TITLE PAGE

SOURCE ROCK EVALUATION AND DEPOSITIONAL ENVIRONMENT OF MIDDLE EOCENE – EARLY MIOCENE SEDIMENTS IN UMUAHIA AND IT'S EVIRONS, NIGER DELTA BASIN, SOUTHEASTHERN NIGERIA.

OFUEBE NGOZI, C

PG/MSc/09/51175

A RESEARCH SUBMITTED TO THE DEPARTMENT OF GEOLOGY, FACULTY OF PHYSICAL SCIENCES, UNIVERSITY OF NIGERIA, NSUKKA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE (MSc) IN PETROLEUM GEOLOGY.

AUGUST, 2015.

APPROVAL PA*GE*

This Research project has been approved by the department of Geology, Faculty of Physical Sciences, University of Nigeria, Nsukka.

By

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CERTIFICATION

Ofuebe Ngozi C, a postgraduate student in the Department of Geology with Registration No: PG/MSc/09/51175 has satisfactorily completed the requirement for course and research work for the degree of Master of Science in Geology with emphasis on **Petroleum Geology**. The work is original and has not been submitted in part or full thereof for any diploma or degree or professional qualification of the University or any other University.

Dr. S.C. Obiora	Dr. A.W.Mode
(Head of Department)	(Project Supervisor)

DEDICATION

This work is dedicated first to God, and secondly to my Husband, my mother, my brothers, my sisters, and my friends.

ACKNOWLEDGEMENT

Firstly and before all, my complete praise is for Almighty God**,** Lord of the universe, who guided and blessed me to make this work a success.

Certainly the author of any thesis like this has been aided by a great array of people. I wish to express my sincere appreciation to Dr. A.W. Mode for suggesting the Lignites of Ogwashi Asaba Formation subject suitable for scientific research. He is also thanked for providing contacts were the samples were analysed, reviewing the manuscript, beside many other assistance rendered. His help and continuous audience gave me the possibility to finish this work.

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I fondly remember my husband; Engr.Faith Ikechukwu Ugwumsinachi, parent; Mrs Regina Ofuebe, my brothers; HRM, Igwe A.I.Ofuebe, Barrister Henry Udenze Ofuebe, Mr Onochie Emmanuel Ofuebe, Mr.Chinedu Innocent Ofuebe, my sisters; Mrs Agnes Ada Ottih, Mrs Theresa Uloma Nwanya; my niece Miss Ijeoma Ottih and others too numerous to mention for their prayerful support and understanding. Their love has been the motivating force pushing me to achieve my goals and aspirations.

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Dozens of people helped in several ways. It is not possible to acknowledge all such appreciated help except by this general statement of hearty thanks. May God’s favour and grace be upon you all.

ABSTRACT

The study area is bounded by latitudes $5^0 27'$N and $5^0 34'$N, and longitudes $7^0 25'$E and $7^0 35'$E. It falls within the Northern Niger delta Basin. The aim of this present study is to evaluate the hydrocarbon potentials of the sediments in the area, determine their age and environment of deposition. To achieve this aim, geochemical analysis (TOC and Rock-Eval) and Palynological studies were carried out on fifteen (15) samples. Results from the analysis indicates that the total organic carbon (TOC) values of the lignites range from 15.65 – 48.61wt.%, averaging (34.23wt.%), while TOC of shales range from 1.07 – 2.61wt.%, averaging (2.11wt.%). The genetic potential (GP) of the lignites range from 0.54 to 31.08 mg HC/g rock, averaging (9.13 mg HC/g TOC), and the shales, range from 0.42 to 2.33 mg HC/g TOC, averaging (1.07 mg HC/g TOC). Hydrogen Index (HI) of the lignites range from 01 to 75 mg HC/g TOC averaging (23.4 mg HC/g TOC), and the shale range from 12 to 85 mg HC/g TOC averaging (42.8 mg HC/g TOC). The above values indicate that the sediments have moderate to high organic matter concentration with potential to generate gas. Hydrogen Index (HI) versus Oxygen Index (OI) diagram classifies the organic matter in the samples as mainly Type IV with minor Type III kerogen. HI versus Tmax plot also showed that the shale and lignite fall within the immature and postmature zone. This indicates that the sediments have potential to generate gas at appropriate maturity while the lignites that fall within the postmature level are recycled, and/or contaminated materials. Tmax and Production Index (PI) of the analysed samples also fall within the thermally immature and post mature organic matter. From Palynofacies studies, the major sporomorphs identified in the samples were pollen grains and spores. These are terrestrial sporomorphs which support type III kerogen. An age range from middle Eocene – Early Miocene is assigned due to some age diagnostic pollen and spore markers species in the samples such as *Pachydermites diederixi, Verrrucatosporites usmensis*, *Inaperturopollenites hiatus, Psilatriporites rotundus, Magnastriatites howardi* in the samples. These species are typical of fresh water swamp forest.

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CHAPTER ONE: INTRODUCTION

Lignite is one of the four fossil fuel resources found in substantial quantities in southeastern Nigeria. The others are sub-bituminous coal, oil and natural gas. Of the four, lignite was the first to be discovered by the Mineral Survey, (1908) (Orajiaka et al., 1990). Nigeria has the largest deposits of lignite in Africa. From several recent studies, the reserves is about two (2) billion tonnes, with approximately 650 million tonnes (Mmt) as proven (CIA, OnlineNigeria, 2010).

These lignites are confined to a narrow belt about 16km wide, trending S.W – S.E and extending from the Niger River, in the west, to the Cameroon frontier, east of Calabar, in the east, a distance of about 240km (Fig.1). Within this belt, lignite seams of variable thickness are exposed sporadically in stream valleys and road cuts.

In 1919 lignite was discovered in Umuahia – Okigwe area by Messrs Falk and Hives, Divisional Officers for Owerri and Okigwe respectively (Wilson, 1925). This lignite belt, of mid-Tertiary age, extends from Orlu in the south-east, through Umuezeala, Umuahia, Nnewi, Oba, in a 20 to 40km - wide belt across the Niger, to Ogwashi, Asaba, Mgbiigliba and Adiase-Uti in Delta State. The lignites have not yet been fully explored, and recently, the Nigerian government has placed a high priority on utilizing these resources.

Studies of the Nigerian lignite deposits date back to more than 80 years (Wilson, 1924; Du Preez, 1945, 1946; Simpson, 1949, 1954; Da Swardt and Piper, 1957; Chene *et al*., 1978; Okezie and Onuogu, 1985; Oboh-Ikuenobe *et al*., 2005; Olobaniyi and Ogala, 2011). Relatively little has been written about the hydrocarbon potential of the Nigerian lignite deposits. Okezie and Onuogu, (1985) presented data from chemical and gas analysis of

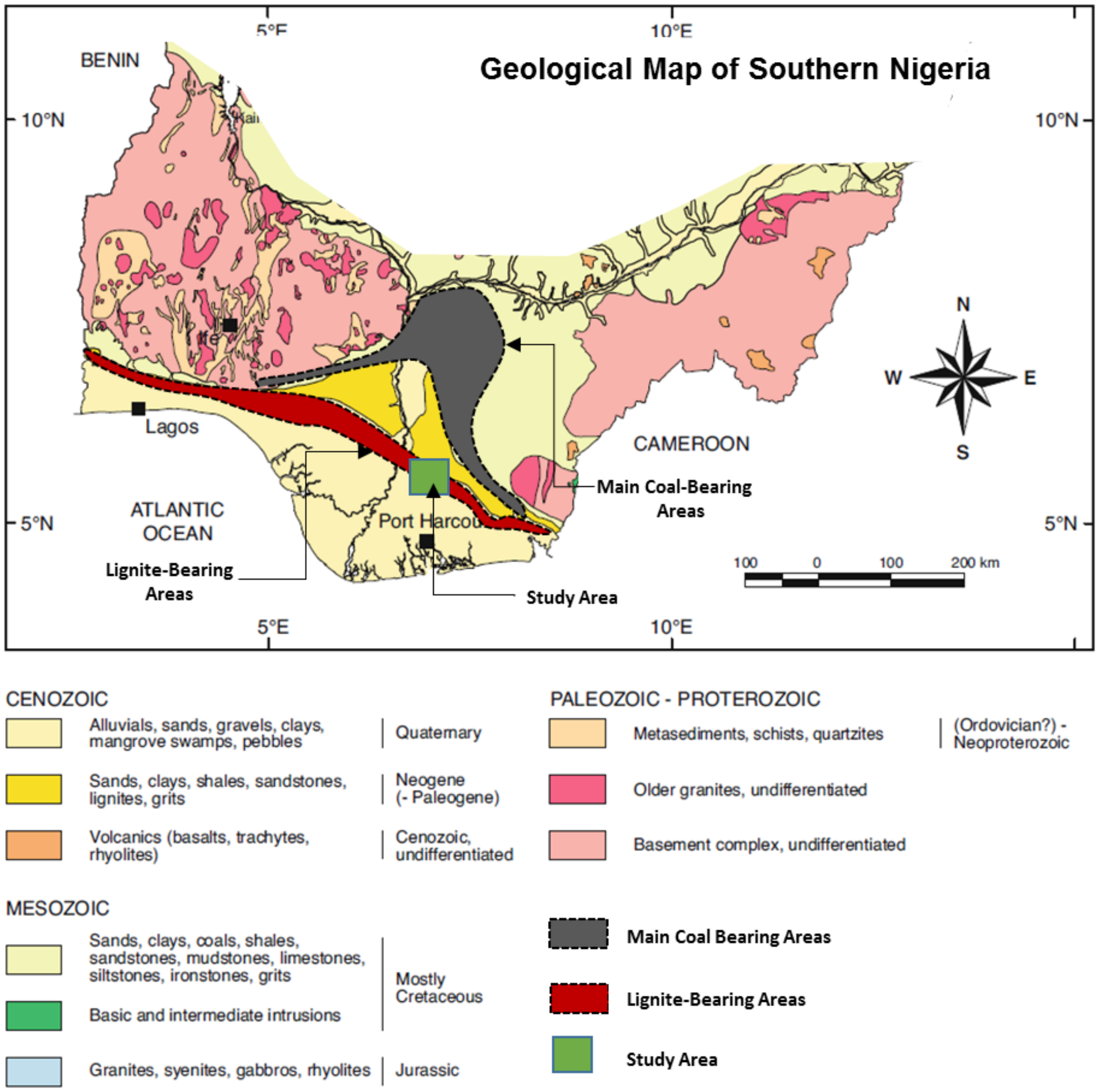


Figure 1. Geologic Map of Southern Nigeria showing the Coal and Lignite Zones (modified after Okezie, 1974)

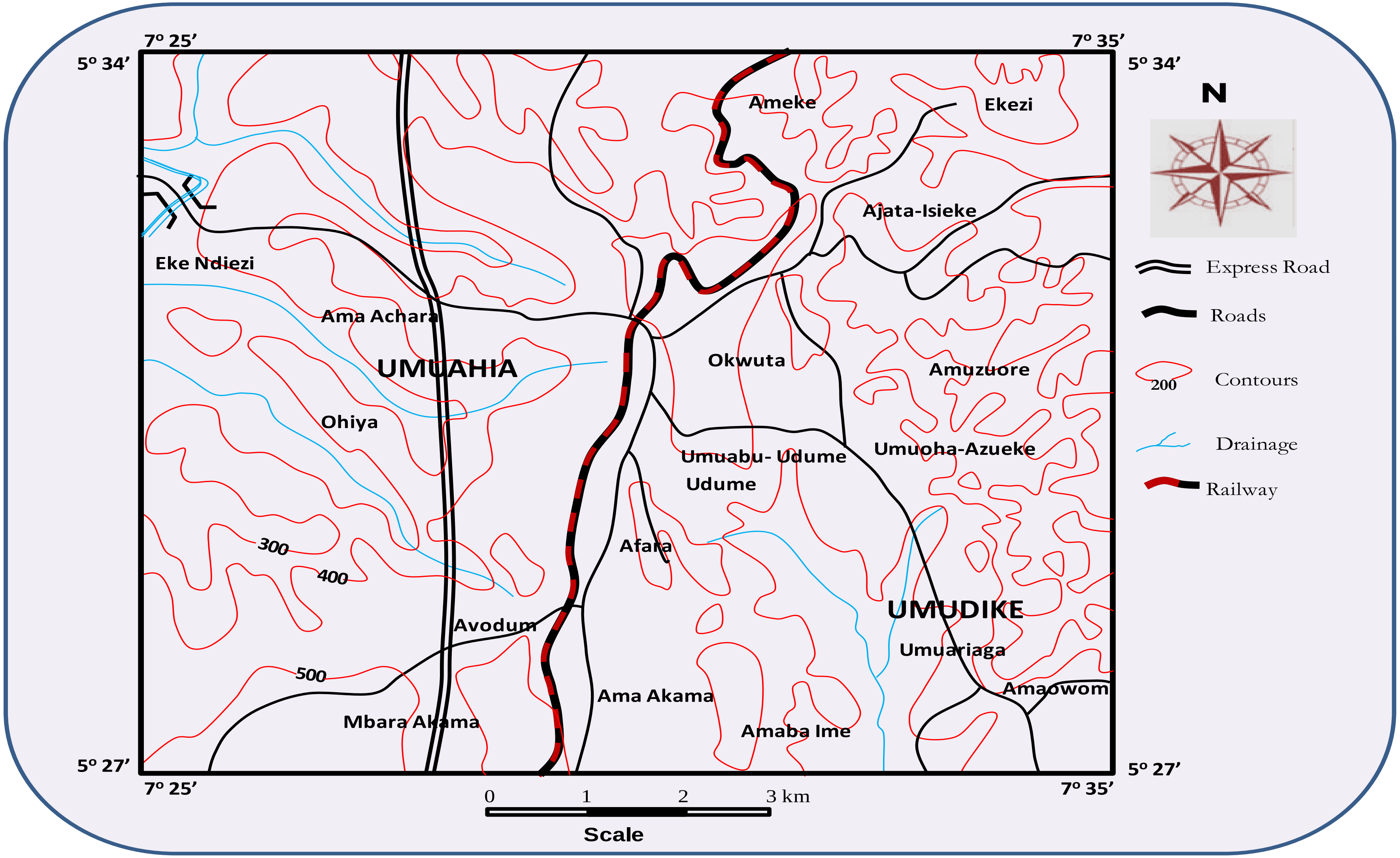


Figure: 2 Map of the study area showing drainage and accessibility.

lignites and showed that the lignite deposits have high calorific values, low sulphur but are generally rich in hydrocarbons, resins and waxes.

This present research will evaluate the hydrocarbon potentials of the lignite and shale units determine their age and environment of deposition from TOC and Rock-eval analysis, and palynological studies.

1.1 THE STUDY AREA

The study area is bounded by latitudes $5^0\,27'$ N and $5^0\,34'$ N and longitudes $7^0\,25'$ E and $7^0\,35'$ E within the rainforest belt. The villages covered by this study include Ohiya, Amawom, Umuariaga, Umudike, Ibeku Okwuta and Isiador Ameke (Fig. 2).

1.2 PREVIOUS WORK

Several studies have been carried out in the Niger delta sedimentary basin of Nigeria due to the petroleum potentials of the area. Most of these studies range from sedimentlogical / stratigraphic, biostratigraphic, paleontological, geophysical to petroleum geology. Generally, fewer works have been done and documented on the Nigerian lignite series of this proliferious basin and their hydrocarbon potentials.

The lignite seams of southern Nigeria have been explored by mapping and drilling and thicknesses of the seams and shale associated with them in different locations recorded by Wilson (1924), Du Preez (1945), Da Swardt and Piper (1957).

Chene et al. (1978) carried out palynological study on the lignites and shales of the Ogwashi – Asaba Formation and assigned a Middle Eocene age for the basal part.

Okezie and Onuogu (1985) presented data from chemical and gas analysis of lignites and showed that the lignite deposits have high calorific values, low sulphur but are generally rich in hydrocarbons, resins and waxes.

Nwadinigwe (1992) studied the wax and resin characteristics of Nigeria's lignites and sub-bituminous coals and concluded that the lower the coal rank the higher the total amount of wax and resin extracted from it.

Akande et al. (1992) examined the rank, petrography, composition and depositional environment of selected Upper Cretaceous and Tertiary coals of southern Nigeria and concluded that thermal maturation in the Cretaceous successions increases from the post-Santonian (Campanian-Maastrichtian) Anambra Basin into the older Benue Trough where strong diagenetic to anchimetamorphic (that is, very low grade metamorphism) conditions were reached.

Later Obaje and Hamza (2000) investigated the liquid hydrocarbon potential of mid-Cretaceous coals and coal measures in the middle Benue Trough of Nigeria and also subdivided the coal beds into three different coal facies, namely: a vitrinite-fusinite, a trimaceritic and shaly coal facies.

Oboh-Ikuenobi et al (2005) carried out a research on the Lithofacies, Palynofacies and Sequence stratigraphy of the Palaeogene strata in the Okigwe, Isiukwuato, Umuahia and Ozuitem districts in Abia State, southeastern Nigeria.

Ogala (2011) researched on source rock potential and thermal maturity of the tertiary lignite series in the Ogwashi-Asaba Formation, Southern Nigeria.

1.3 AIM OF RESEARCH

This present research will evaluate the hydrocarbon potentials of the lignite and shale units determine their age and environment of deposition from TOC and Rock-eval analysis, and palynological studies.

1.4 EXPECTED OUTCOME

In addition to providing additional data on the potential for liquid and gaseous hydrocarbon of the lignite and the associated shales, supplement available data on the hydrocarbon prospects of the area, this research will also at the end present an evaluated:

(1) Quantity and quality of the source rock.

(2) Thermal maturity of the source rock both from Rock- Eval Prolysis analysis and from Palynological analysis.

(3) Hydrocarbon generating potentials of the lignites and the shales in the area.

(4) Age of the formation encountered and depositional environment of the source rock from microfossils study.

1.5 METHODOLOGY

The study of the area was carried out in three phases:

(1) Preliminary review of literature.

(2) Visits to outcrops and field studies.

(3) Laboratory analyses and interpretation of results from collected samples.

(1) Preliminary studies: Reviews of the relevant literature concerning the study area both on regional and local scale were studied to get acquainted with the area. The terrain, regional stratigraphic succession and accessibility of the area were depicted in geologic maps and table.

(2) Visit to outcrop and Field studies:

The area was traversed using the Global Positioning System (GPS) to get the coordinates and elevation of outcrop locations. Brunton compass was used to get the attitude of beds. Other instruments used include digital camera, field hammer. Outcrops were studied and lithological characteristics recorded and samples taken. Lithologic sections and sketches of notable features were jotted down. Collected samples were appropriately packaged, labelled and sealed using sample bags and masking tapes.

