Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2018, 5(11):15-31

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Lithostratigraphy and Palynology of Maastrichtian to Danian Succession in Alo-1 Well, Anambra Basin

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Abstract One hundred and five (105) cutting samples recovered from depths between 540ft to 8,600ft in Alo-1 well sedimentary succession, Anambra basin were subjected to sedimentological and palynological study. Three Lithofacies were established: shale, sandy-shale and shaly-sand respectively. Mineralogical/chemical contents of these lithofacies include mica, carbonate and quartz. A total of 81 species of miospores and 19 dinocysts were identified, evaluated and appraised for their biostratigraphic utilities. Danian to Maastrichtian stage is assigned for the succession penetrated. The Cretaceous -Tertiary (K-T) boundary is delineated by both the FAD of a dinocysts species, *Damassadinium californicum* and LAD of a pollen species, *Constructipollenites ineffectus* at intervals 3,600ft and 4,360ft respectively. A shelf environment was established for intervals between 540ft- 5340ft marked by interfingering of miospores and dinocysts. The paleoenvironment between intervals 5340ft-8600ft was undiagnostic because of absence of sufficient palynological evidence. Palynomorph abundance pattern and the age of the succession penetrated were used to delineate stratal surfaces: two maximum flooding surfaces (MFS) and one sequence boundary (SB) were defined in the Danian, three maximum flooding surfaces (MFS) and two sequence boundaries (SB) were defined in the Maastrichtian. Based on the age established for the succession penetrated, the formations likely penetrated by the well were established to be the Imo (Danian) from 540ft-3600ft and Nsukka (3600ft-4570ft)-Ajali (4570ft-5170ft) and the Mamu (5170ft-8600ft) these have been dated Danian-Maastrichtian. The two maximum flooding surfaces were mainly delineated and defined on the basis of palynological signals while the sequence was identified on the basis of the high resolution lithofacies model generated for the well sedimentary succession. This work has therefore, demonstrated the utilities of palynology for the definition and characterization of stratal surfaces.

Keywords Sedimentology, Maastrichtian-Danian, K-T boundary, Miospores, Dinocysts

Introduction

The Anambra Basin is a Cretaceous/Tertiary basin, which is the structural link between the Cretaceous Benue Trough and the Tertiary Niger Delta basin [1]. It is a triangular shaped embayment covering an area of about 40000 sq. km [2] with approximate sediment thickness of about 6km. The presence of interbeded shales and sandstones with occasional limestones [3] resulted in an initial interest in search for oil and gas within the Lower Benue Trough (including the Anambra Basin) of Nigeria. This sedimentary phase was initiated by the Santonian folding and uplift of the Abakaliki anticlinorium along the NE-SW axis, and the consequent dislocation of the depocenter into the Anambra Basin on the Northwest and the Afikpo syncline on the Southeast [4-5]. The resulting succession comprises the Nkporo group, Mamu formation, Ajali sandstone, Nsukka formation, Imo formation and Ameki group. The Anambra Basin was long abandoned due to its fruitless and unrewarding effort for the exploration of petroleum [6]. The exploration for coal and petroleum in the Anambra Basin culminated into commercial production of coal in 1916 while oil exploration was abandoned as the efforts ended in a number of non-commercial discoveries. The search for commercial hydrocarbons in the Anambra Basin in Nigeria has been a concern, especially to oil companies and research groups. Sedimentology and Palynostratigraphy are useful exploratory tools used to reduce uncertainties associated with hydrocarbon exploration. Sedimentology was the basis for recognizing and differentiating the lithostratigraphic units penetrated by Alo -1 Well and these units were zoned based on their gross sedimentary properties. Thick shales penetrated could serve as unconventional source of hydrocarbon if they are mature. The distribution of palynomorphs with depth in the succession penetrated was the basis for determining the paleoenvironment of deposition; age dating, establishing biostratigraphic zones and delineating stratal surfaces.

The Alo -1 well is situated in the Anambra Basin, Southeastern Nigeria between Latitude 06^{O} 18’58’’ N and Longitude 6^{O} 43’ 11’’E. The well section penetrated 8600ft of sediments.

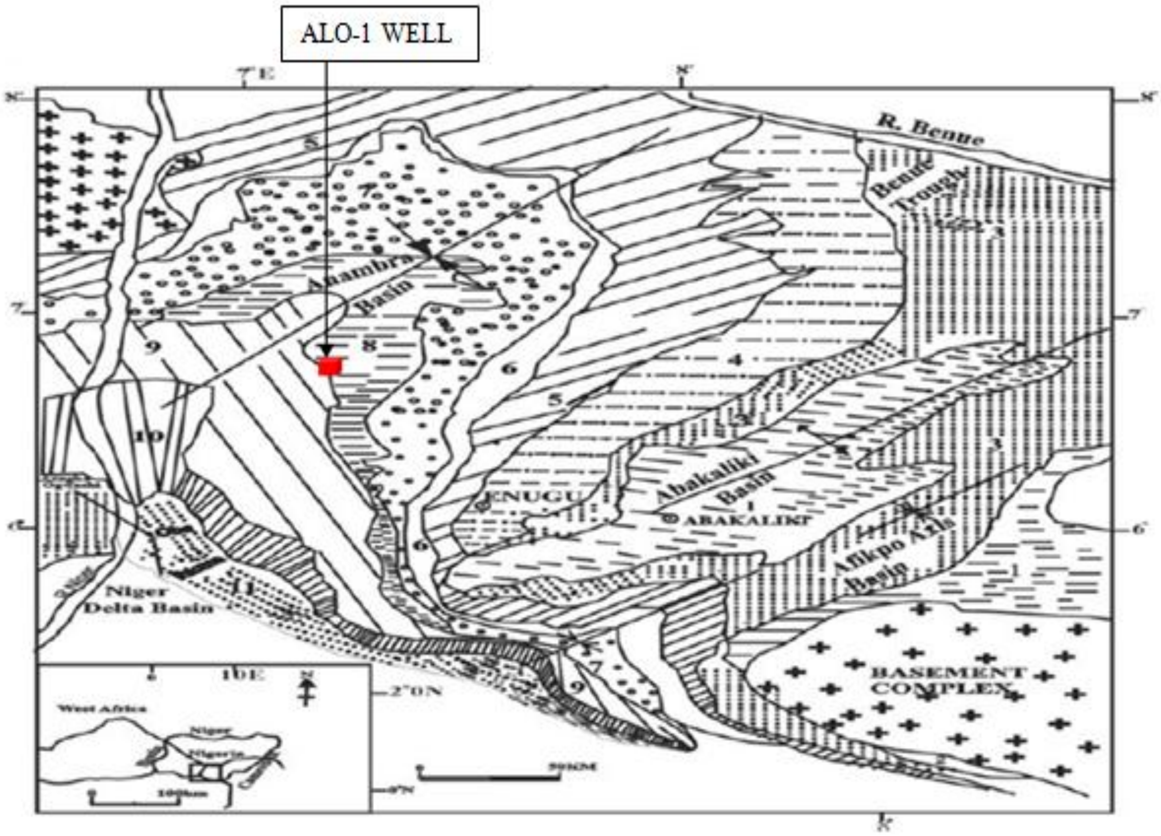

Figure 1: Map showing Location of Alo-1 Well, Anambra Basin, Southeastern Nigeria

Materials and Methods

Samples totaling 105 in number were described to establish a lithologic log. Forty (40) of the total samples were taken at various depth intervals and prepared using standard preparation techniques [7-9] for palynological analysis. Eighty-one miospores and nineteen dinocysts species were recorded and their distribution plotted. The samples for this work were collected from Alo -1 well, drilled in the Anambra Basin. The Sample Depth ranged from 540ft (180m) – 8600ft (2866m). The samples were carefully arranged from top to base of the well. Each sample was recorded and a detailed sedimentological description was done using the petrological microscope.

