Palynological characterization and source rock evaluation of the Anambra Basin, southeastern Nigeria

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Abstract

An integrated palynofacies, organic petrological, and biostratigraphic investigation was carried out on seventeen ditch cutting samples from the Akukwa-2 and Nzam-1 wells in the Anambra Basin, southeastern Nigeria, to assess source rock characteristics and hydrocarbon generation potential. Seventeen samples were analyzed to evaluate organic matter abundance, kerogen type, thermal maturity, depositional environment, and stratigraphic age. Palynofacies data indicate organic matter richness ranging from lean to fairly rich, with assemblages dominated by mixed terrestrial and marine components. The kerogen population is principally composed of Type II and Type III kerogens, suggesting both oil and gas prone source intervals. Thermal maturity assessment based on kerogen color indices and maceral composition indicates that several stratigraphic units have attained conditions favorable for hydrocarbon generation. Palynological assemblages characterized by key marker taxa, including *Echitricolporites spinosus*, *Longapertites* spp., *Wetzeliella* sp., and *Afropollis jardinus*, constrain the age of the penetrated sequences to Albian–Tertiary. The co-occurrence of terrestrial pollen and spores with marine dinoflagellate cysts suggests deposition in a marginal marine to deltaic environment. Overall, the results demonstrate that selected intervals within the Akukwa-2 and Nzam-1 wells possess favorable conditions for hydrocarbon generation, highlighting the petroleum potential of the Anambra Basin.

Keywords: Palynofacies; Hydrocarbon generation potential; Kerogen type; Thermal maturity; Biostratigraphy; Anambra Basin.

1. Introduction

Palynofacies analysis plays a critical role in sedimentary basin studies by providing insights into depositional environments and the hydrocarbon generation capacity of source rocks through the characterization of sedimentary organic matter such as pollen, spores, dinoflagellates, algae, and amorphous organic components *(Ayinla et al., 2023; Ayok et al., 2020; Ola-Buraimo and Ehinola, 2022)*. Variations in organic matter type, abundance, and preservation are closely linked to petroleum generation processes and are therefore essential parameters in basin evaluation *(Ayinla et al., 2017)*.

The application of palynological and organic petrological techniques has gained increasing relevance in hydrocarbon exploration, particularly in underexplored sedimentary basins where subsurface data are limited *(Ayinla et al., 2023, 2024)*. Palynofacies components are broadly classified into terrestrial palynomorphs, marine palynomorphs, and amorphous organic matter, each reflecting specific source inputs and depositional conditions *(Ola-Buraimo and Akaegbobi, 2012)*.

The Anambra Basin is a major inland sedimentary basin in Nigeria with established coal deposits and emerging petroleum prospects. Despite several geological investigations within the basin, detailed integrated studies combining palynofacies, biostratigraphy, and hydrocarbon generation potential across multiple formations remain sparse. This study addresses this gap by evaluating the palynofacies characteristics, organic matter composition, thermal maturity, depositional environment, and stratigraphic age of sediments penetrated by the Akukwa-2 and Nzam-1 wells.

2. Geologic Setting

The Anambra Basin is located in south central Nigeria (Figure 1) and represents a Cretaceous sedimentary basin with sediment thicknesses of up to approximately 9 km *(Whiteman, 1982; Akaegbobi and Schmitt, 2020)*. Its evolution is closely associated with Santonian tectonic movements, which resulted in basin inversion and the development of structural features such as folds and fault controlled traps that are favorable for hydrocarbon accumulation *(Nwajide, 1990)*.

The basin rests on Precambrian basement rocks and is infilled with sedimentary successions ranging in age from Albian to Paleocene *(Nwajide, 1990)*. Major stratigraphic units include the Nkporo Shale, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Shale, and Ameki Formation (Figure 2). These formations comprise alternating shales, sandstones, and coal seams deposited under varying fluvial, deltaic, and shallow marine conditions.

The Nzam-1 well is located within the Ameki Formation, while the Akukwa-2 well penetrates the Nsukka Formation. Both wells intersect several shale dominated intervals that are considered potential source rock facies due to their fine grained nature and organic matter preservation potential.

