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Biostratigraphy and paleoenvironment studies of shales from Owan-1 Well, Niger Delta Basin, Nigeria

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Abstract

An integrated standard sedimentological, foraminifera, and palynological investigations were carried out on twenty (20) ditch-cutting samples from Owan-1 Well in the Niger Delta Basin, with the depth range from 23–456 meters to determine the relative age and depositional environment of the strata penetrated by the well. Standard foraminifera preparation techniques involving sample disaggregation and washing through a 63-micron mesh sieve, drying, and picking of the foraminifera and accessory fauna were employed. Palynological slides were prepared following standard palynological preparation procedures of sample maceration with hydrochloric (HCl) and hydrofluoric (HF) acids. The sedimentological analysis led to the establishment of six (6) lithofacies units comprising shale, claystone, clayey siltstone, fine-grained sandstone, conglomeratic sandstone, and siltstone. Poorly diverse assemblages of benthonic foraminifera with a total of eight (8) species were recorded in which seven (7) species (88 %) are calcareous and one (1) arenaceous (12 %) while planktic foraminifera are generally absent. Foraminifera species such as *Anomalinoides alazanensis*, *Lenticulina grandis*, *Ammodiscus glabratus*, *Valvulineria rugosa*, *Valvulineria jacksonensis*, *species of Anomalina*, *Cibicides* and *Verneuilina* were recovered. Fairly abundant and diverse palynomorphs were recovered from the samples. The palynomorphs were quantitatively dominated by land-derived species such as *Verrucatosporites usmensis*, *Monocolpites sp*., and *Monoporites annulatus* as the diagnostic species. The abundance of massive, dark, and calcareous shales suggests that the studied interval belongs to the marine Akata Formation of the Niger Delta Basin. Foraminifera and palynological results reveal that the studied interval was deposited during the Middle Eocene Epoch corresponding to P470 and P450 Pollen Zonation. Hence, the sediments penetrated by the well were suggested to be deposited in littoral, inner, and middle neritic corresponding to marginal, shallow, and deep marine environments.

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1. Introduction

Foraminifera and palynomorphs are significant microfossil groups that serve as valuable tools in the petroleum industry, applicable at all stages of exploration [1]. Foraminifera, which are protists, construct shells known as "tests" using either calcium carbonate or by cementing sand or silt grains together. Most foraminifera species are benthic, residing on the seafloor, but during the Mesozoic Era, a group of planktonic foraminifera emerged, floating freely in the oceans and thus, are

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more broadly distributed than their benthic counterparts. Upon death, planktonic foraminifera sink to the ocean floor and can be fossilized alongside contemporary benthic species. Benthic foraminifera, which can be calcareous or agglutinated, are usually confined to specific environments, offering paleontologists insights into the conditions of the rock formation's environment. In contrast, planktonic foraminifera, being widely dispersed, provide less environmental deposition information but are often found in greater numbers [2].

Palynomorphs are organic-walled fossils that include pollen, spores, and certain marine organisms like dinoflagellates. The field of study concerning palynomorphs is known as palynology. Pollen and spores can be transported over long distances by wind and water before settling, are resistant to decay, and frequently appear as fossils. Although their extensive transport means they reveal little about the deposition environment, they are useful for biostratigraphy and can offer clues about ancient climates. Furthermore, the color change in palynomorphs due to heat exposure can help determine the temperature history of rock sequences, aiding in predictions about oil and gas formation [3].

Extensive research on foraminifera, palynological biostratigraphy, and paleoenvironmental studies have been conducted in the Niger Delta Basin by Kiamuke *et al.* [3–10] among others. Microfossils have diverse applications including biostratigraphy, paleoenvironmental analysis, biogeography, paleoclimatology, and thermal maturation. This study focuses on the relevance of foraminifera and palynomorphs in biostratigraphy and paleoenvironmental analysis of the strata penetrated by the Owan-1 well in the Niger Delta Basin.