Sedimentological Description

A detailed sedimentological description using the petrological microscope was carried out documenting the sand-shale percentages, texture (grain size, sorting, and roundness) and environmentally sensitive minerals in the samples. Dilute HCl was used to test for presence of carbonate in sample; effervescence indicates the presence of carbonate in sediments. Photomicrographs were taken at some depths. In the absence of a wire-line gamma ray data, the sand-shale percentage was very useful in establishing a pseudo-GR log using the Petrel Software.

Palynological Preparation

The samples for palynological analysis were selected from the litholog prepared based on sedimentological description, forty (40) samples were picked from intervals of interest and processed using traditional methods of laboratory preparation of palynomorphs.

According to Wood *et al* [9] Palynological samples are better concentrated when processed using standard palynological techniques involving the use of Hf, HCl and HNO_3 including heavy-liquid separation ($ZnBr_2$) and sieving of the residue with a 20 µm sieve. The purpose of palynological preparation is to isolate palynomorphs from the rock/sediment matrix, and then to concentrate and present them for study in pristine condition, avoiding any modifications in shape, size and preservation and contamination of the assemblage. Therefore standard conventional method was used to treat and concentrate the recovered microfossils.

The counting and logging were done by straight transects across each slide and coordinates. The recovered palynomorphs species were identified with the aid of relevant publications and manuals such as Shell palynological photo album and web-based albums. Morphological characters of the pollens and spores such as the size, exine, structure, shape, and sculpture and aperture type provided the basis for the identification of the forms. Species name and the number of times they were encountered were recorded in the analysis data sheets. Photomicrographs were prepared with Sony digital camera and the each grain magnification is X400.

Results and Discussion

Lithostratigraphy

Results from sedimentological analysis revealed three lithofacies types which are; shale, sandy-shale and shaly-sand. The penetrated sequence based on detailed sedimentologic properties was grouped into twenty-five lithologic zones (figure 2). The identified minerals includes carbonates, mica, iron oxide and coal.

Lithozone 1

Reference Depth: 540ft-1920ft

This zone consists of shales, grey coloured and fissile. The thickness is about 1380ft. Minerals within this zone were mainly carbonates and mica.

Lithozone 2

Reference Depth: 2100ft-2640ft

This zone consists of sandy shales. The shales are grey coloured and fissile; the sands are whitish, consisting of fine-coarse grained sands. The thickness is about 540ft. Minerals within this zone were mainly carbonates and mica.

Lithozone 3

Reference Depth: 2820ft-3000ft

This zone consists of shaly-sand. The shales are grey coloured and fissile; the sands are whitish, consisting of medium-coarse grained sands. The thickness is about 540ft. Minerals within this zone were mainly carbonates and mica.

Lithozone 4

Reference Depth: 3120ft-3600ft

This zone consists of sandy-shales. The shales are grey coloured and fissile; the sands are whitish, consisting of medium-coarse grained sands. The thickness is about 480ft. Minerals within this zone were mainly carbonates and mica.

Lithozone 5

Reference Depth: 3840ft

This zone is consists of shaly-sand. The shales are grey coloured and fissile; the sands are milky white, consisting of medium-coarse grained sands. The thickness is about 240ft. Minerals were not clearly seen in this zone.

Lithozone 6

Reference Depth: 4000ft

This zone consists of sand-shale. The shales are grey coloured and fissile; the sands are milky white, consisting of medium-coarse grained sands. The thickness is about 160ft. Minerals were not clearly seen in this zone, this could be as a result of weathering effect seen were Iron-oxide, mica and carbonate.

Lithozone 7

Reference Depth: 4060ft

This zone consists of shaly-sand. The shales are grey coloured and fissile; the sands are milky white, consisting of medium-coarse grained sands. The thickness is about 160ft. Minerals were Iron-oxide, mica and carbonate.

Lithozone 8

Reference Depth: 4120ft-4300ft

This zone consists of sandy-shale. The shales are grey coloured and fissile; the sands are milky white, consisting of medium-coarse grained sands. The thickness is about 280ft. Minerals seen were Iron-oxide, mica and carbonate.

Lithozone 9

Reference Depth: 4360ft-4570ft

This zone consists of shaly-sand. The shales are grey coloured and fissile; the sands are milky white, consisting of fine-medium grained sands. The thickness is about 210ft. Minerals seen were Iron-oxide, mica, and coal.

Lithozone 10

Reference Depth: 4600ft-4810ft

This zone consists of shaly-sand. The shales are grey coloured and fissile; the sands are milky white-light grey, consisting of fine-medium grained sands. The thickness is about 190ft. Minerals seen were Iron-oxide, mica.

Lithozone 11

Reference Depth: 4900ft

This zone consists of sandy-shale. The shales are grey coloured and fissile; the sands are light grey-brown, consisting of fine-medium grained sands. The thickness is about 90ft. No obvious minerals seen.

Lithozone 12

Reference Depth: 4960ft-5170ft

This zone consists of shaly-sand. The shales are grey coloured and fissile; the sands are clear-milky white in colour, consisting of fine-coarse grained sands. The thickness is about 210ft.

Lithozone 13

Reference Depth: 5200ft

This zone consists of sandy-shale. The shales are grey coloured, not fissile; the sands are milky-grey in colour, consisting of fine-coarse grained sands. Minerals are generally absent. The thickness is about 30ft.

Lithozone 14

Reference Depth: 5290ft-5410ft

This zone consists of shales. The shales are grey coloured, and fissile. Minerals present include Quartz, Feldspar and Iron-oxide. The thickness is about 120ft.

Lithozone 15

Reference Depth: 5500ft-5860ft

This zone consists of sandy-shale. The shales are grey coloured, not fissile; the sands are milky-grey in colour, consisting of fine-coarse grained sands. Minerals present include Mica and Iron-oxide. The thickness is about 360ft.

Lithozone 16

Reference Depth: 5920ft-6010ft

This zone consists of shales. The shales are grey and fissile. Minerals present include Mica and Iron-oxide. The thickness is about 90ft.

Lithozone 17

Reference Depth: 6100ft

This zone consists of sandy-shale. The shales are grey non-fissile, the sands are milky-grey and fine grained sands. Mineral present is Mica. The thickness is about 90ft.

Lithozone 18

Reference Depth: 6160ft-6860ft

This zone consists of shales. The shales are grey and fissile. Mineral present are Mica, Iron-oxide and Carbonate. The thickness is about 700ft.

Lithozone 19

Reference Depth: 6900ft

This zone consists of sandy-shale. The shale is grey and fissile, the sands is milky- grey and fine grained. Mineral present is Mica. The thickness is about 40ft.

Lithozone 20

Reference Depth: 6960ft-7160

This zone consists of shales. The shales are grey and fissile. Mineral present is Mica. The thickness is about 200ft.

Lithozone 21

Reference Depth: 7200ft-7460ft

This zone consists of sandy-shale. The shales are grey and fissile, the sands are milky-grey and fine grained sands. Mineral present is Mica and Iron-oxide. The thickness is about 260ft.

Lithozone 22

Reference Depth: 7500ft-8140ft

This zone consists of shales, grey and fissile. Mineral present is Mica. The thickness is about 640ft.

Lithozone 23

Reference Depth: 8200ft

This zone consists of sandy-shale; shales are grey and fissile, sands are grey and fine grained. Mineral present is Mica. The thickness is about 60ft.

Lithozone 24

Reference Depth: 8240ft-8500ft

This zone consists of grey and fissile shales. Mineral present is Mica. The thickness is about 260ft.

Lithozone 25

Reference Depth: 8540ft-8600ft

This zone consists of sandy-shale. Shales are grey and fissile; the sands are milky- grey, fine grained. Mineral present is Mica. The thickness is about 60ft.

The shales could be potential source rocks if mature especially at depths with reasonable shale thickness, for instance shales in Lithozones: 25 (540ft-1920ft), 8 (6160ft-6860ft), 6 (6960-7160ft), 4 (7500ft-8140ft) and 2 (8240ft-8500ft). The shaly-sands embedded within impermeable shale acting as seals, could serve as reservoirs. Shaly sands can be found within Lithozones: 14 (4960ft-5170ft), 16 (4600ft-4810ft), 18 (4120ft-4300ft), 23 (2820ft-3000ft).

