

**HYDROCARBON PLAY ELEMENTS OF THE SEDIMENTARY SUCCESSION
PENETRATED BY THE DRILL IN OK-1 WELL, GREATER UGHELLI DEPOBELT,
NIGER DELTA, SOUTHERN NIGERIA**

BY

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**DEPARTMENT OF GEOLOGY
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UNIVERSITY OF BENIN,
BENIN CITY, NIGERIA**

JANUARY, 2023

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**A PROJECT SUBMITTED TO THE DEPARTMENT OF GEOLOGY UNIVERSITY OF
BENIN IN PARTIAL FUFILMENT OF THE REQUIREMENT FOR THE AWARD OF
DEGREE OF BACHELOR OF SCIENCE (B.Sc) IN GEOLOGY**

JANUARY, 2023

CERTIFICATION

This is to certify that this Project '**Hydrocarbon play element of the Sedimentary Succession Penetrated by the Drill in OK-1 Well, Greater Ughelli Depobelt, Niger Delta, Southern Nigeria**' was carried out by **Christian Osarabo AKONEDO** of the Department of Geology, Faculty of Physical Sciences, University of Benin, Benin City, Edo State, Nigeria.

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Supervisor

Date

Professor O.I. IMASUEN

Head of Department

Date

DEDICATION

This work is dedicated to God Almighty for His love, care, kindness and favor upon me.

ACKNOWLEDGEMENT

I give thanks to the God Almighty who stood by me from the beginning of this program to the end.

I appreciate the Head of Department of Geology Professor O.I. Imasuen for your support and training you gave me during this program.

Special thanks to my supervisor Professor F.A. Lucas for your training and guidance in making this project work a success.

I appreciate my lecturers Dr. S.A. Salami, Dr (Mrs.) O. Alonge and all other lecturers of the Department of Geology University of Benin, Benin City, Nigeria.

Special thanks to my lecturer Mr. Kinrin-ola J.O. for the guidance, teachings and trainings you gave me during this program and for making this project work a success.

I also appreciate the management of Shell Petroleum Development Company (SPDC) for providing the data used for this project analysis.

Special thanks to my father Mr J. Akonedo, my mother Mrs G. Akonedo and my siblings for the prayers, support and advice you gave me during this program.

To my friends, I thank you all for your immense support for me during this program.

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ABSTRACT

One hundred (100) ditch cutting samples from OK-1 well, Greater Ughelli Depobelt, Niger Delta Basin, Southern Nigeria, collected from Research and Development Division of Shell Petroleum Development Company was subjected to lithological analysis with the aim of identifying the lithofacies, lithozones, source rocks and seal or caprocks of the analyzed section of the well. The lithological analysis was carried out between six thousand, one hundred and forty (6140ft) and twelve thousand, seven hundred and forty (12740ft). Various lithofacies, together with their associated mineral units were observed mainly by visual examination, taking note of grain sizes, shapes, color, sorting patterns, presence of plant materials and lignitemstreaks of the samples provided. Results of the lithological analysis yielded two (2) lithofacies, which include shale and sandy shale, with presence of plant materials and streaks of lignite, and as a result six (6) lithozones were established. All the lithofacies within the analyzed section of The well were regarded as potential source rocks, because they satisfied the lithological characteristics of source rocks. Seal or caprocks potential of the analyzed section could not however be totally ascertained, because the shales and sandy shales were not observed to be deposited on a reservoir rock by reason of their stratigraphic position, despite satisfying the lithological characteristics of seal or caprock. The analyzed section 6140ft-12740ft of the OK-1 well was inferred to be the Agbada Formation (paralic sequence) of the Niger Delta Basin, by reason of depth and lithofacies within the section which are basically shale and lesser percentages of sand particles.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND STUDY

Hydrocarbon is an organic chemical compound composed exclusively of hydrogen and carbon atoms. Hydrocarbons are naturally occurring compounds and form the basis of crude oil, natural gas, coal, and other important energy sources. Therefore hydrocarbons are highly effective sources of fuel.

The Niger Delta is a wave dominated Delta located on the continental margin of the Gulf of Guinea that formed in the Paleogene. The Delta is fed with sediment from the Niger River which has the ninth largest drainage area in the world and the third largest in Africa at 2.23 million km². The Delta is 75000 km² in size and reaches a maximum thickness of 12 km in the centre of the Basin. (Faloke *et al.*, 2010).

The Niger Delta is one of the world's major hydrocarbon provinces; specifically, it ranks 12th in terms of known accumulation of hydrocarbon with reserves exceeding 34 billion barrels of oil and 93 trillion cubic feet of gas (Turtle *et al.*, 1999). Oil and gas is predominantly extracted from the Agbada formation and is targeted from structural traps there.

The basin is a major hydrocarbon producing Basin in Nigeria where intensive exploration and exploitation activities have been on since early 1960s owing to the discovering of commercial oil in Oloibiri in 1956 (Reijers *et al.*, 1996) much sedimentological work has been done on the Basin but there is little published information due to confidentiality maintained by the oil companies. Oil companies in Nigeria have their individual zonation schemes. The

sediment Fill in the Nigeria Delta is characterized by the three (3) Depobelts. These three cycles show that the Basin experienced an overall regression throughout time as sediment go from deep sea mud sized grains. The present day Delta is a complex of individual fluviomarine systems that have succeeded one another in a stepwise fashion as the Delta prograded towards the southwest. Hydrocarbon are trapped in growth fault related structures throughout the Delta both onshore and offshore. The ultimate recovery in existing fields probably totals of the order of 4billion (10^9) m³ of oil and there is under- valuated, but probably vast gas resource base.

1.2 AIM AND OBJECTIVES OF THE STUDY

AIM

The aim of this project is to carry out a detailed sedimentological study and to observe the hydrocarbon play elements in OK-1 well.

OBJECTIVES

The objective of these research include to:

- i identify the lithofacies of the well.
- ii delineate the associated minerals of wells.
- iii establish formations of the well.
- iv penetrate lithozones.
- v determine the geological formation penetrated by the drill.
- vi generate lithostratigraphic model for the well.
- vii identify the minerals present in the well.
- viii identify the various hydrocarbon play elements in the well.
- ix detailed lithological description of ditch cutting samples.

1.3 SCOPE OF STUDY

In study of OK-1 WELL in Niger Delta Basin, the following were done for a successful study of the well and they are as follows;

- i. Collection of sample.
- ii. Identification of sample.
- iii. Label and name of sample.
- iv. Analysis of sample.
- v. Interpretation of samples.

1.4 LOCATION OF STUDY WELL

The OK-1 Well lies between latitude $5^{\circ} 15'$ N and longitude $6^{\circ} 20'$ E, Greater Ughelli Depobelt in the Niger Delta Basin, Southern Nigeria (fig. 1).

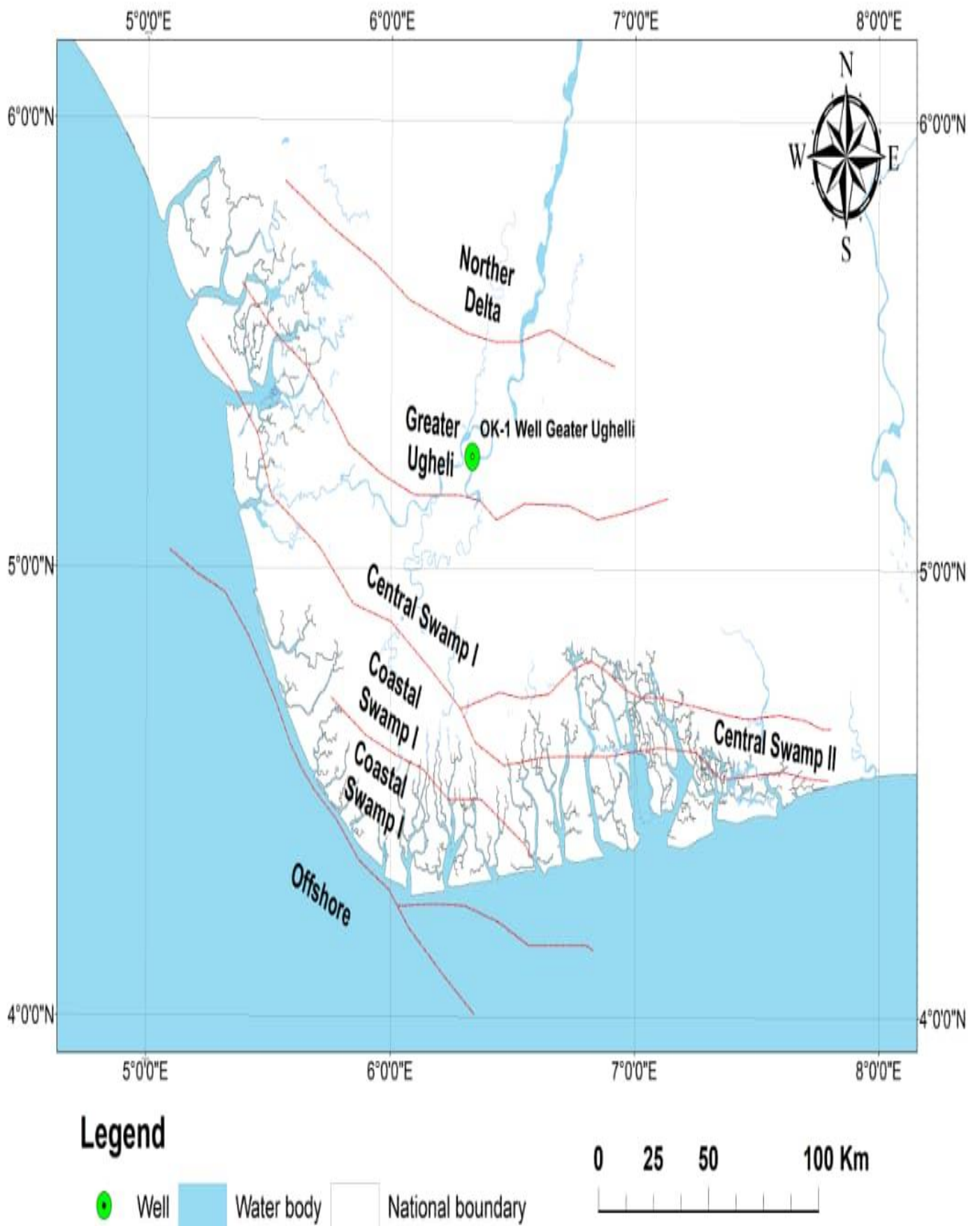


Fig. 1: Map of the Niger Delta Basin showing depobelts and location of OK-1 Well

1.5 IMPORTANCE OF SEDIMENTOLOGY

i. Economic resources

Hydrocarbon reservoirs have organic rich sedimentary source rocks that produced the hydrocarbon when heated, most hydrocarbons migrate through sedimentary rocks and most of the reservoirs are hosted in sedimentary rocks. Water aquifers are dominantly found in sedimentary rocks (although some are in fractured metamorphic and igneous rocks). The composition of the rocks strongly influence water quality due to water rock interaction. Sedimentary rocks also host economic minerals such as gold and diamond, which are eroded from other rocks and concentrated to specific areas during sediment transport.

ii. Environmental geology

Sediments cover $\frac{2}{3}$ of the continents and essentially all of the ocean floor, which totals 89% of the surface of the earth. They host the biosphere and they are most of the rocks we interact with directly and indirectly. Our actions as humans have an extremely strong effect on sedimentation and erosion. Understanding our impact on the environment and the environment's impact on us must include deep appreciation for sediments transport.

iii. Earth history

Sedimentary rocks contains features that allow us to interpret ancient depositional environment including the evolution of organisms and the environments they lived in, how climate has changed throughout earth history where and when faults were active etc.

iv. Energy source

By the study of sedimentology sources of energy are known. Our country is full with resources. It is important to know what resources are found in which kind of soil. Sedimentary rocks also where petroleum deposits are found. Sedimentology is tied to stratigraphy, which

studies the relationship between rock layers and how they can shift and move. This also affects where petroleum deposits can be found, as well as how the extraction of petroleum affects sediments around the deposit.

v. Sea level change

Sedimentology is important to sea level change. The movement of sediment across earth's surface affect sea level by deforming the solid earth, modifying the gravity field and displacing and absorbing water. Sedimentological study helps to account for sediment redistribution for interpreting and predicting sea level change.

vi. Fertility and potentiality

Sedimentological study helps to know the fertility and potentiality of soil. So it can be known what kind of crops and in what amount can grow on specific soil portion.

vii. Architectural uses

Stone derived from sedimentary rocks is used for dimension and in architecture notably slate, meta-shale for roofing, Sandstone for load bearing buttresses.

viii. Plate tectonics

By studying sediments strata plate tectonics history can be known.

ix. Contamination

Sedimentology is the key to understanding the manifestation of some pollution such as rivers and oceans. To investigate contamination, you must first understand how rivers work and particularly a polluted river. Here the deposition of sediments is essential

x. Geotechnics

With sedimentology we find geotechnics, especially focuses on studying the stability of the soils and is extremely important before any civil work. If you want to build a headquarters

building, first assesses the long term stability of the soil. The high technical complexity of many of the large works such as tunnels, bridges, reservoirs, highways and skyscrapers, requires an exhaustive study of the subsoil.

