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Scientific Research

Palynostratigraphy and Paleoclimate of the Sequences Penetrated by Meren 31 Side Tract-2 Well, Offshore Niger Delta

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Abstract

Palynological study of an offshore well in the Niger delta was carried out to document the palynomorphs assemblage and subsequently date and establish paleoclimatic conditions in a portion of the Niger delta. One hundred and thirty seven cutting samples provided by Chevron Nigeria Plc were composited at 27 m interval for the study. The samples yielded forty six palynomorphs, which include *Racemonocolpites hians*, *Zonocostites ramonae*, *Monoporites annulatus*, *Botryococcusbraunii*, *dinocyst Lycopodiumsporites spp.*, *Pachydermitesdiederixi* and *Psilatricolporitescrassus*. A Middle-Late Miocene age belonging to P800 and P700 zones of Germeraad was established for the interval studied. There were clear crests and troughs in the microfloral abundance indicative of alternations of dry and wet climatic conditions during the deposition of the Agbada Formation.

Keywords

Paleoclimate, Meren field, Agbada Formation, *Racemonocolpites hians*

1. Introduction

Meren 31st-2 is one of several development wells drilled in Meren field in oil mining lease (OML)-95 of Chevron Nigeria Limited (**Figure 1**). The well was drilled to a total depth of 2758 m and located on Longitude 4˚50' and Latitude 5˚58' E (N 193335.92; E 273519.3) in the Western part of Niger Delta, West coast of Africa. Several publications directed towards exploration and exploitation of hydrocarbon abound on this prolific oil field. Recent publications particularly [1] on flow units, connectivity, and reservoir characterization of the field revealed that Meren field consists of complex reservoir architecture characterized by shoreface clinoforms and a history of progradation and retrogradation cycles. A high resolution sequence stratigraphic and reservoir

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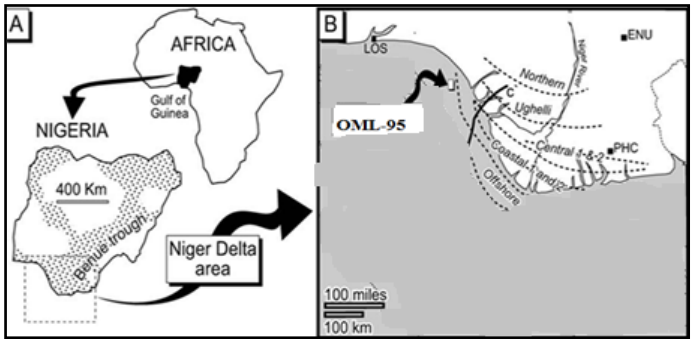


Figure 1. Location of OML 95 containing Meren Field is situated.

characterization of some sand units in the field had been carried out [2]. No previous investigation on miospore assemblage from Meren field has been made public. However, some miospores have been reported to occur in the Niger delta and used for both stratigraphic and climatic studies. For example *Podocarpus milanjianus* marked the boundary between Benin and Agbada Formations of the Niger Delta [3]. Twenty nine informal palynological zonations of the Niger Delta using alphanumerical coding system [4] appear to form the background information for in-house zonal scheme of Shell Petroleum Development Company. Using detailed morphological analysis of pollen groups which were assigned to the genera *Praedapollis*, *Striamonocolpites*, *Arecipites*, *Spirosyncolpites*, *Racemonocolpites*, *Verrutricolpites*, *Retibrevitricolporites* and *Belskipollis*, a refinement of the palynostratigraphic zonation and correlation of the Neogen of the Niger Delta was established [5]. The pollen grains of a 36 m deep core from Niger Delta were analyzed [6] to reach a conclusion that in the Quaternary, there were shifts in the extent of rain forest and savanna with the latter replacing the formal. Paleoenvironmental analysis of a section Niger Delta Basin (Ogbomotoru-1 well) (**Figure 1**) was used to infer transitional environment of deposition with marine interference based on the abundance of *Zonocostrites ramonae*, and occurrence of *Crassoretitriletes vanraadshooveni*, *Magnasriatites bowardii* and *Pachydermites diederixi* savannah [7].

The primary focus of this work is to establish the palynomorph contents, their palaecology and paleoclimate as well as the environment of deposition of the strata penetrated by Meren 31st-2. It is envisaged that the result shall add to information on the miospores recoverable from the western portion of the Niger delta and assist in the ongoing refining of the zonal scheme for the Niger delta.

2. Geological Setting

The Niger delta is the most significant hydrocarbon province on the West African continental margin. It started to evolve in Eocene times and deposition is still ongoing offshore. Three main formations have been recognized in the subsurface of the Delta [8]-[13]. These are the Benin, Agbada and Akata Formations. These formations were deposited in continental, transitional and marine environments, respectively; together they form a thick, overall progradational passive-margin wedge [2].

The Akata Formation is the basal unit composed mainly of marine shales believed to be the main source rock within the basin. The Agbada Formation is made up of alternating sandstone, siltstone and shale sequences that constitute the petroleum reservoirs of the basin. On the other hand, the Benin Formation largely consists of non-marine sands with a few shaly intercalations [2].

