UNIVERSITY OF GHANA

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PALYNOLOGICAL ANALYSIS OF THE ST-5 AND ST -6 WELLS, OFFSHORE TANO BASIN, SOUTH WESTERN GHANA: IMPLICATIONS FOR STRATIGRAPHY AND PALEOENVIRONMENT

BY

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DECLARATION

I, Annan Wendy hereby declare that, except to other people's works, which I have duly acknowledged, this thesis is a result of my own research carried out under the supervision of Department of Earth Science towards the award of the Master of Philosophy Degree in Geology in University of Ghana.

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ABSTRACT

Miospores and dinoflagellates recovered from sediments from the ST – 5 and ST – 6 wells, offshore Tano Basin, Western Ghana were studied in order to determine their ages, establish palynostratigraphy and determine environments of deposition. Based on First Appearance Datum (FAD) and (LAD) of marker palynomorphs, three (3) biozones were erected for miospores and dinoflagellates respectively. The characteristic taxa of each of the biozones have been discussed in detail. The three biozones correspond to an Albian-Cenomanian, Campanian-Maastrichtian and a Paleocene age respectively. There are no representatives of the Turonian/Santonian ages, thus suggesting the presence of an unconformity between the Albian–Cenomanian and Campanian-Maastrichtian sediments. The Albian–Cenomanian sediments are characterised by the presence of elaterate pollen with scarce dinoflagellates which is indicative of deposition in a marginal marine environment under a warm, arid/semi-arid climate. The Campanian–Maastrichtian sediments are characterized by typical *Nypa* species such as *Proxapertites* and *Longapertites* that thrived in a coastal mangrove environment under a hot tropical to sub-tropical climate. The dinoflagellates of the Campanian–Maastrichtian sediments indicate that deposition took place in a marginal marine to open marine environment. These conditions were deduced based on the variations in the relative abundance of peridiniacean to gonyaulacoid cysts. The peridiniacean assemblage observed in the Campanian–Maastrichtian sediments of the ST–5 and ST–6 wells of the Tano basin is dominated by *Andalusiella, Cerodinium, Senegalinium and Phelodinium.* These species are the constituents of the tropical – subtropical Malloy suite of Lentin and Williams (1980). The miospore assemblage of the Albian–Cenomanian horizons shows elements that are typical of the Albian-Cenomanian

Elaterate Province of Africa and South America. The Campanian – Maastrichtian miospore assemblage observed are also typical of the Senonian Palmae Province.

DEDICATION

This research is dedicated to Dr. Rita Olivia Annan and Hilda Annan. I'm eternally grateful for everything.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The Tano Basin is one of the three coastal sedimentary basins in Ghana, the other two being the Saltpond and Keta Basins (Figure 1.1). The Saltpond basin is of Devonian age and the Keta basin is of middle Cretaceous-late Pliocene age. The Voltaian is the largest basin in Ghana, which is inland (Fig 1.1.) and of Neoproterozoic age.

The Tano Basin occupies the south western most corner of the country. This basin was formed as a consequence of complex pull apart tectonics that were associated with the separation of the African and South American continents during early-middle Cretaceous times. The Tano Basin is one of the six basins that constitutes the Gulf of Guinea Province with the other five being the Ivory Coast, Central, Saltpond, Keta and Benin Basins and the Dahomey Embayment (Brown & Charpentier, 2006) (Figure 1.2).

Collectively, these basins form a province since their structural and stratigraphic characteristics are similar. This is because these basins all formed as a result of wrench modified tectonics. Sediments from this province range from Ordovician to Holocene in age (Kjemperud *et al.*, 1992).

The Tano basin has rapidly evolved to become one of the most popular basins in West Africa in the last decade due to its hydrocarbon prospectivity. The Tano basin consists of a rift section which comprises a shallow marine to continental deposits of more than 4000 meters thick. This rift section is of Aptian – Lower Albian age. Overlying these deposits is a thick, relatively more marine influenced, Upper Cretaceous section, which is dominated by basin floor fans, stratigraphic traps and channel systems. This depositional trend represents the transition from an initial rift phase to more open marine conditions, accompanied by marked variations in sea level.

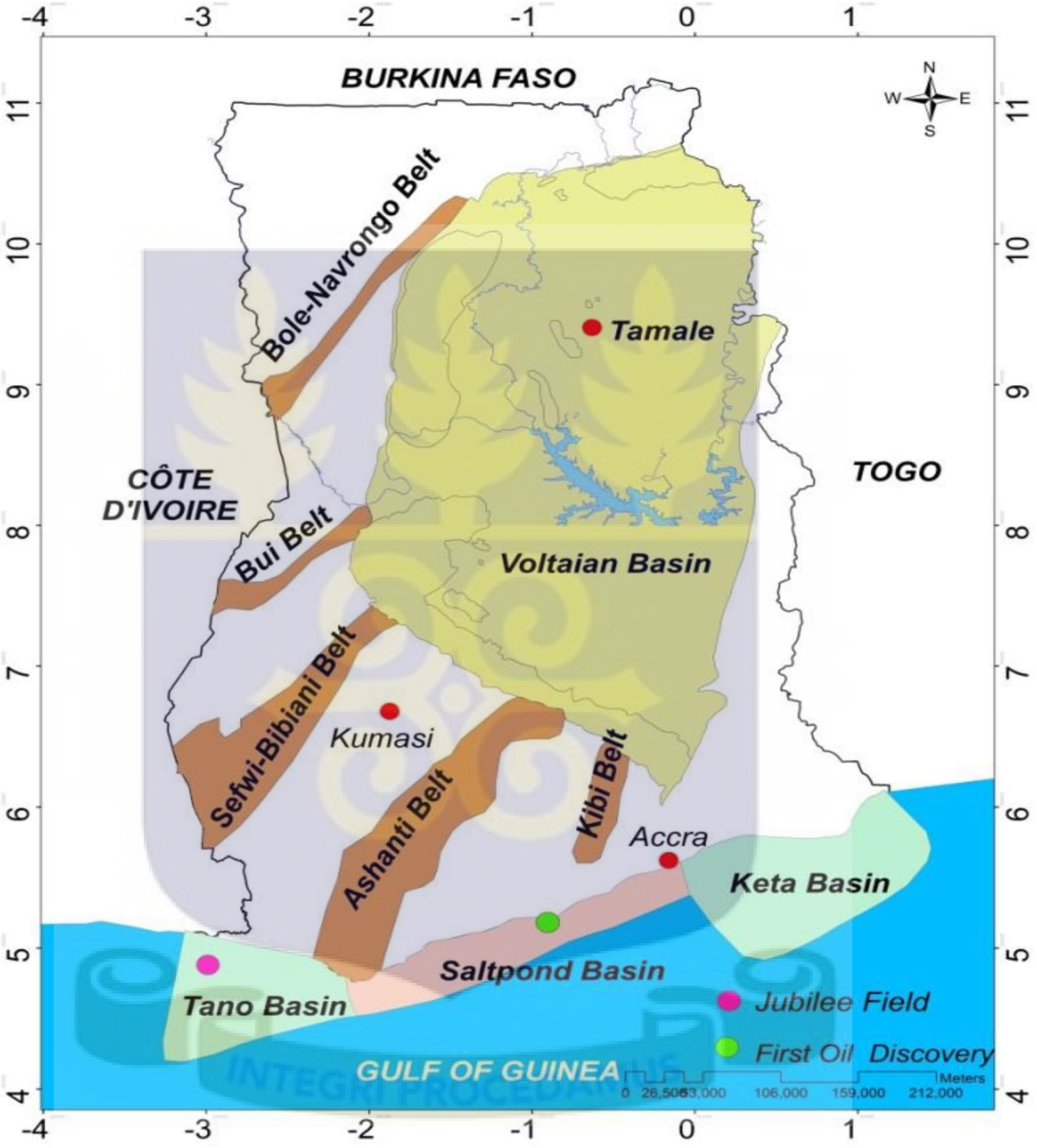


Figure 1.1: Relative positions of the major sedimentary basins in Ghana. (Source; Obeng, 2015)

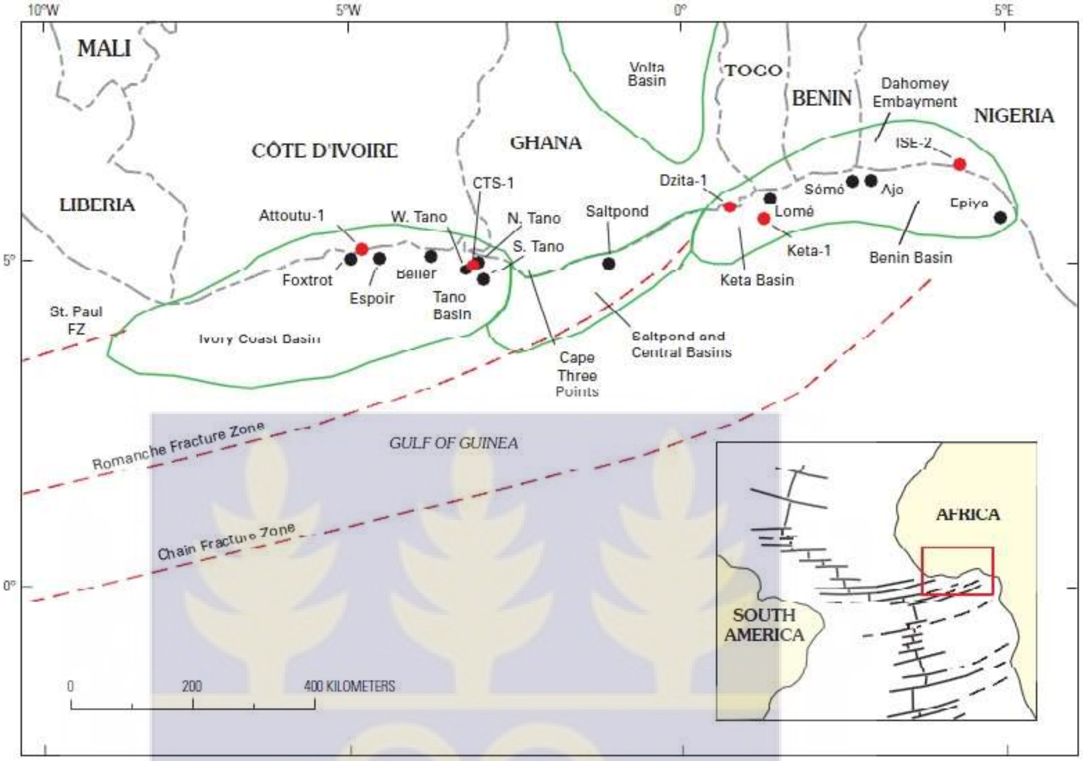


Figure 1.2: Major basins and structural features of the Gulf of Guinea Province. (Source: Brownfield & Charpentier, 2006)

A critical look at these variations in sea level reveals the possibility of corresponding variations in local paleo--environmental conditions. This research therefore, seeks to map out the changes in the paleo--environment at the different phases of deposition within the basin, using palynology.

The working play type within the Tano basin is the Cretaceous Play, which is made up of Albian and Cenomanian-Turonian shales as source rocks with Albian sandstones in tilted fault blocks and Turonian slope fan turbidite sandstones as reservoirs. Trapping of hydrocarbons within the basin is both stratigraphic and structural.

The continuous spudding of wells within the Tano basin provides a constant supply of sediment samples in the form of side cores, ditch cuttings and chips that can be used for research. These sediment samples are often rich in Sedimentary Organic Matter (SOM) including palynomorphs.

In the oil industry, palynology (the study of palynomorphs), is a stratigraphic tool especially valuable in the study of rocks deposited in continental, coastal, and shallow-marine settings (Rull, 2002). Palynological analyses are employed in paleo-environmental reconstructions, chronostratigraphic correlations and the evaluation of potential source rocks. Palynology is one of the primary methods of ascertaining the proper order of strata in the rock record and is also very useful in constraining the age of sediments.

Palynology as a vital tool in paleo- climatic and paleo-- environmental reconstructions of deposits is demonstrated by El Beialy (1995) who studied palynomorphs recovered from sediments from Egypt. Based on the presence of marker palynomorphs and their ecological preferences, El Beialy (1995) was able to predict the environment and climate under which the sediments were deposited. Other authors such as Oboh-Ikuenobe *et al*., (1998); Mahmoud (2003); Boboye, (2012 & 2013); Apaalse & Atta-Peters (2013); Atta-Peters & Salami (2004a, 2004b, 2006) have been able to constrain the ages and predict the environments of deposition of host sediments based on the presence or lack thereof of stratigraphically important palynomorphs that they encountered in the areas they carried out their studies.

1.2 HISTORY OF PETROLEUM EXPLORATION IN THE TANO BASIN

Exploration for hydrocarbons in Tano Basin dates as far back as the 1800's. The search for oil and gas officially commenced in 1896 in the Tano area. Early explorers discovered oil seepages in the Tano areas and this initiated the exploration for hydrocarbons in the Gold Coast. The initial wells drilled were sited onshore and drilled with very little understanding of the geology and also with no seismic data. Since 1896 till now, oil exploration in Ghana has gone through four main phases.

The first phase was between 1896 and 1969. During this time, all the exploration activities that were carried out in the Tano area were all onshore and characterized mainly by wildcatting activities by four companies. These companies are the West Africa Oil and Fuel Company (WAOFCO), Sociètè Francaise de Petrole, African and Eastern Trade Corporation and Gulf Oil Company. As at the close of 1969, a total of seventeen wells had been drilled with no significant oil and gas discoveries.

Between 1970 and 1984, exploration for hydrocarbons became more focused on the prospectivity of the offshore sedimentary basins, including the Tano Basin. This marked the onset of the second phase. Two years into this phase, fourteen wells were spudded offshore. On July 29, 1970, the Tano 1-1 well was spudded by Volta Petroleum Company. The Tano1-1 led to the discovery of the current North Tano Oil and Gas Field within the Tano Basin.

All offshore prospects were mapped using 2D seismic data during this (2nd) phase. Between 1979 and 1980, Philips Petroleum drilled several appraisal wells within the Tano Basin. Significant amongst them is the IS – 3AX well which is located within the South Tano field which struck a gas and condensate find, down dip of the main field. Even though the South Tano discovery was considered to be sub commercial, Philips Petroleum relinquished the block because there was no market for the gas. Similarly, Philips Petroleum had to relinquish the North Tano block after it drilled IN – IX well that struck oil and gas but was declared uncommercial. In 1984, Two appraisal wells were drilled (ST -5 and ST- 6) without much success by Pero Canada International Assistance Cooperation (PCIAC) in the South Tano Field.

Three petroleum laws were enacted under the Provisional National Defence Council (PNDC) later that same year and exploration activities took a drastic turn for the better. The PNDCL 64 set up Ghana National Petroleum Company (GNPC) as a statutory body with the necessary institutional framework that will handle Ghana's Exploration and Production activities. PNDC 84 established the legal and fiscal framework for the conduct of E & P activities and PNDCL 188 was enacted to provide a tax regime for petroleum exploration. During this time the newly launched GNPC sought for funds from external sources. This how the Canadian government acting through PCIAC, disbursed substantial amounts of money to GNPC. PCIAC also aided in the training of personnel and equipping GNPC's research Laboratory. At this time more wells were drilled and more seismic data was acquired. All these events led to the accumulation of large volumes of data and also provided a hands on learning experience for GNPC staff. In the fourth and final phase, GNPC was restructured, downsized and given the directive by the newly elected government to concentrate on its primary function of facilitating the activities of the E & P companies in Ghana to find commercial accumulations of hydrocarbons. The reoriented GNPC was retooled with new state of the art workstations for the Operations Division and other computer equipment for other departments in order to facilitate serious, highly oriented work.

During this time, GNPC opened its doors to foreign and local investors. Some reputable Independent Oil Companies such as Hess Corporation, Kosmos Energy, Tullow Energy, Norsk Hydro Oil and Gas, amongst others showed interest in partaking in the ongoing hydrocarbon exploration in the Tano Basin.

A number of oil companies acquired blocks and explored for oil both in the onshore and offshore areas. Though the wells drilled did not find hydrocarbons in commercial quantities, their results were very promising and provided concrete technical foundation for determining the future direction of petroleum exploration in Ghana.

In June 2007, a consortium of oil companies including Tullow Oil and Kosmos Energy struck oil with Mahogany-1, located 132 km south-west of the port city of Takoradi, in water depths of over 1,000m. The oil encountered is trapped in an Upper Cretaceous (Turonian) turbidite fan system. This find marks almost a 100 years after the first attempt at hydrocarbon exploration in Ghana. This by far was the most significant discovery crowning years of intensive efforts by all parties concerned.

This oil find was followed a few months later by the Hyedua discovery, 5 km south-west of Mahogany and part of the same field, which has been named Jubilee as the field's discovery was coincidental with Ghana's Golden Jubilee year. In February 2008, came further encouragement for the industry, with the success of Odum-1, approximately 13 km east of the Jubilee Field and 117 km south-west of Takoradi. This discovery is also within the Upper Cretaceous (Campanian) and opens a new play fairway in the Tano Basin. Further exciting prospects have been delineated in the Tano Basin, several of which are thought to hold more than 500 MMbo.

These discoveries have opened up a significant new deep water oil domain in the Gulf of Guinea Province. The Jubilee Field discoveries have intensified exploration activities in offshore Ghana. Currently, there are nine offshore licenses, and more than 20 companies have either submitted applications or have expressed interest and are reviewing data. As of now, Tullow Oil holds two (2) Licences in partnership with other entities; Kosmos and co. holds one (1). Other companies are Vanco Energy (1), Hess Corporation (1), Gasop Oil (1), Heliconia (1), Lushann Eternett and partner (1) and Devon Energy (1) (Table 1.1). Applications by other companies to acquire licensing in order to operate some of the open blocks are under consideration.

As of now, GNPC and its newly formed subsidiary, Explorco are concentrating on the development of the Jubilee, Tweneboa, Enyenra, Ntomme, Offshore Cape Three Points, Mahogany Teak and Akasa Fields' Development in the Tano Basin.

All these exploration activities have provided and continue to provide sediment samples as well as well logs and other data sets for palynological and geochemical analysis that are invaluable in research.

Table 1.1 Oil companies with licenses and their areas of operations

COMPANY	**AREA OF OPERATIONS**
Kosmos Energy, Anadarko Tullow Oil	West Cape Three Points
Vanco Ghana Ltd.	Deep Water Tano/Cape Three Points Basin
Tullow Oil	Tano Shallow & Tano Fields Development
Tullow and Kosmos Energy	Tano Deep
Hess Corporation	West Cape Three Points Deep
Heliconia Energy	Cape Three Points Basin

1.3 PROBLEM STATEMENT AND JUSTIIFICATION

In the detailed account of the history of oil exploration in Ghana, as summarized in section 1.2, great emphasis was placed on how seismic data over the Tano Basin was acquired, processed and interpreted by GNPC and its foreign allies. There was no mention of palynology or any form of biostratigraphic tool and how it also played a role, no matter how small in the E and P activities within the basin.

Even though palynology receives very little attention not only in oil exploration in Ghana, but also in research, it remains one of the most cost effective and cutting edge disciplines that provides a definitive means of dating and correlating terrestrial and marine sediments.

Countries such as Brazil, Egypt, Nigeria, Sudan and Ivory Coast who have been in the oil and gas business relatively longer and earlier than Ghana, have invested and continue to invest considerable funds and resources into advanced palynological research. These oil nations recognize and appreciate the value of palynology as a tool that is vital in making concrete inferences about the rocks that are encountered during exploration activities.

The incorporation of palynology with other geological disciplines, such as sedimentology, geophysics, geochemistry, and petrophysics, is essential in geological modeling and petroleum system studies, which in turn are useful in planning and developing better exploration strategies and for optimizing reservoir exploitation.

1.4 AIMS AND OBJECTIVES

This research therefore, aims to project palynology as a necessary means of determining the age and environment of deposition of the sediments recovered from the ST- 5 and ST – 6 wells offshore Tano Basin, by employing detailed palynostratigraphic and paleo- - ecological analysis. This research forms an integral part of a larger project that aims to fully describe and characterize the stratigraphy of the Tano Basin in light of its Sedimentary Organic Matter (SOM) content.

The objectives guiding this research are as follows:

- To identify and describe the palynomorphs from the different levels of the ST-5 and ST -6 wells in order to establish palynostratigraphy.
- To use the encountered palynomorphs as an age determining tool for the host sediments.
- To interpret paleo-- environmental and paleo--climatic conditions that existed at the time the sediments were laid down.
- To correlate the palynomorph assemblages across the two wells.

1.5 SCOPE OF STUDY

This research involves the use of palynomorphs, mainly spores, pollen and dinoflagellates in establishing palynostratigraphy, age determination of host sediments and for paleo-climatic/paleo- environmental reconstructions. The sediments for this study are from the ST- 5 and ST-6 wells, offshore Tano Basin (Fig 3.1).

Since the data for this study is from two closely spaced wells within the same basin, it will be possible to correlate the palyno-assemblages observed from the individual well sections, thereby highlighting the presence or absence of unconformities within both sections.

1.6 LIMITATIONS OF STUDY

The input of geochemical data would have been an excellent way to further justify the results of this research because results obtained from geochemical data analysis often shows strong positive correlation with palynological evidence. Unfortunately, geochemical data for both wells are unavailable.

Another limitation is the lack of complete lithologic log data for the ST-5 well. Addition of lithology logs for both wells would have helped put the results in a better perspective that even others with very little palynological background would better appreciate the results of this research. Nonetheless, this research presents clear, concise findings using the data available.

1.7 GEOLOGY OF THE TANO BASIN

The Tano Basin is found at the south western corner of Ghana and covers a total area of about 1165.50 square kilometers. The basin is sandwiched between the mouths of two rivers. The Tano River to the west and to the east by the Ankobrah River (Fig 3.1).

Kesse (1985) described the Tano Basin as being a portion of the crescent shaped basin along the coast of the Atlantic Ocean. Two transform fracture zones delimit the boundaries of the Tano Basin. These are the St. Paul transform fault zone to the east and the Romanche transform fault zone to west (Figure 1. 2)

The Tano Basin is filled by rocks of the Apollonian System which are of Cretaceous age (Kitson, 1928). These rocks consist mainly of limestones with alternating claystones and sandstones. Junner (1940) in Cox (1952), stated that the limestones are fossiliferous and are inter bedded with clay and formed a continuous crest rising from the beach near the village of Kangan and run in a north-westward direction through a point one-and-a-half-mile north of Nauli and to the Tano river north of Edu. The Precambrian metasedimentary rocks of the Birimian supergroup form the basement rocks of the Apollonian rocks. These metasedimentary rocks are mostly schist, phyllite and greywacke.

Onshore, the Tano basin, is predominantly clays, sands and limestone with a general SSW dip direction and low dip angles. However, at depth, these sands and clays compact to form sandstones and shales. The limestones are extremely fossiliferous and are overlain by recent to Tertiary deposits of sands, clays and laterite.

