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Palynostratigraphy and Lithostratigraphy of Ha-001 Well, Shallow Offshore, Western Niger Delta, Nigeria

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Abstract

The sedimentary intervals from HA-001 well have been analyzed for palynological and sedimentological studies with the aim of generating biozonation, maturation and paleoenvironmental results. Seventy-six ditch cutting samples within the depth intervals of 750 -11610 ft were analyzed. There were few to common recoveries of sporomorphs. Sedimentological inferences were derived from the integration of wire line logs, lithologic characteristic and distribution of index accessory minerals which include ferruginous materials, glauconite, pellets, carbonaceous detritus, shell fragments and pyrites plus minor mica flakes. The lithofacies sequences that characterise the HA-001 well intervals include alternating sand and shale units which suggest rapid shoreline progradation deposited in coastal deltaic to shallow marine settings. The entire interval essentially tested the Benin and the Agbada Formation. The grain increases essentially from 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. Two (2) palynostratigraphic zones of *Cyperaceaepollis* sp. - *Nympheaepollis clarus*, and *Stereisporiles* sp. were established for the well using the International Stratigraphic Guide. The two (2) zones are assemblage range biozones and Late Miocene age was assigned to the interval based on the stratigraphic age range of diagnostic markers such as *Psilatricolporites crassus*, *Echitriletes pliocenicus*, *Elaeis guineensis*, *Corylus* sp. and *Zonocostites ramonae.* Thermal maturity on the basis pollen and spores colours indicated maturity to late degree of maturation.

***Keywords**: Sporomorphs; Lithofacies; Formation; Biozone and Maturation.*

1. Introduction

The demands for petroleum worldwide have been steady over the years if not increasing. Hence, the integration of various geological methods such as palynological, sedimentological and paleoenvironmental analyses are needed for the development of hydrocarbon exploration in the offshore Niger delta. The occurrence of hydrocarbon in Niger delta basin has increased the interest of many researchers in the geologic structure as well as petroleum aspects of the basin. The discovery of commercial deposits of hydrocarbon in 1956 began the establishment of the Niger delta as a world-class petroleum province [1]. The science of petroleum exploration and production is multi-disciplinary with each discipline complementing the other. One of these disciplines is palynology. Palynology is a term coined by [2] and was derived from the Greek word, Palynein which means, "to sprinkle, to spread around". Thus, there is need for intensive research of Niger Delta Basin in order to have the understanding of the stacking pattern of the lithofacies and geologic ages respectively

The aim of this work is to carry out palynological and lithofacies analyses of the strata penetrated by HA-001 well in order to produce the palynostratigraphic zonation using the international stratigraphic procedures as well as assigning ages, inferring the paleoenvironment of deposition and determining the maturation of the well interval for the purpose of hydrocarbon exploration.

2. Study area

The study area lies within the Niger delta basin. HA-001 well lie within latitude 4º 09' 10.9" N and longitudes 6º 14' 1.8" E within the shallow offshore area, western Niger delta, Nigeria. The names of the wells have been coded by Shell Production and Development Company due to proprietary reasons. The location of the wells is shown in Figure 1.

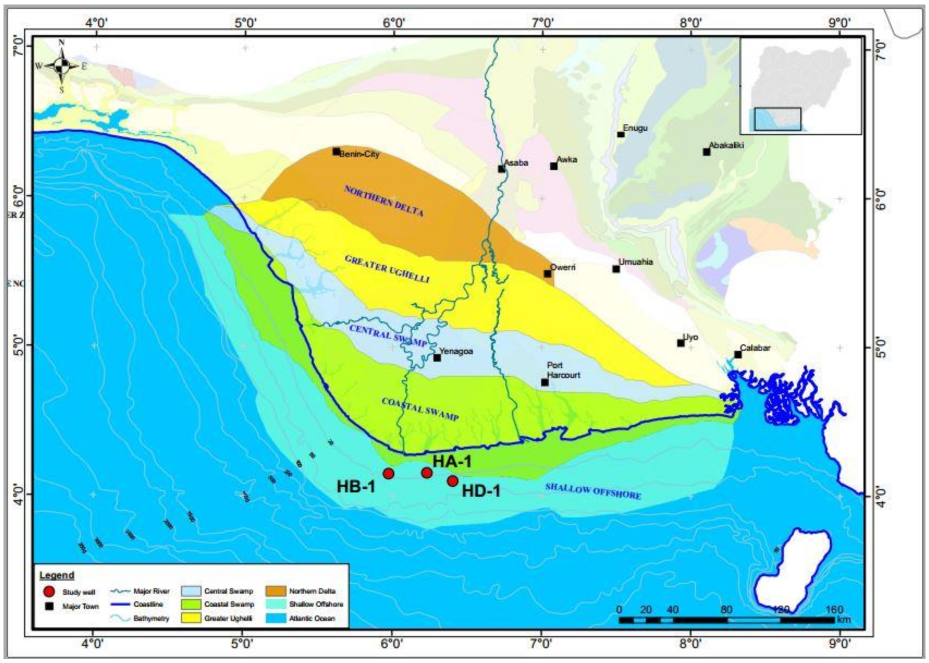

Figure 1. Location of H-wells, shallow offshore depobelt, Niger Delta, Nigeria (modified from [3-4]).

