Asian Journal of Geological Research

2(3): 156-178, 2019; Article no.AJOGER.51884

Sedimentological Resolution of Biostratigraphic and Sequence Stratigraphic Evaluation of Toms-well, OG-field, Greater Ughelli Depobelt, Onshore, Niger Delta Basin, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author FOB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author OE managed the analyses of the study and the literature searches. Both authors read and approved the final manuscript.

Article Information

Editor(s):
(1) Dr. Mohamed M. El Nady, Exploration Department, Egyptian Petroleum Research Institute, Nasr City, Cairo, Egypt.
Reviewers:
(1) Reda M. ElGammal, Egypt.
(2) Ahamd Helman Hamdani, University of Padjadjaran, Indonesia.
Complete Peer review History: http://www.sdiarticle4.com/review-history/51884

Original Research Article

Received 01 August 2019
Accepted 05 October 2019
Published 16 October 2019

ABSTRACT

One hundred and seventy six ditch cutting samples within the interval of 5425ft to 8535ft from Toms-well, OG-Field, Greater Ughelli Depobelt, onshore, Niger Delta basin, were subjected to sedimentological analysis and microscopic analysis using a binocular reflected light microscope and microscopic analysis of palynomorphs and foraminifera using a binocular transmitted light microscope. Textural analysis of ditch cutting samples to build a lithologic model of the penetrated sedimentary succession was established to constrain the alternation of sand packages from proximal to distal. The alternation of shale and sand revealed that the studied intervals belong to paralic Agbada Formation of the Niger Delta basin. The combined results of foraminiferal, palynological and sequence stratigraphy showed that the studied well (Toms-well) was deposited during Oligocene to Early Miocene Epoch of numerical ages of 31.3MaMfs, 33.0 Mfs and 34.0MaMfs; while 24.3MaMfs and 31.3MaMfs indicated by Bolivina 26 and Uvigerina 5 as

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diagnostic marker shale with their corresponding SB delineated at 24.9Ma and 32.4Ma. Prospective reservoirs intervals delineated in Toms-well are 6870 ft-6915 ft, 8175-8205 ft and 8265-8340 ft. The P-zones and F-zones established are P560/F7400, P540/F7600 and P520/F7800. Results from the integration of sedimentological, foraminiferal and palynological suggest sediments deposition in marginal marine to shallow marine environments.

Keywords: Foraminifera; biostratigraphy; oligocene; ditch cuttings.

1. INTRODUCTION

Amongst the sedimentary basins in Nigeria, the Niger Delta basin is most prominent because of its large accumulation of hydrocarbons. This large accumulation of hydrocarbon in the Niger Delta basin ranks Nigeria as one of the most prolific oil producing nation in Sub-Sahara Africa accounting to almost 95% of her foreign exchange earnings [1]. The Niger Delta basin due to its large accumulation of hydrocarbon has been subjected to continuous geologic study [2,3,4,5,6] with study dating back as far as 1956 with the discovery of oil in commercial quantity in the Oloibiri-1 well [7]. As a result of the constant demand for petroleum products and the search for hydrocarbon, researchers have shown continuous interest in the revaluation of the aging fields within the Niger Delta.

In the last decades, advances in seismic data acquisition and processing have led to the discovery of so many large oil reservoirs in the Niger Delta [8]. However, seismic stratigraphy though effective, has the limit of resolution especially when applied in deep basin [8]. Also, seismic acquisitions and personnel hiring for interpretation is usually associated with huge cost.

Biostratigraphy which is a multi-tool plays an important role in the science of hydrocarbon exploitation and exploration in the Niger Delta. It serves as a stratigraphic tool in depositional settings such as continental, coastal and marginal marine environment and can also be useful for chronostratigraphic correlation, palaeoenvironmental studies, evaluation of potential source, reservoir and sealing rocks when integrated with other tools like wireline logs and seismic stratigraphy [9].

Ditch cutting sample which is a biostratigraphy tool is an important tool to the petroleum industry for defining geologic constrains on prediction of exploration and assessment prospects. The sedimentological analysis and biostratigraphic analysis are employed to constrain the interpretation of the lithologic model in space and in time respectively. Integration of the contained biofacies information with sequence stratigraphic and lithofacies information for each depositional system gives a more precise definition of the environment of deposition and hence a better prediction of reservoirs, seal and source rocks [10]. Assigning age to rocks is one of the primary requirements of micropaleontological studies as input to reconstruct stratigraphy. In marine sedimentary strata, foraminifera are known to occur abundantly and have their usefulness as a tool for dating and correlating sediments in the realm of exploration [11,12,13]. Such studies are essential in understanding the depositional conditions and to prepare a depositional model with reasonable predictiveness. In exploration research, micropaleontology remains a vital tool in sequence stratigraphic analysis and resolution but it is still being grossly under-utilized. Information from ditch cutting samples is often an essential component of any lithologic analysis.

This study attempts to identify the reservoir sand bodies in the onshore western Niger Delta, Greater Ughelli Depobelt utilizing ditch cutting samples to evaluate and delineate the stratigraphic resolution and establish the ages of the penetrated sedimentary succession of the well and to sedimentologically evaluate the hydrocarbon potential through stratigraphic resolution and age dating, hence reducing cost of exploration program and thus maximizing profit.

1.1 Study location

The field and well under study are pseudo-named OG-field and Toms-well respectively in accordance with the Nigerian Petroleum Development Company (NPDC) confidentiality agreement. The field is an onshore field, located within the Greater Ughelli Depobelt (Fig. 1). The co-ordinates of the location of this field were concealed due to proprietary reasons. It covers an area extent of 19.93 km^2.

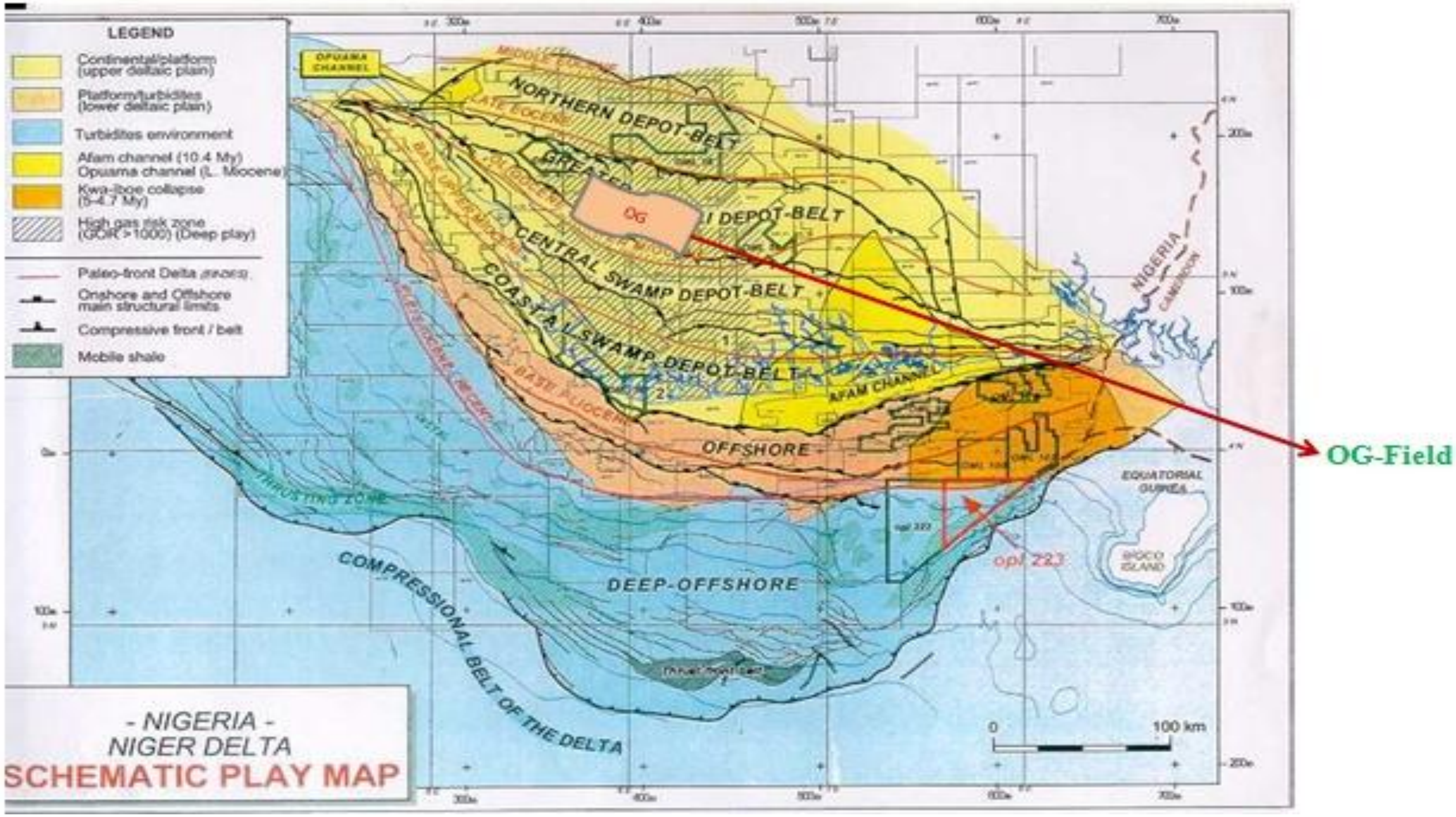


Fig. 1. Map of the Study Area [14]

Fig. 2. Generalized Niger Delta Stratigraphy and Lithofacies Subdivision [17]