1.6 DEFINITION OF TERMS

i. Sedimentology

Sedimentology is the scientific study of sedimentary rocks and the processes by which they were formed. It is concerned with the composition and genesis of sediments and sedimentary rocks and the creation of predict sedimentation. It's used to describe sedimentation processes by interpreting the facies in order to know the characteristics, methodology and principle of sedimentation. Sedimentology is related to stratigraphy which is the study of the physical relationship of sedimentary layers. The study of sedimentology and stratigraphy together gives clearer vision about the layers and provides us with any information we need.

ii. Basin

These are regions of the earth where long term subsidence creates accommodations spaces for accumulation of sediments. As sediments are buried, they are subject to increasing pressure and begin process of compaction and lithification that transform them into sedimentary rock. They occur in diverse geological settings usually associated with plate tectonic activity.

iii. Niger Delta

Also referred to as the Niger Delta province, is an extensional rift Basin located in the Niger Delta and the Gulf of Guinea on the passive continental margin near western coast of Nigeria with suspected or proven access to Cameroon, Equatorial Guinea and Sao tome and Principe. This Basin is very complex and it carries high economic value as it contains a very

productive petroleum system. It has a sub-aerial area of about 75000km², a total area of 300000km² and sediment Fill of 500000km³. The sediment Fill has a depth between 9-12km.

iv. Ditch cuttings

They are broken bits of solid material removed from a borehole drilled by rotary, percussion, or auger methods and brought to the surface in the drilling mud. Boreholes drilled in this way include oil and gas wells, water well and hole drilled for geotechnical investigations or mineral exploration. The ditch cuttings are commonly examined to make record of the subsurface materials penetrated at various depths. In the oil industry, this is often called a mud log.

v. Sample

It is a representative unit of soil, rock, ore, fluid or gas that is from a larger mass or volume to serve as example of that larger body or to reflect some specific feature or variation within it. The simple rationale for sampling (Barnes et al., 1981) is that, one can take a specimen home but not an outcrop. Sampling is undertaken to provide a type specimen for classification purposes, analysis or testing.

vi. Stratigraphy

These is a branch of geology concerned with study of rock layers (strata) and layering (stratification). It is primarily used in the study of sedimentary and layered volcanic rocks. Stratigraphy has three related subfields; Lithostratigraphy(lithologic stratigraphy), Biostratigraphy(biologic stratigraphy), and chronostratigraphy (stratigraphy by age).

vii. Lithology

Lithology of a rock unit is a description of its physical characteristics visible at outcrop, in hand or core samples or with low magnification microscopy. Physical characteristics include

colour, texture, grain size and composition. Lithology may refer to either a detailed description of these characteristics or summary of the gross physical character of a rock e.g sandstone, slate, basalt or limestone.

viii. Model

This is typically used in mine design to delineate geotechnical domains define parameters for design methods and incorporate the geological history of the rock into understanding of future behaviour.

ix. Well

These is an excavation or structure created in the ground by digging, driving or drilling to access liquid resource usually water. The oldest and most common kind of well is water well, to access groundwater in underground aquifers. The well is drawn up by a pump or using containers such as buckets that are raised mechanically or by hand.

x. Hydrocarbon

It is an organic chemical compound composed exclusively of hydrogen and carbon atoms. Hydrocarbon are naturally occurring compounds and form the basis of crude oil, natural gas, coal, and other important energy sources. Therefore hydrocarbons are highly effective source of fuel.

xi. Lithofacies

It is a lateral mappable sub-division of a designated stratigraphic unit, distinguished from adjacent subdivision on the basis of lithology, including all mineralogic and petrographic characteristics and those paleontologic characteristics that influence the appearance, composition, or texture of the rock.

xii. Lithozones

A lithostratigraphic unit; an interval of geological strata defined on the basis of its characteristics lithostratigraphy.

xiii. Mineralogical composition

These is a key determining factor in the micro structure of CS and its potential reactivity when used as a cementitious component in concrete, road, pavement, geotechnical application and ceramics.

1.7 BRIEF HISTORY OF PETROLEUM EXPLORATION IN NIGERIA

Nigeria is the largest oil and gas producer in Africa. Crude oil from the delta basin comes in two types. Light and comparatively heavy, the lighter is around 36 gravity and the heavier is around 20-25 gravity. Both types are paraffinic and low in sulphur.

Petroleum exploration activities in the Niger Delta started in the 20th century with the early wells drilled by the German-Nigeria bitumen corporation (weber and Daukoru, 1975) about fourteen (14) wells were drilled with the butimen accumulation. The advent of the first world war in 1914, led to the winding up of the activities by the company.

A joint venture between the shell and BP under the name shell D'arcy started in 1937. Activities were then concentrated north of the Niger Delta with no promising discovery made. A breakthrough was recorded in 1956 by shell D'arcy with its first commercial discovery at olobiri in Rivers state. Further studies resulted in a number of discoveries spurring other oil companies eg. Mobil, Gulf (chevron)/Agip amongst others to seek for exploration license to operate in the Niger Delta.

Nigeria National Petroleum Cooperation (NNPC) was set up by the federal government of Nigeria in April 1979 under the decree number 33 of 1977 to undertake oil and gas

exploration on its own through its subsidiary the NPDC. Exploration and production activities were disrupted between 1970 as a result of the civil war, leading to increase growth in the energy and production industries, establishments of refineries and the completion of gas reserves has made it necessary for the establishment of a LNG (liquefied Natural Gas) plant.

1.8 REVIEW OF PREVIOUS WORK

Short and Stauble (1967) outlined the general geology of the Nigeria Delta. The coastal sedimentary Basin of Nigeria has been the scene of three depositional cycles. The first began with a marine incursion in the middle cretaceous and was terminated by a mild folding phase in Santonian time. The second included the growth of a proto-Niger Delta during the late cretaceous and ended in a major Paleocene marine transgression. The third cycle, from Eocene to recent, marked the continuous growth of main Niger Delta. A new threefold Lithostratigraphic subdivision is introduced for the Niger Delta subsurface, comprising upper sandy Benin formation, an intervening unit of alternating Sandstone and Shale named the Agbada formation and a lower shaly Akata formation. These three units extend across the whole Delta and each ranges in age from early tertiary to recent. They are related to the present outcrops and environment of deposition. A separate member of the Benin formation is recognized in the Afam clay member, which is interpreted to be an ancient valley Fill formed in Miocene sediments. Subsurface structures are described as resulting from movement under influence of gravity and their distribution is related to growth stages of the Delta rollover anticlines in front of growth faults from the main objectives of oil exploration, the hydrocarbon being found in sandstone reservoirs of Agbada formation.

Billman(1976) established that the Niger Delta is divisible into continental, marginal marine and marine facies. He observed that onshore recent sediments in which the youngest

sediments were not investigated because cutting samples could not be collected from upper hundred feet below sea level.

Doust, (1990) petroleum geology of the Niger Delta. The Niger Delta is one of the world's largest tertiary Delta systems and an extremely prolific hydrocarbon province. It is situated on west Africa continental margin at the apex of the Gulf of Guinea which formed the site of a triple junction during continental breakup in the cretaceous. Hydrocarbons have been located in all of the depobelts of the Niger Delta in good quality sandstone reservoirs belonging to the main Deltaic sequence (the paralic sequence of common usage). Most of the larger accumulations occur in rollover anticlines in the hanging wall of growth faults, where they may be trapped in either dip or fault closures. In the 30 or 50 years since the first discoveries were made approximately $4 \times 10^9 \text{m}^3$ of oil and an unestablished but very substantial quantity of associated gas have been discovered. Most fields are small, ranging up to $50 \times 10^6 \text{m}^3$, though several larger fields contain recoverable reserves in excess of $80 \times 10^6 \text{m}^3$. The hydrocarbons are found in multiple pay sands with relatively short columns and adjacent faults blocks usually have independent accumulation.

Allen (1965) subdivided the Delta into six first order super environment each made up of a second order environment.

Ekweozor and Okoye (1980) carried out petroleum source bed evaluation of tertiary Niger Delta. They established that the dominant sedimentary kerogen in the Niger Delta were humic and mixed types. They also stated that habitats of the hydrocarbons are mainly the sandstone reservoirs in the paralic sequence of the Agbada Formation where hydrocarbons are characteristically trapped by growth faults at the crest of rollover anticlines.

CHAPTER TWO

LITERATURE REVIEW

2.1 GEOLOGY OF THE NIGER DELTA

The Niger Delta underlines an area of about 256,000km², and was initially built over an older transgressive Paleocene pro-Delta. Delta construction proceeded in discrete mini-Basins ranging in tectonic configuration from extensional, through translational to compressional toe-thrust-regions. Outcropping units of the Niger Delta include the Imo formation and the Ameki group consisting of the Ameki, Nanka, Nsugbe, and Ogwashi-Asaba formations. The subsurface Lithostratigraphic units are the major transgressive marine Akata shales, the petroliferous paralic Agbada formation, and the continental Benin sands. Oil reserves of over 40trillion cubic feet. Traps are mainly dip closures (rollover anticlines in growth faults) and relatively rare stratigraphic traps. Hydrocarbons have been sourced from marine shales with land plant materials transforming mainly into type III and II/III organic matter within the oil window between 9000 and 14000ft depth. Reservoirs are mainly shore face, beach, channel sand and occasional turbidites. The bearing, light waxy and non-graded.

The onshore portion of the Niger Delta province is delineated by the geology of the southern Nigeria and the south western Cameroon. The Northern boundary is the Benin flank and the northeast trending hinge line south of the West Africa basement mass. The north eastern boundary is defined by outcrops of the cretaceous on the Abakiliki high and further east. Southeast by the calabar flank, a hinge line bordering the adjacent pre-cambrian. The offshore boundary of the provinces is defined by the Cameron volcanic line to the east, the offshore boundary of the Dahomey Basin (the eastern most west Africa transform fault pressure margin) to the west and the two kilometre sediment thickness contour or the 4000metre bathymetric

contour in areas where sediments thickness is greater than 2km to the south and southwest. The province covers 300,000km³ and includes the geologic extent of the tertiary Niger Delta (Akata-Agbada) petroleum system.

Extensive hydrocarbon exploration and studies of data set obtained within the past three decades have led to vast information on the structures and sediments beneath the present sub-aerial Niger Delta and adjacent inner continental shelf (Short and Stauble 1967; Weber and Daukone, 1975; Ejadewe, 1981; Whiteman, 1982 and Doust and Omatshola, 1990)

The modern Niger Delta covers areas of some 140,000km² and lies on top of a thick prism of regressive clastic sequence, which reaches a maximum thickness of 12,000m at the Basin center (Knox and Omatshola, 1989). This prism of clastic sediments forms the prominent seaward bulge on the continental margin of southern Niger.

