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An Integrated Wireline-Log and Biostratigraphic Appraisal of Olure-1 and Abigboro-1 Wells, Onshore Niger Delta

Olugbenga A. Boboye[1], Abdulkarim S. Oladayo[1], Emmanuel E. Okon[2]

[1]Department of Geology, University of Ibadan, Ibadan, Nigeria
[2]Department of Geology, University of Calabar, Calabar, Nigeria
Email: boboyegbenga@yahoo.com, etyboy911@yahoo.com

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Abstract

Studies of two wells within the coastal swamp onshore Niger Delta were carried out in order to determine the chronology, biozonation, and establishment of sequence stratigraphic framework for the representative wells. A total of twenty-eight (28) cutting samples were recovered and analysed from Abigboro-1 and Olure-1 exploratory wells for their foraminifera, calcareous nannofossils and palynomorphs' compositions. The results indicated the presence of diverse species within the wells, which include *Lenticulina grandis*, *Florilus ex. gr. costiferum*, *Hanzawaia concentrica*, *Hopkinsina bononiensis*, *Marginulina costata* and *pseudonodosaria* sp., *Bolivina mandoroveensis*, *Eponides eshira*, *Lenticulina grandis*, *Lenticulina grandis*, *Cibicorbis inflata*, *Heterolepa floridana*, *Florilus ex. gr scaphum*, *Poroeponides lateralis*, *Uvigerina sparsicostata*, *Uvigerina subperegrina*, *Bolivina ex. gr. scalptrata*, *Valvulineria* sp. and *Epistominella pacifica.* An inner neritic (1694 m - 2161 m), coastal deltaic (1557 m - 1640 m) and shallow inner neritic (1347 m - 1554 m) palaeoenvironment was suggested for Olure-1 well while a broad grouping of the intervals as inner to middle neritic was suggested for Abigboro-1 well. The ratio of species abundance/diversity and integration of log suite data predicted two Maximum Flooding Surfaces (MFS) and one Sequence Boundary (SB) for Olure-1 well. The MFS were encountered at depths 2728 m (MFS 1) and 1797 m (MFS 2), while the SB was predicted at depth 2602 m (SB1). Diverse systems' tracts were identified and delineated from wireline logs of Olure-1 well and the implication for petroleum exploration was discussed. Late Oligocene - early Miocene age has been assigned for the wells based on the recovered diagnostic species.

Keywords

Species, Palaeoenvironment, Palynomorphs, Nannofossil, Biozonation

1. Introduction

The Niger Delta is situated in the Gulf of Guinea and extends throughout the Niger Delta province [1] (**Figure 1**). From Eocene to Present, the delta has prograded south-westward, forming depobelts that represent the most active portion of the delta at each stage of its development [2]. These depobelts form one of the largest regressive deltas in the world with an area of 300,000 km^2 [3], sediment volume of 500,000 km^3 and a sediment thickness of over 10 km in the basin depocenter. The Niger Delta has been identified as an important sedimentary basin in Nigeria because of its reputation as one of the most prolific oil and gas provinces in the world, and it is known to contain one identified petroleum system [3] [4]. With increasing exploration and exploitation of hydrocarbon in the Niger Delta, which in turn has made the search for oil and gas increasingly difficult, it has become pertinent to acquire knowledge and expertise in order to improve geological research and technology to field development and production of this vast hydrocarbon resource. This however has necessitated re-evaluation via the concept of high resolution biostratigraphy and sequence stratigraphy of the basin in order to obtain a clearer resolution of the subsurface stratigraphy of the Niger Delta sedimentary basin. This is made possible by the integration of biostratigraphic, seismic and wireline log data. For each of these data, a sequence stratigraphic model is developed via unconformity bounding surfaces, flooding

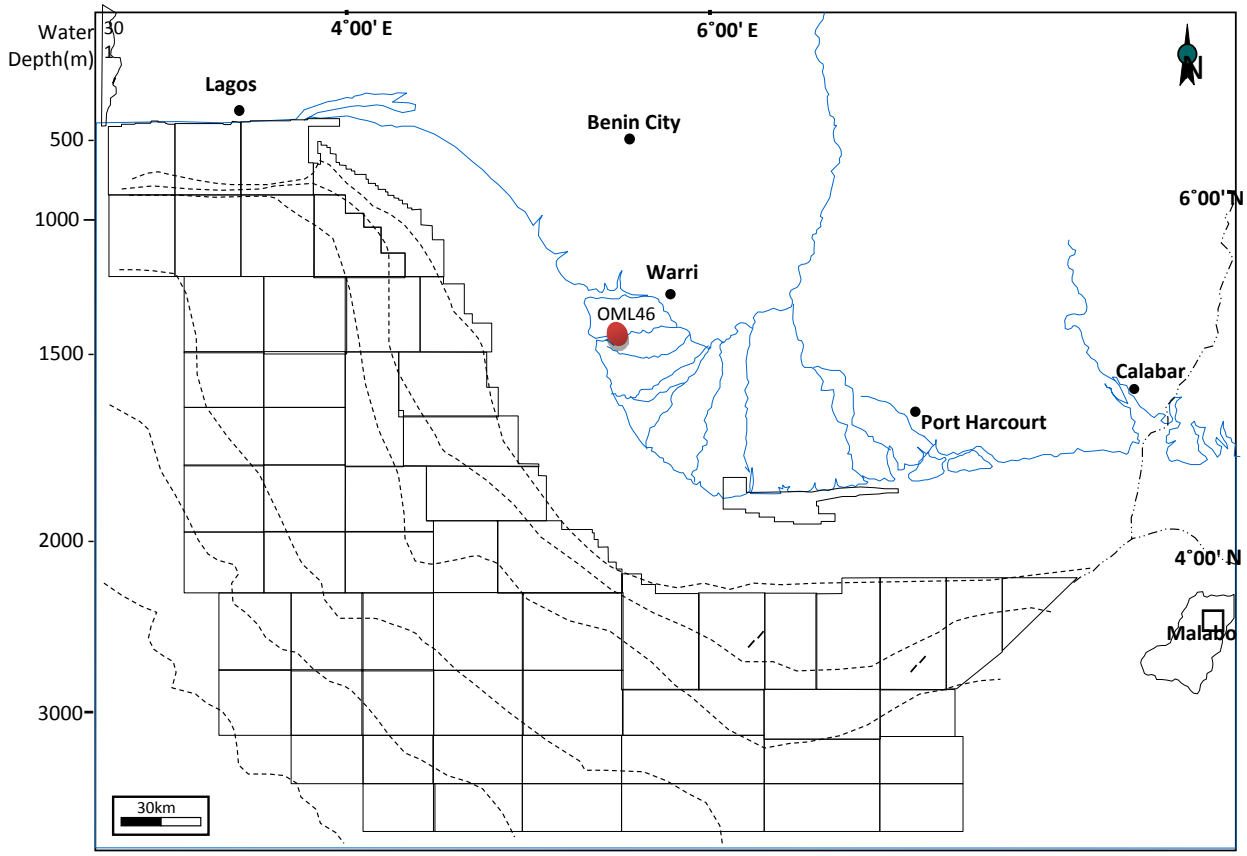

Figure 1. Map of Niger delta showing the location of studied area within OML 46.

surfaces and systems tracts within sequence(s) and comparison of results is made across diverse data sets for accuracy and precision.

