PALYNOLOGICAL AND SOURCE ROCK ANALYSES OF THE SHALE MEMBER OF THE PATTI FORMATION, BIDA BASIN

BY

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GLY/14/2256

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IN

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

February, 2019.

CERTIFICATION/APPROVED PAGE

This is to certify that the research project on the palynological analysis and source rock evaluation of the shale member of the Patti Formation was actually carried out by Kolade Oluwatosin with matriculation number GLY/14/2256 under the supervision of Professor O.J Ojo.

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.

Signature.................. Date. 18/2/2019

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Prof.O.J.Ojo

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Signature Prof. S.A. Opeloye Date. 25/02/19

(Name of External Examiner)

External Examiner

DEDICATION

This report is dedicated to God Almighty with the most profound gratitude to him for endowing me with the ability required in putting this work together, and to my parents for the support they have showed towards this project.

ACKNOWLEDGEMENT(S)

I give God the adoration and glory for his protection, love and divine favour he gave to me during this program. I appreciate the effort of my supervisor, Professor O.J Ojo for his fatherly advice and his assistance in this work.

To the intellectual that helped me in my chosen field of study in the academic cycle, Mrs. Ndukwe, Mr. . Awe, Mr.Bolaji for the guidance and assistance and for always being there, thank you so much, you are appreciated.

My deep gratitude goes to my parents Mr. and Mrs O.J Kolade and my siblings for all the love and commitment to my career, thank you all so much, and God bless you.

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ABSTRACT

The study area is located within the Southern Bida Basin. The study involved the geochemical and palynological analysis of the shale samples from the Patti Formation at Ahoko and Gehuku in the Southeastern Bida Basin. The samples yielded a rich assemblages of Middle to Late Maastrichtian palynomorphs among which were common palynomorphs: *Foveotriletes margaritae, Striatricolpites (Striatopollis), catatumbus,* With dinoflagellate cyst (*Lingulsniodinium machaerophorum*) and abundant palm pollen *Longapertites marginatus, Proxapertites cursus , Monocolpopollenites sphaeroidites, Echitriporites trianguliformis, Longapertites microfoveolatus, Ephredipites sp.* The pollen and spores suggest a tropical climatic condition for the deposition of the Patti Formation. The presence of *Longapertites microfoveolatus, Verrucatosporites* sp. indicates a well drained and wet environment.

The Total Organic Cabon results showed that the organic carbon varies from 0.75 to 2.87 wt. % in the shales, indicating that the sediments contain good organic matter contents. Generative Potential values ranging from 0.9 to 3.52 mg HC/g TOC indicate that the shales are moderate to good source rocks. Hydrogen Index values also range from 51 to 123 mg HC/g TOC indicating that the sediments are fair rocks with potential for oil and gas. Van Krevelen type diagram of Hydrogen Index (HI) against Oxygen (OI) for the sediments of Ahoko and Gehuku Formation shows that the organic matter contained in the sediments are predominantly type II/III and type III kerogen with subordinate type IV kerogen which are capable of generating oil and gas. The Tmax and PI ranges of 420 to 430^{0}C and 0.02 to 0.1 respectively for the sediments indicate immaturity. The source rock evaluation of the Patti Shale indicates immaturity.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND INFORMATION

The Bida Basin also known as the Mid-Niger or Nupe Basin, is located in west-central Nigeria is a Northwest - Southeast trending depression perpendicular to the main axis of the Benue Trough (fig 1.1). Bida Basin is a NW-SE trending intracratonic basin extending from Kotangora (Northern Nigeria) to Lokoja in the central part of Nigeria in the south.The basin is Sub divided geographically into the Northern, Central and Southern Bida basins referred to as sub basins.

The study area lies within the Southern Basin. The basin is a gently downwarped trough whose genesis may be closely connected with the Santonian orogenic movements of southeastern Nigeria and the Benue valley, nearby. The basin is a NW–SE trending embayment, perpendicular to the main axis of the Benue Trough and the Niger Delta Basin. It is frequently regarded as the northwestern extension of the Anambra Basin, both of which were major depocentres during the third major transgressive cycle of southern Nigeria in Late Cretaceous times.

1.2 LOCATION, EXTENT AND ACCESSIBILITY OF STUDY AREA

The study area lies within latitudes $7^0$48'N and $7^0$52' N and longitudes $6^0$40'E and $6^0$45'E at an altitude of 45-125 m, on the western bank of the Niger River, close to its confluence with the Benue River. The samples were from the Patti Formation at Ahoko and Gehuku. The lithology of the study area includes the intercalation of shale and ironstone. Ahoko (08^0 18' 14.9"N) and Gehuku (08^0 18' 51"N) lies within 7.8023° N of the equator and 6.7333° E of the Greenwich meridian.

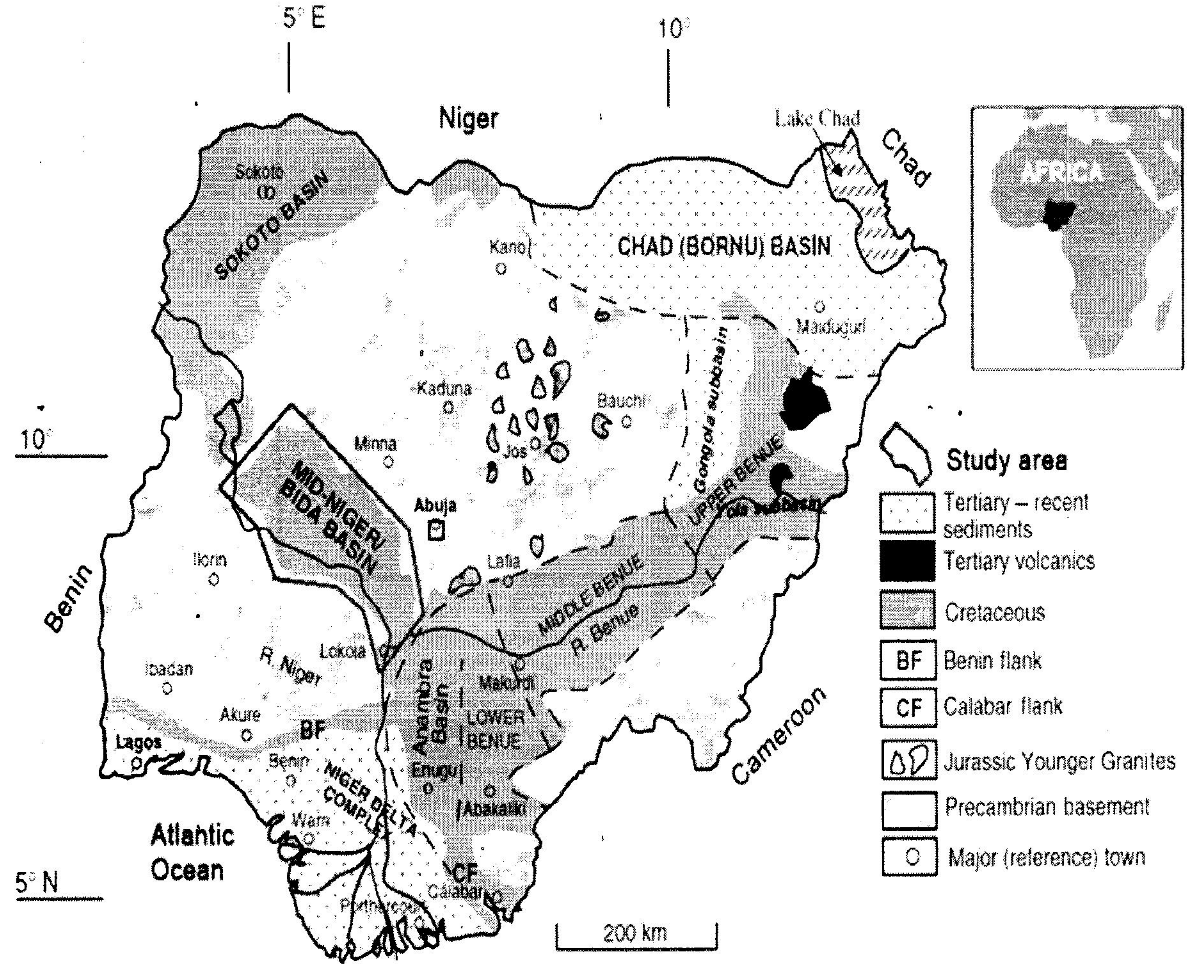

Figure 1.1: Geological map of Nigeria showing the location of the study area (After Obaje et al., 2004)

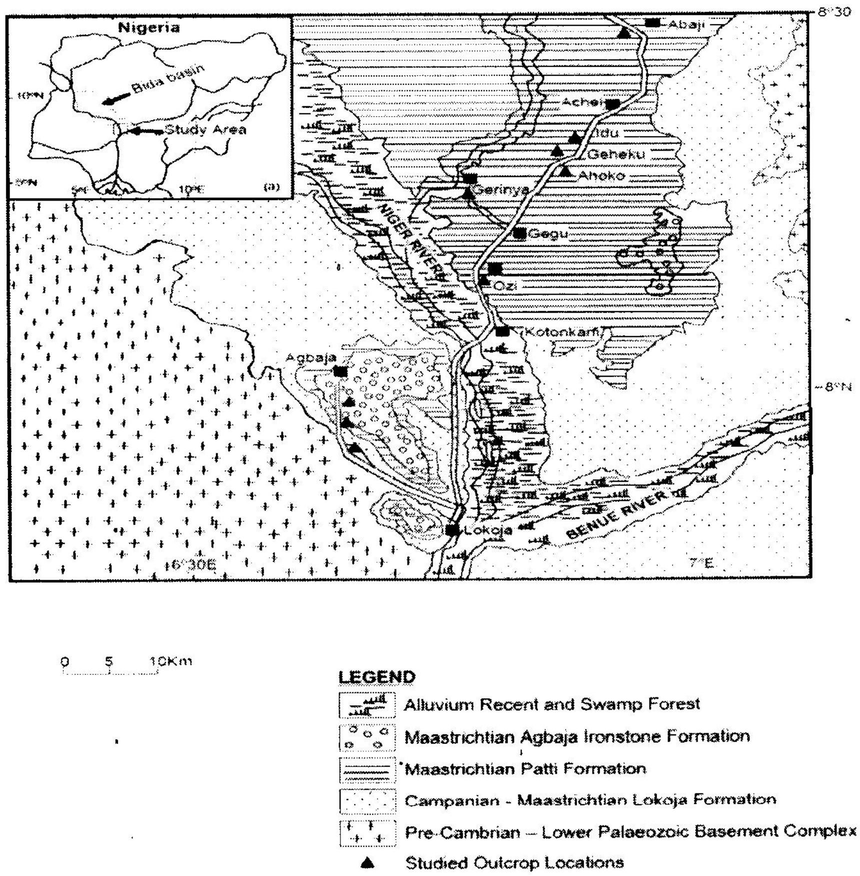

Figure 1.2: Map showing Bida Basin and the various locations (Modified after Ojo, 2009). Note, the location of the investigated exposures of Patti Formation at Ahoko and Gehuku.

