Biostratigraphy of the Nzam-1 well in the Nkporo Formation, Anambra Basin, southeastern Nigeria

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Abstract

This study presents a thorough biostratigraphic analysis of the Nkporo Formation in the Nzam-1 well, aiming to evaluate the age, paleoenvironment, and biozonation of the source rock penetrated by the well using palynological analysis. A total of 17 samples from the Nzam-1 well were subjected to palynological studies. The occurrence of diverse palynomorphs provides a framework for evaluating the age, paleoenvironment, and biozonation of the formation. The assemblage of forms (pollen, spores, and dinoflagellate cysts) indicates that the shales deposited in the Nzam-1 well range between Late Cretaceous, possibly Albian to Maastrichtian age. The presence of these fossils also suggests that the Nzam-1 well represents a marine depositional environment, which can support hydrocarbon generation. Palynomorph distribution analysis (Figure 1) reveals varying abundances across depth intervals, with peak occurrences in the 2411-2438 m zone. Age zonation (Figure 2) demonstrates clear biostratigraphic subdivision from Campanian to Maastrichtian intervals. Paleoenvironmental reconstruction (Figure 3) indicates a marginal marine setting with significant terrestrial input, favorable for organic matter preservation and hydrocarbon source rock development.

Keywords: Anambra Basin; Paleoenvironment; Biostratigraphy; Biozonation; Palynomorphs; Cretaceous.

1. Introduction

Palynomorphs, which are microscopic, acid resistant organic remains and debris produced by a wide variety of plants, animals, and Protista, cover a number of geological ages and are thus useful in age determination *(Ayinla, 2013; Ola-Buraimo and Ehinola, 2022; Ayinla, 2023)*. This scientific approach studies present day and fossil palynomorphs (paleopalynology), such as pollen, spores, orbicules, dinocysts, acritarchs, chitinozoans, and scolecodonts, together with particulate organic matter (POM) and kerogen found in sedimentary rocks and sediments.

The Anambra Basin, a crucial sedimentary basin in Nigeria, boasts a rich fossil record spanning the Late Cretaceous to Paleogene period *(Ayinla, 2024; Obi, 2020)*. A comprehensive understanding of the biostratigraphic framework of the Anambra Basin is vital for correlating the sedimentary succession with other basins in Nigeria, such as the Niger Delta Basin *(Ojo, 2019)*, and evaluating the hydrocarbon potential of the basin *(Ekpo, 2020)*.

The Nzam-1 well, drilled in the Anambra Basin, provides valuable subsurface data for understanding the basin geological evolution and hydrocarbon potential *(Ikejimba, 2018)*. However, the biostratigraphic framework of this well is not well established, hindering accurate correlation and dating of the sedimentary succession *(Aigbadon, 2020)*. This study aims to establish a detailed biostratigraphic framework for the Nzam-1 well using palynological analysis of ditch cutting samples.

The objectives of this study are to examine and provide the age, paleoenvironment, and detailed palynological biozonation of the Nkporo Shale in the Nzam-1 well. The results of this study will contribute significantly to the understanding of the geological evolution and hydrocarbon generation potential of the

Nkporo Formation, serving as a reference for future exploration and production activities.

2. Geologic Setting

The Anambra Basin in south central Nigeria (Figure 1) is a Cretaceous basin with 9 km of sediment, creating conditions favorable for hydrocarbon formation *(Whiteman, 1982; Akaegbobi, 2000)*. Economically, it is significant for coal and hydrocarbon potential, with recent studies assessing its petroleum system, including source rock quality and reservoir characteristics *(Akaegbobi, 2000; Ayinla et al., 2023)*.

Sedimentation in the Anambra Basin commenced during the Late Cretaceous following the Santonian tectonism, which caused a shift in depositional environments and basin configuration. The oldest sedimentary unit in the basin is the Nkporo Group of Campanian age, which consists predominantly of dark grey to black shales (Nkporo Shale), interbedded with sandstones (Owelli Sandstone) and additional shale units (Enugu Shale) *(Nwajide, 1990)*. These sediments were deposited in shallow marine to marginal marine environments under conditions favorable for the preservation of organic matter, thereby contributing to their hydrocarbon source rock potential.

