

INORGANIC GEOCHEMISTRY AS A TOOL FOR SEDIMENTOLOGICAL
STUDY;
A CASE STUDY OF X-WELL, NIGER DELTA BASIN, SOUTHERN NIGERIA

By

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A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF GEOLOGY,
FACULTY OF PHYSICAL SCIENCES, UNIVERSITY OF BENIN, IN PARTIAL
FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF A BACHELOR
OF SCIENCE DEGREE (B.Sc) IN GEOLOGY

SEPTEMBER, 2023

CERTIFICATION

This is to certify that this project work was carried out by **Atebi Ezekiel** with matriculation number **PSC1809011** of the Department of Geology, University of Benin,
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Dr. N.S. IGBINIGIE

Date

Dr. S. A. SALAMI

Date

DEDICATION

This work is dedicated to my parents for his love, care, guidance and support all through the course of this program.

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ABSTRACT

The work embraces the use of inorganic geochemistry for stratigraphic study. In order to further ascertain the sediments provenance, paleo-redox, tectonic settings, and sandstone classification, ditch cutting samples from the X-well on the Niger Delta Basin were collected. According to the geochemical results, the trace element ratios of V/Cr and U/Th indicated an oxic environment for deposition. The source of the sediments was felsic rock, as shown by bivariate plots of Ni vs TiO_2 , La/Sc vs Th/Co, and trace elemental ratios of Th/Sc, Th/Co, Cr/Th, and La/Sc. The graphs of K_2O/Na_2O versus SiO_2 and $\text{Log}(K_2O/Na_2O)$ versus $\text{Log}(SiO_2/Al_2O_3)$ were dominated by the passive margin zone. The sediments were classified by various chemical sandstone classification systems as sublitharenite, Fe-rich sand, and very little quartzarenite.

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CHAPTER ONE

1.1 INTRODUCTION

The demand for oil and gas has skyrocketed in recent years due to the growing energy needs driven by rapid urbanization and industrialization worldwide. This surge in demand has posed a major challenge for geoscientists, urging them to develop innovative and interdisciplinary solutions that can enhance the exploration and production processes. In today's dynamic economic and political landscape, petroleum explorationists and field development geologists bear significant responsibilities. Therefore, it is an encouraging opportunity for geologists to introspect and find ways to add value to the exploration and production business. As a result, chemostratigraphers have been prompted to develop new techniques and approaches, embracing change and aligning scientific advancements with the demands of the industry.

According to Ekweozor and Daukoru (1984), the Niger Delta is the West African Continental Margin's most important hydrocarbon province. It is one of the Tertiary Deltas with the highest petroleum production rates in the world. Due to its petroliferous nature, the basin has long been the focus of considerable, ongoing geologic research for both academic and commercial objectives. Since the early 1960s, there has been active hydrocarbon exploration and extraction in the basin as a result of the 1956 commercial oil finding in the Oloibiri-1 well (Nwajide and Reijers, 1996). The majority of the Niger Delta Basin's significant hydrocarbon reservoirs are typically found in regions with complicated stratigraphy and structural features (Short and Stauble, 1967). Most fields are made up of a number of distinct reservoirs, each of which holds oil and gas with a varied composition and gas/oil ratio. The majority of the world's hydrocarbon reservoirs are found in sequences with very little stratigraphic control. These sequences are frequently sterile, therefore weak links are occasionally made based merely on comparable lithological and/or petrophysical characteristics. Heavy mineral studies and isotopic techniques are frequently used to further the stratigraphy of such sections.

This study uses variations in the geochemical composition of inorganic elements to determine the tectonic context, provenance, characterization, correlation, and paleo-redox state of the sediments. To obtain reliable information on the investigated well, inorganic geochemistry was used.

1.1.1 Background of study

Subsurface uncertainties present one of the main difficulties in hydrocarbon exploration. Applying a number of tools can help the petroleum sector today overcome the difficulty of characterizing reservoir units. Chemostratigraphic methodology was used in this work, which is a method that makes use of changes in inorganic whole rock geochemistry to permit the characterization and subsequent correlation of sediments. The higher resolution interpretations required for field-scale and reservoir correlations are rarely possible with discrete events. The most accurate interpretations of these data are typically those that combine discrete and non-discrete occurrences.

The stratigraphic method used in this work will improve our comprehension of the depositional environments that are relevant to well exploration and development. The outcome of this investigation will also be utilised to define chemozones. The tectonic setting and origin of the sediments that the wells penetrated will be revealed by the inorganic geochemical features.

1.1.2 Location of Study

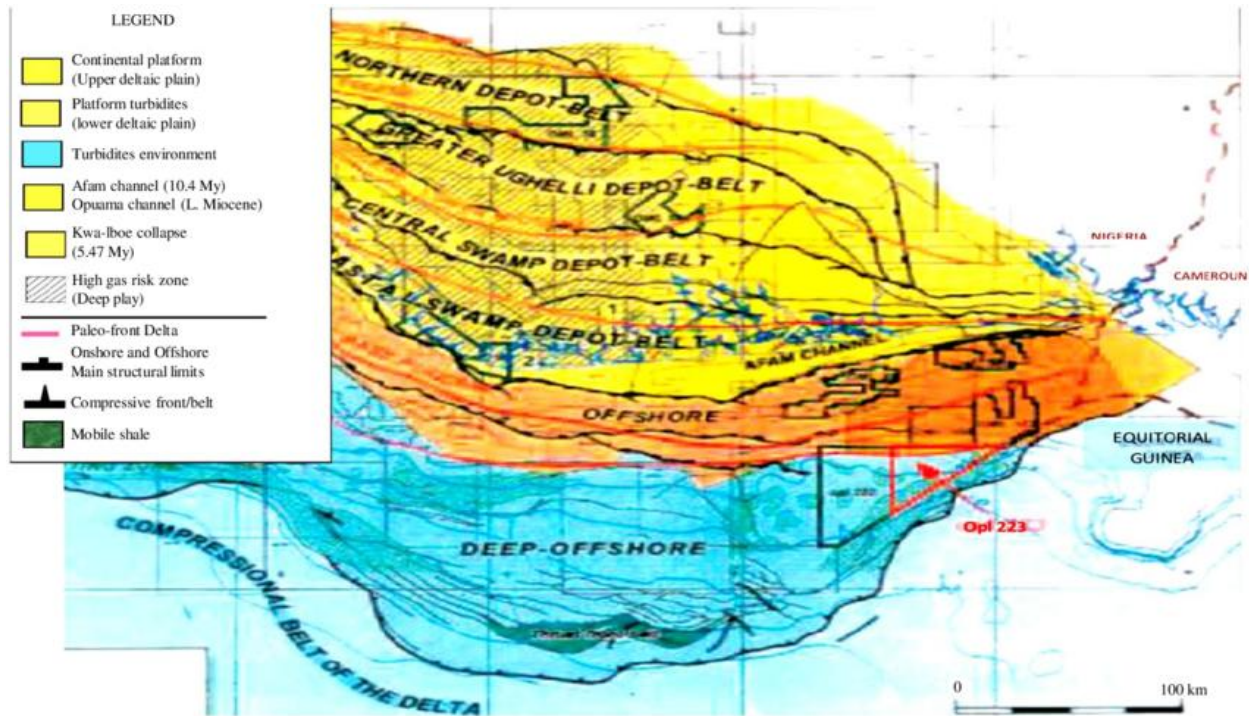


Figure 1.1: Map showing well location

1.1.3 Scope of Work

The study scope includes:-

1. Lithologic description
2. Generation of litholog
3. Documentation of results in form of tables and charts.
4. Give detailed findings and draw up conclusions.
5. Present the report.

1.1.4 Aim and objective

The purpose of this study is to determine the provenance, tectonic setting, and paleo-redox state of the material that was penetrated by the well using differences in inorganic elemental geochemical data.

The following are the study's objectives:

1. A description using lithology and sedimentology
2. To assess the tectonic context, origin, and palaeo-redox state of the sediments using inorganic geochemical ratios.
3. To identify the tectonic environment
4. To ascertain the origin of the sediments
5. To evaluate the deposition's paleo-redox condition
6. To classify the sandstones that were pierced by the

CHAPTER TWO

LITERATURE REVIEW

2.1 GENERAL OVERVIEW OF THE NIGER DELTA BASIN

The Tertiary Deltas with the highest rates of petroleum production worldwide include the Niger Delta Basin (Selley, 1997). It is located in equatorial West Africa on the Gulf of Guinea continental edge between Latitude 30 and 60 North and Longitude 50 and 80 East. Three depositional cycles have occurred in Nigeria's coastal sedimentary basin. The Middle Cretaceous marine invasion that started it all was followed by a minor folding period around Santonian time. The second resulted in a significant Paleocene marine transgression and saw the development of a Proto-Niger Delta during the Late Cretaceous. The major Niger Delta continued to expand during the third cycle, which spanned the Eocene to the Recent (Short and Stauble, 1967). Numerous researchers have examined the stratigraphy, sedimentology, structural layout, and paleoenvironment in which the reservoir rocks accumulated. (Short and Stauble, 1967; Weber and Daukoru, 1975; Evamy et al., 1978; and Selley, 1997) are a few examples.

A subsurface extension of the West African Shield called the Benin Flank surrounds the Niger Delta on its northwest side. According to Murat (1972), the Calabar Flank, which is located south of the Oban Masif, forms the basin's eastern boundary. The Niger Delta is typically divided into three vertical lithofacies: an upper delta top facies, a middle delta front lithofacies, and a lower pro-delta lithofacies. The Benin Formation (Oligocene-Recent), Agbada Formation (Eocene-Recent), and Akata Formation (Paleocene-Recent) of Short and Stauble (1967) are the respective names of these lithostratigraphic units. The coastal plain, continental shelf, and slope of Nigeria, western Cameroun, as well as the northern territorial seas of Equatorial Guinea, west of Bioko Island, are all supported by the Niger Delta Basin. Seafloor escarpments, which are located above oceanic crust, define its southern edge. The Anambra Basin and the Benue Trough gave rise to the Niger Delta Basin, which has an area of about 211,000 km².

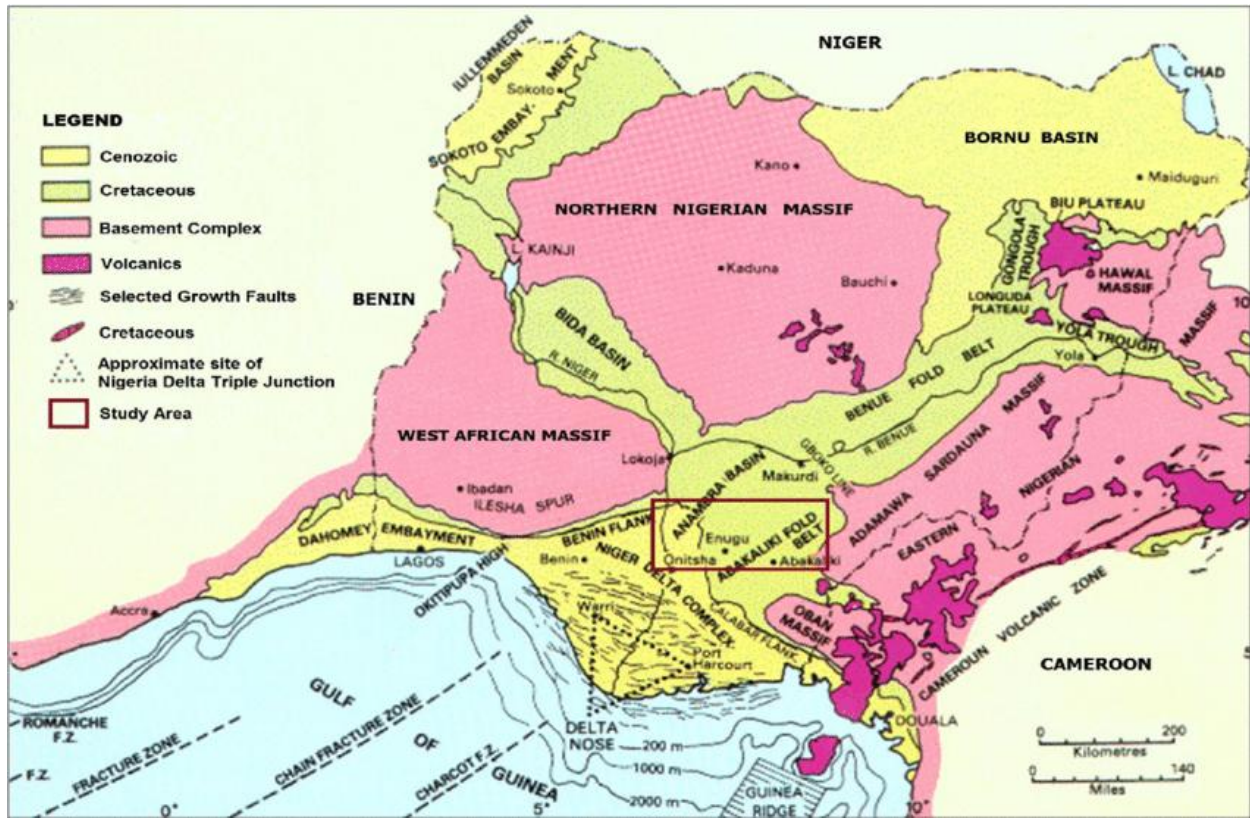


Figure 2.1: Geological map of Nigeria with main sedimentary basins, selected growth faults in the delta and structural trends (after Whiteman 1982)