1.3 AIM AND OBJECTIVE OF THE STUDY

The aim of this study is to determine the potential, age of the shale in Bida Basin

The objectives of this project include the following:

i. To determine the kerogen quality of oil
ii. The type of organic matter and the organic matter richness
iii. Thermal maturity of the organic matter
iv. To determine the age and vegetation of the palynomorphs
v. To infer the paleoenvironment in which the palynomorphs are found
vi. To indicate the paleoclimatic condition of the Patti Formation

1.4 SCOPE OF THE STUDY

The scope of this study includes:

i. The detailed field mapping techniques and samples collection from the Ahoko and Gehuku in the Patti Formation
ii. Laboratory studies involving the palynological and organic geochemical analysis
iii. Integration and interpretation of the results obtained from the laboratory studies.

1.5 RELEVANCE OF THE WORK

The relevance of this work is aimed at studying one of our Nigerian Basin and its potentials for natural resources and to infer the paleoenvironment and age of the palynomorphs.

1.6 PHYSIOGRAPHY

The major means of transportation is by road, sometimes by water using boat to areas which are not motorable. Wetland areas have great advantages for farmers because they provide opportunities for planting different crops such as, rice, sugar cane, corn, vegetables, among others throughout the year.

1.7 CLIMATE

The type of climate in Lokoja is that of the tropical hinterland of Nigeria. The Area is characterized by two distinct seasons namely; the rainy season and the dry season. The Rainy season last for seven months from April to October, Rain begins, on average, in March and peak in June to September, while the dry season begins at about November. Every month has an average temperature close to 30°C. The dry season last for five months from November to March. Average annual precipitation from 2001 – 2010 for the area range between 1000 mm -1500 mm. Daily temperatures in the area vary with the Seasons. Minimum average temperatures of about 25^0C -27^0C are recorded mainly during the Rainy season while maximum temperatures of about 35^0C are experienced during the dry season. The Niger and its main tributaries are characterized by flash flood superimposed on perennial flow. The Niger floods at Lokoja begin in July, peaks in October, and finishes by December. Relative humidity in the area ranges from 55% to 65% during the dry season and from 70% to 80% during the rainy season (Iloeje, 1980).

1.8 VEGETATION

The vegetation of the study area is classified as Guinea savanna of Nigeria or parkland savannah belt. It is characterized by the presence of tall grasses and scattered short deciduous trees. Arrival of rainfall in the area marks the beginning of the growth of grasses in the area. These are green in the rainy season with fresh leaves and tall grasses, but the land is open during the dry season, showing charred trees and the remains of burnt grasses.

1.9 SOILS IN THE STUY AREA

The flood plains of the Niger and Benue river valleys in Lokoja have the hydromorphic soils which contain a mixture of coarse alluvial and colluvial deposits. The alluvial soils along the valleys of the rivers are sandy, while the adjoining laterite soils are deeply weathered and grey or reddish in colour, sticky and permeable. The alluvial soils found along the Niger and Benue rivers show light accumulations of organic matter.

CHAPTER TWO

REGIONAL GEOLOGY

2.1 Tectonic Setting

The study area is part of the southern Bida Basin of Nigeria. The Bida Basin also known as the Mid-Niger or Nupe Basin, is located in west-central Nigeria is a Northwest - Southeast trending depression perpendicular to the main axis of the Benue Trough. Bida Basin is a NW-SE trending intracratonic basin extending from Kotangora (Northern Nigeria) to Lokoja in the central part of Nigeria in the south. It is delimited in the northeast and southwest by the basement complex while it merges with Anambra and Sokoto basins in sedimentary fill comprising post orogenic molasse facies and a few thin unfolded marine sediments (Adeleye, 1974). Inland basins in Nigeria comprise the Anambra and Dahomey Basins in the south, the Lower, Middle and Upper Benue Trough, the Chad (Bornu) Basin in the NE, the Bida Basin, and the Sokoto Basin in the NW. The basin is Sub divided geographically into the Northern, Central and Southern Bida basins referred to as sub basins.

The study area lies within the Southern Basin. The basin is a gently downwarped trough whose genesis may be closely connected with the Santonian orogenic movements of southeastern Nigeria and the Benue valley, nearby. The basin is a NW–SE trending embayment, perpendicular to the main axis of the Benue Trough and the Niger Delta Basin. It is frequently regarded as the northwestern extension of the Anambra Basin, both of which were major depocentres during the third major transgressive cycle of southern Nigeria in Late Cretaceous times. Interpretations of Landsat images, borehole logs, as well as geophysical data across the entire Mid-Niger Basin suggest that the basin is bounded by a system of linear faults trending NW–SE (Kogbe et al., 1983). Gravity studies also confirm central positive anomalies flanked by negative anomalies as shown for the adjacent Benue Trough and typical of rift structures (Ojo, 1984; Ojo and Ajakaiye, 1989). Previous studies on the geology of the Bida Basin were reported in Adeleye (1973) and the micropaleontological studies of Jan du Chene et al. (1979) which documented the palynomorph-foraminiferal associations including the interpretation of the paleoenvironments of the Lokoja and Patti Formations. Akande et al. (2005) interpreted the paleoenvironments of the sedimentary successions in the southern Bida Basin as ranging from continental to marginal marine and marsh environments for the Cretaceous lithofacies. Whereas the origin of the oolitic ironstones in the Bida Basin has been a principal subject of several workers (e.g. Adeleye,1973; Ladipo et al., 1994; Abimbola, 1997), only few investigations have been made on the hydrocarbon prospectivity of the basin.

2.2 Stratigraphic Setting and Paleogeography

The stratigraphic succession of the Mid-Niger Basin, collectively referred to as the Nupe Group (Adeleye, 1973) comprises a twofold Northern Bida Basin (Sub- Basin) and Southern Bida Sub-Basin or Lokoja Sub-Basin. The Bida Basin is assumed to be a northwesterly extension of the Anambra Basin (Akande et al., 2005) The basin fill comprises a north west trending belt of Upper Cretaceous sedimentary rocks that were deposited as a result of block faulting, basement fragmentation, subsidence, rifting and drifting consequent to the Cretaceous opening of the South Atlantic Ocean. Major horizontal (sinistral) movements along the northeast– southwest axis of the adjacent Benue Trough appear to have been translated to the north-south and northwesterly trending shear zones to form the Mid-Niger Basin perpendicular to the Benue Trough (Benkhelil, 1989).The collapse of the Mid-Niger and Anambra platforms led to the sedimentation of the Upper Cretaceous depositional cycle commencing with the fully marine shales of the Campanian Nkporo and Enugu Formations which may have some lateral equivalents in the Lokoja Formation of the Bida Basin. Overlying the Nkporo Formation is the sedimentary units of the Mamu Formation. These consist of shales, siltstones, sandstones and coals of fluvio-deltaic to fluvio-estuarine environments whose lateral equivalents are the conglomerates, cross-bedded and poorly sorted sandstones and claystones of the Lokoja and Bida Formations in the Bida Basin. The Mamu Formation is succeeded by sandstones of the Lower Maastrichtian Ajali Formation laterally equivalent to the Patti, Sakpe and Enagi Formations of the Bida Basin. These sandstones are well sorted, quartz arenite that are commonly interbedded with siltstones and claystones and similar in part to the lithologies of the Patti and Enagi Formations. The Patti and Enagi Formations are overlain by the Agbaja and Batati Formations (lateral equivalents) of Upper Maastrichtian age (Fig. 2.1). These consist of oolitic, pisolitic and concretionary ironstones deposited within a continental to shallow marine setting.

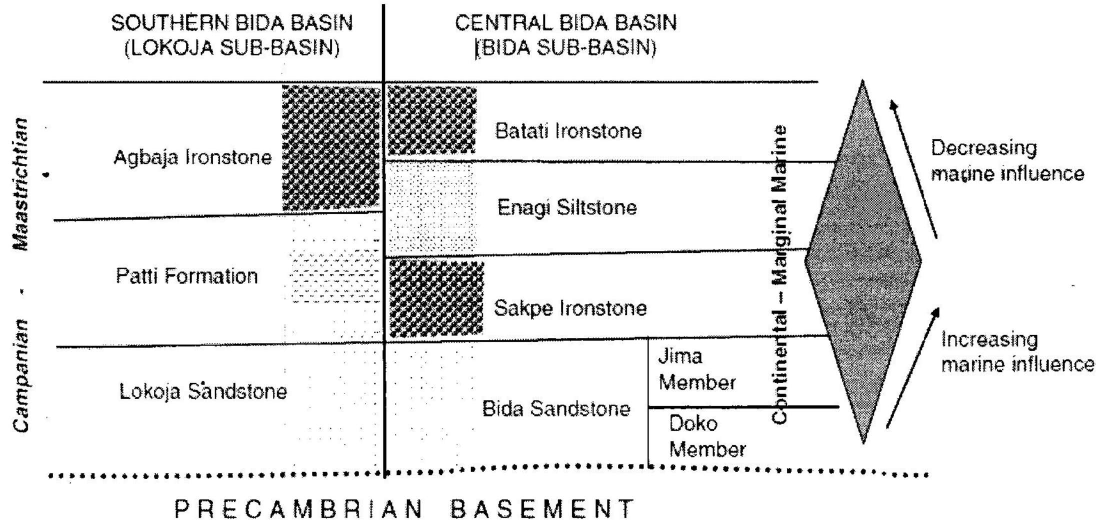

Fig 2.1 Stratigraphic successions in the Mid-Niger Basin (Akande.et.al, 2005)

Four mappable stratigraphic units are recognized in this area, namely, the Bida Sandstone (divided into the Doko Member and the Jima Member), the Sakpe Ironstone, the Enagi Siltstone, and the Batati Formation. These are correlated with the stratigraphic units in the Southern Bida Basin (Fig. 2.1). In the southern Bida Basin (which has been best studied), exposures of sandstones and conglomerates of the Lokoja Formation (ca. 300 m thick) directly over the Pre-Cambrian to Lower Paleozoic basement gneisses and schists. This is overlain by the alternating shales, siltstones, claystones and sandstones of the Patti Formation (ca. 70–100 m) thick and succeeded by the claystones, concretionary siltstones and ironstones of the Agbaja Formation.

Southern Bida Basin

2.2.1 The Lokoja Formation

Lithologic units in this formation range from conglomerates, coarse to fine grained sandstones, siltstones and claystones in the Lokoja area. Sub-angular to sub-rounded cobbles, pebbles and granule sized quartz grains in the units are frequently distributed in a clay matrix. Both grain supported and matrix supported conglomerates form recognizable beds at the base of distinct cycles at outcrop. The sandstone units are frequently cross-stratified, generally poorly sorted and composed mainly of quartz plus feldspar and are thus texturally and mineralogically immature. The general characteristics of this sequence especially the fining upward character, compositional and textural immaturity and unidirectional paleocurrent trends, suggest a fluvial depositional environment dominated by braided streams with sands deposited as channel bars consequent to fluctuating flow velocity. The fine grained sandstones, siltstones and clays represent flood plain over-bank deposits. However, Petters (1986) reported on the occurrence of some diversiy arenaceous foraminifera from clayey interval of the Lokoja Formation indicating some shallow marine influence. These foraminiferal microfossils identified by Petters (1986) are however more common in the overlying Patti Formation where shallow marine depositional conditions are known to have prevailed more.