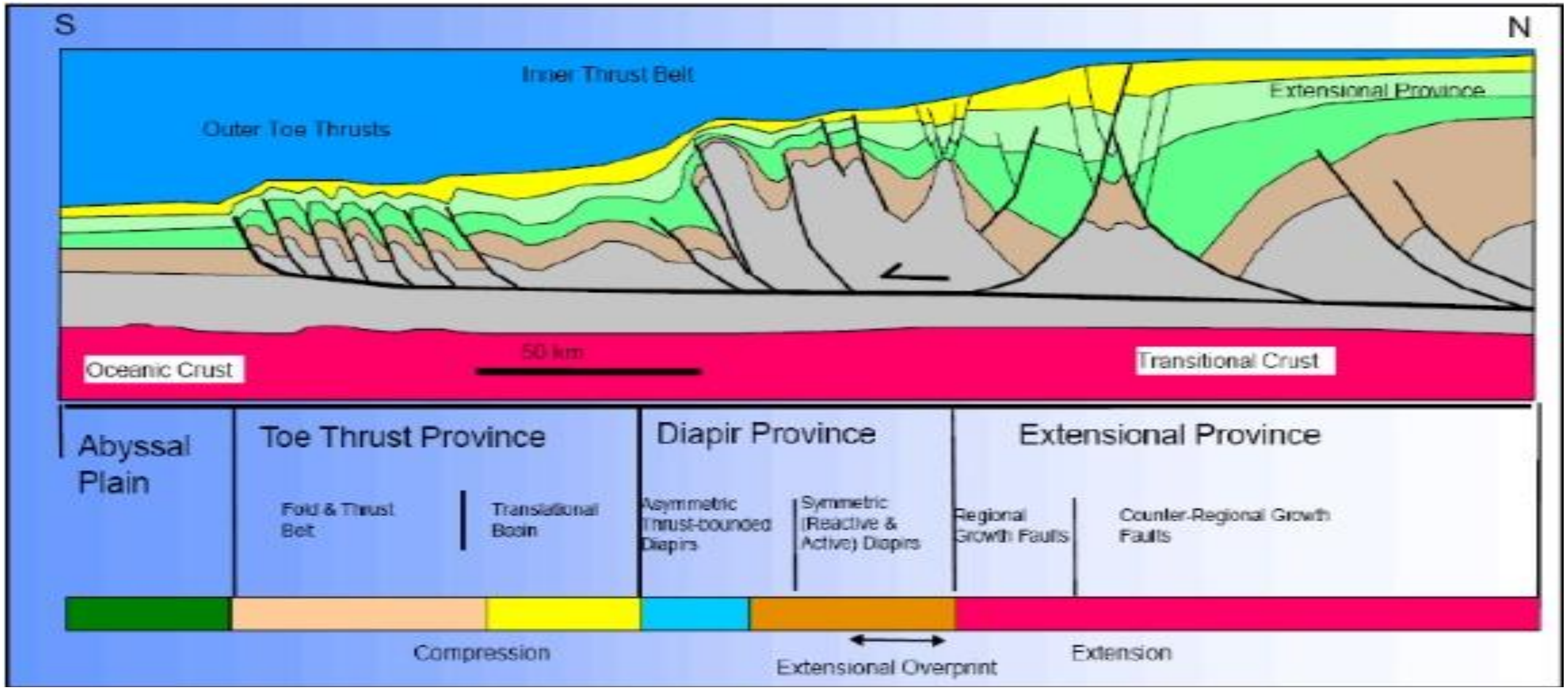


Fig. 3. Seismic Section from the Niger Delta Continental Slope/Rise Showing the Results of Internal Gravity Tectonics on Sediments at the Distal Portion of the Depobelt [22]

1.2 Lithostratigraphic Framework

The Niger Delta sedimentary basin has been subdivided into three lithofacies unit which are; the Benin Formation which consist of the massive continental sandstones, Agbada Formation consisting of the marginal marine sandstones and the Akata Formation which is predominantly marine shale and is the oldest units, which forms the base of the sequence in each depobelt with stratigraphic thickness of about 7000 m in the central part of the delta. Overlying the Akata Formation is the paralic Agbada Formation represented by sands, shales and clays alternations in various proportion and thickness deposited in a number of delta-front, delta-topset and fluvio-deltaic environments. It has a maximum thickness of about 3000 m. The Benin Formation is the youngest unit with variable thickness which becomes thinner offshore [15]. This generally regressive clastic sequence of the delta reaches a maximum thickness of about 9-12 km [16].

1.3 Structural Framework

However, the Niger Delta basin is subdivided into structural zones that are typified by characteristic basinwards variations in structural styles and deformation connected on a regional scale by slow gravity collapse of thick deltaic prism [18,19,20]. The zones are; (*i*) an inner extensional zone of listric growth faults beneath the outer shelf, (*ii*) a translational zone of diapirs and shale ridges beneath the upper slope and (*iii*) an outer compressional zone of imbricate toe-thrust structures beneath the lower slope **(**Fig. 3). However, the Niger Delta basin was further subdivided into five major structural zones based on structural styles imaged in seismic data and high resolution bathymetry [21]. They are; (*i*) an extensional zone beneath the continental shelf that is characterized by both basinward-dipping and counter-regional growth normal faults and associated rollovers and depocenters, (*ii*) a mud-diapir zone located beneath the upper continental slope which is characterized by passive, active, and reactive mud diapirs including shale ridges and massifs, shale overhands, vertical mud diapirs that form mud volcanoes at the seafloor, (*iii*) the inner fold, thrust faults and associated folds, including some detachment folds, (*iv*) a transitional detachment fold zone beneath the lower continental slope that is characterized by large areas of little or no deformation interspersed with large, broad detachment folds above structurally thickened Akata Formation and (*v*) the outer fold and thrust belt characterized by both basinward and hinterland verging thrust faults and associated folds. Deformations across these structural zones are very much active today.

2. MATERIALS AND METHODS

One hundred and seventy six ditch cutting samples within the interval of 5425ft to 8535ft from Toms-well, OG-field, Greater Ughelli Depobelt, Niger Delta basin were subjected to sedimentological analysis. The well was code named Toms-well for confidential reasons. These samples were dried and kept in sample bags which were labeled accurately. The samples and the location map of the selected well were provided by Nigerian Petroleum Development Company (NPDC), Benin City, Nigeria. The samples were then subjected to sedimentological analysis at sedimentology laboratory, University of Benin, Benin City, Nigeria while the foraminifera and palynological analyses were carried out at Earthprobe laboratory, Yaba, Lagos State, Nigeria.

2.1 Palynological Analysis

This study involves an analytical approach which entails ditch cutting samples analysis, biostratigraphic analysis and sequence stratigraphic analysis of the penetrated sedimentary sequence of the Toms-well. These analyses include sample treatment, microscopic analysis of the ditch cutting samples using reflected light microscope, microscopic analysis of palynomorphs and foraminiferas using transmitted light binocular microscope. Textural analysis of the ditch cutting samples was used to build a lithologic model of the penetrated sedimentary succession that was established to constrain the alternation of sand and shale packages from proximal to distal.

Samples were made up of a combination of organic and inorganic materials, and the microfossils that are needed for analysis can only be obtained from the organic materials therefore palynological sample preparation involves the separation of the organic components from the inorganic components before analysis.

2.2 Procedures

The steps for preparation of palynological samples are:

I: Treatment of samples with hydrochloric acid (HCl) to eliminate limestone ($CaCO_3$). This is confirmed by the occurrence of effervescence.

II: Removal of the inorganic materials (SiO_2) in the sample; this is achieved by digesting the sample with HF acid.

III: The samples are subjected to oxidation using concentrated HNO_3 which helps to remove the dark patches/particles in the samples.

IV: The samples were treated with concentrated HNO_3 under heating in order to isolate the palynological species of interest (miospores). The heating is to destroy any possible dinocysts and acritarchs present in the sample.

V: Schultze's solution (a saturated solution of concentrated HNO_3 + $KClO_3$) was further used to treat the samples in order to remove the dark patches in the samples that were still predominant.

VI: The samples are washed clean using KOH solution; the KOH solution neutralizes the HNO_3 and removes/dissolves unwanted particles such as plant twigs and debris.

VII: Zinc bromide ($ZnBr_2$) solution (S.G 2.2 to 2.4) was added to the sample to separate the organic matter from the inorganic matter. The organic matter which contains the palynomorphs floats to the surface and was removed using a pipette. The recovered palynomorphs were then subjected to slide preparation and analysis. The name, number and depth intervals at which the samples were collected from the well were accurately labeled on the sides of each of the prepared slides.

2.3 Slide Preparation (Spotting and Mounting)

The recovered palynomorphs were mounted on a glass slide with dimension 76 mm x 26 mm and cover slips with dimension 32 mm x 22 mm and the set up was placed on slide warmer (low temperature hot plate) to dry them.

2.4 Foraminiferal Sample Preparation

20 gm of each sample was weighed (using a Mettler PC 440 digital balance) into each sample bowl. Depths on samples were correctly transferred to clean aluminium sample bowls. 30 ml of kerosene was poured into samples while still hot to soak for two hours. Kerosene was drained out and sample soaked in water. 20% Hydrogen peroxide was then added to the sample for about 10 minutes. Each sample was then washed over a 63 microns sieve with water from a hand directed water jet. The residue collected from the sieve was replaced in the sample bowl and dried on the hot plate. The residue was then sieved over 20 and 80 mesh sieves for the coarse and medium fractions while the finest residue in the receiver was treated as fine fraction. The coarse, medium and fine fractions were then stored in properly labeled sample phials for onward transfer to the pickers and analyzers.

3. RESULTS AND DISCUSSION

Palynological, biostratigraphy and zonation from the interpreted distribution chart of palynomorphs of Toms-well revealed three P-zones from the penetrated sedimentary succession of the lithologic model erected.

The lithologic description of Toms-well was carried out on one hundred and seventy six ditch cuttings within the interval of 5425 ft to 8535 ft from Toms-well, OG-field, Greater Ughelli Depobelt, Niger Delta basin and subjected to sedimentological analysis. The sedimentological analysis allowed the erection of fifty five lithozones of sandstone, sandy shale, shale and shaly sandstone lithofacies based on the textural properties observed, fossil content and the identification of minerals which include; quartz, iron oxide and mica. Fifty five intervals of shale and sandy shale lithofacies were sampled for standard palynological and foraminifera analysis. From the analysis, a lithostratigraphic model was built whose description is shown in Fig. 4a - 4d. Sedimentological analysis involves the separation of the formations within the well into several lithologic units on the bases of the different physical characteristics exhibited/ displayed by sediments in the well. The sedimentological study of the samples was performed in the Sedimentological/Thin Section Laboratory of the Geology Department, University of Benin, Benin City, Nigeria, with the aid of reflected light microscope.

