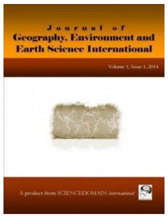

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Palynostratigraphic Study of Well-X (Interval 700Ft-2180Ft), Offshore Niger Delta, South-South Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

A palynostratigraphic study of Well-X in the Niger Delta was carried out with a gamma ray log and a total of sixteen ditch cutting samples collected at different depth interval (700ft - 2180 ft), the samples were made up of sandstone, sandy shale and shale, depicting that the well penetrated Agbada Formation. The various samples were subjected to palynological analysis, the sixteen samples analysed yielded fair to good amounts of palynomorphs except two samples which had a poor recovery. The recovered palynomorphs include a high percentage of Pollen and Spores, some fresshwater algae *(Concentricyst circulus, Botryoccocus braunii*) and a very minute amount of fungal spore, acritarchs and marine forms (*Foram lining, Dinocysts, Leiosphaeridia*), suggesting that the environment of deposition is terrestrial. A lithostratigraphic framework was established for the sample unit and a palynomorph distribution was constructed. From the distribution chart the percentage of the different palynomorphs (pollen, spores, freshwater algae, fungal spore, acritarch, marine forms and some undifferentiated forms) were calclated and used to generate a biostrati graphic plot that shows the Paleoenvironmental distribution of Well-X interval (700 -2180 ft). From the analysis, the sediments were observed to have been deposited during Early? Late Pliocene times. This interpretation is deduced by the co- occrrences of *Stereiporites sp, Nympheapollis clarus and Cypereaopollis sp with Retistephanocolpites gracillis*.

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1. INTRODUCTION

The Well X is located within the offshore depobelt within the Niger Delta basin. The Niger Delta is situated in southern Nigeria (Fig. 1) between latitudes 3°N and 6°N and longitude 5°E and 8°E [1]. It covers an area of 75,000 sqkm. It is bounded to the west and northwest by the western African shield, which terminates at the Benin hinge line and to the east, by the Calabar hinge line. The Anambra basin and Abakaliki anticlinorium mark its northern limit. To the south, it is bounded by the gulf of Guinea.

The Niger Delta Basin to date is the most prolific and economic sedimentary basin in Nigeria by virtue of the size of petroleum accumulations, discovered and produced as well as the spatial distribution of the petroleum resources to the Onshore, Continental shelf through deepwater terrains.

Most of the important hydrocarbon reservoirs in the Niger Delta are within the paralic Agbada Formation [2]. These reservoirs are usually located in zones with structural and stratigraphic complexity. An excellent biostratigraphic framework is crucial for understanding the stratigraphy, characterization of the reservoirs and planning new exploration targets. Biostratigraphy has been shown to play an important role in the exploration of oil and gas in the Niger Delta. Hence the need in the present study, using palynology among other things to reconstruct the palaeoenvironments of the studied section. This is important because different depositional settings imply different reservoir qualities in terms of architecture, connectivity, heterogeneity and porosity permeability characteristics [3]. This work therefore aims at identifying the recovered palynomorphs, using the identified palynomorphs to zone and date the section and combining palynology and sedimentology to decipher the environments of deposition in the studied section in order to assess the reservoir quality.

The approach adopted involved two types of data: electronic log (gamma ray log) and laboratory analysis of sixteen ditch cuttings samples obtained from Well-X (interval 700-2180ft). The non-acid palynological techniques were applied. Well X is one of several wells drilled in shallow offshore depobelt of the Niger Delta region (Fig. 1). The well was drilled to a total depth of 6160 ft in the Western part of Niger Delta.

1.1 Location of the Study Area

The Well-X is located in the offshore Niger Delta basin (Fig. 2). It lies between latitude 06°20′N and 06°26′N and longitude 03°51′E and 03°52′E.

1.2 Geomorphology

In the Niger Delta, various types of depositional environments and morphological unit (coastal flats, ancients/modern seas, rivers and lagoonal beaches, etc.) are recognized but the Niger Delta is sub-divided into five (5) geomorphological units namely:

1. Active and abandoned coastal beaches.
2. Salt water/mangrove swamp.
3. Fresh water swamp.
4. Dry flat land and plain.
5. Sombreiro-Warri deltaic plain with abundant freshwater swamp.

The Niger Delta is a low-land plain consisting mainly of recent unconsolidated sediments of Quatenary age. These sediments are partly of marine and partly of fluvial origin. Land elevation is under 50 m above sea level and there is a marked absence of imposing hills that rise above the general land surface. The area traversed by numerous flat-floored rivers that drain into the Atlantic ocean. The area is prone to flooding especially during the wet season, mainly because of heavy rainfall, high groundwater table and flat-floored valleys.

1.3 Geology of the Study Area

The Niger Delta Basin is situated in the Gulf of Guinea in equatorial West Africa, between latitudes 3°N and 6°N and longitudes 5°E and 8°E [4] (Fig. 1). The Niger Delta is framed on the northwest by a subsurface continuation of the West African Shield, the Benin Flank. The eastern edge of the basin coincides with the Calabar Flank to the south of the Oban Masif [5]. Well sections through the Niger Delta generally display three vertical lithostratigraphic subdivisions: an upper deltatop facies; a middle delta front lithofacies; and a lower pro-delta lithofacies [4]. These lithostratigraphic units correspond respectively with the Benin Formation (Oligocene-Recent), Agbada

Formation (Eocene-Recent) and Akata Formation (Paleocene-Recent) of Short and Stauble [2]. The Akata Formation is composed mainly of marine shales, with sandy and silty beds which are thought to have been laid down as turbidites and continental slope channel fills. It is estimated that the formation is up to 7,000 metres thick [6]. The Agbada Formation is the major petroleum-bearing unit in the Niger Delta. The formation consists mostly of shoreface and channel sands with minor shales in the upper part, and alternation of sands and shales in equal proportion in the lower part. The thickness of the formation is over 3,700 metres. The Benin Formation is about 280 metres thick, but may be up to 2,100 metres in the region of maximum subsidence [7], and consists of continental sands and gravels.

