SEQUENCE STRATIGRAPHIC AND FAULT-SEAL INTERPRETATIONS OF RESERVOIR IN “IKEANI” FIELD, COASTAL SWAMP DEPOBELT, NIGER DELTA NIGERIA

BY

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CERTIFICATION

This is to certify that this work "SEQUENCE STRATIGRAPHIC AND FAULT-SEAL INTERPRETATIONS OF RESERVOIR IN "IKEANI" FIELD, COASTAL SWAMP DEPOBELT, NIGER DELTA NIGERIA" was carried out by EDEMA, SAVIOUR ANIREJUORITSE (Reg. 20124834938) in partial fulfillment of the requirements for the award of Master of Science (M.Sc.) degree in Sedimentary/Petroleum Geology in the Department of Geology, Federal University of Technology, Owerri.

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DEDICATION

I wish to dedicate this thesis to God Almighty for making me the man I have become. To my wonderful son Jason who passed away on 20th of May, 2021 after a very difficult stay on earth, I pray his soul continue to rest in God's bosom.

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ABSTRACT

The aim of this work is to show the spartial distribution of the reservoir architectural elements in “Ikeani” Field, Coastal Swamp depobelt using data from well logs, checkshot, biostratigraphy and 3D seismic in the evaluation of sequence stratigraphy, structural interpretation, seismic stratigraphy and amplitude extraction. The results of the sequence stratigraphy delineates the reservoir geometries, stacking patterns, sequences and parasequences. These were directly interpreted sequel to relative sea level fluctuations and sediments infills. It is observed that the reservoir qualities varies by virtue of the sequences (Highstand Systems Tract, Transgressive Systems Tract and Lowstand Systems Tract). The HSTs as seen in this study have clean and better developed sand reservoirs. They are generally aggradational to progradational. The TST’s are dirty towards the top and are mostly retrogradational channels terminating up dip at the Maximum Flooding Surfaces (MFS). These MFS’s considering their good thickness are likely good top seals to the TST reservoirs. The LSTs are mainly progradational with intercalations of sand and shales typical of prograding wedge deposits, slope deposit and basin floor fan deposits. Fault truncations as interpreted in this research, caused different reservoir closures. However, some other faults as seen in this study has penetrated some stacking geometries of reservoirs resulting to faulted out (missing section typical of C7000 Reservoir) and fault cut (short section typical of C6000) depicting non-testing of hydrocarbon in some wells such as C7000_reservior which could not be penetrated by Ikeani Well 7. Also, hydrocarbon accumulations as delimited at reservoir intervals using both well logs and seismic are complemented with the associated depo environment as interpreted in this study. However, non-faulted or four-way dip closure of a reservoir is also seen in this study. This is typical of C13000. The study adopted seismic stratigraphy to delineate the reflection configurations and patterns such as the divergent and sub-parallel seismic configurations connoting different/fluctuations of depositional environment. These were then complemented with Root Mean Square Amplitude extraction to display the diverse intermingled barrier channel truncated reservoir deposits. The sealing capacity of the reservoir is demonstrated within the fault surface utilizing the Shale Gouge Ratio (SGR) as the sealing parameter – attributing its rock components as stratigraphic juxtapositions, catalasis and influential across fault pressure as the capillary pressure. This disclosed that faults forming closures at studied reservoir levels had over 60% SGR and as such caused good sealing in C6000 reservoir by impeding further oil migration as well as being supported and capped with over 70% Volume of Shale as the top seal rock.

keywords: Sequence stratigraphy, fault-seal interpretations, reservoir, ikeani field, coastal swamp depobelt, Niger Delta

CHAPTER ONE

INTRODUCTION

1.1 Background Information

The goal of oil exploration is to locate economic quantities of hydrocarbon in the subsurface and to consider viable ways of exploitation. These accumulations are usually found to be trapped within stratigraphic and structural features such as: salt or shale diapirs, sand lenses, stratigraphic pinch-outs, unconformities, anticlinal structures as well as fault dependent traps.

Faults do not only control the presence of hydrocarbon in a trap, they also control the volume of hydrocarbons that have accumulated in a trap, as well as their distributions among a series of stacked sands and within a single sand body among series of fault compartments (Opara, Okoro, Onyekuru, Njoku, Onyenegecha, Asedegbega, Ekwe, Okoli & Ezekiel, 2021; Adagunodo, Sunmonu & Adabanija, 2017). For petroleum to accumulate within a fault trap, the faults constituting that trap must be sealing. Sealing mechanism can result from reservoir against non-reservoir juxtaposition whereby permeable rocks occur against non-permeable rocks across a fault surface. It can also form when the reservoir is juxtaposed against another reservoir, but in this case, the materials within the fault itself serve as the barrier to hydrocarbon migration (Onyekuru, Iwuagwu, Ulasi & Ibeneme, 2022; Freeman, Yielding, Needham & Badley, 1998).

Integration of sequence stratigraphy, seismic stratigraphy, amplitude extraction, depositional environment delineation and fault seal analysis in fault dependent reservoirs forms the basis of this study. The sequence stratigraphy and seismic stratigraphy as applied in Ikeani Field reveals the systems tracts, shoreline migrations / relative sea level fluctuations in relation to accommodation spaces created by the faults / subsidence, sediments supply rates / strata infill, strata patterns / motifs and configurations. Strata packages (stacking patterns) such as:

Progradation, Retrogradation and Aggradation - Progradation as descriptive within a sequence which may be within: Low-Stand Systems Tract (LST), Transgressive Systems Tract (TST) and High-Stand Systems Tract (HST) as well as their parasequences occurring within a sequence. Key surfaces such as Maximum Flooding Surfaces (MFSs) and Sequence Boundaries (SBs) are interpreted at both log scale and seismic sections. However, genetic sequences are utilized in this study as (MFS to MFS).

Also, delineations of Depositional Environments indicative and interpretative of the prevailed sequences with their various connotations are interpreted on well logs and 3D seismic sections complemented with amplitude extraction. However, adequate descriptive evaluations of the 3D structural and geometrical assessments was carried out with detailed 3D fault seal analysis to improve the level of certainty of the available hydrocarbon accumulations.

1.2 Statement of the Problem

The risks associated with hydrocarbon exploration include drilling dry holes, abandonment of wells due to loss of circulation, reserve depletion, complex reservoir geometry and characteristics as a result of compartmentalization ((Osinowo, , Ayorinde, Nwankwo, Ekeng & Taiwo, 2017; Jackson, Yoshida & Muggeridge, 2005) as well as very expensive field development (Adagunodo et al., 2017). This risk is increased where proper structural analysis has not been carried out.

Quite a number of structural analysis have been carried out in the Niger Delta, most of them focused on determining the nature of trapping systems (Opara et al, 2021; Obiekezie and Bassey, 2015) and identifying fault dependent prospects (Rotimi, Ameloko & Adeoye, 2010; Oresajo, Adekeye & Haruna, 2015; Anomneze, Okoro, Ajaegwu, Akpunonu, Ahaneku, Ede, Okeugo & Ejeke, 2015). Some authors have recommended that the integrity of faults should be considered to support the accumulation of hydrocarbon.

Therefore fault seal analysis should as a matter of obligation be included in every hydrocarbon exploration activity. This will help to add meaning to any volumetric analysis and also provide information that will guide in well planning and field development that will in turn help to maximize recovery and reduce the risks associated with fault related hydrocarbon exploration and exploitation in the Niger Delta.

1.3 Aim and Objectives of the Study

1.3.1 Aim of the Study

The aim of this work is to show the spartial distribution of the reservoir architectural elements in Ikeani Field, Coastal Swamp depobelts.

1.3.2 Objectives of the Study

The objectives of the study is as follws:

i. To carry out lithologic interpretations using well logs
ii. To identify and correlate the reservoirs in the field in order to define the extent within which analysis can be conducted
iii. To calculate shale gouge ratio which will be ascertained from the volume of shale
iv. To identify fault dependent traps so as to analyze their sealing integrity
v. To interpret the depositional trend of the basin thereby inferring depositional setting of the basin

1.4 Scope of Study

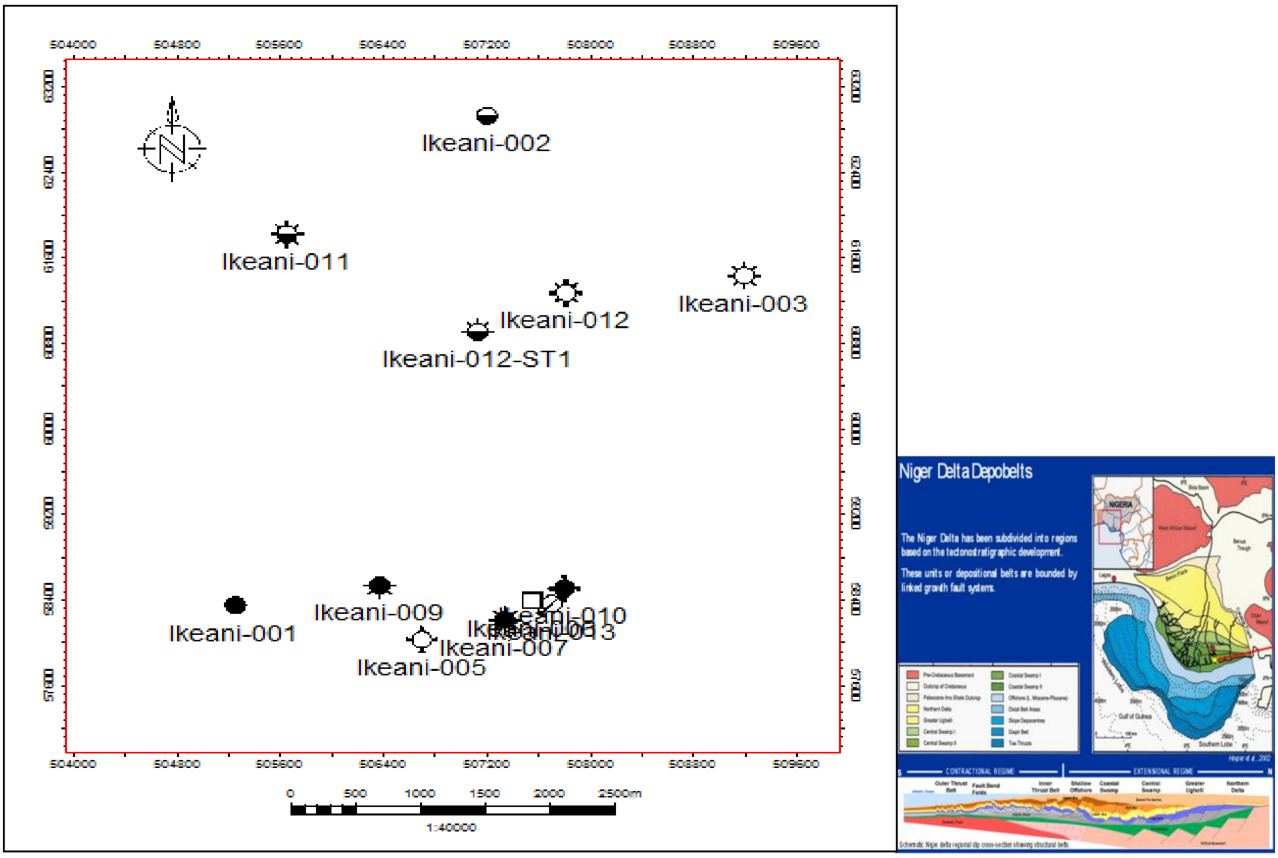
The scope of this project covers 3-D seismic interpretation for fault and horizon mapping, reservoir correlation on well logs, fault seal analysis using an integrated seismic and well log approach. Core data will not be included and reactivation risk is beyond the scope of this project.

CHAPTER TWO

LITERATURE REVIEW

2.1 Location of the Study Area

Ikeani field is located in the coastal swamp depo belt of the Niger Delta as shown in figure 2.1.



The Niger Delta has been subdivided into regions based on the tectonostratigraphic development.

These units or depositional belts are bounded by linked growth fault systems.

Fig.2.1. Location map of the study area (After Weber, 1990)

2.2 Geologic Setting

2.2.1 Basin Evolution and Structure

The Niger-Delta is situated in the Gulf of Guinea and covers an area of about 140,000 km^2 and has an average sedimentary thickness of about 12km (7Mi). According to Burke (1972), the silisiclastic system found in the Niger-Delta began to prograde across the pre-existing continental slope into the deep sea during late Eocene and is still active till this day.

The Niger Delta clastic wedge formed along a failed arm of a triple junction system (aulacogen) that originally developed during break up of the South American and African plates in the late Jurassic (Burke, 1972; Whiteman, 1982). The two arms that followed the southwestern and southeastern coast of Nigeria and Cameroon developed into the passive continental margin of West Africa, whereas the third failed arm formed the Benue Trough. Other depocenters along the African Atlantic coast also contributed to deltaic build-ups. Syn-rift sediments accumulated during the Cretaceous to Tertiary, with the oldest dated sediments of Albian age. Thickest successions of syn-rift marine and marginal marine clastics and carbonates were deposited in a series of transgressive and regressive phases (Doust and Omatsola, 1990).

The Syn-rift phase ended with basin inversion in the Santonian (Late Cretaceous) (Fig 2.2). Renewed subsidence occurred as the continents separated and the sea transgressed the Benue Trough. The Niger Delta clastic wedge continued to prograde during Middle Cretaceous time into a depocenter located above the collapsed continental margin at the site of the triple junction. Sediment supply was mainly along drainage systems that followed two failed rift arms, the Benue and Bida Basins. Sediment progradation was interrupted by episodic transgressions during Late Cretaceous time.

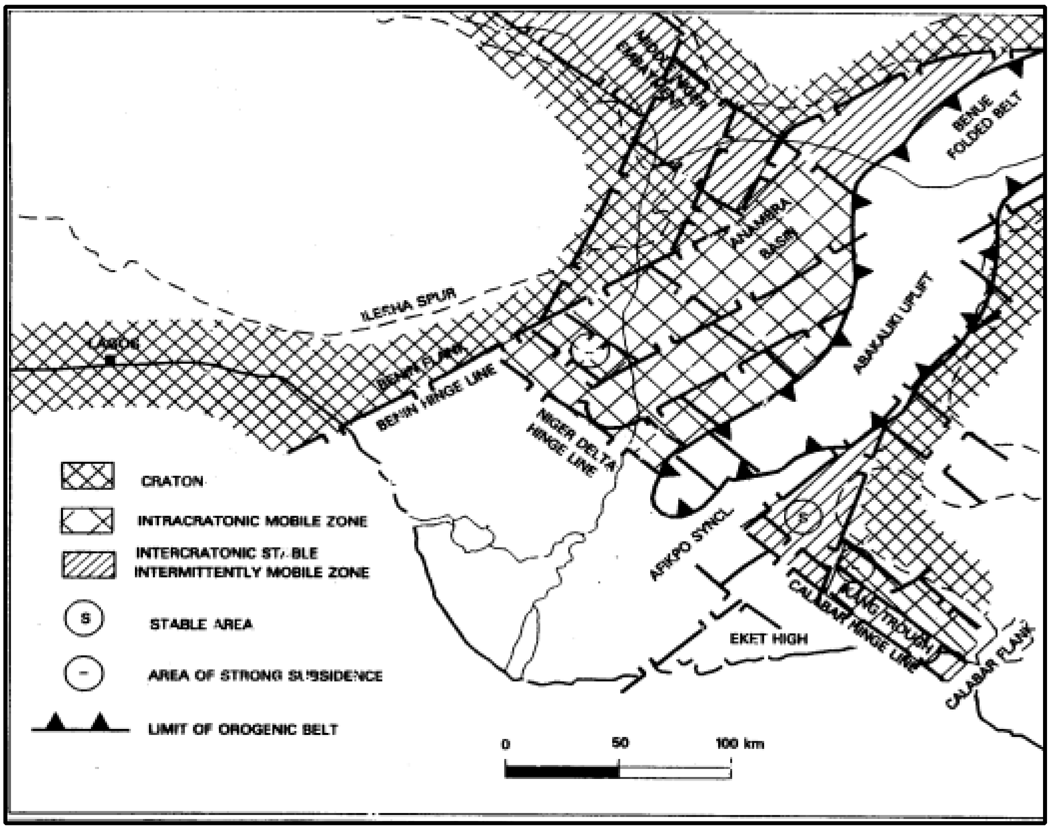


Fig. 2.2 Tectonic framework of southeastern Nigeria sedimentary basins (Burke, 1972)

During the Tertiary, sediment supply was mainly from the north and east through the Niger, Benue and Cross Rivers. Cross and Benue Rivers provided substantial amounts of volcanic detritus from the Cameroon volcanic zone beginning in the Miocene. The Niger Delta clastic wedge prograded into the Gulf of Guinea at a steadily increasing rate in response to the evolution of these drainage areas and continued basement subsidence. Regression rates increased in the Eocene, with an increasing volume of sediments accumulated since the Oligocene.The morphology of Niger Delta changed from an early stage spanning the Paleocene to early Eocene to a later stage of delta development in Miocene time. The early coastlines were concave to the sea and the distributions of deposits were strongly influenced by basement topography (Doust and Omatsola, 1989). Delta progradation occurred along two major axes, the first paralleled the Niger River, where sediment supply exceeded subsidence rate. The Second, smaller than the first, became active during Eocene to early Oligocene basinward of the Cross River where shorelines advanced into the Olumbe-1 area (Short and Stauble, 1967). This axis of deposition was separated from the main Niger Delta deposits by the Ihuo Embayment, which was later rapidly filled by advancing deposits of the Cross River and other local rivers (Short and Stauble, 1967).

Late stages of deposition began in the Early to Middle Miocene, as these separate eastern and western depocenters merged. In Late Miocene the delta prograded far enough that shorelines became broadly concave into the basin. Accelerated loading by this rapid delta progradation mobilized underlying unstable shales. These shales rose unto diapiric walls and swells deforming overlying strata. The resulting complex deformation structures caused local uplift, which resulted in major erosion events into the leading progradational edge of the Niger Delta. Several deep canyons, now clay filled, cut into the shelf and are commonly interpreted to have formed during sea level lowstands. The best known are the Afam, Opuama, and Qua Iboe Canyon fills. Deposits of the last depositional cycle have been divided into a series of six depobelts. (Doust and Omatsola, 1990; also called depocenters or megasequences) separated by major syn-sedimentary fault zones. These depobelts formed when paths of sediment supply were restricted by patterns of structural deformation, focusing sediment accumulation into restricted areas on the delta (Fig. 2.3). Such depobelts changed position over time as local accommodation was filled and the locus of deposition shifted basinward (Doust and Omatsola, 1990).

2.2.2 Stratigraphic Framework

Stratigraphic evolution of the Tertiary Niger Delta and underlying Cretaceous strata is described by Short and Stauble (1967). Petroleum Geology of the Niger Delta is described in Evamy, Haremboure, Kamerling, Knaap, Molloy, & Rowland, (1978)., Doust and Omatsola (1990) & Tuttle, Charpentier, & Brownfield, (1999). Stacher (1995) developed a hydrocarbon habitat model for the Niger Delta based on sequence stratigraphic methods. Allen (1965) described depositional environments, sedimentation and physiography of the modern Niger Delta. The three major lithostratigraphic units defined in the subsurface of the Niger Delta (Akata, Agbada and Benin Formations, (Fig 2.4) decrease in age basinward, reflecting the overall regression of depositional environments within the Niger Delta clastic wedge.