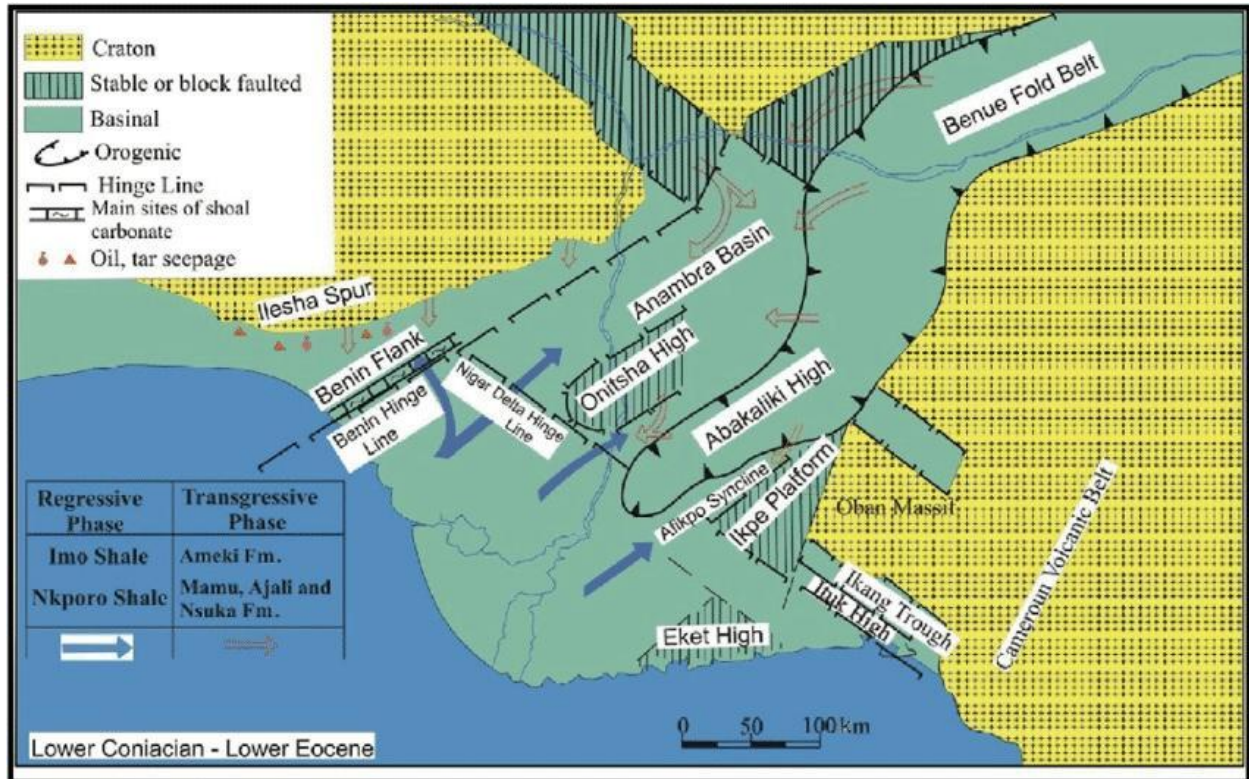


Figure 2.2: Early evolution of the Niger Delta Sedimentary Basin (after Murat, 1972)

2.2 REGIONAL TECTONIC SETTING OF THE NIGER DELTA BASIN.

Pre- and syn-sedimentary tectonics, as outlined by Evamy et al. (1978; Ejedawe, 1981; Knox and Omatsola, 1989; and Stacher, 1995), govern the formation of the Niger Delta. Cretaceous fracture zones manifested as trenches and ridges in the deep Atlantic are in charge of the tectonic framework of the continental margin along the West Coast of equatorial Africa. The Cretaceous Benue-Abakaliki Trough, which deeply incises the West African shield, has boundary faults that are formed in Nigeria by the fracture zone ridges, which split the edge into distinct basins. A failed rift triple junction connected to the opening of the South Atlantic is represented by the trough. According to Lehner and De Ruiter (1977), rifting began in the Late Jurassic and continued until the Middle Cretaceous. The overall paleogeography of the Niger Delta region, as well as the relative positions of the African and South American plates since rifting began, indicate that rifting completely stopped there in the Late Cretaceous. Gravity tectonics took over as the

main deformational activity once rifting stopped. Gravity tectonics was finished for any given depobelt before the Benin Formation was deposited, and it is expressed in intricate structures like shale diapirs, roll-over anticlines, collapsed growth fault crests, back-to-back features, and steeply dipping, closely spaced flank faults (Evamy et al., 1978; Xiao and Suppe, 1992) Near the top of the Akata Formation, these faults flatten into detachment planes and mostly offset various Agbada Formation layers.

The extended intracontinental Benue Trough's southernmost point is where the Niger Delta Basin is situated. It is bordered to the east by the Cameroun volcanic line and to the west by the Okitipupa basement high, which separates it from the Dahomey (or Benin) Basin. Its northern boundary transects the Anambra Basin, Abakaliki Basin, Afikpo Syncline, and the Calabar Flank, four older (Cretaceous) tectonic components.

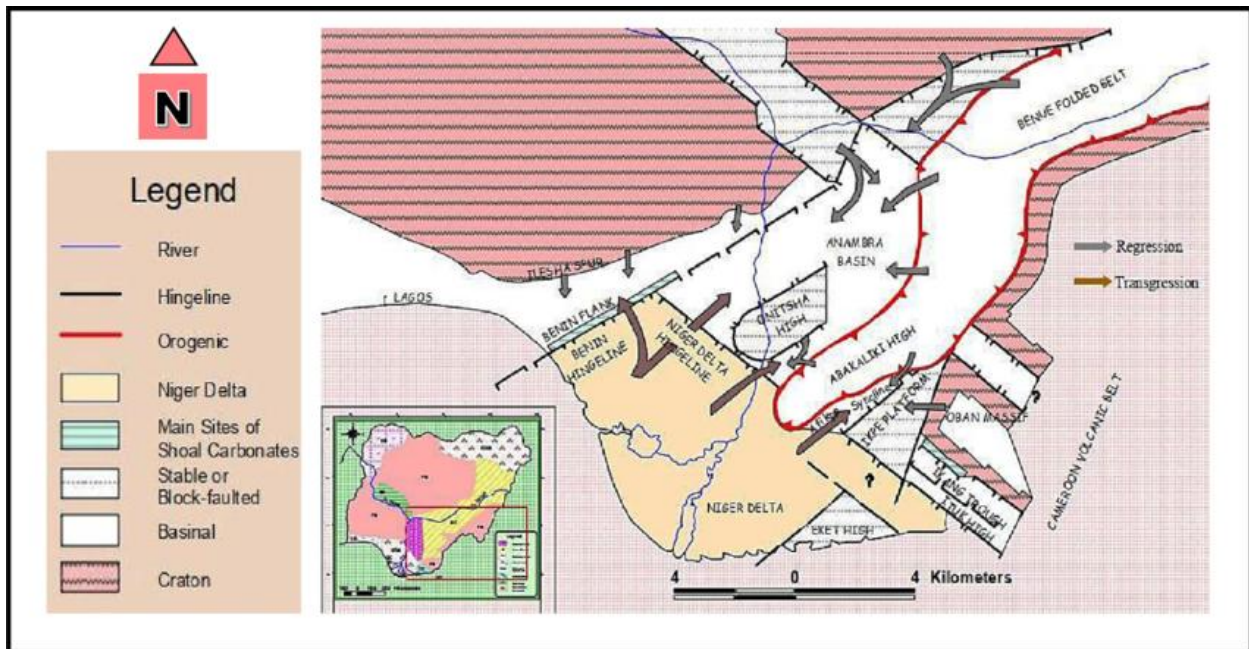


Figure 2.3: Tectonic map showing the Niger Delta (modified after Kogbe, 1989)

According to Weber and Daukoru (1975) and Evamy et al. (1978), the stratigraphic sequence of the Niger Delta consists of an association of Tertiary clastics that are upward-coarsening and regressive and up to 12 km thick. According to Dust and Omatsola (1990), it is roughly divided into three lithofacies: coastal claystones and shales at the base, an alternation of sandstones, siltstones, and claystones that rises in sand content above, and alluvial sands at the top. In the subsurface of the Niger Delta, three lithostratigraphic units have been identified (Short and Stauble, 1967; Frankl and Cordy, 1967; Avbovbo 1978). These are the Akata, Agbada, and Benin Formations, which are all strongly diachronous and arranged from oldest to youngest (Fig. 2.4).

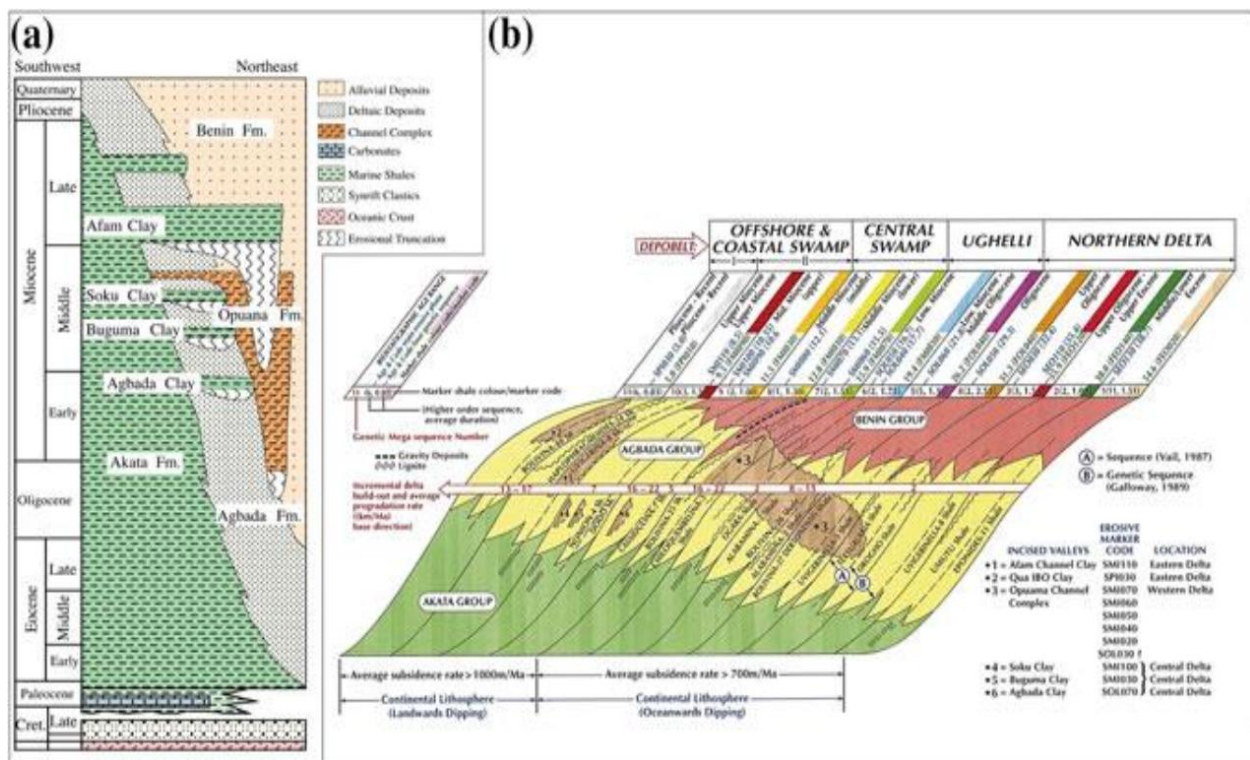


Figure 2.4: (a) Lithostratigraphic units of the Niger Delta (Doust and Omatsola, 1990). (b) Diagrammatic representation of the stratigraphic evolution of the Niger Delta (Reijers, 2011)

2.3 STRATIGRAPHY OF THE NIGER DELTA BASIN

2.3.1 Akata Formation (Marine Shales)

The oldest lithostratigraphic unit in the Niger Delta is the Akata Formation (Eocene-Recent). It is a marine sedimentary succession with a thickness range of 1,968 to 19,680 feet that is positioned in front of the expanding delta. The lenses of sandstone have an abnormally high pressure and are primarily homogenous under-compacted shales, clays, and silts near the base of the recognised delta sequence (Avbovbo, 1978). These sand streaks may be of turbidite origin and were formed in holomarine habitats (delta-front to deeper marine). The shales were deposited in shallow to deep marine environments and are abundant in both planktonic and benthonic foraminifera (Short and Stauble, 1967). The succession in each depobelt ranges from the Paleocene to Holocene in age. They can be found onshore in the northeastern section of the delta, where they are known as the Imo Shale, and offshore as diapirs along the continental slope.

2.3.2 Agbada Formation (Paralic Clastics)

Over 3000 metres of paralic interbedded sandstone and shale make up the Agbada Formation (Eocene-Recent), according to Reijers (1996). The sequence's truly deltaic material, the paralic clastics, were deposited in a variety of fluvio-deltaic, delta-front, and delta-topset settings. The first instance of marine fauna-rich shale that occurs along with the base of the continental-transitional lithofacies is considered to mark the top of the Agbada Formation. The top of the Akata Formation and a sizable sandstone body make up the base (Short and Stauble, 1967). Some Agbada Formation shales were considered to be the source rocks, but (Ejedawe et al., 1981) determined that the main Niger Delta source rocks are Akata Formation shales. The Agbada Formation is part of the Niger Delta's hydrocarbon-prospective sequence. The paralic sequence is present in all depobelts, as it is in marine shales, and ranges in age from Eocene to Pleistocene. The majority of Niger Delta exploratory wells have bottomed in this lithofacies.

