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Biozonation and Paleoenvironmental Evaluation of Sapele Fields, Niger Delta, Southern Nigeria

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ABSTRACT
Palaeoenvironmental and Biozonation analysis was carried out on Sapele fields (Sapele Deep and Sapele Shallow) using the biostratigraphic data, twelve digital wirelines well-log data, and the international stratigraphic guide. Five depositional environments were delineated based on the biofacies information interpreted from the qualitative and quantitative evaluation of the benthonic foraminifers' assemblages. The depositional environments of the study area are Bathyal Depositional Environment, Outer Neritic Depositional Environment, Middle Neritic Depositional Environment, Inner Neritic Depositional Environment and Littoral Depositional Environment. Six biozones were deciphered from the field of study and they include, Catapsydrax dissimilis Concurrent-range zone, Praeorbulina glomerosa interval zone, Globoturborotalita nepenthes Concurrent-range zone, Globorotalia margaritae partial-range zone, Dentoglobigerina altispira interval zone and Globigerinoides fistulosus interval zone. According to the qualitative and quantitative analysis of biofacies data, the study area's interpreted depositional environment fluctuated between shallow marine and deep marine (inner neritic to middle neritic to outer neritic to bathyal depositional environment) for Sapele deep and between marginal marine and deep marine (littoral to inner neritic to middle neritic to outer neritic depositional environment) for Sapele shallow.

Keywords:
Palaeoenvironmental,
Biostratigraphic data,
Depositional,
Biozonation,
Wirelines.

INTRODUCTION

Depositional environment is a geomorphic unit in which deposition takes place. Thus, the study of depositional environment is essentially the study of geomorphology which is the recognition of geomorphic units. Geomorphic units are recognized by features preserved in ancient sediments.

The Depositional Environments are depressions where sediments got deposited. The eroded sediments are transported and deposited by water, glaciers, and wind. Depositional Environments are mostly sedimentary environments. The layers of sediment that accumulate in each type of depositional environment have distinctive characteristics, which provide important information regarding the geologic history of an area. These sediments, form at the surface and provide information about past environments. The catchment area's physical characteristics and geographical location determine the sediment type that will normally be deposited in depressions. Parent rocks of catchment zones play a dominant role in these processes.

Soronnadi *et al.,* (2013), undertook a palaeoenvironmental and sequence stratigraphic study of the D7000 sand 'Erne' field of the Niger Delta using integrated core samples, biostratigraphic data and wireline logs analyses of the D7000 sand. The environments of deposition were established as marine to estuarine settings which revealed that a period of regression was followed by a transgressive phase. Core analysis revealed the existence of ten lithofacies, which were grouped into facies association in a vertical sequence with genetic significance using primary structures and shape of wireline logs.

Head *et al.,* (2003), studied biological activity in the deep subsurface and the origin of heavy oil. He established that microbial degradation reaches optimal temperatures below 800C, promoting oil oxidation, gas/oil ratio (GOR) reduction, and API value reduction.

Whiteman (1982) established that the physical and chemical properties of oil in the Niger Delta are extremely unpredictable. He established that the oil within the Niger Delta has a gravity range of 16-50° API, with the lighter oils having a greenish-brown colour. While Thomas (1995), stated that 56% of Niger Delta oils have an API gravity between 30° and 40° and that oils with less than 25° API account for only 15% of the Niger Delta reserves.

Based on the lithologic and foraminiferal analysis, this study has established that the well interval for Sapele deep penetrated early to late Agbada formation while Sapele shallow penetrated the late Agbada to early Benin formation with deposition occurring during the early Miocene to late Miocene for Sapele deep and late Miocene to early Pleistocene to for Sapele shallow

Geology of Niger Delta

The Cenozoic Niger Delta complex was developed as a regressive offlap sequence. The delta complex which has been described as an arcuate-lobate shape was built across the Anambra Basin and the Cross-River margins and eventually extended onto the Late Cretaceous continental margin (Figure 1). Geologists believe that these sediments were part of the West African miogeocline derived from adjoining older rocks which were transported and deposited by the help of the Rivers Niger and Benue onto the cooling and subsiding oceanic crust which has been generated as the South American and African Continents spread apart (Tuttle *et al.*, 1999).

The Geophysicists and Geologists have shown that the Niger Delta Basin has spectacularly maintained a thick sedimentary apron and salient petroleum geological features favourable for petroleum generation, expulsion and trapping from the Onshore through the Continental Shelf and to the deep-water terrains.

In 1956, the first commercial onshore discovery was made in Oloibiri by Shell and about seven years after, Chevron discovered the Okan field, the first commercial offshore field in 1963. Thus, among the sedimentary basins in Nigeria, aggressive exploration has been concentrated in the Niger Delta Basin. The Niger Delta Basin to date is the most prolific and economic sedimentary basin in Nigeria by virtue of the impact size petroleum accumulations, discovered and produced as well as the spatial distribution of the petroleum resources to the Onshore, Continental Shelf through Deepwater terrains. Classic integrated geological studies have shown that several different depobelts abound in the Niger Delta basin.