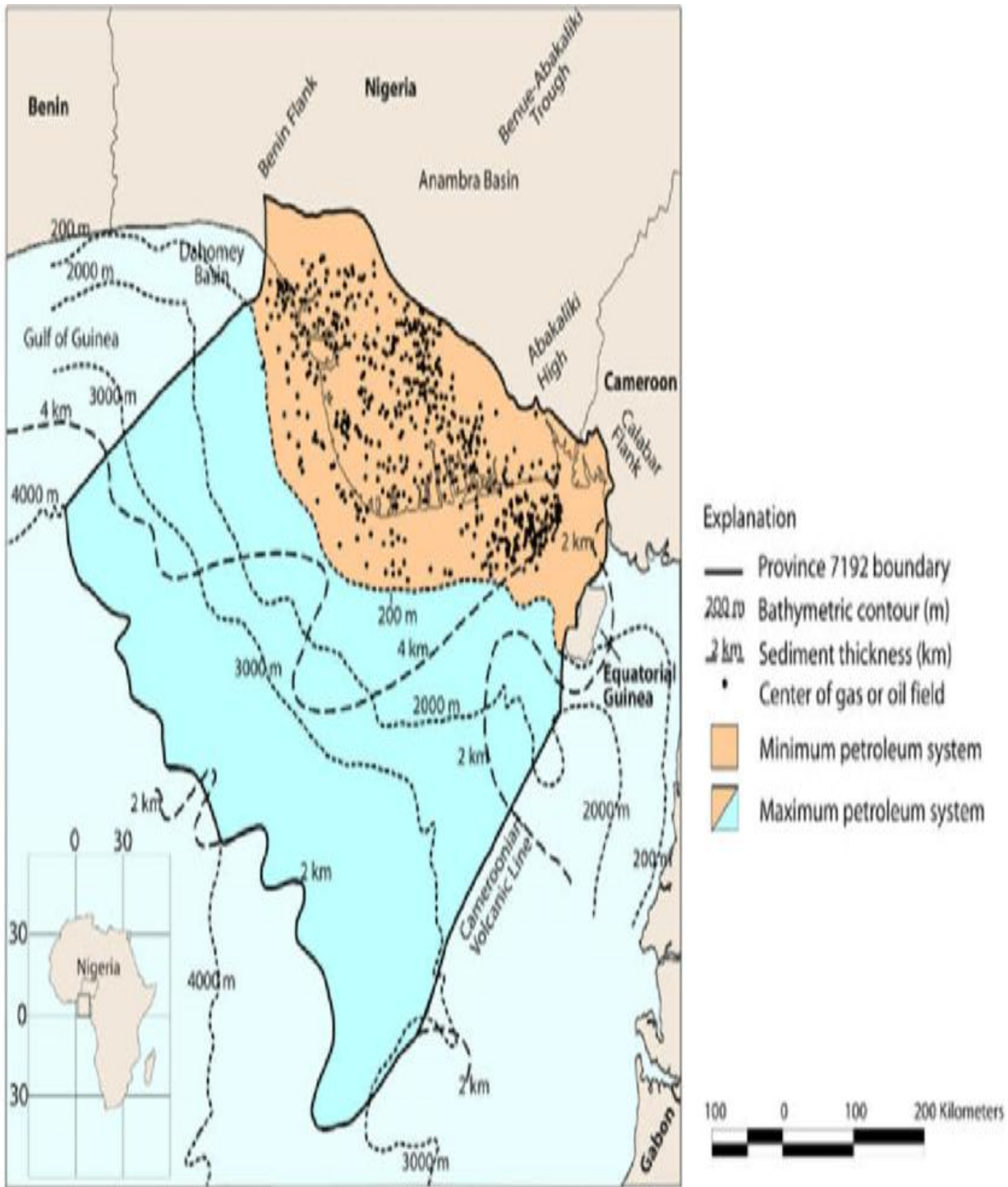


Fig. 2: The structural bounding features of the Niger Delta province (Adapted from Petroconsultants, 1996).

2.2 TECTONIC FRAMEWORK

The tectonic framework of the continental margin along the west coast of Equatorial Africa is controlled by cretaceous fracture zones expressed as trenches and ridges in the deep Atlantic. The fracture zone ridges subdivide the margin into individual Basins and in Nigeria, from the boundary faults of the cretaceous Benue-Abakaliki trough, which cuts far into the West African shield. The trough represents a failed arm of a rift triple junction associated with the opening of the middle cretaceous (Lehner and De ruter, 1977). In the region of the Niger Delta, rifting diminished altogether in the late cretaceous. Figure 3 shows the gross Paleogeography of the region as well as the relative position of the African and South American plates since rifting began.

After rifting ceased, gravity tectonism became the primary deformational process. Shale mobility induced internal deformation and occurred in response to two processes (Kulke 1995). First, shale diapirs formed from loading of poorly compacted over pressured pro-Delta slope clays (Akata formation) for any given depobelt, gravity tectonics were completed before deposition of Benin formation and expressed in complex structures including shale diapirs, rollover anticlines, collapsed growth fault crest, back to back features and steeping dipping, closely spaced flank fault (Evamy and others, 1978; Xiao and suppe, 1992)

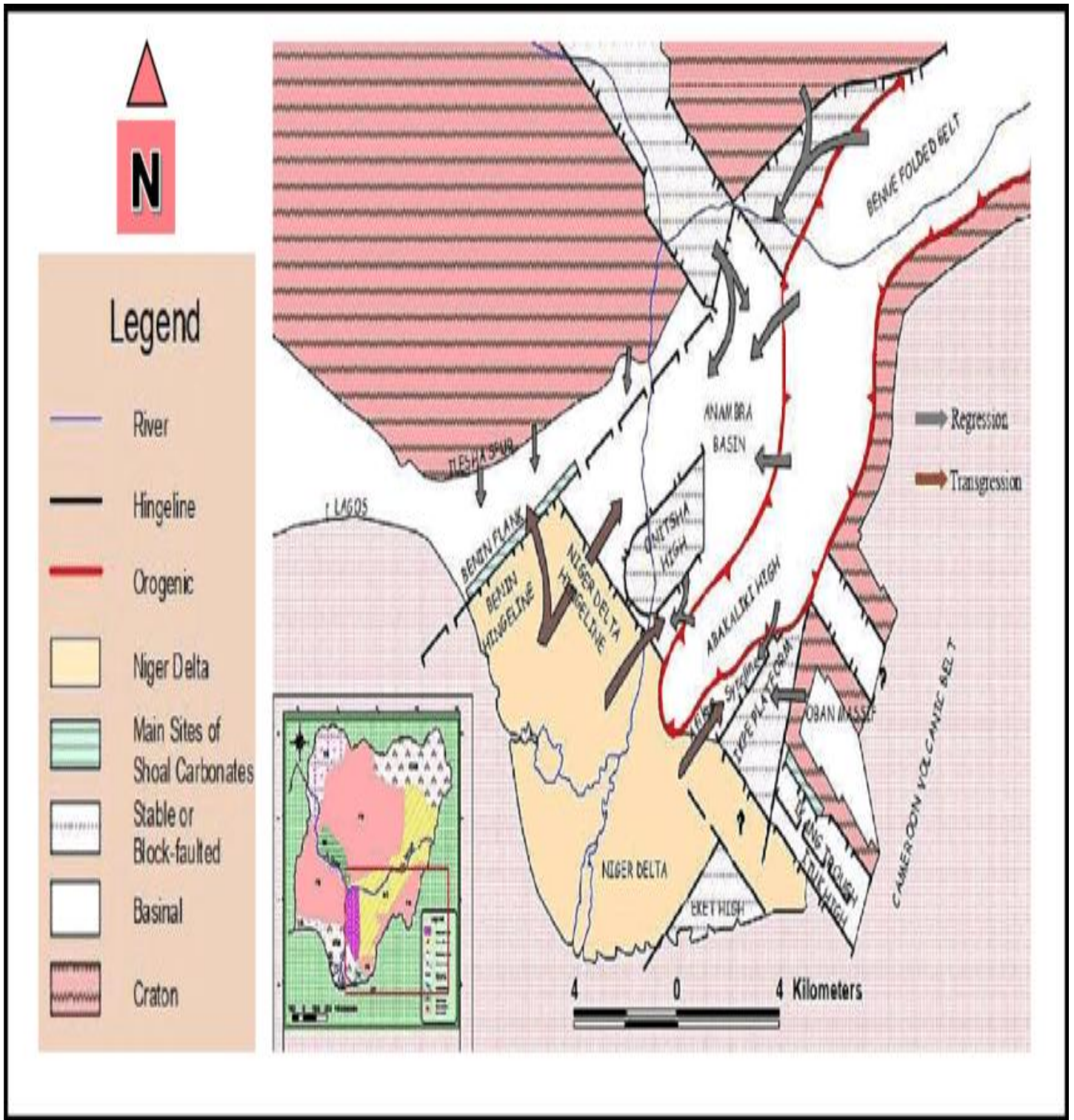


Fig.4: Tectonic map showing the Niger Delta modified after (Kogbe, 1989)

2.3 STRATIGRAPHY OF THE NIGER DELTA BASIN

During the Cenozoic, until the middle Miocene, the Niger Delta grew through pulses of sedimentation over an oceanward-Dipping continental basement into the Gulf of Guinea; thereafter progradation took place over a landward dipping oceanic basement. A 12,000m thick succession of overall regressive, offlapping sediments resulted that is composed of three diachronous siliciclastic units; the deep marine pro-Delta Akata group, the shallow marine delta front Agbada group and the continental Delta top Benin group. Regionally, sediment dispersal was controlled by marine transgressive/regressive cycles related to eustatic sea level changes with varying duration. Differential subsidence locally influenced sediment accumulation. Collectively, these controls resulted in eleven chronostratigraphically confined Delta-wide-mega sequences with considerable internal lithological variation. The various sea level cycles were in or out of phase with each other and with local subsidence, and interfered with each other and thus influenced the depositional processes at the high inflection points of the long term eustatic sea level curve, floodings took place that resulted in Delta wide shale markers. At the low inflection points erosional channels were formed that are often associated, down dip, with turbidites in low stand sediments (LSTS). The megasequence contain regional transgressive claystone units(TST) followed by a range of heterogeneous fine-to coarse progradational or aggradational siliciclastic(para) sequence sets formed during sea level high stand(HST). An updated Bio-stratigraphic scheme for the Niger Delta is presented. It also updated a sedimentation model that takes into consideration local and Delta wide effects of sea level cyclicity and Delta tectonics. Megasequence were formed overtime interval of approximately 5ma within individual accurate megastructure that literally linked into depobelts. The megasequence form the time stratigraphic frame of the Delta and are the backbone for the

new Delta wide Lithostratigraphy is badly needed, in particular because of the vigorous new activity in the offshore part of the Niger Delta (not covered in this contribution) there as well as in the onshore part of the Delta. The traditional lithostratigraphic subdivision of the Cenozoic Niger Delta section in three formations is insufficient for optimum stratigraphic application, moreover, the various informal subdivisions that have been proposed over time are inconsistent.

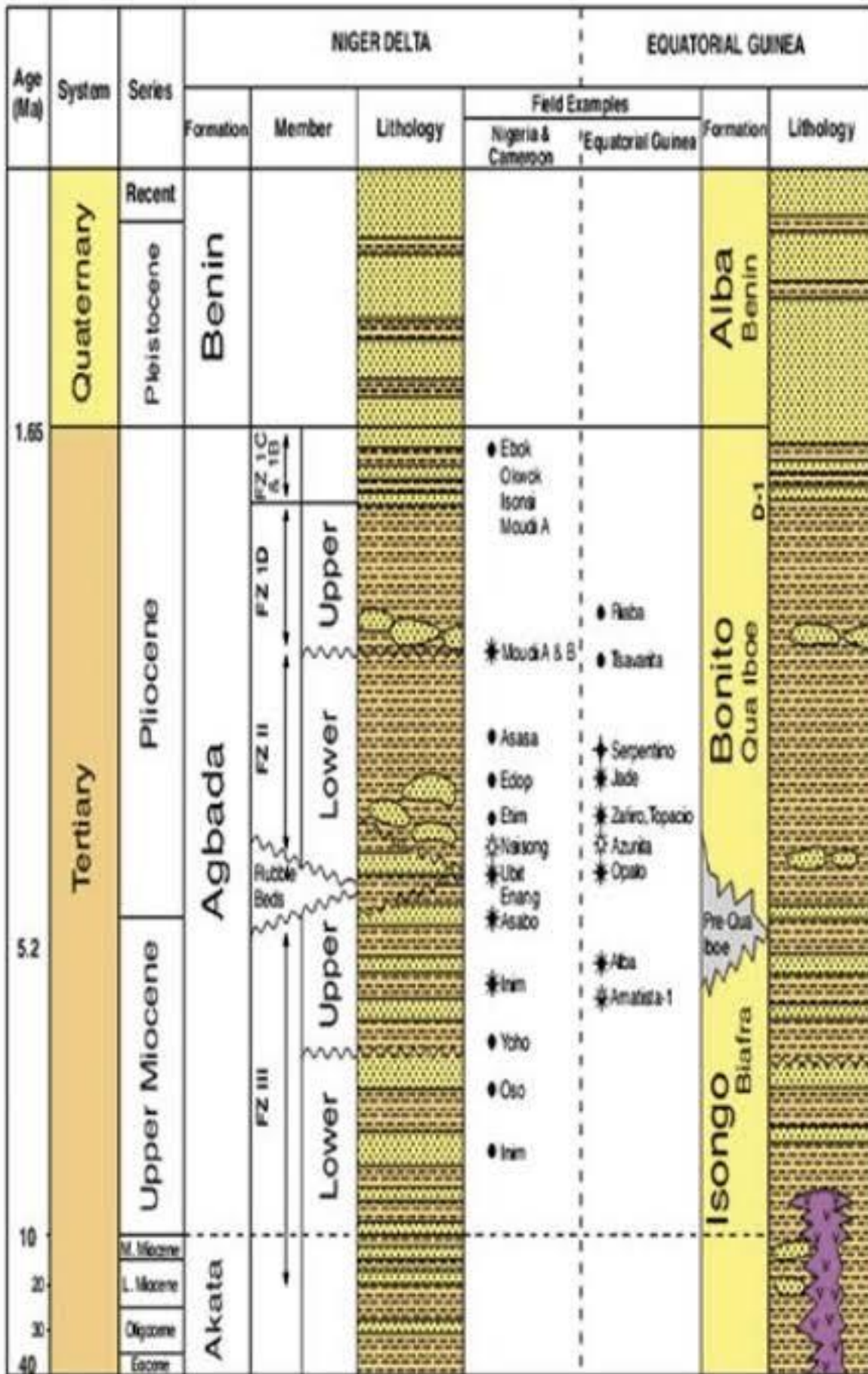


Fig. 5: Stratigraphy of the Niger Delta Basin (Doust and Omatsola, 1990)