2. Geological setting of Niger Delta Basin

The studied area, known as the Owan-1 Well, is situated in the Niger Delta Basin of Nigeria. It is located in the Gulf of Guinea on the west coast of Central Africa (Figures 1 and 2). The study region encompasses the whole Niger Delta Province, as described by Reijers, Petters and Nwajide [4]. The Niger Delta is located within the latitudes of 4° and 6° N and longitudes of 3° and 9° E in the south-south geopolitical region of Nigeria [11]. The Cenozoic Niger Delta is located at the intersection where the Benue Trough and the South Atlantic Ocean meet. This junction was established during the Late Jurassic period when South America and Africa separated, creating a triple junction. Since the Eocene epoch until now, the delta has extended in a southwest direction, creating depobelts that indicate the most active part of the delta during each phase of its growth [7]. The depobelts constitute one of the most extensive regressive deltas globally, covering an area of approximately 300 000 km^2 [4], and containing a sediment volume of 500 000 km^2 [6]. The Niger Delta Province comprises a single known petroleum system. This system is known as the Tertiary Niger Delta (Akata-Agbada) Petroleum System [4]. The basin exhibits a regressive sequence of siliciclastic rocks that become coarser towards the top, spanning a thickness of approximately 12 km [13].

The lithic fill of the basin consists of three layers: the Akata, Agbada, and Benin layers. These formations were deposited in marine, transitional, and continental environments, respectively. They have formed a thick progradational passive margin wedge. The Akata Formation, which dates back to the Paleocene-Recent period, is the oldest and foundational unit in the basin. It mostly comprises marine shales and is recognised as the dominant source rock in the area [14]. The formation consists of under-compamarine sediments, including shales, clays, silts, and sand lenses. These sediments were formed in prodelta to deeper marine environments. The estimated thickness of this formation is 6400 m in the centre section of the clastic wedge [7].

The Agbada Formation (Eocene to Pleistocene) is characterized by alternating sandstone, siltstone, and shale sequences, exceeding 3000 m in thickness [4]. Petroleum reservoirs in the basin are found in fine- to coarse-grained sandstone within this formation, which represents the deltaic portion of the sequence deposited in various deltaic environments such as delta-front, delta-topset, and fluvio-deltaic environments [7]. The interbedded shales of the Agbada Formation may also serve as source rocks, though some sources suggest the Akata Formation is the main source rock [14, 15]. The Benin Formation (Miocene-Recent) is the youngest unit in the basin. With a minimum thickness of over 6000 ft, the formation consists mainly of sand, gravel, and back-swamp deposits [16]. The shallowest part of the sequence is composed almost entirely of continental sand. The sands and sandstones are coarse-grained, sub-angular to well-rounded, and poorly sorted. It was deposited in alluvial or upper coastal plain environments following a southward shift of deltaic deposition into a new depobelt. The formation thins towards the basin and pinches out near the shelf edge [16].

3. Materials and method

A total number of twenty (20) ditch-cutting samples were collected from Owan-1 Well in the Niger Delta Basin (Figure 1) at an increasing depth interval ranging from 23 m to 456 m. The samples were then subjected to sedimentological, foraminifera, and palynological analyses.

3.1. Sedimentological analysis

The features observed in the sediments were used to describe its lithology. The samples were first viewed/studied under the reflected light microscope before being viewed visually at the Geology Laboratory, Al-Hikmah University, Ilorin, Nigeria. Notable aspects of the area include variations in rock composition at different depths, textural properties like colour, grain size, shape (roundness), sorting, effects of iron oxidation, and the occurrence of minerals and fossil content such as plant remnants and fossil fragments. To determine the presence of carbonates, a little amount of the samples at each depth interval were treated with a few drops of hydrochloric acid (HCl). A litho-log was created based on the sedimentological description, as shown in Figure 3.