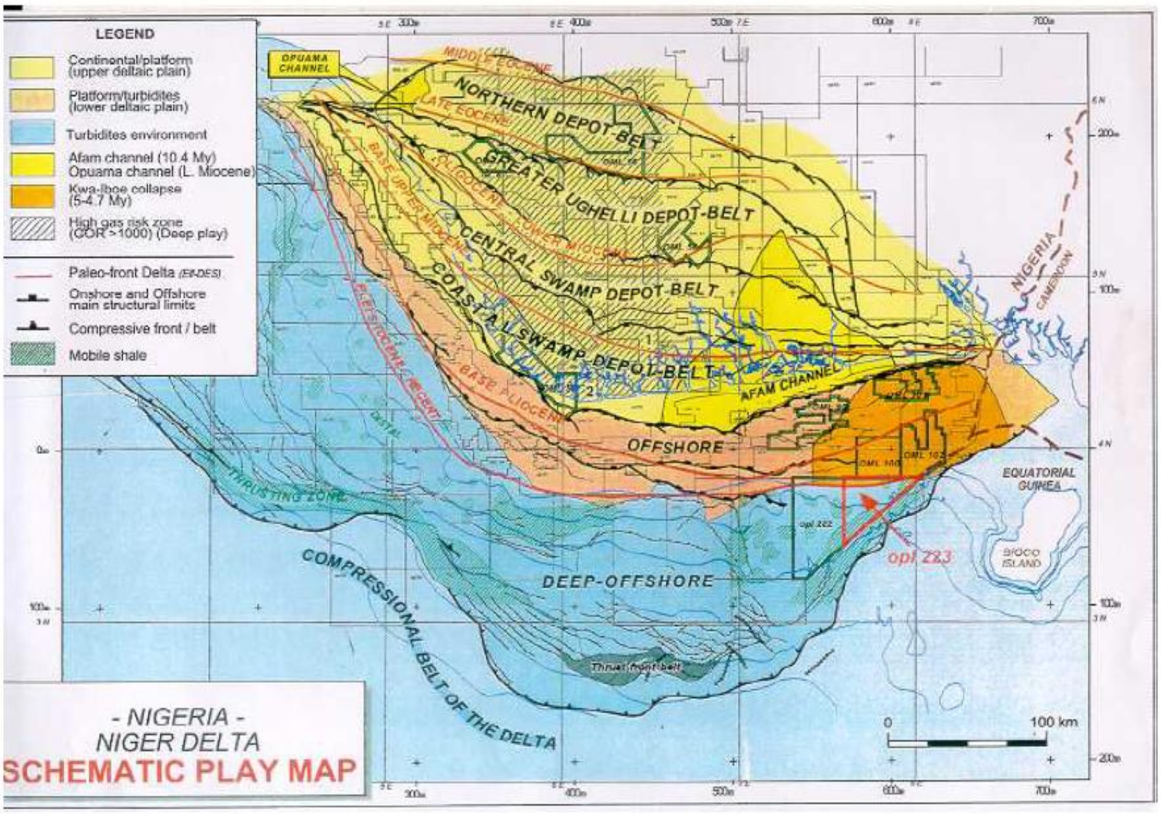


Fig. 2.3 The Depobelts in the Niger-Delta (Doust And Omotsola, 1990).

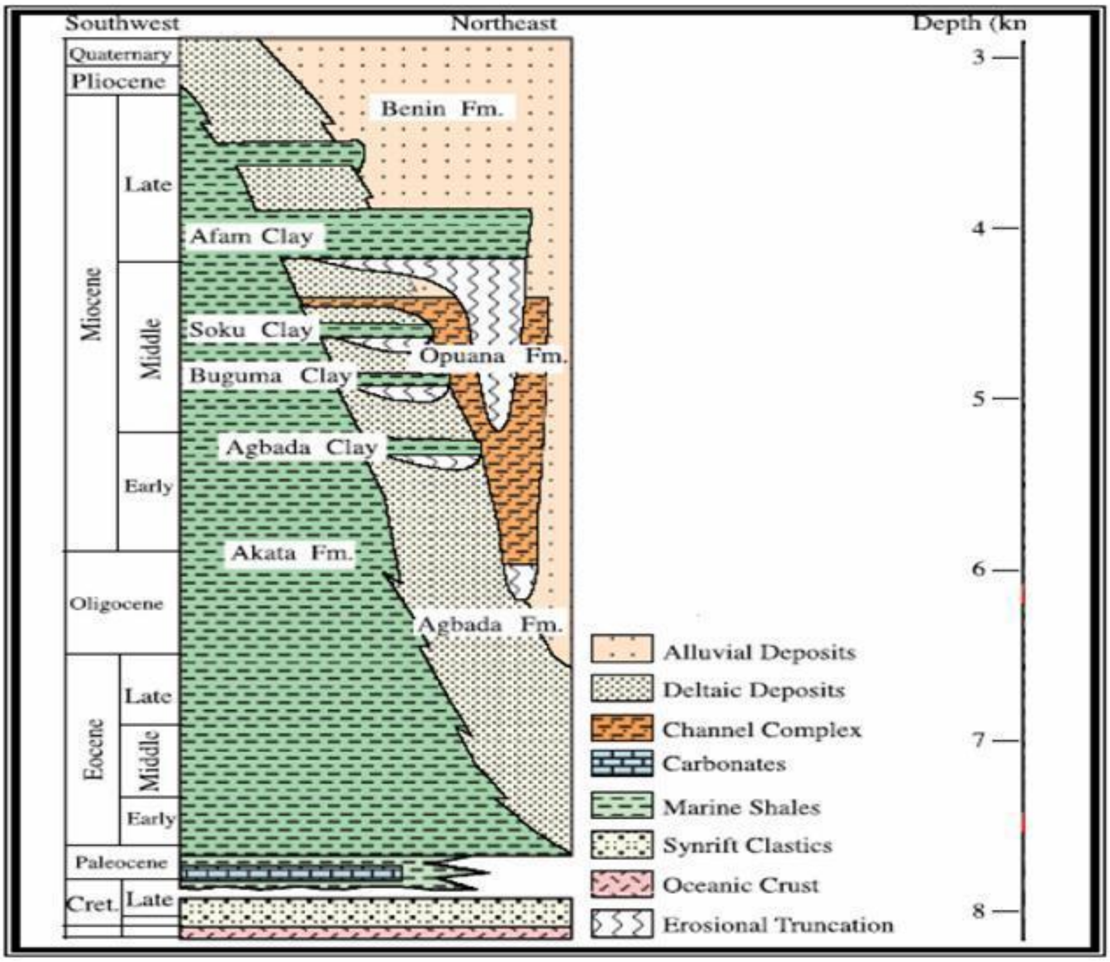
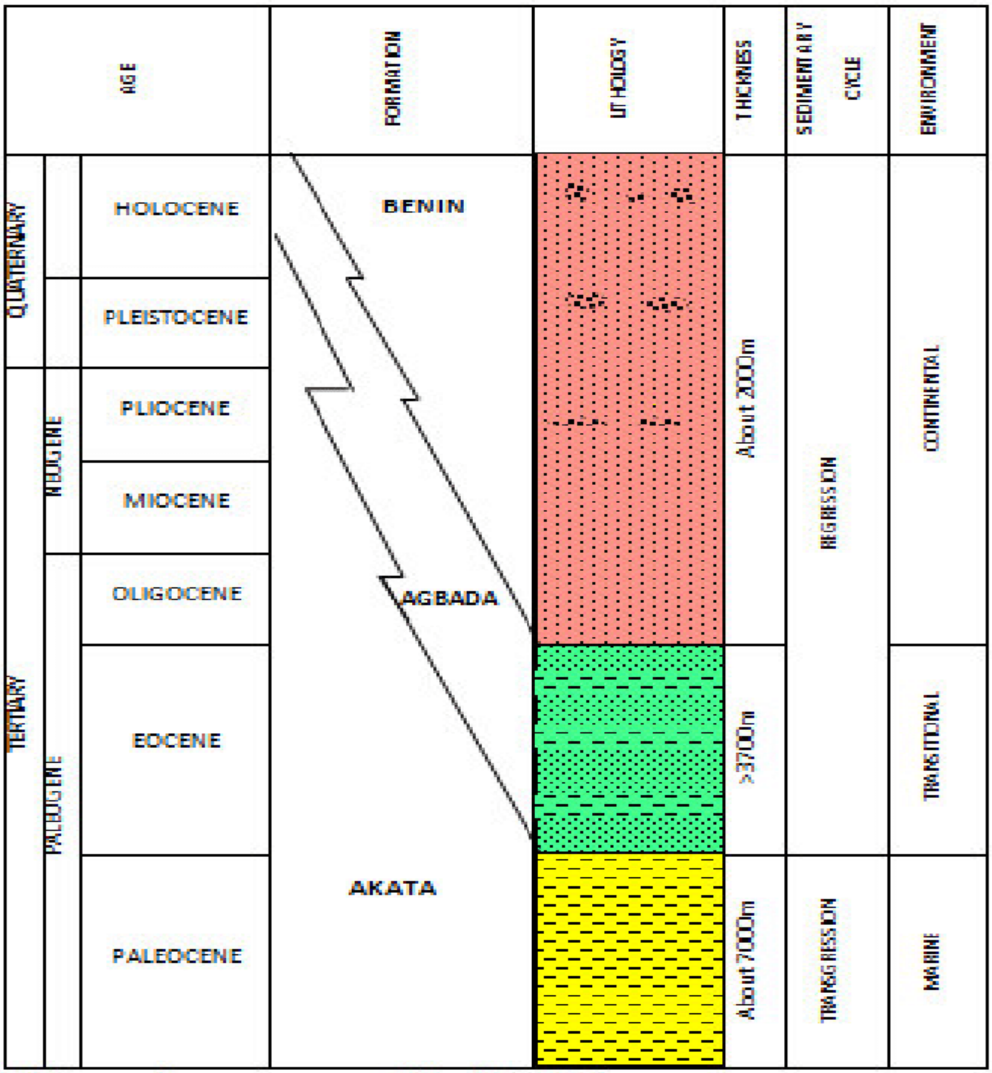


Fig. 2.4 Stratigraphic Column Showing Formations of the Niger Delta (Tuttle et al. 1999).

Stratigraphic equivalent units to these three formations are exposed in southern Nigeria as shown in (Table 2.1). The formations reflect a gross coarsening-upward progradational clastic wedge (Short and Stauble, 1967), deposited in marine, deltaic, and fluvial environments (Weber and Daukoru, 1975; Weber, 1990). The type section of the Akata Formation was defined in Akata 1 Well, 80 km east of Port Harcourt (Short and Stauble, 1967). A total depth of 11,121 feet (3, 680 m) was reached in the Akata 1 well without encountering the base of this formation. The top of the formation is defined by the deepest occurrence of deltaic sandstone beds (7,180 feet in Akata well). The formation is estimated to be 21,000 feet thick in the central part of the clastic wedge (Doust and Omatsola, 1989). The lithologies are dark grey shales and silts, with rare streaks of sand of probable turbidite flow origin (Doust and Omatsola, 1989). Marine planktonic foraminifera make up to 50% of the microfauna assemblage and suggest shallow marine shelf deposition (Doust and Omatsola, 1989).

Table 2.1: Stratigraphic chart of Niger Delta Area, Nigeria. (Modified from Short and Stauble, *1967)*.



AGE			FORMATION	LITHOLOGY	THICKNESS	SEDIMENTARY CYCLE	ENVIRONMENT
QUATERNARY		HOLOCENE	BENIN	🟥	About 2000m	REGRESSION	CONTINENTAL
		PLEISTOCENE					
TERTIARY	NEOGENE	PLIOCENE					
		MIOCENE					
	PALEOGENE	OLIGOCENE	AGBADA				
		EOCENE		🟩	>3700m		TRANSITIONAL
		PALEOCENE	AKATA	🟨	About 7000m	TRANSGRESSION	MARINE

Age of the formations ranges from Paleocene to Recent (Doust and Omatsola, 1989). Those shales, formed during the early development stages of Niger Delta progradation, are thickest along the axis of the Benue and Bida Troughs. Where exposed onshore in the northeastern part of Nigeria, this formation is called the Imo Shale.The formation also crops out offshore in diapirs along the continental slope. When deeply buried, these marine shales are typically overpressured. Akata Shales were interpreted to be deepwater lowstand deposits by Stacher (1995). The formation grades vertically into the Agbada Formation with abundant plant remains and micas in the transition zone (Doust and Omatsola, 1989).

The Agbada Formation is defined in the Agbada 2 well, drilled about 11 km north-northwest of Port Harcourt (Short and Stauble, 1967). The well reached a total depth of 9500 feet without penetrating the base of the formation (the base was defined as the top of the Akata Formation in Akata 1 well). According to Doust and Omatsola, (1989), the formation occurs throughout Niger Delta clastic wedge and has a maximum thickness of about 13,000 feet. Where it outcrops in southern Nigeria (between Ogwashi and Asaba), it is called the Ogwashi-Asaba Formation. The lithologies consist of alternating sands, silts and shales arranged within ten to hundred feet successions defined by progressive upward changes in grain size and bed thickness. The strata are generally interpreted to have formed in fluvial-deltaic environments. The formation ranges in age from Eocene to Pleistocene.

The Benin Formation comprises the top part of the Niger Delta clastic wedge, from the Benin-Onitsha area in the north to beyond the present coastline (Short and Stauble, 1967). Its type section is Elele 1 Well, drilled about 38 km north-northwest of Port Harcourt (Short and Stauble, 1967). The top of the formation is the recent subaerially-exposed delta top surface and its base extends to a depth of 4600 feet. The base is defined by the youngest marine shale. Shallow parts of the formation are composed entirely of non-marine sand deposited in alluvial or upper coastal plain environments during progradation of the delta (Doust and Omatsola, 1989). Although lack of preserved fauna inhibits accurate age dating, the age of the formation is estimated to range from Oligocene to Recent (Short and Stauble, 1967). The formation thins basinward and ends near the shelf edge. Short and Stauble (1967) defined formations based on sand/shale ratios estimated from subsurface well logs. Such definitions, based on subsurface well logs that incompletely penetrate type sections, do not conform to the international stratigraphic code and thus are informal. Conflicting definitions of tops and bases of formations are used by local geologists. The top of the Agbada Formation is often defined as the base of fresh water sand. The top of the Akata Formation is commonly defined as the top of overpressured shale encounter during drilling. Doust and Omatsola (1989) acknowledge problems with their formation definitions (first thick sand defining the Akata-Agbada Formation boundary and last thick marine shale defining the Agbada-Benin Formation boundary) may arise due to local argillaceous intercalations of considerable thickness in sands of the Benin Formation, and the local presence of turbidite sands at considerable depth within the Akata Formation.

2.2.3 Structural Setting of the Niger Delta

The structural development of the Delta is a result of the interplay between sediment supply and rate of subsidence. Subsurface structures (Fig. 2.5) are dominantly synsedimentary and post sedimentary listric normal faults, large rollover anticlines and mud diapirs (Doust & Omatsola, 1990).

Typical of the structural styles in the Niger Delta is as shown in figure 2.6: modified from Doust and Omatsola (1990) and Stacher (1995). These include the roll over anticline, faulted roll over anticline as growth faults (syn-depositional faults), synthetic and antithetic faults, collapse crest etc.

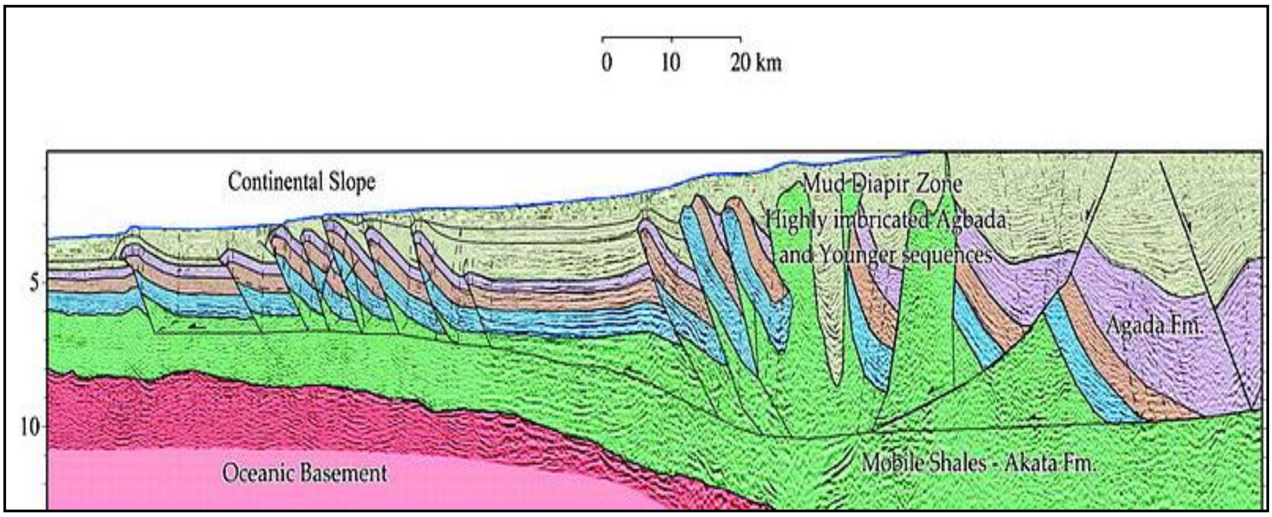
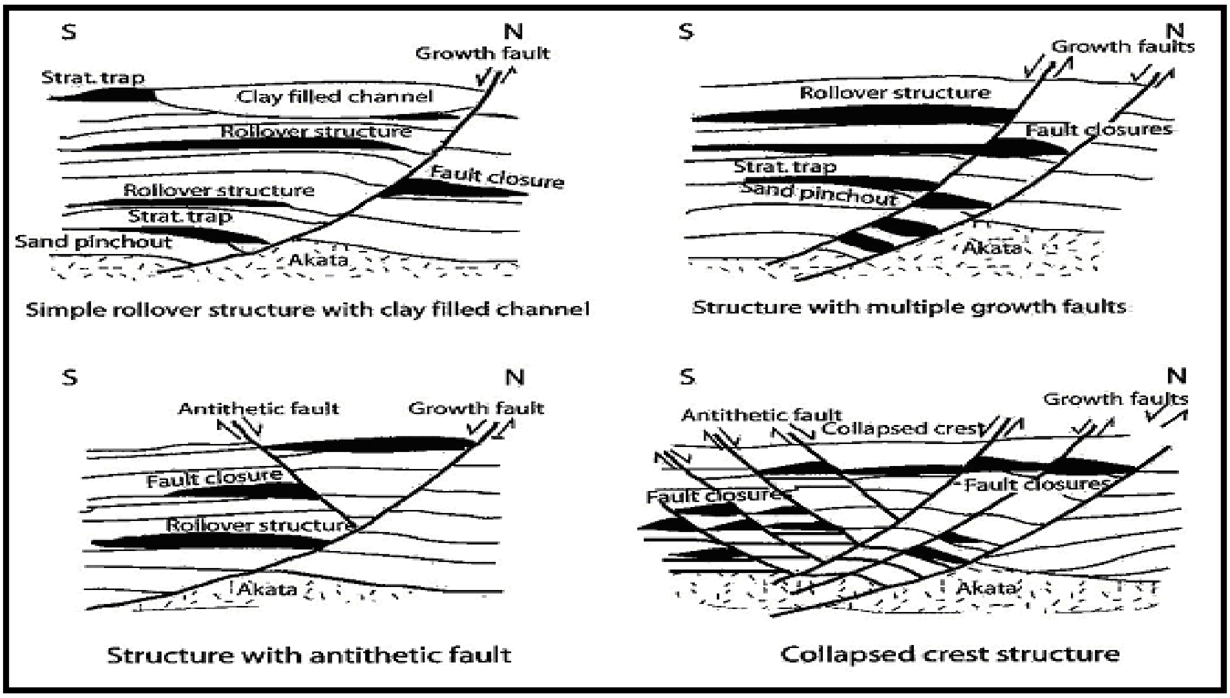