Table 2.1: Correlation of Subsurface and Surface Formations of the Niger Delta Complex. After (Short and Stauble, 1967)

SUBSURFACE			SURFACE OUTCROPS		
Youngest known age		Oldest Known age	Youngest Known age		Oldest Known age
RECENT	Benin Formation	Oligocene	Plio-Pleistocene	Benin Formation	Miocene?
	Afam/ Qua Iboe member				
	Aghada Formation	Eocene	Miocene	Ogwashi - Asaba Formation	Oligocene
			Eocene	Ameki Formation	Eocene
	Akata Formation	Eocene	Late Eocene	Imo Shale Formation	Paleocene
Equivalent not known			Paleocene	Nsuka Formation	Maestrichtian
			Maestrichtian	Ajali Formation	
			Campanian	Mamu Formation	Campanian
			Campanian/Maestrichtian	Nkporo Shale	Santonian
			Coniacian/Santonian	Awgu Shale	Turonian
			Turonian	Eze-Aku Shale	
			Mid-Cenomanian	Keanu Formation	Cenomanian
			Albian	Asu River Group	Albian

2.3.3 Benin Formation (Continental Sands)

The Niger Delta's youngest lithostratigraphic unit is the Benin Formation. It is Miocene-Recent in age, with a minimum thickness of more than 6000 feet, and is primarily composed of continental sandstones and sands (>90%) with a small amount of intercalated shale. Nearly majority of the sequence's shallowest section is made up of non-marine sand. The sands and sandstones are very poorly sorted, coarse-grained, and sub-angular to well-rounded. It was deposited in alluvial or upper coastal plain habitats after deltaic deposition shifted into a new depobelt to the south. Although they don't have the necessary fauna to be accurately dated, the oldest continental sands are likely Oligocene. They get thinner and vanish approaching the edge of the shelf offshore.

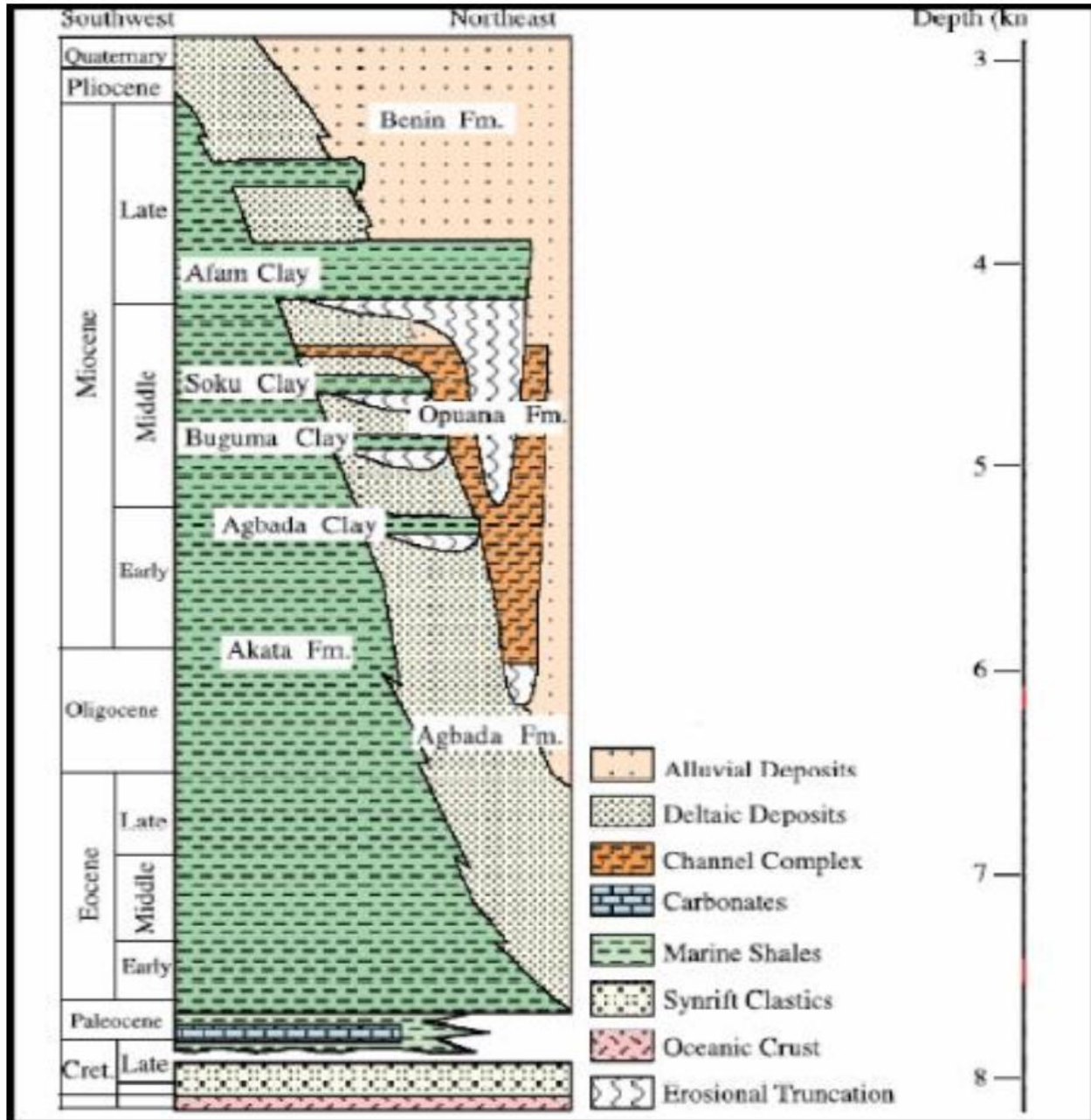


Figure 2.5: Stratigraphic column showing the three formations of the Niger Delta. Modified from (Shannon and Naylor, 1989; and Doust and Omatsola, 1990).

2.4 DEPOBELTS OF THE NIGER DELTA

The Northern Delta, Greater Ughelli, Central Swamp, Coastal Swamp, and Offshore Depobelts are some of these depobelts. Large-scale regional and counter-regional growth faults encircle each of these depobelts (Evamy et al., 1978; Doust and Omatsola, 1990). Step-by-step alluvial progression, aided by extensive shale removal and forward movement, has allowed the activity in each belt to advance in both space and time towards the south-southwest. When additional crustal sinking of the basin could no longer be supported, the focus of sediment deposition shifted seaward, establishing a new depobelt (Doust and Omatsola, 1990). This was the outcome of the interaction between subsidence and supply rates

Each of the five off-lapping siliciclastic sedimentation cycles that make up the Niger Delta resulted in the deposition of one of the three formations that make up the region. According to Doust and Omatsola 1990; Stacher, 1995, these cycles (depobelts), which prograde southwestward 250 km over oceanic crust into the Gulf of Guinea, are 30–60 km wide and are characterised by syn-sedimentary faulting. Depobelts age from Eocene in the north to Pliocene offshore of the current shoreline, getting younger and younger basin-ward. These depobelts are a distinct unit that corresponds to a discontinuity in the regional dip of the delta and is bound seaward by either the growth fault of the subsequent seaward belt or major counter-regional faults on the landward side. A unique shallowing-upward depositional cycle and tripartite assemblage of marine, paralic, and continental deposits are present in each depobelt. A number of punctuations in the progression of this deltaic system are defined by depobelts. The underlying delta front and pro-delta marine shale start to shift upward and basin-ward as the loads of deltaic material rise.

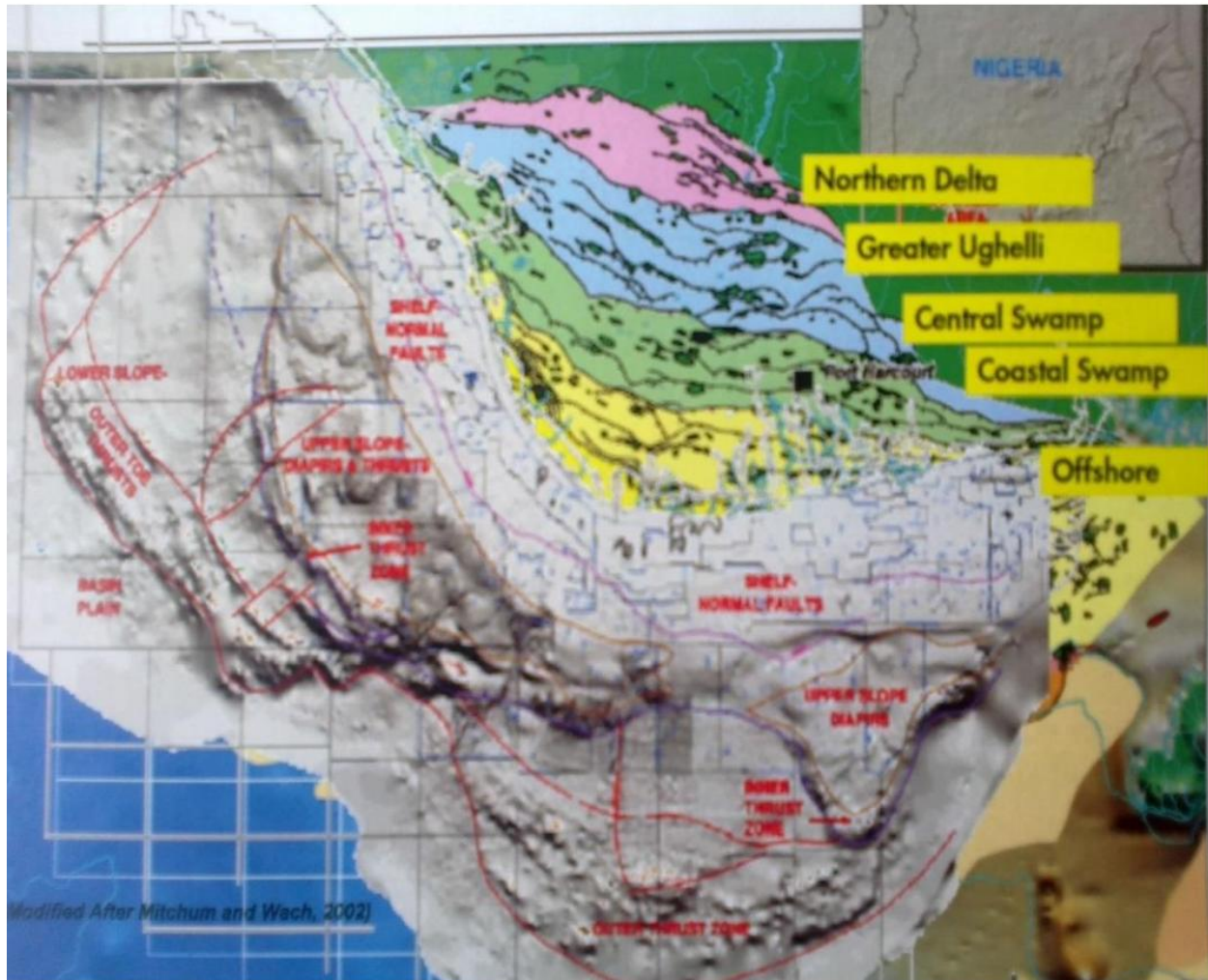


Figure 2.6: Niger Delta Depobelts (Modified after Weber and Daukoru, 1975)

Basal shale mobilisation led to structural collapse along normal faults and provided space for increased buildup of deltaic sediment. Subsidence significantly slows as shale withdrawal approaches completion, leaving little possibility for more sedimentation. A new depocenter forms basin-ward as decreased accommodation drives sediment to prograde basin-ward. The earliest growth faults, which are typically rotating, regularly spaced, and get steeper seaward, are found in the Northern Delta Province, which sits on top of a very shallow basement. The depobelts in the Central Delta Province have distinct characteristics including progressively deeper rollover crests that move towards the sea for any particular growth fault. Due to internal gravity tectonics on the contemporary continental slope, the distal delta province is the most structurally complicated. The

coastal swamp depobelt is where the study area is located. In terms of stratigraphy, building of structures, and dispersion of hydrocarbons, it is classified as shelf contained entities.

2.5 STRUCTURAL GEOLOGY OF THE NIGER DELTA

One of the Niger Delta's most noticeable geologic formations is the growth fault. Syn-sedimentary faults and folds that trend East-West are distinctive to the Niger Delta oil area. The energy that gave rise to them most likely came from within the sediments rather than from orogenic factors outside of them. In actuality, it is thought that they are gravity faults that formed concurrently with fast sedimentation and were brought about by differential loading of the subsurface, mobile (both laterally and vertically under-compacted) Akata Shales. The downthrown block has thicker sediments deposited than the upthrown block as a result of sedimentation and gravity faulting. The rollover anticline structure is where the majority of the oil that has accumulated in the Niger Delta is located. These structures' trapped oil and gas could be in dip closures or up against a synthetic or antithetic fault. Folding and faulting in syn-sedimentary rocks cause the delta sequence to deform. Growth faults and rollover anticlines were cited by Evamy et al. (1978) as the Niger Delta's primary structural characteristics.

2.5.1 Growth Faults

Rapid sedimentation at the Niger Delta's edge, on top of uncompacted clay, causes growth faults to occur. They are distinguished by the presence of thicker sediments on the downthrown block in comparison to the upthrown block. Growth faults are commonly referred to as contemporaneous faults (Weber and Daukoru, 1975; Evamy et al., 1978; Doust and Omatsola, 1990), and they are significant in interpretation because they act as a major pathway for hydrocarbon migration from marine shale of the Akata formation to the reservoir sand of the Agbada Formation of the delta. Numerous syn-sedimentary gravitational faults have formed as a result of the rapid sand deposition along the delta's border on top of poorly compacted clay. These so-called "growth faults" are also well

known throughout the Gulf Coast of the United States. With an increase in depositional slope or an increase in the rate of deposition above the rate of subsidence, the distance between succeeding growth faults gets smaller. Local depocentres frequently become engulfed by growth faults at the time of their formation. Thus, their trend reveals the dominant sedimentological pattern. The term "growth fault" refers to faults that, after their development, continue to be active, allowing the downthrown block to sediment more quickly than the upthrown block. Growth faults were divided into two categories by Evamy et al. (1978): structure-building faults and crestal flank faults. The growing faults' combined impacts result in a significant rollover of the northern flank. As a result, the gravitational instability causes the shale bulge to shift upward and the upper surfaces of the Akata formation to exhibit noticeable curvature. Antithetic flaws then developed as a result of this.

2.5.2 Rollover Anticline

The rollover anticline is created when the dip section reverses, for example, when a block rotates after sliding along a curved fault plane typically connected to gravity faulting and sediment deposition. These are dip direction reversals caused by rotation of a curve (listric) fault plane, which is typically linked to gravity faulting concurrent with deposition.

