UNIVERSITY OF GHANA, LEGON

COLLEGE OF BASIC AND APPLIED SCIENCES

ALBIAN – CENOMANIAN PALYNOFACIES AND PALYNOSTRATIGRAPHY OF CTP-1 WELL, OFFSHORE TANO BASIN

BY

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JULY, 2015

DECLARATION

This is to certify that this thesis is the result of research undertaken by Obeng Marisca Nana Gyamfua towards the award of the Master of Philosophy Degree in Geology in the Department of Earth Science, University of Ghana.

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ABSTRACT

This study describes and identifies palynomorphs (spore/pollen and dinoflagellates) from different levels of the CTP-1 well succession in the offshore Tano Basin in order to establish palynostratigraphy of the studied sediments. The palynomorphs are used as an age tool for the sediments after comparison with other species or sediments reported from other parts of the world, especially the North Gondwana Province (ASA) region. Sedimentary Organic Matter is used to establish palynofacies assemblages to interpret paleoenvironmental and paleoclimatic conditions at the time of deposition, infer kerogen type and establish thermal maturity of the sediments of the succession to infer the hydrocarbon potential.

Based on the first appearance datum (FAD) and the last appearance datum (LAD) of stratigraphically important species, two miospore assemblage zones have been suggested for the sediments. The zones are *(I) The Elateropollenites jardinei- Ephedripites irregularis-Reyrea polymorphus* zone and *(II) The Elaterosporites protensus-Sofrepites legouxiae-Afropollis jardinei zone*. After comparison with similar assemblages from other parts of the world, the Albian-Cenomanian age has been suggested for the sediments.

Based on the similar microfloral assemblage observed from the Ghanaian assemblage to those of the Africa-South America (ASA) province, the paleofloral province suggested for the miospores of this study is the Albian-Cenomanian Elaterate Province.

Miospore assemblages indicate that deposition of the sediments took place in a semi- arid to arid climatic conditions in a coastal or nearshore environment. The dinoflagellate assemblage corroborates the environment of deposition as marginal marine/nearshore environment.

Four palynofacies associations (P-1, P-2, P-3, and P-4) have been identified under the following contortion. P-1 and P-2 are characterized by marginal dysoxic-anoxic basin and shelf to basin transition, P-3 is characterized by a distal suboxic- anoxic basin environment and P-4 is characterized by distal dysoxic-anoxic shelf and distal dysoxic-oxic shelf.

Thermal maturity based on exine colours of psilate spores (*Cyathidites*) indicates mature and immature organic matter of Kerogen Type II (oil prone) with TAI values of 2+, 3-, 3, 3+ and Type III (gas prone) with TAI values of 1+, 2-, 2 respectively.

DEDICATION

I dedicate this work to my future unborn kids and in memory of my grandmother, Madam Elizabeth Abban.

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My sincere appreciation goes to God Almighty for His grace and guidance from the beginning to the end of this study, my family for their moral support, to the Coordinators of the Capacity Building Project for the financial support, to the Core Laboratory of GNPC for the sample cutting slides, to Prof. David Atta- Peters and Prof. Asiedu for their patience, guidance, knowledge and impact upon my life, to Prof. Nude for his AmScope Toup view 3.2 digital camera, to Christopher Achaegakwo for his profound dedication and help and to Paa Kwasi Eduku, Gloria Senyah, Jennifer Agbetsoeamedo, Millicent Obeng Addai, Obed Fynn, Abigail Ayikwei and Daniel Kwayisi for their motivation and support. God bless you all.

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CHAPTER ONE

INTRODUCTION

1.1BACKGROUND

Ghana has four main sedimentary basins, three offshore and one onshore. These are the Keta Basin (mid Cretaceous-late Pliocene), the Saltpond Basin (Devonian), the Voltaian Basin (Neoproterozoic)) and the Tano Basin (Cretaceous) (Fig. 1).

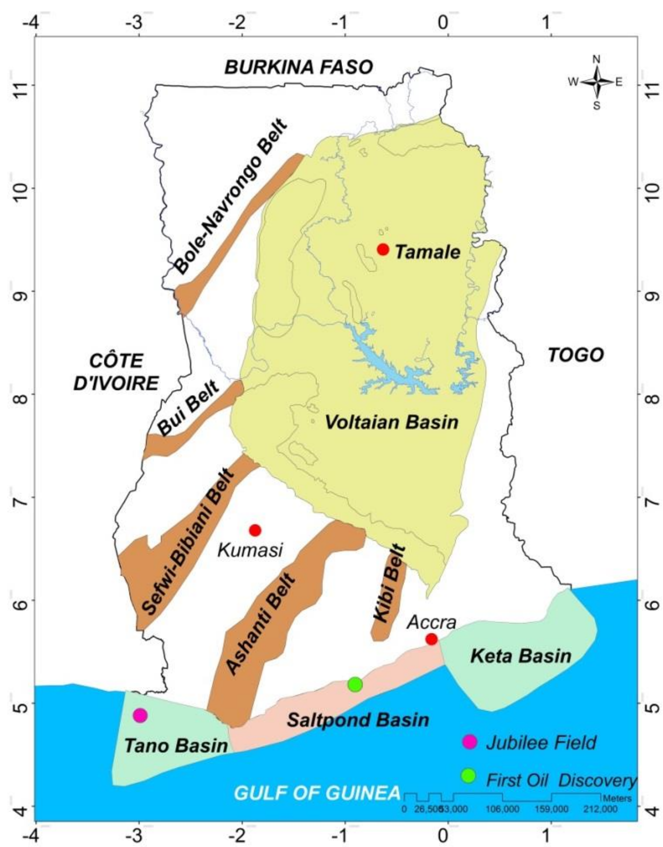


Fig. 1 The major sedimentary basins in Ghana

Hydrocarbon exploration set off in the late 19th century in the Western Region of Ghana. Deep offshore exploration started on the Tano Basin, south-western Ghana, in 1978 but it was precisely in 2007 that several important sedimentary fairways were set up in deep water.

Historically, the development of the country's hydrocarbon exploration can be grouped into four (4) distinct phases due to technological and political issues.

The First Phase (Onshore Exploration Phase) took place from 1896 to 1969 onshore the Tano basin due to finds of oil and gas seepages. Wells drilled at the time lacked seismic data back up and were based on little knowledge in the geology of the area. The West Africa Oil and Fuel Company (WAOFCO) drilled five wells (WAOFCO- 1, 2, 3, 4, and 5) between 1896 and 1903 of which WAOFCO-2 was the only successful well and as such the first well to be documented in the history of oil and gas exploration in Ghana. This well at a depth of 35m produced 5 barrels of petroleum per day (bopd) from 1896 to 1897. Between 1909 and 1913, Société Française de Petrole drilled the SFP-1, 2, 3, 4, 5 and 6 wells, all of which showed good signs of oil at shallow depths with SFP-1 well. However, striking oil to generate 7 bopd at 10-17m depth. AETC-1 and 2 were drilled by the African and Eastern Trade Corporation onshore Tano basin between 1923 and 1925. The wells produced heavy and light oil as well as gas at shallow depths. The Gulf Oil Company obtained the license for Onshore Tano basin and in 1956, the Kobnaswaso-1 and Epunsa-1 wells had been drilled. The Bonyere-1 and Kobnaswaso-2 were subsequently drilled in 1957.

The Second Phase (Onset of Offshore Exploration) took place between 1970 and1984. On 29th July, 1970 the Tano 1-1 well was spudded by the Volta Petroleum Company. The Tano 1-1 well which represented the discovery for the North Tano Oil and Gas Field on the Tano Basin, had good indications of gas shows. During 1972 to 1979, a total of seventeen wells were raised due to encouraging shows both onshore and offshore on the Tano Basin as well as Accra/Keta and the Voltaian basin. This led to a gas discovery by Zapata and Mobil Oil, offshore the Cape Three Points. The CTP-1 well was spudded in 1973 (Table 1, Fig. 2) followed by the 1S-1X well which was spudded in 1978 by Phillips Petroleum on the South Tano Oil and Gas Field. The South Dixcove-1X, offshore Cape Three Points indicated no shows upon drilling by Phillips Petroleum although geochemical data from the well showed the existence of a rich source rock.

Table 1- Wells drilled between 1973 and 1978 (Modified after Boateng, M.O., 2008)

WELL NAME	SPUD DATE	WELL TYPE	OPERATOR	LOCATION	BASIN	WD (FT)	TD (FT)
Dzita 1	24/05/73	Exploration	Diamond Shamrock	Onshore	Keta		13448
CTP 1	1/11/73	Exploration	Mobil/Zapata Expl	Offshore	Cape Three Points	338	13820
Amoco 10-4	23/10/74	Exploration	Amoco	Offshore	Saltpond		9020
Takoradi 6-1	12/2/75	Exploration	Amoco	Offshore	Cape Three Points	216	11544
Dixcove 4-2X	6/5/75	Exploration	Phillips Petroleum	Offshore	Cape Three Points	358	12491
Amoco 16-1	7/5/75	Exploration	Amoco	Offshore	Keta		11527
Komenda 12-1x	25/8/75	Exploration	Phillips	Offshore	Saltpond		9758
Premuase 1	2/7/77	Exploration	Shell	Onshore	Voltaian		1167.5
APG 10-1A	10/5/77	Development	AgriPetco	Offshore	Saltpond	86	8800
APG 10-A2	28/7/77	Development	AgriPetco	Offshore	Saltpond	86	9050
APG 10-A3	16/11/77	Development	AgriPetco	Offshore	Saltpond	86	9009
APG 10-A4		Development	AgriPetco	Offshore	Saltpond	86	9527
APG 10-A5	8/2/78	Development	AgriPetco	Offshore	Saltpond	86	9963
APG 10-A6	17/4/78	Development	AgriPetco	Offshore	Saltpond	86	9070
1S-1X	6/7/78	Exploration	Phillips Petroleum	Offshore	Tano	313	12000
South Dixcove 1X	15/11/78	Exploration	Phillips Petroleum	Offshore	Cape Three Points	2927	16000
1S-2X	22/12/78	Exploration	Phillips Petroleum	Offshore	Tano	366	10901

In 1979, gas and condensate finds were made from 1S-3AX well on the South Tano discovery and in 1981, 1S-4X was also drilled on the South Tano discovery. However, drilling ceased on the block due to the low commercial discovery and unavailable market for its associated gas. The same story was encountered with the 1N-1X 1N-2X wells drilled in 1980 and 1981 respectively. In 1984, Provisional National Defence Council laws (PNDC laws -64, 84 and 188) were enacted to accelerate Exploration and Production (E & P) in Ghana. PNDCL 64 established the Ghana National Petroleum Corporation (GNPC), PNDCL 84 established the legal and fiscal framework for the conduct of Petroleum Exploration and Production in Ghana and PNDCL 188 (the Petroleum Income Tax Law) provided a tax regime for petroleum E & P in the country.

The Third Phase which coincided with the inception of GNPC took place between 1985 and 2000. GNPC started its activities in 1985 and not only did it pioneer E & P activities but it also sought funds as a means to finance its activities such as the drilling of more wells and the training of personnel for the GNPC research Laboratory. GNPC funded the acquisition, processing and interpretation of the first 3D seismic data for the South Tano Field as means to step up the nation's exploration activities. Subsequently, the exploratory well ST-8 and two appraisal wells, ST-7H and ST-9H were drilled as part of the Integrated Tano Fields Development Project, generating power from the gas. Between 1989 and 199, wells drilled such as the Central Tano-1 (CTS-1), The North West Tano-1 (NWT-1) and the West Cape Three Points-2X (WCTP-2X) contained oil and gas but were of sub- to non-commercial quantities.

The Fourth Phase (Restructured and Refocused GNPC) started from 2001 and is still ongoing. It focused on its main function of enhancing E&P activities by companies in

Ghana in order to find commercial accumulations of hydrocarbon for the economic development of the country. By becoming investor friendly, GNPC attracted independent oil companies including Kosmos Energy, Tullow Oil, Hess Corporation, Anadarko and Sabre. In 2002, oil was discovered in the WT-2X well by Dana Petroleum Plc. The E&P companies shifted the their concentration from shallow water areas to deep water areas due to discoveries made in the region from results obtained from the four deep water wells drilled between 1999 and 2003 such as the 14ft column of light oil discovered by Hunt Oil from the WCTP-2X well. Subsequently, Kosmos Energy (block operator), Anadarko (technical operator), Tullow Oil and E.O Group struck a 312ft net column of high grade oil in the Mahogany Prospect from the Mahogany-1 and Hyedua-1 wells, West Cape Three Points Basin. The appraisal and development of the discovered Jubilee Field attracted nine offshore licenses and over 20 submissions from interested companies at the time. Between 1980 and 2005, a total of 40 wells had been drilled by various companies. This number increased to 70 wells, between 2007- 2012. Since 2013 until now, concentration has been on the Jubilee Full Field Development, The Tweneboa Enyenra and Ntomme Field Development, the Offshore Cape Three Points Development, the Mahogany Teak and Akasa Fields Development and the Hess Development. As it stands now, an average of 110, 000 bopd is what is being generated from the Tano Basin and there are plans to increase this value to 120, 000 bopd. The oil being generated from the basin currently has an API value of 36.5˚ meaning it is light and a sulphur content of 0.24% meaning it is sweet. The target of the Petroleum Industry of Ghana is to hit 120bopd. The increase in exploration activities in the offshore Tano Basin recently have led to the substantial discovery of oil and gas in commercial quantities.

The exploration activities have provided sediment samples from exploratory oil wells which contain abundant Sedimentary Organic Matter (SOM) and palynological data. SOM including palynomorphs have many applications. They (i) reflect paleoclimate conditions, (ii) contribute to the establishing depositional environments, (iii) help evaluate the potential of a given horizon as a source rock of hydrocarbon (Batten, 1981; 1996b) and (iv) assign ages to the sediments in the sedimentary basin.

Palynomorphs have been important in the resolution of a host of geological and biological problems: in coal seam correlation, biostratigraphy, and age determination; in source rock, provenance, paleoenvironmental, paleoecological, paleogeographic, phytogeographic studies; and in plant taxonomy, phylogeny and evolution. Inherent in these applications is an interdisciplinary approach in elucidating relationships between biological, geographical and chemical processes. They serve as a powerful tool for stratigraphic correlation, and for dating sediments via integration of marine and non-marine sequences.

Palynomorphs basically serve as a tool in the search of oil and gas since oil bearing strata is known to have strong organic micro fossil affinity. Sedimentary organic matter, when sufficiently buried under anoxic conditions, and at appropriate temperatures, leads to the generation of hydrocarbons. Thus, palynology is an important tool in petroleum reservoir pay zone characterization, evaluation and analysis.

Palynofacies analysis has been defined by Tyson (1995) as the palynological study of depositional environments and hydrocarbon source rock potential based upon the total assemblage of particulate organic matter (kerogen) which can be classified as Kerogen

Types I- IV based on composition. The four main constituents of kerogen according to the classification scheme proposed by Tyson (1993, 1995) are Palynomorphs, Phytoclasts, Opaques and Amorphous organic matter (AOM).

Thermal maturity can be inferred from the degree of thermal alteration of organic matter due to prolonged heating (Tissot and Welte, 1984) and serves as a means to determine hydrocarbon potential of the sediments.

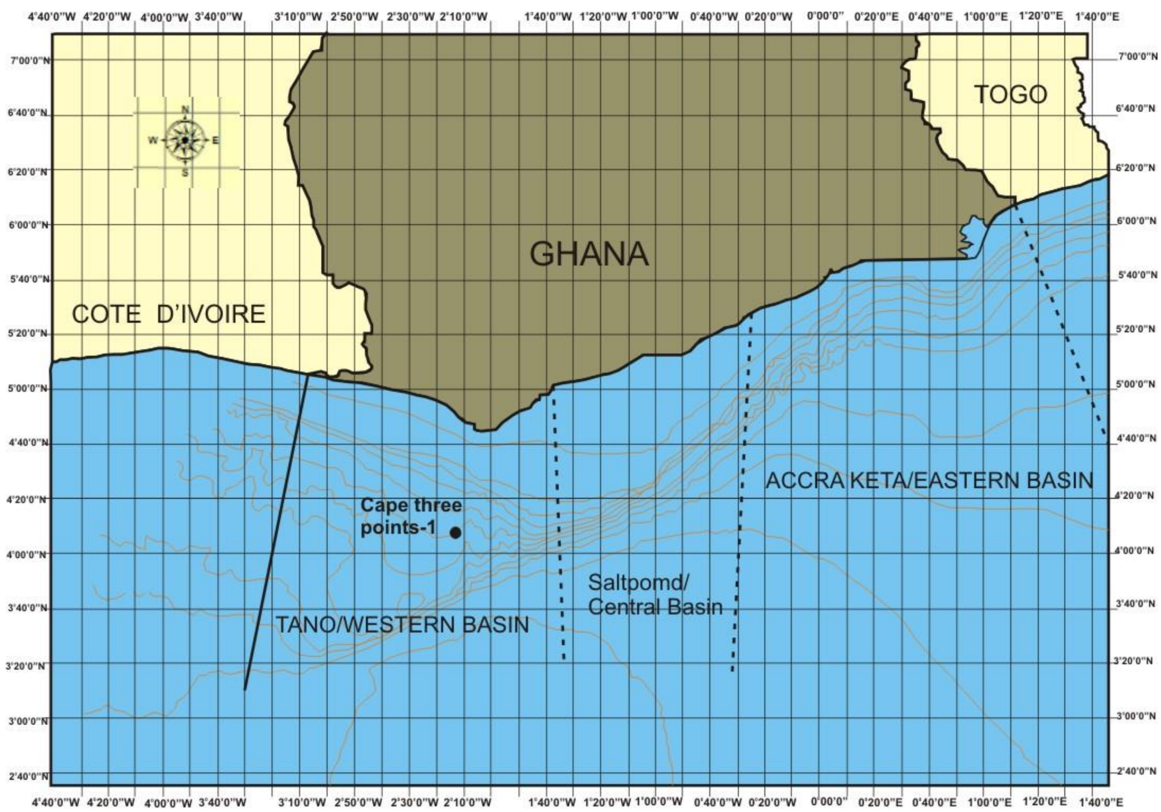


Fig. 2 Location map of CTP-1 well Offshore Tano Basin (Modified after GNPC Report, 2010)

1.2 PROBLEM STATEMENT AND JUSTIFICATION

Acquisition of 2D and 3D seismic data by GNPC has greatly improved the chances of identifying larger fault traps and hence larger reserves. Less interest has however been shown in the Micropalaeontogy and Palynology aspects of the basin as compared to data retrieved from seismic data as an interpretive tool for wells drilled on the basin .

Palynology is one of the techniques that can be adopted to subdivide and correlate subsurface sediments for more precise estimates of the oil and gas resources. Palaeontologic and well log data can be immensely helpful in selecting both sequence boundaries and especially condensed sections, which are characterized by high abundance and diversity of fossils and are often used as paleomarkers of time.

Seismic sequence stratigraphy involves the integration of tools including well logs, paleontology and geochemistry to the interpretation of seismic sections to provide information on facies, lithologies, stratigraphic ages, paleo water depths and paleoclimate and to derive a complete depiction of subsurface rock properties.

The integrated interpretive technique for both regional and prospect levels include the following tools; biostratigraphy with more accurate time subdivisions (for identifying critical sequence boundaries established on the global sea level versus time chart), identification of precise paleo water depths from microfossils (for determining depositional environments) and the use of the geochemical constituents of microfossils, such as oxygen isotopes, as additional indicators of paleoenvironments.

The assembly of an integrated graphical data display, including all of the above tools, tremendously enhances the confidence in deciphering the sequence stratigraphic record, and assessing potential producing zones in terms of source rocks, seals and potential reservoir traps.

The input of biostratigraphic information is essential to a successful sequence stratigraphic interpretation and reduces the risks in exploring for hydrocarbons.

Knowledge of paleoecological changes is helpful in determining suitable levels for petroleum or hydrocarbon generation and accumulation.

Detailed paleontological and palynofacies work is rarely done during exploration of wells. Only surfaces are picked for age purposes using the identified palynomorphs.

This research will address biostratigraphy as a required tool in making accurate deductions and predictions from the succession. This study will show a combined detailed work on palynostratigraphy, palynofacies assemblages for palaeoenvironmental purposes and the evaluation of the hydrocarbon potential for the CTP -1 well succession.