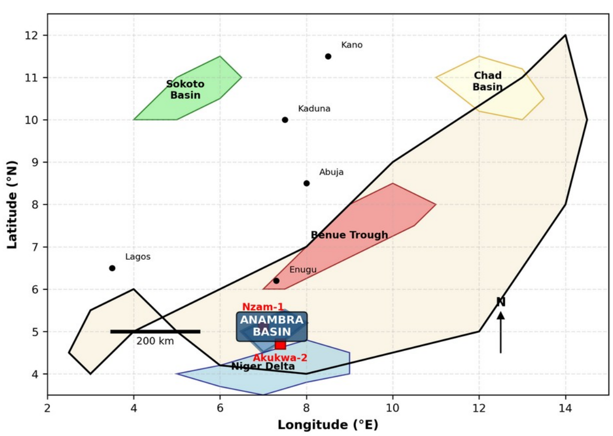

Figure 1. Generalized geological map of Nigeria showing the Anambra Basin location and well positions

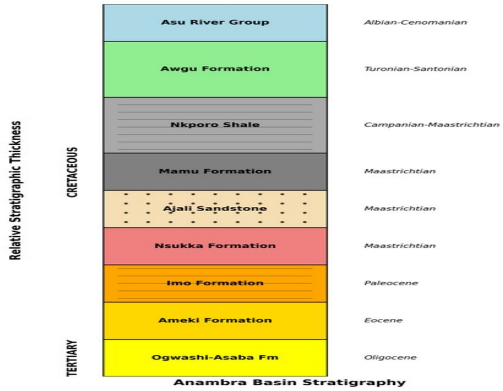

Figure 2. Stratigraphic succession in the Anambra Basin showing major formations

3. Materials and Methods

Seventeen ditch cutting samples from the Nzam-1 and Akukwa-2 wells were obtained from the Nigeria Geological Survey Agency (NGSA), Kaduna. The Nzam-1 samples cover depths between 515 and 10,600 ft, while the Akukwa-2 samples span depths of 1,000 to 11,400 ft.

3.1 Lithological Description

Lithological characterization was conducted based on visual examination of the cuttings, including color, texture, grain size, and sediment type. These parameters were used to infer lithofacies variations and assist in stratigraphic correlation.

3.2 Palynological Preparation and Analysis

Standard palynological preparation procedures were adopted following established methods *(Ola-Buraimo et al., 2015; Ayinla et al., 2023)*. Samples were treated with hydrochloric acid (HCl) to remove carbonates and hydrofluoric acid (HF) to digest silicate minerals. Residues were sieved using a 10 µm mesh and separated using heavy liquid flotation with zinc bromide ($ZnBr_2$).

Permanent slides were prepared using D.P.X. mountant and examined under a Zeiss transmitted light microscope. Palynomorph identification, counting, and documentation were carried out following standard procedures.

3.3 Organic Petrology and Thermal Maturity Assessment

Kerogen was recovered without oxidation to preserve natural color characteristics. Kerogen typing was inferred

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from palynomorph composition and maceral distribution, while thermal maturity was assessed using kerogen color indices based on the Thermal Alteration Index *(Staplin, 1969)* and vitrinite reflectance measurements *(Ola-Buraimo et al., 2015; Ayinla et al., 2023)*.

4. Results and Discussion

4.1 Lithology and Depositional Environment

The lithologic sequences in both wells are dominated by shale and sandy shale facies with minor sandstone interbeds. The presence of marine fossils and mixed terrestrial organic components suggests deposition under marginal marine to deltaic conditions. Similar lithologic trends in both wells indicate broadly comparable depositional environments within the basin.

4.2 Organic Richness and Kerogen Composition

Palynomorph abundance indicates organic richness ranging from lean to fairly rich across the studied intervals (Figure 3). The organic matter assemblage is dominated by Type II and Type III kerogens, reflecting contributions from both marine planktonic and terrestrial plant sources *(Tissot and Welte, 1984)*. Type II kerogen rich intervals are oil and gas prone, whereas Type III kerogen is predominantly gas generating (Figure 4).

Figure 3 illustrates the variation in palynomorph abundance and organic richness classification across both wells. The Nzam-1 well exhibits fair organic richness at depths of 515-595 ft, 7950-8000 ft, 8330 ft, and 8600-8700 ft, while the Akukwa-2 well shows comparable enrichment at 1000-1100 ft, 5000-5100 ft, and 5600-5700 ft. These intervals represent promising source rock horizons within the basin.

