

High Resolution Palynostratigraphy of Well PCL, boundary of Nigeria and Benin Republic sectors of the offshore eastern Dahomey Basin.

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Abstract:

Background: Previous palynological studies on the offshore eastern Dahomey Basin were majorly on low resolution palynostratigraphy covering few to several formations and therefore the need to look at the individual formations in order to achieve high resolution palynostratigraphy studies. It is a known fact that the exploration of hydrocarbons has equally shifted offshore which necessitated the reason to carried out this study in order to know what is happening around boundary between Nigeria and Benin Republic since petroleum exploration utilizes chronostratigraphic correlation.

Materials and Method: Subsurface samples of well PCL from offshore eastern Dahomey Basin were collected and analyzed for palynostratigraphic studies. A total of seventy (70) ditch samples were composited at 12 m (40 ft) interval. The dept range of the well is between 378 m (1240 ft) to 820 m (2690 ft). Twenty five grams (25 g) each of the seventy ditch samples were subjected to standard chemical treatment for palynological study. The processing followed the standard method of maceration of samples to remove the silicate and carbonate minerals with the usage of inorganic reagent such as conc. Hydrofluoric acid (HF), nitric acid (HNO₃) and dilute hydrochloric acid (HCl). This is done to extract the palynomorphs as residue which is subsequently mounted on glass slides for microscopic study.

Results: Palynomorphs recovered from the analysis were then used for identifying three main palynological zones. They are: Polypodiaceoisporites sp./ P670 zone characterised by Base/last occurrence of Echiporites incacinooides at 2200 ft and co-occurrence of Verrucosporites sp., Aletesporites sp., Proteacidites cooksonii, Psilatricolporites crassus with rare Psilatricolporites operculatus and Brevicolporites guinetii. Botryococcus braunii dated Early Miocene followed by Echiporites incacinooides/ P680 zone which is characterized by the base occurrence of Crassoretitrites vanraadshooveni at 2060 ft. The base is defined by the quantitative base occurrence of Echiporites incacinooides at 2200 ft. other common occurrence of Psilatricolporites crassus, Retitricolporites irregularis, Botryococcus braunii, also common are the Psilastephanocolporites sp. (Sapotaceae), Retibrevitricolporites obodoensis, Verrucosporites sp. Laevigatosporites sp, the zone is dated Early Miocene – Middle Miocene. The last zone is represented by Crassoretitrites vanraadshooveni/ P720 zone. The base of this zone is defined by the base occurrence of Crassoretitrites vanraadshooveni at 2060 ft, this zone also records moderately abundant to common occurrences of sporomorphs such as Verrucosporites sp., Laevigatosporites sp., Striatricolporites scatatumbus, Psilastephanocolporites scatatumbus, Psilatricolporites crassus, Acrostichumaureum, and Zonocostites ramonae and dated Middle Miocene and it's the youngest of the three zones. Overall the studied well spanned from Early to Middle Miocene.

Conclusion: The studied PCL well penetrated Neogene sediments which are dominantly claystones, shales and calcareous shales. Palynological analysis revealed the presence of pollen grains, spores, dinoflagellate cysts which were used as the basis for the dating of the sediments in the well. Three informal palynological zones are established for the PCL well namely: the PI (Polypodiaceoisporites sp.) zone, PII (Echiporites incacinooides) zone and the PIII (Crassoretitrites vanraadshooveni) zone. The rock succession in the well is dated Early to Middle Miocene due to occurrence of diagnostic marker species.

Keywords: Palynostratigraphy, offshore Dahomey Basin, Neogene sediment, Early to Middle Miocene.

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I. Introduction

Globally, Palynology has wide applications especially in the field of Geology where it has been applied in stratigraphy (palynostratigraphy), paleoenvironment, paleoclimate and petroleum exploration among others (Germeraad *et al.*, 1968; Evamy *et al.*, 1979; Iakovleva *et al.* 2020). During petroleum exploration, it is utilized in chronostratigraphic correlation and evaluation of potential source, reservoir and cap rocks.

