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Full Length Research Paper

Palynofacies analysis and sedimentary environment of Early Cretaceous sediments from Dixcove 4-2x well, Cape Three Points, offshore Tano Basin, western Ghana

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Abstract

Palynofacies analysis carried out on fifty eight (58) cutting samples from the Dixcove 4-2x well offshore Cape Three Points in the South Tano Basin, identified five palynofacies types (P-I to P-V). Palynofacies types P-I and P-IV suggest proximity to a fluvio – deltaic source in a moderately dysoxic environment, P-II reflects a proximal (pro delta) dysoxic - suboxic environment, P-III is indicative of deposition in an oxidizing condition in proximity to terrestrial sources and P-V is attributed to deposition resulting from high preservation rate and low energy dysoxic- anoxic condition in marginal marine environment. An Aptian to Cenomanian age has been assigned to the interval studied based on known stratigraphically important palynomorphs. The presence of *Afropollis jardinus*, *Classopollis* spp, *Ephedripites* spp, Elaterspores and the pteridophytes *Cicatricosisporites*, *Deltoidspora*, *Cyathidites* etc) suggest a paleoenvironment with parent plants inhabiting wetlands in a humid, warm coastal plain in a semi-arid climate. Thermal maturation of kerogen in sediments of super cluster A (Phytoclast group) has the potential of generating wet gas and condensate and that of super cluster B (AOM group), generation of oil with little or no potential of commercial source.

Keywords: Palynofacies, dysoxic, anoxic, phytoclast, amorphous organic matter, tano basin.

INTRODUCTION

The Tano Basin is part of the Ivory Coast – Tano Basin, located on the continental shelf of southwest Ghana and extends further west into Ivory Coast, West Africa. It is developed between the Coastal Fault System, St Paul's and Romanche Fracture Zones.It is bounded to the north by the Precambrian Birrimian shield and to the south by the Romanche fracture zone. The Tano Basin is situated close to Ghana's western border with Ivory Coast and is the eastern extension of much larger Ivory Coast Basin. The Tano Basin occupies an area of at least 3000 km^2, with the onshore component estimated at about 1165 km^2 (Kesse, 1985). The Tano structure is located approximately 39km from the Ghana coast and approximately 24km east of the Ghana-Ivory Coast border, with a water depth in the area ranging from 91m to 125m.

The Tano Basin began its tectonic-sedimentary life as an extensional rift basin modified by wrench tectonism. This rifting was initiated by complex movements due to the separation of the continents of South America and Africa. This was most likely initiated in the Barremian and Aptian times. It is thought that movement along a series of transform faults including faults in the Romanche Fault Zone during this continental separation led to the development of the large rift basin in the Tano area (Davies, 1989). As a result of these movements, by Aptian- early Albian time, a large rift basin had developed in the Tano Basin area. This was followed in middle-late Albian times by widespread deposition of shallow marine sandstones and shales with minor limestone in the area. General evidence suggests that final separation on the continents took place in latest Albian (Davies 1989). It is speculated that, a thermal anomaly with subsequent uplift occurred at the margin of the newly created African and Brazilian continental plates in the Tano area. This uplift occurred in late Albian time and may be the plate tectonic model for the development of the Tano structural trend.

The Dixcove prospect is located in the southeastern corner of the Tano Basin on the northwest plunging nose of a large structural anomaly centered in block 6 of the Ghana National Petroleum Corporation (GNPC) activity map. It is bound on the north and east by a large down-to-the northeast fault and on the south by a large down-to-the south fault with a sedimentary thickness in excess of 15,000 ft. (GNPC, 2010)

MATERIAL AND METHODS

Fifty eight (58) cutting samples mainly shales, sandstones and some limestones obtained between the intervals 2975- 11010 ft. from the Dixcove 4-2X well (Figure 1) were processed for sedimentary organic matter (SOM).Standard procedure for preparing slides for palynological studies was employed. This involved using hydrochloric (HCl) (10%) and hydrofluoric (HF) (40%) acids to digest and remove the carbonates and silicates from the rock samples respectively. The residue was then sieved through a 10µm nylon sieve, and the organic matter separated using zinc bromide solution. Slides were then prepared for light microscopy and photomicrography. For a detailed palaeoenvironmental study based on palynofacies, 350 palynofacies parameters (SOM) were counted to calculate relative abundances in percentages (Figure 2).

Definition and classification of palynofacies

Combaz (1964) originally defined the term palynofacies to encompass the total complement of acid-resistant organic matter recovered from a sediment or sedimentary rock by palynological processing techniques, using hydrochloric acid and hydrofluoric acid, as seen under a microscope. Powell et al. (1990) redefined the term as “a distinctive assemblage of palynoclasts whose composition reflects a particular sedimentary environment**”.** Tyson (1995), however, added that apart from reflecting a specific set of environmental conditions it is also associated with a characteristic range of hydrocarbon-generating potential. Other workers have referred to organic components in sediments as organic matter, palynodebris, palynomaceral, kerogen, (Gehmann, 1962; Lorente, 1990; Alpern, 1970; Staplin, 1969; Whitaker, 1984, Boulter and Riddick, 1986, Traverse, 1988; Tyson, 1996).

The palynofacies classification terms used here follows that of Tyson (1995): phytoclasts, opaques, (black debris), Amorphous organic matter (AOM) and palynomorphs. Kholeif et al. (2010) has extensively described the palynofacies mentioned above.

Palynmorphs include spores, pollen, dinoflagellates, acritarchs, chitinozoans, prasinopyhtes, foraminferal linings, marine algae. These are abundant in fine grained muds, shales, clays, and sometimes in sandstones and limestone’s (Mudie, 1992; Sarjeant, 1974).

Phytoclasts include structured terrestrial plants fragments such as cuticles, wood tracheid and cortex tissues. The structure may be displayed, only faintly discernible or suggested, sometimes merely by the fact that it is a membrane or filament that has a clearly defined, non-amorphous outline (Batten, 1996). They are mainly derived from terrestrial sources and they show high concentrations in places close to the parent flora, near the mouth of rivers and in oxidizing conditions.