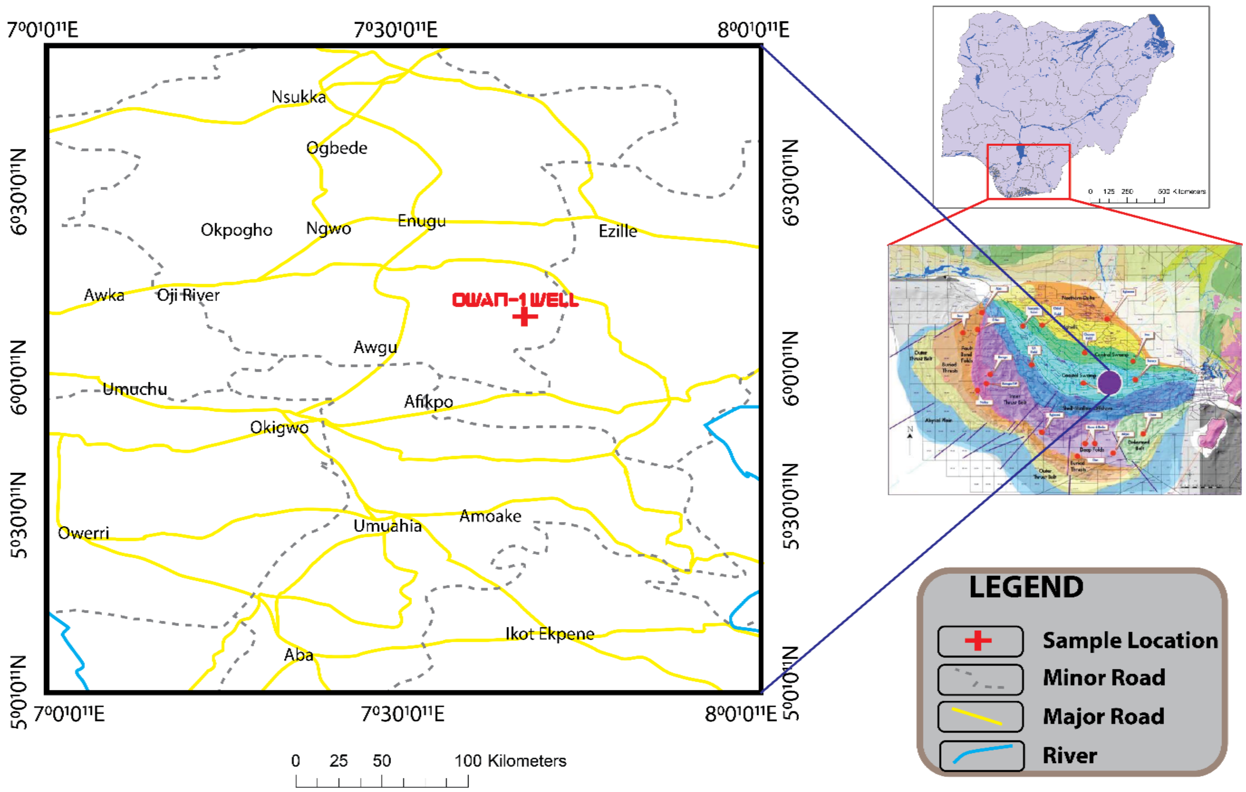

Figure 1. Map of the study area within Niger Delta Basin.

3.2. Foraminifera analysis

Each sample was processed for its foraminifera content using the normal preparation technique, with a quantity of twenty (20) grams for each sample. The sample was immersed and cleansed using hydrogen peroxide and a 63-micron filter. The rinsed remnants were dehydrated on a heated surface and separated into rough, intermediate, and delicate portions using a series of 3 superimposed sieves. Every fraction was scrutinized using a binocular microscope. All the observed foraminifera were carefully collected using a picking needle or toothpick. They were then tallied, placed on slides specifically designed for foraminifera, and covered with a protective cover slide for safekeeping and future reference. The slides were properly labeled with well name and sample depth. The recovered foraminifera were studied and identified to species level using relevant bibliography including eatise on invertebrate paleontology [17].