Among the early and fairly recent notable works on the eastern Dahomey Basin are Reyment (1965), Germeraad *et al.* (1968), Adegoke (1969), Bilman (1976), Bankole *et al.* (2006), Ola-Buraimo (2010) and Ikhane *et al.* (2012) who worked on outcrop samples and provided insight to the palynostratigraphic, sedimentological and paleoenvironmental studies of the area. On the other hand, palynostratigraphic studies of the offshore eastern Dahomey Basin using ditch cuttings were carried out by Adeigbe *et al.* (2013) and suggested Early Miocene to Late Miocene age for the studied samples. The authors observed three (3) zones: i) *Magnastriatitehowardi*/P 680 Zone I (Early Miocene); ii) *Crassoretitreletsvanraadshooveni*/ P 700 Zone II (Middle Miocene) and iii) *Echitricolporites spinosus*/P 820 Zone III (Late Miocene). This was inferred from a total number of sixty four (64) samples and the depth range of 900 to 8000 ft (227 to 2439 m), indicating a low resolution palynostratigraphic studies considering number of sample and the depth range. Similarly, Adebisi (2015) worked on two hundred and ten (210) ditch cuttings representing depth from 4648 ft (1417 m) to 8006 ft (2441 m) and concluded that the sediments in the well spanned from the Late Cenomanian for the lowermost part to the Eocene at its uppermost part. This interval consists of the Abeokuta-Ofowo formations (basal section), followed by the Araromi Formation and the upper most Oshosun Formation. In addition, he observed the absence of the upper and middle Maastrichtian, Lower Santonian, Coniacian and Turonian sections that led him to recognize three (3) major unconformities surfaces; two (2) in the Late Cretaceous and one in Early Tertiary. This well represents deeper part of the basin and consists of sediments ranging from Cretaceous to Tertiary formations. Anthony and Johnson (2020) used fifty (50) ditch cuttings from well that penetrated sediments between depth intervals from 1620 to 3500 ft (494 to 1067 m) belonging to the Oshosun Formation at the bottom with the Afowo Formation directly above. They identified seven (7) subzones from bottom to top and comprises the following: i) *Racemonocolpiteshians*, ii) *Arecipitesxilimuratus*, iii) *Retibrevitricolporitesobodoensis*, iv) *Retibrevitricolporitesprotrudens*, v) *Beskipolliselegans*, vi) *Verrutricolporitesrontundiporus* and vii) *Echiperiporitesestelae* corresponding to P 480, P 520, P 540, P 560, P740, P 770 and P 780, respectively. These intervals depict palynological zones representing the Late Eocene to the Late Miocene. They authors also observed presence of an unconformity due to the total disappearance of P 600 zone between palynological zones P 560 and P 740 subzones.

It is evident from previous studies on this basin that there is need for more detailed and high resolution palynostratigraphic analysis especially within the Tertiary (Neogene) by specifically concentrating on each of the formation which is employed in our current study and also bearing in mind the location of the studied well which is at the boundary between Nigeria and Republic of Benin. In this present study, seventy (70) ditch cuttings from South Atlantic Petroleum Company (SAPETRO) Victoria Island Lagos were sampled from the offshore eastern Dahomey Basin and are used for this purpose. The sampled well PCL penetrated between 378 to 820 m (1240 to 2690 ft) depths of Tertiary (Neogene) sediments and was studied with the aim of achieving a high resolution palynostratigraphy. The studied well location including wells within the Seme oil field is shown in figure 1.

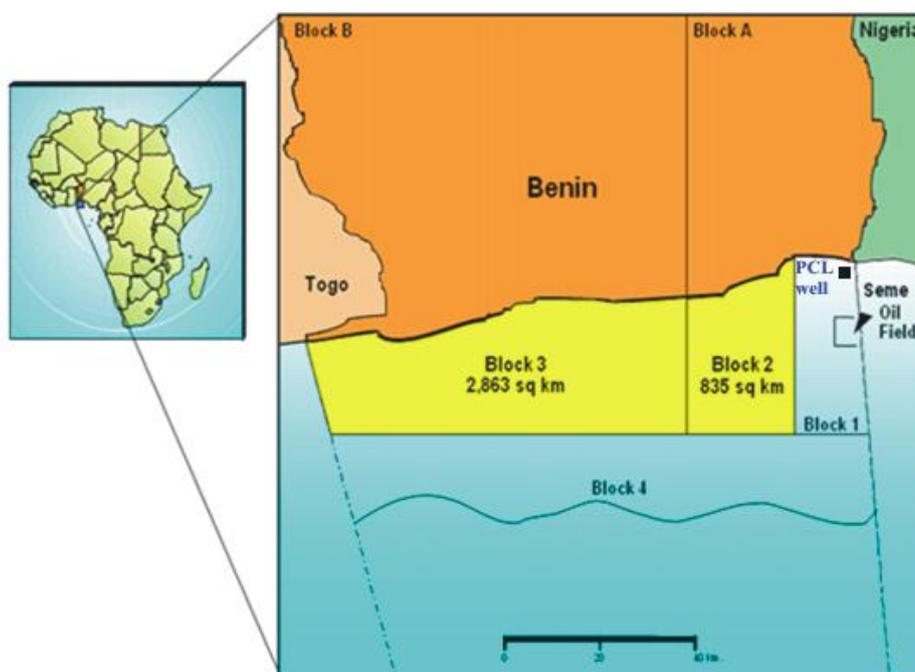


Figure 1: Location map of the study area (Block 1) offshore Dahomey Basin (source SAPETRO).

Geological and Stratigraphic Setting

The Dahomey Basin is a marginal pull-apart basin sandwiched between the eastern margin of the Okitipupa Ridge corresponding with the Benin Hinge line of Murat (1972) and which Omatsola and Adegoke, (1981) regarded as the onshore extension of the Chain fracture zone while its western margin is widely believed to have formed by structures associated with the onshore extension of the Romanche fracture zone (Francheteau and Le Pichon, 1972; Emery *et al.*, 1975; Mascle, 1977; Wilson and Williams, 1979; Omatsola and Adegoke 1981; Coker and Ejedawa, 1987). The basin was formed during the Early Cretaceous separation of the South American from the African plates as a result of rifting associated with the opening of the Equatorial Atlantic in the Late Jurassic to the Early Cretaceous (Omatsola and Adegoke, 1981). The basin covers much of the continental margin of the Gulf of Guinea, extending from Volta-delta in Ghana on the West to the Okitipupa Ridge in Nigeria on the East (see fig. 2).

