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Depositional Environment Reconstruction of OM-4 and OM-A Wells, Niger Delta, Nigeria, Using Palynomorphs and Wireline Logs

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Abstract Microfacies analysis combined with palynological studies were carried out on two wells (OM-4 and OM-A wells) in the Niger Delta to reconstruct the depositional environment of the penetrated wells from 8200 – 11350 ft each in both wells. The succession studied yielded rich terrestrial components of the palynomorph assemblage, which gave zero to low PMI values in both wells, suggesting a paralic (freshwater to marginal marine) environment. Also, the abundance of mangrove swamp species such as, *Zonocostites ramonae, Acrostichum aureum, Botryococcus braunii* and *Psilatricolporites crassus* in both wells (which are brackish water indicators) denotes an environment of deposition with higher terrestrial influences and pockets of marine intrusions, confirming a paralic environment of deposition. The facies established from the wireline log signatures gave an alternating cylindrical to funnel shaped log motif with few units of bell shapes. This was interpreted as continental to marginal marine environment. The results of the facies analyses were correlated with the PMI values of the wells and generally cylindrical to funnel shaped facies were established with corresponding nil to low PMI values, confirming a paralic environment of deposition in both wells.

Keywords Palynological, Facie, Facie Association, Depositional Environment, Paralic, Niger Delta

1. Introduction

Palynological information from present day studies of modern organisms can be used to infer environmental conditions in the past and also predict future environmental conditions, since the distribution of organisms generally, are controlled by a combination of physical conditions of the surrounding area including terrain, vegetation structure, rainfall, sea level rise or fall and temperature. Information on the palynological assemblage is useful in reconstructing paleoenvironment because changes in the environment are reflected in palynologic assemblages [7,8]. Hence, palynomorphs are environment specific and their presence indicates the environment they represent.

Gamma ray log is used to predict varying lithology since its intensity depends on the mineralogy and shaliness of the sediments being measured. Sharp change in lithology suggests deposition break [1], hence abrupt change gamma ray log shapes indicates different environment of deposition.

To ascertain the depositional environment, there is need to carry out an environmental analysis which entails subdivisions of sedimentary successions on the basis of lithology, grain size, biogenic and physical sedimentary structures and stratification that contain direct relationship to the depositional processes that produced them. These processes result in various distributions of grain size (which can be inferred from the wireline logs) and biolologic properties that characterize the deposited sediment. This study focuses on the use of palynomorphs as the biologic component as well as the wireline logs (denoting physical properties of the sediments) in reconstructing the environment of deposition of the studied interval.

Location and Geology of the Study Area

The study area is located in the Western part of the Niger Delta which is situated in the gulf of Guinea on the West Coast of Central Africa. Niger Delta lies between Latitude 4° and 6°N and Longitude 3° and 9°E, in the southern part of Nigeria. The studied wells, OM-4 and OM-A wells are located on the onshore portion of the Western Niger De1ta. They are located on latitude 4^0 40' 28" N and longitude $6^0$48' 00"′E and 4^0 37'38" N and 6^0 47'16"E respectively as presented in Figure 1 fall within the coastal depobelt. The

Niger Delta basin is bounded in the West by the Benin flank, in the East by Calabar flank in the south most part of Nigeria. It contains sediments of Paleogene to Holocene which were deposited in high energy deltaic environment. The sediments were laid in three lithostratigraphical order which are Benin Formation, Agbada Formation and Akata Formation.

The Akata Formation, which is composed of prodeltatic sediments, which are dominantly made up of under compacted marine shales and may contain patches of high pressured siltstone or fine grained sandstones. The age of the formation is between Eocene to Recent, but may be as old as Paleocene. Overlying the Akata formation is the Agbada Formation is composed of alternations of sand and shale sequences of delta-front, distributary channel and deltaic plain origin. The intercalated sequence of sandstones and shales of this formation has been shown by (Weher, 1971) to be a continuous cycles of marine and fluvial deposits. The topmost Benin Formation consists mainly of sandstones which are massive, highly porous and freshwater–bearing with thin shale interbeds distributed locally and are considered to be of braided-stream origin [2] The age of the formation varies from Oligocene (or earlier) to Recent.

