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Palynostratigraphic and palaeoecological studies of the Cretaceous strata in the Bornu Basin, northeastern Nigeria

Palinostratigrafske in paleoekološke študije krednih skladov iz kadunje Bornu v severovzhodni Nigeriji

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Abstract

The palynological and palaeoecological studies have been carried out on one hundred and forty samples retrieved from an exploratory well (Murshe-1) to evaluate the palaeoenvironment, palaeoclimatic conditions, palynofacies zonations and the possible connection of the basin to the Paleo-Tethys Ocean.

The well recorded fairly rich occurrence of microfossils dominated by land derived forms. The pervasiveness of igneous intrusive encountered in the well suggests a high thermal gradient which could have resulted into the "cooking-up" of the deposited marine shale. It was observed that freshwater environment had influenced only on the Campanian-Maastrichtian sediments which suggests the influence of lagoonal and estuarine environment on the sediments by which possibly might have been deposited. The occurrence of *Araucariacites australis* from late Cenomanian-Turonian sediments suggests drought to less humid climate. The prevalent species in the humid conditions were rare and/or absent in the late Cenomanian to Santonian sediments, however they were found in abundance in the Campanian-Paleocene sediments suggesting a prevalence of humid climate in the Campanian-Maastrichtian which prevailed into the Paleocene period. The palynological data supported the concepts that Nigeria belong to the West African-South American (WASA) phytogeographic Province and the Palmae Province during the Maastrichtian.

Key words: palynofacies, palaeoenvironment, palaeoclimate, thermal gradient, phytogeographic Province

Izvleček

Predmet palinološke in paleoekološke raziskave je bil preučiti na podlagi sto štiridesetih vzorcev iz raziskovalne vrtine Murshe-1 paleookolje, paleopodnebne razmere, palinofacialno zonalnost in mogočo zvezo kadunje Bornu s paleotetidnim oceanom.

Z vrtino so razkrili precej bogato najdišče mikrofosilov, med katerimi prevladujejo kopenske oblike. Navrtali so tudi magmatsko predornino, katere značilnosti nakazujejo visok toplotni gradient, ki je očitno povzročil „segretje" okoljskega morskega laporja. Ugotavljajo, da se je sladkovodno okolje uveljavilo samo v kampanijsko-maastrichtijskih sedimentih, sicer pa prevladuje lagunsko in deltno okolje. Najdba fosila *Araucariacites australis* iz poznih cenomanijsko-turonijskih plasti priča o suhem do nizkovlažnem podnebju. Prevladujoče vrste iz vlažnega podnebja so postale redke ali jih ni v poznocenomanijsko-turonijskih plasteh, medtem ko so njihove najdbe spet obilne v kampanijsko-paleocenskih usedlinah, kar priča o ponovni prevladi vlažnih podnebnih razmer v kampanij-maastrichtiju, kar se nadaljuje vse do paleocenske dobe. Palinološki podatki podpirajo zamisel, da je pripadala Nigerija v maastrichtiju zahodnoafriško-južnoameriški fitogeografski provinci (WASA) in provinci Palmae.

Ključne besede: palinološki facies, paleookolje, paleopodnebje, toplotni gradient, fitogeografska provinca

Introduction

The studied well is located in the Bornu Basin NE Eastern Nigeria. It lies within longitude 12° E to 14°20' E and latitude 13°00' N to 12°00' N (Figures 1a and b). The drainage (Figure 1c) shows that the major rivers from Chad Basin flows in a northeast direction with and empties itself into Lake Chad. A lot of work has been done in Bornu Basin by various workers like Burke (1976), Petters (1981), Fairhead (1986), Genik (1992, 1993), Carter et al. (1963), Barber (l965), Cratchley & Jones (1965), Miller et al., (1968) Okosun (1995) and Cratchley et al., (1984) amongst others.

Reyment & Taita (1972) and Boboye (2008) carried out palaeontological and palynological studies of the Bornu Basin. Reyment (1965) correlated the ammonite biostratigraphy of the Benue Trough and Chad Basin. Petters (1982) recognized eleven concurrent – range zones of varying geochronological durations after studying the Albian-Pliocene benthic foraminifera from six Central West African sedimentary Basins. Boboye (2008) revealed that the palynomorphs' assemblages in this basin are moderately rich but poorly preserved. It is also established that the sediments in this basin are moderately poorly sorted to well sorted, the grains are angular to sub-rounded. The fine modal are mainly quartz and k-feldspar with subordinate grains of plagioclase microcline, polycrystalline quartz. The sediments are mineralogically and texturally matured in which the argillaceous sandstone, terrigenous mudstone and subordinate igneous intrusive rocks compositionally dominate. Olugbemiro (1997) revealed that foraminiferal assemblages are low in diversity and medium to high in abundance in Bornu Basin. His work indicated that the Fika Shale Formation was deposited under oxic-suboxic shallow epicontinental sea conditions, the Gongila Formation deposited in marine environment, and the Bima sandstone Formation may not be wholly continental as suggested by previous workers because occurrences of planktonic foraminifera at the top of the formation.

The application of palynological data in palaeoenvironmental reconstruction has been attempted by several authors (Batten, 1973, 1982; Vajda-Santivanez, 1998). Also, Ojo & Akande (2004) have used relative abundance of terrestrially derived pollen and marine derived dinoflagellates to interpret the depositional environment of the Cenomanian to Coniacian sediments in three boreholes penetrated in Gongila and Yola Basins. They showed that pollen and spore percentages decreases downhole which corroborated with this study, as