3. Materials and Methods

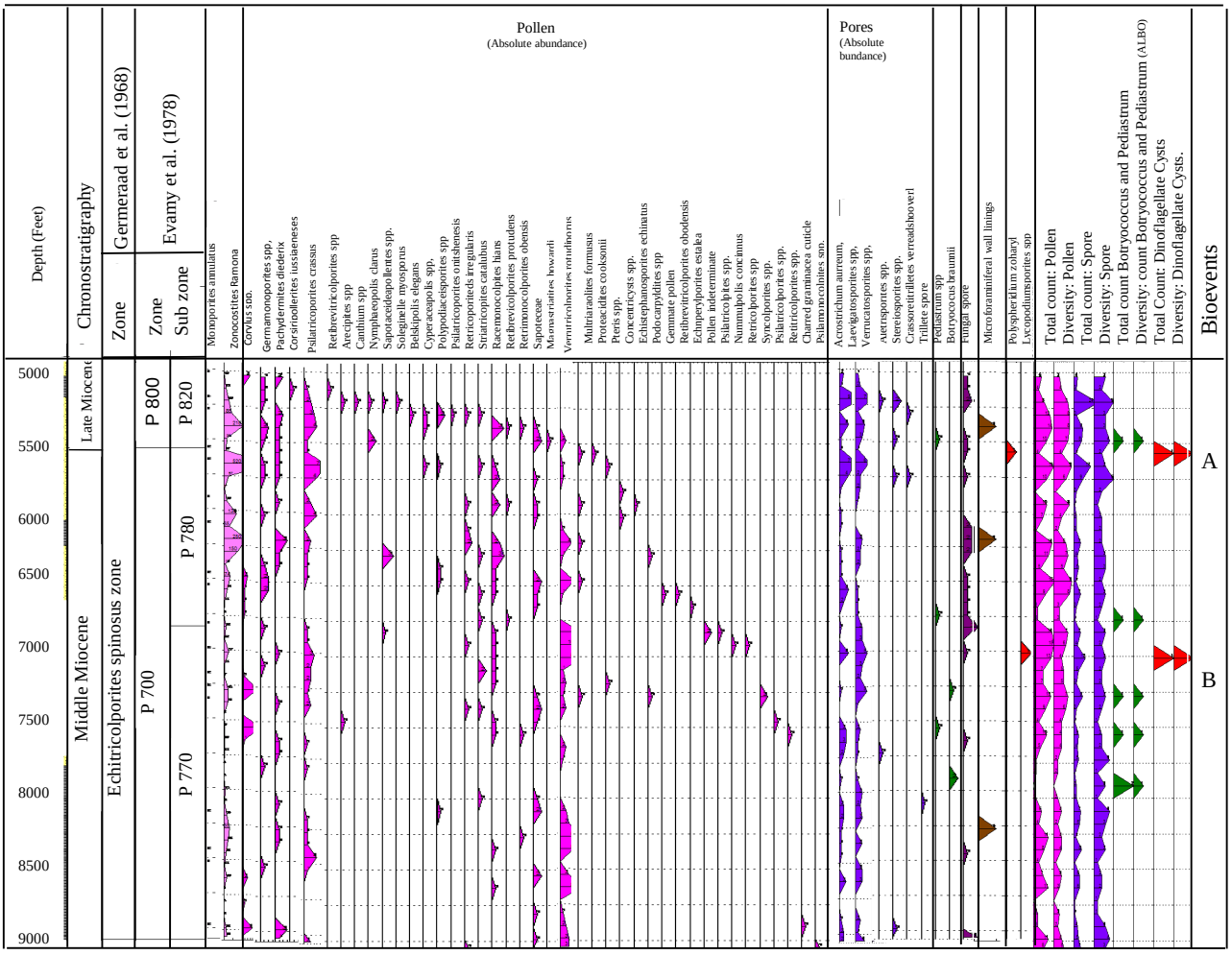
A total of one hundred and thirty seven ditch cutting samples (which were composited to forty six samples) used for this study was provided by Chevron Nigeria Plc. From each sample, about 25 gm was weighed and thoroughly washed/cleaned. The pretreatment of the samples with various acid combinations include removal of unwanted carbonate material by washing with 10 ml diluted hydrochloric acid as well as further treating the residue with 60% hydrofluoric acid and boiling hydrochloric to dissolve/remove all silicates and silicofluoride gel respectively. The ultrasonic centrifuge machine was used to further separate out the dissolved material (*i.e.* dirt, clay, mud etc.) from the organic matter residue for 2 minutes. Subsequently, three drops of Canada balsam in Xylene on the slide and mixed thoroughly allow for proper mixing and then pipette into a cover slip glass slide

on top of the hot plate until dryness and was ready for palynological microscopic evaluation.

The prepared slides for palynomorphs were studied under DP12 Olympus microscope, identification and description were attempted for as many palynomorphs as possible using relevant literature. Photographing of the well preserved palynomorphs was done using attached DP12 Olympus microscope camera.

