PALEOENVIRONMENT AND ORGANIC GEOCHEMICAL ASSESSMENT OF A SECTION OF THE EOCENE BENDI - AMEKI FORMATION EXPOSED AT NNEWI, SOUTHEASTERN NIGERIA

By

Adesoji, Precious Feyi

GLY/14/2248

A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF GEOLOGY, FACULTY OF SCIENCE, FEDERAL UNIVERISTY OYE EKITI

IN

Partial Fulfilment of the Requirements for the Award of Bachelor of Science (B.Sc.) Degree in Geology

February, 2019

CERTIFICATION

This is to certify that the research project on the Paleoenvironment and Organic Geochemical Assessment of a Section of the Eocene Bendi - Ameki Formation exposed at Nnewi, Southeastern Nigeria was actually carried out by Adesoji Precious Feyi with matriculation number GLY/14/2248 under the supervision of Mr Adeoye M.O. The work has been approved as meeting the required standard for the award of Bachelor of Science (B.Sc.) Degree of the department of Geology, Faculty of Science, Federal University Oye-Ekiti, Ekiti State, Nigeria.

.... 18/02/19

Mr Adeoye M.O. Date

Project Supervisor

....

Prof. O.J. Ojo Date

Head of Department

Prof S.A. Opeloye 25/02/19

External Examiner Date

Dedication

I dedicate this project first and foremost to God Almighty who has given me the strength and enablement to complete this work. I also dedicate this work to my Parents, Mr. and Mrs. Adesoji, for their prayers and support throughout the course of this work. Finally, I dedicate this project to every lecturer in the Department of Geology for their selfless efforts directed towards making me a better person as well as a competent geologist.

Acknowledgement(s)

I would like to acknowledge the Almighty God who by his grace and mercy I was able to complete this work.

My profound gratitude goes to my able Supervisor, Mr Adeoye Oluwaseun, for his love, patience, encouragement, corrections and advice towards the success of this work. Your immense contribution, suggestions, coupled with useful discussions are highly acknowledged. God bless you sir.

My reserve appreciation goes to the Head of Department, Department of Geology, Prof. O.J. Ojo, and my able lecturers, Mr Taiwo Bolaji, Mrs Ndukwe Nene, Miss Oyebamiji, Mr Chukwu Emmanuel, and Mr Agibe. Thanks for the scolding, advice and love shown to me throughout my course of study, it made me a better person.

With sincere heart and mind of appreciation, I specially acknowledge the parental, financial and moral support of my dearest parents, Surv. Adeleke Adesoji and late Mrs. Folake Adesoji, I pray that you enjoy the fruit of your labour (amen). My appreciation goes further to my beloved brothers Adesoji Adedayo and Adesoji Kolawole, and my sweet sister Mrs Alademomi Adedolapo. Thanks for your financial support and words of encouragement.

By and large, I will be ungrateful if I fail to acknowledge my incredible course mates and friends, the entire 400 level, class of 2018. You all are awesome, I love you all.

Table of contents

List of Figures

List of Tables

Abstract

The present study investigated the outcrop samples of Bende-Ameki Formation exposed at Edo spring, Nnewi area from the palynological, paleontological, and geochemical viewpoints in order to determine the paleoenvironment and petroleum potential. Exposed rocks of the formation consist of interbedded successions of lignite, shale, claystone, siltstone, sandstone, and conglomerate facies of a paralic environment.

Palynological result for paleoenvironmental reconstruction reveals the predominance of terrestrial angiosperm pollens (64%), subordinate amount of microspore (21%), and low proportion of marine dinocyst (11%). The incursion of the marine dinocysts into the prevailing terrestrial species indicates a paralic environment of deposition for the formation.Also,marker species like *Verrucatosporites usmensis, Retibrevitricolporites triangulatus, Psilatricolporites crassus and Psilatricolporites operculatus* were used to date the sediment as Eocene age.

Paleontological analysis on the shales yielded no foraminifera. This may be attributed to the high amount of coaly fragments, as well as the prevalence of siliciclastics, within the shales. These factors are generally not favourable for the foraminifera species thus constraining their survival.

Also, TOC results of the source rocks range from 44 to 59.56wt% (mean= 51.78wt%) for the samples whereas those of shales range from 10.5 to 22.57wt% (mean=16.53wt%), suggesting that the sediments have excellent quantity of organic matter that can generate hydrocarbon. This was confirmed by the petroleum source potential (S1 +S2) that ranges from 19.4 to 35.48mgHc/g TOC (mean= 27.44mgHc/g TOC) for shales range, and from 109.2 of 316.86mgHC/g TOC (mean= 213.03mgHc/g TOC) for the lignites. The HI values range from 143 to 172 mgHC/gTOC (mean= 155mgHC/gTOC), indicating a Type III gas prone kerogen for the shales, whereas in the lignites, HI range from 202 to 514mgHC/gTOC (mean= 299mgHC/gTOC) indicating a Type II oil prone to Type II/III oil and gas prone kerogen. The thermal maturity values of the source rocks range from 408 to 424°C revealing their level of immaturity.

CHAPTER ONE

INTRODUCTION

1.1 General Statement

The Anambra Basin, located in the southern Benue Trough is a post Santonian synclinal sedimentary structure containing over 5,000m thick of upper Cretaceous to Recent sediments. The basin consists of rhythmic clastic sequences of sandstones, shales, siltstones, mudstones, sandy shales with interbedded coal seams. Its Bende – Ameki Formation is the surface outcrop equivalent of the subsurface Agbada Formation in the prolific petroleum producing Niger Delta. Anambra Basin has been a major geological area for coal exploration since 1909. The basin is one of the sub-basins of the Benue rift structure which form a part of the West African Rift System (WARS) (Fairhead et al, 1987; Genik, 1992). It is a linear, northeast oriented depression in the southern part of Nigeria (Akande et al, 1998).

1.2 Location of the Study Area

The study area for this project falls within the southern part of the Anambra Basin (Fig. 1.1) and is covered by lithologic successions of the Bende Ameki Formation (Fig. 1.2). The location studied is a part of Bende Ameki formation precisely Edo Spring Nnewi (between Latitude 06°01' 12.2"- 06° 10' 48.8" and Longitude 006° 54' 28.8" – 006° 51' 54.9"). Lignites in the study area represent part of the lignite belt of the southern Nigeria that are confined to a narrow belt of about 16km wide, trending NW – SE, and extending for a distance of about 240km from Niger in the west to the Cameroun frontier, east of Calabar, in the east.

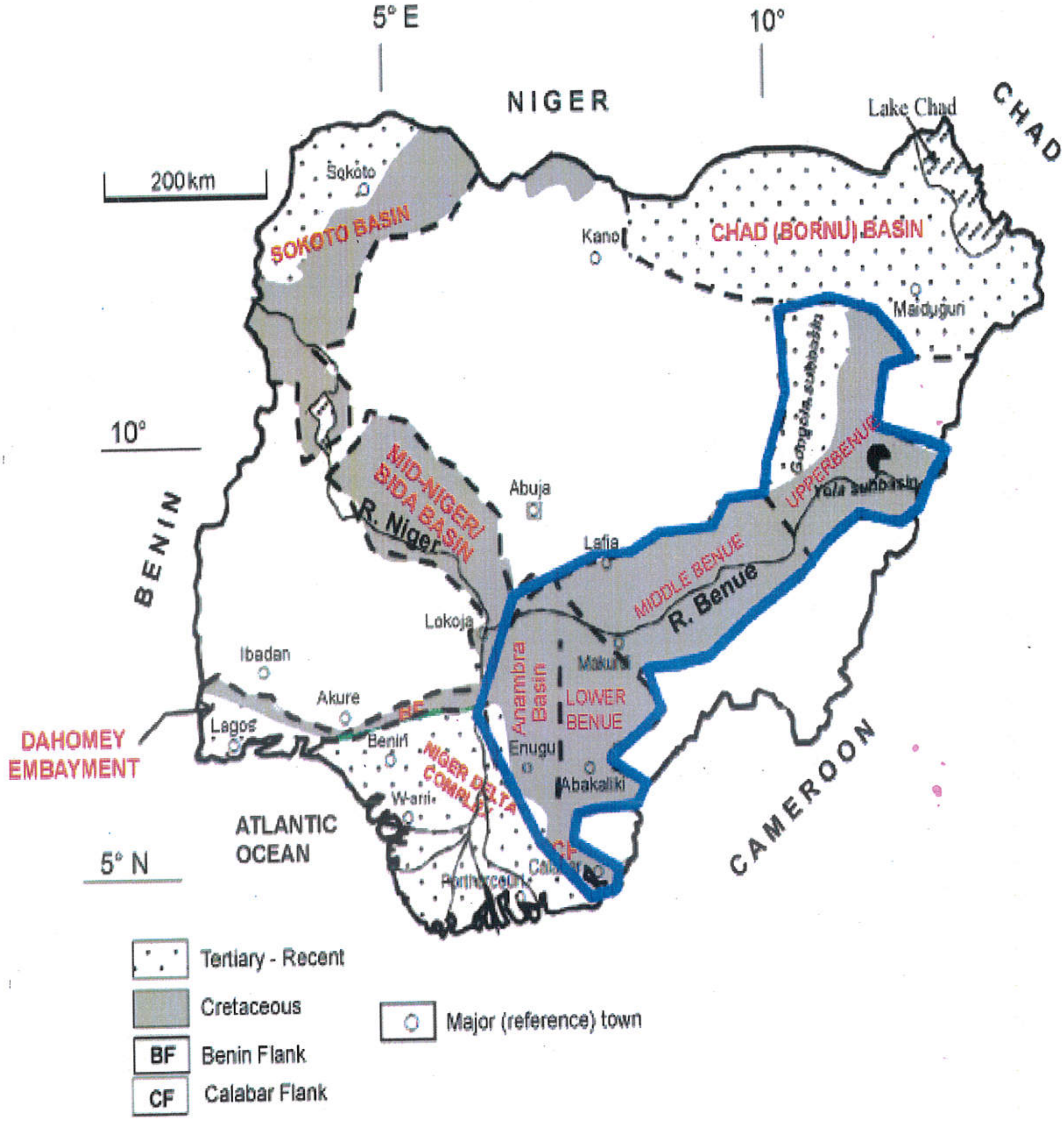

Fig. 1.1: Generalized geological map of Nigeria showing Anambra Basin (Modified after Obaje, et al, 2004).

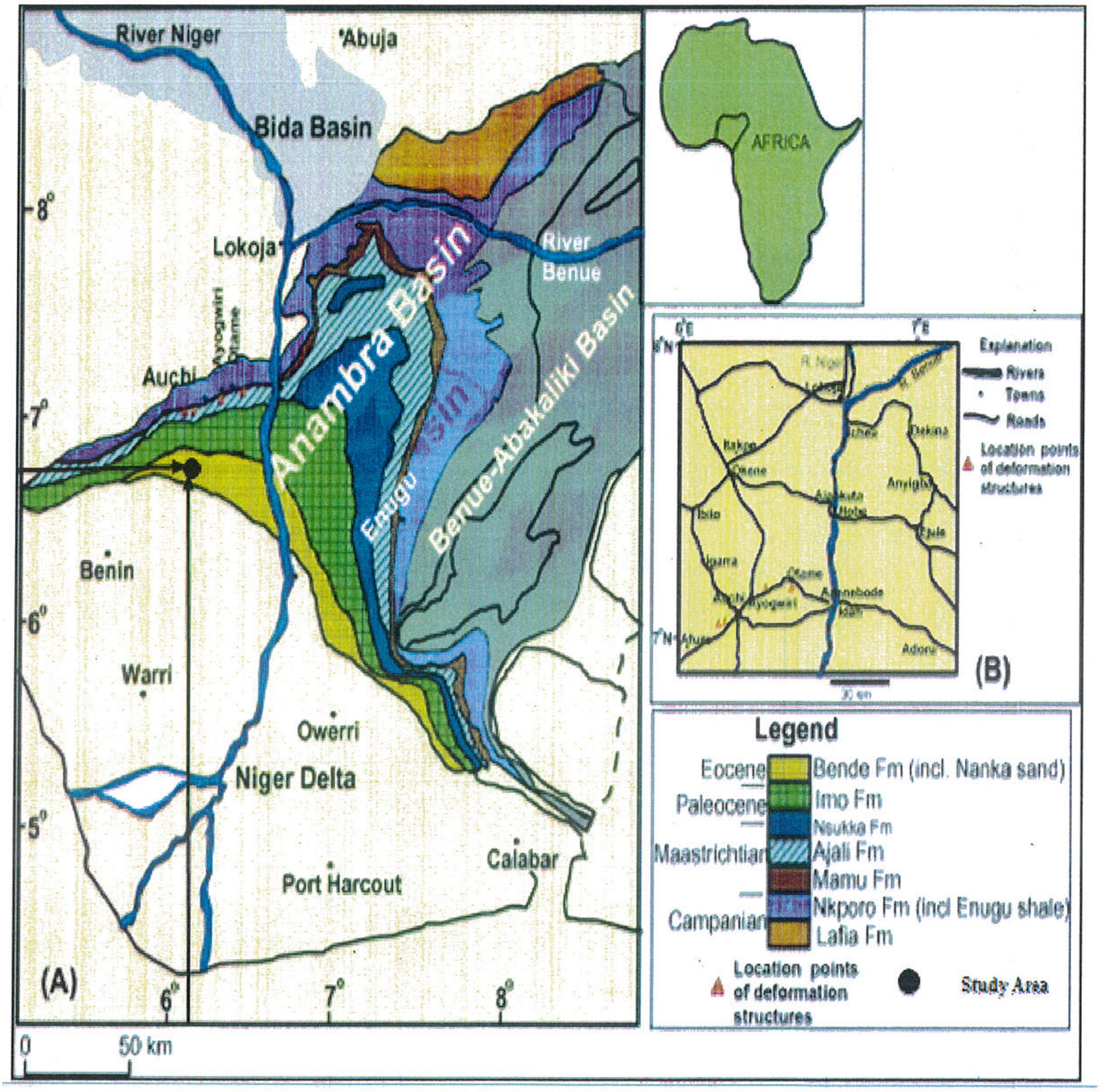

Fig. 1 2: Generalized geological map of southeastern Nigeria showing the study area (modified after Salufu and Ogunkunle, 2015)

1.3 Geomorphology and Climate

The landscape of the area is dominated by a cuesta: an asymmetrical ridge, with its western end at the left bank of River Niger at Idah (Fig. 1.2). From here it stretches northeastwards and, from close to the River Benue, turns south past Enugu to just north near Arochukwu at the right bank of the Cross River. Most of its scarp slope faces the Cross River plain. Its crest constitutes a long sigmoidal drainage divide between the Anambra River plain to the west and the Cross River catchment areas to the east. Most of its scarp slope faces the Cross River plain. Its crest constitutes a long sigmoidal drainage divide between the Anambra River plain to the west and the Cross River catchment areas to the east. The landscape stretching from the foot of the scarp face shows several isolated ridges some of them parallel to the main axis of the cuesta. In the southwest of the area, the Awka-Orlu upland forms such cuestas, whose scarp face and dip slope gullies turned the area into bad lands. The positive land forms are most probably erosional resistors left behind as the scarp face retreats westward at a rate estimated to be 9cm/1000 years. The dip slope of the cuesta is generally broadly undulating due to the activity of the headwaters of the Anambra and the Imo Rivers. Smoothly grassed inselbergs characterize the cuesta crest.