Overlying the Nkporo Group is the Mamu Formation (Early Maastrichtian), characterized by alternating sequences of shales, siltstones, sandstones, and economically important coal seams. This formation reflects a paralic depositional environment with alternating marine and continental influences *(Kogbe, 1989)*. The Ajali Sandstone conformably overlies the Mamu Formation and is composed mainly of poorly cemented, coarse to fine grained sandstones, indicative of high energy fluvial to coastal depositional settings.

The Nsukka Formation caps the sedimentary succession and represents a transitional Maastrichtian–Danian unit, consisting of interbedded sandstones, shales, and coal seams. It is often referred to as the Upper Coal Measures and signifies a continuation of deltaic to continental sedimentation *(Obi et al., 2020)*.

The Nzam-1 well, which forms the focus of this study, penetrates part of the Nkporo Formation within the basin. This formation is particularly significant due to its organic rich shale content and its role as a major source rock within the basin petroleum system. The integration of lithostratigraphic and biostratigraphic data from this well provides valuable insights into the depositional history, paleoenvironmental conditions, and stratigraphic framework of the Anambra Basin.

3. Materials and Methods

A total of 17 samples from the Nzam-1 well were subjected to laboratory palynological studies. Samples were prepared for the determination of age, biozonation, and paleoenvironment following standard palynological procedures. This was followed by oxidation of the organic material with nitric acid. The separated organic materials were then rinsed with ethanol before being mounted onto glass slides for microscopic analysis and photography of the preserved specimens.

Palynological identification was conducted using transmitted light microscopy at magnifications ranging from 400× to 1000×. Diagnostic palynomorph taxa were identified and counted to determine relative abundances across depth intervals. Biostratigraphic zonation was established based on first and last occurrences of key marker species, following established regional zonation schemes for the West African Cretaceous *(Jardine and Magloire, 1965; Lawal and Moullade, 1986)*.

4. Results

4.1 Palynomorph Distribution and Abundance

The palynological analysis of well samples from the Nkporo Group, Anambra Basin revealed varying numbers of palynomorphs based on depths. Figure 1 shows the palynomorph recovery, abundance, and distribution pattern across the studied interval. The palynomorph assemblage comprises pollen, spores, and dinoflagellate cysts, with peak abundances occurring in the 2411-2438 m depth interval.

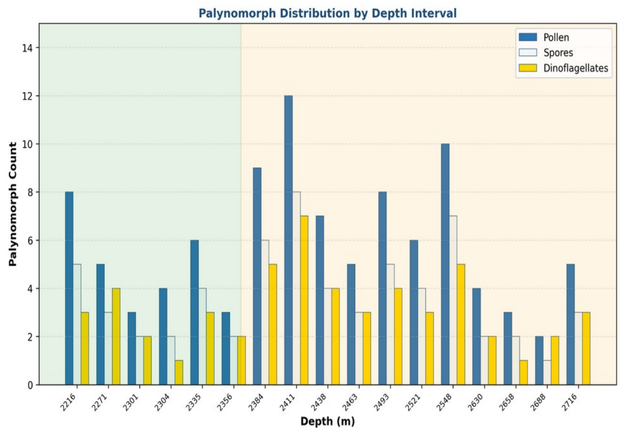

Figure 1. Palynomorph distribution chart showing pollen, spore, and dinoflagellate abundance across depth intervals in the Nzam-1 well

As illustrated in Figure 1, the palynomorph distribution shows distinct patterns across the depth profile. The interval from 2411 to 2438 m exhibits the highest palynomorph diversity and abundance, with pollen counts reaching 12 specimens, spore counts of 8 specimens, and dinoflagellate cysts numbering 7 specimens. This peak zone corresponds to optimal preservation conditions and enhanced marine productivity during deposition. In contrast, the deeper intervals (2658-2716 m) and shallower intervals (2216-2271 m) show reduced palynomorph counts, suggesting either less favorable preservation conditions or lower biological productivity during these periods.

