Original Research Article

High-Resolution Biostratigraphic, and Paleoenvironmental Analysis of AJAYI-01 Well, Niger Delta, Nigeria.

Abstract

A high-resolution biostratigraphy study and paleoenvironment analysis were carried out on composited fifteen (15) ditch-cutting samples retrieved from AJAYI-01 well,offshore Niger Delta,Nigeria.The studied intervals range from 4060feet – 4960feet and were subjected to foraminifera, calcareous nannofossil and palynological analysis to determine their age,biozonation and environment of deposition. The standard laboratory preparation techniques of wet sieving, simplesmear method, and Hydrofluoric (HF) and Hydrochloric (HCl) acids maceration techniques respectively. A sedimentological description of the ditch-cutting samples was carried out.

Three major foraminifera zones of *Turborotalia peripheroacuta/Bolivina mandoroveensis* Zone, *Praeorbulina glomerosa/Nonion centrosulcatum* Zone and *Catapsydrax dissimilis/Buliminella subfusiformis* Zone and the important marker *Heterostegina sp*was recognized in the well based on the critical evaluation of bioevents and correlatable datums. The nannofossil zones of *Helicosphaera ampliaperta* and *Sphenolithus heteromorphus* were erected for this well based on the index taxa and fossil assemblage recorded. The palynological data consists of highly diversified assemblages dominated by terrestrial forms such as *Zonocostites ramonae, Monoporites annulatus, Laevigatosporites sp., Verrucatosporites sp., Retitricolporites sp., Acrostichum aureum.* The important marker recorded was *Crassoretitriletes vanraadshooveni* (FDO) at 4420feet. The well is dated early to middle Miocene (NN4 –NN5) based on the occurrence of marker species *Helicosphaera ampliaperta and Sphenolithus heteromophus* which corresponds to*Crassoretitriletes vanraadshooveni - Echitricolporites spinosus* Zone (P720-P680) subzones.

A tentative sequence stratigraphic framework for the studied sequences was established. A condensed section that is associated with the Maximum Flooding Surface (MFS)was dated 15.20Ma at 4480feet based on peak faunal abundance and diversity. The environment of deposition has sediments deposited in the marine environment fluctuating between middle neritic and inner neritic to the littoral, including coastal deltaic settings based on deductions from foraminiferal, palynological and sedimentological data.

Keywords: Biostratigraphy; Composited; Foraminifera; Calcareous nannofossil; Palynological; Paleoenvironment; Marker; Miocene; Condensed section; Maximum Flooding Surfaces.

1.Introduction

The Niger Delta basin is a prolific sedimentary basin and the most important hydrocarbon province in the West African continental margin (Fig.1).Globally, it contains the 12th largest known occurrence of recoverable hydrocarbons, with ultimate recovery currently estimated at nearly 40 billion barrels of oil and with a conservative estimate of gas reserves staggering40 trillion cubic feet of gas. Significant research in the basin started in the1950s, by shellBP following the first discovery of commercial quantities of petroleum in the basin. Severalstudies on the stratigraphy of the basin have been undertaken by both multinational oil companies and other authors all jeered at elucidating thegeology of the basin [e.g., 1, 2,3,4,5,6,7,8,9]. However, much of the research findings in the basin have been kept secret by the oil companies for proprietary reasons.Since its discovery as a petroliferous basin, biostratigraphy has become a tool used to address an increasing range of geologic, evolutionary and environmental deductions. Considering the complex stratigraphic nature of the Niger Delta basin occasioned by the occurrence of numerous synsedimentary faulting and related structural elements [5], the need for thorough biostratigraphic correlations from well to well cannot be overemphasized [10].

However, based on the high-resolution biostratigraphy analysis, three (3) major fossil groups are focused on. This involves the integration of micropaleontology (foraminifera), nannopaleontology (calcareous nannofossil) and palynology (palynomorphs) with or without lithostratigraphic analysis. These have proven very useful and complementary to each other. Such study permits better characterisation of stratigraphic sections into narrow time slices thereby facilitating reliable correlation within sedimentary basins on areservoir scale [11]. High-resolution biostratigraphy is a well-established method in petroleum exploration that has attained important status in petroleum industries in providing accurate age determination, refined biozonation, and correlations. It is in the consideration of the aforementioned that this study seeks to account for the variations in the assemblages, determine the biozonation and depositional environment of strata penetrated by AJAYI-01 well through integrated sedimentological, micropaleontological and palynological analysis. An attempt is made on the sequence stratigraphic framework for the well.

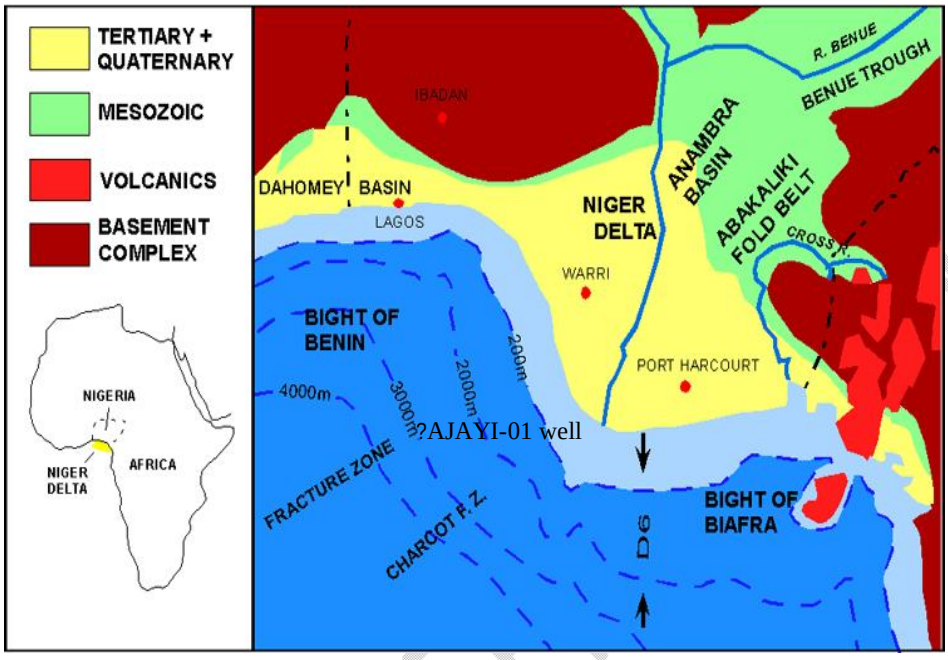


Fig. 1: Index map of Niger Delta and Location of Study Area (Source: [12])

2. Geology and Stratigraphy of the Niger Delta

AJAYI-01 well is located in the Niger Delta basin which covers about 75,000km^2 area and extends from latitudes 4^o and 5^o 2'N and longitudes 3^o and 9^o E (Fig. 1). It is composed of an overall regressive

clastic sequence that reaches a maximum thickness of 9 to 12 km (29,500 to 39,400 ft). It is bounded in the west by the Benin flank and in the east by the Calabar flank-a subsurface expression of the Oban massif. It is bounded in the south by the Gulf of Guinea and in the north by older (Cretaceous) tectonic elements (Fig. 2), such as the Anambra basin, Abakaliki uplift and Afikpo syncline [13]. The Delta is situated at the intersection of the Benue trough and the South Atlantic Ocean where a triple junction developed during the separation of South America and Africa in the late Jurassic [14].It was formed at the site of a rift junction related to the opening of the south Atlantic starting in the late Jurassic and continuing into the Cretaceous. The Niger Delta is one of the basins in West Africa formed as a result of basement tectonics related to crustal divergence and translation during the Cretaceous continental rifting of Gondwanaland[15,16]. The delta developed with a balance between sedimentation rates and subsidence. The resulting sedimentation patterns appear to have been influenced by the structural configuration and tectonics of the basement.Synsedimentary faulting and clay diapirism played a major role in the development of the delta [3]. Deep wells in the basin conform to the Gilbert tripartite model of deltaic sedimentation that reflects the regressive character of the sequences. The basal Akata Formation consists of dark grey marine shale sand silts with rare streaks of sand of probable turbidites (potential reservoirs in deep water) flow origin. It is estimated to be 6,400 m thick in the central part of this clastic wedge [17]. Marine planktonic foraminifera suggests a shallow marine shelf depositional setting ranging from Paleocene to Recent in age [17]. The lithologies of the overlying paralic Agbada Formation consist largely of alternating sands, silts and shales with progressive upward changes in grain size and bed thickness. The strata are generally interpreted to have formed in fluvial-deltaic environments [18]. Its maximum thickness is roughly 3,900 m and ranges in age from Eocene to Pleistocene [17] The last sediment to be deposited is the continental Benin Formation which consists of predominantly massive sands with intercalations of shale lenses. The sands are yellowish brown to white and fine to coarse-grained [19].

