Biostratigraphy and Depositional Environments of Wells BB-3, D-01 and BL-1X Deep Offshore, Niger Delta Basin, Nigeria: Insights from Palynological Studies

[1]Usman, H.O., [2]Unuevho, C.I., [2]Chukwuma-Orji, J.N. and [2]Alkali, Y.B.

[1]Nasarawa State University, Keffi
[2]Federal University of Technology, Minna

Corresponding author: ogelebehu@gmail.com

Abstract

Biostratigraphic studies was carried out on BB-3, D-01 and BL-1X wells deep offshore Niger Delta Basin, Nigeria. Palynological analysis was carried out on 295 ditch cutting samples (BB- 3 = 82, D-01= 109, and BL-1X= 104). Open hole geophysical log data was also provided for the studied intervals 10700-15600 ft, 8060-16860 ft and 7900-13000 ft in BB-3, D-01 and BL-1X wells respectively belonging to the Agbada Formation. Lithologically, the section varies from alternation of sand and shale units with carbonaceous debris, mica flakes, ferruginised materials and glauconite at some interval as accessory minerals. Palynomorphs recovered from the analyzed interval were mainly *Zonocostites ramonae*, *Monopoorites annulatus*, fungal spores/hyphae, species of *Sapotaceoidaepollenites* and *Laevigatosporites and were found to* dominate the microfloral assemblage of the analyzed intervals. Sphaeromorph acritarch species of *Leoisphaeridia* coupled with *Pediastrium, Botryococcus, Operculodinium centrocarpum, Lingulodinium machaerophorum*, *Achomosphaera ramulifera, Spiniferites ramosus* and indeterminate dinoflagellate cysts were the marine indicators present. Samples from the section are dated early Miocene to early Pliocene age based on the independent paleontological evidences. The deduced depositional environments of the strata penetrated by the wells range from outer neritic through bathyal to deep marine.

Keywords: Palynological, Biostratigraphy, Environment, Miocene, Bathyal

Introduction

BB-3 oil well is situated in BB field western part of the Niger Delta, and lies within latitude 5° 08′ 09″ N and longitude 4° 19′ 10″ E. While D-01 and BL-1X are situated in the D and BL fields in the southern part of the Niger Delta, and lie within latitude 3° 28′ 45″N and longitude 6° 31′ 23″ E and latitude 3° 31′ 42″ and longitude 6° 56′ 25″ E respectively.

The studied wells are all located in the deep offshore Niger Delta area, Nigeria (Figure 1). The Niger Delta is situated in the Gulf of Guinea on the west coast of Central Africa. It lies between latitudes 4° and 6° N and longitudes 3° and 9° E in southern Nigeria (Figure 1). The 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 (Obaje and Okosun, 2013). The sediment fill has a depth between 9–12 km. It is composed of several different geologic formations that indicate how this basin could have formed, as well as the regional and large scale tectonics of the area (Fatoke, 2010). The Niger Delta Basin is an extensional basin surrounded by many other basins in the area that all formed from similar processes and lies in the south westernmost part of a larger tectonic structure, the Benue Trough. The other side of the basin is bounded by the Cameroon Volcanic Line and the transform passive continental margin (Fatoke, 2010).

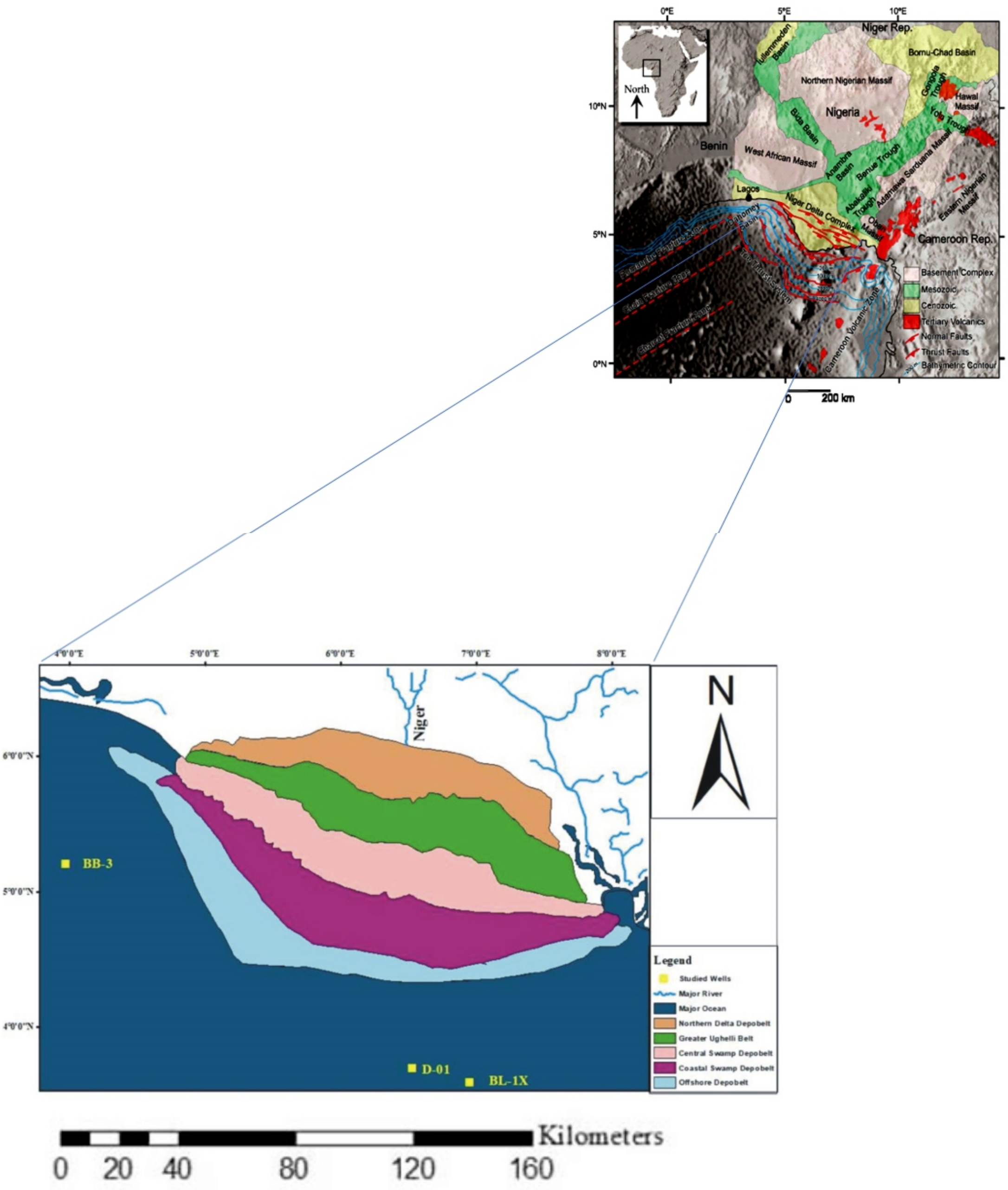


Figure 1: Location of the studied wells in the deep offshore (Redrawn after Okosun and Chukwuma-Orji,2016)

Three lithostratigraphic units have been recognised in the subsurface (Short and Stauble, 1967) which are the basal and oldest Akata Formation that compose primarily of dark shale with occasional sand and considered the hydrocarbon producing unit. The middle Agbada Formation considered the main petroleum bearing unit and consisting of interbeded sandstone and shale. Lastly, is the topmost Benin Formation which consist of continental sand (Short and Stauble, 1967) (Figure 2). These formations were deposited in environments which are marine, transitional and continental respectively; forming a thick, progradational passive-margin wedge (Esan, 2002).

Three major depositional cycles have been identified within Tertiary Niger Delta deposits (Short and Stauble, 1967; Doust and Omatsola, 1990). The first two, involving mainly marine deposition, began with a middle Cretaceous marine incursion and ended in a major Paleocene marine transgression. The second of these two cycles, starting in the late Paleocene to Eocene time, reflects the progradation of a "true" delta, with an arcuate, wave- and tide-dominated coastline. These sediments range in age from Eocene in the north to Quaternary in the south (Doust and Omatsola, 1990). Deposits of the last depositional cycle have been divided into a series of six depobelts (Doust and Omatsola, 1990; also called depocenters or megasequences) separated by major synsedimentary fault zones (Figure 1). These depobelts formed when paths of sediment supply were restricted by patterns of structural deformation, focusing sediment accumulation into restricted areas on the delta. Such depobelts changed position over time as local accommodation was filled and the locus of deposition shifted basinward (Doust and Omatsola, 1990)

