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Palynofacies Analyses of HA-001 well, Offshore Depobelt, Niger Delta Basin, Nigeria

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ABSTRACT

Palynofacies studies of the strata penetrated by HA-001 well were carried out with the aim to establish palynostratigraphic zones and paleodepositional environments. The standard acid palynological method of sample administration was employed to recover the palynofacies, soaking and washing of samples with water for sedimentological analyses and integration of Gamma Ray Log, palynofacies and sedimentological data for interpretation of paleodepositional environments. The study established two new assemblage biozones namely *Cyperaceaepollis* sp. – *Nympheaepollis clarus*, and *Stereisporites* sp. within the sedimentary intervals penetrated in the wells. The *Cyperaceaepollis* sp. – *Nympheaepollis clarus* biozones were further subdivided into *Nympheaepollis clarus* – *Echitriletes pliocenicus and Cyperaceaepollis* sp. – *Elaeis guineensis* subzones. The Late Miocene age is associated with the biozones. The lithologic, textural and wireline log data indicated that the intervals studied in the HA-001 well belong to the Benin Formation and Agbada Formation. Index minerals and accessories are dominated by ferruginous materials, glauconite pellets, carbonaceous detritus, shell fragments and pyrites plus minor mica flakes. Lower delta plain, delta front and prodelta environment of deposition were inferred for the studied well intervals. The research has conformed to international stratigraphic guide for establishment of biozones which serves to increase the knowledge of high resolution biostratigraphy.

1. INTRODUCTION

The onshore Niger Delta Basin has become mature and its exploration has shifted to offshore. The integration of various geological methods such as palynological, palynofacies, paleoenvironmental analyses are needed for the understanding of the subsurface geology and development of its hydrocarbon potentials. The abundance of forms of pollen and spores can be used to determine biostratigraphic sequences and make paleoenvironmental reconstructions.

Industry workers in the Niger Delta Basin have relied on usage of alpha-numeric method for biozonation purposes while some researchers have also used the same method to establish their biozones [1-4]. Hence, standardised biozonation scheme which is in line with the international stratigraphic guideline for the establishment of biozones is necessary.

Some researchers made use of only palynomorphs to analyse paleoenvironment of deposition in the Niger Delta Basin [5-11] explained the usage of palynofacies in analysing paleoenvironment of deposition. Research works on palynomorphs and palynofacies for paleoenvironmental analysis are quite limited. Published works on the integration of pollen and spores' biostratigraphy and biozonation, palynofacies and sedimentology of the Tertiary Niger Delta Basin are scarce to few.

The study attempts a classification of biostratigraphic zones using internationally accepted standard guidelines while incorporating palynofacies and sedimentological data with those of wireline in order to achieve a proper stratigraphic sequence in HA-001 well in the Niger Delta Basin. Research works on biostratigraphy of the prolific Niger Delta Basin are still ongoing. Palynostratigraphic zones should be established in conformity with international stratigraphic guide. This will enable generation of standard biozonation schemes in the Niger Delta Basin.

This research work has contributed to knowledge by successfully utilising the stratigraphic ranges of the recovered pollen and spores marker species to date the strata penetrated by the well and it has established palynostratigraphic biozones that conform to international stratigraphic guide for establishment of biozone. The work has also been able to integrate palynofacies data, sedimentological and Gamma Ray log data to delineate paleodepositional environment of the stratigraphic successions penetrated by the well.

The subsequent part of this paper is as follows: Section two discusses the Geology of Niger Delta Basin, section three describes the materials and methods of the research which are employed in achieving the aim of the work. Section four and five highlights the results and conclusion of the work.

2. GEOLOGY OF NIGER DELTA BASIN

HA-001 well lies within latitude 4º 09' 10.9" N and longitude 6º 14' 1.8" E within the shallow offshore depobelt, Niger Delta, Nigeria. The location of the well is shown in Figure 1. The Niger Delta covers a landmass over 105,000 km^2 [12] and falls within longitudes 3° and 9° E and latitudes 4° and 6° N [13]. The recognized sequence in the Niger Delta Basin consists, in ascending order, of the Akata, Agbada, and Benin Formations.

The prodeltaic shales of Akata Formation are medium to dark grey, fairly, or at some places soft, gumbolike, and sandy or silty. The shales are less closely and firmly united or packed together and may include lenses of unusually high-pressured siltstone or fine-grained sandstone.