1.3 AIMS AND OBJECTIVES

The main aims and objectives for studying palynomorphs and SOM from the CTP 1 well, Tano Basin are as summarized below:

- To describe and identify palynomorphs (spore/pollen and dinoflagellates) from different levels of the well in order to establish palynostratigraphy.
- To use palynomorphs as an age tool for sediments after comparison with other species or sediments reported from other parts of the world, especially the North Gondwana Province, (ASA) region.

- To establish palynofacies assemblages to interpret paleoenvironmental and paleoclimatic conditions at the time of deposition.
- To establish thermal maturity of the sediments of the succession to infer the hydrocarbon potential.

1.4 SCOPE AND LIMITATIONS

This study adopts the use of miospores as a means of establishing palynostratigraphy, as an age tool and and for determining the paleofloral province and paleoclimate. The study also adopts the use of the relative abundances of palynomorphs, opaues, phytoclasts and AOM of the sediments to generate palynofacies associations, to establish paleoenvironments and to infer the Kerogen Types. For a concrete analysis on the hydrocarbon potential of the sediments of the CTP-1 well, geochemical data should have been incorporated into the study. However, this well does not have geochemical data, hence a limitation. Another limitation for this study is that a lithological log was not generated at the time the well was spudded in 1973.

1.5 GEOLOGY AND TECTONICS OF THE TANO BASIN

The Tano Basin extends from the southwestern portion of Ghana to the southeastern corner of Côte d’Ivoire. The Tano Basin occupies an area of at least 3000 km^2, with the onshore component estimated at about 1165 km^2 (Kesse, 1985). The Tano structure is located approximately 39km from the Ghana coast and approximately 24km east of the Ghana-Côte d’Ivoire (CIG) border, with a water depth in the area ranging from 91m to

125m (Atta-Peters and Kyorku, 2013). The Gulf of Guinea Province as defined by the U.S. Geological Survey (USGS) consists of the coastal and offshore areas of Côte d'Ivoire, Ghana, Togo, and Benin, and the western part of the coast of Nigeria, from the Liberian border east to the west edge of the Niger Delta. The province includes the Ivory Coast, Tano, Saltpond, Keta, and Benin Basins and the Dahomey Embayment.

The Tano basin is located between Ankobra River to the east and to the west by the Tano River. Kesse (1985) described the Tano Basin as being a portion of the crescent shaped basin along the coast of the Atlantic Ocean. The St. Paul transform fault zone to the east and the Romanche transform fault zone to west mark the boundaries of the Tano basin (Fig.3).

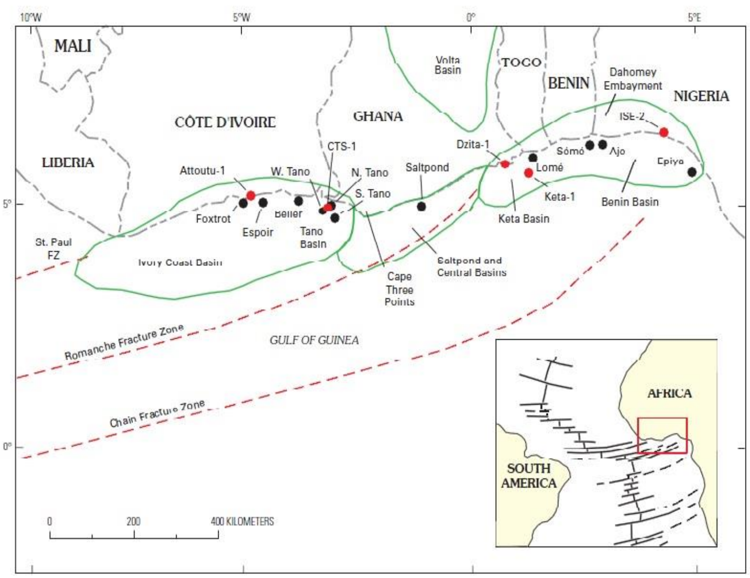


Fig.3 Tano Basin within the St. Paul and Romanche transform fault zones (modified after Brownfield and Charpentier, 2006).

Kitson (1928) reported that the rocks of the Tano Basin are part of the Apollonian System of Cretaceous age and consist mainly of limestones with alternating clays and sands.

Junner (1940) reported that the limestones were fossiliferous and were 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 Pre-Cambrian metamorphosed rocks of mainly schist, phyliite and greywacke of the Birimian system form the Basement rocks of the Apollonian rocks. Onshore Tano basin, the sediments are predominantly clays, sands and limestone with a general SSW dip direction and low dip angles. At depth, these sands and clays compact to form sandstones and shales. The fossiliferous limestones are overlain by recent to Tertiary deposits of sands, clays and laterite. Cox (1952) reported that the limestones and clays have yielded well preserved molluscan specimens of *Plicatula* and *Venericardia* of Campanian-Maastrichian age.

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 about 130km long.

The three main tectonic phases of the Tano Basin is as follows:

- Pre-Rift represented by Precambrian to late Jurassic rocks
- Syn-Rift phase with sediments of early Cretaceous age. The end of the syn-rift stage is delineated by a major unconformity which separates it from the marine post-transform rocks of the uppermost Albian and Cenomanian.
- Post-Rift phase of marine Cenomanian to present day.

Rifting initiated by the complex movements as a result of the separation of the African and South American continental plates commenced the formation of the Tano Basin in the Barremian and Aptian times. As a basin initiated by extensional rifting, the basin was modified by wrench tectonism. Davies (1989) reported that movement along a series of transform faults including major east- west oceanic transform faults in the Romanche Fault Zone and the St. Paul fracture zone during the continental separation led to the development of the large rift basin in the Tano area of Ghana. These movements resulted in the formation of the rift basin around the Aptian - Early Albian time. Davies (1989) reported that the separation of the continents took place in latest Albian. A thermal anomaly with subsequent uplift took place in the late Albian time at the margin of the new African and Brazilian continental plates in the Tano area (Atta-Peters, 2013). By Middle - Late Albian times, there was the widespread deposition of shallow marine sandstones with shales and minor limestone in the area.

Larmarche *et al.* (1997) in Atta- Peters and Salami (2004) 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 makes up the components of the CIG sedimentary wedge. These are dark clays, yellowish siltstones and interbedded greenish fine sandstone with grey coarse sandstones and micro conglomerates. These syn-rift sediments have been assigned shallow marine deltaic environment of deposition of probable early Cretaceous age.

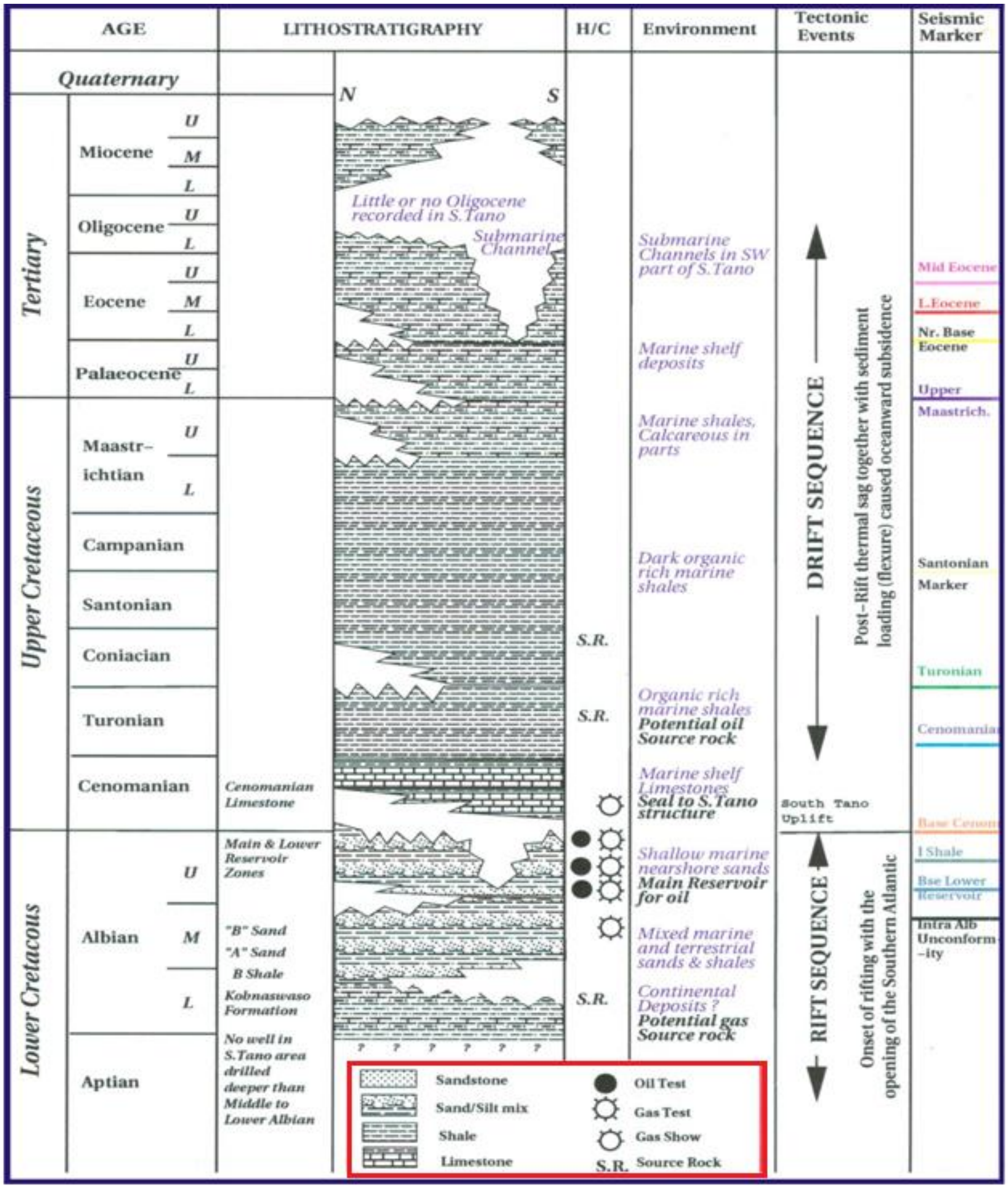
The basin accumulated thick Upper Cretaceous, deepwater clastic sequence in combination with a Tertiary section, provided sufficient thickness to mature an Early to Mid-Cretaceous source rock in the central part of the Tano Basin. This reservoir and charge fairway formed the play which, when draped over the large plunging South Tano high resulted in the formation of numerous trapping geometries that resulted in the the Jubilee and Odum accumulations, and along with other prospects (Daily, P. *et al*., unpublished)

1.6 STRATIGRAPHY OF THE TANO BASIN

Khan (1974) after studying a borehole from the Tano Basin came up with the following conclusion:

- The maximum thickness of the sedimentary rocks in this basin is more than 3048m along the coast and towards the Côte d'Ivoire border
- The oldest rocks met in the boreholes are of Middle Cretaceous age.
- The maximum depth of marine rocks is about 1768m
- An angular discordance 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 2- The General Stratigraphy of the Tano Basin (After: GNPC, 2004)



The stratigraphy of the Tano Basin as reported by GNPC (2004) is summarized in Table

Detailed descriptions are as follows:

1.6.1 Late Cretaceous Section

1.6.1.1 Kobnaswaso Formation (Lower Albian)

This formation is composed of mainly sandstones and shales. The estimated depth is about 4,270meters. The proposed age for these sediments is Lower Cretaceous (Albian) to Jurassic.

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

The Jurassic intrusives mark the onset of rifting in the Gulf of Guinea. Regional seismic surveys indicate thick and different sedimentary wedges within the Kobnaswaso interval; characteristic of rift basin deposits.

1.6.1.2 Bonyere Formation (B-Shale)

The roughly 200m thick Bonyere Formation is the most important strata within the Tano Basin because it can be correlated throughout the whole basin. The lithologies here are dark grey- blocky shales with a few siltstones. Davies (1989) assigned a Middle Albian age to the B-shale strata. These transgressive shales overlie the Kobnaswaso unconformably. The shales serve as a good seal and possibly, source rocks of hydrocarbons within the Tano Basin.

1.6.1.3 Middle to Upper Albian

The shallow marine deposits are mainly composed of sandstones, shales and minor limestones. In the South Tano area, these rocks show a coarsening up sequence of about 600meters thickness. The Upper Albian sandstones were deposited in a near shelf, inter tidal bar and probably a delta front environment (Table 2). The South Tano oil field reservoir is Upper Albian, while the gas field in North Tano is Middle Albian. The middle Albian deposits are of a lacustrine depositional environment and are large 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. The Cenomanian strata are generally flat lying and serve as a cap rock over the steeply dipping, faulted Lower Cretaceous strata. The Cenomanian strata represent a period of local shallow water shoaling which preceded the major transgressions of the Upper Cretaceous and Tertiary times.

1.6.2 Upper Cretaceous Section

1.6.2.1 Cenomanian Limestones

The Upper Cenomanian section consists of the thickest limestone accumulations in the area interbedded with a number of shales, claystones, siltstone and fine sandstone beds. The limestone is partly mottled, slightly argillaceous and chalky. Although laterally continuous, the section has variable thicknesses. The Upper Cretaceous to recent sediments consist of an offshore dipping sedimentary wedge with an increase in thickness from 1,500 metres in the North Tano area to approximately 3,700 metres offshore at South Dixcove 1X.

1.6.2.2 Turonian to Upper Santonian

The lithologies of the Turonian to Upper Santonian section are medium brownish-grey shales and claystones, with occasional dolomite or limestone. Its thickness is about 280 meters. The Turonian also contains a significant portion of the source rock responsible for the Jubilee Field oil. Most deep water reservoirs of commercial importance are in the Turonian in the Jubilee field, Twenebuah field, etc.

1.6.2.3 Campanian

The Campanian interval averages over 276 meters over the South Tano area and was formed under conditions of rapid subsidence of a short time span. This shale-rich interval has occasional stringers of dolomite and limestone. In the deep water area, fields such as Teak, Odum have Campanian reservoirs.

1.6.2.4 Maastrichtian

This thin interval is an indicator that during the late stages of the Upper Cretaceous, subsidence slowed. It is dominantly claystone with occasional thick, highly porous sandstone and dolomite beds with the upper parts being fossiliferous. Although the Maastrichtian section appears to lie above the oil maturation window, numerous oil shows have been reported from the sandstones. It may be that either oil has migrated upward through faults into the Maastrichtian, or oil has been generated at very low maturation levels, or that the Maastrichtian sediments may be found in oil mature deep basinal areas that flank the southwest and northeast sides of the North Tano high.

1.6.3 The Tertiary Section

1.6.3.1 Paleocene, Eocene, Oligocene and Miocene

The Middle and Lower Eocene stratigraphic section consists of finely laminated dark grey/brown claystones with thin beds of fossiliferous dolomite and fine sandstone.

Large portions of the Paleocene, Upper Eocene and Oligocene section are either only present as a thin bed or completely absent. Seismic data from the southern area show the presence of a number of Oligocene to Miocene submarine channels that have removed large amounts of the Eocene section.

Miocene sedimentary rocks found are described as predominantly brown-grey coloured 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.

1.7 PREVIOUS PALEONTOLOGICAL, PALYNOSTRATIGRAPHICAL, PALYNOFACIES AND HYDROCARBON POTENTIAL STUDIES CARRIED OUT ON THE TANO BASIN.

Kitson (1928) reported the occurrence of Upper Cretaceous rocks which he termed the ‘Appollonian System’ based on the evidence of ammonite cast and other fossils along part of the Gold Coast. The fossils were collected by Lamb and Junner from Bonyere, in the south-west area (Cox, 1952).

Riedel (1932) based on the molluscan specimen *Plicatula* reported rocks from Twenani, Cameroon as Campanian-Maastrichtian and the molluscan *Venericardia* from Nauli, Gold Coast also as an indication of Campanian-Maastrichtian age for the rocks of the area.

Cox (1952) suggested a Maastrichtian age based on the presence the ammonite genus *Libycoceras* at north-east Klenomadi, south-eastern Gold Coast.

Cox (1952) suggested a Cenomanian age at North –north-east of Bonyere and in the Anwiafutu localities based on the imperfect preservation of molluscan moulds with few gastropods and abundant *Plicatula auressensis* and the absence of ammonites in the limestone.

Cox (1952) based on the presence of abundant lamelibranchs and occasional gastropods in the limestone beds, two fossiliferous shelly rock, separated by clay containing pyritized Mollusca, assigned a Campanian-Maastricthian age to the North of Bonyere, north-west and north Nauli localities. The presence of the ammonite genus *Texanites* of later forms characteristic of Campanian age was identified in the clay and associated limestones (Cox, 1952).

Atta-Peters and Salami (2004), recovered miospores dominated by angiospermic pollen with trilete and monolete pteridophytic spores from the ST-8 well, offshore Tano Basin. The monosulcate pollen recovered were *Spinizonocolpites, Proxapertites, Longapertites* and *Mauritiides* of late Cretaceous and Lower Tertiary pollen assemblage, which fit well into the palmae and belong to the tropical-subtropical Senonian Palmae Province Province of Africa, South America and India (Herngreen and Chlonova, 1981) which suggest a mangrove environment of warm and humid climate (Atta- Peters and Salami, 2004).

Rull (1997) and Germeraad et al. (1968) in Atta-Peters and Salami (2004) have said that the presence of *Laevigatosporites*, *Pachydermites diederexi*, and *Verrucatosporites usmensis* indicate a swampy fresh water or brackish water environment. The miospore association, together with fungal and algal spores, provided evidence of freshwater swamp or marsh environment (Atta-Peters and Salami, 2004). Atta-Peters and Salami (2004) indicated a Campanian to Eocene age for the well ST-8 palynomorph assemblage based on the data recovered.

Atta-Peters and Salami (2006) recovered Cretaceous dinoflagellate cyts and miospores from the Tano 1-1 and 1S-3AX wells, offshore, Western Ghana.

Based on maker palynomorphs; *Afropollis jardinus, Elaterosporites klaszii, Elaterocolpites castelainii, Sofrepites legouxae, Reyrea polymorphus,* and *Cyclonephelium vannophorum* recovered from the Tano 1-1 well, an Aptian-early Cenomanian age has been assigned to the sediments of this well. The palynomorphs observed were elements of the Albian-Cenomanian Elaterate Province and suggested a warm tropical climate. Paleoenvironmental interpretation based on the identified palynomorphs indicated that the Aptian-Lower Cenomanian sediments were deposited in a marginal marine environment with vegetation on wetland, under relatively dry climate. Atta- Peters and Salami (2006) displayed a palynostratigraphy based on the palynomorphs into Aptian (Tano 1-1 samples 13,460-12,400ft), Albian (Tano 1-1 samples 12,200-7,760ft), and Lower Cenomanian (Tano 1-1 samples 7,540-3,990ft) for the Tano 1-1 sediments. The Aptian zone was recognized based on the presence of smooth pollen grains (Doyle *et al*., 1977) and the absence of elater-bearing pollen and Afropollis jardinus.

From the well 1S-3AX, Atta-Peters and Salami (2006) recovered the palynomorphs *Auriculiidites reticulatus, Spinizonotriletes echinatus, Buttinia andreevi, Longapertites spp.,* and *Echitriporites trianguliformis,* which are typical elements for the Campanian-Maastrichtian. These palynomorphs fit into the late Cretaceous Senonian Palmae Province which also supports a warm tropical climate.

Paleoenvironmental interpretation based on identified palynomorphs indicated that the Campanian-Maastrichtian sediments suggested a fluctuation between marginal to open marine (inner shelf) conditions (Atta-Peters and Salami, 2006). The palynostratigraphy displayed by Atta-Peters and Salami (2006) showed that 1S-3AX palynomorph samples from 6,400-4,200ft were of Campanian-Maastrichtian age.

Atta-Peters (2013) worked on the Elater bearing forms from the 1S-3AX well. The sediments from the well were assigned Albian-Cenomanian age based on the palynomorph assemblage.

The associated plant fossils (*Classopollis, Ephedriods*) with the elaterates from the 1S-3AX well (Atta- Peters, 2013) suggest that a hot-arid to semi-arid climatic condition must have prevailed during the deposition of the Albian-Cenomanian sediments in the Tano Basin. The presence of Afropollis from the well was suggested to infer humid conditions prevailed in Ghana during the Albian-Cenomanian time.