(3) Laboratory Analyses: Lignites and Organic rich shale samples were subjected to Total organic matter Content (TOC) analysis, Rock-eval pyrolysis and Palynological studies.

CHAPTER TWO: GEOLOGIC SETTING

2.1 GEOLOGY OF NIGER DELTA

The Niger delta is situated on the continental margin of the Gulf of Guinea in the Equatorial West Africa between Latitudes 3^0 N and 6^0 N and Longitudes 5^0 E and 8^0 E. It is bounded by the Anambra basin and Abakaliki High to the north, the Cameroun volcanic line to the east, the Dahomey Embayment to the west and the Gulf of Guinea to the south (Benkhelil,1989; Dingle et al.,1975)(Fig.3).

It ranks among the world's most prolific petroleum producing Tertiary deltas that together accounts for about 2.5% of the present day basin areas on earth. The Niger Delta is among the world's largest regressive sequence with a thickness of over 12000m and occupies an area of $7500km^2$ (Murat, 1972).

The Niger delta province is a large arcuate wave and tide dominated delta, with sediments ranging in age from Eocene in the north to Quaternary in the south. The overall regressive sequence of clastic sediments was deposited in series of off lap cycles that were intermittently interrupted by periods of sea level changes. These periods of sea level changes resulted in minor although sometimes widespread, episodes of erosion or marine transgression. The Niger Delta can be subdividing into three broad lithofacies units. The lower part consist of pre-dominantly under compacted, over pressured marine shales, clays and siltstone with some turbidites sandstone (Akata Formation), which is followed by an alternation of paralic sandstone,shales and clays (Agbada Formation). This in turn grade upward into massive continental sandstones (Benin Formation) (Short and Stable, 1967).

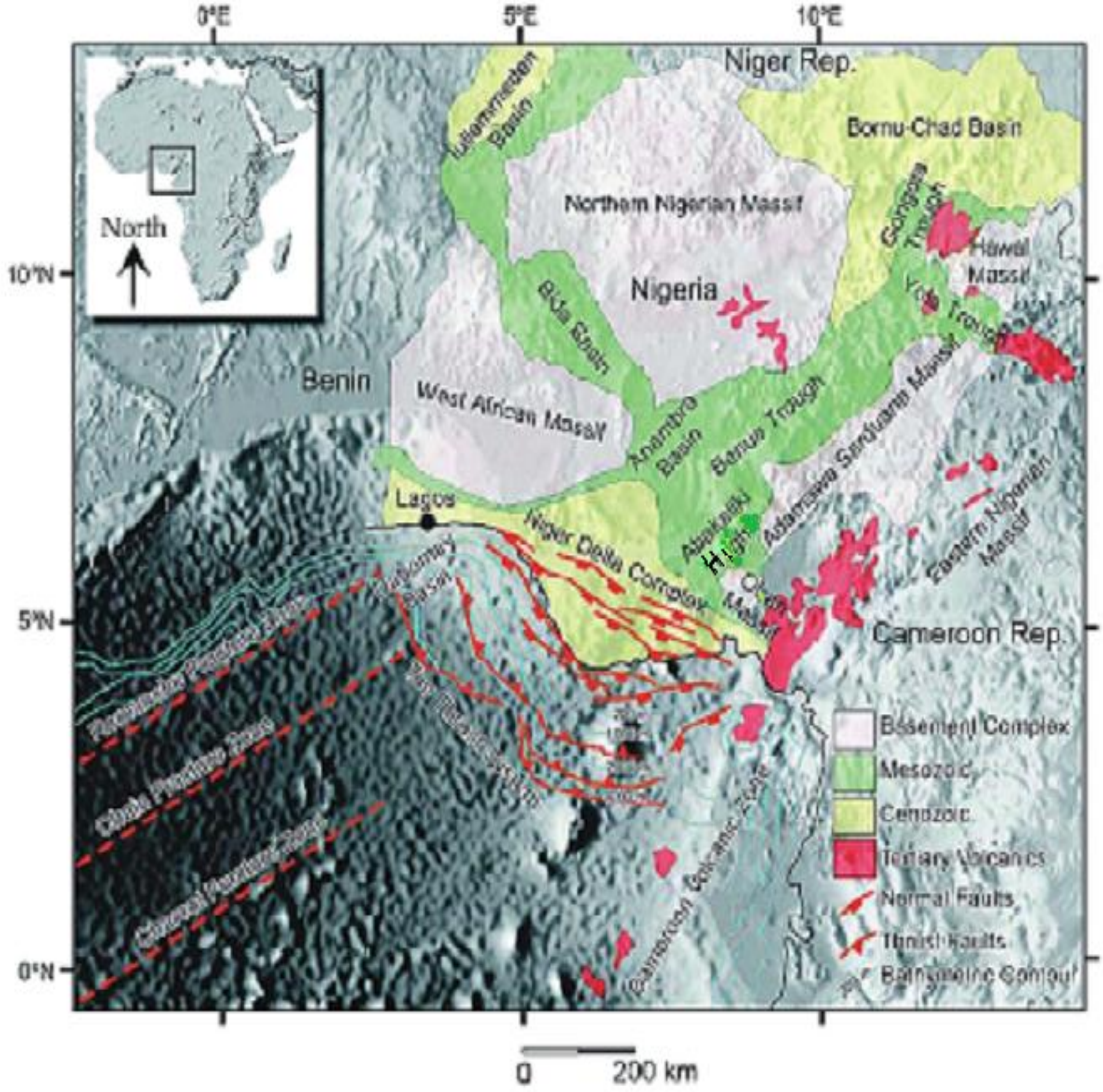


Figure 3: Map of Nigeria showing the Niger Delta complex, the Anambra basin and Benue Trough. (After Corredor et al, 2005)

The progradation of the delta has been dependent on the interaction between rates of subsidence and sediment supply, which are in turn modified by syn-sedimentary faulting. Within the delta, several major growth fault bounded sedimentary units are present. These depo belts succeeded one another southwards as the delta prograded through time (Evamy et al., 1978). Most of the extensional faulting occurs in the paralic part of the deltaic sequence and has influenced the sedimentation pattern and the thickness distribution of sand and shale.

2.2 BASIN EVOLUTION

The tectonic and geological evolution of the Niger Delta basin goes beyond the post Eocene regressive clastic wedge which is normally attributed to the delta in its modern form. The tectonic framework of the continental margin along the west coast equatorial Africa is controlled by Cretaceous fracture zones, expressed as trenches and ridges in the deep Atlantic. The fracture zone sub-divide the margin into individual basins while in Nigeria forms the boundary faults of the Cretaceous Benue-Abakaliki trough cuts far into the shield. The trough represents a failed arm of rift triple junction associated with the opening of the south Atlantic. In this region, rifting started in the late Jurassic and persisted into the middle Cretaceous (Onuoha and Ofoegbu, 1988), (Benkhelil, 1989). In the region of the Niger Delta, rifting diminished altogether in the late Cretaceous (Fig.4).

After the rifting, gravity tectonics became the primary deformation process; shale mobility resulted into internal deformation and occurred in response to two processes (Doust 1989, Emery et al.,1975). First, shale diapers formed from loading of poorly compacted, over pressured, prodelta and delta slope clays (Akata Formation) by higher density delta front sands (Agbada Formation). Then slope instability occurred due to lack of lateral basin ward support for the under compacted delta-slope clays. Gravity tectonics ended before deposition of the Benin Formation and are expressed in complex structures, including shale diapers, roll over anticlines, collapsed growth fault crest, back to back features and steeply dipping closely spaced flank faults (Evamy et al., 1978).

Deformation of the entire delta by wide spread syn-sedimentary faulting was responsible for the deformation of traps in which the present day Niger Delta hydrocarbon accumulations are found. This large scale deformation, caused by growth faulting affected both the Akata

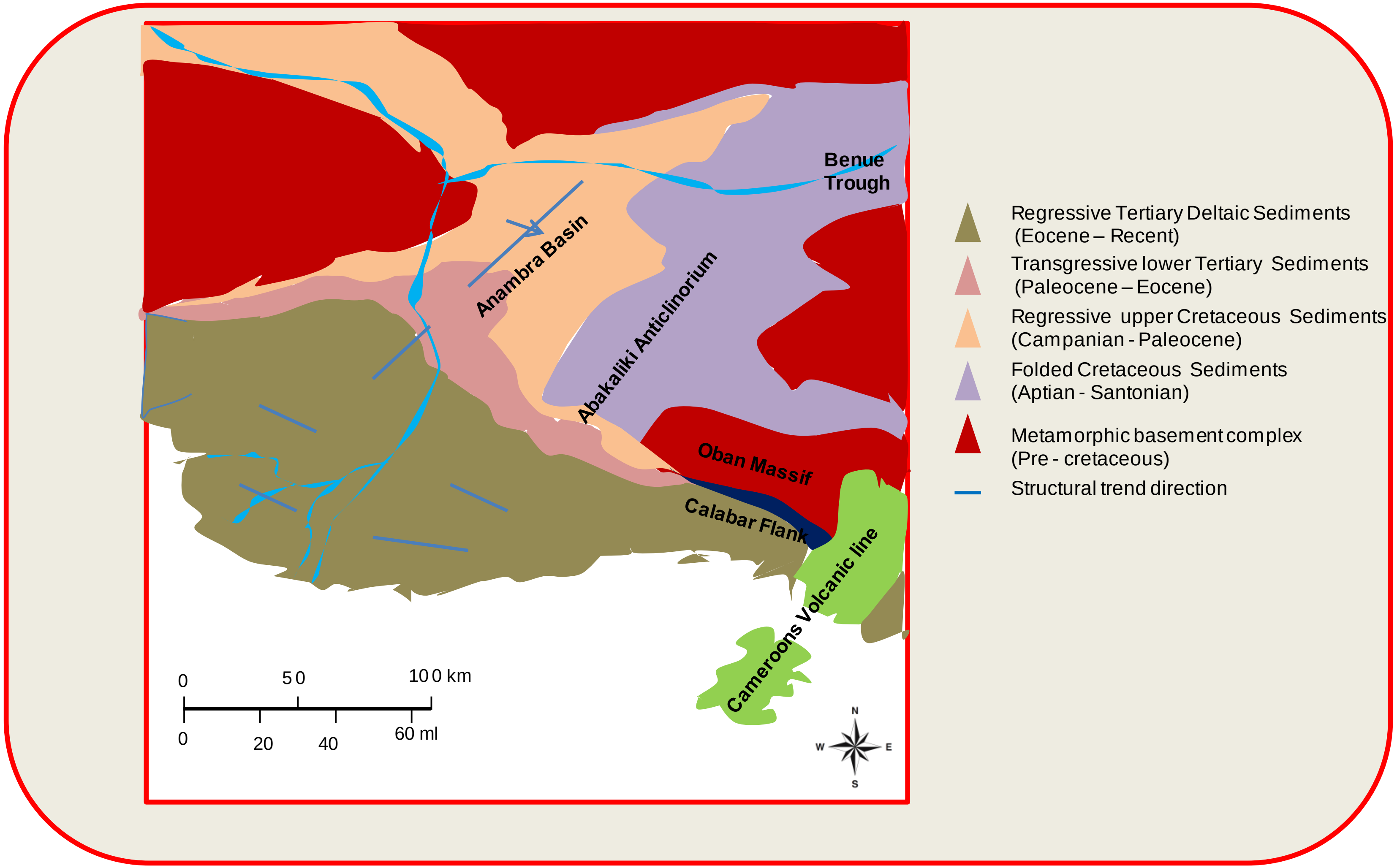


Figure 4: The Abakaliki anticline,Anambra basin and the Niger Delta basin (After Onuoha and Ofoegbu, 1988).

Formation and the Agbada Formation. The progradation of the delta has been accomplished by formation of growth faults, associated rollover anticlines and shale diaprism (Evamy et al., 1978).

2.3 STRATIGRAPHY

The stratigraphic history of the Niger Delta started alongside the stratigraphic history of the Southeastern Nigerian sedimentary basins. The Tertiary Niger Delta basin is a sedimentary structure formed as a complex regressive off lap sequence of clastic sediments ranging in thickness from 9000 – 12000m. The basin has been divided into three major facies units based on the dominant environmental influences by Short and Stauble (1967). These main sedimentary environments are the continental environment, the transitional environment and the marine environment. In an advancing delta, such as the Niger Delta, sediments of these three environments are superimposed.

Three depositional lithofacies are readily identified despite local facies variations, as three regional and diachronous formations ranging from Eocene to Recent. The three major formations from the oldest to youngest are Akata Formation, Agbada Formation and Benin Formation (Table 1).

Akata Formation: This is the oldest formation in the Niger Delta. It is a marine pro-delta megafacies, comprising mainly shales with occasional turbidities sandstone and siltstone. The approximate range of thickness is from 0 -60m and the formation consists of dark grey uniform shale especially in the upper part. The shales are over pressured and occur offshore in diapers along the continental slop and outcrop onshore in the northeastern part of the delta

Table 1: Lithostratigraphic succession in Niger Delta and Anambra Basins (based on Reyment, 1965; Short and Stauble, 1967; Ogala, 2011).

AGE			SUBSURFACE UNITS	OUTCROPPING UNIT		LITHOLOGY	DEPOSITIONAL ENVIRONMENT	DELTA GROWTH PHASE	NET SEA MOVEMENT
QUATERNARY			BENIN FM	NIGER DELTA BASIN	BENIN FM	Sandstones clay,shales	CONTINENTAL	CENOZOIC NIGER DELTA	REGRESSION
TERTIARY	PLIOCENE								
	MIOCENE		AGBADA FM						
	OLIGOCENE				OGWASHI – ASABA FM	Clay,Shales, Sandstones Lignites	CONTINENTAL		
	EOCENE		AKATA FM		AMEKI FM	Sandstones, Clay,Shales,Limestones	ESTUARINE,SHALLOW-MARINE		
	PALEOCENE	THANATIAN			IMO FM	Sandstones, Clay, Shales, Limestones, Marl	SHALLOW-MARINE,DELTAIC		
		DANIAN						TRANSITION	TRANSGRESSION
UPPER CRETACEOUS	MAASTRICHTIAN		PELAGICS AND FANS	ANAMBRA BASIN	NSUKKA FM	Sandstones, Clay,Shales,Limestones, coals	FLUVIO-DELTAIC	ANAMBRA DELTA	REGRESSION
					AJALI FM	Sandstones claystones	FLUVIO-DELTAIC		
					MAMU FM	Sandstones clays, coals	SHALLOW-MARINE,DELTAIC		
					NKPORO GP	Sandstones, Clay,coals,Shales,Siltstone	SHALLOW-MARINE,DELTAIC		
	CAMPANIAN		MAJOR UNCONFORMITY						
	SANTONIAN		PELAGICS AND FANS	BENUE TROUGH	AWGU FM	Sandstones, Clay,coals,Siltstones,Limestone	SHALLOW-MARINE,DELTAIC	PRODELTA	TRANSGRESSION
	CONICIAN								

where they are known as Imo shale (Doust and Omatsola, 1990). The age ranges from Paleocene to Holocene.

Agbada Formation: The Agbada Formation overlies the Akata Formation in the Niger Delta. It is the hydrocarbon prospective sequence in the basin. It comprises of alternation of sands, shales and clays in various proportions, thus representing the cyclic sequences off-lap unit. Short and Stauble (1967) recognised an upper sandstone-shale unit, composed mainly of sandstone and a lower unit made predominantly of thicker shale unit and alternating thinner units of sandstone. This Formation serve as the hydrocarbon prospective sequence in the Niger Delta, where the sands serve as reservoirs and the shales as the source rocks (Short and Stauble, 1967; Frank and Cordry, 1967).

The paralic Ogwashi-Asaba Formation is an outcrop equivalent of the subsurface Agbada Formation. It is underlain by the regressive Ameki Formation and overlain by Benin Formation (Table 1). The Ogwashi-Asaba Formation consists of a sequence of coarse-grained sandstone, light coloured clays and carbonaceous shale within which are intercalations of lignite seams of continental origin (Chene *et al*., 1978). The lignite seams found within the Ogwashi-Asaba Formation are commonly brownish to black in colour and vary in thickness from few millimetres to a maximum of 6 m. They are thinly laminated and fissile with leaf and woody fragments on fresh cleats.

Benin Formation: This has been described as the “coastal Plain Sands” which outcrop in Benin, Onitsha and Owerri provinces and elsewhere in delta area. It consists mainly of sands and gravels with thickness ranging from 0 -2100m. The sand and sandstones are coarse to fine and commonly granular in texture and are friable. The shales are few and thin and they represent back swamp deposits. Among the minor components, limonite coating, lignite streaks, hematite and feldspar are common. The formation has been reported to be of Oligocene – Recent (Doust and Omatsola, 1990). Very little oil has been found in Benin Formation and the formation is generally water bearing.

CHAPTER THREE: FIELD STUDY / OUTCROP DESCRIPTION

The outcropping sections of lignites and shales in the area are mostly along stream channels and road cuts. Outcrops representing the stratigraphic successions of the Ameki Formation and Ogwashi Asaba Formation were sampled at different locations (Fig.5). The two formations encountered were depicted in (Fig. 6). The lignites occur as lenses/fragments in sediments in most of the outcrop locations except in location (OH/LN/03) where it occurred as seam.

3.1 Location one

Locality name: Okahia Uga.

Grids: lat. 5^0 30.3’ 72” and Long. 7^0 26.6’ 44”

Description: This section is about 12m thick consisting of 7m coarse grained, yellowish sandstone at the base and grading into 5m pebbly coarse grained pinkish sandstone (Fig. 7).

3.2 Location two

Locality name: Kelly Quarry, Ohiya

Grids: lat. 5^0 30.6’ 55”and Long. 7^0 27.2’ 51”

Description: This section consist of about 3.5m white plastic clay at the base, 0.5m iron band on top of the white clay, followed by about 3m mudstone with shiny lignites embedded in them; another 0.5m iron band, on top of the second iron band is about 5m greyish mudstone. The contact between the iron band and mudstone is sharp. The lignite appears like log of wood in the mudstone. Overlying the greyish mudstone is about 2.5m overburden weathered mudstone.