2.4 SEDIMENTATION

Deltas reflect a contest between fluvial and basinal processes (sediment supply and subsidence) since they are river-fed depositional systems which result in an irregular progradation of the shoreline (Scott and Fisher, 1979). Basin-fill geometry can be modeled as a function of the relative contribution of the creation of accommodation space (R_s) versus sediment supply (R_d) / unit time: Accommodation space is the surface above which deposition is temporary and below which preservation is possible.

Basin-fill geometry = $f[R_s/R_d]$ ----- Sediment deposition ----- Eqn 1

The above relationship gives rise to either progradation, aggradation or retrogradation when rate of subsidence is less than; equal to or greater than the rate of deposition respectively. The Niger Delta Basin is predominately a prograding complex, in which $R_s < R_d$ has remained the frequently favoured depositional system.

Sedimentation in the basin results in tectonic events in the form of listric syn-sedimentary growth faulting, with the basin-ward progradation of thick sand deposits over the underlying under-compacted marine shales. At a certain stage when further subsidence and sedimentation can no longer be accommodated, the focus of deposition shifts basin-ward to form a depobelt (Doust and Omatsola, 1990). They can be considered as transient basinal areas succeeding one another or as progradational wedges. Five of these depobelts have been recognized in the basin.

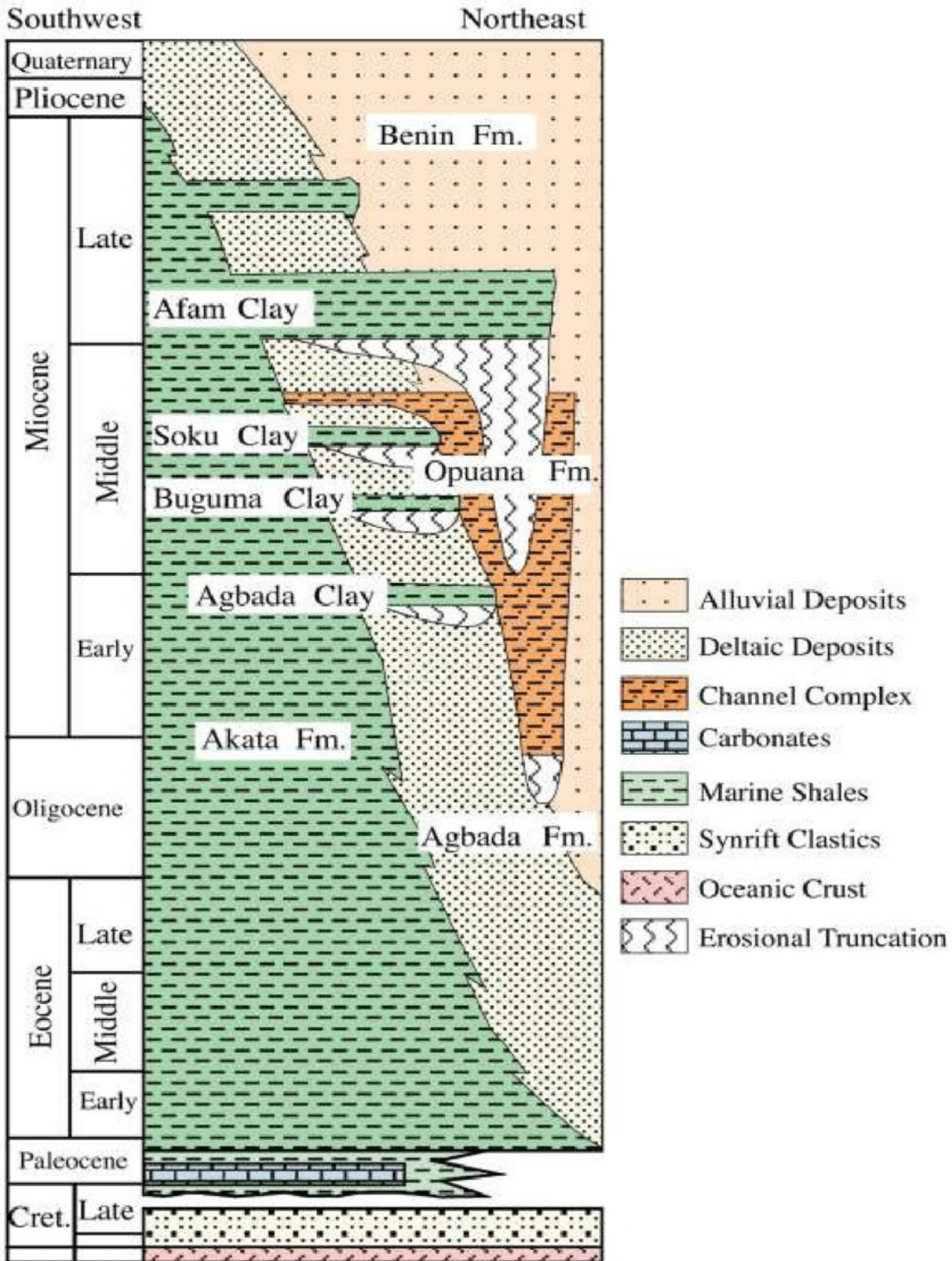


Fig. 6: Stratigraphic column showing the three formations of the Niger Delta, showing several sediments of the various formations (Lawrence *et al.*, 2002; Corridor *et al.*, 2005).

i. The Akata Formation

It is the under compacted, over pressured, marine prodelta megafacies of the Niger Delta basin. It is composed mainly of marine shale with occasional turbidite sandstone and siltstone (Short and Stauble, 1967). The thickness ranges from 600m to over 6000m and depends on the shale diapirism. It is thought to be the sources rock of the Niger delta complex. Abundance of planktonic foraminifera assemblage indicates deposition of the Akata shale on a shallow marine environment (Whiteman 1982).

ii. The Agbada Formation

These underlies the Benin formation and consist of interbedded fluvio marine sands, sandstones and siltstone of various proportion and thickness representing cyclic sequence of offlap unit (Weber, 1971). Texturally the sandstone vary from coarse to fine grained, poorly to very wellsorted, unconsolidated to slightly consolidated. Lignite streak and limonite coating occur with some shell fragment and glauconitic (Short and Stauble, 1967). The shale are medium to dark grey, fairly consolidated and silty with localized glauconite. Shaliness increases downward and the formation passes gradually into the Akata formation.

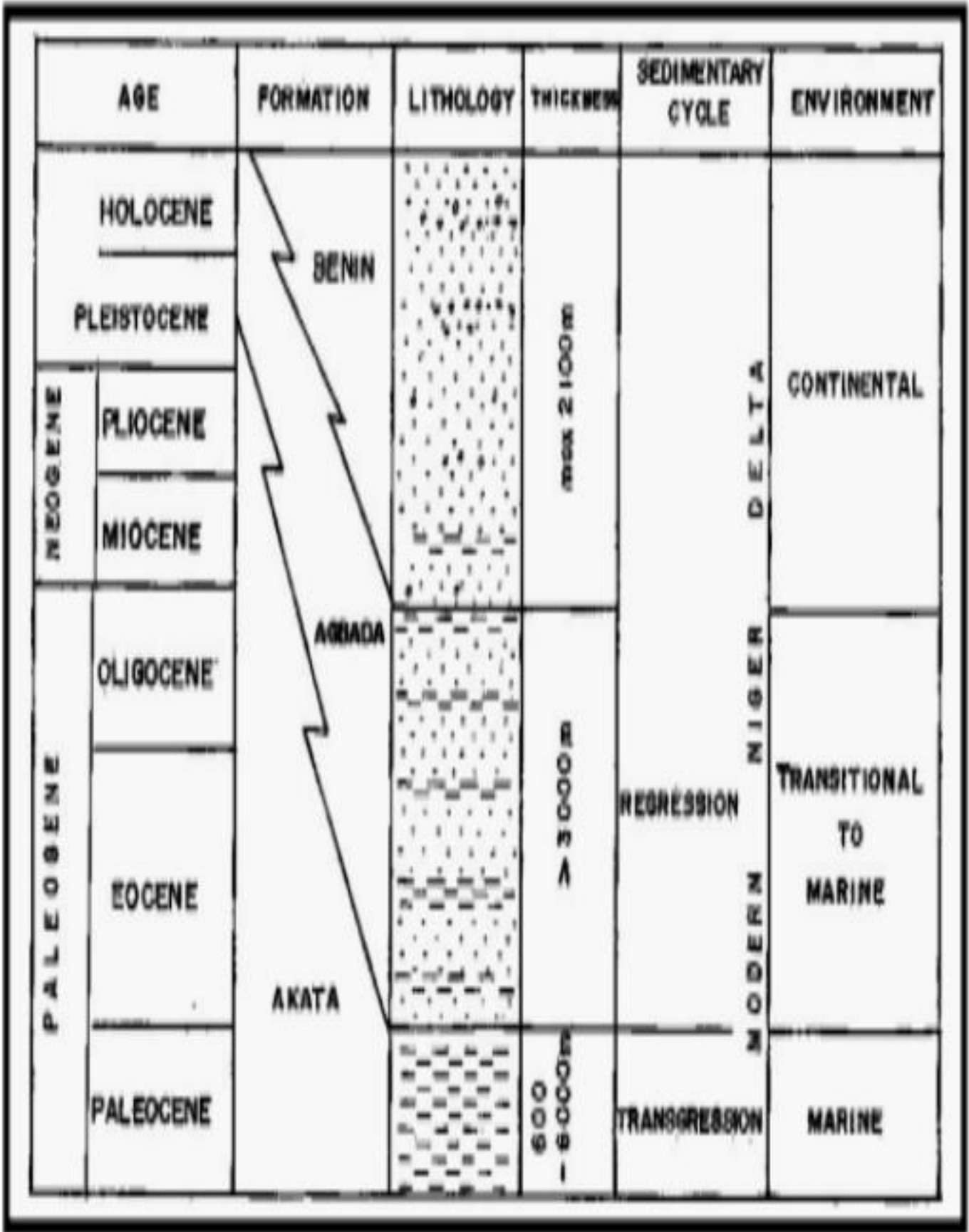


Fig. 7: Stratigraphic section of the Niger Delta adopted from (Doust, 1990)

iii. The Benin Formation

This is the topmost unit, composed of fluvial gravel and sands. It is described as the coastal plain sands which outcrop at Benin, Onitsha and Owerri province and elsewhere in the Delta area (Reyment, 1965).

