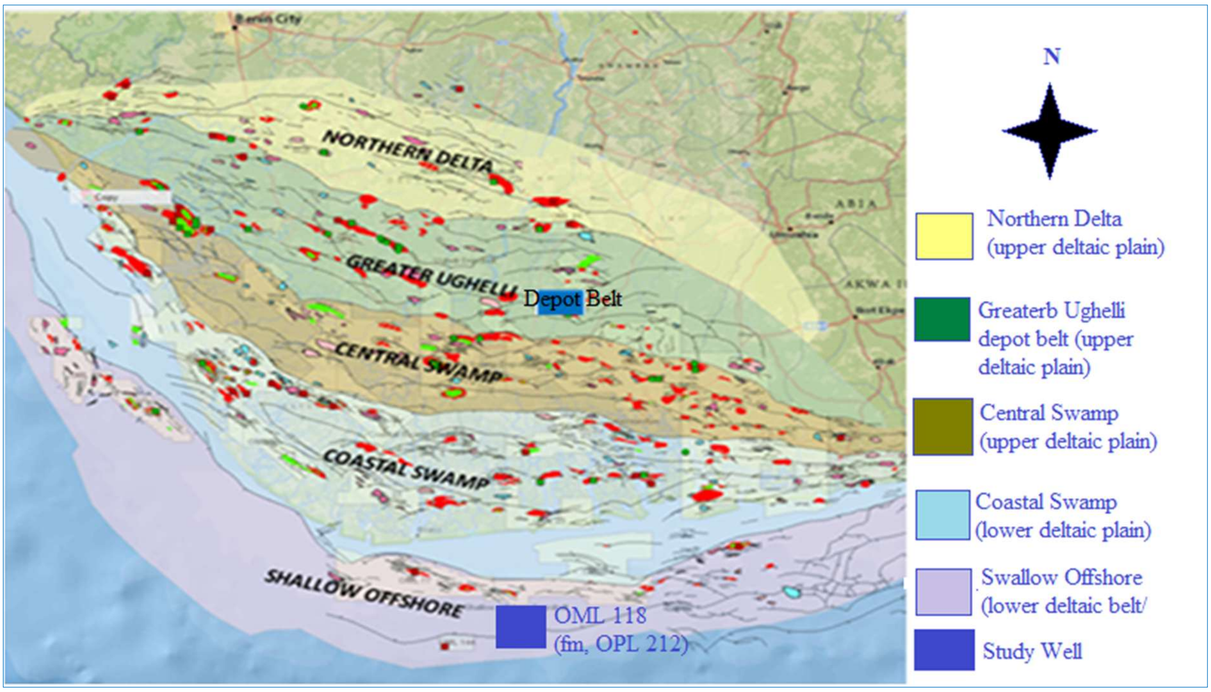

Fig. 1. Niger Delta Depobelt Base map (showing location of study wells)

2. Geological of Niger Delta

The Niger Delta is located in the Gulf of Guinea (Fig. 2) and spans the entire Niger Delta Province. Since the Eocene epoch, the delta has prograded southwestward, forming depobelts that represent the most active portions of the delta at each stage of its development (Doust and Omatsola, 1990). These depobelts constitute one of the largest regressive deltas globally, covering an area of approximately 300,000 km² (Kulke, 1995), with a sediment volume of around 500,000 km³ (Hospers, 1965) and a sediment thickness exceeding 10 km in the basin depocenter (Kaplan and Maxwell, 1994). The Niger Delta Basin itself covers about 75,000 km² and is characterized by an overall regressive clastic sequence with a maximum thickness ranging from 9,000 to 12,000 meters (29,500 to 39,400 feet).