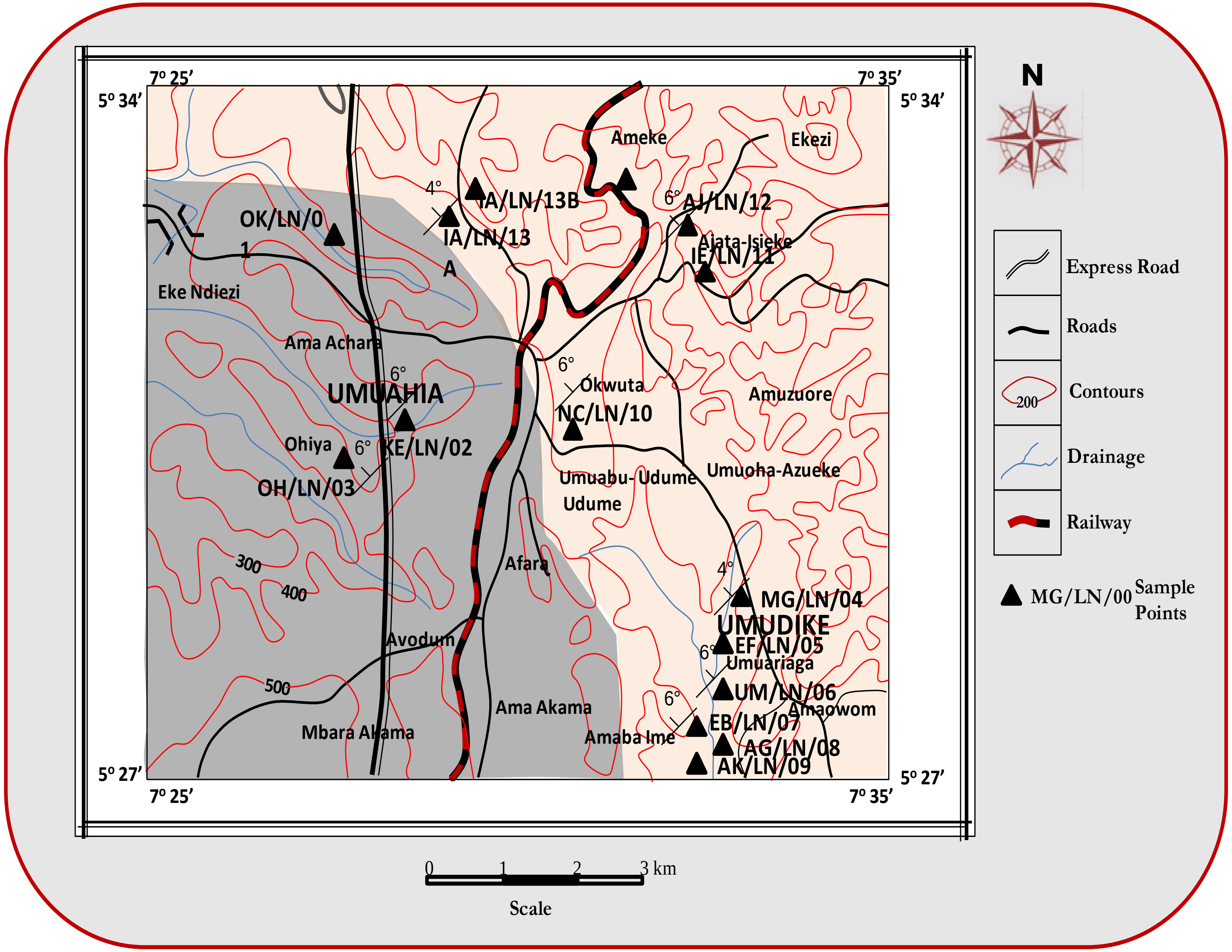


Figure 5: Map showing sampling points.

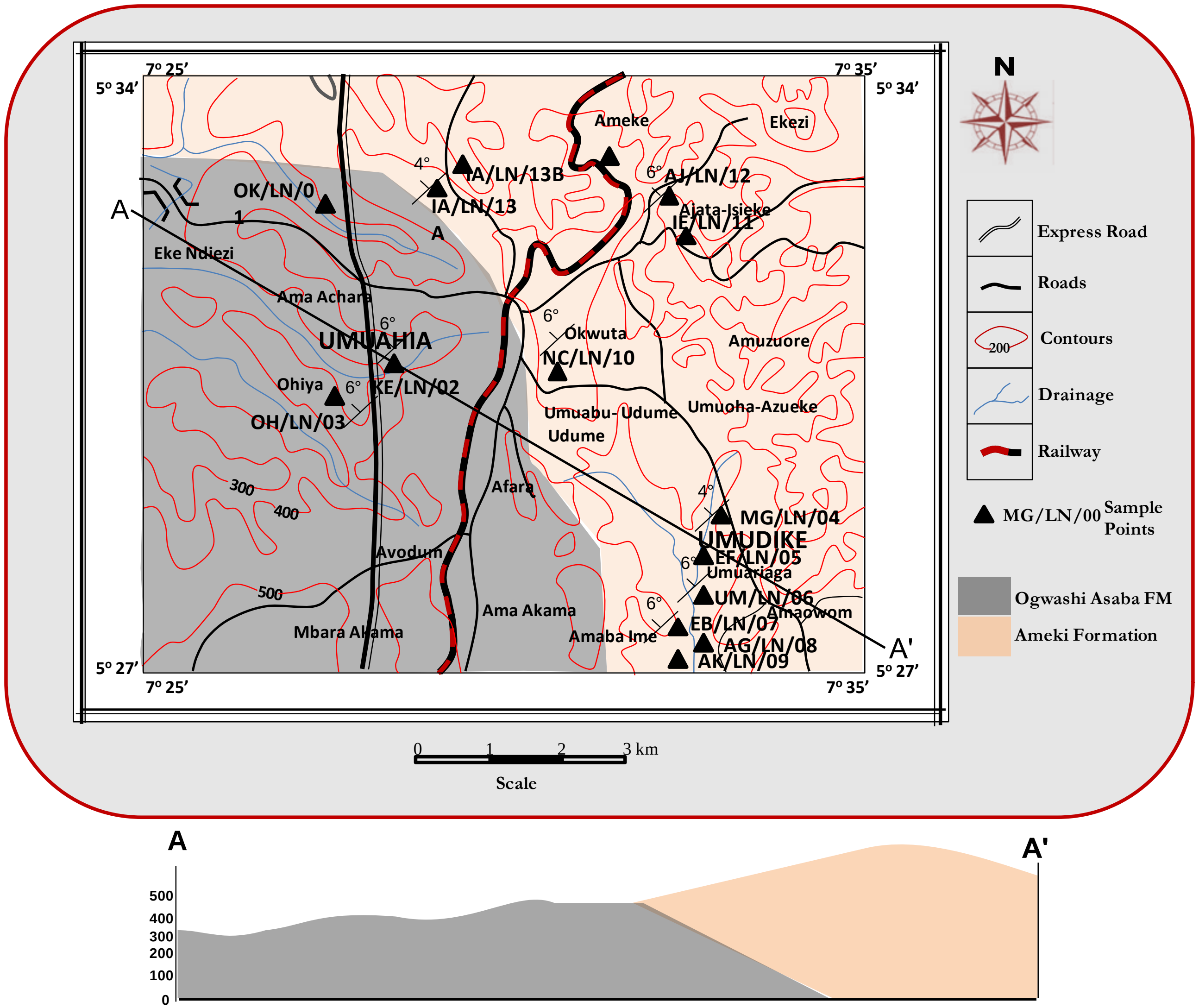


Figure 6: Geologic map showing the Ogwashi-Asaba Formation and Ameki Formation in the study area

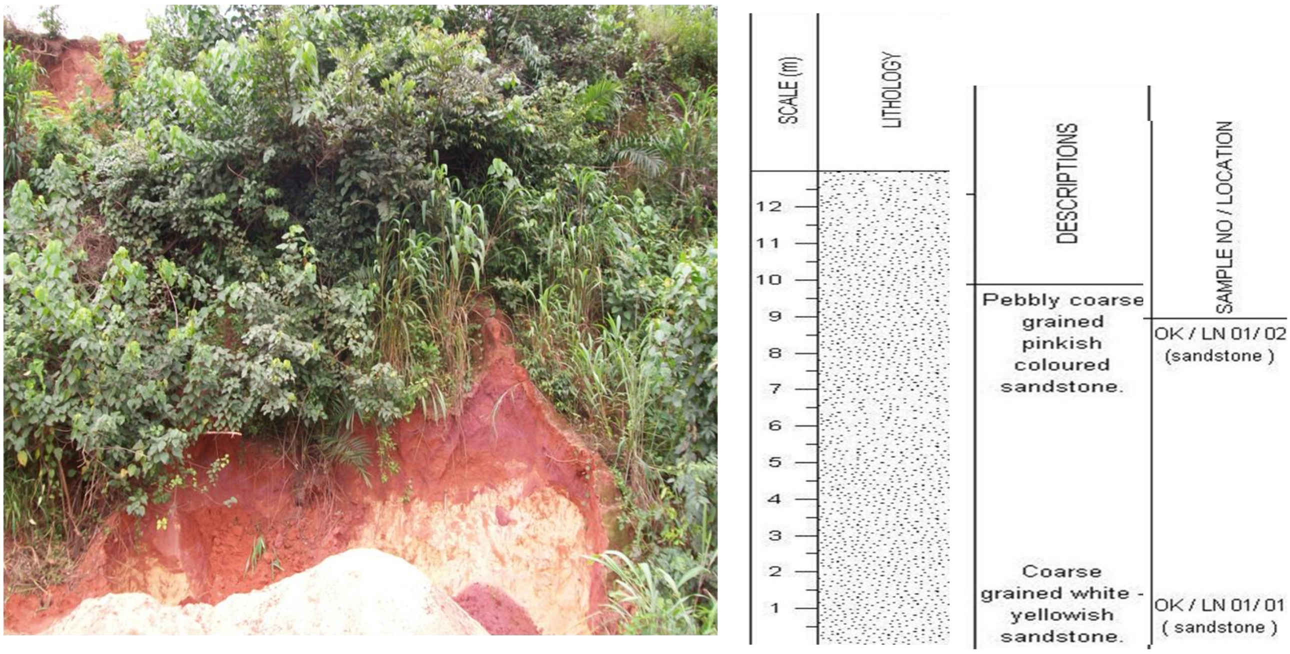


Figure 7. Lithologic log of Okahia Uga outcrop.

Figure 8 shows the section with sedimentary log, whereas the pictures labelled A, B, C and D in figure 9 shows the embedded lignites in mudstone. The arrows in the pictures are pointing to the imbedded coals.

3.3 Location three

Locality name: Royal Quarry, Ohiya

Grids: lat. 5^0 30.3’ 72”and Long. 7^0 26.6’ 44”

Description: The basal unit of this section is 5m white plastic clay and about 1.5m distinctly woody lignite seam overlying the white clay. Overlying the lignite is about 3.5m greyish/dark shale. The contacts between the units below and above the lignite are sharp. Overlying the shale is about 7.5m medium to coarse grained sandstone and about 2.5m weathered mudstone over-burden capping the outcrop. Figures 10 and 11 shows the lithologic section and pictures taken at the outcrop.

3.4 Location four

Locality name: Iyi Mgbe, Umudike

Grids: lat. 5^0 28.9’ 02”and Long. 7^0 33.1’ 72”

Description: This outcrop is a very steep hill. The basal unit is woody lignite fragment in 2.5m greyish/dark mudstone. Overlying the mudstone is about 2.5m fine – medium grained sandstone. On top of the sandstone is another 12m thick unit of fine grained sandstone, followed by 3m and 6.5m mudstone with lenses of coal. Finally about 3m overburden weathered mudstone. The contact between the mudstone and sandstone is gradational. There is no structure in the units (Fig. 12 and13).

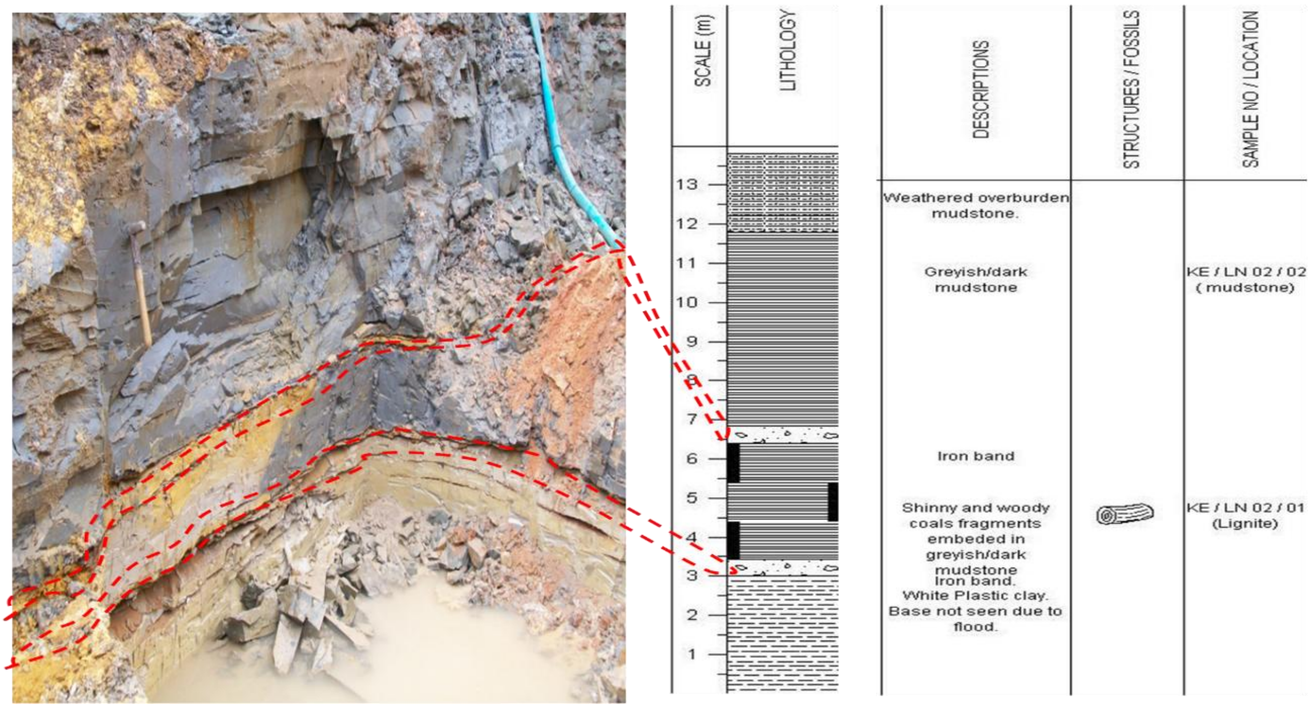


Figure 8. Lithologic log of Kelly Quarry outcrop.

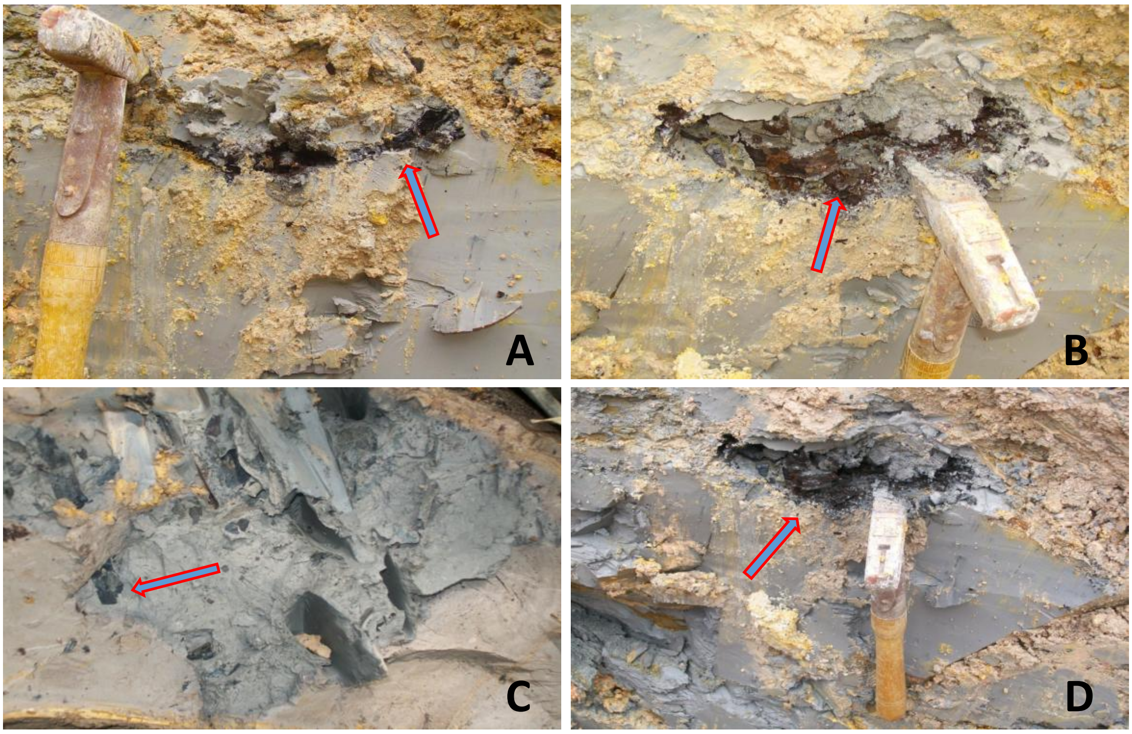


Figure 9. Outcrop pictures of Kelly Quarry.