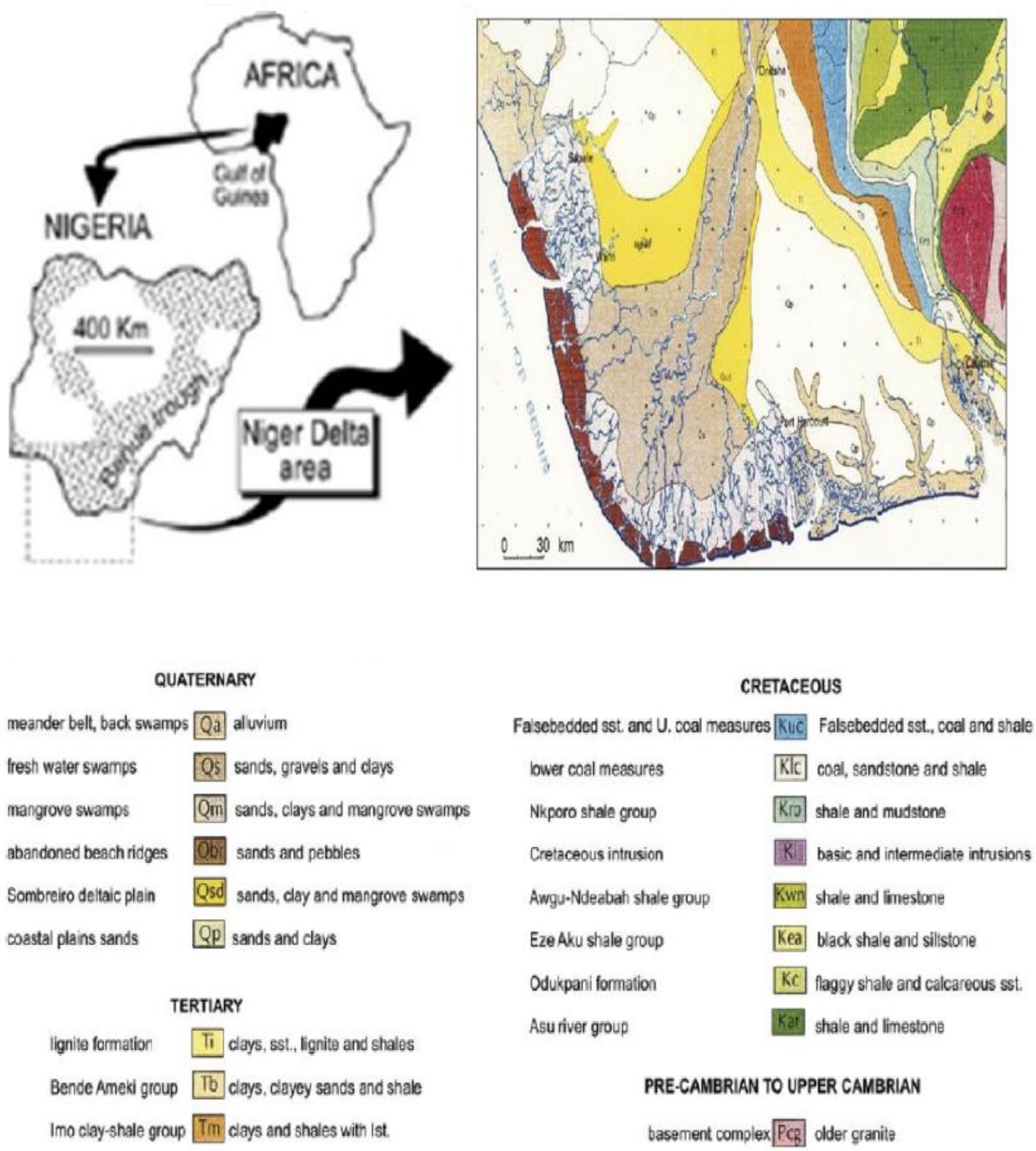

Fig. 1. Geologic map of Niger Delta

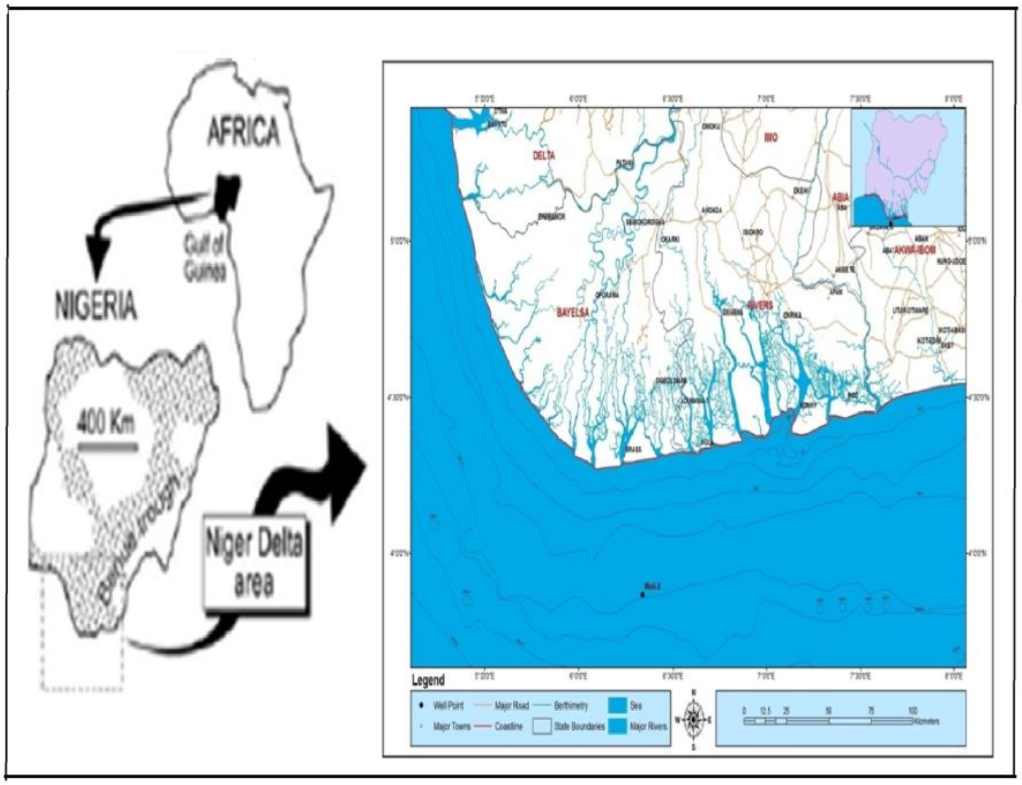

Fig. 2. Map showing the location of Well-X in offshore Niger Delta

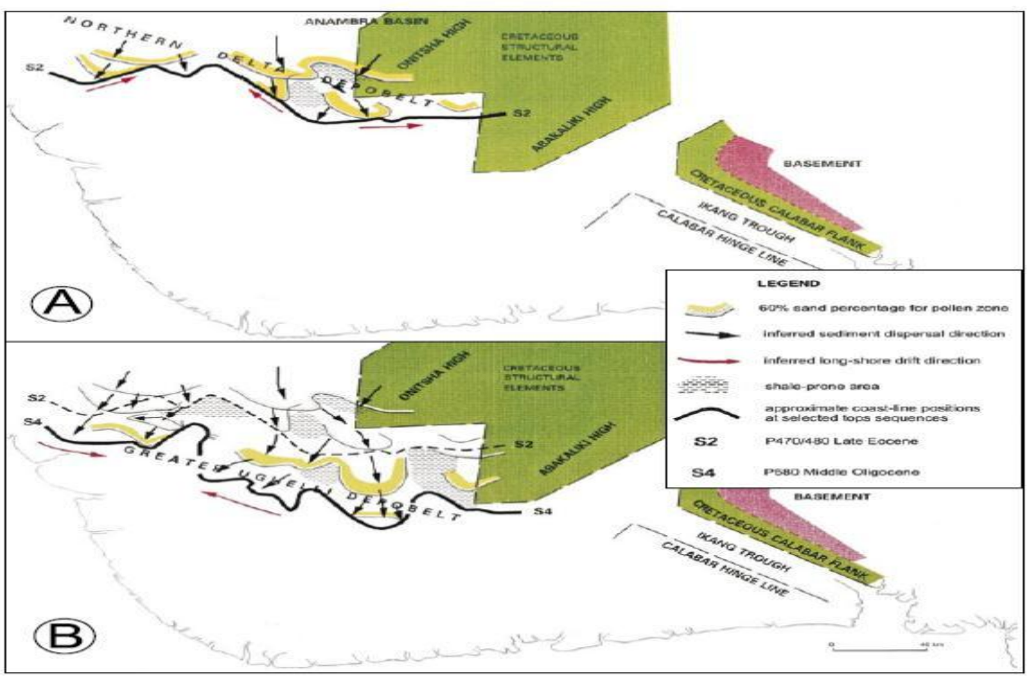

Fig. 3. Paleo-drainage trend and advancing coastline of the Niger Delta (modified after Edjedawe. 1981; Edjedawe et al. 1984). A-position at the start of sequence three (Orogho-shale transgression); B- Position at the start of sequence 5 (Alabamina-1 shale transgression)

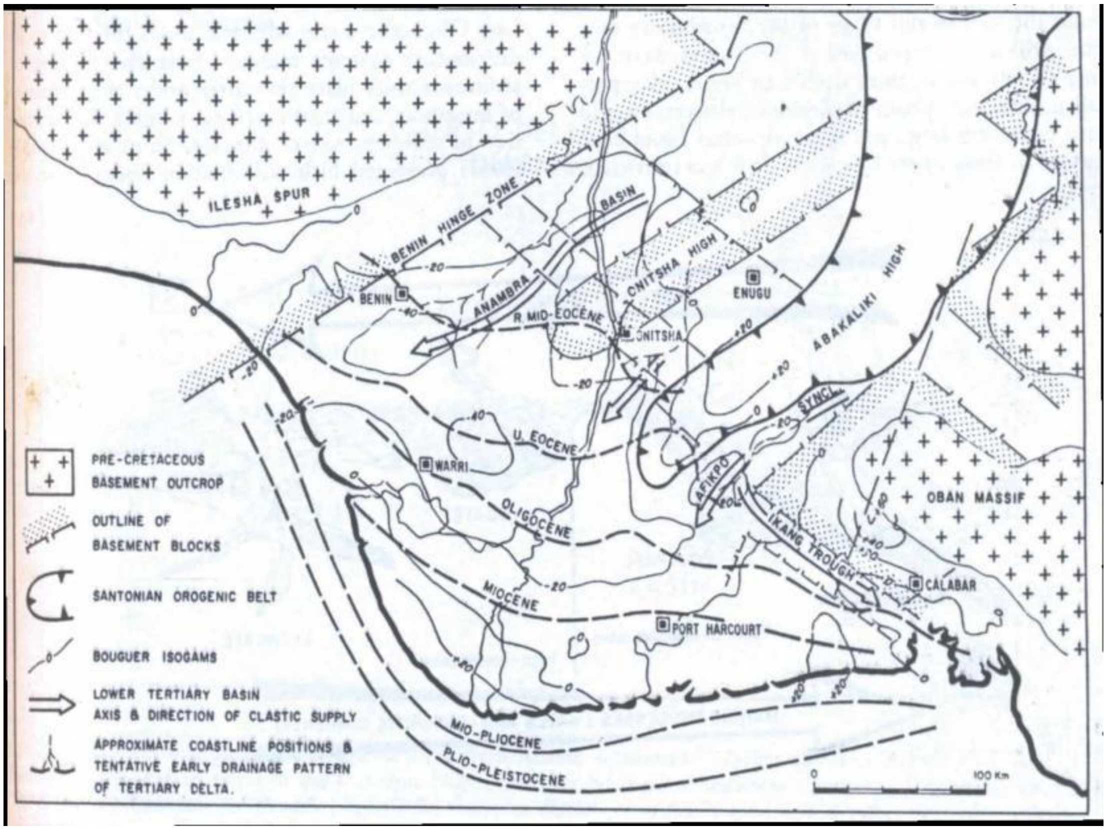

Fig. 4. Map of Niger Delta showing the magatectonic framework of the basin (modified after Murat [5])

The evolution of the Niger Delta basin is strongly tied to the spreading in the north and south Atlantic oceans and the subsequent break up of Gondwana. Regional tectonic and stratigraphic framework of the associated rift systems provide the setting for the development of the Tertiary Niger Delta [8].

The Cenozoic Niger Delta is situated at the intersection of the Benue Trough and the south Atlantic ocean where a triple junction developed during the separation of south America and Africa in the Late Jurassic [7]. This separation was followed in the early Cretaceous times by subsidence of the African continental margin due to cooling of the newly created oceanic lithosphere.

The Niger Delta basin started to evolve in the Early Tertiary times when clastic river input increased. Generally, the delta prograded over the subsiding continental-oceanic lthosphere transition zone and during Oligocene spread onto he oceanic crust of the Gulf of Guinea. The weathering flanks of outcropping continental basement shed the sediments through the Benue - Niger drainage basin. The delta has since Paleocene time prograded a distance of more than 250 km from the Benin and Calabar flanks to the present delta front [9].

1.4 Local Geology of the Study Area

The Niger Delta basin is characterized by three major depobelts. These three cycles show that the basin experienced an overall regression throughout time as the sediments go from deep sea mud sized grains to fluvial denser sand sized grains. According to Doust and Omatsola [6], the Akata shales contain a few streaks of sand, possibly of turbiditic origin which were deposited in holomarine (delta front to deeper marine) environments. These marine shales range from Paleocene to Holocene in age. On the other hand, the Agbada formation is overlain by a paralic sequence of inter-bedded sand and shales, 300 – 4500 m (984 – 14766 ft) thick. It consists of alternating sandstones and shales of deltaic front, distributary's channel and deltaic plain origins. The alternating sequence of sandstones and shales of the Agbada formation has been shown by (Weber, 1971) to be a cyclic sequence of marine and fluvial deposits, determined from electric-log patterns, well, cores and dipmeter data. Furthermore, the topmost unit (the Benin Formation) consists of fluviatile gravels and sand occurring from the contemporary delta surface to depths of about 2134 m (7,000 ft). It consists predominantly of massive, highly porous, fresh water bearing sandstones, with local thin shale inter-beds, which are considered to be of braided stream origin.

Since the inception of the Cenozoic delta in the Paleocene/Lower Eocene, the history has been one of a major regression with a gradual southward offlap of thin, quite extensive lenses of sediments formed as result of deposition occurring simultaneously under full terrestrial (fluviatile) conditions with the interplay between terrestial and marine influence (i.e. paralic) and under fully marine conditions [10]. Thus the sequence observed laterally (i.e. starting with coarse sandy deposits and ending with marine clays) is also observed vertically in the Niger delta. In a cross-section, a time stratigraphic unit of such deltaic sediment is characteristically S-shaped or sigmoidal. The formations are therefore strongly diachronous, their ages becoming progressively younger in a downdip direction and ranging from Paleocene to Recent. Thus the established tertiary sequence in the Niger delta demonstrates a tripartite lithostratigraphic succession (Fig. 3) from marine prodeltaic shale (Akata Formation) through a sand/shale paralic unit (Agbada Formation) to continental sands (Benin Formation). The strata compose and estimated 8535 m of the section at the approximate depocentre in the central part of the delta [2]. The characteristic features of these formations are outlined below:

1.4.1 Akata formation

It is characterized by a uniform shale development. The formation is a marine sedimentary sequence laid down in front of an advancing delta. These prodeltaic shales are medium to dark grey, fairly hard or at places soft, gumbo-like and sandy or silty in several places, the shales of this formation were found to be undercompacted, and therefore mobile, and may contain lenses of abnormally high-pressured siltstone or fine-grained sandstone ([8,11,2,12]). The upper boundary of the formation has been structurally deformed, while diaprism and high-pressure zones developed in it, on a large scale. Generally, the Akata Formation contains rich foraminiferal fauna. Planktic foraminifera may constitute moiré than 50% of the microfauna. The benthonic foraminiferal assemblages indicate that the shale was deposited on a shallow marine shelf and slope. The Akata Formation is considered to be the main source rock in the Niger delta [9,13]. The known age of the Akata Formation is Eocene to Recent [6].

The shale is continuous in the subsurface with its probable outcrop equivalent the Paleocene/ Eocene Imo Formation. The complex movements of the Niger delta sediments are controlled by the adjustments of the shale either by the downward movements in response to the pressure impacted by the overlying sediments or lateral motion of the shale on the continental slope or its upward diapiric motion. These movements are believed to have assisted in the formation of the growth faults and roll over structures, which are common features of the main Niger delta basin. Its thickness is unknown because most wells drilled in the Niger delta did not encounter the base of the Akata Formation, except for the northern part of the delta where the formation has been drilled into the Cretaceous.