Palynology

Palynomorph Count

The analyses of the palynological samples yielded a hundred (100) palynomorph species; eighty one (81) Miospores and nineteen (19) dinocysts respectively (figures 3 and 4). The palynomorph counts are shown on the table 1.

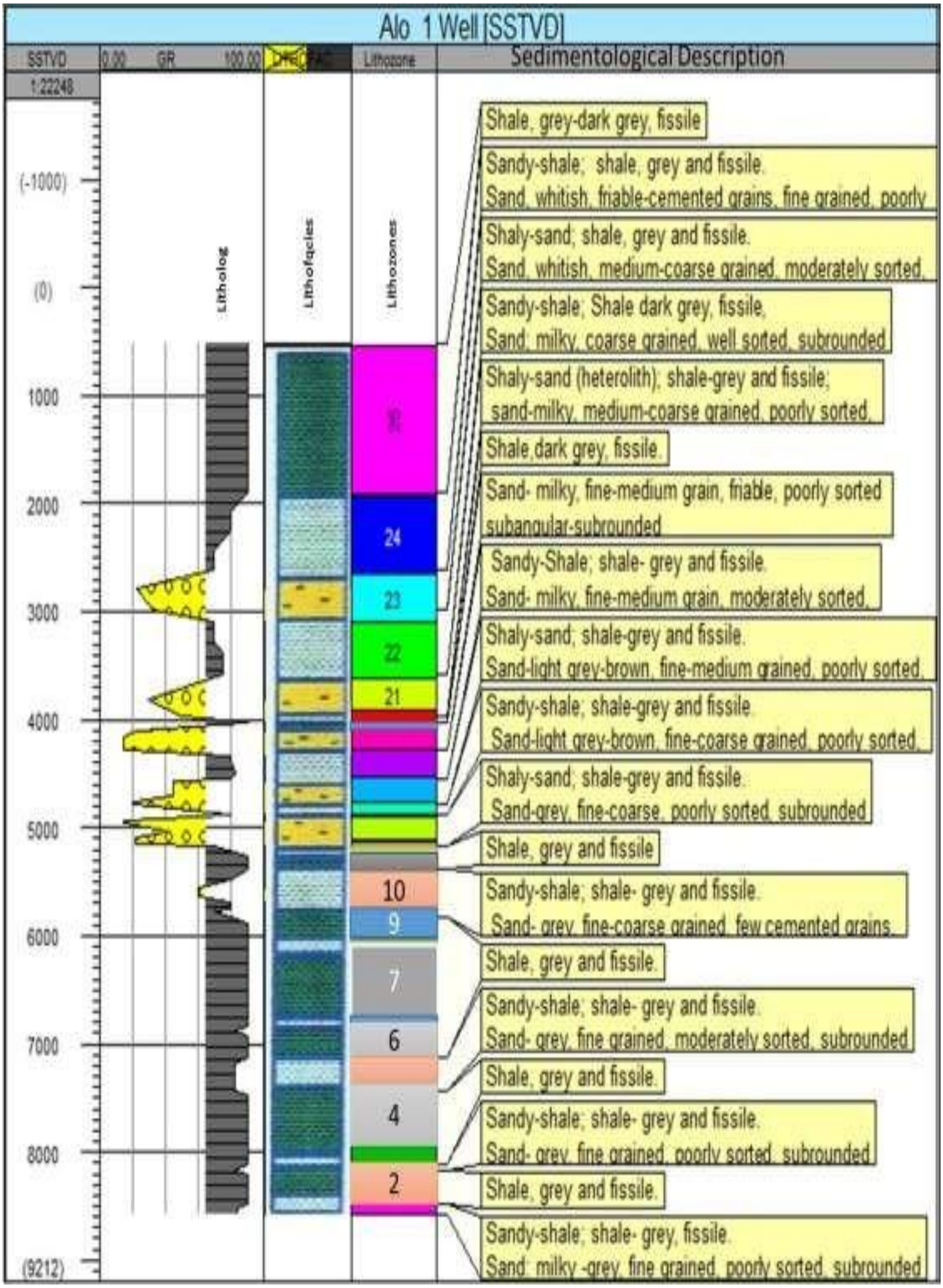

Figure 2: Sedimentological Description for Alo-1 Well

Table 1: Microfossil Distribution with Depth

S/N	DEPTH	MIOSPORE	DINOCYST	FORAM TEST	FUNGAL	TOTAL FORMS
1	540	108	30	3	0	138
2	1080	240	37	5	0	277
3	1740	145	28	3	1	173
4	1800	164	31	10	0	195
5	1920	177	19	6	0	198
6	2280	167	13	4	3	180
7	3600	158	21	7	2	179
8	4060	79	0	0	0	79
9	4360	68	1	0	2	69
10	4570	90	57	0	0	147
11	4900	50	5	0	0	55
12	4990	52	8	1	1	60
13	5110	69	22	1	0	91
14	5170	75	0	17	1	75
15	5350	65	20	1	0	85
16	5590	163	10	0	0	173
17	5770	120	7	0	0	127
18	5920	183	6	1	0	189
19	6100	110	2	0	0	112
20	6250	96	3	2	0	99
21	6540	36	0	1	0	36
22	6700	27	0	0	0	27
23	6860	47	0	0	0	47
24	6990	24	0	0	0	24
\25	7060	34	2	0	0	34
26	7160	42	1	0	0	42
27	7300	41	0	0	0	41
28	7400	46	0	0	0	46
29	7500	40	0	0	1	40
30	7660	69	0	0	0	69
31	7800	56	0	0	0	56
32	7960	70	0	0	0	70
33	8100	65	0	0	0	65
34	8200	17	0	0	0	17
35	8280	14	0	0	0	14
36	8340	16	1	0	0	16
37	8500	21	0	0	0	21
38	8540	14	0	0	7	7
39	8580	23	0	0	0	23
40	8600	43	0	0	0	43

Palynomorph Range Chart

Miospores and dinocysts range (figures 3 and 4) charts was established using the last appearance datum (last appearance datum) of pollens, spores and dinocysts species identified in the well section. Most of the recovered palynomorphs are long ranging except for few forms which are restricted to their stratigraphic ranges. The recovered palynomorphs are listed below and shown on the distribution chart.

The Recovered Miospores were: Afropolis jardinus, Anacolosidites spp., Arecipites spp., Auricullopollenites echinatus, Aquipollenites minimus, Belkispollis elegans, Buttinia andreevi, Cingulatisporites ornatus, Constructipollenites ineffectus, Cretacaeiporites scrabatus, Crototriocolpites crotonisculptus, Concavissimisporites spp., Cyathidites australis, Deltoidsporites spp., Dictyophyllidites harrisii, *Echitricolporites spinosus, Ephedripites ambonoides, Ephedripites costaliferous, Elaeis guineeses, Echiperiporites estalae, Echitriporites trianguliformis, Gematricolpites scrabatus, Gleischenidites spp., Inaperturopollenites spp., Laevigatosporites spp., Lycopodium spp., Longapertites marginatus, Longapertites vaneendenburgi, Longapertites microfoveolatus, Leitrioletes spp.., Monocolpites marginatus, Mauriitidites crassibaculatus, Monosulcites spp., Matonisporites spp., Momipites africanus, Monoporites annulatus, Proxapertites cursus, Psilamonoporites spp., Proxapertites operculatus, Psilatricolporites spp., Praedapollis africanus, Polypodaceiosporites spp., Psilatricolpites spp., Proxapertites tertiaria, Proteacidites longispinosus, Pereglinipollis nigericus, Retibrevitricolpites triangulates, Retimonocolpites spp., Retistephanocolpites spp., Retidiporites magdalenensis, Retitricolpites americana, Retidiporites miniporatus, Retitricolpites irregularis, Rugulatisporites caperatus, Retitricolpites clarensis, Retitricolporites crassicostatus, Sartuna enigmaticus, Striatricolpites catatumbus, Spinizonocolpites baculatus, Syncolporites marginatus, Steevesipollenites orbiculatus, Taxodiaceaepollinites hiatus, Tricolpollenites spp., Tetrad spp., Triplanosporites spp., Verrucatosporites usmensis, Verrucatosporites tenellis, Zlisvisporites blanensis.*

