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Late Eocene to Early Miocene Biostragraphy and Palaeoenvironments in the Beta Field of the Northern-Central Niger Delta, Nigeria

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Abstract

Lithological, palynomorphs and foramininifera studies have been carried on samples from one (1) oil well in the Northern-Central depobelts of the Niger Delta. Fifty six (56) ditch cutting well samples composited at 30ft interval between 3960ft and 9060ft in MT-well Northern Niger Delta. Twenty-two 22 genera of foraminifera comprising mainly benthonic species were identified. Foraminifera and associated palynomorphs recovered from these sandy and shaly sediments permitted the dating, paleoenvironmental and paleoecological interpretation of the analyzed section. The well penetrated the shale and sandstone formations of the Agbada Formation. The studied section was assigned a Late Eocene to Early Miocene age with boundary between Oligocene and Early Miocene marked at 4470ft based on the occurrence of *Cicatricosisporites drogensis* while boundary between Late Eocene and Oligocene is marked at 7500ft based on the top occurrence *Doualaidites laevigatus* observed at that depth. Extremely poor recovery of planktonic foraminifera is evident while benthonic foraminifera, shell fragments and ostracods are well represented from 6090-8100ft with increasing faunal abundance and diversity with depth. The Late Eocene corresponds to the F_{5700} and P_{400} zones, characterized by the occurrence of *Nonionella magnalingua* and *Cinctipoperioporites mulleri* respectively while the Oligocene and early Miocene corresponds to the P_{500} and P_{600} zones of the Niger Delta Cenozoic chronostratigraphic chart [29]. The shell fragments indicate a shelf environment and palaeobathymetry is delineated within 0-30m water depth within the inner neritic delta front environment. The depositional settings were found to be similar to the present day Niger Delta, although palaeocology and paleoclimatic conditions were somewhat differ in Eocene to Miocene times of the Cenozoic Niger Delta.

Keywords: Biostratigraphy; Paleoenvironment; Paleoecology; Paleoclimate; On-shore Niger Delta.

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1. Introduction

Reference [14] described the Niger Delta as the largest on the continental margin of the Gulf of Guinea, covering an area extent of about 300,000 km² and has a sediment thickness of over 10km in the basin centre [13]. According to [29], three principal subsurface lithostratigraphic units are identifiable within the clastic sequences of the Tertiary Niger Delta: Benin, Agbada and Akata Formations respectively. The Akata Formation the oldest comprises of marine black shales and occasional turbiditic and channel fill sands and siltstone interbeds. Overlying the basal Akata is the paralic Agbada Formation characterized by an alternation of sandstone and shale sequences. The youngest, the Benin Formation consists predominantly of massive coarse sands and gravels. The silty shale of Akata Formation and the sandy shale of Agbada Formation are very fossiliferous. The startigraphic framework of the delta is based on pollen and foraminifera biostratigraphy and dated transgressive marker shales [24]. Depobelts otherwise known as sedimentation cycles are common in the Niger Delta. These cycles prograde over the oceanic crust into the Gulf of Guinea [30]. The total delta sequence is marked by a series of belts which reflect the depocentres succeeding each other in time and space by southward progradation. Each depobelt is bounded by major structure-building faults. Regionally, the Niger Delta is further subdivided into five depobelts [10] namely, Northern Delta, Great Ughelli, Central swamp, Coastal swamp and Off-shore (Fig.1). The study area falls within the Northern Delta which is the oldest of the Depobelts.

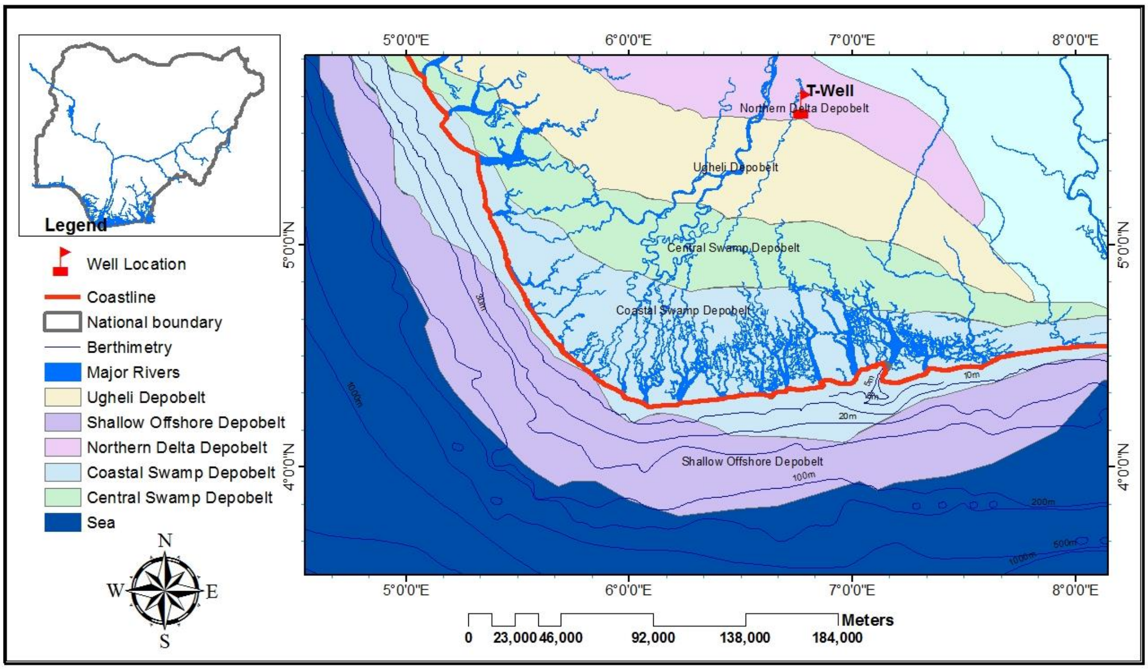

Figure 1: Location map of Beta Field in the Niger Delta

Though considerable data has been generated from many of the drilled wells in Niger Delta and information published is mainly on sedimentology; there is however, few published works on biostratigraphy of the Tertiary Niger Delta. Some of these include [24,31,23]. Paleoenvironmental studies in the Niger Delta are few [3,4;31,4;22,1,6] and they are all based on the use of lithologic data. Reference [22] used both lithologic palynologic data in the reconstruction of paleoenvironment. Therefore, this paper undertakes a lithofacies, palynological and foraminiferal analysis of samples from MT -well in the Beta field of the Niger Delta; with a view to identify the P- and F -zones; to determine age, reconstruct the depositional environments, paleocology and paleoclimatic setting.

2. Location of study

The Niger Delta is situated in southern Nigeria between latitudes 3° N and 6° N and longitude 5° E and 8° E [24]. It has area coverage of 75,000 sq km and is bounded to the northwest and west by the western African shield, which terminates at the Benin hinge line and to the east, by the Calabar hinge line (Fig. 1). The Anambra basin and Abakaliki anticlinorium mark its northern limit. To the south, it is bounded by the Gulf of Guinea. The MT well is in Beta field, located between Northern and Central Depobelt of the Niger Delta (Fig 1). It lies between latitude 5° and 6° north of the equator and longitude 6° and 7° E.

3. Regional geologic setting of the Niger Delta

The Niger Delta occupies the ocean ward part of a larger and older tectonic feature, the Benue Trough. The initiation of the Benue trough and its sequential filling with marine sediments following the Cretaceous marine incursions provided the most important chain of (geologic) episodes that built-up the Niger Delta [26,27]. Other depocenters along the African Atlantic coast also contributed to the deltaic build-ups. In accordance with [33] the stratigraphic history of the Niger Delta Basin regarding tectonic events informs that the basin represents the third cycle in the evolution of the southern Nigerian sedimentary basins; (1) Benue-Abakiliki phase (Aptian-Santonian, (2) Anambra-Benin phase (Santonian- Early Eocene) (3) Niger Delta phase (Late Eocene-Recent). Based on the dominant environmental influence, the sedimentary sequence of the base consists in ascending order of three major lithostratigraphic and diachronous facies units [31], namely, prodelta facies (marine environment), delta front facies (transitional environment) and delta plain facies (continental environment). During the Tertiary, sediment supply was mainly from the north and east through the Niger, Benue and Cross Rivers. The Benue and Cross Rivers provided substantial amounts of volcanic detritus from the Cameroon volcanic zone beginning in the Miocene. The Niger Delta clastic wedge prograded into the Gulf of Guinea at a steadily increasing rate in response to the evolution of these drainage areas and continued basement subsidence. Regression rates increased in the Eocene, with an increasing volume of sediments accumulated since the Oligocene [31]. The Agbada and Akata Formations are Eocene to Recent in age, while the Benin Formation is Oligocene to Recent in age. Normal faults triggered by the movement of deep seated, overpressured, ductile, marine shale have deformed much of the Niger Delta clastic wedge [10]. Many of these faults formed during delta progradation and were syndepositional affecting sediment dispersal. In addition these fault growths were also accompanied by slope instability along the continental margin. Thus structural complexity in local areas reflects the density and style of faulting. Simple structures like crestal folds and flanks occur with the faults. Growth faults comprise antthetic faults and major structure-building faults (some [which bound the depobelts), steep, parallel crestal faults which cut the rollover structures. Growth fault-related structures are the dominant hydrocarbon traps in the Niger Delta (Fig. 2).