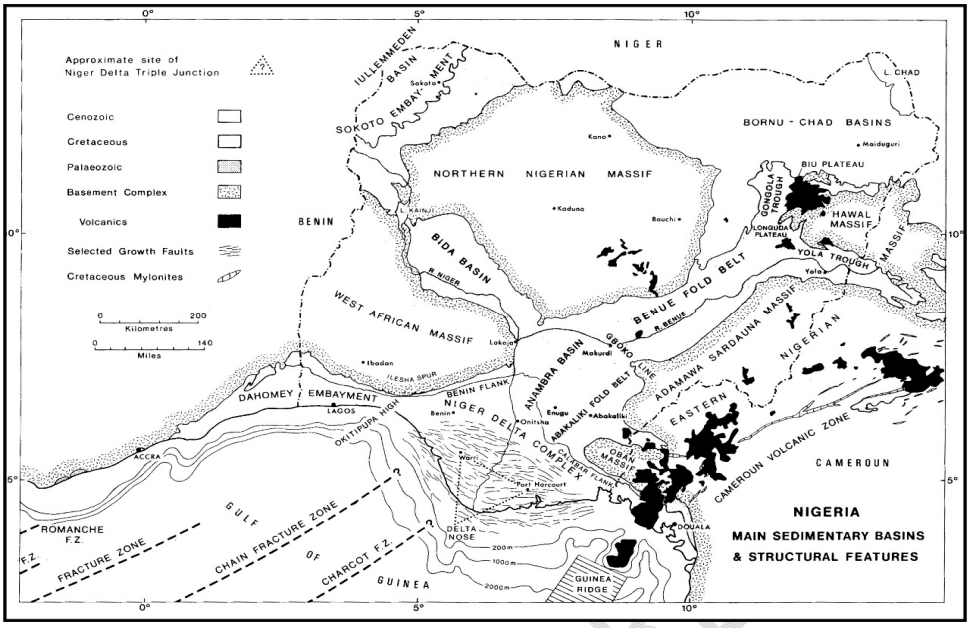


Fig. 2: General geological map showing main sedimentary basins in Nigeria, selected growth faults and general structural data (modified after[20])

3. Materials and Method

Fifteen (15) ditch-cutting samples composited at 60 feet intervalsfrom AJAYI-01 well in the Niger Delta basin were used for the study. The samples came from the intervals of 4060feet – 4960feet. The dried samples were first studied under a light reflecting stereo-binocular microscope to determine their textural attributes of mineralogical composition, colour, grain size, sorting, and roundness.The methods employed in carrying out the preparation of the samples for foraminifera, nannofossils and palynology are of five (5) different stages which include: sample administration, laboratory processing, analysis, interpretation and harmonization and technical report/presentation.

Comment [M1]: Map of the different sampling points

Preparation of the samples for foraminifera followed the standard foraminiferal procedures. A standard weight (25grams of dried samples) was soaked in well-labelled dish pans arranged seriallyfor four (4) hours in kerosene (organic solvent) to allow proper disaggregation of the samples, followed by soaking in soapy water overnight. The disaggregated samples were then washed under slowly running tap water through a 63-micron mesh sieve. The washed residue was then dried over a hot plate at 40^{o}Cand sieved into three fractions (coarse, medium and fine) in well-labelled sample bags before picking. All the foraminifera, ostracod shell fragments and other biota saw were picked from a gridded picking tray and counted under light reflecting binocular microscope. The specimens picked were stored in-depth-labelled slide provided with a cover slip for analysis.

The preparation of samples for calcareous nannofossil analysis followed the standard preparation techniques [21]. Pour a little fresh inner quantity of the two (2) depths composited samples into a clean white paper, and gently fold and crush together with a pestle. Scrape a small portion of sediments onto a cover slip (22mm × 40mm). Add a few drops of distilled water and make a thick sediment suspension using a flat-sided toothpick. Smear the suspension thinly across the surface of the cover slip with a toothpick, and dry rapidly on a hot plate at a temperature of about 60 - 70°C for a few minutes. Label a glass microscope slide (25.4mm × 76mm) using a diamond pen, and affix the dried cover slip (smear-side down) using a few drops of Norland optical adhesive mounting medium. Dry the slides under sunlight for fifteen (15) minutes or usean ultra-violet (UV) light ray box for about forty-five (45) minutes. Clean the slides with baby wipes (neat and easy analysis). The glass slides were examined by using oil immersion under a high-power light transmitting microscope

Preparation of samples for palynological analysis followed the standard procedures described by [22] which involved sample maceration with HCl and HF to remove carbonates and siliceous materials respectively. This was followed by the separation of palynomorphs from residue using a Brason sonifier (sieving) before centrifuging and decantation. Staining pollen and spores with Safranin O, are to get an easy observation, to obtain better photographs, and to remark details in the structure. It was then spotted with a rubber pipette on the cover slip, arranged serially on the plate warmer and mounted on a well-labelled glass slide using a few drops of Norland optical adhesive mounting medium.The glass slides were examined by using oil immersion under a well-condensed transmitted light microscope.

The analysis involved the identification, sorting, naming and counting of forms picked from each sample using relevant published catalogues as a guide [23]. The cascading counting method [24] was employed in determining the relative abundance and diversity of the assemblages per sample for quantitative analysis. The assemblages present in each sample were recorded in an excel spreadsheet before being presented in the assemblage distribution chart using Stratabug software on a scale of 1:2500. Absolute care was taken at all stages of the sample preparation to avoid contamination.

4.0 Lithostratigraphy and Sedimentology Interpretation

The lithologic description of the samples was analysed using a stereo-binocular microscope.The sedimentological and textural trends as well as the vertical changes were noted. The dominant lithofacies consist of sandstone andshale. The sandstones are fine to coarse-grained fractions,sub-angular,and poorly sorted to well sorted. The shale is grey to brown,non-fissile,and soft/moderately hard. Accessory minerals recorded include few carbonaceous matters (CB), shell fragments (SF),

ferruginous materials (FM), and mica flakes (MF). A summary of the lithologic table isprovided in Table 1.

The lithology of the well consists of alternations of sandstone and shale with the proportion of sand becoming more dominant towards the upper part of the well. Thesedimentological data indicates the well-penetratedupper paralic Agbada Formation.[25,26].