The lithologic model as shown in Fig. 4a – 4d ranges from 5425 ft – 8535 ft which depicts the sedimentary succession penetrated at interval of 15 ft from each other. The sedimentary description of each of these units were documented based on its textural properties, sorting, colour changes, fossil content, mineral accessories, percentage of sand to shale ratio, homogeneity and heterogeneity units were equally indicated. The Toms-well shows fifty five lithofacies. Lithofacies can be explained as a rock sequence which accumulates under the same depositional setting in time and space and can be correlated laterally or vertically. The lithofacies are quoted both in feet and meters as shown in Fig. 4a – 4d. Three hydrocarbon prospective intervals were delineated and they are; 6870-6915 ft, 8175-8205 ft and 8265-8340 ft.

3.1 Sequence Stratigraphic Application for Toms-well

Since sequence stratigraphy is based on recognition of depositional systems, stacking patterns and key stratigraphic surfaces. The sedimentological trends from lithofacies interpretation of the ditch cutting samples, foraminifera quantitative analysis, biofacies plot, palynomorphs quantitative analysis and plot, palynological events and palynological zones of Toms-well as well as the Niger Delta chronostratigraphic chart were used to establish a sequence stratigraphic model thus recognizing depositional patterns and key surfaces such as maximum flooding surface and sequence boundaries. The maximum flooding surfaces and sequence boundaries which are of great importance in sequence stratigraphic interpretation are indicated as point of high preservation potential (peaks of biofacies distribution) and erosional surfaces as shown in Fig. 5.

Having established the P-zones and sequence stratigraphic events as shown in Figure 6a, three palynological zones have been identified in the penetrated section of the studied interval. These are:

- P560 defined at 6900-6915ft using the base continuous of *Peregrinipollis nigericus* and the increase in *Retibrevitricolporites oboendensis* with age of 31.3 ma - 30.3 ma.
- P540 defined at 8220-8235ft with the increase in *Retibrevitricolporites oboendensis* and the quantitative base of *Arecipites exilimuratus* with age of 33.0 ma - 32.7 ma.
- P520 defined at 8505-8520ft with the quantitative base of *Racemonocolpites hians* with age of 34.0 - 33.6ma.

These palynological events and zones suggest Early Oligocene – Late Oligocene age for the sedimentary succession penetrated by Toms-well, which has a numerical age of 33.6 – 30.3Ma when straddled with the Niger Delta chronostratigraphic section (see Figure 6b). This established age of Toms-well coincides with the sediments of Greater Ughelli Depobelt, Niger Delta. The sequence stratigraphic model generated, established three maximum flooding surfaces and two sequence boundaries with the established palynological zones used to compliment the abundance and diversity of the foraminifera (biofacies) distribution chart/plot. A palynological zone is constrained at least one maximum flooding surface or at least one sequence boundary.

From the generated sequence stratigraphic model of Toms-well, the maximum flooding surfaces were delineated from points of occurrence of an extensive thick blanket of shale with high abundance peak biofacies (foraminifera) distribution as deduced from the biofacies (foraminifera) plots and litholog of Toms-well within the P–zones. While the sequence boundaries interpreted as unconformity surfaces were identified at the base of the sandstone or shaly sandstone from the litholog of Toms-well within the P–zones when constrained with the Niger Delta chronostratigraphic chart.

The maximum flooding surface within P520 palynological zone occurred as 34.0 MaMFS at 8505- 8520 ft while that within the P540 palynological zone occurred as 33.0 MaMFS at 8220-8235ft. Within the P560 palynological zone, the maximum flooding surface occurred as 31.3MaMFS at 6900 – 6915 ft. These maximum flooding surfaces (surfaces which separate younger strata from older strata across, showing evidence of an abrupt increase in water depth) usually within condensed sections occurred as peaks on the foraminifera population and diversity plots.

The sequence boundary and its respective age within P520 palynological zone occurred as 33.3Ma SB at 8490 – 8535ft while P540 occurred as 32.4Ma SB at 7785 -7800ft. These sequence boundaries represent abrupt basinward shift in deposition and absence of fauna commonly seen as sharp stacking of facies across erosional surfaces marked by environmental changes. The maximum flooding surfaces (MFS) which are thick shale beds can be used in seismic studies to delineate condense sections, thus are potential source rock indicator. The sequence

Table 1. Sedimentological Lithofacies Units Description for Toms-well

Depth (ft)	Depth (m)	Lithology	Lithofacies Units
5425-5485	1648-1671	Shaly sand	55
5485-5500	1671-1676	Sandy shale	54
5500-5515	1676-1680	Shaly sand	53
5515-5530	1680-1685	Sandy shale	52
5530-5545	1685-1690	Shaly sand	51
5545-5790	1690-1764	Sandy shale	50
5790-5820	1764-1773	Shaly sand	49
5820-5895	1773-1796	Sandy shale	48
5895-5910	1796-1801	Shaly sand	47
5910-5925	1801-1805	Shale	46
5925-5955	1805-1815	Sandy shale	45
5955-5970	1815-1819	Shaly sand	44
5970-6030	1819-1837	Sandy shale	43
6030-6090	1837-1856	Sandstone	42
6105-6135	1860-1869	Shaly sandstone	41
6135-6150	1869-1874	Sandstone	40
6150-6195	1874-1888	Shaly sandstone	39
6210-6225	1892-1897	Sandstone	38
6225-6390	1897-1947	Shaly sandstone	37
6390-6420	1947-1956	Sandy shale	36
6420-6435	1956-1961	Shaly sandstone	35
6435-6465	1961-1970	Sandy shale	34
6465-6615	1970-2016	Shaly sandstone	33
6660-6705	2029-2043	Sandy shale	32
6705-6825	2043-2080	Shaly sandstone	31
6825-6855	2080-2089	Sandy shale	30
6855-6885	2089-2098	Shaly sandstone	29
6900-6945	2103-2116	Sandy shale	28
6945-6960	2116-2121	Shaly sandstone	27
6960-7005	2121-2135	Sandy shale	26
7005-7125	2135-2171	Shaly sandstone	25
7125-7170	2171-2185	Sandy shale	24
7170-7230	2185-2203	Shaly sandstone	23
7230-7350	2203-2240	Sandy shale	22
7365-7410	2244-2258	Shaly sandstone	21
7410-7440	2258-2267	Sandy shale	20
7440-7785	2359-2372	Shaly sandstone	19
7785-7800	2372-2377	Sandstone	18
7800-7905	2377-2409	Shaly sandstone	17
7905-7920	2409-2414	Sandstone	16
7920-8115	2414-2473	Shaly sandstone	15
8115-8160	2473-2487	Sandy shale	14
8160-8205	2487-2500	Shaly sandstone	13
8235-8265	2510-2519	Sandy shale	12
8225-8310	2506-2532	Shaly sandstone	11
8235-8265	2510-2519	Sandy shale	10
8265-8355	2519-2546	Shaly sandstone	9
8355-8370	2546-2551	Sandy shale	8
8370-8430	2551-2569	Shaly sandstone	7
8425-8445	2567-2574	Shale	6
8445-8460	2639-2643	Shaly sandstone	5
8460-8475	2643-2648	Shale	4
8490-8505	2653-2657	Shaly sandstone	3
8505-8520	2657-2662	Sandy shale	2
8520-8535	2662-2667	Shaly sandstone	1

boundary (SB) can be used to characterize the potential reservoir rocks since it is an unconformity or erosional surface which is usually at the base of the sandstone. The maximum flooding surfaces (MFS) are regional markers and however are the anchor points of many geological correlations as well as acting as cap rocks.

When imprinted on the seismic sections, the sequence stratigraphic model will help to locate the bright spots that will be drilled for hydrocarbon thus reducing cost by saving the money to drill more wells for further studies.

3.2 Environment of Deposition

A framework for the following paleoenvironmental interpretations has been deduced by integrating the data from the sedimentological analytical result. Two paleoenvironments have been delineated; a continental and a paralic to transitional environment.

Depositional environment of Toms-well, OG-Field is depicted by a heterolic facies distribution in the OG-Field, Niger Delta Basin. The continental environment is chiefly sandstone with lenses of lignite and clay at the upper unit (Continental environment). The unit is coarse to medium grained and fines downward. The base continental is medium to fine grain; thus marks the top of Agbada paralic environment of the Niger Delta Basin. The Toms-well penetrates the marine-paralic environment of OG-Field, Niger Delta Basin.