The identified foraminifera was recorded in the analysis sheet and transferred to the Stratabug biostratigraphic software for charting at a scale of 1:5000. Faunal associations including benthic, planktic, benthic/planktic ratio (normalized) agglutinated/calcareous foraminifera ratios, etc., were plotted. The foraminifera studies were carried out at the geology laboratory, at Al-Hikmah University, Ilorin, Nigeria.

3.3. Palynological analysis

The samples for palynological analysis were selected and rinsed to remove drilling mud. A constant weight (15 g) of each sample was initially treated with hydrochloric acid (HCl) to remove carbonates before complete digestion in hydrofluoric acid (HF) under a fume cupboard. Gentle agitation of the acid/sample mixture is usually carried out to aid digestion. The sample was then treated with a hot hydrochloric acid (HCL) and wet-sieved over a 5-micron mesh polypropylene sieve. The Branson Sonifier 250 is routinely employed during sieving to facilitate the complete removal of silt and clay particles. The sieved residue was given controlled oxidation using concentrated nitric and (HNO_3).

This is followed by treating the sample with potassium hydroxide (KOH). KOH solution washes the samples clean by removing/dissolving unwanted particles such as plant roots and debris. Zinc bromide ($ZnBr_2$) solution was then added to separate the organic matter from the inorganic matter. The residues were spotted with a pipette on a coverslip, left to dry, and were then mounted on glass slides using Loctite as an adhesive mounting medium. Two palynological slides were prepared for each horizon. Both slides are usually analyzed with a minimum count of 300 grains to obtain a complete picture of the palynomorph (pollen, spores, microplanktonic, algae, and fungal microfossils). Fossil taxa were identified through a process of comparing them with published material, including Palynology of Tertiary Sediments from Tropical Area [5] and other published albums. Photomicrographs of the most important palynomorphs were captured using a ×100 oil immersion objective. Chronostratigraphic inferences were derived using the conventional graphic correlation method, which relies on the relative abundances, first appearance datum (FAD), and last appearance datum (LAD) of fossil palynomorphs found in the stratigraphic section to establish palynological zonations [5]. The biozonation of the Owan-1 well is established using palynological zonation schemes from references [6] and [5] for the geologic successions in the Niger Delta.

4. Results and discussions

4.1. Lithologic discusion

Owan-1 Well begins at 23 m and was sampled at an interval of 10 m. At a depth of 53 m to 67 m, a dark shale unit was identified i.e. 14 m thick. At this interval, a lone occurrence of Lenticulina grandis and Ammodiscus glabratus species was observed. The next shale unit was observed to be a very thin unit which is carbonaceous and grey. Another shale unit was observed at 147 m to 176 m and this is the thickest shale unit within the well. This shale unit is a massive grey-colored shale unit.

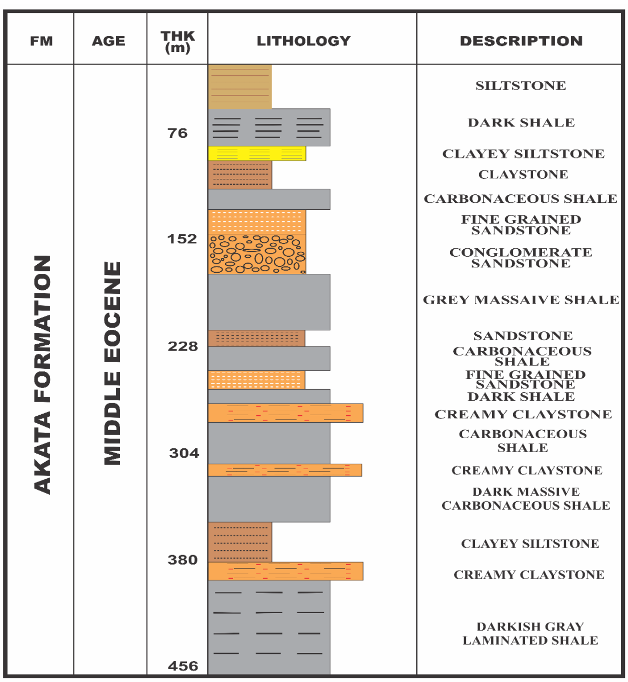

Figure 2. Lithologic section of Owan-1 Well.