Table 1: Summary of Lithologic Table of AJAYI-01 Well

Depth (Feet)	**Code**	**Description**	**SF**	**MF**	**FM**	**CB**
4060-4120	Sand 98%	Light grey, very coarse (upper), sub-angular, well sorted, pebbly				
	Shale 2%	White/light brown, soft/moderately hard, non-fissile				
4120-4180	Sand 98%	Light grey, very coarse (upper), sub-angular, well sorted, pebbly				
	Shale 2%	White/light brown, soft/moderately hard, non-fissile				
4180-4240	Sand 98%	Light grey, very coarse (upper), sub-angular, well sorted, pebbly				
	Shale 2%	White/light brown, soft/moderately hard, non-fissile				
4240-4300	Sand 90%	Light grey, very coarse (upper), sub-angular, well sorted, pebbly				
	Shale 10%	White/light brown, soft/moderately hard, non-fissile				
4300-4360	Sand 65%	Light grey, medium/coarse-grained, pebbly, sub-angular, poorly sorted	5			
	Shale 35%	Whitish/brown, soft/moderately hard, non-fissile				
4360-4420	Sand 65%	Light grey, fine/medium grained, sub-angular, moderately sorted		1		
	Shale 35%	Whitish/brown, soft/moderately hard, non-fissile				

4420-4480	Sand 60%	Light grey, fine/medium grained, sub-angular, moderately sorted		5		
	Shale 40%	Whitish/Brownish, soft/moderately hard, non-fissile				
4480-4540	Sand 60%	Light grey, fine/coarse-grained, sub-angular, poorly sorted				
	Shale. 40%	Whitish/brown, soft/moderately hard, non-fissile				
4540-4600	Sand 65%	Light grey, fine/coarse-grained, sub-angular, moderately sorted				
	Shale 35%	Whitish/brown, soft/moderately hard, non-fissile				
4600-4660	Sand 80%	Light grey, fine/medium grained, sub-angular, well- sorted				
	Shale 20%	Whitish/brown, soft/moderately hard, non-fissile				
4660-4720	Sand 80%	Light grey/brownish, fine/coarse-grained, sub-angular, poorly sorted			30	25
	Shale 20%	Whitish/brown, soft/moderately hard, non-fissile				
4720-4780	Sand 60%	Light grey/brown, fine/medium grained, sub-angular, moderately sorted			28	30
	Shale. 40%	Whitish/brown, soft/moderately hard, non-fissile				
4780-4840	Sand 60%	Light grey/brown, fine/medium grained, sub-angular, well-sorted			20	20
	Shale 40%	Whitish/brown, soft/moderately hard, non-fissile				
4840-4900	Sand 60%	Light grey/brownish, fine/medium grained, sub-angular, well-sorted			34	10
	Shale 40%	Whitish/brown, soft/moderately hard, non-fissile				
4900-	Sand 80%	Light grey, fine/medium grained, sub-angular, well-sorted				

4960	Shale 20%	Whitish/brown, soft/moderately hard, non-fissile				

5. Results and Biostratigraphic Interpretation

5.1 Foraminifera

The AJAYI-01 Well was studied for foraminifera analysis and interpretation in which Fifteen (15) ditch cutting samples composited at 60feetintervals within the ranges of 4060-4960feet were prepared and analysed for their preserved faunas and accessories. The first four (4) slides analysed were completely barren while the remaining species recorded are fairly abundant and diverse of foraminifera (Fig. 3). At the end of the analysis, the sample was moderately diverse in benthic and planktic species, and few micro accessories. The important marker recorded was the FDO of *Heterostegina sp.* at 4300ft and three (3) foraminiferal "zones" were recognized which suggest Early to Middle Miocene using the chronostratigraphic scheme adopted by [27,28] (Fig. 4).

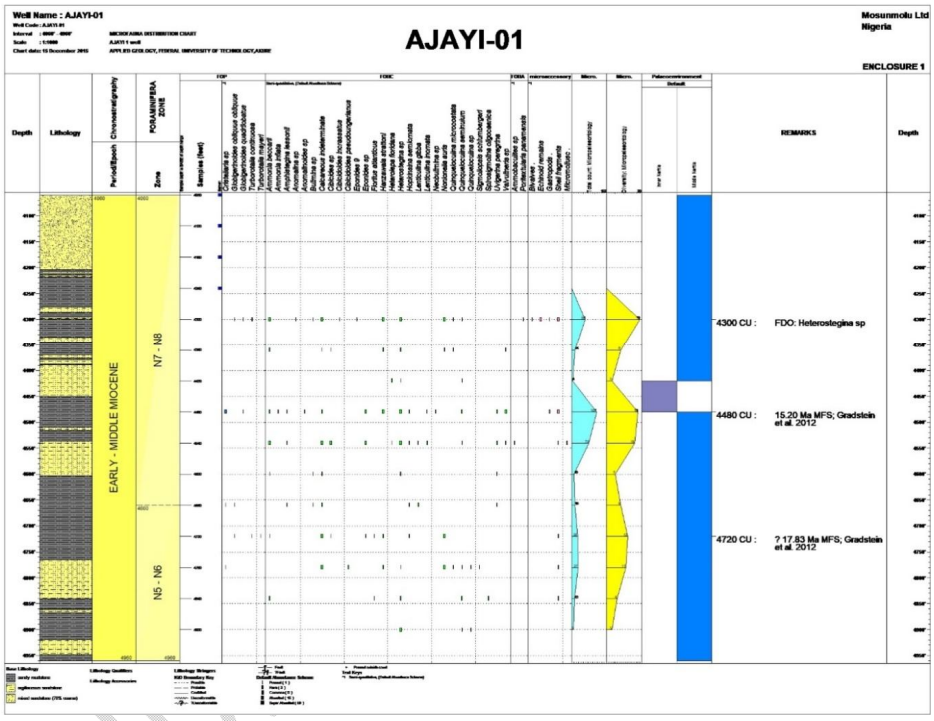


Fig. 3: Stratigraphic distribution of foraminiferal assemblages recorded in AJAYI-01 well.

Comment [M2]:

5.1.1 Foraminiferal Biozonation

Three (3) foraminiferal "zones" are recognized in the studied section interval of the well. The zones are characterized and correlated with the standard planktonic foraminifera zone of [28]as detailed below:

(i) Catapsydrax dissimilis/Buliminella subfusiformis Zone

Stratigraphic Interval: 4720- 4960feet.

Equivalent Planktonic Foraminifera Zone: N5/N6 Zone.

Age: Early Miocene

Diagnosis:The top of this zone is placed at 4720feet and the zonal base is placed at 4960feet which 4720feet marks the maximum flooding surface (MFS) of the studied section and is dated?17.83Ma MFS [28], based on peak faunal abundance and species diversity. The zone is correlated with the N5/N6 Planktic foraminifera zone of [27,28]. The age is early Miocene.

(ii) Praeorbulina glomerosa/Nonion centrosulcatum Zone

Stratigraphic Interval: 4480-4720 feet.

Equivalent Planktonic Foraminifera Zone: N6/N7Zone.

Age: Early to Middle Miocene

Diagnosis:This is the second zone encountered in the studied section. The zonal top is at 4480 feet and the zonal base is placed at 4720 feet which 4480feet marks the maximum flooding surface (MFS) of the studied section and is dated15.20Ma MFS [28]. The zone is correlated with the "middle" N6 and "early" N7 Planktic Foraminifera Zone of [27,29]. The age is early to middle Miocene. The zone was picked based on the law of superposition i.e., the top depth of the well must be younger than the base depth, therefore from the foraminiferal zones scheme [27,28] Praeorbulina glomerosa / Nonion centrosulcatumZone is younger than Catapsydrax dissimilis/Buliminella subfusiformis Zone.

(iii) Turborotalia peripheroacuta/Bolivina mandoroveensis Zone

Stratigraphic Interval: 4060-4480feet.

Equivalent Planktonic Foraminifera Zone: N7/N8Zone.