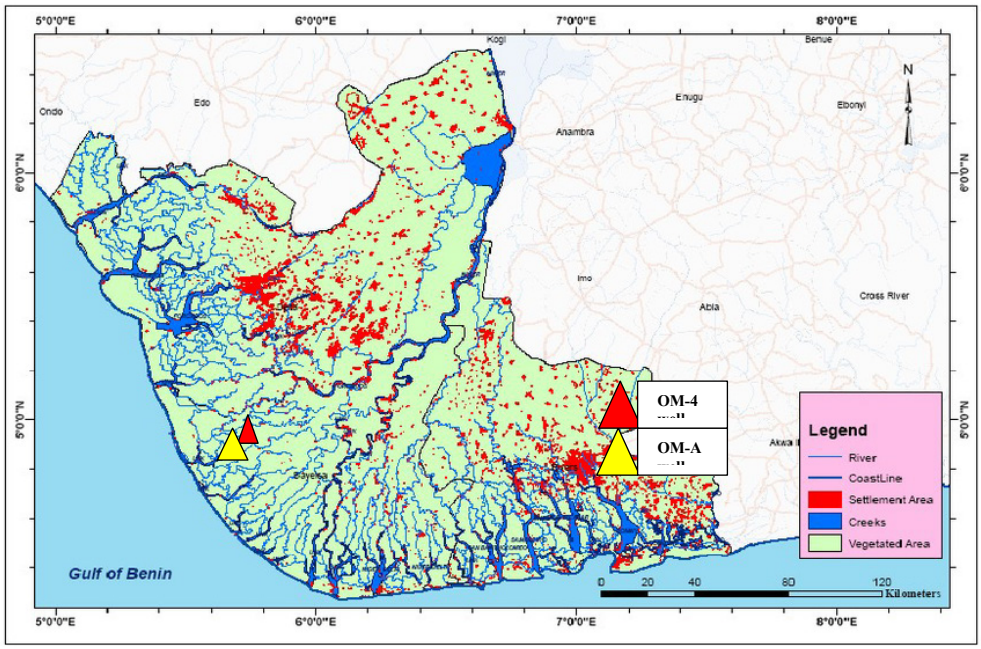

Figure 1. Niger Delta map showing location of wells (modified after ResearchGate)

2. Materials and Methods

Ditch cutting samples and gamma ray logs for both wells were given by Chevron Nigeria Plc. The methodology involved two (2) processes which are; (i) palynological analysis and (ii) gamma ray logs interpretation.

For the palynomorphs to be used for depositional environment analysis, standard procedure for palynological preparation was followed which involved labelling and weighing of the samples, followed by the complete digestion of the samples in hydrochloric and hydrofluoric acid for the removal of carbonates and silicates respectively. The slides prepared were viewed using research binocular microscope. Identified species were noted, counted and recorded on the analysis sheet using the tally system and the results were inputted into the stratabug software to prepare the palynomorphs distribution chart. Environmental palynomorph specie indicators as well as the palynomorphs marine index (PMI) were used for the palynological interpretation of the depositional environment. The PMI index was proposed by [4] to interprete environments of deposition. PMI is calculated using the formula: PMI = (Rm/Rt + 1)100, with Rm being the number of marine palynomorphs, which include dinoflagellates, acritarchs and foraminiferal test linings and Rt, the number of terrestrial palynomorphs (pollens and spores). In this study, Rm and Rt were expressed as the number of species per sample. High PMI values were interpreted to indicate normal marine depositional conditions, low values as brackish and nil values as fresh water [4]. This study adopts 0% as nil PMI values indicating freshwater, 1-50% as low PMI values indicating brackish and 51-100% as high PMI values indicating marine environment.

The gamma ray log used is the gamma ray log interpretation was achieved by establishing gamma ray signatures on the basis of the shapes produced by the logs. Lithofacies were interpreted based on gamma ray log models [3] shown in figure 2.

3. Result and Discussion

The palynomorph distribution chart of OM-4 and OM-A wells shows a fair recovery of species count with fifty-one and forty-four species identified in both wells respectively. The recovered palynomorphs are shown on Table 1 and Table 2.

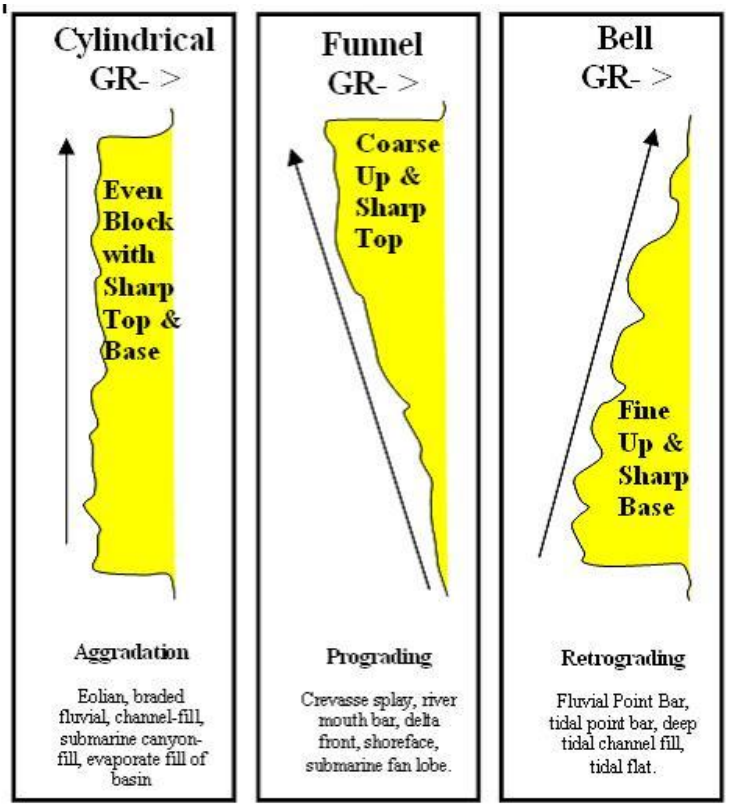

Figure 2. Gamma ray log model showing log motif and depositional environments (Cant, 1992)