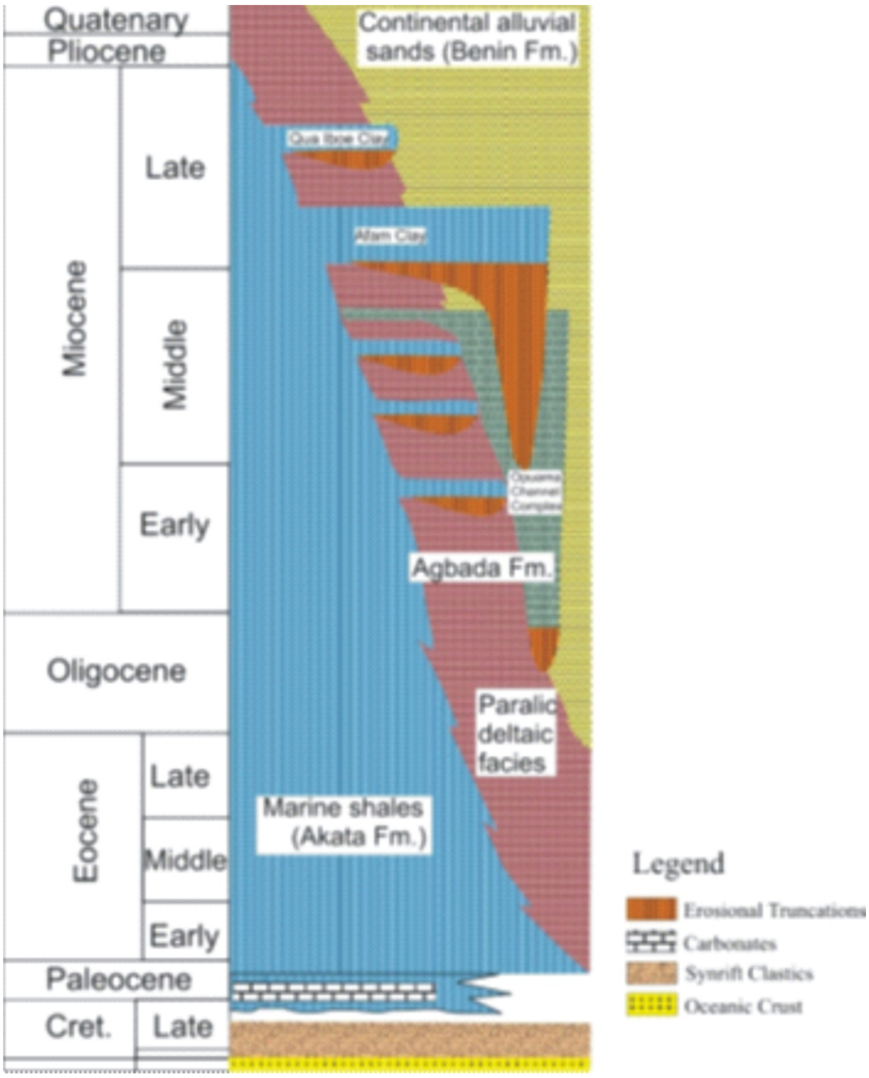


Figure 2: Lithostratigraphic column of the subsurface Niger Delta (After Lawrence *et al*., 2002).

This study encompasses biostratigrahic study involving palynological and open hole geophysical log data from BB-3, D-01 and BL-1X wells deep offshore Niger Delta Basin, Nigeria. Despite numerous works on the basin involving sedimentology, hydrocarbon potential, tectonic evolution, among others, biostratigraphic studies and research on the stratigraphic settings of the deep offshore Niger Delta basin is scanty, hence this study was carried out on strata penetrated by BB-3, D-01 and BL-1X wells in order to highlight the biozones and depositional environment which would assist exploration of other areas by solving geological problems through correlation.

Materials and Methods

Two hundred and ninety-five (295) ditch cutting samples (BB-3 = eighty-two (82), D-01= one hundred and nine (109), and BL-1X= one hundred and four (104)) composited at 60 ft interval provided by SNEPCO were utilized for this study. The intervals studied are 10700-15600 ft, 8060-16860 ft and 7900-13000 ft in BB-3, D-01 and BL-1X respectively. Open hole geophysical log data were also provided for the studied intervals. Palynological processing follows the standard acid preparatory method and is as follows:

Twenty grammes (20g) of each sample was treated with 10% HCl under a fume cupboard for the complete removal of carbonates that may be present in the samples. This was followed by complete neutralisation with distilled water before the next procedure. Then 40% HF was added to the sample which was placed on a shaker for 24 hours to speed up the reaction rate, to ensure a complete dissolution of the silicates that may be present in the samples and for the particles to settle down. Thereafter, the HF was carefully decanted, then followed by complete neutralisation with distilled water in order to remove fluoro-silicate compounds usually formed from the reaction with HF. Sieving and separation was performed using Brason Sonifier 250. Brason Sonifier is an electric device used with the aid of 5-micron sieve to filter away the remaining inorganic matter (silicates, clay, and mud) and heavy minerals to recover organic matters. It operates in a sonic vibration to filter out inorganic matter and heavy minerals. The treatment of samples with HCl and HF is referred to as demineralisation. The sieved residue was given controlled oxidation using concentrated nitric acid (HNO_3) for palynomorph slides. However, the oxidation process is omitted for palynodebris slide in order not to bleach the palynodebris. The level of oxidation required by each sample was closely monitored under a palynological microscope. This oxidation process is known as maceration. Staining with safranin O is done for palynodebris slides in order to enhance the clarity of dinoflagellate cyst. The prepared slides were studied under transmitted binocular microscope. Identification and analysis were attempted for as many forms as possible with the help of publications from Germeraad *et al.* (1968), Legoux (1978) and Bankole (2010).

Results and Discussion

Lithologic Interpretation

The lithology of the studied wells (BB-3, D-01 and BL-1X) consists of alternating shale and sandstone units. The shale is mostly grey to brownish grey in colour, platy to fissile in appearance. The sandstones are white to very light grey, coarse to fine grained, angular to subangular to rounded, and moderately to well sorted in texture. The accessories include ferruginous materials, mica flakes, and carbonaceous detritus. This observation suggested that the studied wells penetrated the Agbada Formation of the Niger Delta basin. These characteristics were also found in the work of Ukpong and Anyanwu, 2018, where it was interpreted that Agbada Formation as consisting of sandstone and shale alternations. The sandstones are light grey to smoky white, fine to coarse grained, moderately to well sorted, sub angular to subrounded, carbonaceous while the shale units are dark grey, subfissile to fissile, mostly hard to moderately hard, slightly calcareous and micaceous. This also agrees with the work of Reijers *et al.* (1997) that the Agbada Formation of the Niger Delta is composed of an alternation of sands and shales of equal proportion in the lower units as well as sands and minor shales in the upper units. This is also in line with the work of Short and Stauble (1967), which opined that the Agbada Formation is characterized by the alternation of sandstone and sand bodies with shale layers. The sandstone and shale alternations observed in the Agbada Formation of the Niger Delta are probably due to differential subsidence, sediment supply variations, as well as the transgression and regression episodes which caused a shift in the sediment depositional axis within the delta (Short & Stauble, 1967).