1.4 Objective of the Study

The objectives of the study include:

i. To reconstruct the depositional environment of the study area based on paleontological and palynological studies.
ii. To determine the age of the sediments within the formation
iii. To evaluate the organic geochemical characteristics of the source rock of Bende Ameki Formation for their petroleum generation potential.

CHAPTER TWO

GEOLOGICAL SETTING

2.1 General Statement

The Benue trough is an intracratonic basin with sediments trending NE-SW direction in Nigeria. Geographically, it is divided into the Southern, Central and Northern Benue regions, with Niger Delta at the southern fringe and Chad Basin at the northern flank. The origin, structure, and stratigraphy of the Benue Trough displayed a unique feature in the West Africa Gulf of Guinea. It has been considered as a part of the three-armed rift system which controlled the break-up of Gondwana. The Gulf of Guinea and the South Atlantic Ocean were the active arms of this triple junction along which spreading occurred which resulted in the Africa plate separating from the South America plate. In the absence of crustal separation, the Benue Trough remained an abandoned rift with over 6000 m of sediments. The term Aulacogen was used to describe the evolutionary pattern in view of the similarity with the Athapuscow Aulacogen described by Olade and Hoffman (1975) in Canada.

2.2 Origin and Evolution of the Benue Trough

The Benue Trough of Nigeria is a mega-rift system termed the West and Central Africa Rift System (WCARS). The WCARS includes the Termit Basin of Niger and western Chad, the Bongor, Doba and Doseo Basins of southern Chad, the Salamat Basin of Central African Republic and the Muglad Basin of Sudan (Fig. 2.1). The Benue Trough is a graben, representing the failed arm of a triple junction. The generated faults in the Trough range from major to small and micro types (Ofoegbu, 1984). The sediment infilling of the Benue Trough ranges from about 5km at its contact with the basement complex in the northern Benue Trough to about 7km, at its boundary with the Niger Delta in the southern Benue. Kings (1950) proposed that the evolution of the Benue trough is associated with stresses resulting from the continental separation of Africa and the South American plates. Olade (1975) postulated the mantle plume theory, which he believed was responsible for the evolution of the trough. Following his proposal, he further stated that the initial stage in the evolution of the trough, involved the rise of a mantle plume in the region of the present Niger delta. This rise caused doming and rifting in the Benue region developing an RRR triple junction (Fig. 2.2).

The accompanying volcanism resulted in the deposition of the Abakaliki pyroclastic during the Aptian to early Albian. Rifting within the trough was accompanied by rapid subsidence and deposition of the Asu river group in the mid to late Albian. Mantle upwelling ceased temporarily by Cenomanian, producing subcrustal contraction and compressive folding of the Asu river group. During the early Turonian, reactivation of the mantle upwelling occurred and was accompanied by rifting along basement faults which formed during extensional movements. Eze-Aku group was deposited during this time on top of the folded Asu group sediments (Nwachukwu, 1972).The final stage in the tectonic evolution of the trough occurred in the Santonian when the mantle upwelling ceased and migrated westward relative to the continent.

This was probably as a result of the rotation of the African plate. The loss of thermal momentum associated with the depth or migration of the thermal plume produced subcrustal contraction and a final collapse of the trough which later evolved into a broad asymmetric down warp (Ajakaiye et al, 1973). Pre-Santonian rocks within the depression were generally affected by a wide spread but gentle compressive deformation. Subsequently, a major Santonian to Maastrichtian regression culminated in the deposition of syn to post deformational sediments. Regional contemporaneous uplift displaced the sea out of most of the trough which initiated a shallow marine transgression into the present Niger valley (Wright 1968).

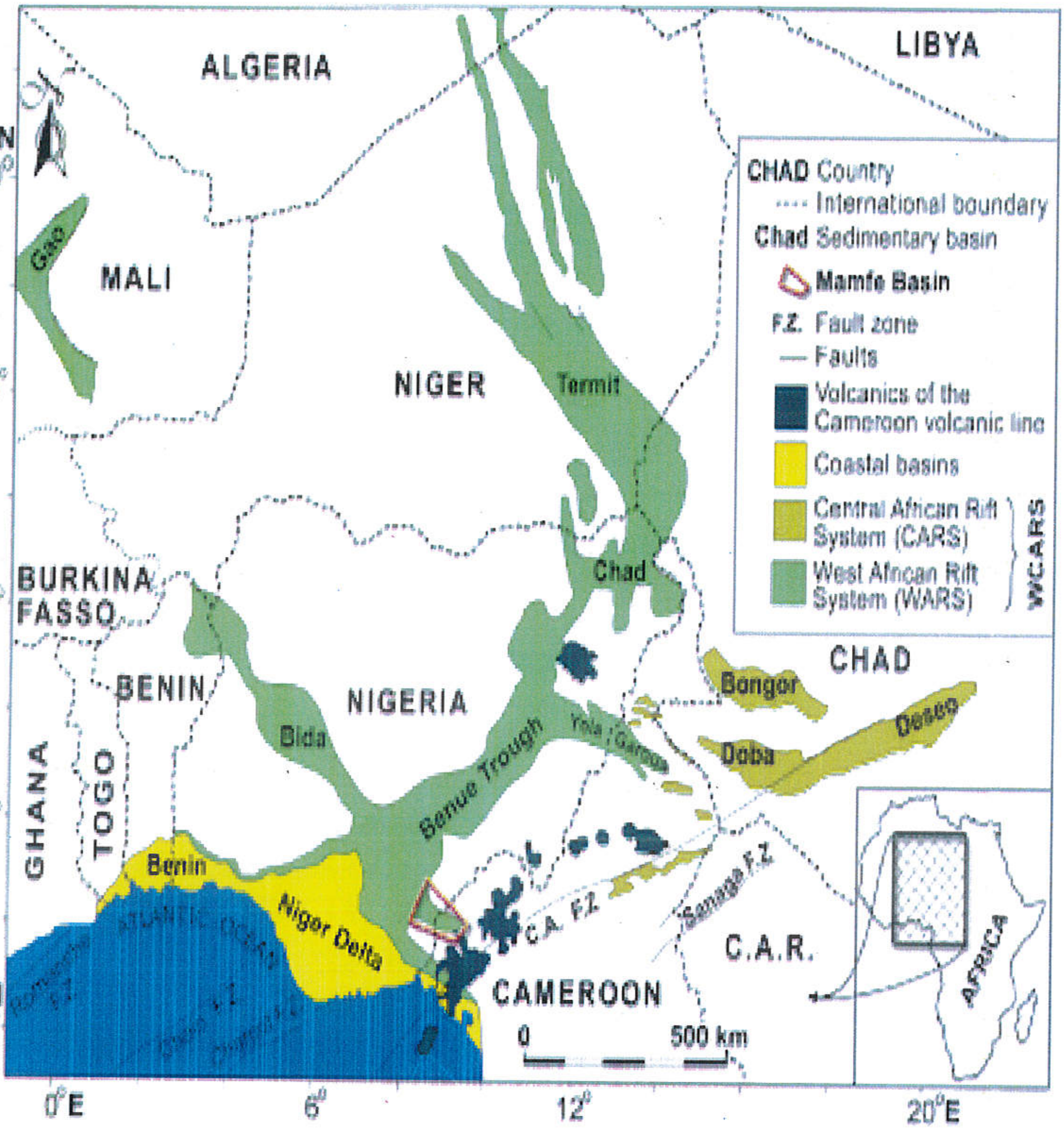

Fig. 2.1: Map of the Benue Trough, the West and Central African rift systems (WCARS) in the western Central Africa (After Genik, 1992).

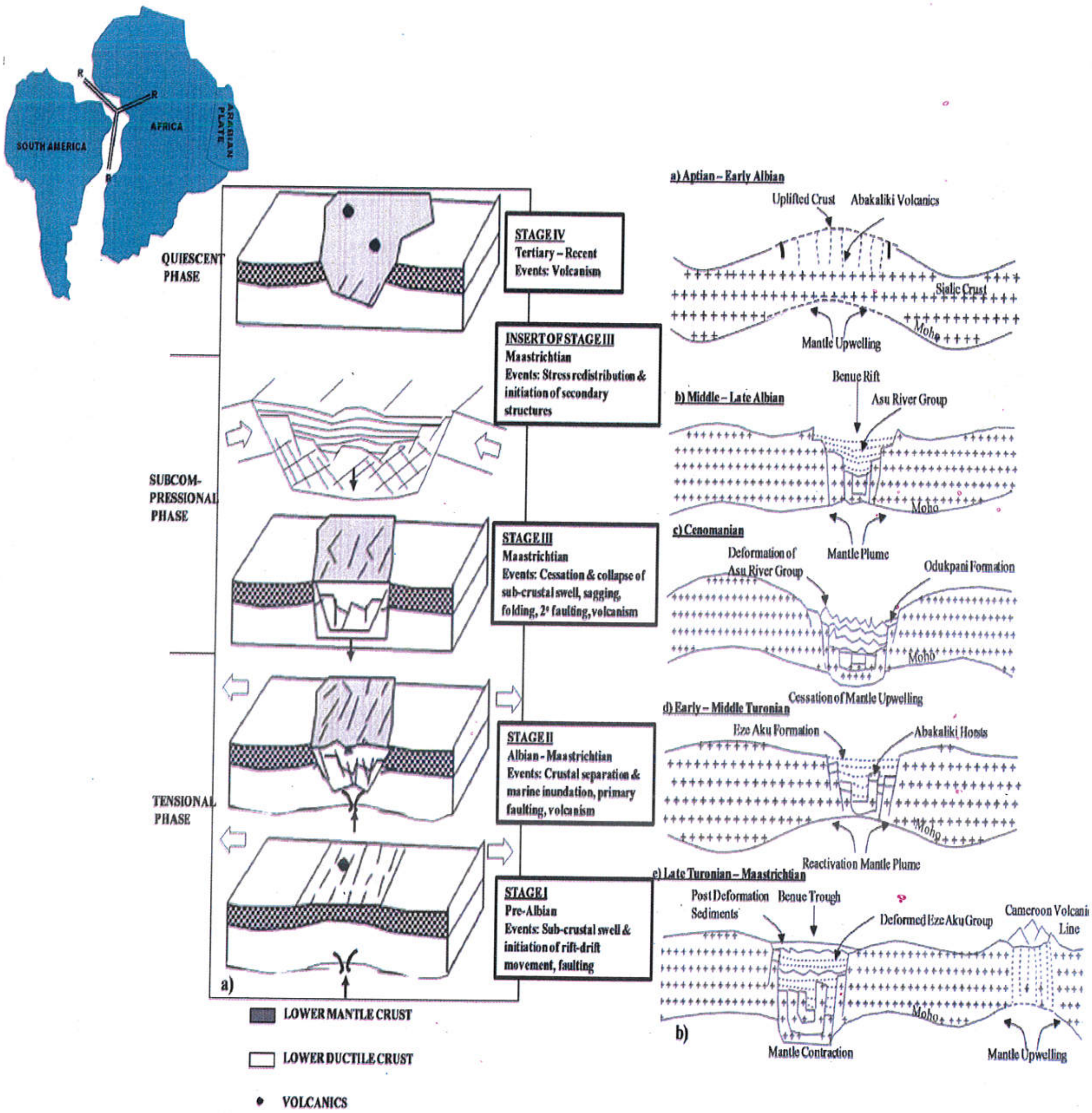

Fig. 2.2: Models for the RRR Rift origin of the Benue Trough of Nigeria. (a) Spreading Ridge Model (Avbovbo et. al, 1986); (b) Aulacogen Model (from Olade, 1975)

2.3 Stratigraphic overview of the Anambra Basin

The Post-Santonian collapse of the Anambra platform led to the emergence of several parts of the Southern and Central Benue Basins during the Campanian-Maastrichtian and shift in the depositional axis of sediments for the third transgressive cycle to the Anambra Basin. Sediment derived from erosion of the anticlinorium and ancestral Niger River filled the Anambra Basin. The various lithostratigraphic units resulting from these depositional cycles are here presented (Fig. 2.3)

Enugu Formation

The Campanian Enugu Formation consists of coarsening upward sequences with thick, dark grey shale at the base, grading upward through siltstones into thin, texturally mature sandstone (Fig. 2.3) (Akaegbobi et al., 2000). The lithologic assemblage suggests deltaic progadation during active delta growth. The carbonaceous shale at the base is interpreted as full marine pro-delta subfacies while the upper part of the section represents shallow water shoreface subfacies (Ojo et al, 2009).