Table 1. Palynomorph distribution in OM-4 well onshore western Niger Delta

Period/Epoch	Depth/ Specie name	Alpollenites verus	Alnus vera	Canthiumdium sp	Chenopodiaceae sp	Cyperaceaepollis sp	Gemmamonoporites sp	Inaperturopollenites sp	Monocolpites sp	Monocolpites annulatus	Pachydermites diederixi	Peregrinipollis nigericus	Podocaridites sp	Pollen indeterminate	Praedapollis flexibilis	Praedapollis sp	Proteacidites cooksonni	Proxapertites sp	Psilamonocolpites sp	Psilatricolporites crassus	Psilatricolporites sp	Psilatriporites sp	Racemonocolpites hians	Retibrevitricolporites protudens	Retitricolporites irregularis	Retitricolporites sp	Sapotaceoidaepollenites sp	Spirosyncolpites bruni	Straitricolpites catatumbus	Syncolpites sp	Tricolporites sp	Triporites sp	Verrustephanocolpites complanatus	Verrutricolporites rotundiporus	Verrutricolporites sp	Zonocostites ramonae	Podocarpus sp	Acrostichum aureum	Charred gramineae cuticle	Crassoretitriletes vanraadshooveni	Fungal spores and hyphae	Laevigatosporites sp	Magnastriatites howardi	Polypodiaceoisporites sp	Selaginella myosurus	Stereeisporites sp	Verrucatosporites sp	Magnastriatites sp	Lycopodium neogenicus	Dinocyst indeterminate	Leiosphaeridia sp	Botryococcus braunii
GROUP		POLLENS																																		SPORES															OTHERS		
ENV		TERRESTRIAL																																																			MARINE		
EARLY-MIDDLE MIOCENE	8200									6													2				1				1		1	64		4		1	2	6		1			2								1
	8350									1								1		1							1				1			4		3			1	3			1	3								
	8380	1						1				1								1							1				1			7		3	1	1		5		1	1	2							
	8440																													1				2		2				3												1
	8470									1				1						1					1						1		1	9		2				5		1		2							
	8500									1	1			1		1					1	1	1				1				1		1	19		4			1	6				1							
	8830									1																			1			1		3		3				4				4						
	9100									1										1							1							2				1		2				1							
	9130								1	2	1																							7		4				5		1		2							1
	9160										1															1					1			1		1				1				2						
	9190																									1								15		3				5											1
	9220									1	1										1													4						1				1							
	9250		1			1					1				1								1					3				1		14		4				6				2						
	9430				1				1												1	1	1											8																	
	9520																									1		1				1		4		1				2				1						
	9580								1	2				1																				3		1				2				1						
	9640									1	1									1												1		7		2				1				1						
	9670									1	1											1					1							9		1				1										
	9700			1						10	1																				1			6		3			1	3				1						
	9730			1																														4		1				2				1						
	9760																																	3		1				3				1					1	
	10120																																	3		1			1	1										
	10330																																	2		1				3	2									
	10360									4					1						1	1										1		7		1				3				3						
	10390									1																								3		1				2				1						
	10420																																			1				1										
	10450																																	2						1										
	10480										1																							1	1	1				1									2		
	10510																			1	4																																1
	10540								1			1																1	1							1				3	1			2						
	10570																																	4						3				1						
	10600												1								1													2							1										
	10660																																	6		2				4										
	10690																										1							4																
	10720									2																								1																
	10960										1		1		1											1	1		1					3		2														
	10990							1						2					2		1		1										5		4				10	2	1	1	1	3					
	11020																																	1		1				1										
	11080									1				2																				5						3										
	11130																																	7		2				4										
	11150									1																	1																								
	11230									1			1													1					1			2																1
	11290									1			2	1																	1			3																
	11320									1			1																			1		3		1				1				1						
	11350													1					1															3						2				2				1		