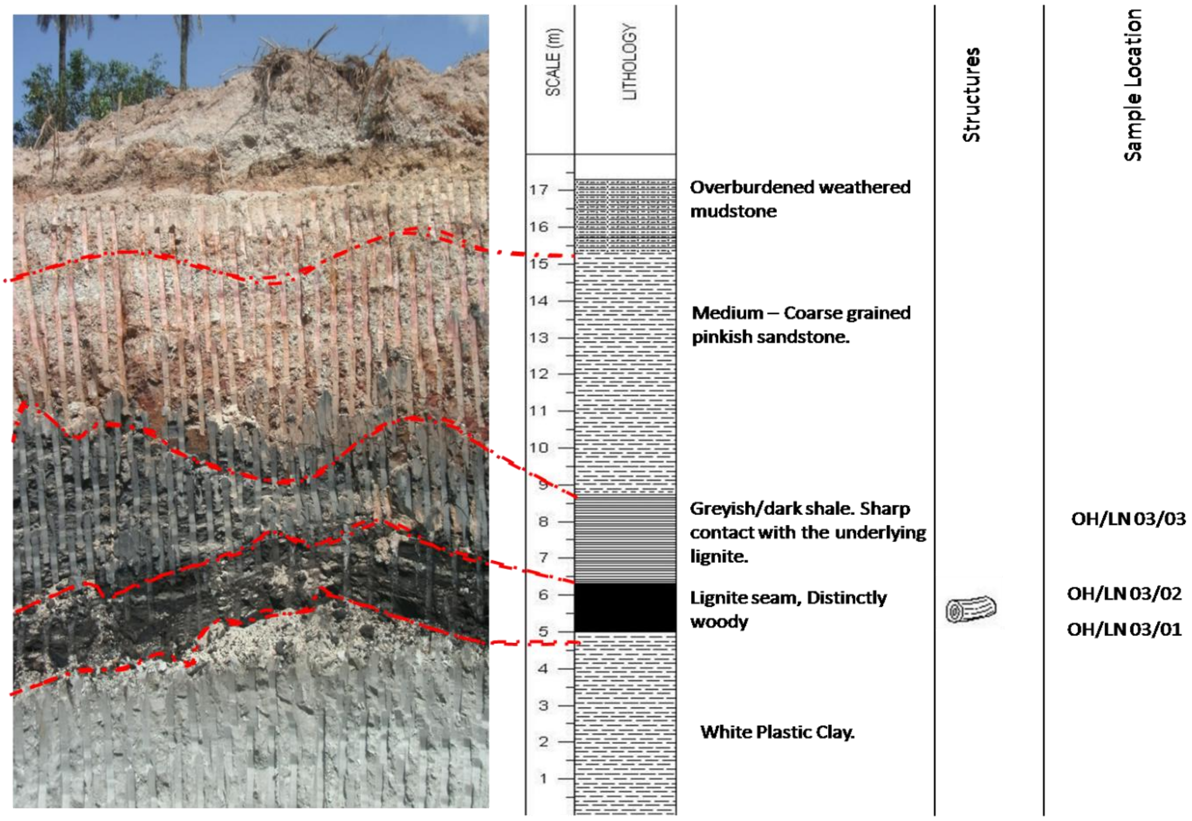


Figure 10. Lithologic log of Royal Quarry outcrop.

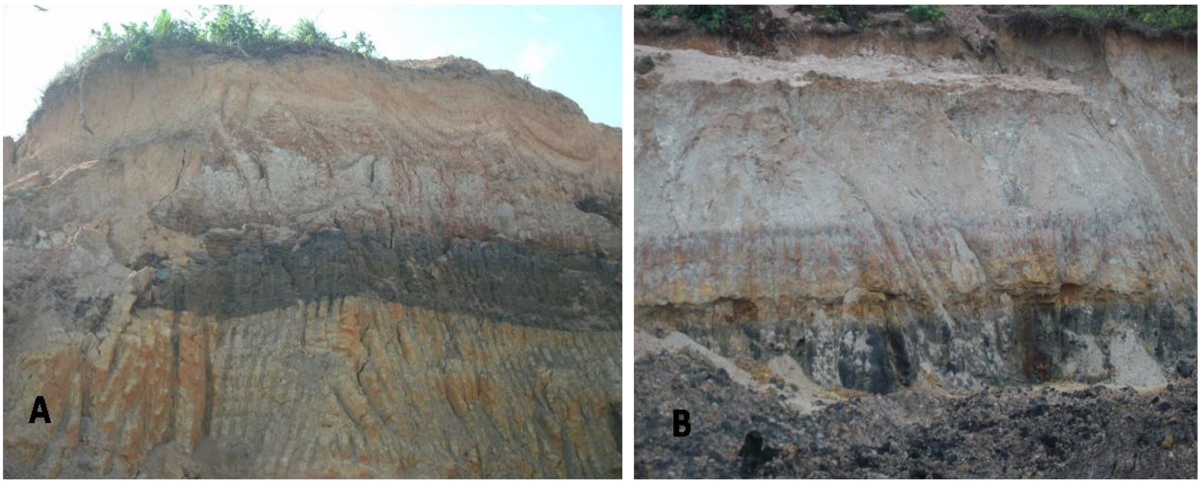


Figure 11. Outcrop pictures of Royal Quarry.

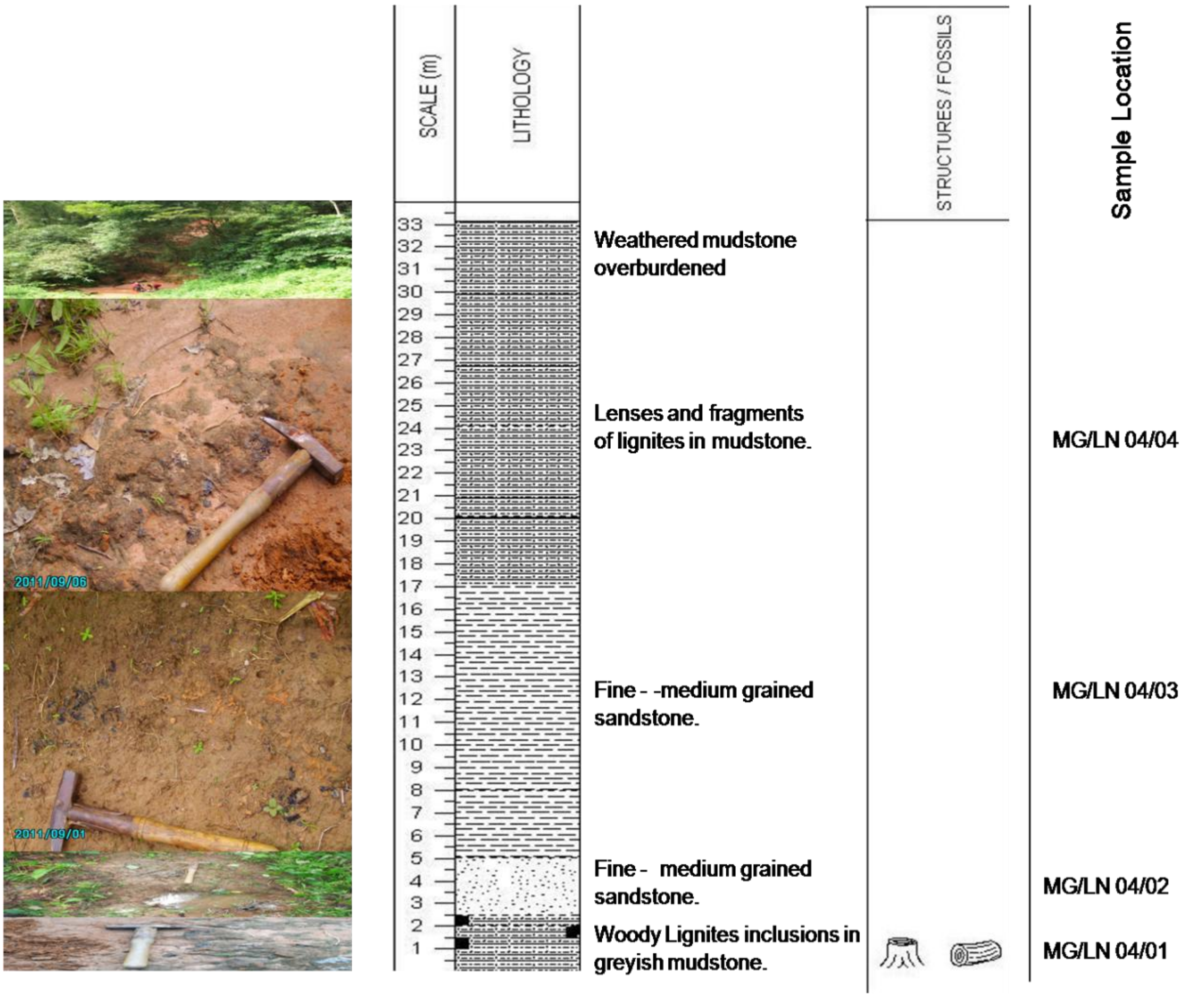


Figure 12 Lithologic log of Iyi Mgbe outcrop.

Figure 13: Outcrop pictures of Iyi Mgbe

3.5 Location five

Locality name: Iyi Efu Umuariaga

Grids: lat. 5^0 28.4’ 88”and Long. 7^0 33.4’ 54”

Description: This section is approximately 46m thick. It is a steeply hill. The lower unit is 7m medium – coarse grained sandstone. Overlying it is 5m thick mudstone with woody materials and coal lamina. The coal is distinctively woody. This is followed by 6.5m fine – medium grained sandstone, 7.5m pebbly mudstone, 19m mudstone with lignites inclusions that are distinctively woody and plant materials embedded in mudstone. The contacts between the units are gradational. Figure 14 and 15 shows the lithologic log and outcrop pictures.

3.6 Location six

Locality name: Iyi Umuokom, Amawom

Grids: lat. 5^0 28.2’ 90” and Long. 7^0 33.3’ 55”

Description: The outcrop sections from base are: about 2m greyish – dark shale without fossil imprints, 7m pebbly greyish sandstone, 3m pinkish mudstone, 7m pebbly greyish – yellowish sandstone and weathered overburdened. The units grade into one another (Figure 16).

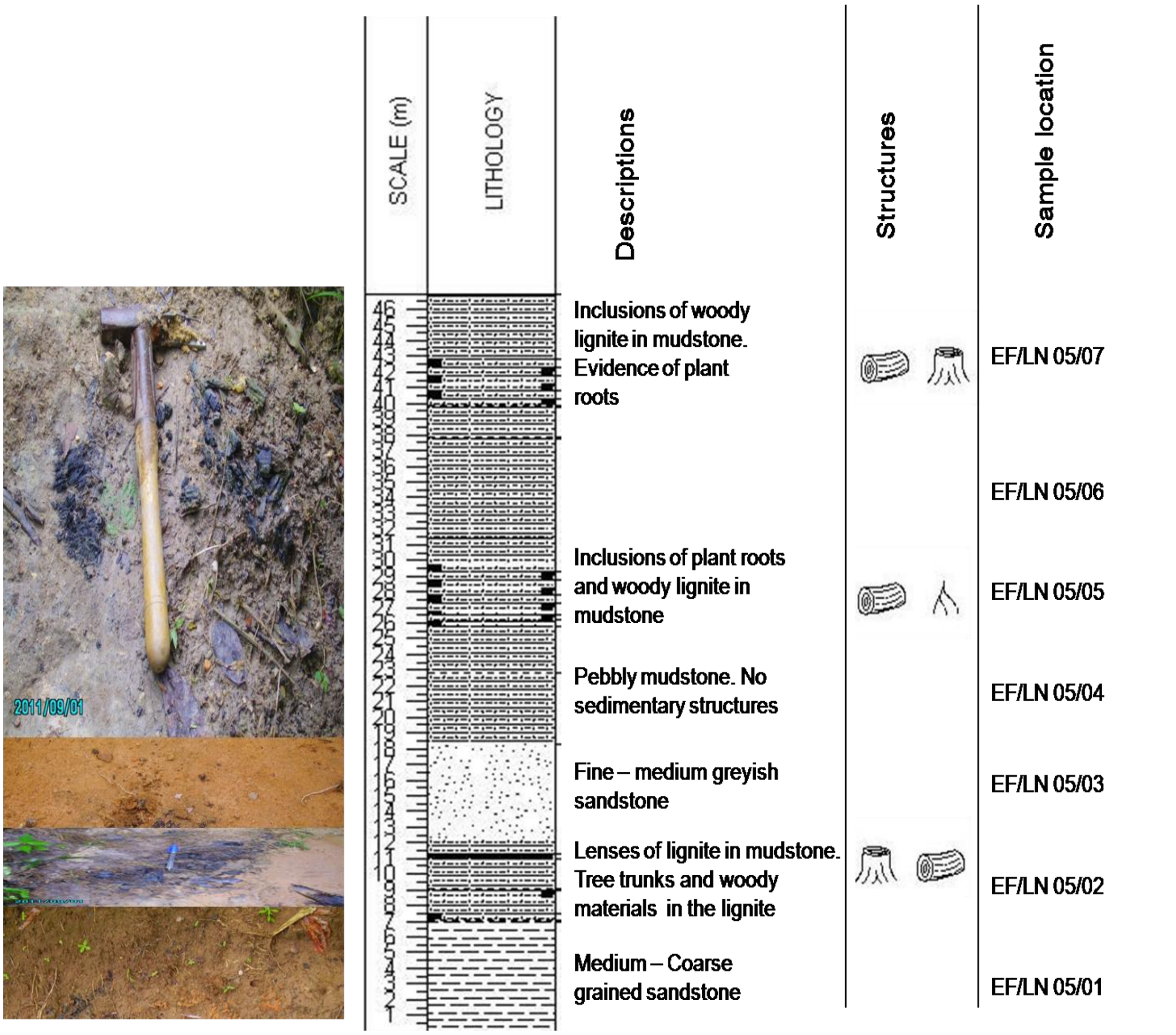


Figure 14: Lithologic log of Iyi Efu outcrop.

Figure 15: Outcrop pictures of Iyi Efu

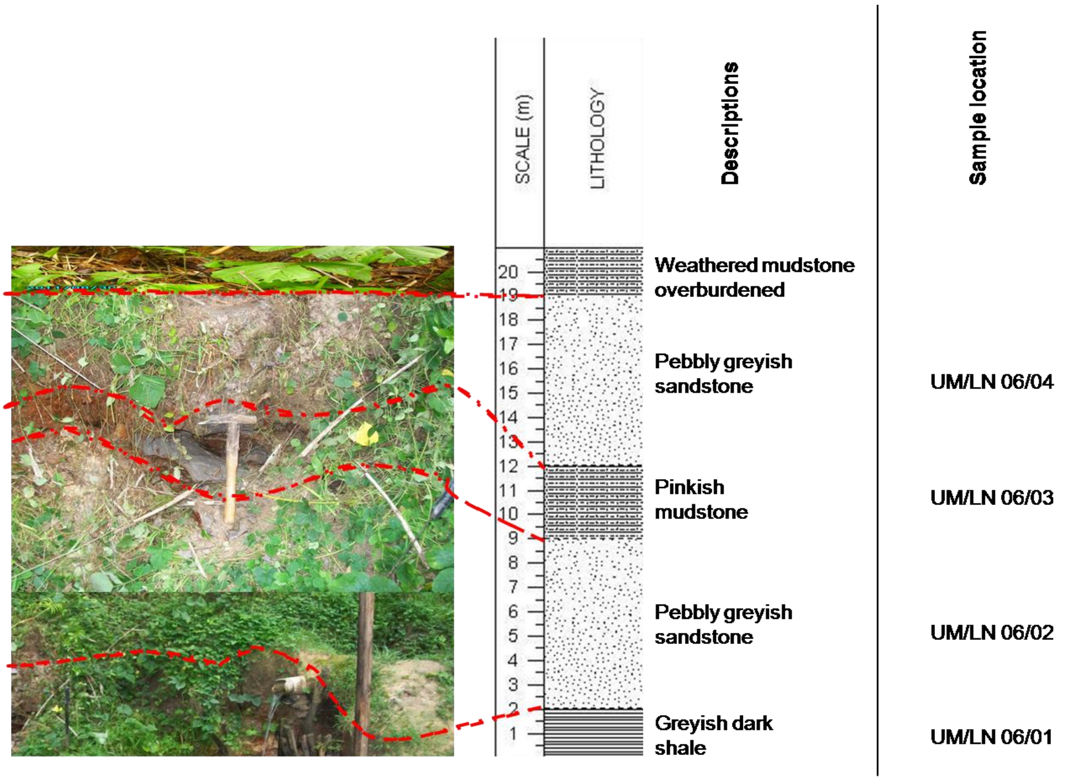


Figure 16: Lithologic log of Iyi Umuokom outcrop.

3.7 Location seven

Locality name: Ebiri stream, Amawom

Grids: lat. 5^0 28.1’ 40”and Long. 7^0 33.2’ 72”

Description: the section has a total thickness of 10m. 7m greyish/dark shale at the base and about 3m overburden weathered mudstone. There is no fossil imprint in the shale (Fig. 17).

3.8 Location eight

Locality name: Iyi Aga, Amawom

Grids: lat. 5^0 27.8’ 84”and Long. 7^0 33.3’ 77”

Description: the section was logged along the stream part and it is about 32m thick. It has whitish plastic clay at the base. Overlying the plastic clay is 4m mudstone with inclusions of lignite. The lignite has the characteristics of plant debris. On top of the lignite is 5m greyish gritty mudstone. Overlying the gritty mudstone is 9m thick medium – coarse grained greyish sandstone. Then followed by another 6.5m thick greyish mudstone without coaly inclusions. Overlying the 6.5m thick unit is 6m mudstone with woody lignite inclusions and 3m weathered overburden respectively. There are no fossils in the mudstone units. The contacts between the units are gradational (fig.18).

The arrow in figure 19(B) is pointing to the plastic clay, 19 (D) is pointing to the lignites.

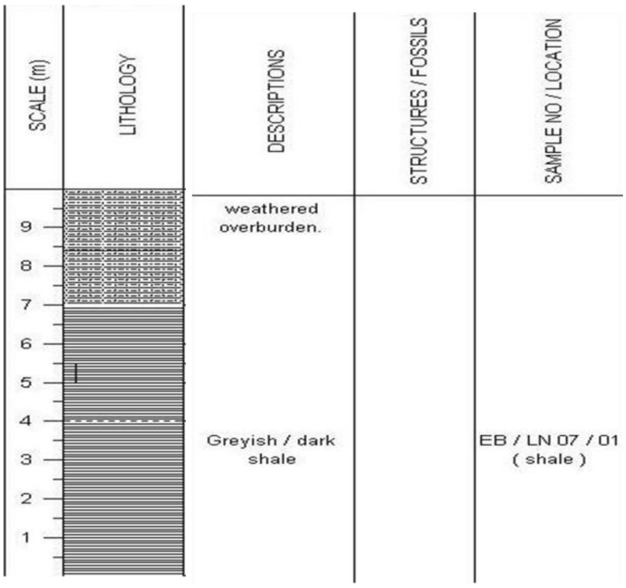


Figure 17: Lithologic log of Ebiri outcrop.