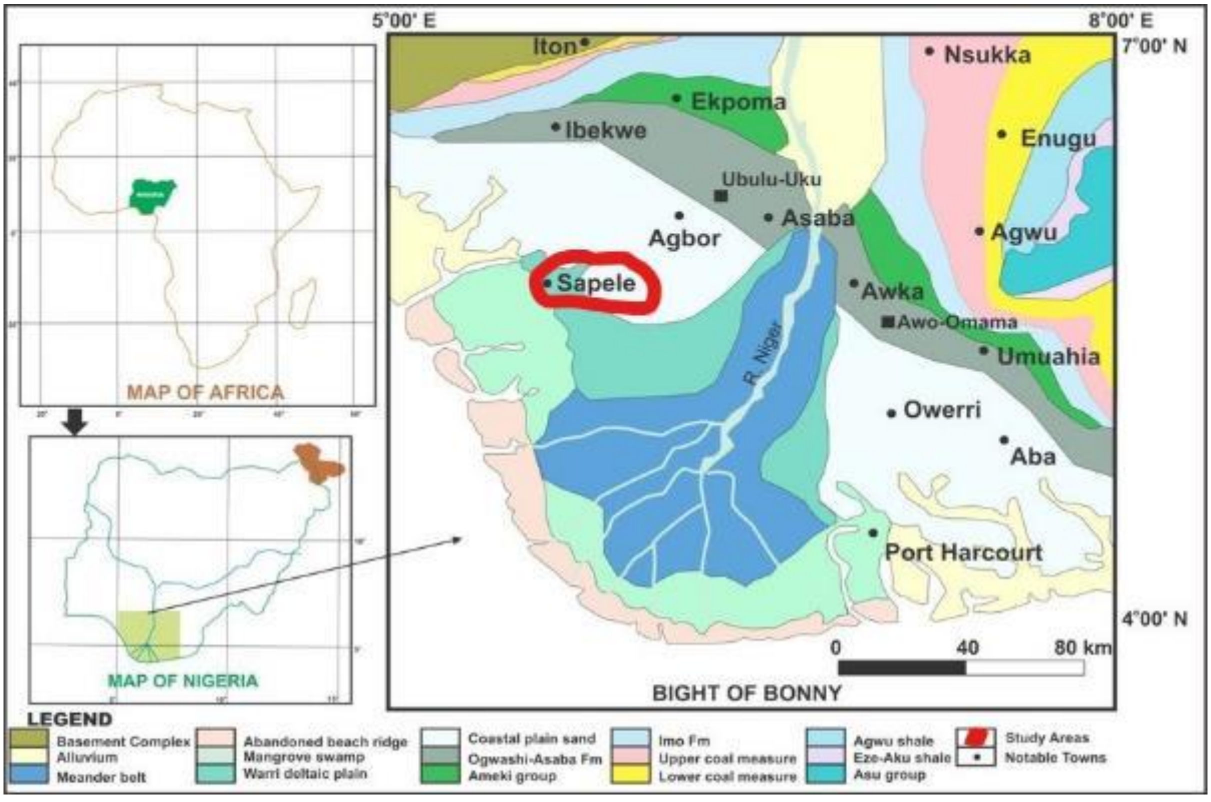

Figure 1: Geological Map of the Niger Delta Basin showing the Study Area (Oyebanjo *et al.*, 2018).

Depositional Environment of the Niger Delta

According to Short and Stauble (1967), the Niger Delta area may be divided into three main sedimentary environments, and they are the continental environment, the transitional environment and the marine environment.

The Continental environment comprises the alluvial environment, including the braided stream and meander-belt system of the upper deltaic plain. The sediments deposited in this zone are predominantly sands. Feldspar grains are common and sand grains commonly are limonite coated. Finer-grained sediments (silt and clay) are deposited in the adjacent fresh-water back swamps and oxbows, together with large quantities of plant remains.

The Transitional environment comprises the brackish-water lower deltaic plain (mangrove swamps, flood-plain basin, and marsh) and the coastal area with its beaches, barrier bars, and lagoons. The sediments in this environment are distinctly fine-grained than in the continental environment. Feldspar is scarce and brackish-water faunas may occur.

The Marine environment includes the submarine part of the delta, the delta fringe with its fine sand, silt, and clay, and the associated marine faunas. This environment grades laterally into the holomarine environment which is not affected by deltaic activity (Figure 2).

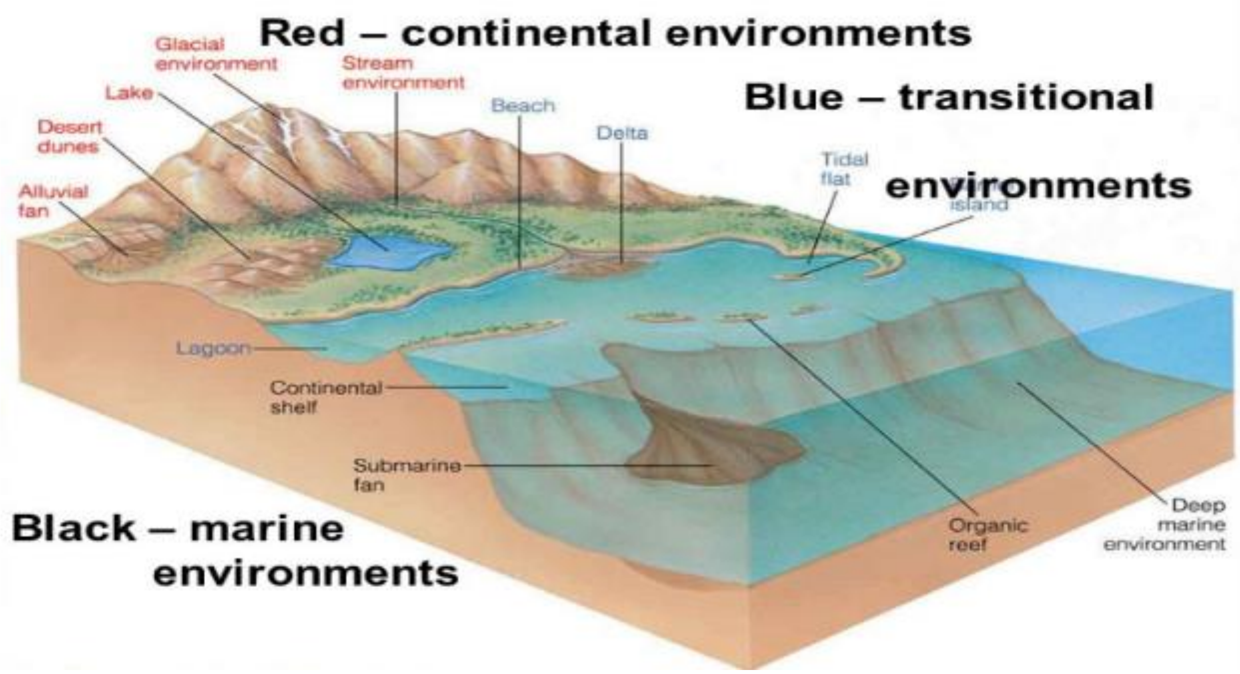

Figure 2: Depositional environments of the Niger Delta (Stacher, 1995).