Table 2. Palynomorph distribution for OM-A well onshore western Niger Delta

Period/Epoch	Depth/ Specie name	Alnus vera	Bombacacidites sp	Corsinipollenites jussiaeensis	Ctenolophonidites costatus	Cyperaceaepollis sp	Echistephanoporites echinatus	Gemmamonoporites sp	Monocolpites sp	Monoporites annulatus	Pachydermites diederixi	Peregrinipollis nigericus	Podocarpidites sp	Pollen indeterminate	Praedapollis sp	Psilastephanocolporites minor	Psilatricolpites sp	Psilatricolporites crassus	Psilatricolporites sp	Psilatriporites sp	Racemonocolpites hians	Retibrevitricolporites protudens	Retitricolpites bendeensis	Retitricolporites irregularis	Retitricolporites sp	Sapotaceoidaepollenites sp	Striatricolpites catatumbus	Syncolpites sp	Tricolporites sp	Verrutricolporites microporus	Verrutricolporites sp	Zonocostites ramonae	Belskipollis sp	Podocarpus sp	Aerostichum aureum	Crassoretitriletes vanraadshooveni	Fungal spores and hyphae	Laevigatosporites sp	Polypodiaceoisporites sp	Selaginella mpsorus	Verrucatosporites sp	Magnastriatites sp	Dinocyst indeterminate	Leiosphaeridia sp	Botryococcus braunii
GROUP		POLLENS																																	SPORES								OTHERS		
ENV		TERRESTRIAL																																									MARINE		
LATE MIOCENE	8200				1					1									1						1		1				9					4			1					
	8230								2	1	1							1	3				1			1						13			2		6	2		5					
	8260																														1					2			1					
	8410							2				2																			4					1			3					
	8440									4															1						16			1		1			1			6	2	
	8650								1			1																			3					2								
	8710									1								1					1								4			1		2								
	8740									2	1								1						1	1					11					1			4					
	9160	1								3									2				1								2						1		1					
	9190									4			1																										1					
	9580									2	1			2	1						1								1		9			1	1	3		1					2
	9610									3			1																1		16			2		4								
	9640				1															1				1		1		1		11			4		1	4		1					
	9670	1	1							1	3		2	2		1		4	1	1	1	3				1				4	1	22			8			4	1	6			1	
	9700						1			1	1		1					4				1				1				1	45			1			5	1	1				
	9760																		1											1	4						1		1				
	9790	1		1						4								4	1			1		1		4	1			4	56		1	4		1	7	2	5				
	10270								2	2	1		2						2			1				3	2				12			3			6	1	8				
	10330					1				1																					4			2									
	10390								1	1									1												1					1	1		2					
	10420									1																					3						4						1
	10450																									1					3												
	10570								1	2																					4			1				1					
	10600																																	3									1
	10630																		1												3			1		2							
	10660									1									2				1			1				1	37					1	1		3				
	10690									3																1		1			11							1	3				
	10720									1																					4						3	1					
	10760																																											1
	10780																												1		2			1		1	3				2	1	1
	10810										1			2																	31												
	10900																														2			1		2							
	10930									2		1															1		2		3			1	1	2			1				
	10960																1									1					1					3							1
	10990					1								1												1			1		8			1					1				
	11140									1				1										1		1					3												
	11230	1												1																	2			1									
	11260								1	3				1										1							10			6		1								
	11290																														3						1		1			1	
	11320																														4						1						
	11350																														13						1						
	11380																										1				10						2		4				

PMI values for OM-4 well were predominantly nil with most depth recording 0.0% PMI values (Table 3). This indicates a fresh water environment. However, at depths of 9160 ft, 9760 ft, 10510 ft, 10990 ft, 11020 ft, 11230 ft and 11350 ft, low PMI values of 14.0%, 20%, 33.3%, 6.7%, 25%, 12.5% and 16.7% were obtained respectively (Table 3; Figure 3). This suggests an environment of deposition characterized by mixed fresh and marine palynomorphs such as brackish environment. In OM-A well, most depths also had PMI values of 0.0%, representing freshwater environment. Depths with low PMI values include 8440ft (14.3%), 9160 – 9670ft (14.3%), 10610 ft (50%), 10810 – 10780 ft (10 – 50%), 10960 ft (20%) and 11260 ft (12.5%) as seen in Table 4, Figure 4. These depths indicate brackish water environment. From the PMI values, it is can be inferred that sediments were deposited in a paralic environment.

Table 3. PMI values for OM-4 well onshore Western Niger Delta

Marine Diversity Rm	Terrestrial Diversity Rt	PMI (Rm/Rt+1)X100	Depth
0	13	0	8200
0	11	0	8350
0	13	0	8380
0	4	0	8440
0	11	0	8470
0	15	0	8500
0	7	0	8830
0	7	0	9100
1	9	10	9130
1	6	14.3	9160
0	0	0	9190
0	6	0	9220
0	11	0	9250
0	6	0	9430
0	7	0	9520
0	7	0	9590
0	8	0	9640
0	7	0	9670
0	11	0	9700
0	6	0	9730
1	4	20	9760
1	2	33.3	10510
0	8	0	10540
0	3	0	10570
0	4	0	10600
0	3	0	10660
0	3	0	10690
0	3	0	10720
0	9	0	10960
1	14	6.7	10990
1	3	25	11020
1	7	12.5	11230
0	7	0	11290
0	7	0	11320
1	5	16.7	11350