2.1. Geology of Niger delta

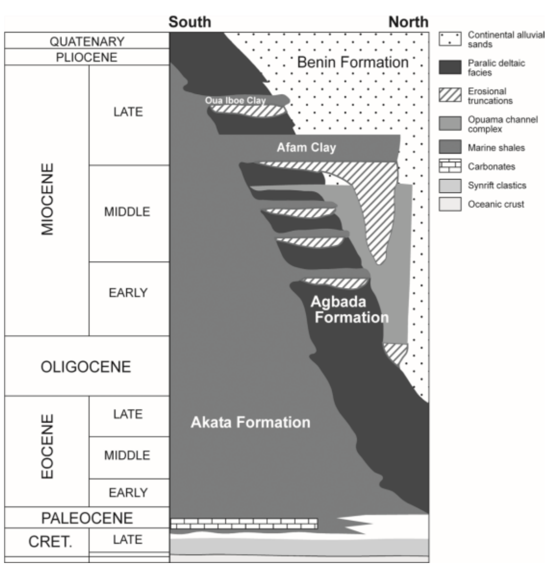

Figure 2. Stratigraphy of the Formations of the Niger Delta [12]

From the viewpoint of size and thickness of sediments, the Niger delta is the most important sedimentary basin in Nigeria. Again, the region is also the most important from the economic standpoint as its petroleum reserves supply a large part of the country's foreign exchange earnings.

The Niger delta covers a land mass in excess of 105,000 km^2 [5]. It is an arcuate shaped [6-7]; and a prograding high energy constructive lobate delta [8]. The sedimentary basin consists of three Formations (Figure 2). These are; Akata, Agbada and Benin Formations. Akata Formation ranges from Paleocene to Recent age. Deposition started in Agbada Formation during the Eocene while Benin Formation experienced deposition during the Oligocene. The Akata Formation is made up mainly of open marine and pro-delta dark shales with lenses of siltstones and sandstones [9].

The Agbada Formation comprises shales, siltstone and sandstone [10]. Benin Formation is made up of indurated sandstones, minor shales, coals and gravels [11].

3. Materials and methods

A total of seventy six (76) ditch cutting samples from HA-001 well and wireline logs were made available by Shell Production and Development Company (SPDC), Nigeria. The well samples which were got from intervals of 750 – 11600 ft were analyzed for their sporomorphs contents and sedimentological analyses through observation under the microscope. The other materials used are; beakers, weighing balance, liquid soap, brush, hot plate, potassium chlorate, 5 and 10 micron sieves, digital sonifier, water, pipette, cover slip, slide, optical adhesive, label, gloves and glass vial. Laboratory procedures involving samples preparation and analyses were carried out at Crystal Age Limited, Lagos, Nigeria.

The standard acid palynological techniques were employed. Ten grammes of each sample were taken through numerous processes to extract the palynomorphs contents from the embedding sediments. The samples were first treated with 10% HCl inside a fume cupboard to remove the carbonates. Neutralization with distilled water was done after 40% HF was added to the sample and placed on a shaker for a period of 24 hours to enable the dissolution of the silicates. After these, the HF was decanted and neutralization with distilled water was carried out to remove fluoro-silicates compounds produced as a result of HF reaction. Brason sonifier 250, which is an electric device, was used to sieve and separate the remaining silicate clay and mud and heavy minerals from the organic matter. A cover slip of 32 mm by 22 mm was placed on the hot plate; a stirrer was then used to stir the residue for even distribution and to transfer some quantity of the residue to the cover slip on the hot plate and then left to dry. The cover slip was then placed on the labelled glass slide with few drops of Canada balsam used as the mounting medium. The glass slide was then left to dry. This process was used for each sample.

The prepared slides for palynomorphs were studied, identified and counted under alight transmitted Olympus CX41 microscope using magnifications of x25 and x40 with relevant literature for description based on size, shape, structure, aperture and sculpture [13-25]. The specimen name and the distribution were recorded on the analysis sheet while those palynomorphs with non-distinguishable features due to either fungal/bacterial attack, corrosion etc. were recorded as indeterminate pollen or spore. Photographs of the palynomorphs were also taken using the attached Olympus DP12 digital camera.

Lithologic description was achieved through the physical examination of the samples and also by feeling between fingers. Fissile samples were observed to be shale while samples with fine to coarse grained sizes are the sandstone units. The lithologic description was made possible by the gamma ray and resistivity logs because high and low values of gamma ray and resistivity logs denote shale and sandstone lithologies, respectively [26]. The paleoenvironmental interpretation of the sedimentary sections was carried out with the framework of the identified lithofacies sequence [27] and [28]. The process was aided by combination of lithologic, textural and wireline log data. Also, the presence of index accessories minerals further helped in the analysis.