1.4.2 Agbada formation

This sequence of strata forms the hydrocarbon prospective sequence in the Niger delta. The formation is characterized by alternating sandstones and shales of the delta front, distributary channel, and deltaic plain origin. Weber (1971) showed that the alternating sequence of sandstones and shales of the Agbada Formation is of cyclic sequences of marine and fluvial deposits. The sand content ranges from 50 to 75%. The sandstones are medium to fine grained, fairly clean locally calcareous, and shelly. They consist dominantly of quartz and potash feldspar with subordinate and illite. The shales are dark to grey, fairly consolidated and silty with local glauconite. They consist dominantly of kaolinite (average value 73%) with small amount of mixed layers of illite and montmorillonite. The formation has a maximum thickness of 3940 meters at the central part and thins northwards and towards the North western and Eastern flanks of the delta. Although, the thickest known section is about 3480 meters, the maximum thickness may well be much greater [2]. Generally, the boundary between the sand and shales is sharp. Where the sands grade into shales, shell fragments, glauconites, limonite coatings are common. The shales are denser at the base than higher up in the column because of compaction. They become silty and sandy towards the Benin Formation while shaliness increases downwards and laterally into the Akata Formation. The Agbada shales contain microfauna that are best developed at the base of individual shale units. The depth of the fossil assemblage ranges from littoralestuarine to marsh types of fauna developed at a water depth of approximately 100 meters. The slightly consolidated sand has a calcareous matrix, but most of the sand is unconsolidated. The coarse and poorly sorted sand indicates a fluviatile origin while the well-sorted sand represents beach or coastal barrier deposits. The mature Eocene to Miocene shales interbedded within the deltaic sands in the lower part of the paralic sequence is considered to be a major source rock [1,14,6,4]. The Agbada Formation is held to contain most of the reservoir rocks of the Niger delta. The porosity is of excellent quality (ranging between 28 and 32%) while permeability is in the darcies. Reservoir quality is closely dependent on the depositional environment. The Agbada Formation is less carbonaceous and more marine than overlying Benin Formation there is also an increase ion microfauna with depth. This could be an indication of increasing rate of sedimentation and changes in salinity and temperature of the delta front. The age of the Agbada Formation varies from Eocene to Recent. Benin Formation: This is the uppermost unit of the Niger delta complex. The formation can be easily distinguished based on its high sand percentage (70 – 1000%). The sand is dominantly massive highly porous and freshwater bearing with locally interbedded shale beds, which are considered to be of braided stream origin. The sands are poorly sorted, ranging from fine to coarse – grained and occasionally pebbly and they contain abundant wood, fragments, which become lignitic with depth. Composition, structure and grain size show deposition in a probably upper deltaic environment. The thickness is variable and may be more than (1990 m) in Warri – Degema area.

Table 1. Correlation of subsurface formation of the Niger Delta complex [2]

Subsurface			Surface Outcrops		
Youngest known Age		Oldest known Age	Youngest Known Age		Oldest Known Age
Recent	Benin Formation (Afam clay member)	Oligocene	Plio/Pleistocene	Benin Formation	
Recent	Agbada Formation	Eocene	Miocene Eocene	Ogwashi-Asaba Formation Ameki Formation	Oligocene Eocene
Recent	Akata Formation	Eocene	Lower Eocene	Imo shale Formation	Paleocene
Unknown			Paleocene	Nsukka Formation	Maestrichtian
			Maestrichtian	Ajali Formation	Maestrichtian
			Campanian	Mamu Formation	Campanian
			Campanian/Maestrichtian	Nkporo Shale	Santonian
			Coniacian/Santonia	Awgu Shale	Turonian
			Turonian	Eze Aku Shale	Turonian
			Albian	Asu River Group	Albian

Most companies exploring for oil in the Niger delta, arbitrarily define the base of the Benin Formation by the deepest fresh - water – bearing sandstone that exhibits high resistivity. Short & Stauble [2], however, defined the base of the Benin Formation by the first marine foraminifera within shale, as the formation is non-marine in origin. Avbovbo [15] partly agrees with Short & Stauble but also demonstrated that the base of the fresh water in the delta sediments extends into the Agbada Formation and thus not coincident with the base of the Benin Formation. The Benin Formation is deposited across the entire Niger delta. It is a continental deposit and consists of various structures such as natural levees channel fills, ox-bow fills etc. these structures indicate a variability of the shallow water depositional medium [2]. It becomes progressively younger from North towards the South. Subsurface Clay Members: A clay section in the subsurface of the Eastern Niger delta, the "Afam clay member" is locally recognized. The member has the form of a canyon fill that strikes in a SSE direction, from slightly north of Afam – 1 to the west of Imo estuary. It also grades southwards into Agbada and Akata Formations. The base is difficult to delineate where it contains basal sand intercalations and rest on the underlying paralic Agbada Formation Lithologically; it is laminated and has a maximum thickness greater than 8,000 m [2,7,6]. The age ranges from Oligocene to Recent. Other subsurface clay members apart from a fan clay Member occur in the delta. The other anomalous shale bodies have been recognized within the Agbada and Benin Formations. The clay bodies within the Agbada Formation are the Opuama, Osare, Qua-Iboe and Elelenwa, while Makaraba, Soku and Amojie clays are members of the Benin Formation. The age of these clays; range from Oligocene to Recent.

2. MATERIALS AND METHODS

Two types of data were used for this study and they are: electronic log (gamma ray log) and palynological data.

The gamma ray is use to delineate the lithology (Fig. 5) of the Well-X encountered within depth 700-2180ft which was further correlated with the lithology log.

This involves the description of the sample physically on the basis of color, grain size and rock type. It also involves checking for effervescence of the sample by adding a small quantity of hydrochloric acid to the rock sample using a pipette. Samples that show effervescence were termed calcareous or slightly calcareous, those that did not show any effervescence were termed non-calcareous.

For the Palynological analysis: The non-acid method was used to prepare the samples using sodium hexametaphosphate and zinc bromide. This procedure involves the following steps:

- The samples were labelled by depth to serve as a guide.
- Approximately 20-25 grams of each sample was then weighed and crushed using a mortar and pistol to break down the sediment in order to liberate the palynomorphs.
- The crushed sample were then placed in a well labelled pyre beaker, and detergent was added (preferrable morning fresh) in order to remove drilling mud.
- Add about 4 to 10ml of water, stir properly then add a spatula of sodium hexametaphspate phosphate (depending on the lithology) and stir properly.
- Add about 20ml of water, allow it to stand for about 20minutes.
- Add water to the brim of the beaker and allow to settle for one hour then decant. Repeat this process up to three times or more in order to wash off the Sodium Hexametaphosphate, detergent and drill mud.

NOTE: At this point the palynomorphs are already liberated and they float if they are not allowed to settle before decanting you are likely to lose them.

- Decant up to 50ml, stir and transfer into a test tube.
- Centrifuge for 2 to 3 minutes at 100 RMP.
- Decant.
- Add zinc bromide (measure 2.2 specific gravity using hydrometer) for separation (zinc bromide separates the palynomorphs from the sediment), alternatively a wash glass can also be used in place of zinc bromide.
- Centrifuge for 10 to 15minutes for seperation, at this point palynomorphs will float.
- Pipette the palynomorph suspended at the top to a well labelled test tube, then pass it through a 5microm sieve. Palynomorphs greater than 5μ will be retained and

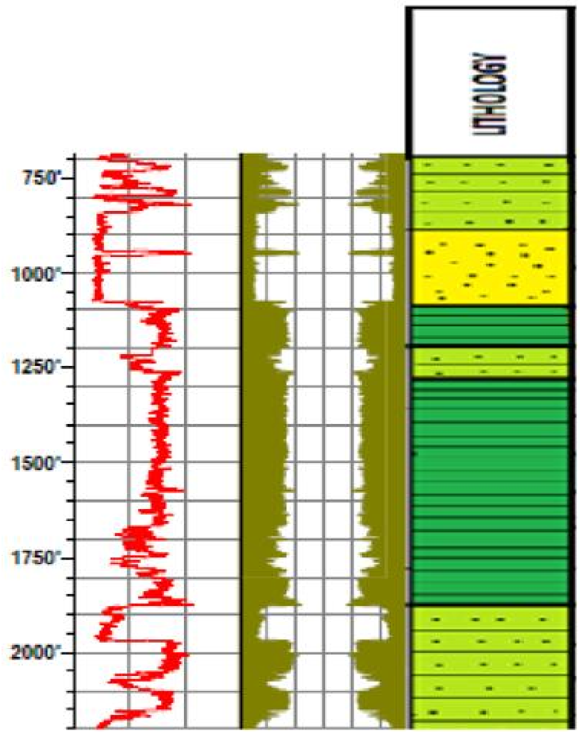

Fig. 5. Gamma ray log and lithology penetrated by Well-X at 700-2180 ft

transferred into a residue phial while those lesser than 5 µ are discarded.

- SPOTTING AND MOUNTING

Place cover slip on a hot plate, shake the residue and pipette the residue on the cover slip, then heat gradually (or air dry). Place your slide on the hot plate then add 2 to 3 drops of norland optical adhesive, when the cover slip is dry remove with your spatula and place on the slide with norland optical adhesive. Remove air bubbles by pressurizing the cover-slip to the slide properly.

3. RESULTS AND DISCUSSION

3.1 Lithostratigraphy

The section of Well-X range from 700 -2180 ft. The different lithostratigraphic unit penetrated by Well-X within the above depth are described Table 2.

3.2 Palynology

The sixteen samples (interval 700 – 2180 ft) analysed palynologically yielded fair to good amount of palynomorphs except two samples which had poor recovery. The recovered palynomorphs were a mixture of fresh water (*Botryococcus*, *Concentricyst circulus* and *Nympheapollis*) and coastal (*Zonocostites ramonae*, *Monoporites annulatus*) swamp indicators with low occurrences of marine (*Foram lining, dinocysts, leiosphaeridia*) elements suggesting deposition within the Delta plain to Delta front setting (marshy swamp or bay).

The table (Table 4) was used to generate Fig. 6 which is the distribution chart of the palynomorphs found in Well-X.

SAMPLE 1

The sample was collected at 700ft . It consist of 41% pollen, spores 36%, Fungal spore 6%, Freshwater algae 13%, marine forms 1%, Acritarch 0% and 3% of undifferentiated forms. The high percentage of pollen and spores indicate terrestrial environment.

SAMPLE 2

The sample was collected at 800ft. It consist of 60% pollen, spores 22%, Fungal spore 6%, Freshwater algae 11%, marine forms 1%, Acritarch 0% and 1% of undifferentiated forms. The high percentage of pollen and spores indicate terrestrial environment.

SAMPLE 3

The sample was collected at 900ft. It consist of 72% pollen, spores 14%, Fungal spore 1%, Freshwater algae 6%, marine forms 2%, Acritarch 1% and 2% of undifferentiated forms. The high percentage of pollen and spores indicate terrestrial environment.

SAMPLE 4

The sample was collected at 1000ft. It consist of 81% pollen, spores 5%, Fungal spore 10%, Freshwater algae 5%. The high percentage of pollen and spores indicate terrestrial environment.

SAMPLE 5

The sample was collected at 1100ft. It consist of 47% pollen, spores 19%, marine forms 1%, Freshwater algae 33%. The high percentage of pollen and spores indicate terrestrial environment.

SAMPLE 6

The sample was collected at 1200ft. It consist of 33% pollen, spores 26%, marine forms 1%, Freshwater algae 39% and 1% of undifferentiated forms. The high percentage of pollen and spores indicate terrestrial environment.

SAMPLE 7

The sample was collected at 1300ft. It consist of 29% pollen, spores 44%, marine forms 6%, Freshwater algae 16% and 5% of undifferentiated forms. The high percentage of pollen and spores indicate terrestrial environment.

SAMPLE 8

The sample was collected at 1400ft. It consist of 20% pollen, spores 30%, marine forms 8%, Freshwater algae 41% and 1% of undifferentiated forms.

SAMPLE 9

The sample was collected at 1500ft. It consist of 60% pollen, spores 22%, Fungal spore 6%, Freshwater algae 38%, marine forms 8%, Acritarch 0% and 4% of undifferentiated forms. The high percentage of pollen and spores indicate terrestrial environment.

SAMPLE 10

The sample was collected at 1600ft. It consist of 18% pollen, spores 40%, Fungal spore 6%, Freshwater algae 32%, marine forms 7%, Acritarch 0% and 1% of undifferentiated forms.

SAMPLE 11

The sample was collected at 1700ft. It consist of 31% pollen, spores 30%, Fungal spore 9%, Freshwater algae 23%, marine forms 2%, Acritarch 1% and 4% of undifferentiated forms. The high percentage of pollen and spores indicate terrestrial environment.