3.1 Niger Delta morphology

The morphology of Niger Delta changed from an early stage spanning the Paleocene to early Eocene to a later stage of delta development in Miocene time. The early coastlines were concave to the sea and the distributions of deposits were strongly influenced by basement topography [4]. Delta progradation occurred along two major axes, the first paralleled the Niger River, where sediment supply exceeded subsidence rate. The second, smaller than the first, became active during Eocene to early Oligocene basinward of the Cross River where shorelines advanced into the Olumbe-1 area [10].

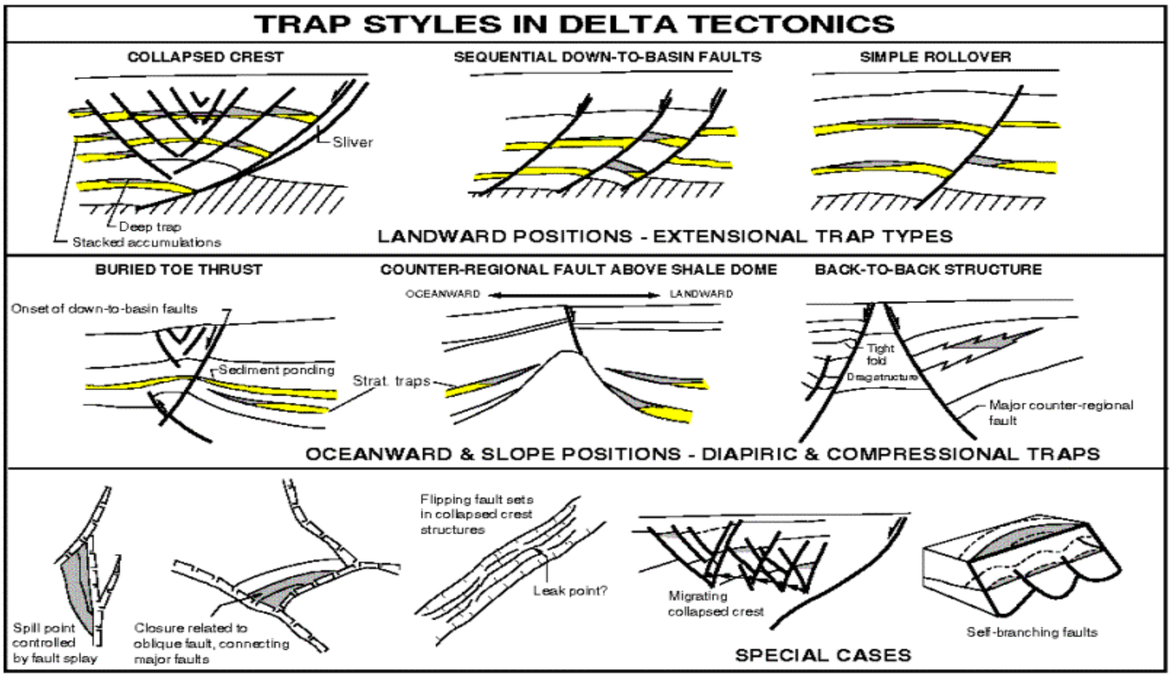

Figure 2: Structural styles in the Niger Delta [29]

In Late Miocene, the delta prograded far enough that shorelines between Warri and Port Harcourt became broadly concave into the basin. Accelerated loading by this rapid delta progradation mobilized underlying unstable shales. These shales for diapiric structures, deforming overlying strata [29].

3.2 The Niger Delta depo-belts

Deposits of the last depositional cycle have been divided into a series of six depobelts [10] also called depocenters or megasequences separated by major synsedimentary fault zones. These depobelts formed when paths of sediment supply were restricted by patterns of structural deformation, focusing sediment accumulation into restricted areas on the delta. Such depobelts changed position over time as local accommodation was filled and the locus of deposition shifted basin ward [10]. Deposition of the three formations occurred in each of the five offlapping siliciclastic sedimentation cycles that comprise the Niger Delta. These cycles (depobelts) are 30-60 kilometers wide, prograde southwestward 250 kilometers over oceanic crust into the Gulf of Guinea [30], and are defined by synsedimentary faulting that occurred in response to variable rates of subsidence and sediment supply rates resulted in deposition of discrete depobelts when further crustal subsidence of the basin could no longer be accommodated, the focus of sediment deposition shifted seaward, forming a new depobelt

[10]. Each depobelt is a separate unit that corresponds to a break in regional dip o f the delta and is bounded landward by growth faults and seaward by large counter-regional faults or the growth fault of the next seaward belt [11,10]. Five major depobelts are generally recognized, each with its own sedimentation, deformation, and petroleum history. Reference [10] describe three depobelt provinces based on structure. The northern delta province, which overlies relatively shallow basement, has the oldest growth faults that are generally rotational, evenly spaced, and increases their steepness seaward. The central delta province has depobelts with well-defined structures such as successively deeper rollover crests that shift seaward for any given growth fault. Lastly, the distal delta province is the most structurally complex due to internal gravity tectonics on the modern continental slope. Classic integrated geological studies have shown that several different depobelts abound in the Niger Delta Basin. The depobelts consists of Northern Delta, Greater Ughelli Onshore, Central swamp, Coastal swamp, Shallow and Deep offshore.

3.3 Tectonic and structural setting of the Niger Delta

Along the west coast of equatorial Africa, the tectonic framework (Fig. 3) of the continental margin along the West Coast of equatorial Africa is controlled by Cretaceous fracture zones expressed as trenches and ridges in the deep Atlantic. The fracture zone ridges subdivide the margin into individual basins, and, in Nigeria, form the boundary faults of the Cretaceous Benue-Abakaliki Trough, which cuts far into the West African shield. The trough represents a failed arm of a rift triple junction associated with the opening of the South Atlantic. In this region, rifting started in the Late Jurassic and persisted into the Middle Cretaceous (Lehner and De Ruiter, 1977). In the region of the Niger Delta, rifting diminished in the Late Cretaceous (Michele and his colleagues 1999).