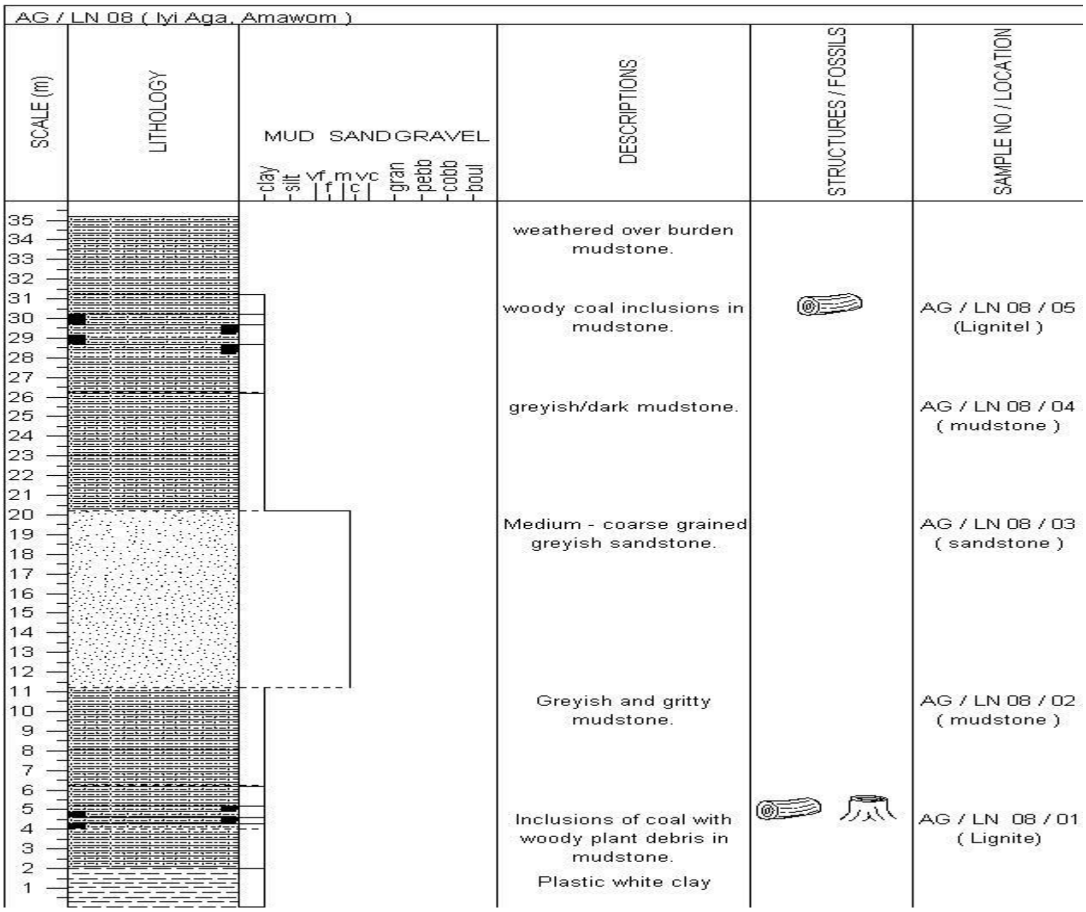


Figure 18: Lithologic log of Iyi Aga (Amawom)

Figure 19: Outcrop pictures of Iyi Aga

3.9 Location nine

Locality name: Akpatala stream, Amawom

Grids: lat. 5^0 28.0’ 65” and Long. 7^0 33.4’ 20”

Description: The section consists of about seven units. The contacts between the units are gradational. There were no sedimentary structures or fossils observed in the units. The sequence of these units from the bottom of section to the top is: about 1m pebbly greyish mudstone grading into 1m yellowish – greyish mudstone, 0.5m fine grained siltstone, 5m pebbly sandstone, the sandstone grades into brownish mudstone, above the mudstone is 5m pebbly sandstone, 6.5m dark – grey mudstone, with 3m overburden (Figs. 20 and 21).

3.10 Location ten

Locality name: Iyi Nchara

Grids: lat. 5^0 28.0’ 65” and Long. 7^0 33.4’ 20”

Description: the unit exposed is about 4m mudstone with iron stain (Fig. 22).

3.11 Location eleven

Locality name: Iyi Enyi, Isieke

Grids: lat. 5^0 28.0’ 65” and Long. 7^0 33.4’ 20”

Description: This section is composed of 3m coarse grained brownish poorly sorted sandstone at the base, whitish plastic clay on top of the sandstone, 1m brownish mudstone and about 1m weathered mudstone. The hammer is placed in the plastic clay, below is brownish sandstone (Fig. 23). The contact between the brownish sandstone and the plastic clay is gradational.

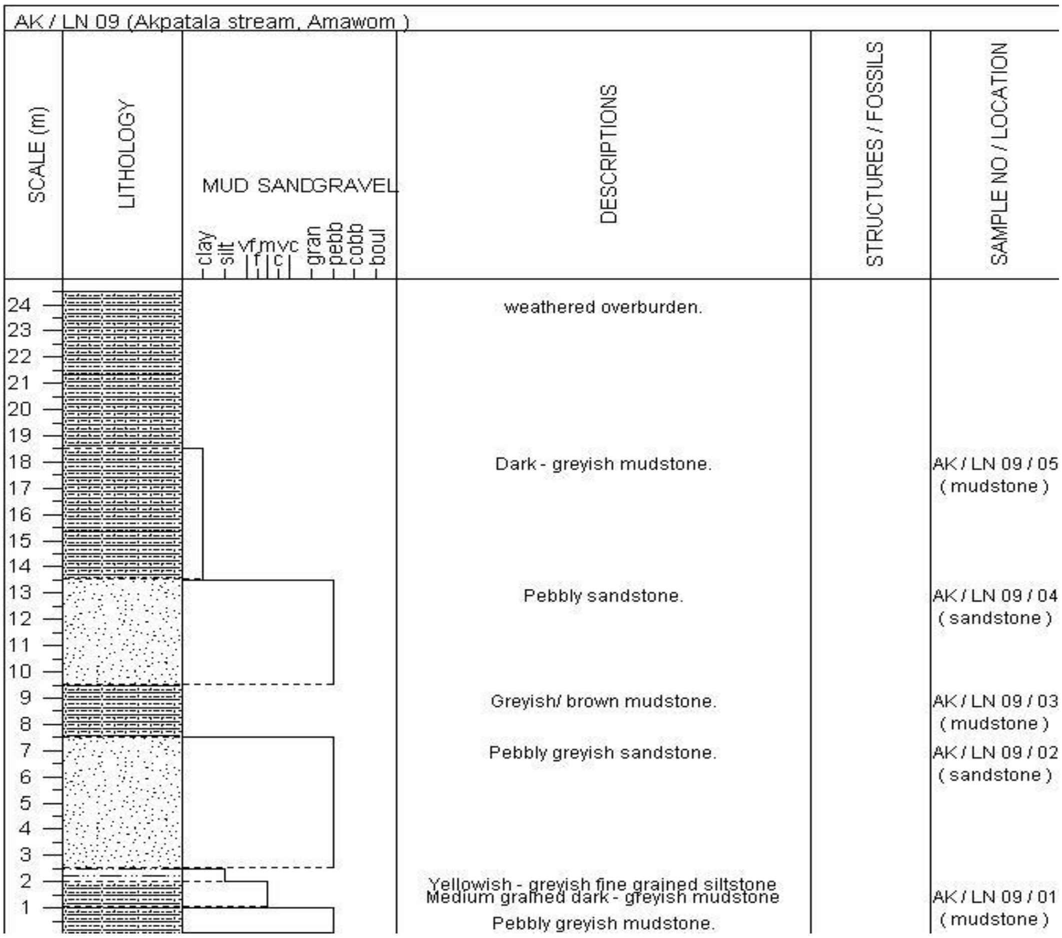


Figure 20: Lithologic log of Akpatala stream outcrop.

Figure 21: Outcrop pictures of Akpatala

Figure 22: Lithologic log of Iyi Nchara outcrop.

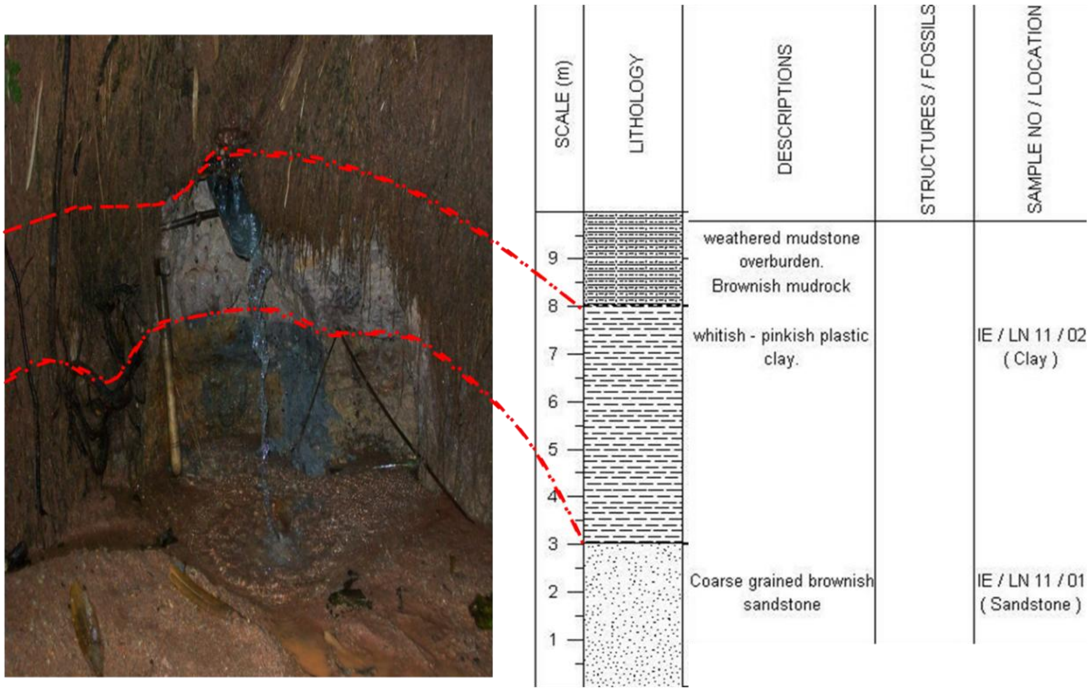


Figure 23: Lithologic log of Iyi Enyi outcrop.

3.9 Location twelve

Locality name: Ajata road cut

Grids: Lat. 5^0 28.0' 65" and Long. 7^0 33.4' 20"

Description: This section is about 3m thick laminated greyish shale and overburden mudstone (Fig. 24).

3.13 Location thirteen (A)

Locality name: Isiador, Ameke

Grids: lat 5^0 33.4' 49" and long 7^0 31.7' 94"

Description: The unit covers a total thickness of 9.5m. The lower most unit of this unit is 4m greyish-dark silty shale. This unit is highly fossilized with bivalves, gastropods, turitela. It also has inclusions of lignite. Overlying the lower unit is 0.5m consolidated siltstone band. On top of the siltstone band is 3m greyish silty shale. The contact between the units is gradational (Fig. 25 A and B).

3.12 Location thirteen (B)

Locality name: Isiador, Ameke

Grids: lat 5^0 33.3' 24" and long 7^0 31.4' 09"

Description: This section is about 30m from location thirteen (A). The lower unit is 6m greyish – dark silty shale, highly fossilized with lenses of shinny lignites. There are shells of bivalves, gastropods turitela etc in the silty shale. The next unit is 4.5m greyish-dark mudstone.

The arrow in picture A and B is pointing to the inclusions and lenses of lignites (Fig. 25C and D).

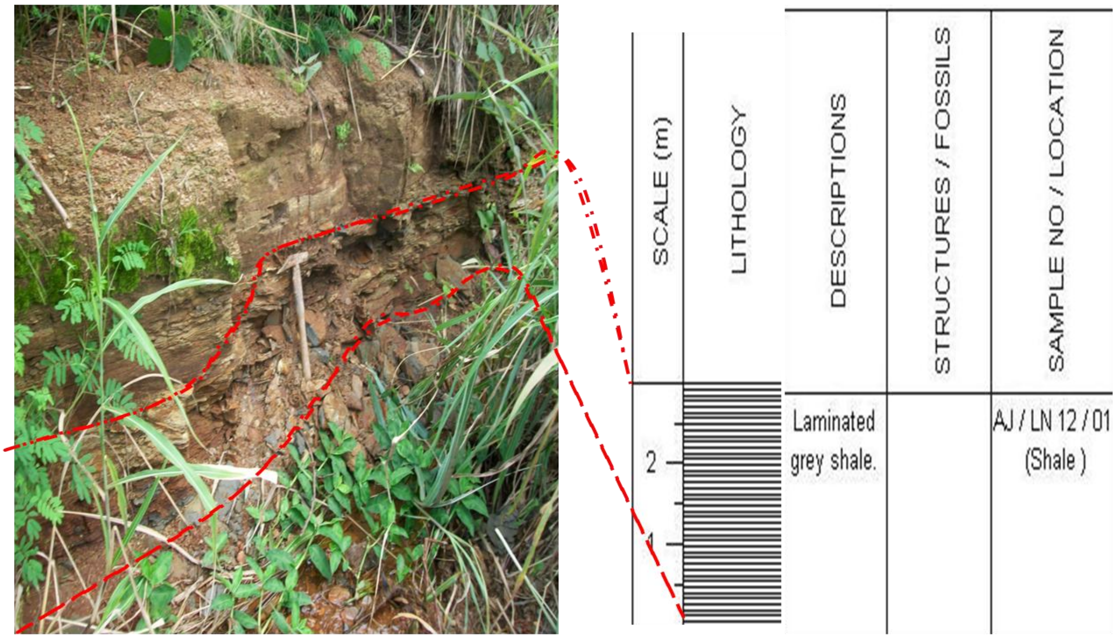


Figure 24: Lithologic log of Agata outcrop

Figure 25 A: Outcrop pictures of Isiador Ameke.

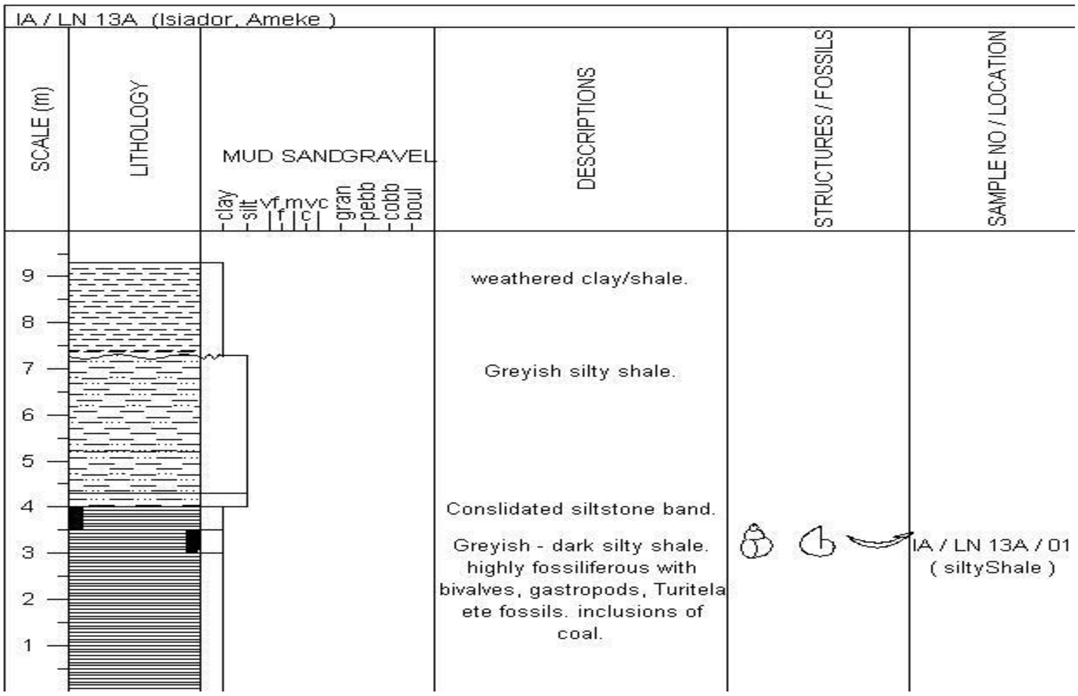


Figure 25 B: Lithologic log of Isiador Ameke (A) road cut outcrop.

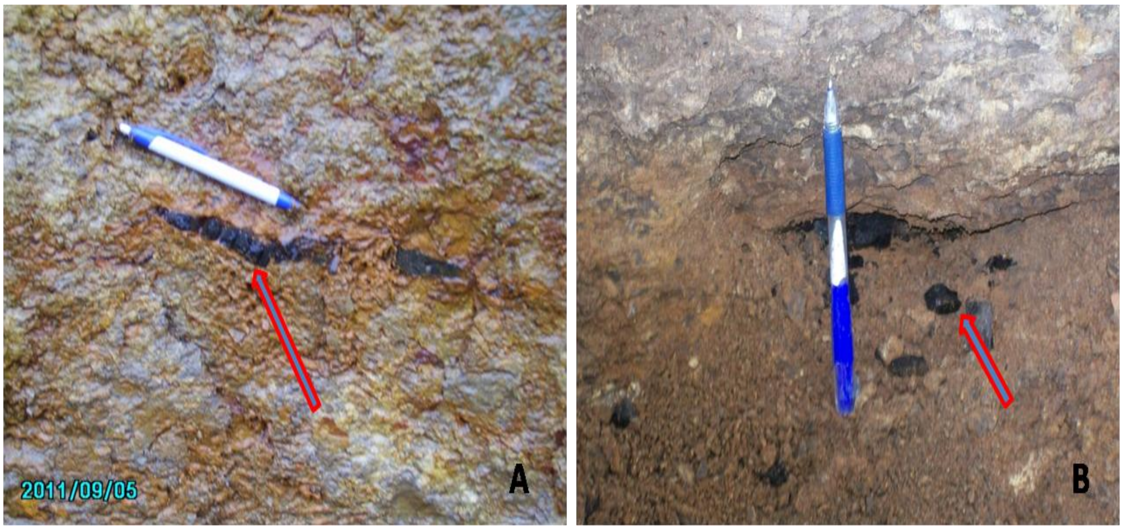


Figure 25C: Outcrop pictures of Isiador

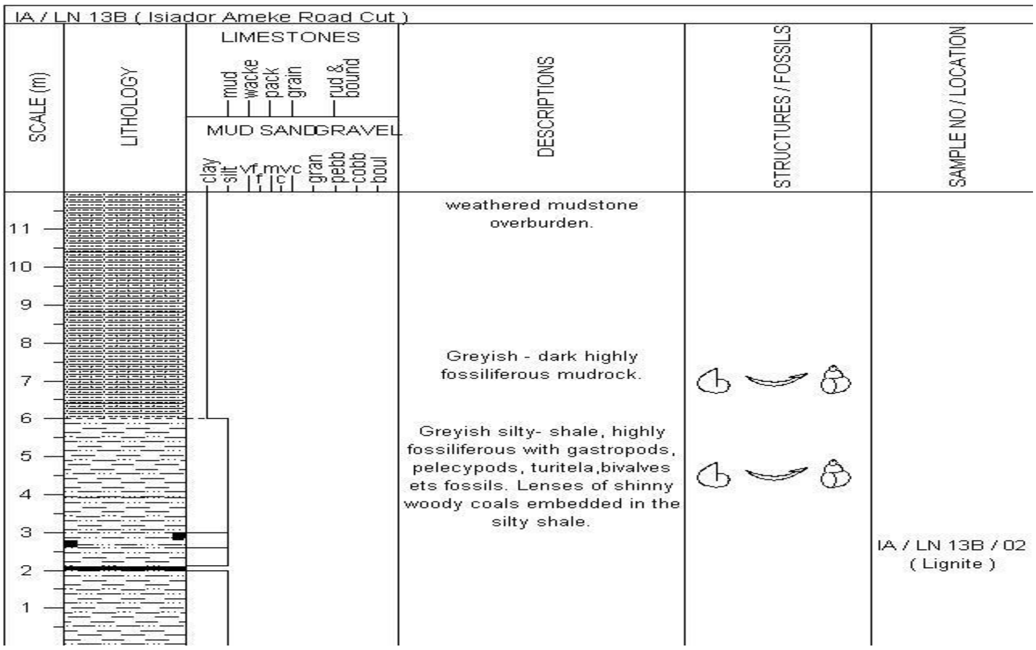


Figure 25 D: Lithologic log of Isiador Ameke.