The Niger Delta is stratigraphically divided into three main formations, which represent prograding depositional facies. These formations are primarily differentiated based on their sand-to-shale ratios. The Akata Formation, located at the base of the Niger Delta, has a marine origin and consists of a thick sequence of shale (potential source rock), turbidite sand (potential reservoirs in deep water), along with minor clay and silt components. Formed during the Paleocene and continuing into the Recent, the Akata Formation developed during periods of low sea level when terrestrial organic matter and clay were transported to deep-water regions characterized by low energy and oxygen-deficient conditions (Stacher, 1995). This formation underlies the entire delta and is typically overpressured, with thickness ranging approximately up to 6,000 meters. Above the Akata Formation lies the Agbada Formation, the major petroleum-bearing unit, which began depositing in the Eocene and continues to the present? This formation comprises paralic siliciclastics that exceed 3,700 meters in thickness and represents the actual deltaic portion of the stratigraphic sequence. The clastics were deposited in delta-front, delta-top set, and fluvio-deltaic environments. The uppermost formation is the Benin Formation, a continental deposit of alluvial and upper coastal plain sands dating from the latest Eocene to the Recent, reaching thicknesses of up to 2,000 meters (Avbovbo, 1978). The tectonic framework of the continental margin along the West Coast of equatorial Africa is influenced by Cretaceous fracture zones, which manifest as trenches and ridges in the deep Atlantic. These fracture zone ridges subdivide the margin into individual basins and, in Nigeria, delineate the boundary faults of the Cretaceous Benue-Abakaliki Trough, extending deep into the West African shield.

The Niger Delta's geology is intricately linked to its tectonic history, marked by the opening of the South Atlantic and the development of the Benue-Abakaliki Trough. This trough represents a failed arm of a rift triple junction associated with rifting that initiated in the Late Jurassic and extended into the Middle Cretaceous (Lehner and De Ruiter, 1977). However, rifting in the Niger Delta region ceased during the Late Cretaceous. Following the end of rifting, gravity tectonism emerged as the primary deformational process, significantly affecting the region's geological structure.

Shale mobility, a result of gravity tectonics, induced internal deformation through two primary mechanisms (Kulke, 1995). First, shale diapirs developed due to the loading of poorly compacted and over-pressured clays from the Akata Formation by the higher-density sands from the Agbada Formation. Second, slope instability arose from a lack of lateral support for the under-compacted delta-slope clays (Akata Formation). In various depobelts, gravity tectonics were completed before the deposition of the Benin Formation and manifested in complex structures such as shale diapirs, rollover anticlines, collapsed growth fault crests, and closely spaced flank faults (Evamy et al., 1978). These faults generally offset different parts of the Agbada Formation and flatten into detachment planes near the top of the Akata Formation.