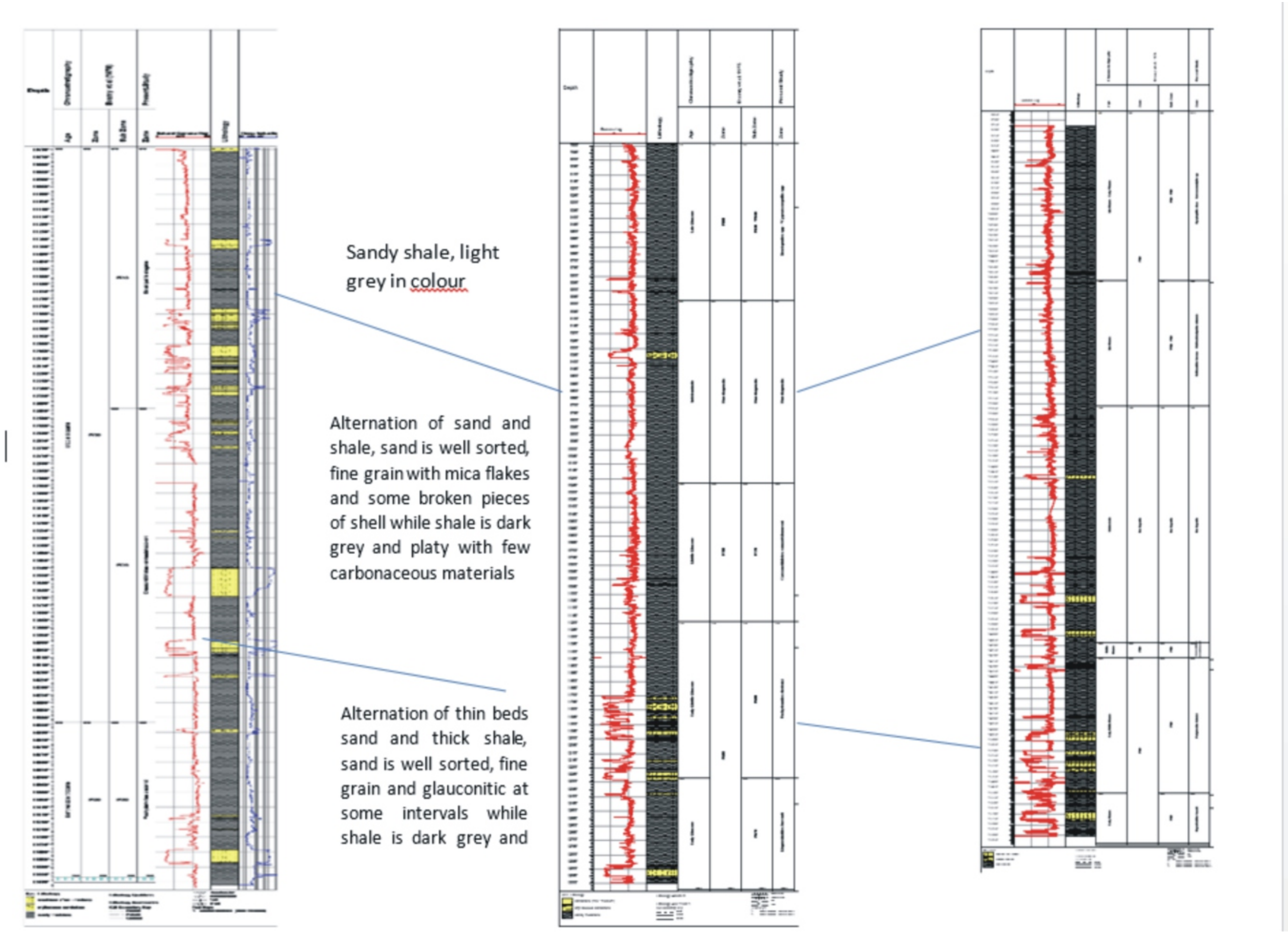


Figure 3: Lithologic logs of the Wells BB-3, D-01 and BL-1X

Biostratigraphy

Moderately rich, well preserved and fairly diverse palynomorph assemblage were recorded within the analyzed interval. *Zonocostites ramonae*, *Monosporites annulatus*, fungal spores/hyphae, species of *Sapotaceoidaepollenites* and *Laevigatosporites* dominated the microfloral assemblage of the analyzed section. Few specimens of marine indicator palynomorphs recorded include *Operculodinium centrocarpum, Lingulodinium machaerophorum*, *Achomosphaera ramulifera, Spiniferites ramosus* and indeterminate dinoflagellate cysts. Some of these forms recovered from the studied wells are illustrated in photomicrographs Plates 1, 2 and 3, while palynomorph and palynofacies distributions chart of well BB-3 is shown in Figure 4.

Highly abundant and fairly diverse miospores characterize the upper (9040-11840ft) while low abundance and low diversity of miospores were recorded within the middle part (11840-14090ft) of the analyzed interval in well D-01. However, moderately rich and fairly diverse miospores were recorded within lower interval (14090-15940ft) of the studied section. *Zonocostites ramonae*, *Monopoorites annulatus*, fungal spores/hyphae, species of *Sapotaceoidaepollenites* and *Laevigatosporites* dominated the microfloral assemblage of the analyzed interval. Only Sphaeromorph acritarch, species of *Leoisphaeridia* coupled with freshwater algae, *Pediastrium* and *Botryococcus* were the only marine indicators present within the analyzed well section. Recovered forms are shown on plates 1,2 ans 3, while palynomorph and palynofacies distributions are shown in Figure 5

Moderately rich and fairly diverse recoveries of miospores were recorded within interval 7710-8970ft while low to very low abundance and low diverse recoveries of miospore were recorded generally within interval 8970-10230ft. However, interval 10230-13020ft recorded a fairly rich and diverse miospores. Miospores such as *Zonocostites ramonae*, *Monopoorites annulatus*, fungal spores/hyphae, species of *Sapotaceoidaepollenites* and *Laevigatosporites* dominated the microfloral assemblage of the analyzed interval. Only freshwater algae, *Pediastrium* and *Botryococcus* were the only marine indicator palynomorphs present within the analyzed well section. Some recovered forms from the studied well is shown in Plates 1, 2 and 3, while palynomorph and palynofacies distributions chart of well BL-1X are shown in Figure 6.