2. Location of the Study Area

The Niger Delta oil province of Nigeria is located on the southernmost end of Nigeria on the West African Continental margin. The study area is located onshore within OML 46. The basin lies between longitude 3˚E and 9˚E and latitude 4˚E and 5˚2'N (**Figure 1**).

3. Previous Work

The geology of Niger Delta in terms of age determination, depositional environment and biostratigraphic zonation has been discussed by many authors amongst which are Clement *et al*. [5] who reported the sequence stratigraphic study of "UNIABR Field" in northern delta depobelt of Niger Delta, and were able to identify five maximum flooding surfaces (MFS) and five sequence boundaries (SB) in which their average depths were tied to their absolute ages. Late Eocene to early Miocene age was proposed for the studied area based on palynological zonation. Oloto and Promise reported on biostratigraphic study and palaeoenvironmental reconstruction indicated early-middle Miocene age for Bongo ST-1, Ngolo and Opukushi–25 wells [6]. Early Miocene was proposed for Bongo-4 well based on the First Appearance Datum (FAD) and Last Appearance Datum (LAD) of diagnostic fauna and flora of *Globorotalia obesa*, *Globigerinoides bisphericus*, *G. obliguus*, *Globigerinoides immaturus*, *Orbulina universa* and *Orbolina suturalis.* The suite of early-middle Miocene benthic foraminiferal assemblage recovered include *Bolivina miocenia*, *Lenticulina rotulata*, *Alveolephragmium crassium*, *Bolivina beyrichi*, *Saccammina complanata* and *Cyclammina minima*. Also establish was the depositional environment and palaeobathymetry of the studied wells based on depth diagnostic benthics, floral and associated accessories like glauconite, mica, faecal pellets foraminiferal test linings, pediastrum and fungal spores within each wells. The depositional environment established range from marginal marine to shallow marine (littoral-middle neritic), corresponding to onshore to offshore within the continental plain to the continental shelf. Two microfossil biozones of *Cyclammina minima* and *Haplophragmoides narivaensis* have been established in the Oborduka-1 well, deep offshore of Niger Delta [7]. They assigned late Miocene age and a nearshore and/or marginal marine environment for the sediments based on the recovered fauna and flora assemblages. Boboye and Adeleye documented the high resolution biostratigraphy of some early Pliocene-late Miocene strata using calcareous nannoplankton and foraminiferal of the deep offshore Niger Delta area of Nigeria. Four condensed sections for the foraminiferal assemblages and four zones for the calcareous nannofossils as correlated to the Global Cycle Chart (NN 13, NN 11, NN 10 and NN 9) were established [8]. A tentative sequence stratigraphy framework was proposed and dated the Maximum Flooding

Surfaces as early Pliocene to late Miocene which was associated with the 5.0 Ma, 7.4 Ma, 8.6 Ma and 9.2 Ma. Van Hoeken-Klinkenbers palynological studies on boreholes samples in the western part of the Niger Delta concluded a Palaeogene age in some part of the Niger Delta exhibiting poor palynomorphs preservation [9]. A continuous temperature-climate optimum was demonstrated for the development of *Globigerina bulloides* and tropical climate for the development of *Globorotalia foshi* [10]. It was concluded that Tertiary fauna provinces were distributed asymmetrically about the equator probably by major ocean currents. Ozumba and Amajor reported a high resolution foraminiferal biostratigraphy of four wells (Kanbo-5, Egbedicreek-1, Angalalli-1 and Opukushi-5) located in the coastal and central swamp in the western Niger Delta [11]. They defined six foraminiferal zones (Assemblage/Partial range zones) for the middle to late Miocene Niger Delta namely: *Globigerina* cf *ciperoensis* Zone, *Nonion centrosulcatum*/*Chiloguembelina victoria* Zone, *Eponides eshira* Zone, *Uvigerina sparsicostata* Zone, *Spirosigmoilina oligoceanica* Zone, and *Florilus ex. gr. costiferum* Zone. The advantages of calcareous nannofossils in the recognition of marine flooding surfaces in the Niger Delta most especially in the late Miocene to late Pliocene time was discussed and recognized four delta wide flooding surfaces based on the *Discoaster quinqueramus*, *Ceratholithus* species and *Gephyrocapsa* species and *Sphenolithus* species. This corroborated the influx of *Sphenolithus abies* in the late Miocene of the Niger Delta [12].

4. Materials and Methodology

Data used in this study include log suites data and cuttings from two exploratory wells (Olure-1 and Abigboro-1) in Niger Delta. Systematic logging and detailed analysis and interpretation of the well logs, preparation and analyses for the fauna and flora contents were carried out. These were integrated to generate a sequence stratigraphic framework for the selected wells. The biostratigraphic analysis was carried out while the other analyses were achieved using Petrel and STRATABUG softwares.

Biostratigraphy Preparations

These cuttings were prepared for calcareous nannofosils, sporomorphs and foraminifera contents using standard preparatory techniques;

The calcareous nannofossil analysis involves the standard simple smear preparation technique of Perch-Nielsen [13]. About 5 g of the sample was gently crushed and dispersed in distilled water in a glass vial. It was dried at 50˚C and mounted on a glass slide with the Norland adhesive mounting medium. Species were identified using relevant reference slides, Chevron and Shell (SPDC) albums.

For the foraminiferal preparation, about 25 g of the sample were soaked in NaOH solution for 24 hours to ensure proper disaggregation of the samples and the liberation of any foraminifera or micro-fauna accessories within the cuttings.

The samples were then washed using a 63 micron sieve under a jet running water. The samples were then dried in an oven at 80˚C.

The palynomorph analysis entails the addition of Hydrofluoric acid (HF) and was then treated with 10% hydrochloric acid in a fume cupboard to remove carbonates. 10% HCl solution was then added and heated for 25 to 30 minutes. The samples were decanted thrice at an interval of 1 hour each through the Branson Sonifer, with the aid of 5 micron sieve to filter away the inorganic matter. The retrieved organic matter was stained with Safranin solution for easy identification of the dinocyst that are almost totally transparent. The Loctite impruv is used for permanent mounting of the slides. The slides were studied under a binocular light microscope and the identification was done via reference slides of Chevron and Shell albums.

5. Results and Discussion

The results showed that the biostratigraphy of Olure-1 and Abigboro-1 wells have fairly good microfossil recovery except for Abigboro-1 well which is barren in foraminifera and calcareous nannofossils (Figures 2-10 and Tables 1-5).