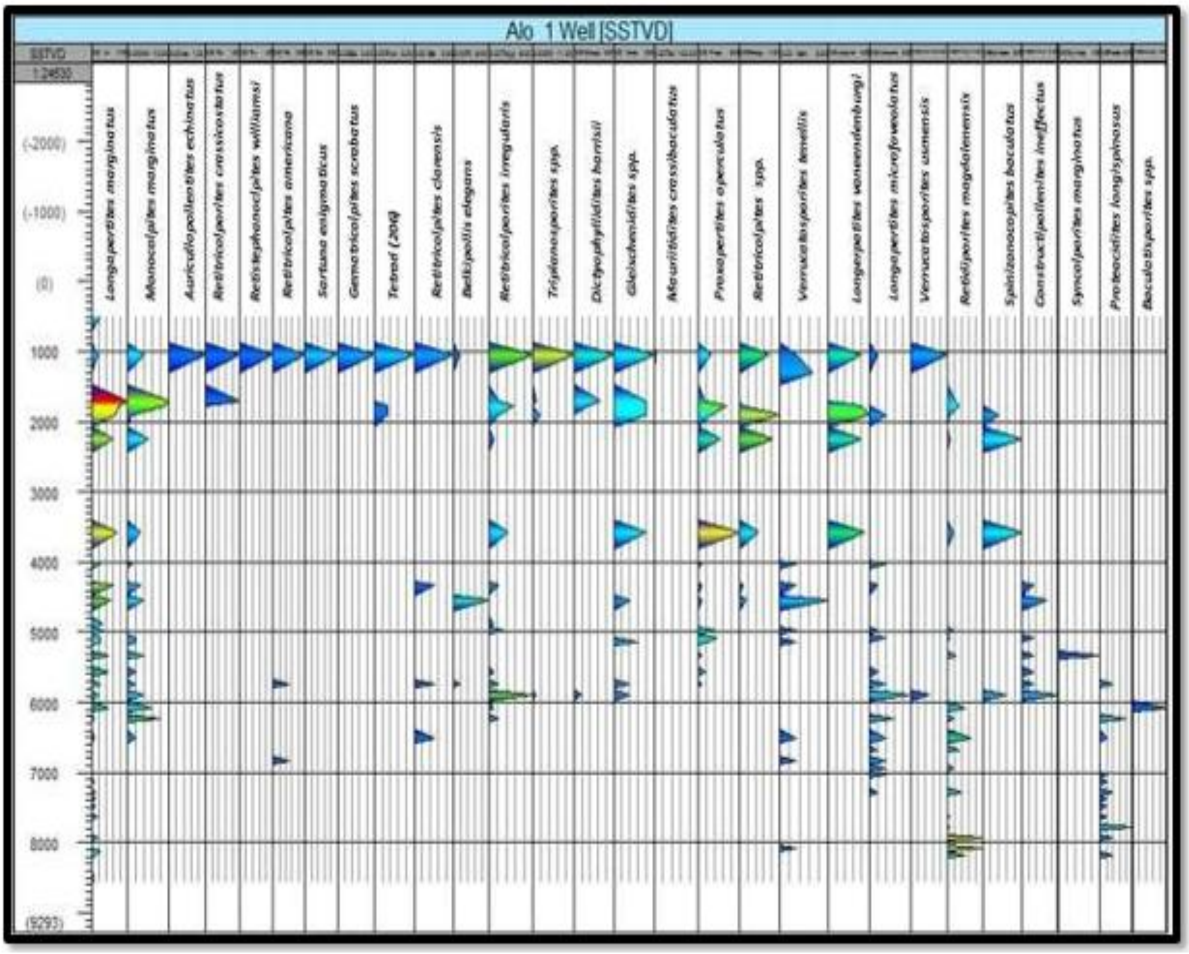

Figure 3: Miospore Range Chart of Key Forms for Alo-1 Well

Dinocysts Recovered were: *Cerodinium debeilii, Cerodinium bolonensis, Damasadinium californicum, Eocladophyxis peniculatum, Fibrocysta lapacea, Fibrocysta bipolar, Homotribilium paLast appearance datumium, Kallosphaeridium yorubaensis, Leiosphaeridia spp., Muratodinium fimbriatum, Paleocystodinium australis, Paleocystodinium golzowense, Spiniferites ramose, Spiniferites cingulatus, Selenopemphix spp., Systematophora spp., Foraminiferal test linings, Fungal spores* and *Tasmanite species.*

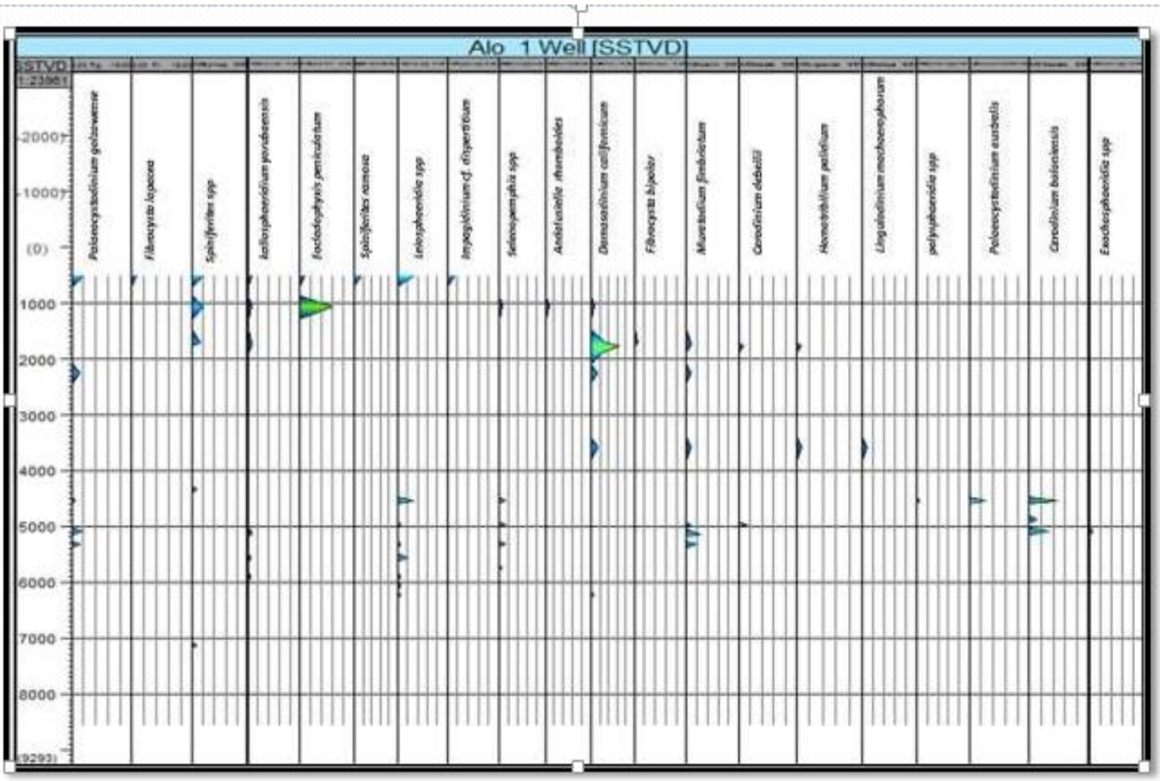

Figure 4: Dinocysts Range Chart for Alo-1 Well

Palynostratigraphy

Age Subdivision

Two chronostratigraphic stages were delineated in the well, a Danian stage in the Paleocene and a Maastrichtian stage in the Cretaceous.