The Tano Basin lies within the West African Transform Margin. Seismic surveys of the Ocean Drilling Programme (ODP) have shown that this margin has a distinctive feature of a NE-SW trending marginal ridge which is about 130km long (Atta-Peters & Salami, 2004a). This transform margin is associated with the Cote d'Ivoire–Ghana transform margin (CIG) which is as a result of the continental disintegration of the South America and Africa. The ridge within the CIG is bounded to the north by the deep Ivorian Rift Basin (Atta-Peters & Salami, 2004b). Larmarche (1997) indicated that the ridge has a sedimentary sequence which bears a close resemblance with the syn-rift sediments of the Ivorian Basin. Guiraud *et al.,* (1997) identified three lithofacies which constitutes the CIG sedimentary wedge. These are yellowish siltstones, dark clays and interbedded greenish sandstone with grey coarse sandstones and micro conglomerates. These syn-rift sediments have been assigned shallow marine deltaic environment of deposition of possible early Cretaceous age.

The Tano basin was initially an extensional rift basin. The rifting was triggered by complex tectonics associated with the separation of the continents of South America and Africa. It is believed that movements along a series of transform faults, (faults within the Romanche Fault Zone inclusive) during the split of the two continents led to the development of the large rift basin in the Tano area (Davies, 1989).

Due to these tectonic activities, a large rift basin had formed in the Tano Basin area by early Albian times. This was followed by widespread deposition of shallow marine sandstones and shales with minor limestone in the middle-late Albian times in the area. Structural evidences (formation of the South Tano structural trend, uplift, faulting and erosion of the external margin of the Tano Basin) suggest that final separation on the continents took place in latest Albian times (Davies 1989).

It is assumed that there was a thermal abnormality which was associated with crustal uplift at the margin of the newly created African and Brazilian continental plates in the Tano area during Late Albian times (Atta-Peters *et al.,* 2012). This theory of crustal uplift may be the plate tectonic model for the development of the Tano structural trend. Basins similar the Tano Basin are common around the world and often contain large oil fields. Examples of such are the Santos, Campos and Espirito Santo basins of Brazil and the parts of offshore West Africa.

1.8 STRATIGRAPHY OF THE TANO BASIN

The Tano Basin consits of various sedimentary sequences that represent different times and environments of deposition. The various lithologies span from Lower Albian to Eocene. A vertical succesion is shown in Table 1.2. The vertical sequence of the various rock units is outlined below, from the base to the top. Available reports and literature from GNPC describes the stratigraphy of the Tano Basin as presented below:

1.8.1 Lower Cretaceous Section

1.8.1.1 Lower Albian

Rocks of the lower Albian are called the Kobnaswaso Formation. They are composed of sandstones and shales. The basement over which the Kobnaswaso formation overlies has never been penetrated. The total depth of the Kobnaswaso is 4,270meters.

The bottom part of the Kobnaswaso Formation comprises dark grey to green shales with occasional beds of very fine sandstone and siltstone. The upper sections overlying these shales is a series of upward coarsening sequences, often referred to as parasequences by Davies (1989).

Intrusives of Jurassic (Dolerite sill) age that mark the onset of rifting in the Gulf of Guinea are found within the Kobnaswaso. Regional seismic surveys also reveal the presence of thick sedimentary wedges within the Kobnaswaso interval which is a characteristic of rift basin deposits.

1.8.1.2 B-Shale (Bonyere Formation)

Overlying the Kobnaswaso unconformably is the Bonyere Formation. The Bonyere Formation can be correlated throughout the whole basin, as such it is considered one of the most important strata in the Tano Basin. It is about 200meters thick. The rocks are mainly dark grey- blocky shales with a few siltstones. Davies (1989) suggests a Middle Albian age to the Bonyere shales these transgressive shales. These shales provide a good seal and possibly, source rock of hydrocarbons within the Tano Basin (Table 1.2).

1.8.1.3 Middle to Upper Albian

The Middle-Upper Albian deposits are mainly composed of sandstones, shales and little limestones. Philips and Petro Canada reported that the upper Albian sandstones were deposited in a near shelf, inter tidal bar and probably a delta front environment. In the South Tano area, these rocks show a coarsening up sequence of about 600meters in thicknes. The South Tano oil field reservoir is Upper Albian, while the gas field in North Tano is Middle Albian. The mid Albian deposits have been interpreted to be of lacustrine depositional environment and are major source rocks for gas in North Tano Basin. The uppermost Albian strata are unconformably overlain by transgressive Cenomanian limestones and limey sandstones along a marked regional angular unconformity.

1.8.2 Upper Cretaceous Section

1.8.2.1 Cenomanian Limestones

The Upper Cenomanian section consists of the thickest limestone accumulations in the basin, interbedded with a number of shales, claystones, siltstone and fine sandstone beds. The limestone is partly mottled, slightly argillaceous and chalky. Although laterally continuous, this Cenomanian section does vary quite considerably in thickness. The Upper Cretaceous and younger sediments thereof comprise an offshore dipping sedimentary wedge which thickens from 1,500 metres in the North Tano area to approximately 3,700 metres offshore at South Dixcove 1X. The Cenomanian strata are generally flat lying and act as a cap rock over the steeply dipping, faulted Lower Cretaceous rocks. The Cenomanian strata represent a period of local shallow water shoaling which preceded the major transgressions of the Upper Cretaceous and Tertiary times.

1.8.2.2 Turonian to Upper Santonian

The Turonian-Upper Santonian section is made up of brownish-grey shales and claystones, with occasional dolomite or limestone. It has about 280 meters thick. Most deep-water reservoirs of commercial importance are in the Turonian, namely Jubilee and Tweneboah. The Turonian section also hosts a significant portion of the source rock responsible for the Jubilee Field oil.

1.8.2.3 Campanian

The Campanian interval averages over 276 meters over the South Tano area. This succession is interpreted to have formed under conditions of rapid subsidence and was laid down in a relatively short period of time. This interval is shale-rich with occasional dolomite and limestone beds. In the deep water area, fields such as Teak and Odum have Campanian reservoirs.

1.8.2.4 Maastrichtian

The Maastrichtian section is relatively thin in comparison to the rest of the Upper Cretaceous sections. This interval is an indicator that during the late stages of the Upper Cretaceous, subsidence slowed. It is described as being principally composed of claystone with minor sandstone and dolomite beds with the upper parts having significant fossils.

The thick, highly porous Maastrichtian sandstones are of great interest. Although the Maastrichtian section appears to lie above the oil maturation window, several oil shows have been reported from these sandstones. It may be that either oil has migrated upward through faults into the Maastrichtian sediments, or hydrocarbon generation occurred at very low maturation levels, or lastly, the Maastrichtian sediments may be found in oil mature deep basinal areas that flank the southwest and northeast sides of the North Tano high.

1.8.3 The Paleogene and Neogene Section

1.8.3.1 Paleocene, Eocene, Oligocene and Miocene

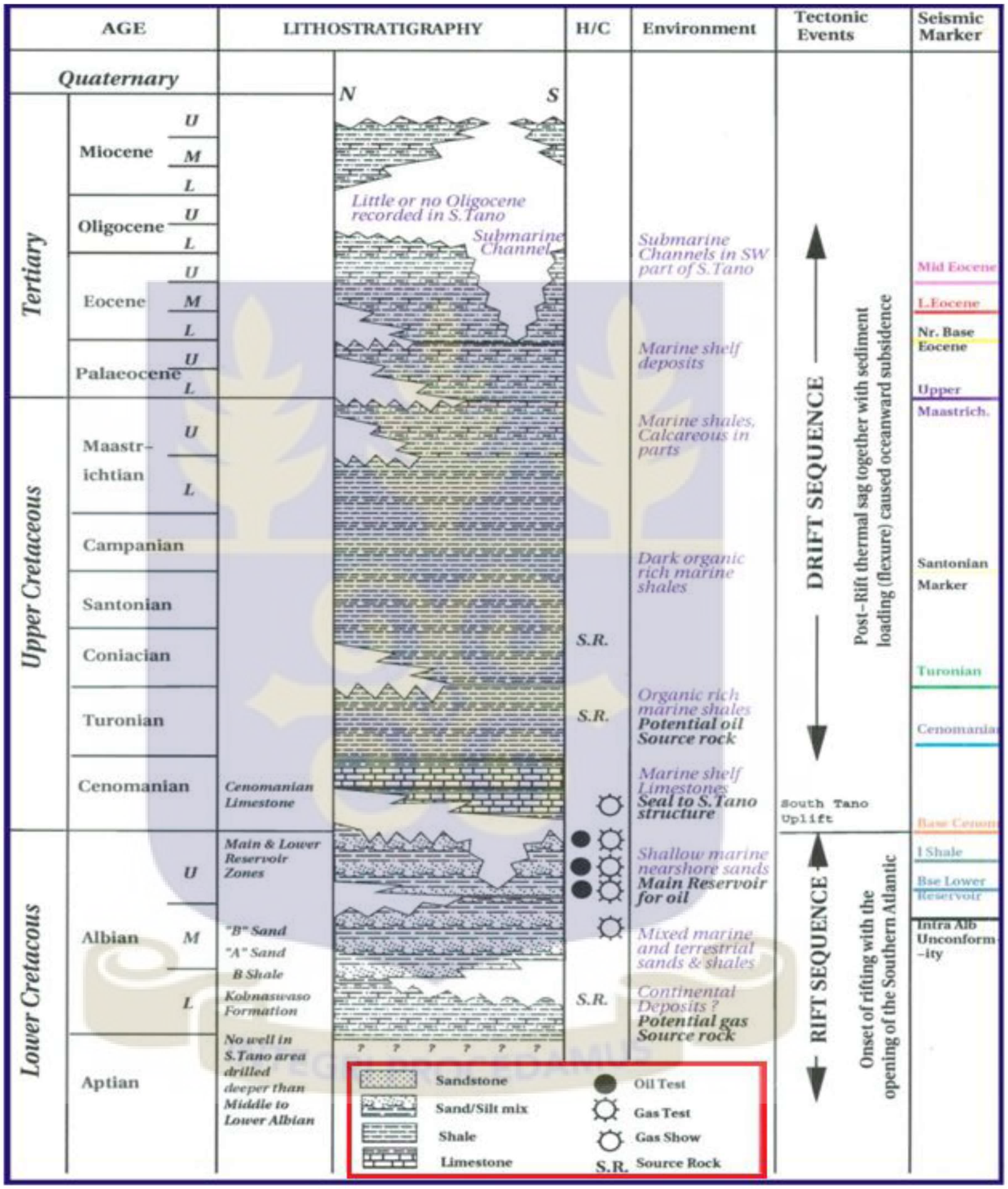
The Middle and Lower Eocene horizons of the Tano Basin is made up of finely laminated dark grey/brown claystones with thin beds of fossiliferous dolomite and fine sandstone.

A greater portion of the Paleocene, Upper Eocene and Oligocene horizons are either represented as a thin bed or totally absent. In the southeastern part of the basin, seismic data shows the presence of a number of Oligocene to Miocene submarine channels that have removed large amounts of the Eocene section.

The Miocene sedimentary rocks that were observed were predominantly brown-grey colored claystones, highly fossiliferous, glauconitic and sandy in part with stringers of dolomitic limestone. Unconsolidated marine sands with shell fragments and some clays grading to claystones and siltstones dominate the Middle Miocene to Recent section. Khan (1974) identified eight (8) stratigraphic units (as discussed above) from the study of borehole data and came up with concrete conclusions about the Tano Basin. He said the gross thickness of the sedimentary rocks in the basin is more than 3048m along the coast and towards the Cote d'Ivoire border and also the oldest rocks encountered in the boreholes are of Middle Cretaceous age. The maximum depth of marine rocks is about 1768m.

Khan (1974) further stated that there is an angular discordance which separates the marine strata from the non-marine. Two horizons with indications of oil are known; one near the surface of the Nauli Limestone horizon and the other at a greater depth, the Black Shale horizon. On-shore, the most promising area for accumulation of oil lies immediately south of the major fault indicated by gravity survey.

Table 1.2. The generalized stratigraphy of the Tano basin (GNPC, 2004)



CHAPTER TWO

LITERATURE REVIEW

Palynology is the study of organic non-mineralized microfossils, especially those in sediments, either of terrestrial, freshwater, or marine origin (Beaudoin, 1996). These microfossils are very small, generally falling into the 5 - 500 µm range, and are found in rocks of all geological ages, spanning the late Precambrian right up to the present (Beaudoin, 1996).

Cox (1952) reported on fossil samples collected from limestones in Nauli in SW Ghana. He stated that the Nauli limestone bed is made up of abundant lamellibranch and occasional gastropods. Exposed outcrops of the Nauli limestones contained shells and their interbedded clays had pyritized Mollusca. The clay samples yielded a single small specimen of ammonite of the *Texanities* genus, which Cox (1952) said was suggestive of a Campanian age.

Cox (1952) also found adequately preserved specimen of *Venericardia* and *Plicatul*a within these limestones. A Campanian-Maastrichtian age was assigned to these sediments after he compared the fossils with similar ones reported by Ridel (1932) from Cameroun. Samples from a well in Kpalikpa valley, also yielded some cretaceous fossils including of *Libycoceras* which also indicates Maastrichtian age (Cox, 1952).

Samples from north of the coastal town of Bonyere (west of Axim) consists of internal and external moulds of molluscan shells poorly preserved in a highly fossiliferous grey limestone. Due to inadequate preservation, very few species of gastropods were present. Ammonites were absent here. The grey limestones were inferred to be of Cenomanian age based on the abundance of *Plicatula auressensis* (Cox, 1952).

Samples were collected from the Anwiafutu limestones as well and their yield consisted of molluscan moulds just like the samples from north of Bonyere. However, the former had majority of its molluscan mould being lamellibranch and few gastropods. The lamellibranch was adequately preserved (Cox, 1952).

Cox (1952) reported that the presence *Plicatula auressensis* suggested a Cenomanian age because it depicts the same age in North Africa. The occurrence of *Exogyra olisiponensis* suggests a Cenomanian age. *Liopistha* is suggestive of a Cenomanian age and has accurate resemblance with other fossils in other horizons. *Trapezium* suggested Cenomanian age because it was assumed to belong to the same group as *Crassatella pusilla* from the Cenomanian of Egypt. Thus, the Anwiafutu limestones were assigned a Cenomanian age (Cox, 1956).

Atta-Peters (2013) reported on elaterate pollen recovered from 39 cutting samples that were obtained from the IS-3AX well, offshore Tano Basin. The study was concentrated between a depth interval of 9070ft and 6300ft. The elaterates encountered include *Elaterosporites verrucatus, Elaterocolpites castelaini, Elaterosporites klazii, Elaterosporites protensus, Galaeocornea causea, Elateropollenites jardinei, Galaeocornea. clavis and Sofrepites legouxae.*

Atta-Peters (2013), interpreted the observed taxa as being representative of Albian – Cenomanian age after comparison with other reports of occurrences of elaterate pollen from (Zobaa et al., 2013; Jardine, 1967; Doukaga, 1980; Abubakar *et al*, 2006) the America South America (ASA) region. These elaterates are elements of the Albian – Cenomanian Province of Africa South America (ASA) of Herngreen (1975).

Atta-Peters (2013) suggested an arid to semi-arid paleo-climatic condition existed at the time of deposition based on the species present. Atta-Peters (2013) remarked that the elaterates were laid down in a fluvial/lacustrine environment and died out after the Cenomanian as a result of the sudden shift to a more open marine environment.

Atta-Peters *et al*., (2012) reported on palynomorphs recovered from sediments of the Bonyere – 1 well, Tano Basin. The palynomorphs are mainly spores, pollen, dinoflagellates and foraminiferal test linings. Based on marker fossils from various depths in the well, an age range of Aptian – Maastrichtian age was assigned to the stratigraphic section encountered in the well.

Sediments between the intervals of 1800-10ft and 90-100ft had an abundance of *Proxapertites spp., Longapertites spp*., *Proteacidites dehaani*, *Glenchinidite*s *spp*., *Cyathidites australis* and *Echitriporites trianguluformis.* Atta-Peters *et al*., (2012) stated that this assemblage had been reported by various authors including Herngreen (1975); Schrank (1994) and Germeraad *et al* (1968) as being Campanian – Maastrichtian age. Herngreen (1998) in Atta-Peters *et al*., (2012) suggested that this assemblage is typically deposited in a warm humid tropical – subtropical climate.

A Turonian - Santonian age was assigned to the 3160 – 70ft to 1980- 90ft depth interval based on the presence of *Droseridites senonicus, Cretacaeisporites spp., Tricolpites, Ephedripites spp., and Zlivsporis blanensis.* Atta-Peters *et al*., (2012) remarked that Schrank (1987) and Muller et al. (1987) report on the occurrence of *Droseridites senonicus* from Turonian – Santonian of north east Africa and Malaysia respectively.

An Aptian age was suggested for the sediments between 8140ft to 3340 – 50ft based on the occurrence of *Cicatricosisporites spp., Reyrea polymorphus, Classopollis classoides* and *Afropollis jardinus* after comparison with similar assemblages reported by Doyle at al. (1982), Schrank (1990) and Abubakar *et al*. (2011).

Atta-Peters *et al*., (2012) inferred that there was an unconformity between the Aptian and Turonian sediments due to the absence of the elaterates pollen that characterize the Albian – Cenomanian sediments of the Africa South America Province (ASA).

Atta-Peters & Salami (2006) studied miospores and dinoflagellate cysts retrieved from the Tano 1-1 and IS-3AX wells, offshore Tano Basin. The taxa observed from the Tano 1-1 well include *Afropollis Jardinus, Elaterosporites klazii, Sofrepites legouxae, Elaterocolpites castelaini and Reyrea polymorphus.* This assemblage was assigned an Aptian – early Cenomanian age was by Atta–Peters & Salami (2006) after comparison with the findings of workers within the ASA province [e.g., Herngreen (1973, 1975), Schrank (1990) and Mahmoud & Moawad (2002)]. Based on Highest Appearance Datum (HAD) and Last Appearance Datum (LAD) of stratigraphically important taxa, Atta- Peters & Salami (2006) established palynostratigraphy that delimits the boundaries of the Aptian (Tano 1-1 samples 13,460 – 12,400ft), Albian (Tano 1-1 samples 12.200 – 7,760ft) and early Cenomanian (7,540 – 3,990ft).

The palynomorphs from the Tano 1-1 well are typical elements of the Albian – Cenomanian Elaterates Province of Africa and South America and are indicative of a warm tropical climate. Paleo- environmental deductions based on the observed taxa from Tano 1-1, show that the sediments were deposited in a marginal marine environment (Atta–Peters & Salami 2006).

Sediments from the IS -3AX well yielded *Buttinia andreevi, Auriculiidites reticulatus, Longapertites spp., Spinizonocolpites echinatus and Echitriporites trianguliformis* which are typical elements of Campanian – Maastrichtian age and fit well into the Late Cretaceous Senonian Palmae Province (Herngreen *et al.* 1996 in Atta–Peters, 2006). Dinoflagellates recovered from the IS -3AX well further supports a Campanian – Maastrichtian age. These include *Andalusiella, Cerodinium, Phelodinium* and

Senegalinium and are thus assigned to the tropical – subtropical Malloy suite of Lentin & Williams (1980).

Atta–Peters & Salami (2006) remarked that the Campanian – Maastrichtian sediments from the IS – 3AX well were deposited in an environment that fluctuates between marginal marine to open marine (inner shelf).

Atta-Peters & Kyorku (2013) studied sample slides retrieved from Dixcove 4-2x well, offshore Cape Three Points, South Tano Basin. The samples were from a depth interval of 2975ft – 11010ft. Age assessment was based primarily on miospore assemblages observed. The lower sections between sample intervals 5640ft – 11010ft is lacking of elaterates, and is dominated by *Reyrea polymorphus, Afropollis jardinus, Ephedripites spp.* as well as pteridophytic spores including *Deltoidospora, Cyathidites, Cicatricosisporites,* and *Concavisporites.*

Afropollis jardinus is a worldwide marker for the early Aptian for regions in equatorial Africa (Doyle et al. 1977) and it occurs in northern Sudan in upper Aptian to lower Cenomanian strata as reported by Schrank (1990). This interval according to Atta–Peters & Kyorku (2013) is of Aptian age due to the presence of *Afropollis jardinus* and the absence of elater bearing pollen.

The interval between 2975ft – 5640ft is characterized by elater-bearing pollen including *Elaterosporites spp., Galaecornea causea* and *Elaterocolpites spp.* Other forms associated with the elaterates are *Afropollis jardinus, Classopollis classoides, Ephedripites spp.* and *Reyrea polymorphus*. This assemblage has been reported to be restricted to the Albian – Cenomanian of the ASA province by (Herngreen *et al.,* 1996; Herngreen, 1975; Atta-Peters & Salami, 2006; Jardine & Magloire, 1965). Based on the presence of *Afropollis jardinus, Ephedripites spp., Classopollis spp.,* elaterates and the pteridophytic forms represented by *Cicatricosisporites, Deltoidspora* and

Cyathidites, the paleo- environment of deposition was suggested to be one with parent plants thriving in wetlands in a humid, warm coastal plain in a semi-arid climate (Atta-Peters & Kyorku, 2013).

A detailed report on miospores recovered from ST-8 well, offshore Tano Basin is presented by Atta-Peters & Salami (2004b). The study was carried out on samples recovered from a depth interval of 6700ft – 1260ft. The miospore assemblage is dominated by *Spinizonocolpites*, *Proxapertites*, *Longapertites* and *Mauritiidites.* These taxa are considered to be elements of fresh water swamp or marsh environment. There is a mixed occurrence of freshwater (non-brackish) taxa including *Laevigatosporites, Polypodiaceiosporites, Pachydermites diederexi and Verrucatosporites usmensis.*

This particular fossil assemblage has been attributed to the palmae and fits into the late Cretaceous (Senonian) Palmae Province of Africa and South America of Herngreen and Chlonova (1981) and Herngreen *et al*. (1996).

The presence of *Laevigatosporites, Pachydermites diederexi*, and *Verrucatosporites usmensis* according to Rull (1997) and Germeraad *et al*. (1968) in Atta-Peters & Salami (2004b) indicates a swampy fresh water or brackish water environment of deposition.

Atta-Peters & Salami (2004b) suggested a Campanian to Eocene age for the sediments based on stratigraphically important markers for this age range such as *Buttinia andreevi, Longapertites marginatus*, *Foveotriletes magaritae* and *Spinizonocolpites echinatus*.

Atta-Peters & Salami (2004a) studied dinoflagellate cysts recovered from a depth interval of 6440ft (1932m) – 600ft (180m) from the IS-3AX well, offshore Tano Basin. From their study, they were able to erect 3 biozones; namely the *Trichdinium castanea, Cordosphaeridium complex and Carperpatella cornuta* Zones, based on LAD (Last Appearance Datum) and FAD (First Appearance Datum) of marker species.

An early to late Campanian, early to late Maastrichtian and early Paleocene ages were constrained for the biozones respectively based on the presence of key stratigraphic marker species (Atta-Peters & Salami, 2004a).

Atta-Peters & Salami (2004a) opined that based on the vertical distribution of the dinocysts assemblage upwards in the well, a near shore or brackish environment of deposition is assigned to the Campanian interval, which transits into a more open environment for both the Maastrichtian and Paleocene intervals.

The peridiniacean assemblage of the IS-3AX well of the Tano Basin as reported by Atta–Peters & Salami (2004a) is dominated by *Andalusiella, Cerodinium, Phelodinium* and *Senegalinium.* These forms are elements of the tropical – subtropical Malloy suite of Lentin & Williams (1980).

