Subsurface Evaluation of Source Rock and Hydrocarbon Potential of the Anambra Basin, South Eastern Nigeria

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USA • 2010

ISBN-10: 1-59942-339-1
ISBN-13: 978-1-59942-339-5

CERTIFICATION

I hereby certify that this report was prepared and written by Ugochukwu Princewill Iheanacho, Matriculation Number 142332, of the Department of Geology, Faculty of Science, University of Ibadan.

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Dr. M.E. Nton Date

Supervisor

DEDICATION

This report is dedicated to God Almighty for his divine mercies, grace and favour.

ACKNOWLEDMENTS

I want to acknowledge the Almighty Father for divine mercies and guidance throughout the research work.

My profound gratitude also goes to my parents Rev. and Pastor Mrs P. C. Iheanacho for their support financially and otherwise, you have been a blessing to me. To my younger brother and sisters for their unalloyed support and advice, I want to say thank you.

I also want to acknowledge my supervisor Dr. M. E. Nton for his support and guidance. My special thanks go to all lecturers of the department of geology for the knowledge acquired from them.

My unreserved appreciation goes to my friends for their understanding, support and cooperation. I will like to mention but a few, Fummilayo Adedeji, Adedipe Olajide, Ashiru Ayodeji, Awarun Nike, Asije Alaba, my fiancée (Ijeoma Ezeogu), Emeka, my friends, colleagues and to all those that contributed to the success of the program, thanks for been there.

I will not fail to thank the staffs of Weatherford Geochemical laboratory, Texas, U.S.A. and staffs Exxon Mobil Geochemical Laboratory, Eket for contributing to the success of this research.

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ABSTRACT

Subsurface samples obtained from Enugu 1325 and 1331 wells within the Anambra Basin were utilized in this study. The work aims at characterizing the organic matter, assessing the quantity as well as determining the maturity status in order to deduce the hydrocarbon potential of the basin. It is also aimed at deducing the palaeo-depositional environment as well as highlighting the source input of the organic matter.

The analytical procedure for total organic matter and rock eval pyrolysis was achieved by the use of LECO 600 analyzer with TOC module. Soluble organic matter (SOM) was determined by the use of Soxhlet Extractor while whole rock analysis and biomarker distributions were determined by the use of gas chromatography (GC) and gas chromatography/mass spectrometry (GC-MS) respectively. The lithologic sequence of both wells consists of coals, shales and siltstones. The coals are dark while the shales are fissile and range from light to dark grey with some coal intercalation. The siltstones are light grey and medium grained.

Results of the Total Organic Carbon (TOC), Soluble Organic Matter (SOM) and Generic Potential (GP) ranged from 1.59 – 70.33wt%, 238.1 – 4095.2 ppm and 2.34 - 177.36 respectively. These imply that the source rocks is moderately to fairly rich in organic matter. Cross plots of hydrocarbon potential versus TOC, SOM against TOC indicated that the source rock is Type III kerogen and therefore gas prone. Tmax value ranges from 426 – 435ºC and Bitumen ratio is from 22.4 - 106 which indicate low maturation level for the source rock. The ratios of C_{29} hopane βα/αβ, C_{30} βα/αβ, and 22S/22S+22R C_{32} hopane ranged from 0.32 to 0.57; 0.20 to 0.59; and 0.49 to 0.56 respectively, thus suggesting immature organic matter. Cross plots of hydrogen index (HI) versus Tmax, production index (PI) versus Tmax both portray the source rock as immature. Methyl Phenanthrene Index (MPI-1), Methyl Dibenzothiophene ratio (MDR) and calculated vitrinite reflectance (Rm), showed ranges of 0.14-0.76; 0.99-4.21; 0.62-0.82 respectively. These further indicate immature to marginally mature status for the sediments. Values of C_{24} tetracyclic/C_{24} tricyclic terpanes and the C_{19}/C_{20} tricyclic terpane ratios, show respective ranges of 1.54-2.25 and 0.74-1.34 respectively, thus signifying terrigenous organic matter. The dominance of C_{29} over C_{28} and C_{27} further indicate higher terrigenous input. The abundance of 1,2,5 TMN(trimethyl naphthalene) suggests a significant land plant contribution to the organic matter. The Pr/Ph ratio values of 7.2 - 8.9 also point to terrestrial organic input under oxic conditions. A cross plot of Ts/Ts+Tm versus dia/(dia + reg) C_{27} steranes and high ratio of C_{30}/C_{29}Ts suggests suboxic depositional condition. The presence of C_{27} to C_{29} steranes and diasteranes indicates mixed sources (marine and terrigenous) with prospects to generate both oil and gas.

