PALYNOLOGICAL ZONATION AND BIOSTRATIGRAPHY OF THE NKPORO FORMATION FROM THE AKUKWA-2 WELL, ANAMBRA BASIN, SOUTHEASTERN NIGERIA

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Abstract

Biostratigraphic analysis of sedimentary sequences remains a fundamental approach for age determination, stratigraphic correlation, and palaeoenvironmental reconstruction, particularly through the study of palynomorph assemblages. The Akukwa-2 well, located within the Nkporo Formation of the Anambra Basin, southeastern Nigeria, provides valuable subsurface data for understanding the depositional history and hydrocarbon potential of the basin. A total of ten ditch cutting samples were subjected to detailed palynological analysis, yielding a diverse assemblage of pollen, spores, and dinoflagellate cysts, including Phelodinium bolonienae, Araucariacites australis, Cribroperidinium edwardsii, Constructipollenites ineffectus, Botryococcus braunii, Longapertites marginatus, and Zlivisporites blanensis. The stratigraphic distribution and abundance of these diagnostic palynomorphs provide a reliable framework for biozonation and age determination. The studied interval is assigned to the Late Cretaceous, specifically the Campanian to Maastrichtian, consistent with established stratigraphic records within the Anambra Basin. Palaeoenvironmental interpretation indicates deposition under marginal to shallow marine conditions, supported by the occurrence of marine dinoflagellate cysts and algal forms such as Botryococcus braunii, which are indicative of marine to brackish environments. The recognition of palynological zones, including the Milfordia spp. Acme Zone, enhances regional stratigraphic correlation with other wells in the basin. The results provide a refined biostratigraphic framework for the Nkporo Formation and improve understanding of its depositional environment and stratigraphic architecture. The organic rich nature and favourable depositional conditions further underscore the hydrocarbon generation potential of the formation within the Anambra Basin.

Keywords: Anambra Basin; palaeoenvironment; biostratigraphy; biozonation; palynomorphs; Cretaceous; correlation

1. Introduction

Palynomorphs are microscopic, acid resistant organic remains derived from a wide range of plants, animals, and protists, and they occur across different geological time scales, a property that makes them highly valuable for age determination and stratigraphic studies (Ayinla et al., 2013; Ola-Buraimo and Ehinola, 2022; Ayinla et al., 2023). The study of these organic walled microfossils, known as palynology, encompasses both modern and fossil forms, the latter constituting palaeopalynology, and includes pollen grains, spores, dinoflagellate cysts, acritarchs, chitinozoans, and other particulate organic matter such as kerogen preserved in sedimentary rocks. Because palynomorphs are robust, widely dispersed, and abundant even in fine grained clastic successions, they frequently supply the only reliable biostratigraphic signal in barren or carbonate poor intervals where calcareous microfossils are absent.

Palynological analysis plays a critical role in biostratigraphy by enabling the identification, classification, and correlation of sedimentary sequences on the basis of fossil assemblages. This approach is particularly effective in reconstructing palaeoenvironmental conditions and establishing chronostratigraphic frameworks in sedimentary basins. In Nigeria, the Anambra Basin represents one of the most significant inland sedimentary basins, characterised by a rich and continuous fossil record spanning the Late Cretaceous to the Paleogene (Ayinla et al., 2025). This extensive stratigraphic record provides a valuable basis for regional correlation and petroleum system evaluation.

A robust biostratigraphic framework for the Anambra Basin is essential for correlating its sedimentary successions with adjacent basins such as the Niger Delta and for improving understanding of its hydrocarbon potential (Whiteman, 1982). Previous studies have highlighted the significance of the basin in terms of organic richness, depositional history, and petroleum generation potential. However, despite these contributions, detailed biostratigraphic data for some wells within the basin remain limited, and the resolution of existing zonation schemes varies considerably from one sub-basin to another.