The Agbada Formation is made up of an irregular sequence of sandstones and shales of delta-front, distributary channel, and deltaic plain origin. The irregular string of sandstones and shales of the Agbada Formation has been revealed by [14] to be a cyclical sequence of marine and fluvial deposits.

The Benin Formation is mainly huge, very porous, freshwater–bearing sandstones, with local thin shale interbeds, which are rated to be of braided-stream origin. Mineralogically, the sandstones are made up dominantly of quartz and potash feldspar and a negligible quantity of plagioclase. The sandstones make up 70 to 100% of the formation.

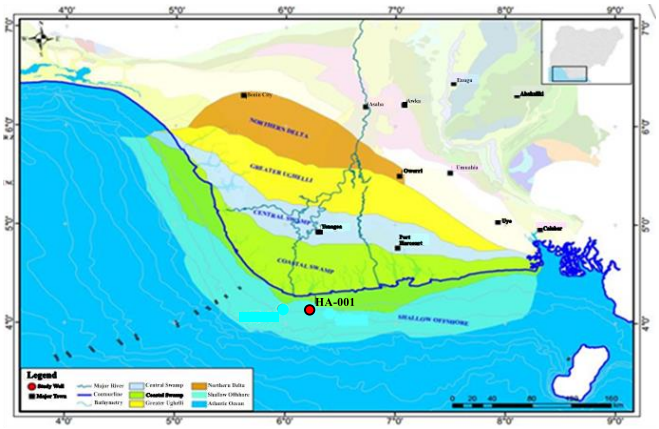


Figure 1. Location map of the study area within the shallow offshore depobelt of the Niger Delta (Modified from the study [15])

3. MATERIALS AND METHODS

Shell Production Development Company, Nigeria provided the ditch cuttings and wireline logs of the studied well. The processing and analyses of the sample were carried out at Crystal Age Limited, Lagos, Nigeria. The lithologic description was carried out by the examination of the samples. Shaly samples were denoted to be fissile while sandstone units are fine to coarse grain sizes. The lithologic description was aided by the Gamma Ray log because high and low values of Gamma-Ray indicate shale and sandstone lithologies respectively [4].

The standard acid palynological sample administration of particulate organic matter recovery was employed. Ten grams of each sample were treated with thirty milliliters of 10% and 40% of HCl and HF successively to remove carbonate and inorganic silicate. The samples were subsequently rinsed with distilled water and sieved using 5 and 10 µm mesh sieves. The remaining silicate clay and mud were filtered away using an electric device known as a digital sonifier. The sample residues were oxidized by thirty milliliters of 60% HNO_3. The samples for palynofacies analyses were not oxidized to avoid bleaching. The samples were placed on a coverslip on the hot plate and left to dry. The coverslip was then placed on a labeled glass slide with a few drops of Canada balsam used as the mounting medium. The glass slide was then left to dry.

Observation and identification of palynomorphs and palynofacies were carried out under a light transmitted Olympus CX41 microscope using magnifications of x25 and x40 with relevant literature for description based on size, shape, structure, aperture, and sculpture [16-26].

4. RESULTS AND DISCUSSIONS

4.1 Lithology

The lithology is made up of predominantly sands with occasional shale intercalation. Sands are predominantly quartzose, slightly feldspathic, occasionally coarse to very coarse-grained in the upper part of the well. The lower part of the well is a heterogeneous sequence of alternating sand and shale/silt units. These indicate that the entire intervals studied in HA-001 well essentially show Benin and Agbada Formations.

4.2 Palynology

The result of palynofacies analyses is shown in Figure 2. The palynomorphs recovered include abundant land-derived forms including *Zonocostites ramonae, Monoporites annulatus, Sapotaceoidaepollenites* sp., *Laevigatosporites* sp., *Achrostichum aureum, Verrucatosporites* sp., *Polypodiaceiosporites* sp., and charred gramineae cuticle. Moderate quantities of *Pachydermites diederixi, Psilatricolporites crassus, Retitricolporites irregularis* and *Nympheaepollis clarus* were also recorded. Abundant freshwater algae, *Botryococcus braunii* were also recorded. Dinoflagellate cysts were not encountered in this well. The palynofacies recovered are palynomaceral 1 and 2 of large sizes with few to common occurrences of palynomaceral 3 and 4. Photomicrographs of some recovered palynomorphs and palynomacerals are shown in Figure 3.