Another carbonaceous shale unit is observed at 193 to 212 metres intervals which are essentially barren. Between depths 253 – 258 m is another dark shale unit.

Going further into the well is a carbonaceous shale unit which is about 6 meters thick. Samples analyzed between 330 - 370 metres intervals were barren and passed into a dark massive carbonaceous shale unit of about 5 m. The last unit is at the base of the well at 453 – 456 m (i.e. 3 meters thick), the shales here are dark grey and laminated. In general, there are six (6) lithofacies in the well comprised of shale, claystone, clayey siltstone, fine-grained sandstone, conglomeratic sandstone, and siltstone (Figure 2). This lithological sequence of the Owan-1 well shows that the studied interval belongs to the marine Akata Formation of the Niger Delta Basin based on the abundance of massive, dark, laminated and carbonaceous shales [7].

4.2. Biostratigraphic interpretation

4.2.1. Foraminifera biostrastigraphy

The results of the foraminifera analysis of the shale samples between 23 m (top) and 456 m (base) of the Owan-1 Well are discussed below. Foraminifera assemblage over the interval is generally poor with several barren intervals and absence of planktic foraminifera (Figure 3). A total number of eight (8) benthic foraminifera species were recovered, seven (7) are calcareous which include *Anomalinoides alazanensis*, *Lenticulina grandis*, *Valvulineria rugosa*, *Valvulineria jacksonensis*, *species of Anomalina*, *Cibicides and Verneuilina*; and one (1) arenaceous benthic foraminifera species that is *Ammodiscus glabratus* representing 88 % and 12 % respectively (Figure 3).

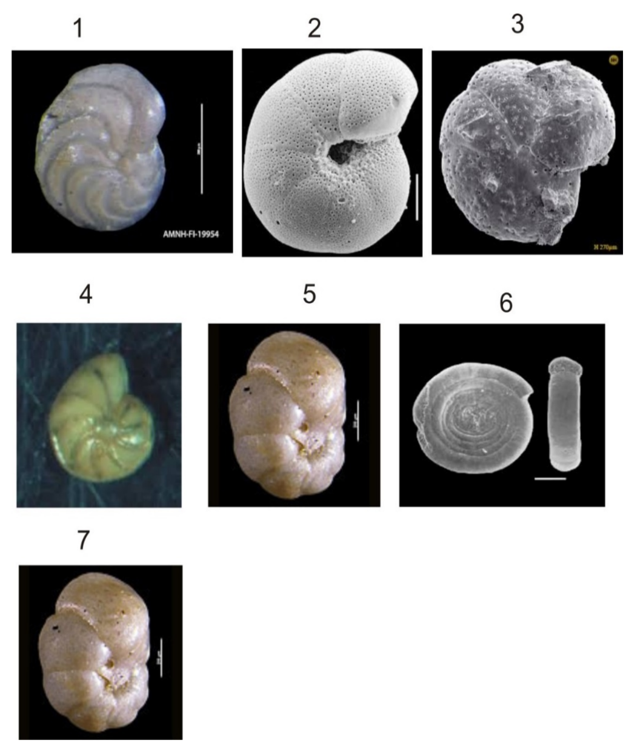

Figure 3. Photomicrography of recovered foraminifera species: 1. *Anomalina sp. alazanensis*, 2. *Anomalinoides*, 3. *Lenticulina grandis*, 4. *Cibicides sp.*, 5. *Valvulineria rugosa*, 6. *Ammodiscus glabratus*, 7. *Valvulineria jacksonensis*.