The succession of the Niger Delta is characterized by an overall coarsening upward regressive sequence from open marine and pro-delta shales of the Akata Formation, through the paralic sediments of the Agbada Formation, to the delta-front and lower-delta plain deposits of the Benin Formation. According to Allen (1965) and Weber (1971), the Niger Delta sequence has been described as a wave and tide-dominated delta characterized by Barrier Island, tidal channels, and tidal deltas.

Weber (1971), established five physiographic provinces in the Niger Delta Basin:

i. Holomarine zone: Predominantly of clay deposition and ranges in depth from the outer shelf to 33m.
ii. Transition zone: Barrier foot or fluvio-marine sedimentation composed typically of laminate clays, silts, and fine sands in water 3-33m deep.
iii. Barrier bars: These occur along the coastal belt and consist of fine to medium-grained sands. At certain depths, the bars may inter-finger with barrier foot sediments.
iv. Tidal coastal plain: Includes tidal swamps and flats and extends behind barrier bars. The sediments vary from medium to coarse-grained sands in channel fills, fine clayey sands in natural levees to clayey and peaty deposits in swamps and lagoons.
v. Flood plains: Deposits of that sedimentary environment consist of medium to coarse-grained point-bar sands and clayey back swamp deposits.

The Cenozoic Niger Delta displays concentric arrangements of terrestrial and transitional depositional environments. According to Short and Stauble (1967), these environments can be broadly categorized into three distinct facies belts, namely; continental delta top facies, paralic delta front facies belt and pro-delta facies. Fluvial processes control sedimentation in the lower flood plain of the delta top environment while tidal influence prevails in the mangrove swamps coastward.

MATERIALS AND METHODS

Inference of the palaeodepositional environments of the studied area was made based on the biofacies information interpreted from the qualitative and quantitative evaluation of the benthonic foraminifers' assemblages of the formation as indicated on the biostratigraphic data. This has been integrated with the lithologic description of the wells across the fields. Foraminifera data was most useful in the estimation of Paleobathymetry, it involved the use of relative abundance and diversity of the foraminifera encountered as well as the occurrence of environmentally significant taxa

Well-log information obtained from gamma-ray log values and signatures/patterns integrated with paleo bathymetric data were used to delineate various rock units and lithofacies belonging to various environments of depositional. Bell-shaped log patterns indicate increasing clay content up section or fining upward trends or an upward increase in gamma-ray value, a typical feature of fluvial channel deposits. Funnel-shaped log patterns indicating decreasing clay content up section or a coarsening upward trend clearly showed deltaic progradation. The Cylindrical (blocky or boxcar) log motif was delineated as a thick uniformly graded coarse-grained sandstone unit, probably deposits of a braided channel, tidal channel, or subaqueous slump deposit. The serrated log motif suggested intercalation of thin shales in a sandstone body, typical of fluvial, marine, and tidal processes (Figure 3).

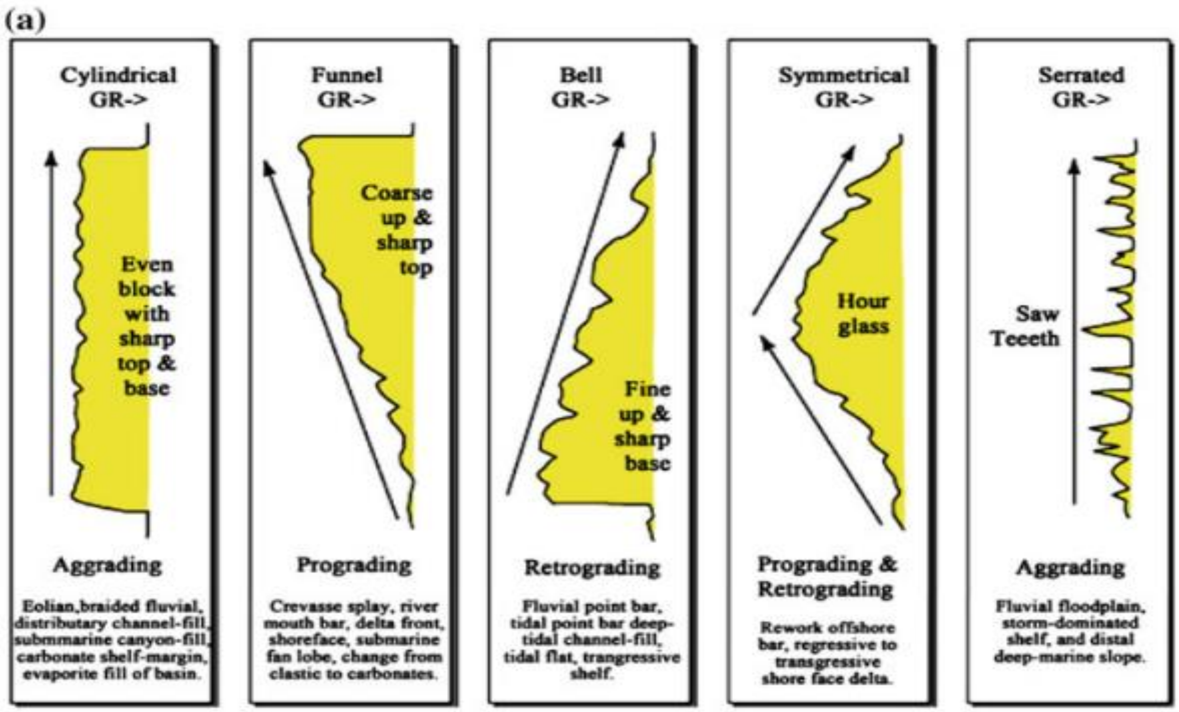

Figure 3: Models for well log response to sediment packages and various stacking patterns. Gamma-ray response to stacking pattern/grain size variation model (Emery and Myers, 1996)