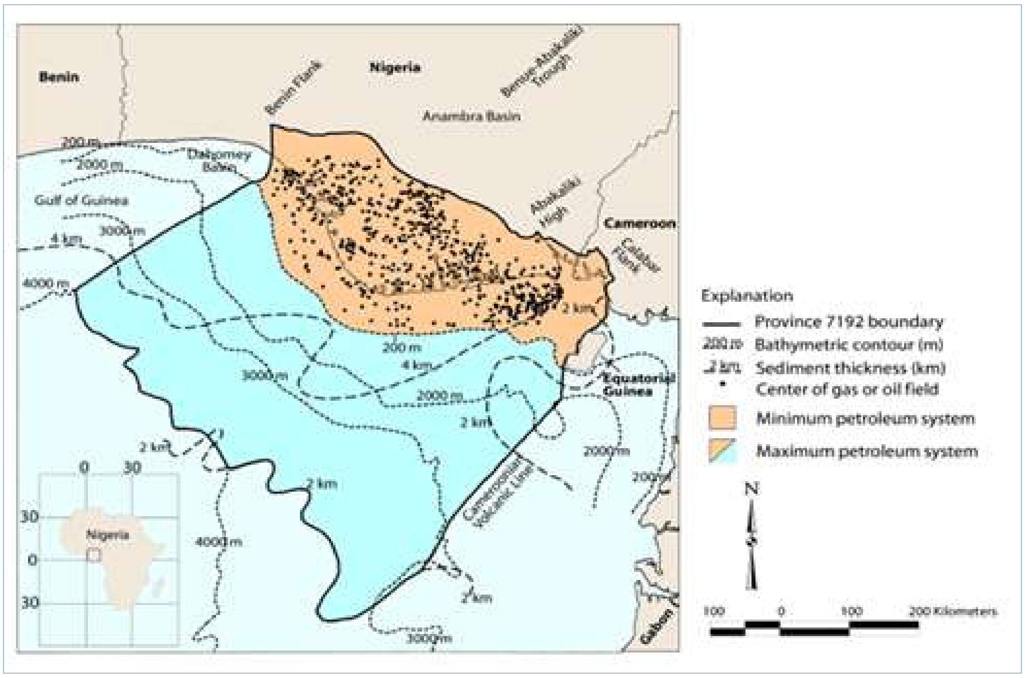

Fig. 2. Index map of the Niger Delta showing province outline (Tuttle et al., 1999)

The deposition of the three formations occurred within five offlapping siliciclastic sedimentation cycles, or depobelts, that characterize the Niger Delta. Each depobelt is 30-60 kilometers wide, prograded southwestward up to 250 kilometers over oceanic crust into the Gulf of Guinea (Stacher, 1995). They are defined by synsedimentary faulting that responded to variable subsidence rates and sediment supply (Doust and Omatsola, 1990). Each depobelt serves as a separate geological unit, marked by a break in the regional dip of the delta, bounded landward by growth faults and seaward by large counter-regional faults or the growth fault of the next seaward belt (Evamy et al., 1978; Doust and Omatsola, 1990).

Doust and Omatsola (1990) identified three structural provinces within the delta. The northern delta province, underlain by a relatively shallow basement, features older growth faults that are generally rotational and evenly spaced, increasing in steepness seaward. The central delta province contains well-defined structures with progressively deeper rollover crests that shift seaward with any given growth fault. The distal delta province is the most structurally complex, shaped by internal gravity tectonics on the modern continental slope.

Cretaceous lithologies within the Niger Delta basin can be inferred from the exposed Cretaceous sections in the adjacent Anambra Basin (Fig 2). From the Campanian through the Paleocene, the shoreline of the Niger Delta was concave toward the Anambra Basin (Hospers, 1965). This configuration led to convergent longshore drift cells that produced tide-dominated deltaic sedimentation during transgressions and river-dominated sedimentation during regressions (Reijers et al., 1997). Shallow marine clastics deposited farther offshore in the Anambra Basin are represented by the Albian-Cenomanian Asu River Group, Cenomanian-Santonian Eze-Aku and Awgu Shale, and the Campanian/Maastrichtian Nkporo Shale, among others (Nwachukwu, 1972; Reijers et al., 1997). The distribution of Late Cretaceous shale beneath the Niger Delta remains poorly understood (Fig. 3).

During the Paleocene, a significant transgression known as the Sokoto transgression (Reijers et al., 1997) commenced, marked by the deposition of the Imo Shale in the Anambra Basin and the Akata Shale in the Niger Delta Basin. By the Eocene, the coastline evolved into a convex curvilinear shape, leading to divergent longshore drift cells and a transition to wave-dominated sedimentation (Reijers et al., 1997). At this stage, the deposition of paralic sediments began in the Niger Delta Basin proper. As the sediments prograded southward, the coastline became progressively more convex, reflecting changes in sediment supply and coastal dynamics. This transition from a concave to a convex shoreline indicates a shift in depositional environments, influenced by factors such as sea-level changes, sediment transport mechanisms, and tectonic activities. The emergence of paralic environments facilitated the accumulation of sediments in deltaic systems, leading to the development of diverse habitats. These settings played a crucial role in the formation of the Agbada Formation, where deltaic processes contributed to the deposition of clastic sediments.

The convex coastline allowed for the establishment of delta-front and delta-topset environments, further influencing the sedimentation patterns and the distribution of different lithologies within the Niger Delta. As sedimentation progressed, the interplay between riverine and marine influences became pronounced, contributing to the complex stratigraphy of the Niger Delta. The evolving coastal configuration also had implications for the migration and trapping of hydrocarbons, ultimately shaping the petroleum systems within the basin. The ongoing processes of sedimentation and tectonic adjustments have continued to define the geological character of the Niger Delta through the present day as shown in Figs. 2 and 3.