Obeng (2015) reported on palynomorphs retrieved from CTP-1 well, offshore Tano Basin. Based on the first appearance datum (FAD) and the last appearance datum (LAD) of stratigraphically important species, two miospore assemblage zones were suggested for the sediments.

The first zone is (I) The *Elateropollenites jardinei- Ephedripites irregularis-Reyrea polymorphus* zone whose associated taxa include *Ephedripites jansonii, Classopollis classoides* and *Cyathidites australis*. The second is (II) The *Elaterosporites protensus-Sofrepites legouxae-Afropollis jardinei* zone whose associated taxa include *Elaterosporites klazii, Ephedripites brasiliensis* and *Steevesipollenites binodosus*. After comparison with similar assemblages from other parts of the world, Obeng (2015) assigned an Albian-Cenomanian age these sediments.

Based on the similar micro floral assemblage observed from the CT- P 1 assemblage to those of the Africa-South America (ASA) province, Obeng et al (2015) reported the paleo- floral province suggested for the miospores of the study is the Albian-

Cenomanian Elaterate Province of Herngreen *et al*. (1996) in Obeng (2015). They further remarked that the miospore assemblages observed indicate that deposition of the sediments took place in a semi- arid to arid climatic setting in a coastal or nearshore environment.

Atta–Peters & Achaegakwo (2016) present results of their study of samples retrieved from Epunsa- 1 well, offshore Tano Basin. The palynomorph forms observed are dominated by Elaterate pollen, *Afropollis* and *Ephedripites* and *Classopollis*. Other taxa present include *Cicatricosisporites*, *Deltoidospora* and *Cyathidites.* The elaterates are dominated by*, Elateroplicites africaensis, Galaeocornea causea, Elateropollenites jardinei, Sofrepites legouxae* and *Elaterosporites castelaini.*

The palynomorphs encountered within the studied depth interval of the Epunsa-1 well, are characteristic of the Albian - Cenomanian Elaterate Province of Herngreen *et al.* (1996) with palaeoequatorial distribution which is indicative of a semi-arid to arid warm climate (Schrank and Ibrahim, 1995 in Atta–Peters & Achaegakwo, 2016).

Atta–Peters & Achaegakwo (2016), remarked that the high occurrence of *Ephedripites, Classopollis* and elaterate pollen indicated a paleo- environment in which parent plants inhabited humid, warm coastal plains in a semi-arid to arid climatic condition. The presence of *Cyathidites* in majority of the studied samples indicates the existence of moist biotopes nearby the depositional sites with conifer forests that thrived in the dry hinterlands in some horizons.

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

Palynological slides prepared from forty (40) and forty-two (42) ditch cutting samples from ST-5 and ST-6 wells (Fig 3.1) respectively, offshore Tano Basin were used for this study. These slides were acquired from Ghana National Petroleum Corporation (GNPC)'s core laboratory.

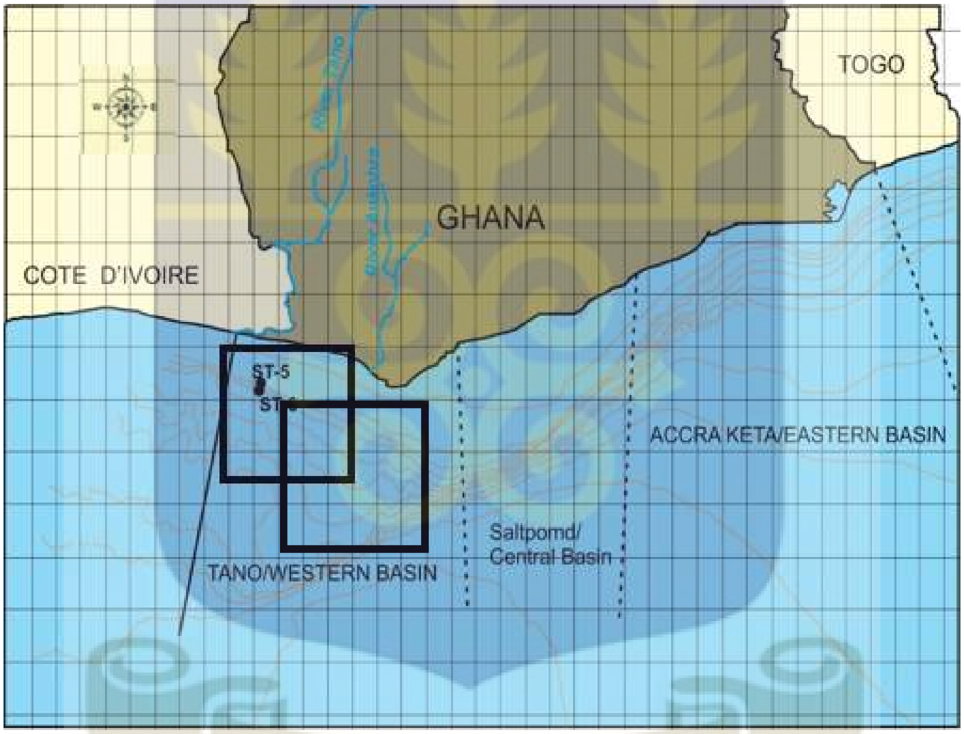


Figure 3.1: Map of Tano Basin showing the location of ST-5 and ST-6 wells, Tano Basin (modified after GNPC Offshore Activity Map, 2010).

3.2 METHODS

3.2.1 SAMPLE PREPARATION

Standard maceration techniques for palynomorphs extraction as put forth by Phipps and Playford (1984) was used for preparation of the slides. The sample preparation technique put forth by Phipps and Playford (1984) are explained below.

3.2.1.1 SAMPLE CRUSHING

Approximately 30gm of sample is processed at a time. The samples from each well are washed, dried then crushed with steel mortar and pestle then transferred into a Nalgene beaker. Nalgene beakers are preferred over glass beakers because Nalgene does not react with hydrofluoric (HF) acid which can dissolve any material made from silica.

3.2.2 PREHYDROFLUORIC ACID (HF) TREATMENT

The crushed samples are digested in concentrated hydrochloric acid (10%) for about four hours. This step is aimed primarily at digesting the carbonate fraction of the samples. This step is particularly important because if not carried out, any carbonates that may be present will react with the Hydrofluoric acid (HF) that will be used in the subsequent step and this will lead to the formation of an insoluble precipitate.

3.2.3 SILICATE REMOVAL

The residue from the pre-hydrofluoric treatment is then neutralized by washing with water before it is treated with Hydrofluoric acid (40%). This process is done to remove the silicate and silica content of the rock. The addition of HF causes disaggregation of the residue with subsequent release of organic matter.

3.2.4 ULTRASONICATION

Once the silica-silicate content is removed, the resulting residue is washed three times with distilled water. The washed residue is then sieved through a nylon sieve of size 20µ. Sieving is done in combination with an ultrasonic probe alongside constant washing. The ultrasonic treatment is useful in sieving off the excessive organic matter that otherwise tends to clog the sieve.

3.2.5 OXIDATION

Oxidation was skipped because the organic matter from ST -5 and ST – 6 were translucent and details could be seen under transmitted light.

3.2.6 HEAVY LIQUID SEPARATION

Zinc Bromide ($ZnBr_2$) of specific gravity 2.0 is added to the residue in a glass tube and the mixture is then centrifuged for 30minutes at 500 revolutions per minute (rpm). The organic fraction that floats on top the mixture after centrifuging is then carefully pipetted into a test tube and washed with distilled water.

3.2.7 MOUNTING

Two drops of the concentrated residue are added to a solution of Poly vinyl alcohol (PVA; 10 gms in 100mls of water). The residue and polyvinyl alcohol are mixed thoroughly for even distribution of the residue on 22 × 32 mm cover slip and allowed to dry on a hot plate. The cover slips are then permanently mounted on labeled glass slides of size 76 × 26 mm by curing in ultra violet light for about two minutes.

3.3 QUALITATIVE ANALYSIS

The qualitative analysis involved the identification and recording of the observed palynomorphs in the samples. For this analysis 39 and 42 ditch cutting samples slides from ST-5 and ST-6 were used respectively. A Leica DM 750 transmitted light microscope fitted with an Am scope Toup view 3.2 digital camera was used in studying the prepared slides.

Since the Leica DM 750 has a well calibrated scale on the mechanical stage, coordinates corresponding to the location of each palynomorph encountered on individual slides were well noted. This made it easy for observed species to be located at a later time. Photomicrographs of well preserved palynomorphs were taken using the Am Scope Toup view 3.2 digital camera fitted to the microscope for plate compilation.

3.4 QUANTITAIVE ANALYSIS

Every slide was scanned thoroughly using magnification of x40 and intermittently switching to x100 when necessary. A total palynomorph count was done for every slide using an automatic point counting software. Biozones were established based on the FAD (First Appearance Datum) and LAD (Last Appearance Datum) of stratigraphically important species. Individual biozones were established using spore/pollen and dinoflagellates. Observed palynomorphs were compared with similar species reported from the ASA regions and other parts of the world in order to establish their ages. Frequency charts were generated to display the relative abundances of the different palynomorph types. Ternary plots were employed to aid the in the elucidation of the depositional environment and paleo- climatic conditions.

CHAPTER FOUR

PALYNOSTRATIGRAPHY

A total of 39 and 42 slides were studied for the ST-5 and ST-6 wells respectively and based on the FAD (First Appearance Datum) and LAD (Last Appearance Datum) of stratigraphically important miospore and dinoflagellate species. Three biozones have been identified. The ages of these zone were constrained after comparison with similar palynomorph associations reported from coeval deposits from Ghana, the ASA palynofloral province and beyond.

4.1 MIOSPORE ZONATION

Based on the micro floral assemblage studied, three (3) biozones have been established for the sediments encountered in the ST-5 and ST-6 wells.

4.1.1 The *Elaterosporites verrucatus* Zone

This zone extends from the base of the well at 2110m through to 1820m of the ST-5 well (Fig 4.1). In the ST-6 well, this zone extends from the lowest point in the well at 1990m to 1840m (Fig 4.2). The FAD of *Elaterosporites protensus*, *Elaterosporites klazii* and *Elaterosporites verrucatus* are observed in this zone in both wells. *Elaterocolpites castelaini* makes its first appearance near the top of this zone at 1915m in the ST-6 well only. *Elateropollenites jardinei* is first observed at 2060m in the ST-5 well. *Galeacornea causea* is observed in ST-6 only at 1990m. This zone also sees the presence of ephedriod forms such as *Ephedripites barghoonii*, *Ephedripites brasiliensis, Ephedripites multicostatus* and *Ephedripites ovalis* in both wells. *Steevesipollenites binodosus* is observed only in the ST-5 well. *Classopollis torosus* is present in both wells. Long ranging species such as *Cicatricosisporites spp.*, *Deltoidospora, Inaperturopollenites spp., Glenchinidites senonicus, Cyathidites* *australis* and *Araucariacites australis* are also present in this zone. The top of this zone is characterized by the LAD of *Elaterosporites protensus*, *Elaterosporites klazii, Elateropollenites jardinei* and *Elaterosporites verrucatus* at 1820m and 1840m for ST-5 and ST- 6 respectively (Fig 3.1 &3.2).

4.1.1.1 Discussion, Comparison and Age of the *Elaterosporites verrucatus* Zone

The presence of elater bearing pollen and their associated taxa (*Classopollis* and *Ephedripites*) in this zone are critical in the age determination. Elaterates are collectively one of the most important genera, chronicled from the early Albian to late Cenomanian in northern Gondwana (Herngreen and Chlonova, 1981).

Elaterosporites protensus has been reported from Maranhao Basin, Brazil, in lower to middle Albian (Mũller, 1966) and (Jardinѐ 1967), middle to upper Albian in Senegal and Gabon (Jardinѐ, 1967). It has also been described by Herngreen, (1973) from the middle Albian to lower Cenomanian in Brazil. In Morocco, *E. protensus* has been reported from the Albian (Bettar & Meon, 2006). In Ghana, *E. protensus* is reported to be of middle Albian to early Cenomanian from the Tano Basin (Atta-Peters & Salami 2006 and Atta-Peters 2013*).* *E. protensus* is of late Albian age in Nigeria as reported by Abubakar *et al.* (2006, 2011).

Elaterosporites verrucatus, according to Schrank &Ibrahim (1995) is an excellent marker of late Albian – early Cenomanian of northern Western Egypt. *Elaterosporites verrucatus* also occurs in the lower to middle Albian of the Maranhao Basin, Brazil (Jardinѐ, 1967). Similarly, Bettar & Meon, (2006) suggests an Albian age for *E. verrucatus* in Morocco. It is also reported form the late Albian – early Cenomanian of Brazil (Herngreen, 1973, 1975) and Venezuela (Mũller et al., 1987). *E. verrucatus* is of late Albian to early Cenomanian age from the Tano Basin, Ghana (Atta- Peters. 2013).

Jardinè & Magloire (1965) reported *Elaterosporites klazii* for the first time from late Albian–early Cenomanian of Senegal. Herngreen (1973, 1975) suggests a late Albian – early Cenomanian age for *E. klazii* in Brazil. In Gabon, Doukaga (1980) suggests a late Albian to early Cenomanian age for *E. klazii*. Jardinè, (1967), reports a similar stratigraphic range for *E. klazii* in Senegal.as Doukaga (1980). *Elaterosporites klazii* is restricted to the middle Albian-lower Cenomanian in Ivory Coast Jardinè (1967). In Peru and Colombia *E. klazii* is reported from late Albian-early lower Cenomanian (Herngreen & Jimenez, 1990). In Ghana, *E. klazii* is reported to be of middle Albian to lower Cenomanian age (Atta- Peters, 2013).

Masure *et al*. (1988) stated that *Elaterosporites verrucatus*, *E. klazii* and *E. protensus* are restricted to the middle to late Albian of Holes 961A and 961B of the Cote D'Ivoire-Ghana (CIG) transform margin.

Mahmoud & Moawad (2002) intimated that *Elaterocolpites castelaini* first occurred in Northern Gondwana from the early Albian to the late Cenomanian. According to Batten & Uwins (1985) *Elaterocolpites castelaini* has an Albian to Cenomanian range in Libya. The FAD of *Elaterocolpites castelaini* marks the base of the Cenomanian (Schrank & Ibrahim, 1995). Herngreen (1973, 1975) assigned an Albian to Cenomanian age for *E. castelaini* in Brazil. Schrank (1990) reported *E. castelaini* together with *Elaterosporites klazii* from upper Albian to lower Cenomanian strata from northern Sudan. Atta-Peters & Salami (2006) report *Elaterocolpites castelaini* in association with *Elaterosporites klazii* and *E. protensus* to be representative of middle Albian to Cenomanian age in Ghana.

Elateropollenites jardinei is reported from the Lower-Middle Albian of Brazil (Herngreen, 1973; 1975; Dion et al., 1990). Muller et al., (1987) recorded *Elateropollenites jardinei* from Albian rocks in Venezuela. Jardiné and Magloire, (1965) report the occurrence of *Elateropollenites jardinei* in Lower-Middle Albian strata in Senegal and Ivory Coast. Atta-Peters & Salami, (2006) report *E. jardinei* from the Albian of the Tano 1-1 well of the Tano Basin. Atta-Peters, (2013) reports *E. jardinei* from the Albian–Cenomanian from Ghana.

Ephedripites barghoonii has been reported by (Jardinè & Magloire, 1965) from upper Albian to lower Cenomanian of Senegal. Similarly, *E. barghoonii* is reported from Albian to Cenomanian sediments form Ivory Coast by (Jardinè & Magloire, 1965). Herngreen (1973) reported same species to be of Albian-Cenomanian of Brazil. *E. barghoonii* occurs in early Albian to early Cenomanian strata of the Tano Basin as reported by Atta-Peter &Salami (2006).

Steevesipollenites binodosus is reported from Albian-Cenomanian of the upper Benue Basin of Nigeria by Lawal and Moullade, (1986). Stover (1964) reports *Steevesipollenites binodosus* from Albian/Cenomanian–Cenomanian/Turonian deposits of Portuguese Guinea and Senegal.

Ephedripites irregularis described by Herngreen, (1973) was reported to be of Lower-Middle Albian of Maranhao, Brazil. *E. irregularis* is reported from the Tano Basin, as being lower to middle Albian in age by Atta – Peters & Salami (2006).

Ephedripites brasiliensis is described from late Albian from Senegal and Ivory Coast. (Jardinè & Magloire, 1965). Atta- Peters & Salami (2006) assigned a late Albian to early Cenomanian age to *E. brasiliensis* from Ghana.

Galaecornea causea has been reported from late Albian–Cenomanian of Senegal and Gabon (Jardiné, 1967). In Brazil (Herngreen, 1973, 1975) reports *Galaecornea causea* from the Albian- Cenomanian. From Peru, Brenner, (1968) reports a similar age for *G. causea* as Jardiné, (1967). In Egypt, *Galaecornea causea* is reported from the late Albian to early Cenomanian (Mahmoud, 1998; Shrank and Ibrahim, 1995; Zobaa *et al*., 2013). In Senegal and Portuguese Guinea, Stover, (1963), describes *G.causea* from the Albian to Cenomanian. *G.causea* is also reported from the Cenomanian of Senegal and Gabon (Jardiné and Magloire, 1965; Jardiné, 1967)

Classopollis torosus is reported from the early to late Cenomanian of north Western Egypt (Zobaa *et al.,* 2008). *C. torosus* is reported from the late Albian/Cenomanian of Peru (Brenner, 1968).

The overlap in the stratigraphic ranges of the above mentioned taxa points to an Albian-Cenomanian age for the sediments between the sample interval of 2110-1820m and 1990-1840m for the of the ST-5 and ST-6 wells respectively.

4.1.2 The *Foveotriletes margaritae - Buttinia andreevi* Zone

This zone is recognized between 1805-1250m and 1830-1195m of the ST-5 and ST-6 wells respectively (Fig 4.1 & 4.2). The FAD of *Foveotriletes margaritae* in this zone is at 1805m and 1675m in the ST-5 and ST-6 wells respectively. *Cingulatisporites ornatus* is first observed at 1805m and 1830m in the ST-5 and ST-6 wells respectively. Pteridophytic spores present in this zone include *Glenchinidites senonicus*, *Deltoidospora, Araucariacites australis, Proteacidites dehaani, Cicatricosisporites* and *Cyathidites australis*. A few ephedriods forms (*multicostatus* and *ovalis*) and foraminiferal test linings are also present in this zone. *Buttinia andreevi* makes its first appearance in this zone at 1395m and 1830m in the ST-5 and ST-6 wells respectively. *Longapertites marginatus*, *Proxapertites cursus* and *Proteacidites dehaani* mark their first appearance in this zone of both wells. The top of this zone is characterised by the

LAD of *Buttinia andreevi* and *Cingulatisporites ornatus* at 1250m and 1195m in the ST-5 and ST-6 wells respectively. The elaterate pollen observed and discussed in sections 3.1.1 and 3.1.2 are not present in this zone in both wells.

4.1.2.1 Discussion, Comparison and Age of the *Foveotriletes margaritae* - *Buttinia andreevi* Zone

Apaalse & Atta- Peters (2013) suggest a Campanian–Maastrichtian age for *Foveotriletes margaritae* from the Keta Basin, Ghana. *Foveotriletes margaritae* is reported from the Maastrichtian of the Cote d'Ivoire-Ghana transform margin (Oboh-Ikuenobe, 1998). Ola- Buraimo *et al.*, (2012) report a similar age as Oboh-Ikuenobe, (1998) for *Foveotriletes margaritae* in Nigeria. Germeraad *et al.* (1968) reported that *F. margaritae* occurs in the early Maastrichtian of Nigeria and Caribbean. Chiaghanam *et al.*, (2012) report *F. margaritae* from late Maastrichtian – early Paleocene range from the Anambra Basin of Nigeria. Atta-Peters & Salami (2004b) suggest a Campanian-Eocene age range for *F. margaritae* in Ghana.

Cingulatisporites ornatus is described from the Campanian - Maastrichtian of Nigeria by (Salami, 1983, 1985) and from the same stratigraphic age in Ghana (Atta Peters & Salami, 2004b).

Longapertites marginatus occurs in the Maastrichtian - Eocene from Ghana (Atta-Peters & Salami, 2004b). Schrank (1987), reported *Longapertites marginatus* from the Late Campanian Phosphate Formation in the Abu Shigaila section, Egypt. Lawal & Moullade (1986) in Schrank (1987) and El-Beialy, (1995) reports *Longapertites marginatus* from the Upper Campanian–Lower Maastrichtian of Nigeria. Similarly, *Longapertites marginatus* is reported to be of Campanian – Maastrichtian age in south eastern Nigeria (Chiaghanam et al, 2012).

Proteacidites dehaani is considered an important marker of the Campanian - Maastrichtian of Egypt as reported by (El Beialy, 1995). In the Caribbean area and Nigeria, it occurs in the Maastrichtian (Germeraad et al., 1968) and occurs in the same stratigraphic range in Cameroun (Salard –Cheboldaeff, (1979) in Schrank, (1987)). Salami (1984, 1985) also suggested a Maastrichtian – Eocene age for *Proteacidites dehaani* in Nigeria.

Longapertites marginatus together with *Proteacidites dehaani* are described as being typical of the Late Cretaceous (Campanian – Maastrichtian) of West Africa – South America phytogeographical province by Herngreen & Chlonova (1981).

Proxapertites cursus generally has a Maastrichtian- Eocene range in Ghana (Atta-Peters &Salami, 2004b). However, in the Caribbean and Cameroun, *Proxapertites* occurs from the Paleocene to Eocene (Germeraad et al., 1968; Salard - Cheboldaeff, 1979). Schrank (1990), also opined that pollen grains of *Longapertites* and *Proxapertites* have a typical Maastrichtian – Tertiary distribution.

Buttinia andreevi's first appearance occurs on either side of the South Atlantic and marks the Santonian/Campanian boundary, and thus makes it a good marker for the late Santonian (Apaalse & Atta- Peters, 2013). Chiaghanam *et al*.,(2012) describes *Buttinia andreevi* as an important taxa for the Campanian – Maastrichtian of Nigeria. Other authors have reported on the occurrence of this pollen from the same stratigraphic interval (Oboh – Ikuenobe et al. 1998; Boltenhagen 1965; Atta Peters & Salami, 2006, 2004a, 2004b, Ola-Buraimo *et al*. 2012). In North Africa, (Egypt, Somalia and Sudan) *Buttinia andreevi* s peculiar to Campanian- Maastrichtian sediments (El Beialy, 1995). Schrank (1994) stated that *Buttinia andreevi* is commonly associated with Campanian-Maastrichtian sediments and does not range into the Paleocene, unless it is as a result of reworking. Atta-Peters & Salami (2004a, 2004b) and Oboh-Ikuenobe et al. (1998)

also remarked that the LAD of *Buttinia andreevi* is observed at the end of the Maastrichtian. The overlap in the stratigraphic ranges of all the above mentioned taxa present in the *Foveotriletes margaritae-Buttinia andreevi* Zone points to a Campanian-Maastrichtian age.