These subsurface data belong to Seplat Petroleum Development Company PLC (Seplat Energy PLC) and were released under the approval of the Department of Petroleum Resources (DPR), Nigeria. The data were calibrated using the established zonation schemes contained in the SPDC (2010), Niger Delta Chronostratigraphic Chart (Figure 6) and Cenozoic Chronostratigraphic Chart of Blow (1969), Berggren *et al.*, (1995), Wade *et al.*, (2011), Gamma-ray response to stacking pattern/grain size variation model of Emery and Myers (1996), and the Paleobathymetric and depositional environment chart of Allen, (1965), as shown in Figures 4, 5 and 7.

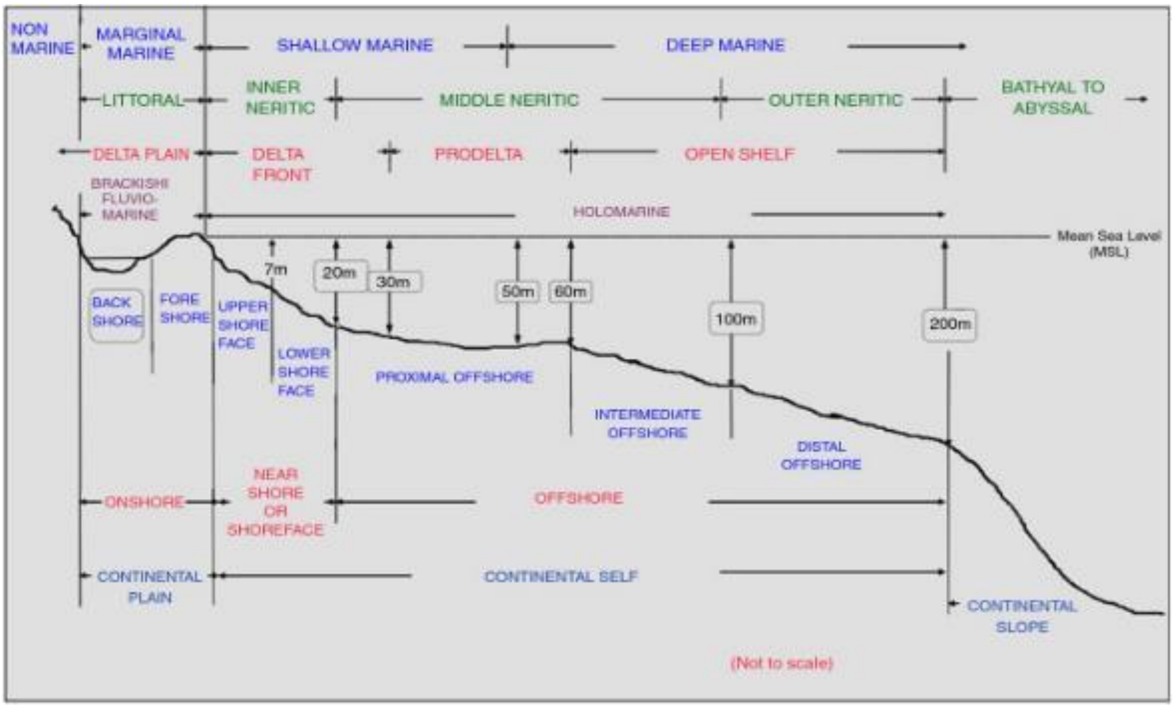

Figure 4: Paleobathymetric and depositional environment chart (Allen, 1965).

