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Palynological and Paleoclimatic Conditions of the Sediments Penetrated by Sahaiawei-1 Well in the Northern Delta Depobelt, Niger Delta Basin

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Abstract
Palynological and paleoclimatic conditions of the sediments penetrated by Sahaiawei-1 Well in the Northern Delta Depobelt, Niger Delta Basin was investgated with the aim of establishing a palynological biozonation, age and the paleoclimatic conditions the sediments were formed. The palynological study was carried out on fifty (50) ditch cutting samples of shaly and sandy shale lithologies at different intervals between 1800ft to 10680ft. This study allowed the recovery of seven hundred and fifty seven (757) palynomorphs which includes six hundred and eighty nine (689) miospores, eighteen (18) dinocysts and fifty (50) ancillary microfossils. Four (4) palynological zones were established using palynological characteristic of the age diagnostic index markers. The palynological zones established are the P480, P470, P450 and lumped P430-P330 Zones. The age of the sediments penetrated by the well using the age diagnostic markers range from Late Maastrichtian to Late Eocene. Based on the dominance of *Zonocostites ramonae* over *Monoporites annnulatus*, it showed that from depth 1800ft to 5280ft the count of *Zonocostites ramonae* is generally higher than that of *Monoporites annulatus* suggesting a predominantly humid climate and the sediment during this period was deposited in cooler and wetter condition. Within 5280ft to 5520ft, the amount of *Monoporites annulatus* is higher than *Zonocostites ramonae* suggesting warm climatic condition. Between 5520ft to 6000ft suggests a humid climate. Below this depth 6000ft, the climatic condition was not ascertained because there were no paleoclimatic indicators.

Keywords: *biozonation, depobelt, paleoclimatic, Agbada Formation, age diagnostic markers.*

Introduction

The Niger Delta is one of the major prolific oil and gas basin in Nigeria. The basin petroleum system is called The Tertiary Akata-Agbada Petroleum System (Doust and Omatsola, 1990; Ekweozor and Daukoru, 1994; Kulke, 1995). Therefore, establishing a palynological and paleoclimatic conditions is necessary for exploration and exploitation of the hydrocarbon resources of the delta. This however has necessitated the need for oil companies and researchers to search for petroleum in new frontiers and also re-assessment of aging fields.

Palynology as a tool of micropaleontology is the study of pollen grains, spores, dinocysts as well as other palynomorphs that are found in geological record. Palynology as a tool in evaluating sedimentary succession penetrated by a drill in different sedimentary basin have become increasingly important in present days as seen in the works of the following authors (Germeraad et al., 1968; Oloto, 1992; Helenes et al., 1998; Chiaghanam et al., 2013; Osokpor et al., 2015; Lucas, 2017; Itiowe and Lucas, 2020a; Itiowe and Lucas 2020b).

The aim of this study is to determine the palynological zonation, age and the paleoclimatic conditions the sediments of the penetrated well were formed. Ditch cutting samples were prepared using palynological preparation technique. The recovered palynomorphs were identified with the aid of relevant publications such as Gemeraad et al., (1968); Legoux et al., (1970); Legoux (1978) and Shell Petroleum Development Company palynological photo album. The study area is located in the Northern Delta Depobelt. The well is geographically located between latitude 6°05'N and longitude 5°15'E (Figure 1).

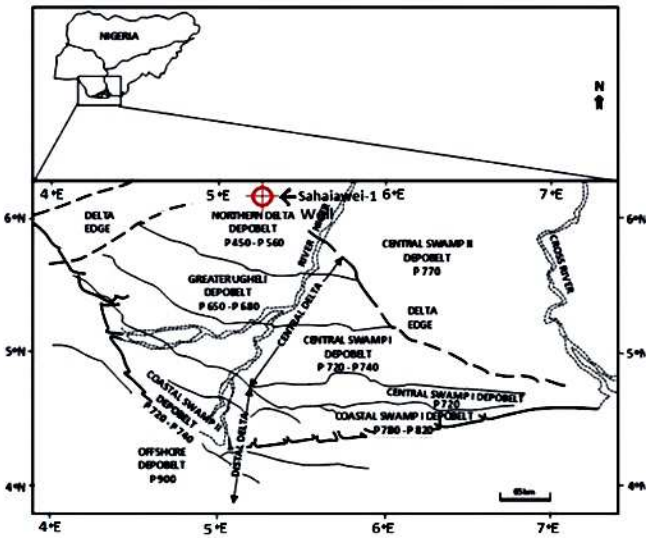


Fig. 1: Location map of study area (Modified after Doust and Omatsola, 1990)

Geologic Setting of the Study Area

The evolution of Niger Delta started during the Cretaceous times, the region presently occupied by the Niger Delta was the failed arm of the R-R-R (ridge-ridge-ridge) triple junction. According to Short and Stauble (1967), South America and African continents separation occurred as a result of the development of the R-R-R triple junction which started the evolution of the Delta.