2.2.2 The Patti Formation

This formation consists of sandstones, siltstones, claystones and shales interbedded with bioturbated ironstones. Argillaceous units predominate in the central parts of the basin. The siltstones of the Patti Formation are commonly parallel stratified with occasional soft sedimentary structures (e.g. slumps), and other structures such as wave ripples, convolute laminations, load structures. Trace fossils are frequently preserved. Interbedded claystones are generally massive and kaolinitic, whereas the interbedded grey shales are frequently carbonaceous. The subsidiary sandstone units of the Patti Formation are more texturally and mineralogically mature compared with the Lokoja sandstones. The predominance of argillaceous rocks, especially siltstones, shales and claystones in the Patti Formation requires suspension and settling of finer sediments in a quiet low energy environment probably in a restricted body of water (Braide, 1992b). The Patti Formation is a sequence of fine to medium-grained, grey and white sandstones, carbonaceous siltstone, claystone, shale and oolitic ironstone. Thin coal seams may be present and white gritty clays are common. The maximum exposed thickness is 70 m, while the oolitic ironstones range from 7-16 m thick. The strata yielded a few non-diagnostic plant remains. A Maastrichtian (and possibly Senonian) age was thus assigned to it based mainly on correlation with other formations e.g Enugu Shale.

2.2.3 The Agbaja Formation

This formation forms a persistent cap for the Campanian – Maastrichtian sediments in the Southern Bida Basin as a lateral equivalent of the Batati Formation on the northern side of the basin. It consists of sandstones and claystones interbedded with oolitic, concretionary and massive ironstone beds in this region. The sandstones and claystones are interpreted as abandoned channel sands and over-bank deposits influenced by marine reworking to form the massive concretionary and oolitic ironstones observed (Ladipo et al., 1994). Minor marine influences were also reported to have inundated the initial continental environment of the upper parts of the Lokoja Sandstone and the Patti Formation (Braide, 1992a; Olaniyan and Olobaniyi, 1996). The marine inundations appear cto have continued throughout the period of deposition of the Agbaja ironstones in the southern Bida Basin (Ladipo et al., 1994).

CHAPTER THREE
MATERIALS AND METHODS

3.1 Materials

The following field equipment were used during the field work

Geological Hammer: This is used for breaking the rocks into a smaller sample

Sample bags: This is used for storage and carrying of samples that were collected on the field.

Marker: This is used for labeling of rock samples bag for proper identification.

Compass clinometers: This is an instrument that contains the four cardinal points (N, S, E, W) used in obtaining one's position on the field.

Field notes: This is used for recording everything that is been observed while on the field.

Chisel: This is used as a support for the hammer when breaking the rock samples.

Masking tapes: This is used for proper identification of the rock samples; the masking tape is labeled with the marker and glued to the body of the sample bag for proper identification.

Measuring tapes: This was used to get the total estimate of the rock from the base to the top of the formation.

Camera: It is used for snapping each outcrop, structures encountered.

Global positioning system (G.P.S): The global positioning system gives the height (latitude and longitude) and distance from one point to another.

3.2 Methods

Exposed Outcrops were sampled by the method of spot sampling defined as the collection of samples at predetermined stratigraphic level. Enough samples were collected by the use of a geological hammer for the purpose of re-sampling if the need arise without having to return to the outcrops. Labeling of the samples was performed on each location with the aid of the masking tapes and the markers indicating the location which was given an abbreviation code and a number. The samples were wrapped inside the sample bags and labeled for proper identification and sealed, at the same time relevant information that shows a rough sketch of the litho log sections with the different scales gotten from measuring the whole rock sections were recorded in the field notes.

3.3 Field Work

The investigation involved both field and experimental work. The field work aspect involved collecting samples and the exercise was carried out with the aid of Global Positioning System (GPS), pen, marker, field note, sample bags and paper tape. Samples for the field exercise were collected during the field trip to Lokoja, the field trip which was carried out in the early January which led to the careful examination of the rocks texture, thickness, and structures The first thing that is done on getting to a location is taking the coordinates of the place and recording it in the field notebook, then thorough analysis of the rock formation from the number of beds to their different textures, structures and using a measuring tape to estimate the thickness of each bed. The geological hammer and chisel was used to break down the rock to get fresh samples for analysis. The samples were then kept in a well-labeled sample bags to avoid mix-up and contaminations, different locations were reached as the rock types ranges from coarse to fine and the rock types ranges from sandstone, shale ,ironstone.

3.4 Field Mapping and Sample Collection

The field mapping covered Felele to Mount Patti in which samples were gotten at different locations. Samples were gotten from the base to the top of the formation and were properly labeled for easy identification for different locations.

3.5 Processing and Analyzing of the sample

The sample was gotten in the Ahoko and Geheku location and the lithologic section of the area shows they were the intercalation of shale and ironstone. The analysis was carried out on the shale and they are the geochemical (rock evaluation pyrolysis) and palynology analysis.

3.6 Preparation Method for Palynology analysis

The samples went through different steps of preparation such as Sample Administration, Removal of silicates and carbonate, sieving and finally slide preparation. Nine (9) samples were used for this preparation.

PREREQUISITE TO PREPARATION

a. Administration

In research works, there is need to spread out the sample one after the other to trace out if there is any missing samples and to know the total number of samples to work on. This was done on this research to ensure proper labeling, sample number and location of each sample

Sample Administration is carried out for the following reason

To verify the sample to be worked on so as not to be exchanged with another sample

To know the total number of samples

b. Dishing

This involves taking a portion of the sample and weighing them and then ditching the weighed portion into plastic cups and the plastic cups would have been labeled properly.

SAMPLE PREPARATION AND STUDY PROCEDURE

The sample procedure in palynological investigation is the first stage in any palynological analysis. It is the most important stage of pollens and spores studies regardless of the intended deduction, maybe archeopalynology, geoarcheopalynology, petroleum palynology, forensic palynology. A good slide preparation will enhance excellent recovery of the palynomophs in paleoenvironmental reconstruction. The ultimate aim is to disaggregate the sediment and concentrate the palynomorphs to know the different types of pollen and spores in the sample.

APPARATUS

1. Fume Cupboard: It is used for soaking the released chemicals
2. Hot Plate: It is used for boiling and heating of the various mixture

3. Brazon Sonifer: It is an electronic devise that is used in sonic vibrations and it does filtering of the organic matter from the inorganic matter.
4. Calibrated Centrifuge tube: It is used for measuring the agent and for centrifugation
5. Weighing Balance: used for weighing and measuring of the samples
6. Sieve holder and 5 micrometer sieve: The sieve holder is used for sieving while the 5micrometre sieve is used for recovering any other sizable sieves
7. Mixing Tubes: Used for mixing several reagents
8. Plastic Cups: Used for dishing and soaking of the samples
9. Glass beaker and Stirring Rod: The glass beaker is used for heating and boiling of the samples while the rod is for stirring process.
10. Water Distiller: It is used for removing the organic matter in the rod

REAGENT USED

i. Hydrochloric acid (HCL)
ii. Hydrofluoric acid (HF)
iii. Zinc Chloride ($ZnCl_2$)
iv. Alcohol or methylated spirit
v. Distilled water
vi. Acetic acid
vii. Concentrated tetraoxosulphate VI acid (H_2SO_4)

There are three stages in the procedure for sample preparation which are:

1. Demineralization
2. Heavy mineral separation
3. Acetolysis

PROCEDURES .

DEMINERALIZATION

i. Pour HCL into pulverized samples in the container to test for carbonates ,then centrifuge samples at 1000r.p.m in 5 minutes and rinse thrice to remove acid

ii. Soak samples into 40% HF in plastic containers or cups (HF attacks glass) and keep in a fume cupboard overnight. This removes silica and silicates present in samples .Rinse soaked sample thrice with distilled water allowing time interval for sediments to settle and stir occasionally (Thus HF is removed and silica disaggregated)

iii. Transfer samples into glass beaker and warm with 36% HCL (to remove silicofluorides). Then decant off 36% HCL using the solifier and rinse sediments into centrifuge tubes

iv. Centrifuge and decant (using the solifier), also add 0.5% HCL ,also centrifuge and decant

HEAVY MINERAL SEPARATION

The desired aim is to separate mainly the palynomophs (pollen and spores) from the disaggregated silica

v. Pour $ZnCl_2$ /HCl solution (specific gravity 2.0) into the tubes and mix, add two drops of alcohol or methylated spirit

vi. Decant the supernatant i.e. organic matters with the aid of the solifiers (mostly pollens and spores into separate centrifuge tube)

vii. Repeat step above to increase the proportion of pollens and spores and centrifuge and decant off its liquid supernatant using the solifier

viii. Rinse and centrifuge thrice with H_2O and leave overnight

ACETOLYSIS

To remove cellulose for oxidation gives greater concentration for pollen and spores and it also shows its structural details. It renders grains translucent and the extine grain structure clearly visible causing identification of palynomorphs to the species level as much as possible

ix Dehydrate by adding Glacial Acetic Acid in the tube and leave for five(5) minutes.

x Add acetolysis mixture (freshly prepared) of 9 part of Acetic acid and 1 part of H_2SO_4

xi Boil in a water bath at 100^0C for 3 minutes with occasional stirring with the glass rods xii Centrifuge while still hot at 200 r.p.m for 5 minutes and decant the supernatant in a special bo ttle labeled acetolysis waste (to prevent its vapour from escaping since it affects the respiratory o rgans)

xiii Rinse thrice with distilled water centrifuging each time to get rid of acetolysis mixture.

xiv Boil in 5% KOH for 10 minutes to remove humic acid

xv Sieve with 5μm sieve for greater concentration of palynomorphs

SLIDE PREPARATION

The recovered organic matter were arranged on a cover slip. The surface of the dried cover slip c ontaining organic matter (pollen and spores) were mounted on a glass slide with the aid of an opt ical adhesive. For permanent slides,the mounted slide was placed under the sunlight to dry perma nently, if there is no sunlight, ultraviolent light box are used instead

There are many sieves 5μ,10μ,20μ sieve, Mounting media includes Canada Balsam, Loctite impr uv, Norland optical adhesive, petro poxy currin agent.

3.7 Preparation Method for rock-eval pyrolysis analysis

Rock-Eval pyrolysis is a relatively rapid screening technique that is widely used to characterise source-rock samples (Espitalié et al., 1977). During the analysis a powdered sample of rock is pyrolysed to simulate the thermal maturation that it would experience during progressive burial and heating in natural settings. There have been several versions of the apparatus, but all attempt to measure the same basic characteristics of the source-rock sample (Peters, 1986), which include the amount of free hydrocarbons present, the remaining hydrocarbon-generating potential of the kerogen, the temperature at which the maximum rate of hydrocarbon generation occurs, and a measurement of the oxygen content of the kerogen. The Rock–Eval pyrolysis of the shales was carried out and the samples were heated in an inert atmosphere to 550^0C using a special temperature program. During the assay, three characteristics peaks are given. The first peak (S1) represents hydrocarbons already present in the sample, which are mainly striped at temperatures of about 300^0C. The second peak (S2) represents the hydrocarbon generated by the thermal cracking of the kerogen at temperature of $300\text{-}550^0$C, while the third peak (S3) represents the CO_2, which is generated from the kerogen during the thermal cracking of the kerogen. The instrument also gives the temperature at maximum S peak (Tmax) and the Total Organic Carbon (TOC) of the oil shale. Parameters such as Hydrogen Index (HI), Oxygen Index (OI) and Production Index (PI) were calculated from the pyrolysis data and recorded by the instrument.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 LOCAL GEOLOGY OF THE STUDYAREA

The lithology of the study area includes the intercalation of shale and ironstone. Ahoko (08^0 18' 14.9"N) and Gehuku (08^0 18' 51"N) lies within 7.8023° N of the equator and 6.7333° E of the Greenwich meridian. The study area is the Southern part of the Bida basin. Bida Basin is part of the tectonic evolution of the Benue Trough which began in the early Jurassic to early Cretaceous with the opening of Gulf of Guinea about a triple junction.