The marked absence of the index Turonian-Santonian marker *Droseridites senonicus* from the sediments of both ST-5 and ST-6*,* indicates the presence of an unconformity between the Albian–Cenomanian and the Campanian- Maastrichtian sediments of both wells. *Droseridites senonicus*, is considered a marker for Coniacian-Santonian sequences in northeastern Nigeria and the Angola Basin, (Lawal & Moullade 1986; Deaf *et al*., 2014). Ibrahim (1995) describes *D. senonicus* as having a late Turonian-Coniacian /Santonian age range from Egypt. Schrank and Ibrahim (1995) also assign a late Turonian - early Santonian age to *D. senonicus* from northwestern Egypt. Atta – Peters & Apaalse (2013) suggest a Turonian – early Santonian age for *D. senonicus* from the Keta Basin, Ghana. Abubakar (2011) reports *D. senonicus* from Coniacian – Santonian sediments from the Gongola Basin, Nigeria. The absence of *D. senonicus* from the samples from the *Foveotriletes margaritae-Buttinia andreevi* Zone eliminates the possibility of this zone being of Turonian – Santonian age. From the above discussions, it is plausible to assign a Campanian-Maastrichtian age for *Foveotriletes margaritae-Buttinia andreevi* Zone of the ST-5 and ST-6 wells of the Tano Basin.

3.1.3 The *Spinizonocolpites echinatus* Zone

This zone extends from 1175-495m and 1135-775m of the ST-5 and ST-6 wells (Fig 4.1 & 4.2). *Spinizonocolpites echinatus* makes its first appearance in this zone at 855m and 835m of the ST-5 and ST-6 wells respectively. The FAD of *Retistephanocolpites williamsii* is recorded within this zone at 1135m in ST-6. This zone is characterized by the presence of *Inaperturopollenites*, *Foveotriletes margaritae*, *Proxapertites cursus, Longapertites marginatus* and *Cyathidites australis* in both wells.

4.1.3.1 Discussion, Comparison and Age of the *Spinizonocolpites echinatus* Zone

Spinizonocolpites echinatus is reported from the Eocene of Venezuela, Late Maastrichtian of Somalia and the Maastrichtian of Egypt and Sudan (Atta-Peters &Salami 2004a and references therein). Schrank (1994) reports *Spinizonocolpites echinatus* from the Maastrichtian–Eocene from northern Somalia. Chiaghanam *et al.,* (2012) posit that *S. echinatus* is associated with middle Maastrichtian-late Eocene strata of the Anambra Basin, Nigeria. Atta-Peters & Salami (2006) report *S. echinatus* from the Campanian-Maastrichtian from Ghana.

Retistephanocolpites williamsii is reported from Maastrichtian–Eocene sediments from the Keta Basin, Ghana (Apaalse & Atta-Peters, 2013) and the Maastrichtian – Eocene of Nigeria (Salami 1985, 1988). *R. williamsii* is also reported from the Maastrichtian–Eocene of the Tano Basin, Ghana. In India, *R. williamsii* is reported from Paleocene – Eocene by Thanikaimoni (1984) in Atta- Peters (2006).

All the taxa present in the *Spinizonocolpites echinatus* Zone of the ST-5 and ST-6 well generally have a Campanian-Maastrichtian/Paleocene age range as discussed in sections 3.1.2.1 and 3.1 .3.1. However, the LAD of *Buttinia andreevi* in the upper boundary of the *Foveotriletes margaritae-Buttinia andreevi* Zone denotes the end of the Maastrichtian (Schrank, 1994; Atta-Peters & Salami, 2004a, 2004b, 2006; Oboh-Ikuenobe *et al.,* 1998). Hence the age of *Spinizonocolpites echinatus* Zone of the ST-5 and ST-6 wells of the Tano Basin is Paleocene.

Seven sample slides from the depth interval 715-415m of the ST-6 well and three sample slides from a depth interval of 465-405m were devoid of diagnostic spores and pollen hence it is difficult to conclude that they represent the same age as the *Spinizonocolpites echinatus* Zone.

Figure 4.1: Distribution of Albian-Paleocene spores and pollen in the ST-5 well

Figure 4.2: Distribution Albian-Paleocene spores and pollen from the ST-6 well

4.2 DINOFLAGELLATE ZONATION

Based on the dinoflagellate assemblage observed in both the ST-5 and ST-6 wells, three (3) biozones were erected.

4.2.1 The *Spiniferites ramosus* Zone

This zone extends from 2110-1820m of the ST-5 well and from 1990-1855m of the ST-6 well (Figures. 4.3 & 4.4). This zone generally has relatively fewer dinoflagellates as compared to spores and pollen. However, long ranging gonyaulacoid species such as *Cleistosphaeridium, Oligosphaeridium complex* and *Spiniferites ramosus* are present in this zone. The FAD of *Dinogymnium undulosum* in this zone is at 2030m and 1945m in the ST-5 and ST-6 wells respectively (Figures 4.3 & 4.4). One specimen of *Paleocystidinium golzowense* is observed in this zone in ST-6 and three are observed in ST-5.

4.2.1.1 Discussion, Comparison and Age of the *Spiniferites ramosus* Zone

Spiniferites ramosus is reported from the Abu Roash Formation as being of early – middle Cenomanian of Western Desert, Egypt by Schrank & Ibrahim (1995). Zobaa et al (2008) reports *S. ramosus* from the early to late Cenomanian of North Western Egypt. Atta- Peters & Salami (2004a) report *S. ramosus* as being of long ranging from the Campanian all the way to Paleocene of the Tano Basin, Ghana. Ola-Buraimo & Boboye (2011) report *S. ramosus* from Albian-lower Cenomanian of Bima Formation, Nigeria. *Cleistosphaeridium huguoniotii* is reported from the Aptian – Santonian of Europe, North America and Australia (Williams &Lentin 1975). In South Western Africa, *Cleistosphaeridium huguoniotii* is reported from the Aptian – Turonian / Early Maastrichtian. It is also reported throughout the Upper Cretaceous (Santonian – Maastrichtian) of North West Territories, Canada by McIntyre (1974). Atta-Peters *et* *al.,* (2012) observed *Cleistosphaeridium*, *Dinogymnium spp.* and *Spiniferites ramosus* associated with Turonian-Santonian sediments of the Bonyere-1 well.

Both *Cleistosphaeridium huguoniotii* and *Spiniferites ramosus* have long stratigraphic ranges hence making it difficult to use them to determine the age of this zone.

Oligosphaeridium complex has been reported from the Albian-Cenomanian of USA western interior by Oboh-Ikuenobe (2006), likewise Below (1981), reported a similar age from Mazagan Plateau, Northwest Africa. Abd El Hakam *et al*, (2012**)** attributed *O.complex* to the Aptian-Cenomanian of North Western desert, Egypt.

Dinogymnium undulosum has a range of late Cenomanian- late Maastrichtian according to Masure et al., (1998). Boltenhagen (1977, 1980) in Schrank (1987) suggested a Cenomanian – Maastrichtian age for *Dinogymnium undulosum,* thus its FAD in this zone at 1945m is plausible.

The age of this zone is difficult to constrain based on dinoflagellates only because no diagnostic forms of dinocysts peculiar to the Albian – Cenomanian such as *Florentinia berran* (Below, 1982; Schrank & Ibrahim, 1995) were observed.

The presence of *Paleo-cystidinuim golzowense* in this zone in both wells is likely as a result of reworking. This is because *Paleocystidinium golzowense* is a typical element of the Maastrichtian as put forth by Schrank (1987), El Beialy (1995) and Atta-Peters & Salami (2004a).

4.2.2 The *Andalusiella gabonensis–Dinogymnium acuminatum* Zone

This zone extends from a depth interval of 1805-1250m in the ST-5 well (Fig. 4.3). In the ST-6 well, this zone is recognized from 1840-1195m (Fig. 4.4). *Andalusiella gabonensis* makes its first appearance in this zone at 1830m and 1790m in the ST-5 and ST-6 wells respectively (Figures. 4.3 & 4.4). This zone is dominated by peridinoid cysts. The peridinoid assemblage is characterized by *Andalusiella gabonensis, Andalusiella mauthei Senegalinium bicavatum, Cerodinium boloniense, Cerodinium diebelli, Phelodinium tricuspis* and *Phelodinium magnificum.* Other taxa that are present in this zone are *Spiniferites ramosus, Dinogymnium undulosum, Dinogymnium acuminatum, Paleocystidinium golzowense, Paleocystidinium australinium, Adnatosphaeridium multispinosum, Cleistosphaeridium spp.* and *Oligosphaeridium complex.* The FAD of *Odontochitina operculata* is observed at 1805m and 1810m in ST-5 and ST-6 respectively. The LAD of *Dinogymnium acuminatum* is observed at 1335m and 1255m of ST-5 and ST-6 wells of this zone (Figures. 4.3 & 4.4).

4.2.2.1 Discussion, Comparison and Age of the *Andalusiella gabonensis – Dinogymnium acuminatum* Zone

Andalusiella, according to Williams *et al*., (1993) occurs in the earliest Campanian. The peridinoids observed in this zone of both wells is dominated by the genera *Andalusiella, Cerodinium, Phelodinium* and *Senegalinium.* A number of authors have reported that these taxa from Campanian – Maastrichtian (Schrank, 1987, 1994; Salami 1982, 1986, 1988; Schrank & Ibrahim, 1995; Atta-Peters &Salami, 2004b).

Senegalinium bicavatum is observed at for the first time at 1555m which is at the topmost section of this zone. Williams et al. (1993) have reported the FAD of *Senegalinium bicavatum* to be suggestive of late Campanian – early Maastrichtian. Masure et al. (1998) reported that collectively, the FAD of *Andalusiella* and *Trichodinium castanea* suggests a Campanian age.

Cerodinium diebelli has been reported from the early-middle Maastrichtian by Hoek et al., (1996) from Israel; Bujak & Williams (1997) from North America; Roncaglia and Corradini (1997) from Italy and Masure et al (1998) from the CIG transform margin.

Paleocystidinium australinium is considered to have its FAD in latest Campanian (May, 1980; Williams & Bujak, 1985; Edet, 1992 in Atta-Peters and Salami 2004a). Malloy (1972) also suggested that *P. australinium* is present in Maastrichtian to Paleocene strata. Williams et al. (1990) report that *Phelodinium tricuspis* has an Early Maastrichtian – Late Danian age range. Williams & Bujak, (1985) suggests an Early Maastrichtian – Late Paleocene range for *Phelodinium tricuspis.*

Odontochitina operculata is usually restricted to pre – Maastrichtian strata in Egypt (Urban *et al.* 1976; Schrank, 1984a, 1987 and El Beialy, 1993) and Denmark (SchiØler, 1992). Its first appearance in the ST – 6 well is at 1810m. Atta-Peters & Salami (2004) report the occurrence of *Odontochitina operculata* in the early Maastrichtian of the Tano Basin. They further stated that the LAD of *O. operculata* is a cosmopolitan 'event' which has often been reported in the proximity of the Campanian/Maastrichtian boundary (Wilson, 1971 in Atta-Peters & Salami, 2004a).

Atta- Peters & Salami (2004a) report that *Adnatosphaeridium multispinosum* is of middle Maastrichtian to Paleocene age. Masure *et al*. (1998) also suggested a Paleocene age for *Adnatosphaeridium multispinosum* in Nigeria. From the IS - 3AX well, Tano Basin, *Adnatosphaeridium multispinosum* is associated with Maastrichtian sediments (Atta – Peters & Salami, 2006).

Dinogymnium spp. are generally known to have their LAD in the latest Maastrichtian. Boltenhagen (1977, 1980) suggested a Cenomanian – Maastrichtian age for *Dinogymnium acuminatum* from Gabon. Brinkhuis & Zachariasse (1988) in Atta–Peters & Salami (2004a) opined that *Dinogymnium acuminatum* has its last occurrence in the latest Maastrichtian. Stover *et al.,* (1996); Costa and Davey, (1999) share this same opinion about *Dinogymnium spp. as* Atta–Peters & Salami (2004a).

Dinogymnium undulosum is reported from the Santonian-Maastrichtian of America and Europe (Schrank, 1987).

Oboh-Ikuenobe *et al.* (1998) intimated that the last fossil record of *Dinogymnium spp.* worldwide is found in uppermost Maastrichtian rocks, before the Maastrichtian/Danian boundary.

There is an overlap in the stratigraphic ages of the taxa observed in the *Andalusiella gabonensis – Dinogymnium acuminatum* Zone. The combined ages of the taxa reported in this zone points to a Campanian-Maastrichtian/Paleocene age. However, the observed LAD of *Dinogymnium spp.,* in this zone is indicative of a Maastrichtian age. Thus, the *Andalusiella gabonensis – Dinogymnium acuminatum* Zone of the ST-5 and ST-6 wells of the Tano Basin represents a Campanian- Maastrichtian age.

4.2.3 The *Glaphyrocysta divaricata* Zone

In the ST-5 well, this zone is recognized from 1175-655m (Fig. 4.3) and from ST-6, it is recognized from 1135-775m (Fig. 4.4). This zone sees the FAD of *Cordosphaeridium exilimurum*, *Cordosphaeridium inodes*, and *Glaphyrocysta divaricata* in both wells. *Glaphyrocysta divaricata* and *Adnatosphaeridium multispinosum* are by far the most abundant species in this zone. Some of the taxa from the *Andalusiella gabonensis– Dinogymnium acuminatum* Zone are also present in this zone. These include *Andalusiella gabonensis, Cerodinium boloniense, Cerodinium diebelli, Phelodinium tricuspis, Spiniferites ramosus, Paleocystidinium golzowense, Adnatosphaeridium multispinosum* and *Oligosphaeridium complex*

4.2.3.1 *Discussion, Comparison and Age of the Glaphyrocysta divaricata Zone*

Cordosphaeridium exilimurum is reported to have its FAD in the late Maastrichtian of the Cote d'Ivoire Ghana transform margin as reported by Oboh-Ikuenobe et al, (1998). They further stated that *Glaphyrocysta divaricata* and *Cordosphaeridium inodes* have their FAD in the late Maastrichtian. Masure *et al,* (1998) report *Glaphyrocysta divaricata* from the late Campanian to early Paleocene of the CIG transform margin. Masure *et al* (1998) also assigned an early Paleocene age for *C. inodes*.

Atta-Peters & Salami (2004a) have suggested a Maastrichtian – Paleogene range for *Cordosphaeridium inodes, Cordosphaeridium exilimurum* and *Glaphyrocysta divaricata* from the Tano Basin.

Eventhough this zone is characterised by elements of the Campanian-Maastrichtian/Paleocene, the marked absence of *Dinogymnium spp*. is suggestive of an age younger than the Maastrichtian as *Dinogymnium* do not range into the Paleocene (Atta-Peters & Salami, 2004a; Oboh-Ikuenobe *et al.,* 1998). Hence, the age of the *Glaphyrocysta divaricata* Zone of the ST-5 and ST-6 well is Paleocene.

The sample slides between of interval 655-405 and 655-385m of the ST-5 and ST-6 wells of the Tano Basin are devoid of dinoflagellates hence it is difficult to conclude that they represent the same age range as the *Glaphyrocysta divaricata* Zone.

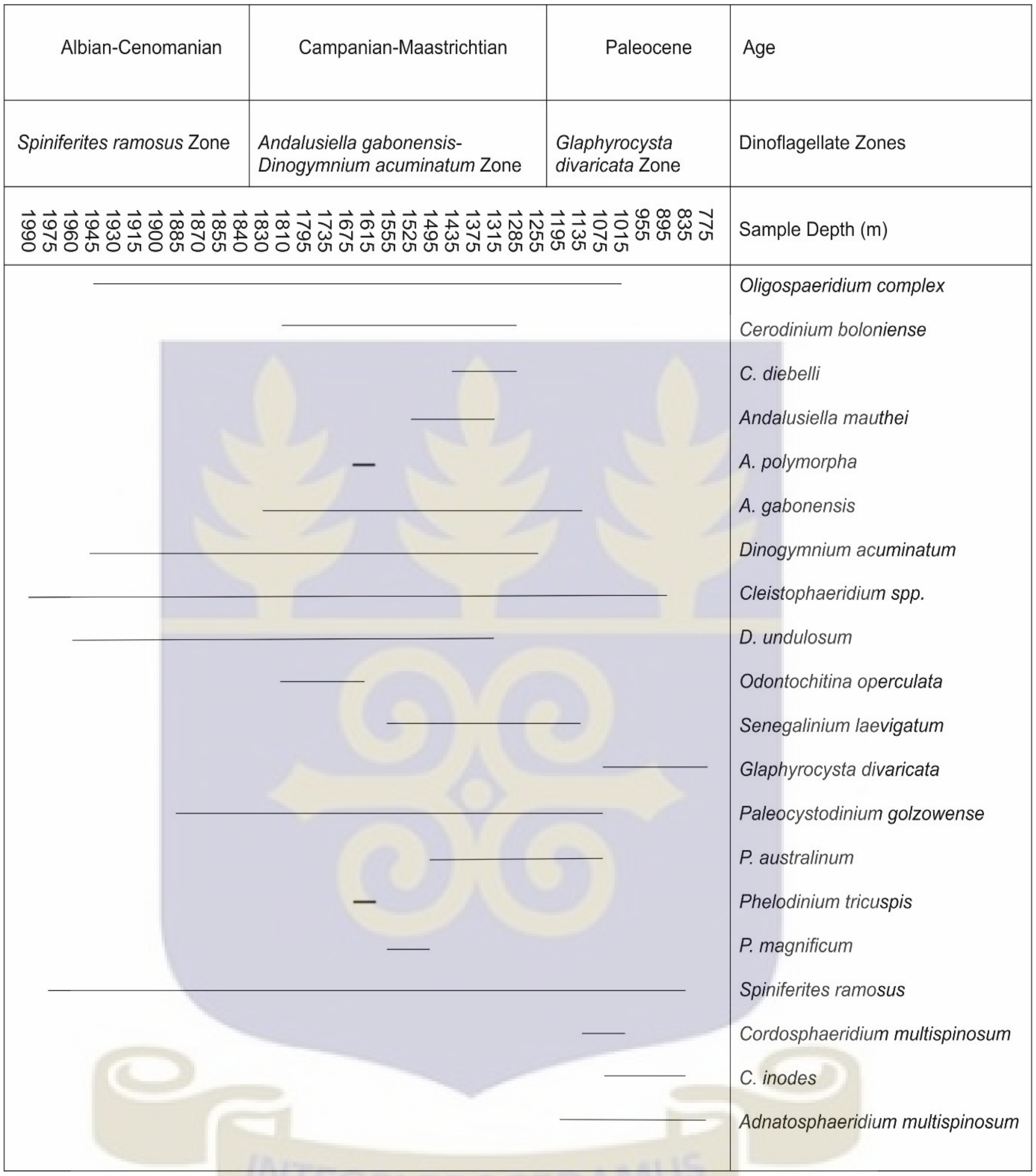


Figure 4.3: Distribution of Albian-Paleocene dinoflagellates in the ST-5 well

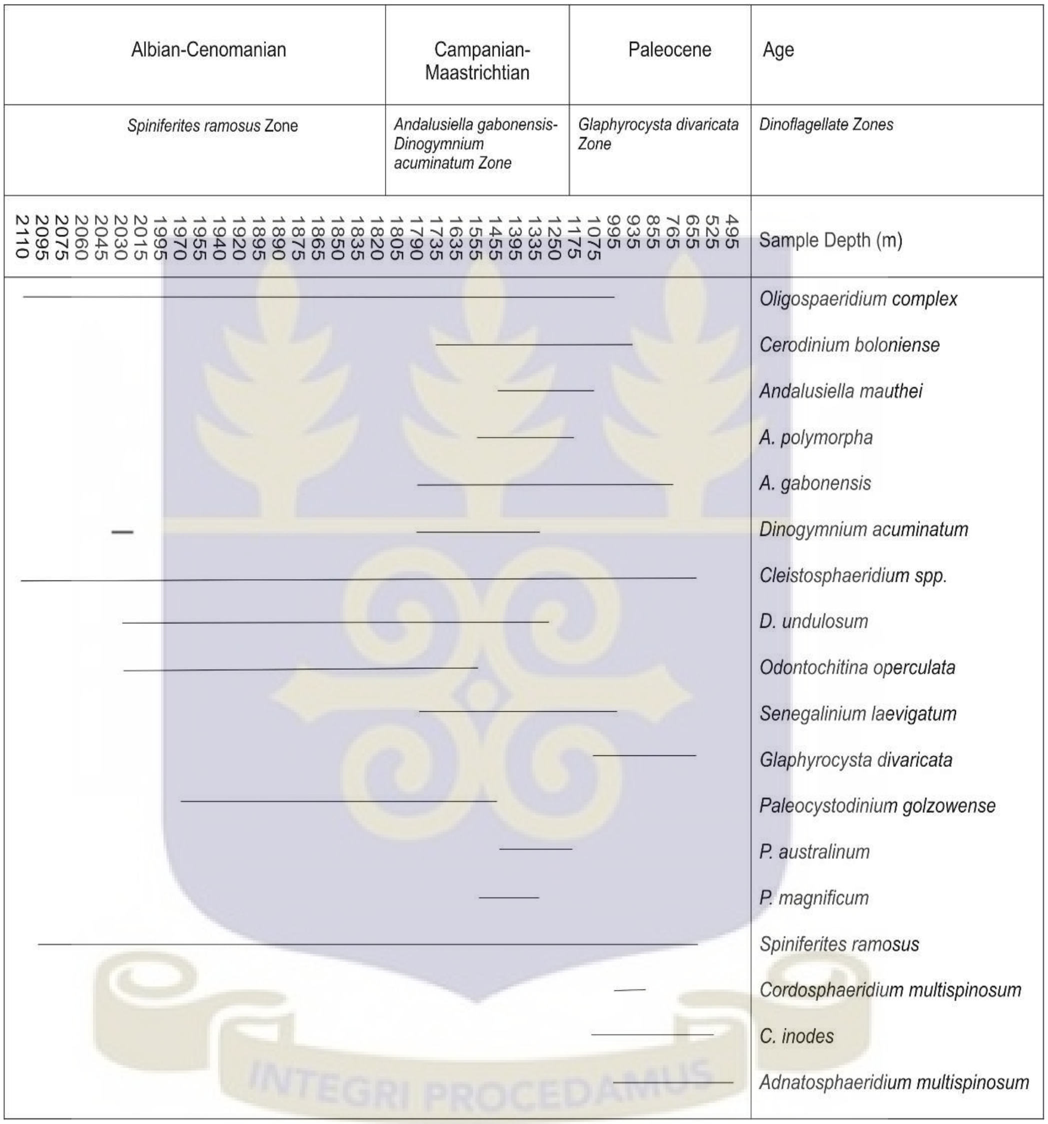


Figure 4.4: Distribution of Albian-Paleocene dinoflagellates in the ST-6 well

CHAPTER FIVE

PALEO-ECOLOGY AND PALEO-PROVINCES

5.1 PALEO-ECOLOGICAL ANALYSIS

The palynomorph assemblages observed from the ST-5 and ST-6 wells are very similar with minor differences in species observed. Almost all the palynomorphs recorded from the ST-6 well are present in the ST-5 well. Inferences about the environment of deposition of sediments were predicted based on the ecological preferences of the observed taxa and also based on the relative abundance of the different palynomorph types.

Frequency charts have been employed to display relative abundances of the palynomorphs types in the biozones erected. Ternary plots of spores, pollen and microplankton (dinoflagellates) have been plotted to elucidate the probable environment under which the sediments were laid down.