The Akukwa-2 well, drilled within the Nkporo Formation of the Anambra Basin, provides important subsurface data for evaluating the geological evolution and hydrocarbon prospectivity of the basin (Abraham et al., 2025). Nevertheless, the absence of a well defined biostratigraphic framework for this well poses challenges for accurate age determination, stratigraphic correlation, and palaeoenvironmental interpretation. Addressing this gap is crucial for refining the stratigraphic architecture of the basin and for strengthening exploration efforts in a frontier inland setting where well control remains sparse.

Therefore, this study establishes a detailed biostratigraphic framework for the Akukwa-2 well through comprehensive palynological analysis of ditch cutting samples. Specifically, the study seeks to determine the age of the sedimentary sequence, to define palynological biozones, and to reconstruct the palaeoenvironment of deposition within the Nkporo Shale. The findings are expected to contribute to understanding of the geological evolution of the basin and to provide relevant insight for hydrocarbon exploration and resource development in Nigeria.

2. Geologic Setting

The Anambra Basin, located in south central Nigeria, is an important inland sedimentary basin formed during the Late Cretaceous as part of the tectonic evolution of the Benue Trough. The basin developed following the Santonian tectonic event, which produced uplift and deformation of the Abakaliki Anticlinorium and the subsequent subsidence of the Anambra Platform, thereby creating accommodation space for sediment accumulation (Obaje, 2009). The basin contains a thick sedimentary succession of up to about nine kilometres, composed predominantly of clastic deposits that provide favourable conditions for hydrocarbon generation and accumulation (Whiteman, 1982; Akaegbobi et al., 2000). Figure 1 shows the regional setting of the basin within the framework of Nigerian sedimentary basins.

The basin is bounded to the south by the Niger Delta and is flanked by the Benin and Calabar flanks, occupying a structurally controlled depression that accumulated sediment from the Campanian onward.

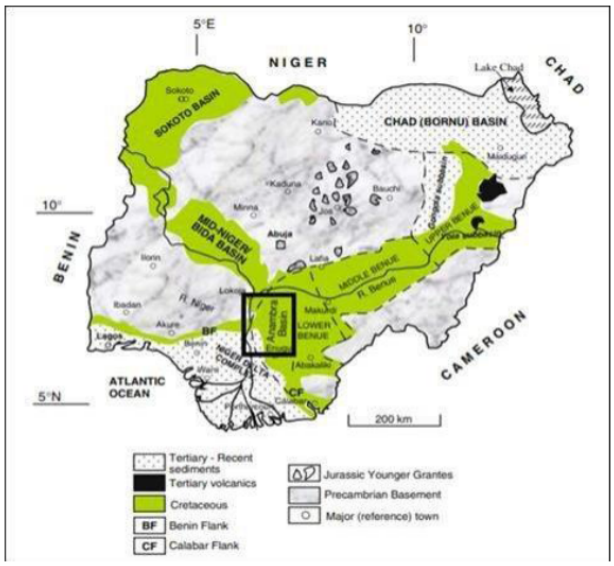

Figure 1: Generalised geological map of Nigeria showing the location of the Anambra Basin, indicated by the rectangle in the southeast (modified after Obaje, 2009).

Stratigraphically, the Anambra Basin comprises a sequence of Campanian to Paleogene sedimentary units. The oldest unit is the Nkporo Group of Late Campanian age, which includes the Nkporo Shale, the Owelli Sandstone, and the Enugu Shale (Nwajide, 1990). The Nkporo Shale in particular is characterised by dark grey to black, carbonaceous, and fossiliferous shale deposits that formed under marine conditions and are considered significant source rocks within the basin. Figure 2 summarises the lithostratigraphic succession and places the studied interval in its regional context.