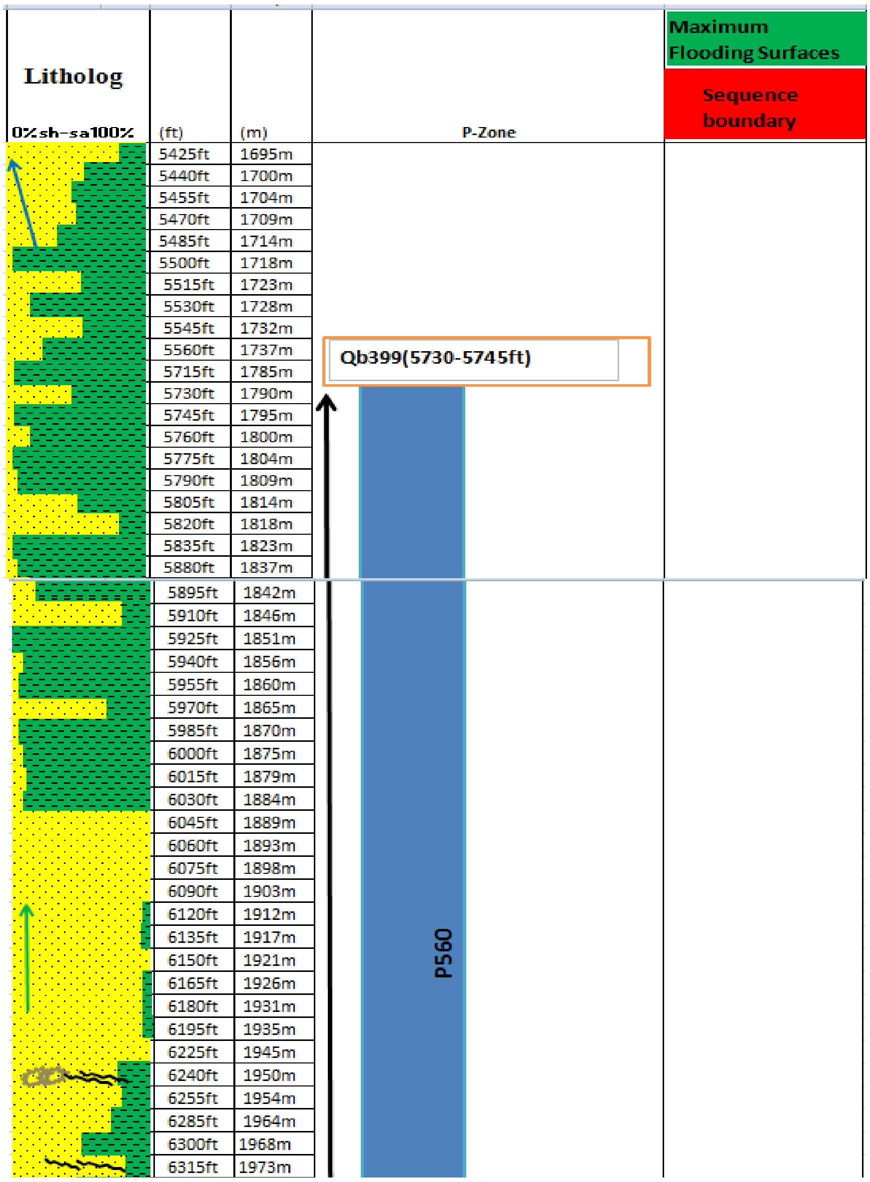


Fig. 4a. Lithologic Model of Lithofacies, P-Zones and Sequence Stratigraphy of Toms-Well within 5425ft – 6315 ft

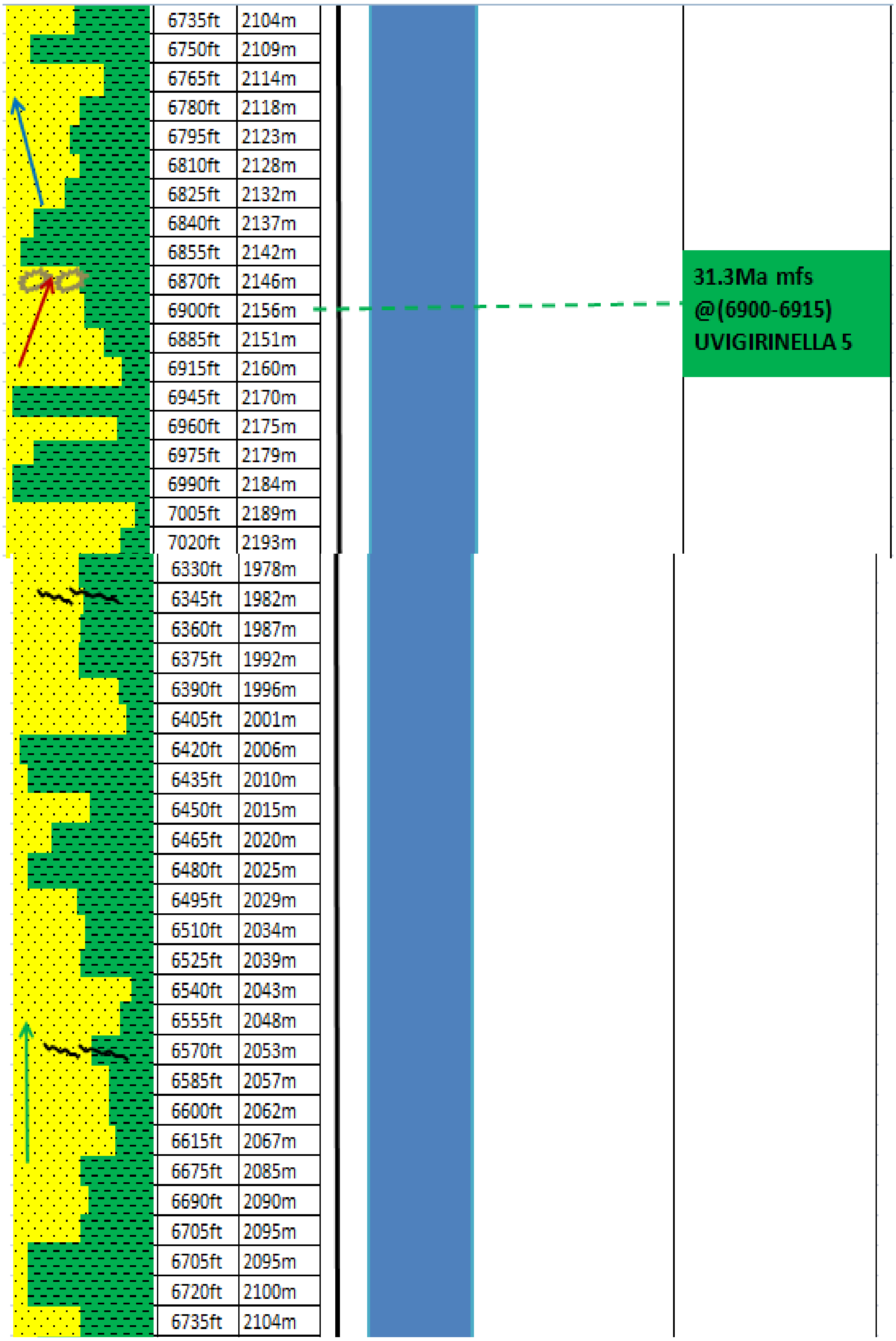


Fig. 4b. Lithologic Model of Lithofacies, P-Zones and Sequence Stratigraphy of Toms-Well within 6330 ft – 7020 ft

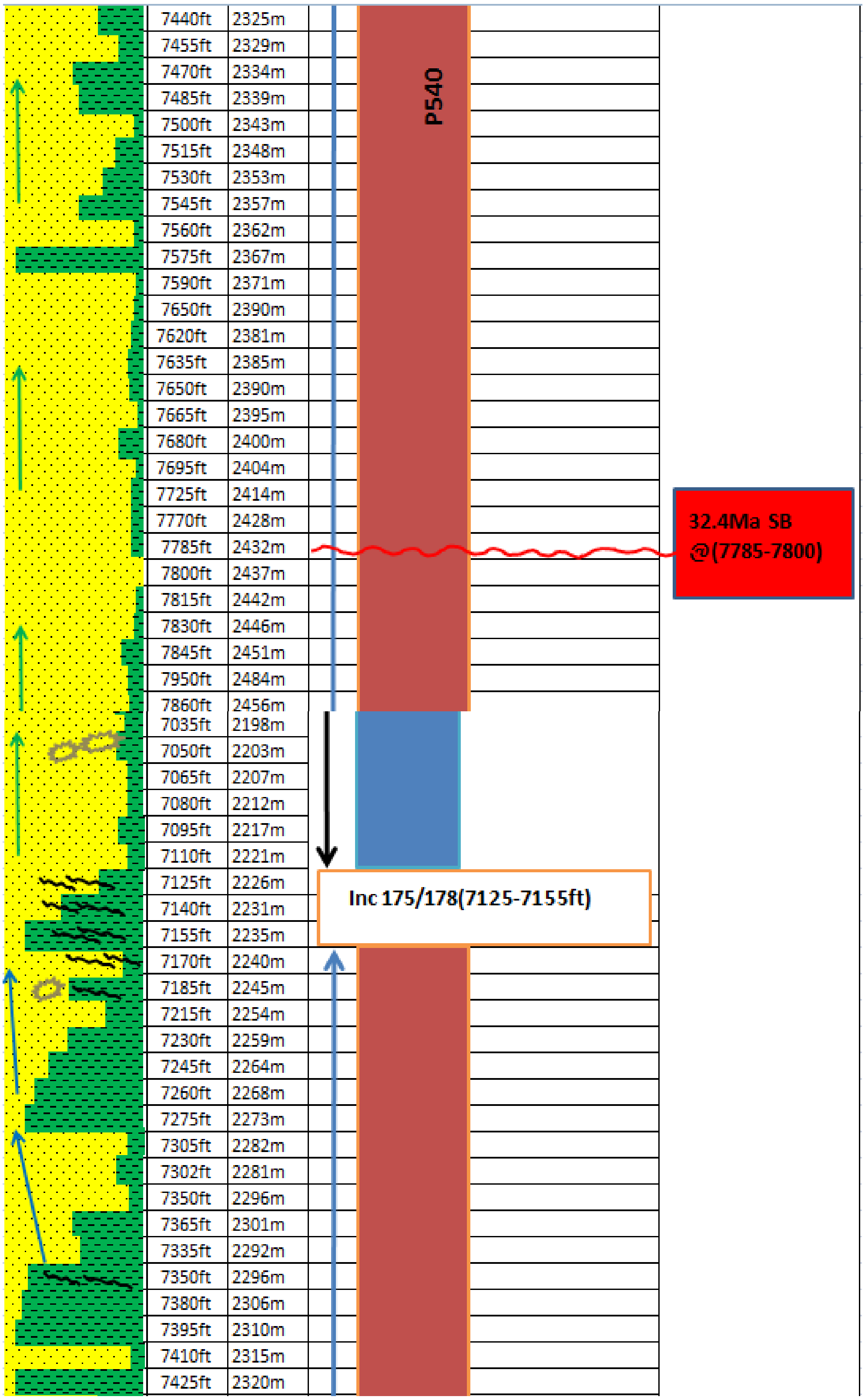


Fig. 4c. Lithologic Model of Lithofacies, P-Zones and Sequence Stratigraphy of Toms-Well within 7035 ft – 7860 ft