It can be deduced that the sediments were deposited in a suboxic, low Eh environment, and contain moderately to fairly rich organic matter with a substantial terrigenous input. The source rock has the potential to generate gas rather than oil given sufficient maturity.

CHAPTER ONE

INTRODUCTION

1.1General Statement

The Anambra Basin has a total sediment thickness of about 9km, and presents an economically viable hydrocarbon deposits. It is characterized by enormous lithologic heterogeneity in both lateral and vertical extension derived from a range of paleoenvironmental settings ranging from Campanian to Recent (Akaegbobi, 2005).

The search for commercial crude oil in the Anambra Basin in Nigeria has remained a real source of concern especially to oil companies and research groups. Initial effort were unrewarding and this led to the neglect of this basin in favour of the Niger Delta Basin where some workers like Reijers (1996) and Nexant (2003) have reported put the hydrocarbon reserves at 32 billion bbl of oil and about 170 trillion standard cubit feet of gas.

According to Akaegbobi, (2005), about 18 and less than 50 wells drilled in the entire basin to date (two discoveries; Anambra River-1, Ihadiagu-1) and very scanty 2-D seismic information, the Anambra Basin is clearly under explored. Consequently, the hydrocarbon resources appraised to be about 1 billion barrels of crude oil and about 10 trillion standard cubic feet of gas could be a gross under estimated quantity.

However, with the increasing/global energy demand, the advent of improved exploration tools, integrated basin analytical methods, the need to circumvent the pending energy crises, and ultimately the allocation of concession blocks in the Anambra Basin, oil/gas exploration and prospecting activities should take a new dimension. It is against these backgrounds that this research focuses on providing information necessary to optimize development in exploration and exploitation of petroleum in the Anambra Basin.

1.2 Location and Accessibility

The study area lies within longitude 7°30′E to 8°15′E and latitude 6°00′N to 6°40′N and falls within the Anambra Basin (fig 1.1). The area has good road network and is also linked up by rail way lines between Enugu-Umuahia and Port Harcourt.