The stratigraphic sequence of the Niger Delta comprises of an upward-coarsening regressive association of Tertiary sediments that are strongly diachronous (Weber and Daukoru 1975; Evamy et al., 1978). The Cenozoic Niger Delta Stratigraphy is a direct product of the various depositional environments. Frankyl and Cordry (1967), Short and Stauble (1967) and Avbovbo (1978), provided the first information on the subsurface distribution units in the Niger Delta, subsequent studies include those of Evamy et al*.,* (1978), Ejedawe et al., (1984), Nwachukwu and Chukwura (1986), Haack et al*.,* (2000), (Reijers, 2011) among others. The Niger Delta is divided into three major stratigraphic units, which are the Akata, Agbada and Benin Formations (Reijers, 2011).

Itiowe *et al*. (2020) carried out foraminiferal biostratigraphy and paleoenvironmental analysis on the sediments penetrated by Sahaiawei-1 Well and they concluded that the entire well was deposited during the Late Maastrichtian to Late Eocene epoch, while the depositional environment varies from littoral, marginal, shallow and deep marine environments.

Table 1: Age and Formations of the Niger Delta Sedimentary Basin (Short and Stauble, 1967).

SUBSURFACE			SURFACE OUTCROP		
YOUNGEST KNOWN AGE	**FORMATION**	**OLDEST KNOWN AGE**	**YOUNGEST KNOWN AGE**	**FORMATION**	**OLDEST KNOWN AGE**
Recent	Benin Fm.	Oligocene	Holocene	Alluvium	Miocene?
			Ear. Holo. To Late Pleistoc.	Deltaic Plain Deposits	
	Afam Shale Mem.		Plio. / Pleist.	Benin Fm.	
Recent	Agbada Fm.	Eocene	Miocene	Ogwashi - Asaba Fm.	Oligocene
			Eocene	Ameki Fm.	Eocene
Recent	Akata Fm.	Eocene	L. Eocene	Imo Shale	Paleocene
		Paleocene	Paleocene	Nsukka Fm.	Maestrich.
	Equivalent not known	Maestrich.	Maestrich.	Ajali Fm.	Maestrich.
			Campanian	Mamu Fm.	Campanian
			Camp./ Mae.	Nkporo Sh.	Santonian
			Conia/ Santo.	Agwu Shale	Turonian
			Turonian	Ezeaku Shale	Turonian
			Albian	Asu River Gp.	Albian

Materials and Methods

Fifty (50) ditch cutting samples were taken from the shaly and sandy shale intervals of interest between interval of 1800ft to 10680ft for palynological slides preparation.

Materials: Microscope, slides, fume cupboard, sieves, centrifuge machine, digital camera, hot plates, palynomorphs photo album and chemicals (Hydrogen peroxide, HF, HCl, HNO_3, Canada balsam)

Methods: Hydrochloric acid (HCL) was added into 20g of ditch cutting samples in a beaker and was allowed to stay for about 30 minutes. The process of decanting the acid and addition of distilled water was repeated three times. Hydrofluoric acid (HF) was added to cover the samples and left for 24 hours. The process of decanting the hydrofluoric acid and addition of distilled water was repeated three times. Concentrated nitric acid (HNO_3) was added to the residue and centrifuge at 2000 RPM for two minutes, and then decanted. This process was repeated until the residue was clear. It was then poured

into a glass beaker and sieved with 5 micron nylon sieve.

Potassium hydroxide (KOH) alkaline solution was added to neutralize the nitric acid (HNO_3). A little residue was pipetted out into another beaker and potassium hydroxide was added to the residue. The solution was centrifuge and decanted. Zinc bromide was added in order to separate the organic matter from the inorganic matter and centrifuge at 2000 RPM for 10 minutes, the floated organic matter was collected with pipette.