Atta-Peters *et al*. (2012) carried out palynostratigraphical and Palynofacies analyses on the Bonyere Well No. 1 in the onshore Tano basin, Western Ghana. The palynostratigraphy displayed Campanian-Maastrichtian, Turonian –Lower Senonian and Aptian zones based on marker palynomorphs.

The Campanian – Maastrichtian zone was identified based on the presence of *Proxapertites spp, Longapertites spp,Echitriporites triangulifromis, Spinizocolpites echinatus, Proteacidites dehaani, Glencheniidites, Retitricolpites sp, Cyathidites australis, Zliviporis blanensis, Ephedripites spp, Triporites sp*, and *Deltoidspora spp*.

The Turonian – lower Senonian (Santonian) zone was identified based on the presence of *Droseridites senonicus, Zlivisporis blanensis, Ephedripites spp, Tricolpites, Cretacaeisporites sp., Echitriporites trianguliformis* and *Hexaporotricolpites sp.*

Aptian zone was identified based on the presence of *Araucariacites spp, Cicatricosisporites spp, Tricolpites, Classopollis classoides, Ephedripites spp, Afropollis jardinus, Reyrea polymorphus,* and *Perotriletes pannuceus.*

Based on the absence of elater bearing palynomorphs (Albian-Cenomaian), Atta-Peters et al., (2012) suggested an unconformity between the Aptian and Turonian sediments.

Atta-Peters et al. (2012) identified five palynofacies assemblages (I-V) based on the percentage relative abundances of the sedimentary organic matter. The identified palynofacies reflected brackish, distal dysoxic-anoxic shelf, proximal dyoxic-suboxic, fluvio-deltaic/nearshore environments with high oxygen levels and low preservation rates respectively.

Data recovered by Atta-Peters and Kyorku (2013) assigned an Aptian to Cenomanian age based on recovered marker palynomorphs from the the Dixcove 4-2x well offshore Cape Three Points in the South Tano Basin. The Aptian interval for the well was based on the presence of *Afropollis jardinus, Cybelosporites pannuceus, Reyea polymorphus, Ephedripites spp*., *Cicatricosisporites*, *Appendicisporites*, *Deltoidspora*, *Cyathidites*, and *Concavisporites* (Atta-Peters and Kyorku, 2013). *A. jardinus*, has been reported on the world record as a stratigraphic marker for the early Aptian age for regions in equatorial Africa (Doyle *et al*., 1977). The Albian-Cenomanian interval was based on the presence of the elater bearing forms and associated taxa (Atta-Peters and Kyorku, 2013). Elater-bearing pollen is stratigraphically restricted to the Albian – Cenomanian sediments in the Africa South America (ASA) region (eg. Herngreen et al., 1996; Jardine & Magloire, 1965; Herngreen, 1975; Atta-Peters, 2006). The presence of *Afropollis jardinus*, *Classopollis* spp, *Ephedripites* spp, Elaterspores and the pteridophytes *Cicatricosisporites*, *Deltoidspora*, *Cyathidites* etc) suggested a paleoenvironment with parent plants inhabiting wetlands in a humid, warm coastal plain in a semi-arid climate (Atta-Peters and Kyorku, 2013).

Atta-Peters and Kyorku (2013) also identified five palynofacies types (P-I to P-V) for the succession from the Dixcove 4-2x well, Offshore Cape Three Points, South Tano Basin. Palynofacies types P-I and P-IV suggested proximity to a fluvio-deltaic source in a moderately dysoxic environment, P-II reflected a proximal (pro delta) dysoxic- suboxic environment, P-III was indicative of deposition in an oxidizing condition in proximity to terrestrial sources and P-V was attributed to deposition resulting from high rate and low energy dysoxic-anoxic condition in marginal marine environment. Atta-Peters and Kyorku (2013) identified wet gas and condensate generative potential for sediments of the Phytoclast group and oil with little or no potential of commercial source for sediments of the AOM group based on thermal maturity of the kerogen in the sediments.

Atta -Peters et al. (2015) established five palynofacies associations (I-V) from samples of the ST-7H well, Offshore Tano Basin, based on the percentage relative abundances of the sedimentary organic matter. Palynofacies type I and type IV reflected a dysoxic-anoxic shelf (nearshore) depositional environment. Palynofacies type II reflected distal dysoxic to anoxic shelf to deep basin environment with abundant AOM. Palynofacies type III indicated distal dysoxic to oxic shelf (fluvio-deltaic) environment of deposition and palynofacies type V, a mud-dominated oxic distal shelf (open marine) environment. Thermal maturity within the well indicated immature to early mature hydrocarbons (Atta-Peters et al., 2015). Based on marker palynomorphs, Atta-Peters et al. (2015) identified an Aptian to Maastrichtian age for the sediments of the ST 7H well, with an unconformity between the Cenomanian and Campanian sediments.

Atta-Peters and Achaegakwo (unpublished) observed the presence of *Afropollis*, *Classopollis*, *Ephedripites*, elaterate pollen and pteridophytic fern spores from the sediments from the Epunsa 1 well, Onshore Tano Basin. This assemblage suggested a paleoenvironment with parent plants inhabiting moist biotopes or wetlands in a humid, warm coastal plain in a semi-arid/arid climate. Based on biostratigraphically important elaterate pollen and associated taxa, they suggested an Albian-Cenomanian age for the sediments of the Epunsa 1 well succession. Based on palynofacies analysis, Atta-Peters and Achaegakwo (unpublished) identified three palynofacies types (P-1 to P-3). Palynofacies 1 (P-1) reflected deposition in near shore environment under a mud dominated oxic shelf (distal shelf) condition, Palynofacies 2 (P-2) reflected deposition in a distal dysoxic-anoxic "shelf" condition in a fluvio-deltaic environment and Palynofacies 3 (P-3) reflected deposition under a shelf to basin transition condition in a fluvio-deltaic environment in proximity to the source of vegetation.

Atta-Peters and Achaegakwo (unpublished) adopted visual kerogen analysis and spore colour for the evaluation of hydrocarbon potential and thermal maturation respectively and suggested a mature oil prone to immature gas prone source rock in the Epunsa 1 well.

CHAPTER TWO

METHODOLOGY

A total of 84 cutting sample slides between intervals 6020ft-13780ft from CTP-1 well, offshore Tano Basin were obtained from the Core Laboratory of the Ghana National Petroleum Corporation (GNPC).

The standard palynological maceration techniques for the extraction of palynomorphs from sediments (Phipps and Playford, 1984) were followed in the preparation of the cutting sample slides.

2.1 SAMPLE PROCESSING TECHNIQUES

2.1.1 SAMPLE CRUSHING

The samples were washed first, then dried and crushed with a clean steel mortar and pestle in order to approximately 1-2mm fragments (physical disaggregation). The crushed samples are then transferred into a 250ml Nalgene beaker.

2.1.2 PRE HYDROFLUORIC (HF) TREATMENT

To prevent the formation of insoluble secondary fluoride precipitate (CaF2, MgF2) the hydrofluoric treatment is adopted. The samples are treated with 10% hydrochloric acid (HCL) to remove any carbonates (calcium and magnesium carbonate) that may be present. After the carbonates have been removed, each sample is washed thrice with distilled water by decantation process.

2.1.3 SILICATE REMOVAL

In order to remove the silica and silicate content of the host rock, commercial HF (40%) is mixed with the samples and allowed to stand for a period between 1-2 days. This process is vital because the bulk of the sample matrices are most at times controlled by the silicates. The action of HF causes digestive disaggregation (slow melting) of the sample with resultant release of organic material.

2.1.4 ULTRASONICATION

The sample is washed three times with distilled water. The residue is then passed through a nylon sieve of size 20µ, in combination with an ultrasonic probe and with constant washing to produce very clean size sorted residues.

2.1.5 OXIDATION

Oxidation is not carried out because it can destroy some of the palynomorphs and SOM which would have implications on palynofacies and thermal alteration index (TAI) interpretations.

2.1.6 HEAVY LIQUID SEPARATION

The residue is mixed with zinc bromide ($ZnBr_2$) solution of specific gravity 2.0 and then centrifuged. The organic fraction floating on top of the test tube is carefully isolated and thoroughly washed with distilled water.

2.1.7 MOUNTING

Two drops of the concentrated residue are added to a solution of polyvinyl alcohol (PVA; 10gms in 100mls of water) and mixed for even distribution of the residue on circular cover slips of 22mm diameter and allowed to dry on a hot plate. The cover slips were then permanently mounted on labeled glass slides of size 25mm by 75mm by curing them in ultra violet light for about 2minutes.

2.2 MICROSCOPIC STUDY AND PHOTOMICROGRAPHY

The slides were placed on the mechanical stage of a LEICA DM 750 microscope, with the labeling to the left of the observer. Each slide was thoroughly scanned for complete cleavage. An AmScope Toup View 3.2 digital camera was connected to the microscope and used for photomicrography of the preserved palynomorphs and palynofacies assemblages for comparison with other similar or different species.

2.3 ACTIVITIES OUTLINE

Literature review: Previous palaeontological, palynostratigraphic, palynofacies and hydrocarbon potential evaluation works done on the Tano basin were gathered to get familiarized with the study area and to serve as references for the work to be done in comparison with work done by previous authors from especially the North Gondwana Province (ASA) region.

Optical Microscopy and photomicroscopy:

- Thin section slides from the succession were observed thoroughly and systematically to identify and describe palynomorphs in order to establish biozones for palynostratigraphy.

Systematic counts of 400 Particulate organic matter (POM) per slide in accordance to standards set by Tyson (1993) of the relative abundances of palynomophs, opaques, phytoclast and AOM in the samples were recorded for kerogen quantitative and qualititave purposes.

- Q-mode (cluster of samples) cluster analysis of the percentage relative abundance of the kerogen constituents using SPPSS v20 were used to create dendrogram plots to model palynofacies associations for paleoenvironmental interpretations.
- Percentage relative abundance of AOM, phytoclasts and palynomorphs were plotted on the ternary diagrams proposed by Tyson (1993) using Deltagraph to elucidate the different depositional environments of the particulate organic matter (POM) and kerogen type.

The exine colours of the thin-walled psilate spore *Cyathidites* which react to temperature changes easily due to their thin exines were used to determine the organic maturity of the identified palynomorphs as well as their associated sediments. The colours were compared with Pearson's (1984) spore/pollen colour standard calibration to estimate the thermal alteration index (TAI).

Representative photomicrographs of palynomorphs and SOM were taken to be mounted as plates.

CHAPTER THREE

PALYNOSTRATIGRAPHY

Sediments of the CTP-1 well, offshore Tano Basin have been analyzed palynologically and based on the miospore assemblages recovered biozonations have been erected for the succession**.** The criteria used to delineate the biozones are based on the first appearance datum (FAD) and the last appearance datum (LAD) of species.

3.1 MIOSPORE ZONATION

Two biozones have been established for the CTP- 1 well succession for stratigraphic purposes.

3.1.1 *I The Elateropollenites jardinei- Ephedripites irregularis-Reyrea polymorphus zone [CTP -1 samples 13,810- 10,780ft (4209-3286m)]*

This zone is recognized in the deepest part of the CTP-1 well at the interval 13,810-10,780ft (4209-3286m). This zone marks the FAD and LAD of the stratigraphically important taxa *Elateropollenites jardinei*, *Ephedripites irregularis* and *Reyrea polymorphus*. In general this zone is characterized by an assemblage of *Cyathidites sp*, *Crybelosporites pannuceus*, small grains *Classopollis classoides, C.perplexus* and *C.aff.senegalensis, Ephedripites spp*., (straight and twisted ridges of *Ephedripites barghoornii-staplinii-jansonii* form group), *Araucariacites australis* and *Cicatricosisporites spp* . Most of the associated species for this zone are long ranging and transgressed into the succeeding zones. *Psila*- and *retitricolpates,* and monocolpate pollen grains are observed in this zone however in lower frequencies.

The elaterate spores make their first appearance for the sediments of the CTP-1 well in this zone with *Elateropollenites jardinei* appearing earliest at the deepest level of the zone at the depth 13,810ft (4209m).

3.1.1.1 Discussion, Comparison and Age of I The Elateropollenites jardinei- Ephedripites irregularis-Reyrea polymorphus zone

Araucariacites and *Classopollis* are long ranging gymnosperm pollen reported from many African Jurassic and early Cretaceous sediments with rare occurrences in the Post-Cenomanian (Schrank, 1990).

Araucariacites australis is known from the Jurassic to the Tertiary from observations from many parts of the world (Singh, 1971). Several species of an araucariod pollen, *Callialasporites* is found in association with *A.australis* in the Egypt during the late Jurassic and early Cretaceous. In many parts of west and northeast Africa, *A.australis* and other araucariod species are missing (Schrank, 1990). Schrank (1987) has revealed that the araucariods are at present an exclusively southern hemispheric group, following the presence of *Araucariacites* in the Maastrichtian of Somalia and absence in the contemporaneous strata of Egypt.

Crybelosporites pannuceus has been reported from the Lower Albian to Middle Cenomanian deposits of Senegal and Ivory Coast (Jardiné & Magloire, 1965), Libya

(Tekbali, 2009), Peru (Brenner,1976) and Brazil (Hergreen, 1973). There have also been reports from Aptian to Cenomanian deposits (Mahmoud and Deaf, 2007).

Ephedripites reported from North Africa becomes common in the Barremian, may be abundant in the Aptian and remains throughout the rest of the Cretaceous (Schrank, 1983; Herngreen and Chlonova, 1981). Hergreen (1973, 1975) has reported *Ephedripites spp* and twisted polyplicate species from the Albian to Cenomanian of Brazil. Azéma &Boltenhagen (1974) stated that *Ephedripites* complex which is of stratigraphic importance in Gabon, evolved during the Albian and diversified in the Cenomanian to Turonian times.

Elateropollenites jardinei has been recorded in early Albian – Middle Albian in Brazil (Regali and Viana, 1989; Herngreen, 1973, 1975; Dino et al., 1999), Venezuela (Muller et al., 1987), Midddle Albian in Ivory Coast (Jardiné and Magloire, 1965), Senegal and Côte d'Ivoire (Jardine et Magloire, 1965).

Elateropollenites jardinei and *Ephedripites irregularis* reported from this interval have had occurrences from the Lower to Middle Albian strata of Brazil (Herngreen, 1973, 1975; Regali and Viana, 1989). Herngreen et al. (1996) and Regali and Viana (1989) reported that the first elaterate, *Elateropollenites* together with *Ephedripites irregularis* occur in the Lower Albian. Muller et al. (1987) recorded the lowest appearance datum (LAD) and the highest appearance datum (HAD) of *Elateropollenites jardinei* from Albian strata in Venezuela.

Reyrea polymorphus has been established to have an Aptian–Albian range (Schrank and Ibrahim, 1995; Thusu and Van der Eem, 1985; Herngreen, 1998). *R. polymorphus* has been recovered from Lower to Middle Albian strata in Brazil by Herngreen (1973, 1975) and unit III of Hole 961 A and B in the CIG transform margin (Masure et al.,1998). Thusu and Van der Eem (1985) and Muller et al. (1987) reported the lowest appearance datum (LAD) of *R. polymorphus* from the Aptian sediments in Libya. Muller et al. (1987) also reported the extinction of *R. polymorphus* and *E. jardinei* in the Albian at the top of their Zone 6. The extinction of *E. jardinei* and *R. polymorphus* is also observed in this zone. Hergreen (1998) reported that *Elateropollenites*, *R.polymorphus* and *E. irregularis* are stratigraphically important taxa with their occurrence in the Middle Albian.

The absence of *Elaterosporites* and the presence of *Elateropollenites*, delimit the age of the lower part of this interval from 13,810- 10,780ft (4209-3286m) as early Albian.

Overall, the age for biozone *I The Elateropollenites jardinei- Ephedripites irregularis-Reyrea polymorphus zone* is lower-middle Albian.

3.1.2 *II The Elaterosporites protensus - Sofrepites legouxiae - Afropollis jardinus zone [CTP-1 samples 10,670-6,950ft (3,352-2118m)]*

This zone is characterized by the appearance of *Elaterosporites protensus, Elaterosporites acuminatus*, *Elaterosporites verrucatus, Sofrepites lexgouxiae* and the total absence of *Reyrea Polymorphus* and *E.jardinei* in the upper portions of biozone I zone. These species are seen in association with *Elaterosporites klaszii, Galeacornea causea*, *Ephedripites brasiliensis* which is reported from the Upper Albian-Lower

Cenomanian (Hergreen, 1973), *Steevesipollenites binodosus* which is reported from Albian-Cenomanian (Lawal and Moullade, 1986), *Classopollis perplexus and C.aff.senegalensis* greater than 30µm which have been reported from Albian-Cenomanian (Brenner, 1968), *Tricolpites sp* is reported from early Upper Albian (Doyle and Robbins, 1977), and *Cicatricosisporites* is reported from the Upper Albian-Lower Cenomanian (Jan du Chene et al., 1978), *Retimonocolpites* and *Retitricolpites*. The FAD of *Sofripites legouxiae* is observed at the depth 10,670ft (3,352m) and the LAD at the depth 9,770ft (2,978m). The FAD of *Retimonocolpites variplicatus* is at the level 8,060ft (2,457m) and continues to the shallowest level of the CTP-1 well at 6,020ft (1,835m) although the *Elaterosporites spp*. and *Afropollis jardinus* both terminate at the level 6, 950ft (2,118m).

3.1.2.1 Discussion, Comparison and Age of II The Elaterosporites- Sofrepites legouxiae - Afropollis jardinus zone

Galaecornea causea has been reported from late Albian – Cenomanian of Brazil (Herngreen, 1973, 1975), Senegal and Gabon (Jardiné, 1967), Peru (Brenner, 1968), Egypt (Schrank and Ibrahim, 1995) and from Senegal and Portuguese Guinea (Stover, 1963), from Albian – Turonian of Guinea Bissau and Senegal (Stover, 1964), Late – Early Cenomanian of Senegal and Gabon (Jardiné and Magloire, 1965; Jardiné, 1967), Albian – Cenomanian of Peru (Brenner, 1968), Late Albian – Early Cenomanian of Egypt (Mahmoud, 1998; Shrank and Ibrahim, 1995; Aboul Ela and Mahrous, 1992; Zobaa *et al*., 2013).

Retimonocolpites variplicatus is a key stratigraphic palynomorph used in recognizing the late Albian- early Cenomanian age.

Afropollis jardinus is mainly distributed in the Upper Albian but ranges into the Lower Cenomanian (Schrank, 1990). *Afropollis jardinus* has been reported from the Aptian-Lower Cenomanian (Doyle et al., 1982), in Brazil (Herngreen, 1973, 1975), from the Upper Aptian–Lower Cenomanian in northern Sudan (Schrank, 1990), from the Barremian–Aptian in Brazil (Muller et al., 1987), from the Late Albian in Senegal (Jardiné and Magloire, 1965) and from the Albian in Peru (Brenner, 1968).

Doyle et al. (1977) reported that *A. (=Reticulatasporites) jardinus* is one of the stratigraphic markers of the C-VII Zone of Early Aptian age in equatorial Africa. Doyle (1999) has however recognised *A. jardinus* as an Albian species due to the subtle difference between *A. jardinus* and *A.operculatus* and other related forms which have a Barremian–Aptian range.

Sofrepites legouxiae has been recorded from Late Albian – Early Cenomanian rocks of Brazil (Herngreen, 1973, 1975; Herngreen et al., 1996), Gabon (Jardiné, 1967), Eygpt (Mahmoud, 1998; Mahmoud and Moawad 1999; Aboul Ela and Mahrous, 1992), Late Albian of Senegal (Jardiné, 1967). *S. legouxiae* is stratigraphically restricted to the Late Albian-Early Cenomanian interval in areas of the Albian-Cenomanian Elaterate Province (Herngreen et al., 1996).