4.1.1 LITHOLOGIC DESCRIPTION OF AHOKO SECTION

Ahoko has the elevation of 85m at the base with the latitude of $8^0$18'14.9" and the longitude of $6^0$51'29.8". It falls within the Patti formation and the lithological log is shown in (fig 4.1.1b) which consists of shale, claystone and ironstone. This area is composed of shale and ironstone with an intercalation of claystone. The shale is carbonaceous and mostly grayish in colour. The ironstone is of two types which are laminated and concretional. The underlying bed is shale and it is overlain by ironstone. At AK1J we have traces of fractured shale overlain by concretional ironstone, At AK1P, there is an intercalation of shale and ferroginized ironstone and claystone which is brownish in color. Overlying this layer is a massive claystone layer (AK1Q). After this bed is the concretional ironstone, AK1U has a massive, whitish claystone which is about 5m thick .The last bed is the concretional ironstone, Ahoko covers a large amount of shale, ironstone and claystone which makes mining more efficient and the beds has been more visible due to the mining activities.

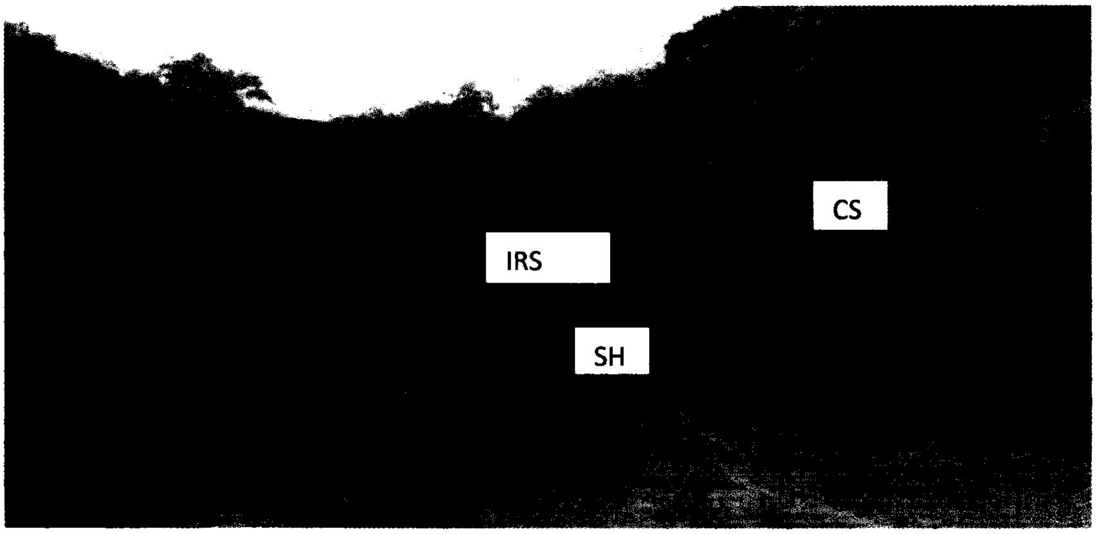

Figure 4.1: Field photograph of Ahoko showing the intercalation of ironstone (IRS), claystone (CS) and shale (SH).

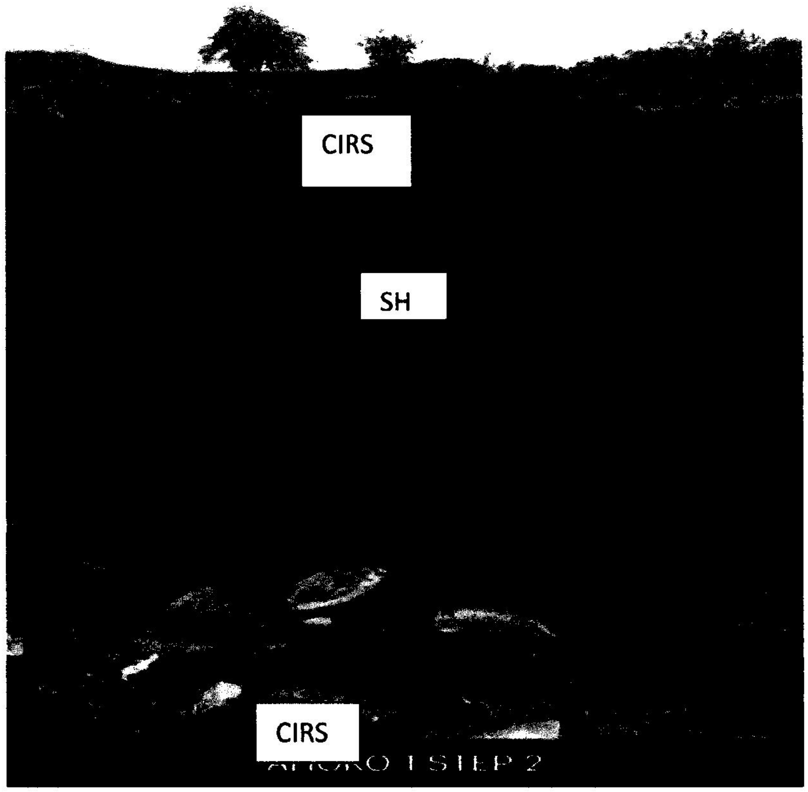

Figure 4.1.1a: Concretional ironstone (CIRS) and intercalation of shale (SH)

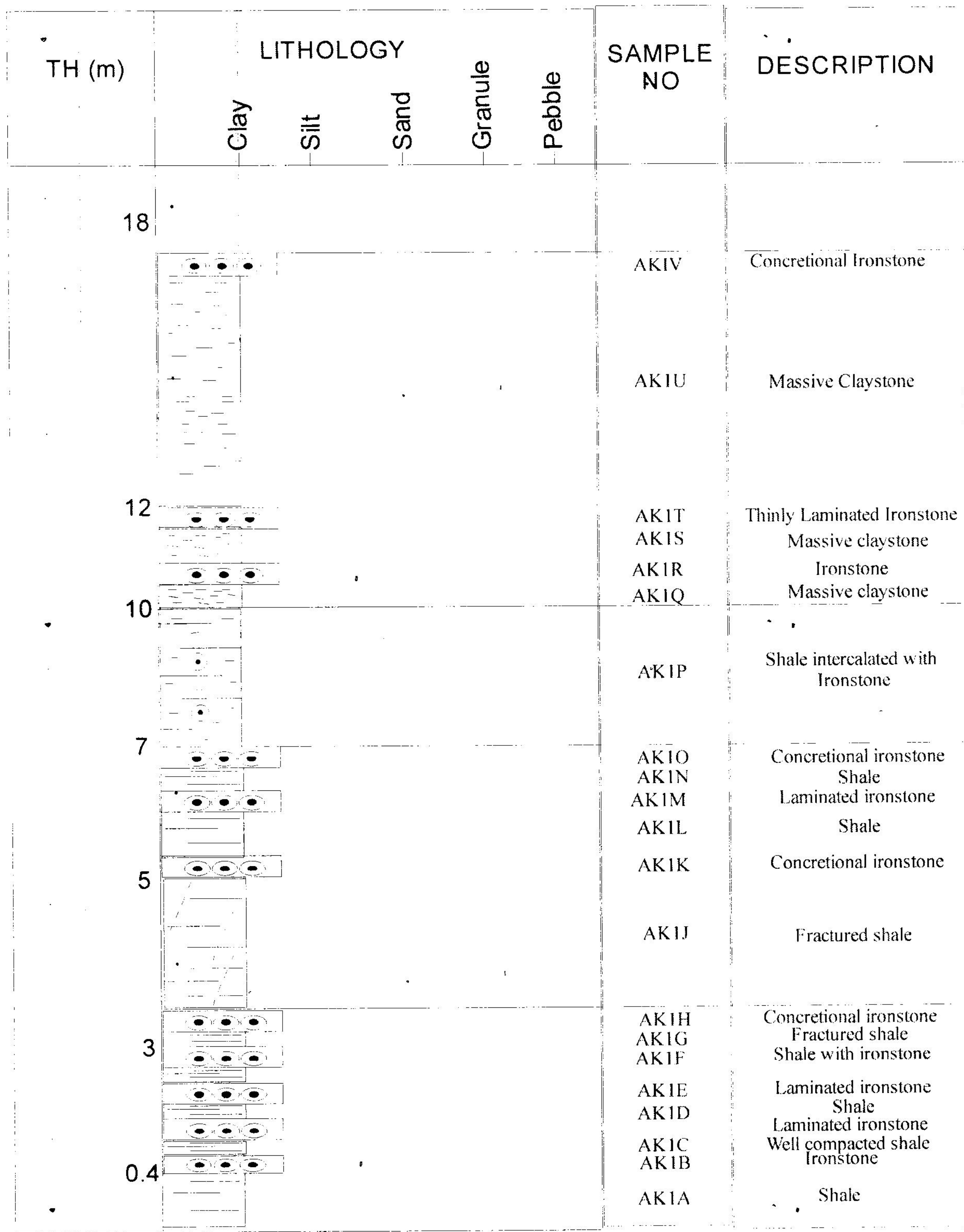

Figure 4.1.1b: Lithologic log of Patti Formation at Ahokò

4.1.2 LITHOLOGIC DESCRIPTION OF GEHEKU SECTION

Geheku is found on latitude $8^0$18'51'' and the longitude $6^0$32'34''. It has the elevation of 98m at the base. It falls within the Patti formation shown on the fig 4.1.2 which consists of shale, claystone and ironstone. Geheku1 is composed of shale and concretional ironstone. The oldest bed is shale preceded by concretional ironstone. At GH1E, there is an intercalation of shale, claystone and ironstone which is grayish in color. The youngest bed is a whitish to milkish intercalation of claystone and ferruginized ironstone.