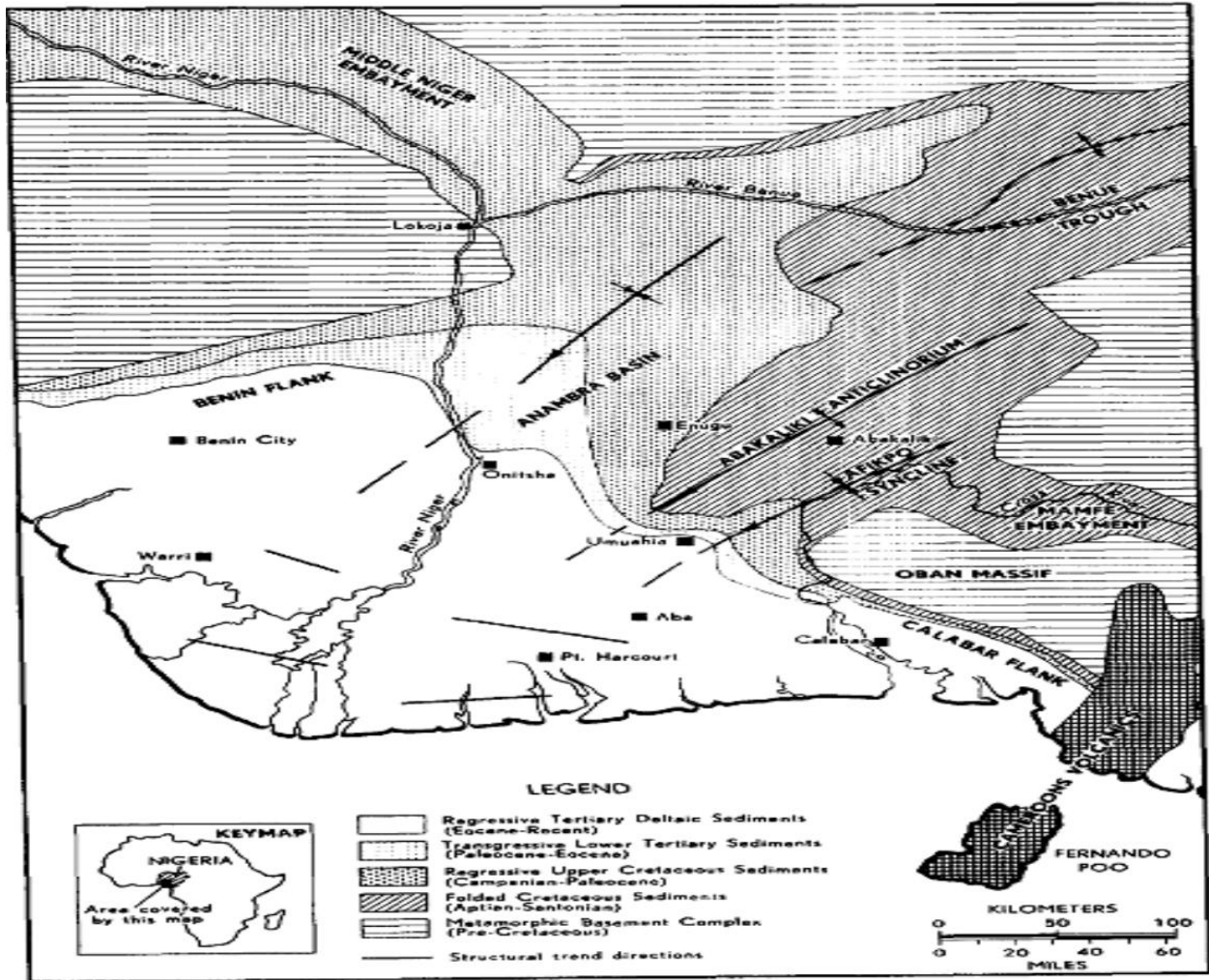


Figure 2.7: Structural units of the Niger Delta Basin (Short and Stauble, 1967).

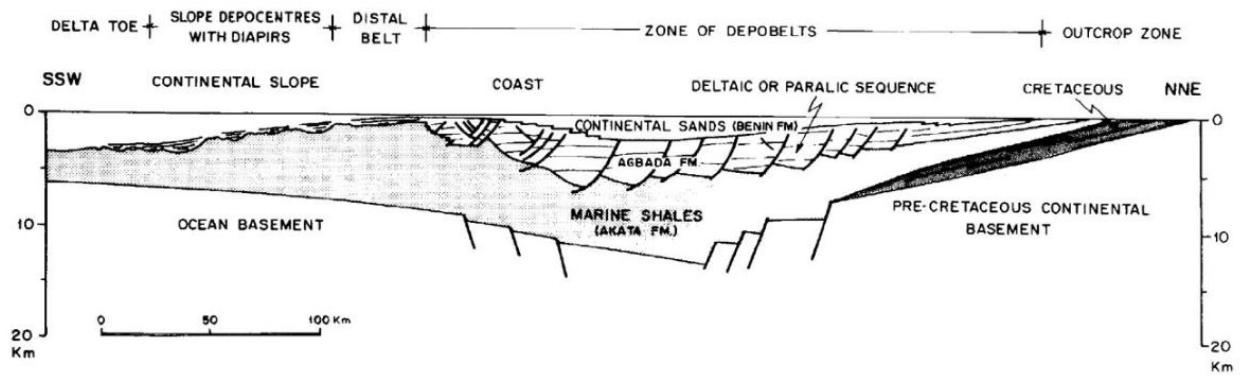
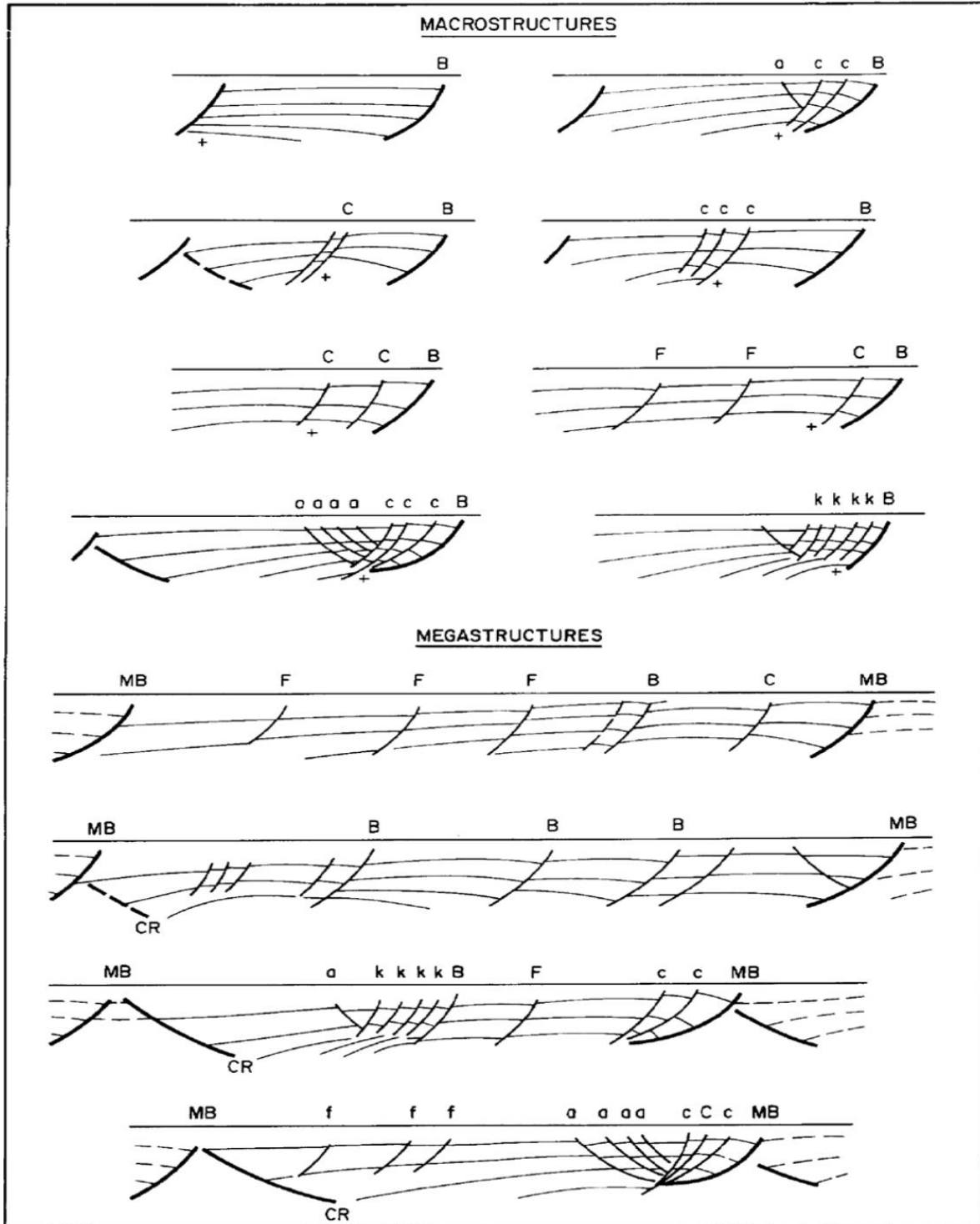


Figure 2.8: Schematic dip section of the Niger Delta Basin (Doust and Omatsola, 1990)



Fig

ure: 2.9: Macrostructures and Megastructures showing A: antithetic fault, B: structure building or boundary faults, MB; if major C: Crestal fault; CR: Counter-regional faults; F: Flank faults and K: k-type faults (Evamy et.,al 1978)

2.6 TRAPS AND SEALS

Structure-based traps are the most prevalent type in the Niger Delta Basin (Figure 2.10). Although they exist, stratigraphic traps are less frequent than structural traps. The Agbada parallel sequence underwent syn-sedimentary deformation, which resulted in the structural traps (Evamy et al., 1978; Stacher, 1995). In response to the increasing instability of the under compacted over-pressured shale, the structural complexity increases from the north (earlier formed depobelts) to the south (later produced depobelts).

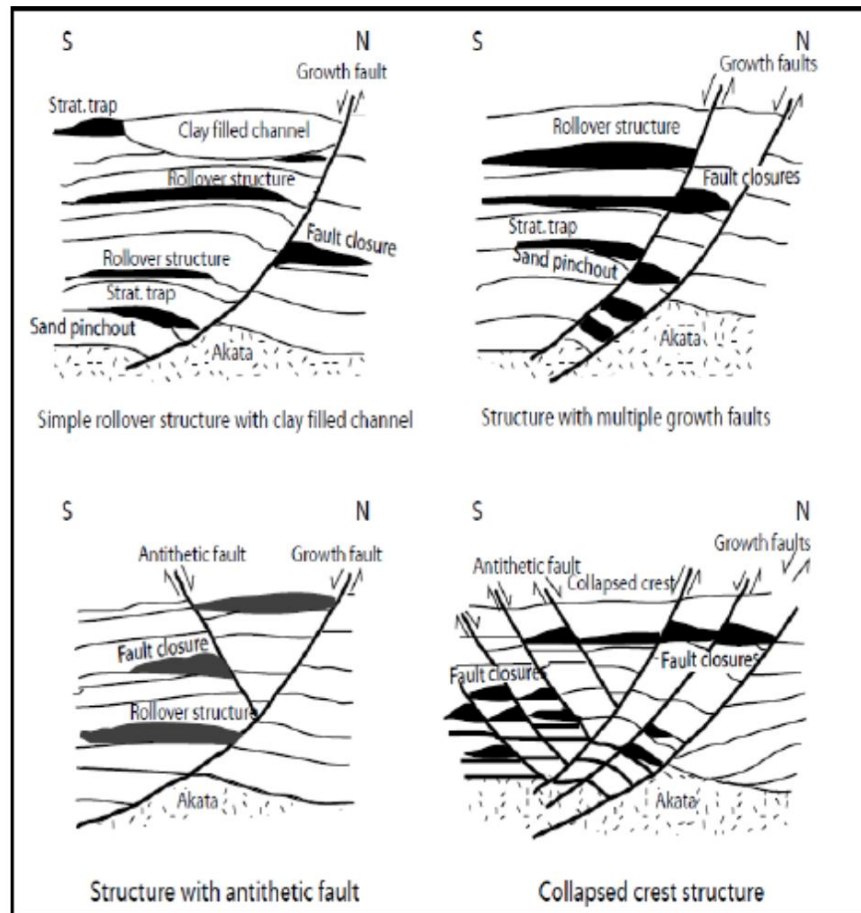


Figure 2.10: Niger Delta oil field structures and associated trap types (Modified from Doust and Omatsola, 1990 and Stacher, 1995).

Several structural trapping elements were described by Doust and Omatsola (1990), including those connected to straightforward rollover structures, clay-filled channels, structures with several growth faults, structures with antithetic faults, and collapsed crest structures. Shale that is interbedded within the Agbada Formation is the main type of seal rock in the Niger Delta. Three different types of seals can be found in the shale: vertical seals, interbedded sealing units that reservoir sands are juxtaposed against as a result of faulting, and clay smears along faults (Doust and Omatsola, 1990). Major erosional events in the early to middle Miocene created clay-filled canyons on the delta's flanks. According to Doust and Omatsola (1990), these clays serve as the top seals for certain significant offshore fields

2.6.1 Structural traps

In the Niger Delta Basin, these are the most typical traps. They were produced by the syn-sedimentary structural deformation of Niger Delta deposits. However, due to a change in shape, size, and amplitude in depth as well as a movement in their lateral position as they pass from the surface to depth, folding is not a trustworthy guide when looking for hydrocarbon pools.

Unconformities that are buried often mask folding and faulting that occurs below the surface. Because oil and gas escape up dip around the end of the fault, pools trapped by typical faulting are virtually always on the upper side of the fault. Rarely, if ever, do those that formed on the lower side surface.