Mamu Formation

The Maastrichtian Mamu Formation consists of rhythmic sequences of sandstones, shales, siltstones, mudstones, sandy shales with interbedded coal seams suggesting deposition under paludal to possibly marginal marine (Nwajide, Reijers 1996). The coal beds and carbonaceous shales are more concentrated in the basal section of the formation and rare towards the top.

Ajali Sandstone

Ajali Sandstone consists entirely of crossbedded sandstones with drapes of claystones extending as stacks of sheetlike bodies from the Calabar flank northwards towards Enugu. It is a regressive phase conformably overlying the Mamu Formation (Fig. 2.3). The lithology of this formation consists of white, friable, coarse-grained, moderately to poorly sorted, with thin beds of whitish claystone as well as numerous bands of variegated rarely carbonaceous shale (Reyment, 1965). Depositional environment of the Maastritchtian sediments was interpreted to be tidal due to several occurrences of herringbone cross-bedding and bioturbations (Agagu et al, 1985).

Nsukka Formation

The Danian Nsukka Formation marks the onset of the transgression and a return to paludal conditions. The fluvio-deltaic formation overlies the Ajali Sandstone and consists of variety of sandstones that passes upward into well-bedded blue clays, fine-grained sandstones, and carbonaceous shales with thin bands of limestone (Ladipo, 1986, Obi et al, 2001).

Imo Shale

The marine Imo Shale is the outcropping equivalent of the Akata Formation in the subsurface Niger Delta. The shales contain a significant amount of organic matter and may be a potential source for hydrocarbons in the northern part of the Niger delta. The author (Arua, 1980) assigned a Paleocene age to the Imo Formation and its depositional environment is mainly marine with littoral to neritic environments.

Ameki Group

The Ameki Group consists of the Nanka Sand, Nsugbe Formation, and Ameki Formation. These formations mark the return to transgressive conditions. The outcropping deposits of the Eocene regression, which marked the beginning of the Niger delta progradation, constitute the "Ameki Group" which includes tidal facies and backshore as well as pro-deltaic facies. The Ameki Formation is predominantly alternating shale, sandy shale, clayey sandstone, and fine-grained fossiliferous sandstone with thin limestone bands (Arua, 1986; Oboh-Ikuenobe et al, 2005).

Ogwashi Asaba Formation

The Oligocene – Miocene Ogwashi Asaba Formation consist of interbedded successions of lignite, shale, sandstone, siltstone, and claystone facies. It is the outcropping equivalent of the Agbada Formation in the subsurface Niger Delta. Depositional environment has been interpreted to be continental (Kogbe, 1976).

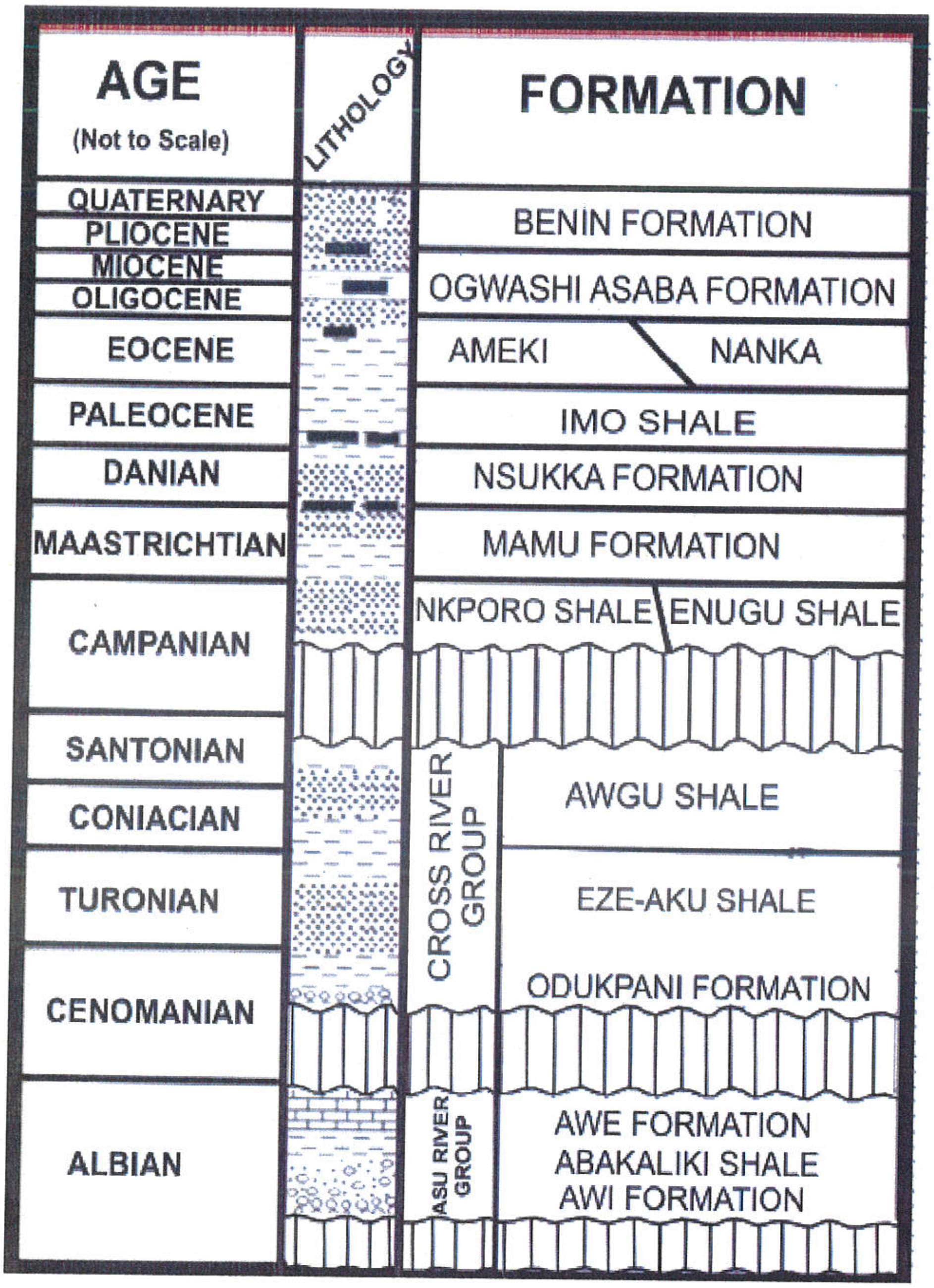

Fig. 2.3: Stratigraphic and Lithologic section of Southern Benue Trough and Anambra Basin from (modified from Akaegbobi *et al.*, 2000).

CHAPTER THREE

METHODOLOGY

3.1 General statement

The methods of investigation employed for the purpose of achieving the objectives of this study are detailed geological field mapping and laboratory studies. Well labeled samples were obtained at different unitsof the section and then stored in sample bags, for further laboratory studies. Measurements, photographs including rough sketches were also made on the field.

3.2 Fieldwork

Fieldwork was carried out between 26^{th} and 27^{th} January, 2018. During these periods, a section of the Eocene Bende Ameki Formation, exposed at the Edo Spring, Nnewi was mapped. The geological mapping involves comprehensive logging, sections measurement, descriptions, and collection of representative samples. The beds were investigated for sedimentary structures, textural and lithologic characteristics e.g colour, presence of fossils, grain size, named and necessary photographs were taken.

3.3 Instrumentation

The mapping was carried out using the following equipment; Global Positioning System (GPS), base map, hammer, chisel, compass clinometers, measuring tapes, marker, pencils, field notes, and sample bags.

3.4 Laboratory Work

Samples from each transect of the fieldwork was subjected to screening through the following analysis:

3.4.1 Organic Geochemistry

Total Organic Carbon

A total of five samples of shale and lignite were collected, washed, pulverized and analyzed for Total Organic Carbon (TOC) by means of LECO – CS analyser. Approximately 100mg of each sample was used and standard method of pulverization and hydrochloric acid (HCl) treatment for carbonate removal was utilized prior to measurement.

Rock-Eval Pyrolysis

The hydrocarbon generation potential, maturity, type of kerogen and Hydrogen Index (HI) values were determined using a Rock – Eval II instrument up to an elevated temperature of ca. 600°C (Espitalie et al., 1977). Pyrolysis of 30 – 40 mg of each sample at 300°C for 4 min was followed by programmed pyrolysis at 25°C/min to 550°C in an atmosphere of helium.

Rock-Eval pyrolysis provides evidence by direct estimation of the free already generated hydrocarbons in the rock (S1) and the hydrocarbons that can be generated from the Kerogen by thermal cracking (S2), S1+S2 represent the rocks total hydrocarbon generation potentials (Dymann, et al., 1996). Tissot and Welte (1984) suggest that a hydrocarbon yield (S1+S2) less than 2 kg HC/t corresponds to little or no oil potential and some potential for gas, S1+S2 from 2 to 6 kg HC/t indicate moderate to fair source rock potential, and hydrocarbon yield above 6 kg HC/t indicate good to excellent source rock potential. The threshold of S1+S2 greater than 2 kg HC/t can be considered as prerequisite for classification as a possible oil source rock (Bissada, 1982) and provides the minimum oil content necessary for the main stage of hydrocarbon generation to saturate the pore network and permit expulsion.

Kerogen type could be identified from the HI values (Tissot and Welte, (1984). Type I kerogen is hydrogen rich (HI greater than 600mg HC/g TOC) and this is considered to be predominantly oil prone. Type II Kerogen is characterized by HI between 350 and 600mg HC/g TOC and this can generate both oil and gas at appropriate level of maturity. Type III Kerogen is characterized by low to moderate HI of between 75 and 200mgHC/g TOC and could generate gas at the appropriate level of thermal maturity. However, humic coals (with Type III kerogen) may have HI up to 300mgHC/g TOC and possess the capacity to generate oil (Petersen and Nytoft 2006). Type IV Kerogen normally exhibits very low HI, less than 50 mgHC/g TOC and is formed under oxic (wild fire) conditions. Peters suggested that at a thermal maturity corresponding to a vitrinite reflectance of 0.6% (Tmax 435°C) rocks with HI above 300mg HC/g TOC will produce oil; those with HI between 300 and 150 will produce oil and gas; and those with HI between 150 and 50 will produce gas and those with HI less than 50 are Inert.

Fig. 3.1: Total Organic Carbon Analyser

3.4.2 Paleontological Studies

Eight agglutinated shale samples were analysed for their microfossil contents. 200g each of the sample were weighed and dried so as to remove the moisture contents in the shale. Solution of concentrated hydrogen peroxide (H_20_2) was diluted with water in ratio 1:3 i.e. 100ml of H_20_2 reacting with 300ml of water. The solution was poured into the weighed shale sample which was already prepared in a container for digestion. The mixture was left for 24 hours for proper digestion after which washing was done using 0.063mm sieve under running water. This was done to identify the species occurrence distribution, paleo-environmental reconstruction and biostratigraphic evaluation. The residues were air dried and stored carefully in well labelled sealed plastic bottles. This was followed with identification, picking and description of the foraminifera species under the binocular microscope.

3.4.3 Palynological Studies

Ten grams of five samples each were taken through numerous processes to extract the palynomorph contents from the embedding sediment. The sample preparation was carried out

3.4.3 Palynological Studies

Ten grams of five samples each were taken through numerous processes to extract the palynomorph contents from the embedding sediment. The sample preparation was carried out following the international standard. Lithified sampleswere crushed with the mortar and pestle in order toenhance maximum recovery of pollen and spores. Thecrushed samples along with the friable samples wereinitially treated with dilute hydrochloric acid (10%) in orderto eliminate carbonate substance present in them. Theywere later soaked in 60% hydrofluoric acid for silica andsilicates digestion. The samples were not oxidized in orderto avoid corrosion; but were sieved with 5µm mesh in orderto maximize concentration of miospore grains and toachieve clean slides for easy identification andphotography. The recovered residues were mounted on glass slides with Deepex (D.P.X.). Total count of miosporegrains present were noted and presented in the checklist for absolute representation of different important pollen and spores grains recovered, while photographs of diagnostic forms were taken.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Lithologic Description

The Bende Ameki Formation exposed at Edo spring is composed of ten (10) lithologic section (Fig. 4.1). The lithologic description of the outcrops was based on sedimentary structure, texture and lithologic characteristics that include; colour and fossil contents. The lithologic section consists of alternating sequences of shales, lignites, claystones, siltstones and sandstones facies. It is about 12m thick with reddish claystone at the base of the section (Fig. 4.1). The claystone is 1.2m thick, and it is overlain by laminated shale and carbonaceous shale with thicknesses of 1.0m and 0.85m respectively. Both shales are grey in colour, with the carbonaceous containing some coaly fragments. These shales pass into the 0.9m thick brownish coloured lignite seam with several woody fragments. The lignite is fractured and appears earthly in lustre. This unit subsequently passes into another cyclic system of shale and lignite depositions with varied thicknesses. At the top of the section is a creamy – greyish claystone with a thickness of 0.4m. The overall section is been capped by 1.6m of lateratized overburden.