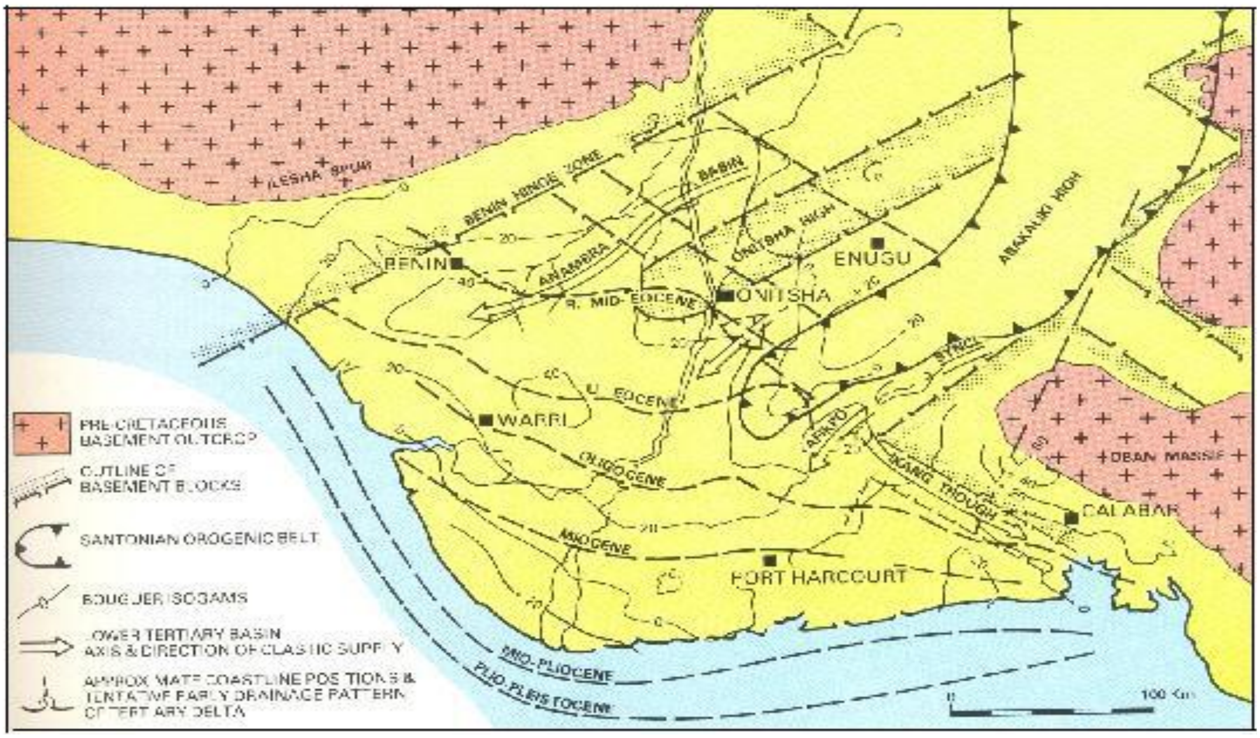

Figure 3: Tectonic framework of the Niger Delta

After rifting ceased, gravity tectonism became the primary deformational process. Shale mobility induced internal deformation and occurred in response to two processes [14]. First, shale diapers formed from loading of poorly compacted, over-pressured, prodelta and delta-slope clays (Akata Formation.) by the higher density delta-front sands (Agbada Formation). Second, slope instability occurred due to lack of lateral, basinward, support for the under-compacted delta-slope clays (Akata Formation). For any given depobelt, gravity tectonics were completed before deposition of the Benin Formation and are expressed in complex structures, including shale diapers, roll-over anticlines, collapsed growth fault crest, back-to-back features, and steeply dipping, closely spaced flank faults [11].

3.4 Stratigraphy of the Niger Delta

The sediments of the Cenozoic Niger Delta may reach a maximum thickness of 9000-12000 m, in the central part of the basin. A detailed description of the sedimentary facies units has been published by [29,32] and Weber and [29]. Based on dominant environmental influences, the units are, continental environment, transitional environment and marine environment, this research work shall adopt their description. The lithostratigraphic subdivision includes: (1) Benin Formation; (2) Agbada Formation; and (3) Akata Formation. Designated from the bottom, the Akata, Agbada and Benin formations respectively (Fig 4).

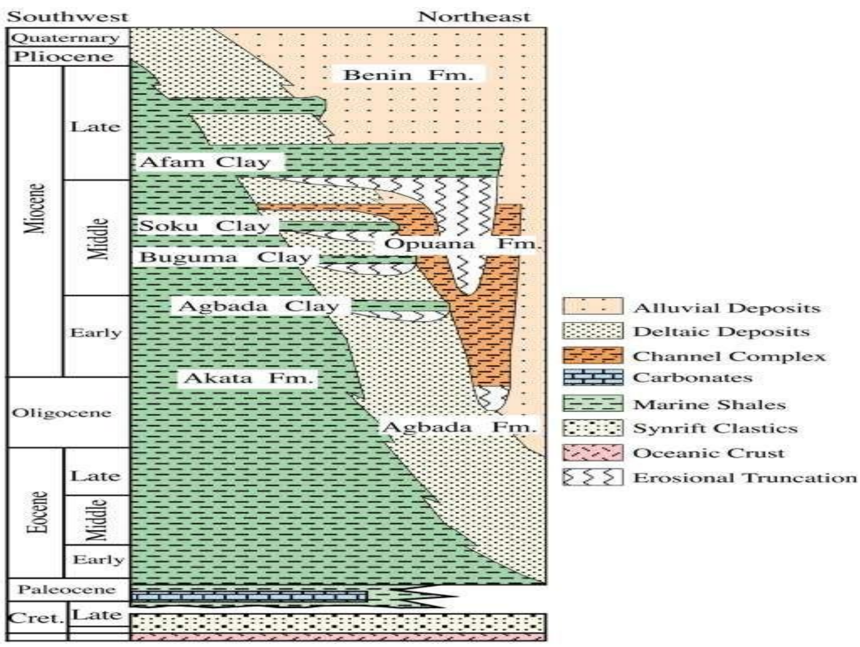

Figure 4: Stratigraphic framework of the Niger Delta modified from [2]

4. Materials and Methods

4.1 Materials

Ditch cuttings containing shaly and sandy samples were collected at 30ft intervals, from 1207m (3960ft) to 2761.4m (9060ft) in the Agbada Formation. Lithologic, palynological and foraminiferal analyses were carried out on the fifty six (56) ditch cutting samples recovered from MT-well.

4.1.1 Lithologic Description

Depth to depth sample description was carried on each sample using a hand lens and 2.0m concentration of HCL to check effervescence which consequently, indicates the presence or absence of carbonaceous materials. The studied sections of the MT-well ranged from 3990ft – 9060ft and sampled at 30ft intervals. The lithology is composed of shales and sandstones intercalations, with more shale at the base than at the top (Fig.5). The sands are predominantly white at the top, light brown in the middle section and dark brown towards the base of the section studied. The shales are dark grey in colour, fissile and mostly non-calcareous. The sandstones ranged in grain sizes from fine to medium grained but mostly medium grained, friable and non-calcareous. Details description of the section is presented in Fig. 5. The shale and sand intercalation suggests the parallic conditions of deposition.