4 Results and discussion

4.1. Palynostratigraphic zonation and biochronology of HA-001 well

Two (2) assemblage biozones were recognised in the study namely the *Cyperaceaepollis* sp. – *Nympheaepollis clarus* assemblage zone (750-9750 ft) and the *Stereisporites* sp. assemblage zone (9750-11510 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 [15] and the P860, P850-P840 and P830 palynological subzones of [29]. Thus a Late Miocene age is interpreted for the HA-001 well (750-11510 ft) Figure 3. Details of the biozones were discussed below.

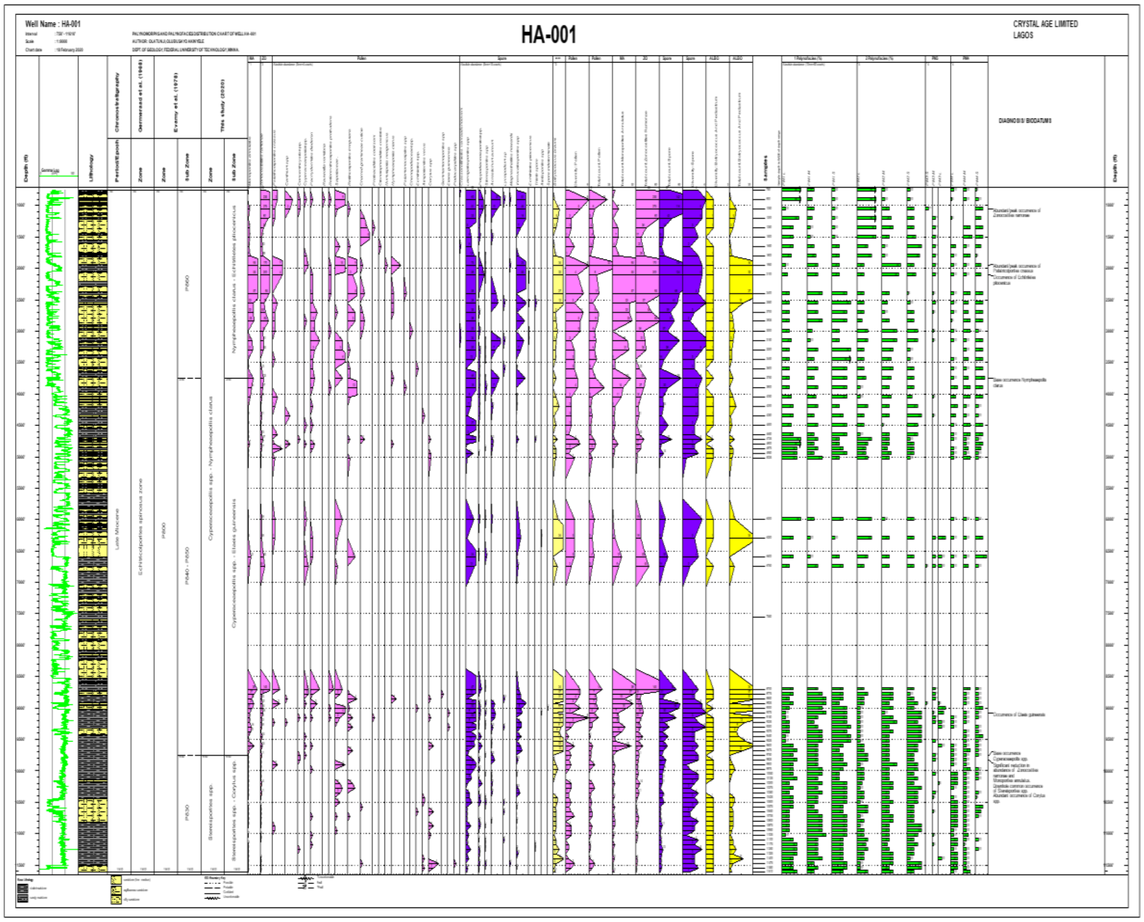

Figure 3. Palynomorphs distribution chart of well HA-001

Cyperaceaepollis sp - *Nympheaepollis clarus* Assemblage Zone

Depth: 750-9750 ft; Age: Late Miocene
Comparable palynological zone: *Echitricolporites spinosus* zone of [15] P860 and P850-P840 palynological subzones of [29].

This biozone is characterised 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 its actual top of the zone is stratigraphically higher than first sample analysed 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 recognised 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 recognised in the study. The base of the subzone is defined by the base occurrence of *Nympheaepollis clarus* identified at 3750 ft. The *Nympheaepollis clarus* subzone is further characterised by the abundant occurrence of *Zonocostites ramonae, Verrucatosporites* sp. and *Retitricolporites irregularis,* 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 [15] and the P860 subzone of [29].