4.3 Palynomacerals

The well generated few to an abundant amount of organic matter. There is a high recovery of palynomaceral 1 and 2 with palynomaeral 3 and 4 yielding low recoveries (Figures 2 and 3).

4.3.1 Palynomaceral 1 (PM 1)

The palynomaceral 1 (Alganite) recovered from this study consists of orange-brown to dark brown structured and structureless material, irregular shape, varied preservation state, and dense appearance. It includes structured plant debris, humic gel-like, and resinous substances, and algal detritus.

4.3.2 Palynomaceral 2 (PM 2)

Palynomaceral 2 (Exinite) from this study consists of brown-orange structured material of irregular shape and structured plant material, algal detritus, and reduced humic gels and resinous substances. Its buoyancy is more than that of palynomaceral 1 due to its thinner lath shape.

4.3.3 Palynomaceral 3 (PM 3)

The recovered palynomaceral 3 (Vitrinite) is pale, relatively thin, irregular shaped, and usually structured material. It has structured plant material and is of curricular origin with degraded aqueous plant material.

4.3.4 Palynomaceral 4 (PM 4)

Palynomaceral 4 (Inertinite) recovered from this study is made up of black or almost black equidimensional or blade-shaped material that is generally uniformly opaque and structureless. It encompasses compressed humic gels, charcoal, and geothermally fusinized material.