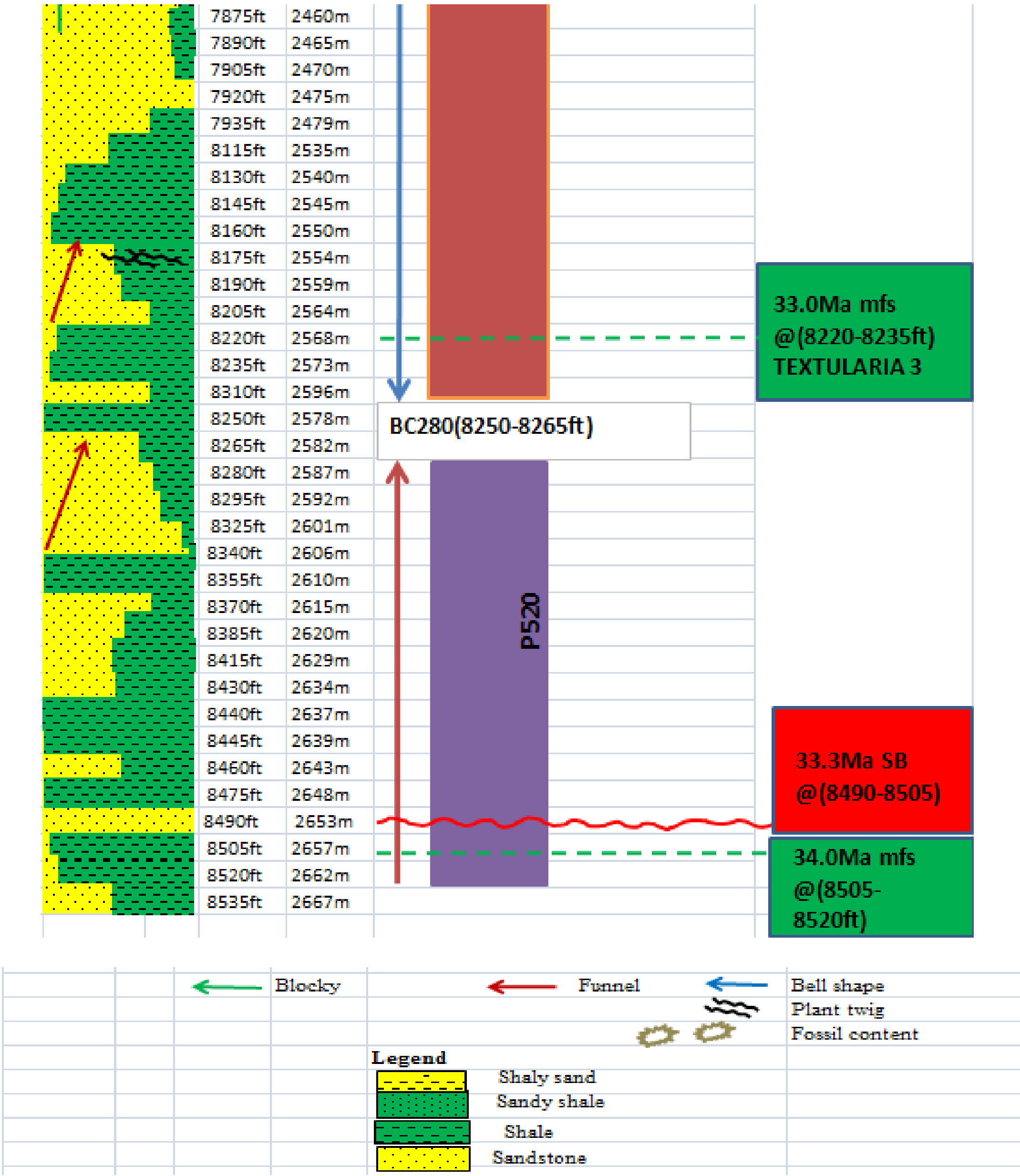


Fig. 4d. Lithologic Model of Lithofacies, P-Zones and Sequence Stratigraphy of Toms-Well within 7875 ft – 8535 ft

The logged interval which is an upward increase in sandstone thickness indicated by Figures 4a-4b for the upper part of Toms-Well suggests Continental-Transitional environment/settings of high energy conditions. This Continental – Transitional environment defined from 7005 ft – 5410 ft as a result of the predominance of Shaly Sandstone and Sandy shale, is also characterized by the presence of Quartz and Iron oxide and this is typical of the Benin Formation of the Niger Delta basin. From the sedimentological description, the logged interval 8520 feet to 7125 feet depicts Paralic environment characterized by the occurrence of both sandstone (continental) and shale (marine). The shale lithology is known to be deposited from suspension load in low energy conditions. Also, closer to coastline with higher energy because of wave activities, coarser sediments are deposited here resulting to the alternation of sandstone and shale. Minerals such as Pyrite formed in a reducing environment, Glauconite formed in marine settings, Mica and Carbonates which probably might be formed from calcareous organisms that typically flourishes in the upper 10 – 15 m of the sea characterized this logged

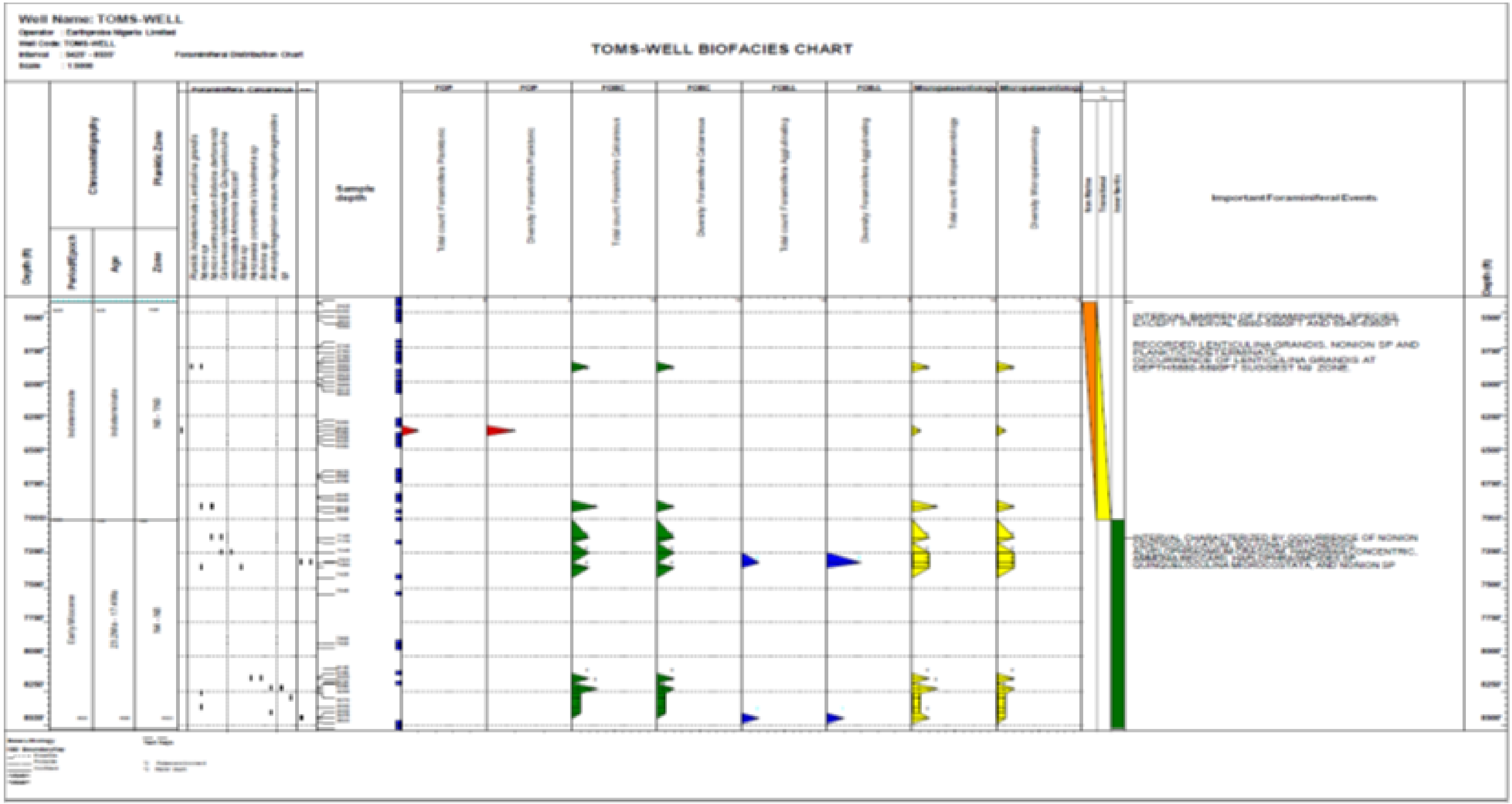


Fig. 5. Biofacies Distribution Chart of Toms-Well Abundance Plot of Foraminifera Trend