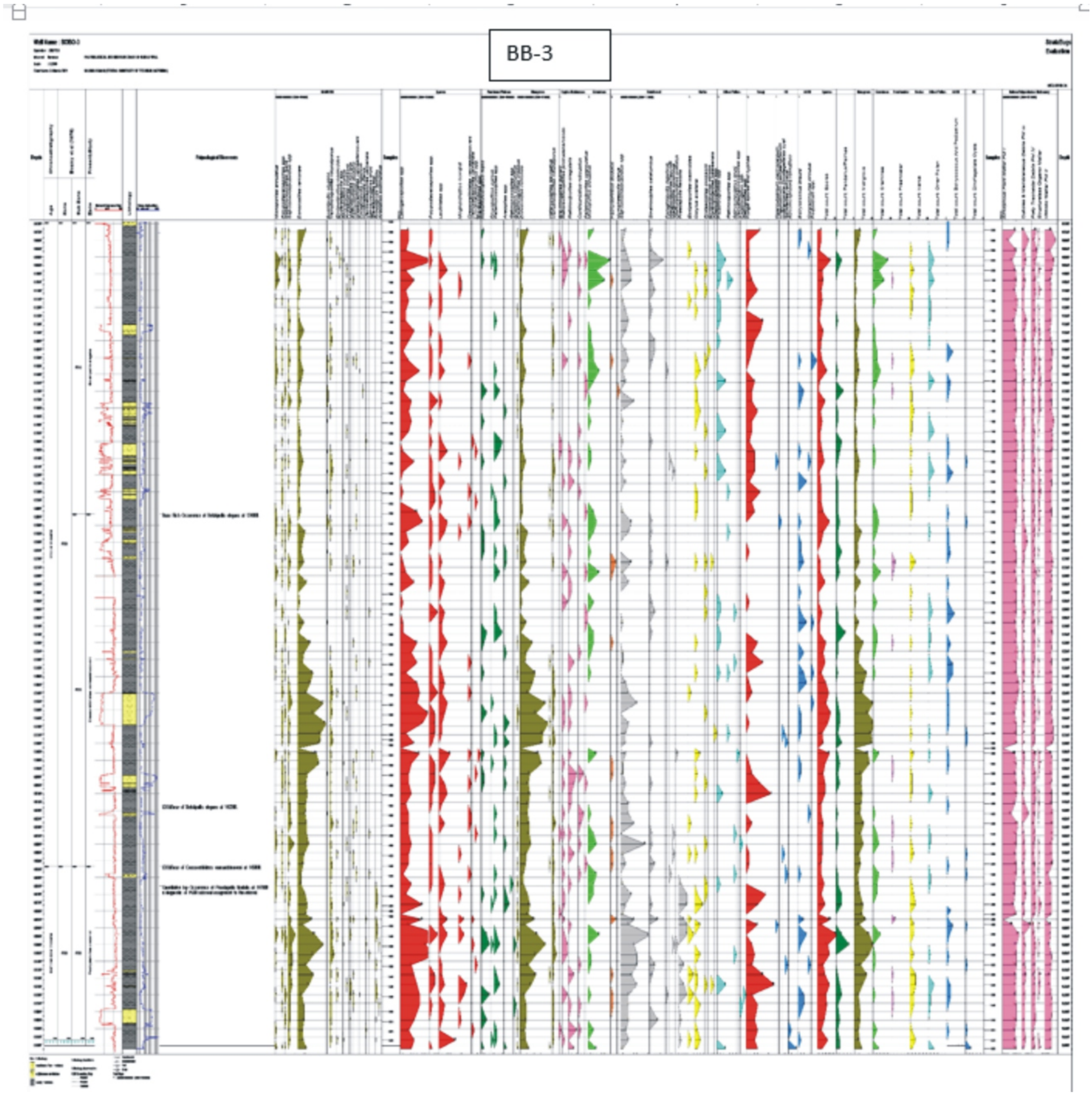


Figure 4: Palynomorph and palynofacies distribution chart of well BB-3

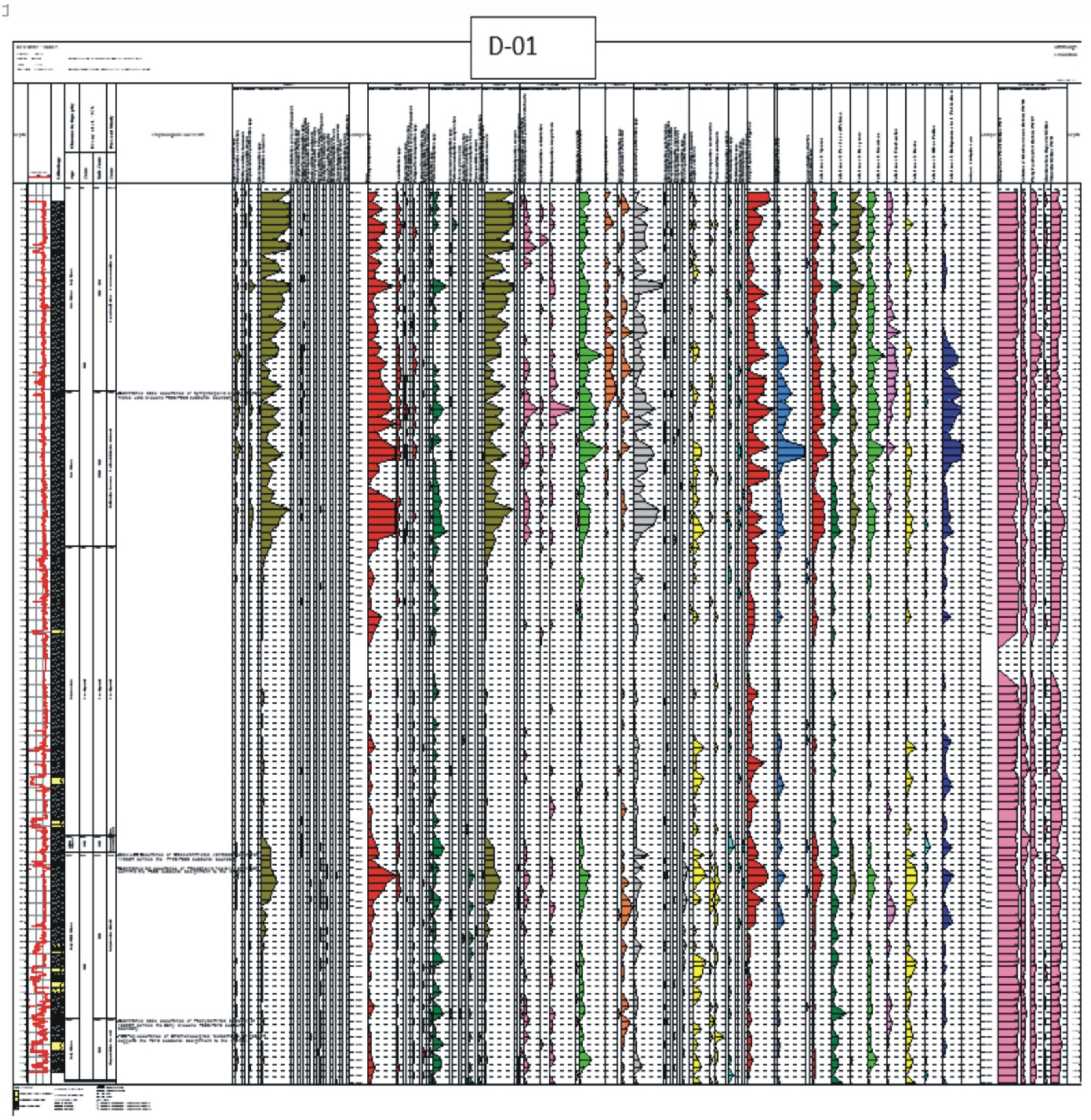


Figure 5: Palynomorph and palynofacies distribution chart of well D-01

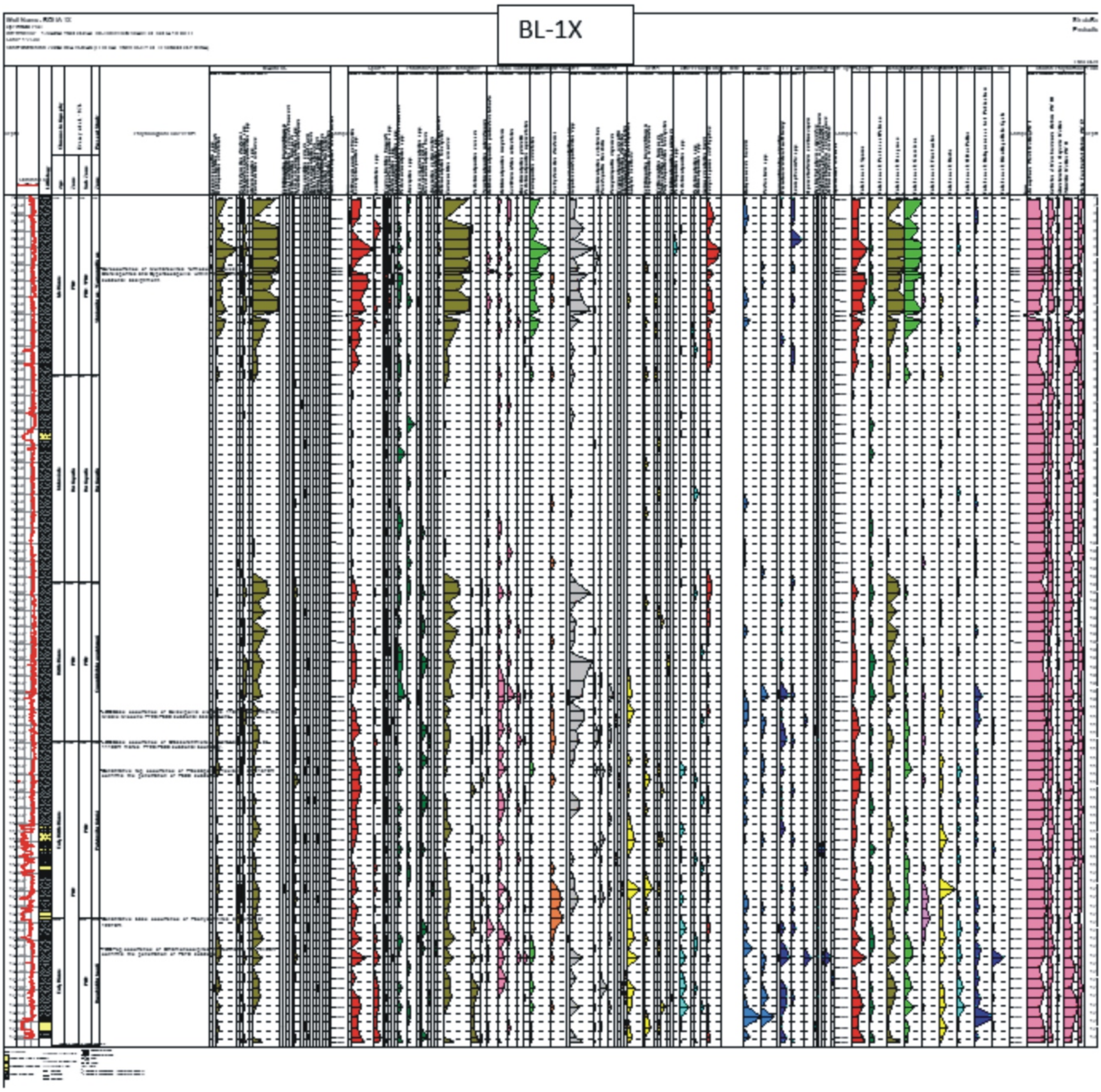


Figure 6: Palynomorph and palynofacies distribution chart of well BL-1X

Only well-established species with known stratigraphic ranges were utilized in deducing the geologic age, zones and subzones. The recovered forms were placed under their phytoecological groups proposed by Poumot (1989). *The occurrences of age diagnostic palynomorphs such as Verrutricolporites rotundiporus, Pachydermites diederixi, Cassoretitriletes vanraadshooveni, Magnastriatites howardii, Racemonocolpites hians, Praedapollis flexibilis, Multiareolites formosus,* and *Zonocostites ramonae at some intervals of the studied wells suggest Early to Middle Miocene.*