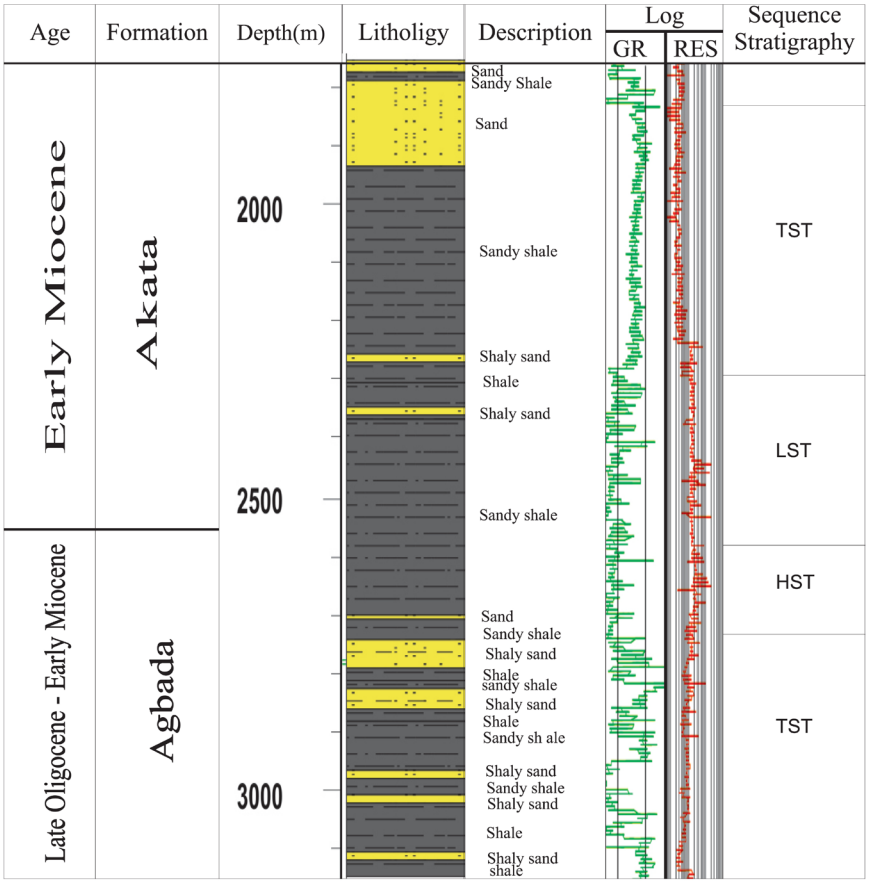

Figure 2. Lithologic section and sequence stratigraphic framework of the Olure-1 well. LST-Lowstand Systems Tract, TST-Transgressive Systems Tract, HST-Highstand Systems Tract.

Table 1. (a) Abundance and diversity of pollen and spores and (b) planktonic and calcareous foraminifera in Olure-1 well.

(a)

Depth (m)	Spores		Pollen	
	Abundance	Diversity	Abundance	Diversity
1664	20	3	35	3
1756	16	6	20	3
1975	30	4	48	9
2304	38	5	51	12
2487	45	4	51	10
2633	14	5	22	8
2652	18	5	28	8
2761	11	2	19	10
2981	30	5	24	6
3182	37	5	37	10

(b)

Depth (m)	Planktonic foraminifera		Calcareous foraminifera	
	Abundance	Diversity	Abundance	Diversity
1664	-	-	-	-
1756	-	-	1	1
1975	-	-	29	7
2304	-	-	52	10
2487	-	-	47	9
2633	2	2	42	8
2652	1	1	174	12
2761	3	2	3	2
2981	-	-	1	1
3182	-	-	3	2

Table 2. The abundance and diversity of calcareous nannofossils (Olure-1 well).

Depth (m)	Abundance	Diversity
1664	-	-
1756	-	-
1975	8	6
2304	1	1
2487		-
2633	1	1
2652	4	2
2761	-	-
2981	-	-
3182	-	-

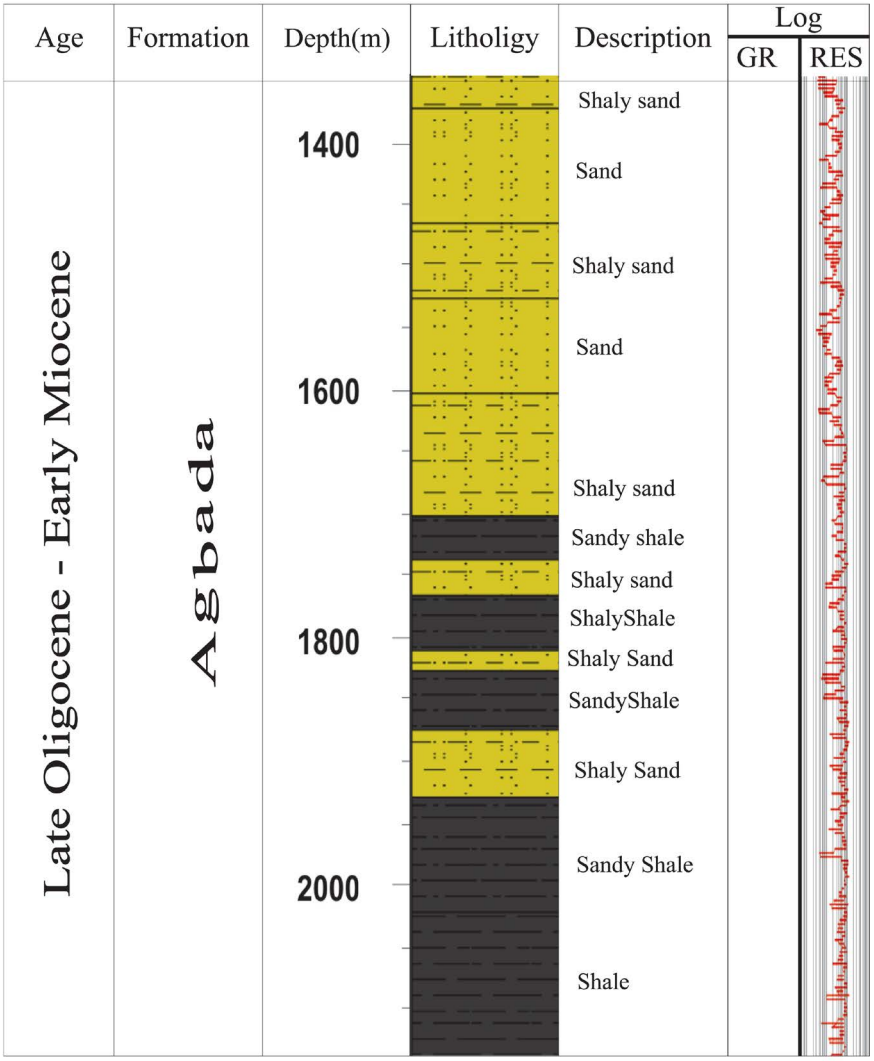

Figure 3. Lithologic section of the Abigboro-1 well. LST-Lowstand Systems Tract, TST-Transgressive Systems Tract, HST-Highstand Systems Tract.

Table 3. Total abundance of palynomorphs and foraminiferal assemblages for Olure-1 well.

Depth (m)	Abundance of spores	Abundance of pollen	Total	Abundance of planktonic foraminifera	Abundance of calcareous foraminifera	Total
1664	20	35	55	-	-	0
1756	16	20	36	-	1	1
1975	30	48	78	-	29	29
2304	38	51	89	-	52	52
2487	45	51	96	-	47	47
2633	14	22	36	2	42	44
2652	18	28	46	1	174	175
2761	11	19	30	3	3	6
2981	30	24	54	-	1	1
3182	37	37	74	-	3	3

Table 4. Total diversity of palynomorphs and for aminiferal assemblages for Olure-1 well.