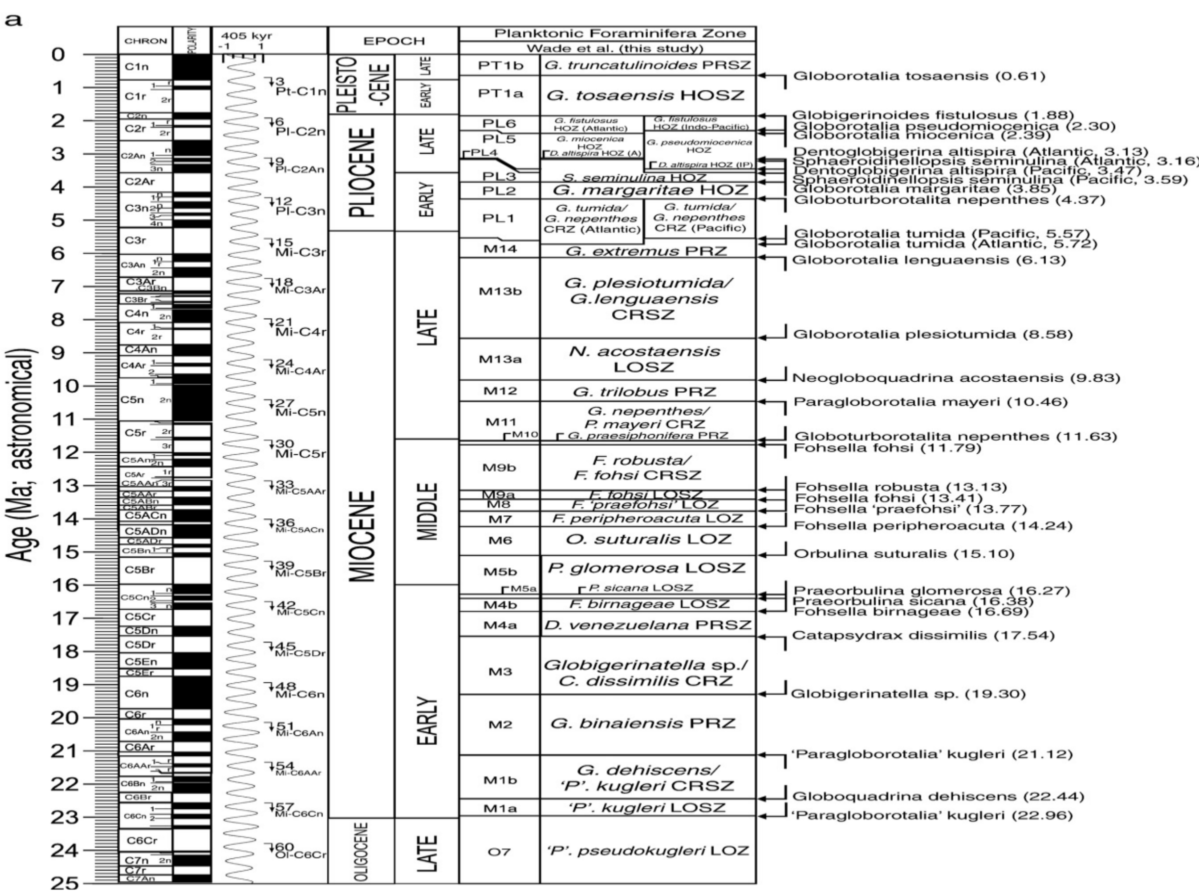

Figure 5: Planktonic Foraminifera Bioevents for Neogene and late Paleogene (Wade *et al.*, 2011)

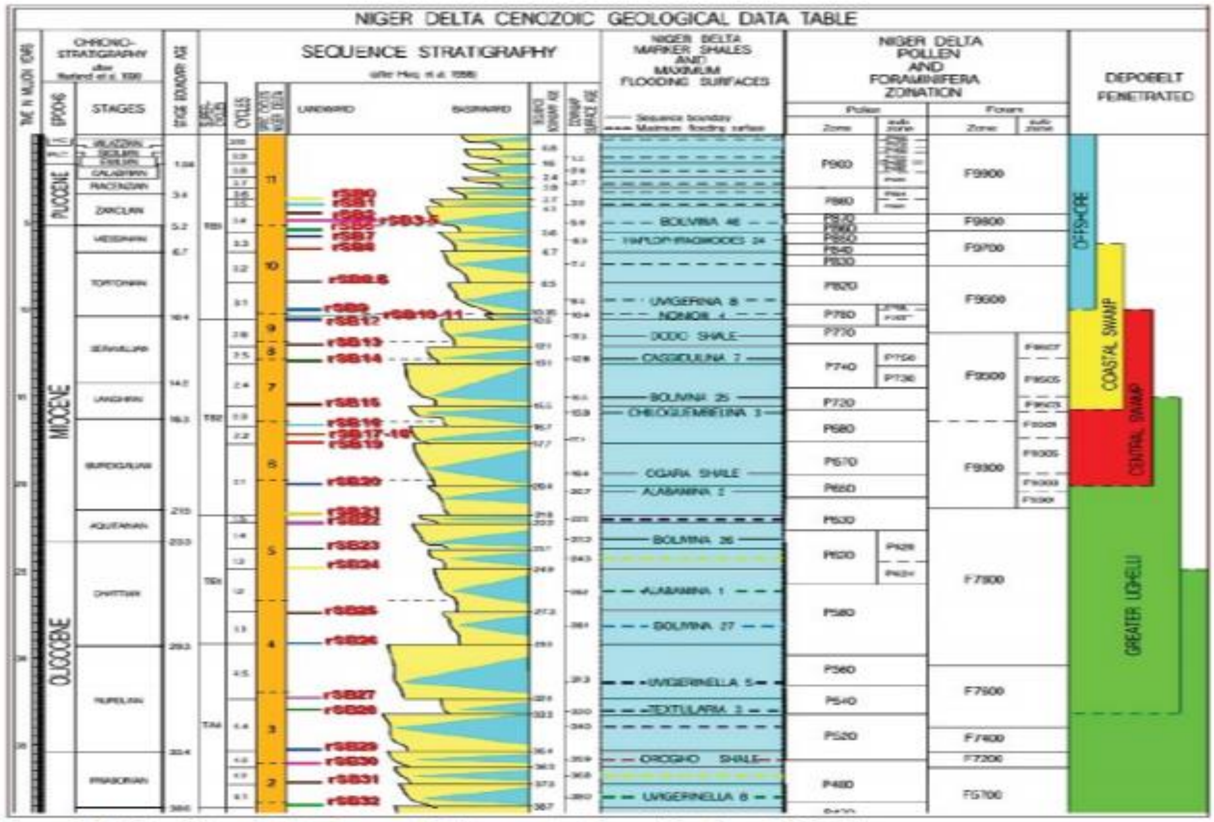

Figure 6: Niger Delta Chronostratigraphic Chart showing geologic interval (SPDC, 2010)