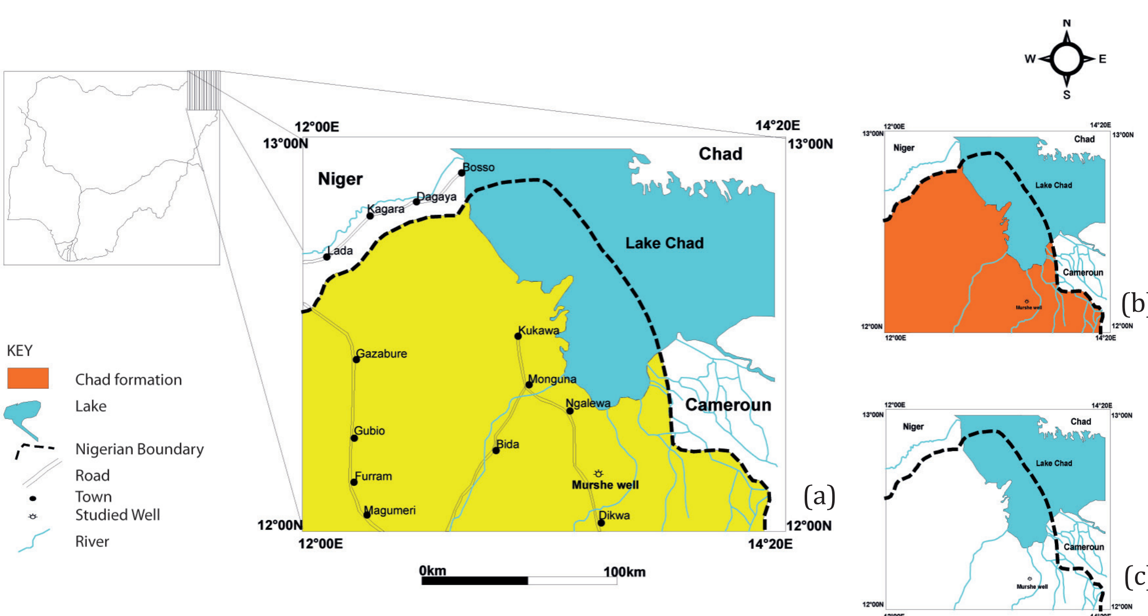


Figure 1: *Location map of the study area indicating the position of Murshe 1 well (a); The geological map of chad basin indicating Chad formation (b); The drainage map of study area showing the upward movement of rivers into lake Chad (c).*

interpreted in Yolde Formation. This fact contradicts earlier works which show that Yolde Formation reflect nearshore marine but is in line with the proposition that continental condition prevailed during this time so it does not suggest a paralic shallow marine environment due to prevalence of drought to humid pollen species. The purpose of this paper is to determine the age, palynomorphs distribution, palaeoenvironment and palaeoclimate conditions as well as the palynofacies zonations. The biostratigraphic study involved the analysis of pollen, spores, dinoflagellates and algae for chronostratigraphic biozonation.

Geology of the study area

The Bornu Basin is a Nigerian sector of Chad Basin which is a broad intracratonic depression in Central West Africa containing buried rifts in the Niger Republic. The sedimentation of the Bornu Basin commenced with the deposition of continental, poorly sorted, sparsely fossiliferous, medium to coarse grained, sandstone (Bima Formation) lying directly on the basement. This study revealed that the formation is composed of intercalation of shale (heterolith) and sandstones, as reported by some authors (Carter et al., 1963, Avbovbo et al., 1986 and Boboye 2008). Overlying the Bima Formation is the Gongila Formation that is composed of sandstones and bluish black shale (calcareous) deposited in a shallow marine environment (Carter et al., 1963, Avbovbo et al., 1986). These deposits mark the onset of marine incursion into this basin. This transgression reached its maximum in the Turonian, (during which the Fika Shale Formation was deposited in an open marine environment) and continue into Senonian after which a regressive phase of deposition occurred (Carter et al., 1963, Avbovbo et al., 1986). In the Maastrichtian, estuarine and/or deltaic environment prevailed which led to the deposition of the Gombe Sandstone in some part of the northeastern Nigeria (Carter et al., 1963, Avbovbo et al., 1986). The formation constitutes intercalated shale, siltstones and ironstones.

An extensional deformation occurred in the Maastrichtian which was later restructured into an elongate NE-SW graben system. The sub basins developed in response to rifting and created space for the emplacement of the Tertiary Kerri-kerri Formation, which overlies unconformably, the Cretaceous sediments (Carter et al., 1963). In the Pleistocene, the continental Chad Formation was unconformably laid down over Kerri-Kerri and/or Gombe Sandstone Formations (Carter et al., 1963, Avbovbo et al., 1986). However towards the end of the Tertiary up to Recent, there are widespread of volcanic activity occurrences in the southern and central part of the basin (Burke, 1976). The lithostratigraphic successions observed in the studied well and the sampled intervals are shown in Figure 2.

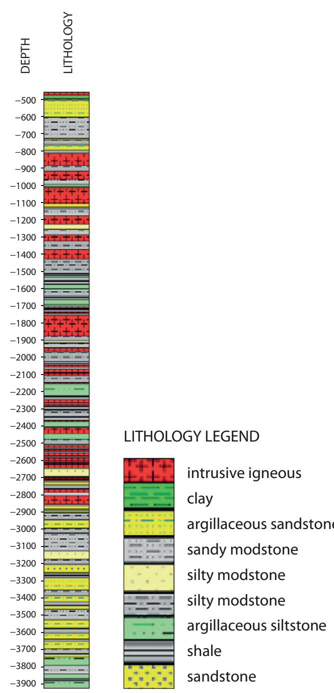


Figure 2: *Lithostratigraphy of the studied well.*

Material and methods

One hundred and forty cutting samples were used for this study and the sampling of the well was done at 5 m interval. The samples were separated into two parts; a part was logged in the sedimentological laboratory while the other part was thoroughly washed with distilled water through 5 μm polyester sieve. This size was used for the preparation in this work. The mesh sizes often used are 10 μm and 20 μm.

The 10 µm gauzes being fine enough to catch all, but if the smallest spores is known to be present, 5 µm mesh size may be used. This was to remove drilling mud contaminants and then dried for 24 hours at 50 ˚C for palynological analysis. Ten grams of each sample were digested with 30 ml of 10 % HCl to remove $CaCO_3$. It was then digested with 30 ml of 40 % HF for 24 h to remove silica. The content was sieve with water and later oxidized in Schulze solution (mixture of nitric acid and potassium chlorate) for 30 min, washed with 10 % potassium hydroxide and centrifuged. The aliquotus was dispersed with polyvinyl alcohol, dried and then mounted on DPX. The distribution charts for the recovered palynomorphs are presented (Figure 4).

Detailed description was used in the generation of the litho- log and for biostratigraphic interpretation of the well (Figures 2 and 3). Fresh sample of clay, sandy mudstone, silty mudstone and shale from this log were selected for routing palynological processing and the details are discussed.