Age: Middle Miocene

Diagnosis:This is the first zone encountered in the studied section. The zonal top is at 4060 feet. The depth of the first sample analysed and the zonal base is placed at 4480 feet which at 4300feet marks the first downhole occurrence (FDO) of the important marker recorded *Heterostegina sp*. of the studied section. The zone is correlated with the "middle" N7 and N8 Planktic Foraminifera Zone of [27,28]. The age is middle Miocene. The zone was picked based on the law of superposition i.e., the top depth of the well must be younger than the base depth, therefore from the foraminiferal zones scheme [27,28] Turborotalia peripheroacuta/Bolivina mandoroveensis Zone is younger than

Praeorbulina glomerosa / Nonion centrosulcatum Zone and Catapsydrax dissimilis/Buliminella subfusiformis Zone (Fig. 4)

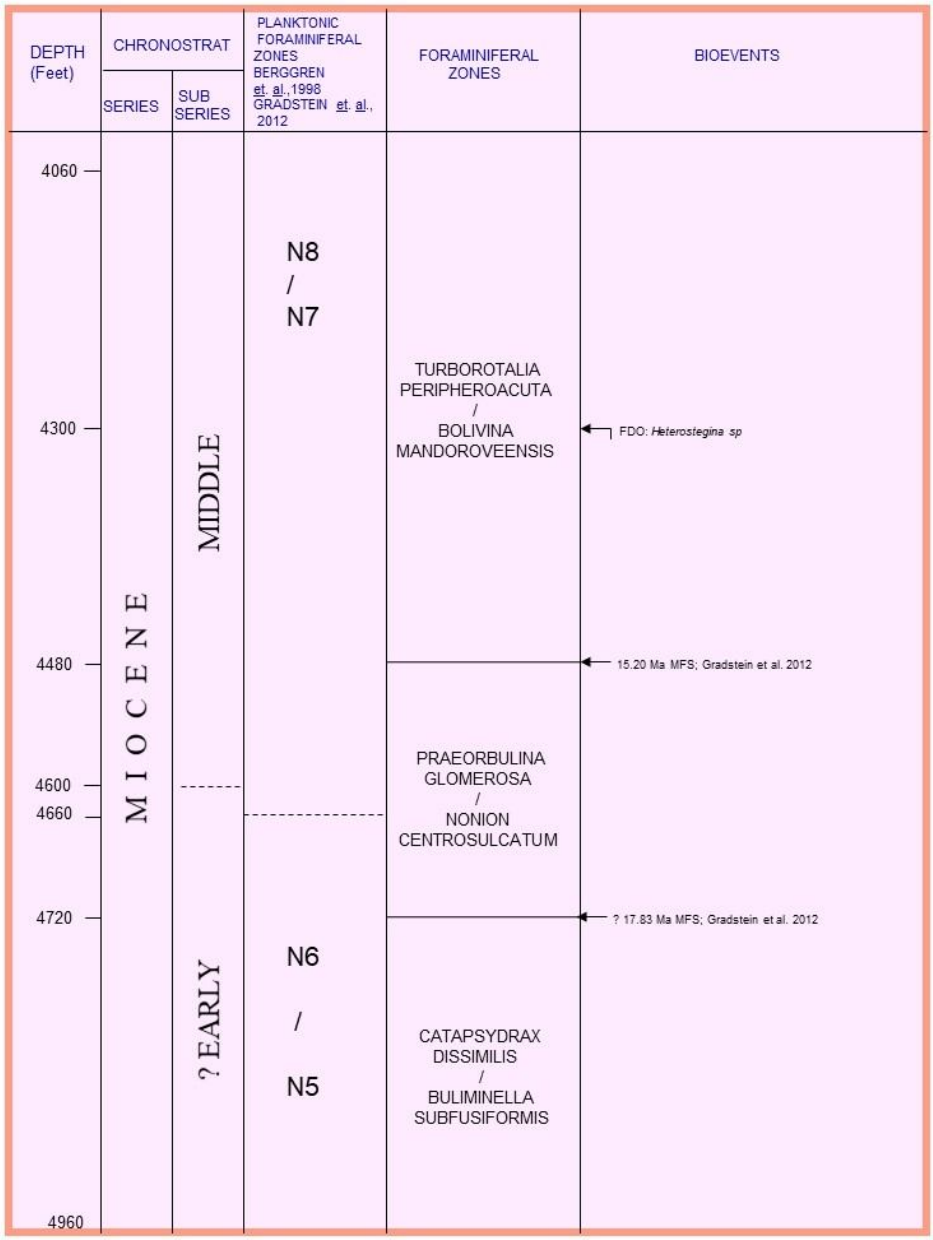


Fig. 4: Foraminiferal zones recognized in AJAYI-01 well.

5.2 Calcareous nannofossil

The AJAYI-01 Well was studied for calcareous nannofossil analysis and interpretation in which Fifteen (15) ditch cutting samples composited at 60feetintervals within the ranges of 4060-4960feet were prepared and analysed for their preserved nannofossils. The first three (3) slides analysed were completely barren while the remaining species recorded are fairly abundant and diverse in calcareous nannofossils (Fig. 5). The maximum flooding surface (MFS) was dated based on peak faunal abundance as well as important marker species such as *Sphenolithus heteromorphus*and *Helicosphaera ampliaperta*(Plate 1). The entire well is believed to penetrate the NN5 and NN4 zone [30] which suggestsan early to middleMiocene age for the sequence (Fig. 6).

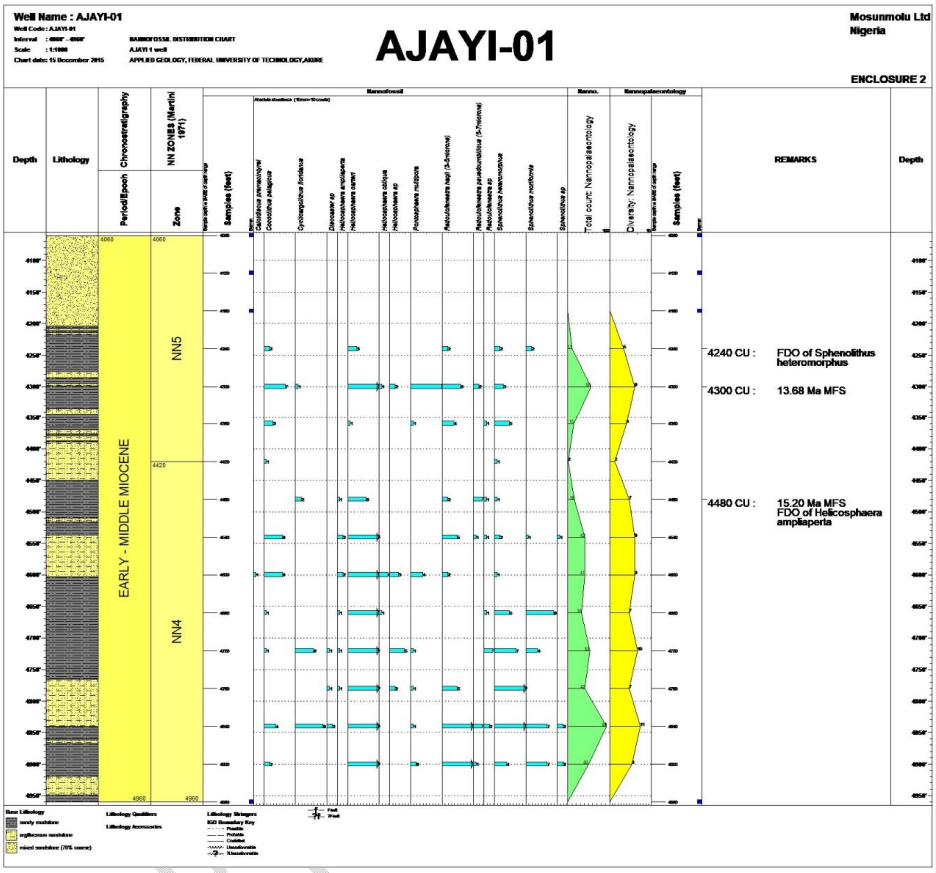


Fig. 5: Assemblage distribution chart of calcareous nannofossils recorded in AJAYI-01 well.