4. Results

The stratigraphic distribution of fifty-six (56) pollen and spore species used for the palynological biozonation and palaeoclimatic interpretation of Meren 31 is shown in **Figure 2** and **Table 1**, **Table 2**, **Table 3**, and **Table 4**. The sediments in this section yielded a rich assemblage of the under listed pollens, spores and dinocysts species. The pollens are: *Monoporites annulatus, Zonocostites ramonae, Corylus spp., Germamonoporites spp., Pachydermites diederixi, Corsiripollerites jussiaeneses, Psilatricoporites crassus, Retibrevitricolporites spp., Arecipites spp., Canthium spp., Nymphaeopolis clarus, Sapotaceideapollentes spp., Soleginelle myosporus, Belskipolis elegans, Cyperaceapolis spp., Polypodiaceisporites spp., Psilatricoporites onitshenesis, Retricoporiteds irregularis, Striatricopites catalubus, Racemonocolpites hians, Retibrevicolporites protudens, Retrimonocolporites obensis, Sapoteceae, Magnastriatites howardi, Verrutricolporites rotudiporus, Multriaraolites formusus, Proteacidites cooksonii, Pteris spp., Concentricysts spp., Echistephanosporites echinatus, Podocarpyldites spp., Gemmate pollen, Retibrevitricolporites obodensis, Echnperylporites estalea, Pollen indeterminate, Psilatricolpites spp, Nummulpolis concinnus, Retricolporites spp, Charred graminacea cuticle and Psilamonocolpites spp.*



Bioevents: A = Top regular occurrence of Racemonocolpites hians; B = Quantitative Top Occurrence of Vertricolporites rotundiporouss)

Figure 2. Palynostratigraphic distribution chart of Meren 31st-2.

Table 1. Meren 31st-2 well ecological groups abundance.

DEPTH (m)	FWSP	DIV	BWSP	DIV	SAVANN	DIV	RAIN	DIV	OTHERS	MONT	BEACH
1507 - 1533	5	4	2	1	4	2	2	1	-	-	-
1533 - 1561	3	2	-	-	-	-	2	2	2	-	-
1561 - 1588	17	5	2	1	5	2	3	3	-	-	-
1588 -1615	5	4	5	2	3	3	1	1	2	-	-
1615 - 1643	9	5	5	2	1	1	6	2	1	-	-
1643 - 1670	15	7	2	2	-	-	3	2	-	-	-
1670 - 1698	3	3	3	3	2	1	2	2	-	-	-
1698 - 1725	15	7	8	2	2	1	9	3	-	-	-
1725 - 1753	7	6	5	2	-	-	6	2	1	-	-
1753 - 1780	2	1	-	-	1	-	1	1	-	-	-
1780 - 1807	3	3	3	2	1	1	5	4	-	-	-
1807 - 1835	4	3	4	1	1	1	1	1	-	-	-
1835 - 1862	3	2	-	-	2	1	3	1	-	-	-
1862 - 1890	11	3	5	2	-	-	5	3	-	-	-
1890 - 1917	8	5	2	2	-	-	4	2	-	1	-
1917 - 1944	6	4	2	2	-	-	2	2	-	-	-
1944 - 1972	11	6	1	1	4	3	4	4	-	-	-
1972 - 1999	10	7	-	-	2	2	5	2	-	-	-
1999 - 2027	2	2	-	-	1	1	2	1	-	-	1
2027 - 2054	3	3	-	-	4	1	-	-	-	-	-
2054 - 2082	15	5	1	1	3	2	2	2	1	-	-
2082 - 2109	3	3	1	1	-	-	1	1	1	-	-
2109 - 2137	17	4	2	2	3	1	5	2	-	-	-
2137 - 2164	9	5	2	1	-	-	1	1	-	-	-
2164 - 2192	5	3	2	1	4	3	1	1	-	-	-
2192 - 2219	12	5	1	1	8	2	2	2	-	1	-
2219 - 2246	8	5	3	2	1	1	1	1	1	-	-
2246 - 2274	2	2	1	1	-	-	2	2	-	-	-
2274 - 2301	2	1	-	-	7	1	5	2	1	-	-
2301 - 2329	3	2	2	2	1	1	3	1	-	-	-
2329 - 2356	4	4	1	1	-	-	2	1	-	-	-
2356 - 2384	2	2	1	1	-	-	-	-	-	-	-
2384 - 2410	2	2	-	-	-	-	1	1	-	-	-
2410 - 2438	5	3	-	-	-	-	-	-	-	-	-
2438 - 2466	9	5	1	1	-	-	2	1	1	-	-
2466 - 2493	7	3	1	1	2	2	2	1	-	-	-
2893 - 2521	9	2	2	2	-	-	1	1	1	-	-
2521 - 2548	7	2	2	2	-	-	2	2	-	-	-
2548 - 2576	-	-	4	1	2	1	1	1	-	-	-
2576 - 2603	11	5	1	1	-	-	-	-	-	-	-
2603 - 2630	11	2	-	-	2	1	4	2	-	-	-
2630 - 2658	1	1	-	-	-	-	-	-	-	-	-
2658 - 2685	3	3	-	-	1	1	-	-	-	-	-
2685 - 2713	5	3	-	-	1	1	-	-	-	-	-
2713 - 2740	7	5	2	1	6	2	2	1	-	-	-
2740 - 2758	8	3	3	2	-	-	2	1	2	2	-

FWSP = Fresh water swamp species; BWSP = Brackish water swamp species; SAVANN = Savannah species; RAIN = Lowland rainforest species; MONT = Montane species; BEACH = Beach vegetation; DIV = No of species.

Table 2. Fresh water algae and marine element composition Meren 31st-2 well.