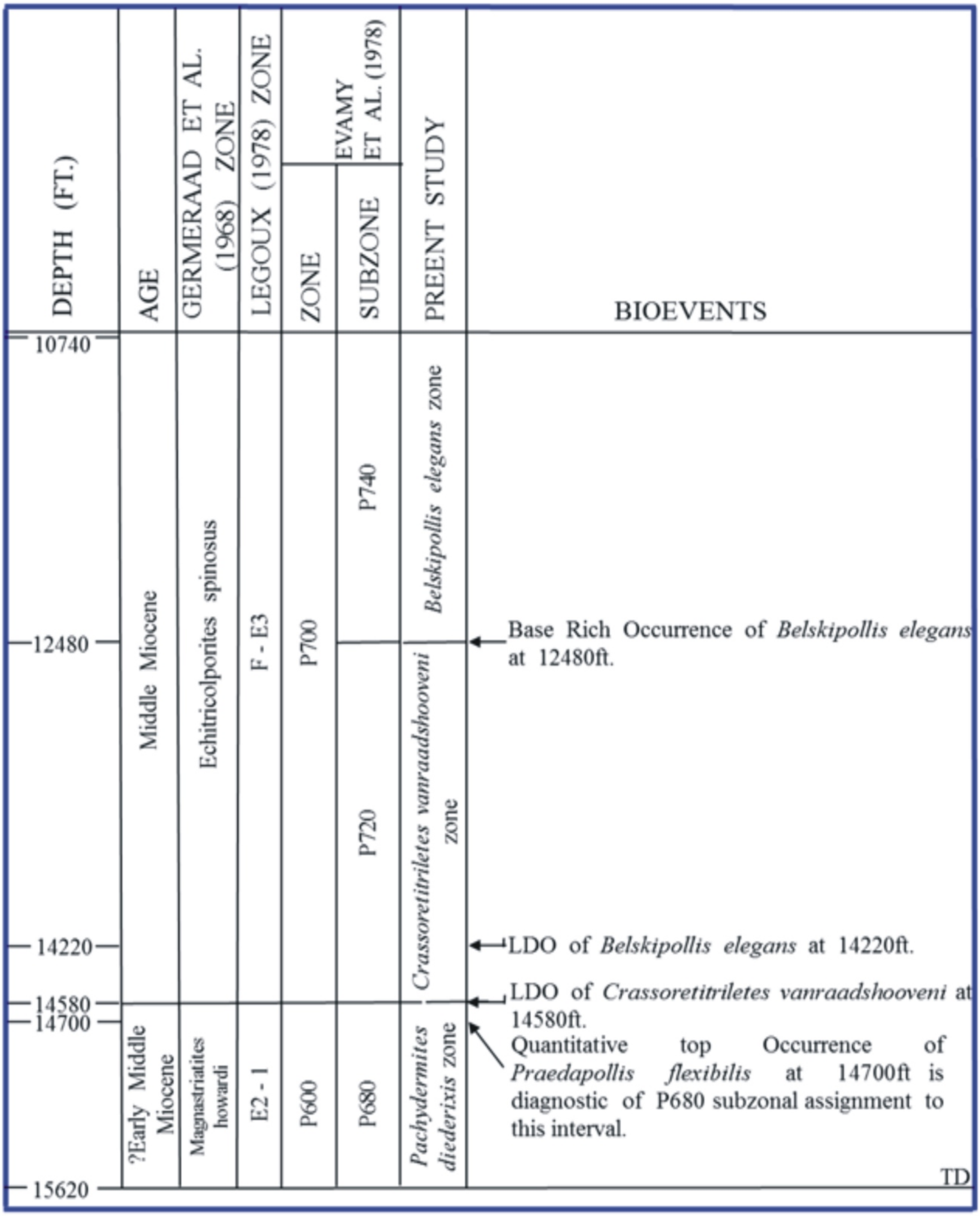


Figure 7: Palynological biozonation of well BB-3

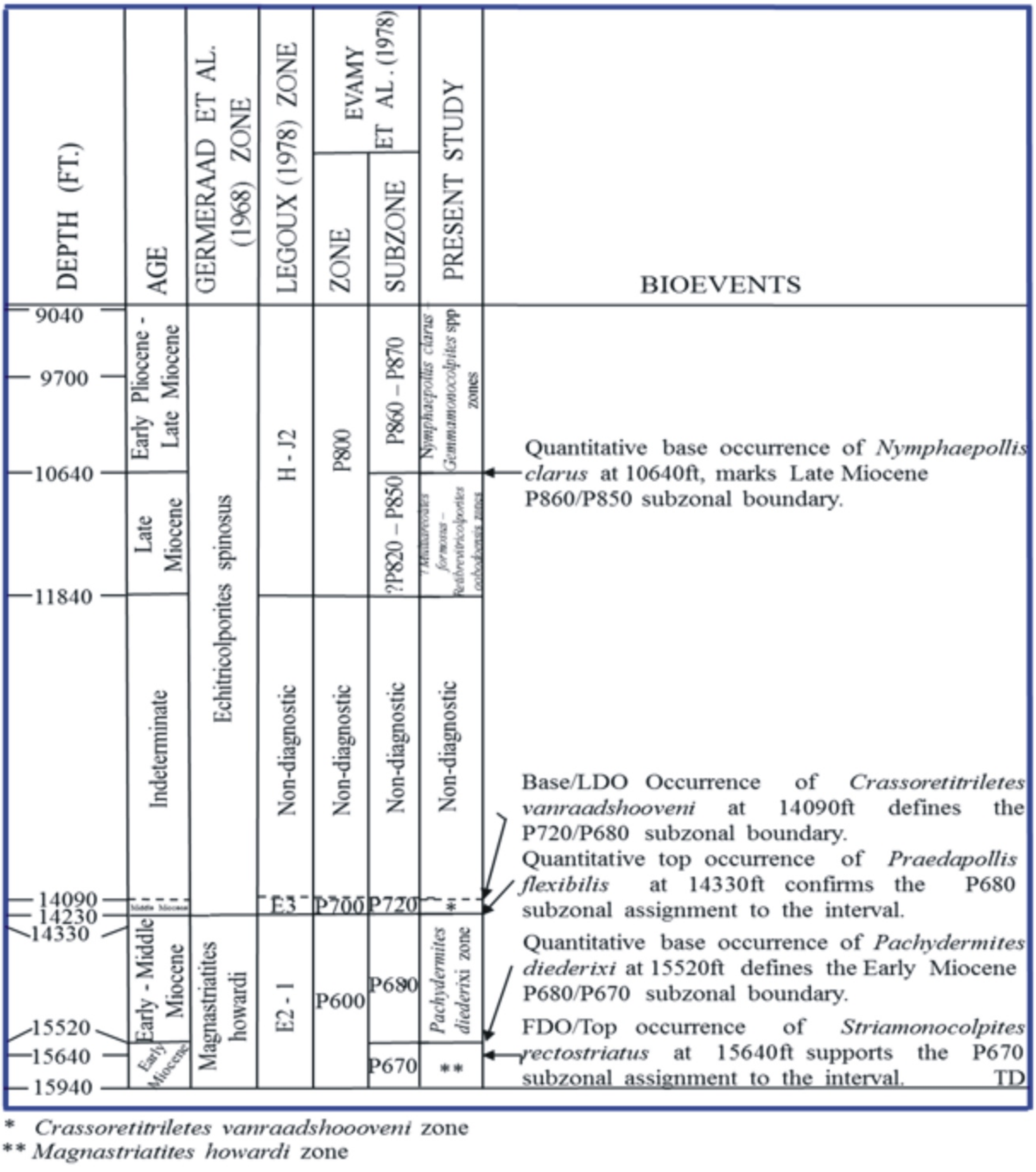


Figure 8: Palynological biozonation of well D-01

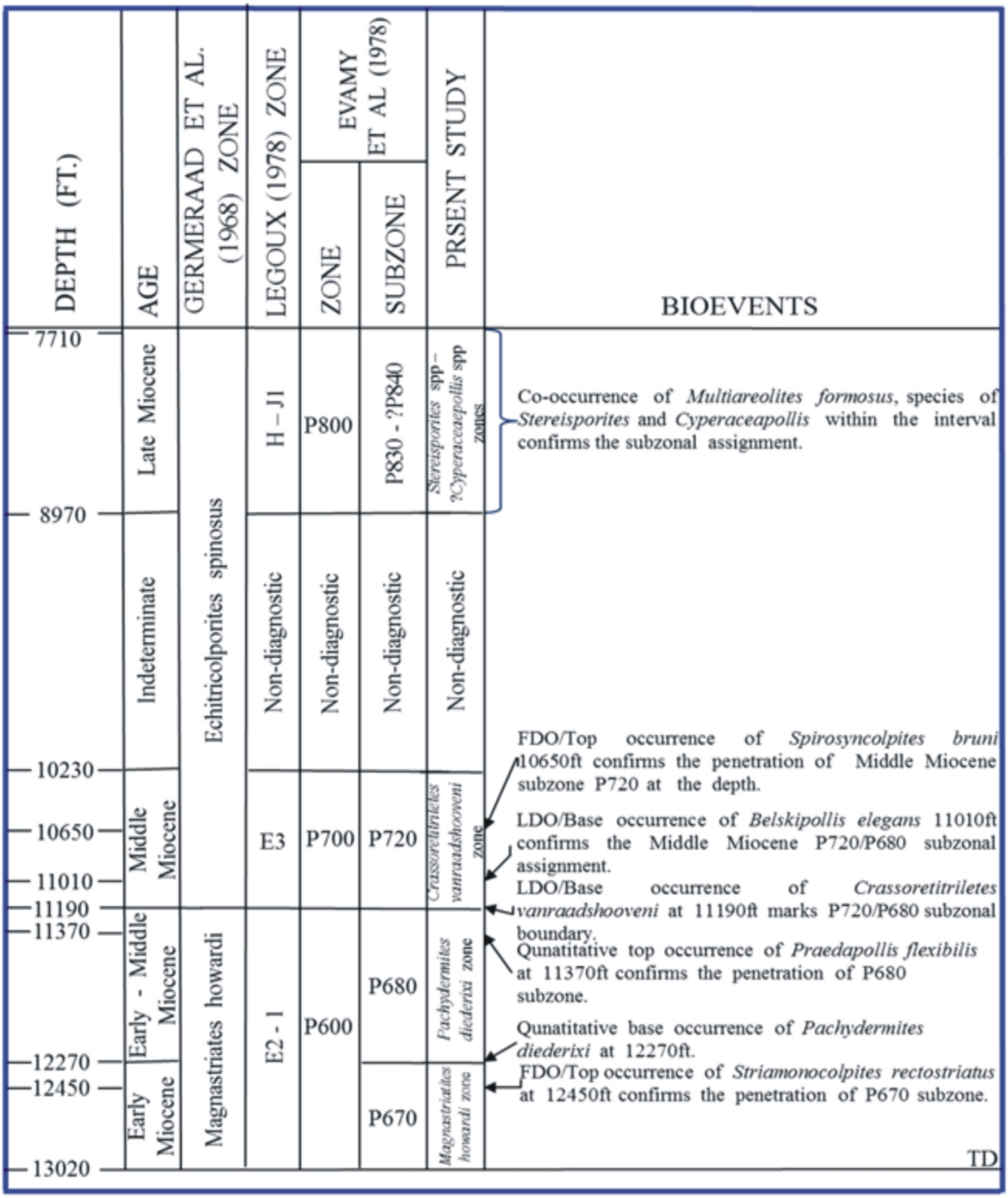


Figure 9: Palynological biozonation of well BL-1X

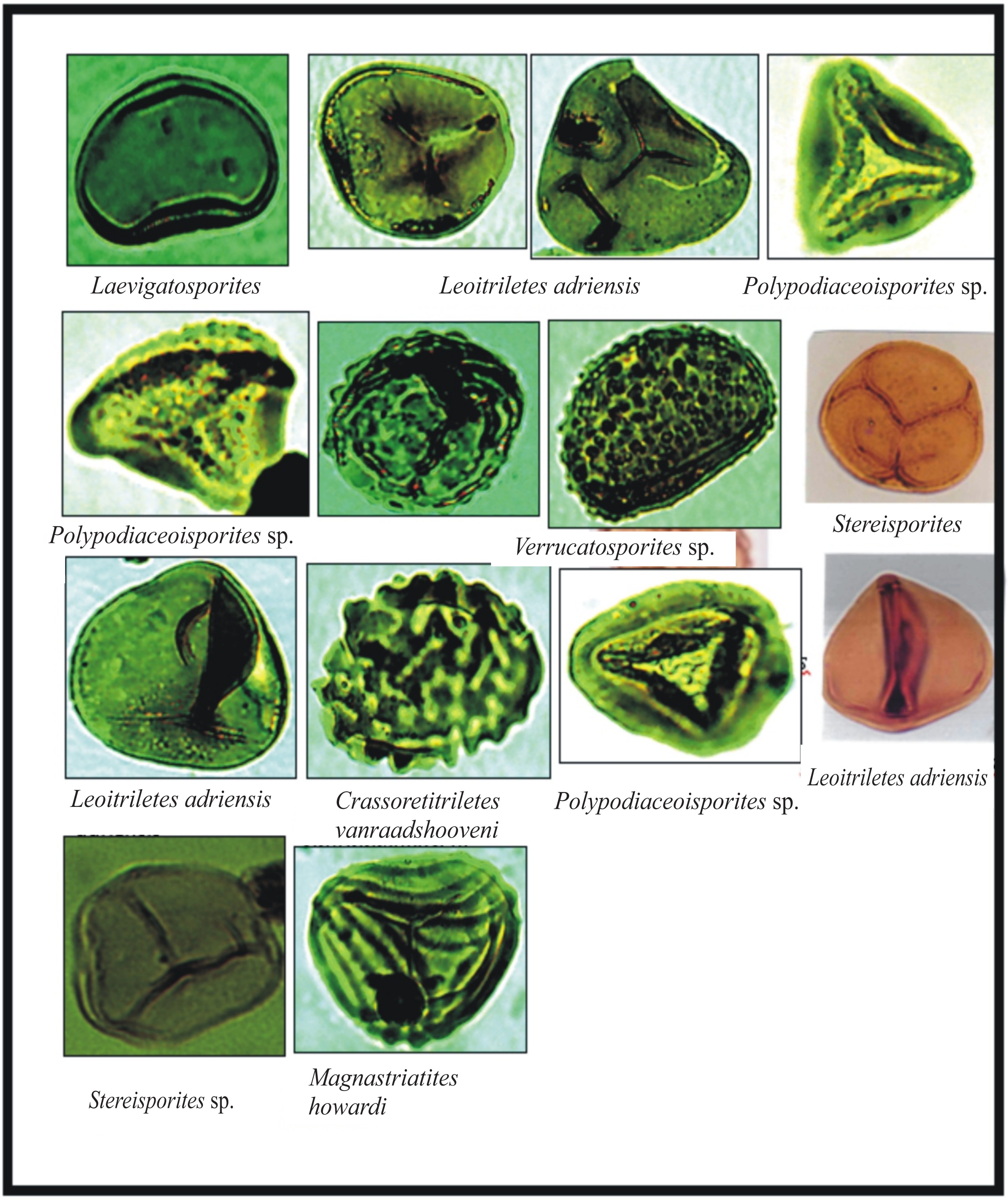


Plate 1: Palynomorphs recovered from the studied wells

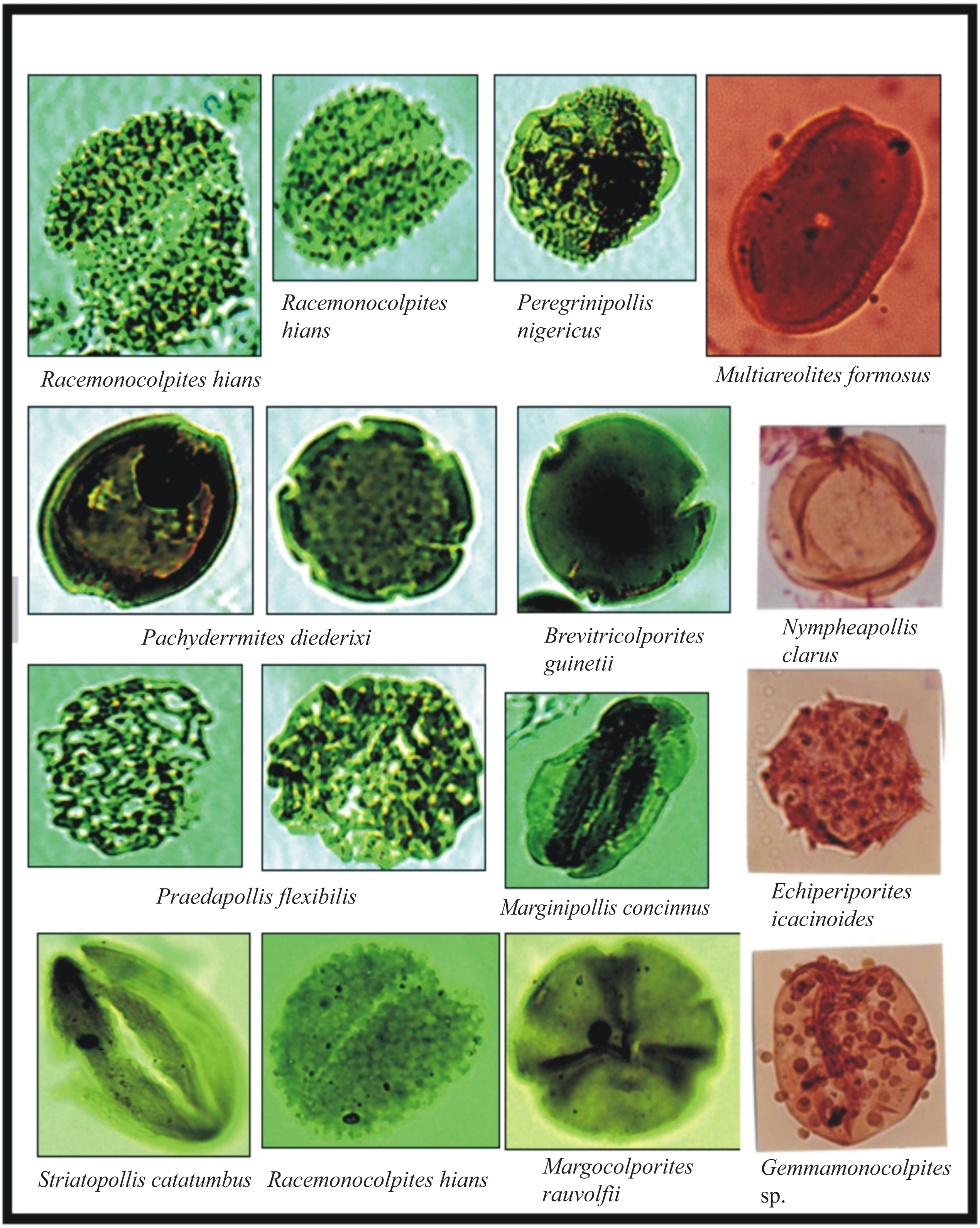


Plate 2: Palynomorphs recovered from the studied wells

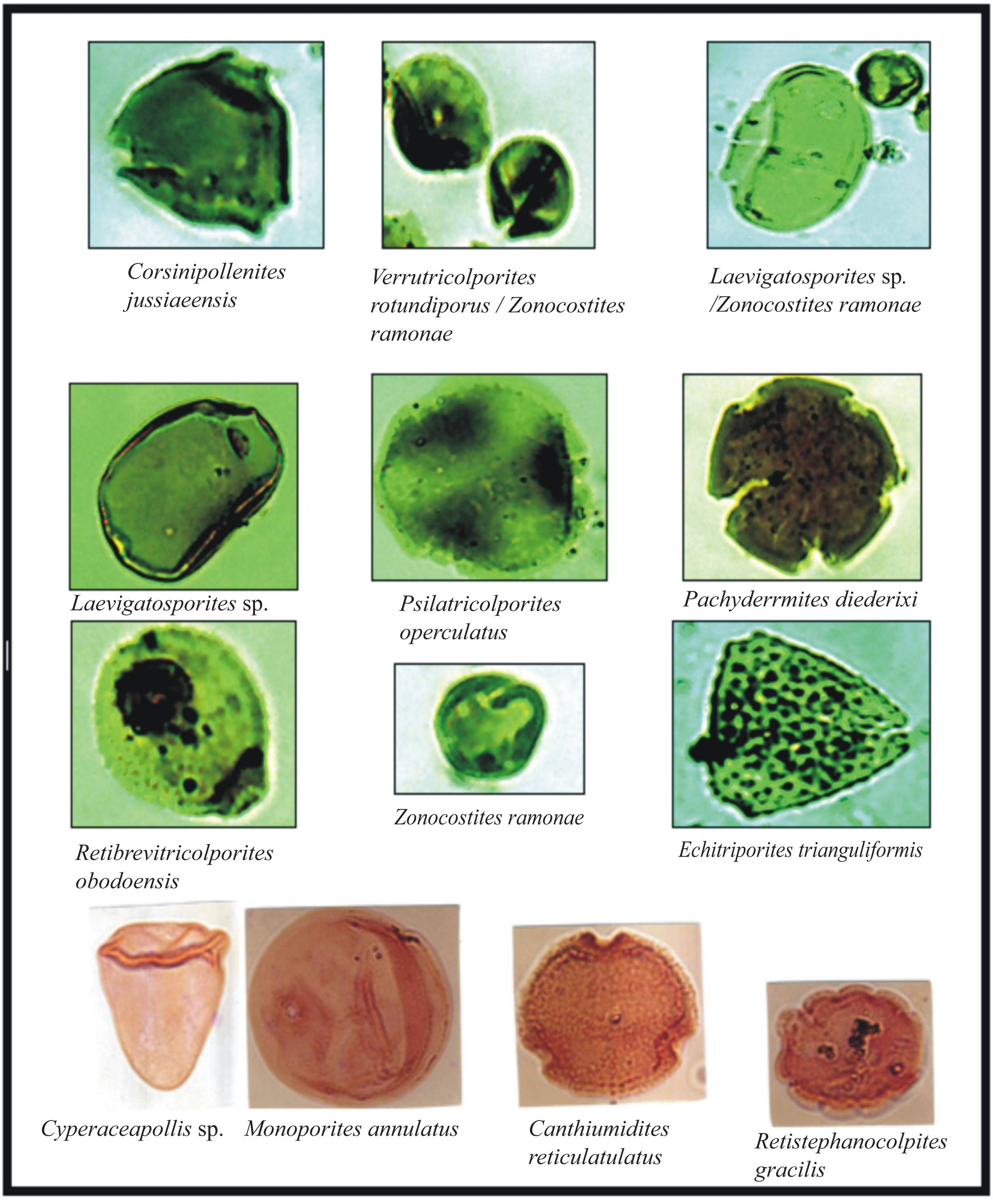


Plate 3: Palynomorphs recovered from the studied wells