Opaque (black debris) are made up of oxidized brownish black to black coloured woody tissues including charcoal. They are produced as a result of oxidation and natural pyrolysis on terrestrial plant tissues.

AOM includes all particulate organic materials that appear structure less with no cellular structure preserved. They appear in different forms and are referred to as fluffy, granular, fibrous, or membranous. AOM normally dominates sediments deposited in oxygen deficient conditions and the increase of AOM indicates reducing conditions, distal dysoxic – anoxic shelf and high marine productivity (Tyson, 1995; Batten, 1981, 1996).

RESULTS AND DISCUSSIONS

In assessing the pattern of the distribution of the sedimentary organic matter (SOM), their relative abundances in terms of percentages were subjected to cluster analysis by Q-mode using IBM SPSS statistics version 20. The cluster for the Dixcove 4-2X well based on the percentage and composition of SOM in the samples, revealed two super clusters, (Figure 3, Table 1). These are super cluster A which is subdivided into A1, A2, A3, A4, and super cluster B. The super clusters also reflect the individual Palynofacies types (P-I to P-V) identified. The phytoclast group is mainly incorporated in super cluster A and is concentrated in the deeper sections of the well and the AOM dominating super cluster B in the shallower section.

From the varying characters and distribution of the sedimentary organic matter (SOM) in the sediments, five Palynofacies types (P-I, P-II, P-III, P-IV, and P-V) have been identified after the cluster analysis (Table 1). Variation is the Palynofacies types and composition of the palynomorphs assemblage may provide information regarding interpretation of depositional environments (Figure 4).

Palynofacies type I (P-I) is dominated by structured phytoclast with an average relative abundance of 52% of total sedimentary organic matter, opaque phytoclast (black debris) with an average abundance of 35.7% and an average content of 9% for AOM. Palynomorphs are few with an average of less than 3.3%. These occur at

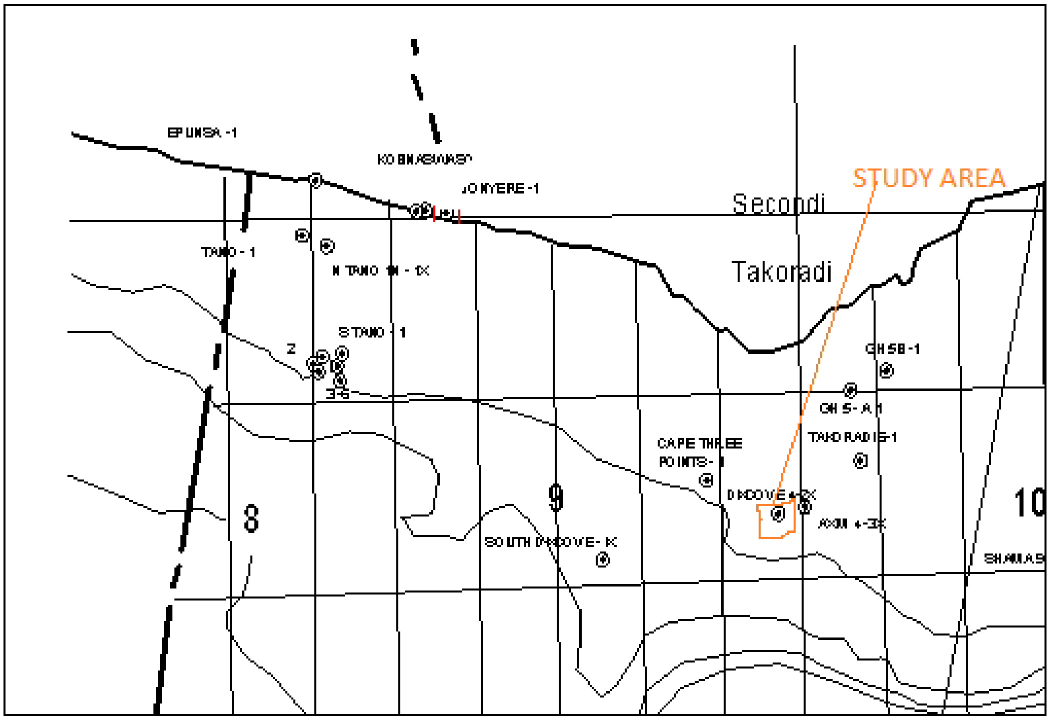

Figure1. Location map of Dixcove4-2Xwell offshore Tano Basin (Modified from GNPC Report, 2010)