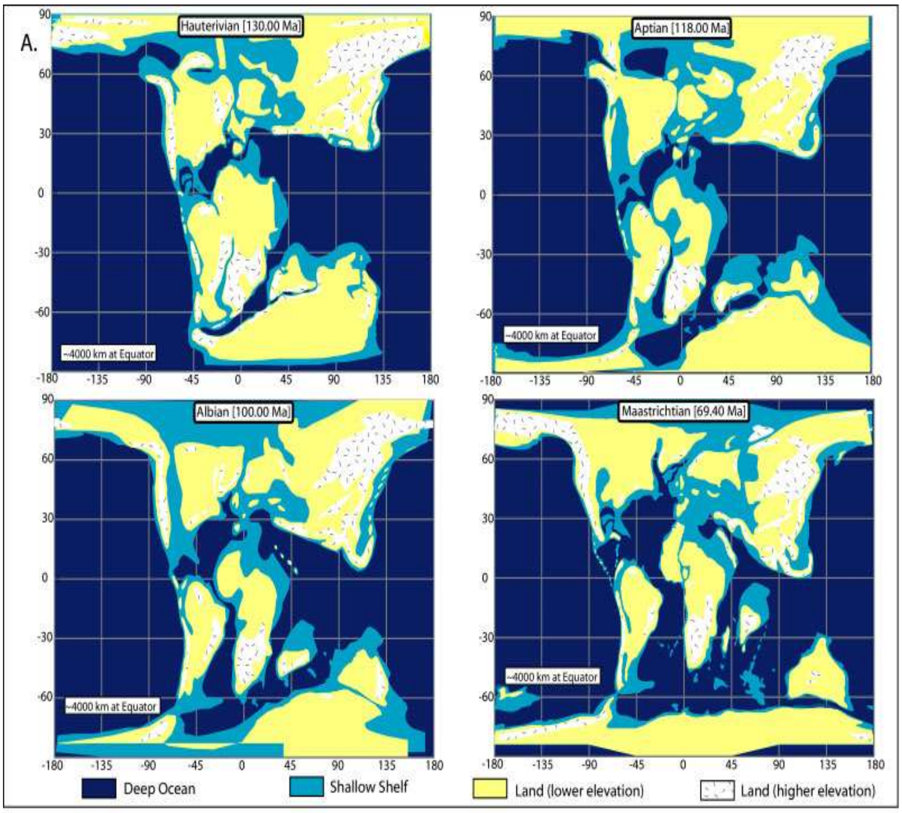

Fig. 3. Paleogeography showing the opening of the South Atlantic, and development of the region around Niger Delta

3. Materials and Method

3.1. Materials

Slide preparation was carried out on the fifteen ditch cutting samples used for this study using the calcareous nannofossil pipette-strew preparation method. The process involved the following steps and materials:

3.1.1. Materials and Apparatus

Distilled Water: Used for rinsing and diluting samples.

Pipette: Essential for transferring small amounts of samples onto slides.

Stirring Rod: Used to mix samples and ensure homogeneity.

Cover Slides and Glass Slides: For mounting the prepared samples for microscopic analysis.
Hot Plate: To dry and heat the slides if necessary.

Mortar and Pestle: Used for grinding and homogenizing the samples.

UV Lamp/Sunlight: For curing the Norland optical adhesive used in slide preparation.

Test Tubes/Beakers and Test Tube Racks: For containing samples during processing and analysis.

3.1.2. Slide Preparation Process

Sample Collection: Fifteen ditch cutting samples were obtained from the IZA-1 well at intervals between 6900-11740 ft.

Grinding: The samples were ground using a mortar and pestle to break them down into finer particles.

Suspension Creation: A small amount of the ground sample was mixed with distilled water in a test tube.

Transfer: Using a pipette, a drop of the sample suspension was placed onto a glass slide.

Covering: A cover slip was placed over the drop, ensuring no air bubbles were trapped.

Curing: The slide was placed under a UV lamp or in sunlight to cure the Norland optical adhesive, ensuring the cover slip was securely attached.

Microscopic Analysis: The prepared slides were examined under a microscope for the identification of nannofossil taxa.