Figure 2.5 A Seismic profile of a section in the Niger Delta Basin showing the predominant subsurface structures such as growth faults, roll-over anticlines, shale diapirs, synthetic and antithetic faults (Adapted from Corredor et al., 2005)


Simple rollover structure with clay filled channel

Structure with multiple growth faults

Structure with antithetic fault

Collapsed crest structure

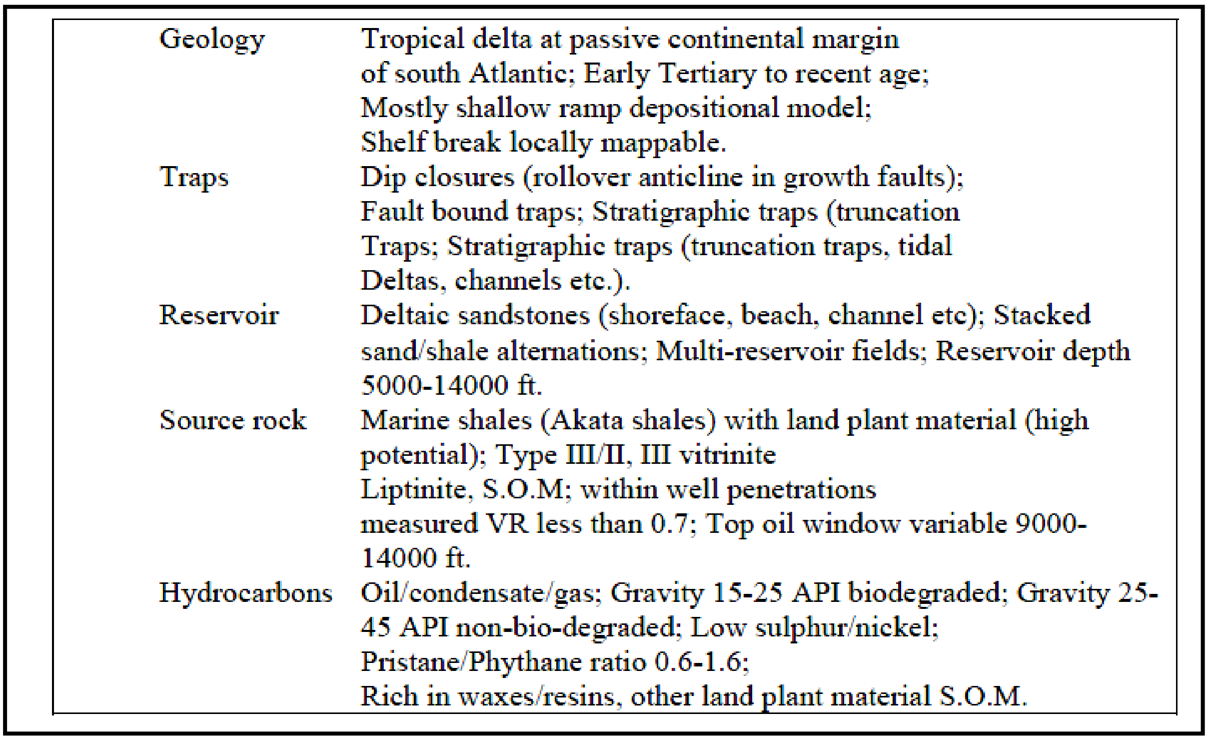
Fig 2.6. Examples of Niger Delta oil field structures and associated trap types. Modified from Doust and Omatsola (1990) and Stacher (1995)

2.2.4 Niger Delta Petroleum System

Petroleum occurs throughout the Agbada Formation in the Niger Delta clastic wedge. Although the distribution of hydrocarbons is complex, there is a general tendency for the ratio of gas to oil to increase southward within individual depobelts (Doust and Omatsola, 1989). Stacher (1995) developed a hydrocarbon habitat model based on sequence stratigraphy of some petroleum-rich belts within the Niger Delta area, and provided a short summary of the basin, trap, reservoir, source rock and hydrocarbon character (Table 2.2). Gas to oil ratios within reservoirs were reported by Evamy et al. (1978), Ejedawe (1981) and Doust and Omatsola (1990). Reservoirs occur along northwest-southeast "oil rich belts" and along a number of north-south trends in the Port Harcourt area. Tuttle et al. (1999) suggest that the belts roughly correspond to the transition between continental and oceanic crust within the axis of maximum sediment thickness.

Other authors have related oil-rich belts to structural and depositional controls, or due to an increase in the geothermal gradient, and shifts in deposition basinward within subsequent depobelts (Ejedawe, 1981; Weber, 1990; Doust and Omatsola, 1990)

Table 2.2: Hydrocarbon Habitat Table (Modified from Stacher, 1995).



Geology	Tropical delta at passive continental margin of south Atlantic; Early Tertiary to recent age; Mostly shallow ramp depositional model; Shelf break locally mappable.
Traps	Dip closures (rollover anticline in growth faults); Fault bound traps; Stratigraphic traps (truncation Traps; Stratigraphic traps (truncation traps, tidal Deltas, channels etc.).
Reservoir	Deltaic sandstones (shoreface, beach, channel etc); Stacked sand/shale alternations; Multi-reservoir fields; Reservoir depth 5000-14000 ft.
Source rock	Marine shales (Akata shales) with land plant material (high potential); Type III/II, III vitrinite Liptinite, S.O.M; within well penetrations measured VR less than 0.7; Top oil window variable 9000-14000 ft.
Hydrocarbons	Oil/condensate/gas; Gravity 15-25 API biodegraded; Gravity 25-45 API non-bio-degraded; Low sulphur/nickel; Pristane/Phythane ratio 0.6-1.6; Rich in waxes/resins, other land plant material S.O.M.

Source rocks in the Niger Delta might include marine interbedded shale in the Agbada Formation, marine Akata Formation shales and underlying Cretaceous shales (Evamy et al, 1978; Ekweozor et al., 1979; Ekweozor and Okoye, 1980; Lambert- Aikhionbare and Ibe, 1984; Bustin, 1988; Doust and Omatsola, 1990). Reservoir intervals in the Agbada Formation have been interpreted to be deposits of highstand and transgressive systems tracts in proximal shallow ramp settings (Evamy et al., 1978). The reservoirs range in thickness from less than 45 feet to a few feet with thicknesses greater than 150 feet (Evamy et al., 1978). Kulke (1995) describes the most important reservoir units as point bars of distributary channels and coastal barrier bars intermittently cut by sand- filled channels. Most primary reservoirs were thought by Edwards and Santogrossi (1990) to be Miocene-aged paralic sandstones with 40% porosity, 2 Darcy permeability, and thickness of about 300 feet. Reservoirs may thicken toward down-thrown sides of growth faults (Weber and Daukoru, 1975). Reservoir units vary in grain size; fluvial sandstones tend to be coarser than the delta front sandstones. Point bar deposits fine upward; barrier bar sandstones tend to have the best grain sorting. Kulke (1995) reported that most sandstone is unconsolidated with only minor argillaceous and siliceous cement. Also potential reservoirs in the outer portion of the delta complex include deep channel sands, lowstand sand bodies and proximal turbidite sandstones (Beka and Oti, 1995). Structural traps were formed during syn-sedimentary deformation of the Agbada Formation (Evamy et al., 1978; Stacher, 1995), and stratigraphic traps were formed preferentially along the delta flanks. (Beka and Oti, 1995), define the most common reservoir locations within the Niger Delta complex. The primary seal rocks are interbedded shales within the Agbada Formation. Three types of seal were recognized: (1) clay smears along faults, (2) interbedded sealing units juxtaposed against reservoir sands due to faulting, and (3) vertical seals produced by laterally continuous shale-rich strata (Doust and Omatsola, 1990). Major erosion events of Early to Middle Miocene age formed canyons which got filled with shale; these fills provide top seals on the flanks of the delta for some important offshore fields (Doust and Omatsola, 1990).

2.3 Review of Related Literature

A number of good publications and attempts have been made to better understand the sequence stratigraphic significances and their associated depositional settings. These numerous findings include but not limited to the works presented in this section of the research.

Salvador, Silvia, Darío, Laura & Marta (2014) said that Bahía Blanca estuary (Argentina) has a morphological configuration resulting from hydrological and sedimentary processes related to Late Quaternary sea level changes. This estuarine system occupies a large coastal plain with a dense net of tidal channels, low-altitude islands and large intertidal flats. Little is known about the sedimentary units of the marine sub-bottom. Therefore, a stratigraphical analysis of the northern coast of Bahía Blanca estuary was carried out using high resolution seismic (3.5 kHz) in order to:(i) define Quaternary sequences, (ii) describe sedimentary structures, and (iii) determine the paleo-environmental conditions of sedimentation. The seismic stratigraphic data collected and their correlation with drilling lithological data show five seismic sequences (S1, S2, S3, S4 and S5), of which S1-S2 were found to be associated with a continental paleo-environment of Miocene-Pleistocene age. Sequences S3 and S4, whose lithology and seismic facies (paleo-channel structures and progradingreflection configurations), were defined on these materials, to evidence the development of an ancient deltaic environment which was part of a large Pleistocene drainage system. The S5 sequence was formed during the Holocene transgressive-regressive process and complete the seismo-stratigraphic column defined in the present study.

John and John (2018) studied the high-resolution sequence stratigraphy: innovation, application and future prospects. They said that Sequence stratigraphy has developed well beyond the global eustatic curves and has become a powerful litho-stratigraphic and facies analysis tool. This volume illustrates that the integration of all lines of evidence (sedimentology, biostratigraphy, structure, seismics etc.) is essential to the development of a high-resolution sequence stratigraphic interpretation. It is notable, however, that although sequence stratigraphy developed from seismic stratigraphy, few of the papers contained within this volume use seismic sections. Seismic reflections are generally thought of as chronostratigraphic surfaces, hence examination of regional stratal termination patterns can establish a chronostratigraphic framework. Related to this well logs can be tied to seismic lines and correlations confirmed in the interwell spacing, this is vital where well spacings are wide. Furthermore, modern seismic surveys, and in particular 3-D surveys, are attaining higher resolutions than was previously possible. Since acoustic impedance can vary across sequence and parasequenceboundaries, Bryant (2020) argues that lateral variations in a reflector along a single reflection, although not revealing the vertical architecture, may enhance the lateral resolution of facies variability within systems tracts.

Nicholas and Neal (1995) carried out a detailed a review on sequence stratigraphy. They said that Sequence stratigraphy is concerned with the analysis of sediments and sedimentary rocks with reference to the manner in which they accumulate layer by layer. As a practical technique and in spite of existing terminology, itrequires no assumptions about eustasy. One of the principal frontiers of the discipline is an effort to develop an understanding of the many interrelated factors that govern sediment transport and accumulation in a great range of depositional settings and environments. The conventional interpretation of sequence boundaries is that they are due to a relative fall of sea level and that they develop more or less instantaneously. They argue that in many cases such boundaries form gradually over a finite interval of geologic time. The widely employed concept of relative sea-level change provides few insights into how sequence boundaries actually develop, especially in tectonically active basins.

Dong, Gwang, Gil, Nyeon, Bo, Young, Jong & Gee-Soo, (2016) presented a work on seismic stratigraphy and depositional history of late quaternary deposits in a tide-dominated setting. They used example from eastern Yellow Sea and commented as follows: Analysis of high-resolution seismic profiles and sediment data from the eastern Yellow Sea reveals that the late Quaternary deposits comprise six seismic units, interpreted as transgressive and highstandsystems tracts formed since the LGM. Each unit was deposited during distinctive portions of the sea-level curve associated with hydrodynamic conditions. During the LGM (>19 ka BP), the study area was completely exposed, resulting in sub-aerial erosion associated with paleo-channel incision by the Huanghe and Korean Rivers. As the shelf wasflooded, the incised channels were backfilled fluvial or coastal sediments, forming incised channel-fill deposits (SU1). The paleo-river may have supplied abundant terrigenous sediments to the study area around the paleo-river mouth and adjacent area.These sediments were trapped within the paleo-estuary and formed SU2, regarded as an estuarine deposit. Two types of serial sand ridges (SU3 and SU5) which correspond to transgressive deposits developed. SU3 on the southern part, west of Jeju Island (80e110 m deep) is regarded as a moribund-type mainly formed during the early to middle stage of transgression. These are thought to have ceased growing and remobilizing. In contrast, SU5 (occurring 30e50 m deep off the Korean Peninsula) is generally regarded as active sand ridges deposited during the late stage of transgression and is partly modified by modern tidal currents. As the transgression continued, the near-surface sediments were reworked and redistributed by shelf erosion, resulting in a thin veneer oftransgressive sands (SU4). The uppermost unit (SU6) formed the Heuksan Mud Belt (HMB), which is one of the most prominent mud deposits in the Yellow

Sea. The lower part of the HMD corresponds to shelf-mud deposited during the late stage of transgression, whereas the upper part consists of a recent shelf-delta developed after the highstand sea level at about 7 ka BP.

Peter (2016) disclosed an attempt to query the future of the sequence stratigraphy paradigm: dealing with a variable third dimension. He incorporated brief history of sequence stratigraphy and questioned sequence stratigraphy if it is a method, model or paradigm. He concluded that Science is about a progression of ideas, methods, and data, and even well-established paradigms change, sometimes through evolution, and sometimes through rapid revolution. Given this, it seems highly unlikely that sequence stratigraphy will stay as it is. More likely is that it will evolve and change as our knowledge and understanding grows, particularly through new methods that lead to new data and new understanding.

Maliva (2016) said that the three-dimensional distribution of bodies of rock and sediments with different sedimentological properties and associated hydraulic properties is controlled to varying degrees by the depositional history of the strata of interest. Primary (depositional) variations in sediment textures and fabrics are modified by diagenetic processes, such as compaction, dissolution, and cement precipitation. A facies is a body of sedimentary rock with specified characteristics, which may include lithology (lithofacies), fossils (biofacies), and hydraulic properties (hydrofacies). Sedimentary facies analysis is based on the concept that facies transitions occur more commonly than would be expected if sedimentation processes were random. A facies model (or type model) is an idealized sequence of facies defined as a general summary of a specific sedimentary environment. Sequence stratigraphy is based on the concept that the sedimentary rock record can be divided into unconformity-bounded sequences, which reflect the sedimentological response to sea level changes, subsidence, and sediment supply.

The value of facies analysis and sequence stratigraphy is that they can provide some predictability to the facies distribution between data points (i.e., wells). Where there is an underlying sedimentological control on the distribution of the hydraulic properties in aquifer systems, facies analysis can be used to better incorporate the underlying sedimentological fabric into groundwater models.

Catuneanu & Zechini, (2012) presented a study on sequence stratigraphic framework and application to the Precambrian. They said that Sequence stratigraphy highlights stratal stacking patterns and changes thereof within a time frame. Each stratal stacking pattern defines a particular genetic type of deposit with a unique geometry and sediment dispersal pattern within the basin. Common genetic types of deposit are referred to as ‘forced regressive’, ‘lowstand normal regressive’, ‘transgressive’, and ‘highstand normal regressive’. These genetic units are the basic building blocks of the sequence stratigraphic framework at any scale of observation, and are bounded by sequence stratigraphic surfaces. The reoccurrence of the same types of sequence stratigraphic surface through geologic time defines cycles of change in accommodation or sediment supply, which correspond to sequences in the rock record. Depending on the scale of observation, sequences and sequence stratigraphic surfaces may be ascribed to different hierarchical orders. The concept of accommodation, which defines the space available for sediments to fill, is central to sequence stratigraphy. Changes in accommodation are in part controlled by regional to local tectonism, and therefore are location specific. The construction of accommodation curves is based on Wheeler diagrams, the preserved thickness of sequences, and the paleo-depositional environment. Accommodation curves may or may not correlate between different sedimentary basins, or even between different sub-basins of the same sedimentary basin, depending on the interplay of local versus global controls on sedimentation. The offset between the accommodation curves that characterize different depozonestends to increase for cycles of increasingly lower rank. While the workflow and principles of sequence stratigraphy remain the same irrespective of the age of strata under analysis, the differences and similarities between the Phanerozoic and the Precambrian rock record provide significant clues to improving our approach to the application of the sequence stratigraphic method.

Catuneanu, (2006) presented a study on sequence stratigraphic context of microbial mat features. He said that microbial mats influenced sedimentary processes and the architecture of the stratigraphic record for at least the past 3.2 Ga of the geological time. The relative importance of microbial activity on sedimentation changed through time as a function of changing environmental energy conditions and the evolution of competing groups of organisms. The influence of microbial mats on sequence architecture is most evident for Proterozoic successions, as the proliferation of microbial mat activity was highest during that time. The strong evolution of grazing metazoan communities following the onset of the Phanerozoic marked a corresponding decline in the relative role of microbial mats on sedimentation. From a sedimentological viewpoint, the organic binding of sediments afforded by microbial mats increases the cohesiveness of the substrate and results in the formation of particular sedimentary structures that provide direct or indirect evidence of syn-depositional activity. The distribution of microbial structures within a sedimentary basin may be used to infer the change in the nature and relative energy of physical processes that operated in different depositional environments during geological time. It is inferred that coastal to shoreface wave erosion may have been stronger in the Precambrian, leading to the preferential preservation of microbial structures within shelf systems. This is contrary to modern trends, where most evidence of microbial activity is preserved in coastal to shoreface environments. Research so far indicates that Precambrian sequences lack well-developed transgressive systems tracts, and are dominated by stacked systems tracts of normal regressive deposits that may be separated by thin veneers of transgressive deposits, often reduced to transgressive lags. This is in contrast to many Phanerozoic sequences, which include fully developed transgressive systems tracts consisting of all depositional systems from fluvial, to coastal and fully marine. The absence (or poor development) of the fluvial to coastal section of the Precambrian transgressive systems tracts may be attributed to the inferred strong wave scouring in the upper shoreface during shoreline transgression. The lack of significant development of transgressive shales above wave ravinement surfaces may be attributed to low sea-floor gradients, promoting rapid transgressions, coupled with a low sediment supply. Within Precambrian sequences, the aggradation of normal regressive deposits in spite of the low sediment supply may be explained by the prolific growth of microbial mats below the fairweather wave-base (within the shelf environment) which prevented deep-water current reworking of sediments, by the organic binding of clastic particles. As such, microbial structures are preferentially preserved within the deeper-water portion of para-sequences.

Catuneanu (2012) said that the study area is divided into three distinct structural zones. It appears that where the autochthonous salt is more extensive, the deformation is more complex and therefore numerous trapping systems are created. In the Annapolis area where the salt is more restricted, deformation is more localized creating small deep basins. To the northeast in proximity to the BSW deformation is less developed because of the limited amount of salt and (except for the BSW itself), geometries are smoother and longer wavelength, leading to fewer trapping systems.

Fielding, Naish, Woolfe, & Lawelle (2002) said that the Oligocene to Quaternary succession encountered in CRP-2/2A is divided into twelve recurrent lithofacies (some of which have been subdivided further), reflecting a range of marine, glacimarine and possibly subglacial environments of sediment accumulation. Acyclical vertical arrangement of lithofacies was noted throughout the core, and is used as the basis for a sequence stratigraphic analysis. Twenty-four sequences are recognized, each of which begins with a Sequence Boundary (Glacial Surface of Erosion), and each is interpreted to record a cycle of glacial advance and retreat with associated changes in relative sea-level. During at least some of these cycles, ice is interpreted to have extended as far as and seaward of the drill-site. A recent reinterpretation of seismic reflection data by Henry et al., (1990) permits the first correlation between seismic reflection records and the stratigraphic surfaces identified herein. All but one of the reflectors recognized correspond to sequence boundaries, and most reflectors correspond to the base of thin, truncated and amalgamated sequences. Additionally, three thick and relatively complete sequences (9 to 11) are identified individually by seismic reflectors. The major surfaces of omission in CRP-2/2A, identified from a variety of evidence, correspond to changes in cross-sectional geometry in the seismic records, and in the case of the unconformity at 307 mbsf can be interpreted as recording the onset of a phase of active tectonic subsidence associated with half-graben development, bounded by periods of more uniform, slower, possibly thermal subsidence. Possible controls on cyclicity are discussed, and include long-term eustatic cycles, Milankovitch frequency cycles, and more local climatic and/or tectonic events. The analysis allows the recognition and separation of tectonic from climatic (glacio-eustatic) controls on the Canozoic stratigraphy of the McMurdo Sound region.