5.1.1 Implications from miospores

The relative proportions of the different palynomorphs types from the Albian–Cenomanian horizon of the ST-5 and ST–6 wells (Tables 5.1 & 5.2) shows that there is a high influx of terrigenous material. This is due to high abundance of miospores as compared with that of dinoflagellates.

Table 5.1 Relative frequencies of palynomorph types from the Albian – Cenomanian from the ST – 6 well.

	DEPTH (m)	SPORES(S)	POLLEN(Po)	PERIDINOIDS (P)	GONYAULACOID(G)	S+Po	P+G	S+Po+P+G	FTL
	1990	0	9	0	1	9	1	10	0
	1975	0	23	1	1	23	2	25	1
	1960	1	18	1	0	19	1	20	0
	1945	4	21	0	4	25	4	29	0
	1930	1	13	0	0	14	0	14	2
	1915	1	10	0	0	11	0	11	0
	1900	2	21	0	3	23	3	26	0
	1885	5	18	4	2	23	6	29	1
	1870	0	3	0	0	3	0	3	0
	1855	0	1	0	1	1	1	2	0
	1840	3	11	5	0	14	5	19	2
TOTAL		**17**	**148**	**11**	**12**	**165**	**23**	**188**	**6**
		9.04%	**78%**	**5.80%**	**6.38%**	**87.04%**	**12.18%**	**100%**	

The Albian – Cenomanian sections in both wells are characterized by the presence of elaterate pollen and their associated taxa such as *Ephedripites* and *Classopollis*. According to Dino *et al.*, (1999) the parent plants of these elaterates were probably gnetales that thrived in humid coastal plains. According to Dino *et al* (1999), elater bearing plants which were inhabitants of dry areas in warm climates, diversified and became abundant in response to changes in climatic conditions associated with the opening and enlargement of the northern parts of the South Atlantic Ocean in the latest Aptian to early Albian times. The continued enlargement and widening of the South Atlantic Ocean at the end of the Cenomanian, resulted in low temperatures that concluded in the obliteration of the elaterates from the sedimentary rock record (Dino *et al.,* 1999).

Table 5.2 Relative frequencies of palynomorph types from the Albian – Cenomanian horizons from the ST – 5 well.

	DEPTH(m)	SPORES(S)	POLLEN(Po)	PERIDINOIDS(P)	GONYAULACOID(G)	S+Po	P+G	S+Po+P+G	FTL
	2110	0	6	0	0	6	0	6	0
	2095	0	6	1	1	6	2	8	0
	2075	0	5	0	0	5	0	5	0
	2060	0	16	2	0	16	2	18	0
	2045	0	6	0	2	6	2	8	0
	2030	0	8	0	1	8	1	9	0
	2015	0	4	1	5	4	6	10	2
	1995	0	9	3	2	9	5	14	1
	1970	0	2	0	0	2	0	2	1
	1955	1	21	1	0	22	1	23	0
	1940	0	6	0	1	6	1	7	1
	1920	2	14	0	2	16	2	18	0
	1895	0	14	2	7	14	9	23	0
	1890	0	13	5	8	13	13	26	0
	1875	1	18	6	4	19	10	29	0
	1865	4	1	14	10	5	24	29	0
	1850	0	4	3	6	4	9	13	1
	1835	0	9	0	3	9	3	12	0
	1820	1	4	0	0	5	0	5	1
TOTAL		**9**	**166**	**38**	**52**	175	90	**265**	**7**
		3.40%	62.64%	14.34%	19.62%	66.04%	33.96%	100%	

The host sediments of the elaterates in this research are predominantly of fluvial and lacustrine facies (Appendix 1). Abubakar *et al*. (2006) who studied elaterate pollen from the Upper Benue Trough of Nigeria, made a similar observation to that of this research in that, the enclosing sediments of the elaterates they recovered, were the continental proto-rift and syn-rift Bima Sandstones that were deposited in alluvial fan, lacustrine and braided river environments. Abubakar *et al*. (2006) thus remarked that, the appearance and subsequent abundance of elater bearing pollen is evolutionary and palaeoclimatic in nature, with the palaeoclimatic influence not necessarily being associated with the opening of the northern part of the southern Atlantic Ocean, as remarked by Dino et al., (1990).

The elater bearing pollen in this study are associated with *Ephedripites brasiliensis, Ephedripites barghoonii, E. multicostatus, E. ovalis* and *E. jansonii* along with *Classopollis*. These ephedroids and *Classopollis* are considered to be xerophytic and as such are suggested to be indicators of some form of environmental stress such as seasonal dryness (Schrank, 1995; Schrank & Nesterova, 1993; Atta-Peters & Salami, 2006). The presence of ephedroids in association with *Classopollis* in the sediments of the Albian-Cenomanian indicates that there were some episodes of dryness during the time of deposition.

The presence of fern spores such as *Cicatricosisporites, Cyathidites, Glenchinidites* and *Deltoidospora* indicates the presence of pteridophytic vegetation thriving on wetlands (Mahmoud and Moawad, 2002; Schrank & Mahmoud, 1998; El Beialy *et al.,* 2011). The presence of *Araucariacites australis* shows that there were dry hinterland sites where conifer vegetation thrived. (Schrank & Mahmoud, 1998; Mahmoud, 2003).

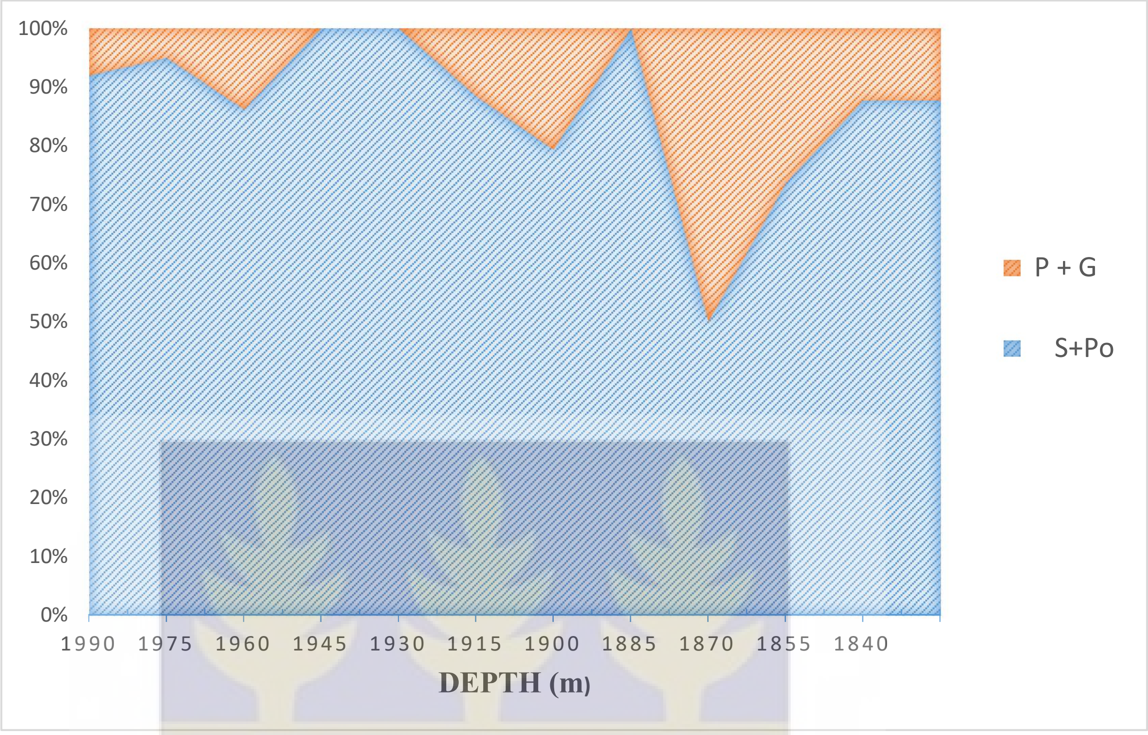


Figure 5.1: Percentage frequency diagram of marine (P+G) / non-marine (S+Po) ratio in Albian – Cenomanian horizon of the ST–6 well

The interpretations above indicate the following paleo- environmental implications for the Albian – Cenomanian miospores from both wells; the relative proportions of spores, pollen and dinoflagellates (Figures 5.1 and 5.2) depicts deposition in a marginal marine/near shore environment. This environment of deposition is inferred from the high inflow of land derived spores and pollen as compared to dinoflagellates (Figures 5.1, 5.2 and 5.3).

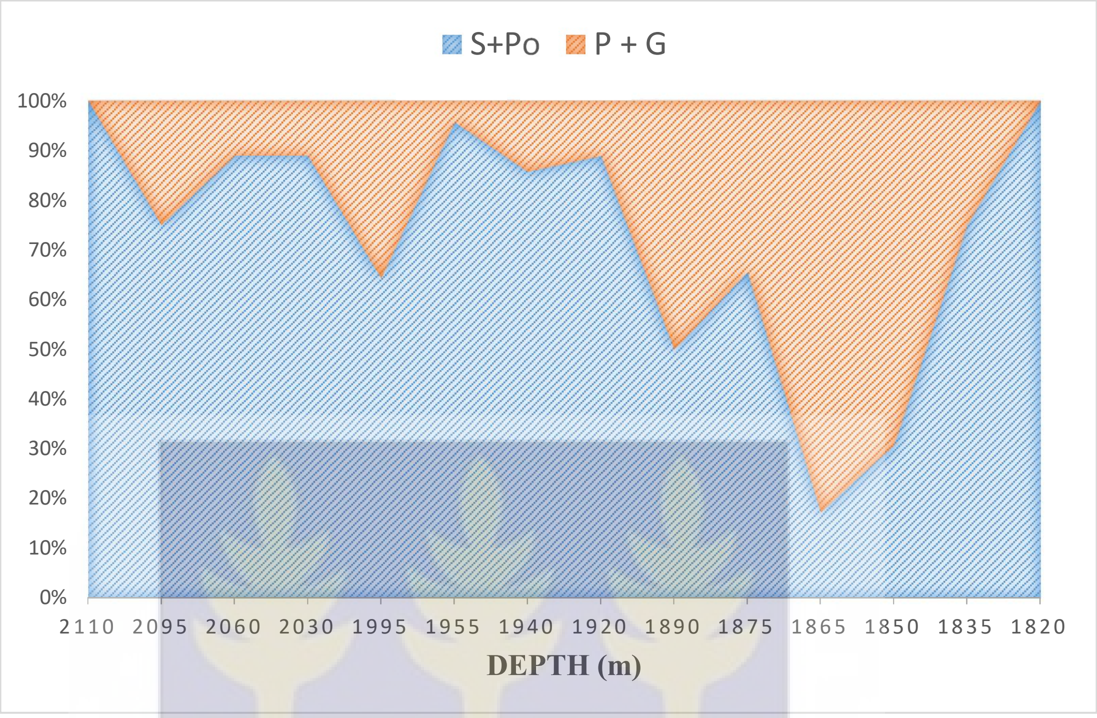


Figure 5.2: Percentage frequency diagram of marine (P+G) / non-marine (S+Po) ratio in Albian – Cenomanian horizon of the ST–5 well

Also the presence of foraminiferal test linings further supports the fact that there was some level marine influence. The occurrence of xerophytic ephedriods indicates that there was episodic dryness during deposition. The presence of fern spores such as *Deltoidospora, Glenchinidites, Cyathidites* and *Cicatriocosisporites* coupled with the presence of the elater bearing pollen depicts a vegetation on wet lands under the influence of a semi-arid to arid climate.

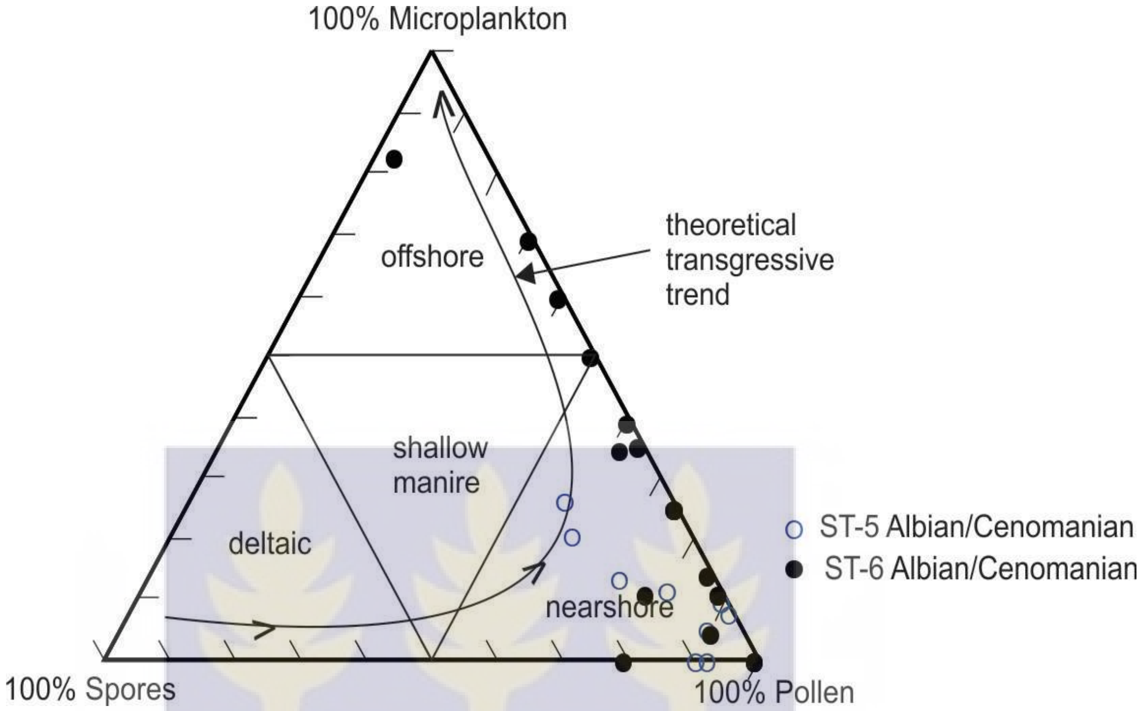


Figure 5.3: Ternary plot of spores, pollen and micro plankton shows the possible depositional environment of samples studied from the Albian- Cenomanian sediments of the ST-6 and ST-5 wells (modified from Ibrahim, 2002).

The miospore representatives of the Campanian–Maastrichtian/Paleocene interval from the ST-5 and ST– 6 wells include *Buttinia andreevi, Spinizonocolpites echinatus, Proxapertites cursus, Proteacidites dehaani, Longapertites marginatus, Retistephanocolpites williamsii and Foveotriletes margaritae.* These miospores present in this intervals of both wells are those Schrank (1987); Herngreen et al, (1996); El Beialy, (1995); described from the Late Cretaceous to Early Tertiary of West, Central and North Africa as well as northern South America. Other authors have reported on the occurrence of this taxa from the Campanian-Maastrichtian, noteworthy amongst them are Apaalse & Atta-Peters, (2013).

Spinizonocolpites along with *Longapertites* and *Proxapertites* are characteristic elements of the palmae (Muller, 1968 in Atta-Peters & Salami, 2004; Schrank, 1987; El Beialy, 1995). The term palmae according to El Beialy (1995), is suggestive of a hot tropical to sub-tropical climate. These taxa are thought to belong to the genus *Nypa* (Germeraad *et al.,* 1968), and are known to thrive in mangrove environments along coastal areas of the humid tropics (Schrank, 1998; Herngreen, 1998; El Beialy, 1995).

Retistephanocolpites williamsi is an angiosperm pollen species that belongs to the family Ctenolophonacae (Schrank, 1984; Atta-Peters & Salami 2006). In recent vegetation, the Ctenolophonacae represents trees living in humid forests, alongside river banks (Salard-Cheboldaeff, 1981 in El Beialy, 1995), thus *Retistephanocolpites williamsi* during the late Cretaceous times must have inhabited a similar humid swamp forest vegetation environment.

Proteaceae are usually rain forest trees but according to Schrank (1987) and El Beialy (1995), the majority of the Family Proteaceae are found in the Southern hemisphere under prolonged dry season environments.

Summarizing the foregoing discussion, there are clear indications that the microflora encountered in the Campanian – Maastrichtian sections of the ST- 5 and ST – 6 wells were deposited in a coastal *Nypa* mangrove environment characterized by the presence of palms such as *Longapertites* and *Proxapertites* with possible elevated habitats of Proteaceae, under a humid tropical climate.

5.1.2 Implication from dinoflagellates

Davies *et al*., (1982) discussed the four categories by which dinoflagellates can be employed in paleo- environmental studies. These are:

- the absolute abundance of dinoflagellates;

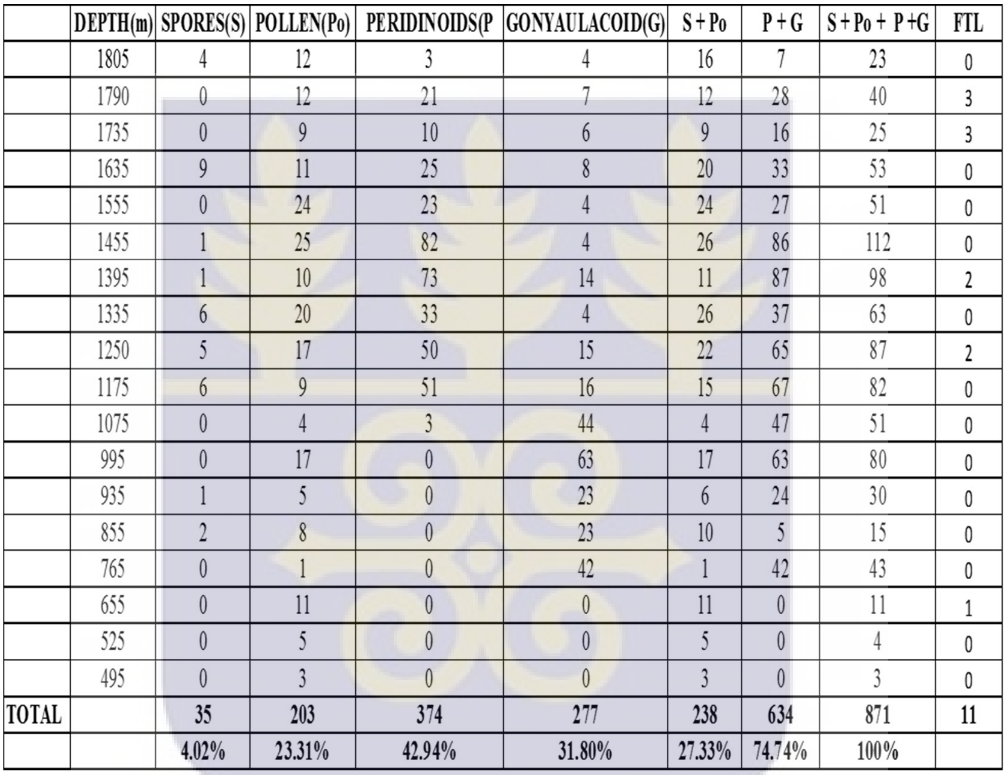
- the relative abundance of dinoflagellates to other palynomorph types;
- dinoflagellate species diversity and dominance
- dinoflagellate assemblage composition.

The dinoflagellate assemblage composition category is significant in the recognition of paleo- environmental. This is due to the fact that ecological modelling relies heavily on the relative abundance of dinoflagellate species and morphotypes.

Downie et al., (1971) and Islam (1984) were able to recognise specific associations of dinoflagellate cysts and related these associations with particular environments. These associations were named after the genus to which the dominant species belonged. The *Wetzeliella* association is characterised by the abundance of peridinoids such as *Andalusiella, Senegalinium, Phelodinium* and *Cerodinium*. The *Wetzeliella* association according to Downie et al., (1971) and Islam (1984) is indicative of a brackish or estuarine environment. The *Spiniferites/ Areoligera* association which is characterised by the abundances of *Spiniferites, Areoligera, Cordosphaeridium, Glaphyrocysta* and *Adnatosphaeridium* points to an open marine environment.

Harland (1973) in his study of the Bearpaw Formation of southern Alberta, Canada, used a different approach and compared the relative abundance of two major types of dinoflagellate cysts. He defined the gonyaulacacean ratio as the number of gonyaulacacean cyst species divided by the number of peridiniacean cyst species and indicated that this may also be an indicator of salinity. Harland (1973) found that the gonyaulacacean ratio was higher in more open marine environments and low in nearshore, reduced-salinity environment. However, salinity is not the only factor that controls the dinoflagellate assemblage composition. Some studies (Wall *et al*. 1977; Bujak, 1984; Powell *et al.* 1990; Lewis *et al*. 1990; Eshet *et al*., 1994) have suggested that the increase of peridinoid cysts relative to gonyaulacacean cysts is related to upwelling systems. Lewis et al. (1990) opined that the gonyaulacacean ratio is also useful as an indicator of upwelling strength.

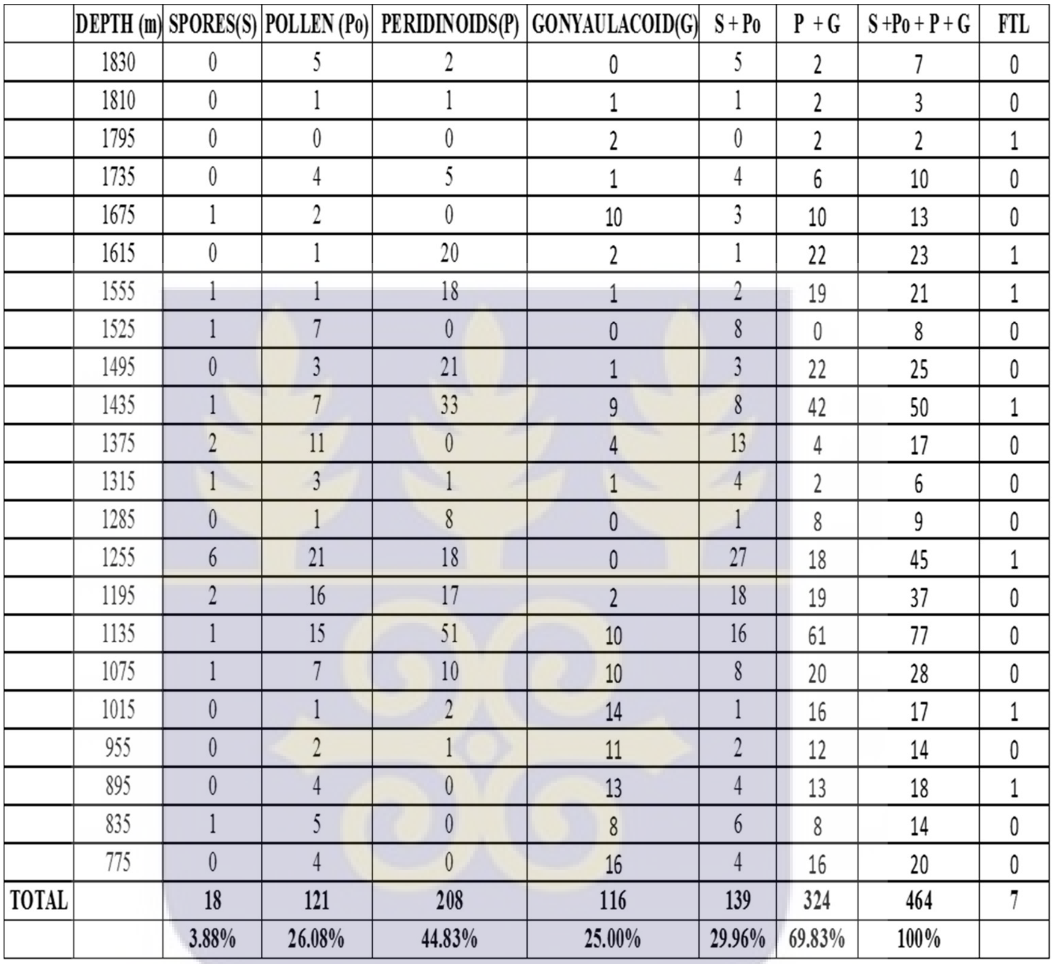
Table 5.3 Relative frequencies of palynomorph types from the Campanian – Maastrichtian section from the ST – 5 well.