2.6.2 Stratigraphic traps

These are traps that have developed as a result of the reservoir rocks' lithology's lateral and vertical variation or a break in their continuity. It is because of the makeup of the reservoir rock's composition and the circumstances surrounding its deposition. It might develop when a porous reservoir rock transforms into a less porous or impermeable rock. If a reservoir rock is terminated by an unconformity, the original deposition of the strata-like channel sandstone, or a lift bar, resulting in lithologic and stratigraphic variation of

the reservoir rock, stratigraphic traps may also arise. Local variations in the porosity or termination of the reservoir rock are brought on by these changes. Because there is not enough acoustic impedance differential between the trap's constituent pieces, stratigraphic traps are not as obvious on seismic sections as structural traps.

2.6.3 Combined structural and stratigraphic traps

These are occasionally referred to as the third category of traps. These traps are created by stratigraphic and structural trap-forming processes. They display both stratigraphic and structural characteristics. A faulted diapiric stratigraphic trap, a salt dome covering other domes and faults compaction anticlines, and a salt dome-cap rock in a reservoir are a few examples. They are best trap systems and typically sophisticated.

2.7 RESERVOIR AND SOURCE ROCKS

There has been discussion about the stratigraphic position of hydrocarbon source rocks in the Niger Delta Basin for many years. According to Weber and Daukoru (1975), the Niger Delta Basin's Akata Formation is the only source rock. Given that its upper part is the primary mature source rock available, particularly in the western half of the Delta, this has been favoured for a very long time. However, Lambert-Aikhionbare et al. (1990) and Short and Stauble (1967) supported the Agbada Formation as the only source rock. They disagree with the idea that the Akata Formation serves as a source rock since it is challenging for oil to escape from vast, overly compressed shales. The Akata and Agbada Shales were both regarded by Ejedawe and Okoh (1981) as the source rocks, with the former being the primary donor. The Akata and Agbada Formations were suggested as the source rock by Evamy et al. (1978) and Ekweozor and Okoye (1980). Given that the compositional findings of source rock and extract analyses indicate that deposition occurred in coastal and swampy environments, Doust and Omatsola (1990) proposed that environmental control is actually a significant indicator of the spread of source rock. Forest swamps, fresh water swamps, and mangrove swamps are three ecosystems thought to have potentially rich source rock deposits. The Agbada Formation comprises the

majority of the Niger Delta's reservoir rocks, according to Nwachukwu and Chukwura (1986), Knox and Omatsola (1989), Shannon and Naylor (1989), and Reijers (1996). The alternation of fine and coarse clastics also provides a number of reservoir seal couplets.

2.8 PREVIOUS WORK IN THE NIGER DELTA

The top works in the Cenozoic Niger Delta are those of Short and Stauble (1967) and Frankl and Cordry (1967). In the Niger Delta Basin, they were trailblazing workers who revealed information on deposits and the subsurface spreading of stratigraphy. Short and Stauble (1967) examined the Niger Delta's geological structure and recommended that the main source rocks be Agbada Formation shales. In accordance with Burke (1972) and Whiteman (1982), the aulacogen that advanced during the collapse of the South American and African plates in the Late Jurassic helped construct the Niger Delta Basin clastic section. The Tertiary Niger Delta (Akata-Agbada) Petroleum System is the sole recognised petroleum system in the Niger Delta Province, according to Kulke (1995) and Ekweozor and Daukoru (1994). The boundaries of the province align with the petroleum system's maximum extent.

2.8.1 Palynology

Palynomorphs have been used extensively in research in the Niger Delta Basin. *Peregrinipollis nigericus*, which is now commonly used as an Early Oligocene marker in the Niger delta Basin, was first identified by Clarke (1966) as a novel sporomorph in the Upper Tertiary of southern Nigeria. Germeraad et al. (1968) conducted the most thorough palynological examination to date on certain Tertiary sediment from tropical South America, Asia, and West Africa. A rigorous palynological zonation for the Niger Delta was conducted by Evamy et al. (1978) using the alpha numeric nomenclature P200, P300, P400, P500, P600, P700, P800 and P900. In order to identify maximum flooding surfaces (MFSs) and sequence boundary(BS), Durugho (2013) looked at the potentials of dinoflagellate cyst abundance and variety in two wells in the Niger Delta. Their findings identified seven maximum flooding surfaces and six sequence boudaries. *Praedapollis*

africanus, *Praedapollis flexibilis*, and *Verrutricolporites rotundiporis* were identified as supplementary taxa for the zonation of various portions of the Neogene Niger Delta by Legoux (1978). Biffi and Grignani (1983) studied Oligocene sediments from fifteen boreholes of underlying Tertiary deposits in the Niger Delta Basin. The end outcome was a heterogeneous assemblage of dinoflagellate cysts characterised by many *Peridinioids*, primarily *Lejeunecysta*, *Pheiodinium*, and *Selenopemphix* species. *Lejeunecysta brassiensis*, *Lejeunecysta communis*, *Lejeunecysta pulchra*, *Lejeunecysta beninensis*, *Lejeunecysta globosa*, *Lejeunecysta lata*, and *Lejeunecysta granosa* were described as new species. There are two new *Pheiodinium* species (*Pheiodinium nigericum* and *Pheiodinium africanum*) and one *Selenopemphix* species (*Selenopemphix warriensis*). Oloto (2014) based on the results of the dinoflagellate cysts found from the well, gave an Upper Miocene to Pleistocene age to the Igbomotoru - 1 Well, Central Swamp, Niger Delta Basin. Soronnandi-Ononiwu et al. (2014) investigated the palynology and paleoenvironment of the Akukwa-1 borehole in the Anambra Basin. They identified four dinoflagellate cyst zones and dated the sediments as Late Campanian-Late Maastrichtian. They also stated that the sediments from the Akukwa-1 borehole were deposited in a terrestrial environment. Osokpor et al. (2015) investigated the palynozonation and lithofacies cycles of Paleogene to Neogene Age Sediments in the Northern Niger Delta Basin's PML-1 Well. They classified the well into four zones (*Ephedra claricristata* Range zone, *Auriculopollenites echinatus* Range zone, *Verrutricolporites laevigatus/Verrutricolporites scabratus* Range zone, and *Verrutricolporites rotundiporus* Abundance zone) and concluded that the lithofacies distribution indicates cyclic sedimentation caused by a combination of sea level and climatic regime

2.8.2 Paleoecology

Several writers have demonstrated the use of palynofloral to establish the paleoecology of sediments, including (Sowunmi, 1981; Poumot, 1989; Samant and Phadtare, 1997; Bankole, 2010; and Dupont and Agwu, 1991). In his research in the Neogene Agbada

Formation of the Niger Delta, Bankole (2010) found five major palynomorphs ecological assemblages.

2.8.3 Palaeoenvironment

By working on three wells (Benin West-1, ANL-1, and E-12), Odedede and Lucas (2014) established the palaeoenvironment for the three wells. Using sedimentary facies, chemostratigraphy, and palynoflora, they claimed that sediments penetrated by the wells were deposited in a distributory channel, marine shelf, and marine environment. For the Olure-1 well, Boboye et al. (2017) reported an inner neritic to coastal deltaic palaeoenvironment, while for the Abigboro-1 well, they broadly grouped the intervals as inner to middle neritic. Based on the presence of naturally confined benthonic foraminiferal species, Chukwu et al. (2012) concluded that the habitats of deposition for the sediments of Oloibiri-1 were from the littoral to the marine. Based on the foraminiferal morphogroup triangle cross-plot of *Textulariina*, *Miliolina*, and *Rotalina* and the biometric study of foraminiferal's abundance and diversity, Obaje and Okosun (2013) revealed shelf palaeoenvironment of deposition. A shallow marine palaeoenvironment was also indicated by the planktic to benthic foraminiferal (P/B ratio) and average percentage ratios of calcareous benthic to arenaceous benthic foraminiferal in the five wells (Tomboy-1, Tomboy-2, Tomboy-4, Tomboy-5, and Tomboy-6). Based on the foraminiferal bathymetric range provided by Harris (1981), Petters (1995) proposed foraminiferal bathymetric zonation for the Niger Delta. In particular, if ditch cuttings were utilised, he recommended that the bathymetric chart be employed for quick, non-statistical, routine assessment of marine benthic ecosystems in the Niger Delta oil well samples. For four wells (Akata 2, 4, 6 and 7 Wells) from the Eastern Niger Delta, Okosun et al. (2012) estimated a littoral (deltaic) to marine (outer neritic) context of deposition based mostly on the presence of naturally limited benthonic foraminiferal species. Ajayi and Agboneni (2016) used the benthic agglutinated foraminiferal in the deep water of the Niger Delta Basin to designate upper to lower bathyal habitats of four wells (A, B, C, and D wells).

2.8.4 Paleoclimate

Using palynomorphs, Akaegbobi et al. (2016) looked at climate changes in Nigeria and several regions around the world. Indicators of sea level, climate, and system tracts in the Niger Delta Basin were first used by Poumot (1989). According to Sowunmi (1987), a region's vegetation, soil, and climate are closely related. She believed that an area's flora provides a clue as to the main climate regimes in such regions.

2.8.5 Micropaleontology (Foraminifera)

The Niger Delta Basin has been the subject of numerous foraminiferal biostratigraphic studies. Based on the foraminifera morpho group triangular cross-plot of the ratios between *Textularina*, *Miliolina*, and *Rotalinna*, the ratio of planktic to benthic foraminifera (P/B ratio), and the presence of paleodepths indicator fossils, Obaje and Okosun (2013) interpreted the Tomboy Field Offshore Western Niger Delta as shelf (inner to outer neritic) environment of deposition. The five wells' lithofacies, fossil accoutrements, and the ratios of calcareous to arenaceous benthic foraminifera (FOBC/FOBA) suggested a shallow marine paleoenvironment. Four wells offshore the Niger Delta Basin were the subject of planktonic foraminiferal biostratigraphic research by Ajayi and Okosun (2014). Three foraminifera zones and 42 foraminifera species were found. The sedimentary sequence was given a Late Miocene to Early Pliocene age. Deep water sediments accumulated in upper to lower bathyal environments make up the wells' analysed section. The foraminiferal biostratigraphy and palaeoenvironment of Well 5, OML 34, Niger Delta, Nigeria, were studied by Nwaejije et al. (2017). *Catapsydrax dissimilis*, *Praeorbulina glomerosa*, and *Orbulina universa*, which stand for partial-range zone, interval zone, and taxon-range zone, respectively, were recognised as three planktonic foraminiferal zones. These zones correspond to the N6-N7, N8-N9, and N9 zones from Blow (1969) and the M4, M4-M5, and M5 zones from Berggren et al. (1995).

The age of the penetrated well is Miocene based on the marker species retrieved from the well. Ifeoluwadun and Saka (2018) established two informal planktonic foraminiferal zones (*Globoquadrina dehiscens* and *Globigerinoides ruber*) and four informal benthonic foraminiferal zones (*Cyclamina cancellata*, *Lenticulina inornata*, *Marginulina costata*/*Quinqueloculina microcostata* and *Heterolepa Pseudogeriana*) from foraminiferal biostratigraphy of Opolo-5 Well, Western Niger Delta, Nigeria. The well's age ranges from the Late Miocene to the Early Pliocene. In the Akata field in the Eastern Niger Delta Basin, Okosun et al. (2012) established three planktonic and benthonic foraminiferal zones from two wells (Akata-2 and Akata-4 wells) and another one in the remaining two wells (Akata-6 and Akata-7). For the Middle to Late Miocene, Ozumba and Amajor (1999) proposed six foraminiferal zones (assemblages) for four wells located in the coastal and central wetland in the western Niger Delta Basin. For the examined interval of the AM-2 well, Niger Delta Basin, Fadiya et al. (2014) proposed four informal benthonic and younger planktic foraminiferal assemblage zones. In their 2012 study, Chukwu et al. examined ditch cutting samples from the Oloibiri-1 well in the Western Niger Delta. To determine the environment of deposition and age of the sediments collected from the well, they used foraminifera. The sediments were given a Miocene age and a middle-to-inner neritic depositional environment.

2.8.6 Sequence stratigraphy

Numerous writers have effectively used foraminiferal abundance and diversity to characterise sequence stratigraphy in the Niger Delta Basin. In Biwa Field, Greater Ughelli Depobelt, Niger Delta Basin, Okengwu and Amajor (2015) identified three sequences from the base to the top using wireline log and high resolution biostratigraphic methods. The sites of the maximum flooding surfaces (MFS) and the geologic ages of the sequence boundaries (SB) range from sequence I (F7800, P630) - 23.7 Ma to sequence II (F7600, P580) - 29.3 Ma to sequence III (F7600, P560) - 32.4 Ma. The MFS ranged from 23.3 Ma to 31.3 Ma. Samuel et al. (2012) performed a sequence stratigraphic analysis of the depositional systems in the field using well logs and biostratigraphic data from six

wells in the "XB Field," Central Swamp Depobelt, Niger Delta. The accompanying systems tracts and four (4) depositional sequences (SEQ1, SEQ2, SEQ3, and SEQ4) were interpreted and mapped in the "XB Field". Using biostratigraphic data, Armentrout et al. (1999) conducted a high-resolution sequence stratigraphic investigation of the Oso Field, Niger Delta Basin. Three sequence stratigraphic models were developed by them: the first was based on the integration of sedimentology and biostratigraphic data; the second was based on core sedimentology; and the third was based on well-log data and predicted regional seismic reflection profiles. The base of the Oso Field producing interval was viewed as a lowstand prograding wedge by merging the three models, while the top interval was interpreted as a prograding distal transgressive or alternatively distant highstand systems tract. Olure-1 Well, Onshore, Niger Delta Basin sequence stratigraphic characterisation was carried out by Boboye et al. (2017) integrating wireline log and biostratigraphic data. For the Olure-1 well, they established two maximum flooding surfaces and one sequence boundary. Two sequence boundaries, one maximum flooding surface, six systems tracts, and upper Miocene sediments from the ANL-1 well offshore in the Niger Delta Basin were discovered by Odedede and Lucas (2014). The examination Ojo and Gbadamosi (2013) conducted in the Del-2 well southwest of the Niger Delta Basin resulted in the identification of one sequence boundary and three systems tracts. A sequence stratigraphic and structural study of the Southern Coastal Swamp in the Niger Delta, Nigeria, was conducted by Chima et al. in 2017. Three MFSs and SBs were used to limit two third order genetic sequences that were found. Alege (2017) studied the sequence stratigraphy in the Akos Field of the Coastal Swamp Depobelt of the Niger Delta. These wells are numbered 007, 009, and 013. He discovered four significant SBs and MFSs, which are represented by the markers Dodo shale, Nonion-4, and Uvigerina-8. Four system tracts, including the LST, TST, HST, and FSST, as well as three depositional sequences, three primary parasequence stacking patterns (progradational, retrogradational, and aggradational), were identified. Three third order maximum flooding surfaces were created by Okosun et al. (2012) in the Akata-2 well and Akata-4 well, while two third order maximum flooding surfaces were recognised in the

Akata-6 well and Akata-7 well. Based on the foraminiferal biostratigraphy and sequence stratigraphic study done in the Akata Field, the wells were categorised into sequences and systems tracts. In two wells in the Niger Delta, Durugbo et al. (2013) explored the potentials of dinoflagellate cyst abundance and diversity to mark maximum flooding surfaces (MFS) and sequence boundaries. Seven maximum flooding surfaces and six sequence boundaries were found after an analysis of their findings.