Depth (m)	Diversity of spores	Diversity of pollen	Total	Diversity of planktonic foraminifera	Diversity of calcareous foraminifera	Total
1664	3	3	6	-	-	0
1756	6	3	9	-	1	1
1975	4	9	13	-	7	7
2304	5	12	17	-	10	10
2487	4	10	14	-	9	9
2633	5	8	13	2	8	10
2652	5	8	13	1	12	13
2761	2	10	12	2	2	4
2981	5	6	11	-	1	1
3182	5	10	15	-	2	2

Table 5. Abundance and diversity of pollen and spores in Abigboro-1 well.

Depth (m)	Spores		Pollen	
	Abundance	Diversity	Abundance	Diversity
1356	29	5	22	7
1676	261	8	242	16
1713	283	7	271	14
1722	275	5	33	17
1731	244	6	19	15
1750	269	6	19	14
1788	371	6	183	16
1850	152	4	79	5
1923	119	3	118	9
1942	289	4	113	15
1960	22	3	13	5
1996	25	4	34	7
2033	22	3	10	6
2070	17	4	28	5
2115	298	3	132	14
2134	296	6	261	14
2143	268	5	98	9
2161	89	3	77	10

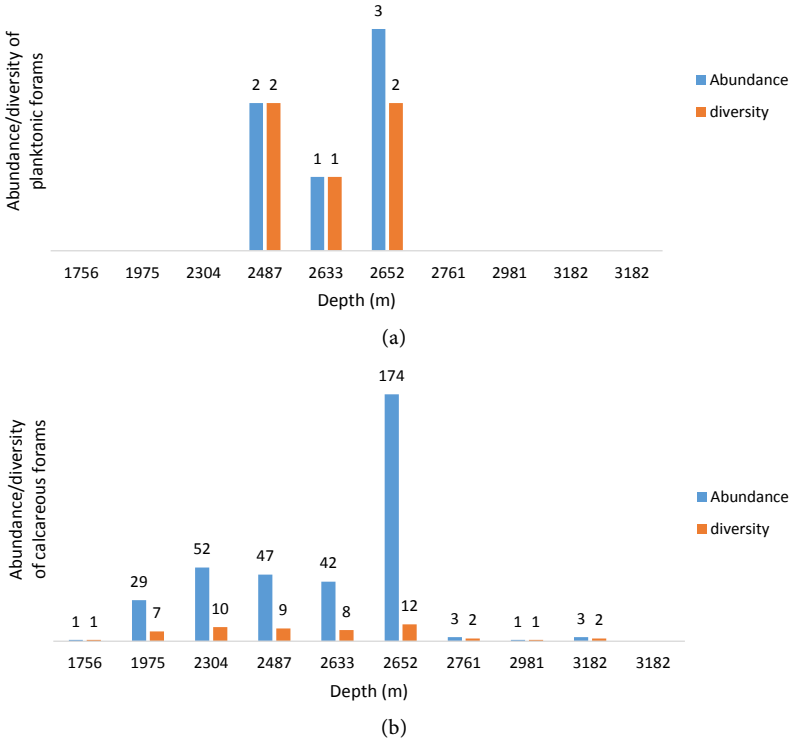

Figure 4. Plots of abundance/diversity of planktonic and calcareous foraminifera against depth (Olure-1 well).

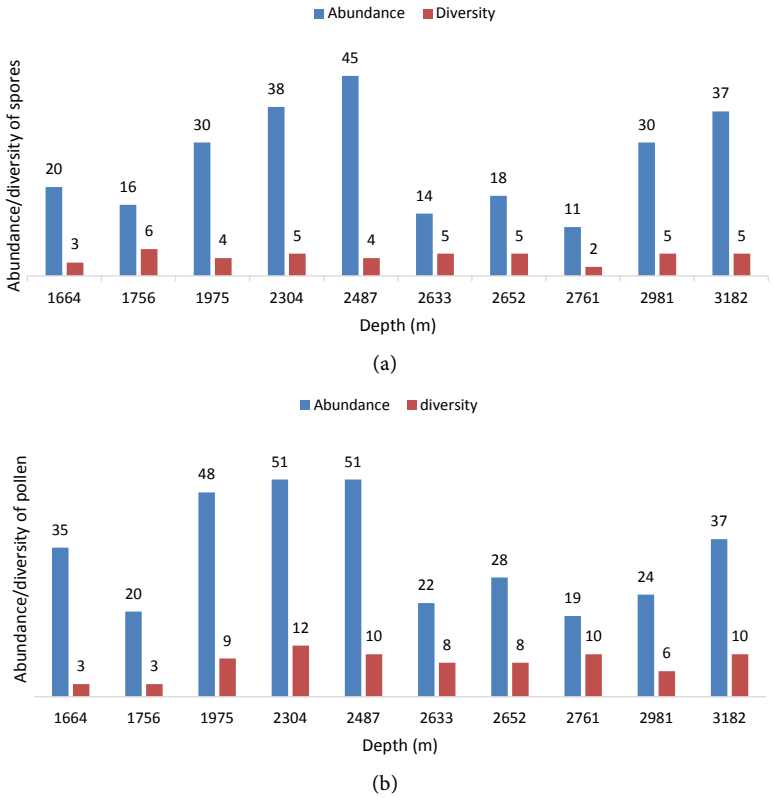

Figure 5. Plots of abundance/diversity of (a) Spores and (b) Pollen against depth (Olure-1 well).

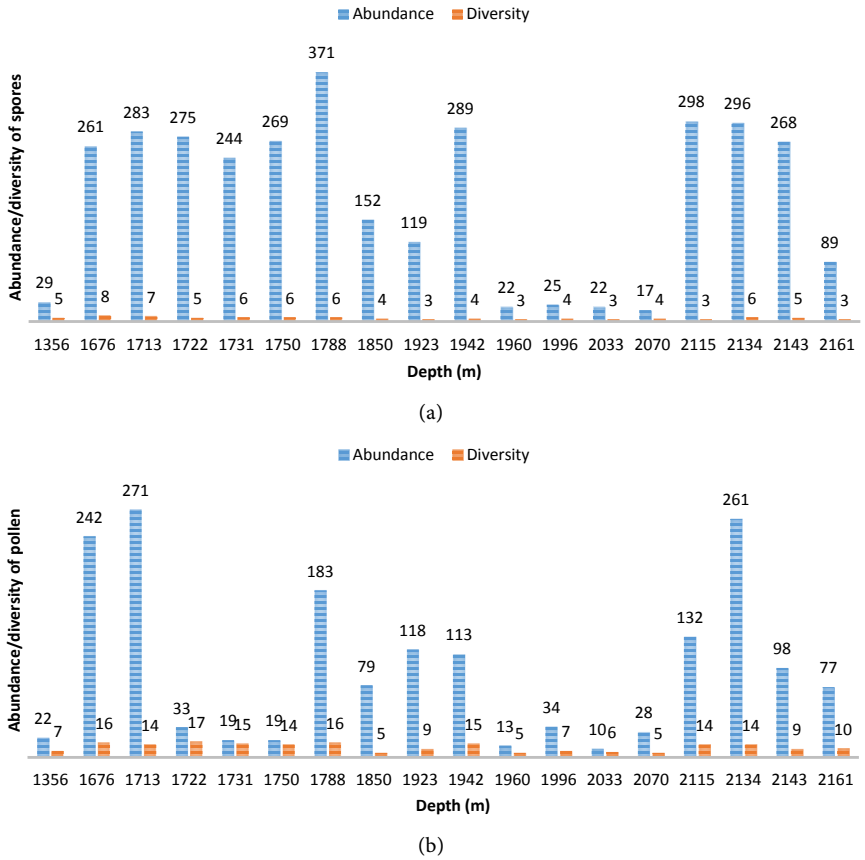

Figure 6. Plots of abundance/diversity of (a) Spores (b) Pollen against Depth (Abigboro-1 well).

