Confluence Journal of Pure and Applied Sciences, Volume 4 Issue 1, June, 2025 Pp 122-134

ORIGINAL RESEARCH

Biostratigraphy of the Akukwa-2 and Nzam-1 Wells in the Anambra Basin, Southeastern, Nigeria

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ABSTRACT

This study presents a comprehensive biostratigraphic analysis of the Nzam-1 and Akukwu-2 wells in the Anambra Basin, southeastern Nigeria. It aims to determine the age, biozonation and paleoenvironment of the sedimentary succession penetrated by the two wells using palynological analysis. In this study, 17 samples from Nzam-1 (9) and Akukwa-2 wells (8) were subjected to palynological analysis. Based on the result of the studied samples, a total of nine (9) palynological zones are identified (6 in Nzam-1 and 3 in Akukwu-2 well). This provides a framework for correlating the palynomorphs across the wells in the basin, as it also reveals a diverse assemblage of forms (pollen, spores, and dinoflagellate cysts). Palynological study indicates that the sedimentary succession in the Nzam-1 and Akukwu-2 wells ranges between the Late Cretaceous to Paleogene periods based on the occurrence/assemblage of palynomorphs such as Echitricolporites spinosus, Wetzeliella sp., Longapertites spp., Afropollis jardinus and Milfordia spp. The presence of these fossils also suggests that both wells have the same environment of deposition (Marine Environment), which can support hydrocarbon generation.

Keywords: Anambra Basin; Biostratigraphy; Biozonation; Palynomorphs; Palaeo-environment

INTRODUCTION

The Anambra Basin, a crucial sedimentary basin in Nigeria, boasts a rich fossil record spanning the Late Cretaceous to Paleogene period (Ayinla et al., 2024; Obi et al., 2020). This fossil record provides invaluable information for biostratigraphy analysis, which is essential for reconstructing the geological evolution of the basin (Adebayo et al., 2017). 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 et al., 2019), and evaluating the hydrocarbon potential of the basin (Ekpo

et al., 2020; Ayinla et al., 2023). The Nzam-1 and Akukwu-2 wells, two key wells drilled in the Anambra Basin, provide valuable subsurface data for understanding the basin's geological evolution and hydrocarbon potential (Ikejimba et al., 2018). However, the biostratigraphic framework of these wells is not well established, hindering accurate correlation and dating of the sedimentary succession (Aigbadon et al., 2020). This study aims to establish a detailed biostratigraphic framework for the Nzam-1 and Akukwu-2 wells using palynological analysis of ditch cutting samples. The objectives of this study are to establish a detailed palynological biozonation, determine the age, and reconstruct the paleoenvironment of both wells. The results of this study will contribute significantly to the understanding of the geological evolution and hydrocarbon potential of the Anambra Basin, serving as a reference for future exploration and production activities in the region.

Geologic Setting

The Anambra Basin in south-central Nigeria (Fig. 1) is a Cretaceous basin with 9 km of sediment, creating conditions favourable for hydrocarbon formation (Whiteman, 1982; Akaegbobi et al., 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 et al., 2000; Ayinla et al., 2023).

The oldest sedimentary sequence in the Anambra Basin is the Nkporo Group (Fig. 2) (Late Campanian), comprising the Nkporo Shale, Owelli Sandstone, and Enugu Shale (Nwajide, 1990). Above it, the Mamu Formation (Early Maastrichtian) consists of siltstones, shales, coal seams, and sandstones (Kogbe, 1989). The Ajali Sandstone (Maastrichtian) follows, characterized by loose, coarse-to-fine-grained, poorly cemented sandstones and siltstones (Kogbe, 1989; Nwajide, 1990). Overlying this is the Nsukka Formation, a diachronous unit known as the upper coal measure, spanning the Maastrichtian-Danian (Obi, 2020)