Shale Facies

Shales are often found with layers of claystone, sandstone or limestone. They typically form in environments where muds, silts, and other sediments were deposited by gentle transporting currents and became compacted. The shale beds in Edo spring occurred are laminated and carbonaceous, while in some units, coaly fragments were noticed. They varied in thicknesses from 0.5 to 2.2m, with the thickest bed observed in unit (EN 04). The beds are essentially grey to dark grey in colour, which is usually indicative of organic richness (Figs. 4.2)

Lignite Facies

Two seams were observed in the section. The lignite seams observed in Edo spring are generally massive, dark brown in colour and occur at the middle part of the section (Fig 4.3). Two seams that were observed are separated by beds of laminated dark shale and carbonaceous massive shale. The thicker seam is about 1.3m thick and occurs on a higher level than the lower seam, which is about 0.55m. The lignites are fractured and appear dull in lustre.

Claystone Facies

This facie occur at the basal part of the section and it has a thickness of 1m. The argillaceous nature of the claystone suggests a low energy depositional system within floodplains. Clay facies represent low energy sedimentation of high sinuosity channels associated with levees, crevasse splays of the floodplains. Its occurrence in Edo stream is massive, reddish to creamy and contains series of fractures in different directions (Fig. 4.4).

Sandstone Facies

This facie occur as fine grained and contains small clay matrix. The thickness of the bed is 0.6m (Fig. 4.5). The sandstone bed is creamy in colour, massive, ferrugnised and is gradationally overlain by a lateritized overburden. The occurrence of the clay rich sandstone is an indication of low energy of deposition probably in a floodplain environment.

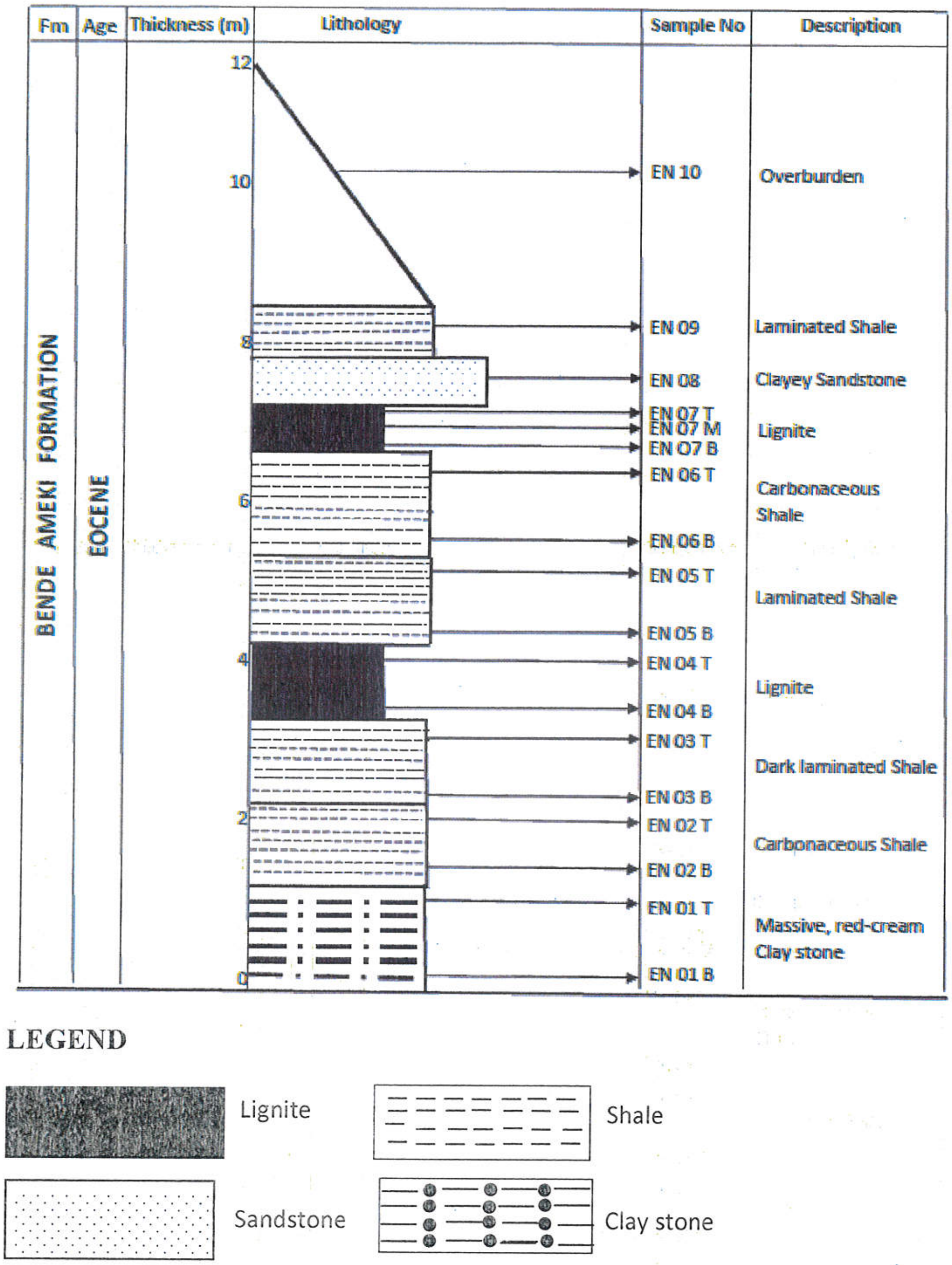

Fig. 4.1: Lithologic section of the Bende Ameki Formation exposed at Edo spring

Fig. 4.2: Laminated shale been overlain by a carbonaceous shale

Fig. 4.3: Lignite facie embedded between two shale beds

Fig. 4.4: Reddish claystone facie at the base of the section being overlain by a carbonaceous shale bed

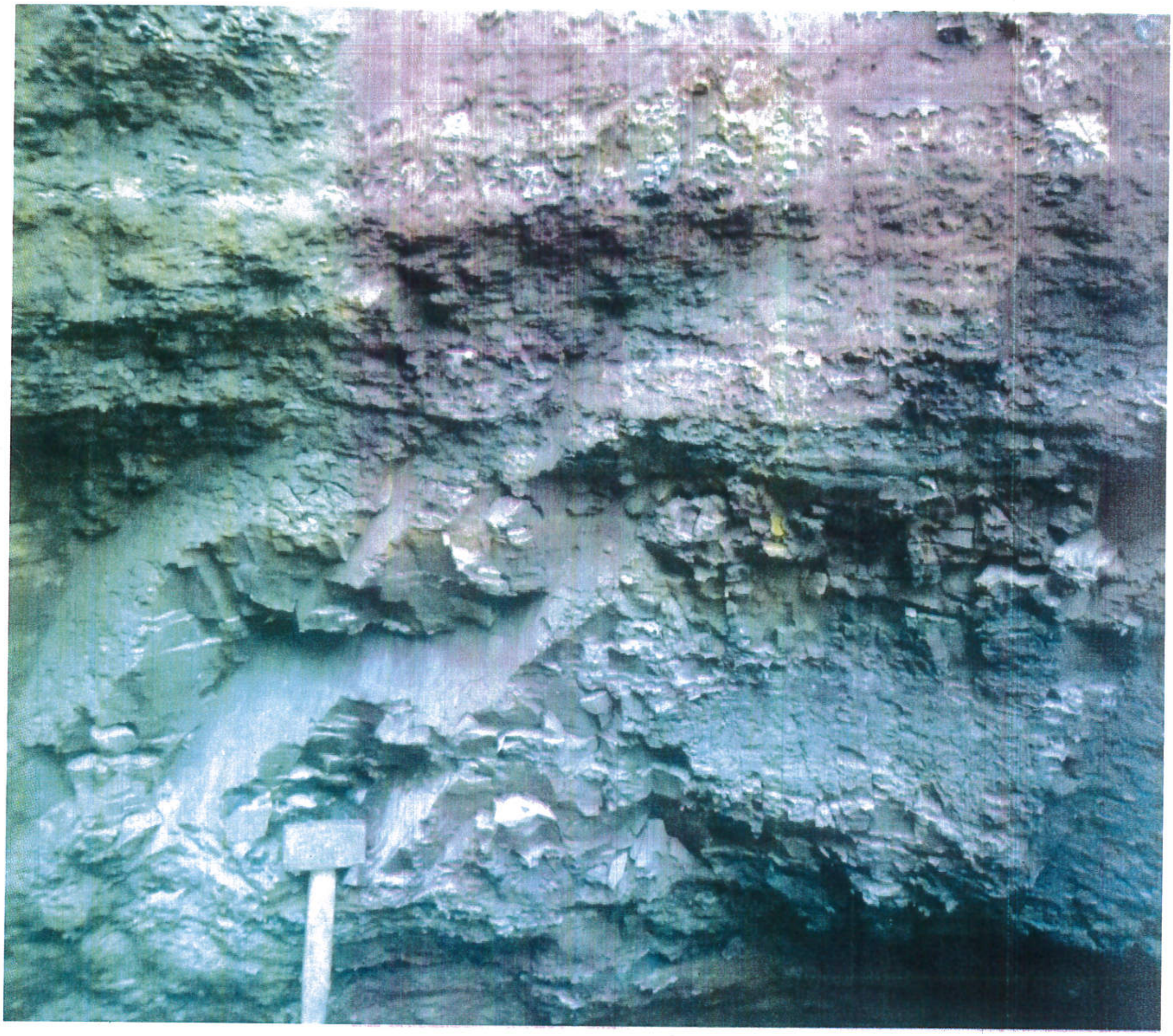

Fig 4.5: Sandstone facie at the top of the section underlain by a shale bed.

4.2 Palynology interpretation

A total of twenty seven (27) palynomorphs were recovered from the studied section of Edo Spring. Some of the palynomorphs identified in the sample include *Psilamonocolpites marginatus, Psilatricolporites crassus, Retibrevitricolporites triangulatus, Psilatricolporites operculatus, Proxapertites operculatus, Spinizonocolpites baculatus, Laevigatosporites spp., Cyathidites minor, Monocolpites marginatus, Cyathidites spp., Ctenolophonidites costatus, Verrucatosporites usmensis, Acrostichum aureum*and *Retimonocolpites obaensis.* Microfloral assemblage is dominated by pollen species (angiosperms) forms identified in the sample but the sample is generally rich in pollen and spores assemblages.

Dinoflagellate cysts such as *Achomosphaera ramulifera, Cleistospaeridium spp.* and *Leiosphaeridia spp.* were also recorded.

Spore and spore diversity: A total of six terrestrial spores are present in the analysed sample namely;. *Laevigatosporites spp., Cyathidites minor, Cyathidites spp., Achrostichum aureum and Verrucatosporite ssp.* They are bilaterally symmetrical and are separated by one aperture which is the centre for growth, germination and identification (Fig. 4.6). Generally, diversity is very low across the section and there is a poor count of the species (Fig. 4.10).

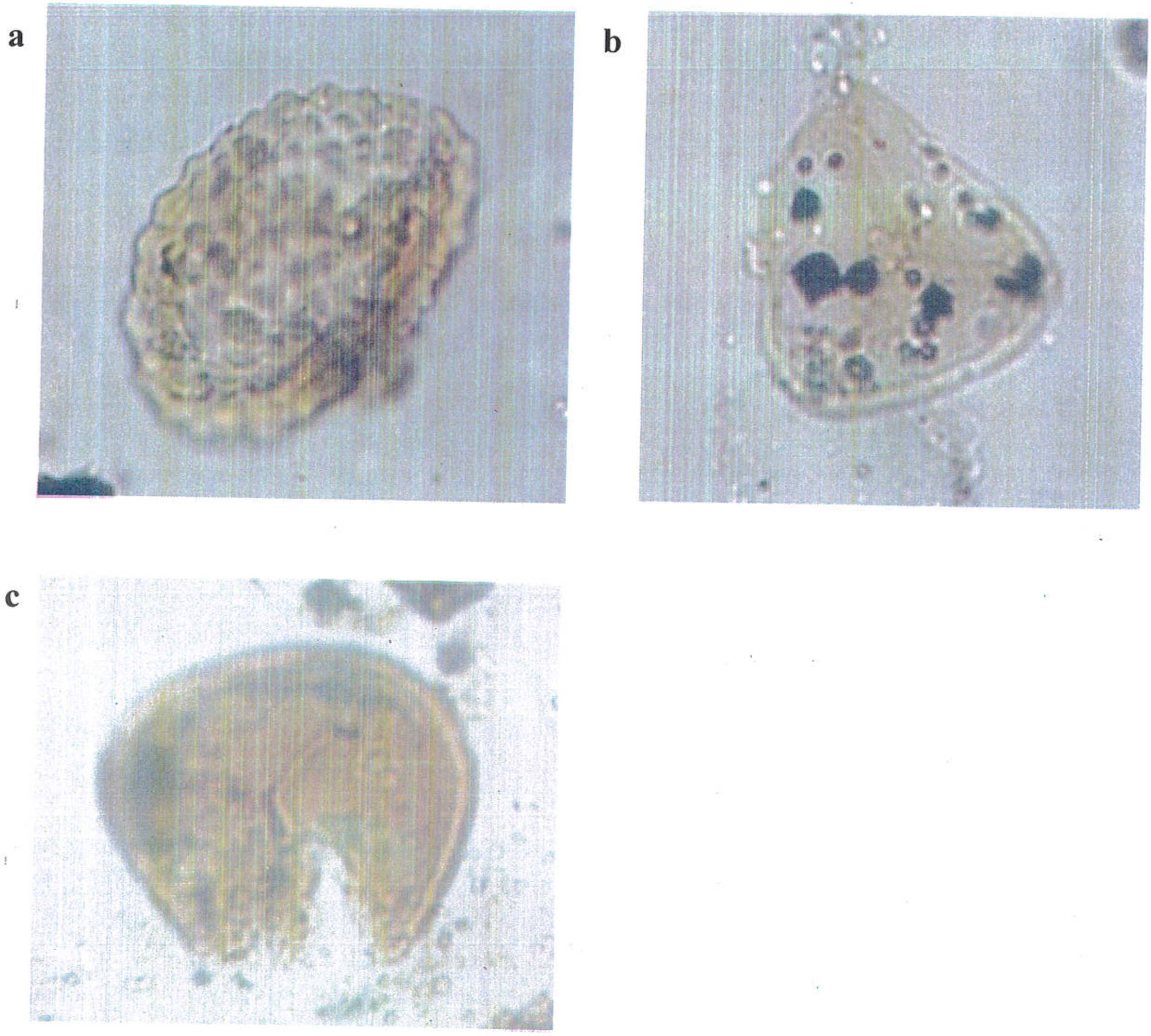

Fig. 4.6: Photomicrograph of the Spore palynomorphs of the Bende – Ameki Formation; Note, a= *Verrucatosporite ssp, b= Cyathidites minor,* c= *Achrostichum aureum*

Pollen: A total of eighteen pollens were recovered fom the analyzed sample namely; *Psilamonocolpites marginatus,, Retibrevitricolporites triangulatus, Psilatricolporites operculatus, Proxapertites operculatus, Spinizonocolpites baculatus, Ctenolophonidites costatus, Retimonocolpites obaensis, Gardenia imperalis (*Fig. 4.7a), *Monocolpites marginatus (*Fig. 4.7b), *Psilatricolporites crassus (*Fig. 4.7c), *Retibrevitricolporites protudens (*Fig. 4.7d), *Proxapertites cursus (*Fig. 4.7e), *Retibrevitricolporites ibadenensis, Retibrevitricolporites obodoensis, Spinizonocolpites echinatus, Spinizonocolpites spp., Proteacidites spp.* They are either radially or bilaterally symmetrical, and have apertures which are opening that serves as the germinating zone (Fig. 4.7).