	DEPTH(m)	SPORES(S)	POLLEN(Po)	PERIDINOIDS(P	GONYAULACOID(G)	S+Po	P+G	S+Po + P+G	FTL
	1805	4	12	3	4	16	7	23	0
	1790	0	12	21	7	12	28	40	3
	1735	0	9	10	6	9	16	25	3
	1635	9	11	25	8	20	33	53	0
	1555	0	24	23	4	24	27	51	0
	1455	1	25	82	4	26	86	112	0
	1395	1	10	73	14	11	87	98	2
	1335	6	20	33	4	26	37	63	0
	1250	5	17	50	15	22	65	87	2
	1175	6	9	51	16	15	67	82	0
	1075	0	4	3	44	4	47	51	0
	995	0	17	0	63	17	63	80	0
	935	1	5	0	23	6	24	30	0
	855	2	8	0	23	10	5	15	0
	765	0	1	0	42	1	42	43	0
	655	0	11	0	0	11	0	11	1
	525	0	5	0	0	5	0	4	0
	495	0	3	0	0	3	0	3	0
TOTAL		35	203	374	277	238	634	871	11
		4.02%	23.31%	42.94%	31.80%	27.33%	74.74%	100%	

The Albian – Cenomanian section (2110-1820m 0f ST-5 & 1990-1855m of ST-6) of both wells relatively had very few dinoflagellates as shown in Tables 5.1 and 5.2. The few forms present are *Oligosphaeridium complex, Spiniferites ramosus* and *Cleistosphaeridium*. The presence of these few gonyaulacacean dinoflagellate species indicate that there was some marine influence during the deposition of these sediments. There were a few foraminiferal test linings (FTL) present as well. (Tables 5.1 and 5.2). Foraminiferal test linings are useful environmental indicators. They are common in marine costal and shallow shelf environments (Tyson, 1993; Batten, 1996

Table 5.4 Relative proportions of palynomorph types from the Campanian – Maastrichtian from the ST – 6 well.



	DEPTH (m)	SPORES(S)	POLLEN (Po)	PERIDINOIDS(P)	GONYAULACOID(G)	S + Po	P + G	S +Po + P + G	FTL
	1830	0	5	2	0	5	2	7	0
	1810	0	1	1	1	1	2	3	0
	1795	0	0	0	2	0	2	2	1
	1735	0	4	5	1	4	6	10	0
	1675	1	2	0	10	3	10	13	0
	1615	0	1	20	2	1	22	23	1
	1555	1	1	18	1	2	19	21	1
	1525	1	7	0	0	8	0	8	0
	1495	0	3	21	1	3	22	25	0
	1435	1	7	33	9	8	42	50	1
	1375	2	11	0	4	13	4	17	0
	1315	1	3	1	1	4	2	6	0
	1285	0	1	8	0	1	8	9	0
	1255	6	21	18	0	27	18	45	1
	1195	2	16	17	2	18	19	37	0
	1135	1	15	51	10	16	61	77	0
	1075	1	7	10	10	8	20	28	0
	1015	0	1	2	14	1	16	17	1
	955	0	2	1	11	2	12	14	0
	895	0	4	0	13	4	13	18	1
	835	1	5	0	8	6	8	14	0
	775	0	4	0	16	4	16	20	0
TOTAL		18	121	208	116	139	324	464	7
		3.88%	26.08%	44.83%	25.00%	29.96%	69.83%	100%	

in Ibrahim, 2002). These taxa depict the open marine *Spiniferites/Areoligera* association. However, due to the paucity of these forms in the Albian – Cenomanian horizons of both wells, a marginal marine/nearshore environment of deposition is suggested for these sediments (Figures 5.1, 5.2 & 5.3).

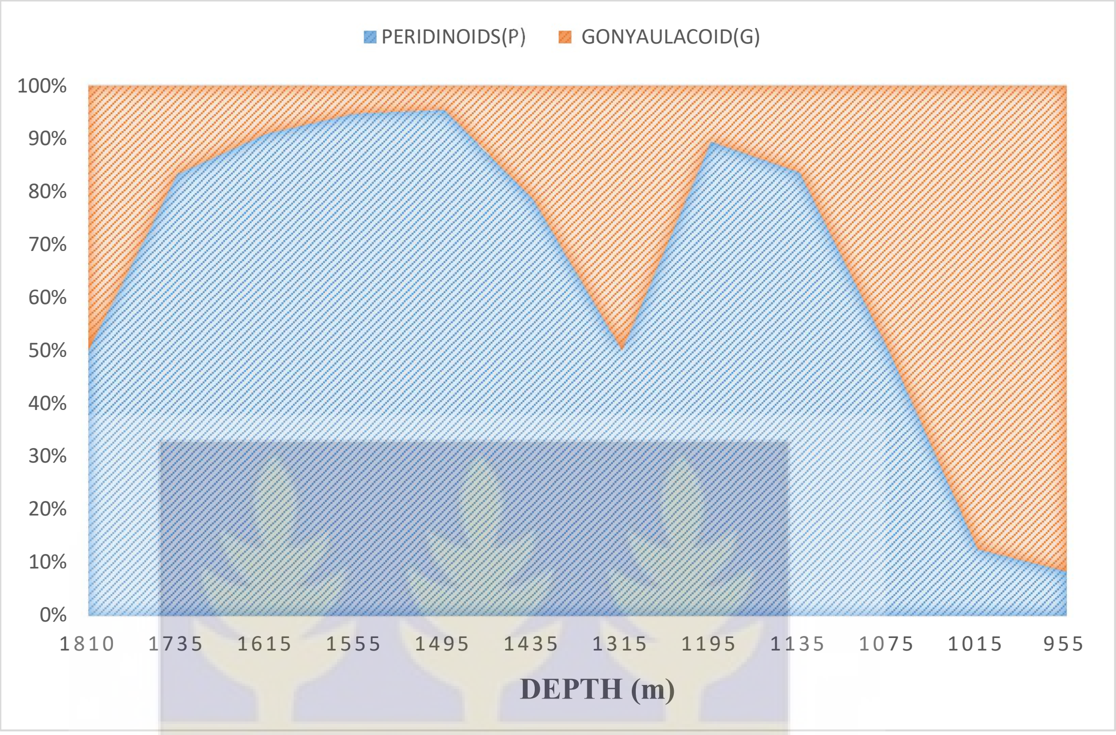


Figure 5.4: Gonyaulacoid/Peridinoid diagram of the ST – 6 well

In the Campanian-Maastrichtian section of the ST–6 well, the interval between 1615 and 1435m, and the interval between 1285 and 1135m of ST-5 is dominated by peridinoids (Table 5.4). Likewise, the interval between 1790 and 1175m for the ST –5 well is dominated by peridinoids (Table 5.3) which belongs to the Campanian age.

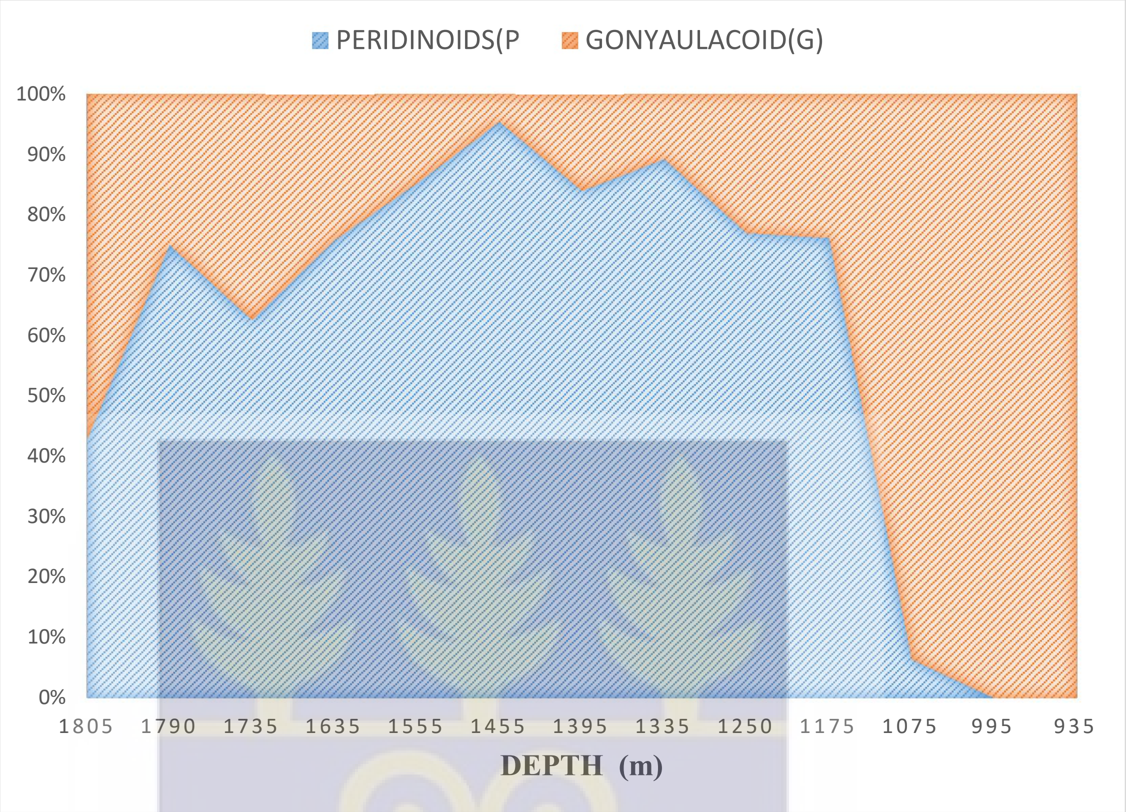


Figure 5.5: Gonyaulacoid/Peridinoid diagram of the ST – 5 well

Harland (1988) opined that peridinoids are heterotrophic dinoflagellate cysts and thereby are indicators of paleo- productivity in upwelling systems with high concentration of nutrients. These upwelling systems are present where cold and nutrient rich waters are brought to the surface of a water body. Thus, the high abundance of peridiniacean cysts from the lower to middle section of both wells is as a result of nutrient rich, relatively low salinity waters that facilitated high productivity.

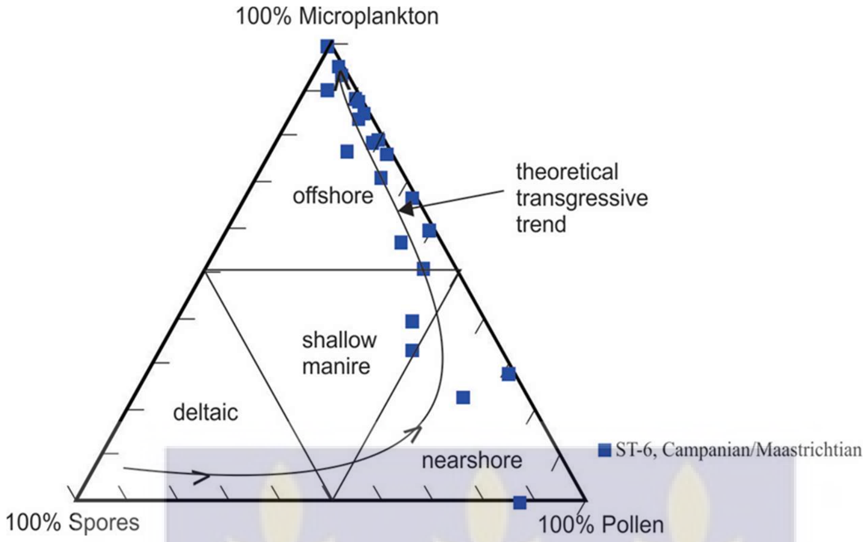


Figure 5.6: Ternary plot of spores, pollen and micro plankton illustrates the probable depositional environment of the Campanian–Maastrichtian samples studied from the ST-6 well (modified after Ibrahim, 2002).

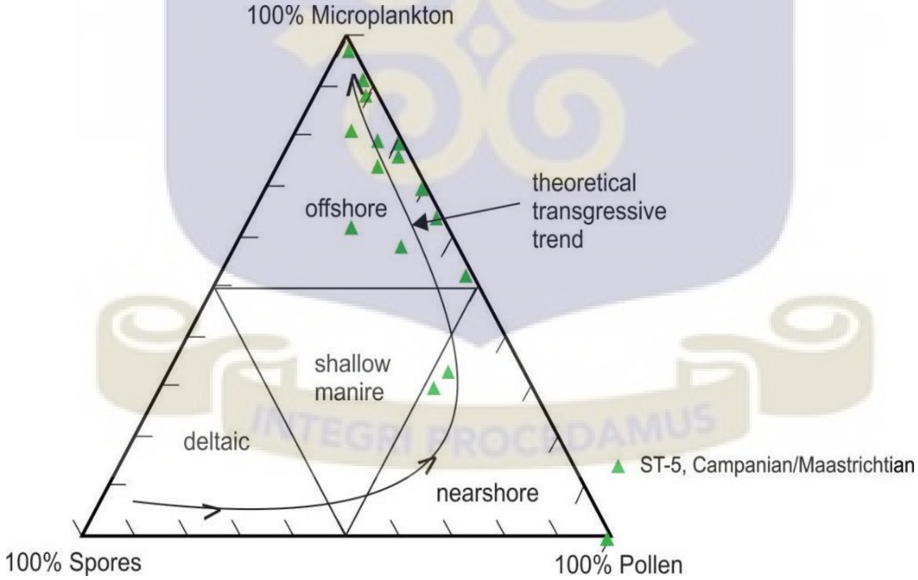


Figure 5.1: Ternary plot of spores, pollen and micro plankton illustrates the probable depositional environment of the Campanian–Maastrichtian samples studied from the ST-5 well (modified after Ibrahim, 2002).

The uppermost intervals between 1075 and 775m of the ST-6 well and between 1075–765m of the ST–5 well are dominated by gonyaulacacean cysts over peridinoids (Tables 5.3 and 5.4). The gonyaulacacean forms present include mostly *Adnatosphaeridium, Cordosphaeridium*, *Glaphyrocysta* and *Spiniferites*. These gonyaulacacean forms are typical elements of the *Spiniferites/ Areoligera* association of Downie et al., (1971) and Islam (1984). According to both authors, the *Spiniferites/ Areoligera* association is suggestive of deposition in an open marine environment.

The gonyaulacacean ratio (Figures 5.4 & 5.5) further suggest that the upper intervals of the Campanian–Maastrichtian sections both wells were indeed deposited in open marine waters with relatively high salinities as Harland (1973) opined.

Summarizing the foregoing discussion on the Campanian–Maastrichtian dinoflagellates, the intervals 1615-1435m and the 1285-1135m section of the ST-6 well is characterized by abundant peridinoids. Likewise, the interval between 1790 and 1175m for the ST-5 well is also dominated by peridinoids (Tables 5.3 and 5.4). This abundance of peridinoids indicates deposition in a marginal marine (brackish/estuarine) environment with low salinities whiles the abundance of gonyaulacacean cysts in the upper most sections of both wells is indicative of deposition in an open marine environment characterised by high salinities (Figures 5.6 and 5.7).

Lentin and Williams (1980) in a study of distribution pattern of Late Cretaceous peridiniacean dinoflagellates cyst from North America, South America, Europe and Africa described three assemblages or provincial suites. These assemblages show regional differentiation rather than local palaeoecological control. These assemblages which seem to show relationship to climate belts were named as:

- The Malloy or Tropical-Subtropical suite, characterised by the genera *Andalusiella, Cerodinium, Phelodinium, and Senegalinium*

- The Williams or Warm Temperate suite, with deflandreoid dinoflagellates generally represented by the genera *Alterbidium, Spinidinium, Chatangiella* and *Isabelidium*
- The McIntyre or Boreal-Arctic suite, is characterised by the *Laciniadinium* and *Chatangiella*

The Campanian - Maastrichtian peridiniacean assemblage of this study shows a lot of similarity with the taxa characteristic of the Tropical - Subtropical Malloy Suite of Lentin and Williams (1980). Thus these sediments were deposited in a tropical to sub-tropical climate.

5.2 PALEO-PROVINCES

Within the Cretaceous, Herngreen & Chlonova (1981) identified four micro floral provinces. The provinces established by Herngreen & Chlonova (1981) were later modified by Herngreen et al. (1996). Three provinces were proposed by Herngreen et al. (1996). These provinces are assumed to be related to the contemporary latitudinal climatic zones where Africa- South America (ASA) province is assumed to occupy an equatorial or near equatorial position. These 3 provinces are:

- Pre Albian Early Cretaceous Dicheiropollis etruscus/Afropollis Province
- Albian-Cenomanian Elaterate Province
- Senonian Palmae Province

The micro floral assemblages observed in the Albian – Cenomanian section this research are elements of the Albian-Cenomanian Elaterate Province and the Campanian – Maastrichtian micro floral assemblage belong to the Senonian Palmae Province.

5.2.1 ALBIAN-CENOMANIAN ELATERATE PROVINCE

The concept of the middle Cretaceous (Albian to Cenomanian) Africa-South America (ASA) Microfloral Province was introduced by Herngreen (1974) and additions made later by Herngreen *et al,* (1996). For this same palynofloristic province, Brenner (1976) termed it the Northern Gondwana Province and *Galeacornea* paleo-phytogeoprovince by Srivastava (1978), later renamed the *Elaterosporites* phytoprovince by Srivastava (1981) in Herngreen et al (1996).

Herngreen & Duenas (1990) opined that the geographic extent of this floral province that is characterised by elater bearing species is greater than initially assumed. Herngreen (1974) assumed that these species were confined to only Africa and South America hence the name. However new data indicates that the distribution of these elaterates transcends the Africa and South America continents and is reported from as far back as China and Papua-New Guinea.

The characteristics of the Africa-South America (ASA) Microfloral Province are;

- Presence of elater-bearing taxa. They belong to the genera *Elaterosporites*, *Elaterocolpites, Elateroplicites, Elateropollenites, Galaecornea, Senegalosporites*, and *Sofrepites.* These taxa are restricted to the Elaterate Province and may be in high percentages.
- Usually high values and extraordinary diversification in the angiospermous pollen grains. Common representatives of the prevalent *Afropollis, Cretacaeiporites, Hexaporotricolpites* and *Triorites* (which appeared in the late Cenomanian) occurs with psilate as well as reticulate tricolpate / tricolporate species. Angiospermous pollen represented up to 70% in the low paleo- latitude areas by the Late Albian time.

- Common ephedroid pollen such as *Ephedripites, Equisetosporites, Gnetaceaepollenites and Steevesipollenites.* These ephedriod forms which includes diverse and abundant polyplicate forms with straight or twisted ridges are typical of the Elaterates Province. Their highest frequencies and morphological variations are recorded in areas within the province.
- Scarcity of fern spores. Most of the spores belong to the psilatrilete group, *Cicatricosisporites* or *Crybelosporites pannuceus*. Many other broad-based taxa occur irregularly and rarely.
- Absence of bi- and trisaccate gymnospermous pollen. *Classopollis* may be very common just as in the preceding Early Cretaceous *Dicheiropollis etruscus/Afropollis* Province.

The presence of elater bearing pollen and their associated taxa within the depth intervals of 2110– 1820m and 1990-1840m for the ST–5 and ST–6 wells respectively indicates clearly that these sections fall within this province.

5.2.2 SENONIAN PALMAE PROVINCE

Herngreen (1980) established the Late Cretaceous Palmae Province of Africa and South America. The term Palmae Province suggests a hot, tropical to sub-tropical climate and the assemblages are interpreted as indicative of a warm and humid climate. Senonian refers to final Cretaceous epoch which is dated at 88.5–65 Ma (Harland et al., 1989) and comprises the Coniacian, Santonian, Campanian, and Maastrichtian Ages.

This province is characterised by;

- Increasing numbers of monocolpate Palmae types of the Psila-/retimonocolpites plexus, *Longapertites* and morphologically similar species

- Typical elements of the province are the pollen taxa of '*Buttinia', Echitriporites* and the monocolpates *Longapertites, Mauritiidites, Spinizonocolpites*, and *Proxapertites* considered to be elements of mangrove environment of the humid tropics.

The sediments from the Campanian-Maastrichtian sections of the ST-5 (1805-495m) and ST-6 (1830-775m) wells of the Tano Basin fall with this province.

CHAPTER SIX

SYSTEMATIC PALYNOLOGY

The palynomorphs are classified based on the nomenclature forth by the International Code of Botanical Nomenclature (ICBN) (Stafleu, 1978) rules on priority and typification. Only well preserved and stratigraphically significant taxa have been described. The descriptions are based on those of common species which have been explained in literature.

6.1 SPORES AND POLLEN

The miospores from sediments of the ST – 5 and ST – 6 wells have been systematic classified according to Potonié and Kremp (1954), Potonié (1956, 1958, 1960), and revisions by Dettman (1963) and Smith and Butterworth (1967).

Turma Polyplicates Erdtman, 1952

Subturman Costates Potonié, 1970

Infraturma Costati Potonié, 1970

Genus: *Ephedripites* Bolchovitina, 1953

Species: *Ephedripites brasiliensis* Herngreen, 1973

ST-6 slide 1915m, coordinates: 11.6, 122.0 (Plate 1, Image J)

Description: This pollen is oval, elongated and polyplicate. It has about 6 smooth ridges that are twisted longitudinally around the grain and merge at the poles. Ridges are smooth Species has furrows of varying thicknesses.

Dimensions of central body: average length axis 26µ, average width 12µ,

Number of species measured: 3

Genus *Elateropollenites* Herngreen, 1973

Species: *Elateropollenites jardinei* (Herngreen, 1973) Jardiné and Magloire, 1965

ST-5 slide 2060m, coordinates: 10.2, 146 (Plate 1, Image I)

Description: This pollen has a subtriangular body that bulges outwardly and it has striate sculpture. Because it has three appendages, the grain has a lobate shape. No distinct apertures are visible. The distal tips are thickened with cavate appearance at the base of the broadened tips. The body structure is complex and possesses folds that are parallel to each other and perpendicular to a line connecting the two appendages at the ends. Two appendages are visible with a possible third one obscured.

Dimensions of central body: (30 x 42) µ, appendage length: 5µ, width: 7 µ

Genus *Elaterosporites* Jardiné, 1967

Species: *Elaterosporites protensus* (Jardiné and Magloire) Jardiné, 1967

ST-6, slide 1990m, coordinates: 14.0, 123.2 (Plate 1, Image C)

Description: The central body is ornamented with spines (3-5 µ long) and has an elliptical to subspherical shape. The distal face has a thick exine and bulges outwardly. It has 2-3 pairs of U shaped appendages. The appendages are almost of equal length.