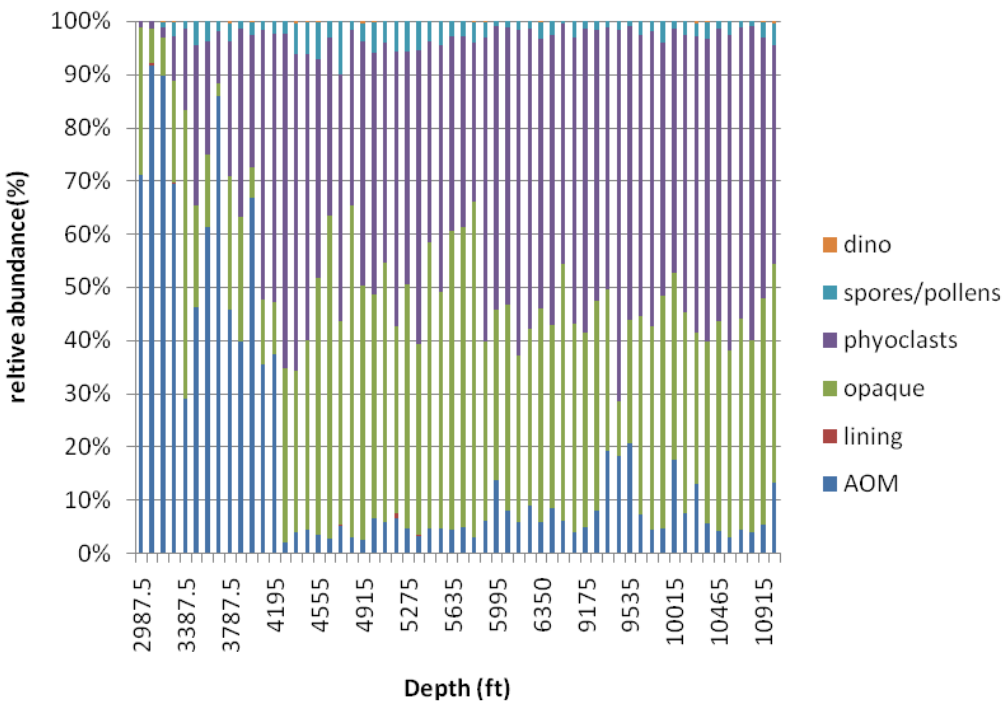

Figure 2. Percentage relative abundances of individual SOM particles

depths 4280-4290ft, 5990-6000ft, 6080-6090ft, 6170-6180ft, 6260-6270ft, 6440-6450ft, 8990-9000ft, 9080-9090ft, 9260-9270ft, 9350-9360ft, 9530-9540ft, 9730-9740ft, 9820-9830ft, 10010-10200ft, 10190-10200ft, 10460-10470ft, 10550-10560ft, 10640-10650ft, 10730-10740ft.

The predominance of phytoclast groups are mostly

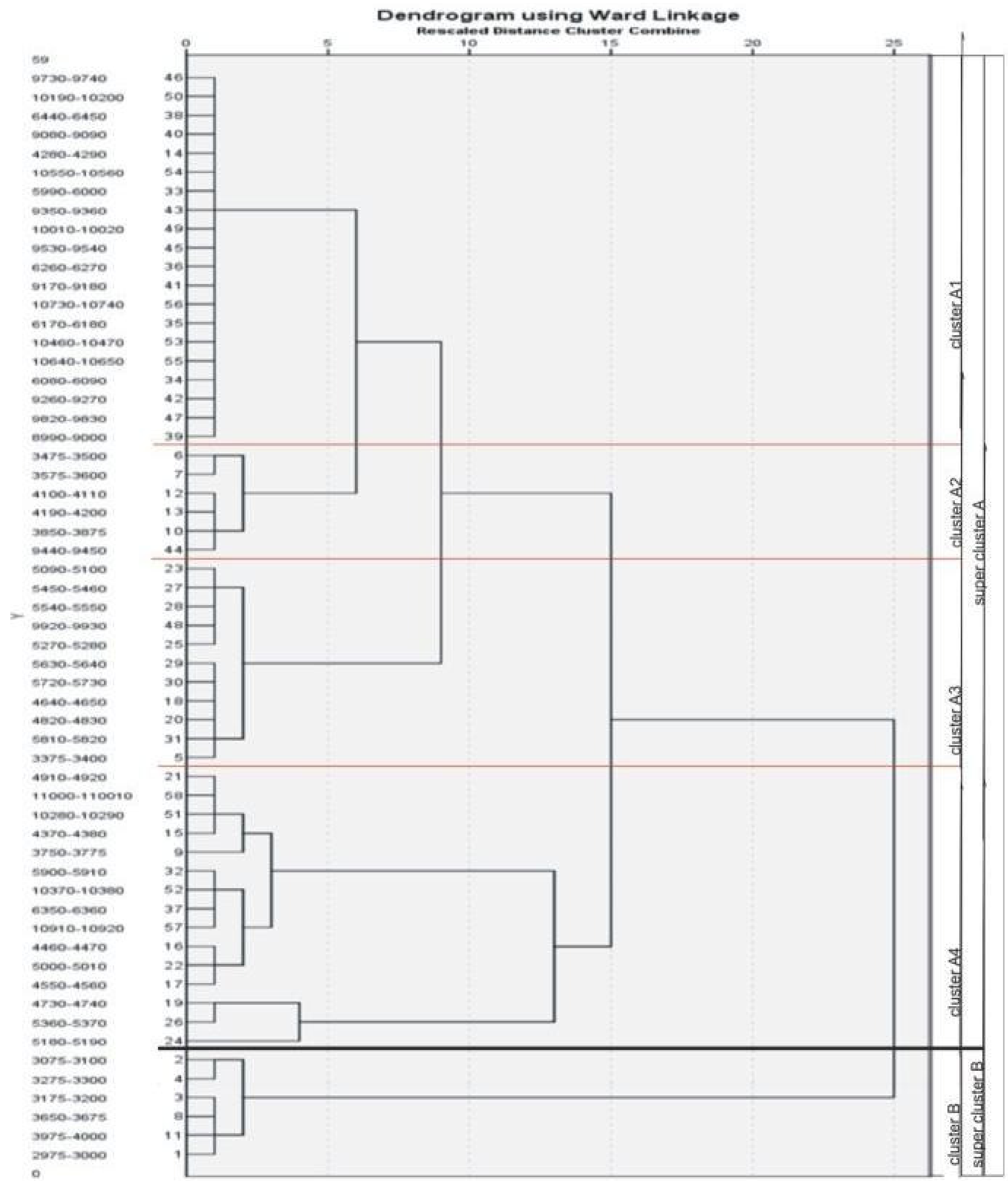

Figure 3. Dendrogram by Q-mode of Dixcove 4-2X well showing grouping of samples in clusters

Table 1. Palynofacies associations identified after the cluster analysis

Palynofacies Type	Description	Cluster	Super cluster
P-1	Predominance of phytoclasts group with a high content translucent phytoclast	A1	
P-II	Equal dominance of phytoclast and AOM group with some opaque phytoclast.	A2	
P-III	Predominance of phytoclast group with high content of opaque phytoclast	A3	A
P-IV	Predominance of phytoclasts group with high content of translucent phytoclast	A4	
P-V	High content of AOM combined with some opaque phytoclast	B	B

related to proximal depositional conditions, with the main controlling factor being the short transport of the particles. The phytoclasts are well preserved, translucent and structured (mainly cuticles, tracheid and brown wood). Palynomorphs though few, are mainly well preserved spores (pteridophytes) with some pollen. Marine organic