DEPTH (m)	BOTRYO	FUNGAL	DINO	D/B
1507 - 1533	-	1	-	-
1533 - 1561	-	1	-	-
1561 - 1588	-	2	-	-
1643 - 1670	1	1	-	-
1670 - 1698	-	1	1	-
1698 - 1725	-	-	-	-
1725 - 1753	-	1	-	-
1753 - 1780	-	-	-	-
1780 - 1807	-	-	-	-
1807 - 1835	-	2	-	-
1835 - 1862	-	2	-	-
1862 - 1890	-	2	-	-
1917 - 1944	-	1	-	-
1944 - 1972	-	1	-	-
1972 - 1999	-	1	-	-
1999 - 2027	1	1	-	-
2027 - 2054	-	3	-	-
2054 - 2082	-	-	-	-
2082 - 2109	-	1	1	-
2109 - 2137	-	-	-	-
2137 - 2164	-	-	-	-
2164 - 2192	1	-	-	-
2192 - 2219	-	-	-	-
2219 - 2246	-	-	-	-
2246 - 2274	1	-	-	-
2274 - 2301	-	1	-	-
2301 - 2329	-	-	-	-
2329 - 2356	-	-	-	-
2356 - 2384	2	-	-	-
2384 - 2410	-	-	-	-
2410 - 2438	-	-	-	-
2438 - 2466	-	-	-	-
2466 - 2493	-	-	-	-
2893 - 2521	-	-	-	-
2521 - 2548	-	1	-	-
2548 - 2576	-	-	-	-
2685 - 2713	-	-	-	-
2713 - 2740	-	3	-	-
2740 - 2758	-	-	-	-

Table 3. *Monoporites annulatus* and *Zonocostites* composition of Meren 31st-2 well.

DEPTH (m)	MONO	ZONO	TOTAL	%MONO	%ZONO
1507 - 1533	1	10	11	9.1	90.9
1533 - 1561	-	23	23	0.0	100.0
1561 - 1588	4	60	64	6.3	93.7
1588 - 1615	1	85	86	1.2	98.8
1615 - 1643	-	215	215	0.0	100.0
1643 - 1670	-	36	36	0.0	100.0
1670 - 1698	2	27	29	6.9	93.1
1698 - 1725	2	520	522	0.4	99.6
1725 - 1753	-	57	57	0.0	100.0
1753 - 1780	-	7	7	0.0	100.0
1780 - 1807	1	30	31	3.2	96.8
1807 - 1835	-	138	138	0.0	100.0
1835 - 1862	2	65	67	3.0	97.0
1862 - 1890	-	250	250	0.0	100.0
1890 - 1917	-	150	150	0.0	100.0
1917 - 1944	-	19	19	0.0	100.0
1944 - 1972	2	74	76	2.6	97.4
1972 - 1999	1	41	42	2.4	97.6
1999 - 2027	-	13	13	0.0	100.0
2027 - 2054	-	3	3	0.0	100.0
2054 - 2082	1	22	23	4.3	95.7
2082 - 2109	-	12	12	0.0	100.0
2109 - 2137	3	57	60	5.0	95.0
2137 - 2164	-	13	13	0.0	100.0
2164 - 2192	2	7	9	28.6	71.4
2192 - 2219	3	45	48	6.3	93.7
2219 - 2246	1	51	52	1.9	98.1
2246 - 2274	-	2	2	0.0	100.0
2274 - 2301	-	9	9	0.0	100.0
2301 - 2329	-	10	10	0.0	100.0
2329 - 2356	-	13	13	0.0	100.0
2356 - 2384	-	4	4	0.0	100.0
2384 - 2410	-	5	5	0.0	100.0
2410 - 2438	-	15	15	0.0	100.0
2438 - 2466	-	6	6	0.0	100.0
2466 - 2493	2	34	36	5.6	94.4
2893 - 2521	-	65	65	0.0	100.0
2521 - 2548	-	46	46	0.0	100.0
2548 - 2576	2	28	30	6.7	93.3
2576 - 2603	1	13	14	7.1	92.9
2603 - 2630	-	30	30	0.0	100.0
2630 - 2658	-	1	1	0.0	100.0
2658 - 2685	-	5	5	0.0	100.0
2685 - 2713	-	3	3	0.0	100.0
2713 - 2740	2	26	28	7.1	92.9
2740 - 2758	-	31	31	0.0	100.0

MONO = total *Monoporitesannulatus*; ZONO = total *Zonocostitesramonae*; %MONO = percentage of *Monoporitesannulatus* in total of *Monoporitesannulatus* + *Zonocostitesramonae*% ZONO = percentage of *Zonocostitesramonae* in total of *Monoporitesannulatus* + *Zonocostitesramonae.*

Table 4. Numerical and percentage pollen and spore spectra.