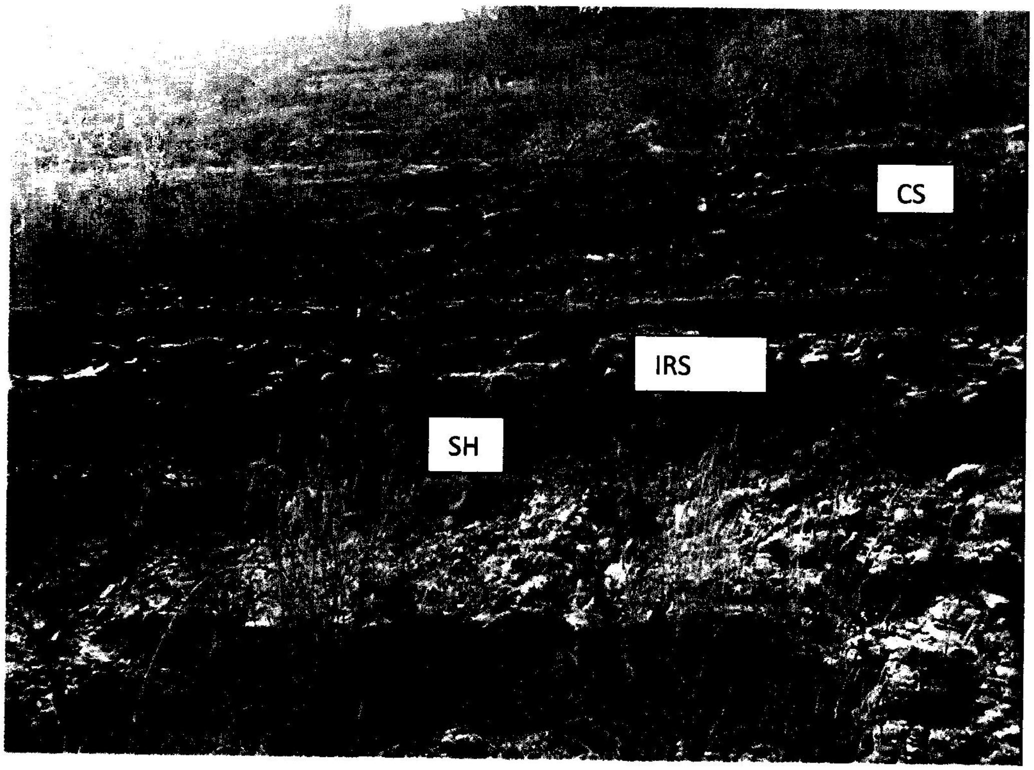

Figure 4.1.2a: Field photograph of the Patti Formation at Geheku showing the intercalation of shale (SH), ironstone (IRS) and claystone (CS)

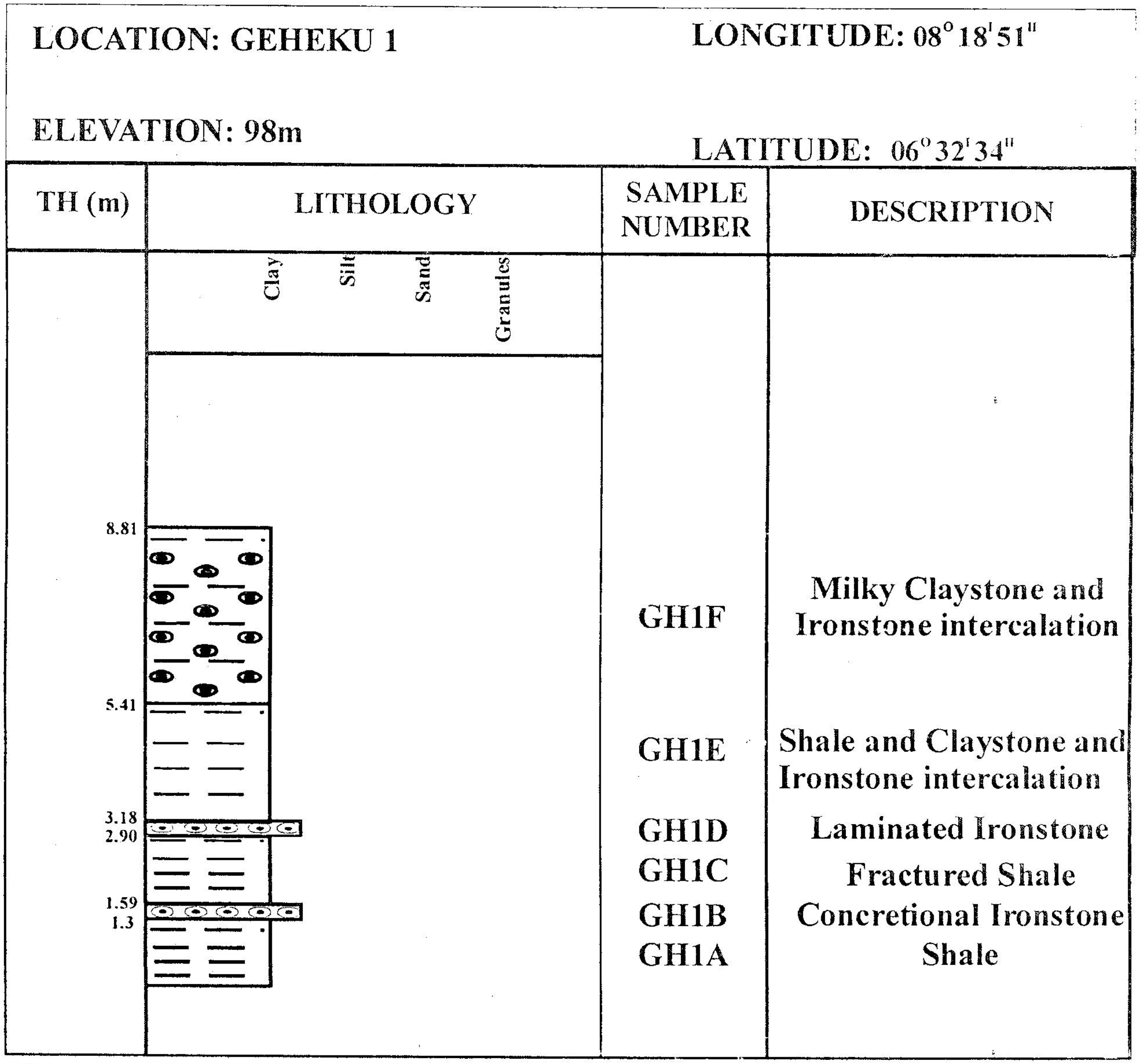

Figure 4.1.2b: Lithologic log of Patti Formation at Gehuku

4.2 ORGANIC GEOCHEMISTRY

4.2.1 Organic Matter Richness

The results of the Total organic carbon (TOC) and Rock-eval Pyrolysis of the samples are shown in Table 4.1 below. The TOC values of the Ahoko and Gehuku shale ranges from 0.75 to 2.87 wt. %. Tissot and Welte (1984) proposed a minimum TOC of 0.3 and 0.5 wt. % respectively for effective carbonate and shale source rocks. Peters (1986) also 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. However, Jones (1987) concluded that there is no significant difference between the required minimal TOC for carbonate and non carbonate source rocks. Peters (1986) 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 4.1: Results of the TOC and Rock-eval Pyrolysis of Ahoko and Gehuku shales

Sample ID	TOC wt. %	S1 (mgHC/g rock	S2 (mgHC/g rock	S3 (mgCO2/g rock	Tmax °C	HI (mgHC/g TOC	OI (mg/g)	PI
AK-1A	2.52	0.19	2.45	1.4	425	97	56	0.07
AK 1F	0.75	0.12	0.78	0.35	420	104	47	0.13
AK1E	0.98	0.02	0.57	0.52	430	58	53	0.03
GH 1C	1.65	0.07	1.35	0.94	425	82	57	0.02
AK1L	2.22	0.28	2.52	1.64	427	113	74	0.1
GH1A	2.43	0.18	2.98	0.96	423	123	40	0.06
AK1C	2.87	0.51	3.01	0.75	430	105	26	0.14
AK1J	1.79	0.21	1.98	0.37	426	111	21	0.1

The TOC results showed that the organic carbon varies from 0.75 to 2.87 wt. % in the shales, indicating that the sediments contain good organic matter contents. The distribution of the TOC across the lithologies shows a fair to good organic matter contents in the sediments. To further highlight the source rock potential of the sediments, the generative potential (GP =S1+S2) is used. Rocks having GP value < 2mg HC/g rock corresponds to gas prone rocks or non-generative rock, rocks with GP between 2 and 6 mg HC/g rock are moderate source rocks and those with GP > 6mg HC/g rock are good source rocks (Peters and Cassa, 1994; Tissot and Welte, 1984). Rock–eval Pyrolysis results showed that the shales have GP values ranging from 0.9 to 3.52 mg HC/g TOC, These suggested that the shales are poor to good source rocks (Peters and Cassa, 1994; Tissot and Welte, 1984). Hydrogen Index values also range from 51 to 123 mg HC/g TOC Suggest generally that the sediments are fair rocks with potential for oil and gas (Peters and Cassa, 1994; Tissot and Welte, 1984).

4.2.2 Type of Organic Matter

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 Oxygen (OI) for the sediments of Ahoko and Gehuku Formation (Figure 4.3.2) shows that the organic matter contained in the sediments are predominantly type II/III and type III kerogen with subordinate type IV kerogen which are capable of generating oil and gas. This view is also supported by the fact that HI values of the shale samples range from 51- 123 mg/g with most values falling between 200 and 300 mg/g (Table 2, Peters and Cassa, 1994). Furthermore, the plot of HI against Tmax (Figure 4.3.4) indicates type II/III and III kerogen with subordinate type IV organic matter in immature window for the sediments. Specifically, shales and mudstones contained predominantly type III kerogen respectively. All the samples are within the immature window. Plot of S2 against TOC (Figure 4.3.1) for the sediments indicates that they are capable of generating oil and gas.

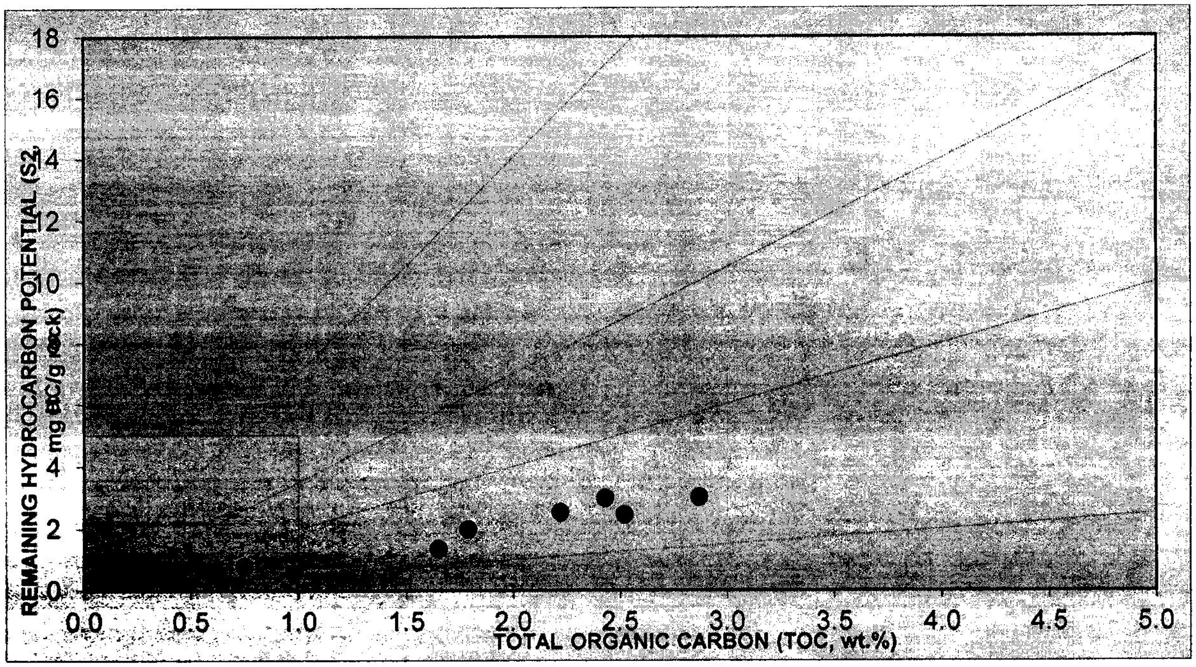

Fig 4.2.1: Plot of S2 against TOC for the sediments of Patti Formation. Note most of the sample fall within Type III organic matter which is gas-prone.