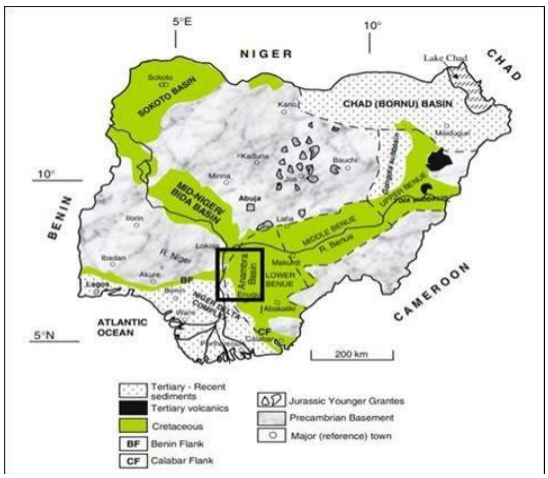

Figure 1: Generalized geological map of Nigeria showing the Anambra Basin in the Thick rectangular (Obaje, 2009)

Materials and Methods

The total of 17 samples from Nzam-1 well and Akukwa-2 well, with eight (8) from Nzam-1 well and nine (9) from Akukwa-2 well, were subjected to laboratory palynological sample preparation for the determination of the age, biozonation and paleoenvironment. This was followed by oxidation of the organic material with nitric acid. The separated organic macerals were then rinsed with ethanol before being mounted onto glass slides for microscopic analysis and photography of the preserved specimens.

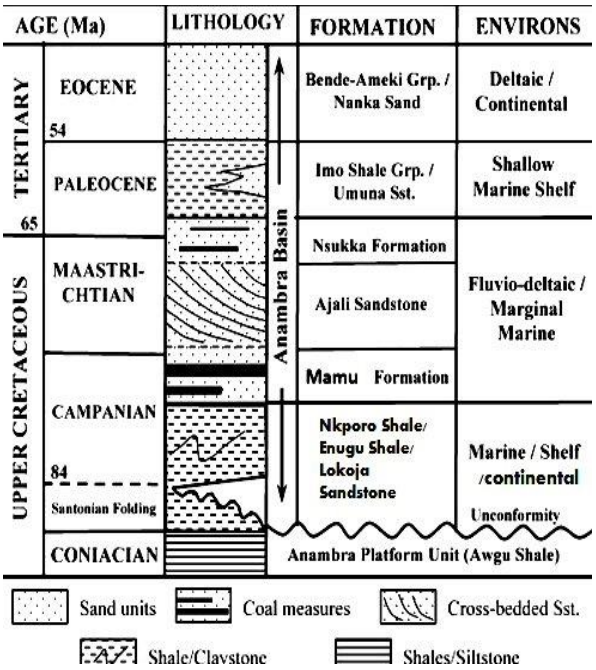

Figure 2: Anambra Basin Stratigraphy and Depositional Environment (Edegbai, 2015)

Results

The palynological analysis studied well samples from the Anambra Basin revealed varying number of palynomorphs based on depths. The results presented in Figs. 3 and 4 shows the palynomorphs recovery, abundance, age and photomicrographs of some diagonistic species (Figs. 5 and 6). Therefore, the following are the description of analysed samples from the Nzam-1 and Akukwa-2 Wells biozonations:

Nzam-1 Well Biozonation

At the depth of 515-595 ft, the key fossils recovered include *Echitricolporites spinosus*, *Anthocerus* sp., and *Psilatricolporites crassus*, indicating a Late Miocene age. As the depth increases to 2480 ft., the interval is marked by the co-occurrence of *Proteacidites* sp., *Longapertites marginatus*, and *Monosulcites* sp. (Fig. 3). This suggests a Paleocene age for the studied interval. Although, between 3410-3500 ft, the record is incomplete due to limited sampling, presence of *Dinogymnium* sp. suggests a possible marginal marine deposit.

The interval spanning 5530-6750 ft is dated to the Middle Maastrichtian age, based on the presence of *Tricolpites giganteus*, *Longapertites marginatus*, and *Inaperturopollenites* sp. (Figs 3 and 5).

At greater depth of 7950-8000 ft, the interval is characterized by an abundance of *Milfordia* sp. and *Milfordia jardinei*, indicating a Campanian age. The presence of these fossils implies a coastal or marine depositional environment. *Zlivisporites blanensis* assemblage zone is identified at 8330 ft, corresponding to a Maastrichtian age (Figs 3 and 5). The upper part of the assemblage zone, suggesting a Coniacian-Santonian age is at 8600-8700ft which likely marks a period of significant change in ancient ecosystems and environments.