Oluwatoyin (2016) said that the sequence stratigraphic analysis of “Unik” Field located in the Coastal Swamp area of Niger Delta Basin has been carried out. Geophysical wire-line logs from nine wells and a 3-dimensional seismic data in SEGY format were utilized. In the study, the lithologies were identified, the potential reservoirs detected and the reservoir characteristics of the field predicted. Also, sequences, systems Tracts and facies were generated on seismic volume. Ten electrofacies characterizing the main facies of the depositional environments were interpreted within correlative well log depth range of the

"Unik" field. These electrofacies includes: floodplain, transgressive shoreline, point bar, channel fill, multistory channel, tidal flat, barrier bar, barrier foot, stream mouth bar and prograding wedge. Six depositional cycles (sequences) comprising of the lowstand systems tracts (LST), transgressive systems tracts (TST) and highstand systems tract (HST) were identified on the geophysical wire-line logs. These sequences were tied to sequences interpreted on seismic data to give a good tie. Seismic facies analysis of each sequence reveals that the reflection configuration patterns is generally of parallel to sub-parallel, divergent with sheet or wedge shaped external form typical of a shelf environment characterized by a high-energy sedimentation environment with high to medium reflection amplitudes.

Velasco, Cabello, Vázquez-Suñé, López-Blanco, Ramos, & Tuba (2012) said that The Quaternary Besòs delta is located on the Mediterranean coast in NE Spain. The Besòs Delta Complex includes 3 aquifers constituted by 3 sandy and gravelly bodies, separated by lutitic units. These aquifers supply water for domestic and industrial use in this area. Management of groundwater has been problematic in the Besòs delta since the 1960s and continues to pose major problems for subsurface engineering works in this highly urbanized region. This study seeks to demonstrate the advantages of detailed geological characterization and modeling for designing and constructing a hydrogeological model. Available information of the subsurface was compiled, integrated and homogenized in a geospatial database. The interpretation of these data enabled us to delimit geological units by means of a sequence stratigraphic subdivision. A three-dimensional facies belt-based model of the Besòs delta was built on the basis of this geological characterization. This model was used to constrain the distribution of hydraulic parameters and thus to obtain a consistent hydrogeological model of the delta, which was calibrated by data of water management and production over the last hundred years. The resulting hydrogeological model yielded new insights into water front displacements in the aquifer during the time-span considered, improving predictions in an attempt to optimize aquifer management.

Mohammad, Aminul, Mohamed & Nurul (2018) in a study carried out in the Pliocene interval of the southern North Sea F3 Block in the Netherlands demonstrated how an integrated interpretation of geological information using seismic attributes, sequence stratigraphic interpretation and Wheeler transformation methods allow for the accurate interpretation of the depositional environment of a basin, as well as locating seismic geomorphological features. The methodology adopted here is to generate a 3D dip-steered Horizon Cube followed by chronostratigraphic analysis, 3D Wheeler transformation, and system tract interpretation. A dip-steered seismic attribute (similarity, dip, and curvature) was performed on each stratigraphic surface of interest and the isopach maps were generated for each stratigraphic surface to help identify the maximum deposition. The results of this study show that the similarity attribute is able to identify distinct stratigraphic features such as sand-waves and deep marine meandering channels. However, its lateral continuity is poorly understood, as the similarity attribute does not take into account the true geological dip and curvatureof the surfaces. Structural features such as faults are not easily recognizable due to these reasons. However, the dip-apparent attributes are found to be very useful in identifying both the structural and stratigraphic features. The seismic dip map is then improved by rotating the dip measurements to user-defined azimuths. Such optimization has revealed the structural and stratigraphic features that are not clearly evident on the similarity and curvature attributes. The maximum curvature attribute is found to be useful in delineating faults and predicting the orientation and distribution of fractures and also in subtle structural features.

Mingxuan, Xiaomin, Wei, Chenbingjie & Rong (2018) said that the Chagan Sag is a small Early Cretaceous intracontinental passive rift sub-basin in the Yingen- Ejinaqi Basin Group generated on the Tianshan-Xingmeng Orogenic Belt. The Lower Cretaceous strata contain the Bayingebi, Suhongtu, and Yingen Formations deposited during the syn- rift phase. The Wuliji Structural Zone bounded by a high- dip syn- sedimentary fault is an intensively studied area with an extent of ~300 km^{2}having abundant available subsurface dataset and great hydrocarbon potential. According to well and seismic based sequence stratigraphic study, the Upper Bayingebi Member generally corresponds to a complete third-order transgressive–regressive sequence in the Wuliji Structural Zone. The transgressive system tract gradually thins towards the north, but the regressive systems tract covers the entire study area in this third-order sequence. Further investigations reveal that tectonic subsidence and climate change are two predominant allogenic factors for controlling stratigraphic development in the Wuliji Structural Zone. During the deposition of the Upper Bayingebi Member, transverse gravity flow dominated fan-delta complexes that was sourced from the MaodunSub-uplift are. The retrogradational conical fan deltas are mainly located in the southern sector during the transgressive system tract stage, but the progradational Gilbert-type fan deltas are widely developed during the regressive stage of the sea.

According to Fielding et al., (2002), the sedimentary evolution and stratigraphic architecture are directly linked with preexisting topography, accommodation, and sediment supply. In addition, climate change and vegetation types are thought to be critical controls for fluid properties originated from feeder drainage systems and depositional processes of the construction of fan delta complexes in the distinct system tracts

Ashton, Donald, Benoit & Piero (2007) described sequence stratigraphy as a stratigraphic discipline in which stratigraphic surfaces that represent changes in depositional trend are used for correlation and for defining specific types of sequence stratigraphic units. On the basis of both empirical observations and theoretical models, numerous different types of surfaces have been proposed as unit boundaries in sequence stratigraphy. The study revealed that only four surfaces are appropriate for bounding units in sequence stratigraphy. These are a sub-aerial unconformity, an unconformable shoreline ravinement, a maximum regressive surface and a maximum flooding surface. Proposed surfaces that are not suitable to act asa sequence stratigraphic unit boundary include hypothetical time surfaces at the start and end base level fall (the basal surface of forced regression and the correlative conformity), highly diachronous sequence stratigraphic surfaces (normal shoreline ravinement, regressive surface of marine erosion) and highly diachronous within-trend facies boundaries (base of turbidites or shallow water strata, marine flooding surfaces).

Michal, Ivan, Mathais, Ivan & Natalia (2004) in a study of the Vienna Basin identified the depositional systems of alluvial plains, deltas, littoral and neritic environments during the paleogeo-graphic evolution of the basin. Their mutual interrelationship was discussed to be triggered by sea-level changes. Based on evaluation of the sedimentary environments, the possibilities of creating an accommodation space by tectonic subsidence, as well as the basin fill by increased input of clastics by deltas it can be stated that only partial comparison between global and regional sea-level changes is possible in the Miocene. Nine third-order cycles of relative sea-level changes are proposed for the Miocene of the Vienna Basin. These cycles, termed VB1 to VB9, resulted from combination of eustatic global sea-level changes, tectonic evolution of the basin and sediment supply mostly by deltas in this area. Some of these cycles correspond fairly to regional chronostratigraphic stages, whilst others, such as VB5–7 cycles, follow other criteria.

Tegan (2015) studied the central northern part of the Bredasdorp Basin of southern offshore South Africa, where the depositional environments of wells E-M1,E-M3 and E-AB1 were inferred through electro sequence analysis and sequence stratigraphy analysis of the corresponding seismic line (E82-005). For that, the Petroleum Agency of South Africa (PASA) allowed access to the digital data which were loaded onto softwares such as PETREL and Kingdom SMT for interpretational purposes. The lithologies and sedimentary environments were inferred based on the shape of the gamma ray logs and reported core descriptions. The sequence stratigraphy of the basin comprises three main tectonic phases: Syn-rift phase, Transitional phase and Drift phase. Syn-rift phase, which began in the Middle Jurassic during a period of regional tectonism, consists of interbedded red claystones and discrete pebbly sandstone beds deposited in a non-marine setting. The syn-rift 1 succession is truncated by the regional Horizon 'C'(1At1 unconformity). The transitional phase was influenced by tectonic events, eustatic sea-level changes and thermal subsidence and characterized by repeated episodes of progradation and aggradation between 121Ma to 103Ma, from the top of the Horizon 'C'(1At1 unconformity) to the base of the 14At1 unconformity. Finally, the drift phase was driven by thermal subsidence and marked by the Middle Albian14At unconformity which is associated with deep water submarine fan sandstones. During the Turonian (15At1 unconformity), highstand led to the deposition of thinorganic-rich shales. Tegan (2005) concluded that the depositional environment is shallow marine, ranging from prograding marine shelf, a transgressive marine shelf and a prograding shelf edge delta environment.

Daniel, Rudy, Mike, Reed & Terry (2014) in their study revealed that Organic-carbon–rich shales of the lower Marcellus Formation were deposited at the toe and basinward of a progradingclino-them associated with a Mahantango Formation delta complex centered near Harrisburg, Pennsylvania. Distribution of these organic-carbon–rich shales was influenced by shifts in the delta complex driven by changes in rates of accommodation creation and by a topographically high carbonate bank that formed along the Findlay-Algonquin arch during deposition of the Onondaga Formation. Specifically, we interpret the Union Springs member

(Shamokin Member of the Marcellus Formation) and the Onondaga Formation as comprising a single third-order depositional sequence. The Onondaga Formation was deposited in the lowstand to transgressive systems tract,and the Union Springs member was deposited in the transgressive, highstand, and falling-stage systems tract. The regional extent of parasequences, systems tracts, and the interpreted depositional sequence suggest that base-level fluctuations were primarily caused by allogenic forcing eustasy, climate, or regional thermal uplift or subsidence insteadof basement fault reactivation as argued by previous workers (Velasco et al, 2012). Paleo-water depths in the region of Marcellus Formation black mudrock accumulation were at least 330 ft (100 m) as estimated by differences in strata thickness between the northwestern carbonate.

Morad, Ketzer, & De Ros (2012) presented that Sequence stratigraphy is a useful tool for the prediction of primary (depositional) porosity and permeability. However, these primary characteristics are modified to variable extents by diverse diagenetic processes. This paper demonstrates that integration of sequence stratigraphy and diagenesis is possible because the parameters controlling the sequence stratigraphic framework may have a profound impact on early diagenetic processes. The latter processes play a decisive role in the burial diagenetic and related reservoir-quality evolution pathways. Therefore, the integration of sequence stratigraphy and diagenesis allows a proper understanding and predictionof the spatial and temporal distribution of diagenetic alterations and, consequently, ofreservoir quality in sedimentary successions.

Kenneth, GregoryJames, Miriam, Donald, Peter, Hisao, Maria, Christian, David, Stephen, Sarp, Jean-Noel. and Marina (2013) noted that We present seismic, core, log, and chronologic data on three early to middle Miocene sequences (m5.8, m5.4, and m5.2; ca. 20–14.6 Ma) sampled across a transect of seismic clinothems (prograding sigmoidal sequences) in topset, foreset, and bottomsetlocations beneath the New Jersey shallow continental shelf (Integrated

Ocean Drilling Program Expedition 313, Sites M27–M29). They recognize stratal surfaces and systems tracts by integrating seismic stratigraphy, litho-facies successions, gamma logs, and foraminiferal paleo-depth trends. Their interpretations of systems tracts, particularly in the foresets where the sequences are thickest, permitted the testing of sequence stratigraphic models. Landward of the clinoform rollover, topsets consist of nearshore deposits above merged transgressive surfaces (TS) and sequence boundaries overlain by deepening and fining-upward transgressive systems tracts (TST) and coarsening and shallowing-upward highstand systems tracts (HST). Drilling through the fore-sets yielded thin (<18 m thick) lowstand systems tracts (LST), thin (<26 m) TST, and thick HST (15–90 m). This contrasts with previously published seismic stratigraphic predictions of thick LST and thin to absent TST. Both HST and LST show regressive patterns in the cores. Falling stage systems tracts (FSST) are tentatively recognized by seismic downstepping, although it is possible that these are truncated HST; in either case, these seismic geometries consist of uniform sands in the cores with a blocky gamma log pattern. Para-sequence boundaries (flooding surfaces) are recognized in LST, TST, and HST. TS are recognized as an upsection change from coarsening to fining upward successions. The study recognized little evidence for correlative conformities; even in the foresets, where sequences are thickest, there is evidence of erosion and hiatuses associated with sequence boundaries. Sequence m5.8 appears to be a single million-year-scale sequence, but sequence m5.4 is a composite of 3 ~100-k.y.-scale sequences. Sequence m5.2 may also be a composite sequence, although our resolution is insufficient to demonstrate this. The study did not resolve the issue of fractal versus hierarchical order, but the data are consistent with arrangement into orders based on Milankovitch forcing on eccentricity (2.4 m.y., 405 and 100 k.y. cycles) and obliquity scales (1.2 m.y. and41 k.y.).

2.4 Research Gap

Integration of sequence stratigraphy, seismic and petrophysics has not been widely employed in the study of the Coastal Swamp depobelt of the Niger-Delta Basin regardless of large data base of 2D/3D seismic lines, well logs and bio facies data obtained from oil exploration activities within the basin. The breakthrough most of the indigenous company are encountering in the marginal fields abandoned by most multinational companies due to their focus on giant fields offshore Niger Delta have shown that there are much to expect in terms of petroleum prospect in the onshore part of the basin.

That is to say that with proper application of sequence stratigraphy, proper structural analysis including fault seal analysis studies in these marginal fields, more and even bigger oil fields or traps could be discovered; that has been bypassed (missed) by previous explorer caused by either complex distinctive structural characteristics or the complexity of the stratigraphic nature of the delta which may have mislead them and hinder the discovering of some trap.

Furthermore, there is need to carry out a qualitative reservoir interpretation and delineation of possible variable depo environment within and across the reservoirs using integrated approach and the assessment of sealing capacities of the faults in fault dependent reservoirs to ascertain hydrocarbon accumulations.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Materials

Data sets from thirteen 913) drilled wells aere used for this study and their location are presented in Fig 4.1. The data used in this study include well data (gamma ray, resistivity, caliper, sonic, neutron and density logs), checkshot, 3D Seismic volume and biostratgraphic data. The various reservoir sand unit's signatures and nomenclatures were interpreted using the gamma ray logs while the fluid identifications were carried out using the resistivity, neutron, sonic, and density logs.

3.2 Methods

3.2.1 Lithology Identification

Gamma ray (GR) log was used to discriminate between shale and non shale units. High GR readings (> 50 API) which indicated high radioactive content was interpreted as shale while low GR readings (< 40 API) indicative of low radioactive content were identified as non shaly lithology. Bearing in mind that the study area is in a siliciclastic environment, the non shaly units were interpreted to be sandstone (Fig. 3.1)

3.2.2 Reservoir Identification and Fluid Typing

Resistivity logs were used to determine the presence of hydrocarbon within the interpreted sandstone units. High resistivity readings were indicative of hydrocarbon bearing sands (reservoir), while those containing saline water showed very low resistivity readings (Keary & Brooks, 1991) (Fig. 3.2). In the hydrocarbon column, an overlay of density and neutron logs were used to discriminate between gas and oil, and to define the hydrocarbon water contacts (Fig. 3.2). Low neutron and a corresponding low density reading was interpreted as gas. When both curves track along close to each other within a high resistivity reservoir, it was interpreted as oil.

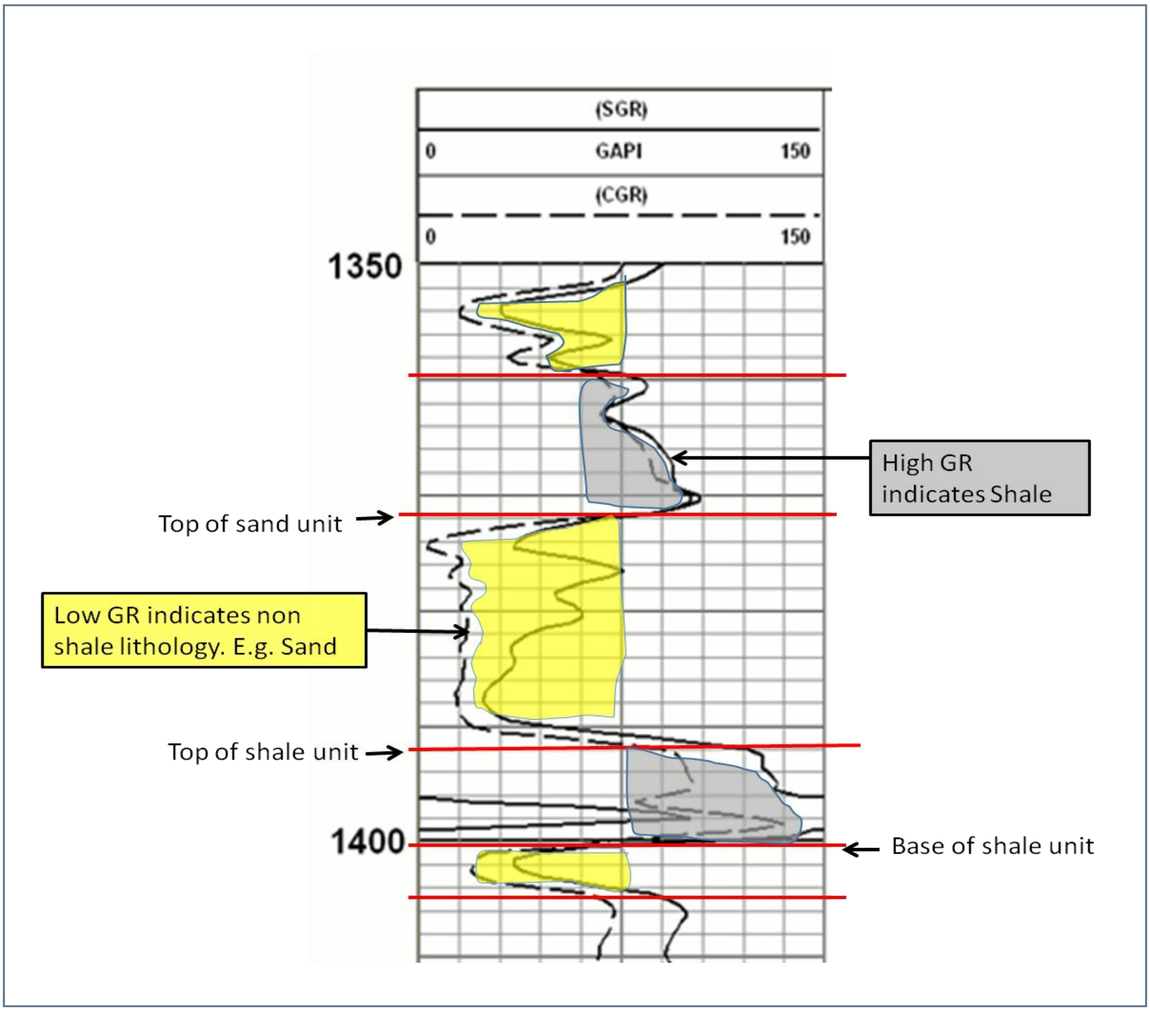


Figure 3.1 Representative GR log showing Lithology identification; High GR readings indicate shale while low GR readings indicate non-shale lithology such as sand (Fielding et al, 2002)