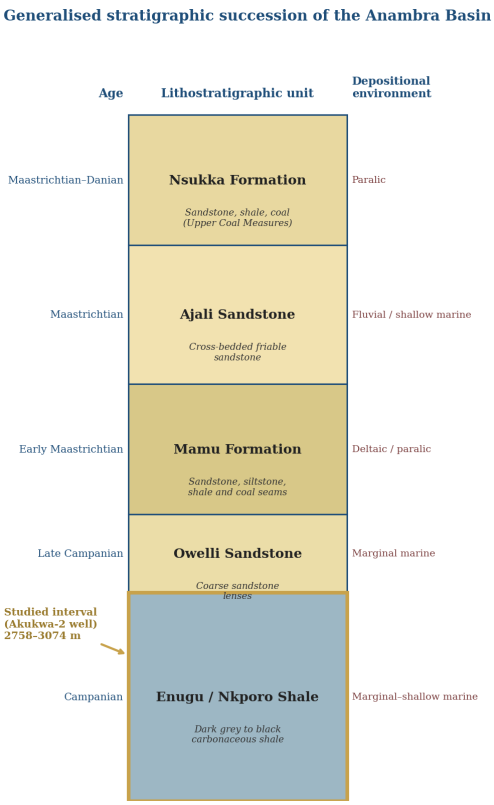

Figure 2: Generalised stratigraphic succession of the Anambra Basin and the outcropping Niger Delta, with the studied Nkporo Shale interval of the Akukwa-2 well highlighted (compiled after Nwajide, 1990; Kogbe, 1989; Ekwenye and Nichols, 2016).

Overlying the Nkporo Group is the Mamu Formation of Early Maastrichtian age, which consists of interbedded sandstones, siltstones, shales, and coal seams, reflecting deposition in deltaic to paralic environments (Kogbe, 1989). This unit is succeeded by the Ajali Sandstone of Maastrichtian age, a predominantly sandy unit composed of poorly cemented, coarse to fine grained sandstones with minor siltstone intercalations, interpreted to have been deposited in fluvial to shallow marine settings (Kogbe, 1989; Nwajide, 1990).

The uppermost unit within the Cretaceous succession is the Nsukka Formation, which spans the Maastrichtian to the Danian and represents the transition from Cretaceous to Paleogene sedimentation. It consists mainly of alternating sandstones, shales, and coal seams and is often referred to as the Upper Coal Measures. These stratigraphic units collectively record a regressive depositional sequence, reflecting a transition from marine to continental environments within the basin.

In terms of economic significance, the Anambra Basin is well known for its coal deposits and hydrocarbon potential. Previous studies have demonstrated that the organic rich shales and coal bearing formations within the basin possess favourable characteristics for petroleum generation, including adequate organic matter content and suitable thermal maturity (Akaegbobi et al., 2000; Ayinla et al., 2023). Consequently, understanding the stratigraphic framework and depositional environments of these units is essential for effective hydrocarbon exploration and basin evaluation.

3. Materials and Methods

A total of ten ditch cutting samples obtained from the Akukwa-2 well in the Anambra Basin were used for this study. The samples were subjected to detailed palynological analysis to determine their age, to establish biozonation, and to interpret the palaeoenvironment of deposition. Sampling intervals were selected to span the full penetrated thickness of the Nkporo Shale, from 2758 metres to 3074 metres, in order to capture the vertical succession of palynomorph assemblages.

The laboratory preparation of the samples followed standard palynological procedures. The samples were first treated with hydrochloric acid to remove carbonate material, followed by hydrofluoric acid digestion to eliminate silicate minerals. The organic residues were subsequently oxidised using nitric acid to enhance the visibility of palynomorphs. After oxidation, the residues were thoroughly rinsed with distilled water and sieved to concentrate the organic fraction. The recovered organic matter, including pollen, spores, and dinoflagellate cysts, was then separated and cleaned. The residues were rinsed with ethanol to remove impurities and to facilitate rapid drying, and the cleaned material was mounted on glass slides using a suitable mounting medium for microscopic examination.