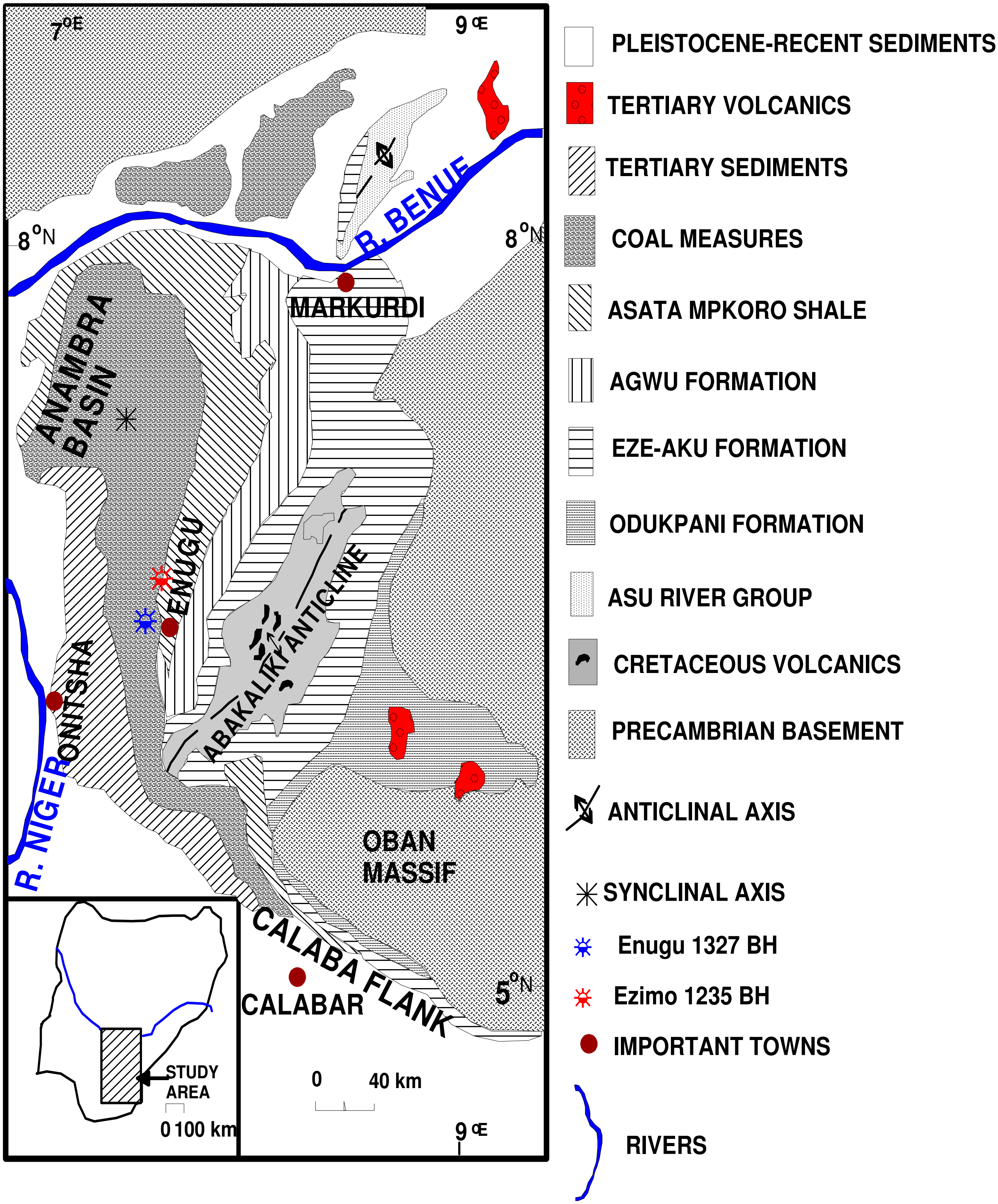

FIGURE 1.1 GEOLOGICAL MAP OF ANAMBRA BASIN SHOWING THE STUDY AREA (After Ojo et al, 2009)

1.3 Relief and Drainage

The height or depth above or below a given datum, normally sea level, is referred to as relief . Sedimentary units dominate the study area and its relief is thus generally hilly and undulating.The study area occupies much of the highlands of Awgu, Udi and Nsukka. The hills are flanked by the rolling lowlands of Oji River, Adada to the west, and the Ebonyi River Basin to the east (fig1.2). All the formations trend generally north to south, and various prominent landforms and related features have been carved out of them as reported by Ofomata, (1975). The prominent landforms include the Nsukka - Okigwe cuesta which, in Enugu area, is made up of two distinctive features the Enugu and Awgu Escarpments and the Udi-Nsukka Plateau (Ofomata, 1975).

According to Ofomata (1978), the scarp face of the cuesta landforms is formed by resistant sandstones of the Lower Coal Measures, while the less resistant Ajali Formation , forms the gentler upper slopes and the crest. The escarpments are very much indented by rivers and results in valleys, and intense gulling has taken place at the headwaters of most of the streams. The plateau is very extensive, some 48km wide in Nsukka area, and 16km in Udi and Awgu,(Ofomata). Apart from the residual hills, the plateau is also characterised by low density drainage and wide, flat bottom dry valleys. The dry valleys are thought to be former normal river valleys that later got dried up by infiltration into the Ajali Formation,(Ofomata,1975). Climatic change is another cause of dry valleys but, in the case of progressive migration of the Enugu Escarpment, the alternative cause may be the progressive migration of the water table caused by gullying and ravination, (Ofomata, 1978).

The area is drained by one main river system the Anambra Mamu River System in the west. The role of tectonics and uplift in modifying drainage patterns and topography in Nigeria was earlier recognized by Falconer (1911). The drainage pattern of the Anambra Basin is dentritic with individual streams, which are often seasonal combining to form rivers. An example of such rivers includes the Trans- Ekulu river. Generally the streams flow from the sandy highlands to the shaly lowlands.The Anambra Mamu River drains extensive areas of Uzo-Uwani in the north west and Awgu in southwest. For most of the rainy season the Uzo-Uwani lowlands in particular, is completely covered by floods. The impeded drainage of the soil provides fertile soil for planting of rice and yams as well as in fish farming, (Ofomata, 2001).