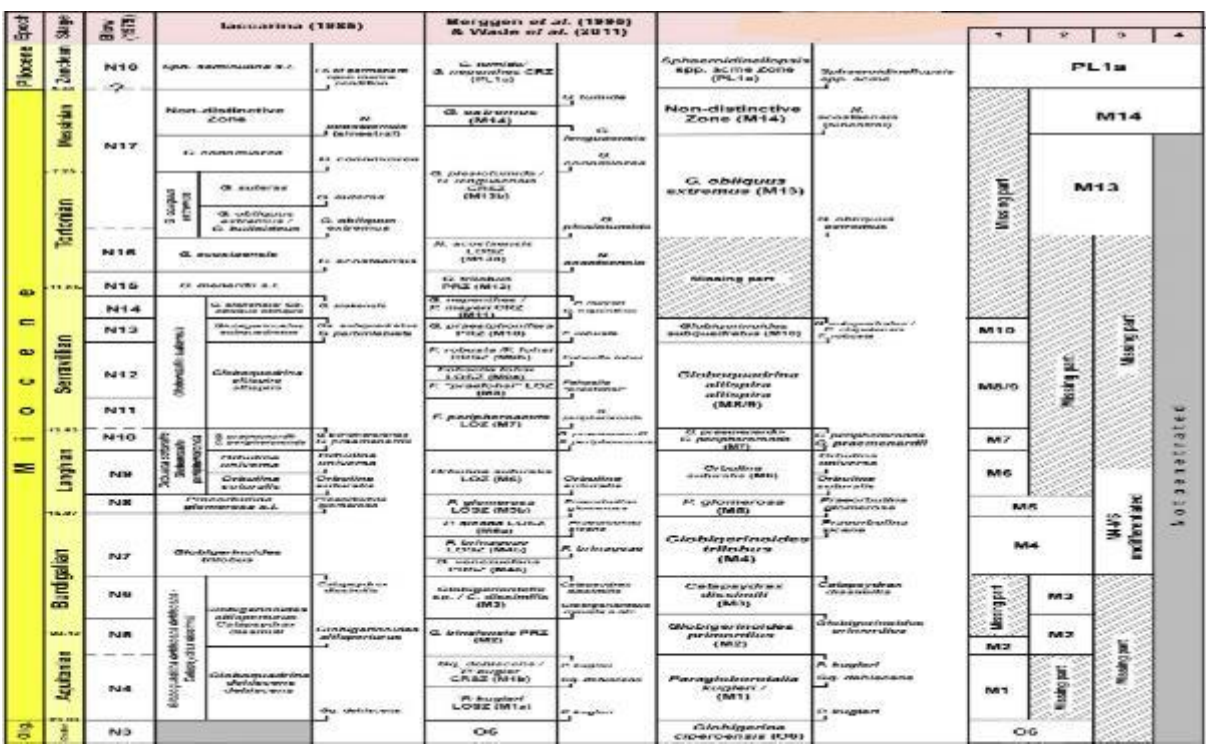

Figure 7: Miocene-Pliocene Chronostratigraphic Chart of Blow (1979), Laccarina (1985), Berggren *et al.*, (1995) and Wade *et al.*, (2011)

RESULTS AND DISCUSSION

Biozonation

Six zones have been proposed in this study based on the International stratigraphic guide of Blow (1969), Berggren *et al.,* (1995), and Wade *et al.,* (2011) and the observation of the ranges of planktonic foraminifera are Catapsydrax Dissimilis Concurrent-Range Zone (Magnetochronologic calibration: Chron C6n–Chron C5Dr. Astronomical cycle calibration: 48Mi–C6n–44Mi–C5Dn. Estimated age: Early Miocene: 19.66–17.62 Ma.

The first zone is the Stratigraphic interval (3810 m or 12573 ft – 3470 m or 11451 ft). This is the first (oldest) zone of Sapele deep, it is defined by the concurrent range of the nominate taxa between the first downhole occurrence (FDO) of *Catapsydrax dissimilis* at the base and the Last Downhole Occurrence (LDO) of Praeorbulina *glomerosa* at the top (Table 1). Other planktonic forms occurring within the zone are *Fohsella birnageae and Globigerinatella insueta*. The zone is equivalent to N6–N7 zone of Blow (1969), M3–M4 zone of Berggren *et al.,* (1995) and M3–M5a zone of Wade *et al.,* (2011). The extinction of *Catapsydrax dissimilis* marks the N6-N7 boundary of Blow (1969). Catapsydrax dissimilis is continuously present in the Early Miocene. The age of this zone is Early Miocene based on the presence of planktonic index forms such as *Fohsella birnageae, Globigerinatella insueta, Praeorbulina sicana and Catapstdrax dissimilis.*

The second zone is Praeorbulina glomerosa interval zone. The zone is defined by the FDO of both *Orbulina suturalis and Praeorbulina glomerosa* at the base and the LDO of *Fohsella robusta and Fohsella fohsi* at the top (Table 2). Other planktonic forms occurring in this zone are *Fohsella peripheroacuta and Fohsella praefohsi.*

This zone is equivalent to the N8–N9 zone of Blow (1969), M5a–M11 zone of Berggren *et al.,* (1995) and M5b–M10 zone of Wade *et al.,* (2011). The age of the zone is Middle Miocene, based on the presence of the above-mentioned planktonic index forms.