Palynomorph identification and analysis were carried out using a transmitted light microscope. The identified species were documented, counted, and their stratigraphic distribution recorded. Photomicrographs of well preserved and diagnostic specimens were taken for documentation and reference. The interpretation of age and biozonation was based on the occurrence and stratigraphic distribution of key index palynomorphs, while palaeoenvironmental reconstruction was inferred from the assemblage composition and the ecological affinities of the recovered species.

3.1 Quantitative palynological indices

To complement the qualitative description of the assemblages, three simple quantitative indices were computed for each productive sample. These indices place the descriptive observations on a numerical footing and allow the vertical trends to be compared between intervals. The relative palynomorph abundance for a sample is expressed as a percentage of the total count, given in Equation (1).

$$A_i = (n_i / N) \times 100\% \quad (1)$$

where A_i is the relative abundance of taxon i, n_i is the number of specimens of taxon i recorded in the sample, and N is the total number of palynomorph specimens counted in that sample. The ratio of marine to terrestrial palynomorphs, a widely used proxy for proximity to the shoreline and for relative sea level, is defined in Equation (2).

$$R_{mt} = N_m / (N_t + \varepsilon) \quad (2)$$

where N_m is the count of marine palynomorphs, comprising dinoflagellate cysts and algal forms, N_t is the count of terrestrial pollen and spores, and ε is a small constant included to avoid division by zero in barren or wholly terrestrial samples. Higher values of R_{mt} indicate stronger marine influence. Assemblage diversity was characterised using the Shannon diversity index, given in Equation (3).

$$H' = -\Sigma\, p_i \ln(p_i) \quad (3)$$

where p_i is the proportion of the assemblage represented by taxon i, computed as $p_i = n_i / N$, and the summation extends over all taxa present in the sample. The index increases with both the number of taxa and the evenness of their distribution, and it provides a compact measure of palynofloral richness that can be tracked through the studied succession.

4. Results

The palynological analysis of the studied well samples from the Nkporo Group of the Anambra Basin revealed a varying number of palynomorphs as a function of depth. The results, presented in the distribution chart and photomicrograph plate that follow, show the palynomorph recovery, abundance, age, and the morphology of the diagnostic species. The description of the analysed samples from the Akukwa-2 well biozonation is presented below.

4.1 Biozonation of the Akukwa-2 well

The basal interval at 3074 metres marks the base of the *Milfordia* spp. Acme Zone, which is characterised by the first up-hole appearance of *Milfordia* sp., *Monocolpopollenites sphaeroidites*, *Milfordia jardinei*, *Monosulcites* sp., *Longapertites* sp. 3, and *Cyathidites* sp. The appearance of these forms indicates the initial deposit of the Nkporo Shale in the basin. The overlying intervals between 2859 metres and 3021 metres yield fair to poor pollen recovery, including *Zlivisporites blanensis*, *Cyathidites* sp., *Triporites* sp., *Longapertites marginatus*, and *Syncolporites marginatus*. The appearance of these pollen and spores suggests a Campanian age.

The upper part of the investigated interval, between 2758 metres and 2813 metres, comprises *Longapertites marginatus*, *Cyathidites* sp., *Monocolpites* sp., *Constructipollenites ineffectus*, *Hexaporopollenites emelianovi*, *Inaperturopollenites* sp., and *Buttinia andreevi*. The appearance of *Hexaporopollenites emelianovi*, which is a Turonian age marker, records its extinction within the Campanian sediments. Therefore the interval between 2758 metres and 3075 metres is here conveniently dated as Campanian in age and is correlative, at a depth of 2411 metres, with the Nkporo Shale in the Nzam-1 well of the Anambra Basin, southeastern Nigeria. The palaeoenvironment of deposition is marginal marine, based on the occurrence of forms such as *Phelodinium bolonienae* dinoflagellate cysts, *Batiacasphaera* sp., and *Botryococcus braunii*.