5.2.1. Calcareous Nannofossils Zonation

Based on the first and last stratigraphic occurrences (Top and Base respectively) of their bioevents as well as their relative abundance and diversity, two (2) zones are characterized as described below using [30]:

Stratigraphic interval: 4060 – 4180feet

Age: Middle Miocene

Nannofossil Zone: NN5

Remark

Interval was entirely barren of calcareous nannofossils.

Stratigraphic interval: 4240 – 4420feet

Age: Middle Miocene

Nannofossil Zone: NN5

Remark

Interval is marked by fairly abundant and diverse calcareous nannofossils. The occurrence of the (FDO) of *Sphenolithus heteromorphus* at 4240feet shows that the interval falls within the NN5 zone of [30]. The maximum flooding surface (MFS) at 4300feet represents the 13.68Ma [28] within the NN5 zone which indicates middle Miocene age (Fig. 6).

Stratigraphic interval: 4420 – 4960feet

Age: Early Miocene

Nannofossil Zone: NN4

Remark

Interval is marked by fairly rich abundant and diverse calcareous nannofossils. The occurrence of the (FDO) of *Helicosphaera ampliaperta* at 4480feet shows that the interval falls within the NN4 zone of [30]. Themaximum flooding surface (MFS) at 4480feet represents the 15.20Ma [28] within the NN4 zone based on the records of the diagnostic species which indicates early Miocene age. Due to the absence of the co-occurrence of the FDO of *Sphenolithus belemnos* and the LDO of *Sphenolithus heteromorphus*in the analysed section, the base of the interval is tentatively placed at the terminal depth of the well (TD) (Fig. 6).

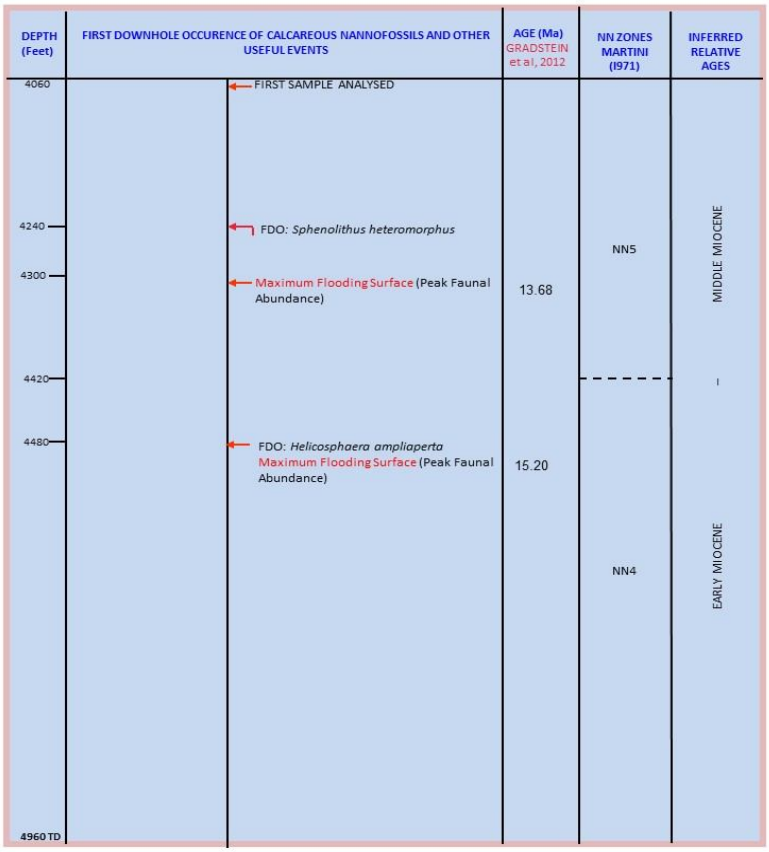


Fig. 6: Summary of calcareous nannofossil biostratigraphy of AJAYI-01 well.

5.3. Palynostratigraphy

The AJAYI-01 Well was studied for palynomorphs analysis and interpretation in which Fifteen (15) ditch cutting samples composited at 60feetintervals within the ranges of 4060-4960feet were prepared and analysed for their preservedfloral and palynomorphs.The palynomorphs recovered were moderately abundant, diverse and well preserved (Fig. 7). The assemblagesare dominated by terrestrial forms such as *Zonocostites ramonae, Monoporites annulatus, Laevigatosporites sp., Verrucatosporites sp., Retitricolporites sp., Acrostichum aureum*(Plate 2)The important marker recorded was the FDO of*Crassoretitriletes vanraadshooveni* at 4420feet. The palynomorph sequences (Fig. 8) of thestudied section fall within the Pan-Tropical *Crassoretitriletes vanraadshooveni Zone- Echitricolporites spinosus Zone*of [31] and is correlated to the P720-P680 subzones of [2] which indicates early to middle Miocene age.

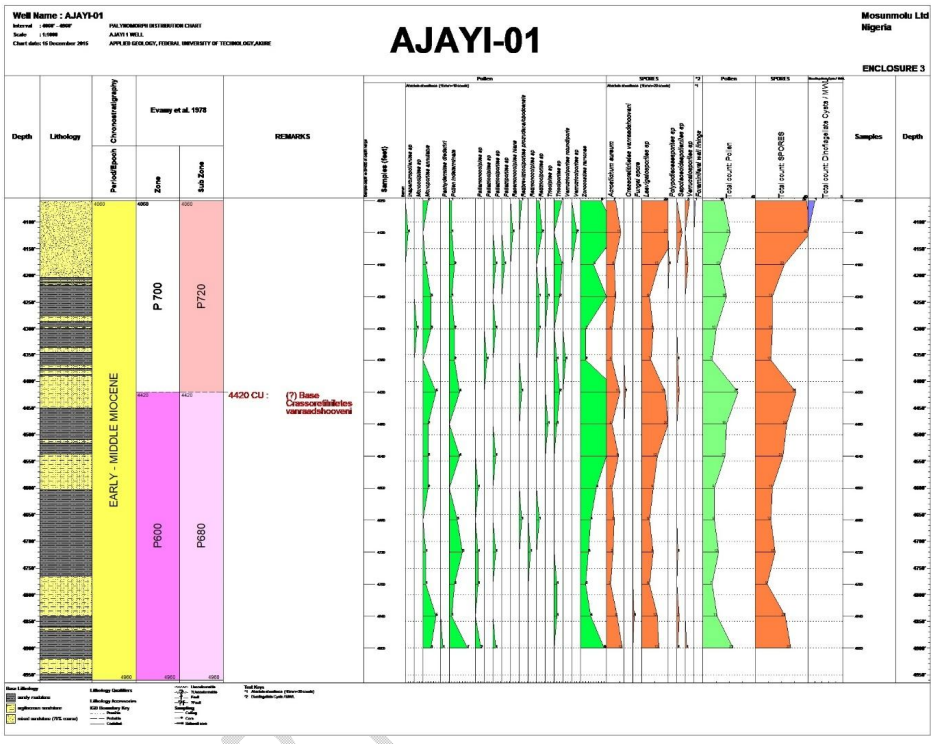


Fig. 7: Stratigraphical distribution of palynological assemblages of AJAYI-01 well.