A Danian stage (540ft-4360ft), established based on the first appearance datum of *Damasadinium californicum* and last appearance datum of *Constructipollenites ineffectus. Damasadinium californicum* is a global microphytoplankton marker and has been used to define the lower Paleocene (Danian) in other parts of the world for example in the Gulf of Mexico and in Northwest Tunisia to delineate the Cretaceous- Tertiary boundary. The dinocyst specie *Muratodinium fimbriatum* was seen to extend from Mid-Maastrichtian to Danian within the well section. The Danian within the well was further subdivided into zones using other dinocysts species recovered.

The Cretaceous-Tertiary boundary (4360ft) was delineated based on the last appearance datum of the pollen *Constructipollenites ineffectus.* Van Hoeken- Klinkenberg [10] in his work using bore samples from Owan-1, Egoli-1 and Gbekebo-1, Nigeria; showed that the stratigraphic range of *Constructipollenites ineffectus* does not exceed the Maastrichtian. A Paleocene age (Danian) has been assigned to intervals above this boundary (540ft-4360ft) while a Maastrichtian age has been assigned to intervals below the boundary (4360ft-8600ft).

A Maastrichtian stage (4360ft- 8600ft), established based on the continuous downhole occurrence of key miospores such as *Constructipollenites ineffectus, Buttinia andreevi, Cingulatisporites ornatus, Syncolporites marginatus.* The Maastrichtian was also further subdivided into zones.

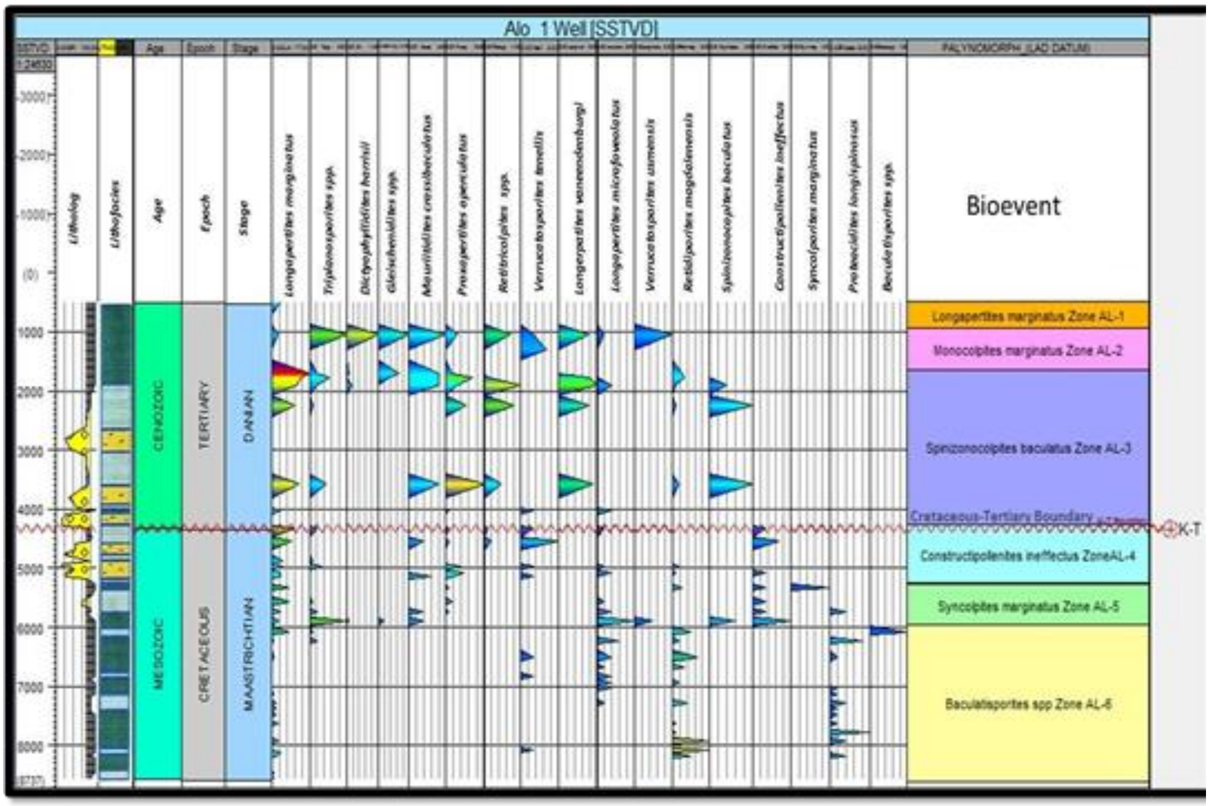

Figure 5: Miospore Chronostratigraphic Chart for Alo-1 Well

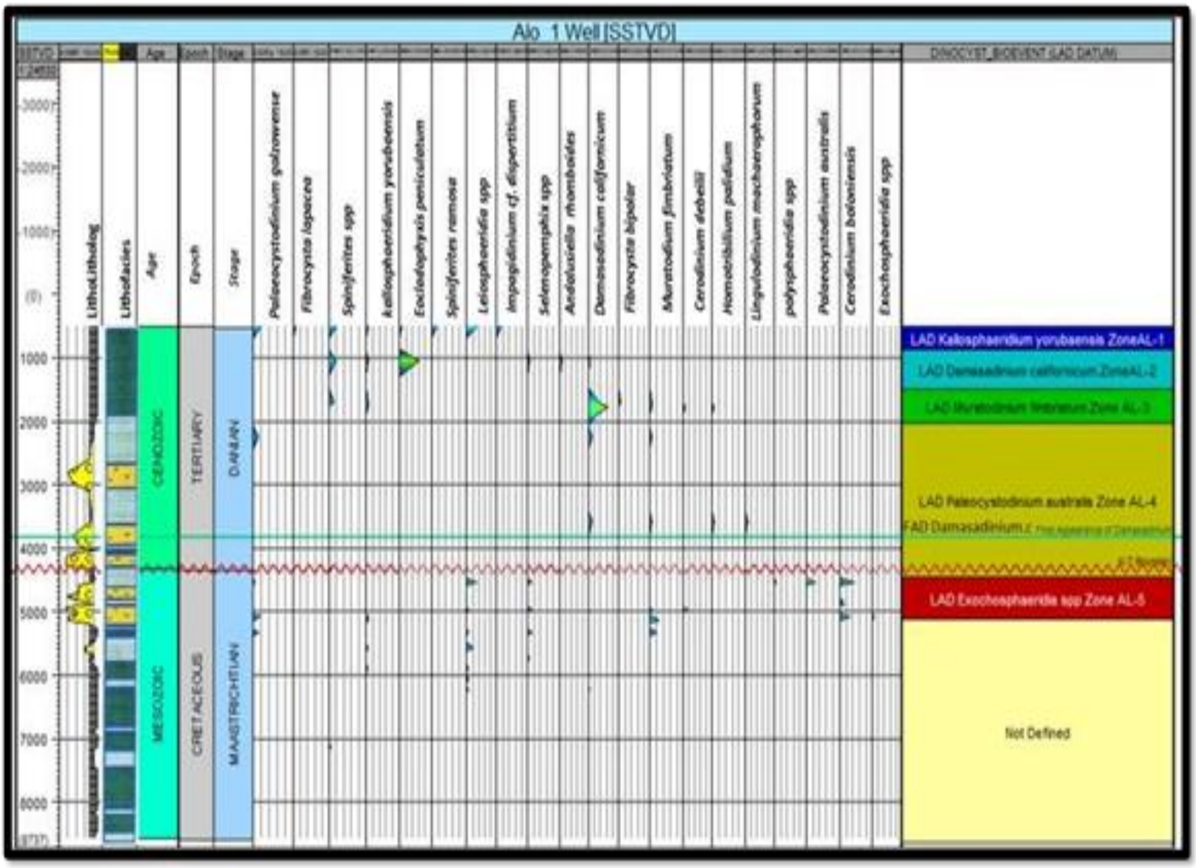

Figure 6: Dinocysts Chronostratigraphic Chart for Alo-1 Well

Dinocysts Assemblage Zones

The *Kallosphaeridium yorubaensis* Assemblage Zone

Reference Depth: 540ft -1080ft

Age: Danian

The top of this zone is marked by the last appearance datum of *Kallosphaeridium yorubaensis* (540ft) and the base of this zone is characterized by the last appearance datum of *Damasadinium californicum* (1080ft). The last appearance datum of species *Paleocystodinium golzowense, Fibrocysta lapacea, Spiniferites spp., Euclydophyxis peniculatum, Spiniferites ramose, Leiosphaeridia spp., Impagidinium spp., Selenopemphix warensis* and *Andalusiella rhomboides* occurs within this zone. Acme occurrence of *Euclydophyxis peniculatum* was recorded within the zone.