Four Pollen Aperture types were observed in the study area, these include;

a) Inaperturate: These are pollen grains that lack any recognisable aperture e.g *Gardenia imperalis (*Fig. 4.7a). It is a spherical grain with no aperture or apertures that are evenly dispersed over the surface of the grain which do not have a discernable pole, therefore polarity cannot be determined.

b) Colpus: These are pollen grains with elongate aperture, and with furrow like structure perpendicular to the equator. E.g *Monocolpites marginatus (*Fig. 4.7b), *Retimonocolpites obaensis, Spinizonocolpites echinatus, Spinizonocolpites spp., Psilamonocolpites marginatus, Spinizonocolpites baculatus.*

c) Colporate: These are pollen grains shaped like a colpus but has a circular region in the center. e.g *Psilatricolporites crassus (*Fig. 4.7c) , *Retibrevitricolporites triangulatus, Psilatricolporites operculatus, Retibrevitricolporites ibadenensis, Retibrevitricolporites obodoensis, Retibrevitricolporites protudens (*Fig. 4.7d).

d) Sulcus: These are pollen grains with an elongate aperture but centered at a pole or more rarely, parallel to the equator e.g *Proxapertites cursus (*Fig. 4.7e).

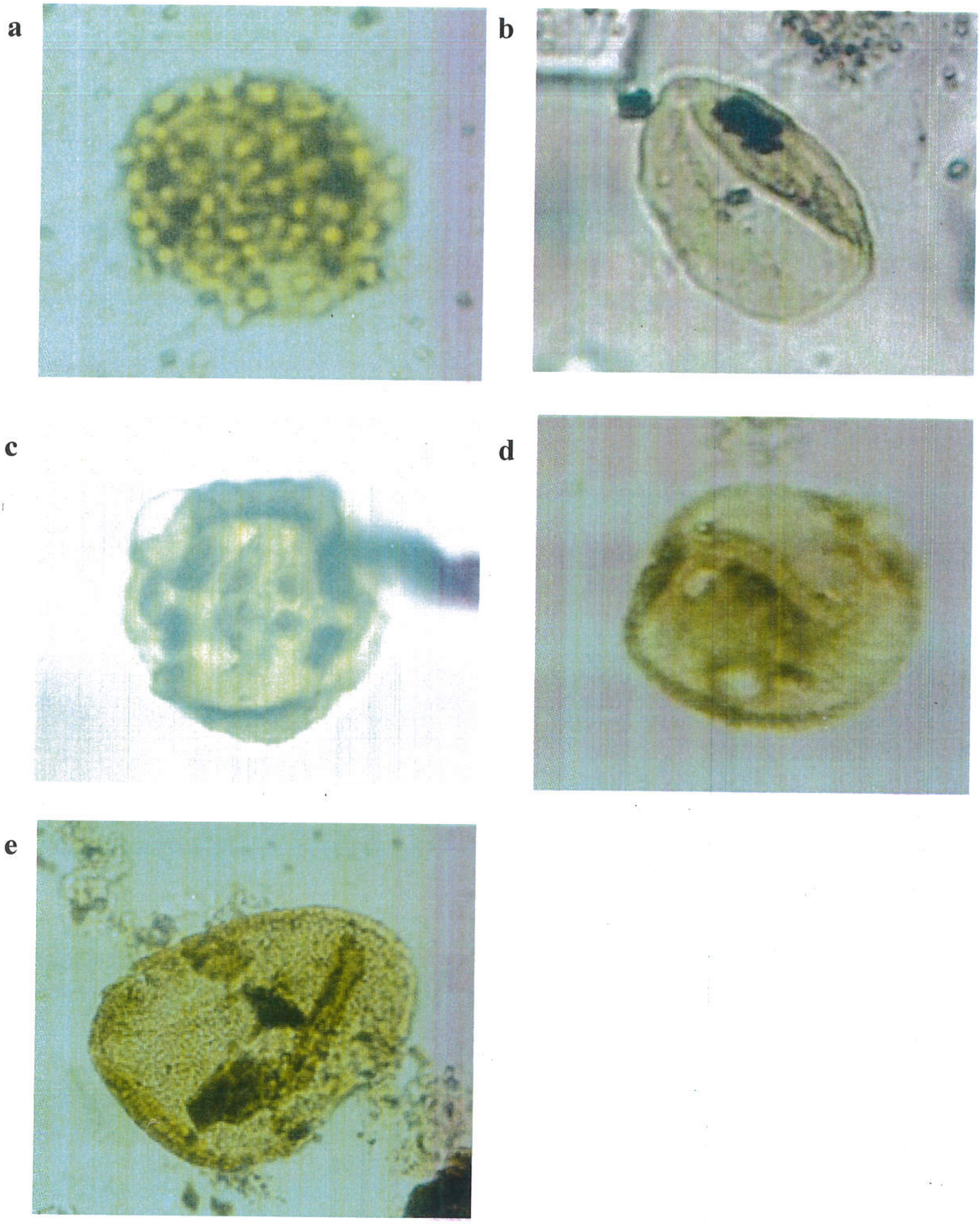

Fig. 4.7: Photomicrograph of the Pollen palynomorphs of the Bende – Ameki Formation; Note, a= *Gardenia imperalis, b= Monocolpites marginatus,* c= *Psilatricolporites crassus, d= Retibrevitricolporites protrudens, e= Proxapertites cursus.*

Pollen Diversity

Diversity in pollen is moderate, to low but population count is fair to highly abundant (Fig. 4.10)

Dinoflagellates

They are unicellular primitive eukaryotes that share both plants and animal characteristics. Most are marine plankton but can also be found in fresh water habitat. Four species of dinoflagellates were found in the analyzed sample namely; *Achomosphaera ramulifera, Cleistospaeridium spp.* (Fig. 4.8) and *Leiosphaeridia spp.* The dinoflagellates in the section EN O3, 05, 06 have a very poor diversity and count.

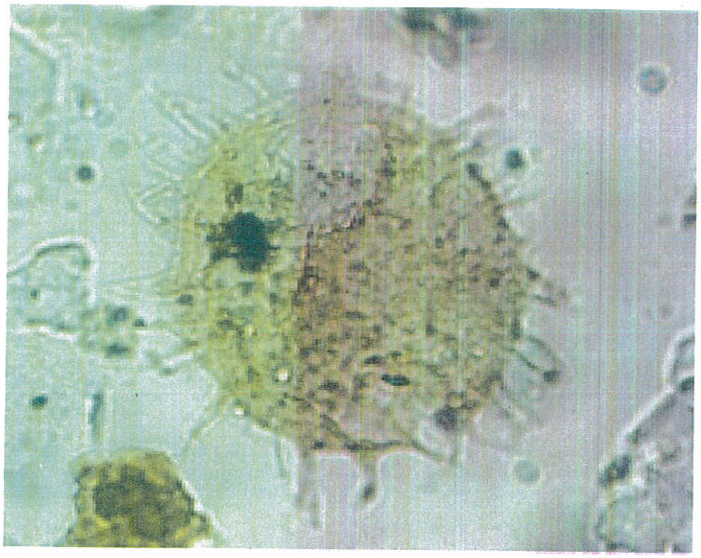

Fig. 4.8: Photomicrograph of the Dinoflagellate palynomorph of the Bende – Ameki Formation. Note, it is *Cleistosphaeridium spp*

Botryococcus braunii is a green algae that often forms extensive blooms and which under appropriate conditions can synthesize and secrete hydrocarbons. Their blooms tend to be toxic to other microbes, plants, and fish populations within the community. They mainly live in fresh to brackish oligotrophic bodies of water with low nutrient content. Botryococcus is absent in all sections apart from EN 02 and it has a poor diversity and count as well (Fig. 4.9).

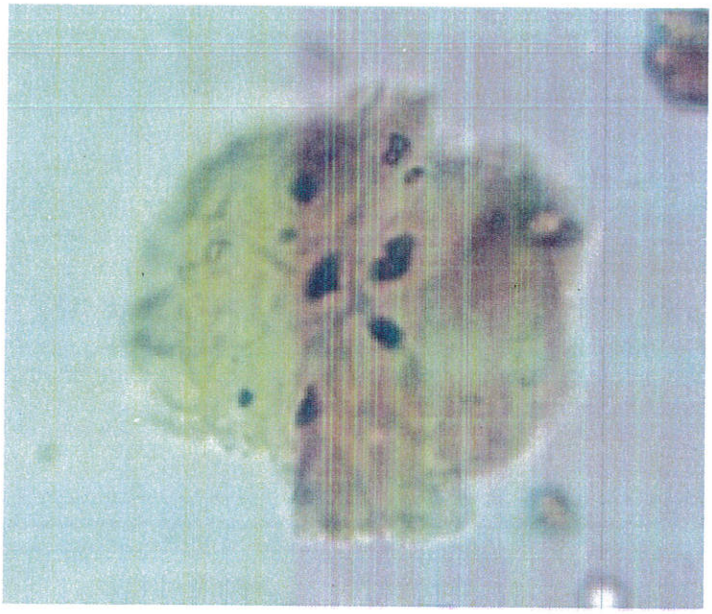

Fig. 4.9: Photomicrograph of the Botryococcus palynomorph of the Bende – Ameki Formation. Note, it is *Botryococcus braunii*

Table 4. 1: Population and diversity count of the Palynomorph speciesbased on the different samples

PALYNOMORPHS	ENO 2	ENO 3	ENO 5	ENO 6	ENO 9
TERRESTIAL SPECIES					
SPORES					
Laevigatosporites spp.	1	12	3	-	3
Cyathidites minor	2	18	1	1	-
Cyathidites spp.	6	-	3	1	1
Acrostichum aureum	11	-	3	1	3
Verrucatosporites usmensis	2	-	-	4	1
Verrucatosporites spp.	-	2	-	-	1
TOTAL COUNT	22	32	10	7	9
POLLEN					

Psilamonocolpites marginatus	4	7	27	19	9
Psilatricolporites crassus	6	-	2	-	-
Retibrevitricolporites triangulatus	3	-	16	1	1
Psilatricolporites operculatus	1	-	-	-	-
Spinizonocolpites baculatus	1	-	-	1	2
Monocolpites marginatus	-	-	2	1	-
Ctenolophonidites costatus	1	-	2	-	1
Retimonocolpites obaensis	-	28	32	2	8
Gardenia imperalis	1	-	-	-	-
Proxapertites cursus	1	3	1	4	5
Retibrevitricolporites ibadenensis	1	-	-	-	-
Retibrevitricolporites Obodoensis	2	-	-	-	-
Retibrevitricolporites protrudens	1	-	-	1	-
Spinizonocolpites spp.	1	1	-	-	-
Proxapertites operculatus	-	2	-	-	-
Proteacidites spp.	-	-	-	1	-
Spinizonocolpites Echinatus	-	-	-	1	-

TOTAL COUNT	23	41	82	31	26
MARINE SPECIES					
Dinoflagellate cysts					
Achomosphaera ramulifera	-	1	-	-	-
Cleistospaeridium spp.	-	-	1	-	-
Leiosphaeridia spp.	-	-	-	1	-
TOTAL COUNT	0	1	1	1	0
Botryococcus Brauni	-	2	-	-	-
TOTAL COUNT	0	2	0	0	0

4.2.1.1 Age determination

Assignment of ages to the sediments from the study areas in the Anambra basin was based on the following stratigraphic ranges of selected key age diagnostic/marker species, (Table 4.2). Species which shows a typical Eocene age include; *Verrucatosporites usmensis (Eisawi and Schrank 2008), Retibrevitricolporites triangulatus (Eisawi and Schrank 2008), Psilatricolporites crassus (Vanderhammen & Wijmstra 1964), Psilatricolporites operculatus (Vanderhammen & Wijmstra 1964).* Others with short range between Paleocene to Eocene includes *Spinizonocolpites baculatus (V. Rull 1999), Proxapertites cursus (Klinkenberg 1966)* (Fig. 4.11).

Based on the identified marker species above, the assemblage is suggestive of an Eocene age for the Bende Ameki Formation, Anambra Basin.