1.4 Weathering and Erosion

The study area and most part of southeastern Nigeria are currently being devastated by soil and gully erosion at alarming rates and magnitudes. Several workers have attributed the prevailance of gully erosion to climatic and anthropogenic factors, (Ofomata,1965). Nwajide and Hoque(1979), Egboka et al, (1990), recognised biologic and hydrogeotechnical characteristics of the gully areas as important factors in the gullying process.

The high incidence of gullying and landsliding result from the susceptibility of the sandy units to erosion under the influence of meteoric and anthropogenic factors, (Egboka etal, 1990). Landslides are common along many of the Nigerian highways particularly those that traverse the sedimentary areas of the country, such as Enugu- Onitsha express road which has suffered a number of landslides some of which are still active as reported by Okagbue etal, 1995.

Okagbue, 1995, reported that between Awka and Otuocha road junctions, a distance of 17km along the Enugu – Onitsha express road, there are about four landslide locations concentrated generally on the road cut. At Obinofia-Ndiuno, about 35km from Enugu, there is a dangerous gully prong advancing by landsliding and cutting into the high way. In another location along the old Awka-Enugu highway, a canyon-like gully with attendant landslides is threatening some of the structures in the area. Some of the cut slope slide have on a number of occasions rendered some portion of the high way unusable, especially during rainy season,(Okagbue et al, 1995).

Erosion has been a major threat in the southeatern Nigeria, however Emmanuel(1995), introduced an index which has been used to classify erosion intensity. The index is reffered to as EFI index which can be very useful for obtaining earthwork volumes in planning rehabilitation or reclamation work particularly in high risk erosion areas. Finally, the EFI Index can be used to obtain quantitative estimates of actual erosion in environmental impact assessment.

1.5 Climate and Vegetation

The study area lies within the equitorial monsoonal climatic belts of Nigeria typified by the rainy to dry seasons. The rainy season lasts for about eight months(March to October) and dry season lasts for four months(November to February) in the study area. Rainfall is not so heavy between the months of March and May while is heaviest between June and September. The driest between November and February.

According to NOAA,(2007),the climate is comparatively congenial and particularly equable in the hilly and ecologically transitional region of Nsukka. The mean monthly temperature in the hottest period of February to April is about 33ºC and the annual rain fall ranges between 152 to 203cm. The rainfall is almost entirely seasonal, most of it falling between May and October.

The study area lies within the Guinea Savannah vegetation belt. This type of vegetation is characterized by short trees and tall grasses.The major crops grown in the area includes; cashew, mango, maize, and vegetables. Trees(mango and orange) are grown to help check the activities of erosion. The vegetation on the highlands of Awgu and stretching through its rocky promontories to link with the undulating hills of Udi, is of the semitropical rainforest type. It is characteristically green and is complemented in the Nsukka area by typical grassy vegetation.(Oformata, 1978).

1.6 Objectives of study

The objectives of this study include :

(i) Examination of the different lithofacies as penetrated by Enugu 1325 and 1331 wells.

(ii) Determination of the Organic richness,type and maturity of the sediment

(iii)Determination of the quality of the organic matter

(iv) Deducing the hydrocarbon potential of the basin, and

(v) Ascertaining the palaeodepositional environment

Deductions from this study will provide information necessary to optimize exploration activities in the Anambra Basin with a view of improving past investigation in the study area.

1.7 Scope of the study

Core samples from Enugu 1325 and 1331 wells were obtained from the Nigerian Geological Survey Agency (NGSA), Kaduna.

The organic matter quantity will be determined by LECO 600 Analyzer while bitumen extraction will be carried out by soxhlet extraction method as well as rock eval method.

The organic matter type will be determined from a combination of rock eval pyrolysis parameters.

The maturity of organic matter will be determined from a combination of Tmax, cross plots, GC, GC-MS as well as the bitumen ratio..

The depositional environment will be determined from a combination GC, GC-MS parameters.

1.8 Review of Previous Studies

Field mapping and exploration activities in the Anambra basin started as far back as the early 1920s by the Geological Survey Agency and the Shell D Arcy (now Shell Petroleum Development Company of Nigeria LTD) which led to the deep well test at Ihuo, nine miles North East of Owerri(Simpson, 1954).