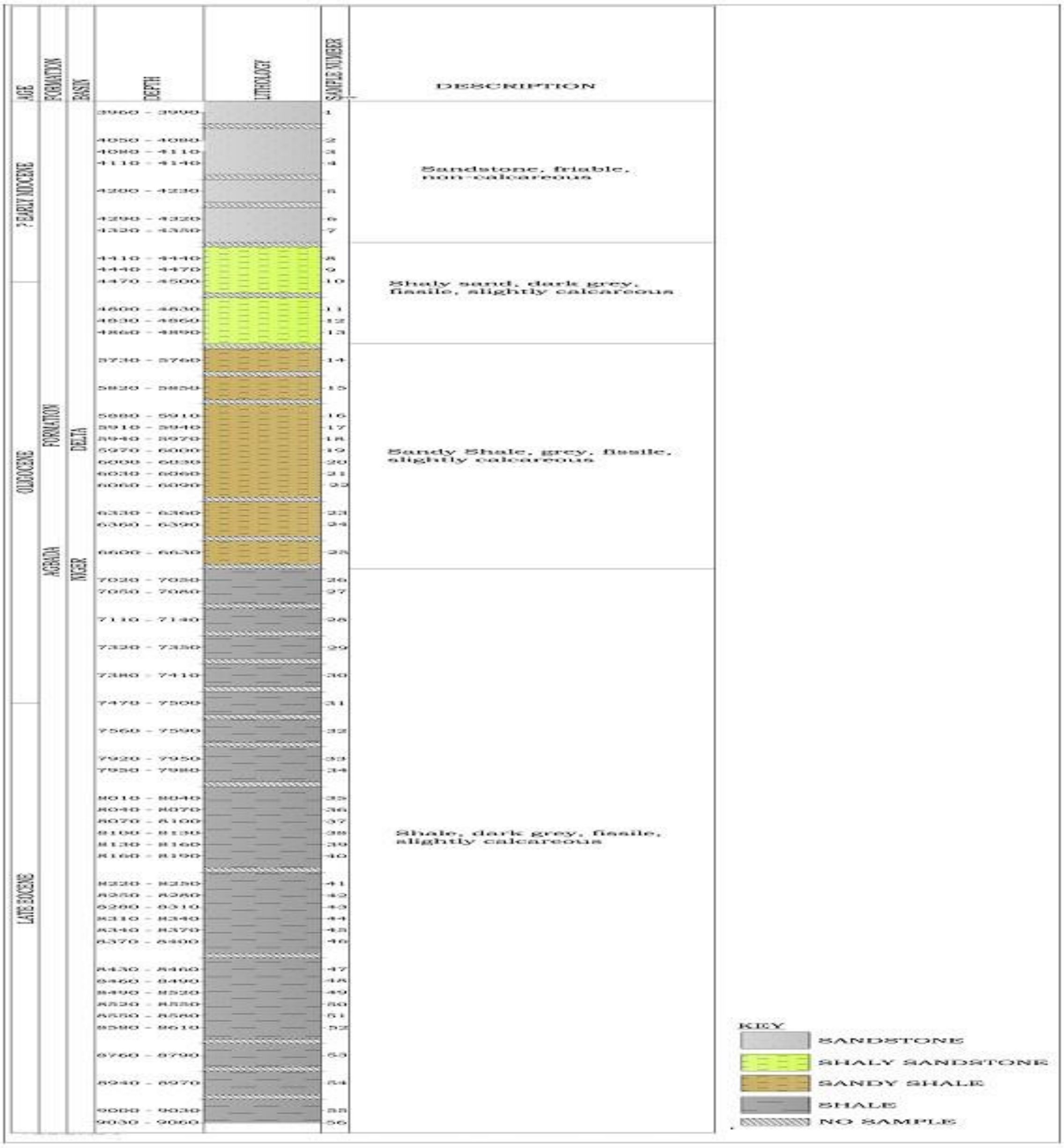

Figure 5: Lithologic description of MT Well

4.2 Foraminifera

4.2.1 Methods

The foraminifera recovered in this study were obtained by the unpublished extraction technique for invertebrate microfossils at the Geological Laboratory of the University of Port Harcourt of Nigeria. This involved soaking crushed samples (I) in kerosene for one to two hours and (2) in hydrogen peroxide overnight and washing through a sieve (diameter 74µm) to remove unwanted mud. Thereafter, the samples were dried and picked for foraminifera.

4.3 Palynology

4.3.1 Methods

Palynological residues were obtained by the standard techniques of digesting unwanted constituents of sedimentary rock samples in mineral acids. Samples were treated with 50% hydrochloric acid and 60% hydrofluoric acid to remove calcium carbonate and silicate materials respectively. Whereas a short oxidation with concentrated nitric acid was necessary to remove humus and humic acids which rendered sculptural features of palynomorphs unrecognizable, this stage was omitted for those samples studied for palynodebris to retain their natural colours. Zinc bromide with a specific gravity of 2.1 was used to concentrate palynomorphs and other organic residues which were subsequently sieved. Oxidized residues were sieved through 10 um and 80 um nylon meshes, but only 10µm mesh was used for unoxidized residues. Transmitted light microscope work was carried out on the 10-80 µm fraction for palynomorphs. The identification of the palynomorphs taxa were done with guided work of [12] and some published palynomorph mircophotographs. The distribution of the recovered palynomorphs is shown in Plates1-4.

5. Results and Discussion

5.1 Lithologic Descriptions

The studied sections are composed of shales and sandstones intercalations, but having more shale at the base than at the top. The sands are predominantly white at the top of the section, light brown in the mid section and dark brown towards the base. The shales are dark grey in colour, fissile and mostly non-calcareous. The sandstones ranged in grain sizes from fine to medium grained but mostly medium grained, friable and non-calcareous. The sand to shale ratio is presented in Fig. 6. The shale and sand intercalation supported the parallic conditions of deposition.

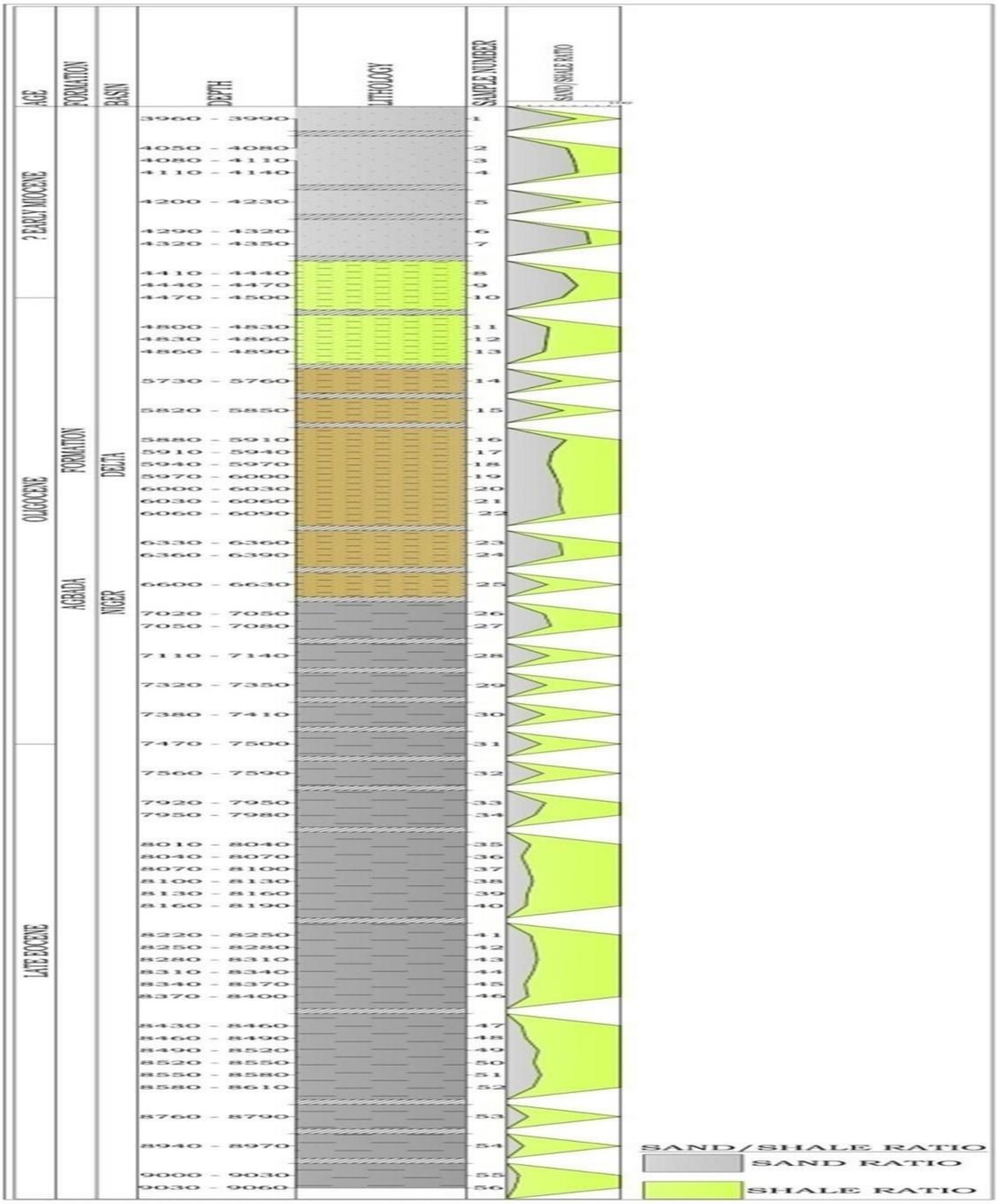

Figure 6: Sand to Shale Ratio

5.2 Biostratigraphy

Biostratigraphic analysis of MT-well involved lithologic sample descriptions, micropaleontologic sample preparations, taxonomic descriptions, analyses and interpretations of trends. The aspect of micropaleontologic sample preparations and analyses involved generation of data for both foraminiferal and palynomorph studies. The statistical counts generated for the occurrence of both palynomorphs and foraminifera are presented in Table1. The photomicrographs of key taxa are presented (Plates 1-4). Biostratigraphy frame work for the studied section is summarized and presented in Table 4. The sections have been subdivided into P and F zones approach of [11,17].