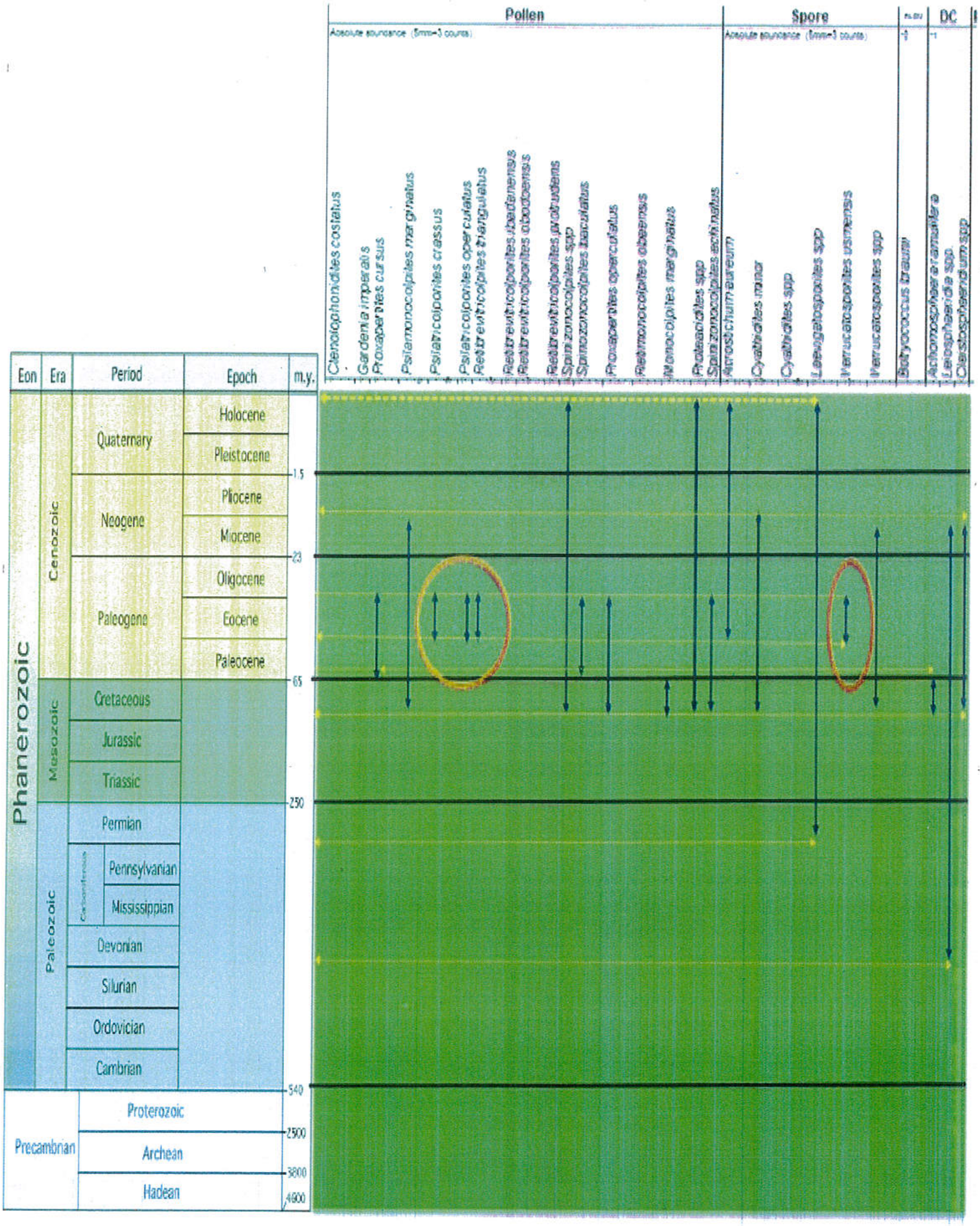

Fig 4.11: Schematic of Palynomorphs in the studied section showing the the Age and notable marker species

Table 4.2: Age and environmental distribution of the palynomorphs in the studied section

Palynomorphs species	**Family**	**Age range**	**Environments**	**Distribution**	**Reference**
SPORES					
Laevigatosporites spp.	*Pteridopsida*	*391 - 0126 Ma*	*Terrestrial, fluvial*	*Permian - Quaternary*	*S. Archangelsky 1973*
Cyathidites minor	*Cyathidites*	*164.7 – 5.332 Ma*	*Fluvial, terrestrial*	*Cretaceous - Miocene*	*Zamaloa 2004*
Cyathidites spp.	*Pteridopsida*	*164.7- 5.332 Ma*	*Terrestrial, fluvial*	*Jurassic- Miocene*	*S. Archangelsky 1973*
Acrostichum aureum	*Pteridophyta*	*55.8 – 0.0 Ma*	*Fluvial, lacustrine, terrestrial*	*Paleocene – Quatenary*	*Fritel 1910*
Verrucatosporites usmensis	*Verrucatospo rites*	*48.6- 37.2 Ma*	*Marine, Fluvial*	*Eocene*	*Eisawi and Schrank 2008*
Verrucatosporites spp.	*Polypodiace ae*	*112.6 – 11.608 Ma*	*Coastal, terrestrial, deltaic*	*Cretaceous – Miocene*	*Eisawi and Schrank 2008*
POLLEN					
Psilamonocolpite s marginatus	*Magnoliophy ta*	*112.6- 5.332 Ma*	*Terrestrial, fluvial*	*Cretaceous – Miocene*	*Vanhoeken - Klinkenberg 1966*
Psilatricolporites crassus	*Psilatricolpo rites*	*48.6-37.2 Ma*	*Mangrove swamp, marginal marine*	*Eocene*	*Vanderhammen & Wijmstra 1964*
Retibrevitricolpor ites triangulates	*Magnoliophy ta*	*48.6 - 37.2 Ma*	*Marine , fluvial- deltaic, terrestrial*	*Eocene*	*Eisawi and Schrank 2008*
Psilatricolporites operculatus	*Ranunculaci dites*	*48.6-37.2 Ma*	*Marginal marine, fluvial*	*Eocene*	*Gonzalez- Guzman 1967*

Spinizonocolpites baculatus	*Spinizonocol pites*	*55.8 – 37.2 Ma*	*Marine , fluvial-deltaic*	*Paleocene – Eocene*	*V. Rull 1999*
Monocolpites marginatus	*Monocolpites*	*70.6 – 66.043 Ma*	*Terrestial, fluvial*	*Cretaceous*	*Nwojiji et al. 2013*
Ctenolophonidite s costatus	*Ctenolophoni dites*	-	-	-	*Vanhoeken - Klinkenberg 1966*
Retimonocolpites obaensis	*Retimonocol pites*	*230-0.01 Ma*	*Terrestial, deltaic, fluvial*	*Campanian-Eocene*	*Jan du chene et al. 1978*
Gardenia imperalis	*Rubiaceae*	-	-	-	-
Proxapertites cursus	*Proxapertites*	*55.8 – 37.2 Ma*	*Marine , fluvial-deltaic*	*Paleocene – Eocene*	*Klinkenberg 1966*
Retibrevitricolpor ites ibadenensis	*Retibrevitric olporites*	-	-	*Late Oligocene*	*Eisawi and Schrank 2008*
Retibrevitricolpor ites *Obodoensis*	*Retibrevitric olporites*	-	-	*Late Oligocene*	*Eisawi and Schrank 2008*
Retibrevitricolpor ites protrudens	*Retibrevitric olporites*	-	-	*Late Oligocene*	*Eisawi and Schrank 2008*
Spinizonocolpites spp.	*Arecales*	*122.46 – 37.2 Ma*	*Terrestial, fluvial- deltaic, floodplain*	*Cretaceous – Quatenary*	*S. Archangelsky 1973*
Proxapertites operculatus	*Proxapertites*	*66.043 – 37.2 Ma*	*Terrestial, fluvial- deltaic, Lagoonal*	*Cretaceous – Eocene*	*Jaramillo and Dilcher 2001*
Proteacidites spp.	*Proteales*	*99.7 – 0.126 Ma*	*Terrestial, fluvial- deltaic*	*Cretaceous - Quatenary*	*S. Archangelsky 1973*
Spinizonocolpites *Echinatus*	*Spinizonocol pites*	*84.9 – 48.6*	*Marine, offshore*	*Cretaceous – Eocene*	*i. Rull 1999*
Dinoflagellates					

Achomosphaera ramulifera	*Achomosphaera*	*84.9 – 70.6 Ma*	*Marine*	*Late Cretaceous*	*Dolding 1992*
Cleistospaeridium spp.	*Gonyaulacales*	*140.2 – 15.97 Ma*	*Marine, coastal, deltaic*	*Cretaceous - Miocene*	*Hedlund and Beju 1977*
Leiosphaeridia spp.	*Acritarcha*	*542.0 – 5.332 Ma*	*Marine, subtidal, marginal marine, shallow subtidal, offshore shelf.*	*Ordovician - Miocene*	*J. Yao et al 2005*

4.2.1.2 Paleoenvironment

A number of workers have used palynomorph content to determine environment of deposition of sediment. These includes; Van Bergen et al. 1990; Oloto, 1989; Petters and Edet, 1996; Vadja Santinavez, 1988; Ojo, 1999. In this study, the interpretation is based on the ratio of land derived miospores to marine dinoflagellates. The total number of occurrence of pollen, spore, botryococcus and dinoflagellate cyst are 18, 6, 3 and 1 respectively. These indicates the dominant palynomorphs in the section with few marine dinoflagellates suggesting a paralic environment (Fig. 4.12).

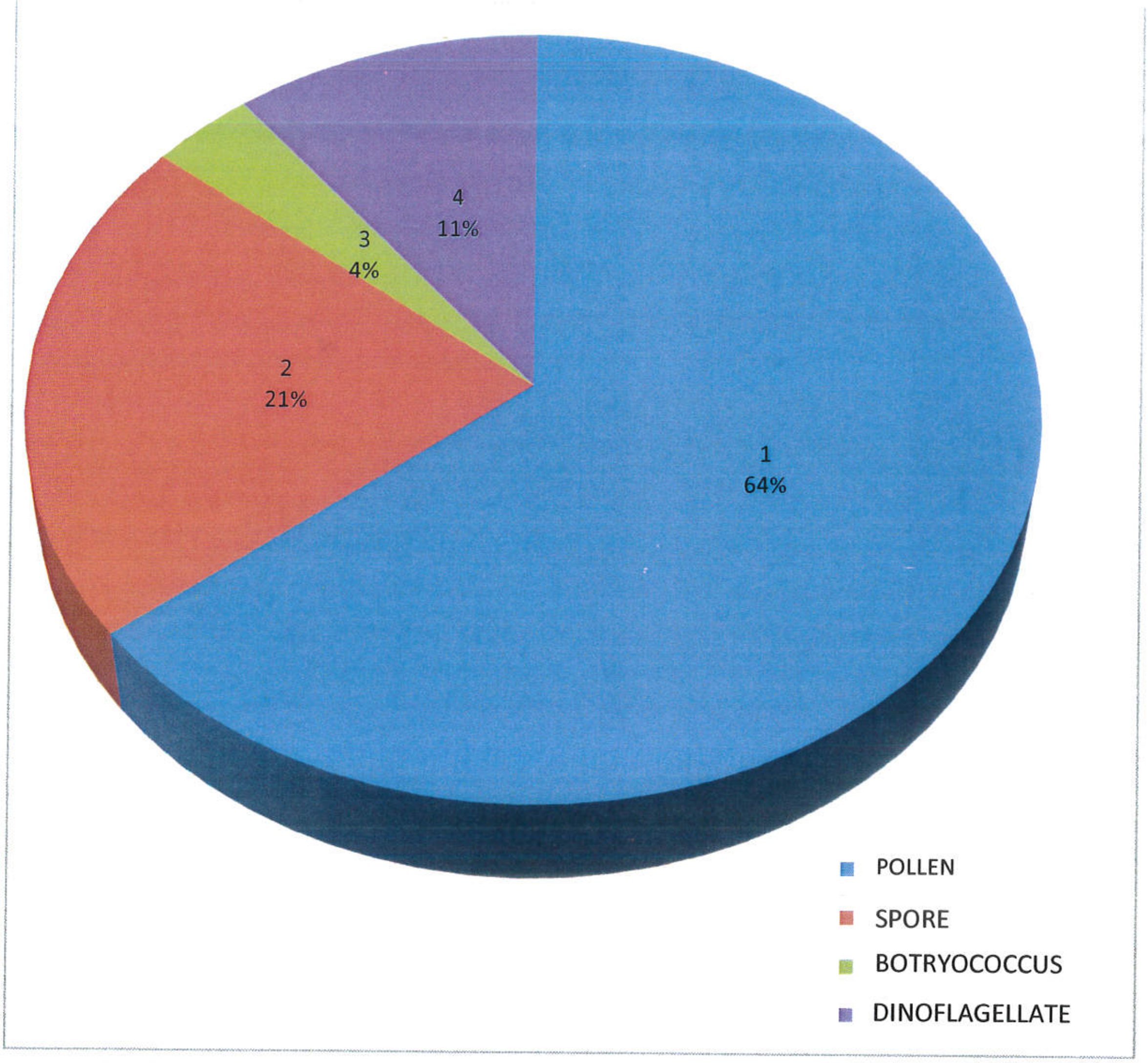

Fig. 4.12: Pie chart showing the percentage of Pollen, Spore, Bryotococcus and Dinoflagellate .