Table 2. Lithologic description of samples (700-2180 ft) of Well-X

S/no	Depth (ft)	Lithology
1	700	Sandy shale, grey in color, medium grain. Highly calcareous.
2	800	Sandy shale, grey in color, medium grain. Highly calcareous.
3	900	Sandstone, grey in color, medium grain. Highly calcareous.
4	1000	Sandstone, grey in color, medium grain. Non- calcareous.
5	1100	Shale, grey in color, medium grain. Highly calcareous.
6	1200	Sandy shale, grey in color, medium grain. Slightly calcareous.
7	1300	Shale, grey in color, fine grain. Highly calcareous.
8	1400	Shale, grey in color, fine grain. Highly calcareous.
9	1500	Shale, grey in color, fine grain. Highly calcareous.
10	1600	Shale, grey in color, fine grain. Highly calcareous.
11	1700	Shale, grey in color, fine grain. Highly calcareous.
12	1800	Shale, grey in color, fine grain. Slightly calcareous.
13	1900	Sandy shale, grey in color medium grain. Slightly calcareous.
14	2000	Sandy shale, grey in color, medium grain. Non- calcareous.
15	2060	Sandy shale, grey in color, fine grain. Slightly calcareous.
16	2180	Sandy shale, grey in color, fine grain. Slightly calcareous.

Table 3. Lithologic description of samples and lithology log (700-2180 ft) of Well-X

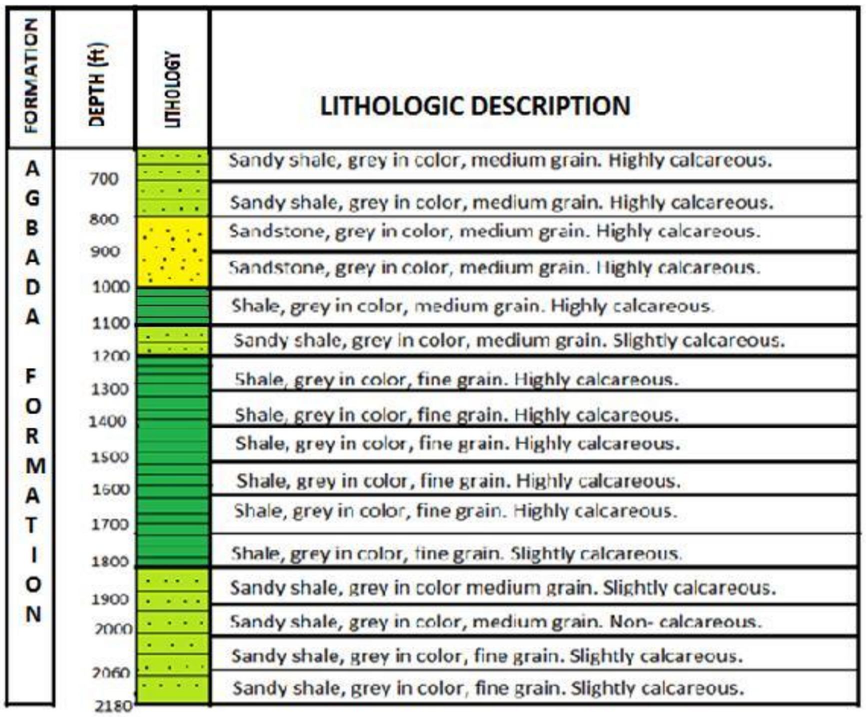

Table 4. Recovered Palynomorphs per depth (700-2180ft) Well-X offshore Niger delta

Sample number	Depth (ft)	S/N	Palynomorphs	Numerical count	Percentage occurrence
1	700	1	*Stereisporites sp*	11	8
		2	Fungal spore	8	6
		3	Charred Gramminae Cuticle	15	10
		4	Smooth trilete spore	15	10
		5	*Pachydermites diederixi*	4	3
		6	*Brevicolporites guinetti*	1	1
		7	*Zonocostites ramonae*	32	22
		8	*Concentricyst circulus*	18	12
		9	*Cypereaopollis sp*	3	2
		10	Smooth monolete spore	20	14
		11	*Monoporites annulatus*	1	1
		12	*Botryoccocus braunii*	2	1
		13	*Selaginella myosurus*	2	1
		14	*Alchornea cordifolia*	1	1
		15	*Rugulatisporites sp*	2	1
		16	*Nympheapollis clarus*	1	1
		17	*Diatom sp*	1	1
		18	*Rugulatisporites caperatus*	2	1
		19	*Praedapollis sp*	1	1
		20	*Psilastephanocolpites sp*	1	1
		21	*Crassoretitriletes vanraadshooveni*	1	1
		22	*Striatricolpites catatumbus*	1	1
		23	*Retitricolporites irregularis*	1	1
		24	*Thompsonipollis magnificus*	1	1
			TOTAL COUNT	145	

Sample number	Depth (ft)	S/N	Palynomorphs	Numerical count	Percentage occurrence
2	800	1	Smooth monolete spore	21	12
		2	*Nympheapollis clarus*	3	2
		3	*Zonocostites ramonae*	17	42
		4	*Botryoccocus braunii*	15	9
		5	Fungal spore	10	6
		6	*Verrucatosporites alienus*	1	1
		7	*Retitricolporites irregularis*	1	1
		8	*Concentricyst circulus*	4	2
		9	*Monoporites annulatus*	16	9
		10	*Psilatriporites sp*	1	1
		11	*Elaeis guineensis*	1	1
		12	*Stereisporites sp*	7	1
		13	*Proteacidites cooksonii*	1	1
		14	*Peregrinipollis nigericus*	1	1
		15	*Crassoretitriletes vanraadshooveni*	1	1
		16	*Glomus sp*	1	1
		17	*Pachydermites diederixi*	6	3
		18	*Magnastriatites howardi*	1	1
		19	Smooth trilete spore	5	3
		20	*Echitriletes sp*	1	1
		21	Charred Gramminae Cuticle	2	1
		22	Polypodiaceoisporites retirugatus	1	1
		23	Multiareolites formosus	1	1
			TOTAL COUNT	173	
3	900	1	*Zonocostites ramonae*	75	59
		2	Fungal spore	5	4
		3	*Elaeis guineensis*	1	1
		4	Charred Gramminae Cuticle	6	5
		5	*Corsinipollenites jussiaensis*	1	1
		6	*Stereisporites sp*	5	4
		7	*Leiosphaeridia sp*	1	1
		8	Smooth monolete spore	10	8
		9	*Psilatricolporites crassus*	1	1
		10	*Aletesporites sp*	2	2
		11	*Pachydermites diederixi*	1	1
		12	*Monoporites annulatus*	7	6
		13	*Concentricyst circulus*	4	3
		14	*Psilastephanocolporites laevigatus*	1	1
		15	*Dinocyst indeterminate*	1	1
		16	*Verrucatosporites alienus*	1	1
		17	*Botryoccocus braunii*	3	2
		18	*Striatricolpites catatumbus*	1	1
		19	*Nympheapollis clarus*	1	1
			TOTAL COUNT	127	
4	1000	1	*Zonocostites ramonae*	15	71
		2	Fungal spore	2	10
		3	Charred Gramminae Cuticle	2	10
		4	Smooth monolete spore	1	5
		5	*Botryoccocus braunii*	1	5
			TOTAL COUNT	21	
5	1100	1	*Stereisporites sp*	5	5
		2	*Pachydermites diederixi*	1	1
		3	*Botryoccocus braunii*	30	32
		4	*Zonocostites ramonae*	40	43
		5	*Aletesporites sp*	1	1

Sample number	Depth (ft)	S/N	Palynomorphs	Numerical count	Percentage occurrence
		6	Smooth trilete spore	3	3
		7	Smooth monolete spore	9	10
		8	*Selenopemphix sp*	1	1
		9	Charred Gramminae Cuticle	1	1
		10	*Concentricyst circulus*	1	1
		11	*Monoporites annulatus*	2	2
			TOTAL COUNT	94	
6	1200	1	*Stereisporites sp*	8	2
		2	*Botryoccocus braunii*	129	38
		3	*Zonocostites ramonae*	54	16
		4	*Concentricyst circulus*	6	2
		5	*Monoporites annulatus*	40	12
		6	*Pachydermites diederixi*	8	2
		7	Smooth monolete spore	61	18
		8	Fungal spore	1	-
		9	*Polypodiaceoisporites retirugatus*	2	1
		10	Charred Gramminae Cuticle	7	2
		11	*Verrucatosporites alienus*	5	1
		12	*Aletesporites sp*	7	2
		13	Smooth trilete spore	5	1
		14	*Cypereaopollis sp*	1	-
		15	*Psilamonocolpites sp*	1	-
		16	*Nympheapollis clarus*	1	-
		17	*Selenopemphix sp*	1	-
		18	*Lycopodiumsporites sp*	1	-
		19	*Pilosisporites sp*	1	-
		20	*Multiareolites formosus*	2	1
		21	*Leiosphaeridia sp*	1	-
		22	*Psilastephanocolporites laevigatus*	1	-
			TOTAL COUNT	343	
7	1300	1	*Monoporites annulatus*	15	19
		2	Smooth monolete spore	21	27
		3	Smooth trilete spore	2	3
		4	*Zonocostites ramonae*	3	4
		5	*Botryoccocus braunii*	12	16
		6	*Concentricyst circulus*	4	5
		7	*Cypereaopollis sp*	2	3
		8	Fungal spore	4	5
		9	*Lycopodiumsporites sp*	2	3
		10	Charred Gramminae Cuticle	1	1
		11	*Verrucatosporites alienus*	2	3
		12	*Stereisporites sp*	4	5
		13	*Lycopodium neogenicus*		-
		14	Polypodiaceoisporites retirugatus	3	4
		15	*Pachydermites diederixi*	1	1
		16	*Dinocyst indeterminate*	1	1
			TOTAL COUNT	77	
8	1400	1	Botryoccocus braunii	112	41
		2	*Stereisporites sp*	10	4
		3	Smooth monolete spore	30	11
		4	*Verrucatosporites alienus*	4	1
		5	*Monoporites annulatus*	30	11
		6	Charred Gramminae Cuticle	11	4
		7	*Polypodiaceoisporites retirugatus*	7	3
		8	Smooth trilete spore	20	7

Sample number	Depth (ft)	S/N	Palynomorphs	Numerical count	Percentage occurrence
		9	Fungal spore	18	7
		10	*Pteris sp*	1	-
		11	*Lycopodiumsporites sp*	2	1
		12	*Aletesporites sp*	3	1
		13	*Pachydermites diederixi*	3	1
		14	*Psilastephanocolporites laevigatus*	2	1
		15	*Rugulatisporites sp*	1	-
		16	*Nympheapollis clarus*	2	1
		17	*Numulipollis neogenicus*	2	1
		18	*Lycopodium neogenicus*	1	-
		19	*Concentricyst circulus*	3	1
		20	*Retistephanocolpites gracillis*	1	-
		21	*Brevitricolporites guinetii*	1	-
		22	*Zonocostites ramonae*	3	1
		23	*Magnastriatites howardi*	1	-
		24	*Selaginella myosurus*	1	-
		25	*Verrucatosporites tenellis*	1	-
		26	*Acacia sp*	1	-
			TOTAL COUNT	271	
9	1500	1	Smooth monolete spore	20	18
		2	*Botryoccocus braunii*	42	38
		3	*Concentricyst circulus*	2	2
		4	*Zonocostites ramonae*	6	5
		5	Fungal spore	7	6
		6	Smooth trilete spore	9	8
		7	*Lycopodiumsporites sp*	2	2
		8	*Monoporites annulatus*	5	5
		9	*Verrucatosporites alienus*	1	1
		10	*Retistephanocolpites gracillis*	2	2
		11	*Distaverrusisporites simplex*	1	1
		12	*Psilatricolporites sp*	1	1
		13	*Lycopodium neogenicus*	1	1
		14	*Stereisporites sp*	3	3
		15	Charred Gramminae Cuticle	3	3
		16	*Multiareolites formosus*	1	1
		17	*Magnastriatites howardi*	2	2
		18	*Pterospermella sp*	1	1
		19	*Elaeis guineensis*	1	2
			TOTAL COUNT	111	
10	1600	1	*Botryoccocus braunii*	80	32
		2	Smooth monolete spore	68	17
		3	Fungal spore	9	4
		4	*Zonocostites ramonae*	20	8
		5	*Nympheapollis clarus*	4	2
		6	Charred Gramminae Cuticle	6	2
		7	*Psilaperiporites minimus*	1	-
		8	*Monoporites annulatus*	8	3
		9	*Elaeis guineensis*	2	1
		10	*Stereisporites sp*	8	3
		11	*Concentricyst circulus*	8	3
		12	*Verrucatosporites alienus*	6	2
		13	*Proteacidites cooksonnni*	1	-
		14	Smooth trilete spore	8	3
		15	*Aletesporites sp*	4	2
		16	*Ctenolophonidites costatus*	1	-