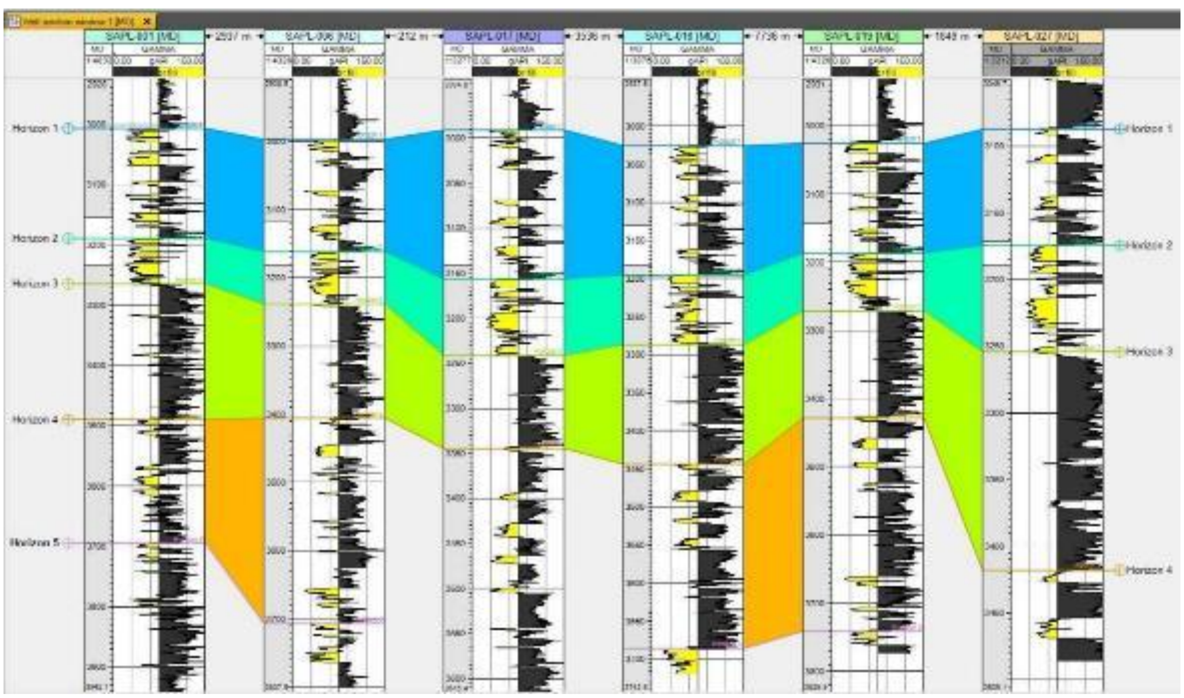

Figure 8: Well log Stratigraphic correlation of Sapele Deep (Using Petrel®2016)

The third zone Globoturborotalita nepenthes Concurrent–range zone. This zone is the youngest zone of Sapele deep and the oldest zone of Sapele shallow. It is defined by the concurrent range of the nominate taxa between the first down hole occurrence of both *Globoturborotalita nepenthes* and *Neogloboquadrina acostaensis* at the base and the last downhole occurrence of both *Globigerinoides extremus and Globorotalia lenguaensis* at the top. Other planktonic forms occurring in this zone are *Paragloborotalia mayeri*, *Globorotalia plesiotumida* and *Cassigerinella chipolensis*.

This zone is equivalent to the N15-N17 zone of Blow (1969), M12-M14 zone of Berggren *et al.,* (1995) and M11-M14 zone of Wade *et al.,* (2011). The age of the zone is Late Miocene, based on the presence of the above-mentioned planktonic index forms.

The fourth zone is the Globorotalia margaritae partial–range zone. This zone is defined by the Biostratigraphic interval between the first downhole occurrence of both *Globorotalia tumida and Globorotalia cibaoensis* at the base and the last downhole occurrence of *Globorotalia margaritae* at the top. Other planktonic forms occurring in this zone are *Globoturborotalita nepenthes* and *Sphaeroidinella dehiscens.*

This zone is equivalent to the N18–N19 zone of Blow (1969), PL1a–PL2 zone of Berggren *et al.,* (1995) and PL1–PL3a zone of Wade *et al.,* (2011). The age of the zone is Early Pliocene, based on the presence of the above-mentioned planktonic index forms.

The fifth zone is the Dentoglobigerina altispira interval zone. This zone is defined by the FDO of *Sphaeroidinellopsis seminulina* at the base and the LDO of *Dentoglobigerina altispira* at the top (Table 1). Other planktonic forms occurring in this zone are *Globorotalia miocenica and Globorotalia pseudomiocenica.*

This zone is equivalent to the N20 zone of Blow (1969), PL3–PL6 zone of Berggren *et al.*, (1995) and PL3b–PL6 zone of Wade *et al.*, (2011). The age of the zone is Late Pliocene, based on the presence of the above-mentioned planktonic index forms.

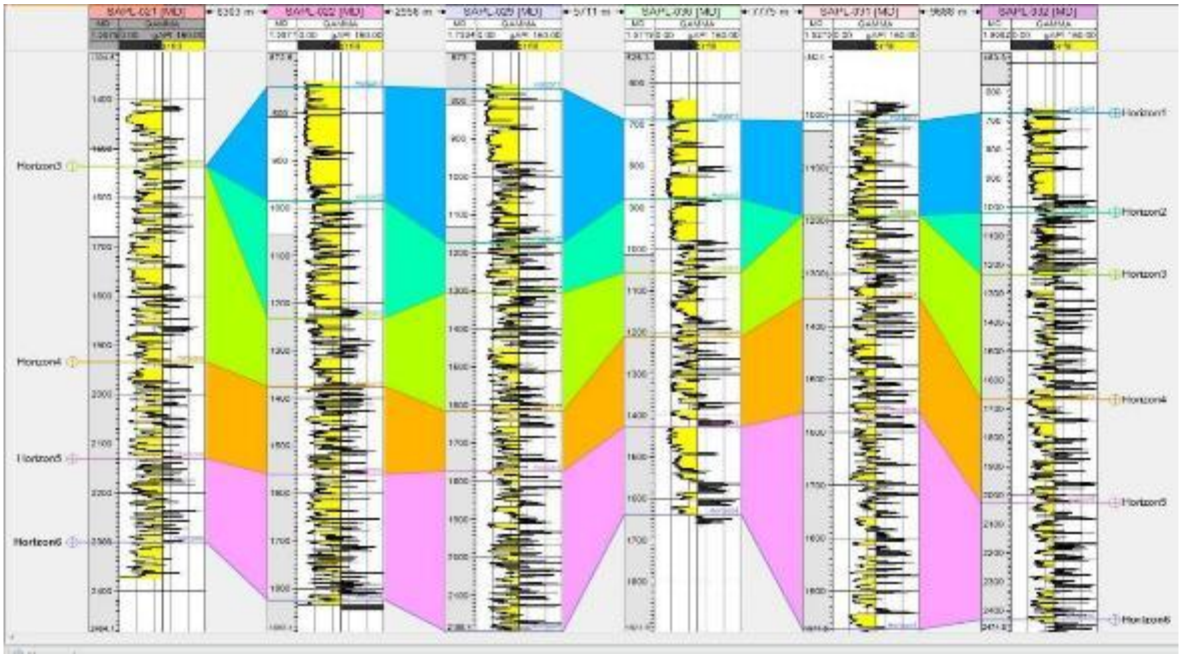

Figure 10: Well Log Stratigraphic correlation of Sapele Shallow (Using Petrel®2016).