Elaterosporites klazii has been recorded from has been reported from Albian – Cenomanian of Libya (Batten & Uwins, 1985), Albian of Morocco (Bettar & Meon, 2006), Late Albian – Early Cenomanian of northern Sudan (Schrank, 1990), Egypt (Zobaa et al., 2013), Late Albian in Nigeria (Abubakar et al., 2006, 2011), Early Albian -

early Cenomanain of Brazil (Herngreen, 1975), Early Albian – Early Cenomanian of Eygpt (Mahmoud & Deaf, 2007), Middle Albian – Late Cenomanian in Gabon (Doukaga, 1980) and Senegal (Jardiné, 1967). Herngreen and Dueǹas-Jimenez (1990) have reported *E. klazii* from the Late Albian – Early Cenomanian in Peru and Colombia.

Elaterosporites protensus has been reported from the Albian of Morocco (Bettar & Meon, 2006), Late Albian of Nigeria (Abubakar et al., 2006, 2011), Middle – Late Albian of Senegal (Jardiné, 1967), Middle Albian in Gabon (Doukaga, 1980), Late Albian – Early Cenomanian of Brazil (Herngreen, 1973, 1975), Peru (Herngreen and Dueǹas-Jimenez, 1990) and Venezuela (Muller et al., 1987), Middle Albian – Early Cenomanian of Cote d'Ivoire (Jardiné, 1967).

Elaterosporites verrucatus occurs in the Albian of Morocco (Bettar & Meon, 2006), Late Albian – Early Cenomanian of Brazil (Herngreen, 1973, 1975), Senegal and Côte d'Ivoire (Jardiné & Magloire, 1965), and Venezuela (Muller et al., 1987). In the zone III, northeastern Egypt, Shrank & Ibrahim, 1995 dated this zone as Middle Albian based on the lowermost occurrence of *E. klaszii* to and below that of *E. verrucatus* and *Galaecornea cf. causea* and dated their zone IV to be late Albian.

Jardiné (1967) reported earlier forms of *Elaterosporites klaszii, Elaterosporites verrucatus, Elaterocolpites castelainii* and *Elateroplicites africaensis* as being restricted to the Upper Albian of the Lower Benue Trough in Nigeria. Batten (1996) stated that elater forms are stratigraphically restricted to the Middle to Late Albian and Early Cenomanian age in Africa and South America.

Several species of *Elaterosporites* and *Galeacornea causea* are other important elaterates in the ‘‘Albian–Cenomanian Elaterates Province’’ (Herngreen et al., 1996). Reports by Jardiné & Magloire (1965) showed the lowest occurrences of *Elaterosporites protensus*, and other forms of *Elaterosporites*, in Senegal and Cote d’Ivoire in sediments of Middle to late Albian age.

Elaterosporites klaszii, Elaterosporites protensus and *Elaterosporites verrucatus* recovered from this interval have also been reported from Middle to Upper Albian sediments in Senegal, Côte d’Ivoire and Gabon by Jardiné (1967), from middle Albian rocks of Brazil (Herngreen, 1973, 1975) and from the CIG transform margin (Masure et al., 1998).

Elatersporites and *Galeacornea causea* are stratigraphically significant taxa from the Albian-Cenomanian Elaterate Province.

This biozone II, is characterized by the first appearance of *Elaterosporites spp*. and is comparable to the subzone IB (*Elaterosporites protensus* and *E. verrucatus* zone) proposed by Hergreen (1975) and also comparable to zone III (*Elaterosporites klaszii-Afropollis- Tricolporopollenites* zone) of Schrank & Ibrahim (1995) which was assigned a Middle Albian age.

Masure et al., (1998) reported that apart from *Triorites africaensis, Elaterosporites protensus, Galaecornea causea* and *Classopollis spp*., from the Hole 962 in the CIG transform margin dated early to late Cenomanian.

The overall age of the *II The Elaterosporites - Sofrepites legouxiae - Afropollis jardinei zone* is Middle Albian to Cenomanian.

?Turonian [CTP 1 sample 6890-6020ft (2100-1835m)]

The elater bearing forms are absent at this depth in the CTP-1 well succession. Herngreen et al., (1996) and Hergreen (1998) established that the elaters disappeared or became extinct at the Cenomanian/Turonian boundary. This characteristic is observed in this study as well as the disappearance of *Classopollis* at the Cenomanian/Turonian boundary as mentioned by Herngreen et al., (1996). *Cretacaeiporites* and *Hexaporotricolpites* which are not recorded in this study as have been recorded the late Cenomanian sediments of northern South America and in high numbers (up to 10%) in the marine Turonian Palynofloras of Brazil and Equatorial Africa (Gabon), (Hergreen et al., 1996; Hergreen, 1981; 1998). Ecological factors which may have confined *Cretacaeiporites* and *Hexaporotricolpites* to a particular latitudinal limit may be the cause of their absence in the present study. The depth interval 6890-6020ft (2100-1835m) is be characterized by long ranging species such as *Araucaricites/Inapperturopollenites sp* can be inferred to late Cenomanian due to the absence of index species for Turonian-lower Senonian sediments in the American South American (ASA) region.

CHAPTER FOUR

PALEOECOLOGY AND PALEOPROVINCES OF PALYNOMORPHS

4.1 POLLEN AND SPORES

4.1.1 Paleoecologic and paleoclimatic implication of pollen and spore assemblages.

Sediments of the study area showed a higher abundance of terrestrial palynomorphs (pteridophytes, gymnosperms and angiosperms as compared to marine palynomorphs (dinocycsts).Many taxa have certain palaeoenvironmental preferences and implications. The environments and climates under which spore/pollen were deposited can be inferred from the study of their assemblages' distributions. Miospores are of continental origin and are mainly distributed in marine water bodies through wind action, water dispersion and current patterns in the basin. The level of pollen production, degree of pollen preservation, degree of exine preservation and nature of the depositional environment are other factors responsible for the distribution of miospores in marine waters. A high diversity and abundance of land-derived palynomorphs implies proximity of depostional sites to the source vegetation. Fern spores including *Deltoidospora, Cyathidites, Concavisporites, Cicatricosisporites* prefer humid conditions. As such the abundance of pteridophytic fern spores (*Cicatricosisporites, Deltoidspora, Cyathidites*) suggests a vegetation that grew on moist biotopes or wetlands. (Playford, 1971; Schrank, 1987; Schrank and Mahmoud, 1998; Mahmoud and Moawad, 2002; El Beialy *et al*., 2011).

Cyathidites and *Concavisporites* have been used by Thusu et al. (1988) to infer local wet conditions in temporary lacustrine environments.

Schrank and Mahmoud (1998) have established that Araucariacean pollen represents conifer vegetation on dry hinterlands.

Crybelosporites, a water fern has been established by Collin (1991) to thrive in aquatic and moist environments such as lakes and ponds. Jardiné et al. (1974) have established that *Cheirolepidiaceae* (the producers of *Classopollis*) and ephedroids are xerophytic; that is arid or semiarid elements. When there is an association of *Classopollis* and marine dinoflagellate cysts, it implies a coastal deposition (Srivastava, 1976; Mildenhall, 1977) in a warm arid climate (Vakhrameev, 1981).

Dino et al., (1990), Schrank (2001) and Mahmoud and Deaf (2007) have reported that parent plants of *Afropollis* and elaterate pollen flourished in humid coastal plains and thus attained high abundances in shallow marine environments.

The presence of fresh water algae such as *Pediastrium* and *Chomotriletes minor* are indicative of fresh water habitats such as lakes, ponds and rivers. It can be inferred that these forms were transported by moving water into its marginal marine depositional site.

Thus, the sediments of the CTP- 1 were deposited in a semi- arid to arid coastal or nearshore environment.

4.1.2 Paleofloral Provinces

Hergreen et al. (1996) have established three palynofloral provinces within the Cretaceous. The provinces seem to be related to the contemporary latitudinal climatic zones where the equatorial or near equatorial Africa-South America (ASA) province lies. The three provinces are:

- the Pre-Albian Early Cretaceous *Dicheiropollis etruscus/Afropollis* Province
- the Albian to Cenomanian Elaterate Province and
- the Senonian Palmae Province

Based on the terrestrial microfloras, the pollen from this study was deposited in the Albian to Cenomanian Elaterate Province.

4.1.2.1 Albian- Cenomanian Elaterate Province

This palynofloristic province has been the name Northern Gondwana province by Brenner (1976) and *Galeacornea* paleophytogeoprovince by Srivasta (1978), who renamed it as the *Elaterosporites* phytogeoprovince in 1981. This province is recognized in South American and African countries (Herngreen, 1974b), China and Papua-New Guinea according to Herngreen & Jimenez (1990), Dino et al (1999). A general trend observed during the Albian and Cenomanian time is the gradual replacement of gymnosperm by angiosperm pollen. The abundance of Elaterate species particularly, from a depth of 6020ft-13780ft within the CTP 1 well along with the other associated palynomorphs present, justifies the assignment of the Albian-Cenomanian African-South America (ASA) palynofloral province.

The characteristics of this province are summarized below:

- Presence and abundance of elater-bearing taxa. These belong to the genera *Elaterocolpites, Elateroplicites, Elateropollenites, Elaterosporites, Galeacornea,* *Senegalosporites* and *Sofrepites*. These taxa which may be present high percentages are restricted to the Elaterate Province.

- Scarcity of fern spores. Most of the spores belong to the psilatrilete group, *Cicatricosisporites* or *Crybelosporites pannuceus*. Many other cosmopolitan 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.
- High percentages and a remarkable morphological diversification of angiospermous pollen grains. Common representatives of the endemic *Afropollis, Cretacaeiporites, Hexaporotricolpites* and *Triorites* (which appeared in the late Cenomanian) occurs with psilate as well as reticulate tricol(por)ate species. Angiospermous pollen represented up to 70% in the low paleolatitude areas by the Late Albian time.
- Common ephedroid pollen such as *Ephedripites, Equisetosporites, Gnetaceaepollenites* and *Steevesipollenites*. This group which comprises of richly diverse and numerous polyplicate forms with straight or twisted ridges are characteristic of the Elaterates Province. In comparison to assemblages from outside the province, they record a much greater frequency and morphological variation.

Biozones I and II have been deposited within the Albian to Cenomanian Elaterate Province as the sporomorph assemblages conform to the above characteristics of the province.

4.2 DINOFLAGELLATES

4.2.1 Dinoflagellate Cyst Paleoecological deductions

Implications made from the rather low frequencies of dinoflagellate cysts from the CTP 1 succession have been made as some forms of dinoflagellates are indicative of certain environments. The relative abundance of the palynomorphic assemblage infers a shallow marine/nearshore environment of deposition. Dinoflagellate habitats ranging from fresh water to marine forms are found under all climatic regimes.

Davies et al., (1982) four categories by which dinoflagellates may be used as a means of paleoenvironmetal recognition. Namely;

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

Downie et al. (1971) and Islam (1984) established that individual associations were related to a particular lithology and environment.

Davey (1970), and Uwins and Batten (1988) have indicated that *Cyclonephelium, Subtilisphaera* and *Systematosphor*a are associated with marginal marine conditions.

Based on the above, the rare occurrence and diversity of dinoflagellate cysts such as *Oligosphaeridium, Spiniferites* in association with *Cyclonephelium*, *Subtilisphaera*, *Florentinia* suggests a marginal marine environment for these CTP 1 sediments.

CHAPTER FIVE

PALYNOFACIES ANALYSIS AND KEROGEN TYPE

5.1 INTRODUCTION

Combaz (1964) originally defined the term palynofacies to comprise the total acid-resistant organic matter recovered from a sediment or sedimentary rock by palynological processing techniques, using hydrochloric acid (HCl) and hydrofluoric acid (HF), as seen under a microscope. Powell et al. (1990) redefined the term as "a distinctive assemblage of palynoclasts whose composition reflects a particular sedimentary environment**".** Organic components in sediments have been termed as organic matter, palynodebris, palynomaceral, kerogen, (Gehmann, 1962; Lorente, 1990; Alpern, 1970; Staplin, 1969; Whitaker, 1984, Boulter and Riddick, 1986, Traverse, 1988; Tyson, 1996).

Palynofacies are used not only for establishing depostional environments but for the purposes of evaluating the potential characterizing a given horizon as a source of hydrocarbons based upon the total assemblage of particulate organic matter. (Batten, 1981, 1996b; Tyson, 1995).

5.2 KEROGEN CLASSIFICATION

Tyson (1993) has defined Kerogen as the dispersed sedimentary organic matter that is resistant to the mineral acids; hydrochloric acid (HCl) and hydrofluoric acid (HF). Type I kerogen corresponds to the highly oil-prone material, of both structured organic matter and AOM of algal/bacterial origin with some resins and cuticles included in this group.

Type II kerogen corresponds to oil-prone material and includes fluorescent AOM, fluorescent palynomorphs, cuticle and membranous debris. Type III kerogen corresponds to gas-prone material and includes non-fluorescent and translucent structured phytoclasts, woody fragments, partially oxidized palynomorphs and plankton-derived material. Type IV kerogen corresponds to the inert material and includes non-fluorescent an opaque, strongly oxidized organic matter such as opaque phytoclasts, fungal and chitinous material.

The four main constituents of kerogen according to the classification scheme proposed by Tyson (1993, 1995) are Palynomorphs, Phytoclasts, Opaques and Amorphous organic matter.

5.2.1 Palynomorphs

Palynomorphs are defined to include all discrete HCl- and HF –resistant organic-walled microfossils. Palynomorphs are mostly abundant in fine-grained muds (Mudie, 1992), shales, clays, marls and sometimes in limestones and sandstones (Sarjeant, 1974). The palynomorph group is the least abundant of the kerogen constituents, as such; its occurrence is controlled by the AOM and phytoclast dilution (Tyson, 1993). Palynomorphs have been recorded from various environments including terrestrial and aqueous environments such as estuarine, lacustrine and open marine (Kholeif and Ibrahim, 2010). Large percentages of palynomorphs, as suggested by Carvalho et al. (2006), indicates proximity of terrestrial sources with associated of oxygenated environments whereas low preservation rates results in small percentages of AOM. Tyson

(1995) has also said that large percentages of palynomorphs can also be found with moderate proximity to land.

5.2.2 Phytoclasts

Phytoclasts are the structured, yellow to brown, dispersed silt- to fine sand-sized particles of plant-derived kerogen other than palynomorphs such as cuticles and tracheids. Phytoclasts are mostly derived from terrestrial sources showing high concentrations in areas close to the parent flora, near river mouths and in oxidizing conditions. A high percentage of cuticle debris derived from leaves characterizes the facies resulting from transport by floatation and suspension loads under low energy conditions (Fisher, 1980; Tyson, 1993). Carvalho et al. (2006) has suggested that high percentages of components of the phytoclast group are mostly related to proximal depositional conditions with the main controlling factor being the short distance of transport of the particles. Large pieces of cuticle have been suggested by Gastaldo (1994) and Tyson (1995) as characterizing prodelta, delta top embayment and distributary facies through deposition by rivers or by turbidity currents in deep waters (Habib, 1982). Phytoclasts are also abundant in submarine fan systems, especially in channel sandstones (Boulter and Riddick, 1986). Patterson et al. (1987) have said that the size of phytoclasts decreases in offshore direction.

Variations in the spore and phytoclast frequency depend upon changes of terrestrial input, proximity to the source, and sorting due to transportational and depositional processes.

5.2.3 Opaques

Opaques are all the structured brownish-black to black oxidized or carbonized particles of plant-derived kerogen including charcoal. Opaque fragments are produced through oxidation of plant tissues whereas charcoal is however produced through natural pyrolysis of terrestrial macropyte material.

5.2.4 Amorphous Organic Matter

Amorphous organic matter (AOM) refers to all structureless dispersed silt- to fine sand-sized particles of kerogen. Tyson (1993, 1995) has defined AOM as all the particulate organic components that appear structureless under the light microscope, including phytoplankton and bacterially-derived AOM, higher plant resins, and amorphous products of diagenesis of macrophyte tissues. AOM has been considered as a degradation product from either marine or non-marine components. The fluorescent algal/bacterial AOM characterizes low energy, stagnant and oxygen-depleted paleoenvironments (Bujak et al., 1977; Staplin, 1969; Tyson, 1987). AOM preservation is highly dependent on physical and chemical degradation but most importantly on the oxygen content (Pacton et al., 2011). AOM usually dominates sediments deposited oxygen deficient condition; generally, the increase of AOM indicates reducing conditions, distal dysoxic- anoxic shelf and high marine productivity (Batten, 1981; Tyson, 1995). A large amount of AOM results from a combination of high preservation rate and low-energy environments (Carvalho et al., 2006). Valdés et al. (2004) suggested that there is a relationship between AOM colour and depositional environment. Light coloured AOM represents oxic conditions of Organic matter (OM) deposited in the coastal zone. Dark coloured AOM however represents the effect of dysoxic/ anoxic bottom conditions in bottom sediments of the pelagic zone. Pacton et al. (2011) however suggested that the difference in AOM colour is due primarily to microbes. A high content in AOM points to reducing (dysoxic and anoxic) environments with high preservation potential of planktonic OM or benthic microbial mat material (Ercegovac and Kostic, 2006).

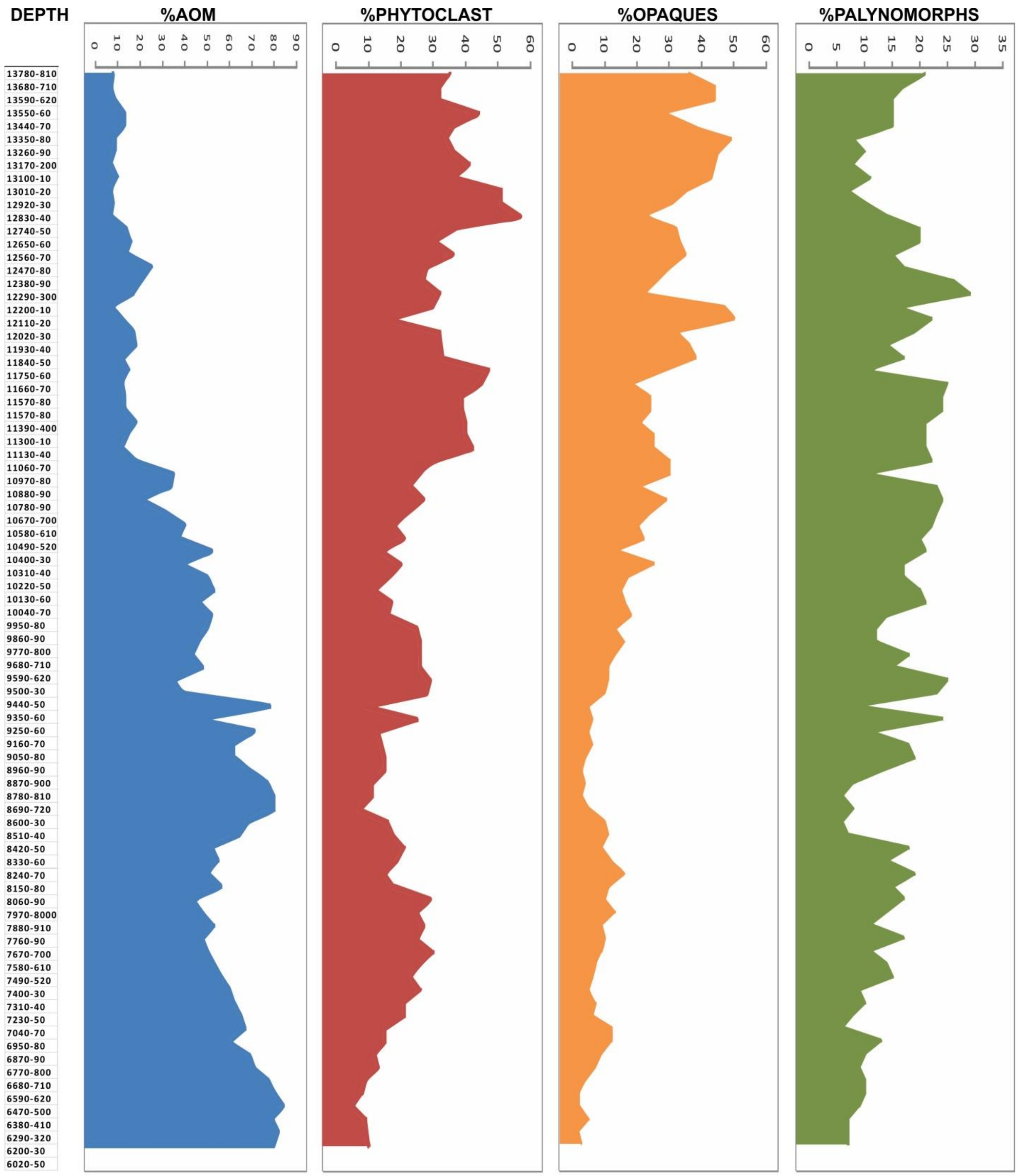


Fig. 4 Percentage distribution of particulate organic matter (palynomorphs, phytoclasts, opaques and AOM) in the sediments of the CTP-1 well.