Cyperaceaepollis - 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*, rare occurrence of *Aletesporites* sp. and *Retibrevitricolporites obodoensis*, reduced abundance of *Verrucatosporites* sp. and rare occurrence of *Acrostichum aureum* also characterised this subzone. This subzone correlates with the *Echitricolporites spinosus* palynological zone of [15] and the P850-P840 (undifferentiated) subzone of [29].

Stereisporites sp. Assemblage Zone

Depth: 9750-11510 ft; Age: Late Miocene (Tortonian).

Echitricolporites spinosus zone of [15], P830 palynological subzones of [29].

This Assemblage zone is characterised 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 not recognised as at the last sample analysed. As such, the base is stratigraphic deeper than the last sample analysed.

The zone is further characterised by the significant reduction the *Zonocostites ramonae* and *Monoporites annulatus,* moderate records of *Corylus* sp., common occurrence of *Stereisporites* sp., and lower records of *Pachydermites diederixi* compared to the higher zones. Some of the recovered pollen and spores from the studied well are shown in Figure 4.

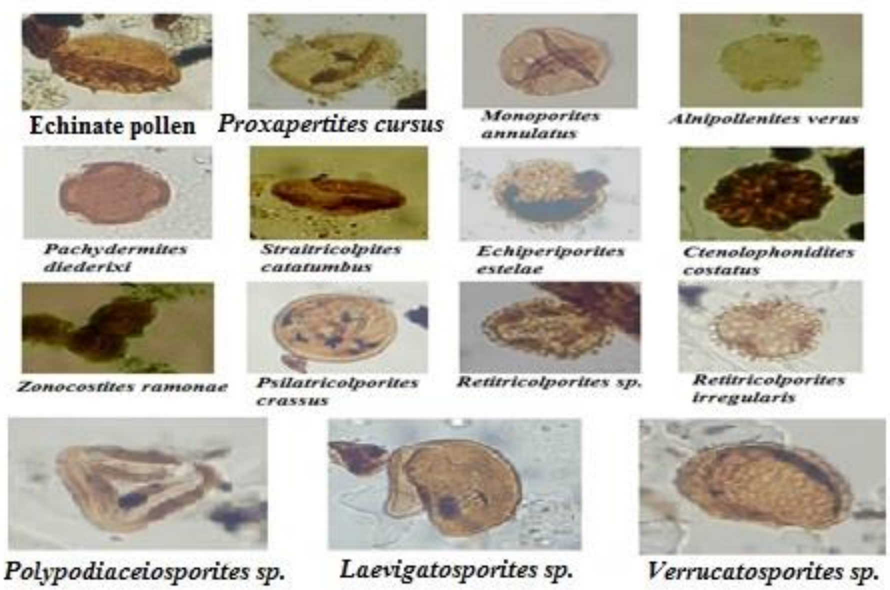

Figure 4. Some of the pollen and spores recovered from well HA-001 (x400)

4.2. Lithologic description and sedimentological analysis

Sedimentological attributes are derived from the integrations of wire line log motifs and textural/ lithologic attributes, the distribution of index accessories as well as our knowledge of the mutual juxtaposition of Niger delta sub-environments. Textural characteristics and the distribution of index accessory minerals, according to [30-31]; allowed the division of the entire intervals within the three well into Continental Benin Formation and Agbada Formation. The lithologic subdivision of the well is shown in the Table 1.

Table 1. Lithostratigraphic subdivision of HA-001 well

Interval - (ft)	Formation	Lithofacies Sequence	Lithological Characteristic
750 – 1,800	BENIN	CONTINENTAL	-Predominantly sands with minor shale intercalations. -Sands are predominantly quartzose, slightly feldsparthic, pebbly to fine-grained. -Sands are generally poorly-sorted. -Sand/ Shale ratio of approximately 90:10.
1,800–3,750	AGBADA	TRANSITIONAL PARALIC	-Predominantly sands with occasional shale intercalations -Sands are predominantly quartzose, slightly feldsparthic, fine to granule-sized with occasional pebbles. -Sands are generally moderately to poorly sorted -Sand/ Shale ratio of 80:20.
3,750-8,250		PARALIC	-Heterogenous sequence of alternating sand and shale/ silt units. -Sands are predominantly quartzose, slightly feldsparthic, fine to medium, occasionally coarse to very coarse-grained. -Sands are generally poorly to well sorted. -Sand/ Shale ratio of approximately 60:40.
8,250-11,600		MARINE PARALIC	-Predominantly shale with relatively thin sands. -Sands are quartzose, fine to medium-grained, occasionally coarse to granule-sized. -Sands are poorly to moderately well sorted. Sand/ Shale ratio of approximately 25:75.