The residue was spotted on cover slips using pipette and the slides were prepared. The palynological slides were examined using olympus binocular microscope and digital camera was used to take the photomicrograph of palynomorphs.

Results and Discussions

The lithostratigraphic description was carried out on 50 ditch cutting samples selected between the interval of 1800 feet to 10620 feet. Five (5) lithofacies types which include sandstone, clayey sandstone, shaly sandstone, sandy shale and shale were identified. Minerals identified within this well include quartz, iron oxide, pyrite, carbonate and mica flakes (Figure 2).

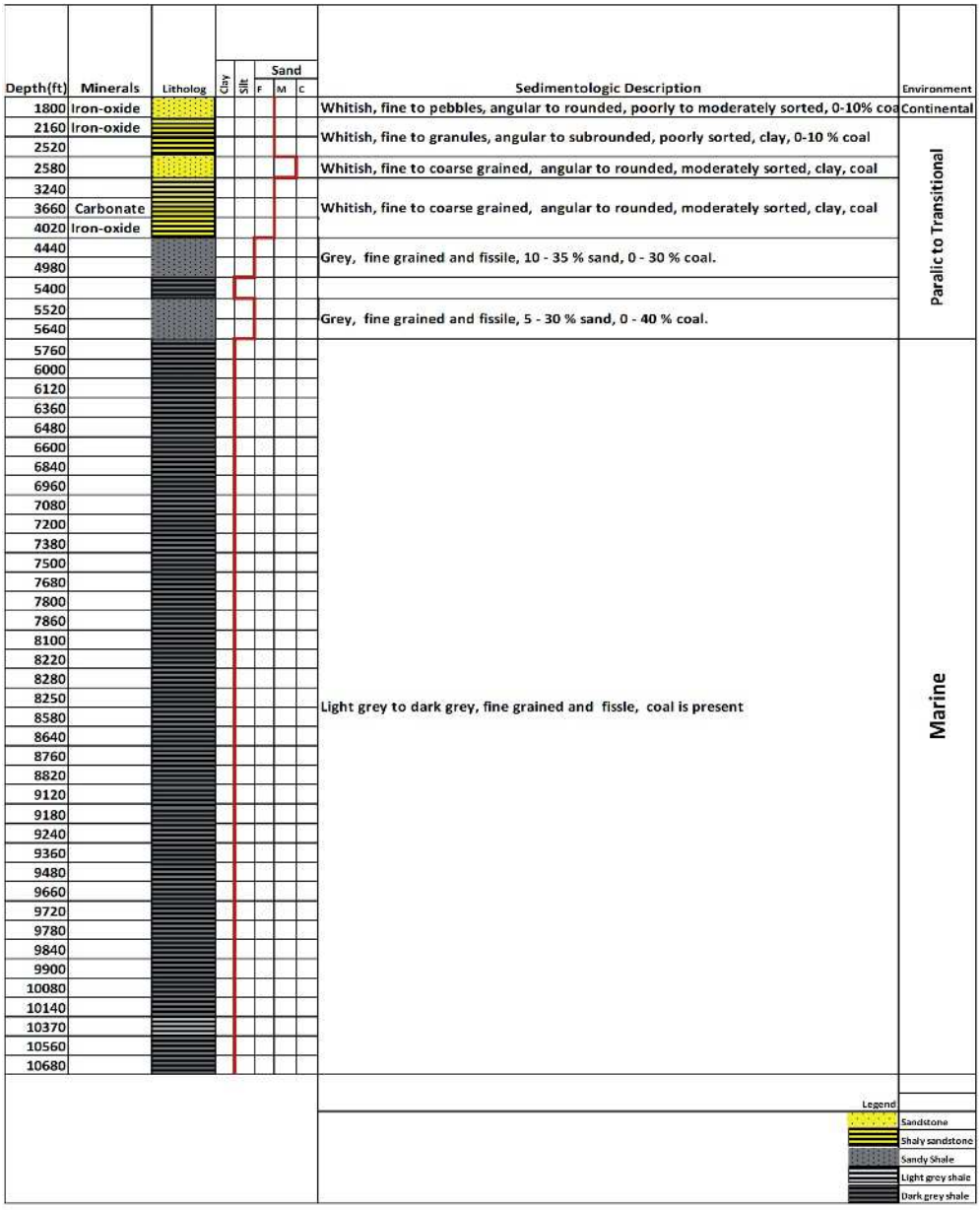


Fig. 2: Lithostratigraphic model for Sahaiawei-1 Well

Microscopic study of the prepared palynological slides resulted the quantitative count of the recovered pollen and spores, dinocysts and ancillary microfossils of which consist of fungal spores, pedistrums, foraminifera test linings and botrycoccus.