2.8.7 Chemostratigraphy

One of the methodologies employed in this research is chemostratigraphy. In this work, chemostratigraphy is used to characterise and correlate strata by using major and trace element geochemistry. When used on sequences with weak biostratigraphic control, this technique, which entails the geochemical characterisation and subsequent correlation of strata using major and trace element geochemistry, has proven to be effective. Due to source composition, facies, paleoclimate, and diagenesis, the elemental content of sediments varies greatly. The geochemical characterisation and palynological analyses of a few Agbada Formation deposits in the Niger Delta Basin were conducted by Ratcliffe et al. in 2007 and Adebayo et al. in 2016. Th/Cr, Cr/Th, Th/Co, and Cr/Ni trace metal ratios indicate that the examined sediments were formed from felsic parent rocks. Th data and rare earth element patterns (such as La/Yb, Gd/Yb, La/Sm, and Eu/Eu) identified the source rocks' felsic composition. Inorganic geochemistry of Upper Miocene sediments recovered from the ANL-1 well, offshore Niger Delta Basin, was studied by Odedede et al. (2014). The outcome showed that the sediments were formed in a passive tectonic environment from granitic and metamorphic rocks. Claystone lithologies often offer spatially durable geochemical indicators, according to earlier research on fluvial systems that are clay-prone (Cullers, 1995; Pearce et al., 1999, 2005a). Based on geochemical study of the Ogwashi-Asaba Formation, Madukwe and Basse (2016) identified the Formation as being formed from continental sandstones derived from mafic igneous rock and passive tectonic setting. Adebayo et al. (2016) claimed that the measured sediments were derived from felsic source rocks based on the trace metal ratios (Th/Cr, Cr/Th,

Th/Co, and Cr/Ni). In a similar manner, ratios of U/Th, Ni/Co, Cu/Zn, and V/Sc show that the bottom water is well-oxygenated. According to authors like Nesbitt and Young (1989) and Nesbitt et al. (1996), the chemical makeup of rocks is greatly influenced by the makeup and weathering circumstances at the source rock location.

CHAPTER THREE

MATERIALS AND METHODS

3.1 AVAILABLE DATA

1. Ditch cutting samples

3.2. MATERIALS

1. A texture assessment chart that shows the sorting grade. Following (Jerram, 2001)
2. A chart of grain pictures to gauge how rounded sedimentary particles are Following (Powers, 1953)
3. Sample scale (Mettler PC 440 digital balance).
4. Reflected light microscopes were utilised to describe the sediment, including the Zeiss binocular 475022 model, the wild Heerbrugg M5 - 81796 model, and the B-Bran Binocular.
5. Brushes and trays
6. X-ray fluorescence (XRF) was used to investigate the major oxides and trace elements in the sediments.

3.3 METHODS

Utilising both sedimentological and inorganic geochemical methods, this investigation was completed. The following results were obtained using the technique: establishing the

source of the sediment, the tectonic setting, the class of sandstone, and the paleo-oxygenation condition of deposition.

3.3.1 Sedimentological Analysis

Using the method described in the Shell Petroleum Development Company's lithofacies description guide, the samples from the well were described in order to provide litholog and lithologic/lithofacies. The steps for preparing a sedimentological sample in detail are listed below.

3.3.1.1 Sedimentological Sample Preparation Procedures

1. Samples were organised in a logical sequence.
2. Samples were cleaned to get rid of addictive substances.
3. Hot plates set to 800C were used to dry wet samples.
4. To prevent contamination, samples were processed in groups of no more than 20 samples each, working from the deepest sample to the shallowest sample.
5. Sample description was carried out visually and using a binocular microscope with reflected light.

3.3.1.2 Description Guide for Shell Petroleum Development Company Lithofacies

1. Add water to the samples to highlight the features of the rock that are hidden in the dry samples.
2. Determine the lithology.
3. Colour

4. Texture, utilising a picture of a standard comparator following Jerram (2001) and Powers (1953), including grain size, grain shape, and sorting.
5. Fossils and auxiliary components (calcite, mica flakes, carbonaceous detritus, ferruginous debris, glauconite, and other shell pieces).
6. Sedimentary structures that couldn't be detected because of the sample method (ditch cutting) were employed.

3.4 Chemostratigraphy

The well was characterised chemostratigraphically using major and trace elements. X-Ray Fluorescence (XRF) spectrometry was used to conduct a chemical study for major oxides and trace elements. The procedure described above was used to determine the elemental composition of the crushed ditch cutting samples.

CHAPTER FOUR

RESULTS AND DISCUSSION

Sedimentological and inorganic geochemical data (major and trace elements) were studied. The interpretation of the inorganic geochemical results was used for tectonic setting, paleo- redox condition, provenance and sandstone classification.

4.1 LITHOLOGIC DESCRIPTION/LITHOFACIES STUDIES

Twenty (20) samples were processed for sedimentological study. The studied interval of X-well penetrated sedimentary succession from 1325 ft to 1625 ft. The main lithofacies identified in X-well were sands, shaly sands, sandy shales.

Table 4.1: Lithology of X-well

Depth intervals	Lithology	Color	Grain size	Grain shape	Sorting	Mineralogy
1325-1340	Sandy Shale	Dark Gray	Fine-Coarse	SubAngular - Angular	Poorly Sorted	Clay Mineral, Quartz
1340-1355	Sandy Shale	Dark Gray	Fine-Coarse	SubAngular - Angular	Poorly Sorted	Clay Mineral, Quartz
1355-1370	Sandy Shale	Dark Gray	Fine-Coarse	SubAngular - Angular	Poorly Sorted	Clay Mineral, Quartz
1370-1385	Sandy Shale	Dark Gray	Fine-Coarse	SubAngular - Angular	Poorly Sorted	Clay Mineral, Quartz
1385-1400	Sandy Shale	Dark Gray	Fine-Coarse	SubAngular	Poorly	Clay

				- Angular	Sorted	Mineral, Quartz
1400-1415	Sand	Light Gray	Fine-Coarse	Subrounded - SubAngular	Moderately Sorted	Quartz
1415-1430	Sand	Light Gray	Mid-Coarse	Subrounded - SubAngular	Moderately Sorted	Quartz
1430-1445	Shaly Sand	Dark Gray	Fine-Coarse	Subrounded - SubAngular	Poorly Sorted	Clay Mineral, Quartz
1445-1460	Sandy Shale	Dark Gray	Fine-Coarse	Subrounded - SubAngular	Poorly Sorted	Clay Mineral, Quartz
1460-1475	Sand	Light Gray	Med-Coarse	Subrounded - SubAngular	Moderately Sorted	Quartz
1475-1490	Sand	Light Gray	Med-Coarse	Subrounded - SubAngular	Moderately Sorted	Quartz
1490-1505	Sand	Light Gray	Med-Coarse	Subrounded - SubAngular	Moderately Sorted	Quartz
1505-1520	Sand	Light Gray	Med-Coarse	Subrounded - SubAngular	Moderately Sorted	Quartz
1520-1535	Sand	Light Gray	Med-Coarse	Subrounded - SubAngular	Well Sorted	Quartz
1535-1550	Sand	Light Gray	Med-Coarse	Subrounded - SubAngular	Well Sorted	Quartz
1550-1565	Sand	Light Gray	Med-Coarse	Subrounded - SubAngular	Well Sorted	Quartz
1565-1580	Sand	Light Gray	Med-Coarse	Subrounded - SubAngular	Well Sorted	Quartz

1580-1595	Sand	Light Gray	Med-Coarse	Subrounded - SubAngular	Well Sorted	Quartz
1595-1610	Sand	Light Gray	Med-Coarse	Subrounded - SubAngular	Well Sorted	Quartz
1610-1625	Sand	Light Gray	Med- Coarse	Subrounde d - SubAngula r	Well Sorted	Quartz

4.2 CHEMOSTRATIGRAPHY

Eight samples comprising of sands, shaly sand and sandy shale were selected for this study using the methods earlier discussed in chapter three. The results derived from the analysis were used for the geochemical characterization of the wells. These analytical method yielded results for eleven (11) major elements, reported as oxide percent by weight (SiO₂, Al₂O₃, Fe₂O₃, TiO₂, CaO, P₂O₅, K₂O, MgO, MnO, Na₂O, and LOI). Results for twelve (12) trace element (Ba, Cu, Cr, Ni, Zn, Co, Th, Pb, Sc, La, V, U) reported in ppm were also recorded.

4.2.1 Inorganic geochemical result

Table 4.2: Major Oxides of the Selected Sandstone and Shales from X-Well.

Sample Number	DEPTH INTERVAL (ft)	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	P ₂ O ₅	K ₂ O	MnO	MgO	Na ₂ O
1(SANDY SHALE)	1325-1340	77.10	9.50	7.10	1.50	0.60	0.30	1.85	0.06	0.75	0.70
2(SANDY SHALE)	1355-1370	87.50	2.85	3.00	0.18	0.16	0.04	0.29	0.03	0.14	0.70
3(SANDY SHALE)	1385-1400	76.50	8.95	5.90	1.30	0.55	0.30	1.85	0.05	0.70	0.75
4(SHALY SAND)	1430-1445	89.50	3.45	3.15	0.18	0.16	0.03	0.34	0.03	0.15	0.70
5(SANDY SHALE)	1445-1460	74.5	8.00	7.00	1.70	0.5	0.30	2.10	0.03	0.74	0.70
6(SAND)	1490-1505	86.60	3.98	2.65	0.34	0.77	0.24	0.88	0.04	0.32	0.20
7(SAND)	1550-1565	88.50	2.45	3.00	0.17	0.16	0.03	0.32	0.02	0.14	0.75
8(SAND)	1610-1625	89.50	3.45	3.50	0.19	0.20	0.05	0.42	0.03	0.17	0.95

Table 4.3: Trace Elements Result for X- well

Sample Number	Depth	Ba	Cu	Cr	Ni	Zn	Co	Th	Pb	Sc	La	V	U
1(SANDY SHALE)	1325-1340	788.50	13	70	40	75	15	17	37	15	75	205	3.5
2(SANDY SHALE)	1355-1370	592	22	40	33	29.7	3.8	4.70	25.7	3.6	13.4	30.1	0.91
3(SANDY SHALE)	1385-1400	1000	13	90	41	101	10	17	37	15	77	100	3.4
4(SHALY SAND)	1430-1445	650	29	40	16	54	3.9	3.1	27.3	2.1	12	50	0.8
5(SANDY SHALE)	1445-1460	1165	13	70	35	70	13	18	37	13	73	201	3
6(SAND)	1490-1505	592	22	40	33	29.7	3.8	4.70	25.7	3.6	13.4	30.1	0.91
7(SAND)	1550-1565	744.50	30.32	45.70	20.65	50.2	3.50	4	28.4	1.45	13	30.50	0.95

8(SAND)	1610-1625	800.5	35.32	50.70	30.65	60.2	4.50	6	30.4	1.49	15	35.5 0	0.97
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4.3 Trace Elements discussion

The geochemical behaviour of trace elements during sedimentary processes has frequently been used to identify paleoenvironmental conditions of deposition (Brumsack, 1989; Calvert and Pedersen, 1993; Warning and Brumsack, 2000; Algeo and Maynard, 2004). Rare earth element (REE) patterns that can be used to identify origin have greatly contributed to our understanding of crustal evolution thanks to trace element abundances in sedimentary rocks (Ganai and Rashid, 2015). Due to their extremely brief residence durations in freshwater or seawater and their distinctive behaviour during fractional crystallisation, weathering, and recycling, trace elements are typically thought to be a helpful diagnostic of the tectonic context (Taylor & McLennan, 1985). Vanadium (V) redox-sensitive element, preferentially abundant in sediments beneath anoxic or near-anoxic waters, according to Calvert and Pedersen (1993). Kimura and Watanabe (2001), and Kimura and Watanabe (2001) propose that the degree of enrichment is best expressed as the V/Sc ratio. Strontium (Sr) is rapidly lost during chemical weathering and the amount of this element lost is proportional to the degree of weathering (Wronkiewicz and Condie, 1987). Because of Barium (Ba) significant association with settling biogenic materials, Dymond et al. (1992) identified it as a proxy for biotic paleoproductivity in the oceans. Krejci-Graf (1972) gave data on the trace element composition of sediments from diverse depositional environments, stating that continental sediments that have been subjected to extended periods of subaerial weathering often contain the trace elements titanium and thorium.