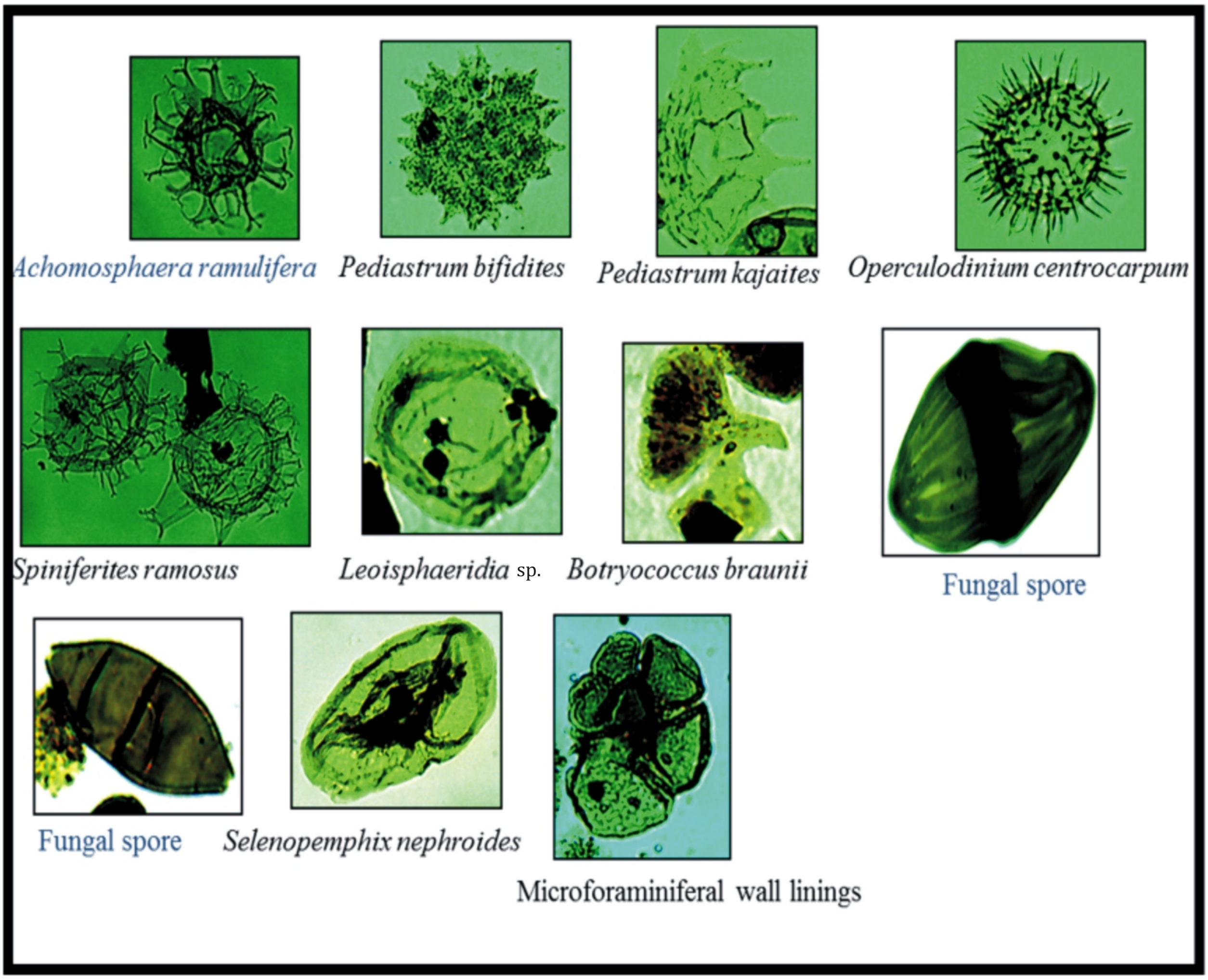


Plate 4: Palynomorphs recovered from the studied wells

Depositional Environments

The environments within which sediments of BB-3, D-01 and BL-1X wells are deposited were deduced based on the integration of well log motifs and palynological characteristics of these sediments. Species diversity and abundance and environmentally diagnostic species are the micropaleontological criteria which aided the deductions. In addition, the type and nature of the accessory microflora recorded within the intervals were also used in interpretations. Palynological criteria were based on the qualitative and quantitative composition of the total acid resistant organic content of sediments within the studied wells. Based on the above-mentioned criteria, wells BB-3, D-01 and BL-1X are deposited in the outer neritic-bathyal and bathyal -deep marine environments (Figure 10)

Bobo-3 intervals (ft)	Doro-1 interval (ft)	Bolia-1X interval (ft)	Inferred Depositional environment
10740-13040	9040-11780	8970-10230	Outer neritic – bathyal
13040-15620	11780-15940	10230-13020	Bathyal – deep marine