3.1.3. Observation and Analysis of Nannofossils

After preparing the nannofossil slides, the next crucial step is the observation and analysis of individual slides. This is typically conducted using specialized microscopes, including:

Polarized Microscope: Utilizes polarized light to enhance the visibility of specimens, particularly useful for examining the optical properties of nannofossils.

Scanning Electron Microscope (SEM): Provides high-resolution images by scanning the surface of samples with a focused beam of electrons, revealing detailed morphological features.

Transmitted Light Microscope: Uses light that passes through the specimen, allowing for the observation of transparent or translucent samples.

Table 1. well sections of calcareous nannoplanktons of IZA–1 Well

X-2 Depth interval (ft)	Shpenolithus eromorphus	Helicosphaera ampliafera	Shpenolithus belemnos	Calcidiscus leptoporus	Coccolithus pelagicus	Coccolithus miopelagicus	D. quinqueramus	H. Intermedia	D. berggrenii	S. neoabies	S. moriformis	R. Pseudoumbilia	D. braarudii	Discoaster druggi	Discoaster deflandrei	Sphenolithus moriformis
6900	2	1	-	1	1	1	1		-	1	-	1	-	2	1	-
7120	3	1	-	1	1	-	1	2	-	7	-	-	1	1	-	1
7650	1	2	-	1	1	-	1	1	-	3	-	1	1	-	-	1
6860	2	3	-	2	-	-	3	1	-	1	-	1	-	-	-	1
8150	1	-	-	-	2	-	-	1	-	-	-	2	-	-	-	2
8420	3	-	-	-	1	-	-	1	-	-	-	2	-	1	-	2
8750	-	-	-	1	1	-	-	2	-	-	2	-	1	1	1	-
9120	1	-1	-	1	1	-	-	-	-	-1	-	-	1	-	1	-
9250	-	1	-	5	3	-	-	-	-	3	-	1	2	-	3	1
9320	-	12	-	1	2	-	1	1	-	3	-	1	1	-	1	1
9480	-	1	-	1	1	-	1	1	-	1	-	-	1	-	-	2
9720	1	1	-	1	-	-	1	-	-	2	-	-	-	1	-	3
10150	-	1	-	1	-	-	1	-	-	-	-	-	1	1	2	-
10550	-	2	-	3	-	-	1	1	-	-	-	2	2	-	-3	1
10760	-	1	6	1	1	-	2	2	-	1	-	3	-	1	-	1
11100	-	-	-	1	1	-	1	1	-	1	-	-	1	1	1	2
11350	-	-	-	1	1	-	1	-	-	1	-	1	2	-	1	1
11550	-	-	2	1	1	-	2	1	-	1	-	1	1	1	-	-1
11620	-	-	3	1	1	-	1	3	-	2	-	1	1	1	2	1
11740	-	-	-	-	2	-	1	-	-	1	-	2	-	-	1	1

3.1.4. Procedure for Observation

Preparation for Observation: A drop of immersion oil is placed on the slide using a disposable pipette. This oil is essential for improving visibility, particularly at high magnifications, as it increases the refractive index of light passing through the sample.

Use of Immersion Oil: Immersion oil is specifically recommended when using the 100X lens. It helps to reduce blurriness that can occur due to a high refractive index at such magnifications. Immersion oil should not be used with lenses of smaller magnifications (e.g., 10X or 40X) as it may hinder the quality of the observation.

Microscopic Analysis: Each nannofossil species observed is carefully recorded, along with their relative abundance. This quantitative data is critical for biostratigraphic interpretations. Observations may include the morphology, size, and specific characteristics of the nannofossils that are indicative of particular stratigraphic zones.

3.1.5. Recording Observations

Create a detailed log for each species identified, noting their abundance, distinguishing features, and any other relevant information that may assist in biostratigraphic analysis.

3.1.6. Data Utilization

The collected data on nannofossil species and their abundance will contribute to establishing biozones, facilitating stratigraphic correlation, and aiding in age determination of the geological sequences within the IZA-1 well. This process ultimately enhances the understanding of the sedimentary environment and geological history of the Niger Delta Region.