5.3.1 Palynostratigraphy Biozonation

Subzone Recognized

Subzone: P720

Interval:4060-4420 feet

Age: Middle Miocene

Remarks

The subzone (P720) is characterized with moderately abundance and diverse forms of *Inaperturopollenites sp., Racemonocolporites hians, Retitricolporites sp., Tricolporites sp., Crassoretitriletes vanraadshooveni, Verrutricolporites rotundiporis, Monoporites annulatus, Zonocostites ramonae, Acrostichum aureum, Laevigatosporites sp., Sapotaceoidaepollenites sp., Foraminiferal wall linings, Psilatricolporites sp., Pollen indeterminate.* The base of the subzone is marked by the presence of*Crassoretitriletes vanraadshooveni* at 4420feet(Fig. 8).

Subzone: P680

Interval:4420-4960 feet

Age:Early Miocene

Remarks

The subzone (P680) is characterized with moderately abundance and diverse forms of *Psilamonocolpites sp., Retitricolporites sp., Tricolporites sp., Crassoretitriletes vanraadshooveni, Verrutricolporites rotundiporis, Monoporites annulatus, Zonocostites ramonae, Acrostichum aureum, Laevigatosporites sp., Sapotaceoidaepollenites sp., Psilatricolporites sp., Pollen indeterminate, Pachydermites diederixi.* The base of the subzone was not encountered as in the last sample analysed (Fig. 8).

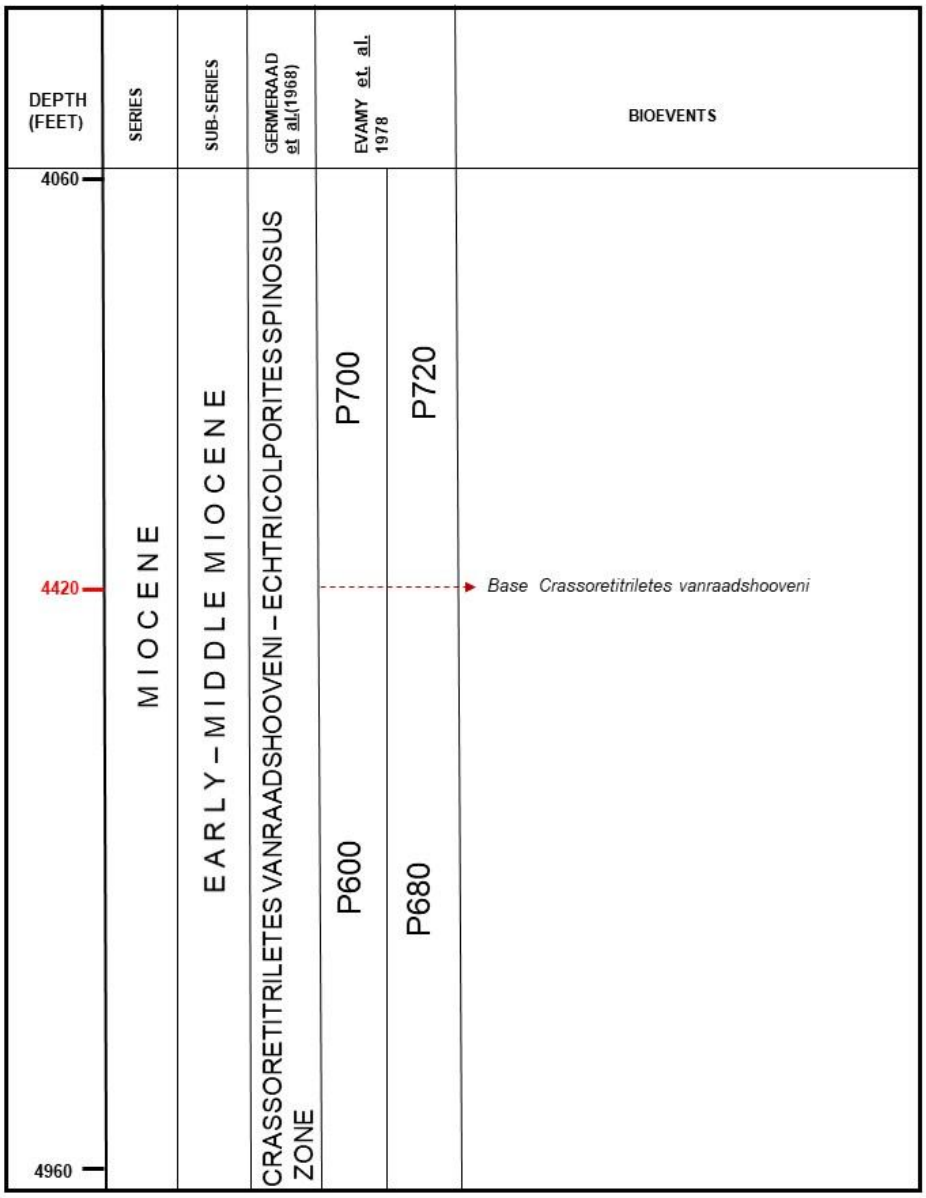


Fig. 8: Palynological Zones recognized in AJAYI-01 well

5.4. Sequence Stratigraphy of AJAYI-01 Well

The procedures for sequence stratigraphic interpretation outlined by [32], a deduction of the depositional environment from foraminifera data and log characters, interpretation of condensed sections from faunal abundance and diversity peaks as well as age dating of the well sequence from biostratigraphic data werecarried out to erect a provisional sequence stratigraphic interpretation framework for the well since lithologic log profile was unavailable.Condensed sections are considered as thin marine stratigraphic units consisting of pelagic to hemipelagic sediments typified by very low sedimentation rates which are most aerially extensive at the time of maximum regional transgression [Loutit]. The most landward surface within a depositional system is associated with a condensed section seaward.The maximum flooding surface (MFS) is the surface corresponding to the time of maximum flooding [33]. The Maximum Flooding Surfaces here represent the peak of a major Condensed Section where marine influence had encroached the greatest distance proximally beyond the shelf. The abundance, and diversity patterns of the foraminifera and nannofossil data calibrated with chronostratigraphically important bioevents facilitated the recognition of a condensed section. This is correlated with the Global cycle chart of [34] and is believed to be associated with the 15.20Ma maximum flooding surface (Table 2). The condensed section associated with the maximum flooding surface comprises a biostratigraphically distinctive event usually with abundant planktonic fossils. It thus has the greatest potential for being dated and correlated across a basin (and possibly globally).

Table 2: Condensed section as correlated to Global Cycle Chart of [34] and [28].

Maximum flooding surface /condensed section Age (Ma), After*[28]*	Suspected Interval (feet)	Dating criteria
CN: 13.68 Ma MFS; 15.20Ma MFS [28]	4300-4480	*Based on Peak Faunal Abundance, Presence: Helicosphaera ampliaperta*
Foraminifera: 15.20 Ma MFS; ? 17.83Ma MFS [28]	4480-4720	Based on Peak Faunal Abundance and Species Diversity

5.5. Depositional Paleoenvironment Interpretation of AJAYI-01 Well.

The interpretation of the depositional environment is based on the deduction fromthe sedimentological and foraminiferal data. The studied stratigraphic sequences of AJAYI-01 well have sediments deposited in marine environments that ranged from coastal deltaic to Middle Neritic with the influence of inner neritic at some horizon. The upper part of the studied section (4060 – 4420feet) was deposited in the coastal deltaic environmentand deepened to the inner neritic (4420 – 4480feet). The lower section of the studied interval is predominantly middle neritic (40 -100 m water depth within the shelf) to inner neritic settings. The occurrence of diversified calcareous benthic foraminiferal fauna such as*Quinqueloculina microcostata,Ammonia beccarii,Hopkinsina semiornata, Lenticulina inornata, Valvulineria sp.,* suggests deposition in inner to middle neritic environment.The occurrence of*Hopkinsina semiornata*amongst otherdeep calcareous foraminiferal fauna from the Niger Delta was used by [35] to deduce the middle neritic environment. Miliolids such as *Quinqueloculina* are adapted to normal salinity shelf environments and their occurrence is indicative of shallow marine to intermediate environments [36]. According to [36] the dominance of*Bulimina sp*. and*Lenticulina sp.* in an assemblage suggests a middle neritic environment. The dominance of calcareous fauna over arenaceous benthics as well as the absence of planktic taxa also supports this deduction. Similarly,[37] used the common association of*Bulimina sp., Lenticulina sp*., and *Cibicides sp.,* to infer the middle neritic environment and stated that *Lenticulinainornata* is a good indicator of the middle neritic environment as well as oxygenated bottom water condition.