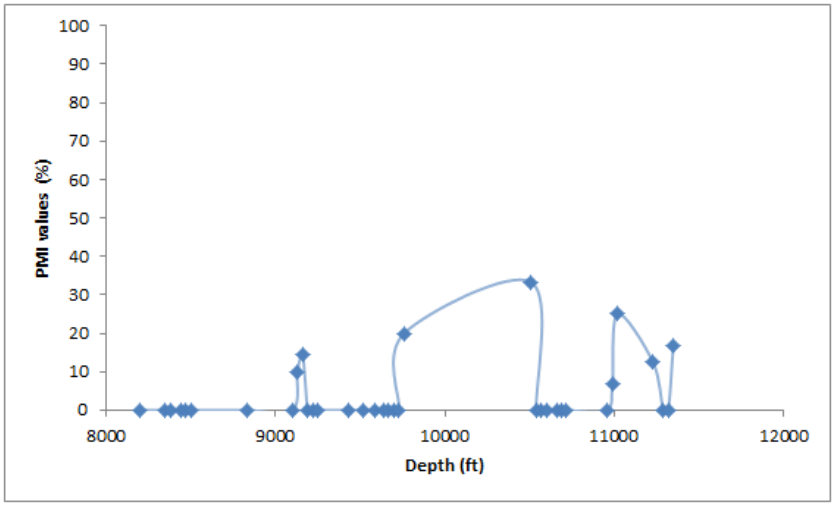

Figure 3. PMI Plot for OM-4 well onshore western Niger Delta

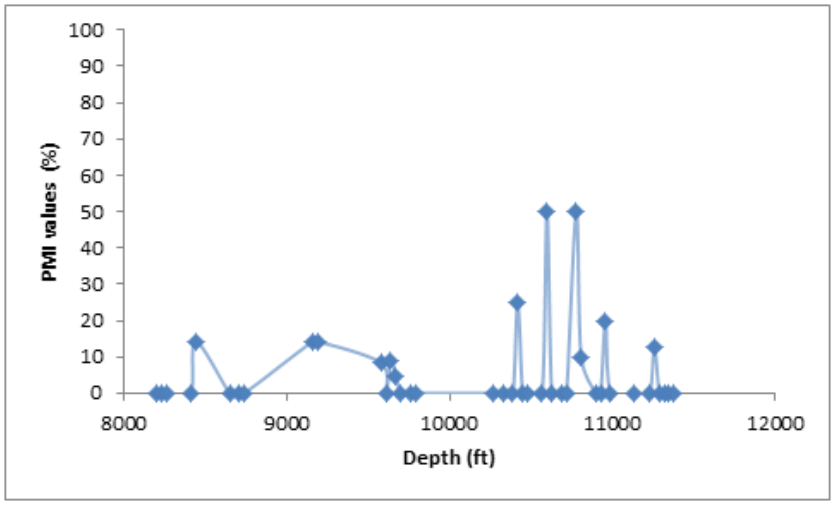

Figure 4. PMI plot for OM-A well onshore Western Niger Delta

Table 4. PMI values for OM-A well onshore western Niger Delta

Marine Diversity Rm	Terrestrial Diversity Rt	PMI (Rm/Rt+1)X100	Depth
0	6	0	8200
0	12	0	8230
0	3	0	8260
0	5	0	8410
1	6	14.3	8440
0	4	0	8650
0	6	0	8710
0	8	0	8740
1	6	14.3	9160
1	6	14.3	9190
1	11	8.3	9580
0	7	0	9610
1	10	9.1	9640
1	20	4.8	9670
0	13	0	9700
0	5	0	9760
0	17	0	9790
0	13	0	10270
0	4	0	10330
0	7	0	10390
0	3	0	10450
0	2	0	10480
0	5	0	10570
1	1	50	10600
0	4	0	10630
0	6	0	10690
0	4	0	10720
1	1	50	10780
1	9	10	10810
0	4	0	10900
0	9	0	10930
1	4	20	10960
0	7	0	10990
0	6	0	11140
0	4	0	11230
1	7	12.5	11260
0	3	0	11290
0	3	0	11320
0	3	0	11350
0	5	0	11380

3.1. Marker Species and Dominant Species Groups for Paleoenvironmental Studies

Generally, the freshwater swamp species which include *Laevigatosporites* sp, *Peregrinipollis nigericus, Racemonocolpites hians, Retitricolporites irregularis, Striatricolpites catatumbus, Crassoretitriletes vanraadshooveni* and *Magnastriates* sp, were observed to be well represented in terms of diversity in both wells (Tables 2 and 3, Figures 5 and 6). These species were observed to occur at depths with 0.0% PMI values (although not restricted to only those depths), hence, confirming those depth intervals to have been deposited in a freshwater environment. Generally, of all the palynomorphs recovered from both wells (OM-4 and OM-A), *Zonocostites ramonae* was the most abundant species accounting for about 48% in OM-4 well and 52% in OM-A well, next to it is *Laevigatosporites* sp with about 19% in OM-4 well and 15% in OM-A well, *Acrostichum aureum* 12%, *Verrucatosporites* sp 7%, *Monoporites annulatus* 5% and other palynomorphs accounting for about 9% in both wells respectively (Figures 5 and 6).