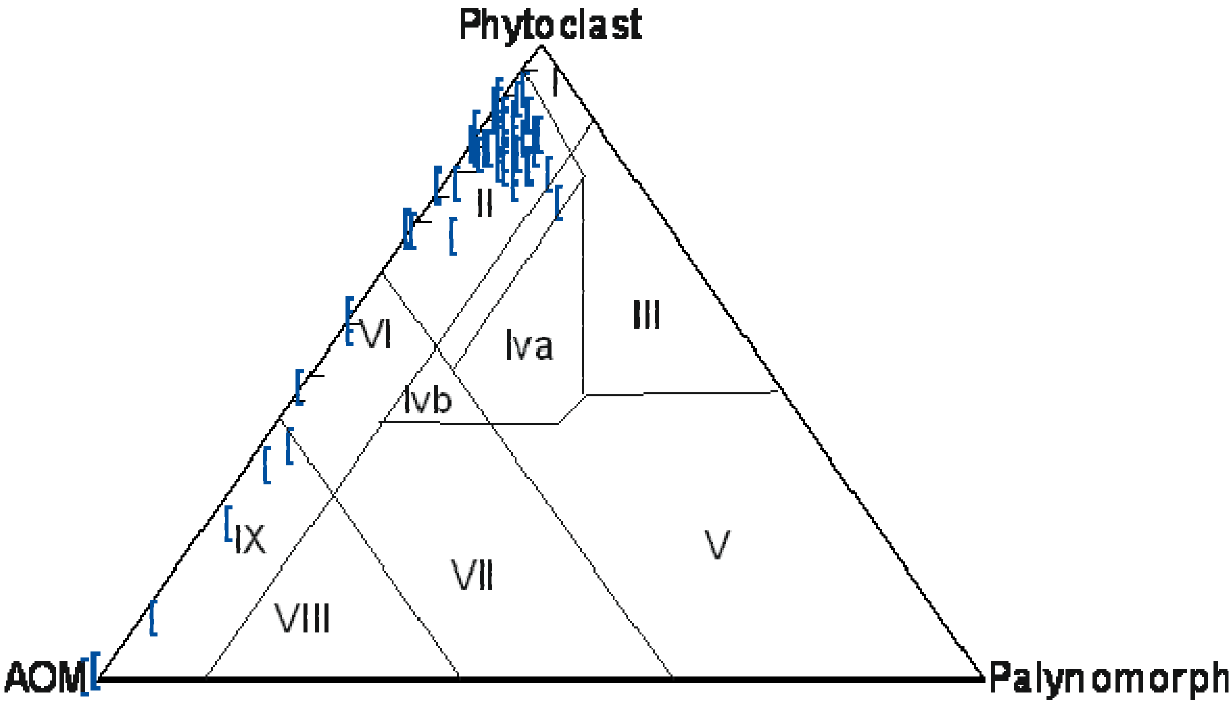

Figure 4. Amorphous organic matter (AOM)-Palynomorph -Phytoclast (APP) ternary diagram of relative abundance of palynofacies parameters used for palaeoenvironmental interpretation (After Tyson, 1995)
I highly proximal shelf or basin
II Marginal dysoxic-anoxic basin
III Hetero lithicoxic shelf ('proximal shelf)
IV Shelf to basin transition
V Mud-dominated oxic shelf ('distal shelf)
VI Proximal suboxic-anoxic shelf
VII Distal dysoxic-anoxic 'shelf'
VIII Distal dysoxic-oxic shelf
IX Proximal suboxic-anoxic basin

walled phytoplankton is scarce. This interval can be interpreted as high energy environment due to the presence of high percentage of cuticle, thus being dominated by terrestrial input (Boulter and Riddick, 1986; Zavattieri et al., 2008). The phytoclast contents of this facies suggest the proximity to a fluvio-deltaic source (Kholeif and Ibrahim, 2010).

Palynofacies type II (P-II) is made up of an almost equal dominance of phytoclast and AOM with an average abundance of 43% and 40% respectively. Opaque phytoclast has an abundance of 13% with palynomorphs being 4.3%. This association occurs in depths 3475-3500ft, 3575-3600ft, 3850-3875ft, 4100-4110ft, 4190-4200ft, and 9440-9450ft. This Palynofacies is marked by an increase in the AOM and relatively low frequency of black phytoclast as compared to Palynofacies type I. This observation reflects a proximal dysoxic – suboxic environment (Tyson, 1995).The low amounts of opaque phytoclast suggest low salinity due to close proximity to active fluvio-deltaic sources (Kholeif and Ibrahim, 2010).The observation of almost equal amounts of AOM and Phytoclasts and of dominant large blade-shaped opaque phytoclast over equidimensional forms is comparable to Palynofacies-type 2 (P-2) of Martinez et al. (2008) from Los Molles Formation in Argentina. Martinez et al. (2008) attributes this observation to proximal conditions (prodelta environment).

Palynofacies type III (P-III) is dominated by opaque phytoclast with a relative abundance of 53.5%, Phytoclasts, 38.3% and very little AOM of 6.4%. Palynomorphs are also less than 2%. This occur in depths 3375-3400ft, 4640-4650ft, 4820-4830ft, 5090-5100ft, 5270-5280ft, 5450-5460ft, 5540-5550ft, 5630-5640ft, 5720-5730ft, 5810-5820ft and 9920-9930ft. According to Kholeif and Ibrahim, (2010), opaque are derived from the oxidation of translucent woody material either during prolonged transport or post-depositional alteration. Tyson (1989) has stated that, the high frequency of opaque phytoclasts indicates oxidizing conditions and either proximity to terrestrial sources or redeposition of terrestrial organic matter from fluvio-deltaic environment. Tyson (1993) has also intimated that percentages of opaque phytoclasts are often high in oxidizing situations and are typical of fluvial and deltaic top settings with strong fluctuating water tables where there is strong post-depositional oxidation of phytoclast material in sandy sediments.