4.2 Biozonation and Age Assignment

At the depth 2216 m, shale deposits are characterized by the first appearance of dinoflagellates from marine or marginal marine environments. The presence of pollen with affinity to tropical plants and spores associated with smooth spore ferns indicate terrestrial input. The occurrence of marine influence alongside terrestrial input provides evidence of consistent mixed depositional conditions. Most of these taxa appearances suggest Cretaceous age, likely Albian to Maastrichtian related to the Nkporo Formation.

The increase in depth at 2271 m shows re occurrence of marine taxa, indicating marine/neritic environment, suggesting Late Cretaceous zones (Campanian to Maastrichtian). At the depth interval 2335 m, the occurrence of terrestrial input reinforces a coastal setup, while dinoflagellates point toward marine influence, often associated with Late Cretaceous sediments dated Cretaceous to Paleocene age.

The depth trend from 2384-2411 m shows appearance across the depth, with presence of dinoflagellates indicating consistent marine influence dated Cretaceous (Albian to Maastrichtian). Terrestrial input is typically of Cretaceous tropical/subtropical regions, suggesting nearby land with diverse vegetation. At greater depth intervals, 2438 m to 2716 m, continuous occurrence is observed. The deepest part of this interval is characterized by the appearance of stratigraphically more diagnostic forms.

Figure 2 presents the biostratigraphic zonation and age assignment based on the integrated palynological evidence. The analyzed interval has been subdivided into three major biozones based on diagnostic palynomorph assemblages and stratigraphic ranges of key marker species.

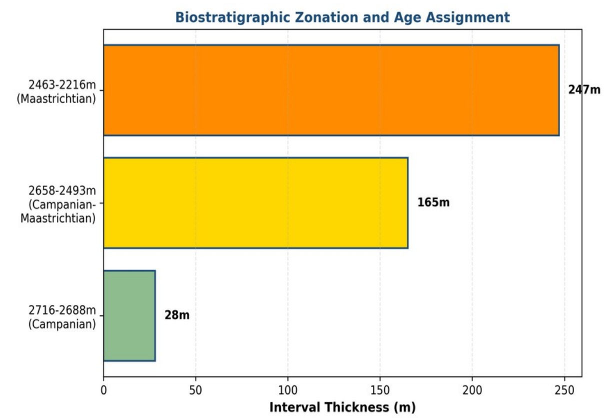

Figure 2. Biostratigraphic zonation and age assignment showing the three major zones identified in the Nzam-1 well

The biozonation illustrated in Figure 2 reveals three distinct intervals. The basal zone (2716-2688 m, thickness 28 m) represents the Campanian age and is characterized by the first occurrences of diagnostic Campanian marker species. The middle zone (2658-2493 m, thickness 165 m) spans the Campanian-Maastrichtian boundary and shows transitional assemblages with overlapping ranges of both Campanian and Maastrichtian taxa. The upper zone (2463-2216 m, thickness 247 m) is assigned to the Maastrichtian based on the presence of typical Maastrichtian marker species and the absence of older Campanian restricted forms. This zonation provides a robust chronostratigraphic framework for correlation with other wells in the Anambra Basin.

4.3 Paleoenvironmental Interpretation

The paleoenvironmental interpretation based on the palynomorph assemblage composition is presented in Figure 3. The co occurrence of marine dinoflagellate cysts with terrestrial pollen and spores throughout the studied interval indicates deposition in a marginal marine to deltaic environment with varying degrees of marine and terrestrial influence.

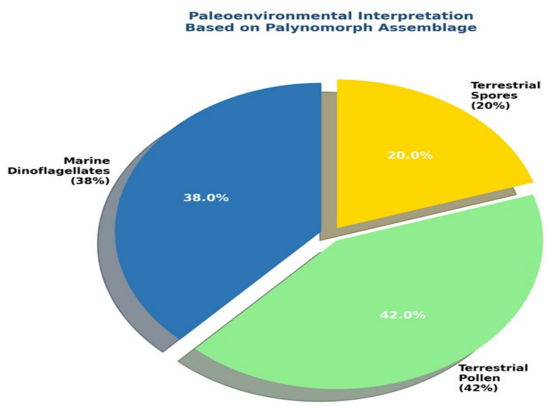

Figure 3. Paleoenvironmental interpretation showing relative proportions of marine and terrestrial palynomorph components

Figure 3 demonstrates that the palynomorph assemblage comprises approximately 42% terrestrial pollen, 38% marine dinoflagellates, and 20% terrestrial spores. This distribution pattern indicates a coastal to marginal marine depositional setting with significant terrestrial input from adjacent landmasses. The substantial proportion of marine dinoflagellates (38%) confirms persistent marine influence, while the combined terrestrial component (62% pollen plus spores) reflects proximity to vegetated land areas and regular influx of terrestrially derived organic matter.