The deposit is predominantly continental in origin and consist of massive, highly porous, fresh water bearing sandstones with little shale intercalation which increases toward the base of the formation

2.5 DEPOBELTS OF THE NIGER DELTA PROVINCE

Deposition of the three formations occurred in each of the five overlapping siliciclastic sedimentation cycles that comprise the Niger Delta. These cycles (depobelts) are 30-60 kilometers wide , prograde south westward 250 kilometer over oceanic crust into the Gulf of Guinea (Stacher, 1995), and are redefined by syn-sedimentary faulting that occurred in response to the variable rates of subsidence and sediment supply (Doust and Omatsola , 1990). The interplay of subsidence and supply rates resulted in deposition of discrete depobelts when further crustal subsidence shifted toward forming a new depobelts (Doust and Omatsola, 1990). Each depobelts is a separate unit that corresponds to break in regional dip of the Delta and is bounded landward by growth faults and seaward belt (Evamy and others, 1978, Doust and Omatsola, 1990). Five major depobelts are generally recognized, each with its own sedimentation, deformation and petroleum history

Various integrated studies have shown that several “Depobelts” exist in the Niger Delta basin which are separated by major synsedimentary fault zones that occurred in response to variable rates of subsidence and sediment supply (Doust and Omatsola, 1990; Evamy, 1979; Tuttle, *et al.*, 1999)

The “Depobelts” include:

- i. Northern Delta
- ii. Greater Ughelli
- iii. Central Swamp
- iv. Coastal Swamp
- v Shallow Offshore

These Depobelts can be thought of as transient basinal areas succeeding one another in space and time as the delta prograded Southward. When further subsidence of the basin could no longer be accommodated the focus of sediment deposition shifts seaward forming a new depobelt (Doust and Omatsola, 1990). At the same time syn-sedimentary and most post-sedimentary faulting would cease within the abandoned depobelt. Therefore, Depobelts form the structural and depositional active portion of the delta at each stages of its development (Doust and Omatsola, 1990; Tuttle *et al.*, 1999)

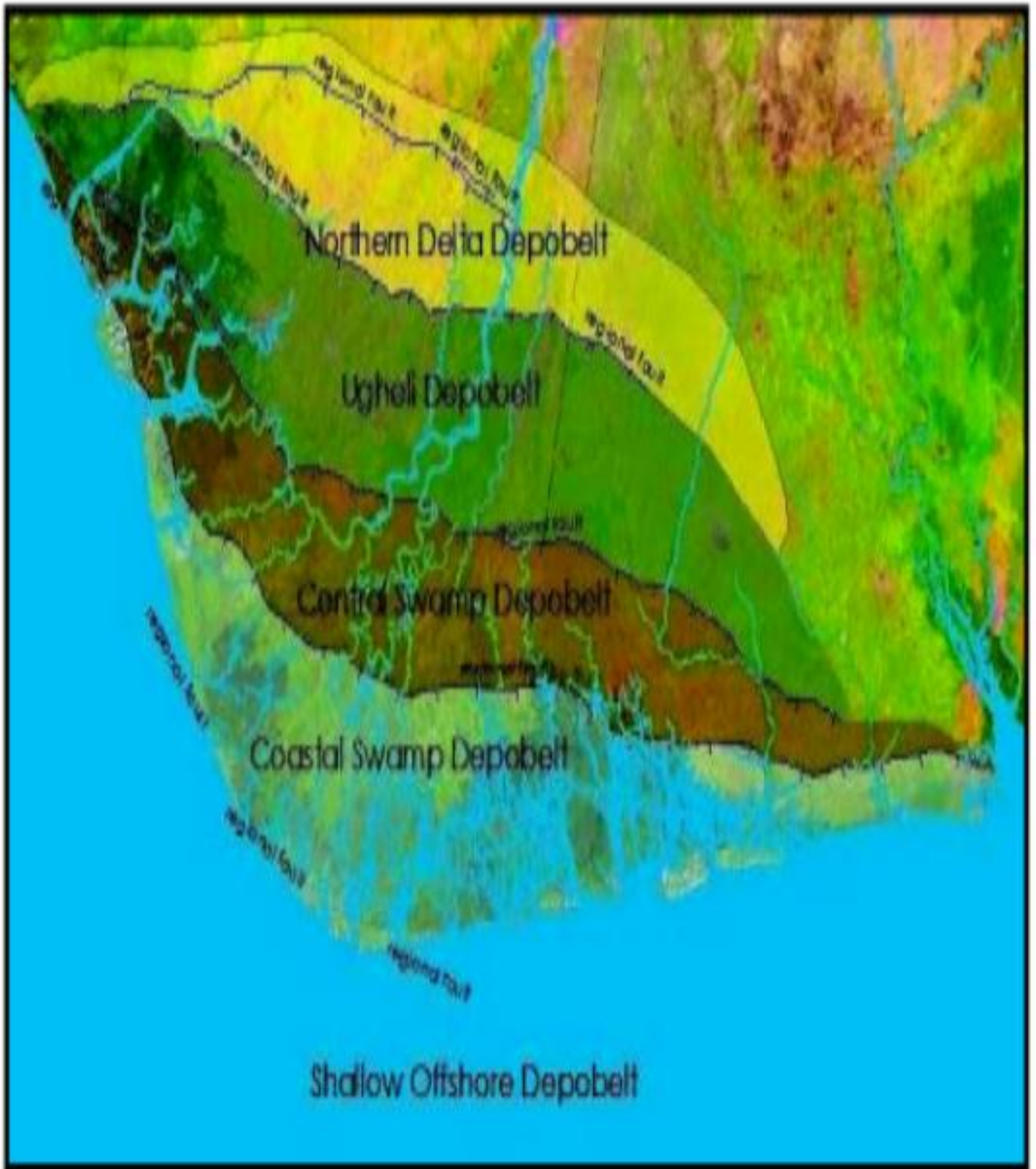


Fig. 8: Schematic diagram of the Niger Delta showing the Depobelts and the regional faults (Modified from Doust and Omotsola, (1990) and Stacher (1995).

2.6 PETROLEUM AND ITS OCCURRENCE

2.6.1 Distribution of petroleum

Petroleum occurs throughout the Agbada formation of the Niger Delta however, several directional trends form an “oil rich belt” having the largest field and lowest gas: oil ratio (Ejedawa, 1981 Evamy & others, 1978, Doust and Omatsola, 1990). Hydrocarbon distribution was originally attributed to timing of trap formation relative to petroleum migration (earlier landward structures trapped earlier migrating oil). Evamy and others (1978), however, showed that in many rollovers, movement on the structure, building fault and resulting growth continued and was relayed progressively southward in the younger part of the section by successive crustal faults, concluding that there was no relationship between growth along a fault and distribution of petroleum. For generation and accumulation to take place, the various systems have to be present within the basin and they include; source rocks.

2.6.2 SOURCE ROCK

The Agbada formation has intervals that contain organic-carbon contents sufficient to be considered good source rocks (Emwozo and Okoye, 1980, Nwachukwu and chuwuma, 1986). The intervals, however, rarely reach thickness sufficient to produce a world class oil province and are immature in various parts of the delta (Evamy and others, 1978, Stacher, 1995). The Akata shale is present in large volumes beneath the Agbada Formation and is at least volumetrically sufficient to generate enough oil province such as the Niger Delta.

Based on organic matter content and type, Evamy and others (1978) proposed that both the marine shale (Akata Formation) and the shale interbedded with paralic sandstone (lower Agbada Formation) were the source rocks for the Niger Delta oils.

Some have proposed that marine Cretaceous shale beneath the Niger Delta is a viable source rock (eg. Pre-Albian super source rock, Frost, 1997). This cretaceous section has never been drilled beneath the Delta due to its great depth, therefore, no data exist on its source-rock potential. Migration of oil from the cretaceous into reservoirs in the Agbada Formation would have required an intricate fault/fracture network as the Akata shale reaches a thickness of greater than 6,000 meters. No data exist to support such a network. However, Stacher, (1995) proposes that the Akata Formation is the only source rock volumetrically significant and whose depth of burial is consistent with the depth of the oil window.

Petroleum source rock are divided into three types namely; Potential, Probable and Effective source rocks.

i. POTENTIAL SOURCE ROCKS

This type of rock are simply defined as immature sedimentary rocks capable of generating and expelling hydrocarbons, if their level of maturity were higher.

ii. PROBABLE SOURCE ROCKS

This are sedimentary rocks whose source potential has not yet be evaluated, but which may generate and expelled hydrocarbon.

iii. EFFECTIVE SOURCE ROCKS

This rocks are sedimentary rocks, which have already generated and expelled hydrocarbon.

The hydrocarbon source evaluation is generally based on the organic matter quantity (organic richness), quality (kerogen type), and the thermal maturation generation capability and of the organic matter disseminated in the rock. Organic matter content can be determined directly from laboratory analyses of the source rock samples (shale), and through indirect methods based on wireline data offer the advantages of economic, ready availability of data, and continuity of sampling of vertical heterogeneous shale section.

2.6.3 RESERVOIR ROCKS

Petroleum in the Niger Delta is produced from sandstone and unconsolidated sands predominantly in the Agbada Formation. Characteristics of the reservoirs in the Agbada Formation are controlled by depositional environment and by depth of burial. Known reservoir rocks are Eocene to Paleocene in age in age, and are often stacked, ranging in thickness from less than 15 meters to 10% having greater than 45 meters thickness (Evamy and others 1998). The thicker reservoirs likely represent composition bodies of stacked channels (Doust and Omatsola, 1990). Based on reservoir geometry and quality Kulke (1995) describes the most important reservoir types as point bars of distributary channels.

Edwards and Santogrossi (1990) describe the primary Niger Delta reservoir as Miocene paralic sandstone with 40% porosity , 2 Darcys permeability and a thickness of 100 meters.

i. Reservoir Porosity

Porosity is the void space in a rock that can store the fluid. It is measured as either a volume percentage or a fraction (expressed as a decimal). In the subsurface this volume may be filled with petroleum, water, a range of non-hydrocarbon gasses (CO₂, H₂S, N₂). Porosity is divided into two types, absolute and effective porosity. Absolute porosity is the ratio of the total pore volume in the rock to bulk volume and Effective porosity is the ratio of interconnected pore volume to bulk volume. Based on the way of its formation, there are two types of porosity namely; primary and secondary porosity. Primary porosity is porosity that formed while sedimentary rock deposited. Secondary porosity is porosity that formed after the sedimentary rock deposited.

ii. Reservoir Permeability

It is an intrinsic property of a material that determines how easily a fluid can pass through it. In the petroleum industry, the darcy (d) is the standard unit of permeability, but millidarcies (1mD = 10⁻³ D) are more commonly used. A Darcy is defined as the flow rate of 10⁻² m³ s⁻¹ for a fluid of 1 cp (centipoise) under a pressure of 10⁻⁴ atm m⁻². Permeability in reservoir rocks may range from 0.1mD to more than 10D.

All types of rock (igneous, sedimentary, metamorphic) can act as reservoir rocks if it can accommodate and drain hydrocarbons. Reservoir rocks around the world is dominated by sedimentary rocks because generally it has primary porosity. Igneous and metamorphic rocks can be reservoir if there are in fracturing state (secondary porosity).

Reservoir rocks are further classified into various types, they are as follow;

i. Siliciclastic reservoir

Siliciclastic sedimentary rocks are the most abundant of the sedimentary rock. They are formed from detritus left over from the weathering of igneous, metamorphic, and older sedimentary rocks.

ii. Shallow and deep marine reservoir

Depending on the type of sedimentary rock, hydrocarbon reservoir can be divided into two groups. There are clastic sedimentary rock and non clastic sedimentary rock. On the clastic sedimentary, contained some precipitation area, as one in marine area. Rock type can be formed in deposition marine areas such as shelf sandstone and turbidity sandstone. Shelf sandstones are formed from precipitating in the shallow marine area. Sands transported by water current from river to shallow marine area. Because of that process, has been formed sands body around the grow delta and maybe form the fan like in delta. Turbidity sandstones are formed in deep marine area with rotation force existing rotation deep current so as formed the coarse layer which has interaction with shale layer in the deep marine. Shape from deposition of turbidity sandstone can be like a lens, dust, or fans.

iii. Lacustrine Reservoir

This type of reservoir formed in basin containing water surrounded by land and initially formed by tectonic processes, volcanic, rifting, soil movement, the erosion by the wind on the coast or in the land. The texture of sedimentary rocks in the environment is usually granules grains.

iv. Eolian Reservoir

It is formed in large areas with the accumulation of sand deposition. The sediment resulting from wind-blown sand. The clastic texture of the environment is granules (2-4 mm) and coarse (over 2mm).

v. Fluvial Reservoir

This type of reservoir is generated by the flow of the river where the process is formed by the erosion, transport and deposition of forming depositional formation.

vi. Deltaic Reservoir

On this type of reservoir, it was formed by the accumulation of lacustrine sediments. Very fine grain sediment rocks.

vii. Carbonate Reservoir

Carbonate rocks is a sedimentary rock with carbonate fraction more than 50%. Carbonate rocks can be used as a reservoir because of its porosity and permeability. Carbonate rocks can be classified to clastic and non clastic sediment. Its environment formation is tropic ocean. The porosity concept of a carbonate rock might be a little bit more complex than other rock, because of its vary secondary porous, from carbonate dissolution made from skeletal remain and microbe with cement. Almost all of carbonate reservoir type accumulated as a shallow marine sedimentary, except on a pelagic chalk and deep marine re-sediment reservoir carbonate in mexico seas.

viii. Reef Reservoir

Reef is a framework made of sea organism containing skeletal, grow in a shallow clean water where sunlight can reach as a nutrition. Reef distribution is varies, some on the edge of the shelf and become a barrier, some scattered called patch reef. Patch reef can reach a few

kilometer size while barrier can be elongated along the edge and limit the exposure with basin.