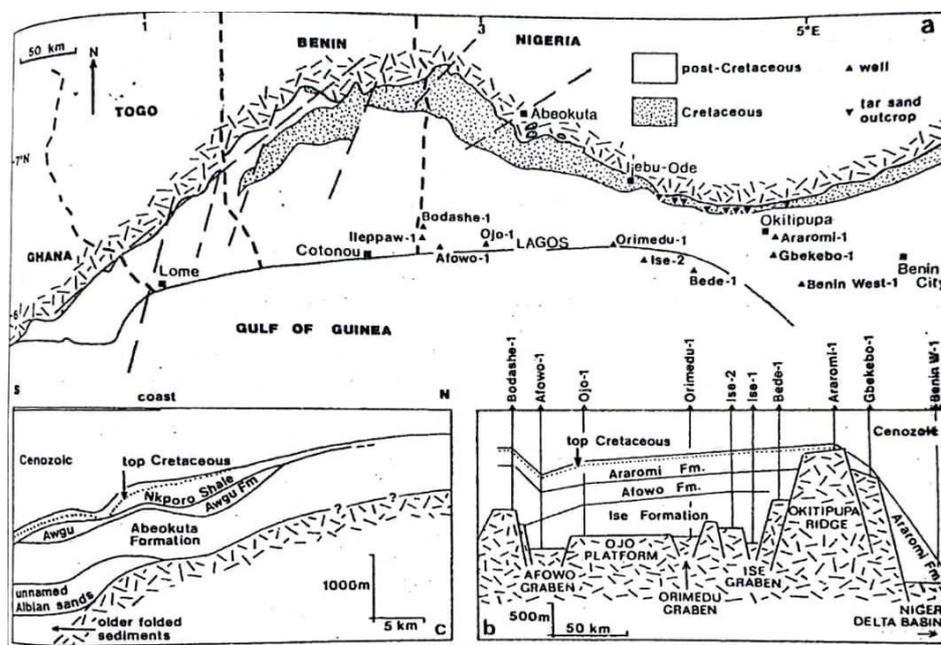


Figure 2: Simplified geological map of the Benin Basin (after Enu, 1985; Coker and Ejedawe, 1987; Billman, 1992). b, E-W regional section through the Nigerian part of the Benin Basin (after Omatsola and Adegoke, 1981). c, N-S section across the Benin Republic sector of the Benin Basin (after Billman, 1992).

The stratigraphic succession of the southwestern Nigerian sector of the Dahomey Basin covers from the Cretaceous to Recent (see table 1) and comprises of the Cretaceous Abeokuta Group which consist of the Ise, Alowo and Araromi formations, the Paleocene Ewekoro Formation, the Late Paleocene to Early Eocene Akinbo Formation, the Eocene Oshosun and Ilaro formations and the Pleistocene to Recent Benin Formation (Omatsola and Adegoke, 1981; Bilman, 1992; Jan Duchene, 1998 and Omosanya *et al.*, 2012). Very recently the following authors (Adeigbe *et al.*, 2013; Adebisi, 2014; Adebisi, 2015; Fadiya and Ojoawo, 2015) provided an updated summarized regional stratigraphic succession for the entire western Nigeria coastal basin. In addition, Gérard *et al.*, (2016) compared the stratigraphic succession of the Republic of Benin component of the Dahomey Basin and the western Nigerian offshore component of the basin (see table 2).

Table1. Comparison from various authors the stratigraphic succession of the southwestern Nigerian sector of the Dahomey Basin.

| AGE | | FORMATIONS | | |
|------------|-------------------------|---------------------------------------|----------------------------|-------------------------------|
| | | SOUTHWESTERN NIGERIA BASIN | | |
| | | Onshore (Omatsola & Adegoke, 1981) | Offshore Billman (1992) | |
| QUART. | PLEISTOCENE-RECENT | BENIN Fm. (COASTAL PLAIN SANDS) | BENIN Fm. | |
| TERTIARY | EOCENE-PLIOCENE | ILARO Fm. | IJEBU Fm. | |
| | | OSHOSUN Fm. | OSHOSUN Fm. | |
| | | AKINBO Fm. | AKINBO Fm. | |
| | PALEOCENE | EWEKORO Fm. | IMO Fm. | |
| CRETACEOUS | CAMPANIAN-MAASTRICHTIAN | ABEOKUTA GROUP | ARAROMI Fm. | NKPORO Fm. |
| | TURONIAN-CONIACIAN | | AFOWO Fm. | AWGU Fm. |
| | NEOCOMIAN-CENOMAIAN | | ISE Fm. | ABEOKUTA Fm. (AFOWO Fm.) |
| | | | | ISE Fm. (FOLDED SEDIMENTS) |