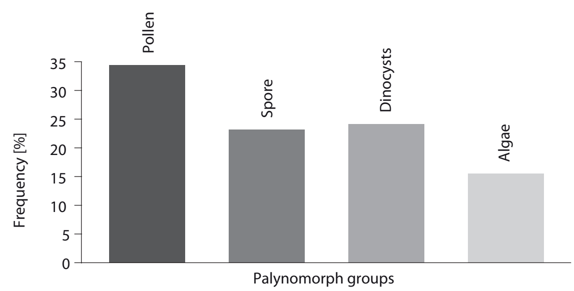


Figure 4a: *Histogram of frequency (%) of palynomorph distribution in the studied well.*

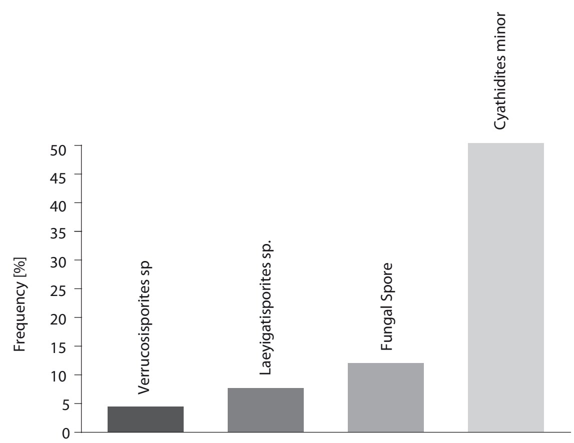


Figure 4b: *Frequency (%) distribution of sporomorph groups in the studied well.*

Clay constitute the upper section of the well with a thickness of about 20 m while shale formed an intercalation ranging from 2 m to 30 m occupying an overall thickness of 95 m in the entire section. Sandy mudstone also formed an intercalation and ranged in thickness from 15 m to 120 m with an overall thickness of 495 m. Finally, the silty mudstone which contained most of the analyzed sample ranges from 35 m to 90 m and it occupies an overall thickness of 869 m in logged section. Argillaceous sandstone range from 3 m to 50 m with a total thickness of 343 m in the log section. Silty Sandstone ranges from 10 m to 50 m with a thickness of 140 m in the log. Also sandstone ranges from 2 m to 50 m occurring in three intervals with a total thickness of 72 m while igneous intrusive occurred throughout the well covering a total thickness of about 797 m.

The chart for the lithofacies shows that 26 % is silty mudstone, intrusive igneous 24 %, sandy mudstone 15 %, argillaceous sandstone 15 %, argillaceous siltstone 10 %, silty sandstone 4 %, sandstone 2 %, shale 3 % and clay 1 % (Figure 3).

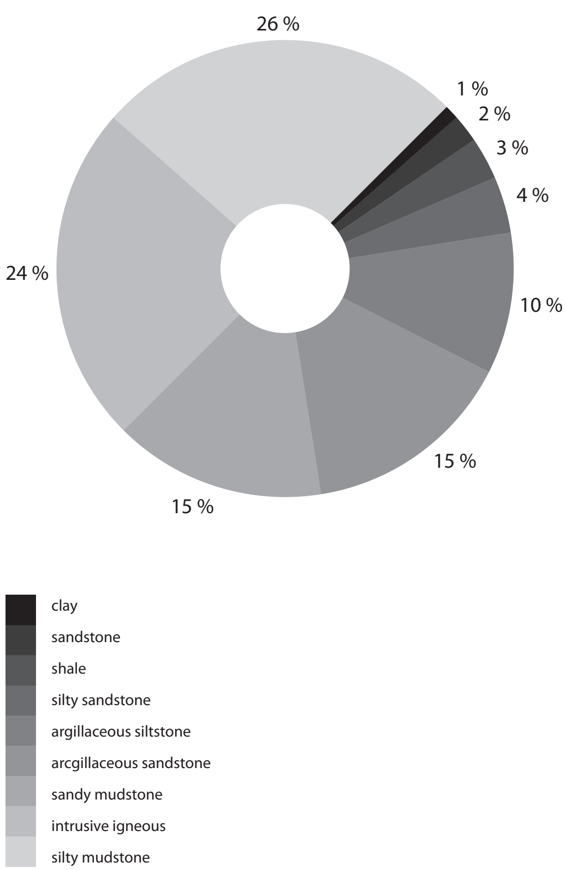


Figure 3: *Lithofacies distribution within the studied well.*

Results and Discussion

Palynomorph distribution

A total of one hundred and seven species of pollen, spores, dinoflagellate, algae and other palynomorphs were recorded from the Murshe -1 well (Figure 4) and some of the key species are well represented (Figures 4 and 5).

A total of fortyfive species of pollen include; *Afropollis jardinus*, *Alnipollenites venus*, *Aquilapollenites minimus*, *Araucariacites australis*, *Cicatricosisporites* sp., *Cretacaeiporites mulleri*, *Cretacaeiporites scabratus*, *Cretacaeiporites* sp., *Droseridites senonicus*, *Echitricolporites trianguliformis*, *Ephedripites ambiguus*, *Ephedripites multicostatus*, *Ephedripites* spp., *Ericipites* sp., *Gemmate pollen*, *Gemmazonocolpites cingulatus*, *Gleicheniidities senonicus*, *Gleicheniidites* sp., *Graminidites* sp., *Auriculiidites reticulatus*, *Inaperturopollenites* sp., *Leptolepidites major*, *Longapertites chlonovae*, *Longapertites marginatus*, *Longapertites microfoveolatus*, *Monocolpites marginatus*, *Monocolpites* sp., *Monocolpopollenites sphaeroidites*, *Pollen indeterminate*,