The works of Jr., Loeblich, Tappan and Blow, [17–19] served as a guide for the foraminiferal zonation of Owan-1 Well. The following significant foraminifera bio-events are taken into consideration:

i. FDO of Planktic/Benthic foraminifera species that are important for chronostratigraphy such as *Acarinina nitida*, *Lenticulina subovata*, *Ammonia beccarii*, *Nummulites gizehensis*, *Globigerinatheka semiinvoluta* [17–19].

ii. The marker species for planktic and benthos foraminifera last downhole occurrence (LDO) such *Acarinina wilcoxensis*, *Globigerina venezuelana*, *Nummulites fabianii*, *Lenticulina laevigata* [17–19] .

iii. Foraminifera markers, which are species with well-established stratigraphic ranges in the Niger Delta and around the world, are used to date peaks in foraminifera abundance and variety such as *Acarinina species* (e.g, *Acarinina primitiva*), *Nummulites species* (e.g., *Nummulites gizehensis*),*Lenticulina species* (e.g., *Lenticulina subovata* etc. [17–19].

The single occurrence of *Lenticulina grandis* and *Ammodiscus glabratus* at 66 and 67 meters suggests that the examined interval (23 – 456 meters) was deposited during the Middle Eocene Epoch, according to the analysis's findings of Refs. [18–20]

4.2.2. Palynological biostratigraphy

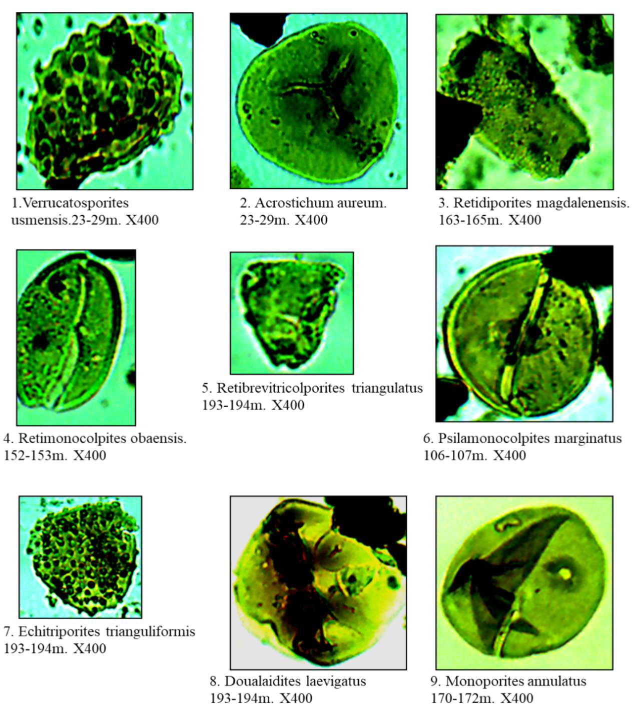

Figure 4. Photomicrography of recovered palynomorphs from Owan-1 Well.

Palynomorphs are highly useful for biostratigraphic and palaeoecological investigations due to their frequent presence in a variety of environments and their ability to evolve quickly [8]. The results of the palynological analysis carried out on the shale samples of the Owan-1 well (23 - 217 m) where abundant and diverse palynomorphs were recovered from the samples were discussed below. The palynomorphs were quantitatively dominated by land-derived species such as *Verrucatosporites usmensis*, *Monocolpites sp.*, and *Monoporites annulatus* (Figure 4).

Two palynological zones were established:

ZONE B

Characteristics: this zone is based on the first downhole occurrence (FDO) or top occurrence of *Psilamonocolpites marginatus* at 106 – 107 m and the quantitative base occurrence of *Verrutricolporites usmensis* / abundant *Retimonocolpites obaensis* at 166 – 167 m corresponds to P470 Pollen Zone of the Niger Delta Chronostratigraphic Chart indicating deposition during Middle Eocene Epoch (Figure 5).

ZONE A

Characteristics: this zone is based on the quantitative base occurrence of *Verrutricolporites usmensis* / abundant *Retimonocolpites obaensis* at 166 – 167 m and abundant occurrence of *Echitriporites trianguliformis* / occurrence of *Doualaidites laevigatus* at 193 – 194 m corresponds to P450 Pollen Zone of the Niger Delta Chronostratigraphic Chart indicating deposition during Middle Eocene Epoch (Figure 5). Hence, both foraminifera and palynological biostratigraphy reveal that the sediments in the Owan-1 Well were deposited during the Middle Miocene Epoch of the estimated numerical age of 42.7 Ma to 38.7 Ma.