Table 2: Correlation of stratigraphic charts of Benin and western Nigeria offshore basins; periods of main unconformities are indicated in blue (After Gérard *et al.*, 2016).

| AGE | | FORMATIONS | | | | |
|------------|-------------------------|--------------------------------------|-------------|-----------------------------|--------------|------------------------|
| | | WESTERN NIGERIA BASIN | | OFFSHORE BENIN BASIN | | |
| | | Onshore Omatsola & Adegoke (1981) | Offshore | | | |
| QUART. | PLEISTOCENE-RECENT | BENIN Fm. | BENIN Fm. | BENIN/IJEBU Fm. | | |
| TERTIARY | EOCENE-PLIOCENE | ILARO Fm. | | AFOWO Fm. | | |
| | | OSHOSUN Fm. | | ILARO Fm. | | |
| | | | | OSHOSUN Fm. | OSHOSUN Fm. | |
| | | AKINBO Fm. | AKINBO Fm. | | | |
| | PALEOCENE | EWEKORO Fm. | EWEKORO Fm. | IMO Fm. | | |
| CRETACEOUS | CAMPANIAN-MAASTRICHTIAN | ABEOKUTA GROUP | ARAROMI Fm. | NKPORO Fm. | ARAROMI Fm. | |
| | TURONIAN-CONIACIAN | | AFOWO Fm. | AWGU Fm. | AWGU Fm. | |
| | | | | AFOWO Fm. (ABEOKUTA Fm.) | ABEOKUTA Fm. | |
| | NEOCOMIAN-CENOMAIAN | | ISE Fm. | | | |
| | | | | ISE Fm. | ISE Fm. | ALBIAN SST. ISE Fm. |

II. Materials and Methods

About 25 g each of a total of seventy (70) ditch cutting samples from well PCL in the offshore eastern Dahomey Basin was obtained from the South Atlantic Petroleum Company (SAPETRO) and palynological analysis was carried out. Lithologic log of the analyzed samples from well PCL was provided by SAPETRO (see figure 3). Drilling muds were removed by washing and drying the samples in readiness for detailed palynological analysis. The analysis follows the standard chemical treatment described by Brasier (1981) where palynomorphs were extracted by sample maceration to remove the carbonate and silicate minerals using dilute hydrochloric acid (HCl) and conc. hydrofluoric acid (HF) respectively. Separation and sieving were done with the aid of Branson Sonifier for the removal of silt and clay size particles. Controlled oxidation was carried out on the sieved residue using nitric acid (HNO₃) and 10% potassium hydroxide (KOH) was added to the residue and stirred. This was left for five minutes, rinsed three times with distilled water and centrifuged for five minutes at 2000 rpm to remove the effects of nitric acid or excess nitrates that were produced through the action of HNO₃ on the organic matter.

Extracted palynomorphs were subsequently mounted on glass slides for microscopic study by means of Norland adhesive and the cover slip. The slides were then stained with safranin O to enhance identification of dinoflagellate cyst. Observed forms were identified using palynological album and published literatures such as Germeraad *et al.*, (1968), Evamy *et al.*, (1978) and Muller *et al.*, (1987). Identified palynomorphs were point counted to produce a palynological chart (see figure 4) to decipher the age of the studied samples. Photomicrographs of diagnostic species were taken and are presented in plate 1.

III. Result:

Microflora characteristics.

A total of seventy (70) palynomorph species were identified from the analyzed ditch cuttings of the PCL well. These marker species, including pollen, spores, dinoflagellates and algae aside the foraminifera test linings are showing varying degree of abundance and diversity from the top to the bottom of the distribution chat (see figure 5). Generally, the samples are made up of more pollen (48/68.6%), and spores (12/ 17.2%) compared with dinocysts (7/10%) and fresh water algae (3/4.3%) as shown in table 3.

Table 3: Table showing abundance distribution of palynomorphs in the studied PCL well.

| Species | Abundant | % Abundant |
|----------------------|----------|------------|
| Pollen | 48 | 68.6 |
| Spores | 12 | 17.2 |
| Dinoflagellate cysts | 7 | 10 |
| Fresh water algae | 3 | 4.3 |

CS1 Well Geologic Prognosis

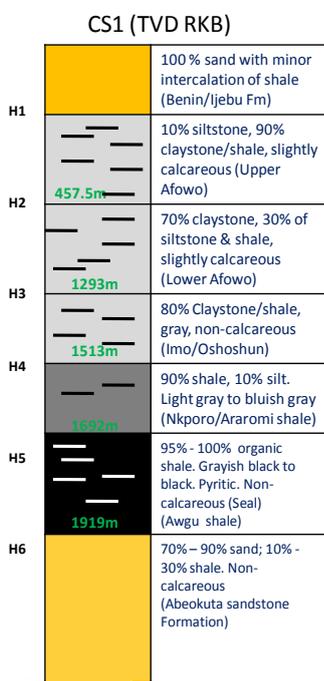


Figure 3: Lithologic log of PCL well offshore eastern Dahomey Basin; H1-upper Afowo Formation, H2-Lower Afowo Formation, H3-Oshoshun Formation, H4-Araromi Formation, H5-Awgu Shale, Abeokuta Formation; source SAPETRO).