Reef is a non-clastic carbonate rocks without transportation process on its formation

2.6.4 TRAPS AND SEALS

Most known traps in Niger Delta fields are structural although stratigraphic traps are not uncommon. The structural traps developed during synsedimentary deformation of the Agbada paralic sequence (Evamy and others, 1978, Stacher, 1995).

Doust and Omatsola (1990) described a variety of structural trapping elements including those associated with simple rollover structures, clay filled channels structures, Clay filled channels structure with simple growth faults, structures with antithetic parts and collapsed.

Crest structures. On the flanks of the delta, stratigraphic traps are likely as important as structural traps (Beka and Oti, 1995). In these region pockets of sandstones occur between diapiric structures (Fig. 5).

The primary seal rock in the Niger Delta is the interbedded shale within the Agbada Formation. The shale provides three types of seals – clay smears along faults, interbedded sealing units against which reservoir sands are juxtaposed due to faulting, and vertical seals (Doust and Omatsola, 1990). On the flanks of the delta, major erosional events of early to middle Miocene age formed canyons that are now clay-filled (Fig. 6). These clays form the top seals for some important offshore fields (Doust and Omatsola, 1990).

i. Structural Trap

This is a type of geological trap that forms as a result of changes in the structure of the subsurface, due to tectonic, diapiric, gravitational and compactional processes. These changes block the upward migration of hydrocarbons and can lead to the formation of a petroleum reservoir. Structural traps are the most important type of trap as they represent the majority of

the world's discovered petroleum resources. The three forms of structural traps are the anticline trap, the fault trap and the salt dome trap. Anticlinal trap is by far the most significant to the hydrocarbon industry, they are usually long oval domes of land that can often be seen by looking at a geological map or by flying over the land. Fault trap is formed by the movement of permeable and impermeable layer of rock along a fault line. The permeable reservoir rock faults such that it is now adjacent to an impermeable rock, preventing hydrocarbons from further migration. In some cases, there can be an impermeable substance smeared along the fault line such as clay that also acts to prevent migration. This is known as clay smear. Salt dome trap, masses of salt are pushed to their greater buoyancy, eventually breaking through and rising towards the surface (see salt dome). This salt is impermeable and when it crosses a layer of permeable rock, in which hydrocarbons are migrating, it blocks the pathway in much the same manner as a fault trap. This one of the reason why there is significant focus on subsalt imaging, despite the many technical challenges that accompany it.

ii. Stratigraphic Traps

These are formed as a result of lateral and vertical variations in the thickness, texture, porosity or lithology of the reservoir rock. Examples of this type of traps are an unconformity trap, a lens trap and a reef trap. Two main group can be recognized as examples of stratigraphic traps namely; primary and secondary stratigraphic traps. Primary stratigraphic traps result from variations in facies that developed during sedimentation. These include features such as lenses, pinch-outs, and appropriate facies changes while secondary stratigraphic traps result from variations that developed after sedimentation, mainly because of diagenesis. These include variations due to porosity enhancement by dissolution or loss by cementation.

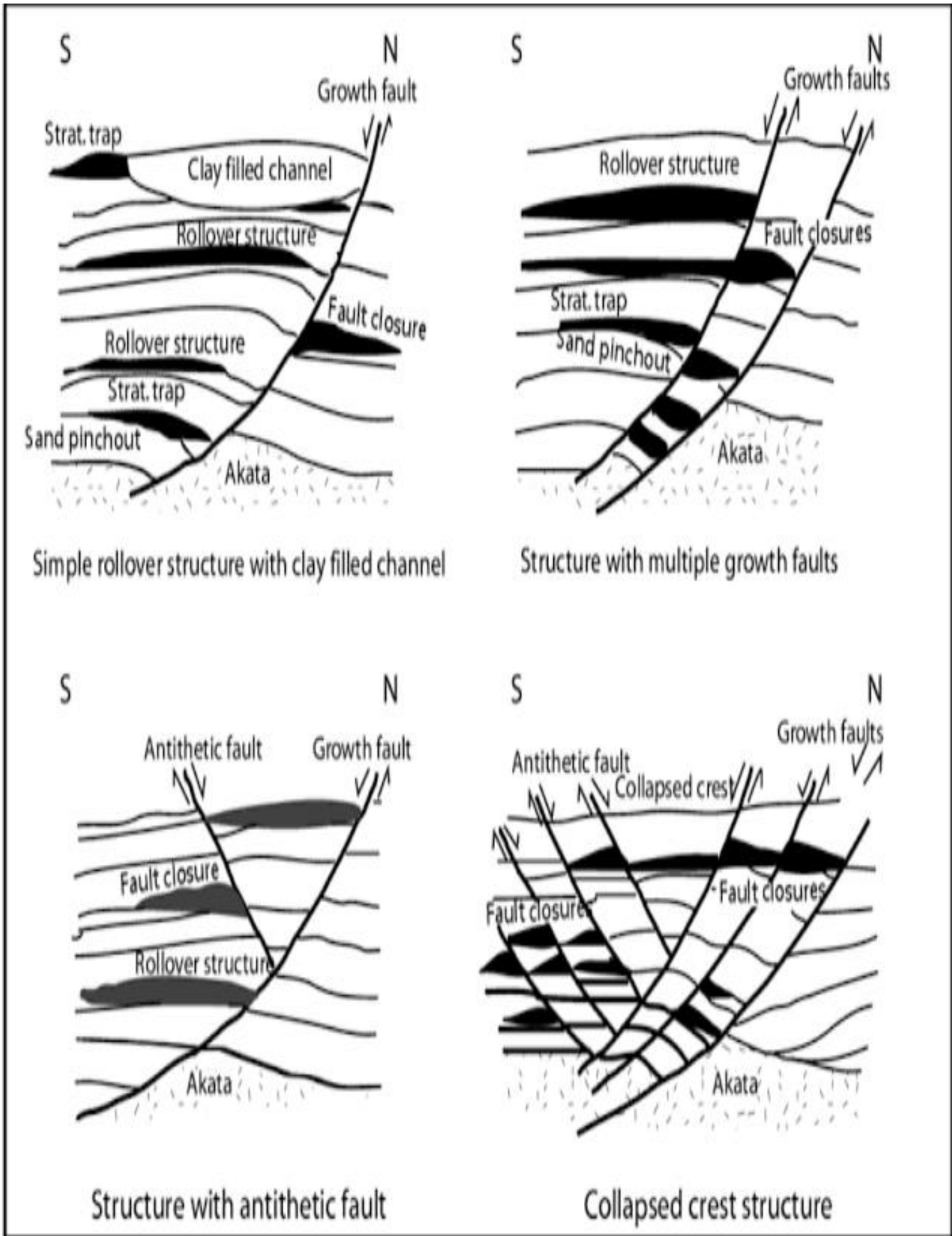


Figure 9: Niger Delta oil field structures and associated traps. Extracted from Doust and Omatsola (1990) and Stacher (1995)

2.6.5 PETROLEUM GENERATION AND MIGRATION

Evamy and others (1978) set the top of the present day oil window in the Niger Delta at the 240°F (115°C) isotherm. In the northwestern portion of the delta, the oil window (active source-rock interval) lies in the upper Akata Formation and the lower Agbada Formation. The depth of the hydrocarbon kitchen is expected to be deeper than in the delta proper because the depth of hydrocarbon kitchen is a combination of factors (temperature, time and deformation relate to tectonic effects) (Beka and Oti, 1995). The Akata/Agbada Formation boundary in the region is currently at a depth of about 4,300m with the upper Akata Formation in the wet/condensation generating zone (vitrinite reflectance value > 1.2. Tissot, B.P and Welte, D.H, (1984). The lower most part of the Agbada Formation have entered the oil window sometime in the late Oligocene.

Migration from mature, over-pressured shale in the more distal portion of the delta may be similar to that described from over-pressure shale in the Gulf of Mexico (Fig.). Hunt (1990) relates episodic expulsion of petroleum from abnormally pressured, mature, source rocks to the fracturing and resealing of the top seal of the over-pressured interval. In rapidly sinking basins, such as the Gulf of Mexico, the fracturing resealing cycles occurs in intervals of thousands of years. This type cycle expulsion is certainly plausible in the Niger Delta basin where the Akata Formation is over-pressured. Beka and Oti (1995) predict a bias towards higher hydrocarbon (gas and condensate) from the over-pressured shale as a result of down-slope dilution of organic matter as well as differentiation associated with explosion from over-pressured sources.

2.7 PROPERTIES OF PETROLEUM FIELDS

Most fields consist of a number of individual reservoirs that contain oil of varying composition with different gas\ oil ratios. Many reservoirs are over pressured and primary production is mainly from gas expansion. Common oil production problems include water coning, unconsolidated sands deposition and high gas/ oil ratios.

2.8 PROPERTIES OF OIL AND GAS

The physical and chemical properties of the oil in the Niger Delta are highly variable, even down to the reservoir level. The oil within the Delta has a gravity range of 16-50API with the lighter oils having a greenish-brown color (Whiteman, 1982). This second group oils are biodegraded and from shallow reserves they have lower API gravity (Average API of 26⁰ Kulke, 1995) and are naphthenic non-waxy oils. Biodegradation and washing is extreme in some Pleistocene sand of the Agbada Formation forming extra heavy oil (API 8-20).

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 MATERIALS

i. Ditch cuttings samples.

Sedimentology analysis was carried out to determine the lithologies, grain size distribution of the various lithofacies to determine the petroleum play elements, the environment of deposition and the hydrocarbon bearing formations. One hundred (100) ditch cutting samples were collected made from Shell Petroleum Development Company (SPDC) at depth of six thousand one hundred and forty feet (6140ft) to twelve thousand seven hundred and forty feet (12740ft) from OK-1 Well and were processed for sedimentological analysis.

Table 1: Ditch cutting Samples

S/No	Depth (ft.)	Depth (m)
1	6140	1871
2	6200	1890
3	6260	2003
4	6320	2022
5	6380	2041
6	6440	2061
7	6500	2080
8	6560	2099

9	6620	2118
10	6680	2138
11	6740	2157
12	6800	2176
13	6860	2195
14	6920	2214
15	6980	2233
16	7040	2253
17	7100	2272
18	7160	2291
19	7220	2310
20	7280	2330
21	7340	2349
22	7400	2368
23	7460	2387
24	7520	2406
25	7580	2426
26	7640	2445
27	7700	2464
28	7760	2483
29	7820	2502
30	7880	2522

31	7940	2541
32	8000	2560
33	8060	2579
34	8120	2598
35	8180	2618
36	8240	2636
37	8300	2656
38	8360	2675
39	8420	2694
40	8480	2707
41	8540	2733
42	8600	2752
43	8660	2771
44	8720	2790
45	8780	2810
46	8840	2829
47	8900	2848
48	8960	2867
49	9020	2886
50	9080	2906
51	9140	2925
52	9200	2944

53	9260	2963
54	9320	2982
55	9380	3002
56	9440	3021
57	9500	3040
58	9560	3059
59	9620	3078
60	9680-9740	3098-3117
61	9800	3136
62	9860-9920	3155-3174
63	9980	3194
64	10400	3328
65	10460	3347
66	10520	3366
67	10580	3386
68	10640	3405
69	10700	3424
70	10760	3443
71	10820	3462
72	10880	3482
73	10940	3500
74	11000	3520

75	11060	3539
76	11120	3558
77	11180	3578
78	11240	3597
79	11360	3635
80	11420	3654
81	11480	3674
82	11540	3693
83	11600	3712
84	11720	3750
85	11780	3770
86	11840	3789
87	11900	3808
88	12020	3846
89	12080	3866
90	12140	3885
91	12200	3904
92	12260	3923
93	12320	3942
94	12380	3962
95	12440	3981
96	12500	4000

97	12560	4019
98	12620	4038
99	12680	4818
100	12740	4077

i. Distilled Water

Water that has undergone boiling and condensation in different container thereby leaving the unboiled impurities in the original water. It is a type of purified water.