Table 4.4: Major elements ratios X-well

SAMPLE NUMBER	DEPTH INTERVAL (ft)	K₂O/Na₂O	Log(SiO₂/Al₂O₃)	Log (K₂O/Na₂O)	Log (Fe₂O₃/K₂O)	Log (Na₂O / K₂O)
1(SANDY SHALE)	1325-1340	2.64	0.91	0.42	0.58	-0.42
2(SANDY SHALE)	1355-1370	0.41	1.49	-0.38	1.01	0.38
3(SANDY SHALE)	1385-1400	2.46	0.93	0.39	0.50	-0.39
4(SHALY SAND)	1430-1445	0.49	1.41	-0.31	0.97	0.31
5(SANDY SHALE)	1445-1460	3.00	0.97	0.48	0.52	-0.48
6(SAND)	1490-1505	4.4	1.34	0.64	0.48	-0.64
7(SAND)	1550-1565	0.43	1.56	-0.37	0.97	0.37

8(SAND)	1610-1625	0.44	1.41	-0.35	0.92	0.35
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Table 4.5: Ratio of Trace element of X-well

SAMPLE NUMBER	DEPTH INTERVAL (ft)	Ni/Co	V/Cr	U/Th	Th/CO	La/Sc	Th/Sc	Cr/Th
1(SANDY SHALE)	1325-1340	2.67	2.93	0.21	1.13	5	1.13	4.12
2(SANDY SHALE)	1355-1370	8.68	0.75	0.19	1.24	3.72	1.31	8.51
3(SANDY SHALE)	1385-1400	4.1	1.11	0.2	1.7	5.13	1.13	5.29
4(SHALY SAND)	1430-1445	4.10	1.25	0.26	0.79	5.71	1.48	12.90
5(SANDY SHALE)	1445-1460	2.69	2.87	0.17	1.38	5.62	1.38	3.89
6(SAND)	1490-1505	8.68	0.75	0.19	1.24	3.72	1.31	8.51

7(SAND)	1550-1565	5.9	0.67	0.24	1.14	8.97	2.76	11.43
8(SAND)	1610-1625	6.81	0.70	0.16	1.33	10.07	4.03	8.45

4.4 PALEO REDOX STUDIES

Redox-sensitive trace element concentrations or ratios are among the main extensively used indicators of redox conditions in modern and ancient sedimentary deposits (Calver and Pedersen, 1993; Jones and Manning, 1994; Crusius *et al.*, 1996; Dean *et al.*, 1997, 1999; Yarincik *et al.*, 2000; Morford *et al.*, 2001; Pailler *et al.*, 2002; Algeo and Maynard, 2004).

According to Jones and Manning, 1994 when the ratio of Ni/Co is below 5, it indicates oxic environments, whereas ratios from 5 - 7, suggest dyoxic environment and ratios greater than 7 infers suboxic to anoxic environments. The ratio of Ni/Co in X-well well ranges from 2.38-5.26 which indicate oxic environments of deposition. When the ratio of U/Th is below 0.75, it indicates oxic environment, whereas ratio of 0.75-1.25 indicate dysoxic, and ratio above 1.25 indicate suboxic to anoxic. The ratio of U/Th in X-well ranges from 0.19-0.28 which indicate oxic environment. When the ratio of V/Cr is less than 2, it indicates oxic environment, a ratio of 2 to 4.25 indicates dysoxic environment while a ratio above 4.25 indicate suboxic to anoxic environment. The ratio of V/Cr in X-well ranges from 0.53-2.68. This indicates oxic environment.

Table 4.6: Elemental ratios to evaluate the paleo-redox condition of sediments after Jones and Manning (1994)

ELEMENTAL RATIO	OXIC	DYSOXIC	SUBOXIC TO ANOXIC
Ni/Co	<5	5-7	>7
V/Cr	<2	2-4..25	>4.25
U/Th	<0.75	0.75-1.25	>1.25

Table 4.7: Ni/Co, V/Cr and U/Th ratios for X-well for the determination of Paleo- redox condition of deposition

X-WELL

SAMPLE NUMBER	DEPTH INTERVAL (ft)	Ni/Co	V/Cr	U/Th
Sample 1	1325-1340	2.67	2.93	0.21
Sample 2	1355-1370	8.68	0.75	0.19
Sample 3	1385-1400	4.1	1.11	0.2
Sample 4	1430-1445	4.10	1.25	0.26

Sample 5	1445-1460	2.69	2.87	0.17
Sample 6	1490-1505	8.68	0.75	0.19
Sample 7	1550-1565	5.9	0.67	0.24
Sample 8	1610-1625	6.81	0.70	0.16

4.5 PROVENANCE STUDIES

The conventional objective of provenance studies is to reconstruct and interpret the history of sediment supply, from initial erosion of a parent rock to the final burial of its detritus and so to eventually deduce the geographic location and characteristics of the source area. Important factors such as the location and nature of source area, hinterland drainage pattern and pathways through which sediment has been transferred from source to basin and factors that influence the composition of the sedimentary rocks (e.g. relief, climate, tectonic setting) generally evolve with time. This evolution may be recorded in the characteristics of the sediment that was deposited in the basin (Cox *et al.*, 1995; Davies and Pickering, 1999; Jarvis *et al.*, 1998; Nesbitt, 1990; Nesbitt and Young, 1982; Pearce and Jarvis, 1995; Vital, 1999)

As suggested by Cullers (2002), the plot of Th/Co versus La/Sc can be used to establish the provenance of sediments. To determine the provenance of X-well sediments, the Th/Co vs. La/Sc plot of Cullers (2002) was utilized which inferred that the sediment from X-wells were derived from felsic source rocks.

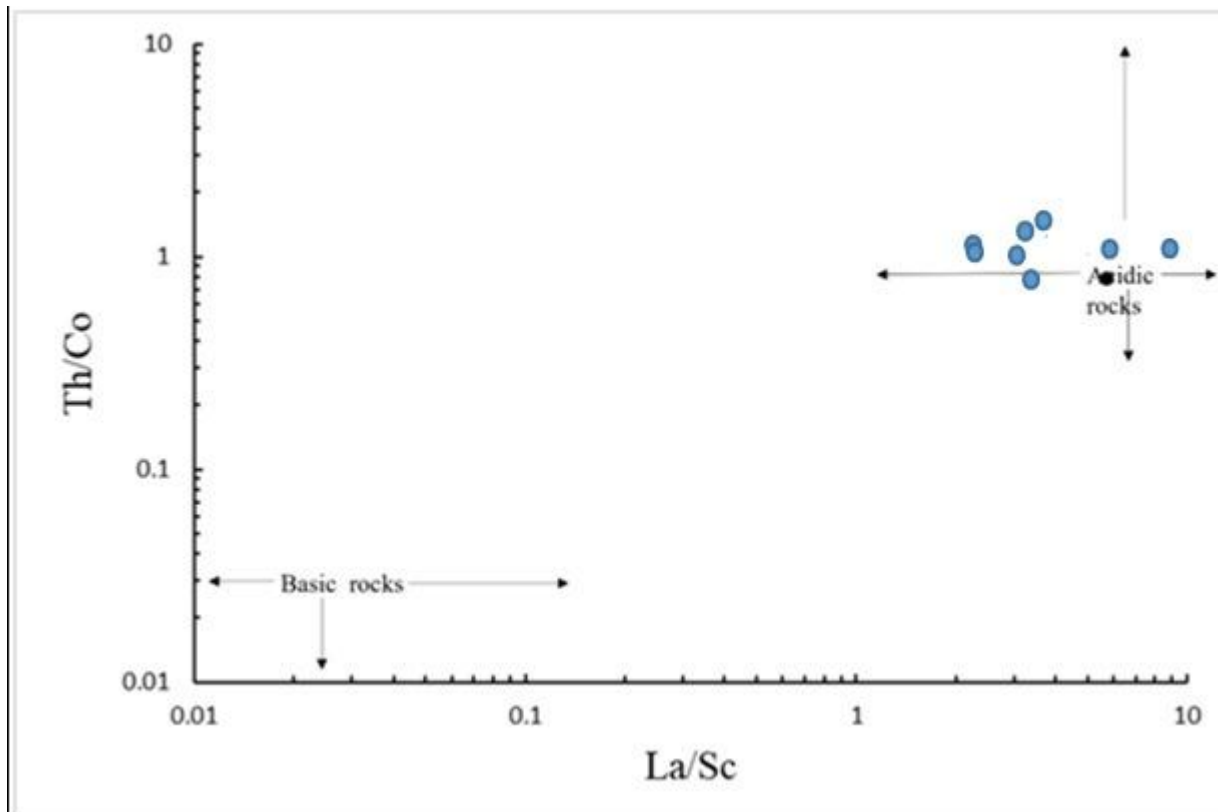


Figure 4.1: Th/Co versus La/Sc diagram for X- wells. (After Culler, 2002)

Furthermore, the concept of Floyd *et al.* (1989) was also adopted to establish the source of the sediments penetrated by X-well. TiO₂ versus Ni bivariate plot was used and it revealed that the source of the sediments penetrated by X-wells is predominantly of acidic nature.

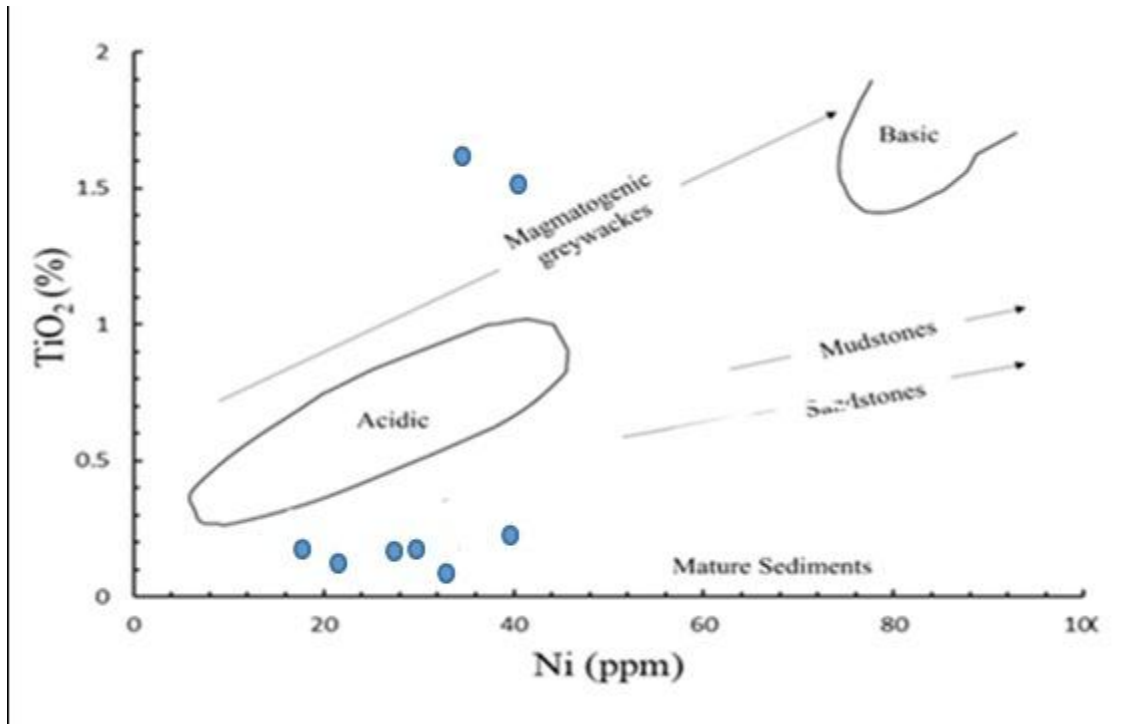


Figure 4.2: TiO₂ versus Ni bivariate of X-wells (After Floyd *et al.* 1989)

The provenance of X-well sediments was further confirmed by considering the ratios of Thorium/Scandium (Th/Sc), Thorium/Cobalt (Th/Co), Chromium/Thorium (Cr/Th), Lanthanum/Scandium (La/Sc). The ratios of these elements were calculated from the result shown in tables 4.5, For X-well, Thorium/Scandium (Th/Sc) range from 1.13-4.03, Thorium/Cobalt (Th/Co) range from 0.79-1.7, Chromium/Thorium (Cr/Th) range from 3.89-12.90 and Lanthanum/Scandium (La/Sc) range from 3.72-10.07.

Table 4.8: Range of Elemental Ratios of X-well compared to the Ratios in Similar Fractions derived from Felsic and Mafic Rocks,

ELEMENTAL RATIO	X-WELL	RANGE FOR FELSIC ROCKS	RANGE FOR MAFIC ROCKS
Th/Sc	1.13-4.03	0.84-20.5	0.05-0.22
Th/Co	0.79-1.7	0.67-19.4	0.04-1.40
Cr/Th	3.89-12.90	4.0-15.0	25-100
La/Sc	3.72-10.07	1.2-6.6	0.43-0.86

4.6 Tectonic Setting

Plate tectonic processes impart a distinctive geochemical signature to sediments in two separate ways. Firstly, different tectonic environments have distinctive provenance characteristics and, secondly, they are characterized by distinctive sedimentary processes. Sedimentary basins may be assigned to the following tectonic settings for active continental margin, passive continental margin, oceanic island-arc, continental island-arc, and collisional setting. Bhatia (1985), Roser and Korsch (1986) stated that the chemical compositions of clastic rocks are significantly controlled by plate tectonic settings of their provenances, consequently clastic rocks from different tectonic settings possess terrain-specific geochemical signatures.

The concept of Roser and Korsch (1986) was also applied to determine the tectonic setting of X-wells. Roser and Korsch (1986) plotted K_2O/Na_2O vs SiO_2 to determine the provenance of sediments. The recognized tectonic settings on the K_2O/Na_2O versus SiO_2 discrimination diagram of Roser and Korsch (1986) are: the passive continental margin (PCM), active continental margin (ACM) and oceanic island arc (OIA). When applied for the samples recovered from X-wells, they plotted mainly in the passive continental margin zone which infer that the tectonic setting for X-well facies is in the passive continental margin.