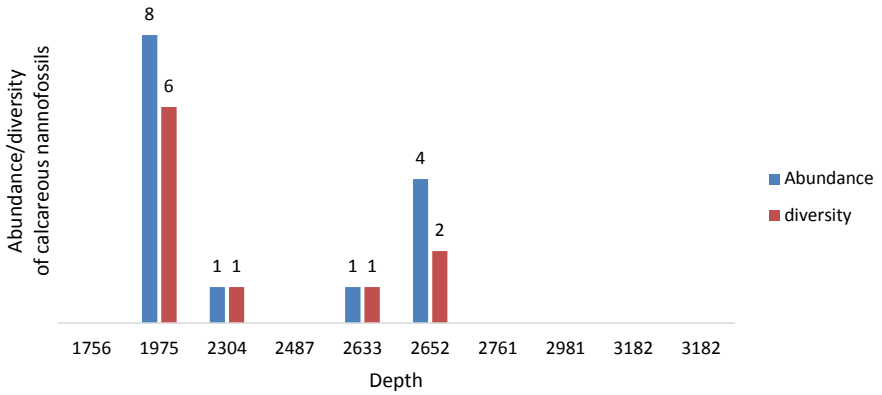

Figure 7. The abundance/diversity of calcareous nannofossils against depth (Olure-1 well).

5.1. Lithostratigraphy

Base on the available well log (gamma ray) and cutting samples, the Olure-1 and Abigboro-1 wells penetrated a total depth of 3182 m (10,440 ft) and 2161 m (7090 ft) depth respectively. The lithology constitutes a mixture of sand and shale units, with the shale occurring in significant amounts in an environment that is wholly marine and in variable proportion for a paralic depositional set-

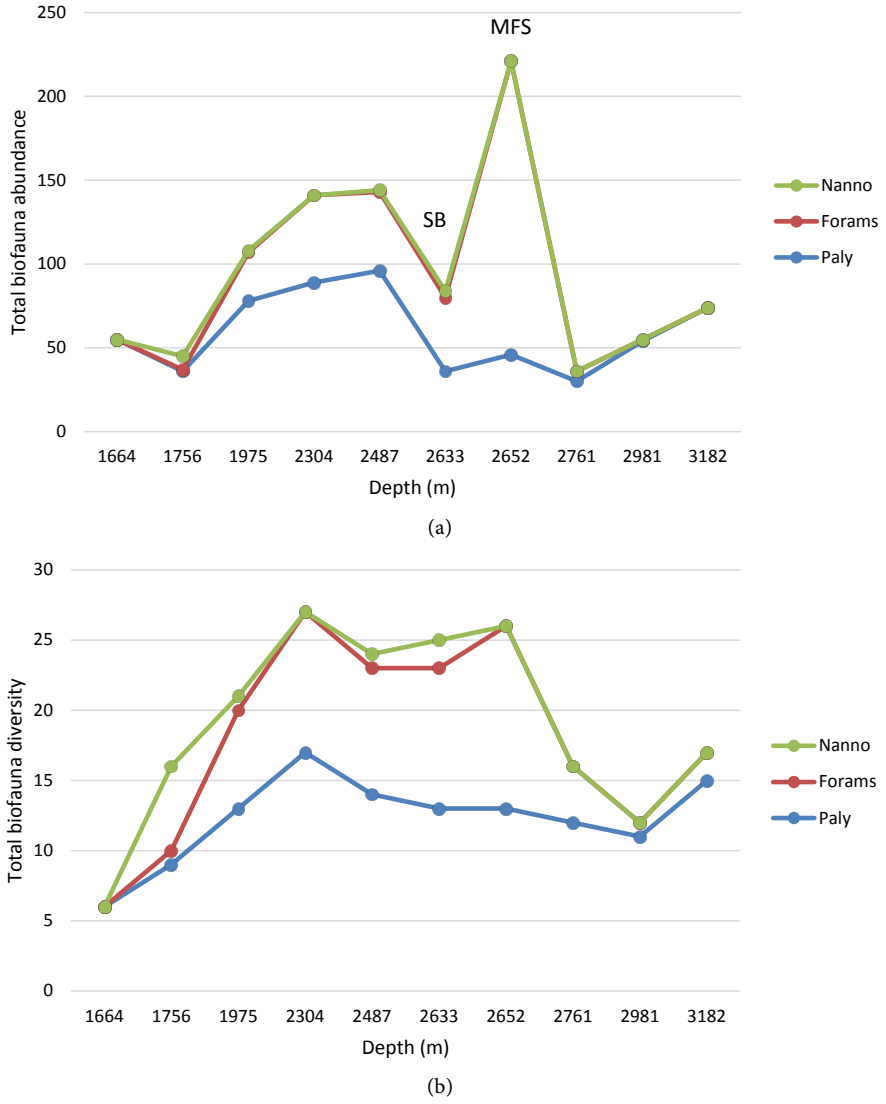

Figure 8. Plots of trend for: (a) biofauna total abundance and (b) total diversity against depth (Olure-1 well). **Note:* Nanno = calcareous nannofossil, Forams = foraminifera, Paly = palynomorphs.

ting. This was simulated by the gamma ray log signature. A coarsening upward or fining upward unit within a forestepping or backstepping successions of the log pattern defines stacking patterns of genetic units. This aided the prediction of the positioning of maximum flooding surfaces, and the identification of the systems tracts when integrated with biostratigraphic data (**Figure 2** and **Figure 3**).