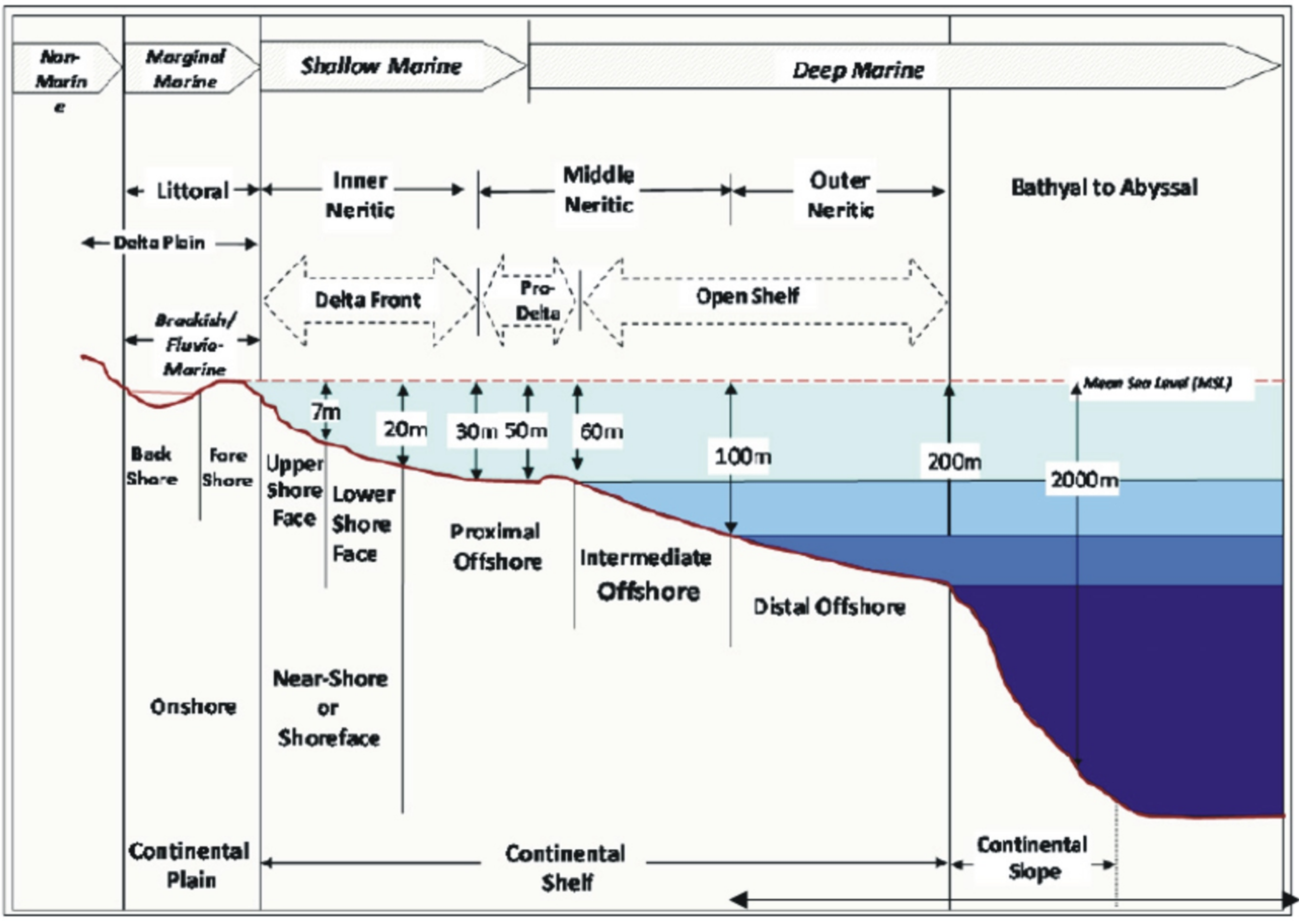
Figure 10: Depossitional environments of wells BB-3, D-01 and BL-1X

The intervals 10740-13040 ft, 9040-11780 ft, 8970-10230 ft in BB-3, D-01 and BL-1X wells respectively were delineated to have been deposited in the outer neritic-bathyal environments. (Figures 10 and 11). The reasons for this deduction are:

i. The intervals are characterised by high representation of *Laevigatosporites spp.* (pteridophyte spores), followed by *Sapotaceoidapollenites spp.* (rainforest taxa), and *Fungal spores and hyphae,* then *Monoporites annulatus* (savanna pollen), and *Zonocostites ramonae* (mangrove pollen). Chukwuma-Orji *et al.* (2021) reported that Pollen and spores like *Zonocostites ramonae, Verrucatosporites usmensis, Monoporites annulatus, Polypodiaceoisporites* sp. and *Praedapollis* sp. occur abundantly right from the top to the bottom of XAD-1 Niger Delta Basin and are suggestive of outer neritic. Other taxa recovered include *Striatricolpites catatumbus, Retibrevitricolporites protudens, Pachydermites diederixi, Retitricolporites irregularis, Psilatricoloporites crasssus, Verrutricolporites rotundiporus, Corylus avellena, Pediastrum sp, Botryococcus braunii. Operculodinium centrocarpium and Lingulodinium machaerophorum were also recovered.*

The occurrence of Operculodinium centrocarpium and Lingulodinium machaerophorum suggest that sediments at these intervals were deposited in the outer neritic-bathyal environment. Head and Norris (1989) considered *Operculodium* sp. to be outer neritic species. Algae species such as *Botryococus braunii, Concentricytes circus* and *Pediastrum* sp. also occur within the intervals and are also suggestive of outer neritic-bathyal environment. This come to an agreement with the work of

Chukwuma-Orji *et al.* (2021) that algae species such as *Botryococus braunii, Concentricytes circus* and *Pediastrum* sp. occurs abundantly within the analysed interval in XAD-1 well and are suggestive of outer neritic. However, the occurrence of *Leisphaeridia* sp. within these intervals suggest an outer neritic – bathyal environment. Stover *et al.,* 1996; Chekar *et al.* 2018 reported the occurrence of *Leisphaeridia* sp. and *Nematosphaeropsis* sp. to be an outer neritic – bathyal (slope) species.



<u>Key</u>

infrerred depositional environment of wells BB-3, D-01 and BL-1X

Figure 11: Depositional environments and bathymetric ranges used in paleoenviromental interpretation (After Allen, 1965)

ii. The abundant records of black–brown, small to medium sized, irregularly shaped plant tissue and wood remains with blunt edges which suggest a possible long distance of transportation for sediment characterized palynomaceral I and II of the studied sections (Oyede, 1992). The *palynomacerals 1 and II indicate low energy deep marine environment of deposition with influx of fresh water from the* appreciable recoveries of SOM and presence of multicellular algal *Botryococcus* *brauni* and *Laevigatosporites sp. recorded within the interval in BB-3, D-01 and BL-1X (Figures 4,5 and 6).* Oyede, 1992; Batten and Stead, 2005, describe palynomaceral II to be more buoyant than palynomaceral 1 because of its thinner lath-shaped character. This implies that PM II floats more on water than PM I.

iii. Aggradational (blocky and serrated), progradational and retrogradational log motifs characterise the intervals. Fine grained sediments (shales, mudstones and sandstone units) characterized the intervals. This is suggestive of submarine canyon-fill deposits in an outer neritic-bathyal environment. (Haq and Boersma, 1998). Lithologically, the sands are milky white, very fine to medium grained, occasionally coarse, poorly to well sorted and sub-angular to subrounded. The shales are grey to dark in colour, silty, platy and fissile, moderately soft to moderately hard. Accessory mineral are mostly mica flakes and few occurences of glauconites.

Similarly, the intervals 13040-15620 ft, 11780-15940 ft and 10230-13020 ft in BB-3, D-01 and BL-1X wells respectively are delineated to have been deposited in the bathyal-abyssal environment. (Figures 10 and 11). The criteria for this deduction are:

I. The interval is characterised by increased representation of *Laevigatosporites spp.*, *Zonocostites ramonae, Sapotaceoidapollenites spp.*, Fungal spores and hyphae compare to the overlying interval in BB-3 well. There is a reduction in the occurences of *Laevigatosporites spp.*, *Zonocostites ramonae*, *Sapotaceoidapollenites spp.*, Fungal spores and hyphae, *Botryococcus braunii* and an increase occurrence of *Concentricytes circus* in D-01. There is an increase in the occurences of *Sapotaceoidapollenites spp*. and *Zonocostites ramonae,* and decrease in *Laevigatosporites spp.* and Fungal spores and hyphae compare to the overlying interval in BL-1X well. There is also an increase in the occurences of *Botryococcus braunii*, *Pediastrum spp., Leoisphaeridia spp.*, *Operculodium centrocarpum, Spiniferites ramosus, Lingulodinium machaerophorum* and microforaminiferal wall lining.

ii. The palynomacerals I and II that occur are more of the well sorted small to medium size than the large size palynomacerals, needle-like in shape (Oyede, 1992).

iii. The predominantly sandstone, shale and sandy shale character of the lower section is characterised by aggradational log motifs (blocky and serrated) with few progradational and retrogradational log motifs suggesting their deposition as submarine canyon fill, deep marine slope and submarine fans in bathyal-abyssal environment. Accessory minerals are dominated by glauconites, mica flakes and pyrites at some intervals especially in BB-3 and BL-1X wells. Absence of shell fragments and or carbonaceous detritus support the above environment.

Summary and Conclusion

The investigated intervals of wells BB-3, D-01 and BL-1X showed fairly abundant, diversified and well preserved palynomorphs assemblage. *Zonocostites ramonae*, *Monopoorites annulatus*, fungal spores/hyphae, species of *Sapotaceoidaepollenites* and *Laevigatosporites and were found to* dominate the microfloral assemblage of the analyzed intervals. Sphaeromorph acritarch species of *Leoisphaeridia* coupled with *Pediastrium, Botryococcus, Operculodinium centrocarpum, Lingulodinium machaerophorum*, *Achomosphaera ramulifera, Spiniferites ramosus* and indeterminate dinoflagellate cysts were the marine indicators present.

Biozonation of the three wells (BB-3, D-01 and BL-1X) were based on First and Last Downhole Occurrences (FDO and LDO) of chronostratigraphically important or index miospore species, abundance distribution of index species together with miofloral assemblage. Based on this, the studied wells were dated early-late Miocene, but well D-01 was able to penetrate early

Pliocene sediments.

Depositional environments of the strata penetrated by the wells range from outer neritic through bathyal to deep marine based on well logs motif and palynomorphs evidence.

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