The sixth zone is the Globigerinoides fistulosus interval zone. This zone is the youngest zone of the Sapele shallow, and it is defined by the FDO of *Globigerinoides fistulosus* at the base and the LDO of *Globorotalia tosaensis* at the top. Other planktonic forms occurring in this zone are *Globorotalia miocenica and Globoturborotalita aperture.*

This zone is equivalent to the N21 zone of Blow (1969), PT1a zone of Berggren *et al.*, (1995) and PT1a zone of Wade *et al.,* (2011). The age of the zone is Early Pleistocene, based on the presence of the above-mentioned planktonic index forms (Table 1).

Table 1: Biozonation of Sapele Fields

Depth (Ft)	Field	Chronostratigraphic Age	Blow (1969) Foram Zone	Berggren *et al.*, (1995) Foram Zone	Wade *et al.*, (2011) Foram Zone	Foraminifera Event	Zones
3755.4 - 3168	Sapele Shallow	Pleistocene Recent (1.88–0 Ma)	N21	PT1a	PT1a	LDO: Globorotalia tosaensis FDO: Globigerinoides fistulosus	**Globigerinoide fistulosus interval zone**
3755.4 - 3224.1	Sapele Shallow	Late Pliocene (3.16–3.13 Ma)	N20	PL3–PL6	PL3b–PL6	LDO: Dentoglobigerina altispira FDO: Sphaeroidinellopsis seminulina	**Dentoglobigerina altispira interval zone**
4042.5 - 3481.5	Sapele Shallow	Early Pliocene (4.36–3.84 Ma)	N18–N19	PL1a–PL2	PL1–PL3a	LDO: Globorotalia margaritae FDO: Globorotalia tumida & Globorotalia cibaoensis	**Globorotalia margaritae partial–range zone**
10477.5 - 6814.5	Sapele Deep	Late Miocene (11.55–10.53 Ma)	N15-N17	M12-M14	M11-M14	FDO: Globigerinoides extremus and Globorotalia lenguaensis FDO: Globoturborotalita nepenthes and Neogloboquadrina acostaensis	**Globoturborotalita nepenthes Concurrent–range zone**
11946 - 10279.5	Sapele Deep	Middle Miocene (16.29–15.10 Ma)	N8–N9	M5a–M11	M5b–M10	LDO: Fohsella robusta and Fohsella fohsi FDO: Orbulina suturalis and Praeorbulina glomerosa	**Praeorbulina glomerosa interval zone**
12573 - 11451	Sapele Deep	Early Miocene (19.66–17.62 Ma).	N6–N7	M3–M4	M3–M5a	LDO: Praeorbulina glomerosa FDO: Catapsydrax dissimilis	**Catapsydrax dissimilis Concurrent-range zone**

Paleoenvironment

Inference of the palaeodepositional environments of the studied area was made based on the biofacies information interpreted from the qualitative and quantitative evaluation of the benthonic foraminifers' assemblages. This has been integrated with the lithologic description of the wells across the fields. It is on these bases, that the sequences of the wells are interpreted to have fluctuated from shallow marine to deep marine (i.e., inner neritic to middle neritic to outer neritic to Bathyal) for Sapele deep and from marginal marine to deep marine (i.e., Littoral to inner neritic to middle neritic to outer neritic) for Sapele shallow.

Foraminifera data was most useful in the estimation of Paleobathymetry, it involved the use of relative abundance and diversity of the foraminifera encountered as well as the occurrence of

environmentally significant taxa. It is on these bases that the sediments of the wells were interpreted to have fluctuated from marginal marine to bathyal as follows Bathyal Depositional Environment, Outer Neritic Depositional Environment, Middle Neritic Depositional Environment, Inner Neritic Depositional Environment and Littoral Depositional Environment.

Table 2: Foraminifera distribution across the Study area

FIELD	DEPTH (M)	ENVIRON	BENTHONIC	PLANKTONIC
Sapele shallow	895m (2953.5 ft)– 1420m (4686 ft)	Lit	27	9
Sapele shallow/deep	960 m (3168 ft) – 3088 m (10190.4 ft)	IN	831	231
Sapele shallow/deep	963 m (3177.9 ft) -3525 m (11632.5 ft)	MD	601	527
Sapele shallow/deep	1020 m (3366 ft) – 3730 m (12309 ft)	ON	286	873

The Bathyal Depositional Environment environment is marked at the interval of 3172 m (10467.6 ft) - 3810 m (12573 ft) across Sapele deep and depth intervals of the studied area that are inferred to this environment are from 1020 m (3366 ft) – 3730 m (12309 ft) across both fields (Sapele Deep and Sapele Shallow).

Based on the paleoenvironmental interpretation provided above, it can be inferred that the Paleobathymetry of the study area ranges from the Littoral (Marginal marine) of the continental plain to the Bathyal (main sea level) of the continental slope depositional environment. This agrees with Oboh-Ikuenobe *et al.,* (2005), Boersma (1978), Bandy (1964), Funnel (1967) and Brasier (1979).

CONCLUSION

From the qualitative and quantitative evaluation of biofacies data, the interpreted depositional environment of the study area fluctuated from shallow marine to deep marine (inner neritic to middle neritic to outer neritic to Bathyal depositional environment) for Sapele deep and from marginal marine to deep marine (Littoral to inner neritic to middle neritic to outer neritic depositional environment) for Sapele shallow. The study area has six planktonic foraminiferal zones (*Catapsydrax dissimilis* Concurrent-range zone, *Praeorbulina glomerosa* interval zone, *Globoturborotalita nepenthes* Concurrent-range zone, *Globorotalia margaritae* partial-range zone, *Dentoglobigerina altispira* interval zone and Globigerinoides fistulosus interval zone). These zones are equivalent to the N6–N7, N8–N14, N15–N17, N18–N19, N20, and N21 zones of research work conducted in other locations and also equivalent to M3-M4, M5a-M11, M12-M14, PL1a-PL2, PL3-PL6 and PT1a zones of previous research conducted by other researchers in other areas.

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