6.0. Conclusion

Three (3) foraminiferal zones were recognized and also marked by the FDO of *Heterostegina sp*at 4300feet which suggest the Early to Middle Miocene age.The maximum flooding surfaces (MFS) were dated 15.20Ma at 4480feet and ?17.83Ma at 4720feetbased on peak faunal abundance. The well penetrated NN5 and NN4 zones suggest an early to middle Miocene age. The maximum flooding surface (MFS) was dated 15.20Ma by the FDO of *Helicosphaera ampliaperta*at 4480feet and 13.68Ma at 4300feet based on peak faunal abundance. The FDO of *Sphenolithus heteromorphus* was marked at 4240feet.The palynomorphs sequences of the studied sectionfall within the Pan-Tropical *Crassoretitriletes vanraadshooveni Zone- Echitricolporites spinosus Zone* and are correlated to the P720-P680 subzoneswhich indicateearly to middle Miocene.The FDO of *Crassoretitriletes vanraadshooveni* marker recorded was at 4420feet.The sedimentological data showed that the studied section penetrated the Upper paralic Agbada Formation typified by the sand-shale intercalations. However, a condensed section of the recorded foraminifera and calcareous nannofossil that is associated with 15.20Ma Maximum Flooding Surface at 4480feet was delineated by correlation to standard eustatic sea level charts. The sediments were deposited in environments ranging from littoral through inner to middle neritic settings based on deductions from sedimentological, foraminifera and palynological data.

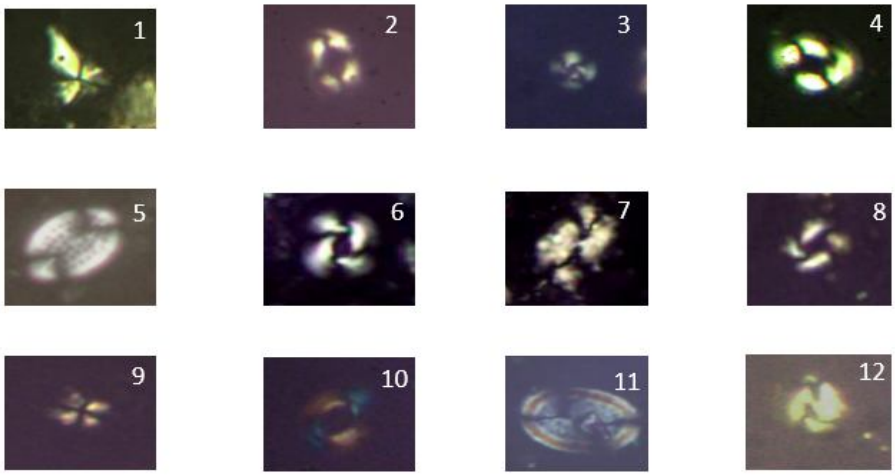
References

1. Weber and Daukoru,(1975). Petroleum Geological aspects of the Niger Delta 9th World Petroleum. Congress, Tokyo, Proc., Vol. 2, pp. 209-221.
2. Evamy, B.D., J. Haremboure, R. Kammerling, W.A. Knaap, F.A. Molloy, and P.H., Rowlands, (1978): Hydrocarbon habitat of tertiary Niger Delta: *American Association of Petroleum Geologists Bulletin*, v. 62, p. 1-39.
3. Doust, H., and E. Omatsola, (1990): Niger Delta, in J.D. Edwards and P.A. Santogrossi, eds., Divergent/passive margin basins: *American Association of Petroleum Geologists Memoir* 48, p. 239-248.
4. Reijers, T.J.A. (2011) Stratigraphy and Sedimentology of the Niger Delta. *Geologos*,Vol 17, 133-162.
5. Nyantakyi, E.K., Hu, W.S., Borkloe, J.K., Qin, G. and Han, M.C. (2013) Structural and Stratigraphic Mapping of Delta Field, Agbada Formation, Offshore Niger Delta, Nigeria. American Journal of Engineering Research, 2, 204-215.
6. Ogbahon, O.A.,and Afolabi, M.O. (2020). High-Resolution Biostratigraphic,Sequence Stratigraphic and Paleoenvironmental Analyses of Motun-1 Well,Niger Delta,Nigeria.Earth & Environmental Science Research & Reviews, Volume 3,Issue 4,pp. 184-190.
7. Sanuade, O.A. (2014): Calcareous Nannofossil Biostratigraphic Analysis of well 'k-2', deep offshore Niger Delta, Nigeria. Advances in Research. 2(12):696-711, 2014.
8. Boboye, O.A., and Adeleye, A.M. (2009) High-Resolution Biostratigraphy of Early Pliocene-Late Miocene Calcareous Nannoplankton and Foraminifera,deep offshore,Niger Delta,Nigeria.European Journal of Scientific Research,ISSN 1450-216X Vol.34,No 3, pp.308-325.
9. Oloto, I.N (2014). Foraminiferal Biostratigraphy Studies of Agbara 17 Well, Niger Delta Basin, Nigeria. *International Journal of Scientific & Technology Research*, volume 3, issue 2, pp. 336-339.