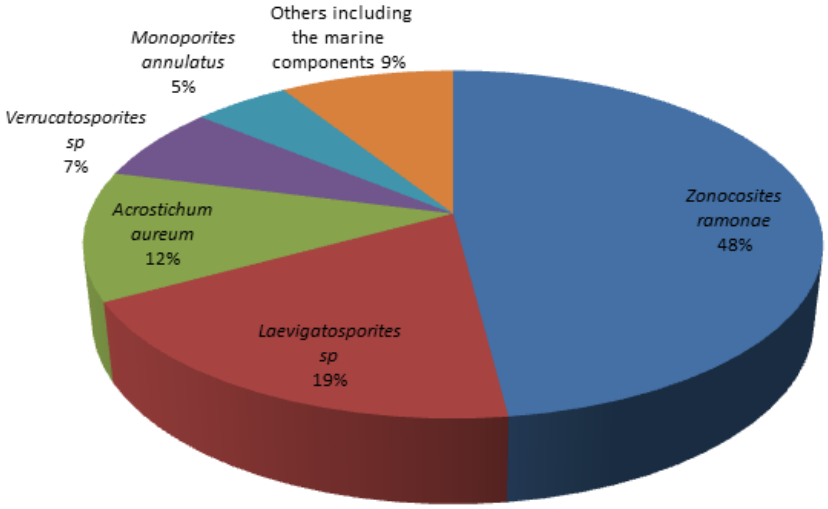

Figure 5. Percentage palynomorph species abundance in OM-4 well

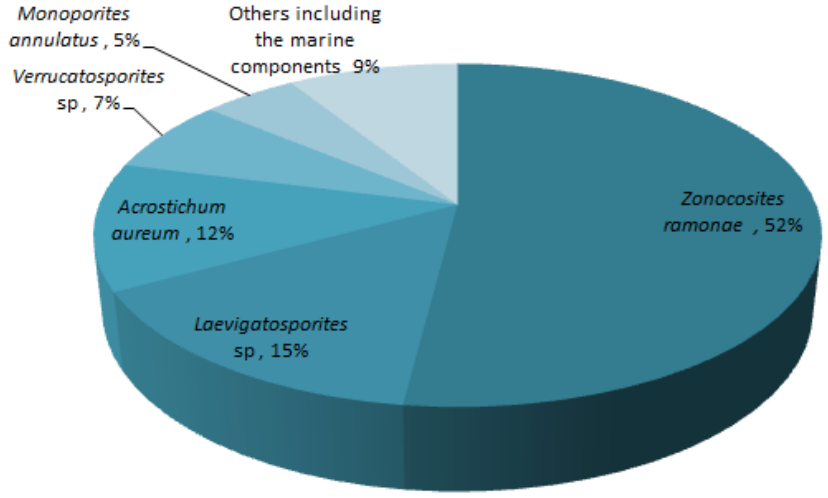

Figure 6. Percentage palynomorph species abundance in OM-A well

In both wells, high percentages of mangrove species (brackish water indicators) which includes *Zonocostites ramonae, Acrostichum aureum, Psilatricolporites crassus, Verrucatosporites* sp and *Botryococcus braunii* [5,6,10], were recorded (Figures 5 & 6). Also depth intervals with low PMI values showed an assemblage of at least two mangrove swamp species. For instance, in OM-A well, at 8440 ft with PMI value of 14.3% (Table 4), *Zonocostites ramonae, Acrostichum aureum,* and *Botryococcus braunii* were present at that depth. Although, the presence of these species was not limited to the depths with low PMI values, their presence at such depths had higher population than the freshwater species. These mangrove species were generally most abundant in terms of population in both wells especially *Zonocostites ramonae* and *Acrostichum aureum.* The presence of these Mangrove swamp species further confirms that the depths with low PMI values were deposited in a brackish environment.

The major palynomorph groups that were used in the paleoenvironmental studies are pollen and spores, representing the terrestrial and dinocysts representing marine influences [9]. From Figures 5 and 6, it can be seen that pollen and spores accounted for 71% and 23% in OM-4 well and 75% and 18% in OM-A well, compared to low counts of marine influences (dinoflagellates) which had 4% and 5% in OM-4 and OM-A wells respectively, it indicates an environment of deposition with greater terrestrial influences. This result indicates paralic environment of deposition with strong terrestrial influence. This character is common to fluvial-coastal environments.