Sample number	Depth (ft)	S/N	Palynomorphs	Numerical count	Percentage occurrence
		17	*Verrucatosporites tenellis*	1	-
		18	*Alchornea cordifolia*	1	-
		19	*Pachydermites diederixi*	3	1
		20	Polypodiaceoisporites retirugatus	1	-
		21	*Lycopodiumsporites sp*	3	1
		22	*Multiareolites formosus*	1	-
		23	*Crassoretitriletes vanraadshooveni*	1	-
		24	Distaverrusisporites simplex	2	1
		25	*Foraminiferal lining*	1	-
			TOTAL COUNT	249	
11	1700	1	Fungal spore	26	9
		2	*Stereisporites sp*	2	1
		3	*Botryoccocus braunii*	66	23
		4	*Zonocostites ramonae*	62	22
		5	*Smooth trilete spore*	16	6
		6	*Foraminiferal lining*	1	-
		7	Retistephanocolpites gracillis	1	-
		8	*Numulipollis neogenicus*	1	-
		9	*Aletesporites sp*	5	2
		10	Smooth monolete spore	56	20
		11	*Elaeis guineensis*	5	2
		12	*Monoporites annulatus*	17	6
		13	*Alchornea cordifolia*	2	1
		14	*Concentricyst circulus*	4	1
		15	*Verrucatosporites alienus*	2	1
		16	*Acacia sp*	2	1
		17	*Polypodiaceoisporites retirugatus*	5	2
		18	*Psilatricolporites crassus*	1	-
		19	*Leiosphaeridia sp*	2	1
		20	*Pachydermites diederixi*	2	1
		21	Charred Gramminae Cuticle	6	2
		22	Retibrevitricolporites obodoensis	1	-
		23	*Nympheapollis clarus*	1	-
		24	*Lycopodium sp*	1	-
			TOTAL COUNT	287	
12	1800	1	Smooth monolete spore	64	17
		2	Fungal spore	18	5
		3	*Botryoccocus braunii*	154	42
		4	*Monoporites annulatus*	14	4
		5	*Zonocostites ramonae*	54	15
		6	*Aletesporites sp*	4	1
		7	Smooth trilete spore	18	5
		8	Retitricolporites amazoensis	1	-
		9	*Stereisporites sp*	5	1
		10	*Retitricolporites irregularis*	1	-
		11	*Verrucatosporites alienus*	7	2
		12	*Pachydermites diederixi*	5	1
		13	*Nympheapollis clarus*	1	-
		14	*Concentricyst circulus*	2	1
		15	*Verrucatosporites tenellis*	1	-
		16	*Elaeis guineensis*	3	1
		17	Polypodiaceoisporites retirugatus	1	-
		18	*Multiareolites formosus*	1	-
		19	*Echitriletes pliocenicus*	1	-
		20	*Dinocyst indeterminate*	1	-

Sample number	Depth (ft)	S/N	Palynomorphs	Numerical count	Percentage occurrence
		21	*Selaginella myosurus*	1	-
		22	*Cypereaopollis sp*	1	-
		23	*Foraminiferal lining*	2	1
		24	*Magnastriatites howardi*	5	1
		25	*Lycopodium sp*	1	-
		26	*Crassoretitriletes vanraadshooveni*	1	-
		27	*Lycopodiumsporites sp*	2	1
			TOTAL COUNT	369	
13	1900	1	Smooth monolete spore	44	14
		2	*Zonocostites ramonae*		
		3	Charred Gramminae Cuticle	6	2
		4	*Elaeis guineensis*	1	-
		5	Smooth trilete spore	6	2
		6	*Botryoccocus braunii*	25	8
		7	Fungal spore	15	5
		8	*Aletesporites sp*	3	1
		9	*Verrucatosporites alienus*	6	2
		10	*Foraminiferal lining*	1	-
		11	*Stereisporites sp*	5	2
		12	*Monoporites annulatus*	5	2
		13	*Lycopodiumsporites sp*	1	-
		14	*Concentricyst circulus*	1	-
		15	*Polypodiaceoisporites retirugatus*	2	1
		16	*Ctenolophonidites costatus*	1	-
		17	*Dinocyst indeterminate*	1	-
		18	*Verrucatosporites tenellis*	2	1
		19	*Cypereaopollis sp*	1	-
		20	*Fusiformisporites sp*	1	-
		21	*Pachydermites diederixi*	1	-
		22	*Retistephanocolpites gracillis*	1	-
			TOTAL COUNT	305	
14	2000	1	*Stereisporites sp*	13	4
		2	*Verrucatosporites alienus*	4	1
		3	*Nympheapollis clarus*	2	1
		4	*Botryoccocus braunii*	57	17
		5	Fungal spore	20	6
		6	Smooth monolete spore	65	20
		7	*Zonocostites ramonae*	108	34
		8	Charred Gramminae Cuticle	6	2
		9	*Leiosphaeridia sp*	2	1
		10	*Diatom sp*	1	-
		11	Smooth trilete spore	17	5
		12	*Aletesporites sp*	5	2
		13	*Dinocyst indeterminate*	1	-
		14	*Monoporites annulatus*	4	1
		15	*Polypodiaceoisporites retirugatus*	3	1
		16	*Pachydermites diederixi*	3	1
		17	*Lycopodiumsporites sp*	1	-
		18	*Multiareolites formosus*	1	-
		19	*Acacia sp*	2	1
		20	*Psilatricolporites operculatus*	1	-

Sample number	Depth (ft)	S/N	Palynomorphs	Numerical count	Percentage occurrence
		21	*Lycopodium sp*	2	1
		22	*Fusiformisporites sp*	1	-
		23	*Magnastriatites howardi*	1	-
		24	*Numulipollisneo genicus*	1	-
		25	*Striatricolpites catatumbus*	1	-
			TOTAL COUNT	322	
15	2060	1	*Zonocostites ramonae*	104	49
		2	*Botryoccocus braunii*	16	8
		3	*Aletesporites sp*	3	1
		4	*Retitriporites sp*	3	1
		5	*Monoporites annulatus*	8	4
		6	*Stereisporites sp*	8	4
		7	Smooth monolete spore	40	19
		8	*Verrucatosporites tenellis*	1	-
		9	Charred Gramminae Cuticle	3	1
		10	*Verrucatosporites alienus*	3	1
		11	*Smooth trilete spore*	9	4
		12	*Cypereaopollis sp*	2	1
		13	*Alchornea cordifolia*	1	-
		14	Fungal spore	4	2
		15	*Pachydermites diederixi*	2	1
		16	*Nympheapollis clarus*	2	1
		17	*Lycopodiumsporites sp*	1	-
		18	*Lycopodium neogenicus*	1	-
		19	*Polypdiaceoisporites retirugatus*	1	-
		20	*Pterospermella sp*	1	-
			TOTAL COUNT	213	
16	2180	1	*Botryoccocus braunii*	80	18
		2	Fungal spore	15	3
		3	*Monoporites annulatus*	13	3
		4	Smooth trilete spore	17	4
		5	Smooth monolete spore	54	12
		6	Charred Gramminae Cuticle	84	19
		7	*Zonocostites ramonae*	115	26
		8	*Nympheapollis clarus*	1	-
		9	*Magnastriatites howardi*	1	-
		10	*Polypodiaceoisporites retirugatus*	8	2
		11	*Pachydermites diederixi*	5	1
		12	*Elaeis guineensis*	1	-
		13	*Stereisporites sp*	10	2
		14	*Rugulatisporites caperatus*	2	-
		15	*Brevicolporites guinetti*	1	-
		16	*Cypereaopollis sp*	2	-
		17	*Lycopodium neogenicus*	1	-
		18	*Peregrinipollis nigericus*	1	-
		19	*Concentricyst circulus*	2	-
		20	*Verrucatosporites alienus*	13	3
		21	*Aletesporites sp*	4	1
		22	*Pteris sp*	1	-
		23	*Retitricolporites irregularis*	1	-
		24	*Echitriletes pliocenicus*	1	-
		25	*Fusiformisporites sp*	1	-
		26	*Pilosisporites sp*	1	-
			TOTAL COUNT	435	

SAMPLE 12

The sample was collected at 1800ft. It consist of 21% pollen, spores 29%, Fungal spore 5%, Freshwater algae 42%, marine forms 1%, Acritarch 0% and 1% of undifferentiated forms.

SAMPLE 13

The sample was collected at 1900ft. It consist of 62% pollen, spores 23%, Fungal spore 6%, Freshwater algae 11%, marine forms 1%, Acritarch 0% and 1% of undifferentiated forms. The high percentage of pollen and spores indicate terrestrial environment.

SAMPLE 14

The sample was collected at 2000ft. It consist of 39% pollen, spores 34%, Fungal spore 7%, Freshwater algae 18%, marine forms 1%, Acritarch 1%.

SAMPLE 15

The sample was collected at 2060ft. It consist of 57% pollen, spores 31%, Fungal spore 2%, Freshwater algae 8%, marine forms 0%, Acritarch 0% and 2% of undifferentiated forms. The high percentage of pollen and spores indicate terrestrial environment.

SAMPLE 16

The sample was collected at 2180ft. It consist of 51% pollen, spores 25%, Fungal spore 4%, Freshwater algae 18%, marine forms 0%, Acritarch 0% and 1% of undifferentiated forms. The high percentage of pollen and spores indicate terrestrial environment.

3.3 Paleoenvironmental Interpretation

The aim of paleoenvironmental analysis is to reconstruct the biological, chemical and physical nature of the environment at the time of deposition. Using the distribution chart the various palynomorphs wre grouped into their paleoecological groups, ranging from Montane, Mangrove, Savanna, Freshwater and Marine. The classification s given below;

3.4 Paleoenvironmental Classification

3.4.1 Pollen

MONTANE
Peregrinipollis ngericus
Numulipollis neogenicus

MANGROVE POLLEN
Zonocostites ramonae
Psilatricolporites crassus

SAVANNA POLLEN
Charred Gramminae cuticle
Proteacidites cooksonni
Monoporites annulatus
Multiareolites formosus

FRESHWATER POLLEN
Brevicolporites guinetti
Pachydermites diederixi
Psilatricolporites operculatus
Pachydermites diederixi
Striatricolpites catambus
Retitricolporites irregularis
Thompsonipollis magnificus
Psilastephanocolporites laevigatus
Nympheapollis clarus
Psilaperiporites minimus
Ctenolophonidites costatus

3.4.2 Spores

Distaverrusporites simplex
Lycopodiumsporites sp.
Selaginella myosurus
Stereisporites sp
Aletesporites sp
Verrucatosporites tenellis
Echitriletes sp
Crassorefitriletes vanraadshooveni
Magnastriatites howardi
Polypodiaceiosporites retirugatus
Smooth trilete spore
Smooth monolete spore
Verrucatosporites alienus
Regulatisporites sp
Rugulatisporites caperatus
Lycopodium neogenicus
Lycopodium sp
Monoporites annulatus
Multiareolites formosus

3.4.3 Freshwater algae

Botryoccocus branuii
Concentricyst circulus

3.4.4 Fungal spore

Fungal spore
Fusiformisporites sp

3.4.5 Marine

Diatom sp
Donocyst indeterminate

Foraminiferal lining
Selenopemphix sp

3.4.6 Acritarchs

Pterospermella sp
Leiosphaeridia sp

3.4.7 Undifferentiated

Acacia sp
Alchornea cordifolia
Retistephanocolpites gracillis
Retibrevitricolporites obodoensis
Corsinipollenites jussiaensis
Glomus sp
Psilastephanocolpites sp
Psilatriporites sp
Psilamonocolpites sp
Pilosisporites sp
Pteris sp
Psilatricolporites sp
Retitricolporites amazoensis
Retitriporites sp
Elaeis guineensis
Echitriletes pliocenicus

The distribution chart (Fig. 6) was used generate a table (Table 5) which shows the percentage of palynomorphs per depth base on their paleoenvironmental classification in Well-X (700-2180 ft) in offshore Niger delta.