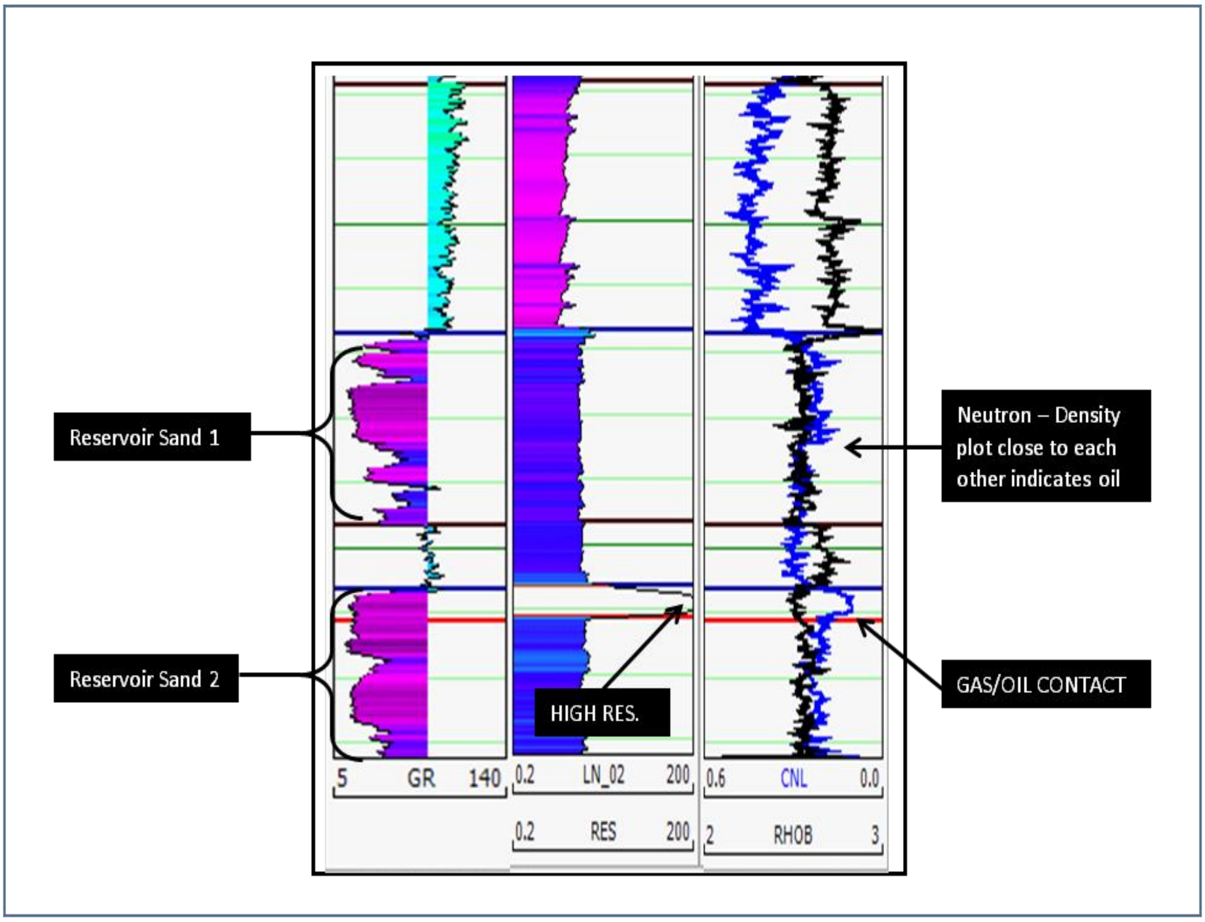


Figure 3.2 Hydrocarbon identification and fluid typing. Separation of neutron and density logs within the hydrocarbon reservoir indicates presence of gas (Keary & Brooks, 1991).

3.2.3 Stratigraphic Correlation

Correlation in this study was conducted along an open ended correlation transect line as shown in Fig. 3.3. This was used to ensure that wells in close proximity and rocks that are stratigraphically related were considered first. The notation of any discontinuities, truncations or outrageous thinning or thickning of strata was also incorporated in the correlation thereby giving them the proper geologic interpretation that might have occured in the field.

Stratigraphic correlation was carried out for this work in order to understand the subsurface lateral distribution or relationship of the reservoir units in the wells within the field. The procedure for correlation involved:

i. Selecting a type log: This is a representative log that shows a complete section of sediments covering the thickest and deepest sedimentary interval in the field. For this purpose, well 3 was selected.

ii. Log display: The wells were displayed side by side with their respective logs on the cross section panel. The wells were then arranged in order of direction of deposition i.e. from proximal to distal.

iii. Correlation: Biostratigraphic results were used to establish different genetic units from which the systems tracts were interpreted (Fig. 3.4) Different reservoir geometries were observed indicating possible effect of faulting as well as fluctuations of the coastline with respect to the sediment influx.

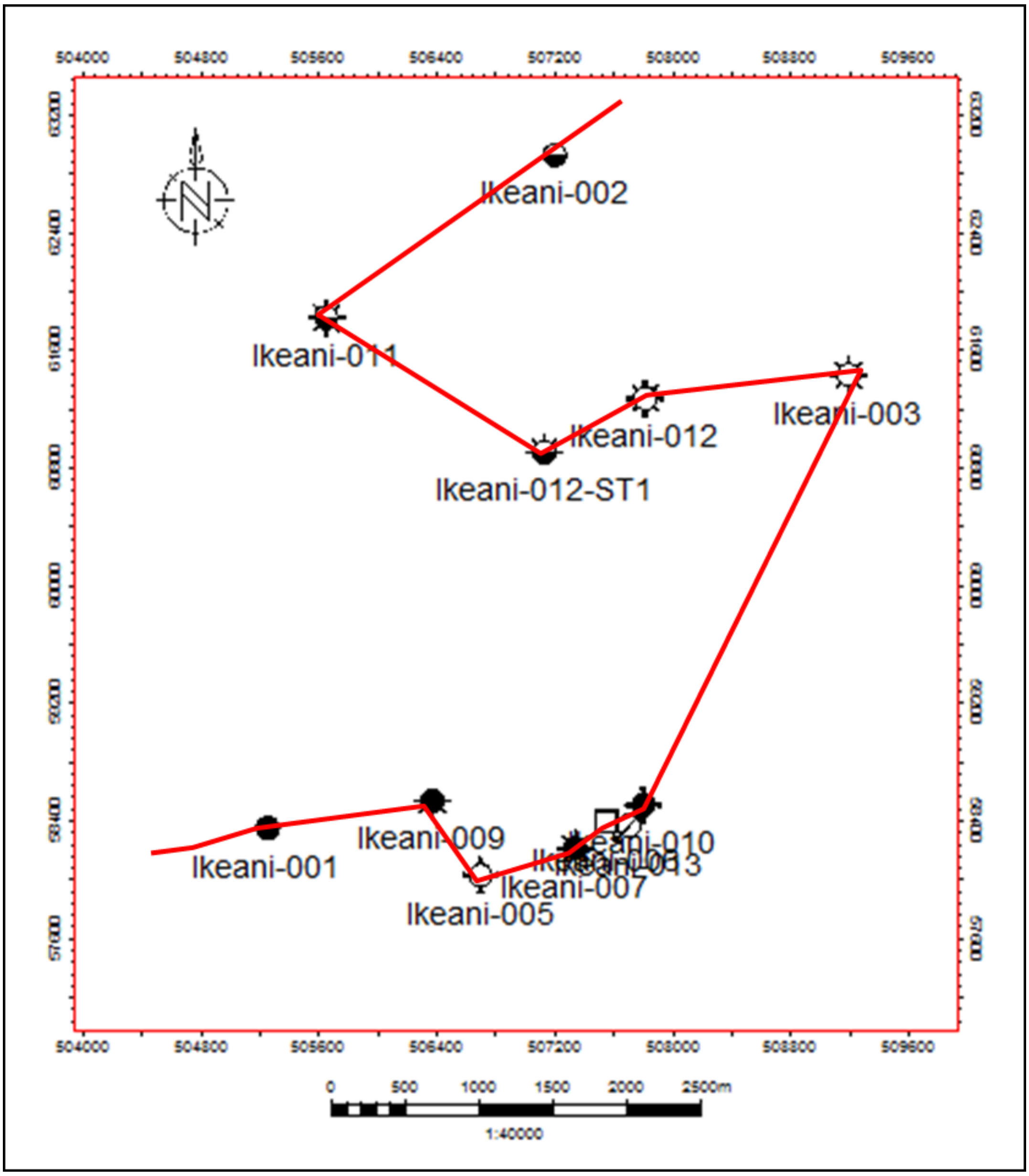


Figure 3.3 Base map of the study area showing transect line for cross-section across wells in the field.

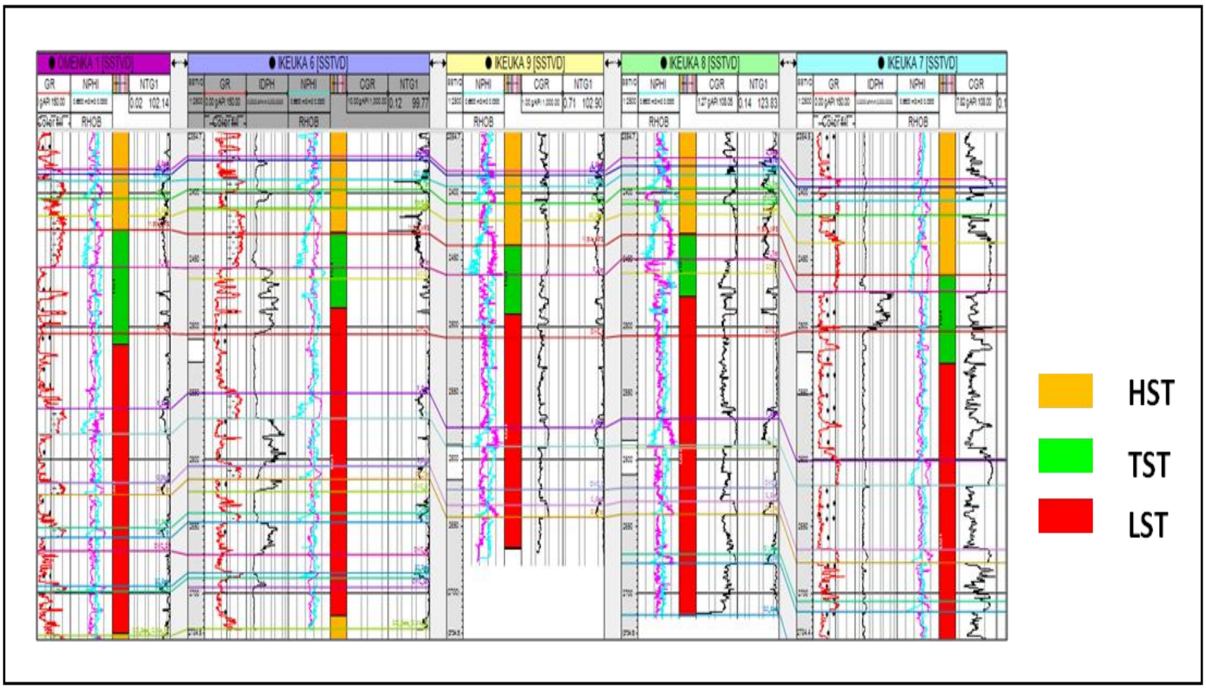


Figure 3.4 Well correlation using identified systems tracts

3.2.4 Volume of Shale (Vshale) Calculation

The volume of shale (Vsh) is a critical parameter in petrophysical analysis that enables the accurate estimation of other petrophysical parameters like effective porosity, saturation and Net-to-Gross.

Shale volume was calculated using gamma-ray logs to first determine the gamma-ray index based on the equation below:

$$GR_{index} = \frac{GR - GR_{\min}}{GR_{shale} - GR_{\min}} \text{ …………………… Eqn. 1}$$

The GR index was then incorporated in the Larionov equation for tertiary rocks (Larionov 1969) as shown below:

$$V_{sh} = 0.083 \times (2^{(3.7 \times GR_{index})} - 1) \text{ ……………..Eqn. 2}$$

Where GR is the gamma-ray (GR) log reading in the zone of interest;

$GR_{\min}$ is the GR log reading in 100% sandy rock;

GR_{shale} is the GR log reading in 100% shale;

GR_{index} is the gamma-ray index;

V_{Sh} is the volume of shale.

3.2.5 Fault Interpretation

This involved picking faults on the seismic data to unravel the structural framework of the study area. On the seismic data, faults were seen as discontinuities in the seismic reflections (Fig. 3.5) Seismic attributes helped to reveal changes in dip magnitude, dip azimuth and reflective amplitude. Seismic interpretation was carried out using a 3-D seismic volume and extracted semblance volume. The extracted semblance volume was dip guided to capture the actual orientation of the faults. This was cut at several time slices to ascertain the range and time penetrations of the faults in milliseconds in order to capture the original geology in the fault interpretation stage. The lateral extents of the faults were also ascertained using the semblance map. Semblance is a discontinuity attribute that was implemented on the seismic volumes to detect edges in the data and accentuate faults (Filbrandt, Naruk, Wilkins, Dula, and Ganz, 2007).

Interpretation was mostly done on the inline because they tended to reveal faults better. This is because inlines run perpendicular to the paleo-shoreline, therefore any structure that lies parallel to the strike will be conspicuous on the seismic inline section. After faults had been interpreted, the fault sticks were then combined into fault surfaces in the 3-D volume.

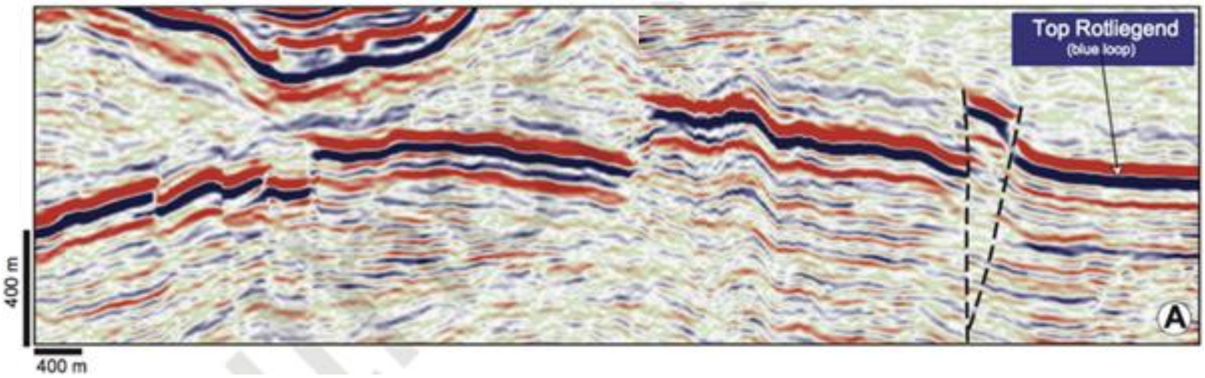


Figure 3.5a. Fault mapping from discontinuities in seismic reflections along profile A-A’

(Filbrandt, 2007)

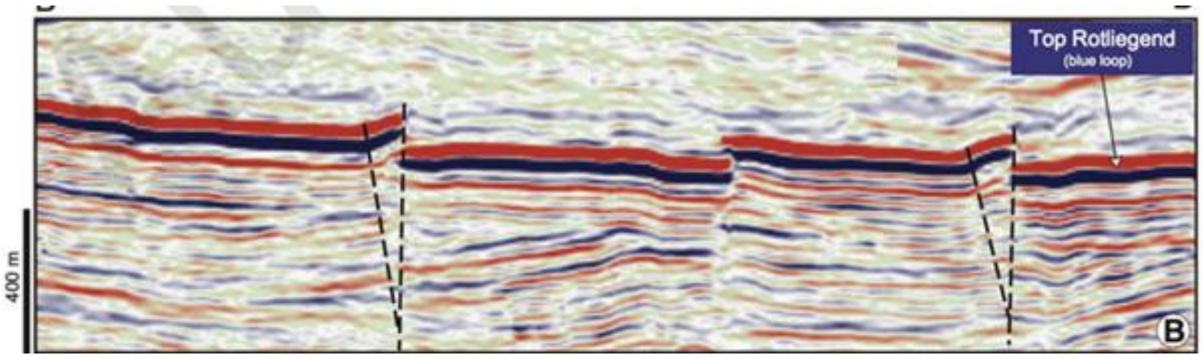


Figure 3.5b Fault mapping from discontinuities in seismic reflections along profile B-B’

(Filbrandt, 2007)

3.2.6 Well to Seismic Tie

This process involved the use of well data (which is measured in depth) to calibrate seismic data (which is measured in travel time) in order to arrive at a harmony so that features from the well could be placed in their proper position on the seismic (Shannon & Naylor, 1989). Velocity information from sonic and density logs were used to generate a synthetic seismogram thereafter, the synthetic was aligned with the seismic reflection data (Fig. 3.6) and adjusted appropriately by stretching and squeezing in order to get a good match. This resulted in a good tie between the well logs and the seismic.

3.2.7 Horizon Mapping

Reservoir tops that were identified from the wells with the use of well logs were then positioned on a seismic section. The top corresponded with the peak of the seismic trace, which marks the seismic event to be traced throughout the seismic volume. The tracing was achieved by using various interactive tools such as auto-pick and manual pick on the interpretation window of the Petrel software (Ashton, Erik, Donald, Benoit and Piero, 2007) Horizons were picked line by line at specified increments both on inlines and crosslines. As the horizons were being picked, a grid was also being generated for it and was displayed on the 2-D window; this helped to monitor the progress of the interpretation. After picking the horizon, a time structure contour map was then generated.

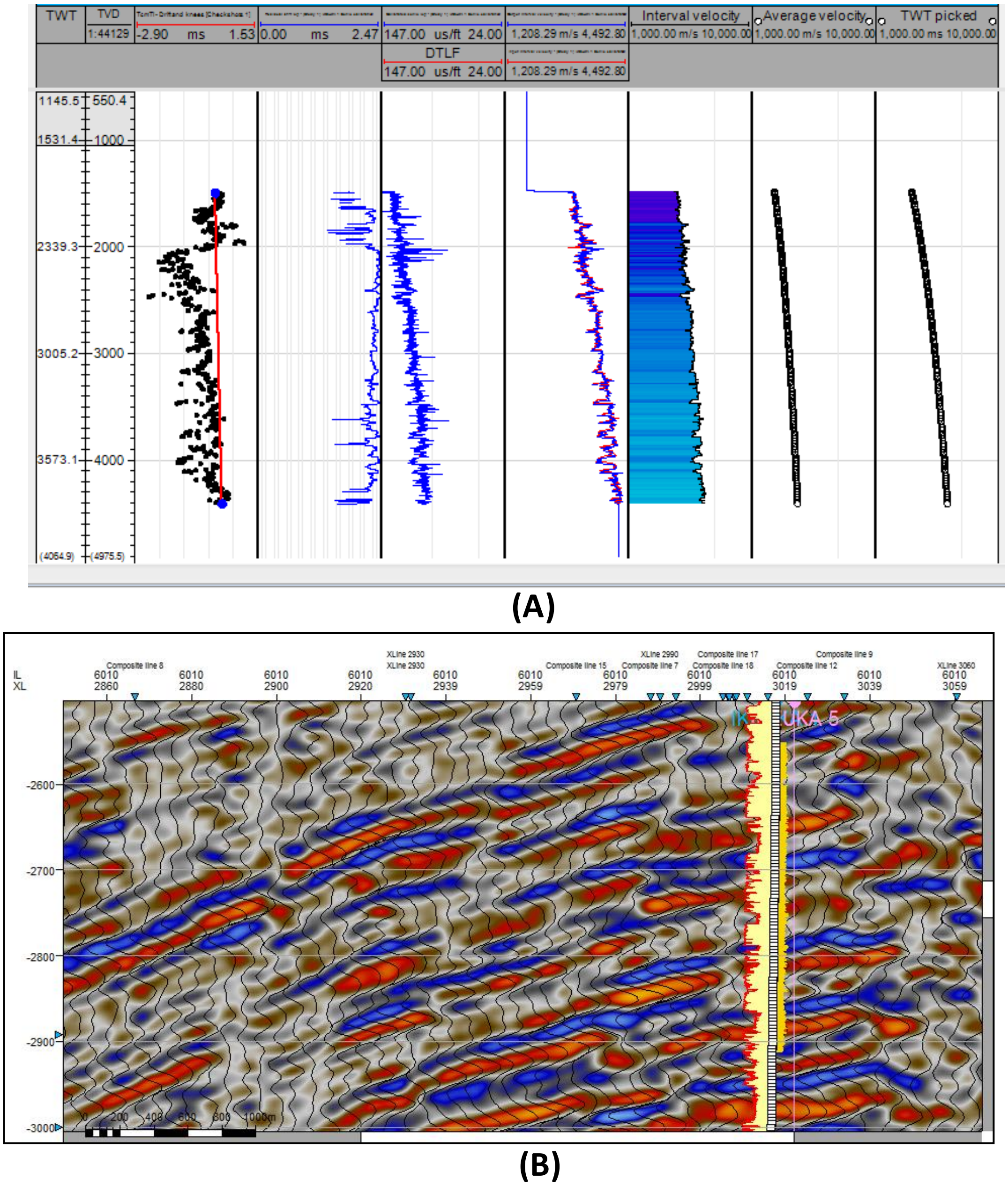


Figure 3.6a-b The process of generating the synthetic seismogram for well to seismic tie (Shannon & Naylor, 1989).