4.4 Palynostratigraphic zonations and biochronology of HA-001

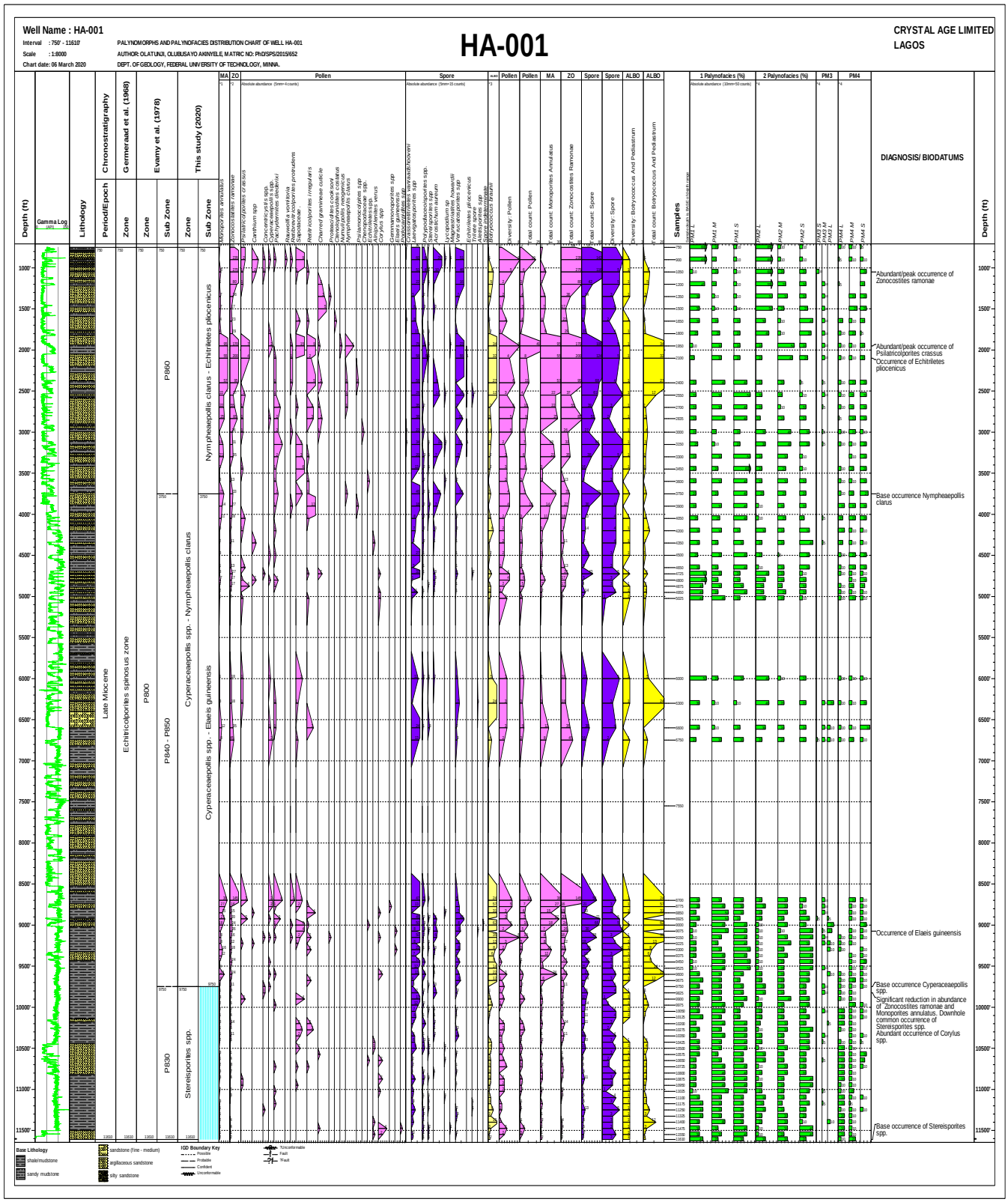


Figure 2. Palynomorphs and palynofacies distribution chart of HA-001 well

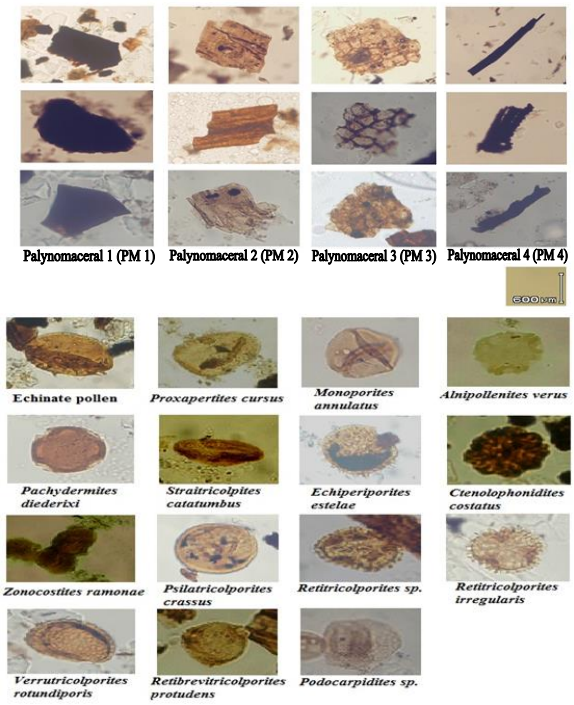


Figure 3. Palynomaceral types recovered from HA-001 well

The age succession established for the HA-001 well (750-11510 ft) was achieved using the palynoflora assemblages of marker and associate marker species assemblages recognized in the well. This aided in erecting two (2) assemblage biozones and two (2) subzones based on published works of Evamy et al. [1, 16, 27]. The palynomorphs recorded include abundant land-derived forms including *Zonocostites ramonae, Monoporites annulatus, Sapotaceoidaepollenites* sp., *Laevigatosporites* sp., *Achrostichum aureum, Verrucatosporites* sp., *Polypodiaceiosporites* sp., and charred gramineae cuticle. Moderate quantities of *Pachydermites diederixi, Psilatricolporites crassus, Retitricolporites irregularis* and *Nympheaepollis clarus* were also recorded. Abundant freshwater algae, *Botryococcus braunii* were also recorded. Dinoflagellate cysts were not encountered in this well.

Two (2) assemblage biozones were recognized in the study namely the *Cyperaceaepollis* sp. – *Nympheaepollis clarus* assemblage zone (750-9750 ft) and the *Stereisporites* sp. assemblage zone (9750-11610 ft). These were further divided into two (2) subzones namely; *Nympheaepollis–Echitriletes pliocenicus* subzone (750-3750 ft) and *Cyperaceaepollis-Elaeis guineensis* subzone (3750-9750 ft). These assemblage biozones were correlated with the *Echitricolporites spinosus* palynological zones of the study [16] and the P860, P850-P840 and P830 palynological subzones of the study [1]. Thus, a Late Miocene age is interpreted for the HA-001 well (750-11610 ft). Details of the biozones were discussed below.