Table 5. Percentage (%) distribution of palynomorphs base on paleoenvironment distribution

Depth (ft)	Total Palynomorph	Pollen	spore	Acritarch	Fungal spore	Freshwater algae	Marine	Others
700	145	41	36		6	13	1	3
800	173	60	22		6	11		1
900	127	72	14	1	4	6	2	2
1000	21	81	5		10	5		
1100	94	47	19			33	1	
1200	343	33	26			39	1	1
1300	77	29	44			16	6	5
1400	271	20	30			41	8	1
1500	111	14	33		6	38	8	4
1600	249	18	40		4	32	7	1
1700	287	31	30	1	9	23	2	4
1800	369	21	29		5	42	1	1
1900	305	62	23		5	9		1
2000	322	39	34	1	7	18	1	
2060	213	57	31		2	8		2
2180	435	51	25		4	18		1

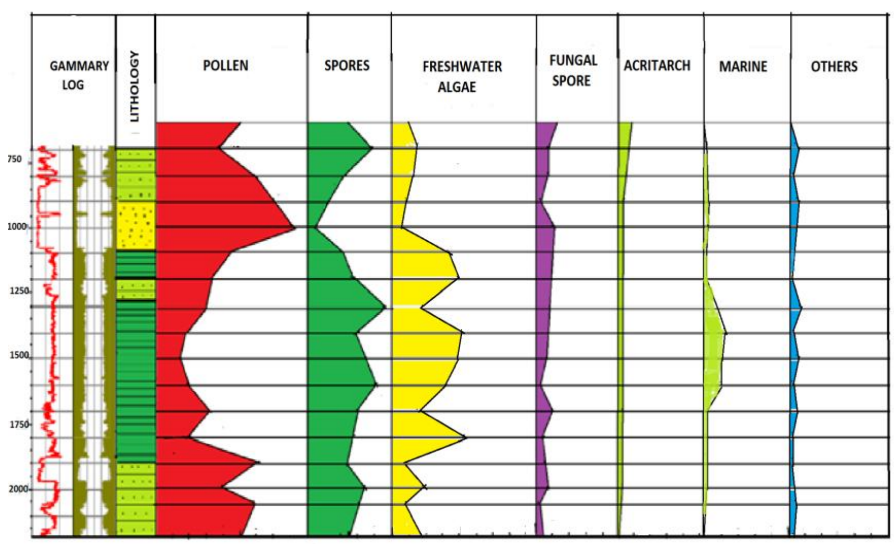

Fig. 7. Biostratigraphic plot of Well-X (700-2180ft)

Fig. 6. Distribution chart of palynomorphs fond in Well-X (700-2180ft)

The pecentage of palynomorphs per depth (Table 5) was used to generate a biostratgraphic plot which explains the paleoenvironment of Well-X (700-2180 ft). From the plot (Fig. 7) it can be seen that pollens and spores are dominant followed by freshwater algae. Fungal spore, acritarch and others have very little pecentage. The high occurrence of pollen and spores further support that the environment is Terrestrial.

3.5 Age Determination

From the analysis, the sediments were observed to have been deposited during Early - ?Late Pliocene times. This interpretation is deduced by the co-occurrences of Stereisporites sp, Nympheapollis clarus and Cypereaopollis sp with Retistephanocolpites gracillis. Podocarpus milanjianus was absent within this interval therefore the penetration of Late Pliocene is not certain. That is why Late Pliocene is questioned in this study.

4. CONCLUSION

A palynostratigraphic study of Well-X in offshore Niger Delta was carried out with a gamma ray log and a total of sixteen ditch cutting samples collected at different depth (700-2180 ft), the samples were made up of sandstone, sandy shale and shale. The various samples were subjected to palynological analysis, the sixteen samples analysed palynologically yielded fair to good amount of palynomorphs except two samples which had poor recovery. from the analysis recovered palynomorphs include a high percentage of pollen and spores, some freshwater algae (*Concentricyst circulus, Botryococcus braunii*) and a very minute amount of fungal spore, acritarchs and marine forms (*Foram Lining, Dinocysts, Leiosphaeridia*), suggesting that the environment of deposition is terrestrial. A lithostratigraphic framework was established for the sample unit and a palynomorph distribution chart was constructed. From the distribution chart the percentage of the different palynomorphs (pollen, spores, Freshwater algae, fungal spore, acritarch, marine forms and some undifferentiated form) were calculated and used to generate a biostratigraphic plot that shows the paleoenvironmental distributon of Well-X (700-2180 ft). From the analysis, the sediments were observed to have been deposited during Early - ? Late Pliocene times. This interpretation is deduced by the co-occurrences of *Stereisporites sp*, *Nympheapollis clarus* and *Cypereaopollis sp* with *Retistephanocolpites gracillis*. *Podocarpus milanjianus* was absent within this interval therefore the penetration of Late Pliocene is not certain. That is why Late Pliocene is questioned in this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Explanation to Plate