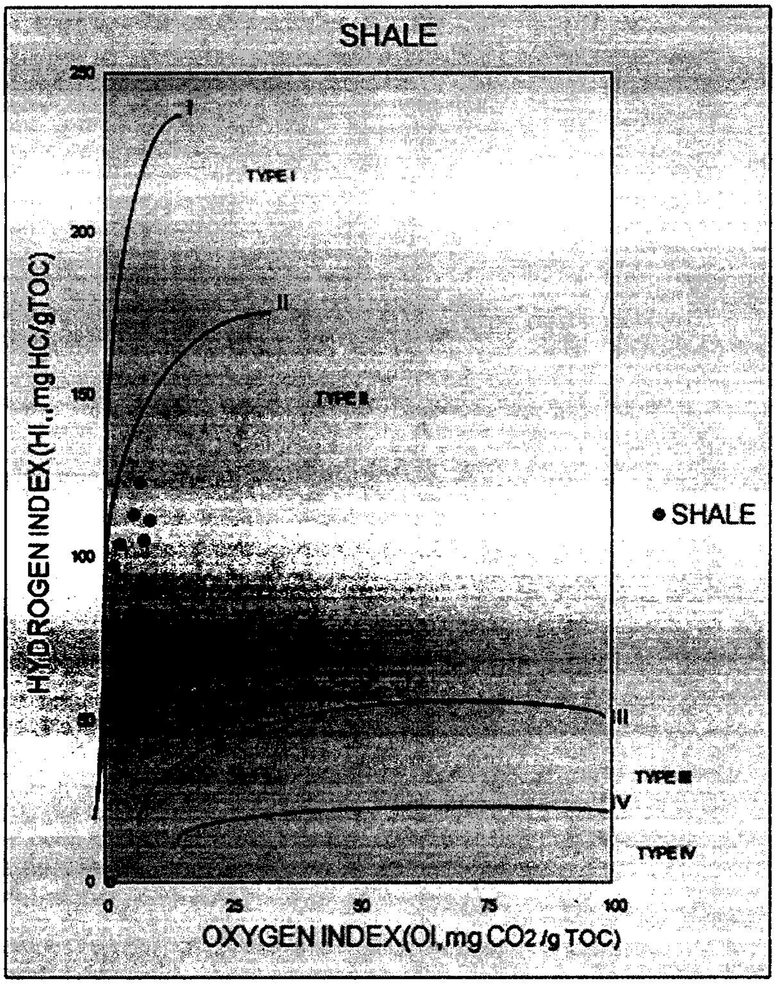

Figure 4.2.2: Plot of Hydrogen Index (HI) against Oxygen Index (OI) for Patti Formation

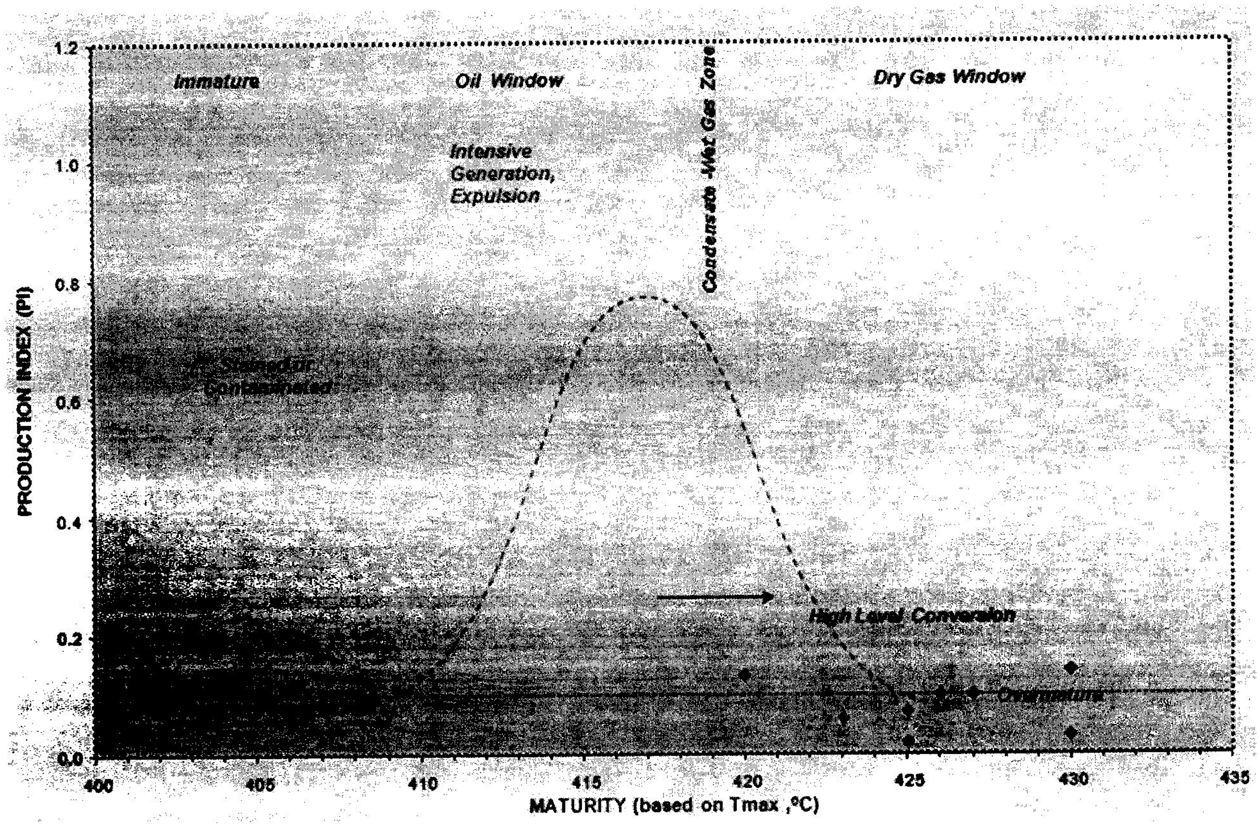

Figure 4.2.3: Plot of Production Index against Tmax for the sediments for Patti Formation

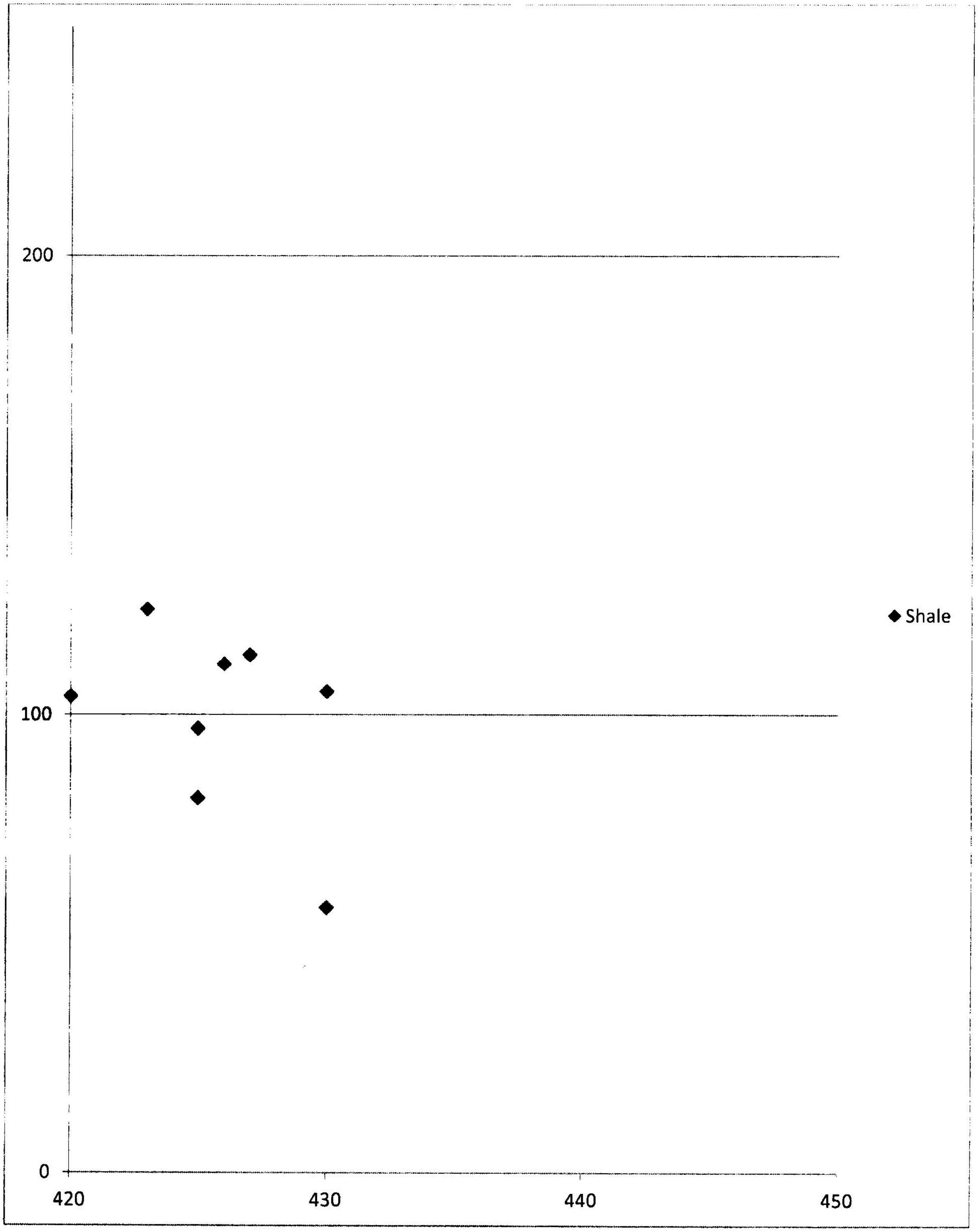

Figure 4.2.4: Plot of Hydrogen Index (HI) against Tmax^{0}C for Patti Formation

4.2.3 Thermal Maturity of the Organic Matter

Thermal maturity (Tmax) provides an indication of source rock maturity but it is influenced by source rock organic matter type and the presence of excess free hydrocarbons together with other factors like mineral matter content, depth of burial and age (Tissot and Welte, 1984). 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, PI and Tmax values less than about 0.1 and 435 respectively indicate immature organic matter while PI and Tmax ranges of 0.1 to 0.4 and 435 to 450 respectively indicate organic matter from early to the peak of maturation respectively. Tmax more than 450 also indicate that the organic matter is over mature.