Figure 3 presents the full occurrence matrix of recorded taxa against sample depth. The chart documents the barren sample at 2822 metres, the concentration of first up-hole appearances at the 3074 metre base, and the assignment of the entire succession to the *Milfordia* spp. Acme Zone of Campanian age, deposited under marginal marine conditions.

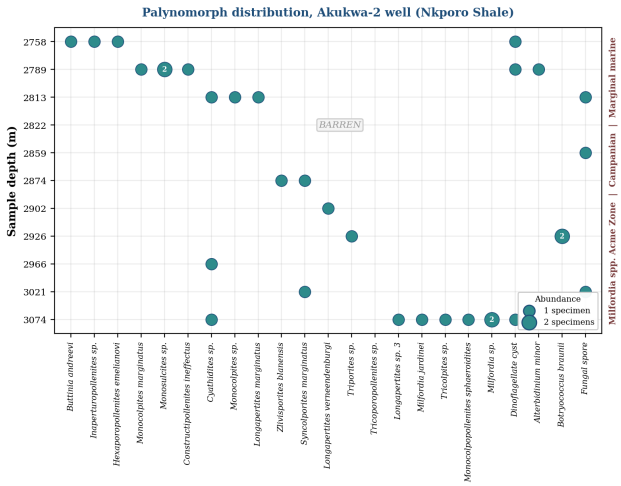

Figure 3: Palynomorph distribution chart showing the stratigraphic range and abundance of recorded taxa against sample depth in the Akukwa-2 well, with the assigned palynozone, age, and palaeoenvironment indicated. Circle size denotes the number of specimens recorded.

4.2 Palynomorph identification

Twenty diagnostic specimens recovered from the studied interval were photographed under transmitted light and are presented in the plate that follows. The specimens span the principal pollen, spore, and dinoflagellate cyst groups used in the biozonation and age assignment, and they document the generally good preservation state of the organic matter in the productive intervals.

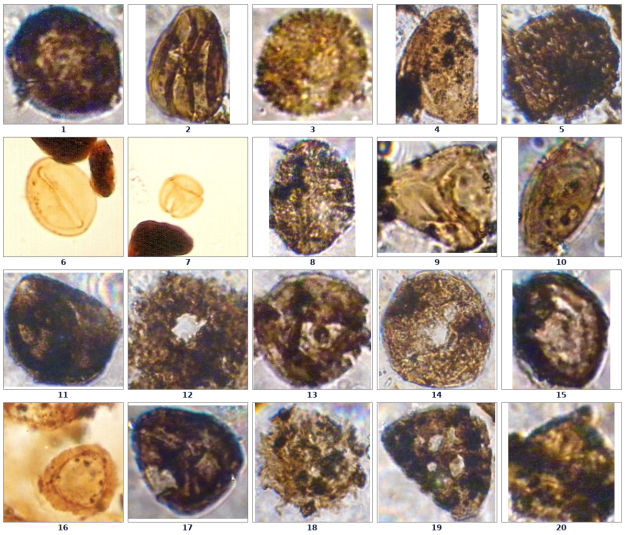

Figure 4: Photomicrographs of palynomorphs recovered from the Akukwa-2 well. 1, *Monocolpopollenites sphaeroidites*; 2, *Tricolpites* sp.; 3, *Constructipollenites ineffectus*; 4, *Longapertites* sp.; 5, *Milfordia* sp.; 6, *Retimonocolpites* sp.; 7, *Syncolporites marginatus*; 8, *Cyathidites* sp.; 9, *Longapertites marginatus*; 10, *Monocolpites marginatus*; 11, *Phelodinium bolonienae*; 12, *Milfordia* sp. 2B; 13, *Araucariacites australis*; 14, *Milfordia jardinei*; 15, *Milfordia* sp.; 16, *Cupanieidites reticulatus*; 17, *Homotryblium* sp.; 18, *Milfordia* sp. 4; 19, *Cribroperidinium edwardsii*; 20, *Cingulatisporites ornatus*.