DEPTH (m)	SPORES	POLLEN	TOTAL	%SPORE	%POLLEN	RATIO P/S
1507 - 1533	4	6	10	40.0	60.0	1.50
1533 - 1561	3	4	7	42.90	57.10	1.33
1561 - 1588	24	8	32	75.00	25.00	0.30
1588 - 1615	3	12	15	20.00	80.00	4.00
1615 - 1643	9	14	23	39.10	60.90	1.56
1643 - 1670	8	10	18	44.44	55.56	1.25
1670 - 1698	2	4	6	33.33	66.67	2.00
1698 - 1725	17	15	32	53.13	46.87	0.88
1725 - 1753	9	10	19	47.37	52.63	1.11
1753 - 1780	3	1	4	75.00	25.00	0.33
1780 - 1807	1	10	11	9.09	90.91	10.00
1807 - 1835	3	7	10	30.00	90.00	2.33
1835 - 1862	3	2	5	60.00	40.00	0.67
1862 - 1890	7	14	21	33.33	66.67	2.00
1890 - 1917	4	11	15	26.67	73.33	2.75
1917 - 1944	5	5	10	50.00	50.00	1.00
1944 - 1972	2	16	18	11.11	88.89	8.00
1972 - 1999	7	9	16	43.75	56.25	1.29
1999 - 2027	3	3	6	50.00	50.00	1.00
2027 - 2054	1	3	4	25.00	75.00	3.00
2054 - 2082	7	14	21	33.33	66.67	2.00
2082 - 2109	4	15	19	26.67	73.33	3.75
2109 - 2137	12	13	25	48.00	52.00	1.08
2137 - 2164	5	7	12	41.67	58.33	1.40
2164 - 2192	3	7	10	30.00	70.00	2.33
2192 - 2219	9	13	22	40.91	59.09	1.44
2219 - 2246	3	9	12	25.00	75.00	3.00
2246 - 2274	1	4	5	20.00	80.00	4.00
2274 - 2301	5	10	15	33.33	66.67	2.00
2301 - 2329	4	5	9	44.44	55.56	1.25
2329 - 2356	5	2	7	71.43	28.57	0.40
2356 - 2384	1	2	3	33.33	66.67	2.00
2384 - 2410	3	-	3	100.00	0.00	0.00
2410 - 2438	3	2	5	60.00	40.00	0.67
2438 - 2466	7	6	13	53.85	46.15	0.86
2466 - 2493	6	4	10	60.00	40.00	0.67
2893 - 2521	2	11	13	15.38	84.62	5.50
2521 - 2548	8	8	16	50.00	50.00	1.00
2548 - 2576	1	4	5	20.00	80.00	4
2576 - 2603	6	7	13	46.15	53.85	1.17
2603 - 2630	6	11	17	35.29	64.71	1.83
2630 - 2658	1	-	1	100.00	0.00	0.00
2658 - 2685	1	3	4	25.00	75.00	3
2685 - 2713	4	3	7	57.14	42.86	0.75
2713 - 2740	5	11	16	32.25	67.75	2.20
2740 - 2758	7	8	15	46.67	53.33	1.14

The spores are: *Acrostrichum aurreum*, *Laevigatosporites spp*, *Verrucatosporites spp*, *Aletrisporites spp*, *Stereiosporites spp*, *Crassoretitrilletes verreadshooverl*, *Trillete spore*, *Pediastrum spp*, *Botryococus braunnii*, and *Fungal spore*. The dynocysts are: *Polyspheridium zoharyl* and *Lycopodiumsporites spp.*

This includes abundant land-derived sporomorphs such as *Zonocopotites romanae*, *Sapotaceiodaepollenites sp*, *Gemmamonoporites spp*, *Racemonocolporites hians*, brackish water swamp species, *Pachydermites diederixi*, *Psilatricolporites crassus* and the *Pterdophytes* spores (**Table 1**). Common records of microforaminiferal wall linings, dinoflagellate cysts and fresh water algae *Botryococcus braunii* were occasionally recorded within the well section (**Table 2**). This assemblage is indicative of shallow marine environment of deposition. The ratio of *Monoporites annulatus* to *Zonocopotites romanae* is shown in **Table 3**, while the numerical and percentage of pollens and spores are shown in 4. **Table 5** is a summary of the biozonaton proposed for the sequences encountered in the studied well. The distribution chart of all the palynomorphs encountered in the studied well and the inferences drawn from them is as displayed in **Figure 2**.

Systematic

Division 1: *Sporites*; Potonie and Gelletich, [14].

Class: *Monoletes* Ibrahim, [15].

Genus: *Verrrucatosporites spp* Potonie, [16].

Plate 1 fig. d and g.

Description: Spore bilaterally symmetrical, heteropolar, boatshaped in the longer equatorial view, monolete; sculpture: Verrucate to gemmate.

Dimension: 45.7 µm × 49.1 µm.

Locations: 1507 m - 2758 m.

Remarks: Common in the well. It occurs in nearly all the sampled intervals within the well.

Botanical Affinity: Resembles the Recent spore of climbing fern *Stenochlana palustria* (Germeraad, Hopping and Muller [17].

Division 2: *Pollennites*; Potonie and Gelletich, [14] Angiospermae.

Class A: *Monoporatae* (Iversen and Troels-Smith, [18].

Genus: *Nympheapollis clarus* NAGY [19].

Table 5. Biozonation of the sequences penetrated by Meren 31.