4.2.1. Marine paralic/paralic lithofacies sequence of HA-001 well (11500 – 3750 ft)

This interval is essentially a heterogeneous sequence of alternating sand and shale/ siltstone units. The regular pattern of sand and shale/siltstone intercalations permits easy recognition (on logs) of six hallocycles (third-order cycles) or sub-cycles of sedimentation within the marine paralic and paralic sequences. Each of these sub-cycles commences with a relatively thick marine shale/silt and progressively shallows into fluviomarine /fluviatile sands, based on the signatures of the gamma ray log and sand to shale ratio [30-31].

4.2.2. The marine paralic lithofacies sequence (11500 – 8250 ft)

The marine paralic lithofacies sequence has thick shale units. The sand/shale ratio is approximately 25:75 [30-31]; two (2) Depositional hallocycles (subcycles A and B) were identified based on the signature of the gamma ray log. Each hallocycle consists of underlying predominantly shaly (transgressive) phase, overlain by a thick sandy (regressive) phase. These hallocycles are:

(i) Subcycle A: (11500 – 10450 ft)

This is the lowermost section of the analyzed interval and it is composed of a monotonously shaly lower section (11,500 – 10,850 ft), overlain by a stack of sands (10,850 – 10,450 ft.). The shale is brownish grey to grey, silty, platy to flaggy, occasionally blocky and moderately hard to hard. The sands are quartzose, very fine to medium- grained, occasionally coarse to very coarse–grained and granular; angular to rounded, and moderately to poorly-sorted. Ferruginous materials, carbonaceous detritus, mica flakes, shell fragments and glauconite pellets characterized the sequence. The monotonously shaly character of the lower section and the presence of shell fragment and glauconite pellets are consistent with low energy, shallow marine settings.

The amplified sand unit of the upper section of the sub cycle (10850 – 10450 ft) consisting of a stack of sands exhibiting upward coarsening profile indicative of a barrier bar build-up, probably deposited during progradational episode. This is further confirmed by the mixture of carbonaceous detritus, mica flakes and glauconite pellets [27].

(i) Subcycle B: (10450 – 8250 ft)

This 2200 ft thick subcycle is composed of hemipelagic shale with silty sand intercalations (10450 – 8500 ft), overlain by a sandy section (8500 – 8350 ft). It constitutes the top of the marine paralic lithofacies sequences. The shale/ siltstone is brownish grey to dark grey, silty, platy to flaggy, occasionally blocky and moderately hard to hard. Lithologically, the sands are quartzose, fine to medium – grained, occasionally coarse to very coarse –grained, sub angular to surrounded and moderately sorted. Ferruginous materials, carbonaceous detritus, glauconite pellets and mica flakes occurring in varying abundances constitute the accessory minerals suite of this subcycle. Also one spot occurrence of shell fragments was recorded at sample interval 9150 ft. The predominantly shaly/silty character of the lower part of the sub-cycle and the presence of glauconite pellets, ferruginous materials and shell fragments suggest deposition in a low energy, oxygenated, shallow marine settings [27]. The stack of sands over intervals 10300 – 10160 ft and 9450 – 9340 ft exhibiting upward coarsening grain-size profiles are probably of barrier bar origins. Elsewhere within the shales are fining upward and symmetrical sands interpreted as tidal channels and offshore bars respectively.

The typical multiserrate cylinder-shaped log character coupled with the regular carbonaceous detritus and glauconite pellets may suggest subaqeous channel deposits of the lower deltaic plain for the sandy upper part (8500 – 8250 ft).

4.2.3. The paralic lithofacies sequence (8250 – 7800 ft)

This lithofacies sequence directly overlies the marine paralic sequence. This interval is essentially a heterogenous sequence of alternating sand and shale/ mudstone units [30-31]. The sand/ shale ratio is approximately 60:40. Four (4) depositional subcycles were differentiated within this sequence, based on the signature of Gamma Ray Log. These are:

(i) Subcycle C (8250 – 7800 ft)

This interval is made up of a thin shaly base (8250 – 8100 ft) with minor sand intercalations, overlain by a more sandy section (8100 – 7800ft). Non-availability of ditch cutting samples for this interval restricted interpretation only on the wire-line log evidence. The subtle symmetrical sands occurring over interval 8200 – 8150 ft are most likely to be of offshore bar origin [28]. The amplified sand unit of the upper section (8100 – 7800 ft) of this sub-cycle consisting of multiple stacks of well-developed sands exhibiting cylinder - shaped grain-size profile is interpreted as distributary channel deposits.

(ii) Subcycle D: (7800 – 6200 ft)

This subcycle is composed of a thick shale unit (7800 – 6400 ft) with several silty sand intercalations, overlain by a sandy interval (6400 – 6200 ft). Like subcycle C discussed above, the ditch cutting samples were not recovered, except for intervals 6750 – 6200 ft. The shale is grey, brownish grey to dark grey, platy to flaggy and moderately hard. The sands are milky white to smoky, predominantly quartzose, slightly feldsparthic, very fine to medium-grained, occasionally coarse/very coarse grained, moderately to moderately well-sorted and sub-angular to sub-rounded. Rare to common carbonaceous detritus, mica flakes, rare ferruginous materials glauconite pellets were recorded. The log character of the sands within the shale unit vary from symmetrical, cresentric and cylinder-shaped motifs, probably interpreted as offshore bars, channel overbank lobes and subaqeous channels. The Gamma Ray Log motifs of the upper section (6400 – 6200 ft) is a hybrid sand units of multiserrate cylinder with minor bells and are most probably subaqeous channel-tidal channel associations [28]. This is corroborated by the presence of carbonaceous detritus and glauconite pellets. The gradual absence of shell fragments shows that the depositional environment probably deepened from base to top [27].