Palynofacies type IV (P-IV) is dominated by phytoclast with a relative abundance of 49.2%, with opaque phytoclast reflecting 37.8% and few AOM of 8.7%. Palynomorphs are 4.4%. This occurs in depths 3750-3775ft, 4370-4380ft, 4460-4470ft, 4550-4560ft, 4730-4740ft, 4910-4920ft, 5000-5010ft, 5180-5190ft, 5360-5370ft, 5900-5910ft, 6350-6360ft, 10280-10290ft, 10370-10380ft, 10910-10920ft, 11000-11010ft. This palynofacies is similar to Palynofacies type I (P-I) except for the relatively small difference between the translucent and the opaque phytoclast. The predominance of phytoclast contents suggests the proximity to a fluvio-deltaic source and moderately dysoxic environment (Kholeifand Ibrahim, 2010).

Palynofacies type V (P-V) is mostly made up of AOM with a relative abundance of 79.3%, with some opaque phytoclast of 12.9% and phytoclast of 7%. Palynomorphs have 1.7%. This occurs in depths 2975-3000ft, 3075-3100ft, 3175-3200ft, 3275-3300ft, 3650-3675ft, and 3975-4000ft. The high percentage of AOM greater than 60%in organic rich sediments indicates enhanced preservation in reducing conditions and increased stability of water column, resulting in dysoxic or anoxic bottom conditions (Tyson, 1993, 1995; Ibrahim et al. 2002). In oxygen-deficient basins, with high AOM preservation, allochtonous terrestrial material is dominant in the immediate vicinity of fluvio-deltaic sources or within turbidites (Tyson, 1987, 1989, 1993). Zavatierri et al. (2008) described similar palynofacies association in their Interval B (Samples 6947-9651) of the Neuquen basin, Argentina, and interpreted it as a relatively high-energy reducing environment with a terrestrial organic input.

Martinez et al. (2008) also described similar palynofacies (P-5) association from the Los Molles formation, Argentina, which was dominated by high percentages of AOM, scarce palynomorphs and almost equal proportions of opaque and translucent palynomorphs. Their interpretation was that the high AOM (70%) and the equal proportions of opaque and translucent phytocalsts suggest a non-marine (marginal marine) environment under dysoxic condition. Carvalho et al. (2006) have indicated that a large amount of AOM results from the combination of the high preservation rate and low-energy environment attributed to dysoxic-anoxic conditions. Kholeif and Ibrahim (2010) suggest that the very low presence of palynomorphs suggest a proximal suboxic –anoxic basin environment. Quattrocchio et al. (2006) interprets a similar association from their sample 2003 from well sections in northeastern Tierra del Fuego, Argentina, as reflecting near shore to deltaic environment.

The visual kerogen (SOM) analysis under the microscope using spore colour, particularly cicatricose spores (*Cicatricosisporites*/*Appendicisporites*) was done to elucidate the potential of the kerogen particles for oil and gas generation. The cicatricose spores encountered in the super cluster A (Figure 5) are characterized by brown to dark brown colour which suggests thermal maturity favourable for wet gas and condensate generation (Hart, 1986; Batten, 1980; Nohr-Hansen, 1989). The rich organic matterwith woody and coaly debris (black phytoclast) confirms this suggestion. Super cluster B which is higher up the well, has orange to light brown cicatricose spores and abundant AOM which suggests marginal thermal maturation facies suitable for the generation of oil albeit with little or no potential of commercial source (Ibrahim and Schrank, 1996).

Age Assignment

Aptian age

The age assignment is based primarily on miospore association from different levels in the well.The lower sections between sample intervals 5640 – 11010 ft. is devoid of Elaterospores, and dominated by *Afropollis jardinus, Cybelosporites pannuceus, Reyea polymorphus, Ephedripites* spp as well as pteridophytic spores including *Cicatricosisporites, Appendicisporites, Deltoidspora, Cyathidites, Concavisporites,.* The presence of *A. jardinus*, is significant because it has been reported on the world record as a stratigraphic marker for the early Aptian age for regions in equatorial Africa (Doyle et al., 1977). It has also been reported from upper Aptian to lower Cenomanian sediments in northern Sudan (Schrank, 1990) and from the lower Albian – lower Cenomanian deposits in Brazil (Herngreen, 1973, 1975), Albian – Cenomanianin Bornu Basin, Nigeria (Ola-buraimo and Boboye, 2011). The absence of any elater–bearing pollen which is a stratigraphically important element of the Albian – Cenomanian, delimits the age of this interval to pre-Albian and suggests an Aptian age.

Albian – Cenomnanian age

The interval between 2975– 5640feet is characterized by elater-bearing forms including *Elaterosporites* spp, *Elaterocolpites* spp. *Galaecornea causea*. Other forms associated with the elaters are *Classopollis classoides, Afropollis jardinus, Reyea polymorphus, Cybelosporites pannaceus, Ephedripites* spp. Literature available indicates that the elater-bearing pollen is stratigraphically restricted to the Albian – Cenomanian sediments in the Africa South America (ASA) region (Herngreen et al., 1996; Jardine et Magloire, 1965; Herngreen, 1975; Atta-Peters, 2006; Jardine, 1 967; Schrank, 1990; Herngreen