***Cyperaceaepollis* sp - *Nympheaepollis clarus* Assemblage Zone**

Depth: 750-9750 ft

Age: Late Miocene

Comparable palynological zone: *Echitricolporites spinosus* zone of the study [16], P860 and P850-P840 palynological subzones of the study [1]. This biozone is characterized by the palynoflora assemblage of marker species such as *Cyperaceaepollis* sp., *Nympheaepollis clarus*, *Echitriletes pliocenicus,* and *Elaeis guineensis*. The stratigraphic significant range of key marker species *Cyperaceaepollis* sp. and *Nympheaepollis clarus* lie within this assemblage zone. The occurrence of *Cyperaceaepollis* sp., at the 900 ft of the well suggests that it's at the top of the zone and is stratigraphically higher than the first sample analyzed at 750 ft.

The lower limit is defined by the base occurrence of *Cyperaceaepollis* sp. marked at 9750 ft. This zone is further characterised by the abundant occurrences of *Zonocostites ramonae, Monoporites annulatus, Laevigatosporites* sp., *Pachydermites diederixi* and *Psilatricolporites crassus*. Two (2) subzones are recognized within this assemblage zone and discussed below:

***Nympheaepollis clarus - Echitriletes pliocenicus* subzone**

Depth: 750-3750 ft

Age: Late Miocene (Messinian-Tortonian)

This is the youngest subzone recognized in the study and as such the top of this subzone is probably higher than the first sample analyzed. The base of the subzone is defined by the base occurrence of *Nympheaepollis clarus* identified at 3750 ft.

The *Nympheaepollis clarus* subzone is further characterized by the abundant occurrence of *Zonocostites ramonae, Verrucatosporites* sp., and *Retitricolporites irregularis,* the rare occurrence of *Numulipollis neogenicus,* fairly abundant *Monoporites annulatus* and common occurrence of *Sapotaceae* and *Nympheaepollis clarus.*

This subzone correlates with the *Echitricolporites spinosus* palynological zone of the study [16], the P860 subzone of the study [1], and the palynological zone of the study [4].

***Cyperaceaepollis* sp. - *Elaeis guineensis* subzone**

Depth: 3750-9750 ft.

Age: Late Miocene (Tortonian)

The top of this subzone is marked by the base occurrence of *Nympheaepollis clarus* at 3750 ft. The base is marked by the base occurrence of *Cyperaceaepollis* sp. defined at 9750 ft.

The occurrence of *Elaeis guineensis*, the rare occurrence of *Aletesporites* sp. and *Retibrevitricolporites obodoensis*, reduced abundance of *Verrucatosporites* sp., and rare occurrence of *Acrostichum aureum* also characterized this subzone. This subzone correlates with the *Echitricolporites spinosus* palynological zone of the study [16] and the P850-P840 (undifferentiated) subzone of the study [1].

***Stereisporites* sp. Assemblage Zone**

Depth: 9750-11610 ft

Age: Late Miocene (Tortonian)