From the PMI values, the dominant species group and presence of marker species, sediments within both wells were deposited in a paralic environment denoting a fluvial to coastal environment.

3.2. Wireline Log Interpretation

Gamma ray log was used to infer the possible depositional environment in the studied area by considering the shapes displayed by the log motif (that is; bell shape, funnel shape and cylindrical shape) which in turn determined the possible nature of sediments deposited (that is; fining upward, coarsening upward and blocky respectively). The summary of the inferred environments from log motif against depth in both wells are shown in Figures 7 & 8 below;

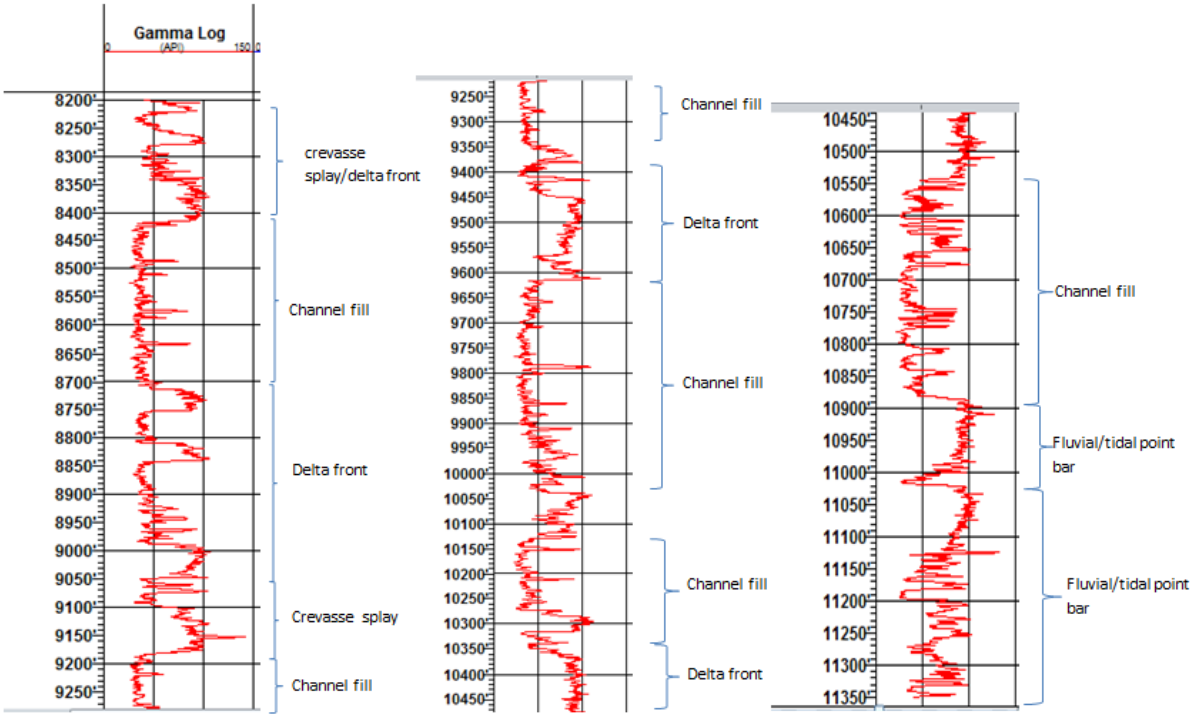

Figure 7. Gamma ray log of OM-4 well onshore western Niger Delta

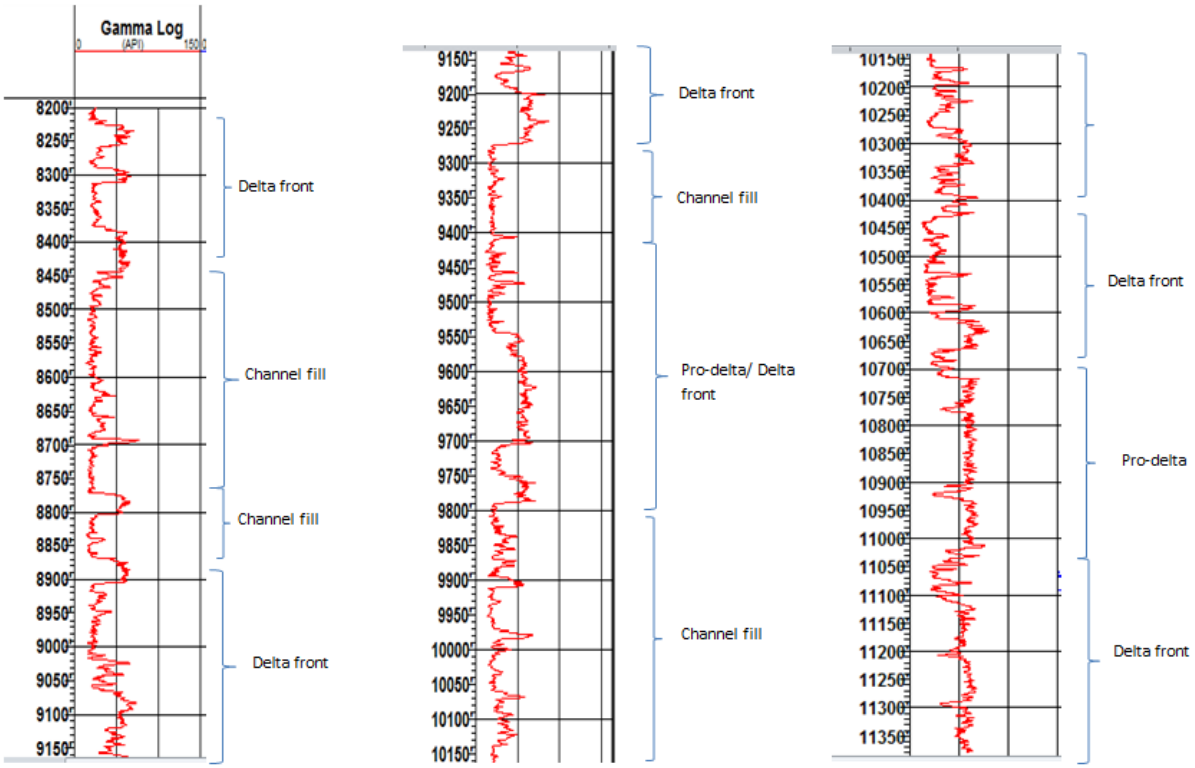

Figure 8. Gamma ray log of OM-A well onshore western Niger Delta

From the gamma ray log, it is observed that the OM-4 well was dominated by crevasse splay/delta front, channel fill and the fluvial point bar facies based on the dominance of cylindrical and funnel shaped log motifs which generally denote a transitional environment with greater fluvial influences. OM-A well on the other hand was dominated by delta front/prodelta facies with fewer channel fill facies. This is also based on the dominance of the funnel shape and fewer cylindrical log motifs. This also denotes a transitional environment with more marine influences. The PMI values in OM-A well were higher and occurred at more depths than those in OM-4 well, with two depths recording up to 50%, marking the highest PMI values recorded in this study.

OM-4 well probably had more terrestrial influence because they are more proximal to the sea than OM-A well, which is relatively more distal (figure 1).

A correlation of the established facies from the log was done with the PMI values to establish concise depositional model in both wells. The F, C and B letters were used to represent the log motifs meaning funnel (coarsening upwards), cylindrical (blocky) and bell shapes (fining upwards) respectively. Tabular illustrations of these facies model established for the study are shown below in Tables 5 & 6;