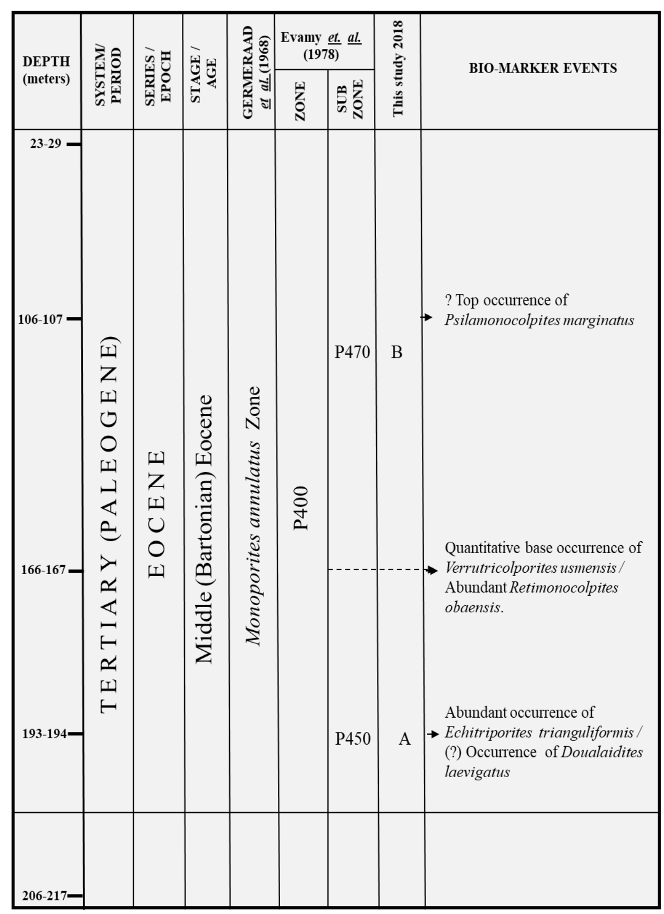

Figure 5. Palynological zones identified in the Owan-1 Well (23 – 212 m).

4.3. Paleoenvironmental analysis

Interpretation of the paleodepositional environment of the studied wells was made based on the integration of lithologic description and biofacies information interpreted from the qualitative and quantitative evaluation of the benthic foraminifera and palynomorph assemblages.

4.3.1. Foraminifera paleoenvironmental reconstruction

The presence of rare foraminifera species at some depths consisting of rare benthic foraminifera species and the absence of planktic foraminifera species indicate deposition in shallow water environments [21] Foraminifera assemblage is characterized by *Anomalinoides alazanensis*, *Lenticulina grandis*, *Ammodiscus glabratus*, *Valvulineria rugosa*, *Valvulineria jacksonensis*, species of *Anomalina*, *Cibicides*, and *Verneuilina* suggesting sediments deposition in inner neritic environmental settings with middle neritic influence corresponding to shallow to deep marine environments [20]. *Anomalinoides alazanensis* and *Valvulineria rugosa* thrive in shallow marine environments, often associated with deltaic or shelf settings [4]. *Ammodiscus glabratus* -an agglutinated benthic foraminifera- suggests deposition in low-oxygen, marginal marine to outer shelf environments, where organic-rich sediments are common [20].

Lenticulina grandis typically found in deeper shelf to slope environments, suggesting a transition to more open marine conditions [4]. Cibicides and Verneuilina species are common in both inner to middle shelf environments, where oxygen levels are moderate to high [20, 21].

Hence, the foraminifera assemblage suggests that the Owan-1 Well sediments were deposited in a shallow to middle shelf environment, influenced by a deltaic system transitioning to open marine conditions [20]. The co-occurrence of agglutinated and *calcareous foraminifera* indicates fluctuating oxygen levels, possibly due to periodic influxes of organic matter and sediment from the Niger Delta [6]. The presence of species like *Ammodiscus glabratus* implies some deposition in marginal marine settings with restricted circulation, while species like *Lenticulina grandis* point to intervals of deeper, better-oxygenated conditions [6, 9].