	Series	Sub-series	Germeraad *et al.*; 1968	Evamy *et al.*; 1978		Diagnosis/Biodatums
				Zone	Sub-zone	
4943		Late		P800	P820	
5000						
5500- 5570-						-Top Regular Occurrence of *Racemonocolporites hians*
6000-					P780	
	Miocene		Echitricolporites Spinosus Zone			
6830- 7000-				P700		Quantitative Top Occurrence of *Verrutricolporites rotundiporus*
8000-					P770	
9050 TD-						

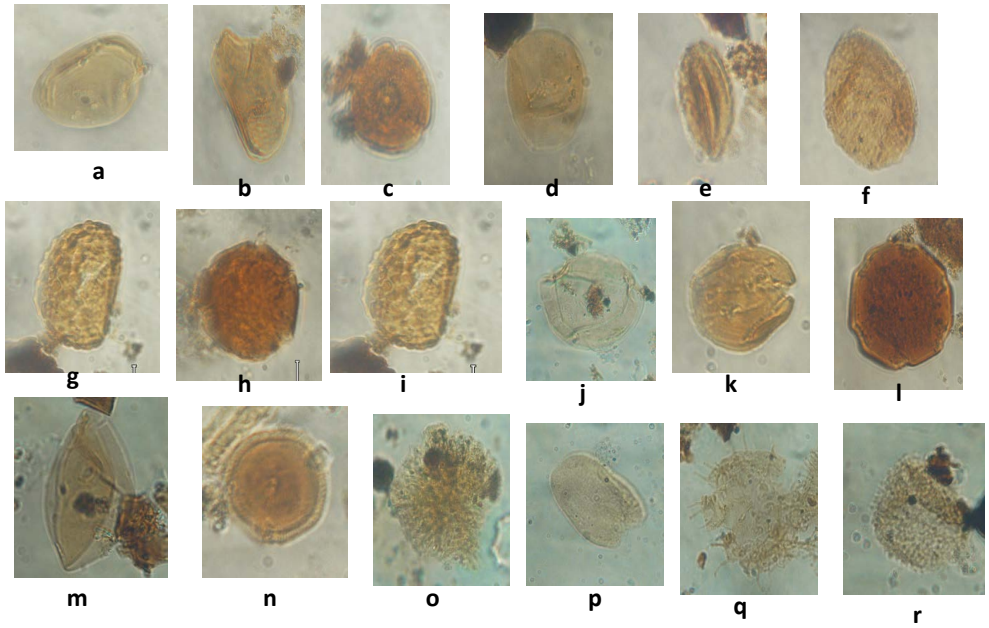


Plate 1. Palynological assemblages of Meren 31, well.

Plate 1 fig. h and k.

Description: Single grain, large radially symmetrical, circular in outline, and occasionally with concentric rings, with uniformly spaced bacules and psilate.

Dimension: 55.0 µm × 46.1 µm.

Lacations: 1561 m - 1670 m.

Remarks: Abundant and regularly distributed within the well. It is stratigraphically important as a lower Pliocene marker species in the Niger Delta.

Botanical Affinity: It has a close resemblance to the species Nyphaceae.

Genus: Gemmamonoporites (Van Der Hammen and Garcia De Mutis, [20].

Germamonoporites sp **Plate 1** fig. b.

Description: Pollen grain globular, *heteropolar*, *monoporate*, grain is gemmate, gemmae are of different dimensions.

Dimension: 33.9 µm × 30.4 µm.

Locations: Common from 1507 m - 2164 m but rare below.

Remarks: It occurs almost in each depth throughout the well. Rare to common in distribution.

Botanical Affinity: Possibly the pollen of a palmae.

Class B: *Tricolporate*. Iversen and Troels-Smith, [18].

Genus: *Verrutricolporites*. Vander Hammen and Wijstra, [21].

Verrutricolporites rotundiporus. Vander Hammen and Wijstra, [21]. **Plate 1** fig. c.

Description: Single grain, radially symmetrical, isopolar, spherical to subprolate, outline in polar view is lobate, tricolporate, pores not distinct. Ora marking indistinct, where distinct, they are circular. Bucules thin, Exine verrucate to psilate.

Dimension: 20.5 µm × 1 8.8 µm.

Locations: 1643 m - 2758 m.

Remarks: Shows variation both in size and sculpture. Stratigrapically very important as marker species in the Lower and Middle Miocene of the Niger Delta. It ranges from Late Miocene to Early Pliocene in the studied well.

Botanical Affinity: Identical to the pollen of recent plants-*Crenea maritime* (Germeraad, Hopping and Muller, [17].

Genus: *Psilatricolporites*. Vander Hamen, [22].

Psilatricolporites crassus. Vander Hammen and Wijstra, [21] **Plate 1** fig. a.

Description: Single grain, radially symmetrical, spherical to subangular. Grain tricolporate; colpi with straight borders and pointed ends. Ora elongated equatorially. Exine is psilate.

Dimension: 50 µm × 44.6 µm.

Locations: 2301 m - 2329 m.

Remarks: Rare to occasionally abundant variable in shape, sculpture and thickness of coastae. It ranges from Miocene to Pliocene in the Niger Delta.

Botanical Affinity: Closely related to the pollen of Hura sp (especially that of Hura polyandra) (Euphorbiaceae).

Class C: *Stephanoporatae.* Inversen and Troels-Smith, [18].

Genus: *Pachydermites*. Germeraad, Hopping and Muller, [17].

Pachydermites diederixi. Germeraad, Hopping and Muller [17].

Plate 1 fig. f and j.

Description: Single grain, radially symmetrical, isopolar, oblate to suboblate, has 4.8 spores, aperture is irregular in shape, inner surface is slightly irregular.