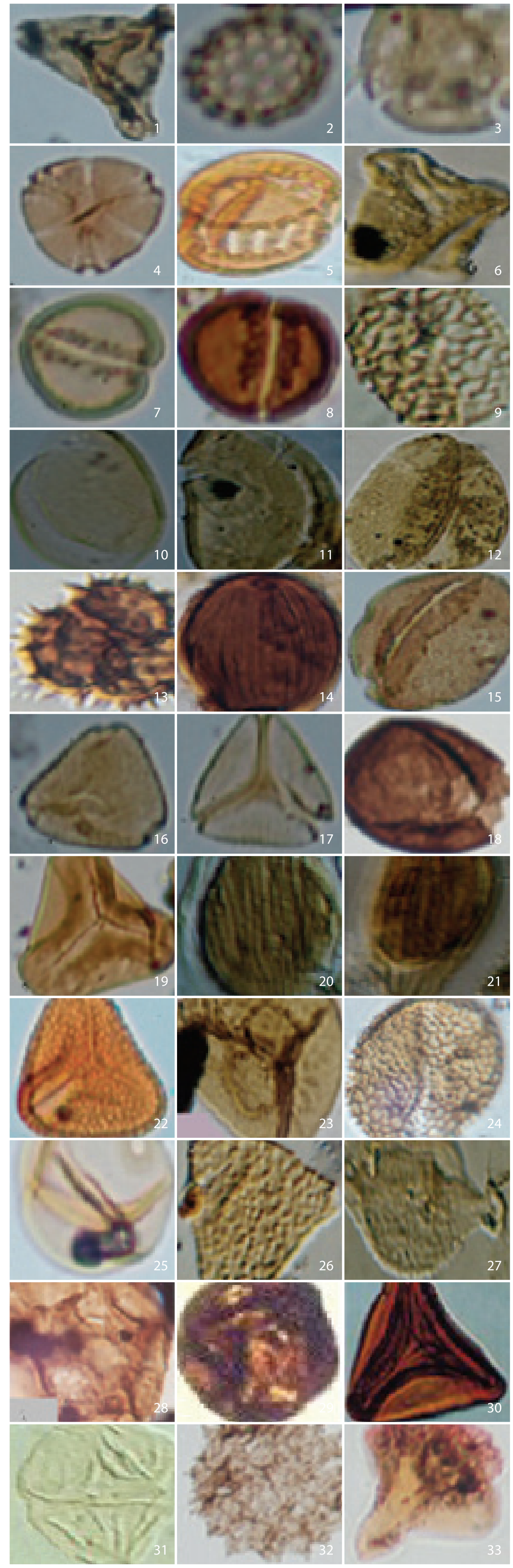


Figure 5: *Some of the palynomorphs' species recovered from the studied well.*

1. *Aquilapollenites sp., × 800*
2. *Chenopodipollis sp., × 800*
3. *Cretacaeiporites mulleri , Herngreen, 1973, × 800*
4. *Tricolporites sp., × 800*
5. *Tubistephanocolpites cylindricus, Salami, 1984, × 800*
6. *Aquilapollenites minimus , Jardiné & Magloire, 1965, × 800*
7. *Monocolpopollenites sp., × 800*
8. *Monocolpopollenites sphaeroidites, Jardiné & Magloire, 1965, × 800*
9. *Dichastopollenites sp., May, 1975, × 800*
10. *Longapertites chlonovae, Jardiné & Magloire, 1965, × 400*
11. *Longapertites microfoveolatus, Jan du Chêne & Adegoke, 1978, × 400*
12. *Longapertites marginatus, Van Hoeken-Klinkenberg, 1964, × 400*
13. *Droseridites senonicus, Jardiné & Magloire, 1965, × 800*
14. *Ephedripites multicostatus, Brenner, 1963, × 400*
15. *Monocolpites marginatus, Van Der Hammen, 1954, × 800*
16. *Triorites africaensis, Jardiné & Magloire, 1965 , × 800*
17. *Syncolporites sp., × 800*
18. *Araucariacites australis, Cookson, 1947 ex Couper, 1953, × 400*
19. *Gleicheniidities senonicus, Ross, 1949, × 800*
20. *Ephedripites sp., × 400*
21. *Ephedripites ambiguous, Azema & Boltenhagen, 1974, × 800*
22. *Foveotriletes margaritae, (Van Der Hammen) G. H. M., 1968, × 800*
23. *Zlivisporis blanensis, Pacltová, 1961, × 800*
24. *Retimonocolpites sp., × 800*
25. *Graminidites sp., × 800*
26. *Proteacidites sigalii, Boltenhagen, 1978, × 800*
27. *Auriculiidites reticulatus, Elsik , 1964, × 800*
28. *Cretacaeiporites sp., × 800*
29. *Cretacaeiporites scabratus, Herngreen,1973, × 800*
30. *Gleicheniidites sp., × 800*
31. *Dinogymnium euclaense, Cookson and Eisenack, 1970, × 800*
32. *Pediastrum sp., × 800*
33. *Botryococcus braunii , Kutzing, 1987, × 800*

Proteacidites sigalii, *Proteacidites* sp., *Chenopodipollis* sp., *Psilamonocolpites* sp., *Psilatricolporites* sp., *Chenopodipollis* sp., *Retimonocolpites* sp. *Steevesipollenites* sp., *Syncolpites* spp., *Syncolporites* spp., *Tricolpites* sp., Tricolporate forms, *Tricolporites* sp., *Tricolporopollenites* sp., *Triorites africaensis*, *Triorites* sp., *Tubistephanocolpites cylindricus*, and *Monosulcites* sp.

A palynoflora contains thirty diverse spore assemblages including the *Cingulati*sporites *ornatus*, *Concavissimi*sporites sp., *Cyathidites australis*, *Cyathidites minor*, *Cyathidites* sp., *Deltoido*spora sp., *Dictyophyllidites harrissi*, *Distaverru*sporites *simplex*, *Zlivisporis blanensis*, *Foramini*sporites *daiiyl*, *Foveotriletes margaritae*, *Fungal* spore, Gemmate spore, Incertae sedis, *Laevigatosporites* sp., *Lycopodium*sporites sp., *Polypodiaceae*sporites sp., *Liliacidites* sp., *Psilatriletes radiatus*, *Psilatriporites* sp., *Rugulatisporites caperatus*, *Rugulati*sporites sp., *Spore indeterminate*, Trilete spores sp., *Verrucato*sporites sp., *Verrucosi*sporites sp.

A total of 32 species of dinoflagellate cysts include; *Achomosphaera* sp., *Andalusiella* sp., *Batiacasphaera* sp., *Chlamydophorella albertii*, *Cometodinium* sp., *Cribroperidinium edwardsii*, *Cyclonephelium* sp., *Dinogymnium euclaensis*, *Exochosphaeridium phragmites*, *Florentinia* sp., *Foram wall lining*, *Gardodinium cf. elongatum*, *Gonyaulacysta* sp., *Isabelidinium* sp., *Leioshaeridia* sp., *Leptodinium* sp., *Nelsoniella aceras*, *Odontochitina costata*, *Oligosphaeridium complex*, *Palaeocystodinium* sp., *Polysphaeridium* spp., *Protoperidinium* sp., *Senegalinium bicavatum*, *Senegalinium* sp., *Spinidinium* sp., *Spiniferites ramosus*, *Spiniferites* sp., *Subtilisphaera pirnaensis*, *Subtilisphaera pontis–mariae*, *Subtilisphaera* sp., *Trichodinium delicatum*, *Trichodinium* sp.

Fresh water algae include only one species of *Pediastrum*, *Botryococcus braunii* and other palynomorphs are *Areoligera* sp., hyphae, fungal fruit body and foraminiferal linings.