The deepest interval, spanning 10500-10600 ft, is characterized by the co-occurrence of *Afropollis jardinus*, *Cretacaeisporites mulleri*, and *Eucommidites* sp., indicating an Albian to Lower Cenomanian age (Figs 3 and 5).

Akukwa-2 Well Biozonation

At 1000-3630 ft, the interval is dated to the Maastrichtian age, based on the co-occurrence of *Proteacidites sigali*, *Retidiporites magdalenensis*, and *Auriculiidites* sp. (Fig. 4) As the depth increases to 4470-4570 ft, it corresponds to the Lowermost Lower Maastrichtian age of the earliest part of the Mamu Formation. From 5000-5100 ft, the interval is characterized by marker fossils, including *Milfordia* sp., *Milfordia jardinei*, and *Retidiporites magdalenensis*, indicating a Campanian age (Figs 4 and 6).

The interval spanning 5600-5700 ft is marked by an assemblage of marker forms, including *Droseridites senonicus, Triorites africaensis*, and *Ephedripites* sp., suggesting a Coniacian to Santonian age (Figs 4 and 6). At 7950-8000 ft, the interval is characterized by abundant *Milfordia* sp. and *Milfordia jardinei*, with peak development of *Milfordia* sp. (Fig. 6) This interval belongs to the *Milfordia* sp. Acme zone and is dated to the Campanian. The presence of key pollen taxa, including *Auriculiidites reticularis*, *Syncolporites* sp., and *Longapertites*

sp., suggests a marginal marine deposit. The *Zlivisporites blanensis* Assemblage Zone at 8330ft, corresponds to the base of the *Milfordia* spp. Acme zone. The interval is characterized by the continuous occurrence of *Zlivisporites blanensis*, *Triorites* sp., and a high frequency of monosulcates and colpate angiosperms, indicating a marginal marine environment (Figs 4 and 6). A tentative Upper Cenomanian age is assigned to the interval at 8919-8920 ft, with a possible continental environment. Finally, at 11300-11400 ft, the interval cannot be precisely dated, but the sediment was deposited in a marginal marine environment characterized by the recovery of *Andalusiella polymorpha* and *Phelodinium bolonienae* (Figs 4 and 6).