Table 2. Interpreted Palynomorphs Distribution Chart of Toms – Well

DEPTH (FEET)	Arecipites exilimuratus (280)	Striatmonocolpites rectostriatus (252)	Racemonocolpites hians (250)	Retibrevitricolporites obodoensis (178)	Pachydemites diederixi(317)	Zonocostites ramonae (531)	Pradapollis africanus(443)	Praedapollis flexibilis (420)	Echiperiporites estelae (200)	Retitricolporites irregularis (511)	Cicatricosisporites dorogensis (30)	Peregrinipollis nigericus(399)	Fenestrites spinosus (347)	Psilamonocolpites marginatus (237)	Bombacacidites (400)	Gemmatriporites sp (573)	Spirosincoporites brunnii(412)	Verrutricolporites rotundiporis (440)	Psilatricolporites crassus (535) cf (533)	Monoporites annulatus (125)	Magnastriatites hawardi (9) cf (14)	Crassoretitriletes Vanraadshooveni (17)	Striatricolpites catatumbus (445)	Cinctiperiporites mulleri(190)	PALYNOLOGICAL ZONES
5410-5425	3	1	1																						
5425-5440	1		3	1	1																				
5485-5500	9		1			1	1	1																	
5515-5530	8	1	1					4	1	1	2	1													
5545-5560	1		1									1	1												
5730-5745							1					1													qb(399) @ (5730-5745ft)ft; P560
5745-5760	2		2	1	1	2								1											
5775-5790			1							1															
5820-5833	2		4		2						1				1										
5865-5880			1		1					1															
5880-5895		2	1	1	1		3	1		2															
5910-5925		2	1		2			2		3						1									
5940-5955		1								2															
5970-5985	2		2			1		1	1	1							1	1							
6000-6015			2				1			1							1		1	1	1				
6015-6030	2			2	3			1		2							1								
6285-6300	1				1	2				1							3								
6315-6330	3	2	1	1																		1			
6345-6350	1		2				2	1		2															
6390-6405							1																		
6405-6420		2								1															
6435-6450	3		1	1															1						
6675-6690	5	1	2				1			1					1										
6690-6705	14	1	2		1	2	1	1																	
6825-6840	11	1																							
6840-6855	6	2	3	1		2				3										1					
6900-6915	3		1																						
6930-6945	6	1	1							1							1								
6990-7005	9	1	2					1						1		1	1	1	1				1		
7125-7140	2		4	2			1		1	3									1					1	inc(175/178) @(7125-7155)ft; P540
7155-7170		1		1																					
7230-7245	1	2	1																						
7300-7320	2	5				1																			
7335-7350	2	2					1																		
7410-7425	2	1	4																						
7530-7545	2	2								1								1							
7890-7905	3	3	5	1			1															2			
7920-7935						1																			
8130-8145	4		1							1															
8145-8160	2																								
8205-8220	7		1				1																		
8220-8235	1															1									
8235-8250	7	2																							
8250-8265	3	2			1																			1	bc(280) @ (8250-8265)ft; P520
8355-8370	3								1																
8425-8440	3			2																					
8440-8455	5	2	1				2																1		
8460-8475	2	2		2				1																	
8505-8520	1		2				1	1																	b(250) @ (8505-8520)ft

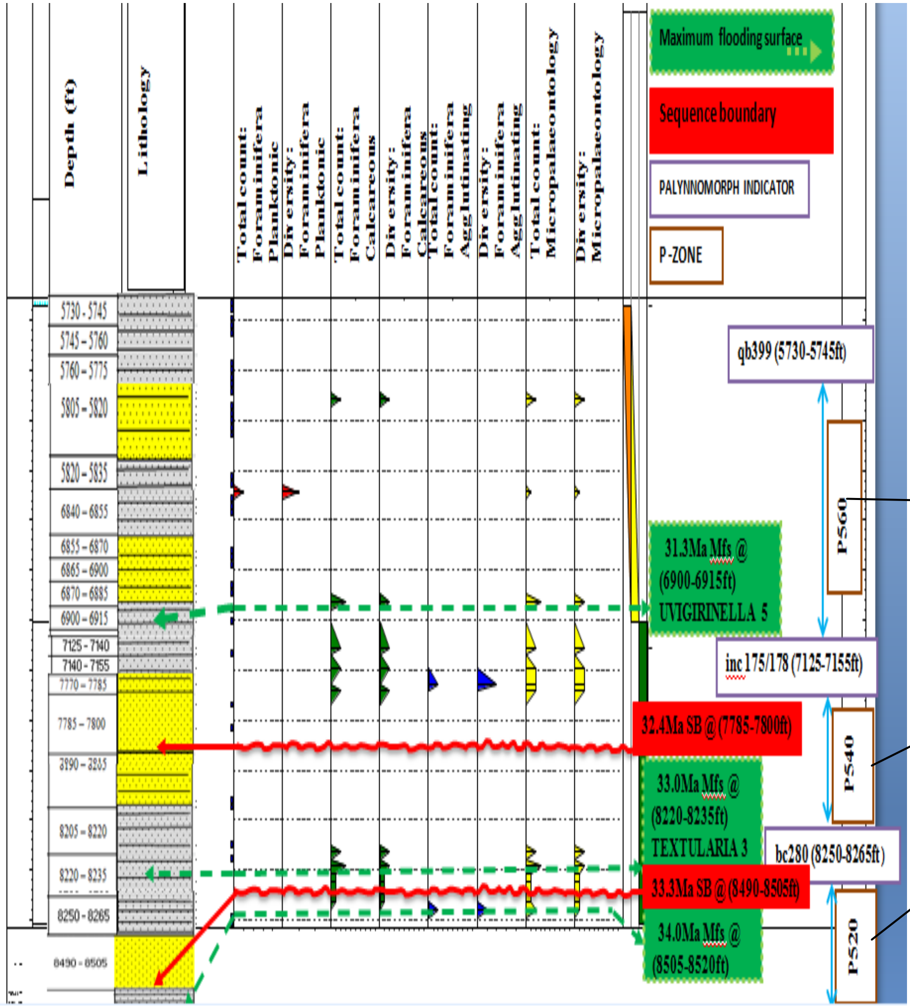


Fig. 6a. Geologic Model of Lithofacies, P-Zones and Sequence Stratigraphic Events of Toms -Well

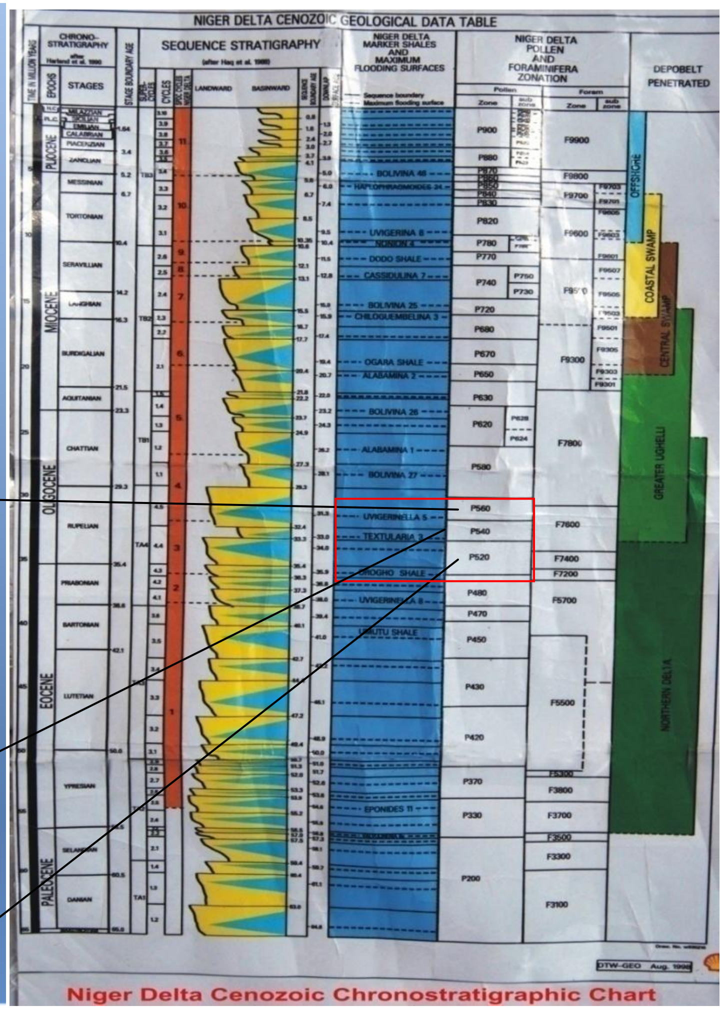


Fig. 6b. Niger Delta Cenozoic Chronostratigraphic Section [23]

section (8520 feet to 7125 feet) in Toms-Well. Thus the logged interval 8520 feet – 7125 feet characterised by the alternation of Sandstone, Shale, Sandy shale and Shaly sandstone as well as the presence of glauconite, carbonate and mica suggest Paralic environment typical of the Agbada Formation with the Shale becoming thicker downward. However the marine Akata Shale is not penetrated thus indicating that Toms-Well only penetrated the sediments of the Benin and Agbada Formation in the Niger Delta basin.

3.2.1 Continental – transitional environment

The logged interval which is an upward increase in sandstone thickness indicated by Fig. 4a-4b for the upper part of Toms-Well suggests Continental-Transitional environment/settings of high energy conditions. This Continental–ransitional environment defined from 7005 ft – 5410 ft as a result of the predominance of Shaly Sandstone and Sandy shale, is also characterized by the presence of Quartz and Iron oxide and this is typical of the Benin Formation of the Niger Delta basin.

3.2.2 Paralic environment

From the sedimentological description, the logged interval 8520 feet to 7125 feet depicts Paralic environment characterized by the occurrence of both sandstone (continental) and shale (marine). The shale lithology is known to be deposited from suspension load in low energy conditions. Also, closer to coastline with higher energy because of wave activities, coarser sediments are deposited here resulting to the alternation of sandstone and shale. Minerals such as Pyrite formed in a reducing environment, glauconite formed in marine settings, mica and carbonates which probably might be formed from calcareous organisms that typically flourish in the upper 10 – 15 m of the sea characterized this logged interval (8520 ft – 7125 ft) in Toms-well. Thus the logged interval 8520 ft -7125 ft characterized by the alternation of sandstone, shale, sandy shale and shaly sandstone as well as the presence of pyrite, glauconite, carbonate and mica suggests paralic environment typical of the Agbada Formation with the shale becoming thicker downward. However, the marine Akata shale is not penetrated thus indicating that Toms-well only penetrated the sediments of the Benin and Agbada Formations in the Niger Delta basin. The environment of deposition and lithofacies zonation of Toms-well was based on d Boggs zonation scheme [24]. The scheme has the following classes: continental (> 90% sand), continental to transitional (90-85% sand), transitional to paralic (70-60% sand), paralic (60-40% sand), paralic to marine (40-20% sand) and marine (< 20% sand). The result of this is shown in Table 6.