Palynostratigraphy

The well yielded fairly rich and diverse abundance of palynomorphs, although some of them have been highly carbonized due to volcanism that characterized the region towards the end of Tertiary to Recent (Burke, 1976) which has affected their preservation. There is a significant decrease in the abundance of microfossils at the basal section (1 910–3 928 m) of the well. The middle part (630–1 910 m) recorded fairly rich occurrence of microfossil dominated by land derived species such as *Zlivisporis blanensis*, *Araucariacites australis*, *Proteacidities sigalii*, *Tricolporopollenites* spp., *Cyathidites minor* and *Monocolpites* sp. while the uppermost section (120–630 m) recorded scanty occurrence of microfossil.

Moderately rich and diverse occurrence of dinoflagellate cysts such as *Dinogymnium* spp., *Subtilisphaera* spp., *Cribroperidinium* spp., *Odontochitina costata* and *Oligosphaeridium complex* were recorded at several horizons within the studied section, with common records of fresh water to slightly brackish algae (*Botryococcus braunii* and *Pediastrum* sp.) which suggests a shallow marine environment with frequent freshwater incursion. Few rare species are restricted to each zone. It is worth mentioning here the occurrence of rare to spot records of Albian/Cenomanian markers such as A*fropollis jardinus* and *Cretacaeiporites scabratus*. They usually show single occurrences in isolated samples and this can be assumed to be reworked from older sediments into younger horizons. The Cretaceous/Tertiary (K/T) boundary is placed at 630 m which is defined by the top/extinction of *Dinogymnium* sp. recorded at that horizon.

Four microflora zones have been established for the Murshe-1 well based on the stratigraphic distribution of diagnostic palynological markers (Figure 6). This has been correlated with palyno-zones of Salard Cheboldaeff (1990), Lawal and Moullade (1986), Muller et. al. (1987), Jan du Chêne et al., (1978 and Boboye, 2008).

PJ1 Microflora Zone (late Cenomanian)

This zone is marked with the rare occurrence of microflora. It is characterized by the presence of several taxa including *Araucariacites australis, Cretacaeiporites scabratus, Ephedripites* sp.*, Graminidites* sp.*, Inaperturopollenites* sp.*, Monocolpites marginatus, Proteacidites sigalli, Tricolporites, Triorites africaensis*, *Triorites* sp.*, Deltoidospora* sp.*, Incertae sedis, Lyco-*

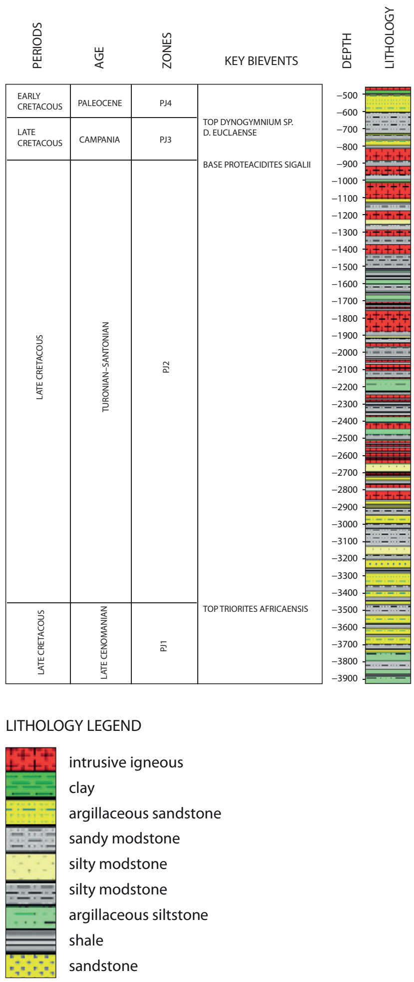


Figure 6: *Palynostratigraphic zonation of the studied well.*

podiumsporites sp., *Polypodiaceoisporites* sp., Spore indeterminate, *Araucariacites australis, Zlivisporis blanensis*, *Pediastrum* sp., fungal spore and foraminiferal linings.

This is the oldest zone recorded in the studied well section. The top of this interval is defined by the last occurrence of *Triorites africaensis*, while the base is stratigraphically deeper than the last sample encountered. The interval records a decrease in the abundance and diversity of palynomorphs with few occurrences of freshwater algae. This zone correlates with the *Classopollis* spp. Zone of Jan du Chêne et al., (1978).

PJ2 Microflora Zone (Turonian-Santonian)

This zone is rich in well preserved palynomorph; it is marked with the absence of *Cicatricosisporites* sp., *Droseridites senonicus*, *Gemmazonocolpites angulatus*, *Psilatricolpites* spp., *Psilatricolporites* sp., *Retimonocolpites* sp., *Steevesipollenites* sp, *Tricolporites*, *Triorites* sp., *Concavissimisporites* sp., *Polypodiaceoisporites* sp.

The top of this broad zone is defined by the first occurrence of *Proteacidites sigalii* recorded at 890 m, while the last occurrence of *Triorites africaensis* recorded at 3 450 m defines the base of this zone. Also characterized with this zone is *Cretacaeiporites scabratus* which could be reworked from older sediments into younger horizons. The Turonian-Coniacian and the Coniacian-Santonian boundaries could not be established due to poor recovery and stratigraphic distribution of the marker species that define these ages. The zone records a decrease in abundance and diversity of palynomorphs. This zone correlates with *Droseridites senonicus-Cretacaeiporites scabratus* Zone of Salard Cheboldaeff (1990) and Boboye (2008).