4.3 Paleontology

Foraminifera are a group of organisms that are ubiquitous throughout the world's oceans, but the distribution of individual species especially the benthics is constrained by their environmental preferences. Therefore, these organisms have the potential to provide important environmental information. Foraminefera species have the potential to provide important environmental information. Eight agglutinated shale samples from the studied section were selected for foraminifera analysis, but the samples were found to be barren of foraminifera. The barrenness of foraminifera in the sample may be attributed to the high percentage of coaly fragments within the shales and the prevalence of siliciclastics, making the shales to be sandy. These factors are generally not the most favourable for the foraminifera species thus constraining their survival.

4.4 Organic Matter Richness

The results of the Total Organic Carbon (TOC) and Rock-eval pyrolysis of the samples are shown in Table 4.3. Peters (1986) has reported that the commonly accepted minimum TOC content for a potential source rock is 0.5%, while rocks containing less than 0.5% TOC are considered to have negligible hydrocarbon source potential. He further stated TOC values ranging between 0.5 and 1.0 % indicate marginal and more than 1.0 % TOC often has substantial source potential. TOC values between 1.0 and 2.0 % are associated with depositional environments intermediate between oxidizing and reducing, where preservation of lipid-rich organic matter with source potential for oil can occur. TOC values above 2.0% often indicate highly reducing environment with excellent source potential. Measurement of TOC in sediments is not sufficient enough to identify potential hydrocarbon source beds because transported terrestrial organic matter from a previous sedimentary cycle can create an organic richness of about 4 wt.%, yet this concentrated organic matter could be hydrogen poor and without significant petroleum generating potential (Demaison and More, 1980; Demaison and Shibaoka, 1975; Dow, 1977).

Table 4.3: Results of the TOC and Rock-Eval Pyrolysis of Bende Ameki Formation sediments

Sample ID	Lithology	TOC Wt.%	S1 (mgHC/g rock)	S2 (mgHC/g rock)	S1+S2 (kg HC/t rock))	Tmax (°C)	HI (mgHC/ g TOC)	OI (mgHC/ g TOC)	PI
EN 02	Shale	10.5	3.6	15.8	19.4	424	151	53	0.19
EN 03	Shale	22.57	3.23	32.25	35.48	415	143	7	0.03
EN 04T	Lignite	51	5.9	103.3	109.2	408	202	42	0.05
EN 04B	Lignite	59.56	10.48	306.38	316.86	417	514	22	0.03
EN 05	Shale	13.1	5.2	20.2	25.4	421	154	25	0.21
EN 06	Shale	13.8	3.5	23.7	27.2	421	172	36	0.11
EN 07T	Lignite	44	6.2	105.4	111.6	411	239	50	0.06
EN 07B	Lignite	56.62	7.10	137.19	144.29	410	242	36	0.05

The Total Organic Carbon (TOC) results of the four lignite samples range from 44 to 59.56 wt% (mean= 51.78 wt%) for four samples, whereas those of the four shales range from 10.5 to 22.57 wt% (mean=16.53 wt%) (Table 4.3). This indicates that the sediments contain good to excellent organic matter contents associated with highly reduced environment of deposition. To further highlight the source rock potential of the sediments, the generative potential (S1+S2) results showed that the shales have GP values ranging from 19.4-35.48 mgHc/g TOC, while those of lignite range from 109.2-316.86 mgHC/g TOC (Table 4.3). These suggest that the shales and lignites are very good potential source rocks (Peters and Cassa, 1994; Tissot and Welte, 1984).

4.4.1.1 Hydrogen Index (HI)

Hydrogen Index is a measure of the hydrogen richness of the source rock, and is the ratio of S2 (mg HC/g rock) to Total Organic Carbon (TOC) in weight percent. Although organic matter content in sediments is usually estimated by a determination of organic carbon, the limiting element in the petroleum forming reaction is not carbon but hydrogen. The more the hydrogen content in a source rock, the more tendency to generate oil Hunt (1991). The HI values range from 143 to 172 mgHC/gTOC with an average value of 155 mgHC/gTOC indicating a Type III gas prone kerogen for the shales, whereas in the lignites, HI range from 202 to 514 mgHC/gTOC with an average of 299 mgHC/gTOC indicating a Type II oil prone to Type II/III oil and gas prone kerogen (Table 4.3).

4.4.1.2 Oxygen Index (OI)

Oxygen Index measures the oxygen richness of a source rock and can be used in conjunction with the hydrogen index to estimate the quality and thermal maturity of source rocks. This index is unreliable in rocks with high carbonate content. High OI values (>50 mg/g) are characteristic of immature hydrocarbons. Result of the OI for both the shales and lignites range from 7 – 53 mgHC/gTOC with an average of 33.88 mgHC/gTOC, this reveals that both source rocks are thermally immature.

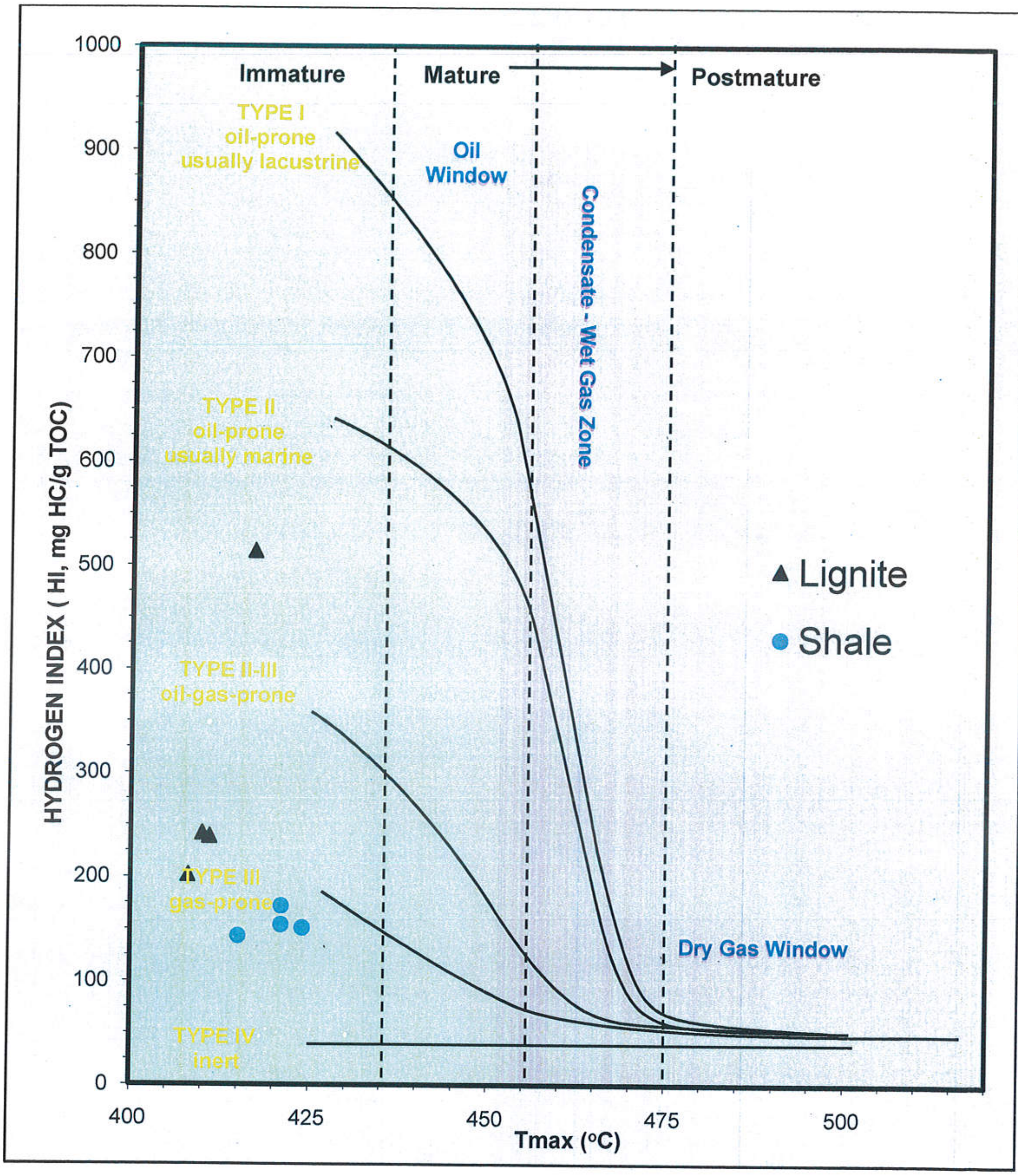

Fig. 4.13: Plot of Hydrogen Index (HI) against Tmax revealing the immaturity of the source rocks

4.4.1.3 Type of Organic Matter

Characterization of organic matter in source rocks can be accomplished through a number of parameters from Rock-Eval Pyrolysis measurements and their derivatives. The amount of hydrogen in kerogen is the most important factor with respect to the capacity of source rocks to generate petroleum (Hunt, 1996). Hydrogen-rich organic matter commonly generates more oil than hydrogen-poor organic matter (Demaison and Moore, 1980). Hydrogen index is a measure of hydrogen richness in kerogen and has a direct relationship with elemental hydrogen to carbon ratios. The index is used to define the type of kerogen and approximate level of maturation (Tissot et al., 1974). Van Krevelen diagram of Hydrogen Index (HI) against Tmax for the sediments of Bende Ameki Formation (Fig. 4.13) shows that the organic matters contained in the sediments are predominantly Type II/III oil and gas prone and Type III gas prone kerogen which are capable of generating oil and gas.

4.4.1.4 Thermal Maturity of the Organic Matter

Thermal maturity (Tmax) provides an indication of source rock maturity and likewise represents the temperature at which the largest amount of hydrocarbons can be produced in the laboratory when a whole rock sample undergoes a pyrolysis treatment (i.e. S2).The Tmax values correlates directly with vitrinite reflectance values and can be used to depict the maturity of the organic matter. Peters (1986) suggested that a thermal maturity equivalent to a vitrinite reflectance of 0.6% (Tmax 435) of rocks with HI >300mg HC/gTOC produces oil. Plots of PI versus Tmax (Fig. 4.15) further shows that sediments are predominantly immature with respect to hydrocarbon generation as a result of contamination and low level of conversion.

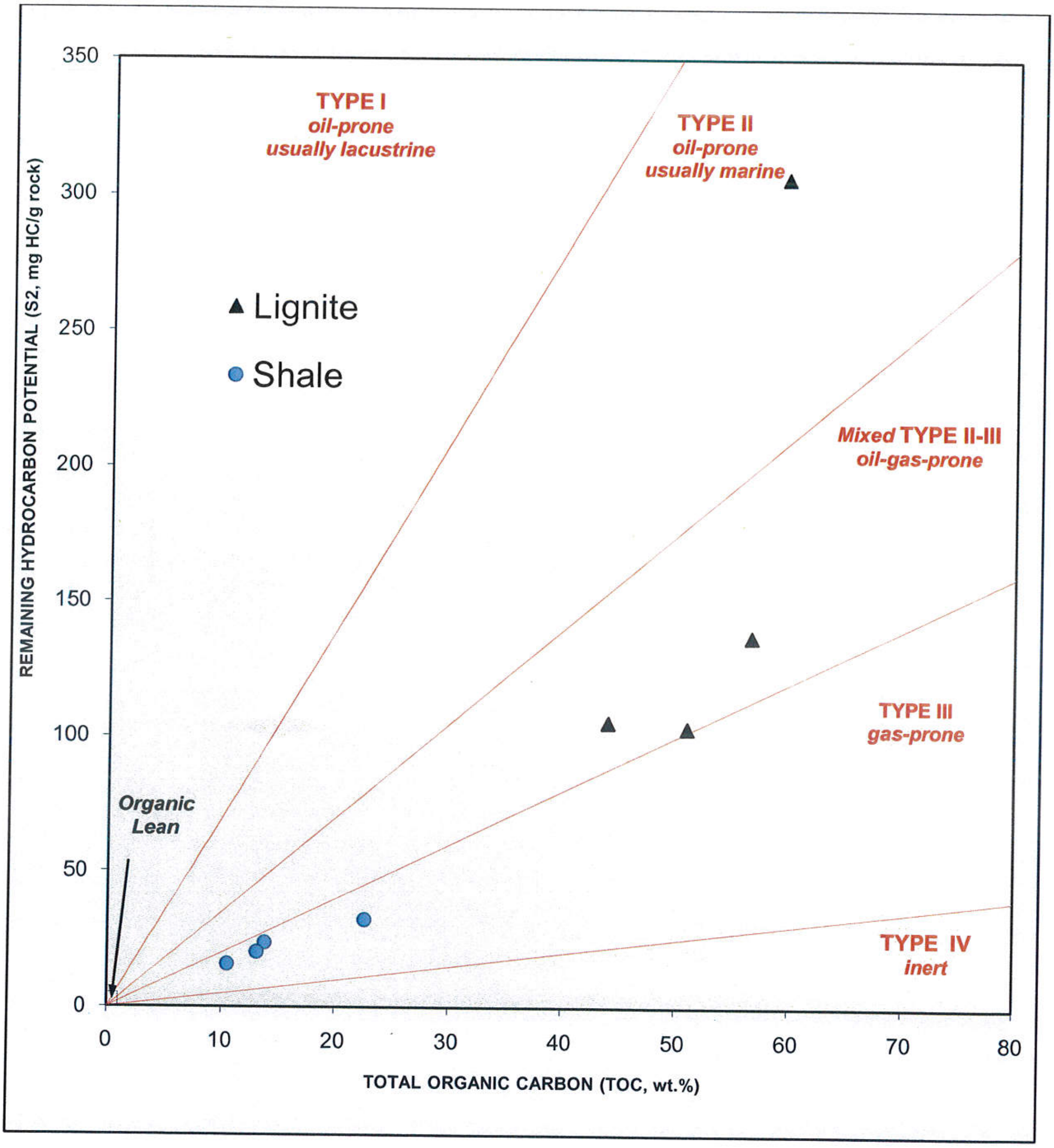

Fig. 4.14: Plot of S2 against TOC for the source rocks of Bende Ameki Formation.