Fig.10 Distilled water

ii. Seives

Devices containing sieves or holes that finer particles of a mixture (as of ashes, flour or sand) of many sizes can be sorted pass to enable liquid substances expulsion from the materials leaving fine particles.



Fig.11 Sieves

iii. Laboratory coat

This is a critical component of worker protection in the laboratory. In order to protect against accidental spill or contact, laboratory coats must be worn whenever working in the laboratory. In addition to the appropriate type and size of Personal Protection coat. The lab coat when used properly provide protection of skin and personal clothing from accidental contact and small splashes. It also prevent the spread of contamination outside the lab (provided they are not worn outside the lab). Not only does it protect, it also provide a removable barrier in the event of an incident involving a spill or splash of hazardous substances

iv. Hydrochloric acid (HCL)

Hydrochloric acid is one of the main six strong minerals used in chemistry and laboratory. It is an excellent acidifying reagent.

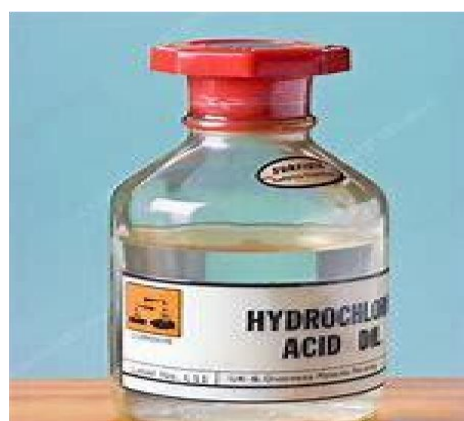


Fig.12 Hydrochloric acid

v. Stereo microscope.

Microscope are instruments used in viewing tiny objects not visible by the naked eye. The scientific study of tiny objects and structures with the aid of this instruments is called microscopy. Microscopic means invisible to the eye unless aided by a microscope.

Several kinds of microscopes exist and may be classified diverse ways. Describing the medium of interaction with a sample in creating images by passing a beam of light or electrons to a sample in its optical path or by scanning across, and a short distance from the surface of a sample using a probe is one way. Commonest among all microscopes (first invention) is the optical that involves which the passage of light through a sample to produce an image. Others includes fluorescence, electron microscope (both the transmission electron microscope and the scanning electron microscope) and the Scanning probes.



Fig.13 A stereo microscope

Water Jet

Industrial instruments having the ability to cut a several materials with very high – pressure jet of water, or a mixture of water and abrasive material.



Fig.14 Water jet

Sample Bowl

Nearly hemispherical concave material, usually a rounded container larger than a cup used for packing samples in the laboratory during analysis.



Fig.15 A sample bowl

Kerosene

Kerosene is a combustible hydrocarbon liquid that originated from petroleum. It is a paraffin, lamp oil, and coal oil.

3.2 METHODOLOGY

One hundred (100) ditch cutting samples ranging from intervals 6140ft – 12740ft were used for lithofacies and sedimentological studies. The following methods used are:

- i. Ditch sample collection
- ii. Microscopic analysis
- iii. Sedimentology analysis

All the steps were vital in obtaining precise and accurate result for this work.

3.2.1 DITCH CUTTING SAMPLES

The ditch cuttings samples were gotten from OK-1 well in the Greater Ughelli deposit of the Niger Delta Basin, Southern Nigeria. The samples were collected at depth intervals of 6140ft – 12740ft and a total of one hundred (100) samples were analyzed using a reflected microscope to determine the lithology of the well section.

3.2.2 MICROSCOPIC ANALYSIS

A detailed description of the ditch cutting samples based on examination under a reflected microscope with a magnification of x10. Lithologic description was carried out using textural characteristics such as rock type, grain size, shapes, sorting, roundness and sand percentage calculation and presence of diagnostic minerals while the presence of carbonate was determined using HCL on sediment.



Plate 1: Process of samples being viewed with a stereo microscope.

3.2.3 SEDIMENTOLOGICAL ANALYSIS

This includes the lithology description and granulometric analysis of the ditch samples obtained from the location under study. With the aid of the stereo microscope, a brief lithologic description was obtained from which insights on the depositional processes as well as some turbidite structures which helped in interpreting the borehole samples with absolute certainty was achieved.

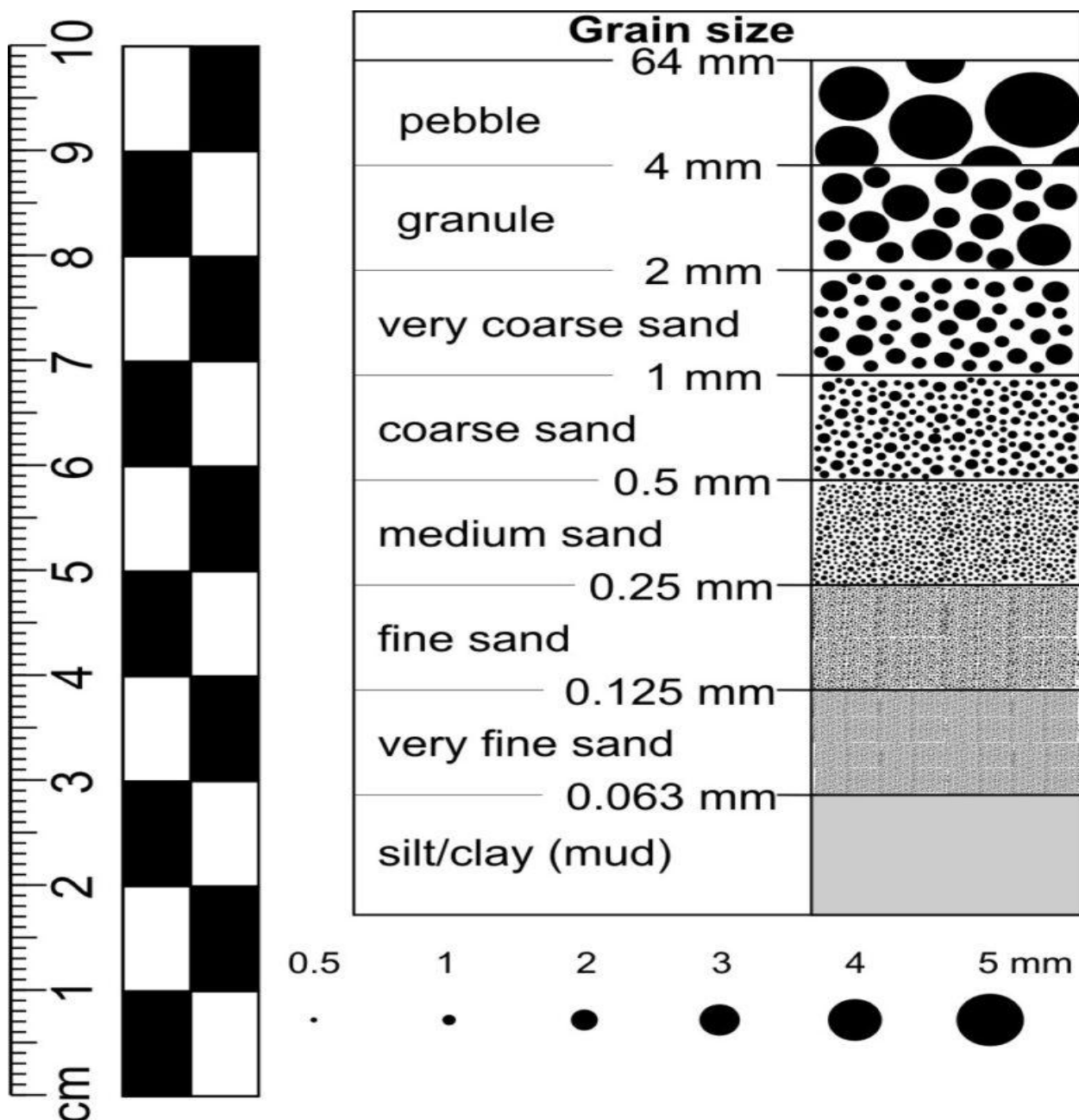


Fig. 10: Textural Comparison Chart (Modified from Powers, 1953).

3.3 SAFETY PRECAUTION

A couple of safety measures applied by myself during sampling include;

- i. I ensured that I was properly covered from head to toe by putting on a laboratory coat, hand gloves, face mask and a safety boot.
- ii. I ensured that the preparation aspect involving the use of hazardous chemicals was carried out in a fume cupboard to avoid gas poisoning.
- iii. I ensured proper labeling of the samples and chemicals I used to avoid mix up.
- iv. I ensured that the vessels I used in storing and handling the specimen was properly washed to avoid introducing external purities that could affect the sampling process.
- v. I ensured that the chemicals used were properly disposed of to avoid environmental contamination, pollution and eventual hazards.

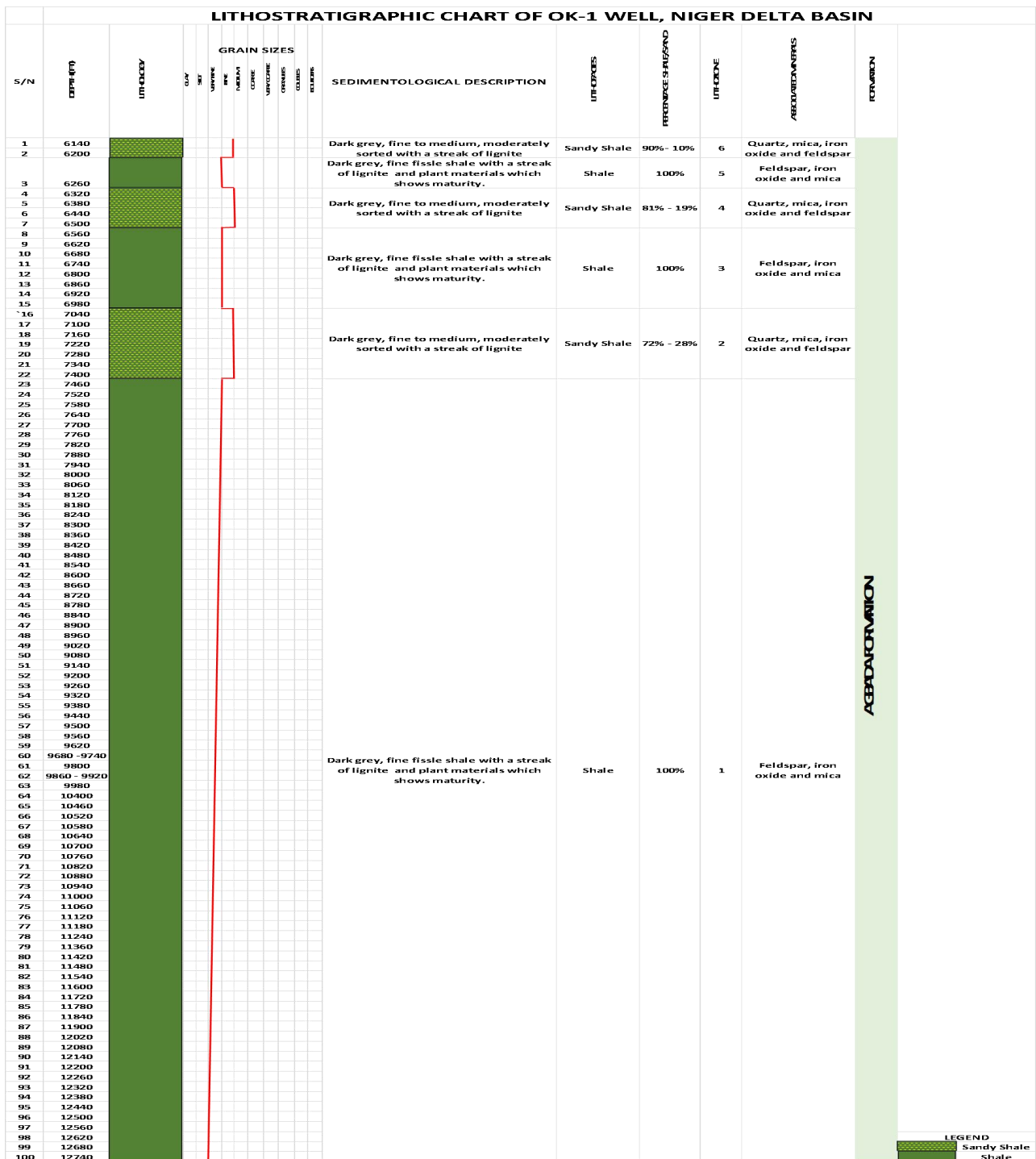
CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS FROM THE LITHOLOGY

The following one hundred (100) samples were analysed in the laboratory with a microscope and (Table. 2) was generated.