The *Damasadinium californicum* Assemblage Zone

Reference Depth: 1080ft-1740ft

Age: Danian

The top of this zone is defined by the last appearance datum of *Damasadinium californicum* (1080ft) and the base of the zone is defined by the last appearance datum of Muratodinium *fimbriatum* (1740ft). The only event within the zone is the last appearance datum of *Fibrocysta bipolar.*

The *Muratodinium fimbriatum* Assemblage Zone

Reference Depth: 1740ft-1800ft

Age: Danian

The top of this zone is marked by the last appearance datum of *Muratodinium fimbriatum* (1740ft) and the base of the zone is marked by the last appearance datum of *Lingulodinium machaerophorum* (1800ft). Events within this zone include the last appearance datum of *Cerodinium diebeilli* and acme occurrence of *Damasadinium californicum.*

The *Lingulodinium machaerophorum* Assemblage Zone

Reference Depth: 1800ft-4570ft

Age: Late Maastrichtian-Danian

The top of this zone is marked by the last appearance datum of *Lingulodinium machaerophorum* (1800ft) and the base of the zone is marked by the last appearance datum of *Paleocystodinium golzowense* (4570ft). Events within this zone include the last appearance datum of *Polysphaeridia spp.* and acme occurrence of *Leiosphaeridia spp.*

The *Paleocystodinium australis* Assemblage Zone

Reference Depth: 4570ft-5110ft

Age: Late Maastrichtian

The top of this zone is marked by the last appearance datum of *Paleocystodinium australis* (4570ft) and the base of the zone is marked by the last appearance datum of *Exochosphaeridia spp.* (5110ft). Events within this zone include the consistent and acme occurrence of *Cerodinium boloniensis.*

MIOSPORE ASSEMBLAGE ZONES

The *Longapertites marginatus* Assemblage Zone

Reference Depth: 540ft-1080ft

Age: Danian

The top of this zone is defined by the last appearance datum and consistent occurrence of *Longapertites marginatus* (540ft) *and* the base of the zone is defined by the last appearance datum of *Monocolpites marginatus* (1080ft). Events within this zone include the occurrence of *Deltoidspora spp., Inaperturopollenites spp., Laevigatosporites spp., Lycopodium spp., Monoporites annulatus, Proxapertites curcus, Auricullopollenites echinatus, Retitricolporites crassicostatus, Retistephanoclpites williamsi, Retitricolpites* *americana, Sartuna enigmaticus, Gematricolpites scrabatus, Tetrad (206), Rretitricolpites clarensis, Belkipollis elegans.*

The *Monocolpites marginatus* Assemblage Zone
Reference Depth: 1080ft-1800ft
Age: Danian
The top of this zone is defined by the last appearance datum of *Monocolpites marginatus* (1080ft) and the base of this zone is define by the last appearance datum of *Echitriporites trianguliformis* (1800ft). Events within this zone includes the occurrence of species such as Species *Retitricolporites irregularis, Triplanosporites spp., Dictyophyllidites harrisii, Gleischenidites spp., Mauriitidites crassibaculatus, Proxapertites operculatus, Retitricolpites spp., Longerpatites vaneendenburgi, Longapertites microfoveolatus, Longapertites microfoveolatus, Verrucatosporites usmensis, Retidiporites magdalenensis, Monosulcites spp., Psilatricolporites spp., Mantonisporites spp., Dictyophyllidits spp.,* and *Anacolosidites spp.*

The *Echitriporites trianguliformis* Assemblage Zone
Reference Depth: 1800ft-1920ft
Age: Danian
The top of this zone is defined by the last *Echitriporites trianguliformis* (1800ft) and the base is defined by the last appearance *Spinizonocolpites baculatus* (1920ft). Events within this zone are the occurrence of species *Echiperiporites estalae, Psilamonocolpites spp., Tricolpollenites spp., Elaeis guineenses, Ephedripites costaliferous, Leitrioletes spp. Momipites africanus,* and *Striatricolpites catatumbus.*

The *Spinizonocolpites baculatus* Assemblage Zone
Reference Depth: 1920ft-4360ft
Age: Danian
The top of this zone is defined by the last appearance datum of *Spinizonocolpites baculatus* (1920ft) and the base this defined by the last appearance of *Constructipollenites ineffectus* (4360ft). Events within this zone include the occurrence of *psilatricolporites transversalis, Retimonocolpites spp., Cretacaeiporites scrabatus, Concavissimisporites spp.* and Praedapollis *africanus.*

The *Constructipollenites ineffectus* Assemblage Zone
Reference Depth: 4360ft-5350ft
Age: Maastrichtian
The top of this zone is defined by the last appearance datum of *Constructipollenites ineffectus* (4360ft) and the base is defined by the last appearance datum of *Syncolporites marginatus* (5350ft). Events within the zone include the occurrence of *Polypodaceiosporites spp., Rugulatisporites caperatus, Psilatricolpites spp., Buttinia andreevi, Taxodiaceaepollinites hiatus, Cingulatisporites ornatus, Aquipollenites minimus and Proxapertites tertiaria*.
The presence of *Buttinia andreevi*, *Cingulatisporites ornatus* and *Constructipollenites ineffectus* has been used to confirm a Late Maastrichtian age for this interval in this study.

The *Syncolporites marginatus Assemblage* Zone
Reference Depth: 5350ft-5770ft
Age: Maastrichtian
The top of this zone is defined by the last appearance datum of Syncolporites marginatus (5350ft) and the base is defined by the last appearance datum of *Proteacidites longispinosus* (5770ft). The zone is also marked by the last appearance datum of *Zlivisporis blanensis, Cyathidites australis, Ephedripites ambonoides* and *Steevesipollenites orbiculatus.*

The *Proteacidites longispinosus* Assemblage Zone
Reference Depth: 5770ft-6100ft
Age: Maastrichtian
The top of this zone is defined by the last appearance datum of *Proteacidites longispinosus* (5770ft) and the base is defined by the last appearance datum of *Baculatisporites spp.* (6100ft). The zone is also marked by the last appearance datum of *Syndemicolpites typicus,* the first appearance datum and acme occurrence of *Constructipollenites ineffectus.*

The *Baculatisporites spp.* Assemblage Zone
Reference Depth: 6100ft-7060ft
Age: Maastrichtian
The top of this zone is defined by the last appearance datum of *Baculatisporites spp.,* (6100ft) *and* the base is defined by the first appearance datum of *Buttinia andreevi* (7060ft). The FAD of *Monocolpites marginatus* occurs within this zone, a regular occurrence of *Verrucatosporites usmensis* also marks this zone.

The *Deltoidospora spp.* Assemblage Zone
Reference Depth: 7060ft-7400ft
Age: Maastrichtian
The top of this zone is defined by the first appearance datum of *Buttinia andreevi* (7060ft) and the first appearance datum of *Deltoidospora spp.* (7400ft). The first appearance datum of *Verrucatosporites usmensis* and *Cyathidites australis* occurs within this zone.