(iii) Subcycle E (6200 – 4700 ft)

This interval is composed of alternating sand and shale interbeds. The basal section (6200 – 5570 ft) is essentially shaly with few sand breaks, grading upwards into a predominantly sandy sequence (5570 – 4770 ft). The shale is grey, brownish grey to brown, platy to flaggy, occasionally blocky and moderately soft to hard. The sands are milky white, predominantly quartzose, slightly feldsparthic, fine to medium- grained, occasionally coarse to very coarse-grained, moderately to poorly sorted and sub-angular to sub-rounded. This subcycle recorded an increase in the abundance of accessory minerals carbonaceous detritus, shell fragments, glauconite pellets and ferruginous materials. They occur regularly in rare to common quantities.

The cresentric, funnel and symmetrical-shaped log motifs of the sands within the shaly lower section, coupled with the present of glauconite pellets and shell fragments may suggest these are channel overbank lobes, barrier bar and offshore bar deposits. These criteria indicate marine deposition in close proximity to the ancient shoreline [30].

The bell, serrate/ slightly serrate cylinder-shaped log motifs by the sands occurring over the upper section (5570 – 4700 ft), are interpreted as tidal channel and subaqeous channel deposits. Supportive of this deduction is the occurrence of carbonaceous detritus and glauconite pellets. The appearance of shell fragments may also suggest an infilling of the channel to shallower depth. This subcycle holds a total of 100 ft net hydrocarbon sands at intervals 6070 – 6030 ft, 5710 – 5680 ft and 4730 – 4700 ft.

(iv) Subcycle F (4700 – 3750 ft)

This is composed of alternating beds of sands and shales with a lower thick shale section (4700 – 4200 ft.) with few sand breaks, overlain by a more sandy sequence (4200 – 3750 ft). It constitutes the top of the paralic lithofacies sequence. Lithologically, the sands are milky white to smoky, predominantly quartzose, slightly feldsparthic, fine to medium – grained, occasionally coarse to very coarse –grained, moderately to poorly sorted and sub-angular to sub-rounded. The shale is grey, dark grey to brown coloured, silty, platy to flaggy, occasionally blocky and moderately hard to hard. The accessory mineral suites are mostly shell fragments, mica flakes, carbonaceous detritus ferruginous materials and glauconite pellets in decreasing order of abundance. These criteria indicate deposition in the lower deltaic plain environment. The cresentric-shaped motif occurring over interval (4560 – 4500 ft) is interpreted as channel overbank lobes. The amplified sand unit occurring over the interval 4420 – 4350 ft exhibiting a subtle upward coarsening grain-size profile is most likely to be of barrier bar origin. The underlying high gamma shale bed is interpreted as a barrier foot [10]. Elsewhere in the shale lower section, symmetrical-shaped sands occur and are most probably offshore bar deposits.

The serrate cylindrical with overall coarsening upward Gamma Ray log motifs of the upper section (4200 – 3750 ft) may suggest subaqeous channel and barrier bar deposits respectively. This is corroborated by the present of glauconite pellets and carbonaceous detritus [30]. Sediments of this subcycle are believed to have been laid down in an inner shelf to coastal deltaic settings. Also the trend of increasing abundance of shell fragments from the bottom to the top of this subcycle could be attributed to progressive shallowing of the environment.

4.2.4. The transitional paralic lithofacies sequence (3750 – 1800 ft)

This is composed of alternating sequence of sands (20 – 150 ft. thick) and relatively thinner shales (10 – 100 ft thick). The sequence exhibit a sand/shale ratio of approximately 80:20. The sands are predominantly quartzose, slightly feldspathic; fine to medium; occasionally coarse to granule-sized and pebbles, moderately to poorly sorted and sub-angular to rounded. The shale is grey, dark grey to reddish brown, platy to flaggy and moderately soft to moderately hard. Index accessories are dominated by carbonaceous detritus, shell fragments and ferruginous materials. Rare glauconite pellets and mica flakes are recorded with one spot occurrence of pyrites at interval 2400 ft. This suggests deposition in a high energy, subwave, suboxic to anoxic, deltaic environment [27].

The sand/ shale alternation of the sequence suggest frequent interchanging high and low depositional energy regimes which might have resulted from a frequently shifting depositional axis on a gently subsiding passive continental margin. However, the higher proportion of sand and the ubiquitous occurrence of carbonaceous detritus suggest that it was deposited under a generally higher energy regime than the underlying paralic Sequence and definitely represent an environment proximal to the underlying paralic/marine paralic sequence within a general deltaic environment.