Quantitative Counts: Palynological analysis resulted in the recovery of seven hundred and fifty seven (757), six hundred and eighty nine (689) miospores (pollen and spores) and eleven (18) dinocysts. The ancillary microfossils recovered were fifty (50) (Table 1).
The Miospores recovered are*: Acrostichum aureum, Arecipites exilimuratus, Arecipites sp., Cicatricosisporites dorogensis, Cicatricosisporites sp., Cinctiperipollis mulleri, Cingulatisporites cingulatus, Cingulatisporites ornatus, Classopollis sp., Crassoretitriletes vanraadshooveni, Cyathidites australis, Deltoidspora minor, Dictyphyllidites harrassi, Echistephanoporites echinatus, Echitriporites triangulatus, Elaeis guineenes, Filtrotriletes nigericus, Fungal cordia, Gemmastephanocolporites sp., Gemmatricolpites scabratus, Gemmatriporites sp., Magnariatites howardi, Laevigatosporites haarditi, Lycopodium sp., Gemmamonoporites sp., Margocolporites vanwiihei, Marginipollis concinnus, Monoporites annulatus, Multiareolites formosus, Pachydermites diederixi, Pereglinipollis nigericus, Periretitricolpites anambransis, Pilosisporites sp., Polydopollenites vercamporites, Polypediaceisporites sp. (33), Polypediaceisporites sp.(35), Polypodiaceiosporites saxonicus, Praedopollis flexibilis, Praedopollis protudentiporatus, Psilastephanocolporites boureaui, Psilastephanocolporites sp., Psilatricolporites crassus, Psilatricolporites pseudostriatus, Racemonocolpites hians, Retibrevitricolporites Ibadensis, Retibrevitricolporites protudensis, Retidiporites magdalenensis, Retistephanocolporites willaimsii, Retitricolporites crassireticulatus, Retitricolporites irregularis, Regulatisporites caperatus, Retibrevitricoporites obodoensis, Retibrevitricolpites triangularis, Stramonocolpites rectostratus, Striatricolpites catatumeus, Spirosyncolpites bruni, Syncolporites marginatus, Triorites africaensis, Verrucatosporites laevigatus, Verrucatosporites tenellis, Verrutricolporites rotundiporis, Verrucatosporites sp., Verrucatosporites usmensis, Verrutricolporites scabratus, Zonocostites ramonae.*

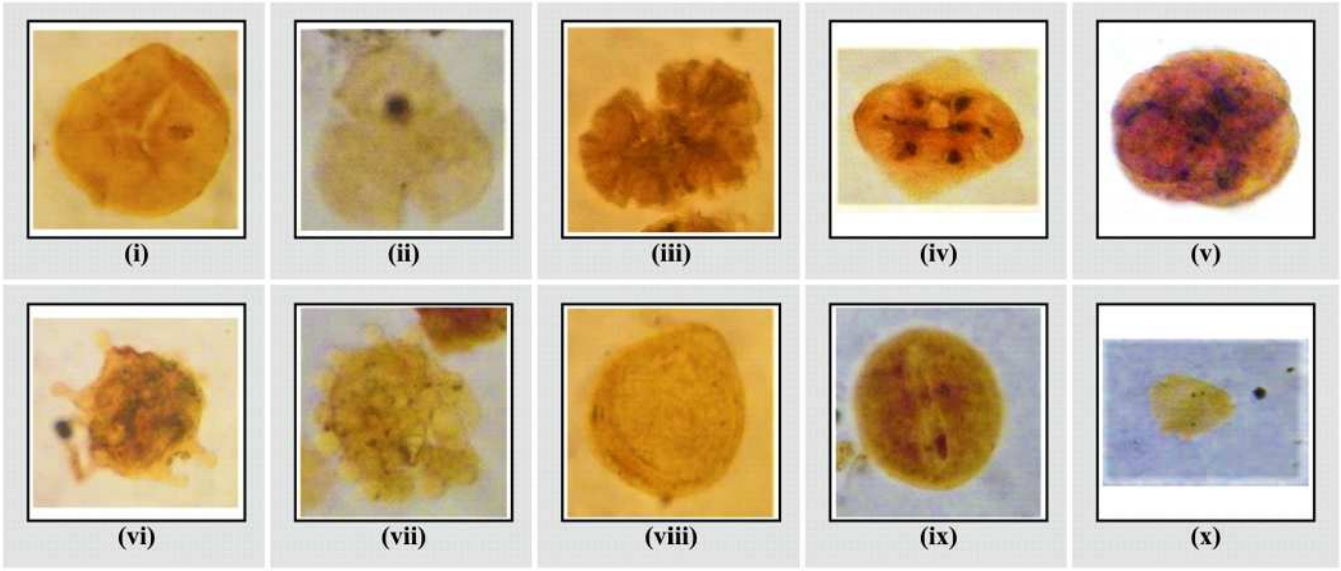
The Dinocysts recovered are: *Pentadinium laticinctum granulatum, Protoperidiniaceae* and *Selenopenphix sp.*