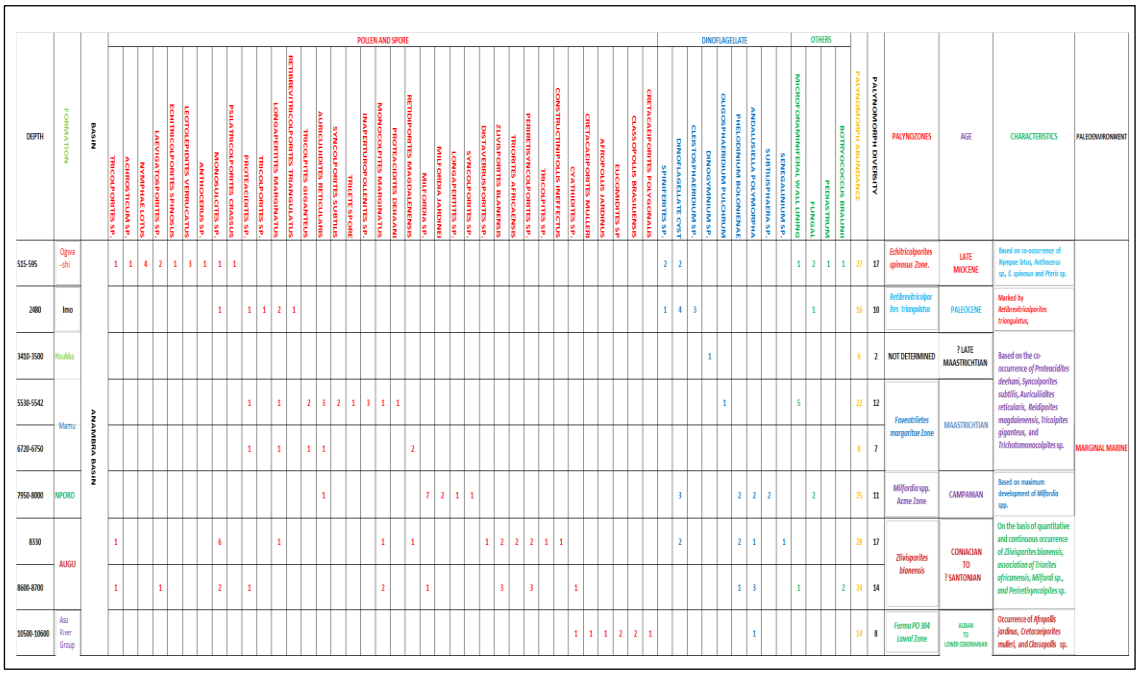

Figure 3. Checklist distribution of palynomorphs with depth, zones, age, and paleoenvironment of deposition of Nzam-1 Well

Confluence Journal of Pure and Applied Sciences, Volume 4 Issue 1, June, 2025 Pp 122-134

DEPTH	FORMATION	BASIN	POLLEN AND SPORE																															DINOFLAGELLATE					MICROFORAMINIFERAL WALL LINING	FUNGAL	TOTAL ABUNDANCE	TOTAL DIVERSITY	PALYNOZONE	AGE	CHARACTERISTICS	PALEOENVIRONMENT
			INAPERTUROPOLLENITES SP.	CYATHIDITES SP.	TRICOLPOROPOLLENITES SP.	SYNCOLPORITES SP.	MONOCOLPOPOLLENITES SPHAEROIDITES	SYNCOLPORITES INCOMPTUS	UMOIDEIPITES KREMPII	RETIMONOCOLPITES SP.	LAEVIGATOSPORITES SP.	MONOSULCITES SP.	MONOPORITES SP.	LONGAPERTITES SP.	AURICULIIDITES SP.	RETIDIPORITES MAGDALENENSIS	PSILATRICOLPORITES SP.	TRICOLPITES SP.	PROTEACIDITES SIGALI	CINGULATISPORITES ORNATUS	MILFORDIA SP.	PROXAPERTITES SP.	PROTEACIDITES SP.	MILFORDIA JARDINEI	VERRUPOLLENITES SP.	CUPANIEIDITES RETICULARIS	DROSERIDITES SENONICUS	CRETACAEIPORITES POLYGONALIS	TRIORITES SP.	EPHEDRIPITES SP.	CRETACAEIPORITES MULLERI	CRETACAEIPORITES INFRABACULATUS	TRIORITES AFRICAENSIS	ANDALUSIELLA SP.	DINOFLAGELLATE CYST	SENEGALINIUM SP.	ANDALUSIELLA POLYMORPHA	PHELODINIUM BOLONIENAE								
1000-1100	MAMU	ANAMBRA BASIN	2	2	1	2	3	1	1	1	2																							1	2					1	20	14	*Foveotrilets margaritae* Assemblage Zone	MAASTRICHTIAN	Based on the co-occrences of *Proteacidites sigali*, *Retidiporites magdalenensis*, *Auriculiidites reticularis*, *Syncolporites* sp., and *Periretisyncolporites* sp.	MARGINAL MARINE
2600-2700							4					2	1	3	1	1	1	1																		1					16	10				
3620-3630				1									1	1					1																	1				1	6	6				
4470-4570				2			2									2				1	1	1																			9	6				
5000-5100	NKPORO			1	1							8		4		3					7		1	4	1											1	1	1	1	1	37	16	*Milfordia* spp. Acme Zone	CAMPANIAN	Based on maximum development of *Milfordia* spp.	
5600-5700	AUGU TO EZE-AKU			1							2															1	3	3	3	1	4				1			5		1	26	13	Cretacaeiporites spp. Acme Zone	Lowermost Turonian To Upper	Based on the maximum development of *Cretacaeiporites* spp.	
8919-8920				3																											3	1	1								8	4				CONTINENTAL
11300-11400	ASU RIVER GP.			1		1						1						1															1		1		1	1			9	9	UNDETERMINED	UNDETERMINED	UNDETERMINED	MARGINAL MARINE

Figure 4: Checklist distribution of palynomorphs with depth, zones, age, and paleoenvironment of deposition of Akukwa-2 Well.