Table. 2: Lithostratigraphic chart of OK-1 well, Niger Delta Basin



4.2 LITHOFACIES DESCRIPTION

Two (2) major lithofacies which include shale and sandy shale were observed from the lithological analysis carried out on ditch cutting samples from OK-1 Well.

4.2.1 Shale units:

Shale is a fine-grained, clastic sedimentary rock, composed of mud that is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals, especially quartz and calcite. It is characterized by breaks along thin laminae or parallel layering or bedding less than one centimeter in thickness called fissility. This lithofacies is observed in lithozone 5, 3, 1. It is typically grey in color. Intervals 7400ft-12740ft, 6500ft-6980ft, and 6200ft-6260ft are all shaly lithofacies.

DEPTHS (FT)	ROCK TYPE	DESCRIPTION
7400ft-12740ft	SHALE	Dark grey, fine fissile shale, well sorted with a streak of lignite Minerals: Feldspar, iron oxide, lignite, mica and plant materials.
6500ft-6980ft	SHALE	Dark grey, fine fissile, well sorted with streaks of lignite Minerals: Feldspar, mica, iron oxide, lignite, plants

6200ft-6260ft	SHALE	Dark grey, fine fissile, well sorted with a streak of lignite Mineral: Feldspar, iron oxide, mica, lignite and plant materials
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4.2.2 Sandy shale units:

It is composed predominantly of shale with some proportion of sand. Dark grey in color, fine to medium and moderately sorted grains with a streak of lignite. It is observed in lithozones 6, 4, 2. Intervals 6980ft-7400ft, 6260ft-6500ft, and 6140ft-6200ft are all sandy shale units. Sandy shale of lithozone 2 has the greater thickness (6980ft-7400ft).

DEPTH (FT)	ROCK TYPE	DESCRIPTION
6980ft-7400ft	SANDY SHALE	Dark grey, fine to medium, moderately sorted with a streak of lignite Minerals: Quartz, mica, iron, oxide and feldspar

6260ft-6500ft	SANDY SHALE	Dark grey, fine to medium, moderately sorted with a streak of lignite Minerals: Quartz, mica, iron, oxide and feldspar
6140ft-6200ft	SANDY SHALE	Dark grey, fine to medium, moderately sorted with a streak of lignite Minerals: Quartz, mica, iron, oxide and feldspar

4.3 LITHOZONES DESCRIPTION

A well detailed description of ditch cutting samples provided was carried out mainly by visual examination, textural characteristics, color and associated mineral. The predominant lithofacies encountered were shale and sandy shale. The lithofacies encountered led to the establishment of six (6) informal lithozones. These are as follows:

4.3.1 Lithozone unit one (1) (7400ft-12740)

Lithozone (unit 1) extends from 7400ft-12740ft. composed of 100% shale with feldspar, iron oxide and mica as the associated minerals. The grains are dark grey in color, fine fissile, with a streak of lignite and plant materials showing its maturity.

4.3.2 Lithozone unit two (2) (6980ft-7400ft)

This simply extends from 6980ft-7400ft. it is composed of 72% shale and 28% sand, which indicates a sandy shale. Grains are dark grey, fine to medium, moderately sorted with a streak of lignite. The associated mineral units are quartz, iron oxide, mica and feldspar.

4.3.3 Lithozone unit three (3) (6500ft-6989ft)

Lithozone unit three extends from 6500ft to 6989ft. it is simply composed of 100% shale, which is dark grey in color, fine fissile, with streak of lignite. Feldspar, mica and iron oxide.

4.3.4 Lithozone unit four (4) (6260ft-6500ft)

Lithozone unit four (4) extends from 6260ft-6500ft. It is composed of 81% shale and 19% sand which infers a sandy shale lithofacies. The grains are dark grey, fine to medium, moderately sorted, with a streak of lignite. The associated mineral units are quartz, mica, iron oxide and feldspar.

4.3.5 Lithozone unit five (5) (6200ft-6260ft)

Lithozone unit five (5) is 100% shale, dark grey, fine fissile shale, with a streak of lignite and plant materials which indicates some level of maturity. The lithozone extends from 6200ft-6260ft. The associated minerals observed within this lithozone are feldspar, iron oxide and mica.

4.3.6 Lithozone unit six (6) (6140ft-6200ft)

The grains observed within this lithozone that extends from 6140ft-6200ft are dark grey, fine to medium, moderately sorted, with a streak of lignite. It is composed of 90% shale and 10% sand, hence the name sandy shale. Quartz, mica, feldspar and iron oxide can be observed to be the associated mineral units within grains of this lithozone.

4.4 GRAIN SIZE AND SHAPE ANALYSIS

A stereo microscope with a magnification x10 was used to examine the ditch cutting samples provided. This was simply carried out to view the grain size and shape of the samples provided.

Grain sizes within the 6140ft-6200ft appeared to be fine to medium, moderately sorted, whereas in 6200ft-6200ft, the grain size generally became fine and fissile. 6200ft-6500ft, the grain sizes and shapes changed again to fine to medium and moderately sorted. It can be observed that grain sizes became fine and fissile at 6500ft-6980ft. In the 6980ft-7400ft, it was observed that grains became fine to medium and moderately sorted. 7400ft-12740ft, the grain became fine fissile again.

4.4 MINERALOGY

The mineralogy entails the study of minerals, physical properties and electrical properties in some cases. The studied interval of the OK-1 well with the help of visual and microscopic examination, it shows feldspar, quartz, mica and iron oxide as the associated minerals within the lithofacies.

4.4.1 Quartz

Quartz is a hard, crystalline mineral composed of silica (silicon dioxide). It is hexagonal and may be colorless, white, rose or violet and has a vitreous to greasy lustre, from the examined samples, quartz is observed to be in association with other minerals in lithofacies of lithozones 2, 4, 6.

4.4.2 Feldspar

Feldspar is the name of a large organization of rock forming silicate minerals that make up over 50% of Earth's crust. They have very comparable structures, chemical composition, and bodily properties.

4.4.3 Mica

Mica is a monoclinic mineral belonging to the phyllosilicates. Biotite, muscovite, and chlorite fall within the mica family. Mica is purple, rosy, brown or colorless, with a pearly or vitreous lustre. It is observed in lithofacies of all six (6) lithozones within the examined interval of the well.

4.4.4 Iron Oxide

Appears mostly as red-brown in color and could either be hematite, goethite or magnetite. Iron oxide is found in association with feldspar and mica in all lithofacies of all six (6) lithozones within the examined interval of the well.

4.5 PETROLEUM GEOLOGY

Petroleum geology is the study of origin, occurrence, movement, accumulation and exploration of hydrocarbon. Source rocks, reservoir rocks, seal or caprocks and traps are the main hydrocarbon play elements that bring about hydrocarbon accumulation.

Much emphasis is laid on the potential source rocks and caprocks within the interval of the well being investigated.

4.5.1 Source rocks

Shales of lithozones 1, 3, and 5 can be said of to be probable source rocks, because they contain some organic materials which could have generated hydrocarbon under favorable conditions. The idea is gotten from the definition of a source rock; a formation where

hydrocarbon has been generated or being able to generate hydrocarbon, which must also be organically rich.

Grains within the lithozones 1, 3, and 5 are fine and fissile, dark in color, and also considering the great depths of these intervals coupled with the organic materials present, gives an almost perfect inference to depict the aforementioned lithozones as the main potential source rocks within the analyzed interval of the well. The sandy shales of the remaining lithozones 2, 4, and 6 could also make good potential source rocks, because they contain much of shale than sand and some streaks of lignite can also be seen within these lithozones. The lithofacies of lithozones 1, 3, and 5 could be the main source rocks within the analyzed interval of the OK-1 well, because they possess the most of the characteristics to call a rock 'source rock'.

4.5.2 Reservoir rocks

A reservoir rock is any formation that is porous and permeable and allows the accumulation and release of the accumulated fluid, and must possess structures such as seal rock, faults and folds which will prevent the fluid from migrating. In the light of the above, no lithofacies of the lithozones delineated satisfies the characteristics of a potential reservoir rock.

4.5.3 Seals or cap rocks

A cap rock or seal provides a barrier to the migration of fluid or gas out of intended trap, due to its low permeability, high capillary-entry pressure nature. Examples of seals or cap rocks are shales, anhydrite or salt, because they possess a very low permeability rate that form a barrier or seal above and around reservoir rock, so that the fluid cannot migrate beyond the reservoir.

The lithofacies of all six (6) lithozones being all shales and sandy shales possess the properties of a seal or cap rock, but as a result of stratigraphic position, they have not been

deposited on a body of sandstone for them to be regarded as potential seal or cap rocks within the analyzed interval of the well under investigation.

4.5.4 Traps

Hydrocarbon traps form where permeable reservoir rocks (carbonates, sandstones), are covered by rocks with low permeability (cap rocks) that are capable of preventing the hydrocarbon from further upward migration. Traps are usually classified according to the mechanism that produces the hydrocarbon accumulation. Two main groups of traps are those formed by structural deformation of rocks (structural traps), examples are fold traps, fault traps etc and those that are related to depositional or diagenetic features in sedimentary sequence (stratigraphic traps), a third class; combination traps could also occur.

From the lithostratigraphic chart of the well interval under study presented, only a potential stratigraphic trap could have been deciphered by virtue of stratigraphic location of the facies if only the shales were deposited on sandstone or carbonate rocks. Other forms of traps cannot be ascertained since the research does not involve seismic analysis which can give detailed view of structures.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 SUMMARY

The studied interval in OK-1 Well consists of two lithofacies; shale and sandy shale, and these lithofacies contain plant materials and streaks of lignite within some parts, and were also divided into six (6) lithozones. Feldspar, mica, quartz and iron oxide are the minerals units observed to be in association or embedded within the lithofacies of the delineated lithozones. Furthermore, from the analysis the entire analyzed section can be regarded as potential and probable source rocks because they satisfy the lithological characteristics of source rocks. Seals or cap rocks potential of the analyzed section could not however be totally ascertained because the shales and sandy shales were not observed to be deposited on a reservoir rock by reason of their stratigraphic position. The analyzed section 6140ft-12740ft of the OK-1 well can be inferred to be the Agbada Formation (paralic sequence) of the Niger-Delta Basin, by reason of depth and lithofacies within the section which are basically shale and lesser percentages of sand particles.

5.2 CONCLUSION

The Niger Delta Basin is a prolific basin with abundance oil and gas deposits that spread across all the depobelts. The studied OK-1 well is situated in one of the prolific depobelts; the Greater Ughelli depobelt. The lithostratigraphical description and sedimentological analysis of OK-1 well reveals lithofacies, associated minerals, lithozones, geological formation, percentage ration and the hydrocarbon play elements of the well.

5.3 RECOMMENDATION

Further studies and research on data from wells in the region will give a much more detailed correlation to justify the 'Agbada Formation' as given by this work. The analyzed section can also be subjected to seismic studies to further look up for traps, because this study only gives an account of the potential seal rocks by reason of their stratigraphic positions. From the lithostratigraphy of the well, the shale and sandy shale intervals contain plant materials and streaks of lignite which can also be subjected to further studies for organic content and source rock maturity.

Paleontology should be carried out to establish the depositional history of the sediments as well as provenance studies.

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