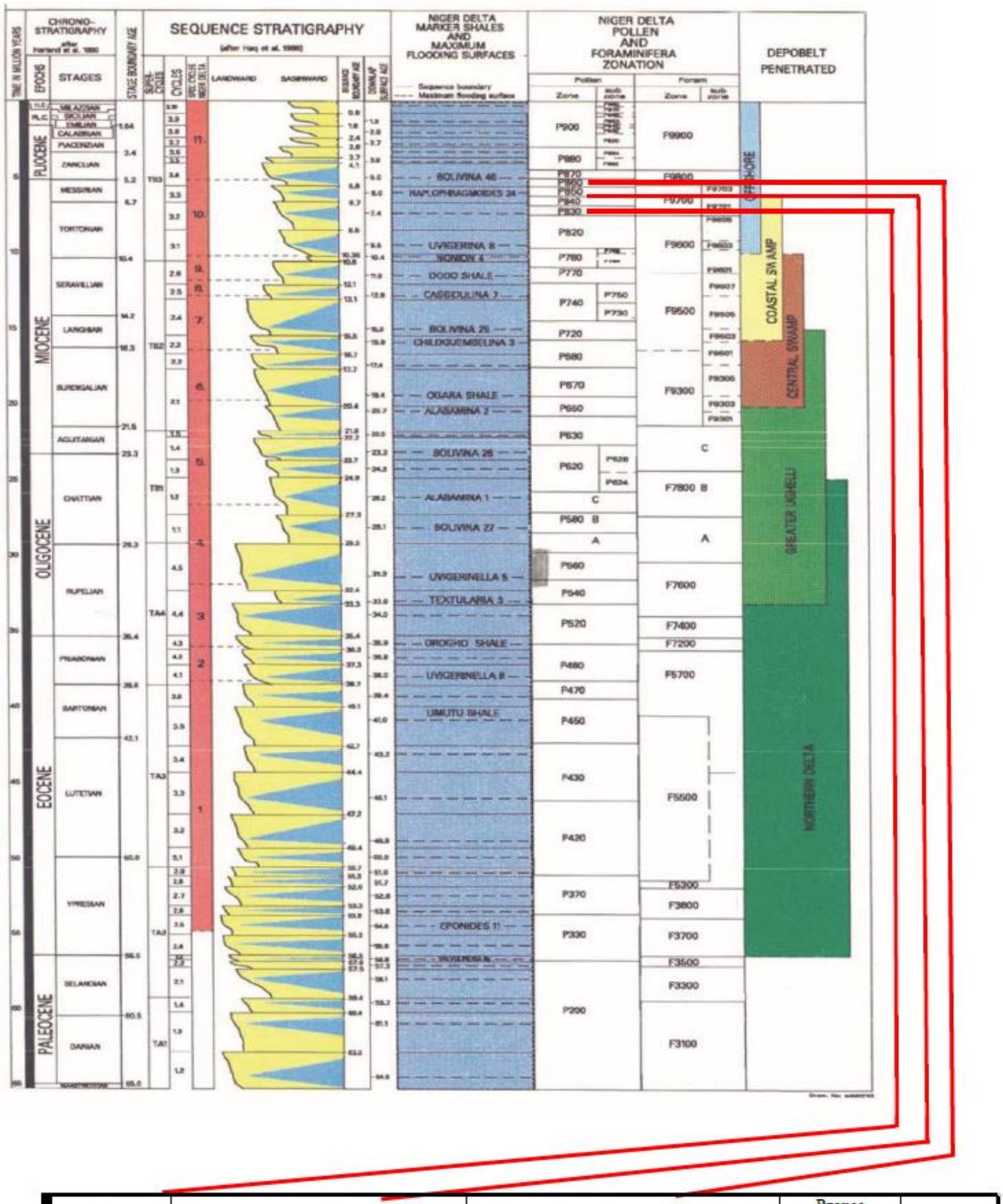
This zone has been correlated with the *Echitricolporites spinosus* zone of the study [16], the P830 palynological subzones of the study [1]. This Assemblage zone is characterized by the occurrences of marker species such as *Stereisporites* sp., *Corylus* sp., low records of *Pachydermites diederixi,* and *Canthiumidites* sp.

The top of the zone is marked at 9750 ft by the base occurrence of *Cyperaceaepollis* sp., while the base occurrence of *Stereisporites* sp. which marks the base of the zone was recognized at the last sample analyzed.

4.5 Correlation of the established palynostratigraphic zones with the Niger Delta Cenozoic chart

The biozones established in the study and their equivalent P zones of the study [1] are correlated with Niger Delta Cenozoic chronostratigraphic chart (Figure 4). The correlation shows the studied well is located in the Coastal Swamp to Shallow Offshore Depobelt. Late Miocene (Tortonian –

Messinian) age is assigned to the studied well intervals.



P830	P840/P850	P860	Pzones Evamy *et al.* (1978)	This Study 2020
	Cyperaceaepollis sp. - *Elaeis guineensis*	*Nympheaepollis clarus* - *Echitriletes pliocenicus*	Subzones	
Stereisporites sp.	*Cyperaceaepollis* sp. - *Nympheaepollis clarus*		HA-001 Well	
LATE MIOCENE				Period/Epoch

Figure 4. Age correlation of the established palynostratigraphic zones in HA-001 well with the Niger Delta Cenozoic chronostratigraphic chart.

4.6 Paleoenvironment of Deposition

The paleoenvironment of deposition is used to describe the periodic changes in the depositional environment over geologic time. The knowledge of various depositional environments and their reservoirs' properties such as porosity, permeability, and architecture are aided by the interpretation of the paleodepositional environment. Deductions of the paleodepositional environment of the studied well were inferred based on the following criteria:

1. Quantitative variations of the palyno-ecological groups of the studied palynomorphs such as *Zonocostites ramonae, Psilatricolporites crassus, Monoporites annulatus, Cyperaceaepollis* sp., *Pachydermites diederixi* and *Botryococuss braunii*.
2. The palynomaceral type recovered from the studied samples: The coastal and marine depositional environments are categorized to possess unique characteristics of palynofacies [5]. The coastal environments are distinguished by poorly sorted palynomacerals 1 and 2, common to rich occurrences of fungal spores and the absence of dinocysts. The marine environment is recognized by small to medium organic matter that is well sorted, common to abundant palynomaceral 1 and 2, some needle-shaped to lath-shaped palynomaceral 4, and the presence of foraminiferal linings and dinocysts.