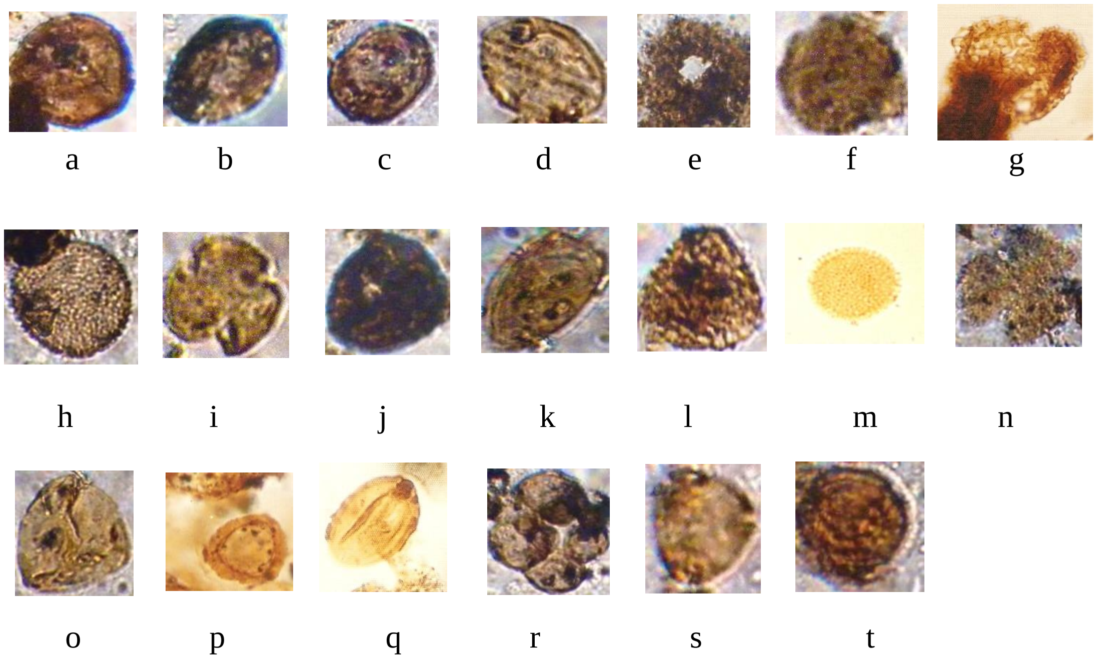

Figure 5: Photomicrographs of Palynomorphs in Nzam-1 Well X800

a)Zlivisporites blanensis b) Monocolpopollenites sphaeroidites c) Milfordia sp. d) Monocolpites marginatus e) Milfordia jardinei f) Retidiporites magdalenensis g) Periretisyncolporites sp. h) Cingulatisporites ornatus i) Cupanieidites reticularis j) Tricolpites sp. k) Longapertites sp. l) Trichoromonosulcites sp. m) Constructipollenites imeffectus n) Tricolpies giganteus o) Auriculiidites reticularis p) Proxapertites cursus q) Tricolpites sp. r) Microforaminiferal wall lining s) Retibrevitricolporites triangulatus t)Psiltricolporites crassus