4.3 Quantitative trends

The quantitative indices defined in the methods place the qualitative observations on a numerical footing. Palynomorph abundance and taxonomic richness vary systematically through the succession, as shown in Figure 5. The basal acme interval at 3074 metres returns both the highest specimen count and the greatest

richness, while the sample at 2822 metres is barren, and recovery is otherwise fair to moderate across the intervening intervals.

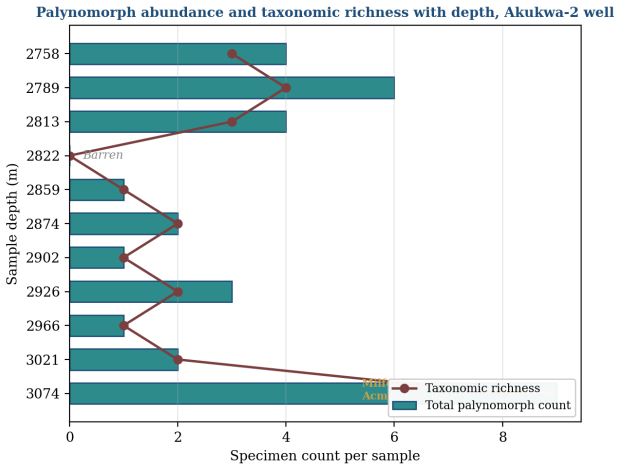

Figure 5: Vertical variation in total palynomorph abundance, shown as bars, and taxonomic richness, shown as the line, against sample depth in the Akukwa-2 well. The concentration of first appearances at the base of the section marks the Milfordia spp. Acme Zone.

The proportion of marine to terrestrial palynomorphs through the section is shown in Figure 6. Terrestrial pollen and spores dominate most productive samples, consistent with a strong continental supply, while the persistent presence of dinoflagellate cysts and algal forms confirms a sustained marine connection throughout deposition. The interplay between the two components records a marginal marine setting subject to fluctuating salinity and variable sediment input.

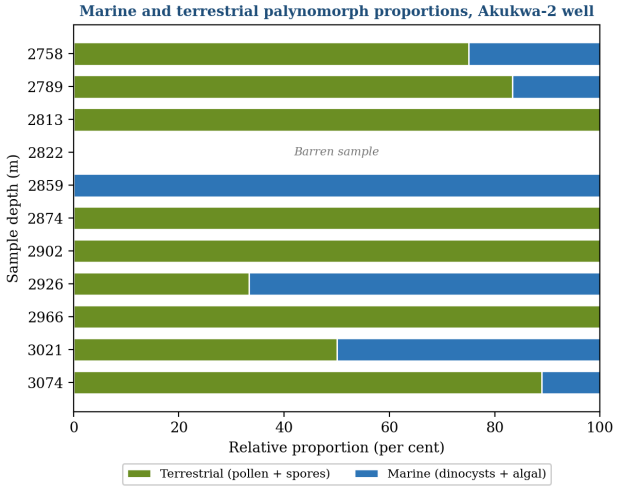

Figure 6: Relative proportions of terrestrial pollen and spores against marine dinoflagellate cysts and algal forms with depth in the Akukwa-2 well. The barren sample at 2822 metres is indicated.

5. Discussion

The palynological investigation of the Akukwa-2 well provides significant insight into the biostratigraphy, age determination, and depositional environment of the Nkporo Formation within the Anambra Basin. The distribution, abundance, and preservation state of the recovered palynomorphs form the basis for stratigraphic interpretation and regional correlation, and they allow the studied interval to be placed within a coherent palaeoenvironmental and chronostratigraphic model.