3.1.7. Precautions for Nannofossil Preparation and Analysis

To ensure the integrity and accuracy of the nannofossil preparation and analysis process, the following precautions should be strictly followed:

Thorough Washing of Materials: All materials and apparatus used in the preparation process, such as glass slides, pipettes, and containers, should be thoroughly washed to eliminate any residual contaminants that could interfere with the samples.

Serial Arrangement and Labeling: Each glass slide must be arranged serially and labeled according to its corresponding depth interval. This practice helps prevent the mixing up of samples, which could lead to contamination and incorrect interpretations.

Serial Processing of Samples: Samples should be processed in a serial manner, following the order of depth, to minimize errors or mix-ups that could compromise the results.

Proper Crushing and Stirring: Ensure that the samples are crushed and stirred carefully to avoid damaging the nannofossils. Excessive force can lead to the destruction of delicate specimens.

Immediate Washing of Tools: The stirring rod and pipette should be washed immediately after using each sample. This practice prevents cross-contamination that could skew results or lead to misinterpretation.

Controlled Drying Conditions: Apply moderate heat while drying the samples to prevent the splashing of bubbles from one sample to another. Such splashes can result in contamination and compromise the integrity of the samples.

4. Presentation and Interpretation of Results

The analysis of the fifteen ditch cutting samples from the IZA-1 well, spanning the interval of 6900 to 11740 feet, yielded significant findings regarding calcareous nannoplankton:

4.1. Abundance and Diversity

The analysis revealed a very high abundance and diversity of calcareous nannoplankton across most samples. This indicates favorable environmental conditions for nannoplankton growth and preservation during the deposition of the sediments in this interval. However, a few samples were found to be barren of nannofossils, suggesting variations in depositional environments or potential biostratigraphic gaps in those intervals.

4.2. Biostratigraphic Interpretation

The well is inferred to penetrate through Early Miocene to Middle Miocene strata, correlating to biostratigraphic zones NN3 to NN5 as defined by Martini (1971). These zones are significant for understanding the chronological framework of the sedimentary sequence. The presence of specific nannofossil species and their relative abundances within these zones provide essential insights into the paleoenvironment and biostratigraphic history of the region.

4.3. Key Nannofossil Datums

Several significant dated calcareous nannofossil datums were identified throughout the analyzed section of the well. These datums serve as essential reference points for determining the timing of geological events and the development of nannofossil assemblages within the studied interval. Table 1 illustrates the distribution of these datums within the well section. Additionally, Table 2 and Fig. 4 provide a summary of the calcareous nannofossil zones and the biostratigraphic interpretation of the IZA-1 well.

Table 2. Summary of calcareous nannofossil zones, biostratigraphic interpretation of IZA–1 Well