5.3 PALYNOFACIES ANALYSIS

Cluster analysis was employed based on relative percentage abundance and composition of kerogen components to establish groupings and to recognize the relationship between them. Q-mode (cluster of samples) cluster analysis was performed on the counts using the SPSS vs20 software to identify the divisions of the studied succession based on palynofacies approach. Based on the characteristics of the relative percentages of the kerogen constituents, the cluster analysis revealed four discrete groupings within two superclusters which were displayed in a dendogram for assessment of the clusters (Fig.5). Palynofacies 1 (P-1) and Palynofacies 2 (P-2) are within Supercluster A and Palynofacies 3 (P-3) and Palynofacies 4 (P-4) are within Supercluster B.

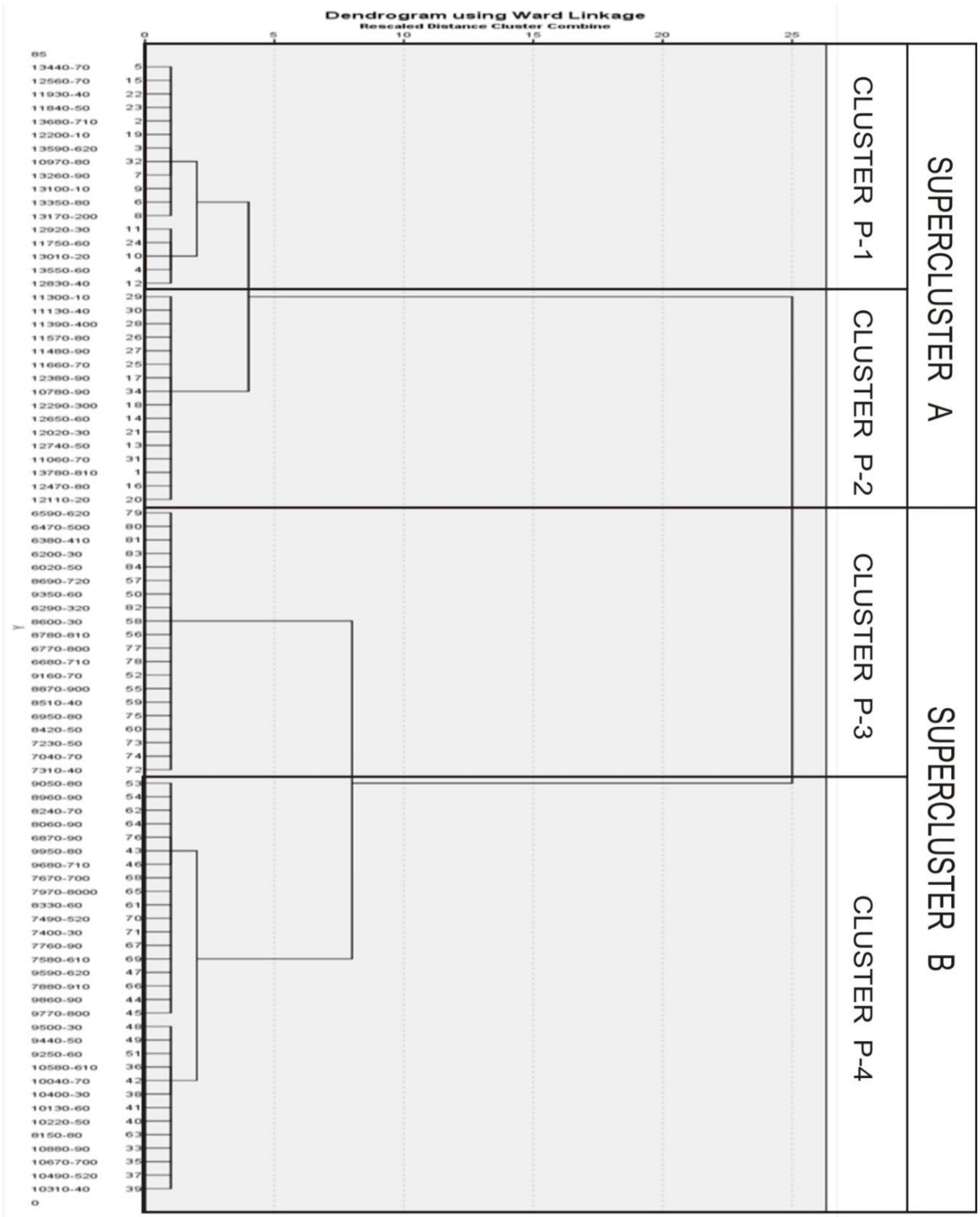


Fig.5 Dendrogram by Q-mode of CTP-1 well shows the grouping of samples

5.3.1 Palynofacies 1 [*Phytoclasts (PHY) and Opaques (OPA) -Equal Dominance*]

Palynofacies 1 is characterized by an almost equal dominance of phytoclast and opaques of relative percentage abundance of 38% and 37% respectively (Fig.6). The AOM are the least in this cluster with relative percentage abundance of 12%, followed by palynomorphs (mainly terrestrial) of relative percentage abundance of 13%. The phytoclasts mainly pale brown and often well preserved structured plant fragments. The AOM which is orange to brown in colour often have diffused edges. Opaque phytoclasts (equant to lath-shaped fragments) are mainly products of oxidation of translucent woody material from prolonged transport or post-depositional alteration (Kholeif and Ibrahim, 2010). Tyson (1989) has also said that high values of opaque phytoclasts (Fig. 4) suggest oxidizing conditions and either proximity to terrestrial sources or redeposition Organic Matter (OM) from fluvio-deltaic sources. Kholeif and Ibrahim (2010) suggested that high percentages of cuticle of the range 15-40% are characteristic of delta top embayment, prodelta and distributary facies.

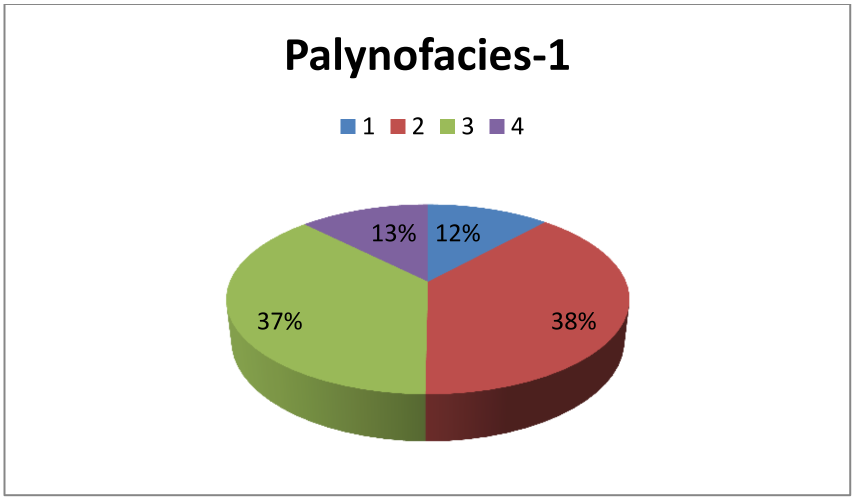


Fig.6 Pie chart showing relative abundance of AOM=1, PHY=2, OPA=3 and PALY=4 for Palynofacies 1

5.3.2 Palynofacies 2 [*Phytoclasts(PHY) Dominant*]

Palynofacies 2 is characterized by the dominance of phytoclasts (high abundance of cuticle) with relative percentage abundance of 34% (Fig. 7). The relative percentage abundances of AOM, opaques and palynomorphs (mainly terrestrial) for this cluster are 16%, 29% and 22% respectively. AOM is the least preserved in this cluster. Boulter and Riddick (1986) observed that, a high abundance of cuticle is recorded in the high energy parts of submarine fan systems, precisely the channel sandstones. Kholeif and Ibrahim (2010) also suggested that a high record of phytoclast (Fig. 4) could indicate a greater abundance of inland vegetation due to improved climatic conditions.

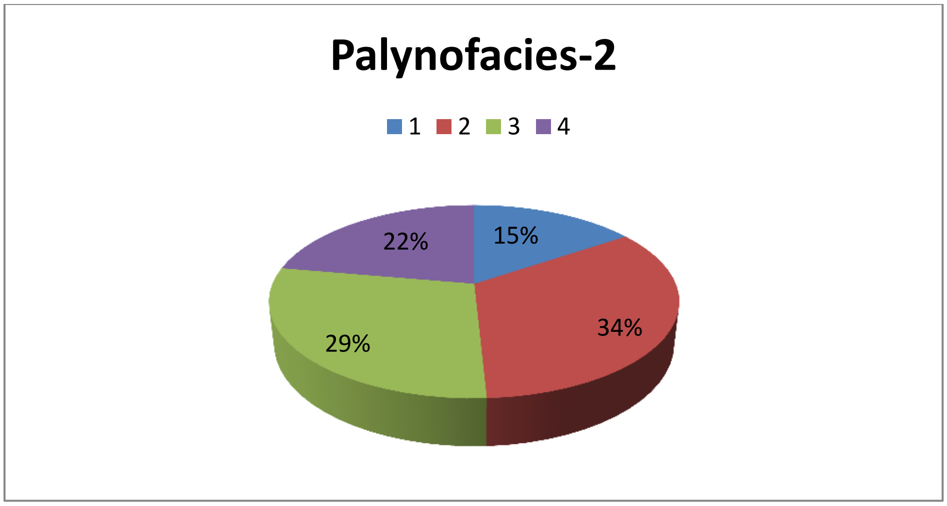


Fig.7 Pie chart showing relative abundance of AOM=1, PHY=2, OPA=3 and PALY=4 for Palynofacies 2

5.3.3 Palynofacies 3 [*Amorphous Organic Matter (AOM) Dominant*]

Palynofacies 3 is characterized by the dominance of AOM (Fig. 4) with relative percentage abundance of 73% with minor proportions of phytoclast (13%), opaques (6%) and palynomorphs (8%) as shown in Figure 8. Tyson (1995) has established that high preservation of AOM is due to basin conditions, often in combination with increased stratification as a result of higher freshwater runoff (Aksu et al., 1995b, 1999; Abrajano et al., 2002). Batten (1983) and Tyson (1993) established that a high percentage of AOM simply indicates reducing conditions of a dysoxic-anoxic environment and a percentage of greater than or equal to 60% of AOM suggests water column stability as well (Ibrahim et al., 2002). Low counts of opaques have been suggested by Kholeif and Ibrahim (2010) to represent low salinity due to close proximity to active fluvio-deltaic sources.

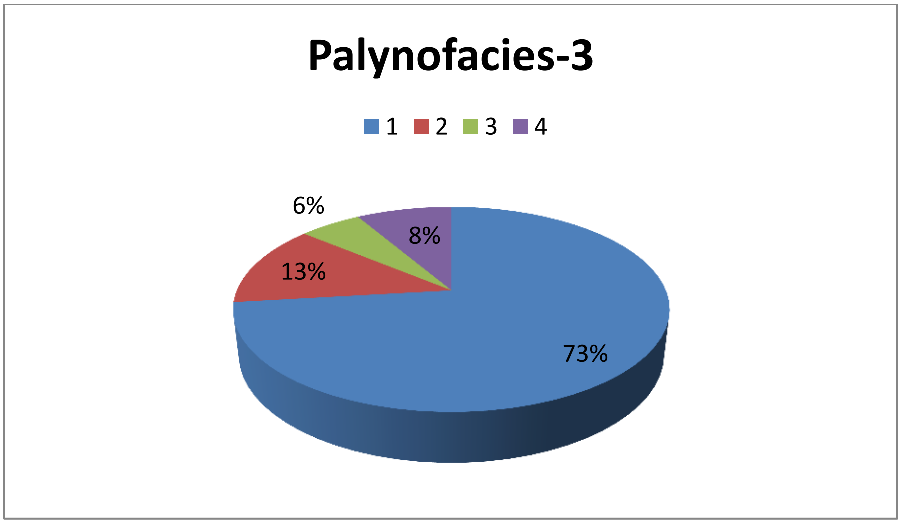


Fig.8 Pie chart showing relative abundance of AOM=1, PHY=2, OPA=3 and PALY=4 for Palynofacies 3

5.3.4 Palynofacies 4 [*Amorphous Organic Matter (AOM) relatively dominant with Phytoclasts (PHY)*]

Palynofacies 4 is characterized by a relative dominance of AOM with phytoclasts of relative percentage abundance of 48% and 22% respectively (Fig.9). This cluster shows minimal occurrence of opaques and palynomorphs of relative percentage abundance of 13% and 17% respectively. The AOM is mainly diffused at the edges, well preserved and pale yellow to orange in colour. The phytoclasts are brown in colour, the brown to black opaques are equant and lath- shaped and the palynomorphs are orange to medium brown in colour.

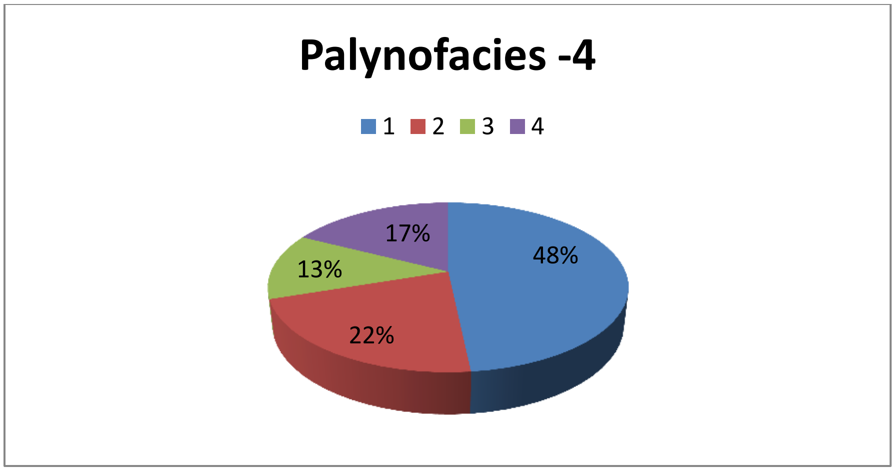


Fig.9 Pie chart showing relative abundance of AOM=1, PHY=2, OPA=3 and PALY=4 for Palynofacies 4

5.4 PALEOENVIRONMENT

For a detailed paleoenvironmental study based on palynofacies, a count of the kerogen found in the slides is necessary. According to Tyson (1995), in order to compute the individual kerogen constituents as percentage of Total Sedimentary Organic Matter (TSOM), a minimum of 400 clasts count should be employed. Tyson (1989, 1993, 1995) used the AOM-Phytoclasts-Palynomorphs (APP) ternary plot to infer depositional environments and the relative proximity to terrestrial organic matter sources (Fig.10. This method was adopted for in this study.

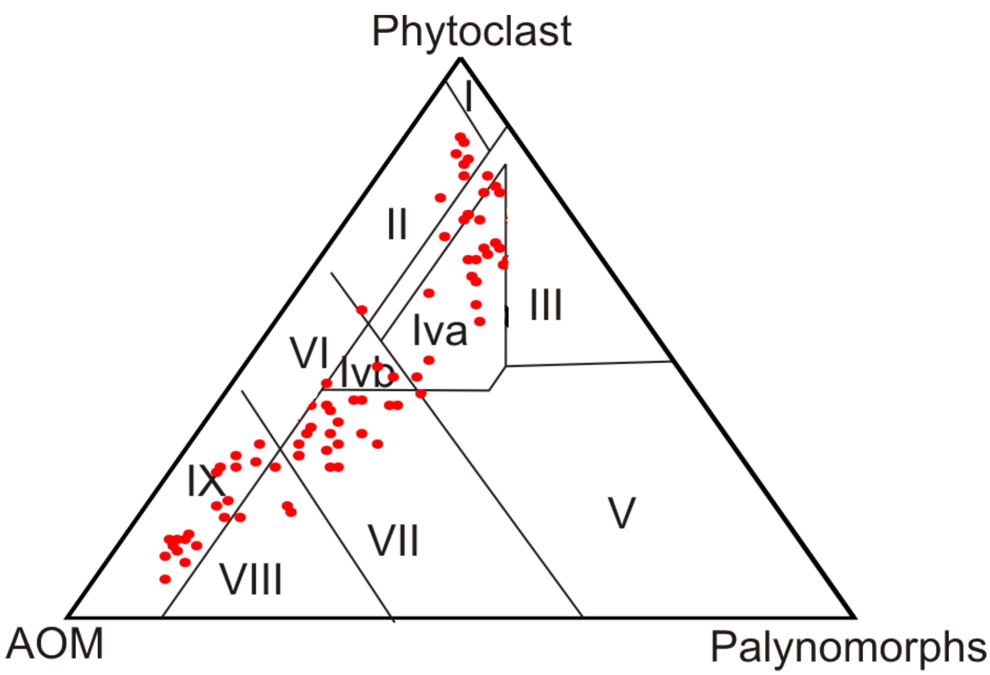


Fig.10 A ternary AOM-Phytoclast-Palynomorph plot (Tyson, 1993), field I= highly proximal shelf or basin; field II= marginal dysoxic-anoxic basin; field III = heterolithic oxic shelf (proximal shelf); field IV= shelf to basin transition, field V = mud-dominated oxic shelf (distal shelf); field VI = proximal suboxic- anoxic shelf; field VII = distal dysoxic- anoxic shelf; field VIII = distal dysoxic- oxic shelf; field IX = distal suboxic-anoxic basin.

In this study, plots on the APP ternary revealed deposition in five fields; fields II, IV, VII, VIII and IX.

5.4.1 Marginal dysoxic-anoxic basin

Field II indicates deposition in a marginal dysoxic-anoxic basin. This field is characteristic of Palynofacies 1 and 2 (P-1 and P-2). Field II is defined by Tyson (1995) as having AOM dilutes by high phytoclast input, however with a good preservation of

AOM. The amount of marine Total Organic Carbon (TOC) in this field is dependent on the basin's redox state and dilution. The relative percentage abundance of terrestrial spores is high with very low records of microplankton. This field exhibits Kerogen Type III which is gas prone (Table 3).

5.4.2 Shelf to basin transition

Field IV indicates a shelf to basin transition. Fields IVa and IVb have been interpreted as dysoxic-suboxic and suboxic-anoxic conditions of the depositional area respectively by Tyson (1995). Based on the Tyson (1995) interpretation for the fields, the passage from shelf to basin is in time or space. With the time component being likely due to increased subsidence or space and the space component being due to basin slope for example (Table 3). The interpretation also explains that the abundance of phytoclast depends on proximity and degree of re-deposition, with the amount of marine TOC being dependent on the basin redox state (Tyson, 1995). Field IV characterizes Palynofacies 1 (P-1) and Palynofacies 2 (P-2). Records of moderate to high spores and very low to low microplankton of Kerogen Types III or II (mainly gas prone) has been associated with this field (Table 3).

5.4.3 Distal dysoxic-anoxic shelf

Field VII indicates deposition in a distal dysoxic-anoxic shelf condition from the Tyson's APP ternary plot (1993). This field exhibits moderate to good AOM preservation and low to moderate palynomorphs (Tyson, 1995). Field VII characterizes Palynofacies 4 (P-4) of Kerogen type II; oil prone (Tyson, 1995).

5.4.4 Distal dysoxic-oxic shelf

Field VIII indicates deposition in a distal dysoxic-oxic shelf according to interpretation acquired from Tyson's APP ternary plot (1993). This field is characterized by AOM-dominated assemblages, excellent AOM preservation, low to moderate palynomorphs and low counts of spores (Tyson, 1995). Field VIII characterizes Palynofacies 4 (P-4), exhibiting Kerogen Type II>I which is oil prone (Tyson, 1995).

5.4.5 Distal suboxic-anoxic basin

Field IX indicates deposition in a distal suboxic-anoxic basin with AOM-dominates assemblages, with associated low abundance of palynomorphs (Tyson, 1995). This depositional environment is frequently alginite-rich and are deep basins or stratified shelf sea deposits especially sediments starved basins and characterized by Kerogen Type II>I which is highly oil prone (Tyson, 1995). Palynofacies 3 (P-3) can be qualified by field IX.