The basal interval at 3074 metres, which marks the base of the *Milfordia* spp. Acme Zone, is characterised by the first up-hole appearance of key taxa such as *Milfordia* sp., *Monocolpopollenites sphaeroidites*, *Milfordia jardinei*, *Monosulcites* sp., *Longapertites* sp., and *Cyathidites* sp. The occurrence of these diagnostic palynomorphs is significant, as it indicates the onset of sedimentation within the Nkporo Shale under conditions favourable for the preservation of terrestrial organic matter. The dominance of *Milfordia* species in this interval is consistent with previous studies, notably Ola-Buraimo (2020), in which the taxon is recognised as an important biostratigraphic marker for Late Cretaceous sediments in West Africa. This acme event reflects a period of increased floral productivity and sediment influx, possibly linked to climatic and tectonic controls within the basin, and it provides a robust datum for correlation across the platform.

The overlying intervals between 2859 metres and 3021 metres are characterised by relatively low palynomorph abundance and moderate preservation, with assemblages dominated by *Zlivisporites blanensis*, *Cyathidites* sp., *Triporites* sp., *Longapertites marginatus*, and *Syncolporites marginatus*. The reduced abundance in this interval may be attributed to oxidative degradation, dilution by clastic input, or fluctuations in depositional energy. Despite this, the taxa present remain stratigraphically significant, as several are well established indicators of Campanian age (Ola-Buraimo and Akaegbobi, 2012; Abraham et al., 2025). In particular, *Longapertites marginatus* and *Zlivisporites blanensis* are widely reported in Upper Cretaceous palynofloras across tropical regions and are therefore useful for regional correlation.

In the upper interval between 2758 metres and 2813 metres, the assemblage becomes more diverse, with the occurrence of *Constructipollenites ineffectus*, *Hexaporopollenites emelianovi*, *Inaperturopollenites* sp., and *Buttinia andreevi* alongside previously recorded taxa. The presence of *Hexaporopollenites emelianovi*, a known Turonian marker species, is particularly noteworthy. Its occurrence in this interval, despite a known extinction prior to the Campanian, suggests reworking from older sediments or stratigraphic mixing during deposition. This phenomenon is not uncommon in active clastic basins and may result from erosional recycling during transgressive and regressive cycles. Its presence therefore does not contradict the overall Campanian age assignment but rather highlights the complexity of depositional and reworking processes within the basin, and it cautions against age determination based on a single index taxon.

The integration of these palynomorph assemblages across the studied interval, from 2758 metres to 3075 metres, supports a Campanian age for the Nkporo Shale penetrated by the Akukwa-2 well. This age assignment is consistent with established stratigraphic frameworks for the Anambra Basin and correlates well with findings from other wells such as Nzam-1 (Ola-Buraimo, 2020). The identification of the *Milfordia* spp. Acme Zone further strengthens this correlation and provides a reliable biostratigraphic marker for regional stratigraphic alignment, particularly where independent age control from calcareous microfossils is lacking.

5.1 Palaeoenvironmental synthesis

From a palaeoenvironmental perspective, the palynomorph assemblage reflects deposition under marginal marine to shallow

marine conditions. This interpretation is supported by the coexistence of terrestrial pollen and spores with marine palynomorphs such as the dinoflagellate cysts *Phelodinium bolonienae* and *Cribroperidinium edwardsii* and the algal remains of *Botryococcus braunii*. The presence of *Botryococcus braunii*, which thrives in brackish to freshwater environments but is frequently transported into marginal marine settings, suggests fluctuating salinity and proximity to continental sources. Similarly, the abundance of peridinioid dinoflagellate cysts indicates nutrient rich nearshore marine environments subject to periodic freshwater influx.

The predominance of terrestrial palynomorphs, particularly pollen and spores, points to a strong continental influence and a high sediment supply, most likely derived from adjacent landmasses during periods of active erosion. This is consistent with the regressive depositional history of the Anambra Basin during the Late Cretaceous, when sedimentation shifted progressively from deeper marine to more proximal deltaic and paralic environments (Nwajide, 1990). The interplay between marine and terrestrial inputs, captured numerically by the marine to terrestrial ratio, reflects a dynamic depositional system governed by sea level fluctuations, climatic conditions, and tectonic activity. The integrated biozonation and palaeoenvironmental model is summarised in Figure 7.