Palynological Zonation and Age: Palynological zonation for Sahaiawei-1 Well was achieved by

Table 2: Quantitative Count of palynomorhs

Depth (ft.)	Pollen	Spores	Miospores	Dinocyst	Total	Pediastrium	Foram lining	Fungal sp.	Botrycoc.
1800	17	7	24	0	24	0	0	2	0
2160	11	7	18	0	18	0	0	0	0
2520	13	1	14	0	14	0	0	0	0
3240	1	1	2	0	4	0	0	0	0
3660	9	0	9	1	10	0	0	0	0
4020	6	2	8	2	10	0	0	0	0
4440	9	9	18	0	18	0	0	0	0
4980	44	12	56	1	57	0	2	1	0
5280	92	26	108	0	108	0	1	0	0
5400	57	15	72	1	73	0	0	0	0
5520	71	28	99	4	103	0	0	2	0
5640	42	15	57	0	57	0	1	0	0
5760	27	4	31	0	31	0	0	1	0
6000	46	6	52	0	52	0	0	0	0
6120	1	1	2	2	4	0	3	3	0
6360	8	2	10	0	10	0	4	2	0
6480	3	0	3	1	4	0	0	2	0
6600	2	4	6	0	6	0	0	8	0
6840	2	5	7	0	7	0	0	0	0
6960	6	1	7	0	7	0	0	0	0
7080	3	1	4	1	5	0	0	0	0
7200	4	0	4	0	4	0	0	0	0
7380	0	1	1	0	1	0	0	0	0
7560	0	3	3	0	3	0	0	1	0
7680	3	3	6	0	6	0	0	0	0
7800	7	0	7	0	7	0	0	0	0
7860	12	0	12	0	12	0	0	2	0
7980	5	0	5	0	5	0	0	6	0
8100	2	0	2	0	2	0	0	4	0
8220	3	0	3	0	3	0	0	2	0
8280	1	0	1	0	1	0	0	1	0
8520	0	0	0	0	0	0	0	0	0
8580	1	0	1	0	1	0	0	0	0
8640	8	0	8	0	8	0	0	0	0
8760	8	0	8	5	13	0	0	0	0
8820	0	0	0	0	0	0	0	0	0
9120	2	0	2	0	2	0	0	0	0
9240	1	0	1	0	1	0	0	0	0
9360	3	0	3	0	3	0	0	0	0
9480	0	0	0	0	0	0	0	0	0
9660	0	0	0	0	0	0	0	0	0
9720	0	0	0	0	0	0	0	0	0
9780	0	0	0	0	0	0	0	0	0
9840	0	0	0	0	0	0	0	0	0
9900	0	0	0	0	0	0	0	0	0
10080	0	0	0	0	0	0	0	0	0
10140	0	0	0	0	0	0	0	0	0
10370	1	3	4	0	4	0	0	0	0
10560	1	0	1	0	1	0	0	0	0
10680	1	0	1	0	1	0	0	0	0
	552	**157**	**689**	**18**	**707**	**0**	**11**	**39**	**0**

PLATE 1



(i) *Acrostichum aureum* (2160ft to 7680ft) **(ii)** *Bombacacidites sp* (4980ft) **(iii)** *Ctenolophonidites costatus* (4440ft to 5400ft) **(iv)** *Doualaidites laevigatus* (2160ft to 8760 ft) **(v)** *Erecipites sp*. (1800ft to 10560ft) **(vi)** *Grimsdalea polygonalis* (4980ft to 5280ft) **(vii)** *Gemmamonoporites sp.* (5280 ft) **(viii)** *Proxapertites cursus* (5400ft to 7560ft) **(ix)** *Psilamonocolpites marginatus* (4980ft to 6600ft) **(x)** *Retibretricolporites triangulates* (5280ft to 8760ft).

considering the palynological characteristics of the index markers/age diagnostic palynomorphs to indicate the palynological zones. The age of the well was deduced by juxtaposing these palynological zones with the standard chronostratigraphic chart and microfloral zonation in the Niger Delta by Boom (1977).