3.2.8 Fault Seal Analysis

This fault analysis was focused on the relationship between stratigraphic juxtaposition and fault rock properties to form seal across the identified fault surface. Juxtaposition diagrams were plotted to determine the stratigraphic relationship across the fault surface. The displacement of major and minor fault segments within the reservoir juxtaposed the reservoir across the fault surface against dissimilar lithologies, which could impact the fluid flow.

Integrating identified lithologies with mapped horizons and faults enabled the determination of the stratigraphic distribution across the fault using the Allan Diagram after Allan (1989), (Fig. 3.7)

The technique involved selecting a fault surface and mapping the positions of both footwall and hanging-wall on it. The trap and spill points were then determined from the juxtaposition of the lithologic units.

The property of the fault rock was determined using Shale Gouge Ratio (SGR) algorithm (Eqn. 3) to calculate the fault zone shale content and to quantitatively evaluate fault rocks seal. SGR is a function of the volume of shale, thickness of each lithologic unit as well as the throw (Fig. 3.8)

$SGR = \frac{\sum(Vsh * \Delta z)}{Throw} * 100\%$ -------------- Eqn. 3

Where Vsh = Volume of Shale

Δz = change in thickness of the lithologic units

Values between 15 and 20 % represented a threshold value between non-sealing and sealing faults (Yielding & Freeman, 2010). SGR<20 % (or a ratio of < 0.2) are typically associated with cataclastic fault gouge and sealing of the fault is considered as unlikely. Higher values of Shale Gouge Ratio correlate with greater fault seal potential. SGR 0.2-0.4 (20 %-40 %) is associated with phyllosilicate framework and some clay smear fault rocks. Here fault is taken as poor seal and will be retarding to fluid flow. For SGR 0.4-0.6 (40 %-60 %) fault is considered to be moderate seal. It will be associated mainly with clay smears. For SGR > 0.6 (60 %) is taken as a likely sealed fault.

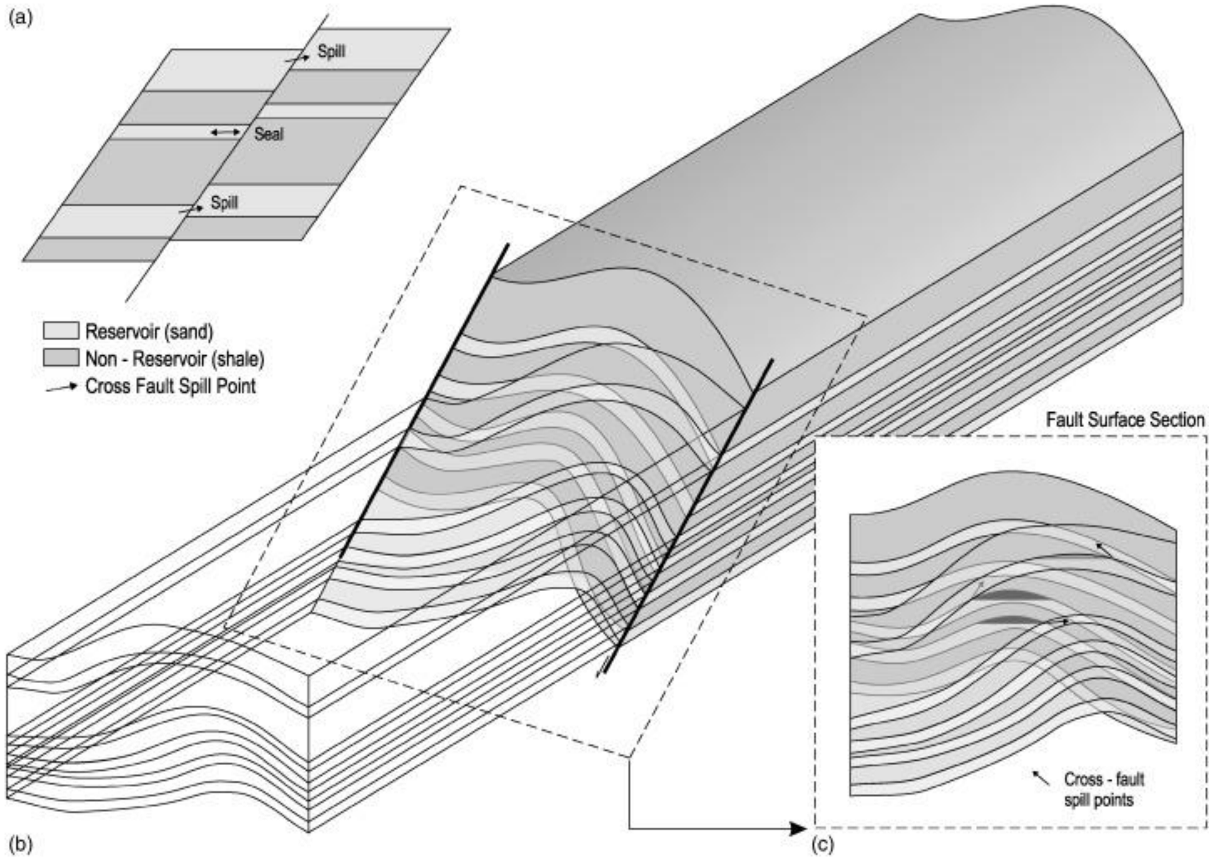
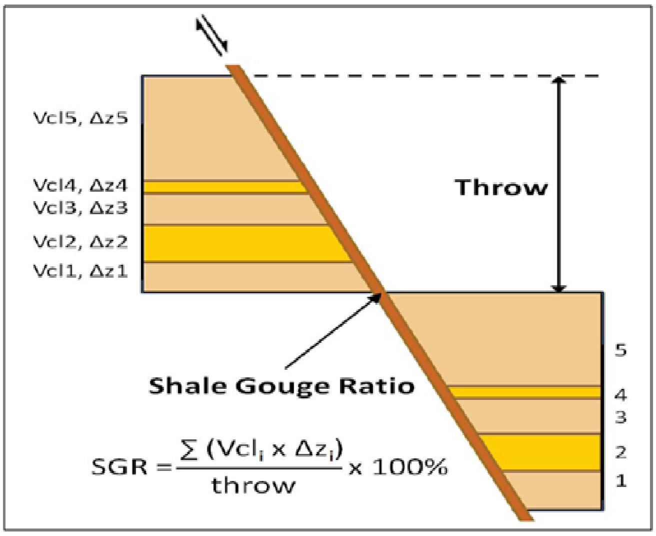


Figure 3.7 The principles of Allan Mapping (after Allan, 1989). (a) Fault displacement can provide cross-fault seal by juxtaposing impermeable units against potential reservoir units. (b) In three dimensions, the interaction of juxtaposed units across the fault surface section can be complex. (c) The Allan Mapping technique resolves the fault surface into a flat plane and maps the positions of both footwall and hanging-wall cut-offs. Traps and spill points can then be determined from the juxtaposition of lithological units.



Vcl = Volume of clay
Δz = Thickness of individual bed

Figure 3.8 Shale Gouge Ratio calculations (after Allan, 1989)

3.2.9 Biostratigraphic Analysis

Biostratigraphy data was used to correlate and assign relative ages of rock strata by using the fossil assemblages contained within them. It was used to show how a particular horizon in one geological section correlates with the same period of time at another horizon at some other section. Biostratigraphic data enabled delineation of the maximum flooding surface, age and paleoenvironmental control for system tract interpretations. The population and diversity of the benthic and planktonic foraminifera with corresponding lithofacies were used for interpretation of environment of depositionand paleobathymetry accortding to the biostratigraphic model of Allen, (1965) and Petters, (1995) as shown in Figure 3.9.

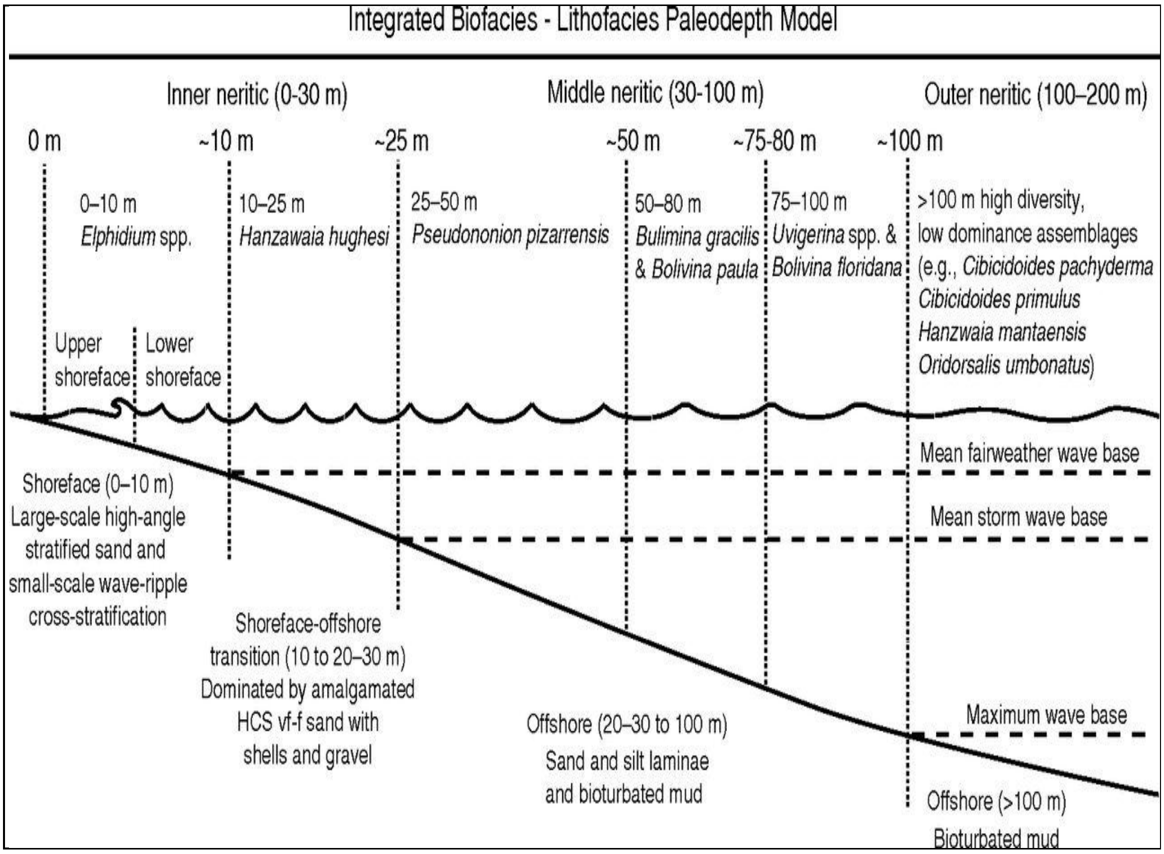


Figure 3.9: Paleobathymmetry and Depositional Environment Chart (Modified After Allen, 1965).

3.2.10 Sequence Stratigraphic Analysis

The genetic stratigraphic sequence (Galloway, 1989) is the method of sequence delineation adopted in this research. It uses maximum flooding surfaces as sequenceboundaries, and it is subdivided into highstand, lowstand (fall and early rise), and transgressive systems tracts. This model overcomes the recognition problemsrelated to the correlative conformity.Its advantage is that maximum flooding surfaces are relatively easyto map across a basin. The sequence stratigraphic analysis utilized genetic sequences constrained within chronostratigraphic packages. The maximum flooding surface (MFS) within the condensed section were used to define the genetic packages.

3.2.10.1 Stacking patterns and parasequences

The well log suites made available for this research displayed at consistent scales to reveal log trends and enhanced the identification of facies stacking patterns and parasequences. Parasequence stacks (vertical occurrences of coarsening or fining upward sequences of repeated cycles) identified resulted to progradational, retrogradational, or aggradational parasequence sets (Onyekuru & Iwuagwu, 2010).

3.2.10.2 Stratigraphic surfaces, systems tracts and depositional sequences

The maximum flooding surface (MFS) was mapped using wireline logs and biostratigraphic data. It was marked as the surface that caps the transgressive systems tract and marks the turnaround from retrogradational stacking in the transgressive systems tract to aggradational or progradational stacking in the early highstand systems tract. It was further delineated as units with maximum positive Neutron-Density separation, high gamma response, minimum shale resistivity and high faunal diversity and abundance and maximum water depth (Catuneanu & Zecchin, 2012).

The transgressive surface of erosion (TSE), a prominent flooding surface that caps the lowstand systems tract, is the first significant flooding surface to follow the sequence boundary and forms the lower boundary of the retrogradational parasequence stacking patterns of the transgressive systems tract. This was delineated and inferred from a characteristic signature on the resistivity logs caused by presence of carbonate cements probably derived from the carbonate fauna eroded during ravinement of already deposited sediments. Sequence boundaries were identified in areas where faunal abundance and diversity were low and/or bio-events were lacking, this corresponded to high resistivity value and low gamma ray responses within the shallowing section (Catuneanu, 2006).

Sequence boundaries were identified at the base of thickest and coarsest sand units between two adjacent maximum flooding surfaces, which naturally coincided with the shallowest environments marked by low or total absence of foraminiferal abundance and diversity.

Three systems tracts comprising lowstand systems tract, transgressive systems tract, and highstand systems tract were identified and mapped with the aid of depositional sequence models (Fig 3.10) (Emery & Myers, 1996)

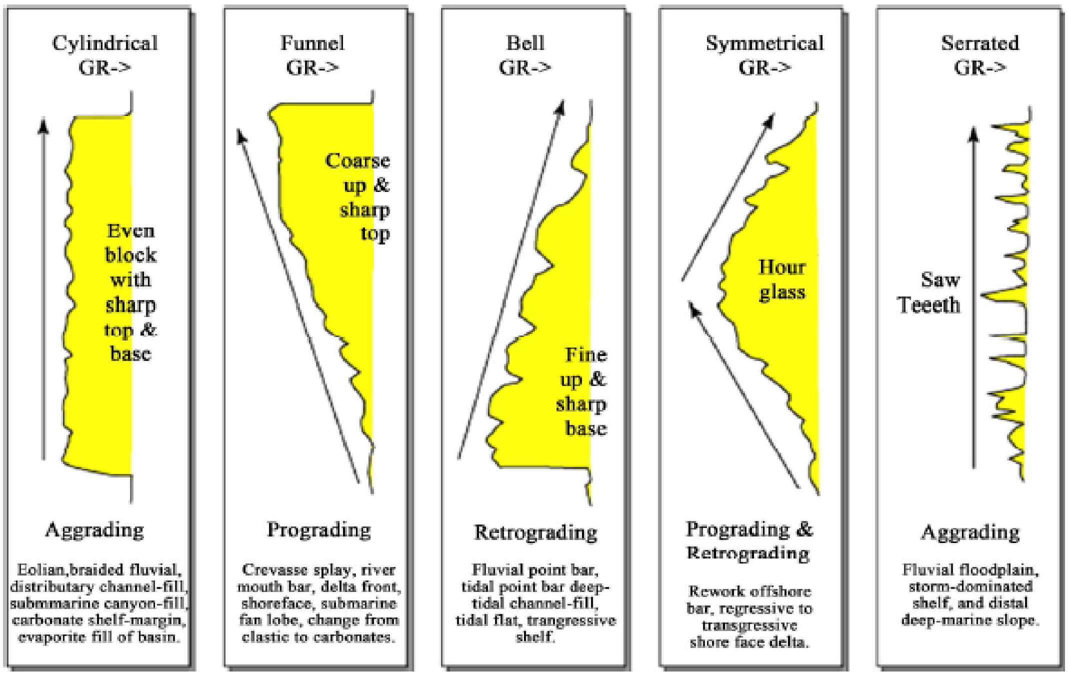


Figure 3.10: Gamma ray response to grain size variation model (Emery & Myers, 1996)

3.2.11 Seismic sequence stratigraphy

Seismic stratigraphy was incorporated to provide a geologic approach to the stratigraphic interpretation of seismic data. Seismic studies provided the lateral continuity to the sequence stratigraphic framework. It was employed to recognise and correlate regional stratal surfaces to define genetically related rock units that represent discrete chronostratigraphic intervals (Vail *et al.*, 1977). Primary seismic reflections were generated by time correlative bedding surfaces and surfaces that separate sets of contemporaneous system tracts (Van Wangoner *et al.*, 1988).

3.2.11.1 Seismic facies analysis

Seismic facies analysis was carried out by describing and interpreting seismic reflections of lithofacies with parameters such as continuity, amplitude, frequency, and interval velocity.

3.2.11.2 Seismic attribute analysis

Seismic attribute analysis to examine subtle changes in properties of particular reflections to determine rock properties, including fluid contents (Sengbush, 1962).

Seismic interpretation was carried out using below procedure:

a. Depositional sequence and system tracts was delineated
b. Seismic facies within each system tracts were delineated and mapped.
c. Attributes within specific seismic facies were evaluated.

Seismic Attribute extraction applied in this study involves the Root Mean Square (RMS) Amplitude to delineate depo facies as a base to complement the seismo facies interpretations.

Then, fluid delineations were supported with 3D structural analysis depicting fault sealing capacities and top seal predictions.

3.2.12 Root Mean square Amplitude

In statistics, the RMS of (x1, x2……xn) is equal to the square root of the sum of the squares of the values divided by n.

In geophysics, RMS amplitude is the square root of the average of the squares of a series of measurements. The auto correlation value (without normalizing) for zero lag is the mean square value. For a sine wave, the RMS value is $\frac{1}{\sqrt{2}}$ times the peak amplitude.