From Table 2, it is clear that there are moderately abundant and diverse pollens and spores recovered from the studied PCL well. These palynomorphs are quantitatively dominated by land derived species such as *Sriaticolporitescatatumbus*, *Retitricolporitesirregularis*, *Psilastephanocolporites* sp. (*Sapotaceae*), *Psilatricolporites* sp., *Monocolpites* sp., *Verrucatosporites* sp., *Laevigatosporites* sp. and fresh water algae – *Botryococcusbraunii* (see figure 5 and plate 1). It is important to note that, pollens of *Psilatricolporites* sp. and *Monocolpites* sp are well represented on the palynomorph distribution chat especially at depth interval of 278-686 m (1240-2250 ft; see figure 5). On the other hand, spores of *Verrucatosporites* sp., *Laevigatosporites* sp. and *Polypodiaceoisporites* occur more within the studied well (see figure 5)

The studied samples are also characterized by few records of marine dinoflagellate cysts such as *Lingulodiniummachaerophorum*, *Operculodiniumcentrocarpum*, *Leoisphaeridiasp* and *Systematophoratareolata*. These forms were identified more within the interval 531-573 m (1740-1878 ft; see figure 5).

PLATE 1

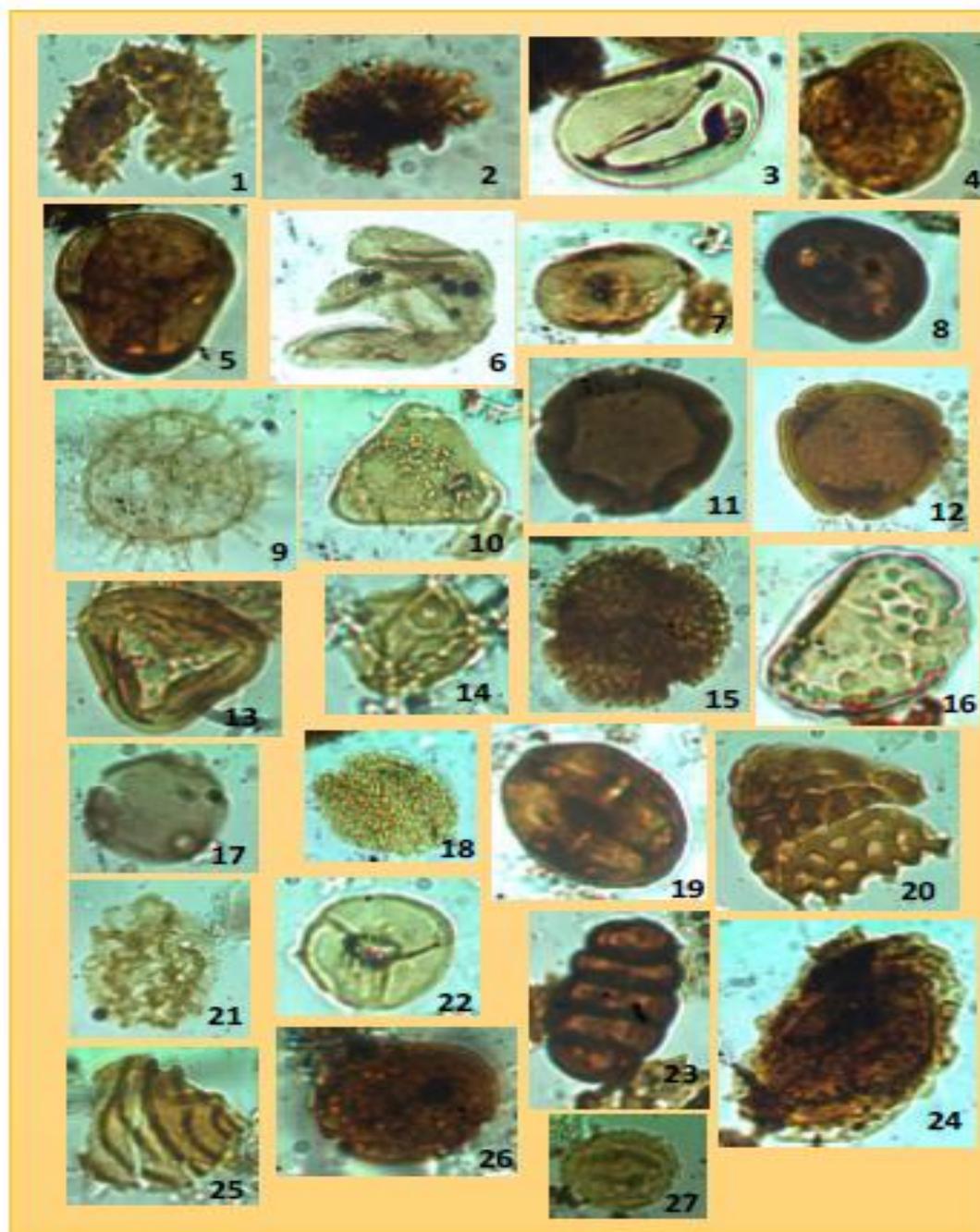


PLATE 1

1. ECHIPERIPORITES INCACINOIDES
2. BOTRYOCOCCUS BRAUNII
3. LAEVIGATOSPORITES SP
4. MONOCOLPITES SP
5. ACROSTICHUM AUREUM
6. STRIATRICOLPORITES CATATUMBUS