Four (4) palynological zones have been established using the palynological characteristics of the index/age diagnostic markers. They are lumped P330-P430 Zone, P450, P470 and P480 Zones. These characteristics are quantitative top of *Erecipites sp*., base of *Doualaidites laevigatus*, Quantitative top of *Psilamonocolpites marginatus*, base of *Cinctiporipollis mulleri* and top occurrence of *Doualaidites laevigatus*. The palynological distribution chart for Sahaiawei-1 well shows the palynological characteristics, palynological zones and age of the well (Figure 3).

Stratigraphic Interval: 7560 – 6360ft
Zone: P330-P430
Age: Early to Mid - Eocene

The top of this zone is marked by the base occurrence of *Doualaidites laevigatus* and the bottom by quantitative top of *Ereciptes sp.* (Figure 3). Characteristics that occur within this zone include low occurrence of *Pilososporites sp.,* rare occurrence of *Retimonocolpites asabaensis, Bacutricolporites sp., Monoporites annulatus, Proxapertites operculatus, Retimonocolpites obaensis, Striamonocolpites undatostriatus, Gemmatricolporites sp., Grimsdalea diversiclavata* and *Psilatricolporites costatus.*

Stratigraphic Interval: 6360ft – 5520ft
Zone: P450
Age: Mid to Late Eocene

The top of this zone is marked by the quantitative top occurrence of *Psilamonocolpites marginatus* and the bottom by base occurrence of *Doualaidities laevigatus* (Figure 3). There is abundance of *Retimonocolpites asabaensis, Retibrevitricolporites triangulatus* and *Retimonocolpites sp.;* There is rare occurrence of *Gemmamonoporites sp., Retitricolpites bendeensis, Proxapertites operculatus, Spinizonocolpites echinatus, Pachydermites diederixi, Striatricolporites melane, Margocolpites vanwiihei, Margocolporites sp., Scabratriporites simpliformis, Psilatricolporites pseudostriatus* and *Auriculopollenites simplex.*

Stratigraphic Interval: 5520ft – 3240ft
Zone: P470
Age: Late Eocene

The top of this zone is characterized by the base of *Cinctiporipollis mulleri* and its base is marked by the quantitative top of *Psilamonocolpites marginatus*. Abundance of *psilatricolporites crassus*; rare occurrence of *Ctenolophonidites costattus,*

Striamonocolpites rectostriatus, Leiotriletes sp., Cythidites sp., Lypocodium sp., Bombacacidies sp., Grimsdalea polygonalis, Retistephanocolpites williamsi, Retitricolporites sp., Striamonocolpites bellus, Gemmamonoporites sp., Retidiporites magdalenensis, Spinozonocolpites bacculatus, Retitricolporites ituensis, Psilastephanocolpites boureaui, Retitricolporites irregularis, Laevigatosporites ovatus, Omnipites africanus, Striatricolporites melane, Bulanopollis minutus and *Retimonocolpites obaensis***.**

Stratigraphic Interval: 3240ft -2160ft

Zone: P480
Age: Late Eocene

The top of this zone is characterized by the top occurrence of *Doualaidites laevigatus* and the bottom by the base of *Cinctiporipollis mulleri*. This zone has common occurrence of *Deltoidspora minor, Verrucatosporites tenellis* and *Retibrevitricolporites ibadensis*. There is also abundance of *Zonocostites ramonae* and *Cinctiporipollenites mulleri*; rare occurrence of *Verrucatosporites sp., Psilatricolporites sp.* and *Acrostichum aureum.*