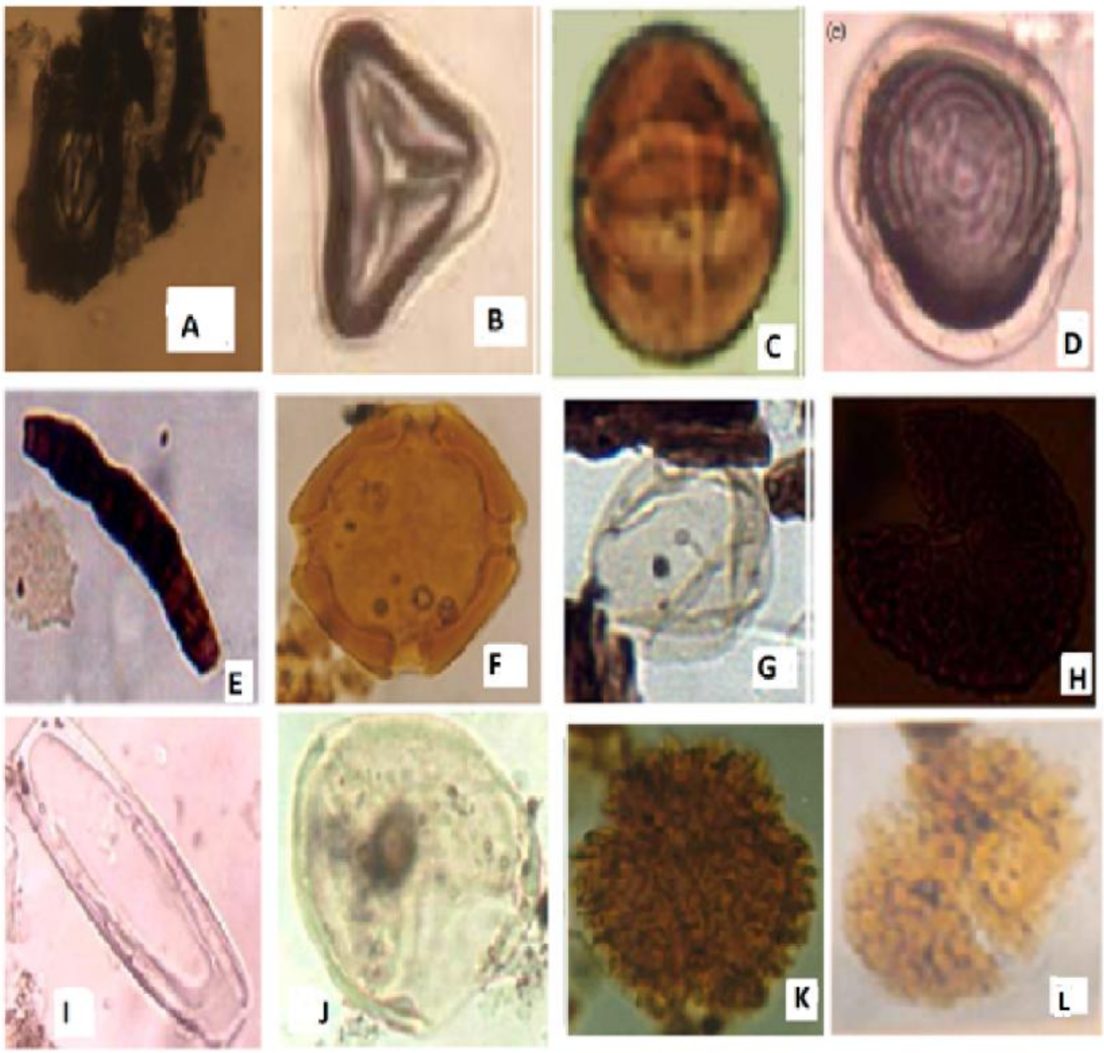


Plate 1

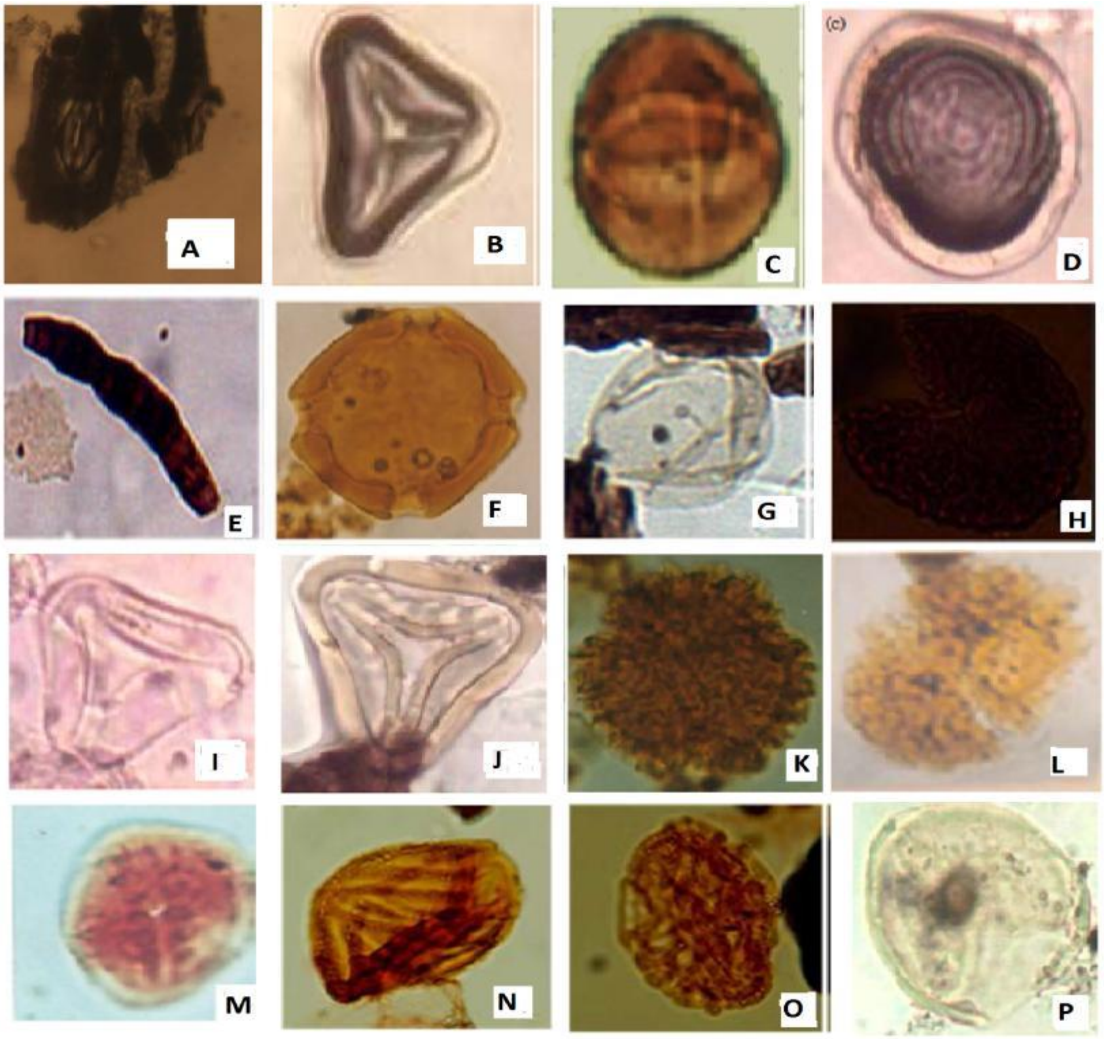
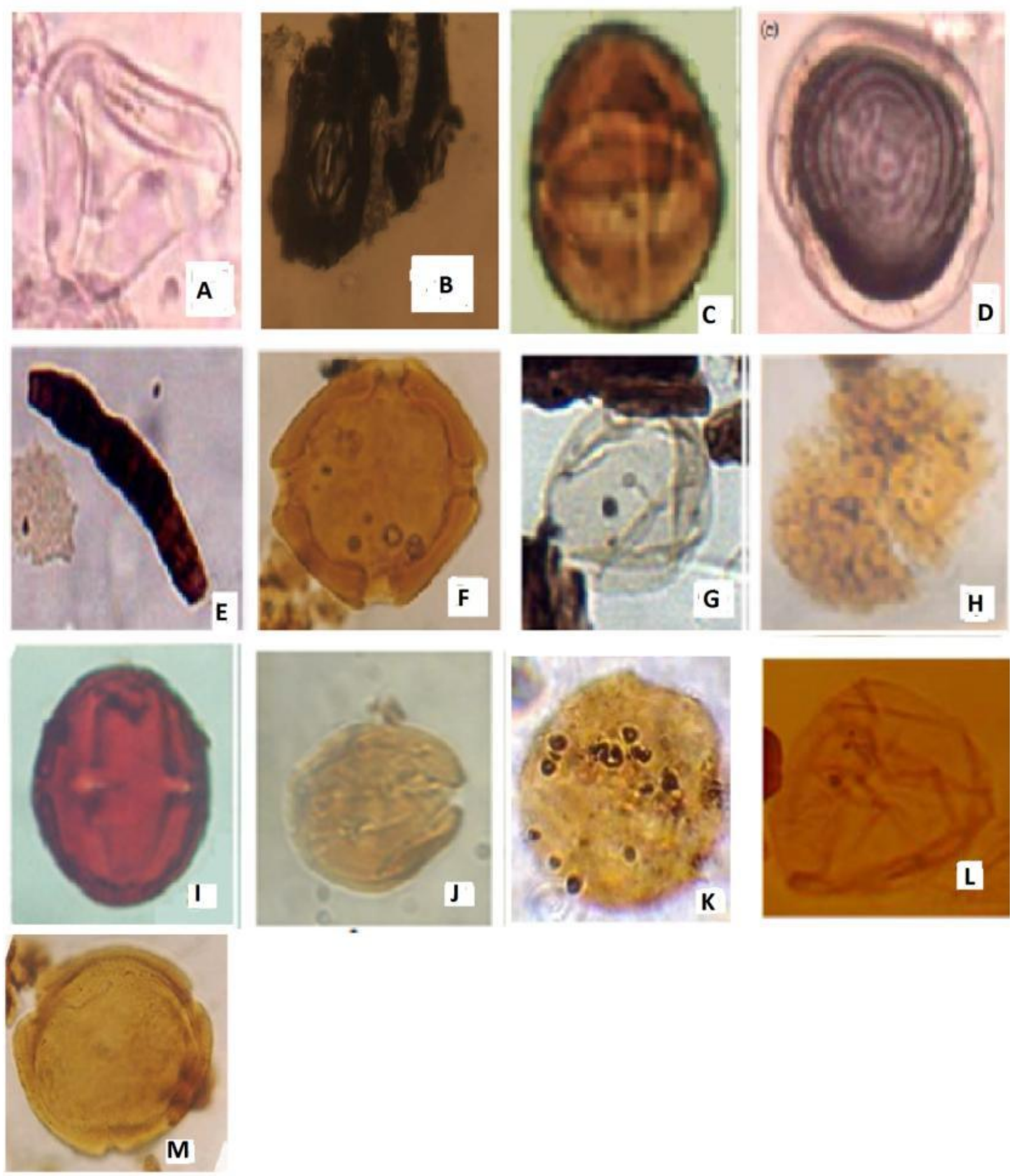


Plate 2



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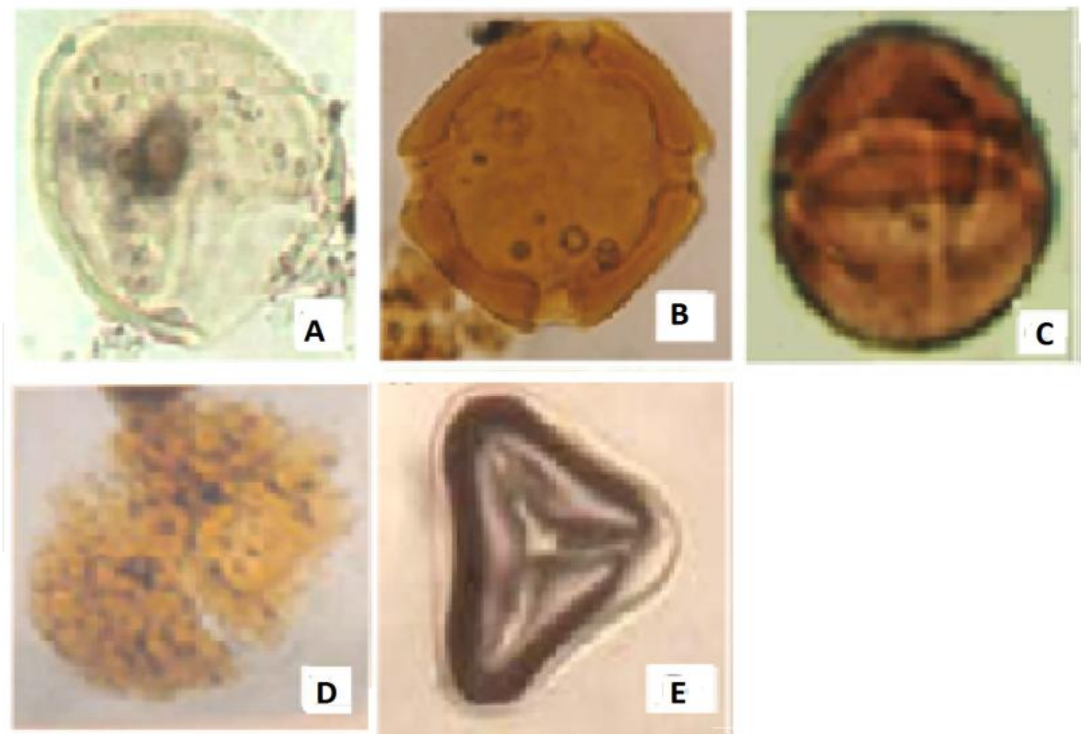

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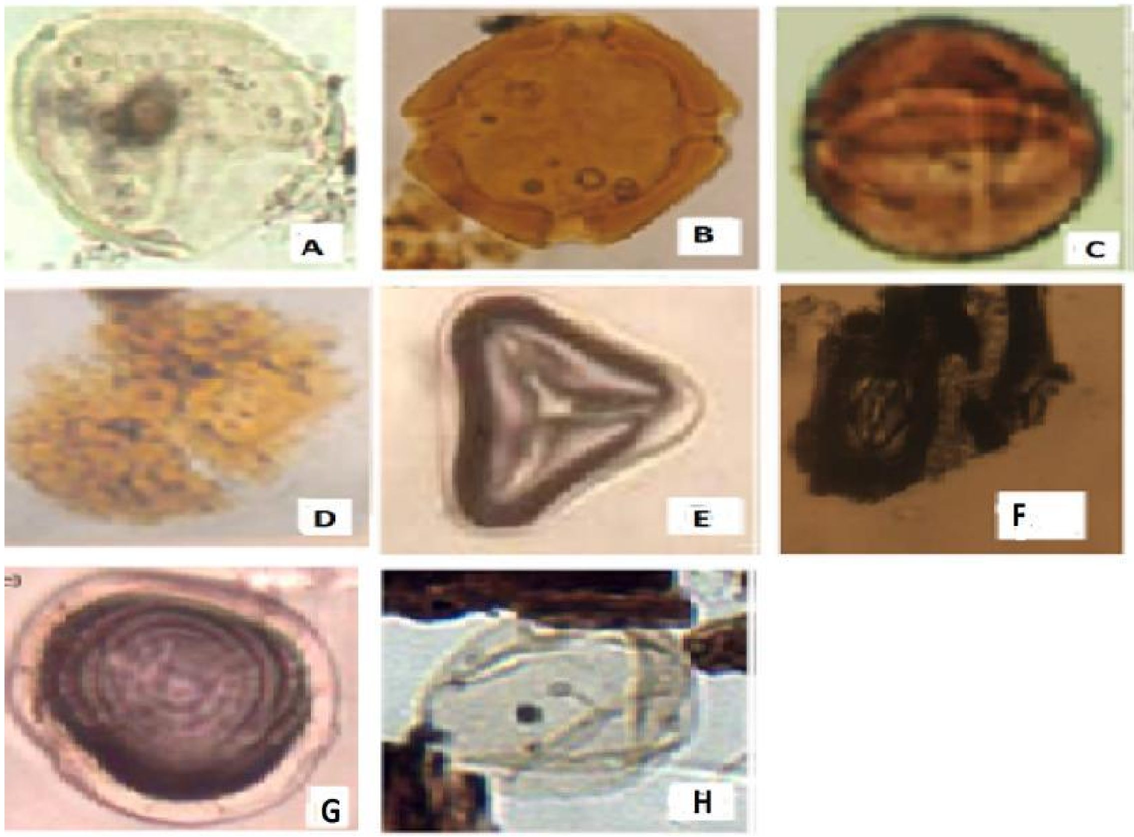

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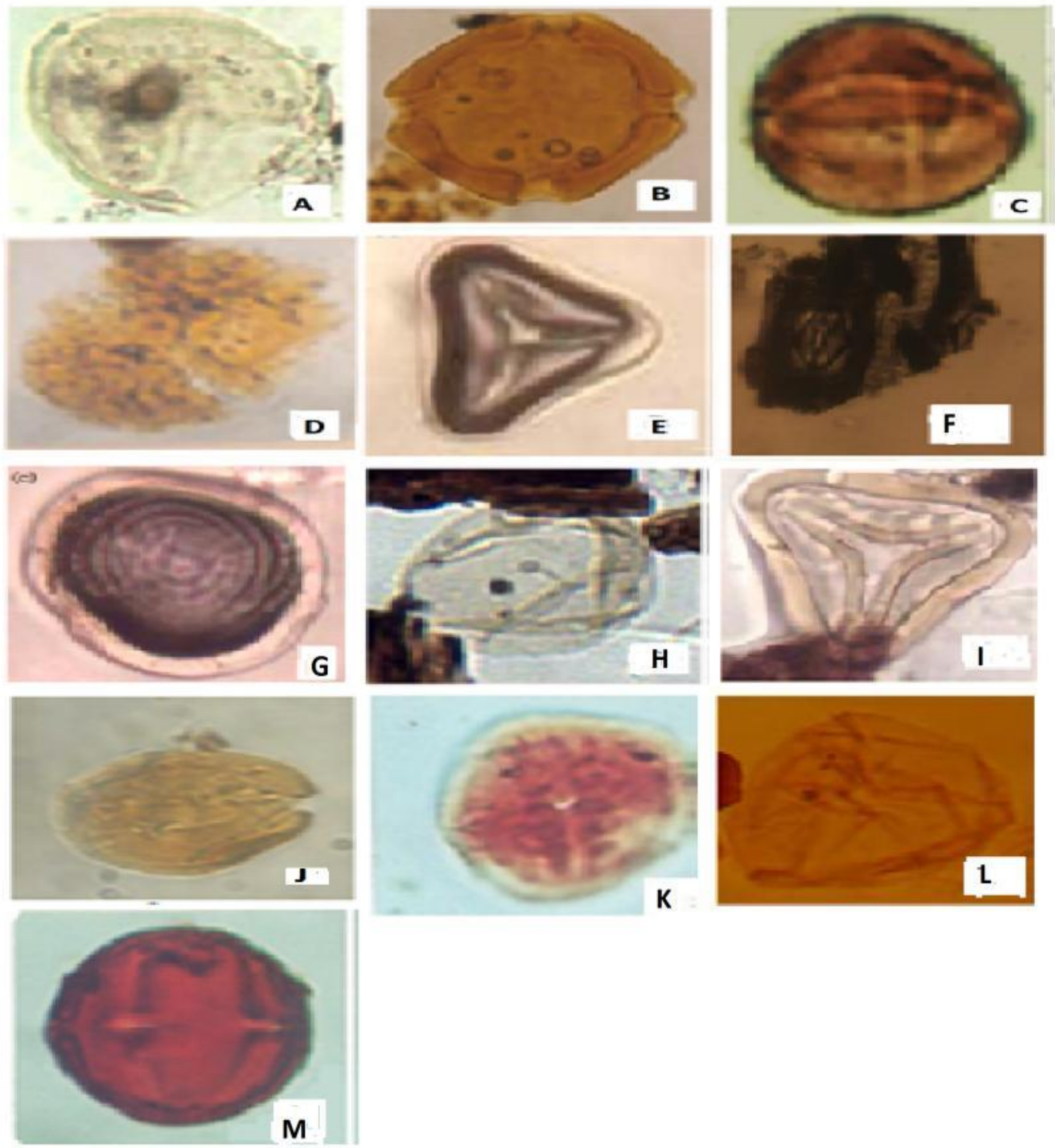