Dimension: 35.7 µm × 42.9 µm.

Locations: 1507 m - 1945 m.

Remarks: Recovered at various intervals in the studied well. Common at upper part but rare at the lower part of the well.

Botanical Affinity: Similar to the pollen of *symphonia globulifera* (Guttiferae). Germeraad, Hopping and Muller; [17].

CLASS D: Periporate. Inverse and Troels-Smith [18].

Genus: *Echiperiporites* (Van Der Hammen and Wymstra, [21].

Echistephanoporites echinatus. Germeraad, Hopping and Muller, [17].

Plate 1 fig. e.

Description: Single grain, circular in outline, periporate, pore range between 10 - 24 or more and are situated at base of spines, ektexinous and edexinus; sculpture spinose, spines are supported by bacules; exine is intrabaculate and spinose.

Dimension: 67.9 µm × 63.4 µm.

Locations: 1780 m - 1807 m.

Remarks: The species has rare occurrence in the well. There is considerable variation in the number of pore size and spinosity. The age is Miocene.

Botanical Affinity: Majority of the pollen resemble the pollen of *Thespesia populnea* (Malvaceae) (Germeraad, Hopping and Muller, [17]. Larger grains are closer to *Hibiscus tiliaceus.*

5. Discussion

5.1. Palynological Biozonation

The well section is sub divisible into two biozones: P800 and P700 zones. The P820 subzone was only recognized within the P800 zone while the P700 is further subdivided into P780 and P770 subzone of [4]. This sequence is further correlated with the *Echitricolporites spinosus* zone [17]. The zone and subzones recognized are discussed briefly below and represented graphically in **Table 5** and **Figure 2**.

ZONE P800

Subzone P820

Interval: 1507 - 1698 m.

Age: Late Miocene

Diagnosis: This is the youngest subzone recognized in the studied section of the Meren-31st-2 well. The top of this subzone is placed at the depth (1507 m) of the first sample analyzed while the base is defined by the top regular occurrence of *Racemonocolpites hians*. This interval is further characterized by the regular records *Gemmamonoporites sp* and the abundant numbers of *Zonocoltites ramonae.*

ZONE P700

Subzone P780

Interval: 1698 m - 2082 m.

Age: Middle Miocene

Diagnosis: The top of this subzone is marked by the top regular occurrence of *Racemocolpites hians* at 1698 m while the base is defined by the quantitative top occurrence of *Verrutricolporites rotundiporus* at 2082 m. This subzone is further confirmed by the regular and abundant records of *Verrutricolporites rotundiporus*, *Psilatricolporites crassus and Acrostichum aureum*.

(iii) Subzone P770

Interval: 2082 m - 2758 m

Age: Middle Miocene

Diagnosis: This is last and oldest subzone recognized in Meren-31st-2 well. The top of this subzone was defined by the quantitative top occurrence of *Verrutricolporites rotundiporus.*

5.2. Palaeoclimate

The climatic fluctuation in Meren 31st-2 well is discussed according to the "floral" zones.

Depth 2758 m - 2082 m

At the total depth of the well (2758 m), there was a very low to zero percentage of grass pollen, *Monoporites annulatus*, with an observed increase in the percentage ratio of *Monoporites annulatus* to *Zonocostites ramonae* from 0% to about 7.1% from 2713 m up to 2576 m and peaked at 2219 m (about 28.6%) (**Table 3**). This increase was accompanied by a rather more consistent record of mangrove pollen, *Zonocostites ramonae*, with sharp increase in numerical quantities of this wet climate indicator at 2356 m and between 2493 m and 2521 m where (it)*Cyperaceapolis spp.*, *Pteris* attained the highest quantitative occurrence within this "Floral" zone with 65 counts (**Table 3**). Within this zone, the rare occurrence of marine element, dinocyst *Lycopodiumsporites spp* was also recovered (**Table 3**). A wet condition would have been suggested for this zone due to the regular occurrence of mangrove pollen and abundance of fresh water alga, *Botryococcus braunii* along with brackish water swamp species, *Pachydermites diederixi* and *Psilatricolporites crassus*, which were abundant within this zone coupled with the rare occurrence of Gramineae pollen, but for the rare record of *Cyperraceaepollis* spp., which is a humid climate indicator [23] [24]. The zone was probably experiencing a humid climate during this time. According to [25], the abundance of *Rhizophora* pollen above 40% (**Table 4**) in sediments indicates a good representation of mangrove swamp, suggesting a humid tropical lowland climate during the deposition of the mentioned interval.

Some of the savannah pollens recorded in the above named zone include Corylus spp., etc while the wet climate indicators are freshwater swamp rainforest species like *Sapotaceae*, *Verrutricosporite rotundiporus*, *Gemmamonoporites spp.*, *Striatricolpites catatumbus* and a few others. The presence of the dinocyst species, *Lycopodiumsporites spp* suggests sediment deposition in a shallow marine environment with frequent freshwater incursions and lowered sea levels following glacial maxima [26].