Table 1. The environment of deposition of HA-001 well

HA-001 WELL intervals (ft.)	An inferred environment of deposition
750-5,000	Delta Plain (Lower Delts Plain)
5,000-8,800	Subaqueous Delta Plain (Delta Front)
8,800-11,610	Subaqueous Delta Plain (Delta Front to Prodelta)

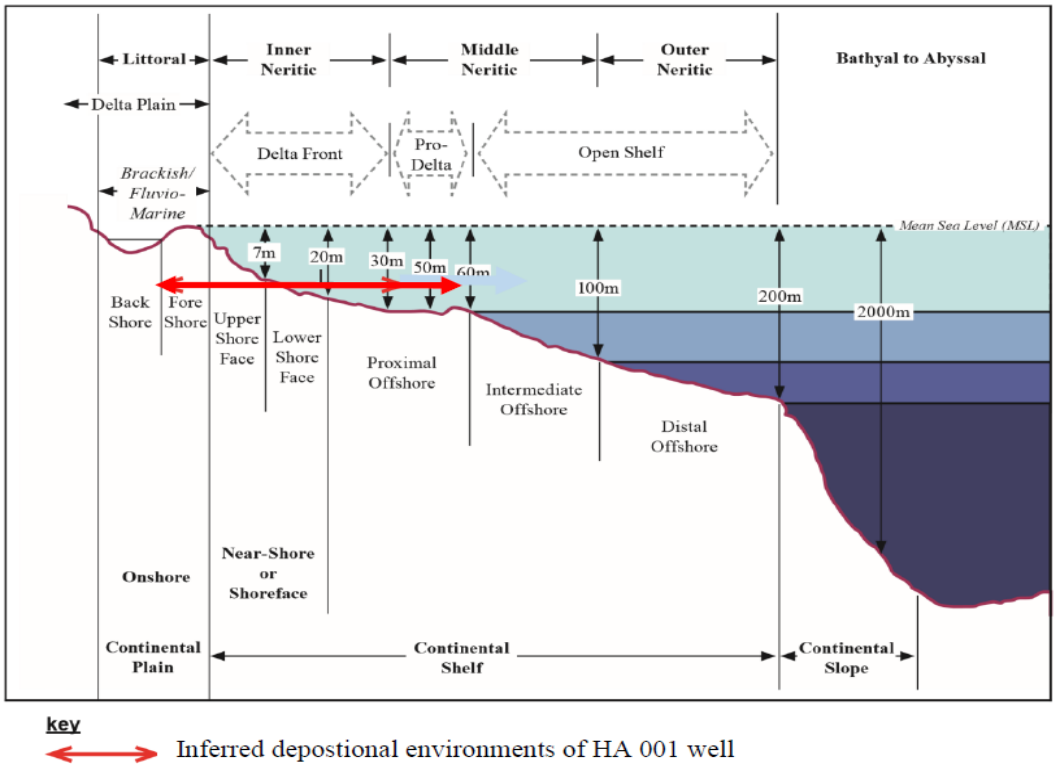


Figure 5. Depositional Environments and Bathymetric Ranges used in Paleoenvironmental Interpretations (Modified after the study [28])

Lower delta plain to delta front and prodelta environment within coastal deltaic to shallow marine environment of deposition were inferred for the studied intervals of HA-001 well (Table 1 and Figure 5)

The intervals 750–5000 ft in the HA-001 well were interpreted to be deposited in the lower delta plain environment. The criteria for interpretation are:

1. The intervals are characterized by the increased occurrence of freshwater swamp taxa, followed by mangrove, savanna, and rainforest swamp taxa and reduced presence of montane taxa [4, 29]. *Zonocostites ramonae*, *Retitricolporites irregularis, Sapotaceoidaepollenites* sp., *Psilatricolporites crassus, Laevigatosporites* sp., *Verrucatosporites* sp., and *Acrostichum ahereum* are the examples of the taxa recorded. Abundant freshwater algae *Botryococcus brunii* was also recorded during this interval which is indicative of a high influx of freshwater.
2. Common to abundant occurrences of poorly sorted, small to large palynomacerals I and II with small to common occurrences of poorly sorted, small to medium-sized PM III and IV [5] and
3. The sands exhibit cylinder and funnel-shaped Gamma-ray log motifs suggesting distributary channel and distributary mouth bar deposits of the lower deltaic plain [30].