Dimensions of central body: (35-38) x (26-29) µ, average (36 x 28) µ.

Length of appendages: (15-20) µ, mean 17µ

Width at base: (5-10) µ mean 8 µ

Number of species measured: 4

Genus *Elaterosporites* Jardiné, 1967

Species: *Elaterosporites verrucatus* (Jardiné and Magloire) Jardiné, 1967

ST-6, slide 1975m, coordinates: 7.7, 129.7; 9.8,126 (Plate 1, Image B)

ST-5 slide 1955m, coordinate: 8.5, 118.0 (Plate 1, Image G)

Description: This species has verrucate or warty ornamentation of height (2-3) µ on the distal face. Proximal face is flat or depressed. Species has about 3 pairs of U shaped appendages.

Dimensions of central body: (25-35) x (20-24) µ, average (27 x 22) µ

Length of appendages 12- 15µ, average 13µ

Width at base: (5-8) µ, average 8 µ

Number of species measured: 4

Genus *Elaterosporites* Jardiné, 1967

Species *Elaterosporites klazii* (Jardiné and Magloire) Jardiné, 1967

ST-6, slide 1975m, coordinates: 17.5, 136 (Plate 1, Image F & A)

ST-6, slide 1930m, coordinates: 6.9, 116.5 (Plate 3, Image G)

Description: This species has smooth or punctate membrane with a central body that usually possesses an annular band. It also has 3 to 4 pairs of tube-shaped appendages on the distal face.

Dimensions of central body: (19-22) x (27-30) µ, average (20 x 28) µ.

Length of appendages: 5-8 µ, average 6µ.

Width at base: (6-10) µ average 7 µ

Number of species measured: 4

Genus *Elaterocolpites* Jardiné, Jardiné & Magloire, 1967

Species *Elaterocolpites castelaini* Jardiné & Magloire, 1967 forma A Jardiné 1967

ST-6, slide 1915m coordinates: 5.7, 135.6 (Plate 1, Image L)

Description: Specimen has a vestige of annular band that surrounds the spore body. It bears up10 short appendages that are parallel and end in blunt rounded apices. In the observed species, only four appendages are visible.

Dimensions: (10 x 18) µ. Length of appendage: 4-5 µ, width of appendage: 4 µ

Genus: *Galeacornea* (Stover) Jardine´, 1967

Species: *Galeacornea causea* Stover, 1963

ST-6 slide 1900m, coordinates 11.6, 122.0 (Plate 3, Image F)

Description: The pollen grain has an ellipsoidal shape. It has smooth ornamentation and it possesses zona of different lengths. The zona is attached to the central body at an oblique angle. This species has no appendages but instead has a distal flap.

Dimensions: (27 x 16) µ

Length of zona: 10-12 µ

Width of zona: 16-19 µ

Speceis: *Deltoidospora minor* (Couper) Pocock, 1970

ST-5, slide 1835m, coordinates: 4.5, 144.3; slide 1820, coordinates: 20.0, 117.0 (Plate 7, Image J)

ST-6 slide 1315m, coordinates: 8.5, 120; slide 1915m, coordinates: 12.0, 123.2

Description: This spore has a visible trilete mark which extends to the amb, with a straight to slightly concave sided triangular amb. The exine is smooth to punctate and the laesura is simple and its length is almost 2/3 of the spore radius.

Dimension: (24-32) x (25-34) µ, average (25 x 30) µ.

Number of species measured: 10

Genus: *Glenchinidites* Ross, 1949 ex Delcourt & Sprumont, 1955 emend. Dettmann, 1963

Species: *Glenchinidites senonicus* Ross, 1949

ST-5 slide 1805m, coordinates: 10.0, 13.6.9, slide 1635m, 18.0, 130 (Plate 3 Image A)

ST-6 slide 1255m, coordinates: 10.4, 137.0 (Plate 3, Image B)

Description: A trilete spore, with a straight to marginally concave sided triangular amb with a distinct laesura that reaches the equator, with raised lips. Observed on proximal face are exine thickenings (>5μ) which outline trilete mark rays and disappear at corners. The distal face has strong concave continuous exinal thickening at the corners.

Dimensions of spore body: (28-32) x (32-34) μ, mean (29 x 32) μ.

Number of species measured: 5

Genus: *Araucariacites* Cookson, 1947, ex Couper, 1953

Species*: Araucariacites australis* Cookson, 1947

ST-5 slide 2110m, coordinates: 10.7, 116.7; slide 1865m coordinates: 9.0, 136.7 (Plate 7, Image K)

ST-6 slide 1855m, coordinates: 15.5, 1441

Description: Outline of species is circular to oval and usually folded due to flattening of the thin-walled grain. There is no distinct apertural area. Species is very finely and densely scabrate.

Dimensions of species: Diameter of body (25-30) μ average 25 μ

Number of species measured: 6

Genus *Spinizonocolpites* Muller, 1968

Species: *Spinizonocolpites echinatus* Muller, 1968

ST-5 slide 855m, coordinates: 13.0, 137.9 (Plate 5, Image D)

ST-6 slide 835m, coordinates: 17.5, 119.8

Description: *S. echinatus* is oval in shape, flattened along the polar axis and has pointy projections emanating from the whole body. These echinate processes are closely spaced and have expanded bases.

Dimensions of central body: (24 x 16) µ mean (20 x 14) µ

Length of processes: (3-4) µ average 3 µ

Width at base: (4-5) µ average 4 µ

Number of species measured: 3

Genus *Longapertites* Van Hoeken- Klinkenberg, 1964

Species: *Longapertites marginatus* Van Hoeken- Klinkenberg, 1964

ST-6 slide 1195m, coordinates: 5.5, 146.3; 10.5, 140.3 (Plate 5, Image K)

Description: Specimen has a curved sulcus and is triangular in shape. The distal side is V shaped as compared to the proximal side that is straight to moderately convex. It has sculptural elements that are very fine foveae.

Dimensions: (17-25) x (13-20) µ average (20 x 18) µ

Number of species measured: 4

Genus *Proxapertites* Van der Hammen, 1956

Species: *Proxapertites cursus* Van Hoeken-Klinkenberg, 1966

ST-6 slide 895m, coordinates: 7.3, 125.8 (Plate 5, Image L)

Description: *P. cursus* has an oval or slightly triangular shape and is flattened along the polar axis. The pollen grain is made up of two parts hence it is described as being a dyad. There is a single membrane that connects these two slightly unequal parts of the pollen. The surface of the pollen grain is covered by very fine foveae.

Dimensions of species: (22-30) x (15-23) μ average (20 x 15) μ

Number of species measured: 4

SUBTURMA Polyptches Potonié, 1970

INFRATURMA *Stephanocolpati* Potonié, 1970

Genus *Retistephanocolpites* Leidelmeyer, 1966 emend. Germeraad et al., 1968

Species: *Retistephanocolpites williamsi* Germeraad et al., 1968

ST-6 slide 835m, coordinates: 18.0, 128.3 (Plate 7, Image I)

Description: *R. williamsi* is a polycolpate with 6 colpi and its body outline generally resembles a sphere with serrations.

Dimension of species: Diameter of 25 μ

Length of colpi: (3-4) μ average 4 μ

Width of colpi: (6-8) μ average 5 μ

Number of species measured: 2

SUBTURMA Azonolete Potonié, 1970

INFRATURMA Tuberini Potonié, 1970

Genus *Buttinia* Boltenhagen, 1967

Species: *Buttinia andreevi* Boltenhagen, 1967

ST-5 slide 1395m, coordinates: 13.5, 133.5 (Plate 5, Image B)

ST-6 slide 1870m, coordinates: 11.5, 129.0; 6.0, 130.2 (Plate 5, Image C)

Description: Pollen grain has a foveolate sculpture. It has pores that are circular, elliptical or oblate and a muri of about 4 µ thick.

Dimensions of pollen: Diameter of pollen (21-27) µ average 24 µ

Number of species measured: 5

SUBTURMA Zonotriletes Waltz, 1935

INFRATURMA Cingulati Potonié & Klaus, 1954

Genus *Cingulatisporites* Thompson in Thompsonand Pflug emend. Hiltman, 1967

Species: *Cingulatisporites ornatus* Van Hoeken-Klinkenberg, 1964

ST-5 slide 1555m, coordinates: 14.0, 130.0 (Plate 5, Image F)

Description: This species has an oval to spherical shape. Small sized verrucae covers the distal face of specimen. The trilete mark is not very pronounced in the species observed.

Dimensions: Diameter (23-28) µ mean 24 µ

Number of species measured: 4

Genus *Foveotriletes* Van der Hammen, 1954 ex. Potonie, 1956

Species: *Foveotriletes margaritae* (Van der Hammen) Germeraad *et al.,* 1968

ST-6, slide 1395m, coordinates: 16.7, 144.1 (Plate 7, Image G)

Description: *F. margaritae* has a convex triangular shape. Species has a foveolate or pitted distal face.

Dimensions of Species: (20-22) x (18-20) µ average (20 x 19) µ

Number of species measured: 4

6.2 DINOFLAGELLATES

The descriptive terminologies employed for the description of dinoflagellates of recovered from both wells are according to Evitt et al. (1977), Williams et al. (1973), Stover and Evitt (1978) and Norris (1978). The dinoflagellates are classified according to the "Cysts Genus" proposed by Stover and Evitt (1978). The Cyst Genus recognizes three morphological groups. These groups are (a) Spiniferate/Gonyaulacoid, (b) Peridinoid and (c) Dinogymnoid.

Division PYRRHOPHYTA Pascher, 1914

Class DINOPHYCEAE Fritsch, 1935

SPINIFERATE/GONYAULACOID

Cyst Genus *Spiniferites* Mantell emend. Sarjeant, 1970

Species *Spiniferites ramosus* Loeblich Jr. and Loeblich III, 1966

ST-5 slide 935m, coordinates: 5.9, 137.5

ST-6 slide 1855m, coordinates: 16.0, 139.5 (Plate 6, Image D)

Description: Species has spiny processes of variable lengths and sutural ridges that are attached at their bases. *Spiniferites* shows considerable differences in surface ornamentation.

Dimensions: Diameter of central body: (18-25) µ mean (20) µ.

Length of processes: (6-8) µ mean 6 µ

Number of species measured: 6

Cyst Genus *Glaphyrocysta* Stover and Evitt, 1978

Species *Glaphyrocysta divaricata* Williams & Downie 1966

ST-5 slide 995m, coordinates: 14.0, 141.6 (Plate, Image)

ST-6 slide 775m, coordinates: 8.5, 140.3 (Plate 6, Image G)

Description: Specimen has a lenticular to ellipsoidal shape and has no parasutural elements. Processes are formed by a smooth to scabrate autophragm and are joined distally a series of trabeculae. Species has some isolated processes. The mid-ventral and mid dorsal areas do not possess processes.

Dimensions: (18-23) x (25-30) µ average (20 x 28) µ.

Length of processes: (7-15) µ mean 13 µ

Number of species measured: 4

Cyst Genus *Adnatosphaeridium* Williams & Downie in Davey *et al.,* 1966

Species *Adnatosphaeridium multispinosum* Williams & Downie, 1966

ST-5 slide 1075m, coordinates: 8.3, 135 (Plate 6, Image C)

Description: Specimen has a spherical body and has numerous slender processes that branch out distally. These branched out processes tend to interlock distally. The processes are half the mean diameter of the total body length.

Dimensions: Diameter (27-33) µ mean 30 µ.

Length of processes: (7-12) µ mean 10.

Number of species measured: 4

Cyst Genus *Cordosphaeridium* Eisenack, 1963b emend. Morgenoroth, 1968

Species *Cordosphaeridium inodes* (Klumpp) Eisenack, 1963b

ST-5 slide 1075, coordinates: 15.0, 130 (Plate 6, Image E)

Description: the processes are intratabular, fibrous, and hollow and expand distally. The terminally flared funnel shaped processes are characteristic of this species.

Dimensions: Diameter (22-30) µ average 25 µ.

Length of processes: (8-10) µ mean 9 µ.

Number of species measured: 4

Cyst Genus *Cordosphaeridium* Eisenack, 1963b emend. Morgenoroth, 1968

Species *Cordosphaeridium multispinosum* Davey & Williams, 1966

ST-5, slide 995, coordinates: 10.5, 139.4 (Plate 6, Image F)

Description: This species has numerous, simple, short and parallel-sided fibrous processes. Processes are single or branched with slight expansion distally.

Dimensions: Diameter (20-30) µ mean 26 µ.

Length of processes: (6-10) µ mean 8 µ.

Number of species measured: 2

Cyst Genus *Odontochitina* Deflandre, 1935

Species *Odontochitina operculata* (Wetzel) Deflandre & Cookson, 1955

ST-5 slide 1835m, coordinates: 17.0, 132.3 (Plate 2, Image G)

ST-6 slide 1675m, coordinates: 14.2, 130.0 (Plate 2, Image I)

Description: This species is ceratoid in shape and possesses three long horns. One horn is at the apical end, the other at the antapical end and the third one possibly in the paracingular area. The horns are smooth to scabrate in nature.

Dimensions: (22-31) x (25-31) µ mean (26 x 27) µ.

Length of horns: (20-40) µ mean 29 µ. Width at base: (3-17) µ mean 11 µ

Number of species measured: 4

Cyst Genus *Oligosphaeridium* Davey & Williams in Davey *et al*., 1966

Species *Oligosphaeridium complex* (White) Davey & Williams, 1966

ST-6 slide 1675m, coordinates: 9.0, 132.8 (Plate 6, Image A)

Description: This species has intratabular processes that are open, serrated, expanded, and are often branched distally. *Oligosphaeridium complex* lacks paracingular processes. The central body is spherical and the rims of its processes bear long and pointy spines that are sometimes bifurcated. This species lacks paracingular processes.

Dimensions: Diameter of central body (21-28) µ mean 25 µ.

Length of processes: (8-14) µ mean 11 µ

Number of species measured: 4

PERIDINOID CYST

Cyst Genus: *Andalusiella* Riegel, 1974

Species *Andalusiella gabonensis* (Stover & Evitt) Wrenn & Hart, 1988

ST-5 slide 1555m, coordinates: 11.2, 141.0; slide1455m, coordinates: 7.2, 137.5 (Plate 4, Images J, B)

ST-6 slide 1795m, coordinates: 14.2, 129.6; slide 1795m, coordinates: 14.2, 129.6

Description: *A. gabonensis* has an antapical horn that is close to the base of the cyst body. The apical horn may be reduced. The shape of the central body is rhomboidal.

Dimensions: (38-50) x (25-35) µ mean (42 x 35) µ

Length of horn: (4-12) µ mean 9 µ

Number of species measured: 6

Cyst Genus *Senegalinium* Jain & Millepied, 1973

Species *Senegalinium bicavatum* Jain & Millepied, 1973

ST-5 slide 1395m, coordinates: 9.0, 145.7 (Plate 5, Image H)

Description: This species has a globose to spherical shape. The periphragm is thin and has a smooth surface, often with wrinkles. The species has an apical horn and two antapical horns that are discernible.

Dimensions: (35-38) x (35-40) µ mean (35 x 40) µ.

Length of horns: (5-8) µ mean 7 µ

Number of species measured: 3

Cyst Genus *Paleocystidinium* Alberti, 1961

Species *Paleocystidinium golzowense* Alberti, 1960

ST-5 slide 1895m, coordinates: 4.0, 148.8 (Plate 4, Image A)

Description: *P. golzowense* has an apical and antapical horn. Both horns are long and visible. *P. golzowense* lacks the antapical spine-like projection of *P. australinium*.

Dimensions: (38-42) x (25-30) µ mean (40 x 28) µ.

Length of horns: (10-15) µ mean 15 µ

Number of species measured: 4

Cyst Genus *Cerodinium* Vozzhennikova, 1963

Species *Cerodinium boloniense* (Riegel) Lentin & Williams, 1989

ST-5 slide 1335m, coordinates: 8.0, 145.4 (Plate 4, Image E)

Description: The body of *C. boloniense* is diamond shaped with straight sides and well developed short to moderately long apical and antapical horns. These horns tend to be broader and shorter relative to that of *Phelodinium tricuspis*.

Dimensions of central body: (35-43) x (34-40) µ mean (36 x 39) µ.

Length of horns: (4-9) µ mean 6 µ.

Number of species measured: 5

Cyst Genus *Cerodinium* Vozzhennikova, 1963

Species *Cerodinium diebelli* (Alberti) Lentin & Williams, 1987

ST-5 slide 1250m, coordinates: 22.5, 143.5 (Plate 4, Image D)

Description: This specimen has an elongate central body, with long apical and antapical horns.

Dimensions: (30-65) x (29-55) µ mean (50 x 45) µ.

Length of horns: (13-17) µ mean 16 µ.

Number of species measured: 5

Cyst Genus *Phelodinium* Stover & Evitt, 1978

Species *Phelodinium tricuspis* (Wetzel) Stover & Evitt. 1978

ST-5 slide 1395m, coordinates: 9.5, 143.0 (Plate 4, Image F)

Description: This species is characterised by its conspicuous protrusion in the precingular area. The paracingulum is indicated at the widest part of cyst by folds or transverse parallel ridges.

Dimensions: (45-48) x (50-54) µ mean (45 x 50) µ.

Length of horns: (14-18) µ mean 16 µ

Number of species measured: 3

DINOGYMNIOD CYST

Cyst Genus *Dinogymnium* Evitt, Clarke & Verdier, 1967

Species: *Dinogymnium acuminatum* Clarke & Verdier, 1967

ST-5 slide 1395m, coordinates: 9.0, 140.4 (Plate 2, Image D)

Description: The surface of the cyst body is ornamented with numerous longitudinal ridges that are straight and have pores. The acuminate nature of the proximal end of the hypocyst is what makes this species unique.

Dimensions: (24-28) x (16-18) µ (25 x 18)mean µ

Number of species measured: 5

Cyst Genus *Dinogymnium* Evitt, Clarke & Verdier, 1967

Species: *Dinogymnium undulosom* Clarke & Verdier, 1967

ST-5 slide 1555m, 13.5, 143.7 (Plate 2, Image E)

Description: This species is characterised by more closely spaced longitudinal ridges. The epicyst is slightly more elongate and pointed compared to the hypocyst.

Dimensions: (50-70) x (26-40) µ mean (57 x 32) µ

Number of species measured: 3

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATION

7.1 CONCLUSION

This study identifies and describes palynomorphs from sediments recovered from the ST – 5 and ST – 6 wells of the Tano Basin, Western Ghana. Based on the FAD and LAD of marker species, three (3) biozones each were erected using miospores and dinoflagellates for the wells respectively. The three zones correspond to an Albian-Cenomanian, a Campanian-Maastrichtian and a Paleocene age respectively. There are no representatives of the Turonian – Santonian sediments thus implying the presence of an unconformity between the Albian–Cenomanian and the Campanian-Maastrichtian sediments.

The Albian–Cenomanian sediments are characterised by the presence of elaterate pollen with scarce dinoflagellates which is indicative of deposition in a marginal marine environment under a warm, arid/semi-arid climate. The Campanian–Maastrichtian sediments are characterized by typical *Nypa* species such as *Proxapertites* and *Longapertites* that thrived in a coastal mangrove environment, under a hot tropical to sub-tropical climate.

The miospore assemblage of the Albian–Cenomanian horizons shows elements that are typical of the Albian-Cenomanian Elaterate Province of Africa and South America. The Campanian-Maastrichtian miospore assemblage observed are also typical of the Senonian Palmae Province.

The dinoflagellates of the Campanian–Maastrichtian sediments indicate that deposition took place in an environment that fluctuates between a marginal marine and open marine environment. These conditions were deduced based on the variations in the relative abundance of peridiniacean to gonyaulacoid cysts.

The peridiniacean assemblage observed in the Campanian–Maastrichtian sediments of the ST – 5 and ST – 6 wells of the Tano basin is dominated by *Andalusiella, Cerodinium, Senegalinium and Phelodinium.* These species are the constituents of the tropical – subtropical Malloy suite of Lentin & Williams (1980).

7.2 RECOMMENDATIONS

Geochemical data and complete well log data must be incorporated into future research in order to put the study in a better perspective and also further validate palynological results. Addition of complete lithology logs for the ST-5 and ST-6 wells would have helped put the results of this research in a better perspective so that it can be appreciated by others with very little palynological background. Results obtained from geochemical data (rock eval pyrolysis & Total Organic Carbon) analysis often have a positive correlation with results from palynological data. Thus in future research of this nature, lithology logs and geochemical data must be incorporated.