The sand bodies exhibiting the funnel-shaped motifs over this sequence are proposed to be of barrier bar origin. The other sand bodies showing cylinder and cylinder on funnel-shaped motifs are suggested to be of subaqeous channel and subaqeous channel-barrier bar association origin. The shales interbedded with the sands are suspected to be of interdistributary/ prodelta origin [30].

The alternation of high and low energy regime is probably related to the well documented frequent shift of depositional axis in the Niger delta.

4.2.5. The continental lithofacies sequence (1800 – 750 ft)

This consists predominantly of poorly sorted pebbly to fine-grained sands with minor shale intercalations. The sequence exhibit a sand/ shale ratio of approximately of 90:10. The base is always defined by a major shift of resistivity to the left, probably marking the bottom of fresh water. (Resistivity log for this sequence is unavailable).

On gamma ray log the sands (10 – 250 ft thick) exhibit cylinder and funnel-shaped motifs. The sequence is very rich in accessory minerals dominated by shell fragments, carbonaceous detritus, mica flakes and ferruginous materials with glauconite pellets restricted to intervals 1800 – 1050 ft. The aforementioned criteria suggests that the sediments of this sequence are probably distributary channel and distributary mouth bar deposits of the upper deltaic plain in close proximity to the lower deltaic plain [30]. The increase in sand- percentage suggests relative shallowing or tremendous shallow water clastic influx. The depositional environment probably shallowed from base to top.

4.3. Thermal maturity of miospores in HA-001 well

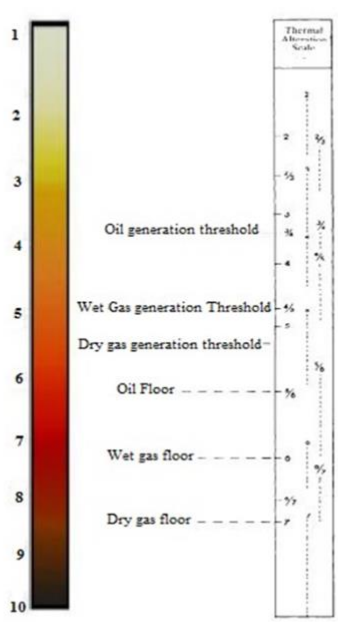

Figure 5. Relationship between thermal alteration and spore colour indices of [32] and [33] based on threshold of oil generation

Microscopic study of dispersed organic matter under transmitted light during the 70s increased ideas in recognizing the actual relation between the physical properties of dispersed organic particles and petroleum potential. The composition of pollen and spores and the degree of thermal alteration of sedimentary rocks based upon changes in colour of miospores have been used bin the oil industries in determining the level of organic maturation and hydrocarbon source rock potential.

A thermal alteration scale of [32] and Spore colour index chart of [33] (Figure 5) were adopted for this study. Palynological analysis is a fast, efficient and reliable method of determining hydrocarbon maturation level.

4.4. Organic maturation levels for miospores in HA-001 well

Thermal Alteration Scale: Ranges between 4/5 – 5/6 (4/5 – 5/6) [32]. Palynomorph colours: Ranges from light -medium brown to medium-dark brown [33]. Degree of Maturation: Ranging from maturity degree to late degree of maturation (Figure 6).