The *Retidiporites magdalenensis* Assemblage Zone
Reference Depth: 7400ft-8200ft
Age: Maastrichtian
The top of this zone is defined by the first appearance datum of *Deltoidospora spp.* (7400ft) *and* the base is defined by the first appearance datum of *Retidiporites magdalenensis* (8200ft). The zone is marked by a consistent occurrence of *Laevigatosporites spp.* and *Echiperiporites estalae.* The last appearance datum of *Afropolis jardinus* occurs within this zone.

The *Afropolis jardinus* Assemblage Zone
Reference Depth: 8200ft-8600ft
Age: Maastrichtian
The top of this zone is defined by the first appearance datum of *Retidiporites magdalenensis* (8200ft) *and the base is marked by the first appearance datum of Afropolis jardinus. Other bioevents includes the first appearance datum of Monoporites annulatus* and *Monosulcites spp.*

Paleoenvironmental Reconstruction
The Paleoenvironment of deposition of the sedimentary succession penetrated by the well was established based on the palynomorph abundance pattern with depth.
Shelf Environment
***Reference Section:* 540ft-5340ft**
A shelf environment was established for this environment based on occurrence of both abundance of miospores and microphytoplankton (Gonyaulacacean and Peridiniacean dinocysts) as seen from the graphical plot (Table 5.3). Although the miospore abundance dominates over the microphytoplankton abundance, the regular occurrence of the dinocyst is indicative of marine influence, this too is supported by the near regular occurrence of foram test lining in this interval. The energy of the environment is inferred to be high because of the regular occurrence of both Gonyaulacacean and Peridiniacean dinocysts. The salinity of the environment is high, this was established based on the regular occurrence of the dinocysts.

The paleoenvironment between 5340ft-8600ft is undiagnostic. There was a general decrease in palynomorph abundance with depth. The dinocysts became scarce with depth, but a few miospores were seen. The general decrease in abundance has been attributed to over maturity of the sediments; this is supported by the very dark colour of the few palynomorphs recovered. Though there were miospores, a terrestrial environment will not be fitting for this interval because the lithologic type is mainly shale.

Conclusion

Sedimentologic and Palynological study of sedimentary succession of Alo -1 well yielded about a hundred palynomorphs species. The assemblage was dominated by miospores, dinocysts and minor occurrence of foram test linings and fungal spores. Three lithofacies comprise the sedimentary succession within the well; shale, sandy shale and shaly sand. Important minerals identified were carbonate, mica and Fe- oxide.

A shelf environment was delineated for part of the succession penetrated (540ft- 5340ft) based on the mixed occurrence of miospores and phytoplankton (dinocyst), the depth between 5340ft-8600ft is obscured because of insufficient palynomorph recovery attributed to destruction probably from over maturity of the sediments. The relative salinity of the environment is high; also the relative energy level of the environment is high. A Danian stage was delineated for successions between 540ft-4360ft and the Formation inferred to be Imo Formation. A Maastrichtian stage between 4360ft- 8600ft and the Formations inferred are: Nsukka Formation-Ajali-Mamu.

Two maximum flooding surfaces (MFS) (61.1 Ma and 64.6 Ma are their respective age) and one sequence boundary (63.0Ma) was delineated in the Danian succession. Three maximum flooding surfaces (MFS) and two sequence boundaries (SB) were delineated in the Maastrichtian successions and their respective ages. The maximum flooding surfaces are 67.9 Ma (Present at the base of Lithozone-17), 69.8Ma (Present in Lithozone-14) and 73.5Ma (Present within Lithozone-6) and sequence boundaries 65.0Ma and 68.0Ma. The maximum flooding surfaces delineated are events that are traceable on seismic and as such can be used to define tops and base (seals) for potential reservoirs within the well.

Acknowledgement

The authors are grateful to Integrated Data Services Limited - Nigerian National Petroleum Corporation IDSL-NNPC for providing ditch cutting samples used for these findings. Special thanks to the National Petroleum Investment Management Services (NAPIMS) for the assistance accorded the authors.

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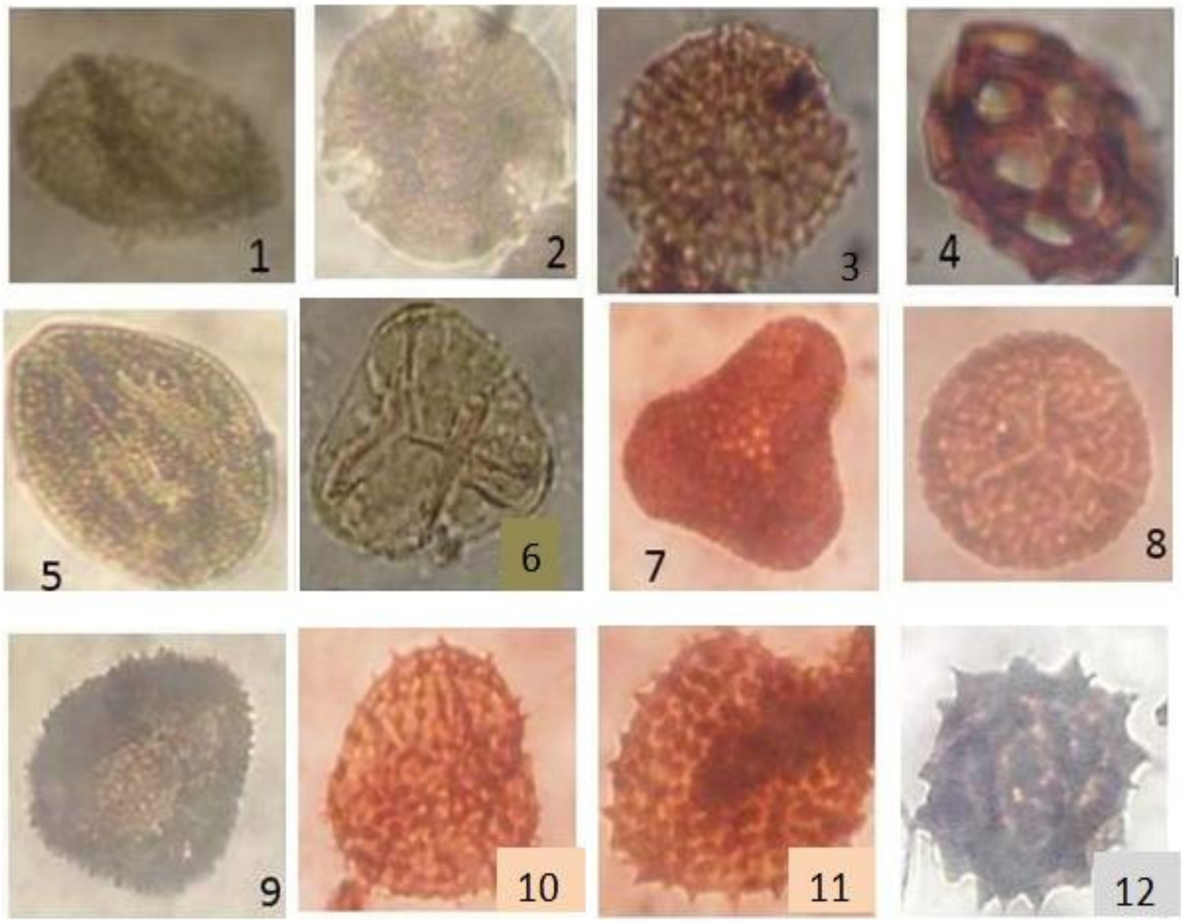
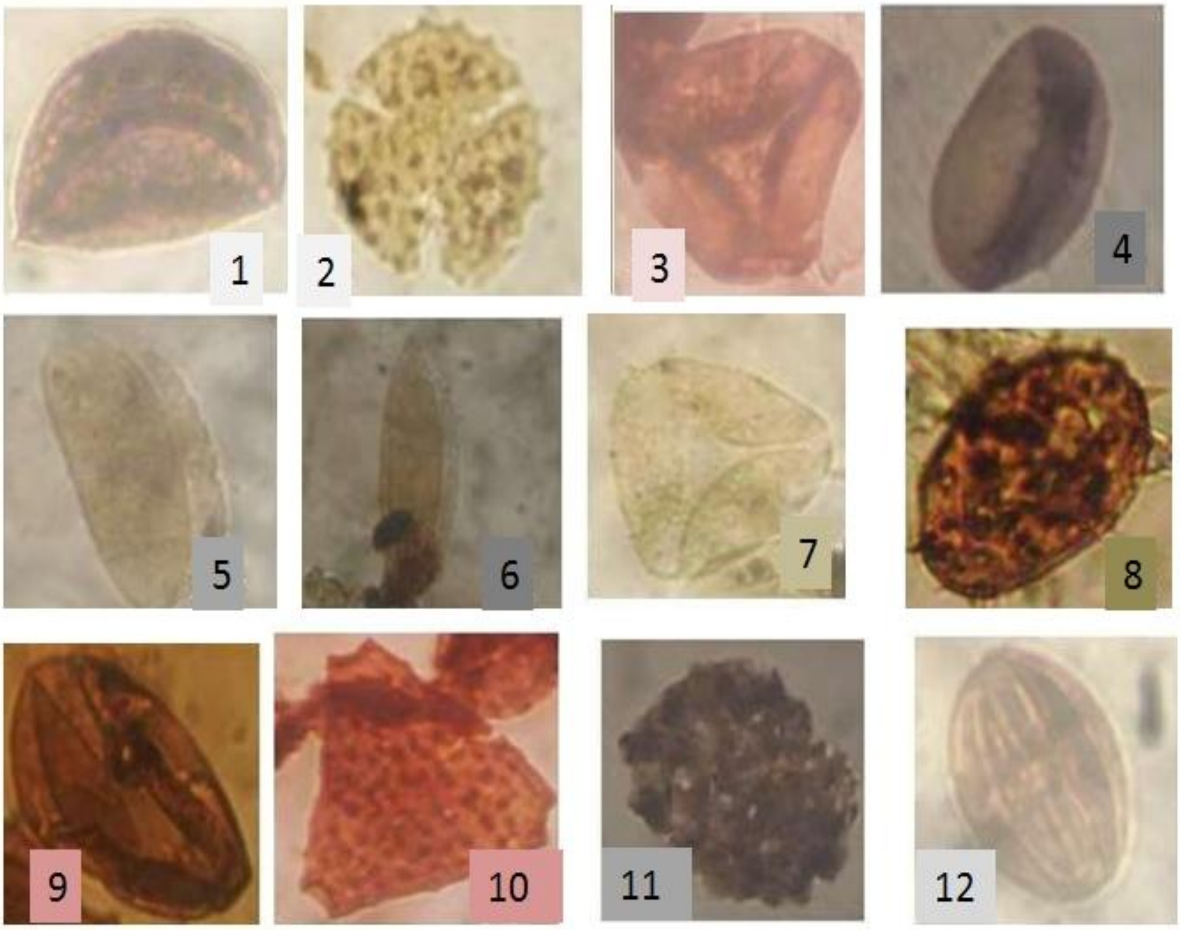
Appendix