7. PSILATRICOLPORITES SP
8. NYMPHAEAPOLLIS CLARUS
9. OPERCULODINIUM CENTROCARPUM
10. PROTEACIDITES COOKSONNI
11. PACHYDERMITES DIEDERIXI
12. PSILATRICOLPORITES CRASSUS
13. POLYPODIACEOISPORITES SP
14. MONOPORITES ANNULARUS
15. RETITRICOLPORITES IRREGULARIS
16. VERRUCATOSPORITES SP
17. RETIBREVITRICOLPORITES OBODOENSIS
18. RACEMONOCOLPITES HIANS
19. PSILASTEPHANOCOLPORITES SAPOTACEAE
20. CRASSORETITRILETES VANRAADSHOOVENI
21. PEREGRINIPOLLIS NIGERICCUS
22. STEREISPORITES SP
23. FUNGAL SPORE
24. SPIROSYNCOLPITES BRUNI
25. MAGNASTRIATITES SP
26. CANTHIUM SP
27. VERRUTRICOLPORITES SP

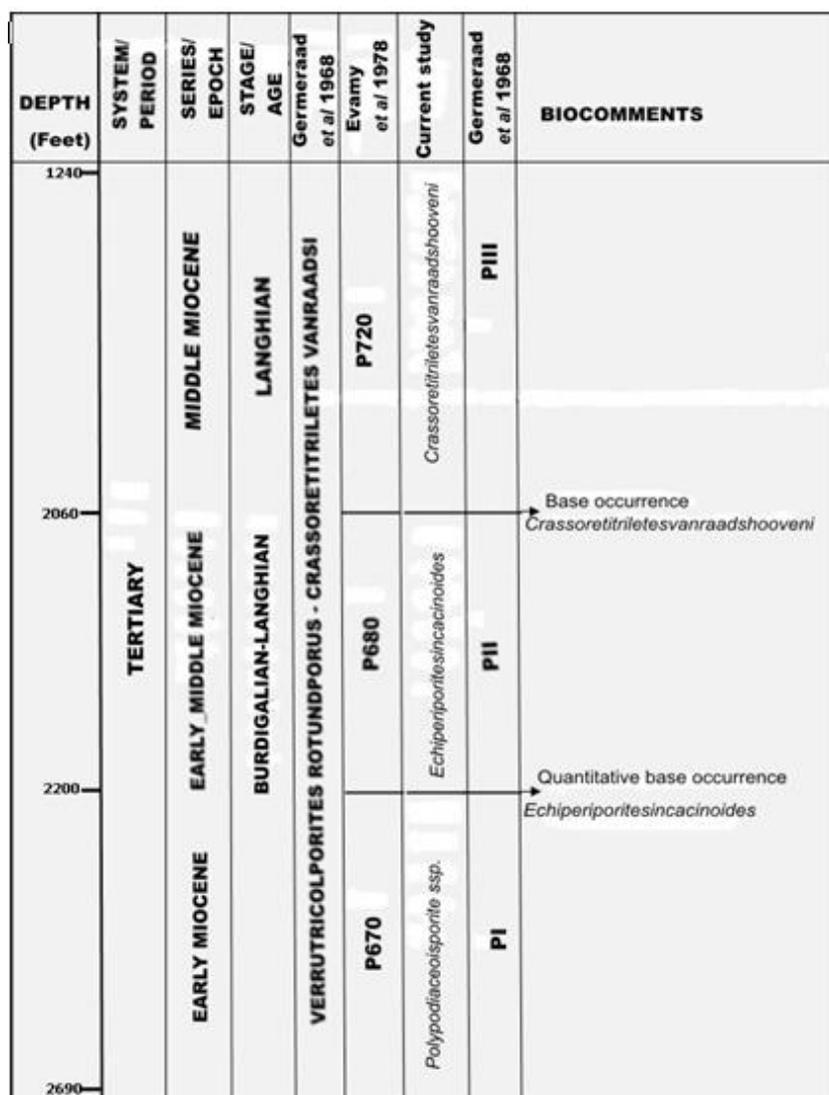


Figure 4: Palynozones recognized in the studied interval 1240 to 2690 ft (378 to 820 m) of well PCL1, offshore.

Dahomey Basin.