The degree of thermal evolution of the sedimentary organic matter for the samples deduced from Rock-eval data such as Tmax, Production Index (PI) and calculated vitrinite reflectance (% Ro) shows that the maturity of the sediments ranges from immaturity to early maturity. Plots of PI against Tmax (Figure 4.3.3) further shows that sediments are predominantly immature with respect to hydrocarbon generation and all the samples are at low level conversion except a shale sample which is marginally within the intensive generation phase of oil window

4.2.4 Discussions

The Total organic carbon (TOC) of the sediments ranges from 0.75 to 2.87 wt. % in the shales, suggesting that they are potential source rocks for hydrocarbons. Generative Potential and Hydrogen Index indicate that the shales are good to moderate source rocks, with the sediments generally having potential for oil and gas generation. The organic matter types in the sediments are predominantly type II/III and type III kerogen with subordinate type IV kerogen which are oil and gas prone. Shales are dominated by gas prone type III kerogen. Thermal maturity derived from Rock-eval data indicates that the sediments are predominantly immature with respect to hydrocarbon generation and are generally at low level conversion. It is hereby concluded that the organic matter ranges from immaturity to the peak of maturity (late diagenetic stage to peak catagenetic stages of hydrocarbon formation). The Tmax and PI ranges of 420 to 430^{0}C and 0.02 to 0.1 respectively for the sediments indicate immaturity.

4.3 PALYNOLOGY

4.3.1 Introduction

Palynological studies have become valuable tools and universally accepted methods of evaluating the stratigraphy and source rocks potentiality of sedimentary basins. Palynology deals with the study of plant remains in the sedimentary successions and their applications in biostratigraphy. Patti Formation contains well exposed carbonaceous shale which provides a good section for the recovery of palynomorphs.

The angiospermous pollen is abundant, diverse and well preserved (plate1&2). They represent flowering plant that were evolving rapidly and were distributed during the deposition of sediments. The depositional environment was said to be a continental fluvial sedimentation while the presence of intercalated concretional or oolitic ironstones and some arenaceous foraminifera has been ascribed to occasional marine incursion duing the seal level rise (Ojo and Akande, 2003).

4.3.2 Palynological assemblages

The angiosperms are made up of several species of *Echitriporites trianguliformis*, *Monocolpopollenites sphaeroidites.* Other important Monocolpates and Fungal spore was found.

Age determination

Only the relative abundance of significant angiospermous species was used in assigning the age to the shale unit of the Patti Formation .This is due to the paucity of age diagnostic organic walled microplanktons probably because of the terrestrial nature of the Formation. The present palynoflora association emcompasses several palmae palynomorphs that are found in rocks of Maastrichtian age (Herngreen et al.,1996,Mahmoud 2003).This is clearly evident from the occurrence of palmae *(Monocolpollenites)* and triporates (*Echitriporites trianguliformis*) .The presence of well preserved *Echitriporites trianguliformis, Monocolpites Marginatus, Constructipollenites ineffectus, Proteacidites sigalii, Foveotriletes margaritae, Longapertites marginatus* supports and confirms a Middle to Late Maastrichtian age for the Patti Formation shale. Hoeken-Klinkenberg (1964) has listed *Echitriporites trianguliformis, Constructipollenites ineffectus, Longapertites marginatus* among the common palynomorphs from the Upper Cretaceous in Nigeria.

4.3.3 Paleoecological Interpretation

The dominance of the palynomorph assemblage by Palmae *(Monocolpopollenites sphaeroidites)* and Proteacean (*Echitriporites trianguliformis*) angiosperms is indicative of terrestrially derived palynomorph. This is supported by the abundant woody and plant material that are land-derived The environment during the deposition of Patti Formation shale is fluviatile.

Pollen and Spore Assemblages

The Pollens found are the *Echitriporites trianguliformis, Longapertites microfoveolatus, Monoco lpites marginatus, Monocolpopollenites sphaeroidites, Constructipollenites ineffectus, Striatricol pites (Striatopollis), catatumbus, Longapertites marginatus, Ephredipites sp, Proxapertites curs us* which accounted for 37.5%.The Spores found are the *Cyathidites sp, Verrucatosporites* sp, *Ci ngulatisporites ornatus, Laevigatosporites sp, Polypodiaceoisporites* sp, *Foveotriletes margarita e, Distaverrusporites senonicus, Gleicheniidites senonicus* which accounted for 33.3%,other poll ens found are *Milfordia, Proteacidites sigalii, Proteacidites longispinosus* which accounts for 12. 5% ,algae, dinoflagellate cyst (*Lingulodinium machaerophorum*) and others accounted for 16.7%.

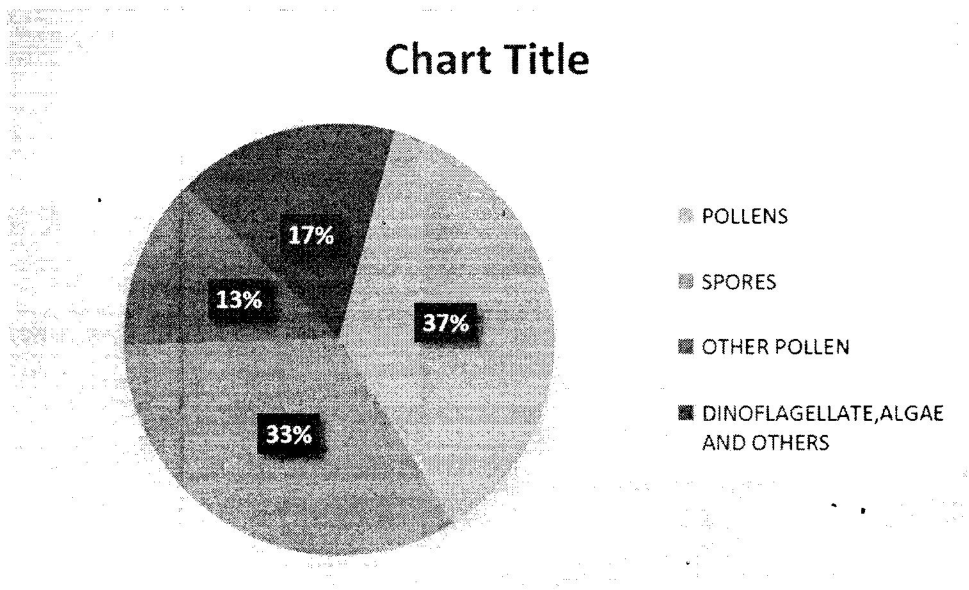

Fig 4.3.2: Distribution of palynomorphs in the Patti formation

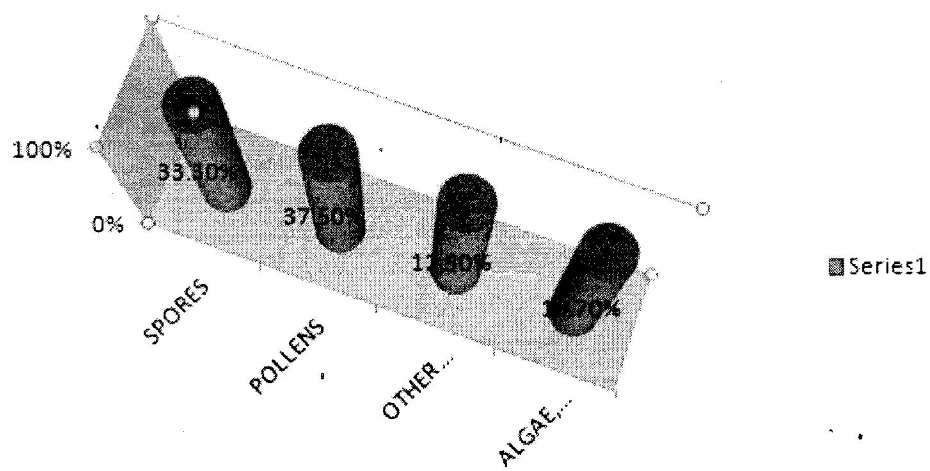

Fig 4.3.3: Percentage distribution of palynomorphs in the Patti Formation

4.3.4 Paleoenvironments

The vegetation of a certain area mostly depends on ecological conditions, thus any flora association is characteristic for a specific environment. The fossil palynoflora assemblage found in the shale is rich in green algae such as *Botryococcus braunii*. The presence of appreciable palm pollen such as *Longapertites sp and Verrucatosporites* sp suggests a brackish condition of sedimentation; its presence also indicates a high sea level (Vander Hammen, 1963; Akkiraz *et al*., 2008). Recent investigation by Ojo and Akande (2006) and Akande et al. (2005) however recognized and reported certain marine sedimentological features such as herringbone and hummocky cross beddings and ophiomorpha burrows in these sediments. An indication of shallow marine environment is evident. Shallow marine and brackish environments reflects a marine transgression (Oboh-Ikuenobe *et al*., 2005) and the presence of algae; *Botryococcus braunii* also suggest an influx of freshwater or redeposition (Demetrescu).

4.3.5 Paleoclimatic interpretation

The Paleoclimatic scenario of the studied section of the Patti Formation is examined based on the pollen/spores data which offer clues for paleoclimatic deductions. Several studies have indicated that the major differences in vegetation across the globe at various geological times are due to variation in climates (Akande *et.al.*2005). (Akande *et.al.*2005 and Herngreen *et.al*., 1981) established eight microfloral provinces, the pre-Albian West Africa- South America province (WASA), the boreal Lower Cretaceous province of the north hemisphere, the middle Cretaceous (Albian to Cenomanian) Africa- South Americaprovince (ASA), the Upper Cretaceous Normapolles province and Aquillapollenites province, the late Cretaceous Palmae province of Africa and northern south America, the Godwana province and Senonian Northofagidites province. The Cretaceous microfloral province as discussed by (Herngreen *et.al*., 1981) shows that West Africa belongs to the late Cretaceous Palmae province. This position is supported by the recovered pollen and spores in the studied area. Palmae pollen and spores such as *Proxapertites cursus,, Longerpertites marginatus, Echitriporites trianguliformis, Gleicheniidites senonicus* recovered from the studied section of Patti Formation in this study indicate that the sediments belong to the Late Cretaceous Palmae Province. The pollen and spores suggest a tropical climatic condition for the deposition of the Patti Formation.

4.3.6 Palynofacies and Petroleum potential

The algae (Botryococcus braunii) is a green, pyramid-shaped planktonic microalgae that is of potentially great importance. The species is notable for its ability to produce high amount of hydrocarbon and it is known from both temperate and tropical climates throughout the world. Three different states have been recognized in *Botryococcus braunii*: the two most common are a green state, active, exponential growth stage (with <32wt% hydrocarbon) and orange –red-brown resting state with 40-75wt% hydrocarbon, Botryococcus colonies are known from every geologic period beginning in the Ordovician and extending to the present day, and they can be the dominant plankton of certain freshwater ecosystems(Wolf and Cox, 1981).