The RMS value of a set of values is the square root of the arithmetic mean of the squares of the values, or the square of the function that defines the continuous-time waveform. [3] It's also known as the quadratic mean of amplitude and is a particular case of the generalized mean with exponent 2. In a set of n values (x1, x2……xn) the RMS is

$$x_{\mathrm{RMS}} = \sqrt{\frac{1}{n}\left({x_1}^2 + {x_2}^2 + \cdots + {x_n}^2\right)}.$$

The corresponding formula for a continuous function (or waveform) *f*(*t*) defined over the interval $T_1 \leq t \leq T_2$ is

$$f_{\mathrm{RMS}} = \sqrt{\frac{1}{T_2 - T_1}\int_{T_1}^{T_2} [f(t)]^2\, \mathrm{d}t},$$

and the RMS for a function over all time is

$$f_{\mathrm{RMS}} = \lim_{T\to\infty}\sqrt{\frac{1}{2T}\int_{-T}^{T} [f(t)]^2\, \mathrm{d}t}.$$

The RMS over all time of a periodic function is equal to the RMS of one period of the function. The RMS value of a continuous function or signal can be approximated by taking the RMS of a sample consisting of equally spaced observations.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Field Location

The Ikeani field is located within the coastal swamp depo belt of the Niger Delta (figure 4.1). This depo belt underlies the central swamp depo belt and overlies the shallow offshore depo belt. The area coverage of the study field is as shown in the base map (figure 4.1) indicating the distributions of the drilled wells. A total of thirteen (13) drilled wells are used for the research study and their locations are as shown in the base map.

4.1.2 Correlation Plan and Transect used

The stratigraphic correlations were guided using an open ends correlation transect line. The essence of the used transect line is to ensure that proximity in well to well correlation. These were done to ascertain that wells that are stratigraphically related were correlated first while using such (transect line) to enhance strata relationships within the field. The correlation transect line also have structural connotations. The structural significances include the delineations of faults across the transect line inorder to define points of strata missing sections (faulted out) and short sections partly (faulted out or fault cut) as the case may be. These were integrated in the well correlation and seismic interpretations to avoid the misunderstanding of faults implications from stratigraphic variations. Details of the correlation transect line is as shown in (figure 4.2).

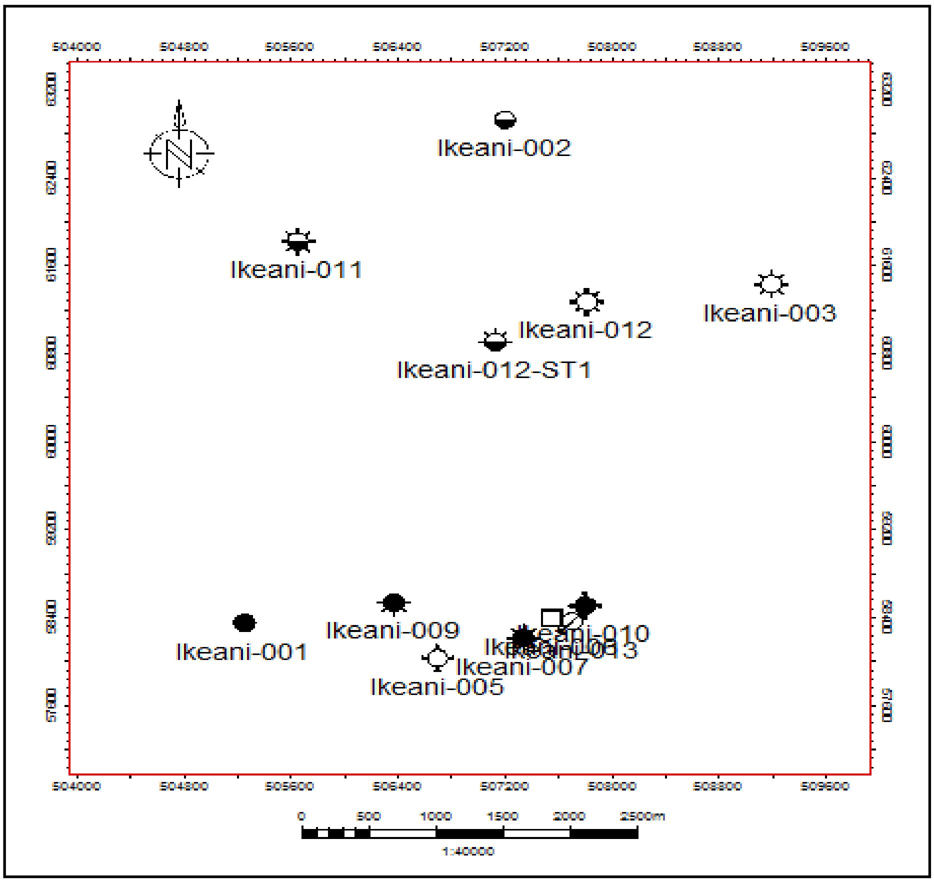


Figure 4.1.Base map of the study area (Ikeani Field) showing well locations

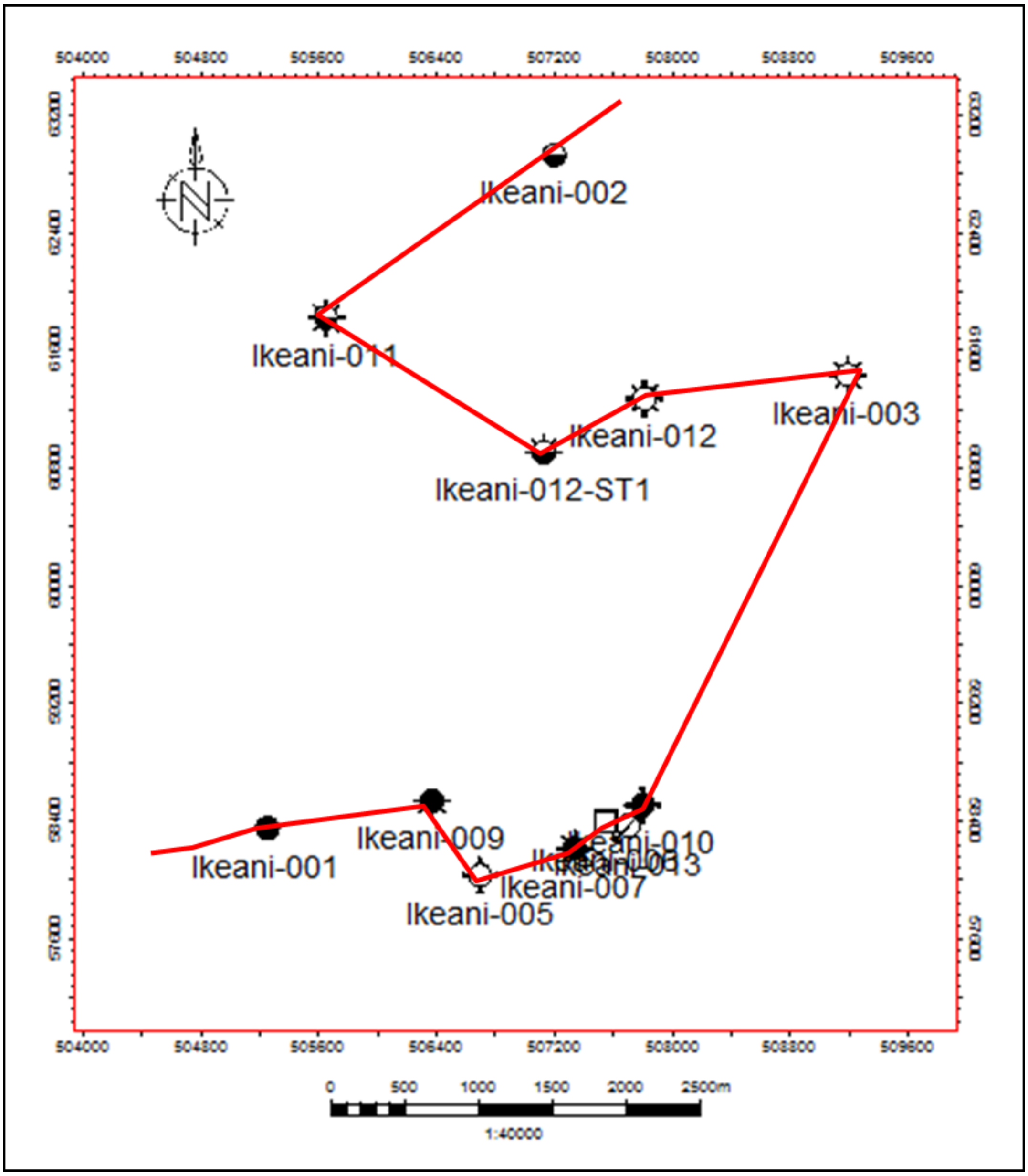


Figure 4.2. Base map of the study area (Ikeani Field) showing correlation transect line

4.2 Discussion of Results

4.2.1 Chronostratigraphic Correlation

The stratigraphic correlations were constrained chronostratigraphically using biostratigraphic data: Maximum Flooding Surfaces (MFS's) and Sequence Boundaries (SB's). The MFS's and SB's as can be seen in (figures 4.3 and 4.4) were used to constrained the reservoir units chronostratigraphically. However, genetic sequence stratigraphic correlation is applied in this study (MFS to MFS).

The Maximum Flooding Surface's being fauna abundance zone, clay rich shales, highest gamma ray reading and lowest resistivity (MFS's) were used as Stratigraphic Markers in this research. Markers (shales) as they are rarely faulted across the field (see figures 4.3 and 4.4). However, whenever they are faulted, they are always easily identified both in dip and lateral directions as may be compared with the erosional truncations of the SB's. In (figure 4.3), the reservoirs were correlated to delineate the possible lateral continuities. It is observed that stratigraphic missing section occurred in well 'Ikeani 7' at reservoir 7000. This, however could have indicated either an omitted section due to faulting or stratigraphic pinch out section. However, the missing section as seen in this study is restricted between two well section and in no form showed no gradual tilting or gradual lateral diminishing of strata and as such interpreted as a fault in this study. This however indicates that well Ikeani 7 tested stratigraphy younger than c7000 reservoir. It suggests that well Ikeani 7 encountered the nick of a fault just below reservoir c5000 at fault straddle point, after which the well penetrated the fault gap and tested an older stratigraphy (c12000) at a shallower depth. This however implies that reservoir c7000 is not seen in well Ikeani 7 and as such if this reservoir is hydrocarbon bearing, one should not expect any reserve at this interval in well Ikeani 7.

Also, it is observed that reservoir c12000 is better developed in Ikeani 5 and this is attributed to favorable and more accommodation space created by the faults / subsidence and sediment supply rate.

The stratigraphic distributions as shown in (figure 4.4) indicates that strata thickness across the wells are quite consistent as no missing section can be observed in this regard. These are interpreted as sequential deposition of sediments resulting to different rock layers without any indication of fault truncations. However, the stratigraphic thickness varies from one well to another across the wells and as such represents stratal infills influenced by compaction of the overburden strata within the available accommodation space.

The gamma ray motif indicates that wells Ikeani 001 and 005 are very much similar. These similarities based on the log architectures are indicative on non/less varying environments. This can as well be said that these wells are closely drilled (e.g. Ikeani 001 and 005 are drilled along the strike and they very much close to each other. Evidence of the earlier statement is the reservoir c6000 (highlighted in yellow). This reservoir (c6000) showed finning upward (retrogradational stacking geometry) in both wells Ikeani 001 and 005 capped by a Maximum Flooding Surface as the overlaying shale (MFS 9.9ma). Also, wells Ikeani 002 and 006 have similar stratigraphic thickness, though with series of ratty sands and shale intercalations indicative of mixed clastic deposits, inter-mingled depositional environment, thinning of strata that may lead to possible pinch out elsewhere. The reservoir C600 is one of the hydrocarbon bearing reservoir as depicted by the resistivity logs (lateral log deep). This in relation to the stratal thickness distribution insinuates that thinner reserves will be seen towards the crest compared with the flanks of the reservoirs (see figure 4.4) for details.

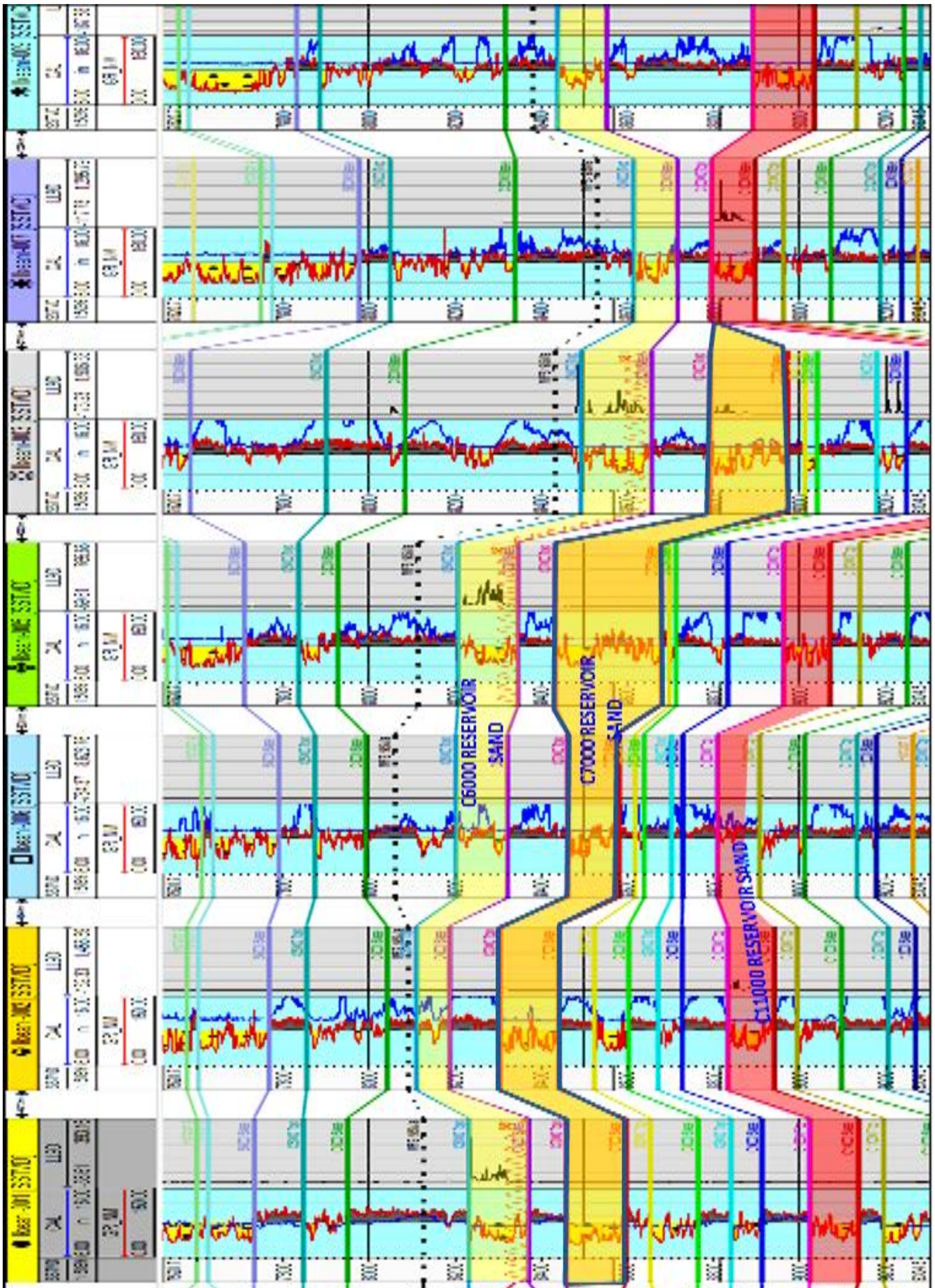


Figure 4.3. Chronostratigraphic correlation of the study area (IkeaniField) showing studied reservoirs

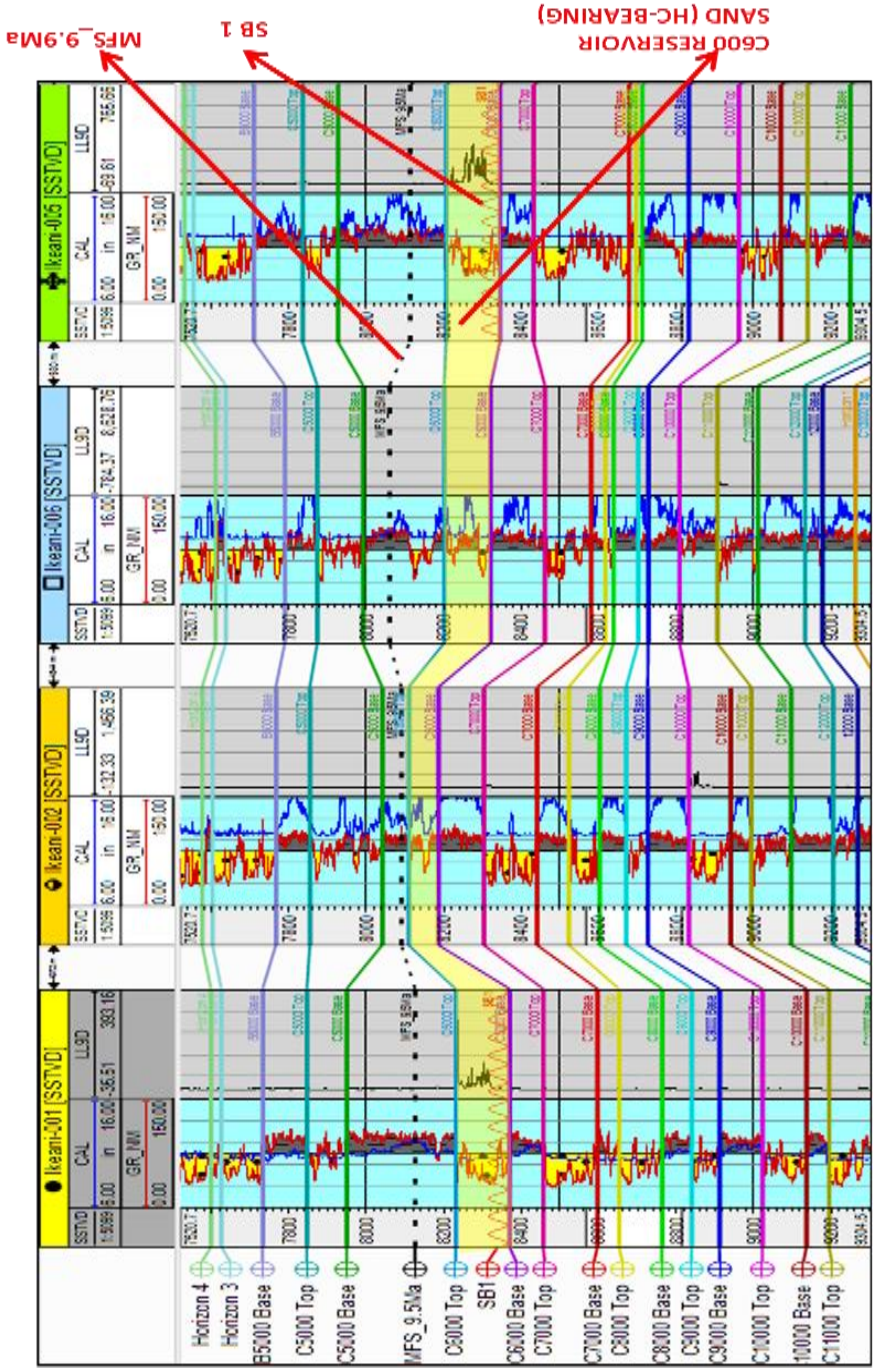


Figure 4.4. Chronostratigraphic correlation of the study area (Ikeani Field) showing fewer wells.

Another reservoir of interest in this study is the hydrocarbon bearing C13000 reservoir (figure 4.5 and 4.6).

The C13000 reservoir is typical of amalgamated multi story stacked channel reservoir underlain by a thick shale sequence (fauna abundance peak/MFS 10.4ma). This C13000 reservoir in general showed fining upward textural gradient and as such said to be retrogradation. However, minor barriers can be seen within the gross channel reservoirs and as such described as minor fluctuations of the sea level resulting to parasequences.