3.3 Foraminiferal Micropaleontology

Fifty five ditch cutting samples from interval 5425 ft – 8520 ft of Toms-well were processed for micropaleontological study. The samples were subjected to standard micropaleontological (foraminifera) sample processing techniques.

The results of the foraminifera analysis of the ditch cutting samples between 5425ft and 8520ft of Toms-well are presented in Figure 6a. Foraminifera assemblages over these intervals are generally poor with some barren intervals. Most of the species recorded are calcareous and arenaceous benthic foraminifera species with planktics generally absent in the well. Species recorded include: *Bolivina dertonensis, Poritextularia panamensis, Spirosplectammina wrightii, Textularia* sp., *Nonion* sp., *Bolivina* sp. *and Bolivina imperatrix.* Ten species out of the total twenty foraminifera recovered are calcareous benthics while the arenaceous benthics accounted for the remaining ten species.

Table 3. Summary of Palynological Biostratigraphy and Zonation of Toms -Well

Depth (ft)	P Zone	Diagnostic marker shale	Age (Ma)	Epoch	Depobelt	Formation
6900-6915	P560	Top/FDO(443)	31.3			
		QB (399)		Oligocene-Early Miocene	Greater Ughelli	Agbada
8220-8235	P540	Inc (178)(175)	33.0			
8505-8520	P520	(250)	34.0			

Table 4. Summary of SB, Age, P-Zone, F-Zone and Epoch of Toms-Well

Depth (ft)	Chrono-sequence	Age (Ma)	P-zone	Depobelt	Epoch	Depobelt
7785-7800	SB1	32.4(Ma)	P540	F7600	Early Miocene	Greater Ughelli
8490-8505	SB2	33.3(Ma)	P560	F7800	Early Miocene	Greater Ughelli

Table 5. Summary of MFS, Age, P-Zone, F-Zone and Epoch of Toms-Well

Depth (ft)	Chrono-Sequence	Marker Shale	Age (Ma)	P-zone	F-zone	Epoch	Depobelt
6900-6915	MFS 1	Uvigerinella 5	31.3	P560	F7400	Early Miocene	Greater Ughelli
8220-8235	MFS 2	Textularia 3	33.0	P540	F7600	Early Miocene	Greater Ughelli
8505-8520	MFS 3		34.0	P520	F7800	Oligocene	Greater Ughelli

Table 6. Boggs Zonation Scheme for Toms-Well

Depth (ft)	Lithology	Description
5485-5500, 5790-5805, 5805-5802, 5895-5910, 6030-6045, 6045-6060, 6060-6070, 6075-6090, 6135-6150, 6210-6225, 6105-6120, 6120-6135, 6150-6165, 6165-6180, 6180-6195, 6240-6255, 6225-6240,6360-6375, 7485-7500, 7545-7560, 7560-7575, 7575-7590, 7590-7605,7605-7620, 7620-7635, 7635-7650, 7650-7665, 7665-7680, 7710-7725, 7755-7770, 7770-7785, 7785-7800, 7800-7815, 7815-7830, 7890-7905, 7905-7920, 8220-8235, 8310-8325, 8325-8340	Continental	These intervals have more than 90% sand
5425-5440, 5440-5455, 5455-5470, 5500-5515, 5955-5970, 6300-6315, 6375-6390, 6465-6480, 6480-6495, 6495-6510, 6510-6525, 6525-6540, 6540-6555, 6555-6570, 6570-6585, 6585-6600, 6600-6615, 6945-6960, 7395-7410, 7440-7455, 7500-7515, 7515-7530, 7680-7695, 7830-7845, 7845-7860, 7875-7890, 7920-7935, 8265-8280, 8280-8295,8445-8460, 8490-8505	Continental – Transitional	These intervals are characterized by thick sand bodies with minor (very thin) shale content of between 90-85%.
5470-5485, 5530-5545, 6285-6300, 6330-6345, 6420-6435, 6660-6675, 6735-6750, 6750-6765, 6765-6780, 6795-6810, 6865-6900, 7365-7380, 7380-7395, 7470-7485, 7530-7545, 8160-8175, 8175-8190, 8190-8205, 8370-8385, 8400-8415, 8415-8430, 8520-8535	Transitional-Paralic	These intervals consist of about 70-60% sand.
6675-6690, 6705-6720, 6315-6330, 6345-6360, 6780-6795, 6810-6825, 6825-6840, 6855-6870, 7455-7470, 8100-8115,	Paralic	These intervals have between 60-40% sand content with shaly section getting thicker downward.
5515-5530, 5695-5715, 5715-5730, 5925-5940, 5940-5955, 6390-6405, 6405-6420,6435-6450, 6450-6465, 6690-6705, 6720-6735, 6840-6855, 6960-6975,7320-7335, 7335-7350, 7425-7440, 8355-8370, 8505-8520	Marine-Paralic	This has about 40-20% sand with thick shale intervals.
5545-5560, 5730-5745, 5745-5760, 5760-5775, 5775-5790, 5910-5925, 5820-5835, 5865-5880, 5880-5895, 5970-5985, 5985-6000, 6000-6015, 6015-6030, 6900-6915, 6930-6945, 6975-6990, 6990-7005, 7300-7320, 7320-7335, 7410-7425, 8115-8130, 8130-8145, 8145-8160, 8205-8220, 8235-8250, 8250-8265, 8340-8355, 8425-8440, 8430-8445, 8460-8475	Marine	This is characterized by <20% sand having very thick shale intervals.

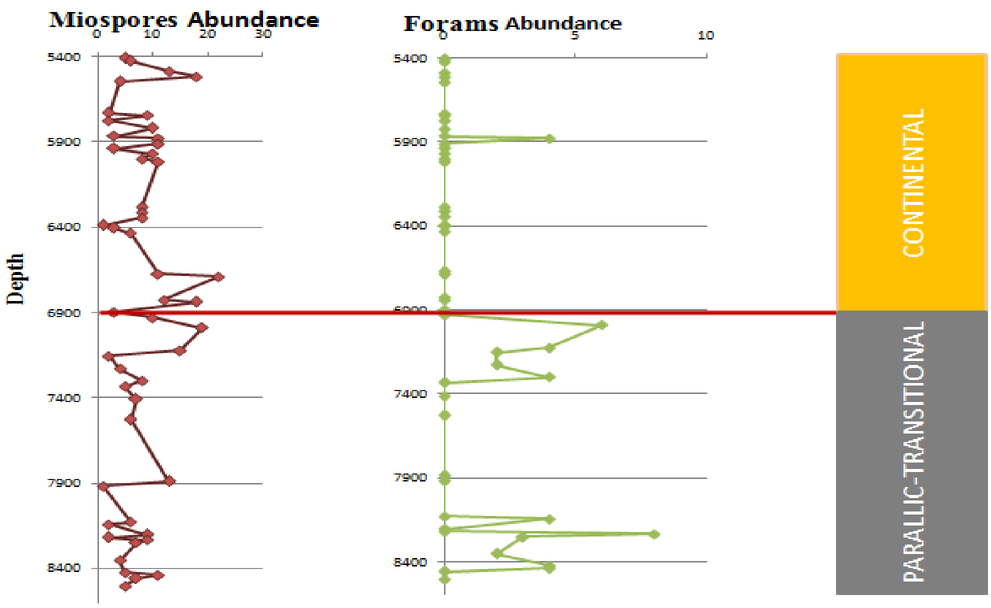


Fig. 7. Environment of Deposition Depicted from Plot of Palynomorphs Abundance

Table 7. Foraminifera Biostratigraphic Summary of Toms - Well

(First Downhole Occurrence of stratigraphically important Foraminiferal species)				
Depth (m)	**Epoch/Period**	**Age (Ma)**	**Zones (Blow 1969, 1979)**	**SignificantForaminiferaldatums**
5410-5425	*First sample analysed*			
5410 – 7005	Indeterminate	-	?N9- N8	Interval barren of Foraminiferal species Except intervals 5880-5890ft5 and 6345 -6360ft that recorded *Lenticulina grandis*, *Nonion sp.* and *Planktic indeterminate* Occurrence of *Lenticulina grandis* at depth 5880-5890ft suggests N9 zone
7125-8520	Early Miocene	17.4 – 23.2	N8 – N4	Interval characterized by occurrences of *Nonion centrosulcatum*, *Bolivina dertonensis*, *Alveolophragmium crassum*, *Hanzawaia concentric*, *Ammonia beccarii*, *Haplophragmoides sp.*, *Quinqueloculina microcostata*, *and Nonion sp.*
10,632	*Last sample analysed*			

4. CONCLUSION

The combined results of the biostratigraphy showed that the studied well (Toms-well) in OG-field was deposited during Oligocene to Early Miocene Epoch of estimated numerical age of 31.3MaMfs, 33.0MaMfs and 34.0MaMfs. Prospective intervals of reservoirs delineated in

Toms-well are; 8175 – 8205 ft, 8265 – 8340 ft and 6870 – 6915 ft respectively with reservoir thickness of about 10m. The result from the integration of sedimentological, foraminiferal and palynological suggests sediments deposition in marginal marine to shallow marine environments. The geologic ages of SB interpreted, ranges between 32.4Ma to 33.3Ma while the positions of MFS were obtained to be 31.3Ma, 33.0Ma and 34.0Ma, corresponding to Greater Ughelli depobelt. The studied intervals were dated Oligocene to Early Miocene (32.4-33.3Ma).The alternation of sandstone shale, shaly sand and sandy shale revealed that the well interval belongs to paralic Agbada Formation of the Niger Delta basin.