5.2. Biostratigraphy

Foraminifera study of the wells

The biostratigraphic studies of the wells involved a total of eighteen (18) representative samples from 1347 m - 2161 m intervals (Abigboro-1 well) and ten (10) representative samples from 1920 m - 3182 m intervals (Olure-1 well) which

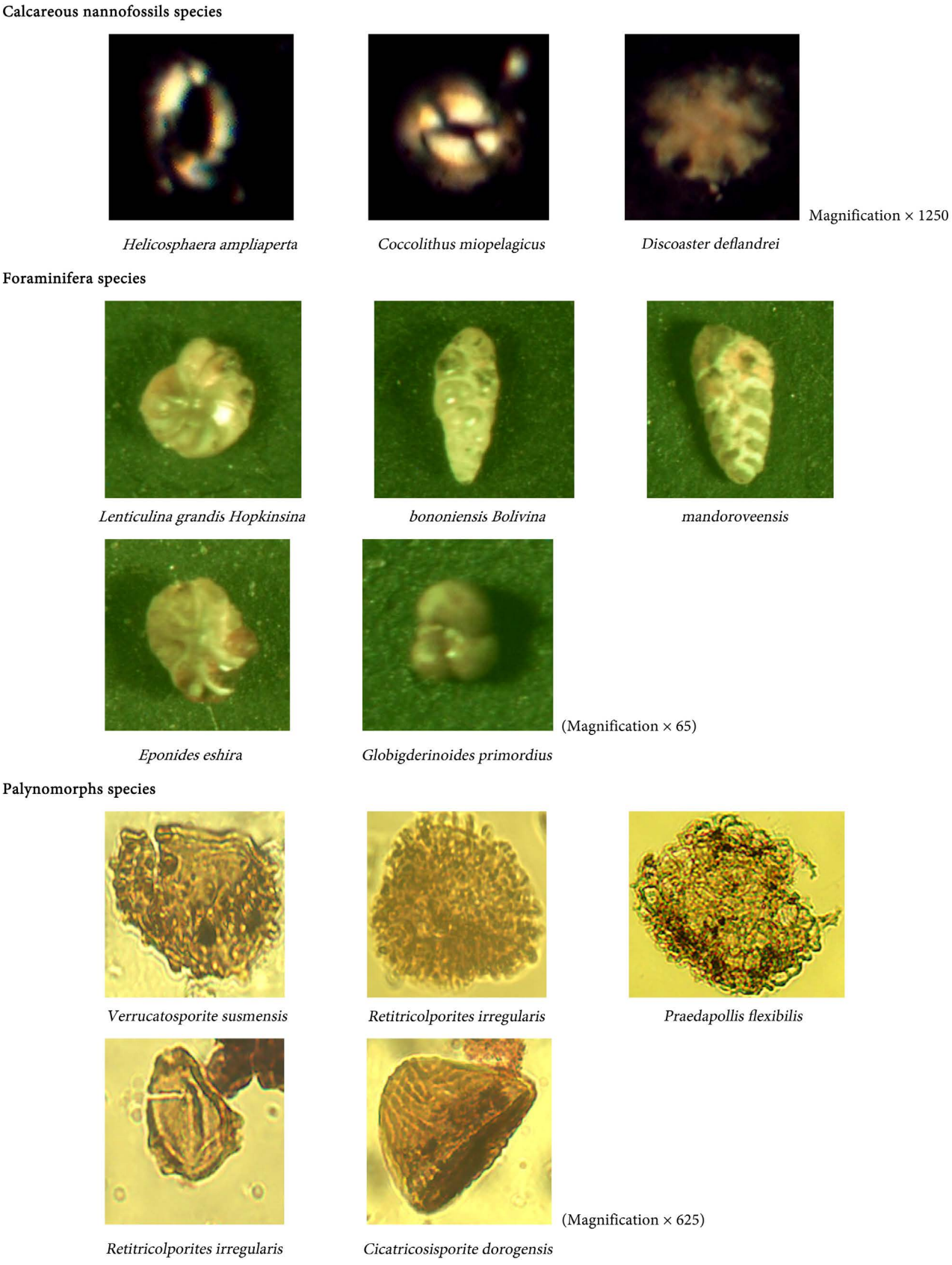

Figure 9. Photomicrograph of some selected diagnostic pollen and spores, calcareous nannofossils and foraminifera.

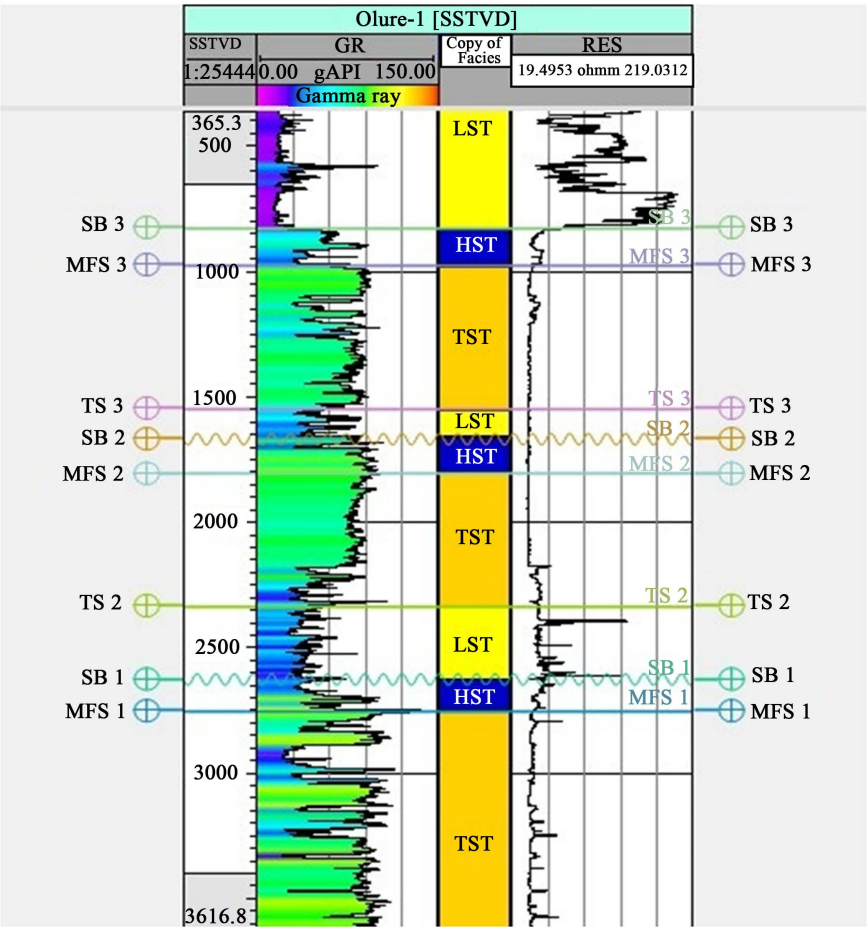

Figure 10. Wireline log of the key chronologic surfaces for the Olure-1 well.

were prepared and analysed for their microfossils. The foraminiferal recoveries in Abigboro-1 well within the studied sections are poor and the absence of planktic species precludes a refined zonal delineation for the analysed interval using the Blow planktic scheme [14] [15]. However on the basis of the recovered assemblages and the Niger Delta SPDC faunal zone scheme, the analysed intervals have been dated late Oligocene to early Miocene age corresponding to the N3 - N4 and F7800 - F9300 Zones for the two wells. The occurrence of *Globigerinoides primordius* at depth 2651 m within the Olure-1 well enabled the subdivision of the well section. The stratigraphic distributions of the recorded taxa are presented (**Table 1**, **Table 3**, **Table 4** and **Figure 4**).