CHAPTER FOUR: ANALYTICAL METHOD

Analytical techniques commonly in use for geochemical analysis over the last two decades are Rock –Eval Pyrolysis and Total Organic Carbon (TOC). A total of fifteen outcrop samples were analysed (ten lignite samples and five shale samples) to determine the Total Organic Carbon (TOC) and Programmed Pyrolysis. For Palynological studies, six samples (two lignite and four shale samples) were analysed.

4.1 Sample Preparation

4.1.1 Samples for Organic Geochemistry

The outcrop samples for organic geochemical analysis were initially cleaned by seeping in 100% dichloromethane with shaking followed by decanting of the solvent until the rocks were clean. After drying, the rock was washed under running tap water and then dried again in an oven at a pre-set temperature of 30^0C.

The samples were powdered and soxhlet-extracted in cellulose thimbles for a total of 36 hours in each case using 100 % dichloromethane. The solvent from the resultant solution was removed by means of a rotary evaporator under vacuum (pressure not greater than 200 mbar) and finally by a flow of nitrogen at not more than 30^0C to yield the extractible organic matter (EOM). This assessment served as preliminary screening for further detailed TOC and Rock-Eval analysis and to determine the organic richness of the source rocks.

Samples for Total Organic Carbon (TOC) and Programmed Pyrolysis were pulverized and material passing through 250 micron sieve was used for analysis. The samples were treated with concentrated hydrochloric acid to remove carbonates and Total Organic Carbon (TOC) contents of pulverized samples were determined using a LECO 600 carbon analyzer. In Programmed Pyrolysis pulverized samples are heated in an inert environment to measure the yield of three groups of compounds (S_1, S_2 and S_3), measured as three peaks on a program using a Delsi Rock-Eval II analytical equipment.

4.1.2 Sample for Palynomorphs analysis

Dispersed organic and palynomorph groups were used to identify palynofacies assemblages. Standard laboratory techniques of digesting sediments in hydrochloric and hydrofluoric acids were used to process samples. Oxidation stage with nitric acid was omitted for kerogen residues used for palynofacies analysis in order to preserve the colours of the organic debris, which were sometimes critical for identification.

Sample preparation for Palynological studies was carried out using the conventional maceration technique for recovering acid insoluble organic-walled microfossils from sediments. Each sample was digested for 30 minutes in 40% hydrochloric acid to remove traces of carbonate and 72 hours in 40% hydrofluoric acid for removal of silicate. The extracts were sieve-washed through 10 microns nylon mesh. The sieve-washed residues were oxidized for 30 minutes in 70% HNO_3 and 5 minutes in schulze solution to render the fossils translucent for transmitted light microscopy; rinsed in 2% KOH solution to neutralize the acid; swirled to sediment resistant coarse mineral particles and organic matter; and stained with Safranin – O to increase the contrast for study and photography.

For the coal sample, HCL & HF treatment was not necessary and treatment started with 30 minutes oxidation in Schulze solution and continued for the clastic sediments .Aliquots were dispersed with polyvinyl alcohol, dried on cover-slips and mounted in petro- poxy resin. Two slides were made from each sample, from which 200 grains were counted. The occurrence of each species was converted to percentage frequency in order to eliminate differences in counting. Light photomicrographs were taken with a Kyowa microscope.

4.1.3 Samples for Kerogen analysis

Four kerogen slides were prepared; each slide was examined using the transmitted light microscopy at X60 and X100 magnification. From the kerogen slide, the kerogen type, spore colouration and organic thermal maturation were determined.

CHAPTER FIVE

RESULTS AND INTERPRETATION

5.1 RESULTS

5.1.1 Total Organic Carbon (TOC)

Total organic carbon content (TOC) and Rock-Eval analysis were performed on 15 potential source rock samples (Table 2).Total organic carbon in a source rock comprises three basic components: [(1) organic carbon in retained hydrocarbons as received in the laboratory; (2) organic carbon that can be converted to hydrocarbons, called convertible carbon (Jarvie, 1991a) or reactive or labile carbon (Cooles et al.,1986); and (3) a carbonaceous organic residue that will not yield hydrocarbons because of insufficient hydrogen commonly referred to as inert carbon (Cooles et al.,1986; Jarvie,1991; Langford et al.,1990). It is known that adequate amount of organic matter, measured as percentage total organic carbon (TOC wt. %), is a necessary pre-requisite for sediment to generate oil or gas (Cornford, 1986; Nwachukwu et al., 1986; Murchison, 1987).

The TOC content of the lignite samples range from 15.65 – 48.61wt.% averaging 34.23wt. % and the TOC of the shales range from 1.07 – 2.61wt.%, averaging 2.11wt.%. There are variations in the TOC values of the lignites. Within the same locations there were samples that have high and low TOC values. Samples from outcrop location eight (AG/LN 08/01 and AG/ LN 08/05), location five (EF/ LN 05/01 and EF/ LN 05/05) and location three (OH/LN 03/ 01) have high TOC values, while samples (OH/LN 03/03), (EF/LN 05/07) have low TOC. There was no extreme variations in the TOC of shales except location KE/LN 02/ 02 which has TOC value less than two (TOC<2). Considering the depth at which these samples were collected, the variation could not be attributed to the degree of burial.

Table 2: TOC and Rock-eval pyrolysis results.

SAMPLE NO	LECO TOC	S1	S2	S3	TMAX	HI	OI	GP S1+S2	S2/S3	S1/TOC *100	PI
KE/LN 02/01	24.89	0.50	5.71	13.94	372	23	56	6.21	0.4	2	0.08
KE/LN 02/02	1.07	0.15	0.55	0.79	383	51	74	0.7	0.7	14	0.21
OH/LN 03/01	39.15	1.67	29.41	18.77	406	75	48	31.08	1.6	4	0.05
OH/LN 03/02	2.61	0.11	0.31	2.28	361	12	88	0.42	0.1	4	0.26
OH/LN 03/03	27.03	3.28	16.03	23.34	405	59	86	19.31	0.7	12	0.17
MG/LN 04/01	33.12	0.13	0.41	12.55	496	1	38	0.54	0.0	0	0.25
EF/LN 05/02	42.94	0.17	1.07	13.77	532	6	42	1.24	0.1	1	0.11
EF/LN 05/05	32.27	0.11	0.94	10.53	531	3	33	1.05	0.1	0	0.11
EF/LN 05/07	15.65	0.20	0.75	7.11	492	5	45	0.95	0.1	1	0.21
UM/LN 06/01	2.32	0,37	1.96	1.47	392	85	63	2.33	1.3	16	0.16
EB/LN 07/01	2.41	0.21	1.21	1.42	368	50	59	1.42	0.9	9	0.15
AG/LN 08/01	45.74	0.36	2.87	19.20	523	6	42	3.23	0.1	2	0.10
AG/LN 08/05	48.61	0.85	20.72	17.73	374	43	36	21.57	1.2	2	0.04
IA/LN 13A/01	2.18	0.14	0.34	2.07	356	16	95	0.48	0.2	6	0.29
IA/LN 13B/02	32.98	0.63	5.47	38.80	395	17	85	6.1	0.1	2	0.10

[NOTE: shale samples: KE/LN 02/02, OH/LN 03/02, UM/LN 06/01, EB/LN 07/01, IA/LN 13A/01., the rest are lignite samples].

EXPLANATIONS:

TOC – Total Organic Carbon, wt.%,
S1 – volatile hydrocarbon (HC) content, mgHC/g rock,
S2 – remaining HC generating potential, mgHC/g rock,

S3 – carbon dioxide content, mgCO2/g rock,

OI – Oxygen index = S3 X 100/TOC, mgCO2/g TOC,
Hi – Hydrogen index = S2 X 100/TOC, mgHC/g TOC,
PI – Production index = S1/ (S1+S2),
Tmax – Maximum Temperature ^{0}C,
GP – Generative potential = S1+S2.

5.1.2 Rock – Eval Pyrolysis

S1 yields of the lignite samples (table 2) range from 0.11 to 3.28 mg HC/g rock, and 0.11 to 0.37 mg HC/g rock in the shale. Sample no OH/LN 03/03 has high S1 value (3.28 mg HC/g rock).

S2 yields range from 0.41 to 29.41 mg HC/g rock in the lignite samples and 0.31 to 1.96 mg HC/g rock in the shale. Samples (OH/LN 03/01, OH/LN 03/03, and AG/LN 08/05) have high S2 values (29.41 mg HC/g rock, 16.03 mg HC/g rock and 20.72 mg HC/g rock respectively).

S3 yields range from 7.11 to 38.80 mg CO_2/g rock in the lignite samples and 0.79 to 2.28 mg $C0_2$/g rock in the shale.

Maximum temperature (Tmax) value, range from 372 to 532^0C in the lignite and 356 to 392^0C in the shale.

Hydrogen Index (HI) values range from 1 to 75 mg HC/g TOC (averaging 23.4 mg HC/g TOC) in the lignite sample and range from 12 to 85mg HC/g TOC (averaging 42.8 mg HC/g TOC) in the shales.

Production index (PI) value, range from 0.04 to 0.25 in the lignite samples and 0.15 to 0.29 in the shale samples.

5.1.3 Palynofacies Assemblages

Visual observation of the samples for dispersed organic matter and palynomorphs was carried out (Table 3). The most encountered groups were Palynomorphs, structured and unstructured phytoclasts, Opaque organic matter.

(1) Palynomorphs – These are embryophytic spores and pollen grains derived from land plants with colour ranging from yellow to dark brown and nearly black (Fig.26, picture A-N.).

Table 3: Occurrence and distribution of palynomorph species in the study area.

SAMPLE NO / PALYNOMORPHS	KE/LN02/02 shale	OH/LN03/01 Lignite	OH/LN03/02 shale	OH/LN03/03 Lignite	EB/LN07/01 shale	UM/LN06/01 shale
POLLEN						
Retistephanocolporites minor	-	X	-	-	-	-
Racemonocolpites hains	X	X	X	X	X	X
Retibrevitricolpites triangulatus	X	X	X	-	-	X
Psilatricolporites crassus	X	X	X	X	X	X
Monoporites annulatus	X	X	X	X	X	X
Echiperiporites icacinoides	X	X	X	-	-	X
Echiperiporites minor	-	x	-	-	X	-
Retibrevitricolporites obodoensis	-	-	-	-	-	-
Pachydermites diederixi	X	-	X	X	X	-
Cycadopites ovatus	-	-	-	X	-	-
Proxapertites cursus	-	-	-	-	-	-
Tricolpites hains	X	-	X	-	-	-
Liliacidites nigeriensis	x	X	X	X	X	X
Retibrevitricolporites ibadanensis	-	-	-	-	-	-
Calystegiapollis microechinatus	-	X	-	-	-	-
Chenopodipollis dispersus.	-	X	-	-	-	-
Inaperturopollenites hiatus	-	-	-	-	-	X
Psilatricolporites operculatus	X	X	X	X	X	-
Longapertites marginatus	X	X	X	X	-	X
Bombacidites sp.	-	-	-	-	-	-
Proteacidites sp.	-	-	-	-	X	-
Psilatricolpites minutus	X	-	X	X	-	-
Psilatriporites rotundus	X	X	X	-	-	-
Araucariacites austrialis	-	X	-	-	X	-
Graminidites minor	X	X	X	X	-	X
Inaperturopollenites hiatus	-	X	-	-	-	X
Retistephanocolporites laevigatus	-	X	-	-	-	X
Retitricolporites irregularis	X	X	X	X	X	-
Zonocostites ramonae	-	X	-	-	-	X
Retibrevitricolporites protrudens	X	X	X	-	-	-
Smilacipites echinatus	X	-	X	-	-	-
Ctelonophonidites costatus	-	-	-	-	X	-
Spinizonocolpites echinatus	X	-	X	-	X	-
Striatopollis catatumbus	X	-	X	-	-	-
Proxapertites operculatus	-	X	-	-	X	-
Mauritiidites crassibaculatus	X	-	X	-	-	-
Scabratriporites simpliformis	-	-	-	-	-	-
Quecoidites microhenrici	-	X	-	-	-	-
Retistephanocolpites williamsi	-	-	-	X	-	-
Alnipollenites verus	-	X	-	-	-	-
SPORE						

Magnastriatites howardi	-	-	-	-	-	-
Verrrucatosporites usmensis	X	X	X	X	X	X
Laevigatosporites ovatus	X	X	X	X	X	X
Cyathidites minor	-	-	-	-	-	X
Leiotriletes adriennis	-	X	-	-	-	X
Polypodiaceoisporites sp	X	X	X	-	-	X
Cyathidites australis	-	X	-	-	-	-
Leiotriletes maxoides	-	X	-	-	-	-
Schizosporis sp	-	X	-	X	-	X
Fungal spore	X	X	X	X	-	X
MICROPLANKTON						
Spiniferites sp.	X	-	x	-	-	-
Ceistospaeridium tribuliferum	-	-	-	-	X	X

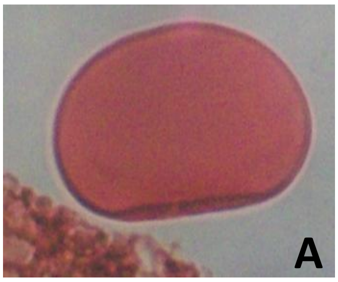
- Absent	
X Present	

(2) Phytoclasts – (a) structured phytoclasts- Structured remains of land plants, including lath-shaped or blocky wood particles, parenchyma, and thin cuticle fragments (Fig. 27, pictures 1B, 3B ,4C and 5B).

(b) Unstructured phytoclasts- This category included highly degraded plant remains without much structure with colours ranging from yellow to dark brown and nearly black, comminuted brown debris and amber-coloured, globular to angular particles of resin (Fig. 27, pictures 3F and 6F).

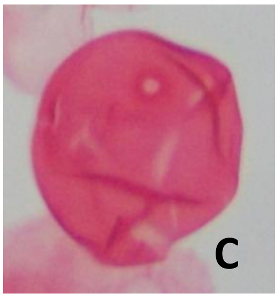
(3) Amorphous Organic matter (AOM) - Fluffy, clotted and granular masses with colours ranging from almost colourless to yellow and pale brown. This category is marine in origin, and formed as a result of degradation of algal matter (Fig.27, pictures 1A and 2A)

(4) Opaque (Black debris) - Most particles are opaque and often have shapes similar to wood, although some are rounded and appear to be highly oxidized palynomorphs (Fig.27, picture 1E)

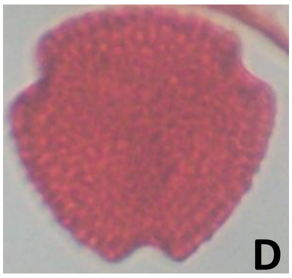


Laevigatosporites ovatus
Wilson and Webster, 1946 (x40)

Verrucatosporites usmensis
(Van der Hammen) Gemeraad, Hopping and Muller, 1968(x100)

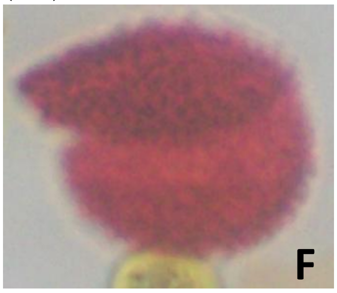


Monoporites annulatus
van der Hammen, 1954 (x40)



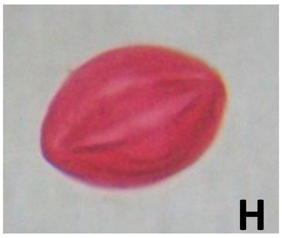
Retibrevitricolpites triangulatus
van Hoeken-Klinkenberg, 1966 (x60)

Psilatricolporites operculatus
Van der Hammen et Wymstra, 1964 (x40)

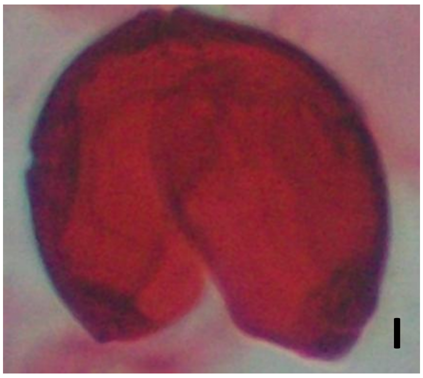


Racemonocolpites hains
Legoux 1971(x40)

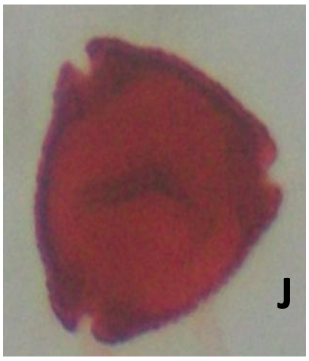
Bombacidites sp.
Gemeraad, Hopping and Muller, 1968 (x100) **oil immersion**



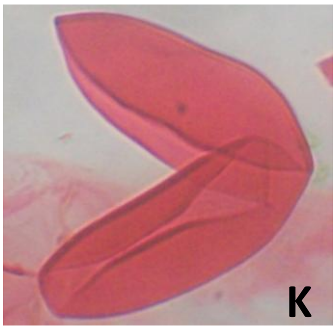
Striatopollis catatumbus
Takahashi and Jux, 1989(x40)



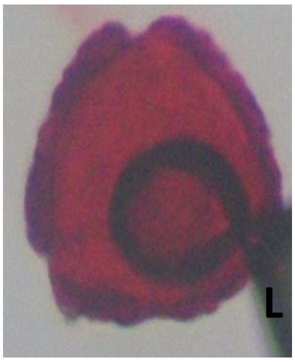
Pachydermites diederixi
Germeraad, Hopping and Muller,
1968 (x100) **oil immersion**



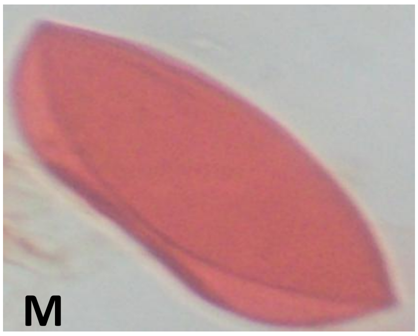
Retibrevitricolporites obodoensis
Legoux, 1971(x40)



Inaperturopollenites dubius
Ptonie and Venitz) Thomson and Pflug,
1953 (x60)



Psilatricolporites crassus
van der Hammen et Wymstra,
1964 (x60)



Liliacidites nigeriensis
(Van Hoeken-klinenberg, 1966) Salami,
1985(x60)

Retibrevitricolporites protrudens
Legoux, 1971(x40)

Figure 26: Photomicrographs of Palynomorphs recovered from the study area.