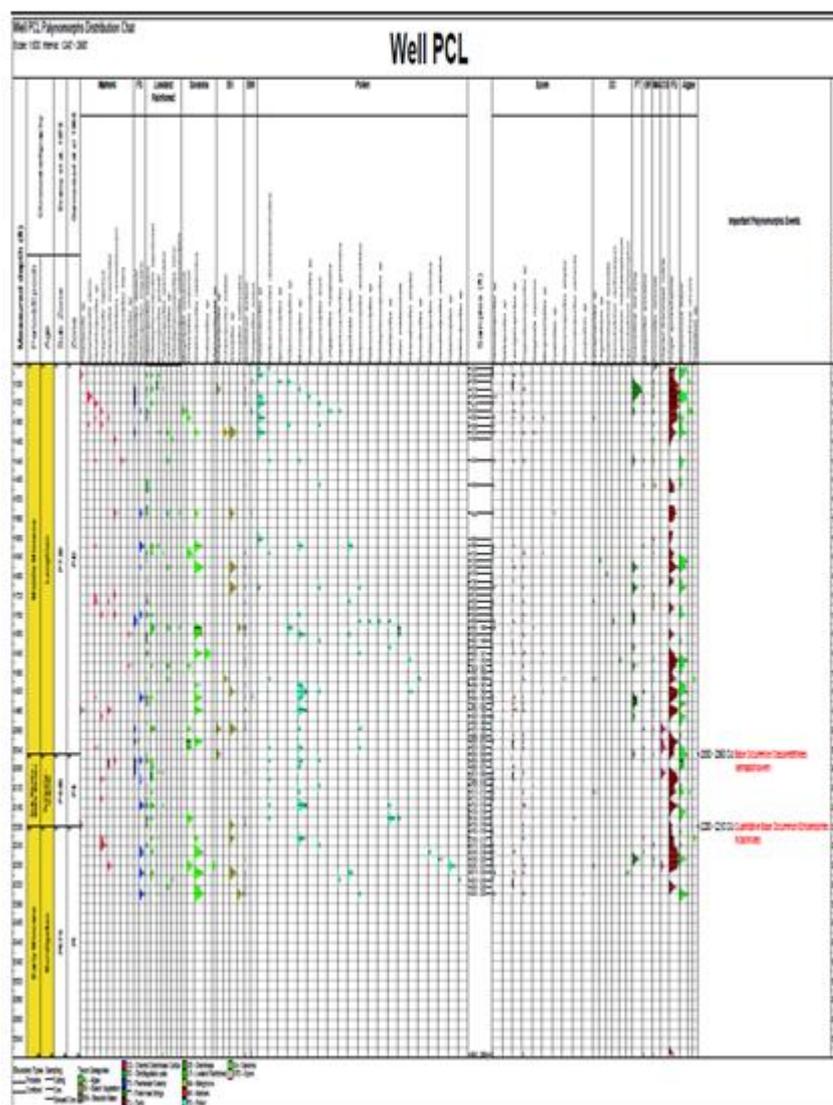


Figure 5: Palynomorphs distribution chart of interval 1240 to 2690 ft (378 to 820 m) of well PCL, offshore Dahomey Basin.

IV. Discussion:

Microflora biozonation of the PCL Well 378-820 m (1240-2690ft)

Observed palynomorph species and their characteristics have proved useful in microflora biozonation of sedimentary basins around the globe (Ayinla *et al.*, 2013, Adeigbe *et al.*, 2013, Iakovleva *et al.* 2020). Thus, in establishing the age and subsequently establishing an informal biozonation template for the studied interval from the PCL well of the offshore eastern Dahomey Basin, marker species and associate diagnostic palynoflora associations were considered. Stratigraphic events such as Base/Last Downhole (LDO), Quantitative Base (QB) occurrence and occurrences of diagnostic species were employed. Their applications were correlated with the published works of Germeraad *et al.*, (1968), Evamy *et al.*, (1978) and Muller *et al.*, (1987).

Basically, three informal palynological zones were established for the PCL well namely: the PI (*Polypodiaceoisporites* sp.) zone, PII (*Echiperiporitesincacinooides*) zone and the PIII (*Crassoretitritesvanraadshooveni*) zone (figures 4 and 5). These were correlated with the *Verrutricolporitesrotundiporus-Crassoretitritesvanraadshooveni* palynological zone of Germeraad *et al.*, (1968); the P670, P680 and P720 zones of Evamy *et al.*, (1978) and the *Verrutricolporitesrotundiporus – Echitricolporitespinosus* zone of Muller *et al.*, (1987), respectively.

Based on the palynological zones recognized in the studied interval, the PCL well penetrated sediments of Early to Middle Miocene age. This is similar to age range observed by Adeigbe *et al.*, 2013. A graphical presentation of the identified zones is provided in figures 4 and 5 and detailed descriptions of the various zones are discussed below:

Polypodiaceisporites sp. zone

Palynological code : PI
 Interval : 820-671 m (2690-2200 ft)
 Age : Early Miocene

From the available data in this study, *Polypodiaceisporites* sp. zone is the oldest zone mapped. The top of this zone is marked by the (?) base occurrence of *Echiperiporitesincacinooides* at 671 m (2200 ft; see figures 4 and 5) while the base tentatively coincides with the last sample analyzed at 820 m (2690 ft; see figures 4 and 5). This zone is further characterized by the common occurrence of *Verrucatosporites* sp., *Aletesporites* sp., *Proteaciditescooksonii*, *Psilatricolporitescrassus* with rare *Psilatricolporitesoperculatus* and *Brevicolporitesguinetii*. *Botryococcusbraunii* and rare records of *Leoisphaeridi* sp were also identified (see figure 5). A sample gap exists between intervals 713-818 m (2340-2680 ft; see figure 5) within this zone. This might possible indicates unconformity surface in the studied well.