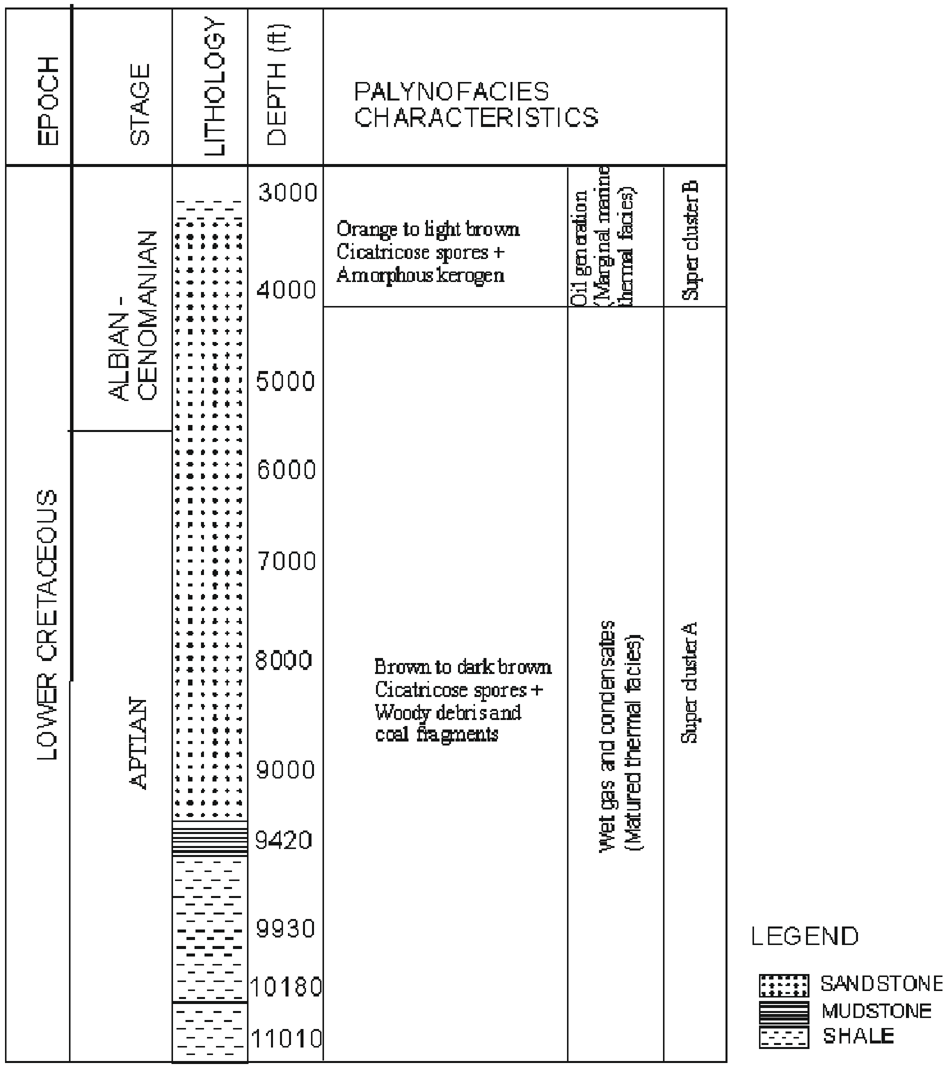

Figure 5. Palynofacies characteristics of the Aptian-Cenomanian in the Dixcove 4-2X well. (Modified after Ibrahim and Schrank, 1995)

and Duenas-Jimenez, 1990, Batten and Uwins, 1985; Thusu and Van der Eem, 1985). *A. jardinus, R. polymorphus* and *C.classoides* which are associated with the elater forms in this interval have been reported from Aptian – Cenomanianage and are not found in sediments younger that the Cenomanian

Palaeoecological implications from palynomorphs

Schrank (2001) stated that the high abundance of *Afropollis* and elaterate pollen in Marine section in northern Egypt suggests the parent plants inhabiting humid coastal plains. The Occurrence of *Ephredripites* and *Classopollis* which are xerophytes (Schrank and Nesterova, 1993; Schrank and Ibrahim, 1995; Schrank and Mahmoud, 1998) suggest drier conditions. Abundance of *Classopollis* has been correlated with evidence of warmth and aridity (Zavattieri et al., 2008). The presence of pteridophytic spores (*Cicatricosisporites, Deltoidspora, Cyathidites Concavisporites*) have been attributed to vegetation growing on wetland (Playford,1971; Mahmoud and Schrank, 1998).From interpretations based on the above, the common occurrences of the xerophytes *Ephedripites, Classopollis*, elaterate pollen as well as the pteridophytes indicate a paleoenvironment with parent plants inhabiting wetlands in a humid, warm coastal plain in an arid climate.

CONCLUSIONS

Five palynofacies types (P-I to P-V) have been identified in the Dixcove 4-2X well based on SOM association.

Palynofacies types P-I and P-IV suggest deposition in proximity to a fluvio – deltaic source in a moderately dysoxic condition, P-II reflects deposition in a proximal (prodelta) dysoxic - suboxic environment, P-III is indicative of deposition in an oxidizing condition in proximity to terrestrial sources and P-V is attributed to deposition resulting from high preservation rate and low energy dysoxic - anoxic condition in marginal marine environment.

Based on the presence of stratigraphic important palynomorphs, an Aptian age is assigned to sediments within interval 5640-11010ft and an Albian - Cenomanian age assigned to sediments within interval 2975-5640ft. The presence of the pollen, *A.jardinus*, *C. classoides*, Elaterspores, *Ephedripites* and pteridophytic spores, *Appendicisporites*, *Cicatricosisporites*, *Deltoidspora*, *Cyathidites* suggest a paleoenvironment with parent plants inhabiting wetlands in a humid, warm coastal plain in a semi-arid climate.

Visual observation of spore colour suggests thermal maturity in favour of wet gas and condensate generation in super cluster A and generation of oil with little or no potential of commercial source in super cluster B.