4. Conclusions

Facies units were established from the gamma ray wireline log in both wells using the log motif after [3]models with OM-4 well, showing a transitional environment with higher terrestrial influences and OM-A well showing higher marine influences. PMI values were generated with dominantly nil PMI values recorded at most depths, and few depths having low PMI values. A correlation of the facie units established with the PMI values indicated a continental (Channel fill) to marginal marine (ranging from crevasse splays/delta front to prodelta) depositional environments.

Recovery of freshwater swamp species as well as abundance of mangrove species also confirms deposition in a paralic environment.

Table 5. Depositional environments for OM-4 well onshore western Niger Delta

Depth (ft)	PMI Value	Log Motif	Depositional Environment
8200 – 8400	Nil	F	Marginal marine (Crevasse splay/Delta front)
8400 - 8700	Nil	C	Continental (Channel fill)
8700 – 9050	Low	F	Marginal marine (Delta front)
9050 - 9200	Nil	F	Marginal marine (Delta front)
9200 - 9400	Nil	C	Continental (Channel fill)
9400 - 9620	Nil	F	Marginal marine (Delta front)
9620 – 10320	Low	C	Continental (Channel fill)
10320 - 10550	Low	F	Marginal marine (Delta front)
10550 - 10900	Nil	C	Continental (Channel fill)
10900 – 11350	Low	B	Continental (Fluvial/tidal point bar)

Table 6. Depositional environments for OM-A well onshore Western Niger Delta

Depth (ft)	PMI Value	Log Motif	Depositional Environment
8200 – 8450	Low	F	Marginal marine (Delta front)
8450 – 8880	Nil	C	Continental (Channel fill)
8880 – 9700	Low	F	Marginal marine (Delta front)
9700 - 10450	Nil	C	Continental (Channel fill)
10450 – 10720	Low	F	Marginal marine (Delta front)
10720 – 11020	Low	C	Marginal marine (Prodelta)
11020 - 11350	Low	F	Marginal marine (Delta front)

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