The intervals 5000-8800 ft in HA-001 well respectively were interpreted to have been deposited in the delta front environment of deposition. The reasons for these deductions are:

1. The intervals consist of abundant freshwater swamp and mangrove swamp taxa with increased occurrence of

savanna taxa. There is a little representation of rainforest swamp and montane taxa. Examples of taxa recovered in the intervals are *Zonocostites ramonae, Monoporites annulatus, Psilatrocolporites crassus, Retribrevitricolporites protrudens, Sapotaceoidae pollenites,* and abundant freshwater algae *Botryococcus braunii*.

2. Common to moderate occurrences of poorly sorted, small to large palynomacerals I and II with few palynomacerals III and IV [5]; and
3. The log characters of the intervals are essentially funneled, cylinder, and minor bell-shaped motifs suggesting deposition in the delta front varying from barrier bars, distributary channels, and tidal channels [30, 31]. The shale is grey, dark grey to brownish grey, platy to flaggy, occasionally blocky, and moderately hard.

The intervals 8800–11610 ft are the lowermost parts of the HA-001 well were delineated to be deposited in the delta front to prodelta environment of deposition. The criteria for this inference are:

1. There is a high occurrence of freshwater swamp and mangrove swamp taxa in the intervals with increased occurrence of rainforest swamp taxa. There is a reduction in the presence of savanna and montane taxa indicating proximal offshore [4, 29].
2. Common to abundant moderately sorted, small to large, palynomacerals I and II with common palynomacerals IV [5].
3. Log characters of the sand suggest that the multiserrate upward coarsening, cylinder, and fining upward profiles are barrier bars, subaqueous channel, and tidal channel deposits. The sediments of those intervals are laid down in coastal deltaic to inner shelf environments.

5. CONCLUSIONS

Palynofacies analyses were carried out within the sedimentary intervals penetrated by the HA-001 well. Shell Production and Development Company, Nigeria provided the ditch cuttings and Gamma-Ray Log for the analyses.

Seventy-six ditch cutting samples within the depth intervals of 750–11610 ft were analyzed in the well. Large-sized palynomaceral 1 and 2 with few occurrences of palynomaeceral 3 and 4 were recovered from the analyses. The well is moderately abundant and fairly diverse in pollen, spores, and freshwater algae.

The lithology is made up of alternating sand and shale units which suggests rapid shoreline progradation. The grain size increases from essentially fine to medium-grained, occasionally coarse to granule-sized at the basal part of the well, to dominantly coarse to pebble-sized, occasionally medium to fine-grained at the upper part. The sands are mostly sub-angular to rounded and generally poorly to well sorted. The lower part consists of sands with brownish-grey to dark grey, silty platy to flaggy, occasionally blocky moderately hard to hard shales indicating Benin and Agbada Formations.

The Late Miocene is associated with the studied intervals based on the recovery of *Elaeis guineensis, Acrostichum aurem, Corylus* sp*., Pachydermites diederixi,* and *Psilatricolporites crassus*. Two new assemblage biozones namely *Cyperaceaepollis* sp. – *Nympheaepollis clarus* and *Stereisporites* sp. were established within the sedimentary intervals penetrated in the well using the International Stratigraphic Guide of establishing biozones.

The correlation of the P Zones of the study [1] with the Niger Delta chronostratigraphic chart reveals Coastal Swamp to Shallow Offshore Depobelt of the Niger Delta. This could further increase the knowledge of palynofloral biozonation in the Niger Delta. Coastal deltaic palaeodepositional environments were inferred for the studied stratigraphic intervals based on lithology and palynofacies association.

It is recommended that acquisition of side wall core be utilised as a routine procedure for well analyses for biostratigraphic researches. Due to the occasional discrepancies between ditch cutting samples and logs, such that the sample may not be representative of the lithology as indicated by the logs.

It is also recommended that further studies be integrated with side wall or core samples rather than ditch cutting samples because they are less affected by contamination due to caving in the strata and drilling mud. Although core samples are costly, they are the most ideal representative of paleodepositional conditions. Sedimentary structures, fossils and trace fossils in the sediment are well preserved in core samples.

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