The environment of deposition is interpreted as marginal marine based on the recovered assemblage. The presence of both marine and terrestrial palynomorphs indicates fluctuating depositional conditions, likely influenced by changes in sea level, sediment supply, and proximity to the shoreline. These conditions were favorable for the accumulation and preservation of organic matter, thereby enhancing the hydrocarbon source rock potential of the Nkporo Formation.

5. Discussion

The interval studied belongs to an acme zone similar to previously established zones *(Lawal and Moullade, 1986; Jardine and Magloire, 1965)*. Similar palynomorph assemblages have been reported by *Adebayo et al. (2015)*, *Ola-Buraimo (2015)*, and *Bankole and Ola-Buraimo (2017)*. The acme zone belongs to the interval 2216-2716 m, of Campanian to Lowermost Maastrichtian age.

This zone is comparable with the interval zone of *Ola-Buraimo (2012, 2013)* from the Bornu Basin, northeastern Nigeria. The base of the interval placed at 2716 m is characterized by the first occurrence of diagnostic taxa. The continuous appearance of key species shows continuous occurrence up hole, as demonstrated in Figures 1 and 2.

The lower part of the interval is characterized by the appearances of stratigraphically more diagnostic forms. The top of the interval at 2216 m is characterized by the top occurrence of characteristic Maastrichtian taxa. The acme zone here erected shows similarity with work of *Ola-Buraimo (2020)* where there is continuous appearance of diagnostic species described to be quantitatively restricted within specific zones.

Some taxa which are Maastrichtian markers also have their appearance within this zone. Other miospores present within the interval include various tropical pollen and spore forms. The environment of deposition is marginal marine, as evidenced by the mixed assemblage of marine and terrestrial palynomorphs shown in Figure 3.

The biostratigraphic framework established in this study enables correlation with other wells in the Anambra Basin and provides age constraints for understanding basin evolution. The integration of palynomorph distribution data (Figure 1), age zonation (Figure 2), and paleoenvironmental analysis (Figure 3) offers a comprehensive view of the depositional history and source rock potential of the Nkporo Formation.

6. Conclusion

This study has successfully established a detailed biostratigraphic framework for the Nkporo Formation penetrated by the Nzam-1 well in the Anambra Basin through palynological analysis. The recovered assemblage of palynomorphs, including pollen, spores, and dinoflagellate cyst species, provides reliable age diagnostic markers.

The palynological evidence indicates that the studied interval falls within the Late Cretaceous, specifically ranging from Campanian to Early Maastrichtian. The recognition of the acme zone further supports this age assignment and allows for correlation with established palynostratigraphic zones within Nigeria and other parts of Africa.

Paleoenvironmental interpretation based on the palynomorph assemblage suggests a predominantly marginal marine setting with significant terrestrial input. The coexistence of marine dinoflagellate cysts and terrestrial pollen and spores reflects fluctuating depositional conditions, likely influenced by changes in sea level and proximity to the shoreline. These conditions were favorable for the accumulation and preservation of organic matter.

Importantly, the results highlight the hydrocarbon potential of the Nkporo Formation, as the organic rich shales and appropriate depositional environment provide essential conditions for source rock development. The study therefore contributes valuable data for stratigraphic correlation, basin analysis, and hydrocarbon exploration in the Anambra Basin.

Overall, this research enhances the understanding of the geological evolution, age relationships, and depositional environments of the Nkporo Formation and serves as a useful reference for future geological and petroleum studies within the basin.

Conflict of Interest

The authors declare no conflict of interest.

Ethics Approval and Informed Consent

Not applicable.

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