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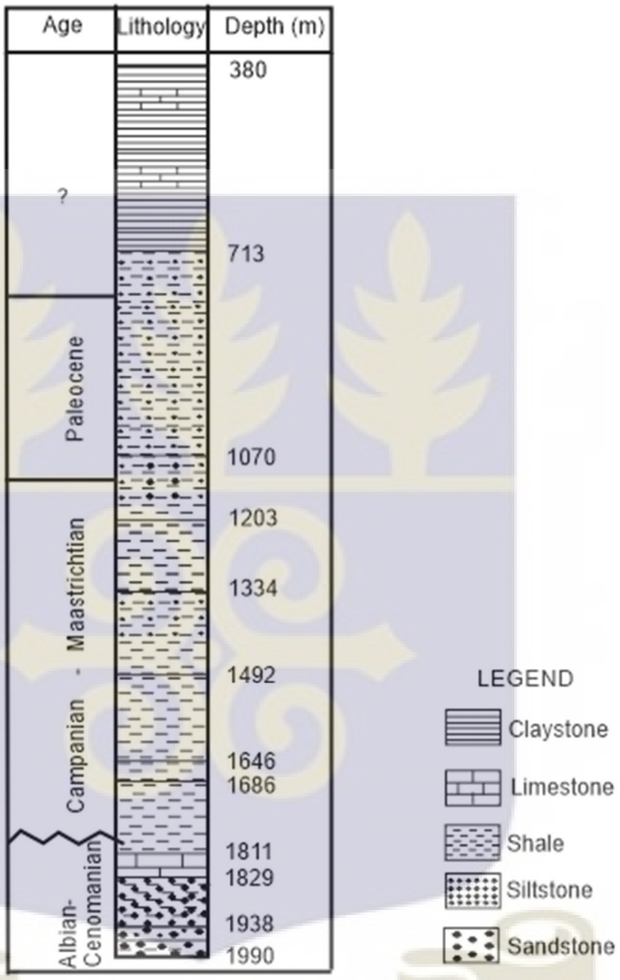
APPENDIX

APPENDIX 1 Stratigraphic section of the ST-6 well



PLATES

Plate1 Explanation

All photomicrographs were taken at a magnification of X400

Image A, F. *Elaterosporites klazii*

Image B, E, G, H. *Elaterosporites verrucatus*

Image C, D. *Elaterosporites protensus*

Image G, H. *Elaterosporites verrucatus*

Image I. *Elateropollenites jardinei*

Image J. *Ephedripites brasiliensis*

Image L. *Elaterocolpites castelaini*

PLATE 1

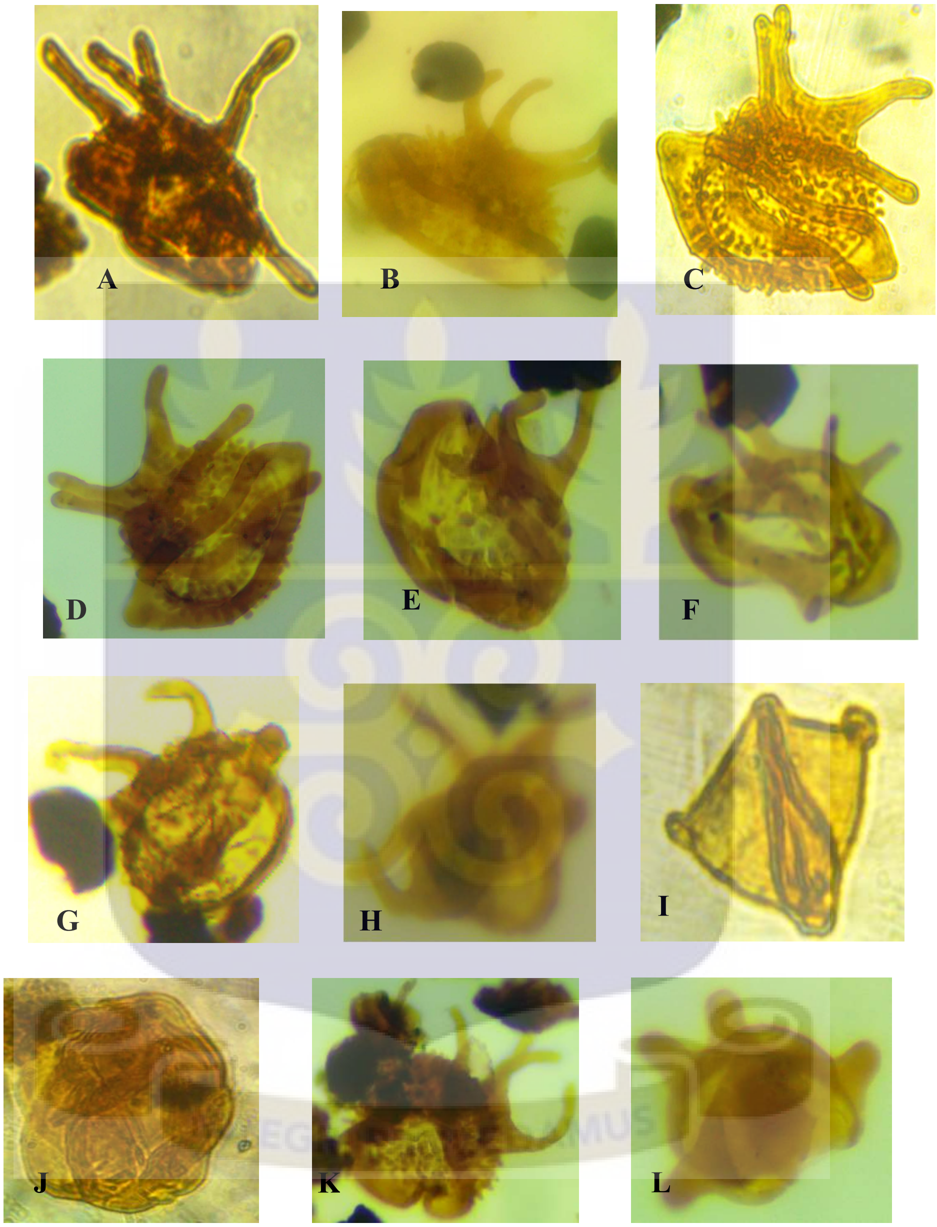


Plate 2 Explanation

Image A. *Dinogymnium spp*. 1

Image B. *Dinogymnium spp*. 2

Image C, E *Dinogymnium undulosum*

Image D, F. *Dinogymnium acuminatum*

Image G, H, I, J. *Odontochitina operculata*

PLATE 2

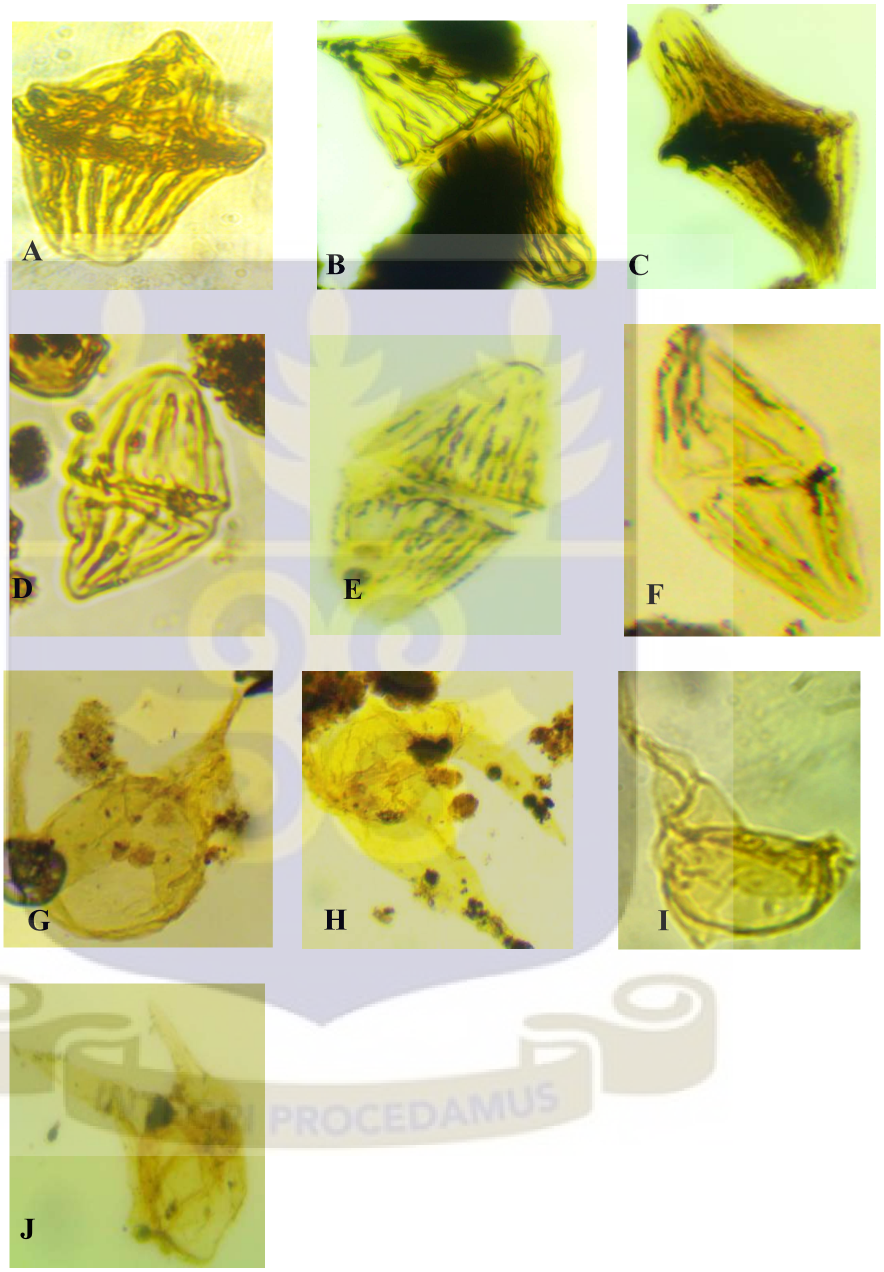


Plate 3 Explanation

Image A, B, E. *Glenchinidites senonicus*

Image C, D. *Cyathidites australis*

Image F. *Galeacornea causea*

Image G. *Elaterosporites klazii*

Image H, I. *Elaterosporites verrucatus*

Image J. *Foraminiferal test lining*

Image K. *Cicatricosisporites spp.*

Image L. *Ephedripites strigatus*

PLATE 3

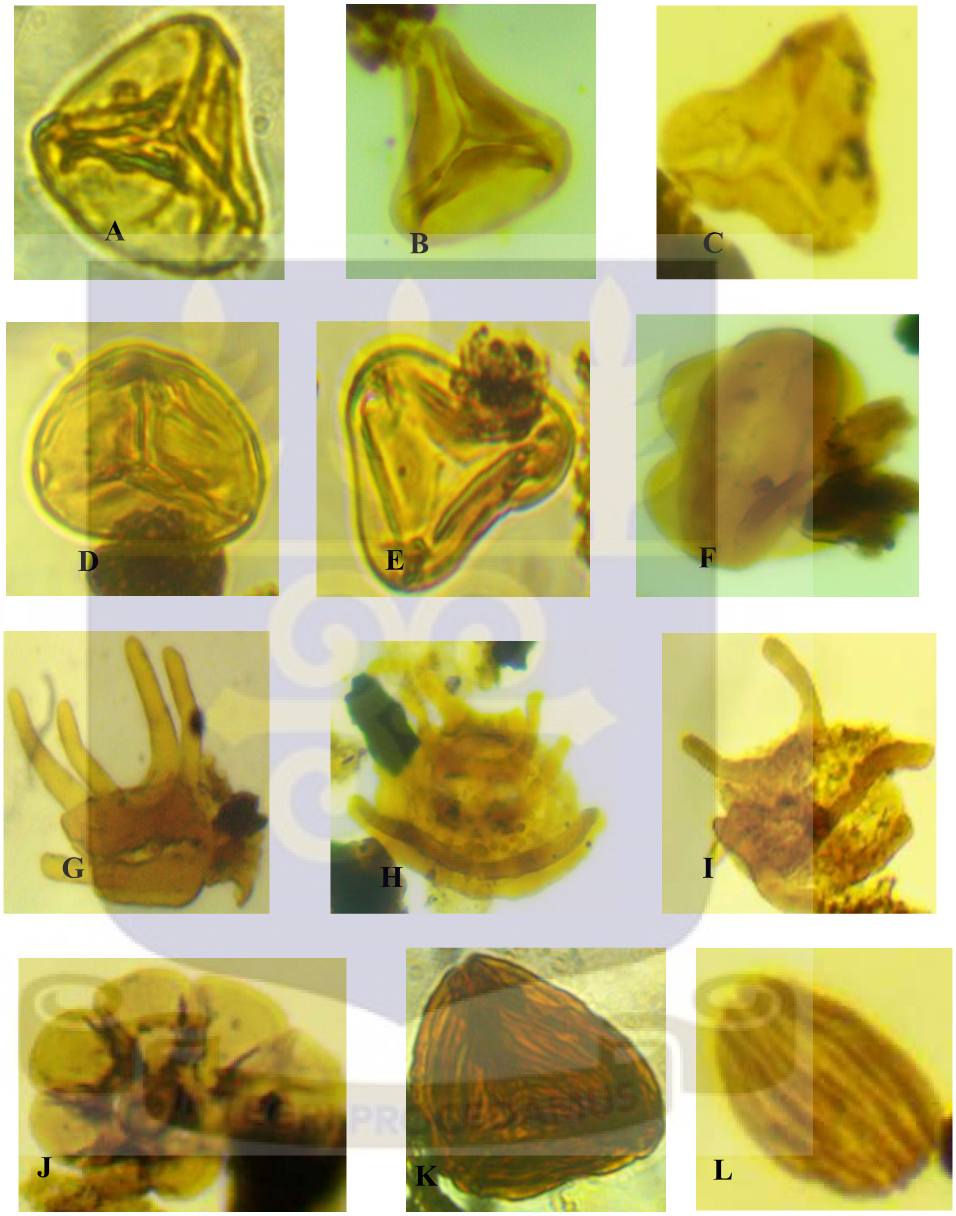


Plate 4 Explanation

Image A. *Paleocystidinium golzowense*

Image B, C, J. *Andalusiella gabonensis*

Image D. *Cerodinium diebelli*

Image E. *Cerodinium boloniense*

Image F. *Phelodinium tricuspis*

Image G, H, I. *Senegalinium bicavatum*

PLATE 4

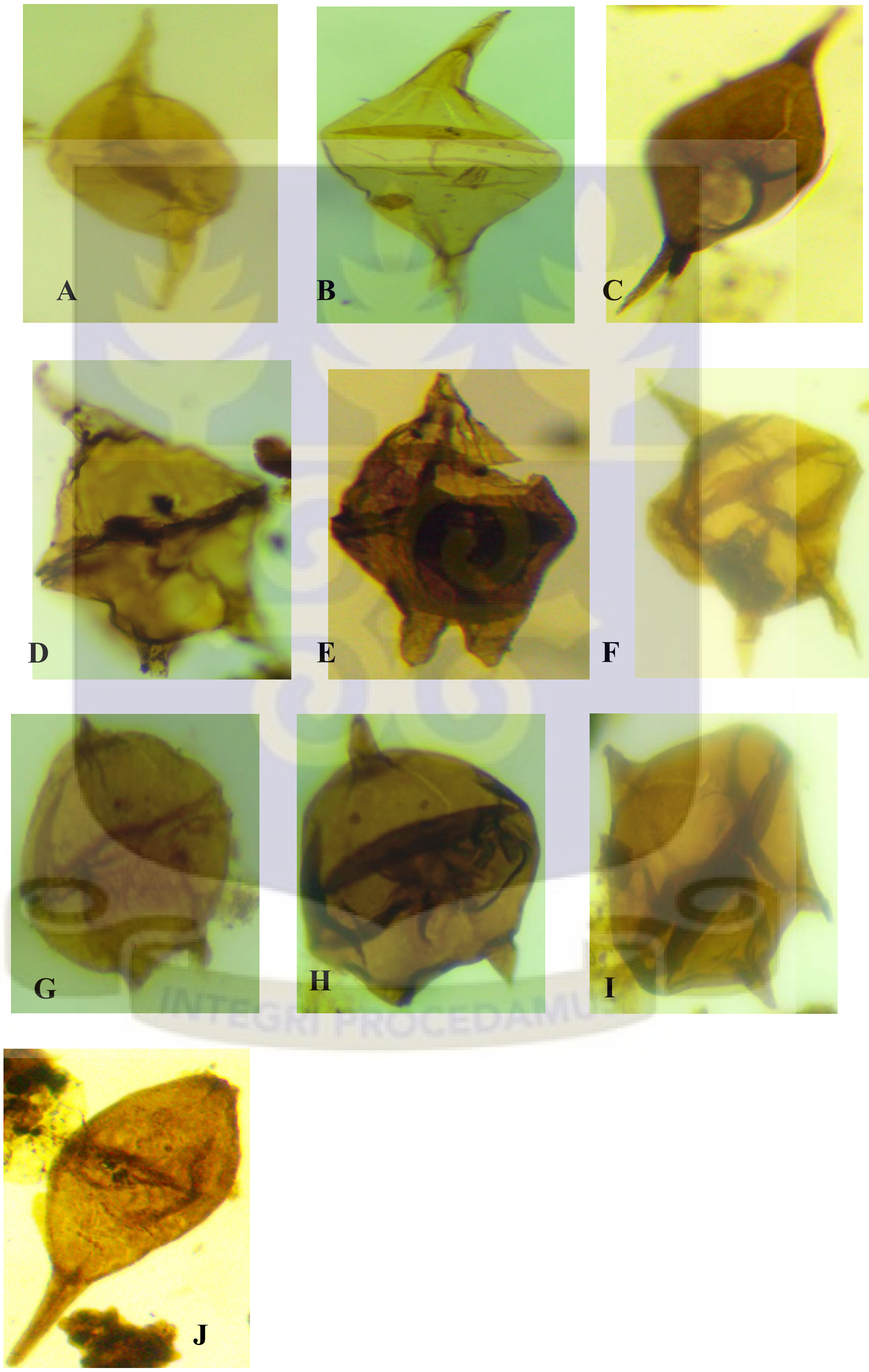


Plate 5 Explanation

Image A, B, C. *Buttinia andreevi*

Image D. *Spinizonocolpites echinatus*

Image E, F. *Cingulatisporites ornatus*

Image G. *Proteacidites dehanni*

Image H, I, L. *Proxapertites cursus*

Image J. *Longapertites spp.*

Image K. *Longapertites marginatus*

PLATE 5

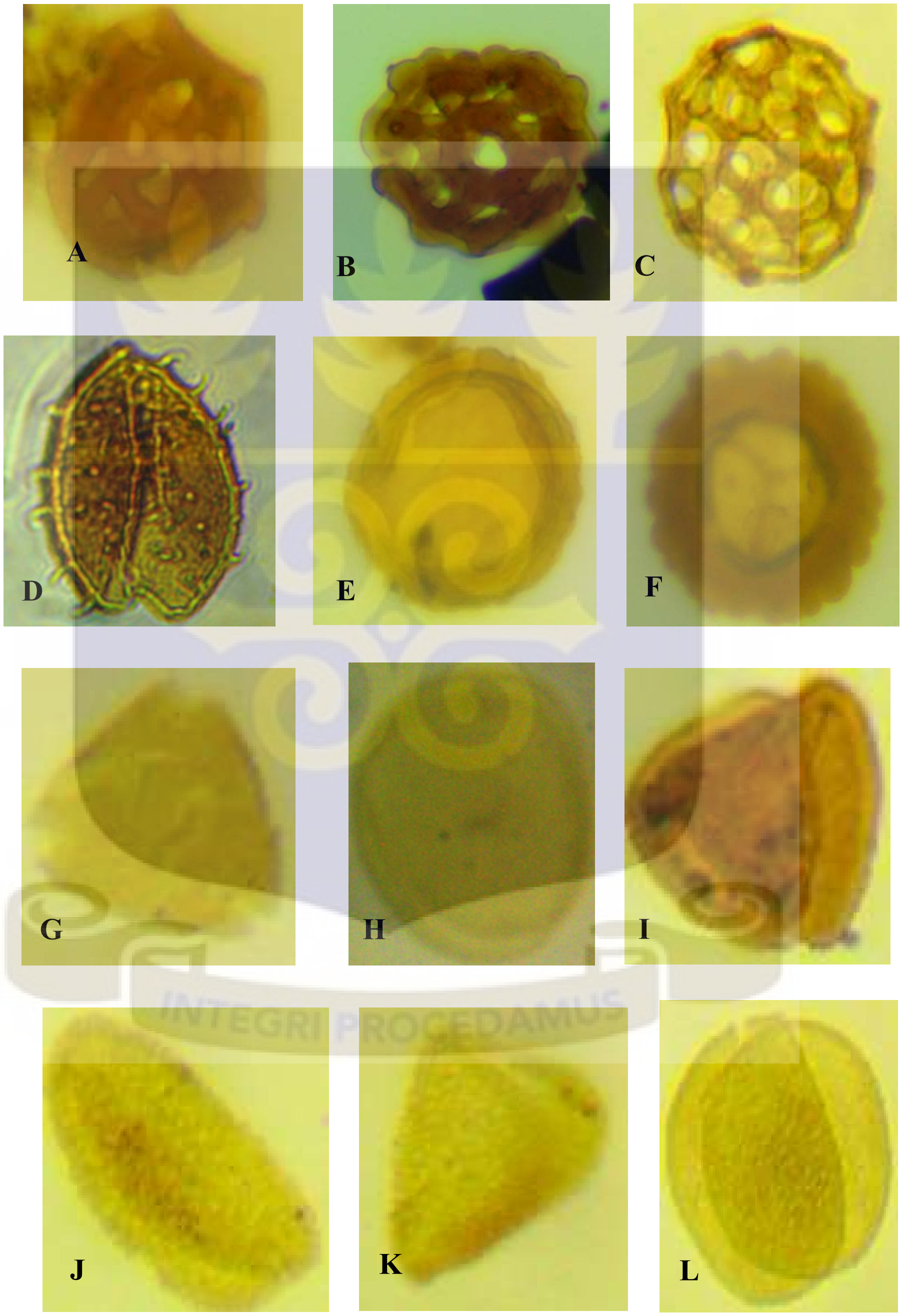


Plate 6 Explanation

Image A, B. *Oligosphaeridium complex*

Image C, H. *Adnatosphaeridium multispinosum*

Image D. *Spiniferites ramosus*

Image E. *Cordosphaeridium inodes*

Image F. *Cordosphaeridium multispinosum*

Image G. *Glaphyrocysta divaricata*

PLATE 6

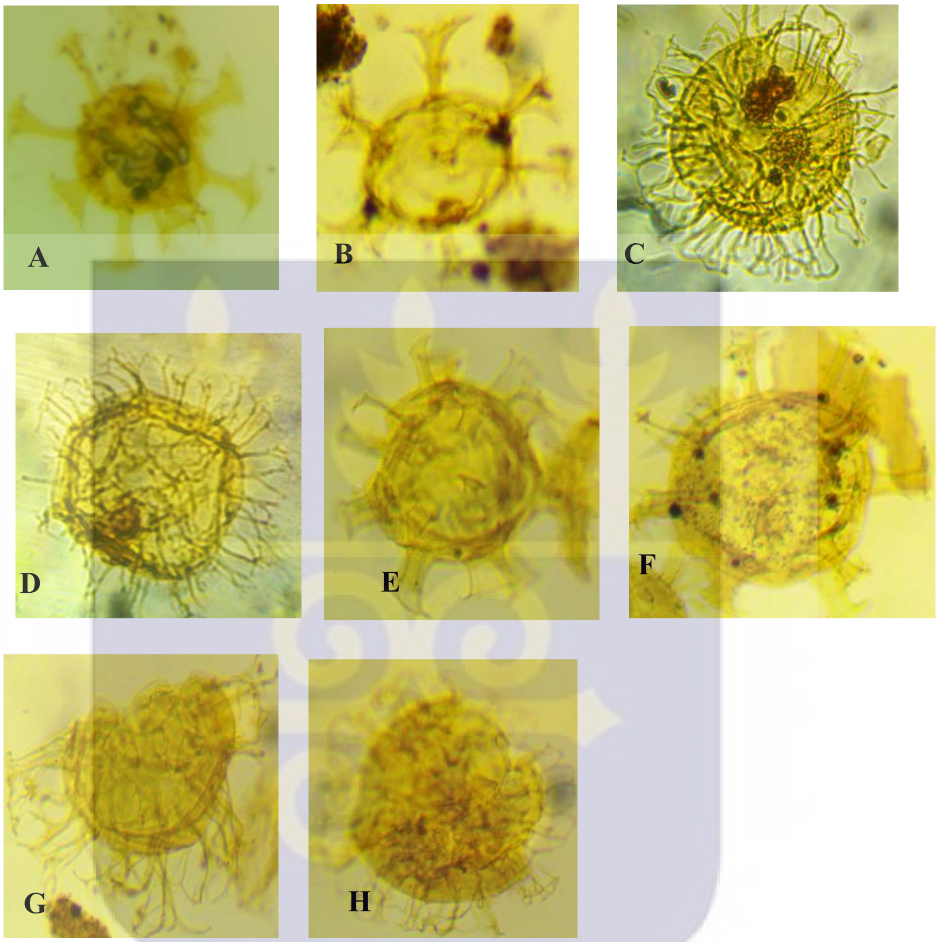


Plate 7 Explanation

Image A. *Ephedripites barghoornii*

Image B. *Steevesipollenites spp.*

Image C, D. *Cicatricosisporites spp.*

Image E. *Ephedripites spp.*

Image F. *Classopollis torosus*

Image G, H. *Foveotriletes margaritae*

Image I. *Retistephanocolpites williamsi*

Image J. *Deltoidospora spp.*

Image K. *Araucariacites australis*

PLATE 7