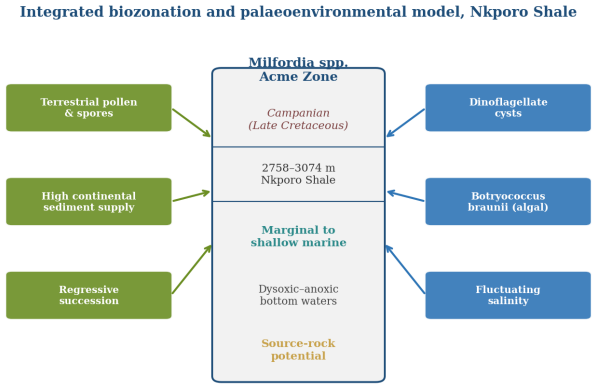

Figure 7: Integrated biozonation and palaeoenvironmental model for the Nkporo Shale in the Akukwa-2 well, linking the Milfordia spp. Acme Zone and Campanian age to a marginal to shallow marine setting with source-rock potential.

Furthermore, the generally good preservation of palynomorphs in several intervals indicates low oxygen, dysoxic to anoxic, bottom water conditions, which are favourable for organic matter preservation. Such conditions are critical for the development of potential hydrocarbon source rocks, as they enhance the accumulation and retention of organic rich sediments. This observation supports previous assertions that the Nkporo Shale constitutes an important source rock within the Anambra Basin (Akaegbobi et al., 2000; Ayinla et al., 2023). When combined with the documented thermal maturity of the basin, the palynofacies signature recorded here strengthens the case for a working petroleum system in this part of the basin.

The results of this study are broadly consistent with the regional palynostratigraphic schemes erected for the Asata and Nkporo shales by Ola-Buraimo and Akaegbobi (2013) and with the palynofacies and source rock assessments of Edegbai and Emofurieta (2015), while extending that framework to a well that had previously lacked detailed biozonation. The convergence of independent lines of evidence, namely index taxa, assemblage composition, and quantitative abundance trends, lends confidence to the Campanian age assignment and to the marginal marine interpretation advanced here.

6. Conclusion

This study provides a comprehensive biostratigraphic evaluation of the Nkporo Formation penetrated by the Akukwa-2 well in the Anambra Basin. The palynological analysis revealed a diverse and well preserved assemblage of pollen, spores, and dinoflagellate cysts, which served as key indicators for age determination, biozonation, and palaeoenvironmental interpretation.

The identified palynomorphs, including *Phelodinium bolonienae*, *Araucariacites australis*, *Cribroperidinium edwardsii*, and *Longapertites marginatus*, constrain the studied interval to the Late Cretaceous, specifically the Campanian to Maastrichtian. The establishment of the *Milfordia* spp. Acme Zone further enhances the biozonation framework and enables correlation with other wells within the basin, such as the Nzam-1 well.

Palaeoenvironmental reconstruction indicates that the sediments were deposited under marginal to shallow marine conditions, as evidenced by the abundance of marine dinoflagellate cysts and algal remains such as *Botryococcus braunii*. These conditions are conducive to the accumulation and preservation of organic matter, which is critical for hydrocarbon generation. The study thereby improves understanding of the stratigraphic framework and depositional history of the Nkporo Formation, and the integration of palynological data with regional stratigraphy provides valuable input for basin analysis and exploration. Overall, the findings confirm that the Nkporo Formation in the Akukwa-2 well possesses significant potential as a source rock within the Anambra Basin, and they serve as a useful reference for future geological, biostratigraphic, and petroleum exploration studies in the region.

Declarations

Conflict of Interest Statement

The authors declare that there is no conflict of interest with respect to the research, authorship, or publication of this article.

Ethical Approval and Informed Consent

Not applicable. This study is based on the analysis of subsurface geological samples and did not involve human participants or animal subjects.

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