4.3.2. Palynological paleoclimate and paleoenvironmental reconstruction

Understanding the ecological characteristics of the parent plants of fossil palynomorphs was employed to aid in the identification of temporal variations in ecology and climate. The environment of deposition and climate are the primary factors that shape lithofacies as well as the composition and diversity of palynofloras [8]. The vegetation of any province is primarily influenced by the geological characteristics of the area and the prevailing climatic conditions [22]. Hence, climate exerts a significant impact on the main regulation of vegetation. The presence of mangrove swamp species (such as *Acrostichum aureum*, *Zonocostites ramonae*, *Psilatricolporites crassus*) and savanna species (e.g Monoporites annulatus) (Figure 4) are indicative of coastal plain environment [23, 24].

Ige [22] Suggested that *Acrostichum aureum* was adapted to mangrove vegetation, especially areas prone to frequent saline water inundation, including open salt marshes, estuaries, and coastal swamps while Ogbahon [8] suggested that the presence of *Monoporites annulatus* indicates the prevalence of open vegetation and development of extensive grassland in a generally dry climate with marked rainy seasons. Similarly, the presence of brackish water swamp species such as *Brevicolporites guinetii*, *Polypodiaceoisporites sp*, *Laevigatosporites sp*, *Retitricolporites irregularis*, and *Striatricolpites catatumbus* is indicative of transitional settings, especially deltaic environment. Also, the association of freshwater swamp species like *Cyathidites sp*, Fungal spores and hyphae, *Polypodiaceoisporites sp*, *Verrucatosporites sp*, and *Verrucatosporites usmensis* (Figures 4) suggest deltaic depositional environments. The fungal spores indicate a shallow marine condition of deposition for the Owan-1 Well sediments [24].

However, the presence of freshwater algae such as *Botryococus braunii* and main marine-loving dinoflagellates like *Leiosphaeridia sp* and *Spiniferites* suggest the influence of freshwater incursion into the marine, thereby giving marginal marine sedimentation [23]. In conjunction with marine elements like Spiniferites, the interval containing a high concentration of mangrove elements —*Zonocostites ramonae*, *Acrostichum aureum*, and *Psilatricolporites crassus* (Figure 4) —likely indicated deposition in open salt marshes, brackish lagoons, or nearshore to the inner neritic environment [8]. Mangrove species including *Zonocostites ramonae*, *Acrostichum aureum*, and *Psilatricolporites crassus* are also abundantly found during periods with copious records of pollen, spores, freshwater and brackish water species, such as *Laevigatosporites sp*. and *Verrucatosporites usmensis*. This most likely pointed to sedimentation in riverine environments, such as marshes [8]. It is therefore convenient to propose that the Owan-1 Well sediments were deposited in marginal marine and shallow marine depositional environments that approximate littoral to inner neritic, with some influence from freshwater incursion.

5. Conclusion

The sedimentological analysis revealed that the studied well dominantly consists of shale. Generally, planktic foraminifera are absent in the studiedinterval while benthic foraminifera are poorly recovered with a total of eight (8) species comprises seven (7) calcareous and one (1) arenaceous representing 88 % and 12 % respectively. The palynomorphs recovered were dominantly terrestrial-derived species such as *Verrucatosporites usmensis*, *Monocolpites sp.*, and *Monoporites annulatus*. The biostratigraphic interpretation of results reveal that the studied interval was deposited during the Middle Eocene Epoch corresponding to P470 and P450 Pollen Zonation of the estimated numerical age of 42.7 Ma to 38.7 Ma. Hence, the integration of sedimentological, foraminifera and palynological data reveals that the sediments penetrated by the Owan-1 Well were deposited in littoral, inner, and middle neritic within marginal to shallow and deep marine environments.

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