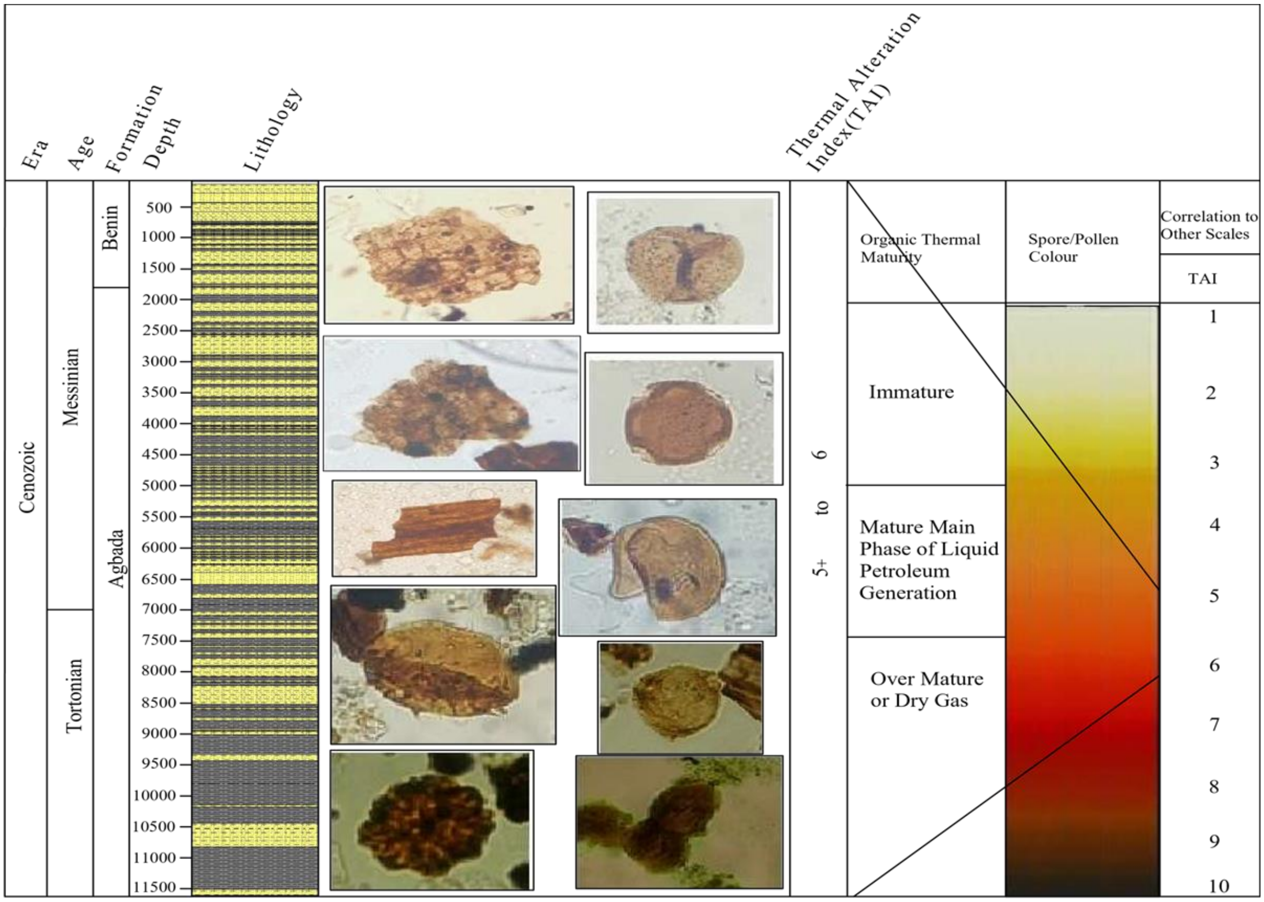

Figure 6. Miospores and organic thermal maturation of HA-001

5. Conclusions

Palynolostratigraphic and lithostratigraphic analyses were carried out on the sedimentary intervals of HA-001 well using ditch cutting samples and wireline logs provided by Shell Production and Development Company. Seventy-six (76) ditch cutting samples within the depth intervals of 750 – 11,610 ft in the well were analysed. The standard palynological method of sample preparation and sedimentological analyses were employed.

The stratigraphic age range of the recovered diagnostic marker species indicates Late Miocene age for the studied intervals. *Nympheaepollis clarus* has been assigned Late Miocene age in Nigeria [29] *Cyperaceaepollis* sp. and *Elaeis guineensis* have not been reported earlier than Late Miocene age [29] and [15] and they are Late Miocene markers. The recovery of the diagnostic marker species from the intervals of the studied wells gave the indication that the stratigraphic interval were deposited during the Late Miocene. Two palynostratigraphic zones each were established in the well using the international stratigraphic guide. *Cyperaceaepollis* sp. – Nympheaepollis clarus and *Stereisporites* zones were established in HA-001 well. *Nympheaepollis clarus* – *Echitriletes pliocenicus* and *Cyperaceaepollis* sp. – *Elaeis guineensis* subzones were established for the *Cyperaceaepollis* sp. – *Nympheaepollis clarus* zone in the well. The two zones are assemblage zones. The subzones and the zone erected in the studied wells are equivalent to P860, P840 – P850 and P830 of [29].

The sedimentological analysis showed lithological alteration of sand and shale units which suggests rapid shoreline progradation. The grain size increases from essentially fine to medium-grained, occasionally coarse-grained at the basal part of the wells, to dominantly fine to medium-grained, occasionally coarse to granule sizes at the upper part. The sands are mostly sub-angular to sub-rounded and generally poorly to well sorted. Index minerals and accessories are dominated by ferruginous materials, glauconite pellets, carbonaceous detritus, shell fragments and pyrites with irregular occurrences of mice flakes. The lithologic, textural and Gamma Ray Log data indicate that the entire interval studied in the HA-001 well essentially tested the Benin and Agbada Formation.

Thermal maturity of miospores encountered in the well using the thermal alteration scale of [32]] and spores colour index chart of [33] indicated early degree of maturation to late degree of maturation. The upper intervals in the well showed early degree of maturation for the miospores and palynomacerals while the lowest interval displayed late degree of maturation. The composition of palynomacerals and the degree of thermal alteration of sedimentary rocks based upon change in colour of miospores have been used in the oil industries in determining the level of organic maturation and hydrocarbon source rock potential.

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