Table 1: Occurrence of Foraminifera and Palynmorphs

Depth Interval (ft)	PALY	FORAM	TOTAL	PALY %	FORAM %
3960 – 3990	4		4	100	0
4050 – 4080	5		5	100	0
4080 – 4110	13		13	100	0
4110 – 4140	6		6	100	0
4200 – 4230	5		5	100	0
4290 – 4320	8		8	100	0
4320 – 4350	17		17	100	0
4410 – 4440	15		15	100	0
4440 – 4470	44	1	45	98	2
4470 – 4500	30		30	100	0
4800 – 4830	9		9	100	0
4830 – 4860	6		6	100	0
4860 – 4890	26		26	100	0
5730 – 5760	117		117	100	0
5820 – 5850	12		12	100	0
5880 – 5910	20		20	100	0
5910 – 5940	26		26	100	0
5940 – 5970	16		16	100	0
5970 – 6000	249	5	254	98	2
6000 – 6030	21		21	100	0
6030 – 6060	67		67	100	0
6060 – 6090	32	3	35	91	9
6330 – 6360	17	1	18	94	6
6360 – 6390	24		24	100	0
6600 – 6630	60	1	61	98	2
7020 – 7050	29		29	100	0
7050 – 7080	86	31	117	74	26
7110 – 7140	5	2	7	71	29
7320 – 7350	15		15	100	0
7380 – 7410	41		41	100	0
7470 – 7500	307		307	100	0
7560 – 7590	73	11	84	87	13
7920 – 7950	14	1	15	93	7
7950 – 7980	46	1	47	98	2
8010 – 8040	65		65	100	0

8040 – 8070	196	16	212	92	8
8070 – 8100	253	14	267	95	5
8100 – 8130	43	1	44	98	2
8130 – 8160	221	6	227	97	3
8160 – 8190	127	28	155	81	19
8220 – 8250	115	8	123	93	7
8250 – 8280	115	53	168	68	32
8280 – 8310	164	10	174	94	6
8310 – 8340	78		78	100	0
8340 – 8370	125	63	188	66	34
8370 – 8400	183	45	228	80	20
8430 – 8460	146	74	220	66	34
8460 – 8490	111	33	144	77	23
8490 – 8520	11	5	16	69	31
8520 – 8550	109	8	117	93	7
8550 – 8580	87	43	130	67	33
8580 – 8610	130	1	131	99	1
8760 – 8790	60		60	100	0
8940 – 8970	106		106	100	0
9000 – 9030	29	1	30	97	3
9030 – 9060	31	1	32	97	3

The results from the foraminifera analysis was poor and only benthonic foraminifera were recovered which is an indication of a shallow marine depositional environment. The absence of planktonic foraminifera in the analyzed samples made it difficult to assign ages of the sections encountered with foraminifera but rather with palynomorphs. The total recoveries of foraminifera and dinoflagellate (marine indicators) are presented in Table 2; and marine Index data is presented in Table 3. The organic constituents observed in the studied samples have been grouped according to the classification proposed by [36]. A summary of this classification is proposed in Fig. 7 (modified from [33].

Table 2: Cumulative percentage distributions of fauna and flora Data

Depth Interval (ft)	% Pollen	% Spore	% Dinoflagellate	% Fungal spore	% Foram test lining	% Algae	% Diatom	% Acritarch	Total %
3960 – 3990		75%		25%					
4050 – 4080		100%							
4080 – 4110		61%	8%	15%	8%			8%	100%

4110 – 4140	33%	17%	33%					17%	100%
4200 – 4230	20%	20%	40%	20%					100%
4290 – 4320	38%	50%			12%				100%
4320 – 4350	12%	64%	6%	6%	6%			6%	100%
4410 – 4440	7%	53%	33%	7%					100%
4440 – 4470		91%	7%					2%	100%
4470 – 4500	7%	66%	13%	7%				7%	100%
4800 – 4830	11%	45%	22%			11%		11%	100%
4830 – 4860	17%	66%						17%	100%
4860 – 4890	34%	54%	8%	4%					100%
5730 – 5760	36%	46%	17%					1%	100%
5820 – 5850		75%	17%		8%				100%
5880 – 5910		65%	5%	15%	10%			5%	100%
5910 – 5940	8%	73%	15%		4%				100%
5940 – 5970	6%	31%	63%						100%
5970 – 6000	5%	93%	2%						100%
6000 – 6030	5%	75%	10%					10%	100%
6030 – 6060	8%	73%	8%	3%	4%			4%	100%
6060 – 6090	13%	59%	22%		6%				100%
6330 – 6360	12%	76%			12%				100%
6360 – 6390	8%	63%	13%	4%		4%		8%	100%
6600 – 6630	11%	75%	7%	3%	2%	2%			100%
7020 – 7050	21%	66%	7%	3%		3%			100%
7050 – 7080	13%	48%	23%	2%	2%			12%	100%
7110 – 7140		60%	20%	20%					100%
7320 – 7350	47%	40%	13%						200%
7380 – 7410	18%	69%	13%						100%
7470 – 7500	33%	65%	1%	1%					100%
7560 – 7590	22%	45%	9%	1%		1%		22%	100%
7920 – 7950	50%	50%							100%
7950 – 7980	11%	59%	24%	4%				2%	100%
8010 – 8040	31%	55%	14%						100%
8040 – 8070	23%	70%	6%		1%				100%
8070 – 8100	19%	68%	9%	1%	1%	1%		1%	100%
8100 – 8130	28%	47%	23%					2%	100%
8130 – 8160	8%	88%	3%	1%					100%
8160 – 8190	16%	73%	9%					2%	100%
8220 – 8250	33%	49%	18%						100%
8250 – 8280	24%	41%	35%						100%

8280 – 8310	16%	56%	26%	1%	1%				100%
8310 – 8340	18%	53%	27%	1%				1%	100%
8340 – 8370	17%	69%	14%						100%
8370 – 8400	10%	83%	4%	1%	1%		1%		100%
8430 – 8460	45%	44%	10%	1%					100%
8460 – 8490	38%	50%	5%			7%			100%
8490 – 8520		100%							100%
8520 – 8550	34%	45%	18%		3%				100%
8550 – 8580	11%	64%	24%		1%				100%
8580 – 8610	11%	83%	6%						100%
8760 – 8790	22%	63%	13%	2%					100%
8940 – 8970	22%	70%	7%	1%					100%
9000 – 9030	28%	38%	31%	3%					100%
9030 – 9060	46%	36%	16%	2%					100%

Table 3: Marine Index Data

Depth Interval (ft)	CONTINENTAL INDICATOR				MARINE INDICATORS			
	Pollen	Spore	Total	%	Dinoflagellate	Foraminifera test lining	Total	%
3960 – 3990		3	3	100				0
4050 – 4080		5	5	100				0
4080 – 4110		8	8	80	1	1	2	20
4110 – 4140	2	1	3	60	2		2	40
4200 – 4230	1	1	2	50	2		2	50
4290 – 4320	3	4	7	88		1	1	12
4320 – 4350	2	11	13	87	1	1	2	13
4410 – 4440	1	8	9	64	5		5	36
4440 – 4470		40	40	91	3	1	4	9
4470 – 4500	2	20	22	85	4		4	15
4800 – 4830	1	4	5	71	2		2	29
4830 – 4860	1	4	5	100				0
4860 – 4890	9	14	23	92	2		2	8
5730 – 5760	42	53	95	83	20		20	17
5820 – 5850		9	9	75	2	1	3	15
5880 – 5910		13	13	81	1	2	3	19
5910 – 5940	2	19	21	81	4	1	5	19
5940 – 5970	1	5	6	38	10		10	62
5970 – 6000	13	231	244	96	5	5	10	4

6000 – 6030	1	16	17	89	2		2	11
6030 – 6060	5	49	54	87	5	3	8	13
6060 – 6090	4	19	23	66	7	5	12	34
6330 – 6360	2	13	15	94		1	1	6
6360 – 6390	2	15	17	85	3		3	15
6600 – 6630	7	45	52	90	4	2	6	10
7020 – 7050	6	19	25	93	2		2	7
7050 – 7080	11	42	53	50	20	33	53	50
7110 – 7140		3	3	50	1	2	3	50
7320 – 7350	7	6	13	87	2		2	13
7380 – 7410	7	27	34	87	5		5	13
7470 – 7500	102	201	303	99	3		3	1
7560 – 7590	16	33	49	74	6	11	17	26
7920 – 7950	7	7	14	93		1	1	7
7950 – 7980	5	27	32	73	11	1	12	27
8010 – 8040	20	36	56	86	9		9	14
8040 – 8070	46	138	184	87	11	17	28	13
8070 – 8100	48	175	223	85	24	15	39	15
8100 – 8130	12	20	32	74	10	1	11	26
8130 – 8160	10	115	125	93	4	6	10	7
8160 – 8190	20	92	112	74	12	28	40	26
8220 – 8250	38	56	94	76	21	8	29	24
8250 – 8280	28	47	75	45	40	53	93	55
8280 – 8310	26	93	119	69	43	11	54	31
8310 – 8340	14	41	55	72	21		21	28
8340 – 8370	21	86	107	57	18	63	81	43
8370 – 8400	19	153	172	76	7	46	53	24
8430 – 8460	66	63	129	59	15	74	89	41
8460 – 8490	42	56	98	72	5	33	38	28
8490 – 8520		11	11	69		5	5	31
8520 – 8550	37	49	86	74	19	11	30	26
8550 – 8580	10	56	66	51	20	44	64	49
8580 – 8610	14	102	116	93	8	1	9	7
8760 – 8790	13	37	50	86	8		8	14
8940 – 8970	23	74	97	92	8		8	8
9000 – 9030	8	11	19	66	9	1	10	34
9030 – 9060	14	11	25	81	5	1	6	19

Table 4: Summary of Palyno/ Foram Stratigraphic Succession in MT-Well (3990 – 9060ft)

Interval (ft)	P-Zone	F-Zone	Age	Events	
				Palynology	Foraminifera
3990 – 4470	**? P_{600}**		**? Early Miocene**	**Top Occurrence of *Cicatricosisporites dorogensis* at 4470ft**	**BARREN**
4470 - 7500	**P_{500}**		**Oligocene**	**Top occurrence of *Doualaidites laevigatus* at 7500ft**	**BARREN**
7500 – 9060	**P_{400}**	**F_{5700}**	**Late Eocene**	**Occurrence of *Cinctiperiporites mulleri* within this interval**	**Occurrence of *Nonionella magnalingua* at 8370ft**

5.2.1 Palynomaceral group (PM)

It comprises all fragments derived from higher plant debris and is subdivided to their degree of oxidation: PM_1, PM_2, PM_3 and PM_4.