5.3. Foraminiferal Biozonation

The zonation of these study wells are based on the comparison of the recovered assemblages with that of the SPDC Niger Delta Faunal Zone;

Abigboro-1 Well

Interval: 2161 m - 1347 m

Zone: (N3 - N4)-Bolli and Saunders (1985)

Age: Late Oligocene to early Miocene

Correlation: F7800 - F9300 (SPDC Faunal Zone)

Top: Placed at the first sample analysed at 1347 m

Base: Placed at the base of the analysed section at 2161 m

Description:

These intervals are characterized by rare and sporadic occurrences of foraminifera within 2060 m - 2069 m depths. The presence of *Lenticulina grandis, Hopkinsina bononiensis* and *Bolivina mandoroveensis* defined the assigned zones and ages. Other foraminifera found within the interval include *Florilus ex. gr costiferum, Hanzawaia concetrica, Pseudonodosaria* sp.*, Rotalia* sp. and *Marginulina costata.*

Olure*-1 *Well

Interval: 1920 m - 2651 m

Zone: (N4)–Bolli and Saunders [16]

Age: Early Miocene

Correlation: F9300 (SPDC Faunal Zone)

Top: Placed at the first sample analysed at 1347 m

Base: Placed at the base of *Globigerinoides primordius* at 2651 m.

Description:

This interval is characterized by rare and sporadic occurrences of foraminifera except at 2651 m depth. This lower interval was delineated based on the Last Downhole Occurrence of *Globigerinoides primordius* at 2651 m depth and it is taken as the zonal boundary marker between N4 and N3 Zones and consequently the late Oligocene/early Miocene boundary. The benthic assemblages present within the interval include *Bolivina mandoroveensis, Eponides eshira, Hopkinsina bononiensis* and *Lenticulina grandis*. Other foraminifera found within the interval include *Bolivina ex. gr. scalptrata, Buliminella* sp., *Cibicorbis inflata, Heterolepa floridana, Florilus ex. gr scaphum, Poroeponides lateralis, Uvigerina peregrina, Uvigerina sparsicostata, Uvigerina subperegrina, Valvulineria* sp. and *Epistominella pacifica.*

Interval: 2633 m - 3182 m

Zone: (N3)—Bolli and Saunders [16]

Age: Late Oligocene

Correlation: F7800 (SPDC Faunal Zone)

Top: Placed at the Last Downhole Occurrence of *Globigerinoides primordius* at 2633 m.

Base: Placed at the last analysed sample at 3182 m.

Description:

This interval is characterized by fairly abundant and diverse foraminifera. The interval was delineated based on the presence of the Last Downhole Occurrence (LDO) of *Globigerinoides primordius* at depth 2651 m. The taxon's LDO has been consistently used to indicate the boundary between the N4 and N3 Zones and consequently the late Oligocene/early Miocene boundary. The benthic assemblages present within the interval include *Bolivina mandoroveensis*, *Epon-*

ides eshira, *Lenticulina grandis* and *Lenticulina grandis*. Other foraminifera found within the interval include *Bolivina ex. gr. scalptrata*, *Cibicorbis inflata*, *Heterolepa floridana*, *Florilus ex. gr scaphum*, *Poroeponides lateralis*, *Uvigerina sparsicostata*, *Uvigerina subperegrina*, *Valvulineria* sp. and *Epistominella pacifica.*

Palynological study of the wells

A detailed palynological study was carried out on systematically selected eighteen (18) cutting samples from Abigboro-1 well at different intervals. The analysed intervals contain well preserved and abundant pollen, spores, fungal spores and dinoflagellate cysts. The recovered palynomorphs include abundant land derived forms such as *Retibrevitricolporites protrudens*, *Retitricolporites irregularies*, *racemonocolpites hians*, *Arecipites exilimuratus*, *Psilatricolporites crassus*, *Praedapollis flexibilis*, *Gemmamonoporites* sp., *Laerigatosporites* sp, *Verrucatosporites usmansis*, *Verrucatosporites* sp., *Pteris* sp., and *Acrostictrum aureum.* Moderate numbers of dinoflagellate cysts particularly *Lingulodinium machaerophorum*, *Spiniferites* sp., *Homotryblium* sp., *Homotryblium pallidum*, *Polysphaeridium zoharyi*, *Lepospheridia* and *Hystricholcolpona* sp. which are indicative of a marine depositional environment were also recovered (**Table 1** and **Figure 5** and **Figure 6**).

5.4. Palynological Biozonation

This well falls within the broad Pan Tropical *Magnastriatites howardi* Zone of Germeraad *et al*. [17] and the P500 Zone of Evamy *et al*. [18]. Only the P560 and P540 Subzones were identified within the P500 Zone;

Zone P500

Subzone P560

Interval: 1347 m - 1749 m

Age: Middle Oligocene

Description

The top of this subzone is placed at 1347 m and the base is defined by the increased occurrence of *Retibrevitricolporites protrudens* at 1749 m. This subzone corroborated with the abundant records of *R. protrudens*, *Verrucatosporites usmensis*, *Praedapollis flexibilis*, and *Pteris* sp.

Subzone P540

Interval: 1749 m - 2161 m

Age: Middle Oligocene

Description

The top of this subzone is placed at 1749 m and it is defined by the increased occurrence of *Retibrevitricolporites protrudens.* The base is placed at the depth of 2161 m. This subzone is further characterized by the presence of *Cicatricosisporites dorogensis*, *Gemmatriporites* sp., *Striamonocolpites rectostriatus*, *Arecipites exilimuratus* and *Grimsdalea poligonalis*.

Calcareous nannofossil study of the wells

This entails a total of ten (10) cuttings from interval 1920 m - 3182 m (Olure-1 well) and total of eighteen (18) cuttings selected from interval 1347 m - 2161 m (Abigboro-1 well) were prepared and analysed for nannofossils at various intervals. The study revealed rare to few and scattered occurrences of nanno-fossils in Olure-1 well while intervals have been found to be barren of nannofossil occurrences in Abigboro-1 well. The occurrence of few index markers within the analysed section of Olure-1 well facilitated the subdivision of the well sections into zones based on the zonation scheme of Martini [19]. Interval 1920 m - 2633 m has been dated early Miocene (NN2 - NN4 Zones) while interval 2633 m - 3182 m is believed to be of late Oligocene to early Miocene (NP24 - NN1 Zones) (**Table 2** and **Figure 7**).

5.5. Calcareous Nannofossil Biozonation

The zonation scheme of Martini [19] was employed for the zonation of the wells;

Interval: 1920 m - 2633 m

Zone: NN4 - NN2

Top: Placed at the first sample analysed at 1920 m

Base: Top *Helicosphaera truempyi*

Age: Early Miocene

Description:

This interval is characterized by rare to sparse occurrence of nannofossils. This interval has been delineated based on the presence of characteristic early Miocene (NN4 - NN2) taxa including *Discoaster deflandrei*, *Coccolithus miopelagicus* and *Helicosphaera ampliaperta*.

Interval: 2651 m - 3182 m

Zone: NN1 - NP24

Top: Top *Helicosphaera truempyi*

Base: Tentatively placed at the last analysed sample at 3182 m

Age: Early Miocene to late Oligocene

Description:

This interval is characterized by very rare and sporadic occurrences of nannofossils. The occurrence of *Helicosphaera truempyi* at 2633 m depth is an indication that the well is not younger than the early Miocene NN1 Zone, while the other intervals stands for the total range (NN1 - NP24) of *Helicosphaera truempyi* Zonal marker.

5.6. Sequence Stratigraphic Framework

Case Study Appraisal for Olure-1 Well

This was based on the gamma ray and resistivity log signatures of the well. The key surfaces and systems tract were identified (**Figure 10**).