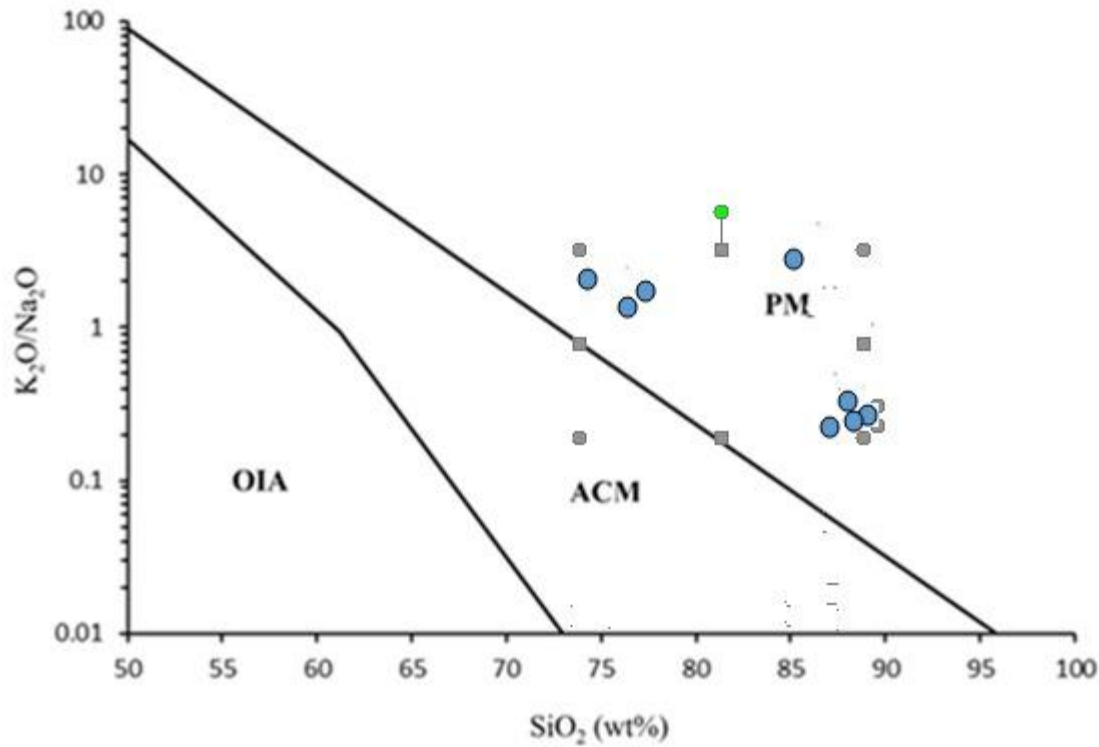


Figure 4.3: Tectonic discrimination plot for X-wells. After Roser and Korsch (1986). PCM: passive continental margin, ACM: active continental margin and OIA: oceanic island arc.

Log (K_2O/Na_2O) versus Log (SiO_2/Al_2O_3) was used to determine the tectonic setting as proposed by Maynard *et al.* (1982). The recognized tectonic settings on the Log (K_2O/Na_2O) ratio versus Log (SiO_2/Al_2O_3) ratio discrimination diagram of Maynard *et al.* (1982) are: A1 - arc setting and andesitic detritus; A2 - evolved arc setting, felsic pluton detritus; ACM - Active continental margin; PM - passive margin. When utilized for the samples of X-wells, they plotted mainly in the passive margin zone which infers that the tectonic setting for the X-wells facies is in the passive continental margin.

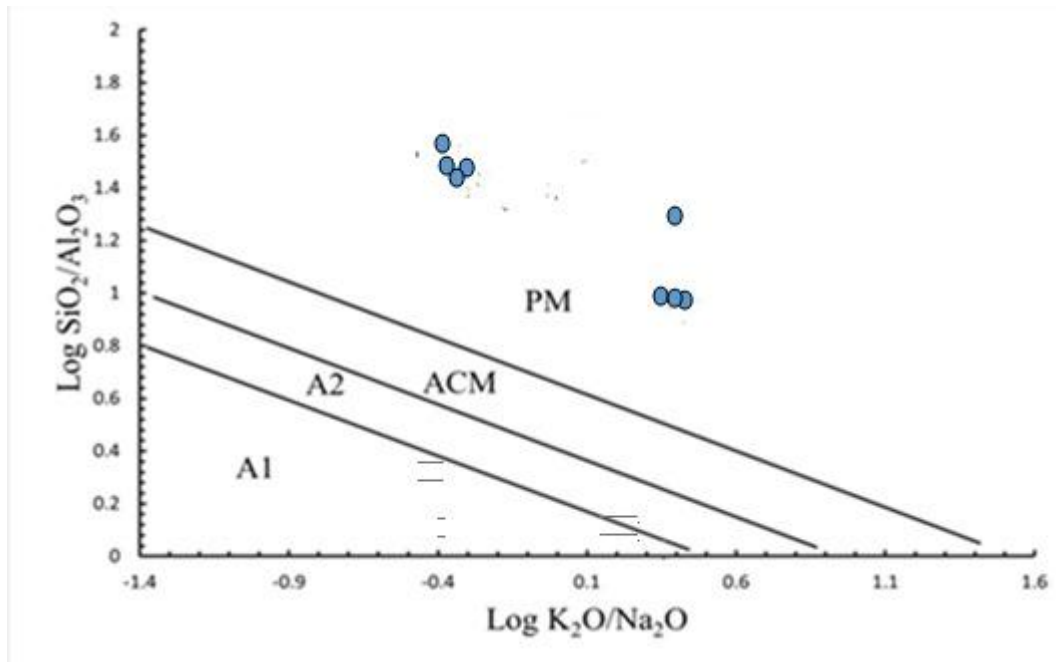


Figure 4.4: Log (K₂O/Na₂O) ratio versus Log (SiO₂/Al₂O₃) ratio tectonic discrimination diagram of Xwells. After Maynard *et al.* (1982). A1 - arc setting and andesitic detritus, A2 - evolved arc setting, felsic pluton detritus, ACM - Active continental margin, PM - Passive Continental Margin.

4.10.7 SANDSTONE CLASSIFICATION

The classification of sandstone can give us a sound understanding of its origin Boggs (1967). Additionally, the classification of sandstone plays a key role in understanding and interpreting the paleogeography and tectonic background of the provenance. Herron (1988) came up with a classification scheme in which Log (SiO₂/Al₂O₃) is plotted against Log (Fe₂O₃/K₂O). By plotting Log (SiO₂/Al₂O₃) against Log (Fe₂O₃/K₂O) in this work, the sandstone facies of X-well plotted mainly in Fe-sand

domain.

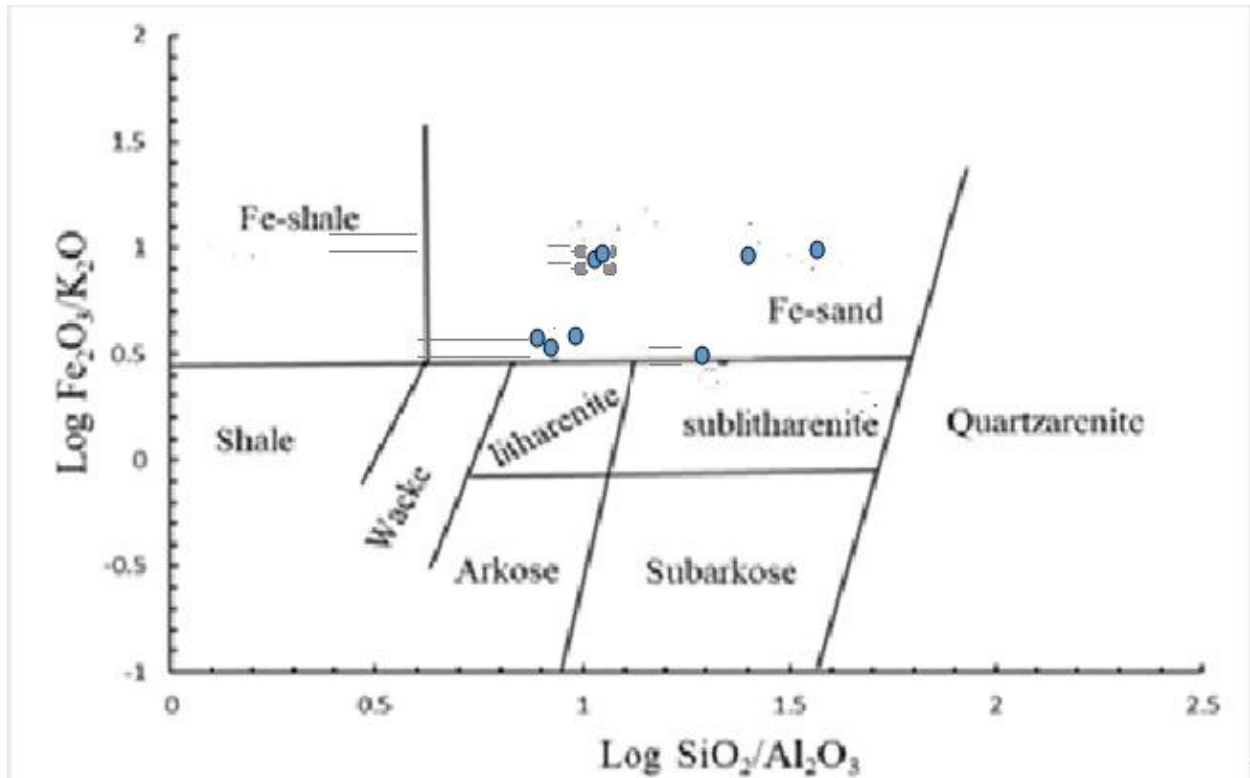


Figure 4.5: Chemical Classification of the sandstone of X-well based on $\text{Log}(\text{SiO}_2/\text{Al}_2\text{O}_3)$ vs. $\text{Log}(\text{Fe}_2\text{O}_3/\text{K}_2\text{O})$. After Herron (1988).

Pettijohn (1972) proposed a classification in which $\text{Log}(\text{SiO}_2/\text{Al}_2\text{O}_3)$ is plotted against $\text{Log}(\text{Na}_2\text{O}/\text{K}_2\text{O})$. By adopting Pettijohn's concept in this work, the sandstones penetrated by X-wells plotted mainly in quartzarenites and sublitharenite domain.

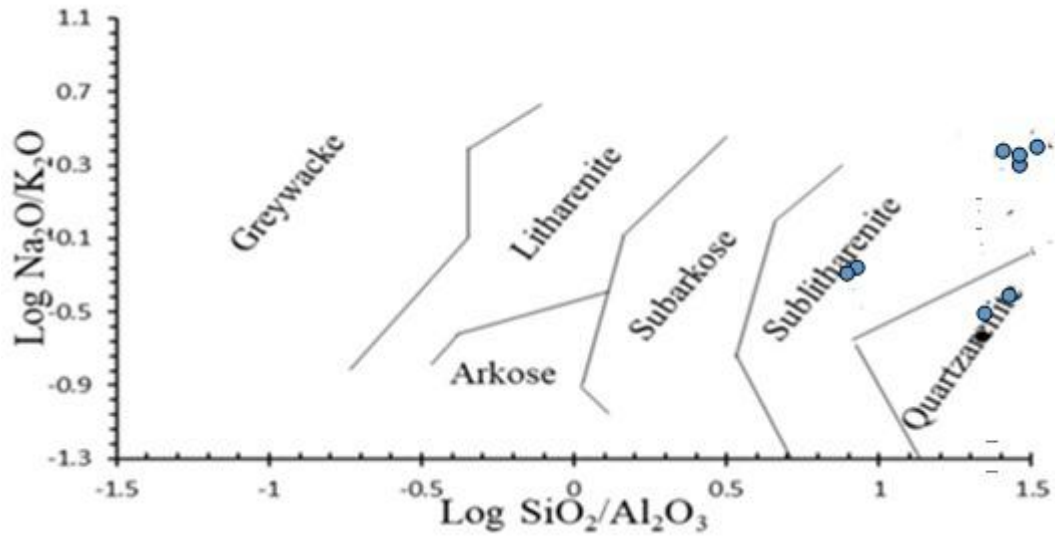


Figure 4.6: Classification of NS-1 and NS-2 wells sandstone facies based on Log (SiO₂/Al₂O₃) vs. Log (Na₂O/K₂O). After Pettijohn (19

CHAPTER FIVE

SUMMARY, CONCLUSION AND SUGGESTION FOR FURTHER STUDIES

5.1 SUMMARY

Twenty (20) samples underwent a sedimentological study, and eight (8) of the twenty (20) samples from the X-well in Niger Delta were chosen for chemostratigraphic research employing major oxides and trace elements. Below is a summary of the study's findings;

1. The sedimentological examination identified Sandy shale, Shaly sand, and Sand lithology throughout.
2. The sedimentological examination also showed that the samples' grain sizes ranged from fine to coarse, their degree of sorting varied from poorly to moderately to well, and their grain shape ranged from subrounded to angular.
3. The paleo-redox environment, provenance studies, tectonic setting, and sandstone classification of the sediment of the X-well were determined using chemostratigraphic characterisation employing major oxides and trace elements.

5.2 CONCLUSION

Sands and sandy shale made up the majority of the X-well, according to a sedimentological investigation. A felsic rock and a passive margin zone were inferred from chemostratigraphic characterisation of the X-well sediments utilising major oxides and trace elemental ratio. Additionally, the sublitharenite, Fe-rich sand, and quartzarenite categorization methods utilised

in this investigation revealed that the X-well sediments were deposited in an oxic environment based on the trace elements ratios of U/Th and V/Cr.

5.3 SUGGESTION FOR FURTHER STUDIES

To accurately determine the age, environment of deposition, and paleobathymetry of the sediments, biostratigraphy should be used.

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