PJ3 Microflora Zone (Campanian-Maastrichtian)

This zone is defined by the last appearance of *Dinogymnium* sp. (*D. euclaense*). It is marked by abundance of microflora fossils with the absence of some which includes; *Alnipollenites verus*, *Aquilapollenites minimus, Droseridites senonicus, Echitricolporites trianguliformis, Ephedripites ambiguus, Ephedripites* sp.*, Ericipites* sp.*, Gemmazonocolpites cingulatus*, *Gleicheniidites* sp.*, Leptolepidites major, Syncolpites* spp.*, Syncolporites* sp,. *Tricolporites* spp.*, Triorites africaensis, Cyathidites australis.* Gemmate spore, Incertae sedis, *Cycopodisporites* spp.*, Monosulcites* sp.*, Polypodiaceaesporites* spp.*, Achomosphaera* sp.*, Andalusiella* sp.*, Batiacasphaera* sp.*, Laevigatosporites sp., Chlamydophorella albertii, Cometodinium* sp.*, Cribroperidinium edwardsii, Cyclonephelium* sp.*, Exochosphaeridium phragmites, Florentinia* sp.*, Gardodinium cf. elongatum , Gonyaulacysta* sp.*, Isabelidinium* sp.*, Nelsoniella aceras, Odontochitima costata, Oligosphaeridium complex, Palaeocystodinium* spp.*, Protoperidinium* sp.*, Senegalinium bicavatum, Spinidinium* sp.*, Spiniferites ramosus, Spiniferites* sp.*, Subtilisphaera pirnaensis, Subtilisphaera pontis-mariae, Trichodinium* sp.*, Areoligaera* sp., fungal spore, fungal fruit body, foraminiferal linings, *Cre-*

tacaeiporites scabratus, Cretaceaporites sp. The occurrence of *Cretacaeiporites scabratus within this zone is assumed to have been reworked from older sediments.* The base is marked by the first occurrence of *Proteacidites sigalii*.

The top of this zone is marked by the last occurrence of *Dinogymnium* spp., while appearance is tentatively placed at 890 m, coinciding with the first occurrence of Proteacidites sigalii. Among other microflora encountered include Auriculiidites reticulatus *Foveotriletes margaritae*, *Cyathidites* sp., *Dictyophyllidites harrissi, Concavissimisporites* sp. and *Cicatricosisporites* sp. There is a marked increase in the abundance and diversity of palynomorphs within this interval. Significant occurrences of dinoflagellate cysts are also recorded. This zone correlates with the *Dinogymnium* spp.–*Proteacidites sigalii* Zone of Jan du Chêne et al., (1978).

PJ4 Microflora Zone (Paleocene and younger)

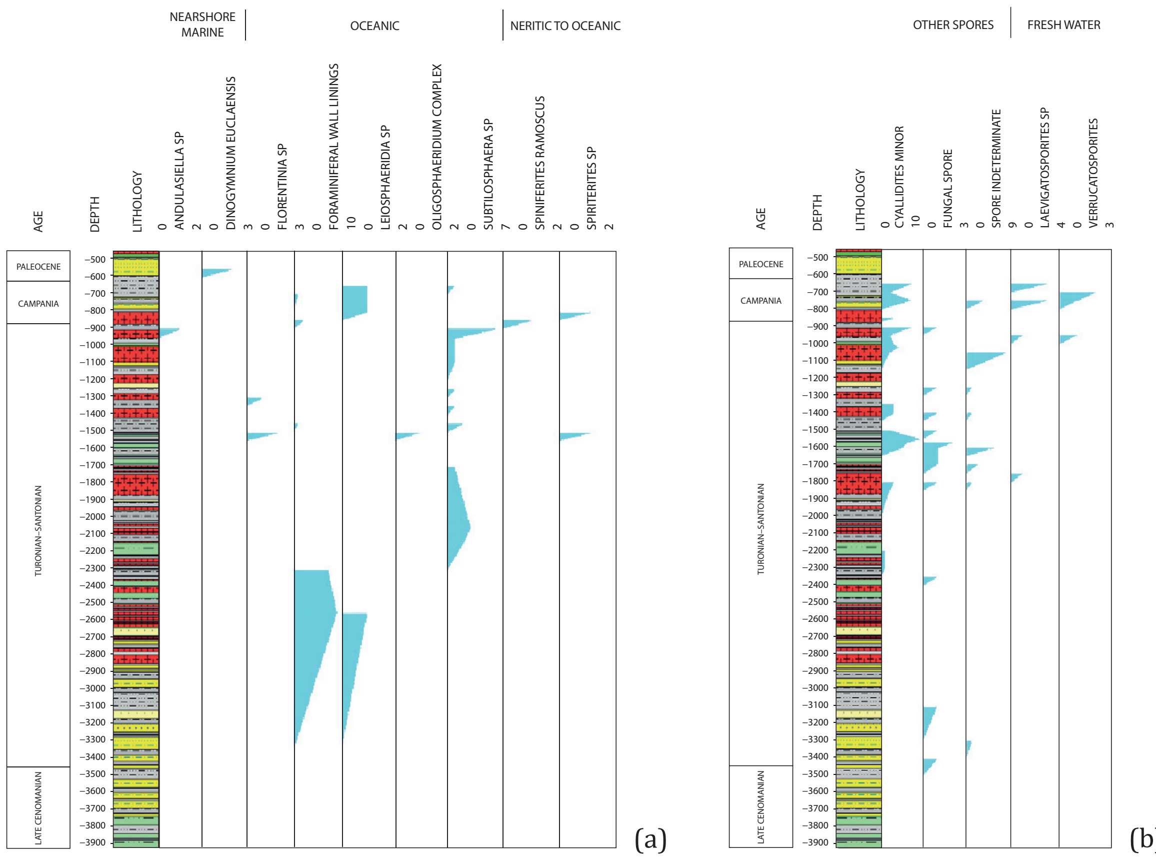
This zone is defined by the basal occurrence of *Dinogymnium* sp. (*D. euclaense*). It is marked by rare and/or absence of microflora. Among the few encountered include *Graminidites* sp., *Inaperturopollenites* sp., indeterminate pollen, *Psilamonolcolpites,* sp., *Psilatricolporites,* sp., *Tricolpites* sp., *Tricolporites, Rugulatisporites caperatus, Pediastrum* sp., fungal spores and hyphae. There is high abundance of *Dinogymnium* sp. (*D. euclaense*), fungal spore and hyphae. The top of this zone is stratigraphically higher than the first sample analyzed and as such was not encountered in the well section. The base is defined by the last occurrence of *Dinogymnium* spp. recorded at 630 m. Sparse records of palynomorphs were recorded within this interval. This zone correlates with S*pinizonocolpites baculatus* Zone of Muller et al., (1987) and Boboye (2008).

Palaeoecology and Palaeoenvironments

Changing climate over the period of 93.9 Ma to 56 Ma has been the driving force for the gradual disappearance of drought and humid elements and the appearance of palmae and brackish elements in the palynofloras of northeastern Nigeria. Spores, dinoflagelletes and algae were used for the palaeoenvironment inferences (Figure 7). Fern and allied spores are generally dominant throughout the whole section. (Figure 4). Pollen and fungal spores show low values (36 % and 23.6 %). Dominant and less abundant elements show little variations throughout the section. Characteristics of the zones are the mangrove element, *Psilatricolporites* sp., the marine representatives (foraminiferal linings) and fresh water algae *Botryococcus braunii*, indicating sedimentation in coastal and shallow marine environments, close to mangrove vegetation. *Botryococcus*, although more typical of fresh water environments, can also occur in slightly brackish water, due to its tolerance to salinity variations (Rull, 1997). Other elements that characterize the study section are fern spores (*Laevigatosporites* sp., *Verrucatosporites*, *Cyathidites minor*), together with *Retimonocolpites* sp. and the fresh water algae, *Pediastrum*.