10. Ogbahon, O.A (2019). Palynological Study of OSE 1 Well in offshore Niger Delta Basin: Implications for age, paleoclimate and depositional paleoenvironment. International Journal of Geosciences, vol. 10, No 10.
11. Fadiya S.L. and Adebambo, B.A. 2016. Campano-Maastrichtian foraminiferal stratigraphy and paleoenvironment of Fika Shale, Bornu Basin, northeastern Nigeria. *Ife Journal of Science* vol. 18, no. 3, pp. 753-762.
12. Doust, H. and Omatsola, M.E. (1989) Niger Delta. In: Divergent Passive Margin Basins, J. D. Edwards and P. A. Santogrossi, Eds., A.A.P.G. Memoir 48, pp. 201 - 238.
13. Ejedawe, J.E. (1981) Patterns of incidence of oil reserves in Niger Delta Basin: American Association of Petroleum Geologists, v. 65, p. 1574-1585.
14. Whiteman, A. (1982): Nigeria-Its petroleum geology, resources and potential: London, Graham and Trotman, p. 394.
15. Selley R.C. (2017). Geology of the Niger Delta. In: Adegoke, O.S., Oyebamiji, A, Edet, J., Osterloff, P., Olu, O (eds.). Cenozoic Foraminifera and calcareous nannofossil biostratigraphy of the Niger Delta. Elsevier, 570p.
16. Burke, K, Desssauvagie, TFG, and Whiteman, A.J. (1972). Geological history of the BenueValley and Adjacent areas.In Desssauvagie, TFG, and Whiteman, A.J. (Eds.).African Geology, Ibadan University Press, Ibadan, pp.187-206.
17. Fadiya , S. L., Jaiyeola-Ganiyu , F. A. and Fajemila , O. T. (2014) Foraminifera biostratigraphy and paleoenvironment of sediments from Well AM-2, Niger Delta. Ife Journal of Science vol. 16, no.1, pp. 61-71.
18. Stacher, P., 1995. Present understanding of the Niger Delta hydrocarbon habitat. [In:] M.N. Oti& G. Postma (Eds): *Geology of deltas*. Balkema, Rotterdam, 257–268.
19. Short, K.C., andStauble, A.J. (1967): Outline of Geology of Niger Delta: American Association of Petroleum Geologists Bulletin v. 51, p. 761-779.
20. Obaje, N.G. (2009): The Niger Delta Basin, Lecture notes in earth sciences. Geology and Mineral Resources of Nigeria. Springer Berlin Heidelberg. 2009;120: pp. 109-113.
21. Hay WW, Mohler HP, Roth PH, Schmidt RR, Boudreaux JE. Calcareous nannofossils from Nal'chik (northwest Caucasus). Eclogae Geologicae Heloetiae. 1967; 59:379-399.
22. Traverse, A. (2007) Palaeopalynology. 2nd Edition, Springer, Berlin, 811 p.
23. Germeraad, J.H., Hopping, C.A. and Muller, J. (1968) Palynology of Tertiary sediments from tropical areas. Review of Palaeobotany and Palynology, 6, pp.189-348.
24. Styzen, M. (1997): Journal of Nannoplankton Research V19 (1).
25. Short, K.C., and Stauble, A.J. (1967): Outline of Geology of Niger Delta: American Association of Petroleum Geologists Bulletin v. 51, p. 761-779.
26. Avbovbo, A. A. (1978): Tertiary lithostratigraphy of Niger Delta: American Association of Petroleum Geologists Bulletin, v. 62, p. 295-300.
27. Berggren, W. A., Kent, D. V., Swisher, C. C. & Aubry, M. (1998): A revised Cenozoic Geochronology and Chronostratigraphy. p. 128-212.
28. Gradstein, F. M., Ogg, J. G., 2012. The Chronostratigraphic Scale. In: Gradstein et al., The Geologic Time Scale 2012. Elsevier Publ. Co.
29. Gradstein, F. M., Ogg, J. G., and Smith, A. G. (2004). "Chronostratigraphy: linking time and rock," in A Geologic Time Scale 2004, eds F. M. Gradstein, J. G. Ogg and A. G. Smith (Cambridge: Cambridge University Press), 20–46. doi: 10.4095/215638.
30. Martini, E. (1971): Standard Tertiary and Quaternary Calcareous Nannoplankton Zonation. In Farinacci (Editor), proceedings 11 Plankton Conference, Roma.1970, 2 pp.739-785.
31. Germeraad, J.H., Hopping, C.A. and Muller, J. (1968) Palynology of Tertiary sediments from tropical areas. Review of Palaeobotany and Palynology, 6, pp.189-348.
32. Vail PR., Wornardt, W.W. (1990). An integrated approach to exploration and development in the 1990s: Well log seismic sequence stratigraphy analysis, Trans. Of the 41st Annual Convention of the Gulf Coast Assoc. of Geological Societies, Houston, Texas, pp. 630-650.
33. Van Wagoner, J.C., Mithchum (Jr), R.M., Posamentier, H.W. and Vail, P.R. (1988): Seismic stratigraphy interpretation using sequence stratigraphy.In: A.W. Bally, (ed), Atlas of seismic stratigraphy, 1. American Association of Petroleum Geologists Studies in Geology, 27, 11-14
34. Haq, B.U., Hardenbol, J. and Vail, P.R. (1988): Chronology of fluctuating sea levels since the Triassic. Science, 235, pp.1156-1157.

35. Koutsoukos, E.A.M. (2005). The K–T Boundary: In Koutsoukos, EAM (ed.) Applied stratigraphy. Springer; 488p.
36. Mandur, M.M.M., Baioumi, A.A. 2013. Palaeoenvironment of the lower and middle Miocene successions in the Gulf of Suez region based on both planktonic and benthonic foraminifera. Egyptian Journal of Petroleum 22, PP. 405–425.
37. Chukwu, J.N., Okosun, E.A., Alkali, Y.B. (2012). Foraminiferal biostratigraphy and Depositional environment of Oloibiri- 1 Well, Eastern Niger Delta. Journal of Geography and Geology, Vol. 4, no 4, pp. 114-122.

APPENDIX



1. ***Sphenolithus heteromophus*** 2. ***Helicosphaera ampliaperta***
3. ***Cyclicargolithus floridanus*** 4. ***Coccolithus pelagicus***
5. ***Pontosphera multipora*** 6. ***Reticulofenestra psuedoumbilicus 5-7µ***
7. ***Helicosphera cateri*** 8. ***Reticulofenestra haqii 3-5µ***
9. ***Sphenolithus moriformis*** 10. ***Calcidiscus premacintyrei***
11. ***Pontosphera discopora*** 12. ***Helicosphera obliqua***

Plate 1: *Photomicrographs of some calcareous nannofossils recovered in* AJAYI-01 *well*

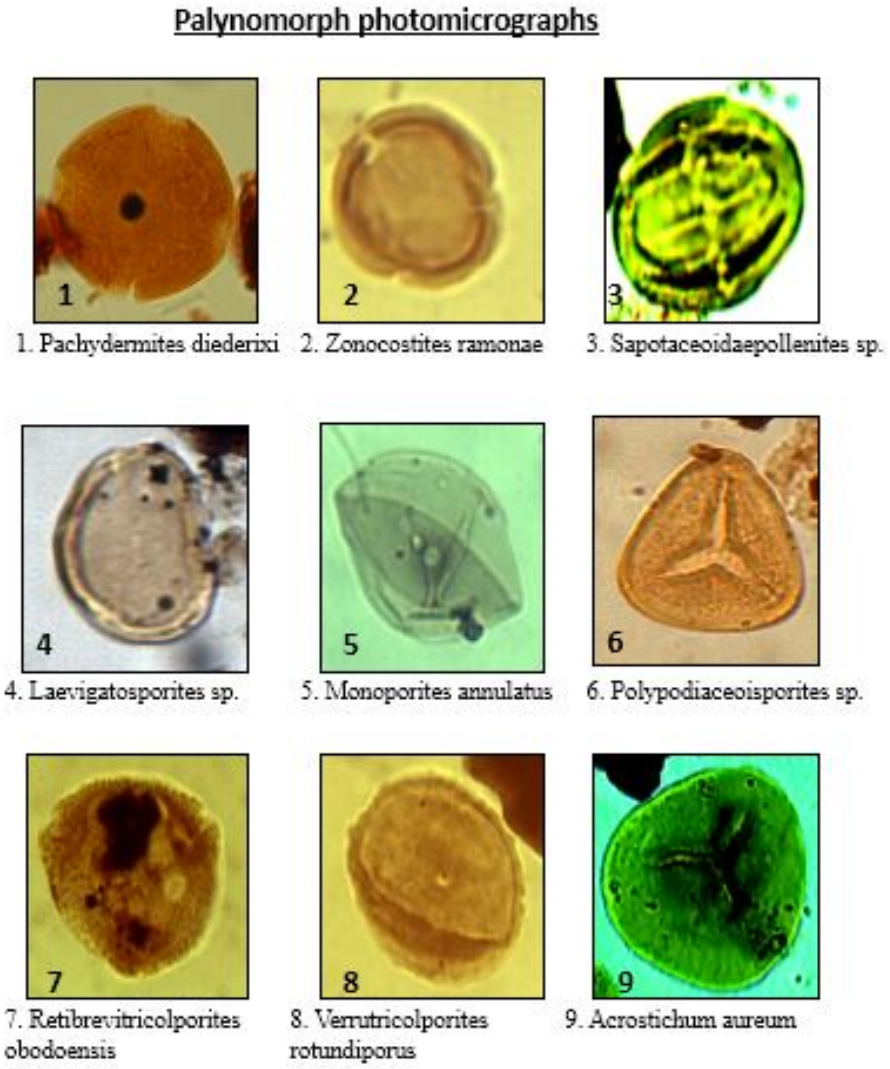


Plate 2: *Photomicrographs of some palynomorphs recovered in* AJAYI-01 well.