The deposition of organic sediments in the Benue Trough under paleoanoxia was first reported by Murat (1972) and examined in greater details by various workers (Petters 1982, Petters and Ekweozor 1982; Ibe 1990; Ehinola 1995 and Akaegbobi and Schmitt, 1998). Tebo (2000), while evaluating the geochemical characters of the Asata/ Nkporo Shale reported that the shales were probably deposited under a strong anoxic (euxinic) water condition.

Avbovbo and Ayoola (1981), Unomah (1989), Ehinola (1995), Njumbe and Onuoha (2002) and Akaegbobi (2005) reviewed exploratory drilling results for the Anambra Basin and proposed that, but for the deeper unexplored sub-delta parts of the Cretaceous strata, most parts of the basin probably contain gas-condensates due to abnormal geothermal gradients. In a similar discourse, Nwachukwu (1985) applied the time-temperature index of Lopatin to evaluate petroleum prospects using the geothermal gradients model. He concluded that the Benue Trough contains only little oil, formed after the Santonian event, which occurs stratigraphically higher than gas (the major hydrocarbon constituent.

Agagu and Ekweozor (1982) worked on the source rock characteristics of the Senonian shales in the Anambra syncline and concluded that the shales have good organic matter richness with maturity increasing significantly with depth.

Ekweozor (1982) reported on the application of petroleum geochemistry to exploration in Nigerian sedimentary basin, and carried out preliminary geochemical investigations, of the concentration and thermal maturity of the sedimentary organic matter isolated from certain sections of Imo, Nkporo, Awgu, and Eze-Aku Formations of the Anambra Basin. He reported that the organic matter was deposited under an oxic condition . Earlier, Agagu (1978) had carried out a comprehensive study on the geology and petroleum potential of the Senonian to Maastrichtian sediments in the Anambra Basin and recorded that the sediments are organically rich but immature. All these preliminary reports confirmed the presence of abundant organic-rich shales as source rocks with organic carbon ranging from 0.22 to 4.16% within the Anambra basin, (Agagu and Ekweozor, 1982).

According to Petters (1978), a possible increase in organic richness from older to younger shales could have been due to a decrease in the preponderance of planktonic foraminifera. The idea was substantiated by Agagu and Ekweozor (1982) who reported an increase in the abundance of coarse terrigenous clastic particles and coal beds (a tendency towards less marine conditions) as another reason.

Agagu and Ekweozor (1982) pegged the threshold of intense hydrocarbon generation (TIGH) at about 1900m in the southern Anambra Basin. The threshold temperature was inferred to be 60^{o}C. They further ascertained that the onset of mature source facies in the southern end of Anambra syncline is relatively in shallower than it is in the southern onshore and western offshore of the producing Niger Delta Basin.

Unomah (1989) evaluated the quality of organic matter in the Upper Cretaceous shales of the Lower Benue Trough as the basis for the reconstruction of the factors influencing organic sedimentation. He deduced that the organic matter and shales were deposited under a low rate of deposition. Specific references to the organic richness, quality and thermal maturity in the Mamu Formation and Nkporo Shales have been reported by Unomah and Ekweozor (1993), Akaegbobi and Schmitt (1998), Obaje et. al. (1999), Akaegbobi (2005), Ekweozor (2006) and Ajayi (2006). They reported that the sediments are organic-rich but of immature status.

Unomah and Ekweozor (1993) proposed that the shale in the Anambra basin and Afikpo syncline contain mainly terrestrial derived organic matter and essentially gas prone. They equally stated that the outcrops and near surface sections of the Nkporo shale are immature while the lower section is overcooked. Later, Akaegbobi and Shmitt (1998), observed that the Campanian and Maastichtian Nkporo Shale is a good example of mixed terrestrially marince source rock within the Anambra Basin. They recorded that the relationship between the hydrogen index (HI) and oxygen index (OI) in the said Nkporo Shale and other episodes of suboxic and anoxic conditions for the deposition of Nkporo/Enugu Shale.

Obaje et al (1999) have investigated the source rock potential of various formations in the Benue Trough and Anambra Basin. They proposed the Nkporo/Enugu Shale to be the source rock for the petroleum system in the Anambra Basin , having TOC values ranging from 1.1 – 4.2wt% and vitrinite reflectance values ranging from 0.44 - 0.60 Ro%. Later, Obaje et. al (2004), while viewing the hydrocarbon prospectivity of Nigeria's inland basins, where they proposed that the coal beds of the Mamu Formation have total organic carbon (TOC) content of as much as 60.8wt%, mean hydrogen index (HI) of 364 mgHC/g TOC, vitrinite reflectance (Ro) of 0.54 0.56% and Tmax 430 – 433ºC. They reported that the Mamu Formation is capable of expelling hydrocarbon given sufficient maturity.