Sequence Boundary (*SB*) *and Maximum Flooding Surface* (*MFS*)

Three Maximum Flooding Surface (MFS) and Sequence Boundaries (SB) were identified respectively. These points corresponds to depths of 2728 m (MFS 1), 1797 (MFS 2), and 971 (MFS 3) for the Maximum Flooding Surfaces and 2602 m

(SB 1), 1661 (SB 2), and 825 (SB 3) for Sequence Boundary (Figure 10). MFS 1 and MFS 2 and SB 1 correspond to intervals where we have the peak and least abundance of biofauna respectively.

Lowstand Systems Tract (*LST*)

From the log signatures, the LST is bounded at the base by SB 1, SB 2, and SB 3 and at the top by TS 1, TS 2, and TS 3, showing the coarsening upward log motif. These system tracts represent sand packages that signify the basin floor fan, which is overlain by slope fan and capped by shaly lowstand wedge. The biostratigraphic study also showed progressive decrease in abundance and diversity of biofauna due to fall in water level and shallowing of the shore.

Transgressive Systems Tract (TST)

In Olure-1 well, the TST is bounded at the top by MFS 1, MFS 2, and MFS 3 and at the base by TS 1, TS 2, and TS 3. The stacking pattern showed a finning upwards log motif. Also the parasequences within the TST backstep in a retrogradational parasequence set. The progressive increase in biofauna indicated progressive increase in water level and that the systems tract progressively deepens upward as successively younger parasequences step farther landward.

Highstand Systems Tract (*HST*)

The HST is bounded at the base by MFS 1, MFS 2, and MFS 3 and at the top by SB 1, SB 2, and SB 3. The early highstand consists of an aggradational parasequence set as evidenced on the log signatures. However, the late highstand is composed of one or more progradational parasequence sets (Figure 10). The biofauna trend for this systems tract shows a peak in abundance and diversity of species followed by a progressive decrease.

5.7. Depositional Environment

The depositional milieu of the study wells were determined based on the sedimentological and biostratigrapical inferences (Figure 8). Based on the foraminifera recovered from Olure-1 well, the environment was suggested to have been deposited within the inner neritic environment with the occurrence of *Lenticulina grandis*, *Florilus ex. gr. costiferum*, *Hanzawaia concentrica*, *Hopkinsina bononiensis*, *Marginulina costata* and *pseudonodosaria* sp. Within the interval of 1557 m - 1640 m which is predominantly sandy lithofacies indicated a coastal deltaic environment while the shaly upper section within 1347 m - 1554 m suggested a shallow inner neritic environment with the presence of *Lenticulina grandis* at 1347 m - 1356 m depth.

The recovered palynomorphs suggested a marine depositional environment with fresh water influx based on the occurrence of abundant land derived forms such as *Racemonocolporites hians*, *Psilatricolporites crassus*, *Pachydermites diederixi*, *Retitricolporites irregularies*, *Laevigatosporites* sp., *Verrugatosporites* sp., *Acrostichum aureum* and *Pteris* sp., as well as moderate numbers of dinoflagellate cysts which include *Leiophaeridia* sp., *Lingulodinium Machaerophorum*, *Polysphaeridium zoharyi*, *Operculodinium centocarpum*, *spiniferites*

sp. Few marine indicators microforaminiferal wall linings with sparse occurrences of dinoflagellate cysts and fresh water algae *Botryococcus brauni* suggested a littoral-marine depositional environment. However, the benthic foraminifera distribution suggest a broad grouping of the intervals as inner to middle neritic based on characteristic depth indicator foraminfera recorded within the intervals. This include *Bolivina mandoroveensis*, *Eponides eshira*, *Lenticulina grandis*, *Lenticulina grandis*, *Cibicorbis inflata*, *Heterolepa floridana*, *Florilus ex. gr scaphum*, *Poroeponides lateralis*, *Uvigerina sparsicostata*, *Uvigerina subperegrina*, *Bolivina ex. gr. scalptrata*, *Valvulineria* sp. and *Epistominella pacifica*.

5.8. Exploration Implication

The application of sequence stratigraphic framework in the study wells have made prediction possible, the positioning of the key chronostratigraphic surfaces, such as flooding and erosional surfaces as well as the System Tracts (ST) and their parasequences stacking patterns. This allows for the identification of plays and potential prospect evaluations in exploration for oil and gas. The sequence stratigraphic study of the two wells indicated that the lowstand consist of sand packages that can serve as hydrocarbon reservoirs. It is suggested that during periods of lowering of the sea level, when the rate of sediment input far exceeded the subsidence rate (progradation), deposition of sandstone reservoir occurred in the form of incised valley fills, slope fan complexes and prograding complex within the lowstand wedges. As the sea level began to rise, the earlier formed reservoirs were sealed by the deposition of relatively organically rich shale prone sediments of the Transgressive Systems Tract (TST). This model produces a reservoir/seal relationship whereby hydrocarbon expelled by the organically rich lithofacies, upon maturation may be trapped within the sealed reservoir rocks either by structural, and/or stratigraphic trapping mechanism.

6. Conclusions

The integration of biostratigraphic data with wireline log data exemplified a sequence stratigraphic model to be generated for Olure-1 and Abigboro-1 wells. Lithologic description from logs and cutting samples indicated a mixture of sand and shale units. The various biostratigraphic plots for Olure-1 well show the presence of Maximum Flooding Surfaces at depth intervals 2304 m - 2487 m and 2652 m - 2730 m, while Abigboro-1 well shows the presence of Maximum Flooding Surfaces at depth range between 1750 m - 1788 m and 2115 m - 2134 m. This was corroborated by the composite plot from biostratigraphical data and wireline log signatures which also indicated the presence of Maximum Flooding Surface at about 2728 m (MFS 1) and 1797 m (MFS 2) depths (Olure-1 well). The presence of a Sequence Boundary at depth of 2602 m (SB 1) was also identified which also corroborated with the depth interval where there appeared to be the least abundance and diversity of species as shown in the biostratigraphic data

of the well. The deposition environmental studies suggested an inner neritic to coastal deltaic setting for Olure-1 and Abigboro-1 wells. The presence of some diagnostic species such as *Lenticulina grandis*, *Florilus ex. gr. costiferum*, *Hanzawaia concentrica*, *Hopkinsina bononiensis*, *Marginulina costata* and *Pseudonodosaria* sp. (Olure-1 well) and *Bolivina mandoroveensis*, *Eponides eshira*, *Lenticulina grandis*, *Lenticulina grandis*, *Cibicorbis inflata*, *Heterolepa floridana*, *Florilus ex. gr scaphum*, *Poroeponides lateralis*, *Uvigerina sparsicostata*, *Uvigerina subperegrina*, *Bolivina ex. gr. scalptrata*, *Valvulineria* sp. and *Epistominella pacifica* (Abigboro-1 well) suggests late Oligocene - early Miocene age. A sequence stratigraphic model generated for exploration suggest the sand packages of the Lowstand Systems Tract can serve as reservoir rock while the fossiliferous shale units of the Transgressive Systems Tract could serve as the seals and source rock for hydrocarbon.

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