Table 3- Palynofacies defined on the triangle –APP (Modified after Tyson, 1995)

	Palynofacies field and Environment	Comments	Spores	Microplankton	Kerogen Type
I	Highly proximal shelf or basin	High phytoclast supply dilutes all other components	Usually high	Very low	III, gas prone
II	Marginal dysoxic-anoxic basin	AOM diluted by high phytoclast input, but AOM preservation moderate to good. Amount of marine TOC dependent on basin redox state and dilution.	High	Very low	III, gas prone
III	Heterolithic oxic shelf (proximal shelf)	Generally low AOM preservation.Absolute phytoclast abundance dependent on actual proximity to fluvio-deltaic source. Oxidation and reworking common.	High	Common to abundant. Dinocycts dominant	III or IV gas prone
IV	Shelf to basin transition	Passage from shelf to basin in time (eg. Increased subsidence, water depth) or space (eg. Basin slope). Absolute phytoclast abundance depends on proximity to source and degree of redeposition. Amount of marine TOC depends on basin redox state. Iva dysoxic-suboxic, Ivb suboxic-anoxic.	Moderate to high	Very low-low	III or II, mainly gas prone
V	Mud-dominated oxic shelf (distal shelf)	Low to moderate AOM (usually degraded) palynomorphs abundant. Light coloured bioturbated. calcareous mudstones are typical.	Usually low	Common to abundant. Dinocysts dominant	III>IV, gas prone
VI	Proximal suboxic-anoxic shelf	High AOM preservation due to reducing basin conditions. Absolute phytoclast content may be moderate to high due to turbidite input and /or general proximity to source.	Variable low to moderate	Low to common. Dinocysts dominant	II, oil prone
VII	Distal dysoxic-anoxic shelf	Moderate to good AOM preservation. Low to moderate palynomorphs. Dark coloured slightly bioturbated mudstones are typical.	Low	Moderate to common. Dinocysts dominant	II, oil prone
VIII	Distal dysoxic-oxic	AOM –dominated assemblages. Excellent AOM preservation. Low to moderate palynomorphs (partly due to masking). Typical of organic-rich shales deposited under stratified shelf sea conditions.	Low	Low to moderate. Dinocysts dominant, % prasinophytes increasing	II>I,oil prone
IX	Distal suboxic-anoxic basin	AOM-dominated assemblages. Low abundance of palynomorphs partly due to masking. Frequently alginitic-rich. Deep basin or stratified shelf sea deposits, especially sediments starved basins.	Low	Generally low prasinophytes often dominant	II>I, highly oil prone

5.5 THERMAL MATURITY AND HYDROCARBON POTENTIAL

Source rock maturity or thermal maturity which is influenced by source rock organic matter type, the presence of excess free hydrocarbon, mineral matter, content, burial depth and age can be inferred from the degree of thermal alteration of organic matter due to prolonged heating (Tissot and Welte, 1984).

Organic matter undergoes three levels of maturity; immature, mature and post-mature (Peters and Cassa, 1994). The phases have been broken down as:

I. Immature, which has not been affected by temperature but may be affected by biological diagenesis process. Temperature range (Tmax) for this phase is <435˚C;
II. Mature, which occurs at a temperature range of 435-450˚C is or was within the oil window and has been converted via thermal processes to petroleum; and
III. Post-mature, which occurs at a temperature range of 450-470˚C is in the gas window as it is hydrogen deficient as a result of high temperature

The exine colours of the thin-walled psilate spore *Cyathidites* was used to determine the organic maturity of the identified palynomorphs as well as their associated sediments for this study. The colours were compared with Parson's (1984) spore/pollen colour standard calibration to estimate the thermal alteration index (TAI), Vitrinite Reflectance (Ro) and Organic maturity.

Dow (1977) and Waples (1985) have said Vitirinite Reflectance provides an overview of maturity distribution as it is the most reliable and commonly used maturity indicator. Ro values between 0.5 and 0.7% are indicative of a low source rock grade. That between 0.7

to 1.0% indicates a moderate source rock grade and values between 1.0 and 1.3% refers to a high source rock grade.

Observed pollen colours ranged from pale yellow to orange with TAI values of 1+, 2-,2 and Ro values of 0.3-0.5%. Kerogen Type III is interpreted for these values implying immature organic matter that is gas prone for Palynofacies 1 (P-1) and Palynofacies 2 (P-2).

Type II is observed in Palynofacies 3 (P-3) and Palynofacies 4 (P-4) and reflects medium to dark brown exine colours with TAI values of 2+, 3-, 3, 3+ and Ro values of 0.5-0.9%. The organic matter is mature and oil prone.

CHAPTER SIX

SYSTEMATIC PALYNOLOGY

The systematic classification of the miospores from sediments of the CTP-1 well follow that of Potonié and Kremp (1954), Potonié (1956, 1958, 1960), and revisions by Dettman (1963) and Smith and Butterworth (1967). Nomenclature follows the International Code of Botanical Nomenclature (ICBN) (Stafleu, 1978) rules on priority and typification. The dinoflagellates are classified based on the 'Cysts Genus" proposed by Stover and Evitt (1978) and descriptive terminologies according to Evitt et al. (1977), Williams et al. (1973), Stover and Evitt (1978) and Evitt (1985). Descriptions of only well preserved, stratigraphically important taxa of common species which have been illustrated in literature have been made.

6.1 SPORE AND POLLEN

Anteturma Pollenites Potonié, 1931

Subturma Monocolpates Iversen and Troels-Smith, 1950

Genus: *Retimonocolpites* Pierce, 1961

Species: *Retimonocolpites sp.*

Image number: Plate 3, Figure K

Dimensions: Equatorial diameter 45µ, 56µm (8 specimens).

Description: Pollen grain is elliptical to elongate in shape with the colpus extending to about two thirds of pollen grain diameter. The specimen possesses a reticulate exine of 5µm thickness. The lumia measures 1µ wide and the muti is 0.5µm thick.

Genus: *Retimonocolpites* Pierce, 1961

Species: *Retimonocolpites variplicatus* Schrank & Mahmoud, 1998

Image number: Plate 3, Figure C

Dimensions: (56-72) x (48-54) µ, mean (66 x53) µ. (5 specimens)

Description: Monocolpate pollen grain of elliptical to variable shapes. The exine is thin (1µ) and reticulate with minute foveae < 0.5µ wide occurring at mural intersections occasionally. The lumina is (1-4) µ with the muri measuring <1µ. The grains are often folded due to the thin nature of the exine. The colpus covers nearly the full length of the elongated grains, and may be closed and slit-like to wide, open, elliptical or irregular.

Remarks: Schrank & Mahmoud (1998) distinguished *R. variplicatus* from other *Retimonocolpites* species by its large size 62 (82) 100 µm, strongly folded exine, and variable outline.

Turma Polyplicates Erdtman, 1952

Subturman Costates Potonié, 1970

Infraturma Costati Potonié, 1970

Genus: *Ephedripites* Bolchovitina, 1953

Species: *Ephedripites brasiliensis* Hergreen, 1973

Image number: Plate 4, Figure W

Dimensions: longitudinal axis (52-78) μ mean 65μ, diameter 40-59μ, mean 49.5μ (5 specimens)

Description: Specimen is polyplicate, elongated-oval in form. Smooth and somewhat granulate ridges of about 5 or 6 in number, and twist longitudinally around the grain and fuse at the extremeties. The ridges measure 6-15 μ, 12-20 μ equatorially, 16μ at the bulge-outs and reduce to ±5 near the poles. Furrows are unbranched with varying thicknesses.

Remarks: The specimen described is similar to that given by Hergreen (1973) from the Albian- Cenomanian from Brazil.

Species: *Ephedriptes irregularis* Hergreen, 1973

Image number: Plate 2, Figure S

Dimesions: longitudinal axis (38-78) µ, mean 58µ, diameter 35-59µ, mean 47µ (10 specimens)

Description: polyplicate grain of very irregular shape bearing a long and short axis. About 5 or 6 psilate ridges (±6.5 µ wide, ±2.5 µ thick) of variable position and thickness and are sometimes parallel to the long axis. The ridges are often diagonal or twisted and fuse at the poles. Furrow size measure less than 1µ.

Remarks: The specimen differs from *E. brasiliensis* by having thinner ridges although the number of ridges may be the same.

Species: *Ephedripites jansonii* (Pocock) Muller, 1968

Image number: Plate 2, Figure C

Dimension: (58-66) x (30-38) µm, mean (64 x 34) µm. (8 specimens)

Description: Specimen is polyplicate with smooth and twisted ridges (2-4µ thick) that do not fuse at the poles. The ridges number about 10-14.

Remarks: *E. jansonii* is morphologically similar to *E.barghoorni-staplinii* form group although morphologically similar to E. jansonii, has thicker, parallel, straight to slightly twisted ridges, fewer in number.

Turma Aletes Ibrahim, 1993

Subturma Azonaletes (Leuber) Potonié and Kremp, 1954

Infraturma Circumpollini (Plug) Klaus, 1960

Genus: *Classopollis* (Pflug) Reyre, 1970

Species: *Classopollis classoides* Pflug, 1953 emend. Pocock & Jansonius, 1961

Image number: Plate 2, Figure A

Dimension: (28-34) x (30-38) μ, mean (31 x 35) μ. (5 specimens)

Description: Alete specimen with about 5 or more striations of exoexinal thickening which forms a girdle (9μ wide) around the equatorial region.

Remarks: the specimen does not fit the description given by Pocock and Jansonius (1961) and Singh (1964, 1971) due to the absence of a pore.

Genus: *Classopollis* (Pflug, 1953) Reyre 1970

Species: *Classopollis spinosus*

Image number: Plate 4, Figure O

Dimensions: (9-30) x (13-27) μ, mean (19.5x 17) μ. (6 specimens)

Description: Grain is spherical with exine (excluding sculpture) being of massive intrastructure. Sculpture type is echinate with height of echinae as ±1μ, of basal diameter ±0.3μ. About 5 to 6 equatorial striations recorded. No equatorial thickness was observed.

Subturma Zonotriletes Waltz, 1935

Infraturma Cingulati Potonié and Klaus, 1954

Incertae Sedis/Varia

Cf Pollen *incertae sedis*, Reyre, 1966

Genus: *Reyrea* Herngreen, 1973

Species: *Reyrea polymorphus*, Herngreen, 1973

Image number: Plate 3, Figure F

Dimensions: (36-66) µ, mean 51µ (10 specimens)

Description: Specimen comprises of inaperturate grains of unknown regular positions with a long and short axis. Numerous sculpturing elements; clavae, baculate and gemmae can be observed on the same specimen of 4µ high and 4µ in diameter. About 10-14 sculpturing elements are arranged along the longitudinal edges. The edges are almost parallel to the long axis, sometimes slightly twisted.

Genus: *Elateropollenites* Herngreen, 1973

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

Image number: Plate 2, Figure O

Dimensions: (30-36) x (41-45) µ, mean 33 x 43 µ. (6 specimens measured)

Length of appendages: 6-12 µ, mean 6 µ.

Width at base: 3-5 µ, mean 4 µ

Description: A grain with a swollen subtriangular body. The sculpture type is striae (<0.5µ). No distinct apertures are visible except in two specimens where a slit running from the central part of the body to half-way was observed. The three appendages give the grain a lobate habitus. The extremeties of the elatere-like elements are thickened with cavate appearance at the base of the broadened tips. There are complications by some folds parallel to each other and perpendicular to a line connecting normally only two appendage extremeties. Remarks: Elateropollenites differs from Elaterosporites which has 3 pairs of U- shaped appendages. Elateropollenites has not been reported from post-Middle Albian.

Genus: *Elaterosporites* Jardiné, 1967

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

Image number: Plate 3, Figure V

Dimension: (32-50) x (28-46) µ, mean 41 x 37 µ. (8 specimens measured)

Length of appendages 26.5-42 µ, mean 34 µ

Width at base 5-15 µ, mean 8 µ.

Description: Elliptical to subspherical central body with a strongly convex distal face, thick exine and ornamented with spines (4-6 μ long, 2 μ wide at base). There are 3 and sometimes 4 pairs of U-shaped cylindrical appendages of almost equal lengths.

Remarks: Stover (1963) reported that *Elaterosporites protensus* cann be distinguished from *Elaterosporites acuminatus* by its larger size.

Genus: *Elaterosporites* Jardiné, 1967

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

Image number: Plate 3, Figure X

Dimension: (35-52) x (45-50) μ, mean 43 x 48 μ (8 specimens measured)

Length of appendages 20-38 μ, mean 29 μ

Width at base 4-15 μ, mean 9 μ.

Description: Specimen has verrucate ornamentation of height (2.5-3) μ which are loosely arranged on the distal face. Specimen has about 3 pairs of appendages.

Genus: *Elaterosporites* Jardiné, 1967

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

Image number: Plate 3, Figure W

Dimension: (30-48) x (46-58) μ, mean 39 x 52 μ. (8 specimens measured)

Length of appendages 22-35 μ, mean 28 μ.

Width at base 5-8 μ, mean 6.5 μ.

Description: Specimen has smooth or punctate membrane, a central body, an annular band and about 3 to 4 pairs cylindrical appendages on the distal face.

Remarks: Specimen differs from the other *Elaterosporites* forms by its membrane type and the annular band that expands and detaches from the central body.

Genus: *Galeacornea* Stover, 1963

Species: *Galeacornea causea* Stover, 1963

Image number: Plate 2, Figure N

Dimension: (32-48) x (25-35) μ, mean 40 x 30 μ. (8 specimens measured)

Length of appendages 25-40 μ, mean 35 μ.

Width of appendages 3-6 μ, mean 5 μ

Description: the specimen *G. causea* has a zona of variable width. The long axis of the zona is oblique to that of the body and possesses a distal flap.

Remarks: *G. causea* possess a distal flap instead of a horn or appendage as it is in *G. clavis.*

Genus: *Sofrepites* Jardiné, 1967

Species: *Sofrepites legouxiae* Jardiné, 1967

Image number: Plate 3, Figure G, H

Dimensions (21-42) x (18-32) µ, mean 35-26 µ (8 specimen measured)

Length of appendage 10-18 µ, mean 15 µ

Width at base 4-8 µ, mean 6 µ

Description: Specimen has an ellipsoidal body with elliptical to subcircular outline. The exine is psilate to granulate with 2 or 3 appendages of almost equal lengths are observed.

Remarks: Most of the specimen observed occurred as dyads

Genus: *Afropollis* Doyle et al., 1982

Species: *Afropollis jardinus* (Brenner) Doyle et al., 1982

Image number: Plate 4, Figure I

Dimensions: (26-33) x (36- 42) μ, mean (30 x 39) μ. (10 specimens)

Description: The pollen grain is spheroidal, heteropolar, inaperturate and radially symmetrical. The lumina is polygonal to irregularly shaped (2-5 μ) whiles the muri (0.5 μ) is usually sinuous with ridges on the upper surface.

Remarks: No sexine and nexine was seen in the specimen. The sexine is usually non-columellate and reticulate to rugulo-reticulate spreading over the surface of the grain with an inner dark and conspicuous to almost invisible nexinal layer. The nexine is thin, smooth and spherical and is about half or less the diameter of the entire grain.

Genus: *Deltoidospora* Miner, 1935 emend. Van Buggenum, 1985

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

Image number: Plate 4, Figure N

Dimension: (32-39) x (35-42) μ, mean (36-40) μ. (4 specimens)

Description: A trilete spore, with a straight to slightly concave sided triangular amb. Smooth to slightly punctate exine (<2μ thick). The laesura is simple and is about 2/3 of the spore radius.

Remarks: *D. minor* is smaller in size as compared to *D. australis*.

Species: *Deltoidospora psilostomata* Rouse, 1959

Image number: Plate 4, Figure R

Dimension: (38-46) x (46-56) μ, mean (42 x 50) μ. (5 specimens)

Description: A trilete spore, with a straight to slightly concave sided triangular amb. Smooth to slightly punctate exine (<2μ thick). The laesura is simple and slits at the equator.

Species: *Deltoidospora toralis* (Leschik) Lund, 1977

Image number: Plate 4, Figure Q

Dimension: (30-36) x (38-46) μ, (34 x 42) μ. (5 specimens)

Description: A trilete spore, with a straight to slightly concave sided triangular amb. The laesura is distinct, almost reaches the equator with raised lips. The trilete mark rays are delineated by concave labra very close to the centre of the trilete mark and thickens in the interradial area (3-4 μ), and becomes thinner (1.5-2 μ) and broader near the apices and continues around the whole apex. The specimen has a smooth exine which is ±1μ thick.

Genus: *Dictyophyllidites* Couper, 1958 emend. Dettmann, 1963.

Species: *Dictyophyllidites harrisii* Couper, 1958

Image number: Plate 2, Figure I, Plate 5, Figure A

Dimensions: (38-44) x (42-47) µ, mean (42-45) µ. (5 specimens)

Description: A trilete spore, with a straight to slightly concave sided triangular amb. The exine is smooth (<2µ thick) with a distinct laesura reaching the equator with raised lips that is bounded by parallel labra.

Remarks: *Dictyophyllidites* is differs from *Deltoidospora* by having a laesura enclosed within membranous elevated lips (Dettmann, 1963).

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

Species: *Gleicheniidites senonicus* Ross, 1949

Image number: Plate 2, Figure P, Plate 4, Figure X

Dimension: (46-54) x (52-58) µ, mean (50-54) µ. (4 specimens)

Description: A trilete spore, with a straight to slightly concave sided triangular amb with a distinct laesura that reaches the equator with raised lips. Exinal thickenings (2-4 μ) which delineate trilete mark rays and disappear at corners are observed on the proximal face unlike the strong concave continuous exinal thicknening at the corners on the distal face.

Remarks: *Gleicheniidites* is differs from *Concavisporites* by having more variations in wall thickness, as the exine is of unequal thickness in the equatorial regions (Krutzsch, 1959), and is also distinguished by having
exinal thickenings on the distal face.

6.2 FRESH WATER ALGAE

Genus: *Chomotriletes* Naumova, 1939

Species: *Chomotriletes minor* (Kedves) Pocock, 1970

Image number: Plate 2, Figure J

Dimension: (30-37) x (40-50) μ, mean (34 x 45) μ. (5 specimens)

Description: Pale colourless thin wall, alete, brown sub-circular amb and ridges that are separated by furrows with concentric circles pattern parallel to the equatorial margin.

Remarks: *Chomotriletes minor* is a synonym of *C. fragilis* (Pocock, 1970; Pons, 1988). *Chomotriletes minor* a fresh water algae occurs in mostly terrestrially- dominated assemblages. The reported occurrences are in the Jurassic, Canada; Early Cretaceous,Canada, USA, Brazil, Colombia, Libya, Germany, Ukraine; Albian-Cenomanian, western Siberia, western Africa, Sudan; Late Cretaceous, USA, offshore South Africa; Cretaceous, Spain; Eocene, Hungary; Tertiary, China and other areas (Schrank, 1994).

Division Chlorophyta

Class Chlorophyceae

Order Chlorococcales

Family Hydrodictyaceae

Genus: *Pediastrium* Meyen, 1829

Species: *Pediastrum sp.*

Image number: Plate 5, Figure W

Dimension: (10-28) μ, mean 18μ. (3 specimens)

Remark: Radially- symmetrical colonial algae. Have variations in number of horns and cells and cell shape. Common in freshwater bodies and lakes at certain depths.

6.3 DINOFLAGELLATES

Division Dinoflagellata (Bütschli) Fensome et al., 1993b

Subdivision Dinokaryota Fensome et al., 1993b

Class Dinophyceae Pascher, 1914

Subclass Peridiniphycidae Fensome et al., 1993b

Order Gonyaulacales Taylor, 1980

Suborder Ceratiineae Fensome et al., 1993b

Family Ceratiaceae Willey & Hickson, 1909

Cyst Genus: *Odontochitina* Deflandre, 1937 emend. El-Mehdawi, 1998

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

Image number: Plate 5, Figure G

Dimensions: Maximum length without operculum 102µ, length of central body 52 µ, 42µ, length of operculum 80µ. (1 specimen)

Description: The cyst is cornocavate ceratioid, having three pointed, long and straight horns at the apical, antapical, and right lateral of the cyst. The endocyst is sub-spherical with a small rounded bulge at the base of the lateral horn and a more oval outline at the base of the antapical horn. The cyst has an apical archeopyle.