Schmidt (1998) evaluated the economic potential of the Mamu Formation and Nkporo/Enugu geological units and gave a detailed comparative analysis of geochemical qualities of the shally facie of the Mamu Formation and the underlying Nkporo/Enugu Shale facies. The shales of the Nkporo/Enugu Shale presented better evidence of organic matter preservation and petroleum potential. On the basis of available geochemical and organic petrographic data, he identified only one petroleum system (Upper Cretaceous – Lower Paleocene Petroleum system) which consists of Types II and III/II gas/oil prone kerogen . Schmidt (1998), therefore put the total volume of oil generated by the Nkporo Shale and the lower Coal Measure at 7790 million bbl of oil or 5.08×10^{13} ft^3 of gas which is excess of the threshold value of 50 million bbl, required for expulsion of oil.

Akande (2004), reported that the coal sequence in the Mamu Formation are dominated by huminites with fewer amounts of liptinites and inertinites. The vitrinite reflectance and Tmax values showed that the coals are immature to marginally mature and proposed oil and gas generative potential for the coal. Akande et al (2007) concluded that the associated coals in the Mamu Formation have the capability to generate and expel liquid hydrocarbons given sufficient maturity, and may have generated a currently unknown volume of liquid hydrocarbons and gases as part of an active Cretaceous petroleum system.

Boore (2007), evaluated the hydrocarbon potential of shales from Mamu shales and deduced that the shales have fair to moderate, gas to minor oil-gas prone source rock potential at low thermal maturity. Emmanuel (2008), assessed the petroleum potentials of the post Santonian sedimentary units in the Anambra basin and revealed that the possible zones of abnormal formation pressures within specific formations are the Santonian Nkporo and Maastrichtian Mamu Formations. He concluded that they are the most stratigraphically important for any hydrocarbon search targeted at the Upper-Cretaceous sediments in the Anambra Basin.

Adedosu et al. (2010), assessed the hydrocarbon potential of coals obtained from Okaba, Okpara and Onyeama mine belonging to the Mamu Formation and concluded that Okaba samples are immature, whereas Okpara and Onyeama mines are at the beginning of the oil window.

CHAPTER TWO

2.0 GEOLOGICAL SETTING AND BASIN EVOLUTION

2.1 Geological Setting

The Anambra Basin is located in the southeastern part of Nigeria(figure 2.1). The Anambra basin is bounded to the north by Bida basin and Northern Nigerian massif, to the east by Benue trough, to the west by West african massif, and to the south by Niger delta complex(figure 2.2). The basin is a Cretaceous basin having almost a roughly triangular shape (figure 2.3) with a total sediment thickness of about 9km, covers an area of about 40,000 sq.km. Anambra basin is characterized by enormous lithologic heterogeneity in both lateral and vertical extensions derived from a range of paleoenvironmental settings, (Akaegbobi,2005).

2.2 Basin evolution

Anambra Basin is a structural (synclinal) depression and one of the intracratonic basin in Nigeria. whose origin is related to the separation of Africa from South America and the opening of South Atlantic Ocean (Ofoegbu, 1982). According to Akaegbobi (2005), the sedimentation history in the Lower Benue Trough is related to the evolution of the Anambra basin depression and Abakaliki domain. The evolutionary trend is patterned by shifting of the depocenters.

The initial area of important sedimentation and subsidence was located in the Abakaliki Trough, which was active from Aptian to Santonian. The Anambra basin became an active depocenter after the Santonian tectonic event, (Reyment,1965). Gravity studies reveal appreciable thickness of the pre-Santonian sediments, overlying the basement and reconfirm the subdivision of the basin into two sub-basins by the "Nsukka High" Reyment (1965).

The sequence of depositional events demonstrates a progressive deepening of the Anambra Basin, from lower coastal plain and shoreline deltas to shoreline and shallow marine deposits Obi et al (2001). Coals and other organic rich materials occur within the Upper Campanian to lowermost Maastrichtian facies, where they are associated with extensive swamp/flood plain and shoreline deposits. The main feature of the Anambra Basin succession is the lateral facies variations caused either by distance from the shoreline and/or by the rate of