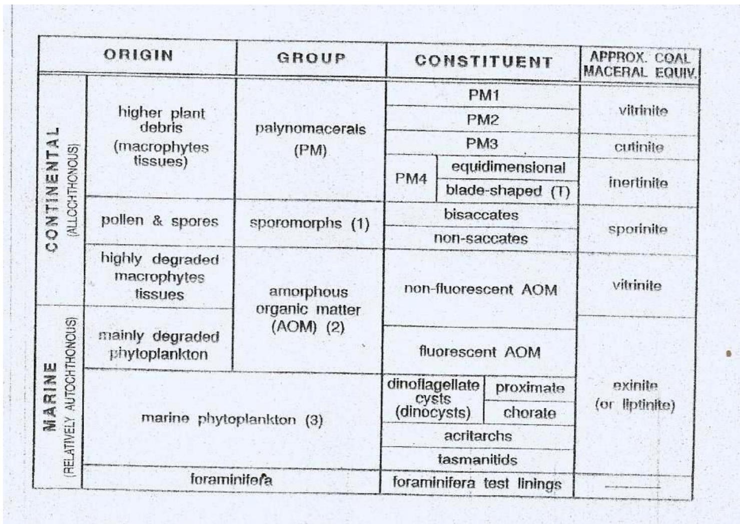

Figure 7: Origin and classification of particulate organic matter as used in this study (modified from [33].

PM1- Orange to dark brown, translucent, partially oxidized.

PM2- Orange to dark brown fragments exhibiting cell-structures, moderately oxidized. When degraded, PM1 and PM2 are distinguished by the suffix B (PM1/2-B).

PM3- Yellow to orange fragments exhibiting cell-structures.

PM4- Black opaque fragments highly oxidized. It is also considered as the most stable palynomaceral and can be transported far out to a marine environment before being degraded [11][33]. PM4 is subdivided into two fractions: equidimensional PM4 and blade-shaped or tabular PM4 (PM4-T).

5.2.2 Sporomorphs

This term includes pollen and spores. Because of their scarcity in the studied samples they are grouped together in this paper. Dinoflagellates cysts (Dinocysts) Dinocysts are the main representatives of the organic microplankton. All species encountered here are strictly marine.

5.2.3 Foraminifera linings

They are organic linings (tectin) of some foraminifera, and considered as a marine indicator. The palynomaceral group and sporomorphs constitute the allochthonous fraction (land derived), whereas Dinocysts and Foraminera linings represent the (relatively) autochthonous fraction (marine) of the organic residue.

5.3 Paleobathymetry

The benthic foraminifera species found in studied section allowed the interpretation of the paleoenvironment to be marginal to shallow marine environment (Inner Nerritic). According to [3][4] this environment falls within 0-50m water depth (Fig.6).

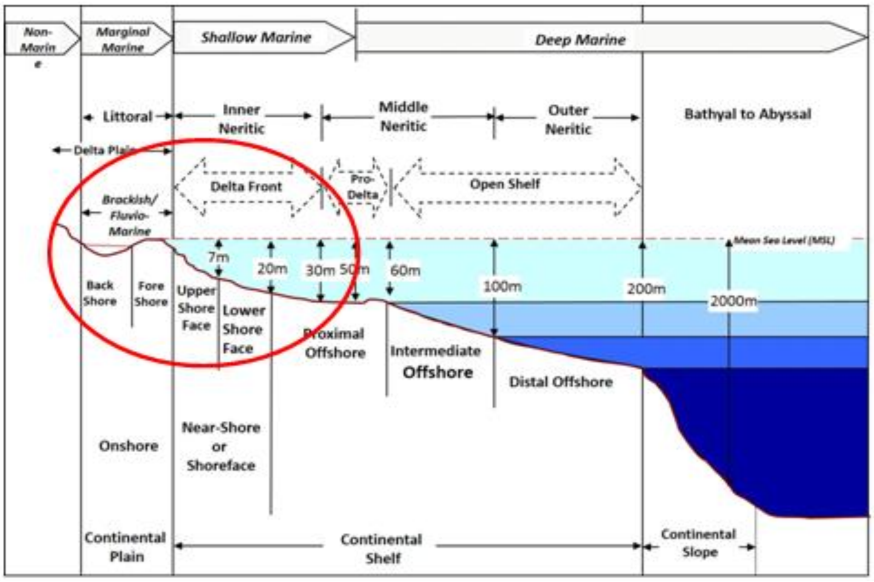

Figure 8: Depositional Environment and Bathymetric ranges used in Paleoenvironmental Interpretation Modified after [3,4,5]

5.4 Age of the section

Age determination of the studied sections was basically characterized using palynomorphs. This was because the recoveries from foraminifera were very poor and only included benthonic foraminifera. The occurrence of the benthonic foraminifera started sparsely from 6060 – 6090ft and increased at 8070 – 8100ft from where biozonation (F-Zone). From the palynological analysis, the sediments were observed to be deposited during Late Eocene to ?Early Miocene times with the boundary between Oligocene and Early Miocene marked at 4470ft using the top occurrence of *Cicatricosisporites dorogensis* while that between Late Eocene and Oligocene was fixed at 7500ft using the top occurrence of *Doualaidites laevigatus* observed at that depth. Only the late part of Eocene was penetrated. Oligocene was not subdivided due to poor data and missing sections.

5.5 Paleoenvironmental interpretation

Based on the palynomorphs and foraminifera recoveries, the paleoenvironment of deposition for the samples studied ranged between the shallow marine (the lower shale section of the study well) to marginal marine (littoral). The presence of benthonic foraminifera is also an indication of shallow marine paleoenvironment of deposition. The paleoenvironment of deposition interpretation was based on the palynomorph recoveries of the sample analyzed. The recoveries showed the presence mangrove swamp species, freshwater species, rain forest and savanna species (Table 6). However the mangrove swamp and freshwater species were dominant compared to the rain forest and savanna species. This suggests a paleoenvironment of mangrove swamp/fresh water environment. The presence of the rain forest and savannah species may have as a result of reworking by fluvial processes into the mangrove/freshwater environment. Based on palynology and foraminifera recoveries, the paleoenvironment of deposition for the samples studied ranged between the shallow marine i.e marginal marine (littoral).

5.6 Paleocology and Paleoclimatic Setting

The palynomorphs recovered from the studied samples were classified into paleoecologic groups according to the vegetation zones of their extent parent plants or their nearest living relatives. The paleoecology groupings according to [18] were followed which was on the bases of nature, quantity and quality of recovered pollen and spores are dependent on their proximity to shore, ecology and eustacy. Fig. 9 is a schematic illustration of different environments with the extent and living plant relatives from where the pollens and spores where generated.