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Explanation of Plates

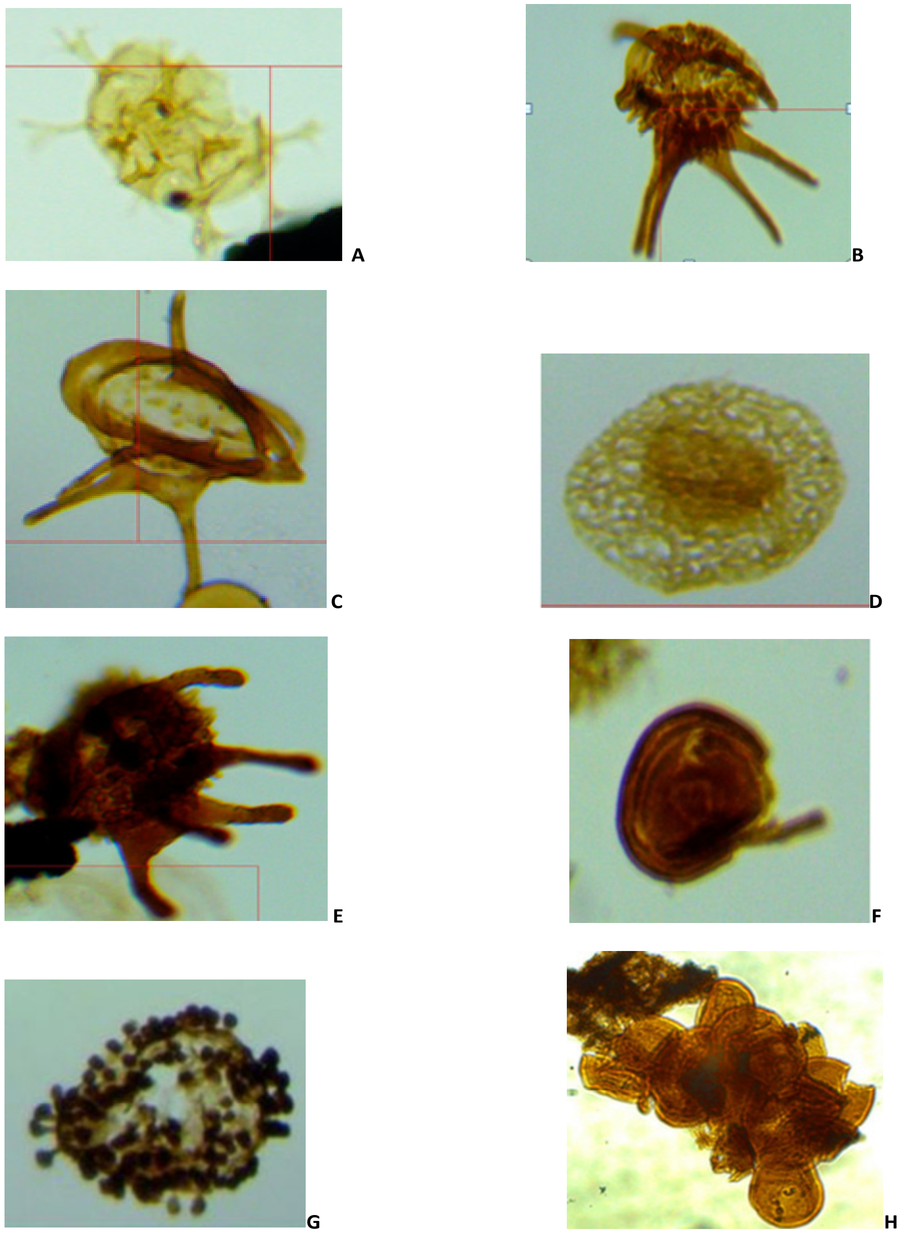

Plate 1.A. *Oligosphaeridium complex*; B, E. *Elaterosporites protensus*; C. *Elaterosporitesverrucatus*; D. *Afropollis jardinus*; F. *Classopollis* sp.; G. *Reyrea polymorphus*; H. *Classopollis classoides*(Bunch of pollen)