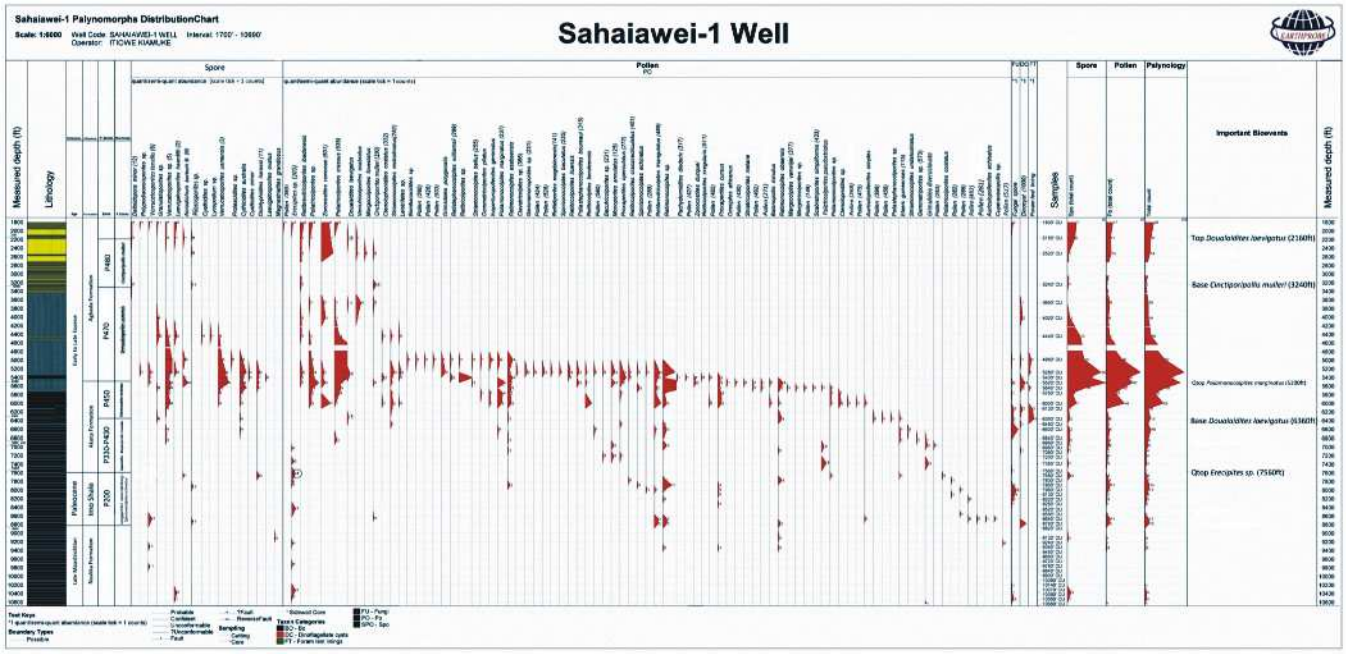


Fig. 3: The Palynological distribution chart for Sahaiawei-1 Well

Paleoclimatic Condition: The paleoclimatic condition of the studied intervals of Sahaiawei-1 Well was based on the palynomorphs recovery which offered clue to the paleoclimatic interpretation. *Zonocostites ramonae* and *Monoporites annulatus* against depth is shown in Table 3.The paleoclimatic condition across the sediments of the well was determined by the plot of mangrove swamp pollen (*Zonocostites ramonae*) and compared to graminae pollen (*Monoporites annulatus*) (Figure 2). *Zonocostites ramonae* is an indicator of humid climate and indicates that sediments were deposited during cooler and wetter condition, while *Monoporites annulatus* is a warm climatic indicator (Hooghiemstra et al., 1986).

For Sahaiawei-1 Well, from depth 1800ft to 4980ft the count of *Zonocostites ramonae* is generally higher than that of *monoporites annulatus* suggesting a predominantly humid climate and the sediment during this period was deposited in a cooler and wetter condition. Within 5280ft to 5520ft, the amount of *Monoporites annulatus* is higher than *zonocostites ramonae* suggesting warm climatic condition. Between 5520ft to 6000ft suggests a humid climate. Below this depth 6000ft, the climatic condition was not ascertained because there were no paleoclimatic indicators (Figure 4).