Laevigatosporites sp. and *Verrucatosporites* has been reported in fresh water swamps, while dinoflagellates, *Andalusiella* sp. and *Dynogymnium* euclaensis are near shore marine environment (Vadja-Santinavez, 1998, Awad, 1994, May, 1977). The occurrence of chorate dinocysts such as *Florentinia* sp., *Leioshaeridia* sp., *Oligosphaeridium complex*, *Subtilisphaera* sp. and foraminifera lining are prevalent in open marine environment (Ojo & Akande, 2004, Okosun, 1995, Reyment & Dingle, 1987 and Peters, 1978), while the presence of *Spiniferites ramoscus* and *Spiniferites* sp. suggests oceanic to neritic environment (Vadja-Santinavez, 1998, Awad, 1994, May, 1977). The fungal spores, *Psilamonocolpites* sp., *Laevigatosporites* sp. and *Verrucatosporites* assemblages could be considered to be a mangrove assemblage deposited in shallow brackish water. The assemblages recovered in this study are composed of palms (*Psilamonocolpites* sp.), ferns (*Laevigatosporites* sp. and *Verrucatosporites*), and fungal spores, representing coastal swamps (palm/fern swamps) common in the Neotropics.

The succession of these assemblages through time shows dominant pollen signal from palm/fern to mangrove swamps with little changes and the replacement of mangrove swamps. This is also evident in the lithofacies that characterized this section which is controlled by the climate (Boboye, 2010). Indeed during the deposition of the sequence, pollen sedi-



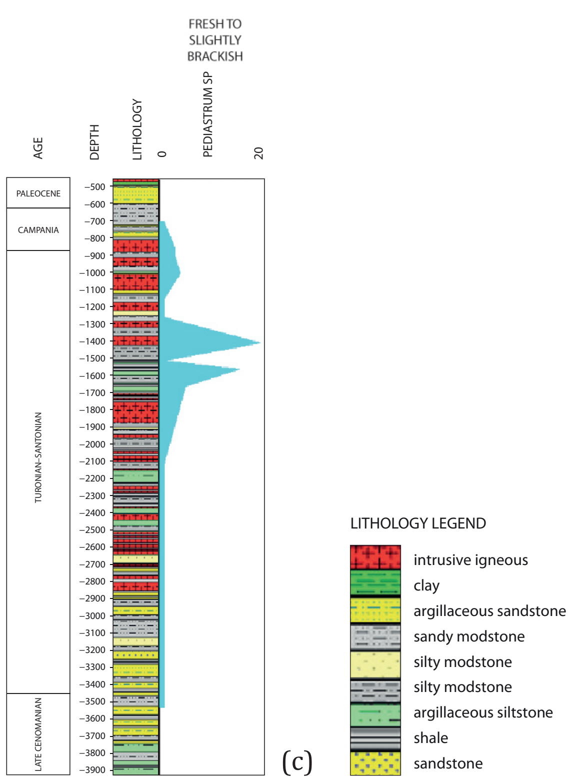


Figure 7: *The palaeoenvironmental reconstruction based on: (a) Dinoflagellates (b) Spores and (c) Algae.*

mentation was mainly composed of palm/fern swamp sporomorphs and pollen deposited under oceanic to fresh water environment. During deposition of the formations in this section (PJ1 to PJ4 Zones), although sporomorphs from palm/fern swamps continue to dominate, sporomorphs from herbaceous swamps increased, and the mangrove pollen was substantially reduced to very few species of fresh to brackish water algae probably transported landward by wind. Therefore the replacement of dinoflagellate assemblages (neritic to oceanic) by fungi spore and algae assemblages (fresh to slightly brackish water) across the zones (Figures 4 and 7) can be interpreted as a regressive trend from shallow shelf to mangrove environments of deposition.

It was observed that fresh water environment had influence only during the Campanian-Maastrichtian to the earliest part of late Cenomanian suggesting that the sediments had lagoonal and estuarine influence on the environment of deposited.

Figure 8 shows that *Ephedripites ambiguus*, *Ephedripites multicostatus*, *Ephedripites* sp., and *Ericipites* sp. are more dominant in drought conditions while the occurrences of *Araucariacites australis* is more common during times of drought and less abundant in humid climate. *Gleicheniidites* sp., *Gleicheniidites senonicus*, *Tricolpites* sp., and tricolporates species are humid forms which thrive with reasonable rainfall. The result in this study shows that between the intervals of 1 400 m to 1 500 m, the silty mudstone that was deposited contained pollen that found during the drought periods which indicated that dry climate had prevailed at a time in the Turonian to Santonian.

However, the occurrence of *Araucariacites australis* in the late Cenomanian to Santonian suggests a drought to less humid climate which was not observed in Campanian to Maastrichtian. However, the species that were prevalent in humid condition were absent in the late Cenomanian to Santonian while they were found in abundance in the Campanian to Paleocene sediments. This suggests a prevalence of humid climate during this period.

The basal section of Turonian to Santonian sediments (Gongila Formation) also shows paucity of sporomorphs. The middle and upper units' exhibits higher content of terrestrial and marine species. The marine dinoflagellates were more abundant in the upper section compared with the terrestrially derived (Turonian to Paleocene) species. This is corroborated with the presence of fresh water pollen (*Laevigatosporites* sp. and *Verrucatosporites* sp.) and the algae, *Pediastrum* sp. Ojo and Akande, (2004) reported a maximum marine transgression in Pindiga Formation and this is reflected in the results (upper section of Turonian to Santonian sediments), which is marked by common chlorate dinoflagellate cysts which include the genera *Spiniferites*, *Florentina* and *Oligosphaeridium* (Schrank, 1991). The fact that the typically open marine dinocyst genera, such