ACKNOWLEDGEMENTS

We wish to express our profound and unreserved appreciation to the Nigerian Petroleum Development Company, Benin for the data used in this study. Special thanks also go the University of Benin and Earthprobe Company for their undaunted support throughout the study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Adebayo OF, Akinyemi SA, Madukwe HY, Aturamu AO, Ojo AO. Geochemical characterization and palynological studies of some Agbada Formation deposits of the Niger Delta basin: Implications for paleodepositional environments. Turkish Journal of Earth Sciences. 2016;25:573-591.
2. Olayiwola PO. Petroleum and structural change in a developing country: The case of Nigeria. New York, NY, USA: Praeger; 1987.
3. Okosun EA, Chukwu JN, Ajayi EO, Olatunji OA. Biostratigraphy, depositional environment and sequence stratigraphy of Akata Field (Akata 2,4,6 and 7 wells), Eastern Niger Delta, Nigeria. International Journal of Scientific and Engineering Research. 2012;3(7):1-27.
4. Fajemila OT. Foraminifera biostratigraphy and paleoenvironmental studies of two wells from offshore Western Niger Delta. Ife Journal of Science. 2012;14:369-384.
5. Adenugba AA, Dipo SO. Non-oil exports in the economic growth of Nigeria: A study of agricultural and mineral resources. J. Educ. Soc. Res. 2013;3:403-418.
6. Oloto IN, Promise W. Biostratigraphic study and paleo environmental reconstruction of cores from offshore (South Western) Niger Delta, Nigeria. International ournal of Scientific and Technology Research. 2014;3:279-286.
7. Nwajide CS, Reijers TJA. Sequence architecture in outcrop: examples from the Anambra Basin, Nigeria. NAPE Bulletin. 1996;11:23-32.
8. Oyedele KF, Oladele S, Ogagarue DO, Bakare K. Sequence startigraphic approach to hydrocarbon exploration in Bobsaa Field, Onshore Niger Delta. Journal of Petroleum and Gas Exploration Research. 2012;2:106-114.
9. Zellers SD. Foraminiferal sequence biostratigraphy and seismic stratigraphy of a tectonically active margin; the Yakataga Formation, northeastern Gulf of Alaska. Marine Micropaleontology. 1995;26:255-271.
10. Armentrout JM. High resolution sequence biostratigraphy: example from the Gulf of Mexico Plio-pleistocene (London). Geological Society Special Publication. 1996;104:65-86.
11. Oloto IN. Palynological study of Igbomotoru-1 Well, Central Coastal Niger Delta, Nigeria. International Journal of Scientific and Technology Research. 2014; 3:287-292.
12. Ukpabi N, Osterloff PL, Oloto IN. Biostratigraphy studies of miocene sediments. In The onshore/offshore area, Niger Delta Basin, Nigeria. International Journal of Science Invention Today. 2014; 3:330-345.
13. Obaje SO, Okosun EA. Taxonomic notes on marker benthic foraminifera of Tomboy Field, offshore Western Niger Delta, Nigeria. International Journal of Science and Technology. 2013;3:357-364.
14. Nwozor KR, Omudu MI, Ozumba BM, Egbuachor CJ, Onwuemesi AG, Anike OL. Quantitative evidence of secondary mechanisms of overpressure generation: insights from parts of Onshore Niger Delta, Nigeria. Petroleum Technical Development Journal. 2013;3:64-83.
15. Doust H, Omatshola E. Niger Delta in edwards divergent/passive margin basins.

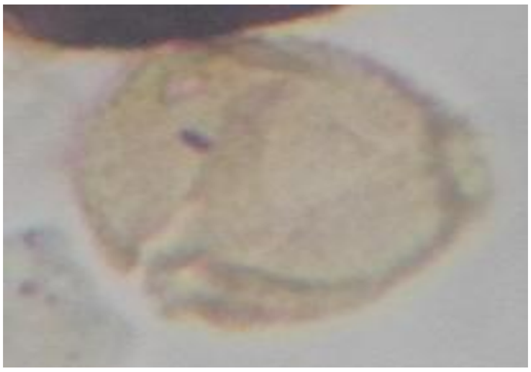
American Association of Petroleum Geologists Bulletin memoir. 1990;48:201-238.

16. Koledoye AB, Aydin AA. 2000. Three-dimensional visualization of normal faults segmentation and its implication for faults growth. The Leading Edge. 2000;19:692-701.
17. Obiadi II, Obiadi CM. Structural deformation and depositional processes: Insights from the Greater Ughelli Depobelt, Niger Delta, Nigeria. Oil and Gas Research. 2016;2(3):1000118(1-8).
18. Magbagbeola OA, Willis BJ. Sequence stratigraphic and syndepositional deformation of the Agbada Formation Robertkiri field Niger Delta, Nigeria. American Association of Petroleum Geologists Bulletin. 2007;91:945-958.
19. Hooper RJ, Fitzsimmons RJ, Grant N, Vendeville BC. The role deformation in controlling depositional patterns in the south-central Niger Delta. West Africa Journal of Structural Geology. 2002;24: 847-859.
20. Damuth JE. Neogene gravity tectonics and depositional processes on the deep Niger Delta continental margin. Marine and Petroleum Geology. 1994;11:320-346.
21. Corredor F, Shaw JH, Bilotti F. Structural styles in the deep-water fold and thrust belts of the Niger Delta. American Association of Petroleum Geologists Bulletin. 2005;89:753-780.
22. Olabode SM, Won J, Udoekong GO, Ibilola OO, Dixon D. Resolving the structural complexities in the deepwater Niger-Delta fold and thrust belt: a case study from the Western Lobe Nigerian offshore depobelt. Search and Discovery Article. 2010;10289:1-30.
23. Rotimi OJ. Sequence stratigraphy study within a chronostratigraphic framework of ‘Ningning field’, Niger Delta. RMZ– Materials and Geoenvironment. 2010;57:475–500.
24. Boggs S. Principles of sedimentology and stratigraphy, 4th ed. Pearson, Upper Saddle River, New Jersey; 2006.

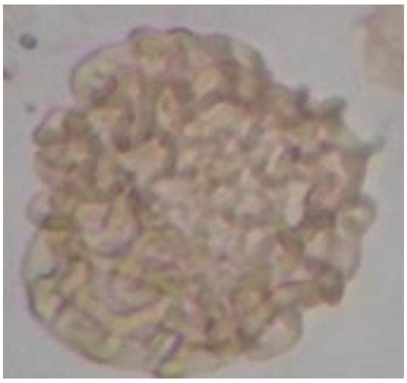
APPENDIX

Diagnostic Marker Fossils Recovered

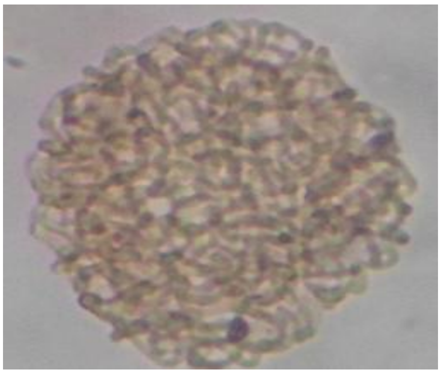
Magnastriatites hawardi (9)



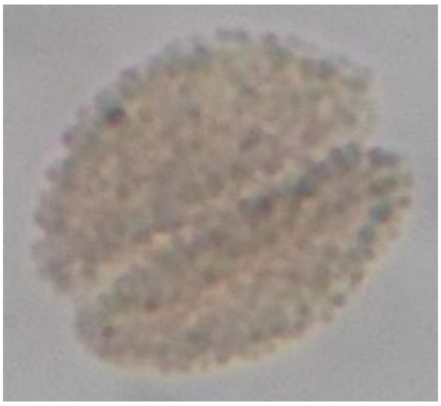
Retibrevitricolporites obodoensis (178)



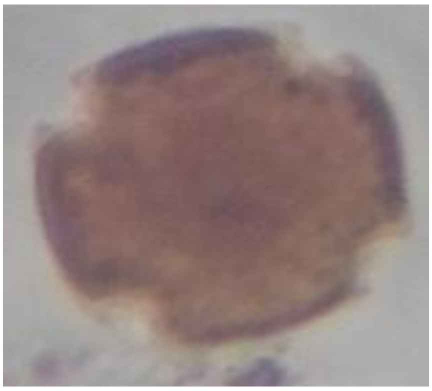
Peregrinipollis nigericus (399)



Peregrinipollis flexibilis (420)

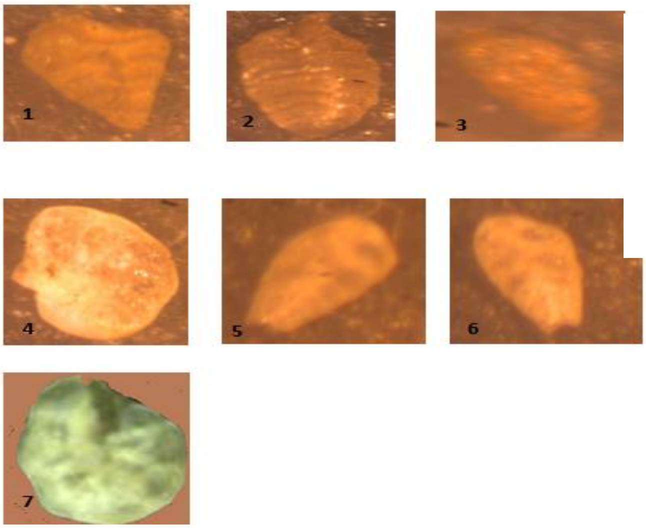


Racemonocolpites hians (250)



Pachydemites diederixi (317)

Diagnostic Palynomorphs



1) *Spirosplectamina wrightii*
2) *Poritextularia panamensis*
3) *Textularia sp.*
4) *Nonion sp.*
5) *Bolivina dertonensis*
6) *Bolivina imperatrix*
7) *Amonia biccarii*

Diagnostic foraminiferas

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The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/51884