Depth 2082 m - 1698 m

There was a sharp quantitative (numerical) increase in mangrove pollen *Zonocostites ramonae* from about 65 counts at 2493 m to 520 counts at 1698 m, 250 counts at 1862 m and 138 counts at 1807 m, with a gentle downhole increase in *Monoporites annulatus* (**Table 3**) within this zone. This observation could be hardly visible when considering it in terms of percentage composition of the total mangrove pollen and *Gramineae* pollen, where *Zonocostites ramonae* attained 100% in some depth within this floral zone (**Table 3**). There were also noticeable fluctuations in the occurrence of ferns, *Laevigatosporites spp*., *Verrucatosporites spp*. and *Stereiosporites spp.* within this interval.

This zone is probably a dry climate phase with warm temperatures. In a study by [27] in SW Turkey high percentages of *Gramineae* pollen types in sediment was taken to point to drier local conditions. A noticeable presence of savanna species *Echistephanoporites echinatus*, further confirms the prevalence of a dry climate within this interval. Other important savanna species occurring within this zone include *Concentricytis spp*., *Cyperaceaepollis spp*., *Corylus spp*., *Pteris spp*. and more. However, a few rainforest/fresh water swamp species were recorded within this zone. These include *Canthium spp*., *Retibrevitricolporites spp.*, *Psilatricolporites onitshaensis* etc., (**Table 1**) and a rare to common record of *Botryococcus braunii*. The occurrence of small quantities of mangrove pollen in this zone was probably due to minor local short-lived transgressions of the sea, thereby allowing only very limited extension of mangrove vegetation.

Depth 1698 m - 1524 m

By the time of deposition of the sequences within this interval, the pollen record indicates that mangrove

swamp forest vegetation was now well established, with the quantitative occurrence of *Zonocostites ramonae* reaching its highest numerical value (520 counts) at 1698 m (**Table 3**). So also was a high occurrence of fresh water swamp species, *Sapotaceae*, *Retitricolporites irregularis*, *Retibrevitricolporites protudens* etc., with rare occurrences of other fresh water *sporomorphs of Verrutricolporites rotundiporus, Gemmamonoporites spp.*, *Verrutricolporites* microporus, Magnastriatites howandi etc. Also recorded were rare to common occurrences of brackish water swamp species of *Pachydermites diederixi* and *Psilatricolporites crassus* and fresh water algae, *Botryococcus* braunii. It is worthy to note the increase in abundance of *pteridophytes* (fern spores), *Laevigatosporites spp*., *Verrucatosporites spp*. and *Stereiosporites spp*. coupled with an almost consistent occurrence of *Acrostichum aureum* and rare occurrences of lowland rainforest species like *Nympheaepollis clarus*, *Echistephanoporites echinatus*, *Racemonocolpites hians*, *Canthium spp.*, etc. (**Table 1** and **Figure 2**). There is also an overall increase in the recorded quantities of grass pollen, *Monoporites annulatus*, both numerically and in ratio to mangrove pollen. There was a visible common to abundant occurrences of *Corylus spp*., *Cyperaceaepollis spp*. and *Pteris spp*., and rare to common occurrences of *Ctenolophondites costatus*, Charred *Gramineae cuticle*, *Chenophondipollis spp.*, *Elaeis guineensis*, *Numulipollis neogenicus*, *Peregrinipollis nigericus* etc., which are all savanna species (**Table 1**).

An initial rise in sea level with the mangrove vegetation increasing in extent is suggested for this zone. The fluctuations in percentage occurrence of *Zonocostites ramonae* may probably be a result of variations in the intensity and extent of the tidal streams thereby causing fluctuations in the extent of mangrove forest. This rise and fall of the tides may also bring about drier conditions resulting in a reduction of forest vegetation and subsequently promoting expansion of the savanna [26]. This agrees with the reports of [23] which revealed cyclic fluctuations in the vegetation and continental climatic condition of North-West Africa in the Pliocene, when river discharge ceased, wind transport of pollen grains prevailed over fluvial transport.

6. Conclusions

The recovered palynomorphs in the studied well consists of abundant land-derived sporomorphs such as *Zonocopotites romanae*, *Sapotaceiodaepollenites sp.*, *Gemmamono porites spp.*, *Racemonocolporites hians*; brackish water swamp species, *Pachydermites diederixi*, *Psilatricolporites crassus*; Common records of microforaminiferal wall linings, dinoflagellate *cysts*; and rare occurrence of fresh water algae *Botryococcus braunii.*

Based on the top regular occurrence of *Racemonocolpites hians* and *Racemocolpites hians*, the P820 and P780 subzone, respectively were recognized within the section of the well studied. The top of subzone P770 was defined by the quantitative top occurrence of *Verrutricolporites rotundiporus*, which enabled assignment of middle Miocene to the deepest part of the well.

Paleobathymetric analysis based on microfloras indicated that the majority of the spores and pollen species showed minor variations in abundance and diversity within the studied section of the well. Abundant occurrence of *Monoporites annulatus* in some sections of the well enabled delineation of the sequences that were deposited under wet conditions during the Miocene. In most cases, such interval is characterized by the dominant occurrence of pollen grains of *Rhizophora spp*., *Zonocostites ramonae*, and spores of *pteridophytes* and fungi. The sequences within interval 2082 m - 1698 m were probably deposited under a dry climatic phase with warm temperature based on the occurrence of *Echistephanoporites echinatus Concentricytis spp.*, *Cyperaceaepollis spp.*, *Corylus spp*., and *Pteris spp.*

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