This palynological assemblage zone is related to the P670 zone of Evamy *et al.*, (1978), *Verrutricolporitesrotundiporus* zone of Germeraad *et al.*, (1968) and *Verrutricolporitesrotundiporus-Echiperiporitespinosus* zone of Muller *et al.*, (1987). Therefore, the studied interval 671-820 m (2200-2690ft)is dated Early Miocene (see figure 4).

Echiperiporitesincacinooides zone

Palynological code : PII
 Interval : 671-628 m (2200-2060 ft)
 Age : Early Miocene-Middle Miocene

Echiperiporitesincacinooides zone (PII) represents the second zone in the studied PCL well marking the transition from Early Miocene to Middle Miocene. The top of this zone is defined by the base occurrence of *Crassoretitriletesvanraadshooveni* marked at 628 m (2060 ft; see figures 4 and 5). The base is defined by the quantitative base occurrence of *Echiperiporitesincacinooides* at 671 m (2200 ft; see figures 4 and 5).

In this zone, abundant occurrence of *Psilatricolporitescrassus*, *Retitricolporitesirregularis*, and *Botryococcusbraunii* were recorded. Other species such as *Psilastephanocolporites* sp. (*Sapotaceae*), *Retibrevitricolporitesobodoensis*, *Verrucatosporites* sp. *Laevigatosporites* sp are also common with scanty presence of *Leoisphaeridi* sp (see figure 5).

Moreover, this zone is related to the P680 zone of Evamy *et al.* (1978), the *Verrutricolporitesrotundiporus* zone of Germeraad *et al.* (1968) and the *Verrutricolporitesrotundiporus-Echiperiporitespinosus* zone of Muller *et al.* (1987). An Early Miocene-Middle Miocene age is inferred for this interval (see figure 4).

Crassoretitriletesvanraadshooveni zone

Palynological code : PIII
 Interval : 628-378 m (2060-1240 ft)
 Age : Middle Miocene

Crassoretitriletesvanraadshooveni zone (PIII) is the third zone in the analyzed PCL well marking the transition from Early-Middle Miocene to Middle Miocene. The base of this zone is defined by the base occurrence of *Crassoretitriletesvanraadshooveni* at 628 m (2060 ft; see figures 4 and 5) while the top of this zone coincides with first sample analyzed. This is the youngest zone recognized in the studied well and it records moderately abundant to common occurrences of sporomorphs such as *Verrucatosporites* sp., *Laevigatosporites* sp., *Striatricolporitescatatumbus*, *Psilastephanocolporitescatatumbus*, *Psilatricolporitescrassus*, *Acrostichumaureum*, and *Zonocostitesramonae*; see figure 5).

Other characteristic palynoflora recognized within this zone include few records of *Echiperiporitesestelae*, *Pachydermitesdiederixi*, *Crassoretitriletesvanraadshooveni* (shows an LDO at 611 m/ 2005 ft; see figure 5), *Aletesporites* sp and *Nymphaeapollisclarus*. In addition, dinoflagellate cysts such as *Lingulodiniummachaerophorum*, *Operculodiniumcentrocarpum*, *Systematophoratareolata* and *Leoisphaeridi* sp. were identified especially within the interval 531-573 m (1740-1878ft; see figure 5).

This zone correlates with the P720 zone of Evamy *et al.* (1978), the *Crassoretitriletesvanraadshooveni* zone of Germeraad *et al.* (1968) and the *Verrutricolporitesrotundiporus-Echiperiporitespinosus* zone of Muller *et al.* (1987). This zone also correlates with the P720 zone in the Tertiary Niger-Delta forms described by Evamy *et al.*, (1978), the *Crassoretitriletesvanraadshooveni* zone of the tropical palynomorphs of Germeraad *et al.*, (1968) and the *Verrutricolporitesrotundiporus-Echiperiporitespinosus* zone of Muller *et al.*, (1987). Hence, the interval represents Middle Miocene age representing in the studied well (see figure 4).

V. Conclusion

High resolution palynostratigraphic analysis of PCL well which penetrated the mudstones including claystones, shales and calcareous shales was carried out and the results revealed the presence of pollen grains, spores, dinoflagellate cysts which were used as the basis for the dating of the sediments in the well. Three informal palynological zones are established for the PCL well namely: the PI (*Polypodiaceisporites* sp.) zone,

PII (*Echiperiporitesincacinooides*) zone and the PIII (*Crassorettriletesvanraadshooveni*) zone. The sediments in the well section are dated Early to Middle Miocene due to occurrence of diagnostic marker species.

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