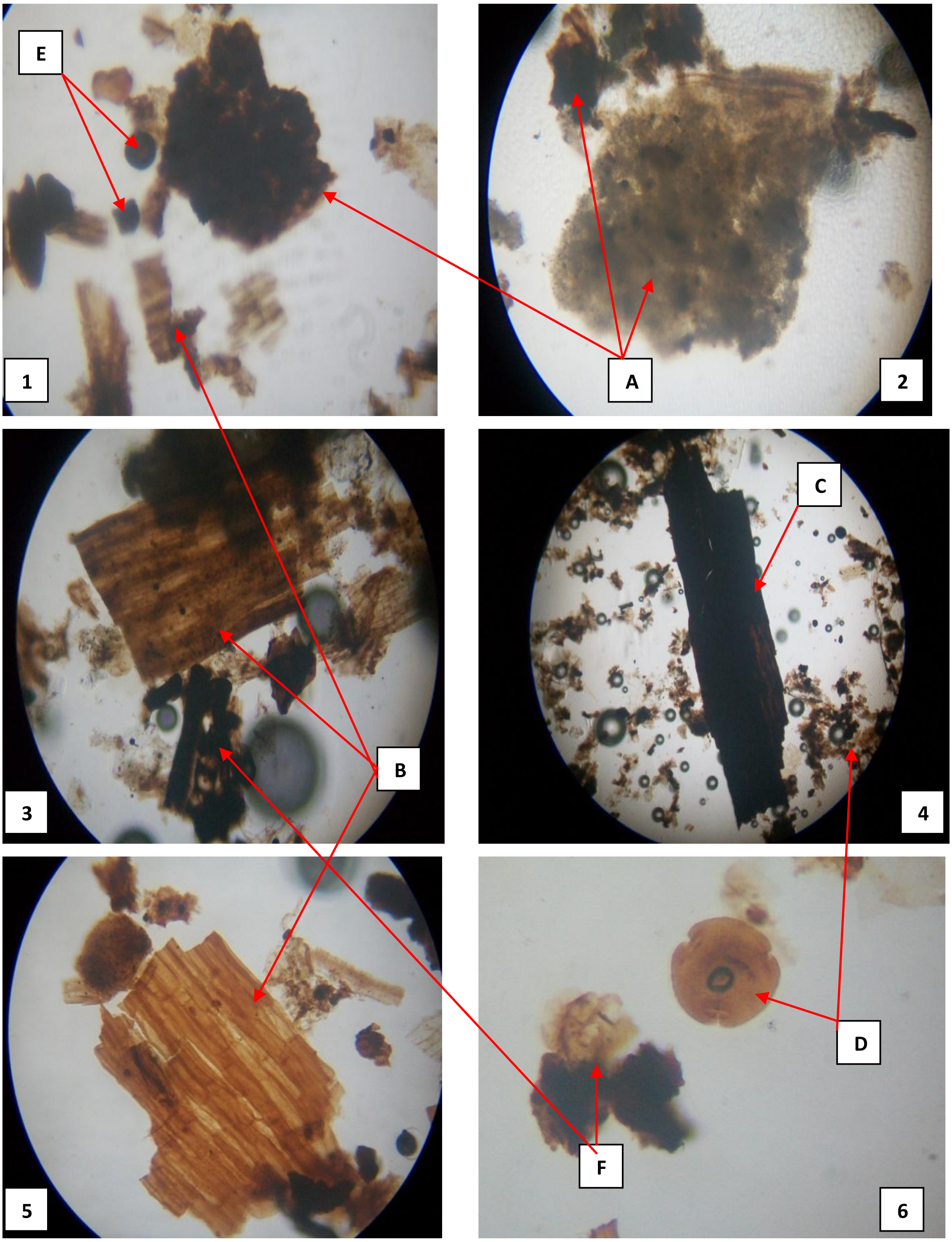


Figure 27: Photomicrographs of Kerogens from the analyzed samples in the study area.

Magnification X60.

(A) Structureless Organic Matter (AOM); (B) Well Preserved Structured Woods; (C) Carbonized Wood; (D) Light to Medium brown Palynomorphs; (E) Opaques (black) debris.

5.2 INTERPRETATION

5.2.1 Quantity of Organic matter

Petroleum is a generative product of organic matter disseminated in the rock and therefore the quantity of hydrocarbon directly correlates with organic matter concentration of the potential source rocks (Tissot and Welte, 1984; Killops et al., 1993).The amount of organic carbon is usually measured as a percentage total organic carbon (TOC wt.%).

TOC of the analysed sediments showed that the sediments have comparable average TOC contents, which are greater than the 0.5 wt. % threshold value required for a potential source rock to generate hydrocarbons for clastic sediments.

The TOC values averaging 34.23wt. % in lignites and 2.11wt. % for shale samples indicate a moderate to high organic matter concentration (Herdberg and Moody, 1979; Hunt, 1991; Peters and Cassa, 1994). This shows that the total organic content in the samples is adequate for generation of hydrocarbon.

Generally, variations in the TOC values among sediments could probably be attributed to localized changes in biological productivity, proximity to organic sources and preservation condition (Bustin and Chonchawalit, 1997; Ojo and Akande, 2002).

Lignite or coal lenses/fragments occur as a result of inclusions of plant remains in sediments. Sedimentation and preservation of these plant materials in other sediments occur as lignite/coal lenses/fragments. The variations in the TOC of the lignites may be attributed to their origin, sedimentation rate and preservation. Contamination may also cause variations in TOC.

5.2.2 Types and Quality of Organic matter

Typing of organic matter is typically accomplished using the hydrogen index (HI) and oxygen index (OI) values obtained from whole-rock samples via Rock-Eval pyrolysis.

The relatively low hydrogen index (HI) values with respect to oxygen index (OI) values of the studied samples, that is (01 mg HC/g TOC to 75 mg HC/g TOC, averaging (23.4 mg HC/g TOC) in the lignites and (12 mg HC/g TOC to 85 mg HC/g TOC averaging (42.8 mg HC/g TOC) in the shale with respect to (33 mg CO_2/g TOC to 118 mg CO_2/g TOC averaging (54.4 mg CO_2/g TOC) in the lignite samples and 63 mg CO_2/g TOC to 95 mg CO_2/g TOC averaging (75.8 mg CO_2/g TOC) in the shale (Table 2) suggest that the source rocks have potential for gaseous hydrocarbon (Pyrolysis result).

The most significant factor with respect to the capacity of source rock to generate petroleum is the amount of hydrogen in the kerogen (Hunt, 1996; Sykes et al., 2002). Hydrogen-rich organic matter commonly generates more oil than hydrogen poor organic matter because oil is rich in hydrogen. From samples analysed, the amount of hydrogen is relatively low.

Hydrogen index (HI) from the analysed samples fall into two main groups according to Peters 1986 classification; HI < 50mgHC/g TOC and HI 50 – 200mgHC/g TOC (Table 4). This indicates a type III and IV kerogen type.

The hydrogen type index (S2/S3) of the samples are less than 2 (i.e. S2/S3 < 2) which is typical for gas generation. The hydrogen and oxygen indices in (Table 2) from the samples plot between the type III and IV reference curves (Fig.28), with the majority showing affinity for the type IV reference curve in the modified van Krevelen diagram.

This simple classification by (Petersen,2006) for rapid assessment of hydrocarbon potentials will enhance our understanding of the components of the individual kerogen types mentioned in (Table 4) below.

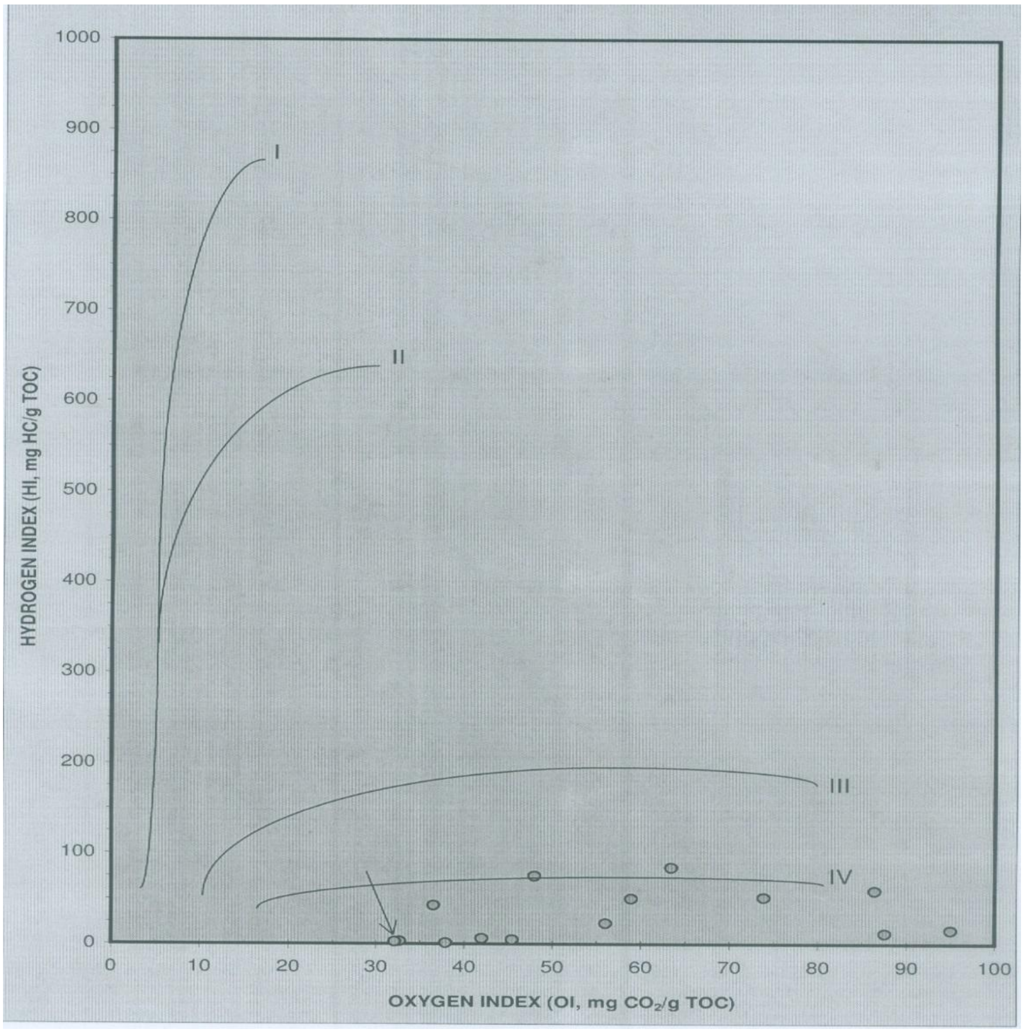


Figure 28: Plot of HI versus OI. Modified Van Krevelen diagram.

Table 4: Parameters for describing Kerogen Type (Quality) of an immature Source Rock (Modified after Peters, 1986).

Kerogen type	HI (mgHC/g TOC)	S2/S3
I	> 600	> 15
II	300 – 600	10 – 15
II/III	200 – 300	5 – 10
III	50 – 200	1 – 5
IV	< 50	< 1

1 Kerogen type I (highly oil-prone material): It includes alginitic material derived from chlorococcale algae, prasinophyte algae, and cyanobacteria. Resins are the only significant terrestrially derived components associated with this group.

2 Kerogen type II (oil-prone material): It includes amorphous organic matter (AOM), but sporopollenin palynomorphs, cuticle and non-cellular membranous debris are also included.

3 Kerogen type III (gas-prone material): Orange or brown, translucent, phytoclasts or structureless materials. Woody fragments are typical.

4 Kerogen type IV (inert material): Opaque to semi-opaque, black, or very dark brown particles, representing oxidized or carbonized phytoclasts.

The plot of Rock-Eval HI versus OI (Fig.28) is also used in determining kerogen type. (Langford et al., 1990; Peters, 1986). The slopes of lines radiating from the origin are directly related to hydrogen index (HI= S2 × 100/TOC, mg HC/g TOC). Hydrogen index values of the samples fall below 100 mg HC/g TOC. This classifies the organic matter into type III and IV kerogen.

5.2.3 Thermal Maturity of Organic Matter

The organic maturation of the studied samples is evaluated based on Tmax and Production index (PI) values of the shales and the lignites. Rock-Eval Tmax is the pyrolysis temperature (^{0}C) at the maximum rate of kerogen conversion (Baskin, 1997; Petersen, 2006). The thermal maturity of organic matter is commonly derived from this Rock-Eval Tmax.

The Tmax values for the lignites range from 372 to 532^{0}C, averaging (453^{0}C) and 356 to 392^{0}C, averaging (372^{0}C) in the shale. Production index values range from 0.04 to 0.26 in the lignite and 0.15 to 0.29 in the shale (Table 2).

Peters (1986) noted that PI for hydrocarbon generation range from 0.1 to 0.4; PI less than 0.1 indicate immature organic matter. The PI value for the studied samples fall within two groups: (PI < 0.1) which indicate immature organic matter and (PI 0.1 – 0.4) postmature (gas generation).

He also stated that Tmax values less than 435^{0}C indicate immature samples, for mature samples: Tmax values from 435 – 445^{0}C (Early mature), 445 – 450 ^{0}C (Peak), 450 – 470 ^{0}C (late), and Tmax greater than 470^{0}C indicates Dry gas zone. (Table 5).

Tmax values of the analysed samples fall within the thermally immature (356^{0}C, 362^{0}C, 368^{0}C, 372^{0}C, 374^{0}C, 383^{0}C, 392^{0}C, 395^{0}C, 4050C, 406^{0}C,) and post mature (492^{0}C, 4960C, 523^{0}C, 531^{0}C, 532^{0}C) organic matter with respect to petroleum generation.

Plot of PI versus Tmax (Fig.29), HI versus Tmax (Fig.30) also show that the lignite and shale samples are partly within the immature and postmature zone.

In this study, the temperature of the sediments shoots from immature to post mature. All the shale sediments fall within the immature level. Lignite sample (OH/ LN 03/ 01 and OH/ LN 03/ 03) sampled from the lignite seam and samples (KE/ LN 02/ 01, AG/ LN 08/ 05 and IA / LN 13B/02) fall within the immature level, the rest of lignite plot within the post mature level. The samples within the post mature level could be attributed to recycled material. It could be that these samples are not indigenous to their present location but were transported from the older Anambra basin. These sediments could have been deposited from organic materials of terrestrial sources in the rift basins during the upper Cretaceous in Nigeria.

Table 5: Parameters for describing the levels of thermal maturity of Source Rock (Modified after Peters, 1986).