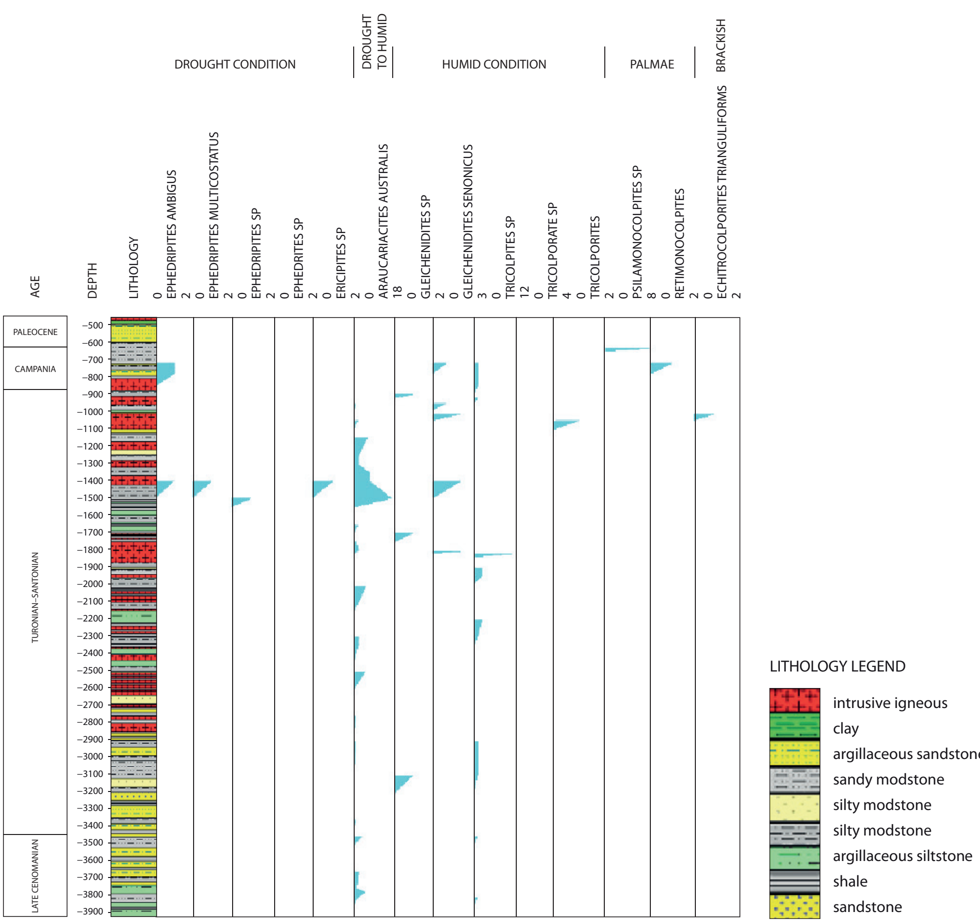


Figure 8: *The palaeoclimatic reconstruction of the studied well.*

as Florentina, Oligosphaeridium and Subtilisphaera which are cosmopolitan and have Tethyan affinities (Dave & Verdier, 1973, 1976, Below 1982; Batten & Uwins, 1985) present in Turonian to Maastrichtian intervals of the well, lends more credence to possible connection of the Tethys Sea in the north and south to the south Atlantic Ocean (Petters, 1978; Kogbe, 1976; Reyment & Dingle, 1987; Okosun, 1995). All the palynological data supported that Nigeria belong to the West African-South American Phyto-geographic Province and the Palmae Province during the Maastrichtian.

Variations in the vegetation are directly related to fluctuation in climatic conditions during the Cenomanian to Paleocene period. (Awad, 1994; Mauseth, 1991; Crane, 1987).

All through the Cenomanian to Paleocene, palynological assemblage of higher gymnosperm content were deposited, this include Araucariaceae, the producer of *Araucariacities*. A less humid (relatively dry) or even arid condition is assumed by the presence of xerophytic elements. This drought condition is corroborated by the presence of some ephedroids, which can tolerate relatively dry habitat conditions. This is observed from 1 400 m to 1 500 m depths with the association of pteridophyte families, such as Gleicheniaceae which indicate tropical humid environment. A simultaneous subtropical condition and dry phase probably occurred during the Turonian and Santonian (Ojo & Akande, 2004), as inferred by the relatively high diversity of angiosperm pollen such as tricolpate, tricolporate, indicating some reasonable rainfall and local occurrences of xerophytes and ephedroids.

Conclusions

A total of one hundred and forty cutting samples were analyzed and used in the generation of the litho log and for biostratigraphic interpretations. Argillaceous sandstone ranges from 3 m to 50 m with a total thickness of 343 m in the log section. Silty sandstone has an average thickness of 140 m, the sandstone is 72 m, while the igneous intrusive occurred throughout the well with a total range thickness of 797 m.

A total of one hundred and four species of pollen, spores, dinoflagellates, algae and others were recorded in the well. Diagnostic species identified (*Triorites scabratus, Proteacidites sigalii, Dinogymnium* sp. *(D. euclaense*) were used for the age determination and palynostratigraphic zonation of the study area. These are the late Cenomanian (PJ1 Zone, the Turonian-Santonian (PJ2 Zone), the Campanian-Maastrichtian (PJ3 Zone) and Paleocene and younger (PJ4 Zone) ages.

The well yielded fairly rich and diverse abundance of palynomorphs. The uppermost section (120–630 m) recorded scanty occurrence of microflora, while the middle part (630–1 910 m) recorded fairly rich occurrences of microflora dominated by land derived species, such as Zlivisporis blanensis, Araucariacites australis, Proteacidites sigalii, Tricolporopollenites spp., Cyathidites minor and Monocolpites sp. There was significant decrease in the abundance of microflora at the basal section (1 910–3 928 m) of the well.

It is evident that the fresh water environment had influence on the sediment only during the Campano-Maastrichtian to the earlier part of the late Cenomanian. This suggests that the sediments had lagoonal and estuarine influence during emplacement. The results show that the sediments between 1 400 m to 1 500 m depths (silty mudstone) is characterized by drought climate pollen during the Turonian to Santonian period. However, *Araucariacites australis* occurred only from late Cenomanian up to Turonian and Santonian sediments which suggests that a drought to less humid climate existed during these periods.

The species that are prevalent in humid condition were absent in the Santonian and lower - middle part of Turonian periods and also in the late Cenomanian sediments. However, it was found in abundance in the Campano-Maastrichtian and Paleocene sediments, which indicate that humid climate, prevailed into the Paleocene period in the study area. This study has shown the pervasiveness of igneous intrusive in the well which implies a high thermal gradient during the course of deposition which could have led to the “cooking up” of the marine shale (Boboye, 2008).

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