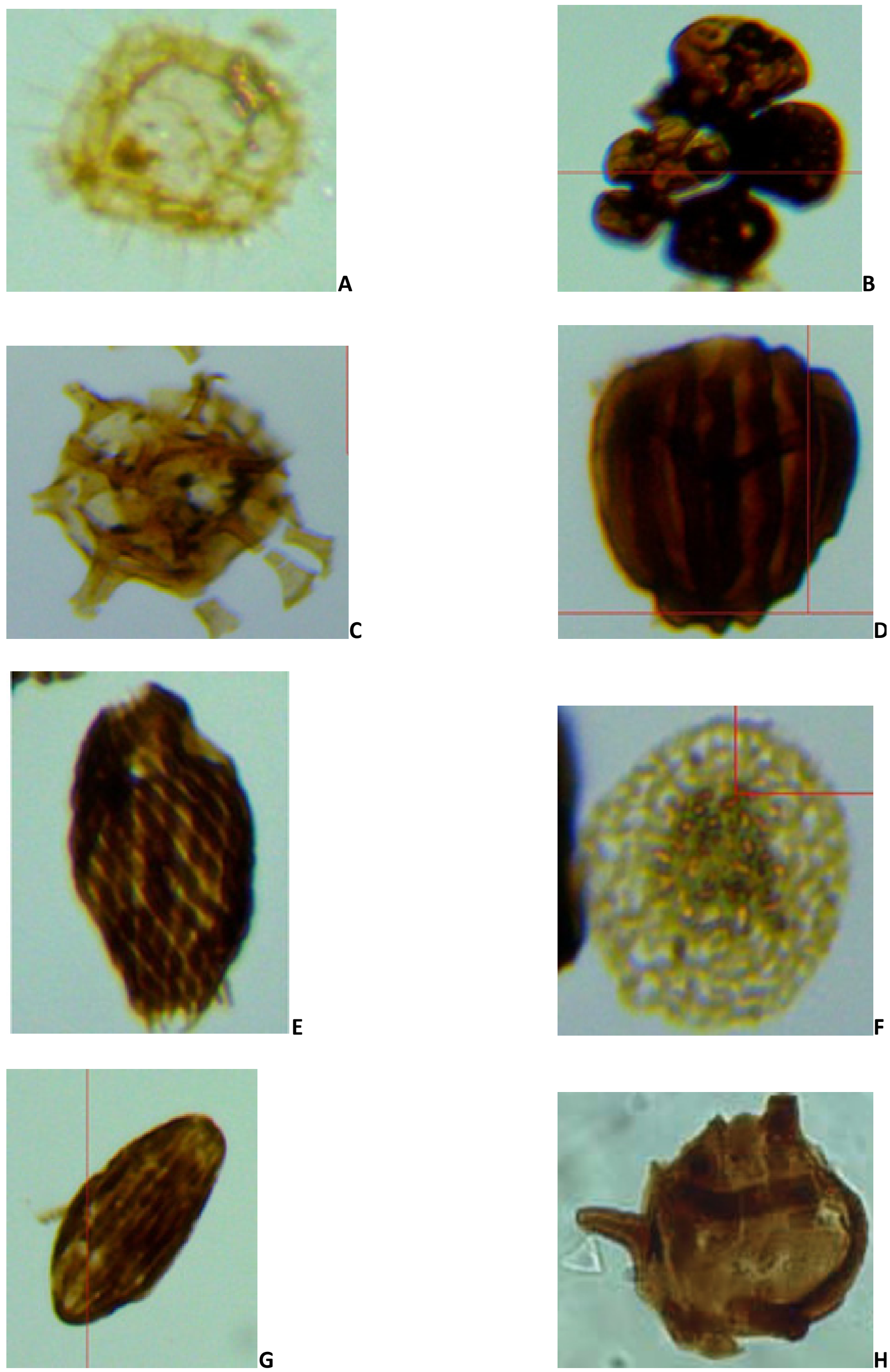

Plate 2. A.*Cleistosphaeridium* sp.; B. Foraminiferal lining; C. *Hystricosphaeridium* sp. ;D *Cicatricosisporites* sp.; E. *Ephedripites jansonii*; F. *Afropollis jardinus*; G. *Ephedripites* sp.

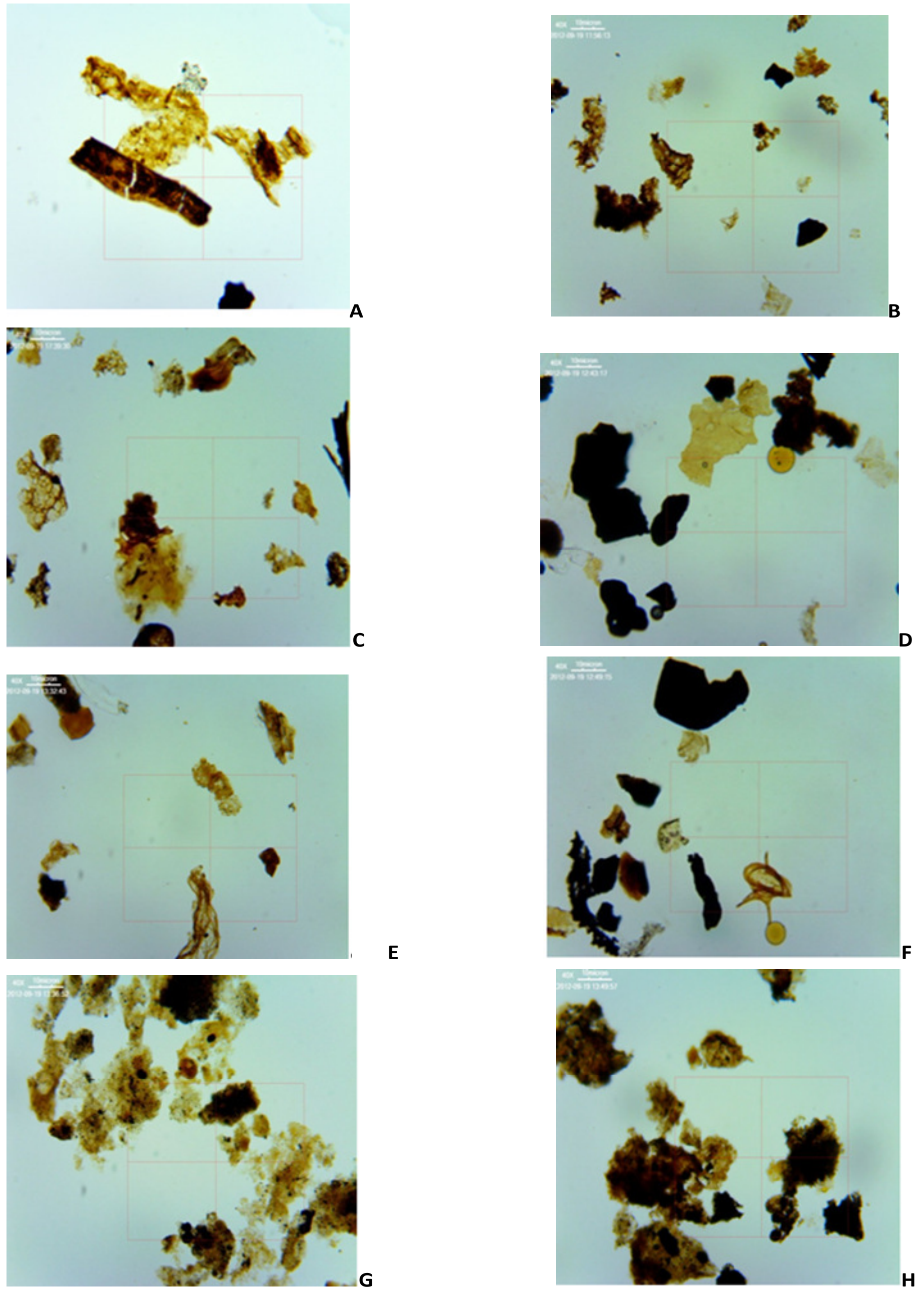

Plate 3. A, B. Palynofacies type I and IV (P-I and P-IV). Dominance of phytoclast group with high content of translucent Phytoclasts; C, E. Palynofacies type II (P-II). Equal dominance of AOM and Phytoclasts; D, F. Palynofacies type III (P-III). Dominance of opaque Phytoclasts with some translucent Phytoclasts and palynomorphs; G, H. Palynofacies type V (P-V). High amounts of AOM with some structure less opaquesphytoclasts