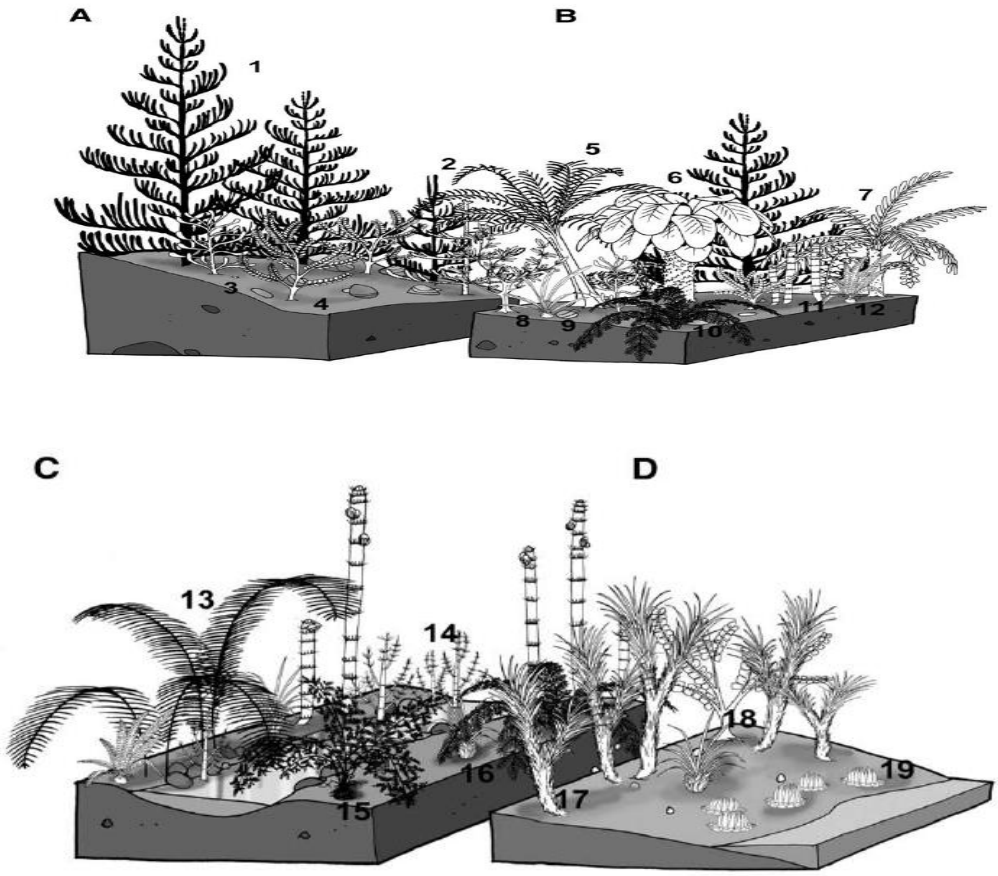

Figure 9: Paleoecology based on extant parent plant proximity to shore after Poumot (1989)

Four different environments (A – D) has been charaterized into paleoecology groupings based on the vegetation zones of the extant parent plants or their nearest living relatives.

A. Upland flora which are dominated by conifers. Most modern conifers are arborescent (big trees with large branches (1 & 2)), and few shrub-like plants with multiple branched shoots, covered with spirally attached, elliptic leaves (3 & 4).
B. Lowland flora with arborescent cycadophytes. These are plants with probably 1m high, large trunks and long leaves (5 – 11).
C. Wetland areas dominated by hygrophytic plants such as sphenophytes, ferns and lycophytes. Sphenophytes include the dorsetails with short internodes which results in vertical, articulated stems with whorls of microphylls. the ferns are smaller, with fronds at least 15cm long attached to a more or less bulbous rhizome. The lycophytes include the herbaceous and subarborescent taxa (14 – 16).
D. Coastal assemblage dominated by lycophytes and seed ferns. The seed ferns are probably an arborescent plant or at least a shrub with 0.05 – 1m long pinnate leaves. The leaf shape is variable in relation to their growing position on the trunk (17 – 19).

About 111 different flora and fauna species were recovered from the sample preparations, these included: 47 pollen, 15 spores, 14 dinoflagelates, 2 fungal spores, 1 foraminifer test lining, 3 algae, 3 acritarch, 22 foraminifera and 4 miscellaneous marine species. The paleoecology identification was based on the sporomorph recoveries as continental species and foraminifera as marine species, the sporomorphs recovered were grouped into the following paleoecology groups based on their ecological affinities to the different envornments (A – D). The predominant paleoecology groups identified from the sporomorphs recovered included the mangrove swamp, the fresh water swamp, the rain forest and the savanna. The paleoecology of the studied section of MT-well ranged between inner neritic (foraminifera recoveries), to littoral (mangrove swamp - fresh water swamp). The fresh water swamp represents the wetland areas dominated by hygrophytic plants such as sphenophytes, ferns and lycophytes while the mangrove swamp represents the coastal assemblage dominated by lycophytes and seed ferns. Species of savanah sporomorphs (Hinterland) recovered may be from terrestrial palynomorphs which become incorporated into marine sediments mainly due to fluvial transport which occur predominantly as silt-sized alluvial particles (Morley, 1995). The presence of *Zonocostites ramonae* – *Rhizophora* and dinoflagellates taxa such as *Selenopemphix* and *spiniferites sp* suggests a lagoonal to shallow marine environment [17,18].

Table 5: Palaecological groupings and climatic conditions for P pollen and spores

	Palaecological Groupings	Miospores	Climatic Indicators
1	Mangroove Swamp Forest	*Zonocostites ramonae, Spinizonocolpites echinatus, Psilatricolporites crassus, Psilatricolporites annuliporis, Verrucatosporites usmensis, Smooth monolete spore, Smooth trilete spore, Cicatricosisporites dorogensis Granulatisporites spp.*	WET
2	Fresh Water Swamp	*Retibrevitricolporites protrudens, Proteacidites spp, Pachydermites diederixi, Retistephanocolpites williamsi, Retibrevitricolporites ibadanensis*	WET
3	Rain Forest	*Verrucatosporites usmensis, Verrucatosporites tenellis Verrucatosporites farvus.*	WET
4	Savannah	*Striatricolpites catatumbus, Polyadopollenites vancampori, Retibrevitricolporites triangulates Retitricolporites irregularis.*	DRY

5.7 Summary and Conclusions

The results generated from the micropaleontological analyses showed poor foraminifera recoveries. The sample is dominated by benthonic foraminifera,therefore cannot be used for age determination,but age was determined using diagnostic palynomorph markers. The ages ranged from Late Eocene to ?Early Miocene times with the boundary between Oligocene and Early Miocene marked at 4470ft using the top occurrence of *Cicatricosisporites dorogensis* while that between Late Eocene and Oligocene was fixed at 7500ft using the top occurrence of *Doualaidites laevigatus* observed at that depth. The preponderance of benthonic foraminifera is an indication of shallow marine deposition. This is also supported by high occurrence of terrestrially derived palynomorphs. The sand/shale ratio plot showed an intercalation of sand and shale which is interpreted to correspond to the Agbada Formation of the Niger Delta. The marine index plot also showed an indication of deposition within the continental environment more than the marine environment. The paleoecological groupings based on marker extant species indicated a dominant Mangrove swamp and Fresh water environments while rain forest and savanna species suggests a reworking of the few species into the mangrove swamp environment.

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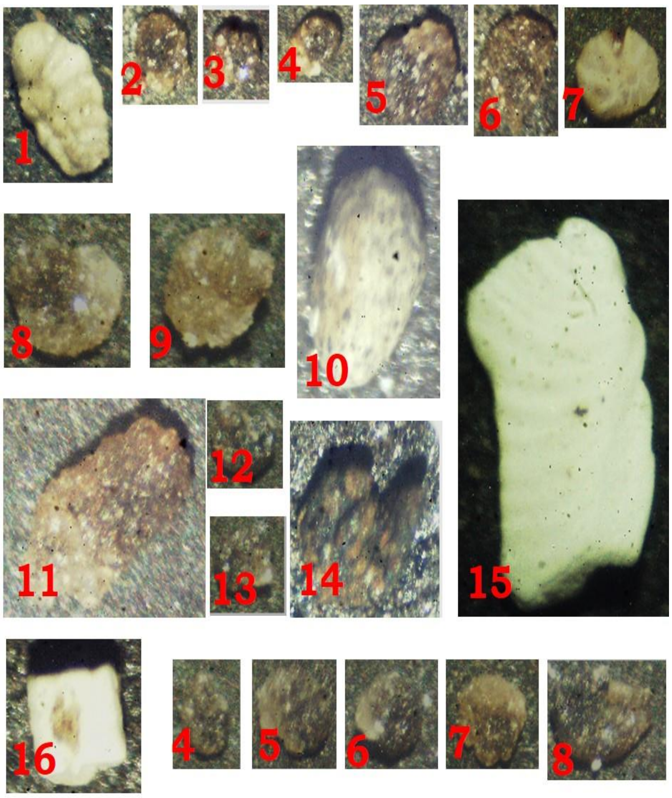
Plate 1



Explanation To Plate 1

Fig. 1: ***Textularia concava,*** **T – Well, 4440 – 4470 ft.**

Figs. 2, 3, 4, 5 & 6: ***Haplophragmoides rugosa,*** **T – Well, 5970 – 6000 ft.**