Conclusion and Recommendation

The palynological analysis of the studied samples was used to determine the palynological zonation, age and paleoclimatic condition of the sediments penetrated by the drill. Four (4) palynological zones which are lumped P330-P430, P450, 470 and P480 Zones have been established using the palynological characteristics of

Table 3: *Zonocostites Ramonae* and *Monoporites Annulatus* against depth

Depth (ft)	*Z. Ramonae*	*M. Annulatus*
1800	6	0
2160	7	0
2520	9	0
3240	0	0
3660	2	0
4020	3	0
4440	0	0
4980	0	0
5280	2	3
5400	1	0
5520	3	3
5640	0	0
5760	0	0
6000	7	0
6120	0	0
6360	0	0
6480	0	0
6600	0	0
6840	0	0
6960	0	0
7080	0	0
7200	0	0
7380	0	0
7560	0	0
7680	0	0
7800	0	0
7860	0	0
7980	0	0
8100	0	0
8220	0	0
8280	0	0
8520	0	0
8580	0	0
8640	0	0
8760	0	0
8820	0	0
9120	0	0
9240	0	0
9360	0	0
9480	0	0
9660	0	0
9720	0	0
9780	0	0
9840	0	0
9900	0	0
10080	0	0
10140	0	0
10370	0	0
10560	0	0
10680	0	0

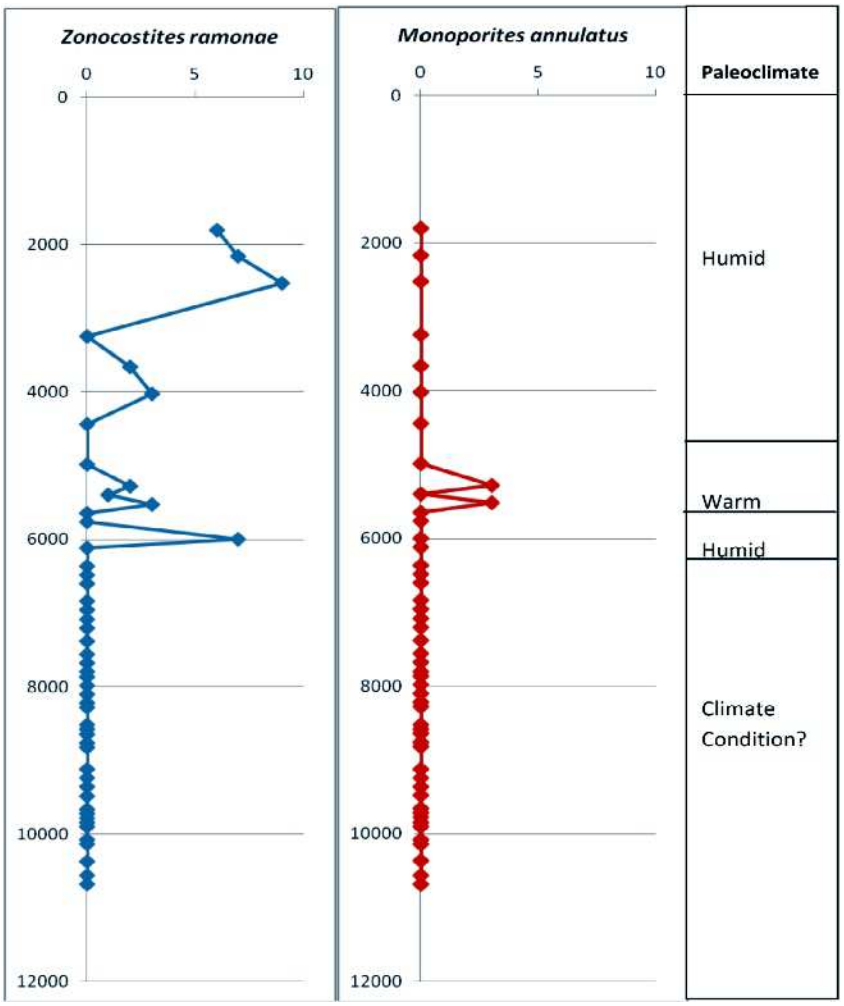


Fig. 4: Paleoclimatic indicator plot of the amount *Zonocostites ramonae* and *Monoporites anulatus*

the index/age diagnostic markers and the age of the well ranges Paleocene to Late Eocene. This research has been able to use *Erecipites sp*. to delineate the Paleocene Imo Shale in the North Delta Depobelt, which has provided more information of the stratigraphy of the Northern Delta Depobelt. The sediments of Sahaiawei-1 Well were formed majorly in a humid climate and in cooler and wetter condition based on the dominance of *Monoporites annulatus* over *Zonocostites ramonae*.

More sampling points below the total depth of the samples analysed should be taken for analysis to research if a Cretaceous Formation is associated with the Northern Delta Depobelt.

Aknowledegement

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