Calcareous Nannoplankton Zonation (Martini 1971)	Stratigraphic interval (ft)	Gradstein et al., 2005	Biostratigraphic interpretation
NN5 Top: Top of *Sphenolithus heteromorphus* Base: Top of *Helicosphaera ampliaperta*	6900–7720 ft	Middle Miocene	The top of this interval is identified by the presence of *Sphenolithus heteromorphus*, although its identification is noted as questionable, suggesting some uncertainty in the exact stratigraphic position. The base is marked by the first appearance of *Helicosphaera ampliaperta*, indicating the beginning of this nannofossil zone. This interval shows moderate abundance and diversity of nannofossils, suggesting a relatively stable and productive marine environment. The recovered species indicate a diverse assemblage, including *Calcidiscus leptoporus*, *Coccolithus pelagicus* and various *Sphenolithus* species, which are typical indicators of a productive marine ecosystem during this time.
NN4 Top: Top of *Helicosphaera ampliaperta* Base: Top of *Sphenolithus belemnos*	7800–10620 ft	Early – Middle Miocene	The base of this interval is characterized by the first appearance of *Sphenolithus heteromorphus* at 9870 ft, indicating the transition from the NN5 to the NN4 zone. This interval is marked by high abundances and diversities of nannofossils, suggesting a dynamic environment conducive to the proliferation of these organisms. Notably, two peaks in abundance/diversity are observed at depths of 7800 - 8820 ft and 9000 - 9540 ft, which may correspond to a condensed section related to maximum flooding surfaces (15.9 Ma and 17.4 Ma). These condensed sections indicate periods of rapid sedimentation or a transgression that led to enhanced preservation of nannofossils. The top occurrence of *Helicosphaera ampliaperta* at 7800 ft and *Sphenolithus belemnos* at 10660 ft aligns with the expected ages, reinforcing the biostratigraphic framework. Recovered species include *Sphenolithus heteromorphus*, *Calcidiscus leptoporus*, *Sphenolithus moriformis*, *Discoaster druggii*, *Helicosphaera ampliaperta*, *Reticulofenestra pseudoumblica* and *Discoaster deflandrei*.
NN3 Top: Top of *Sphenolithus belemnos* Base: Top of *Triquetrorhabdulus carinatus*	10660–11740 ft	Early Miocene	The top of this zone is defined by the occurrence of *Sphenolithus belemnos*, while its base is marked by the first appearance of *Triquetrorhabdulus carinatus*. This interval exhibits moderate abundances and diversities, indicating a stable marine environment but less productive compared to the NN4 zone. The species recovered within this interval include a mix of well-known calcareous nannofossils like *Calcidiscus leptoporus*, *Coccolithus pelagicus* and *Discoaster druggii*, suggesting continuity in the ecological settings of the early Miocene.

Unit	Age	Depth Interval	Lithology	Description
AGBADA FORMATION	MIOCENE	6900–8750 ft		Sandstone: Quartz, clear to smoky white, fine to medium grain, occasionally coarse, sub-angular to sub-rounded well sorted, non-calcareous
		8750–9150 ft		Shale: light brown, moderately hard to hard platy to blocky, sub-fissile to fissile, calcareous, carbonaceous and micromicaceous
		9150–9320 ft		Sandstone: Quartz, clear to smoky white, fine to medium grain, occasionally coarse, sub-angular to sub-rounded well sorted, non-calcareous
		9320–9480 ft		Shale: dark grey, sticky shale, grading to fissile
		9480–10550 ft		Sandstone: Quartz, clear to smoky white, fine to medium grain, occasionally coarse, sub-angular to sub-rounded well sorted, non-calcareous
		10550–10760 ft		Shale: light grey to light brown, moderately hard to hard platy to blocky, sub-fissile to fissile, calcareous, carbonaceous and micromicaceous
		10760–11550 ft		Sandstone: Quartz, clear to smoky white, fine to medium grain, occasionally coarse, sub-angular to sub-rounded well sorted, non-calcareous
		11550–11740 ft		Shale: light grey to light brown, moderately hard to hard platy to blocky, sub-fissile to fissile, calcareous, carbonaceous and micromicaceous

Fig. 4. Summary of zones, chronostratigraphic subdivisions and lithology of ditch cuttings range from 6900–11740 ft

The analysis of the ditch cutting samples from the IZA-1 well has uncovered a distinct calcareous nannoplankton zonation based on Martini (1971), which correlates with specific stratigraphic intervals and the Gradstein et al. (2005). The calcareous nannoplankton zonation based on Martini (1971) provides insights into the biostratigraphy and geological history of the sampled intervals in the IZA-1 well. Detailed interpretation of the findings, organized by each zonation level (NN3, NN4, and NN5) and summary of stratigraphic intervals and biostratigraphic interpretations as shown in Table 2 and Fig. 4.

5. Conclusions

The analysis of the nannoplankton zones in the IZA-1 well reflects significant paleoenvironments and sedimentary processes within the Niger Delta region. The identified zones (NN3, NN4, NN5) correlate with distinct geological time frames of the Miocene epoch, revealing changes in marine productivity and sedimentation patterns. The presence of various nannofossil species provides insights into the paleoecological conditions, with periods of high diversity suggesting favorable environmental conditions and periods of less diversity indicating stability or environmental stress. The data gathered can be valuable for further stratigraphic correlation and understanding the geological history of the region.

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