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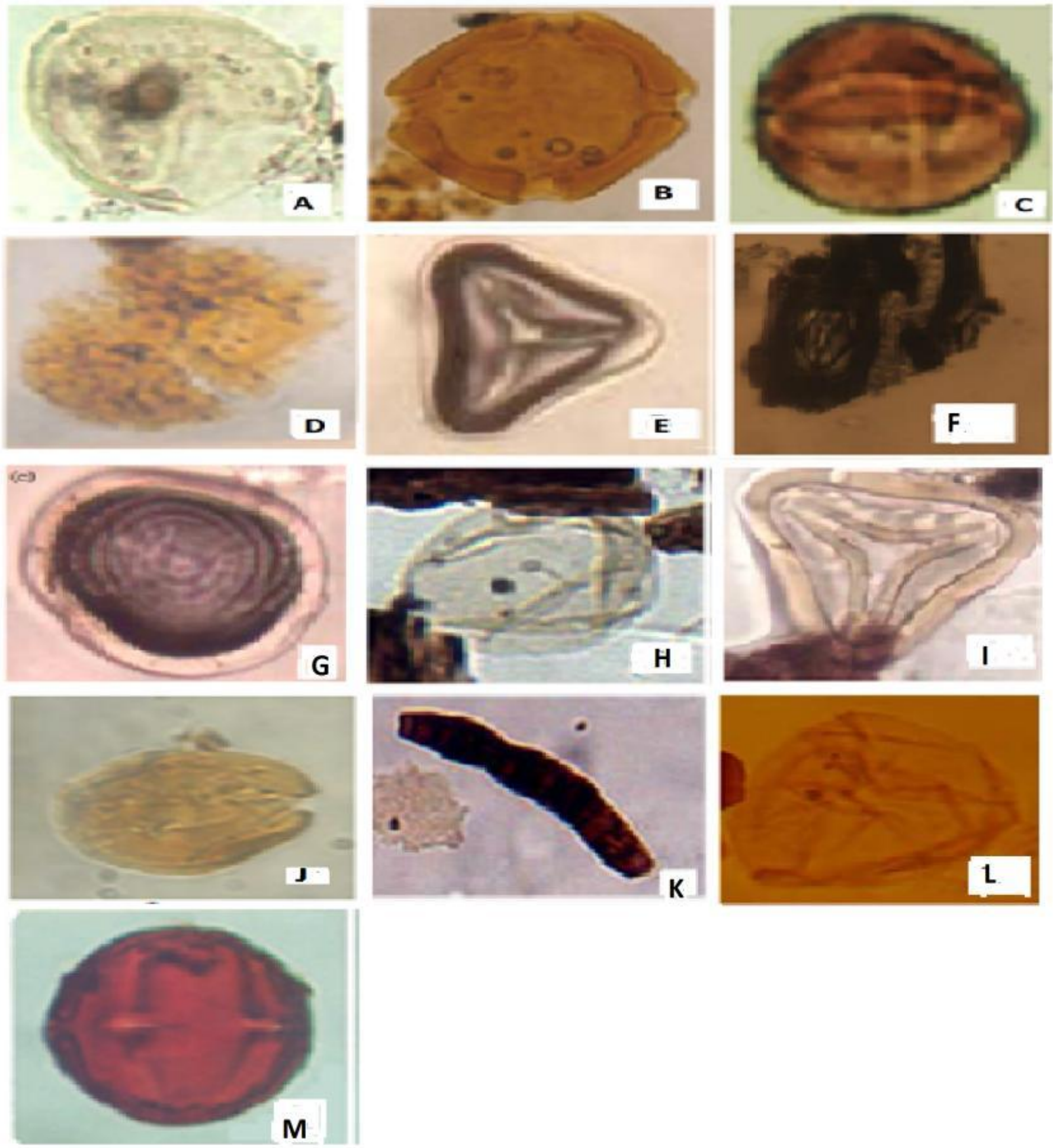

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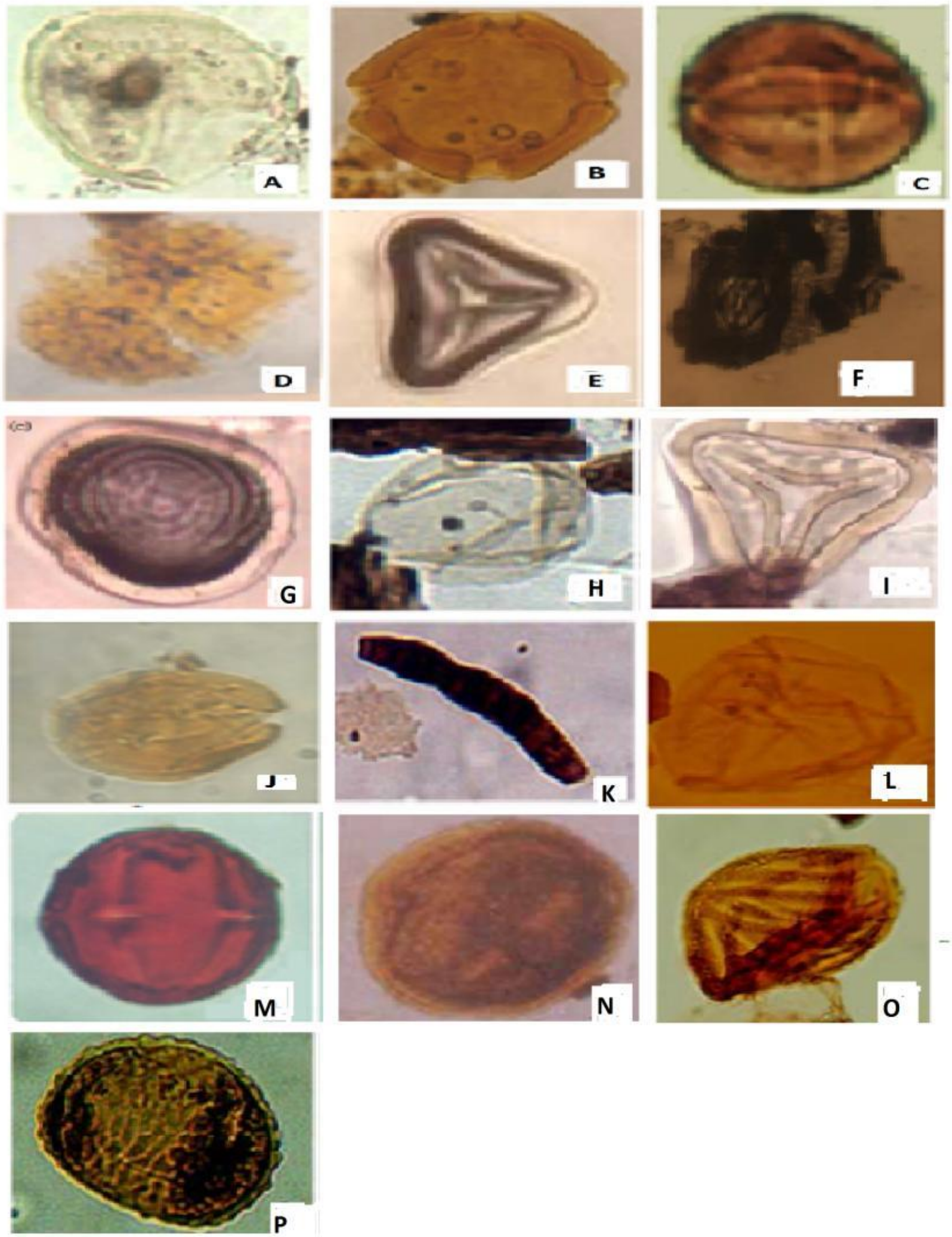

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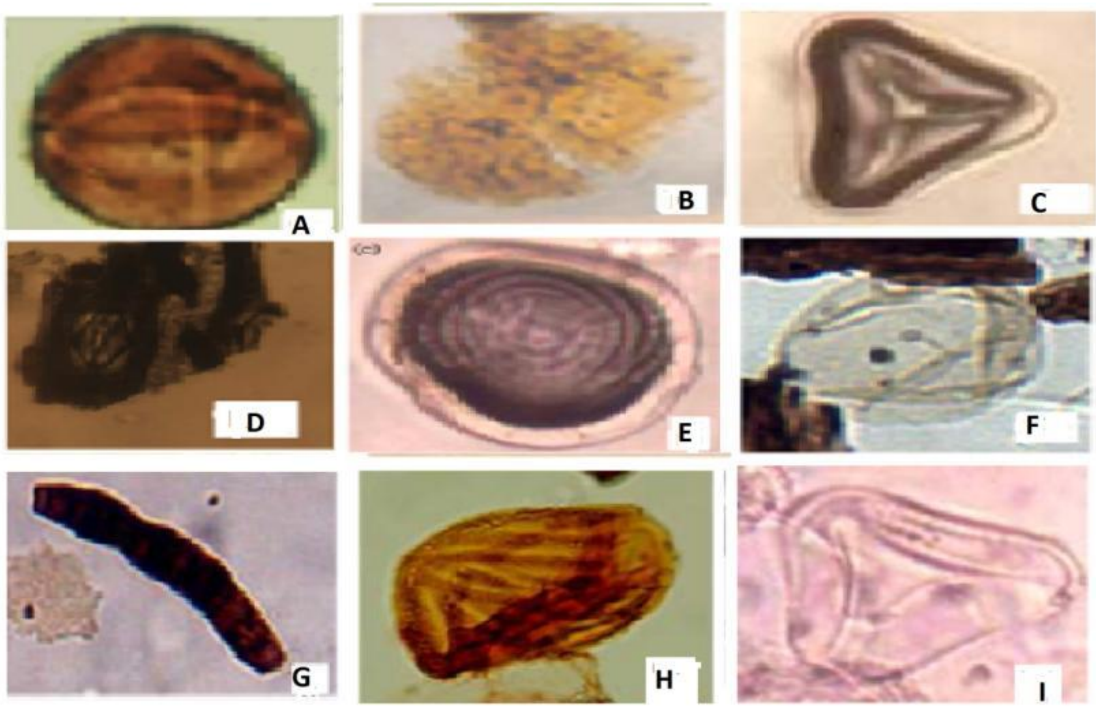

Plate 9 (1500 ft)

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