Stage of thermal maturity for oil	Maturation	
	Vitrinite reflectance (%)	Rock – Eval Tmax (°C)
Immature	0.2 – 0.6	<435
Mature		
Early	0.6 – 0.65	435 - 445
Peak	0.65 – 0.9	445 – 450
Late	0.9 – 1.35	440 - 470
Postmature	> 1.35	>470

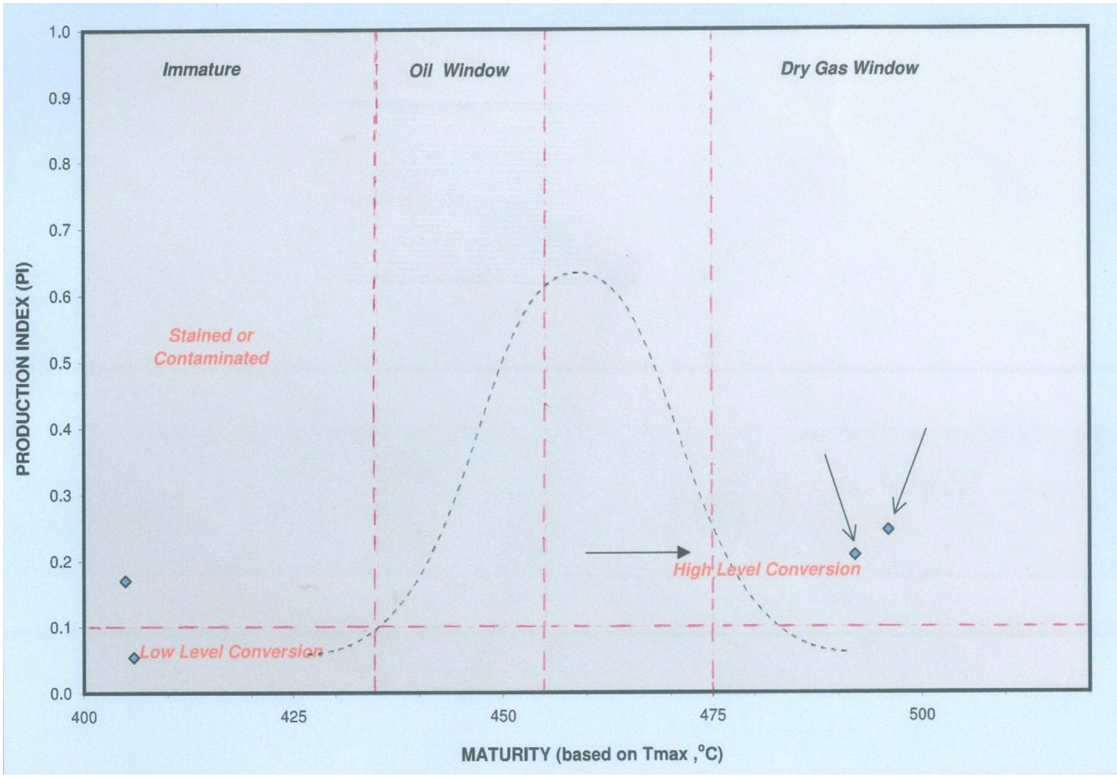


Figure 29: Plot of PI versus Tmax of the samples from the study area

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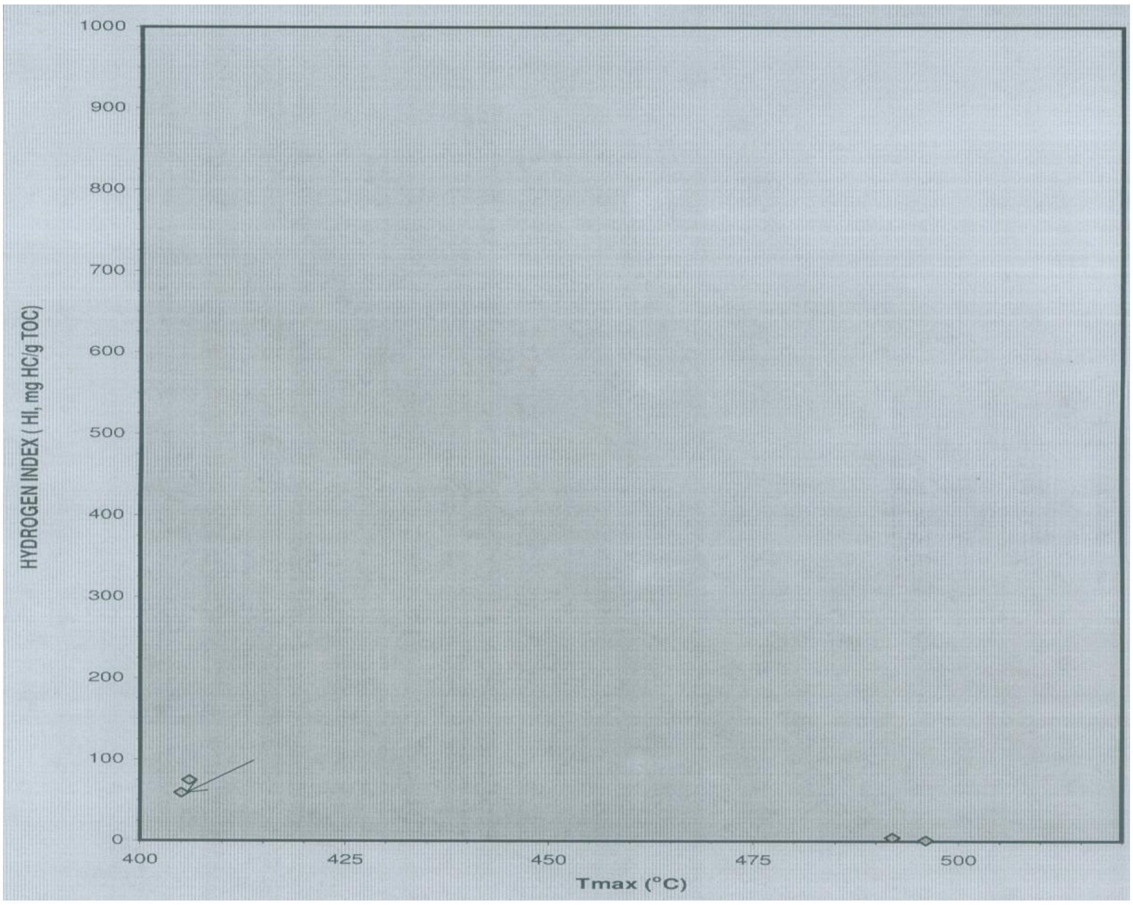


Figure 30: Plot of HI versus Rock-Eval T_{max} for the samples from the study area.

5.2.4 Hydrocarbon Source Potential

The source rock potential of the samples is assessed by Pyrolysis derived generative potential. Rock-Eval Pyrolysis reveals that the total generative potential (S1+S2) of the samples range from 0.54 to 31.08 mg HC/g rock averaging (9.13 mg HC/g rock) in the lignites and 0.42 to 2.33 mg HC/g rock averaging (1.07 mg HC/g rock) in the shale samples.

S1 is the quantity of free hydrocarbon liberated by volatilization at 300^0C while S2 is the quantity of hydrocarbon produced by further thermal cracking of kerogen both expressed as mg HC/g rock.

Most of the samples showed Genetic potential (GP), exceeding the minimum required value for hydrocarbon source rocks (Table 6). The assessment is based on Tissot and Welter's, (1984) classification; rocks with less than 2 mg HC/g rock have little or no oil source rock potential but potential for gas whereas rocks with GP from 2 to 6 mg HC/g rock are classified as having moderate to fair oil source rock potential and some potential for gas. GP values greater than 6 mg HC/g rock are considered as good or excellent petroleum source rocks.

Shale samples GP values are less than 2 mg HC/g rock and as such exhibit yields consistence with potential for gaseous source rock; also majority of the lignite samples exhibit yields with moderate to fair source rock potential for gas generation. The extremely high GP values evident in some of the lignite samples is due to the exceptional high values in the corresponding S2 values of same samples. This exceptional high value might be attributed to contamination.

The cross plot of S2 verse TOC (Fig.31) shows that the values plot within the type IV and III curves, indicating gaseous materials.

Values of the total organic carbon content (TOC), hydrogen and oxygen index values (HI and OI respectively) and maturity indices discussed above are consistent with the palynofacies characteristics of the studied samples.

The palynomorph assemblages recovered and results from kerogen slide are synonymous with geochemical results showing that the samples have potential for gaseous hydrocarbon. The colour of the pollen grains and spores from the samples are characterised by light to yellowish through orange and brown which suggests low to high thermal conditions. The relationship between the colour of pollen and spores and, petroleum generation and expulsion from kerogens have been proposed by Tissot and Welte (1984), explaining a progressive colour change from light to brown (diagenesis) through brown to dark brown (catagenesis) and finally black (metagenesis). Kerogen ssessment and interpretation was surmarised in table 7.

Table 6: Parameter for describing the petroleum potential of source rock. (Modified after Tissot and Welte, 1984).

Petroleum potential	Organic matter			
	Rock -Eval Pyrolysis			TOC (wt.%)
	(S1+S2) (mgHC/g rock)	S1 (mgHC/g rock)	S2 (mgHC/g rock)	
Little or no gas but oil	<2	0 – 0.5	0 - 2.5	0 - 0.5
		0.5 - 1	2.5 - 5	0.5 – 1
Moderate to fair oil and gas	2 – 6	1 - 2	5 – 10	1 – 2
		2 - 4	10 - 20	2 - 4
Good/excellent oil	>6	2 – 4	10 – 20	2 – 4
		>4	>20	>4

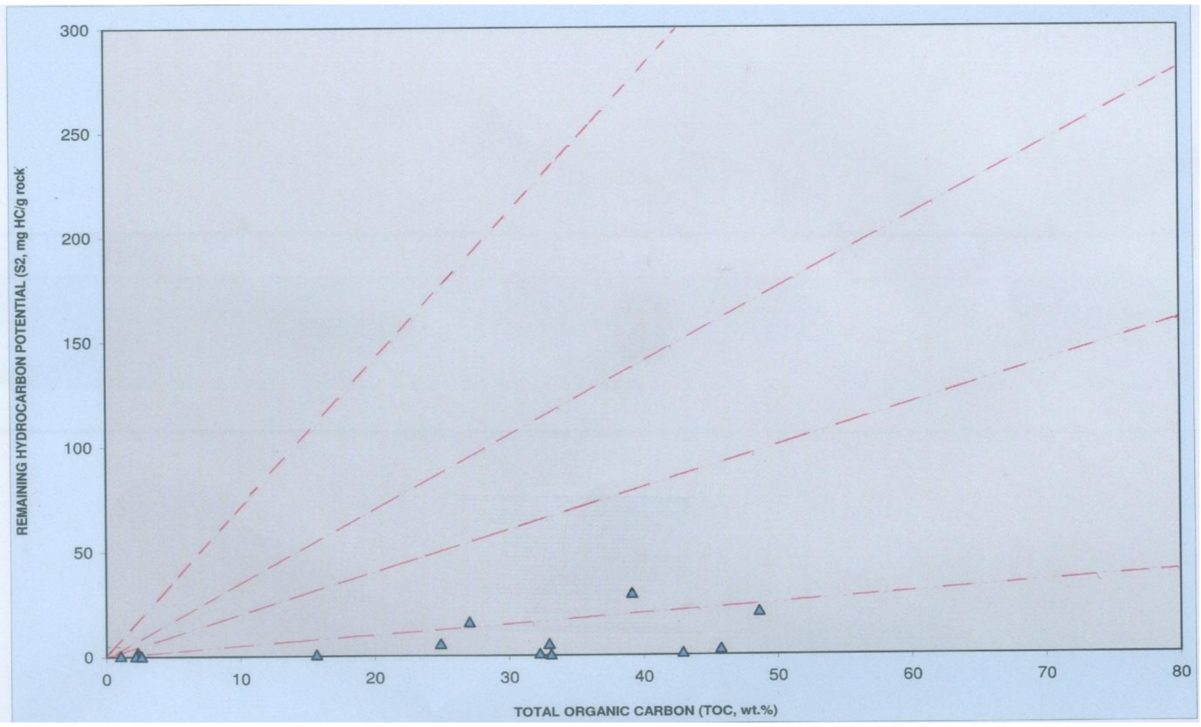
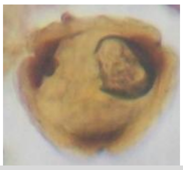
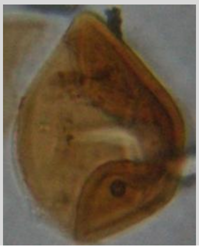


Figure 31: Plot of remaining hydrocarbon potential (S_2) versus TOC (after Langford and Blanc-Valleron, 1990).

Table 7: Summary of the kerogen assessment and interpretation

SAMPLE NO	PALYNOFACIES ASSOCIATION	SPORE COLOUR	TAI	R%	THERMAL MATURITY	KEROGEN TYPE	SOURCE ROCK PTENTIAL
KE/LN 02/02	AOM & Phytoclasts	Orange, Light brown - medium brown	2-to 2	0.3 to 1.1	Immature 	Type III	Gas Prone
OH/LN 03/02	Phytoclasts & Opaque Debris.	Yellow – Yellowish Orange	2- to 2	0.3 to 0.5	Immature 	Type III	Gas Prone
UM/LN 06/01	Phytoclasts & Opaque Debris.	Yellow – Yellowish Orange	2- to 2	0.3 to 0.5	Immature 	Type III	Gas Prone
EB/LN 07/01	Phytoclasts & Opaque Debris.	Yellow – Yellowish Orange	2- to 2	0.3 to 0.5	Immature 	Type III	Gas Prone

5.2.5 Age Determination and Palaeoenvironment of deposition

The pollen and spores, dinoflagellates and other particulate organic matter which can be recognized and identified from a succession of rocks can be used effectively to define precisely the age and palaeoenvironment that prevailed during the deposition of the rocks. The palynofacies types and abundance provide information regarding the interpretation of the age and environment of deposition of the sediments in this area.

Pollen and spores play a major role in dating and palaeoenvironmental determination due to their abundance and good preservation.

The definition of the proposed age and palaeoenvironment is based on the data gathered from both the abundance and distribution of range species of the Palynomorphs. The analysis of the slides yielded fifty-two (52) palynomorph species (Table 3).

The age of the sediments was assigned based on identified age diagnostic pollen and spore markers species according to the zonation schemes of Evamy *et al.*, (1978) and Legoux (1978).

An age range from Middle Eocene – Early Miocene is assigned due to the presence of *Pachydermites diederixi, Verrrucatosporites usmensis, Inaperturopollenites hiatus, Psilatriporites rotundas, Magnastriatites howardi* in the samples (Table 8).

It is pertinent to note that the study area at the time of deposition was dominated by diverse forest plant species. Some of these forest species include *Verrrucatosporites usmensis,* Zonocostites ramonae, *Retibrevitricolporites protrudens, Laevigatosporites ovatus* and *Psilatricolporites crassus, Retitricolporites irregularis,* etc.

The percentage abundance of the different species at a particular time, gives rise to the different depositional environments (Table 9), thus generally it was assigned fresh water swamp forest.

Table 8: Stratigraphic chart of selected key sporomorph species in the study area.

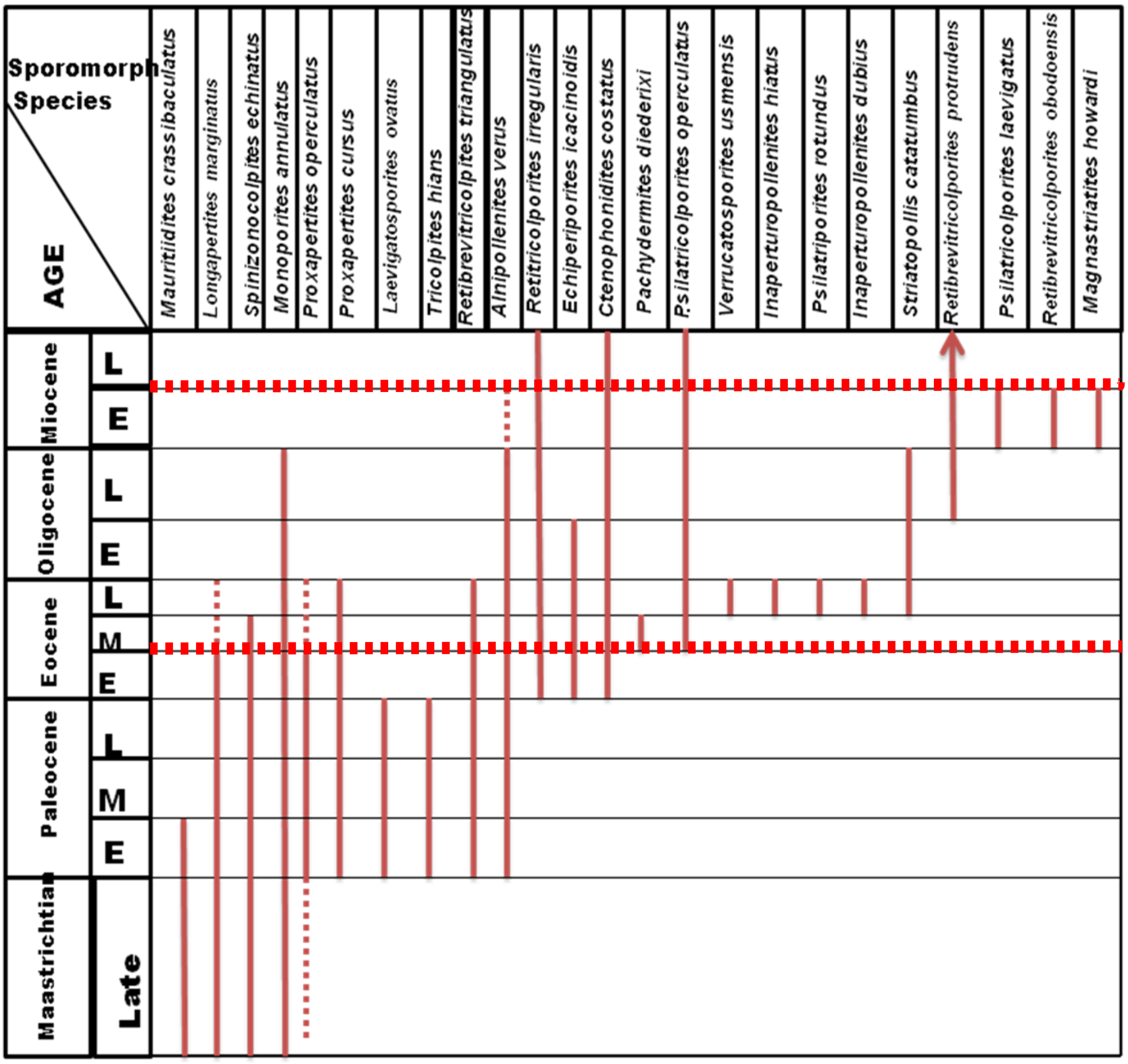


Table 9: Summary of the palynomorphs distribution and palaeoenvironmental inference for the analyzed samples.

Sample No	Lithology	Palynomorphs frequency (%)			Palaeoenvironment	Age
		Spore	Pollen	Dinocyst		
OH/LN 03/03	Shale	56	43	1	Lower deltaic plain/lagoon	Early Miocene
OH/LN 03/02	Lignite	64	36	0	Freshwater Swamp/ upper deltaic plain	
OH/LN 03/01	Lignite	71	29	0	Freshwater swamp/upper deltaic plain	Late Eocene
KE/LN 02/02	Shale	44	55	1	Lower deltaic plain/ upper deltaic plain	
EB/LN 07/01	Shale	56	44	0	Lower deltaic plain/ lagoon	
UM/LN 06/01	Shale	29	70	1	Blackish water/lagoon	Middle Eocene

CHAPTER SIX

SUMMARY/CONCLUSION

This study has shown that the Lignite and shale samples outcropping at Umuahia and its environs in the Niger delta Basin, South - East Nigeria have an average total organic carbon (TOC) contents of 34.23wt.% and 2.11wt.% respectively, and as such have adequate organic carbon to generate hydrocarbon.

The hydrogen index (HI) and generative potential (GP) of the samples were above the minimum values required for a potential source rock; [average values: 23.4mgHC/gTOC (lignites), 42.8mgHC/gTOC (shale) and 9.13mgHC/g rock (lignites), 1.07mgHC/g rock (shale)] respectively.

The level of thermal maturation derived from Rock-Eval data showed that the lignites and shale sediments are partly within the immature and postmature level.

The palynomorph assemblages from the study indicate predominance of Phytoclasts and terrestrially derived pollen and spores. This suggests a fresh water swamp forest. The sediments were assigned a Middle Eocene to Early Miocene age based on the identified age maker species in the samples.

In conclusion, it can be deduced that the sediments were derived from mainly terrestrial biota with immature to postmature status. The immature sediments have prospects to generate gas at appropriate maturation rather than oil, while the post mature sediments are recycled materials transported from older Anambra basin..

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