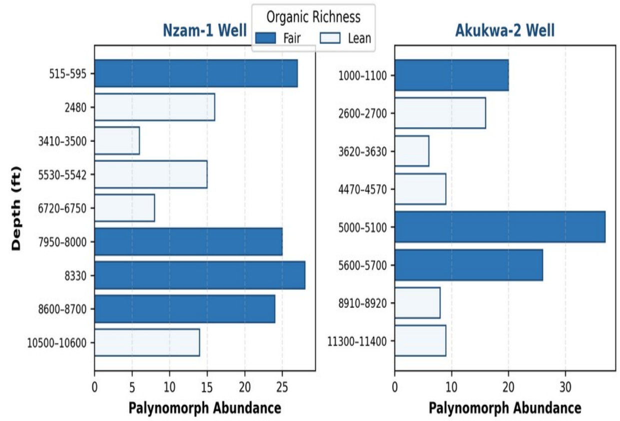

Figure 3. Comparison of palynomorph abundance and organic richness between Nzam-1 and Akukwa-2 wells

The kerogen type distribution (Figure 4) reveals that while both wells contain mixed Type II/III kerogen assemblages, there is spatial variability in the relative proportions. The Nzam-1 well generally displays higher Type II kerogen counts in the upper intervals, suggesting enhanced marine productivity or better preservation of labile marine organic matter. In contrast, the Akukwa-2 well shows terrestrial dominance in most intervals, consistent with proximity to fluvial or deltaic input sources.

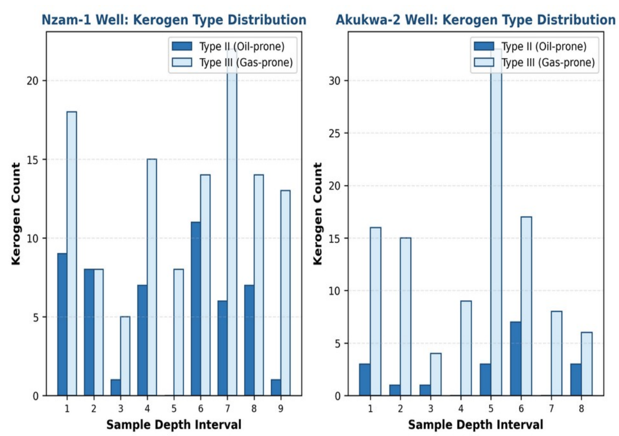

Figure 4. Kerogen type distribution showing oil prone (Type II) versus gas prone (Type III) organic matter

4.3 Thermal Maturity

Kerogen color variations from yellow through brown to black indicate progressive thermal maturation from immature to over mature stages (Figure 5). Several stratigraphic intervals, particularly within the Nkporo and

Awgu Shales, fall within the oil and gas generation window.

Figure 5 presents a comprehensive thermal maturity profile based on kerogen color distribution. The predominance of yellow brown and brown kerogen in most samples indicates that the majority of the analyzed intervals have reached early to peak oil generation maturity. Notably, samples from greater depths (>8000 ft in Nzam-1 and >5000 ft in Akukwa-2) show increased proportions of brown to black kerogen, suggesting advancement into gas generation windows at these depths. This depth dependent maturity trend is consistent with normal geothermal gradients and burial history in sedimentary basins.

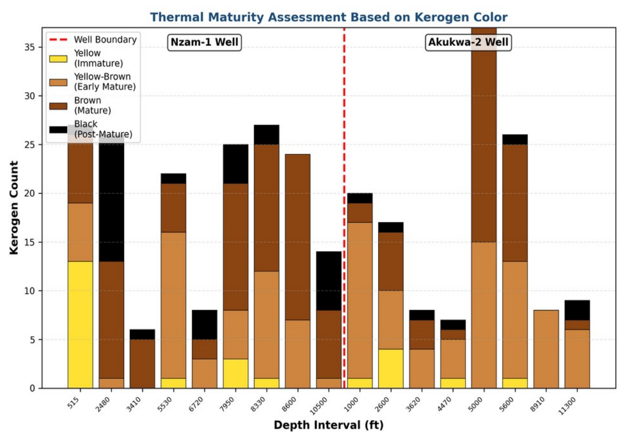

Figure 5. Thermal maturity assessment showing kerogen color distribution across all analyzed depth intervals