Plate 1 (Miospores)



1. *Afropollis jardinus*
2. *Anacolocidites spp.*
3. *Constructipollenites ineffectus*
4. *Buttinia andreevi*
5. *Belkispolis elegans*
6. *Dictyophyllidits harrisii*
7. *Concavissimisporites punctatus*
8. *Rugilatisporites caperatus*
9. *Cingulatisporites ornatus.*
10. *Echiperiporites estalae*
11. *Echitriporites trianguliformis*
12. *Echitricolporites spinosus* (All magnification at X400)

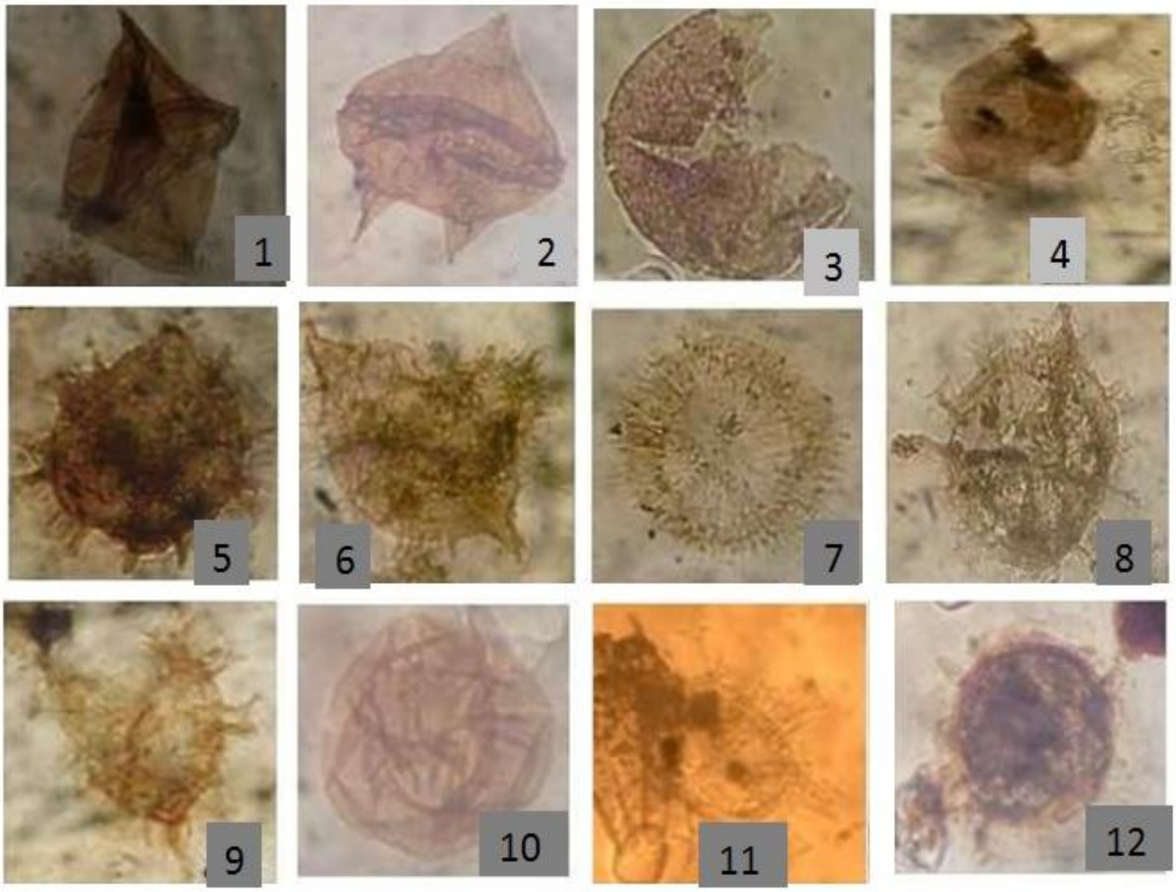
Plate 2 (Miospores)



1. *Ephedripites amobionides*
2. *Gematricolpites scabratus*
3. *Kyrtomisporis spp.*
4. *Laevigatosporites spp.*
5. *Longapertites marginatus*
6. *Longapertites microfoveolatus*
7. *Longapertites vaneendeburgi*
8. *Momipites africanus*
9. *Monoculpites marginatus*
10. *Mauriitidites crassibaculatus*
11. *Proteacidites longispinosus*
12. *Proxapertites cursus*

(All magnification at X400)

Plate 3 (Dinocysts)



1. Andalusiella rhomboids
2.Cerodinium boloniensis
3. kallosphaeridium yorubaensis
4. Cerodinium diebelii
5. Damasadinium californicum
6. Damasadinium californicum
7. Euclydophyxis peniculatum
8. Fibrocysta lapacea
9. Fibrocysta bipolar
10. Leiosphaeridia spp.
11. Homotribilium pallidium
12. Muratodinium fimbriatum

(All magnification at X400)