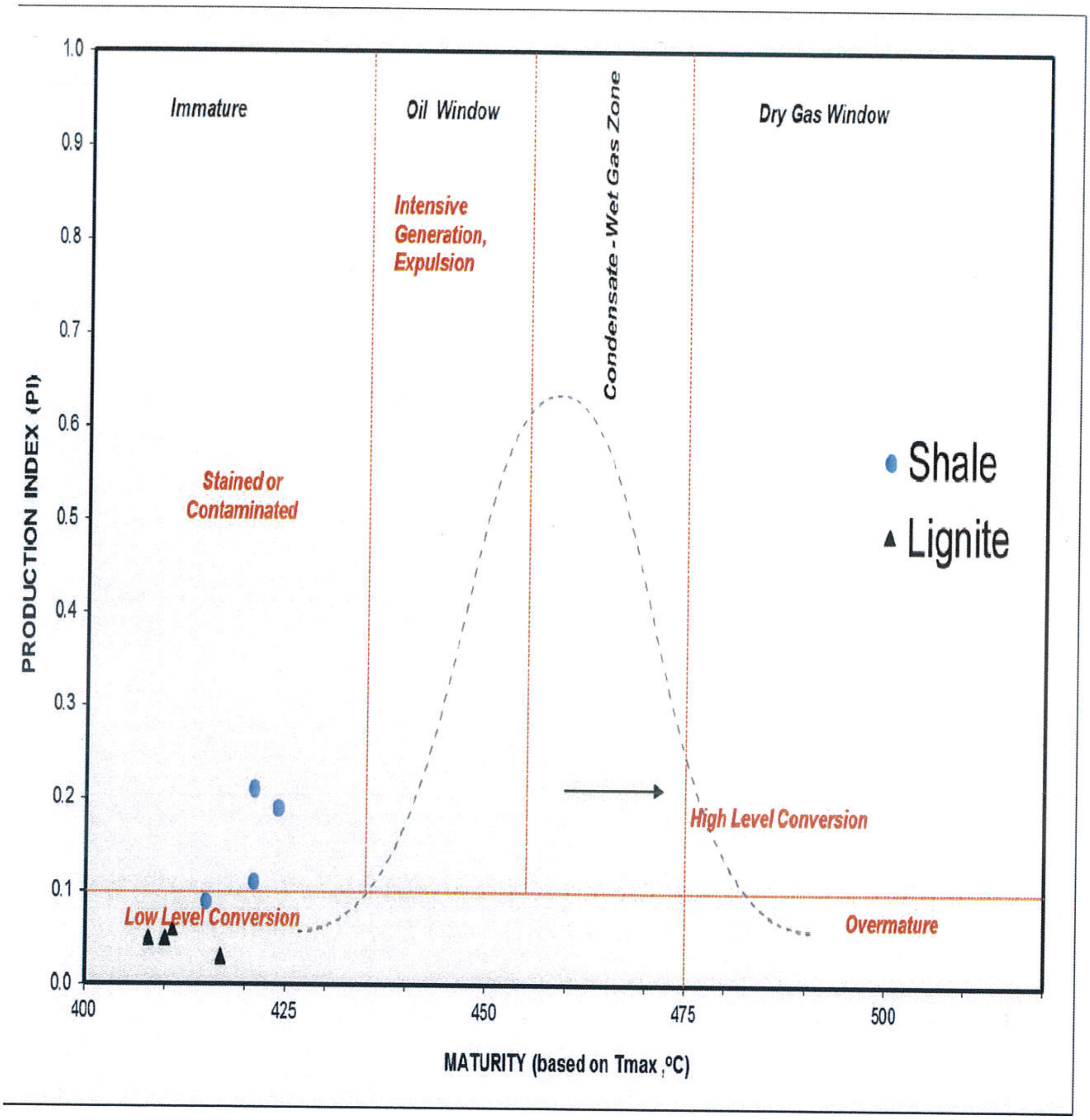

Fig. 4.15 Plot of Production Index against Tmax revealing the thermal maturity

Chapter Five

Conclusions

The Eocene Bende Ameki Formation exposed at the Edo spring, Nnewi in the Anambra Basin consist of interbeded lignite, shale, sandstone, claystone facies. This was studied in order to reconstruct the paleoenvironment and assess their petroleum source rock potentials. The study concluded on the following:

1. The barrenness of foraminifera in the sample may be attributed to the high percentage of coaly fragments within the shales and the prevalence of siliciclastics, making the shales to be sandy. These factors are generally not the most favourable for the foraminifera species thus constraining their survival.
2. Based on the predominance of terrestrial pollen and spore assemblages, as well as marine dinoflagelates, a paralic environment of deposition is suggested for the formation. More so, the occurrences of significant marker species in the section have indicated the age to be Eocene.
3. Source rock facies investigated have good to excellent organic matter content and can therefore be considered as potential petroleum source rocks but yet to reach thermal maturity.

References

Akaegbobi, I. M., Nwachukwu, J. I., and Schmitt, M., 2000. Aromatic hydrocarbondistribution and calculation of oil and gas volumes in post-Santonian shale and coal, Anambra Basin, Nigeria: In M. R. Bello and B. J. Katz, eds., Petroleum systems of South Atlantic margins: Amer. Assoc. Petrol. Geol. Memoir. v. 73, p. 233-245.

Agagu, O. K., Fayose, E. A., Petters, S. W., 1985. Stratigraphy and sedimentation in the Senonian Anambra Basin of Eastern Nigeria: Journal of Mining and Geology. v. 22, p. 25–36.

Ajakaiye, D.E. & Burke K., 1973. A Bouger gravity map of Nigeria.Tectonophys. v. 16,p. 90-103.

Akande S.O., Erdtmann B.D., 1998. Burial metamorphism (thermal maturation) in Cretaceous sediments of the Southern Benue Trough and Anambra Basin, Nigeria. AAPG Bulletin. v. 82, p. 1191–1206.

Arua, I., 1980. Palaeocene macrofossils from the Imo Shale in Anambra Basin, Nigeria. Journal of Mining and Geology. v. 17, p. 81– 84.

Arua, I., 1986. Paleoenvironment of Eocene deposits in the Afikpo Syncline, Southern Nigeria. Journal of African Earth Sciences. v. 5, p. 279–284.

Avbovbo, A. A., Ayoola, E. O. and Osahon, G. A., 1986. Depositional and Structural Style in Chad Basin of Northeastern Nigeria. AAPG Bulletin. v. 70(12), p. 1787-1798.

Bissada, K. K., 1982. Geochemical constraints on the petroleum generation and migration– a Review. Proceed. v. Asian Council on Petroleum (ASCOPE „ 81), p. 69 – 87.

Demaison, G. J. and Shibaoka M., 1975. Contribution to the study of hydrocarbongeneration from hydrogen-poor kerogens. 9th World Petroleum Congress, Tokyo. Proceedings. v. 2, p 195-197.

Demaison, G. J. and Moore G. T., 1980. Anoxic environments and oil source bed genesis.*AAPG Bulletin*. Vol. 64, pp 1179-1209.

Dolding P.J.D., 1992. Palynology of the Marambio Group (Upper Cretaceous) of northern Humps island. Antartic Science. v. 4(3), p. 311-326.

Dow, W. G. 1977. Kerogen studies and Geological interpretations. Journal of Geochemical Exploration. v. 7, p. 79-99.

Dymann, T. S., Palacos, J. G., Tysdal, R. G., Perry, W. J. and Pawlewicz, M. J., 1996. Source Rock Potential of Middle Cretaceous Rocks in Southwestern Montana:AAPG Bulletin, v. 80, p. 1177-1184.

Eisawi A. and Schrank E., 2008. Upper Cretaceous to Neogene palynology of Melut Basin,Southeast Sudan. v. 32, p. 101-129.

Espitalie, J., Madoc, M., Tissot B. P. Menning, J. J., Leplat, P., 1977. Source rockcharacterisation method for exploration. In: Offshore Technology Conference Paper 2935. 11th Annual OTC, Houston. v. 3, p. 439-444.

Fairhead, J.D. and Okereke, C.S., 1987. "A Regional Gravity Study of West African Rift system in Nigeria and Cameroon and its Tectonic Interpretation". Tectonophysics. v. 143, p. 141-159.

Fritel P.H., 1910. Etude sur les vegetaux fossils de letage sparnacien du Bassin de Paris. Memoirs de la Societe Geologique de france, Palaeontologie. v. 40, p. 1-37.

Genik GJ., 1992. Regional framework, structural and petroleum aspects of rift basins inNiger, Chad and Central African Republic (C.A.R.). Tectonophysics. v. 213, p. 169–185.

Gonzalez-Guzman A.E., 1967. A palynological study on the upper Los Cuervos and Mirador Formations (Lower and middle Eocene; Tibu area, Colombia). p 1-68.

Hedlund R.W. and Beju D., 1977. Straigraphic palynology of selected Mesozoic samples, DSDP Hole 327A and site 330. Deep sea drilling project. v. .XXXVI, p. 817-827.

Jan du Chene, R.E. et al., 1978. Some new Eocene pollen of Ogwashi Asaba Formation, southeastern Nigeria. v 10, p. 285-322.

King, Lester 1950. Speculations upon the Outline and the Mode of Disruption of Gondwanaland. Geological Magazine. v. 87, issue 05, p. 353.

Kogbe, C. A., 1976. Paleogeographic history of Nigeria from Albian times. In: Kogbe,C.A. (Ed.), Geology of Nigeria. Elizabethan Publishers, Lagos. p. 237–252.

Ladipo, K.O., 1986. Tidal shelf depositional model for the Ajali Sandstone, Anambra Basin, Southern Nigeria. Journ. Afr. Earth Sciences. v. 5, p. 177-185.

Nwachukwu, J. I., 1972. The tectonic evolution of the southern portion of the BenueTrough, Nigeria. Geology Magazine. v. 109, p. 511-419.

Nwajide, C. S, Reijers T. J. A., 1996. Sequence architecture in outcrops: examples from the Anambra Basin, Nigeria. Nigerian Association of Petroleum Explorationists Bulletin. v. 11: p. 23–33.

Nwojiji C.N., Osterloff P., Okoro A. and Ukeri P.O., 2013. Palynostratigraphy and Age of the Sequence Penetrated by the Kolmani River 1 Well in the Gongola Basin, Northern Benue Trough, Nigeria. Journal of Geosciences and Geomatics. v. 1(1), p. 15-21.

Obaje, N. G., Wehner, H., Scheeder, G., Abubakar, M. B. and Jauro, A., 2004. Hydrocarbon prospectivity of Nigeria"s inland basins: From the viewpoint of organic geochemistry and organic petrology. Amer. Assoc. Petrol. Geol. Bull.. v. 88, no. 3, p. 325-353.

Obi, G. C., Okogbue, C. O., Nwajide, C. S., 2001. Evolution of the Enugu Cuesta: A tectonically driven erosional process. Global Journal of Pure Applied Sciences. v. 7. p. 321–330.

Oboh-Ikuenobe, F. E., Obi C. G. and Jaramillo C. A., 2005. Lithofacies, palynofacies, and sequence stratigraphy of Paleogene strata in Southeastern Nigeria. Journal of African Earth Science. v. 41, p. 79-101.

Ofoegbu, C. O., 1984. A model for the tectonic evolution of the Benue Trough of Nigeria: Geol. Rundsch. v. 73, p. 1009-1020.

Ojo, O. J., Kolawole, A. U. and Akande, S. O., 2009. Depositional environments, organicrichness, and petroleum generating potential of the Campanian to Maastrichtian

Enugu Formation, Anambra Basin, Nigeria. The Pacific Journal of Science and Technology. v. 10, no. 1, p. 614 – 628.

Olade M. A., 1975. Evolution of Nigeria"s Benue Trough, a tectonic model: Geological Magazine. v.112, p..575-583.

Olade M. A. D., 1975. Trace element and isotopic data and their bearing on the genesis of Precambrain spilites from Athapuscow aulacogen, Great Slave Lake, Canada. Geological Magazine. 112,283-293.

Peters K.E., 1986. Guidelines for evaluating petroleum source rock using programmed pyrolysis: AAPG Bulletin. v.70, p. 318-329.

Peters K. E. and Cassa M.R., 1994. Applied source rock geochemistry. In: The Petroleum System, From Source to Trap (L.B. Magoon and W.G. Dow, eds.), *AAPG Memoir*. v. 60, Tulsa, OK, p. 93-117.

Petersen H. I., 2006. The petroleum generation potential and effective oil window of humic coals related to coal composition and age. Int. J. Coal Geol.. v. 67, p. 221–248.55.

Reyment R. A., 1965. In: Aspects of the Geology of Nigeria. University of Ibadan Press,Nigeria.p. 145.

Rull. V., 1999. Palaeofloristics and paleovegetational changes across the Paleocene/Eocene boundary in northern South America. Review of Paleobotany and Palynology. v. 107, p. 83-95.

Salufu, S. O. and Ogunkunle, T. F., 2015. Source Rock Assessment and Hydrocarbon Prospects of Anambra Basin: Salient Indications for Maturity. The Pacific Journal of Science an Technology. v. 16(1), p. 336-344.

Tissot, B. P. and Welte, D. H., 1984. Petroleum Formation and Occurrence, 2nd ed. Springer-Verlag, Berlin. p. 699.

Van der Hammen, T. and Wymstra, T.A., 1964. A palynology study on the Tertiary and Upper Cretaceous of British Guiana. Leidse Geologische Mededelingen, D1. v. 30, p. 183-241.

Van Krevelen D. W., 1993. Coal, Typology-Physics-chemistry-Constitution. 3rd Ed., Elsevier, Amsterdam. p. 979.