Fig. 7: ***Truncatulina ungeriana,*** **T – Well, 6060 – 6090 ft.**

Fig. 8: ***Haplophragmoides rugosa,*** **T – Well, 6060 – 6090 ft.**

Fig. 9: ***Cibicides corticatus,*** **T – Well, 6060 – 6090 ft.**

Figs. 10 & 16: ***Ostracoda,*** **T – Well, 7050 – 7080 ft.**

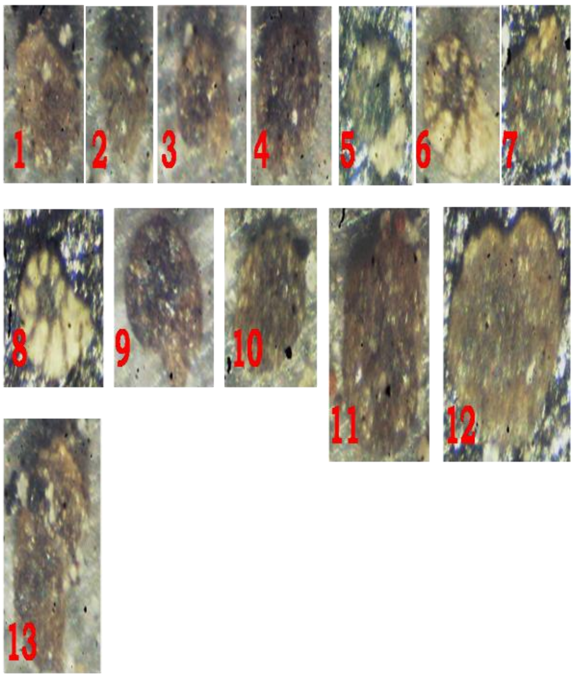
Fig. 11: ***Haplophragmoides wilbertirugosa,*** **T – Well, 6600 – 6630 ft.**

Figs. 12 & 13: ***Ammobaculites exiguus,*** **T – Well, 7560 – 7590 ft**

Fig. 14: ***Dissammina fallax,*** **T – Well, 7050 – 7080 ft.**

Fig. 15: ***Shell fragment,*** **T – Well, 6330 – 6360 ft.**

PLATE 2



Explanation To Plate 2

Figs. 1, 2, 3, 4 & 9: ***Trochammina inflata,*** **T – Well, 8250 – 8280 ft.**

Fig. 5: ***Ammobaculites-exiguus,*** **T – Well, 8250 – 8280 ft.**

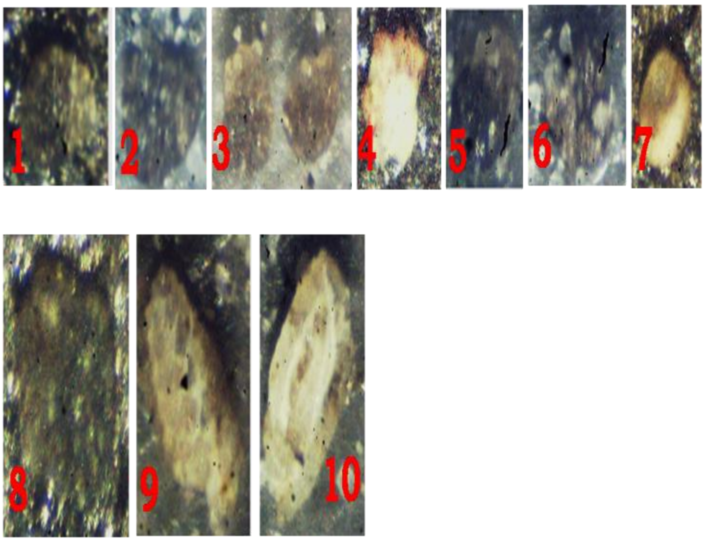
Figs. 6 & 8: ***Haplophragmoides wilberti,*** **T – Well, 8250 – 8280 ft.**

Fig. 7: ***Anomalina-ammonoides,*** **T – Well, 8250 – 8280 ft.**

Figs. 10 & 12: ***Planorbulina larvata,*** **T – Well, 8250 – 8280 ft.**

Figs. 11 & 13: ***Haplophragmoides wilbertirugosa,*** **T – Well, 8250 – 8280 ft.**

Plate 3



EXPLANATION TO PLATE 3

Figs. 1, 2, 3 & 6: ***Elphidium simplex,*** **T – Well, 8340 – 8370 ft.**

Fig. 4: ***Haplophragmoides wilberti,*** **T – Well, 8340 – 8370 ft.**

Fig. 5: ***Nonionina umbilicatula,*** **T – Well, 8340 – 8370 ft.**

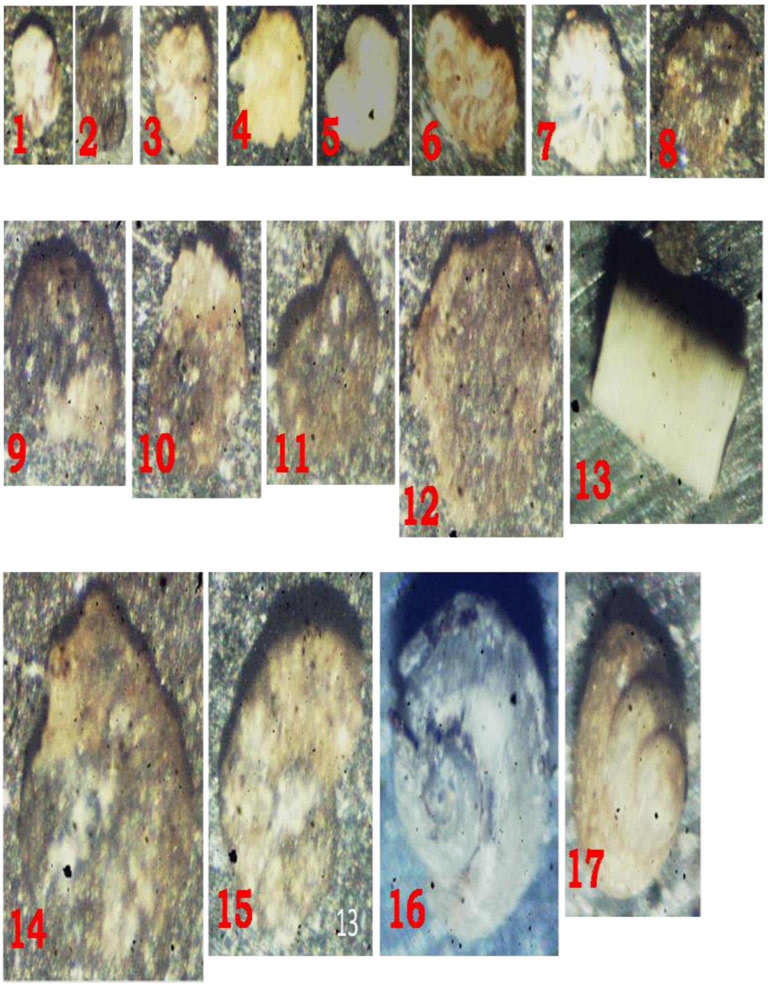
Fig. 7: ***Nonionella magnalingua,*** **T – Well, 8340 – 8370 ft.**

Fig. 8: ***Planorbulina larvata,*** **T – Well, 8340 – 8370 ft.**

Fig. 9: ***Brizalina dilatata,*** **T – Well, 8340 – 8370 ft.**

Fig. 10: ***Quinqueloculina costata,*** **T – Well, 8340 – 8370 ft.**

PLATE 4



EXPLANATION TO PLATE 4

Figs. 1, 3, 5 & 6: ***Planulina wuellerstorfi*****,** **T – Well, 8430 – 8460 ft.**

Fig. 2: ***Trochammininoides protues*****,** **T – Well, 8430 – 8460 ft.**

Fig. 4: ***Truncatulina ungeriana*****,** **T – Well, 8430 – 8460 ft.**

Fig. 7: ***Discorbis vencularis*****,** **T – Well, 8430 – 8460 ft.**

Figs. 8, 9 & 12: ***Haplophragmoides rugosa*****,** **T – Well, 8430 – 8460 ft.**

Figs. 11, 14 & 15: ***Dissammina fallax*****,** **T – Well, 8430 – 8460 ft.**

Fig. 13: ***Ostracoda*****,** **T – Well, 8430 – 8460 ft.**

Figs. 16 & 17: ***Gastropoda*****,** **T – Well, 8430 – 8460 ft.**