4.4 Biostratigraphy and Age Interpretation

Recovered palynomorph assemblages including *Echitricolporites spinosus*, *Longapertites* spp., *Wetzeliella* sp., and *Afropollis jardinus* suggest an age range spanning Albian to Tertiary. The association of marine dinoflagellate cysts with terrestrial pollen and spores supports deposition in a marginal marine setting *(Ola-Buraimo, 2020)*. The presence of *Longapertites* and *Afropollis* is particularly diagnostic of Cretaceous tropical to subtropical paleoenvironments, while *Wetzeliella* occurrences mark Paleogene marine transgressions.

Figure 6 illustrates the depositional environment interpretation using a ternary diagram of organic matter sources. Most samples plot within the marginal marine zone, confirming a transitional depositional setting with varying contributions from terrestrial and marine organic inputs. This environmental interpretation is consistent with the tectonic and paleographic evolution of the Anambra Basin during the Late Cretaceous to Paleogene interval.

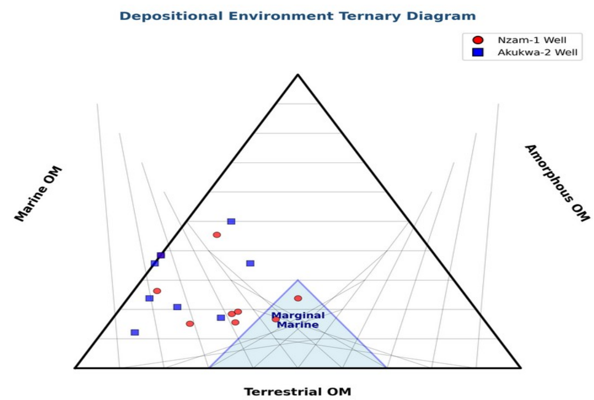

Figure 6. Ternary diagram showing depositional environment interpretation based on organic matter composition

4.5 Hydrocarbon Generation Potential

The integration of organic richness, kerogen type, and thermal maturity data provides a robust framework for evaluating hydrocarbon generation potential. Intervals classified as fairly rich in organic matter, containing Type II kerogen, and exhibiting mature thermal indices represent the most prospective source rock horizons. Specifically, the 515-595 ft interval in Nzam-1 and the 5000-5100 ft interval in Akukwa-2 demonstrate optimal conditions for active oil generation.

Gas generation potential is particularly significant in the deeper, more thermally mature sections where Type III kerogen predominates. The coexistence of oil prone and gas prone kerogen types across different stratigraphic levels suggests a vertically stacked petroleum system with potential for both oil and gas accumulations depending on local thermal history and migration pathways.

These findings align with previous geochemical studies in the basin *(Akaegbobi et al., 2000)*, which documented hydrocarbon shows and established the presence of thermogenic gas in post Santonian shales. The current study provides additional palynological and organic petrological constraints that refine our understanding of source rock distribution and maturation patterns.

5. Conclusion

This study integrates palynofacies, organic petrological, and biostratigraphic data to evaluate the hydrocarbon generation potential of the Akukwa-2 and Nzam-1 wells in the Anambra Basin. Organic matter richness varies from lean to fairly rich, with kerogen assemblages dominated by mixed Type II–III kerogens derived from both terrestrial and marine sources. Thermal maturity indicators reveal that several stratigraphic intervals have reached conditions suitable for oil and gas generation. Biostratigraphic evidence indicates an Albian to Tertiary age and marginal marine depositional environments. The findings confirm that the Anambra Basin contains intervals with favorable petroleum potential and provide a refined framework for future exploration efforts.

Declaration of Authors Contribution

Ayinla, H.A. and Abraham, G. designed the research which was supervised by Ayinla, H.A. and all the authors contributed to fieldwork, sample collection, laboratory and data analysis. Ayinla, H.A. and Abraham, G. prepared the initial manuscript draft. Odoma, A.N. reviewed and edited the manuscript for intellectual content. All the authors contributed to the development of the final manuscript and approved its submission.

Conflict of Interest

The authors declare no conflict of interest.

Ethics Approval and Informed Consent

Not applicable.

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