Remarks: *O. operculata* has a smooth to scabrate horn whiles *O.porifera* has perforations. *Odontochitina operculata* has been reported from Aptian–Maastrichtian sediments by several authors (Williams and Bujak, 1985; Helby et al., 1987; Williams et al., 1993; Schrank and Ibrahim,1995; Mohr and Mao, 1997).

Species: *Odontochitina porifera* Cookson, 1956

Image number: Plate 5, Figure H

Dimensions: Maximum length without operculum 110µ, length of central body 56µ, breadth 52µ, 55µ. (1 specimen).

Description: Cyst has apical horn totally perforated by small four-sided or oval longitudinal row patterns. The antapical and the right lateral horns are regularly perforated.

Division Pyrrhophyta Pascher, 1914

Class Dinophyceae Fritsch, 1935

Spiniferate/Gonyaulacoid

Cyst Genus: *Spiniferites* (Mantell) Sarjeant, 1970

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

Image number: Plate 5, Figure N

Dimension of cyst body: (32-38) μ, mean 36μ. (6 specimens)

Length of processes: (8-16) μ, mean 12μ

Description: Specimens showed variable process lengths and surface ornamentations. Processes are spine-like.

Remarks: Evitt (1963) reported that the spine-like processes of *Spiniferites* are similar in structure and distribution to those of *Achomosphaera*. The difference is due to the presence of sutural ridges that connect the bases of the processes in the *Spiniferites*. These ridges are absent in *Achomosphaera.*

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

Species*: Oligosphaeridium complex* (White) Davey and Williams, 1966

Image number: Plate 5, Figure O

Dimension of cyst body: (34-54) μ, mean 46μ. (8 specimens)

Length of processes: (9-24μ), mean 18μ

Width of process base: (4-15) μ, mean 9μ

Description: Specimen processes are intratabular, broad, serrated to distally branched with long pointed to irregular bifurcation spines at the rims.

Remarks: *Oligosphaeridium* can be distinguished from *Hystrichosphaeridium* by the lack of paracingular processes.

Cyst Genus: *Cyclonephelium Deflandré* and Cookson, 1955

Species: *Cyclonephelium vannophorum* Davey, 1969

Image number: Plate 5, Figure A

Dimensions: Length of cyst body (68-82) μ, mean 78μ (6 specimens)

Width of cyst body: (60-72) μ, mean 66μ

Length o fprocesses: (1-3) μ, mean 2μ

Description: Specimen has fine processes with expanded at the tips. Specimen has an apical archeopyle.

Remarks: Some of the specimens do not show indented margins as seen in some other forms of this species.

Order Peridiniales Haeckel, 1894b

Suborder Peridiniineae (Autonym)

Family Peridiniaceae Ehrenberg, 1831

Subfamily Palaeoperidinioideae (Vozzhennikova) Bujak & Davies, 1983

Genus: *Subtilisphaera* Jain & Millepied, 1973

Species: *Subtilisphaera senegalensis* Jain & Millepied, 1973

Image number: Plate 5, Figure F

Dimension: (44-62) x (38-50) μ, mean (54 x 46) μ (4 specimens)

Description: Peridinoid bicavate cyst with an ovoidal to sub-circular ambitus. Has a short pointed apical horn, and one eccentrically located left (or two unequal symmetrically located) antapical horn. The endocyst is adpressed to pericyst in the dorsal and ventral regions and is surrounded by small apical and antapical pericoels. The periphragm can be laevigate, scabrate or finely granulate.

Remarks: Record of *Subtilisphaera senegalensis* specimens show partial paratabulation patterns with the paracingulum seen as an equatorial depression in the precingular region. *Subtilisphaera* ecozone has been recorded from the Hauterivian to Albian strata of Northern and Northeastern Brazil.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

This study has revealed that sediments of the CTP-1 well, offshore Tano Basin are

characterized by microfossil assemblage of abundant and diverse miospores and subordinate dinoflagellates. Two miospore assemblage zones have been proposed for the sediments based on the first appearance datum (FAD) and last appearance datum (LAD) of stratigraphically important species. The zones are:

- *I The Elateropollenites jardinei- Ephedripites irregularis-Reyrea polymorphus zone*
- *II The Elaterosporites protensus - Sofrepites legouxiae - Afropollis jardinei zone*

The zones after comparison with similar published species reported by other authors from other parts of the northern and southern hemisphere revealed an Albian-Cenomaian age for the sediments of the well.

Implications from the spore and pollen assemblages reveal deposition of the sediments took place in a semi- arid to arid coastal or nearshore environment. The dinoflagellate assemblage indicates a marginal marine environment.

A detailed study of the miospores from the sediments show that majority of the elements can be compared to those in the Africa- South America (ASA) province. The miospore assemblage belongs to the Albian-Cenomanian Elaterate paleofloral Province. The similarity of the Ghana microfossil assemblage suite to the northern South America microfossil assemblage suite supports the evidence of a similar geologic setting of the Atlantic coasts of the two continents during the middle Cretaceous to Early Tertiary times.

Cluster analysis carried out on the relative abundances of SOM and palynomorphs of the CTP-1 well sediments revealed four palynofacies associations, Palynofacies 1(P-1), Palynofacies 2 (P-2), Palynofacies 3 (P-3) and Palynofacies 4 (P-4).

P-1 revealed Phytoclasts and Opaques of equal dominance, P-2 revealed dominance of Phytoclasts, P-3 revealed dominance of AOM and P-4 revealed dominance of AOM with Phytoclasts. P-1 and P-2 are characterized by marginal dysoxic-anoxic basin and shelf to basin transition with immature organic matter of Kerogen Type III, implying its proneness to gas (Tyson, 1995). P-3 is characterized by a distal suboxic- anoxic basin environment and P-4 is characterized by distal dysoxic-anoxic shelf and distal dysoxic-oxic shelf with mature organic matter of Kerogen Type II that implies the sediments are oil prone (Tyson, 1995).

7.2 RECOMMENDATION

To ascertain a better evaluation of the potential of a given horizon as a source rock of hydrocarbons, geochemical data should be incorporated in the studies.

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APPENDICE

APPENDIX 1. Alphabetical list of other playnomorphs encountered in the CTP-1 Well

SPORES

Aequitriradites spinulosus (Cookson & Dettman, 1958) Cookson & Dettman, 1961

?*Balmeisporites sp. cf. B.auriculatus* Hall sensu. Saad, 1978

Biretisporites potoniaei Delcourt & Sprumont, 1955

Cicatricosisporites australiensis (Cookson) Potonié, 1956

Cicatricosisporites brevilaesuratus Couper, 1958

Cicatricosisporites sp.

Concavisporites jurienensis Balme, 1957

Concavisporites sp.

Crybelosporites pannuceus (Brenner) Srivastava, 1977

Cyathidites australis Couper, 1953

Cyathidites sp.

Deltoidospora australis (Couper) Pocock, 1970

Deltoidospora cf. balinkaense (Kedves, 1975) Frederiksen et al., 1983

Deltoidospora hallii Miner, 1935

Deltoidospora mesozoica (Thiergart 1949) Schuurman, 1977

Deltoidospora sp.

Dictyophyllidits sp.

Distaverrusporites simplex Muller, 1968

Gleicheniidites sp.

Grandispora sp.

Leptolepidites psarosus Norris, 1969

Lycospora sp.

Murospora florida (Balme) Pocock, 1961

Todisporites minor Couper, 1958

*Triplanosporites sinuousus (*Pflug, 1952) Thomson & Pflug, 1953

Triplanosporites sp.

Uvaesporites sp.

Verrucosisporites rotundus Salami, 1983

Verrucosisporites sp.

POLLEN

Araucariacites australis Cookson ex Couper, 1953

Classopollis perplexus Boltenhagen, 1973

Classopollis sp.

Cretacaeiporites polygonalis (Jardine & Magloire) Herngreen, 1973

Cycadopites carpentieri (Delcourt & Sprumont) Singh, 1964

Elaterosporites acuminatus (Stover) Jardine, 1967

Ephedripites ovalis Muller, 1968

Ephedripites barghoornii Jardine &Magloire, 1965

Ephedripites sp.

Foveotricolpites gigantoreticulatus (Jardine & Magloire) Schrank, 1987a

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

Inaperturopollenites dubius (Potonié & Venitz 1934) Thomson & Pflg, 1953

Inaperturopollinites sp.

Monocolpites sp.

?Monosulcites cf. minimus Cookson 1947 ex Couper, 1953

Retitricolpites vulgaris Pierce, 1961

Spheripollenites sp.

Steevesipollenites binodosus Stover, 1964

Striatopollis sp.

Striopollenites dubius Jardiné & Magloire, 1965

Tricolpites cf. *crassimurus* (Groot & Penny) Singh, 1971

*Tricolpites vulgaris (*Pierce) Srivastava, 1969

Tricolpites sp.

DINOFLAGELLATES

Coronifera oceanica Cookson & Eisenak, 1958

Coronifera tubulosa Cookson & Eisenak, 1974

Florentinia berran Below, 1982

Florentinia laciniata Davey & Verdier, 1973

Florentinia radiculata (Davey & Williams) Davey & Verdier, 1973

Florentinia sp.

Oligosphaeridium complex (White) Davey & Williams, 1966

Oligosphaeridium perforatum (Gocht) Davey & Williams, 1969

Oligosphaeridium poculum Jain, 1977

Oligosphaeridium pulcherrimum (Deflandre & Cookson) Davey & Williams, 1966

Palaeohystrichophora infusiorioides Deflandre, 1935

Spiniferites multibrevis (Davey & William, 1966) Below, 1982

Spiniferites ramosus (Ehrenberg, 1938) Loeblich & Loeblich, 1966

Spiniferites sp. cf. S.fluens (Hansen) Stover and Williams, 1987

Spiniferites sp.

Subtilisphaera senegalensis Jain & Millepied, 1973

Subtilisphaera sp.

Systematophora sp.

ACRITARCHS

Neoveryhachium carminae (Cramer) Cramer, 1970

Veryhacium downiei Stockmans & Williere, 1962

CONODONT

Scolecodont fragment

APPENDIX 2. Point Count of SOM and Palynomorphs

DEPTH/FT	AOM	PHYTOCLASTS	OPAQUES	SPORE/POLLEN	DINOFLAGELLATES
6020-50	319	40	12	29	0
6200-30	326	35	10	29	0
6290-320	317	37	18	28	0
6380-410	334	21	8	36	1
6470-500	321	30	10	38	1
6590-620	309	35	15	41	0
6680-710	282	50	36	30	2
6770-800	274	48	38	40	0
6870-90	238	61	51	48	2
6950-80	269	59	48	24	0
7040-70	261	85	23	29	2
7230-50	247	82	30	41	0
7310-40	239	103	24	34	0
7400-30	224	92	26	58	0
7490-520	211	103	32	51	3
7580-610	200	120	38	42	1
7670-700	192	99	41	68	0
7760-90	212	108	35	45	0
7880-910	193	99	53	54	1
7970-8000	176	114	40	65	5
8060-90	224	71	45	55	5
8150-80	198	64	66	70	2
8240-70	218	76	51	51	4
8330-60	209	82	38	69	2
8420-50	254	72	45	24	5
8510-40	270	65	42	20	3
8600-30	320	29	21	24	6
8690-720	320	42	16	22	0
8780-810	309	44	16	29	2
8870-900	275	61	15	42	7
8960-90	246	59	19	60	16
9050-80	249	56	26	55	14
9160-70	285	50	20	40	5
9250-60	179	100	29	74	18
9350-60	313	34	22	31	0
9440-50	155	111	42	92	0
9500-30	140	114	49	94	3
9590-620	190	104	49	50	7
9680-710	170	104	53	69	4
9770-800	183	102	66	49	0

APPENDIX 2.Point Count of SOM and Palynomorphs (contd.)

9860-90	199	99	57	43	2
9950-80	209	62	74	49	6
10040-70	184	66	68	67	15
10130-60	211	48	63	72	6
10220-50	198	65	70	59	8
10310-40	150	81	100	69	0
10400-30	209	55	56	78	2
10490-520	149	82	91	76	2
10580-610	158	73	80	89	0
10670-700	124	87	99	90	0
10780-90	78	107	119	95	1
10880-90	135	90	84	91	0
10970-80	141	98	120	41	0
11060-70	73	118	120	89	0
11130-40	48	166	105	79	2
11300-10	57	158	102	83	0
11390-400	71	161	86	82	0
11480-90	49	158	98	95	0
11570-80	51	155	100	94	0
11660-70	47	180	73	100	0
11750-60	61	187	110	41	1
11840-50	47	133	154	66	0
11930-40	72	129	145	54	0
12020-30	69	127	120	74	0
12110-20	46	65	202	87	0
12200-10	28	121	189	62	0
12290-300	67	128	90	115	0
12380-90	83	106	109	102	0
12470-80	99	113	120	68	0
12560-70	54	144	143	58	1
12650-60	65	122	135	78	0
12740-50	54	136	130	80	0
12830-40	29	226	91	54	0
12920-30	30	203	129	38	0
13010-20	29	204	138	29	0
13100-10	41	145	169	45	0
13170-200	28	162	178	32	0
13260-90	37	142	182	39	0
13350-80	35	137	198	30	0
13440-70	52	145	145	58	0
13550-60	50	177	112	61	0
13590-620	35	128	178	59	0
13680-710	26	128	178	68	0
13780-810	32	138	144	85	1

APPENDIX 3.Relative percentage abundance of SOM, Spore/Pollen and Dinocyts

DEPTH (FT)	AOM (%)	PHYTOCLASTS (%)	OPAQUES (%)	SPORES/POLLEN (%)	DINOFLAGELLATES (%)
6020-50	80	10	3	7	0
6200-30	82	9	2	7	0
6290-320	79	9	5	7	0
6380-410	84	5	2	9	0
6470-500	80	8	2	10	0
6590-620	77	9	4	10	0
6680-710	71	13	7	8	1
6770-800	69	12	9	10	0
6870-90	60	15	12	12	1
6950-80	67	15	12	6	0
7040-70	65	21	6	7	1
7230-50	62	21	7	10	0
7310-40	60	26	5	9	0
7400-30	56	23	6	15	0
7490-520	53	26	7	13	1
7580-610	50	30	9	11	0
7670-700	48	25	10	17	0
7760-90	53	27	9	11	0
7880-910	48	25	13	14	0
7970-8000	44	29	10	16	1
8060-90	56	18	11	14	1
8150-80	50	15	16	18	1
8240-70	55	19	12	13	1
8330-60	52	21	9	17	1
8420-50	64	18	11	6	1
8510-40	68	16	10	5	1
8600-30	80	7	5	6	2
8690-720	80	11	3	6	0
8780-810	77	11	4	7	1
8870-900	69	15	3	11	2
8960-90	62	15	4	15	4
9050-80	62	14	6	14	4
9160-70	71	13	5	10	1
9250-60	45	25	6	19	5
9350-60	78	9	5	8	0
9440-50	39	28	10	23	0
9500-30	35	29	11	24	1
9590-620	48	26	11	13	2

APPENDIX 3.Relative percentage abundance of SOM, Spore/Pollen and Dinocyts (contd.)

9680-710	43	26	13	17	1
9770-800	46	26	16	12	0
9860-90	50	25	13	11	1
9950-80	52	16	18	12	2
10040-70	46	17	16	17	4
10130-60	53	12	15	18	2
10220-50	50	16	17	15	2
10310-40	38	20	25	17	0
10400-30	52	14	13	20	1
10490-520	37	21	22	19	1
10580-610	40	18	20	22	0
10670-700	31	22	24	23	0
10780-90	20	27	29	24	0
10880-90	34	23	20	23	0
10970-80	35	25	30	10	0
11060-70	18	30	30	22	0
11130-40	12	42	25	20	1
11300-10	14	40	25	21	0
11390-400	18	40	21	21	0
11480-90	12	40	24	24	0
11570-80	13	39	24	24	0
11660-70	12	45	18	25	0
11750-60	15	47	28	10	0
11840-50	12	33	38	17	0
11930-40	18	32	36	14	0
12020-30	17	32	32	19	0
12110-20	12	16	50	22	0
12200-10	7	30	47	16	0
12290-300	17	32	22	29	0
12380-90	21	27	26	26	0
12470-80	25	28	30	17	0
12560-70	14	36	35	15	0
12650-60	16	31	33	20	0
12740-50	14	34	32	20	0
12830-40	7	57	22	14	0
12920-30	8	51	31	10	0
13010-20	7	51	35	7	0
13100-10	10	36	43	11	0
13170-200	7	41	44	8	0
13260-90	9	36	45	10	0
13350-80	9	34	49	8	0
13440-70	13	36	36	15	0
13550-60	13	44	28	15	0
13590-620	9	32	44	15	0
13680-710	7	32	44	17	0
13780-810	8	35	36	21	0

APPENDIX 4. Relative Percentage Abundance of SOM and Palynomorphs

DEPTH (FT)	AOM (%)	PHYTOCLASTS (%)	OPAQUES (%)	PALYNOMORPHS (%)
6020-0050	80	10	3	7
6200-0030	82	09	2	7
6290-0320	79	09	5	7
6380-0410	84	05	2	9
6470-0500	80	08	2	10
6590-0620	77	09	4	10
6680-0710	71	13	7	9
6770-0800	69	12	9	10
6870-0090	60	15	12	13
6950-0080	67	15	12	6
7040-0070	65	21	6	8
7230-0050	62	21	7	10
7310-40	60	26	5	9
7400-30	56	23	6	15
7490-520	53	26	7	14
7580-610	50	30	9	11
7670-700	48	25	10	17
7760-90	53	27	9	11
7880-910	48	25	13	14
7970-8000	44	29	10	17
8060-90	56	18	11	15
8150-80	50	15	16	19
8240-70	55	19	12	14
8330-60	52	21	9	18
8420-50	64	18	11	7
8510-40	68	16	10	6
8600-30	80	07	5	8
8690-720	80	11	3	6
8780-810	77	11	4	8
8870-900	69	15	3	13
8960-90	62	15	4	19
9050-80	62	14	6	18
9160-70	71	13	5	11
9250-60	45	25	6	24
9350-60	78	9	5	8
9440-50	39	28	10	23
9500-30	35	29	11	25
9590-620	48	26	11	15
9680-710	43	26	13	18

APPENDIX 4. Relative Percentage Abundance of SOM and Palynomorphs (contd.)