PALYNOMORPH PHOTOMICROGRAPHS (Plate-1)

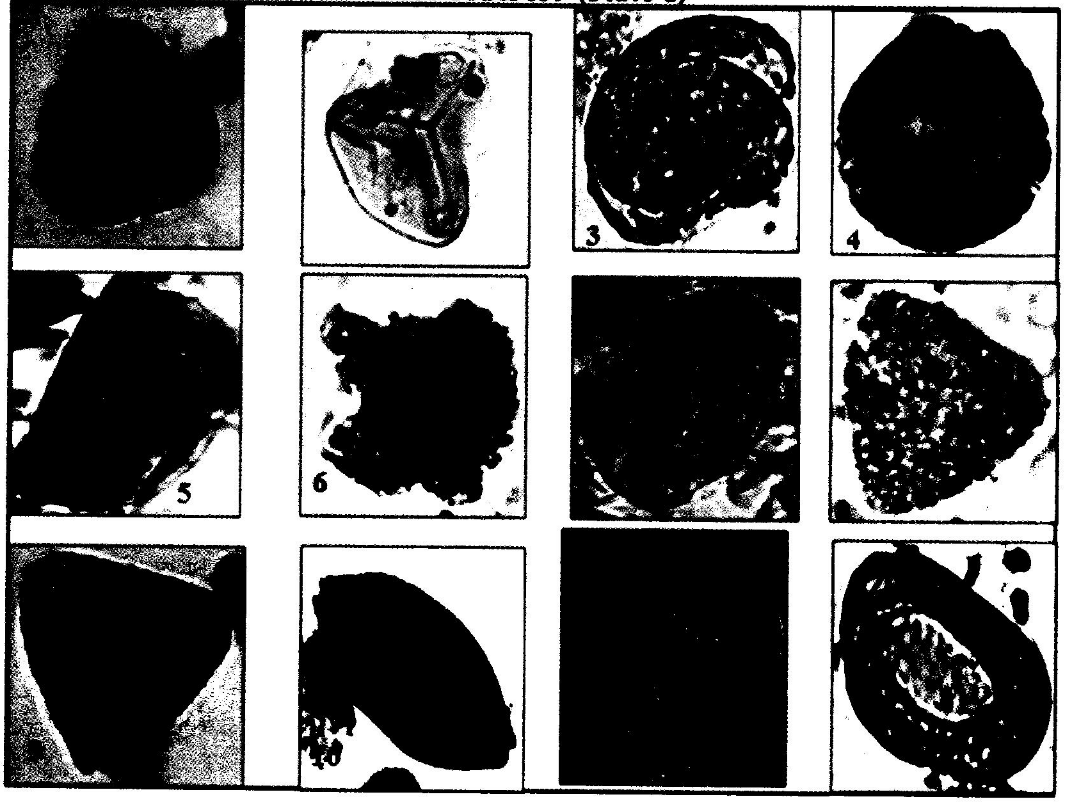

PLATE 1

1. *Cyathidites sp.* X400

2. *Cyathidites* sp.X400

3. *Verrucatosporites* sp.X400

4. *Cingulatisporites ornatus.* X1000

5. *Longapertites marginatus.* X1000

6. *Botryococcus braunii.* X400

7. *Ephredipites sp.* X400

8. *Echitriporites trianguliformis.* X400

9. *Proteacidites sigalii.*X1000

10. Fungal spore. X400

11. *Proxapertites cursus* X400

12. *Milfordia* sp.X400

PALYNOMORPH PHOTOMICROGRAPHS (Plate 2)

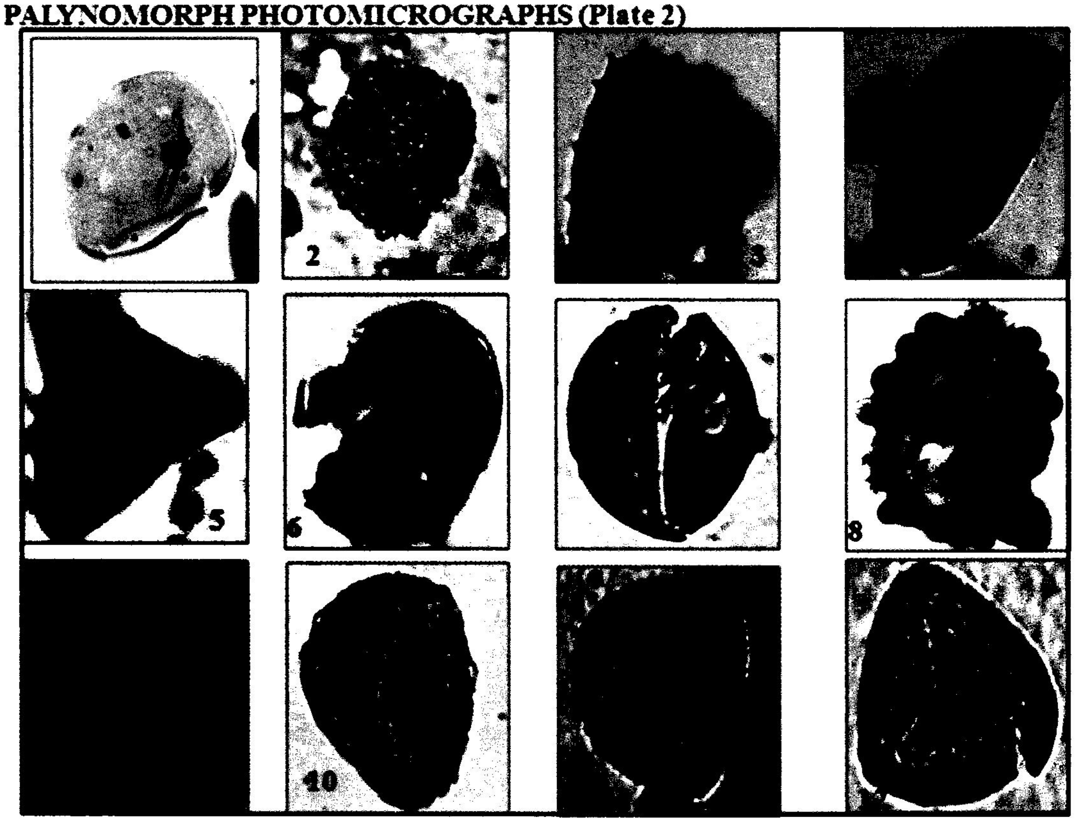

PLATE 2.

1.*Laevigatosporites sp.* X400

2. *Constructipollenites ineffectus.* X400

3. *(?)Proteacidites longispinosus.*X400

4. *Longapertites microfoveolatus.*X400

5. *Gleicheniidites senonicus.* X400

6. Monocolpopollenites sphaeroidites.X1000

7. Monocolpites *marginatus.* X400

8. *Distaverrusporites senonicus.*X1000

9. *Lingulodinium machaerophorum.* X400

10. *Striatricolpites (Striatopollis) catatumbus.* X400

11. ***Foveotriletes margaritae.***X400

12. ***Polypodiaceoisporites*** sp. X400

Table 4.2: Occurrence of the different palynomorph groups in the Patti Formation

SPORES	POLLEN	OTHER POLLEN	ALGAE	OTHERS	DINOFLAGELLATE CYST
Cyathidites sp	*Echitriporites trianguliformis*	*Milfordia*	*Botryocccus Braunii*	Fungal spore	*Lingulsniodinium machaerophorum*
Verrucatosporites sp	*Longapertites microfoveolatus*	*Proteacidites sigalii*			
Cingulatisporites ornatus	***Monocolpites marginatus***	*Proteacidites longispinosus*			
Laevigatosporites sp	Monocolpopollenites sphaeroidites				
Polypodiaceoisporites sp	*Constructipollenites ineffectus*				
Foveotriletes margaritae	*Striatricolpites (Striatopollis), catatumbus*				
Distaverrusporites senonicus	*Proxapertites cursus*				
Gleicheniidites senonicus	*Ephredipites sp*				
Cyathidites sp	*Longapertites marginatus*				

Table 4.3: Distribution of palynomorphs into their ages,environment

SPECIES					
SPORES					
Laevigatosporites sp	Pteridopsida	391-126ma	Terrestrials,fluvial,lacustrine,marine,coastal	Permian-Quatenary	S.Archangelsky., 197
Cyathidites sp	Pteridopsida	164.7-332ma	Terrestrial,Coastal,Marine,Fluvial	Jurrasic-Miocene	S.Archangelsky:, 197
Verrucatosporites sp	Polypodiaceae	112.6-116.08ma	Coastal,terrestrial,deltaic,marine	Cretaceous-miocene	Eisawi and Schrank., 20
Gleicheniidites senonicus	Gleicheniales	167.7-5.332Ma	Terrestrial,marginal marine,marine,	Cretaceous	L.R Mautino et.al.,200
Distaverrusporites senonicus	none	66.043-61.7Ma	deltaic,marginal marine	Cretaceous	Nwojiji et.al.2013
Foveotriletes margaritae	Foveotriletes	58.7-37.2Ma	Marine,fluvial-deltaic	Paleocene-Eocene	Germeraad et.al 1968
Polypodiaceoisporites sp	Polypodiaceae	112.6-116.08ma	Coastal,terrestrial,deltaic,marine	Cretaceous-miocene	Eisawi and Schrank., 20
Cingulatisporites ornatus	Cingulatisporites	65-72Ma	marginal marine,marine	Maastrichtian	Hoeken-Klinberg.,196

POLLEN					
Proxapertites cursus	Proxapertites	55.8-37.2ma	Marine,fluvial,deltaic,	Late Maastrichtian	Klinkenberg 1964
Proteacidites sigalii	Proteales	99.7-126ma	Terrestrial,marine,coastal,fluvial-deltaic,lagoonal	Late Maastrichtian	S.Archangelsky.,1973
Proteacidites longispinosus	Proteales	99.7-126ma	Terrestrial,marine,coastal,fluvial-deltaic,lagoonal	Late Maastrichtian	Nwojiji et.al.2013
Monocolpites marginatus	Monocolpites	70.6-66.043ma	Terrestrial,marine,fluvial	Late Maastrichtian	Nwojiji et.al.2013
Echitriporites trianguliformis	Echitriporates	84.9-37.2Ma	deltaic,fluvial-deltaic,marine	Early Maastrichtian-Late Campanian	Hoeken.,1964
Longapertites marginatus	Longapertites	84.9-37.2Ma	deltaic,fluvial-deltaic,marine	Early Maastrichtian-Late Campanian	Hoeken.,1964
Ephredipites sp	Ephredipites	84.9-37.3Ma	Marine,fluvial,deltaic	Early Maastrichtian-Late Campanian	Couper.,1956
Constructipollenites ineffectus	constructipollenites	70.6-66.043Ma	river,estuarine	Early Maastrichtian-Late Campanian	Van-Hoeken-Klinkenberg.,1964
Monocolpopollenites sphaeroidites	Monocolpites	70.6-66.043Ma	Terrestrial,marine,fluvial	Cretaceous	Nwojiji et.al.2013
DINOFLAGELLATE					
Lingulsniodinium machaerophorum	Lingulodinium	66.4-1.8Ma	Fluvial,marine	Upper Paleocene - Recent	Zonneveld.,2015
ALGAE					
Botryococcus Braunii	Botryococcaceae	1.2Ma	fresh water,brackish water	Recent	Thomas.et.al.,2009

CHAPTER FIVE
CONCLUSIONS

5.1 CONCLUSIONS

The Source rock evaluation of the Patti Formation shows the shale are thermal immature and the Hydrogen Index of the shales indicate good to moderate source rocks. The organic matter types in the sediments are predominantly type II/III and type III kerogen with subordinate type IV kerogen which are oil and gas prone.

The samples yielded a rich assemblages of Middle to Late Maastrichtian palynomorphs in age among which were common *Foveotriletes margaritae, Striatricolpites (Striatopollis), catatumbus,* With dinoflagellate cyst (*Lingulsniodinium machaerophorum*) and abundant palm pollen *Longapertites marginatus, Proxapertites cursus* , *Monocolpopollenites sphaeroidites, Echitriporites trianguliformis, Longapertites microfoveolatus, Ephredipites sp.* The pollen and spores indicates a tropical climatic condition for the deposition of the Patti Formation.

The presence of *Longapertites microfoveolatus, Verrucatosporites* sp.suggests a wet environmen t.

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