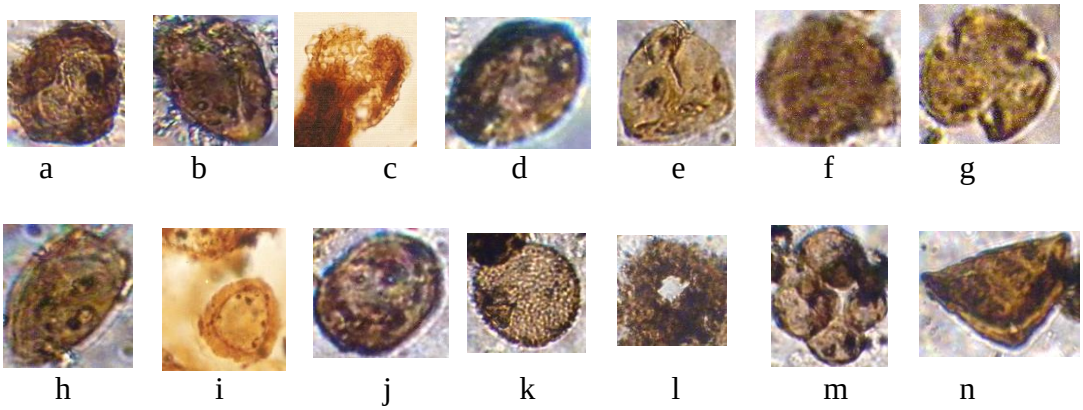

Figure 6: Photomicrographs of Palynomorphs in Akukwa-2 Well X800

a)Nymphae lotus b)Monosulcites sp. c)Periretisyncolporites sp. d)Syncolporites ssp. e)Monocolpopollenites sphaeroidites f)Cupanieidites reticularis g)Retidiporites magdalenensis h)Tricolpites sp. i) Longapertites marginatus j) Cingulatisporites ornatus k) Proxapertites cursus l)Milfordia sp. m) Milfordia jardinei n) Microforaminiferal wall lining

Discussion

Nzam-1 well

The Late Miocene age assigned to the interval at 515-595 ft. is consistent with the stratigraphic position of the sediments and their correlation with the Ogwashi/Asaba Formation in the Anambra Basin (Germeraad et al., 1968; Ola-Buraimo and Akaegbobi, 2012; Ola-Buraimo, 2020). At 2480 ft., the Paleocene age assigned is based on the presence of *Proteacidites* sp., *Longapertites marginatus*, and *Monosulcites* sp. (Ola-Buraimo, 2020). The marine environment of deposition is supported by the recovery of dinoflagellate cysts, *Cleistosphaeridium* sp., and *Spiniferites* sp.

At greater depths, the sediments between 5530-6750 ft. were assigned a Middle Maastrichtian age, based on the presence of *Tricolpites giganteus*, *Longapertites marginatus*, and *Inaperturopollenites* sp. (Ogala et al., 2009; Ola-Buraimo, 2020). The marine deposit is further supported by the presence of microforaminiferal wall lining and dinoflagellate cysts, which are characteristic of marine environments. The sediments at 7950-8000 ft. were assigned a Campanian age, based on the presence of *Milfordia* sp. and *Milfordia jardinei* (Ola-Buraimo and Akaegbobi, 2013; Ola-Buraimo, 2020). The marginal marine deposit is supported by the recovery of dinoflagellate cysts, *Andalusiella* sp., and *Phelodinium bolonienae*, which are indicative of a marginal marine setting. At depth 8330 ft., the interval is suggested to mark the top of *Zlivisporites blanensis* Assemblage zone which marks the base of *Milfordia* sp. Acme zone. However, the interval is characterized by the continuous occurrence of *Zlivisporites blanensis*, *Triorites* sp., and high frequency of monosulcates and colpate angiosperms.

The environment of deposition is marginal marine, marked by peridinacean forms such as *Phelodinium bolonienae*, *Andalusiella polymorpha*, and *Senegalinium* sp. The top of *Zlivisporites blanensis* assemblage zone at depth 8600- 8700 ft. is characterized by the extinction of Cretacaeiporites sp. (Ola-Buraimo, 2013; 2020). However, the zone is marked by relative abundance of *Zlivisporites blanensis*, fair dominance of monosulcate, monocolpate and tricolpate pollen (Ola-Buraimo, 2020). The interval is further marked here by the first and rare appearance of *Milfordia* sp., and *Proteacidites* sp (Figs. 3 and 5).

The dinoflagellate cysts present in the interval are *Andalusiella* sp. and *Phelodinium bolonienae* which were described by Ola-Buraimo (2020) for the zone. The interval is tentatively dated Coniacian-Santonian and also stratigraphically belong to Augu Shale in Anambra Basin (Ola-Buraimo, 2013; 2020).