9770-800	46	26	16	12
9860-90	50	25	13	12
9950-80	52	16	18	14
10040-70	46	17	16	21
10130-60	53	12	15	20
10220-50	50	16	17	17
10310-40	38	20	25	17
10400-30	52	14	13	21
10490-520	37	21	22	20
10580-610	40	18	20	22
10670-700	31	22	24	23
10780-90	20	27	29	24
10880-90	34	23	20	23
10970-80	35	25	30	10
11060-70	18	30	30	22
11130-40	12	42	25	21
11300-10	14	40	25	21
11390-400	18	40	21	21
11570-80	13	39	24	24
11570-80	13	39	24	24
11660-70	12	45	18	25
11750-60	15	47	28	10
11840-50	12	33	38	17
11930-40	18	32	36	14
12020-30	17	32	32	19
12110-20	12	16	50	22
12200-10	7	30	47	16
12290-300	17	32	22	29
12380-90	21	27	26	26
12470-80	25	28	30	17
12560-70	14	36	35	15
12650-60	16	31	33	20
12740-50	14	34	32	20
12830-40	7	57	22	14
12920-30	8	51	31	10
13010-20	7	51	35	7
13100-10	10	36	43	11
13170-200	7	41	44	8
13260-90	9	36	45	10
13350-80	9	34	49	8
13440-70	13	36	36	15
13550-60	13	44	28	15
13590-620	9	32	44	15
13680-710	7	32	44	17
13780-810	8	35	36	21

PLATES

Plate 1 Explanation

All figures X400

Figure

Fig. A, B Palynofacies 1 (P-1). Phytoclasts and Opaques of equal dominance

Fig. C, D Palynofacies 2 (P-2). Phytoclasts dominant

Fig. E, F Palynofacies 3 (P-3). Amorphous dominant

Fig. G, H Palynofacies 4 (P-4). Amorphous relatively dominant with Phytoclast

Plate 1

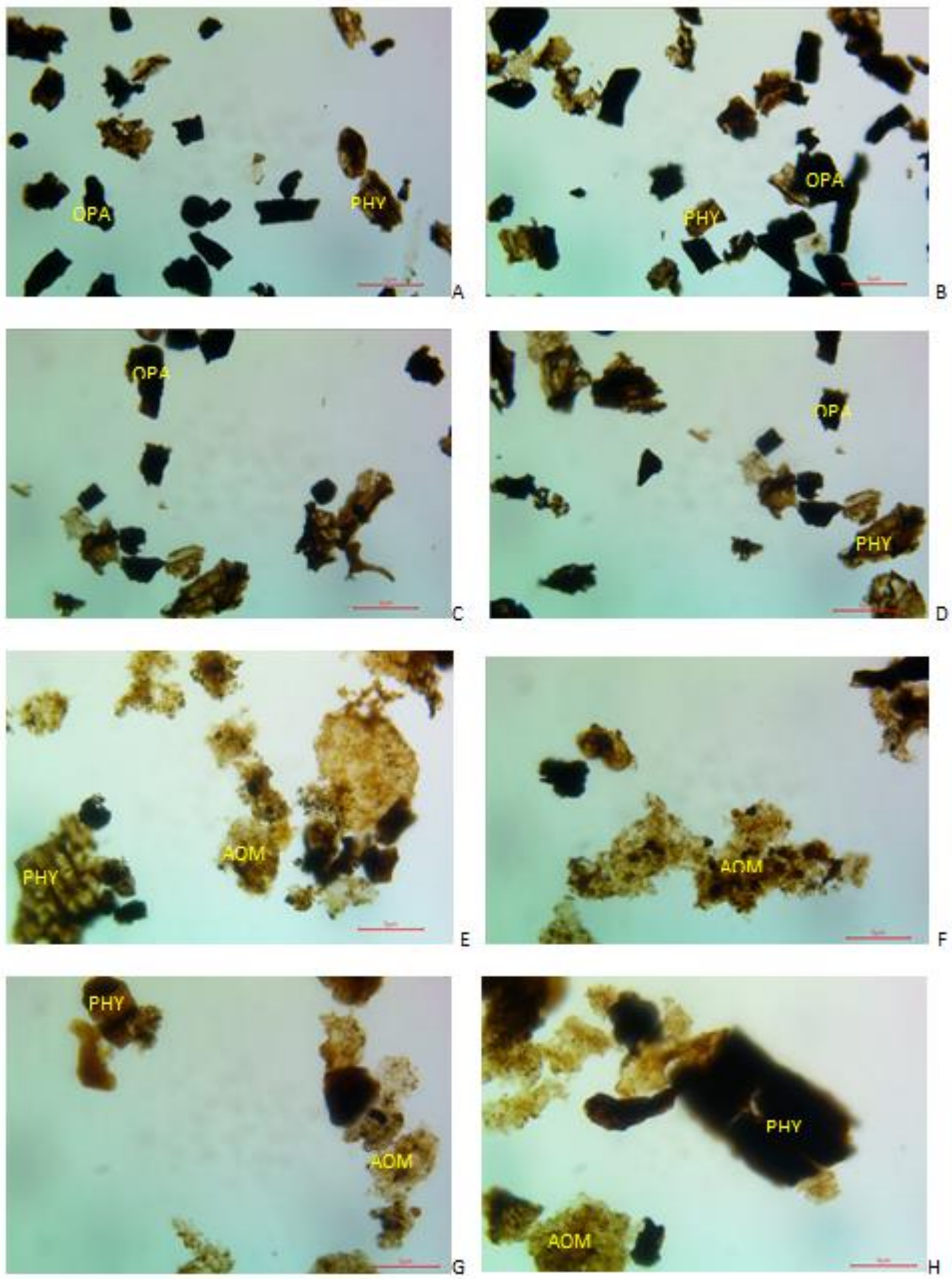
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Plate 2 Explanation

All figures X 40

Fig. A. *Classopollis classoides*

Fig. B. *Leptolepidites psarosus*

Fig. C. *Ephedripites jansonii*

Fig. D. *Cycadopites carpentieri*

Fig. E. *Steevesipollenites sp.*

Fig. F. *Cyathidites australis*

Fig. G. *Striatopollis sp*., two foci

Fig. H. *Biretisporites potonaei*

Fig. I. *Dictyophyllidites harrisii*

Fig. J. *Chomotriletes minor*

Fig. K. *Crybelosporites pannuceus*

Fig. L. *Deltoidospora cf. balinkaense*

Fig. M. ?*Balmeisporites sp. cf. B.auriculatus*

Fig. N. *Galeacornea causea*

Fig. O. *Elateropollenites jardinei*

Fig. P. *Gleicheniidites senonicus*

Fig. Q. *Todisporites minor*

Fig. R. *?Monosulcites cf. minimus*

Fig. S. *Ephedripites irregularis*

Fig. T. *Cicatricosisporites australiensis*

Fig. U. *Tricolpites vulgaris*

Fig. V. *Aequitriradites spinulosus*

Fig. W. *Araucariacites australis*

Fig. X. *Inaperturopollenites dubius*

Plate 2

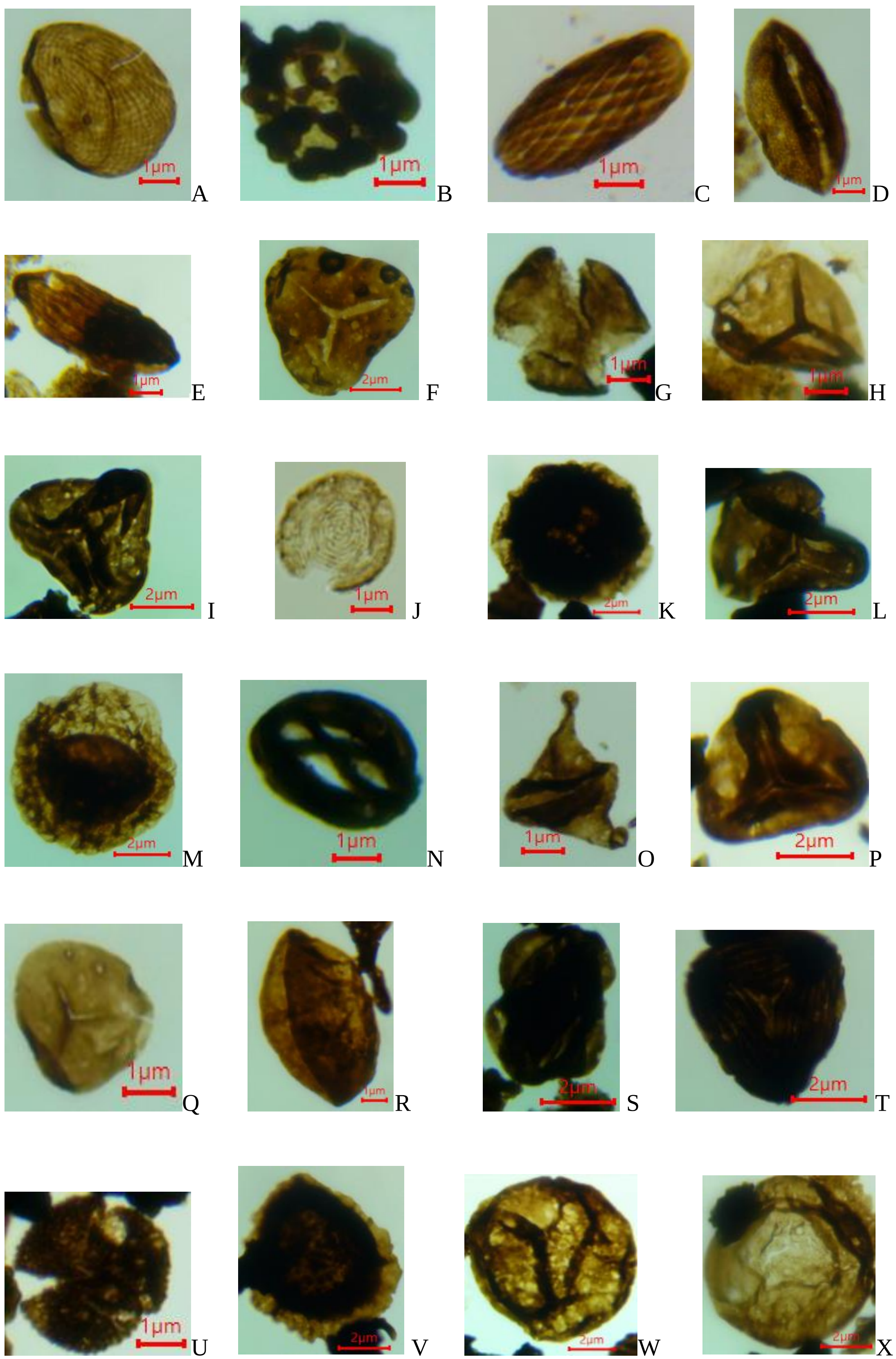
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Plate 3 Explanation

All figures X 40

Fig. A. *Steevesipollenites binodosus*

Fig. B. *Classopollis perplexus*

Fig. C. *Retimonocolpites variplicatus*

Fig. D. *Striatopollis sp*.

Fig. E. *Monosulcite sp*

Fig. F. *Reyrea polymorphus*

Fig. G. *Sofrepites legouxiae*

Fig. H. Dyad of *Sofrepites legouxiae*

Fig. I. *Ephedripites sp.*

Fig. J. *Tricolpites sp.*

Fig. K. *Retimonocolpites sp.*

Fig. L. *Striatopollis sp.*

Fig. M. *Striopollenites dubius*

Fig. N. *Classopollis aff. senegalensis*

Fig. O. *Cretacaeiporites polygonalis*

Fig. P. *Gnetaceaepollenites barghoornii*

Fig. Q. *Distaverrusporites simplex*

Fig. R. *Spheripollenites sp*

Fig. S. *Murospora florida*

Fig. T. *Triplanosporites sinuosus*

Fig. U. *Elaterosporites acuminatus*

Fig. V. *Elaterosporites protensus*

Fig. W. *Elaterosporites klaszii*

Fig. X. *Elaterosporites verrucatus*

Plate 3

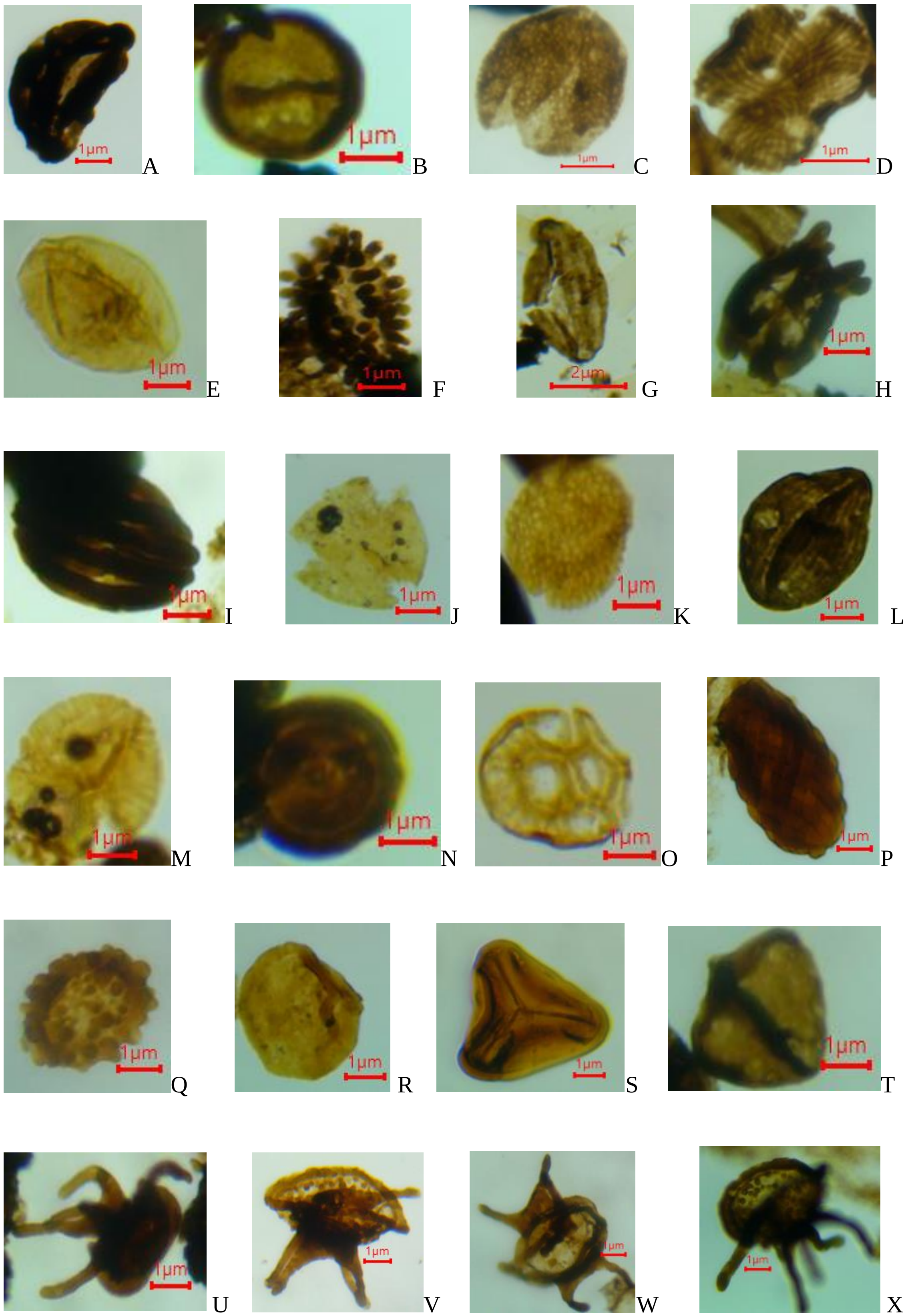
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Plate 4 Explanation

All figures X 40

Fig. A *Dictyophyllidites harrisii*

Fig. B. *Cicatricosisporites brevilaesuratus*

Fig. C. *Ephedripites elsikii*

Fig. D. *Foveotricolpites gigantoreticulatus*

Fig. E. *Ephedripites barghoornii/staplinii*

Fig. F. *Matonisporites crassiangulatus*

Fig. G. *Foveotriletes margaritae*

Fig. H. *Deltoidospora mesozoica*

Fig. I. *Afropoliis jardinus*

Fig. J. *Grandispora sp.*

Fig. K. *Deltoidospora australis*

Fig. L. *Uvaesporites sp.*

Fig. M. *Lycospora sp*

Fig. N. *Deltoidospora minor*

Fig. O. *Classopollis spinosus*

Fig. P. *Ephedripites ovalis*

Fig. Q. *Deltoidospora toralis*

Fig.R. *Deltoidospora psilostomata*

Fig. S. *Triplanosporites sp.*

Fig. T. *Cicatricosisporites sp.*.

Fig. U. *Triplanosporites sp*.

Fig. V. *Concavisporites jurienensis*

Fig. W. *Ephedripites brasiliensis*

Fig. X. *Gleicheniidites senonicus*

Plate 4

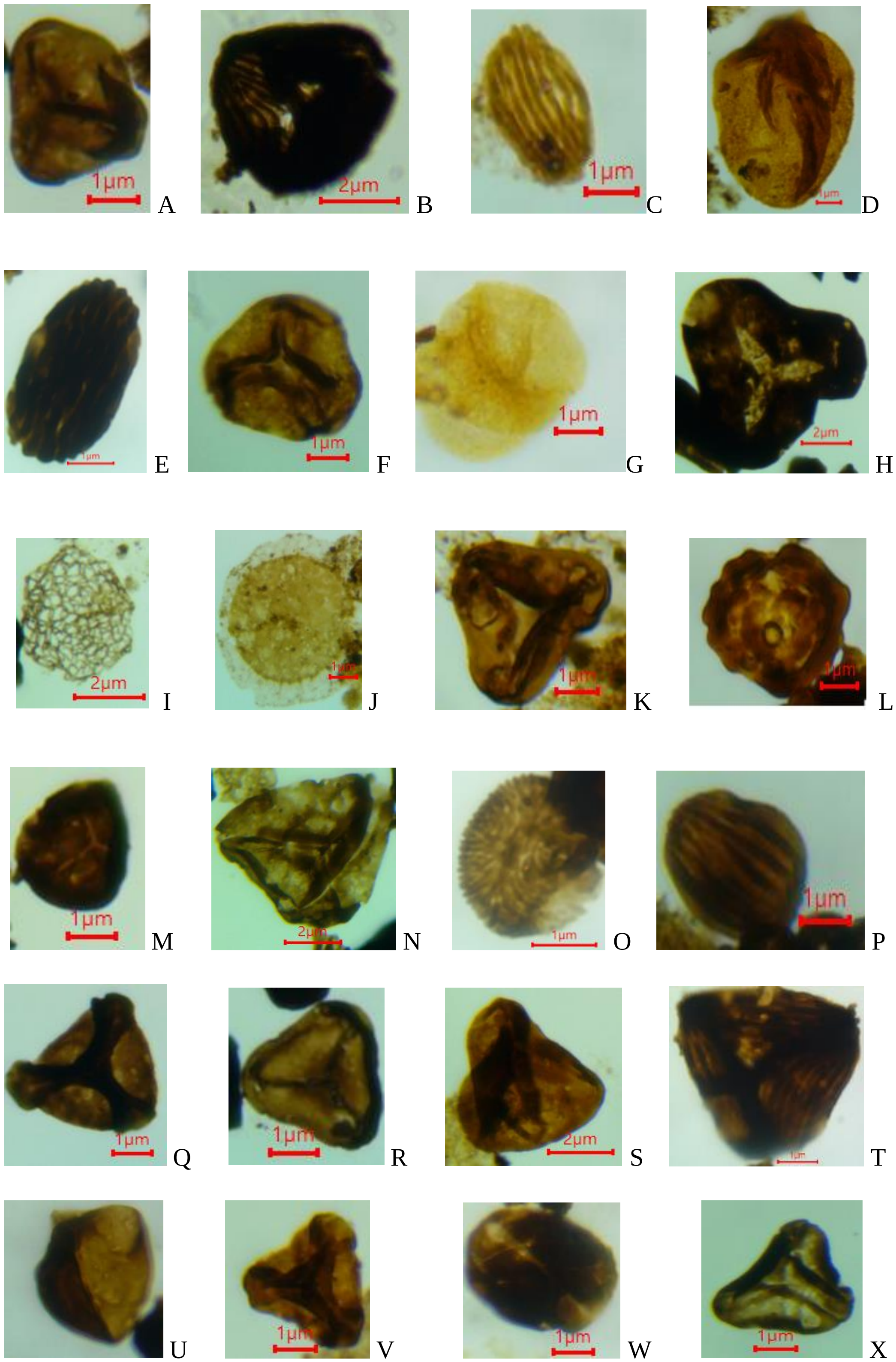

Plate 5 Explanation

All figures X 40

Fig. A. *Cyclonephilium vannophorum*

Fig. B. *Coronifera tubulosa*

Fig. C. *Spiniferites multibrevis*

Fig. D. *Coronifera oceanica*

Fig. E. *Systematophora sp.*

Fig. F. *Subtilisphaera senegalensis*

Fig. G. *Odontochitina operculata*

Fig. H. *Odontochitina porifera*

Fig. I. *Florentinia laciniata*

Fig. J. *Florentinia radiculata*

Fig. K. *Coronifera tubulosa*

Fig. L. *Florentinia berran*

Fig. M. *Palaeohystrichophora infusiorioides*

Fig. N. *Spiniferites ramosus*

Fig. O. *Oligosphaeridium complex*

Fig. P. *Oligosphaeridium pulcherrimum*

Fig. Q. *Oligosphaeridium poculum*

Fig. R. *Oligosphaeridium perforatum*

Fig. S. *Spiniferites sp cf. S.fluens*

Fig. T. *Scolecodont* fragment

Fig. U. *Veryhacium downei*

Fig. V. *Neoveryhachium carminae*

Fig. W. *Pediastrum*

Plate 5