The paleoenvironment of deposition is suggested to be marginal marine because of the recovery of peridinacean forms and co-occurrence with land derived forms (Ola-Buraimo, 2020; Ola-Buraimo and Ehinola, 2021).

Finally, at depth 10500-10600 ft., The interval is marked by the co-occurrence of *Afropollis jardinus*, a marker form in association with *Cretacaeisporites mulleri*, *Cretacaeiporites infrabaculatus*, *Eucommidites* sp., and *Classopollis brasiliensis*. The Interval shows similarity in composition of pollen reported in the work of Ola-Buraimo and Akaegbobi (2013), Ola-Buraimo (2018), and Ola-Buraimo (2020). The assemblage is also characterized by the presence of dinoflagellate form of *Andalusiella polymorpha*. The interval belongs to Assemblage zone, where the interval is dated Albian to Lower Cenomanian (Ola-Buraimo, 2020). The age deduced here, further establishes the fact that the oldest sediment in Anambra Basin is Abian (Ola-Buraimo and Akaegbobi, 2013; Ola-Buraimo, 2020).

Akukwa-2 well

The interval at 1000-3630 ft. is tentatively assigned a Maastrichtian age, based on the co-occurrence of *Proteacidites sigali, Retidiporites magdalenensis*, and other marker forms (Fig. 6), consistent with previous studies in Senegal and Cote D'Ivoire (Jardine and Magloire, 1965). These sediments were deposited in a marginal marine environment. Below this interval, the section at 4470-4570 ft. is characterized by a paucity of palynomorphs, but the presence of *Monocolpites sphaeroidites* suggests a Lowermost Lower Maastrichtian age.

In contrast, the interval at 5000-5100 ft. is rich in pollen and dinoflagellate cysts, with a dominance of *Milfordia* sp., indicating a Campanian age consistent with the *Milfordia* sp. (Fig. 6) acme zone of the Nkporo Shale (Ola-Buraimo and Akaegbobi, 2013; Ola-Buraimo, 2020). These sediments were deposited in a marginal marine environment. The interval at 5600-5700 ft. contains an assemblage of marker forms, including *Droseridites senonicus* and *Cretacaeiporites* sp., suggesting an age range from Upper Cenomanian to Santonian, with

deposition occurring in a marginal marine setting. The presence of *Cretacaeiporites mulleri* at 8919-8920 ft., suggests an Upper Cenomanian age, with deposition likely occurring in a continental environment. Finally, although the interval at 11300-11400 ft. cannot be precisely dated, its stratigraphic position suggests it is older than the overlying interval, with deposition occurring in a marginal marine environment.

Conclusion

This study has shown the significance of palynological analysis in understanding the age, biozonation and environment of the Akukwu-2 well and Nzam-1 well in the Anambra basin. The results indicate that both the Nzam-1 and Akukwu-2 wells span the Late Cretaceous to Paleogene period in age due to the occurrence of *Echitricolporites spinosus*, *Wetzeliella* sp., *Longapertites* sp., *Afropollis jardinus* and *Milfordia* sp. The presence of these fossils suggests that both wells have the same environment of deposition (Marine Environment).

Declaration of Authors Contribution

Ayinla, H.A. and Abraham, G. designed the research which was supervised by Ayinla, H.A. and Odoma, A.N. All the authors contributed to field work, sample collection, laboratory and data analysis. Ayinla, H.A., and Abraham, G. prepared the initial manuscript draft. Amobi, J.F. Sanni, Z., Toyin, A., Ibrahim, A. and Baba Aminu, M 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

Ethnics Approval and Informed Consent

Not applicable.

Funding

The authors declared no external source of funding.

Aknowledgement

The authors are grateful to the Department of Geology, Federal University Lokoja, Nigeria and the management of Nigerian Geological Survey Agency, Kaduna state, Nigeria. We would also like to sincerely thank the Editor-in-Chief and anonymous reviewers for their constructive and useful comments that improved the revised manuscript.

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