The underlying shale sequence may have served as a source of hydrocarbon to this reservoir. Though depending on the maturity of the shale as no charge analysis was carried out in this study. However, this shale lithology is still within the Agbada Formation as many school of thought (Weber & Dauloru, 1975; Weber, 1990; Doust & Omatsola, 1990) have shown that the Agbada Formation may be too immature base on thermal maturity to serve as hydrocarbon source and as such interpreted in this study as a possible top seal to the underlying reservoir.

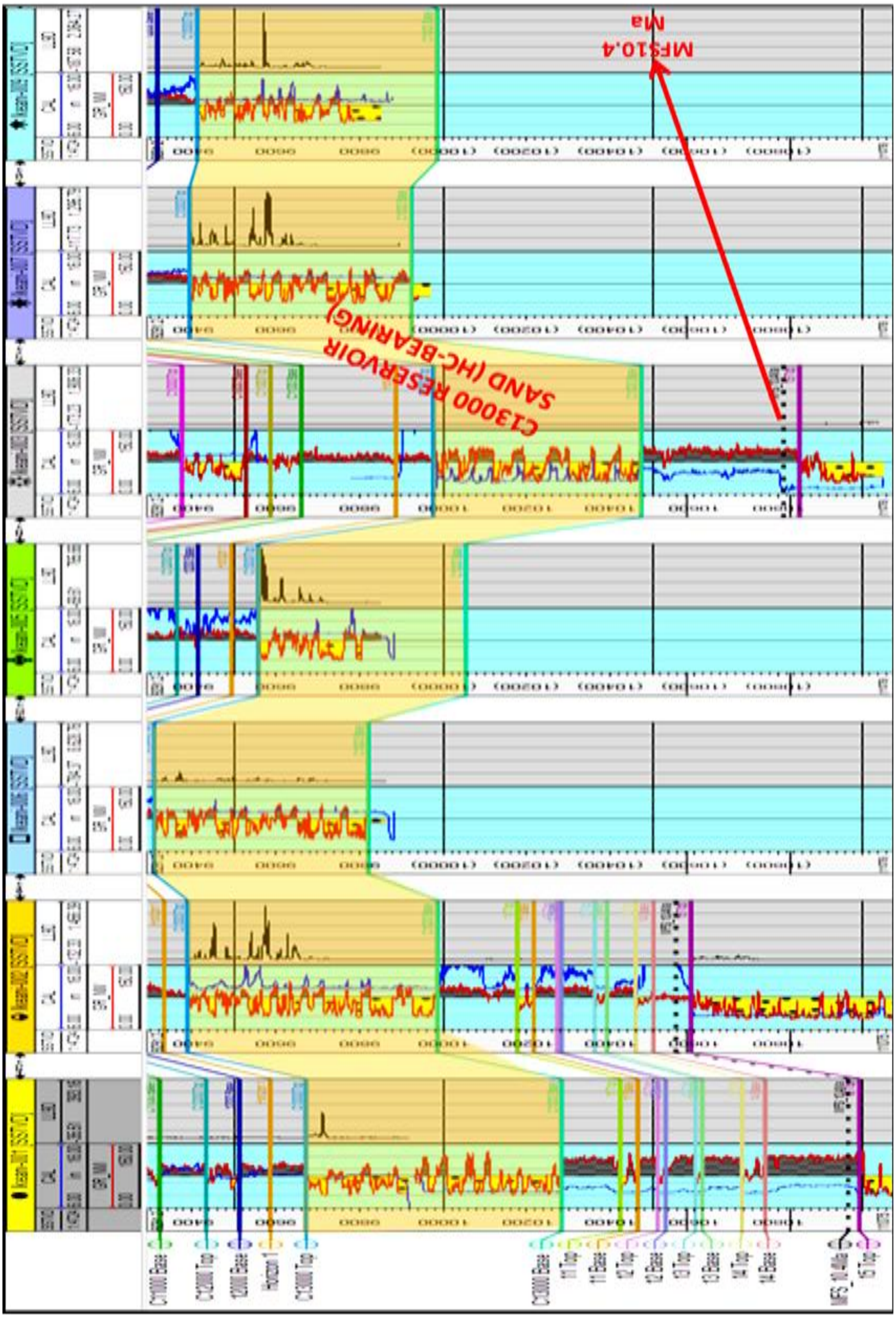


Figure 4.5.Chronostratigraphic correlation of the study area (Ikeani Field) showing deeper reservoirs (C13000)

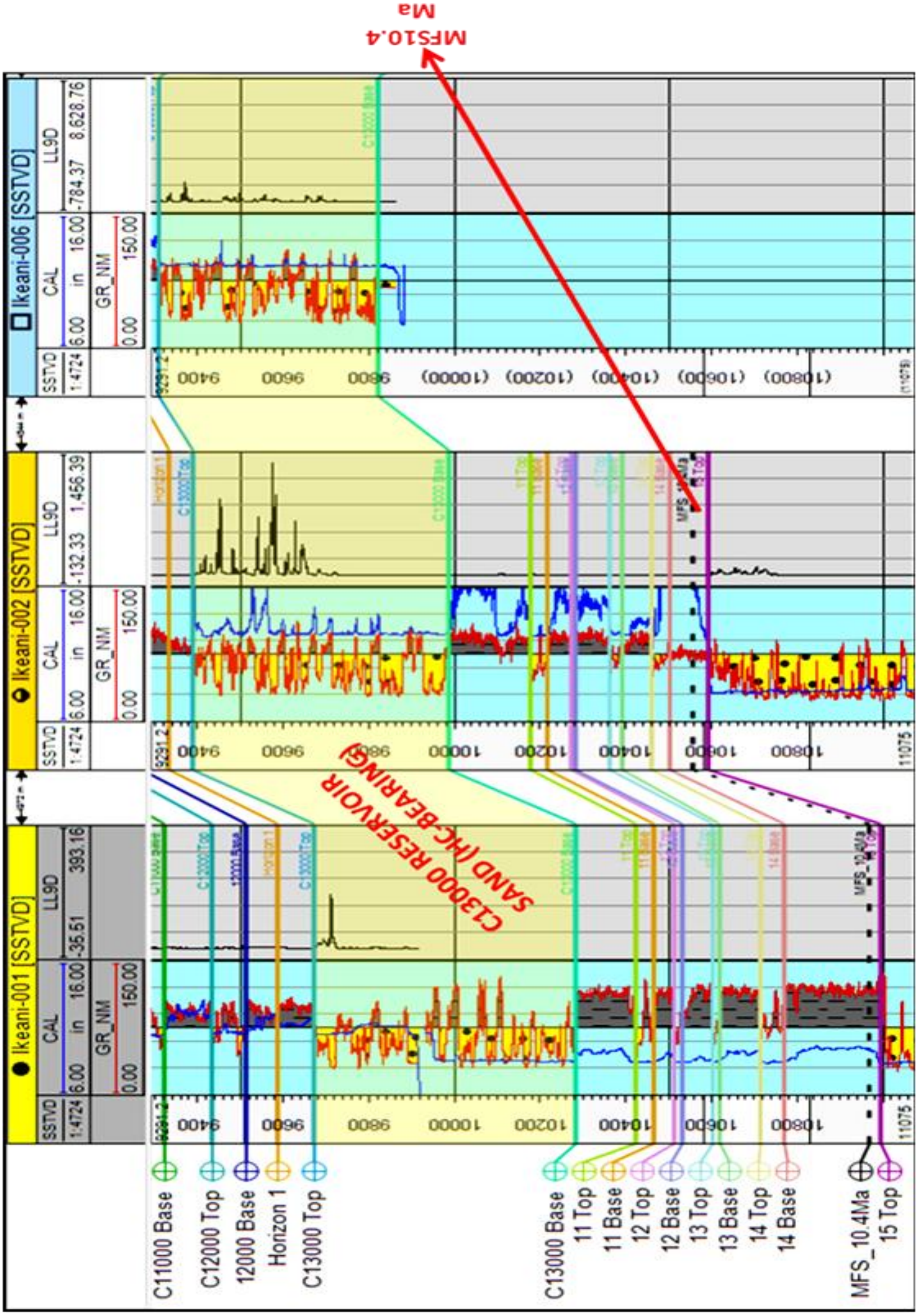


Figure 4.6. Chronostratigraphic correlation of the study area (Ikeani Field) showing deeper reservoirs (C13000) with fewer wells

4.2.2 Sequence Stratigraphic Interpretations

The reservoir quality and property distributions were assessed using genetic sequence stratigraphic correlation. That is reservoir correlations were constrained within chronostratigraphic packages using MFS's. This was used because of the consistence and continuities of most shale lithologies.

The reservoir stacking geometrics were interpreted within the sequence. The sequences encountered in this study include the Low-stand Systems Tract (LST) (Green color code), Transgressive Systems Tract (TST) (Pink Color code) and the High-stand Systems Tract (HST) (Yellow color code), see (figure 4.7 and 4.8).

The LST reservoirs as shown in figures 4.7 and 4.8 include reservoirs C7000, C8000, C9000, C10, 000 and C11, 000. These reservoir (LST's) are interpreted to have been influenced by fine sediments in the deeper part but predominated by the progradational sequences of possible progradding wedge and partly slope sediments.

The reservoirs (below C11, 000) overlies a sequence boundary above an older High-stand (above C12, 000) reservoir packages. They also underlies another erosional surface with the C7000 terminating on SBI. These reservoirs generally indicate coarsening upward textural gradient described in this study as progradational barriers. Their thickness is smaller compared with the HST packages. The LST reservoirs as seen in (figures 4.7 and 4.8) indicates the earliest base level rise with normal regression leading to progradational within the LSTs and are interpreted in this study to represent any of the following (prograding wedge, slope fan and basin floor fan sediments) as no core data was used to precisely delineate and depict the depo environments. The hydrocarbon distributions as shown with resistivity logs are mostly not continuous because of lateral facies changes.

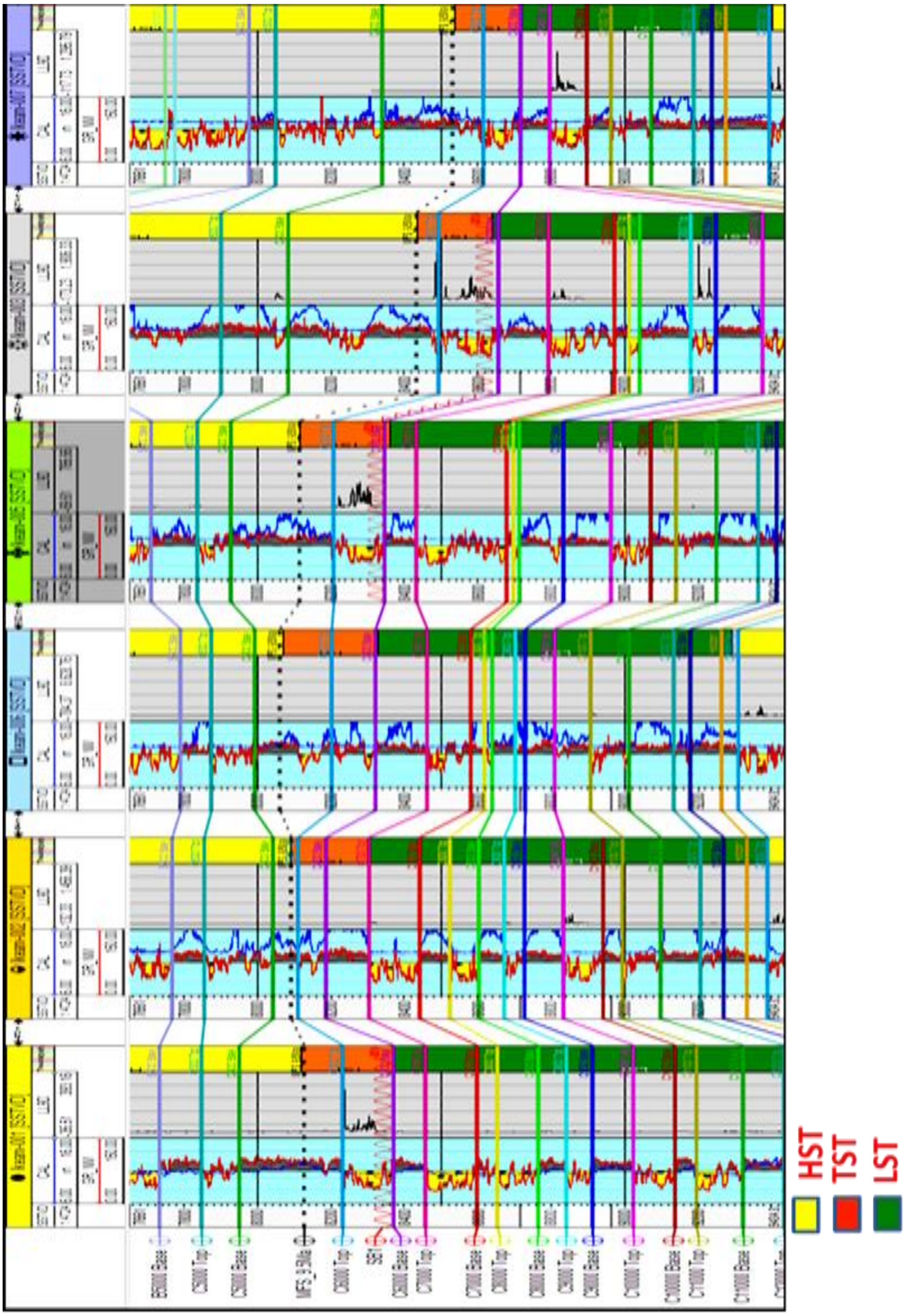


Figure 4.7. Sequence stratigraphic correlation of the study area (Ikeani Field)

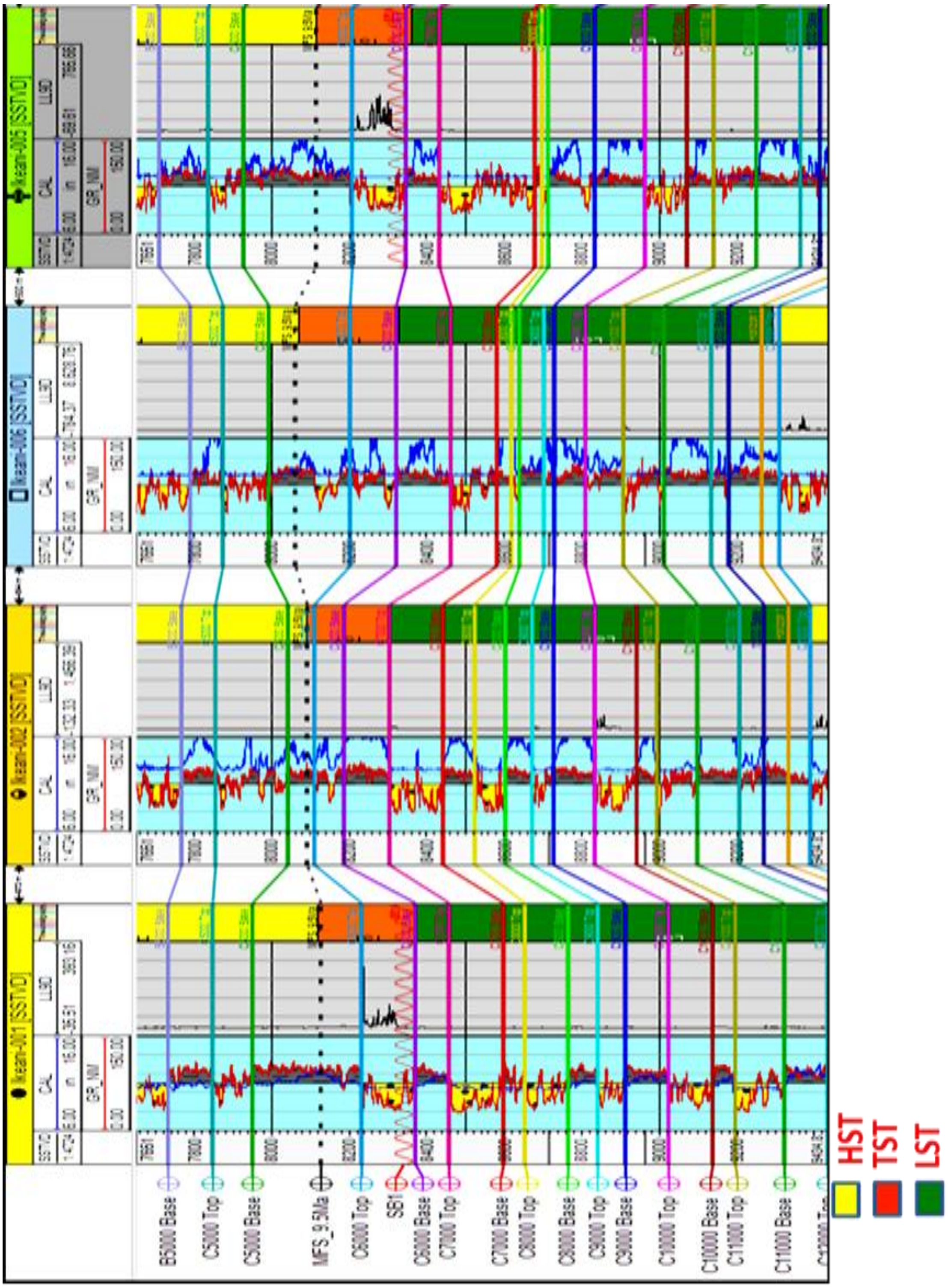


Figure 4.8. Sequence stratigraphic correlation of the study area (Ikeani Field) showing fewer wells

4.2.2.1 Transgressive System Tract (TST) Reservoir

This reservoir is typical of reservoir C6000 as shown in (figure 4.7 and 4.8). The C6000 TST reservoir overlies the SB1 and terminates on the Maximum Flooding Surface (MFS 9.5ma). The C6000 reservoir is hydrocarbon bearing across the wells (figures 12 and 13). However, the channel nature of this reservoir varies from one well to another. The C6000 sands are better developed in wells 001, 005, 003 and 007 compared with wells 002 and 006. Also, the stacking geometry showed generally retrogradational (fining upward textural gradient). The short section of this reservoir as shown in well 002 is as a result of fault cut (partly faulted) while stratigraphic variation brought about the intercalations of sand and shale of the same reservoir is well 006.

4.2.2.2 High-stand System Tract (HST)

Typical of the HST reservoir include C5000 above (MFS 9.5ma), see figure 4.7 and 4.8. The HST reservoirs here are generally aggradation to progradation and depicts the late phase of base level rise with normal regression resulting to coarsening upward textural gradients. The sand reservoirs here are well developed as indicated by the grammar ray log signatures.

The HST reservoirs are good reservoirs as encountered in this study and are hydrocarbon bearing in some parts e.g. C12000 depending on the depth of hydrocarbon charged level and sealing factors / entrapments.

4.2.3 Structural Interpretations

Ikeani field is complexly faulted with virtually all the reservoir levels affected by faults. Some faults are laterally extensive while many of the associated fault are not laterally extensive. The depth of the faults penetrations varies greatly with some of the faults emanating at some depths and dying out at some depths with another regime of fault(s) succeeding them. Typical of the lateral distribution of the faults and the complexity of the faults in the field are shown in (figure 4.9) using time slice 2252ms.

Typical structural styles in the field include both synthetic and antithetic faults (figure 4.10). These faults resulted to different structural styles which include the faulted roll-over structures, collapse crest, host causing fault dependent reservoirs. The reservoir geometries are generally fault dependent anticline with stacking flexural faulted zones. These however made the structural significances and controls important to the study of the stratigraphy. Most importantly, every hydrocarbon accumulation in this field does not just depend on stratigraphy but are also structurally influenced / dependent.

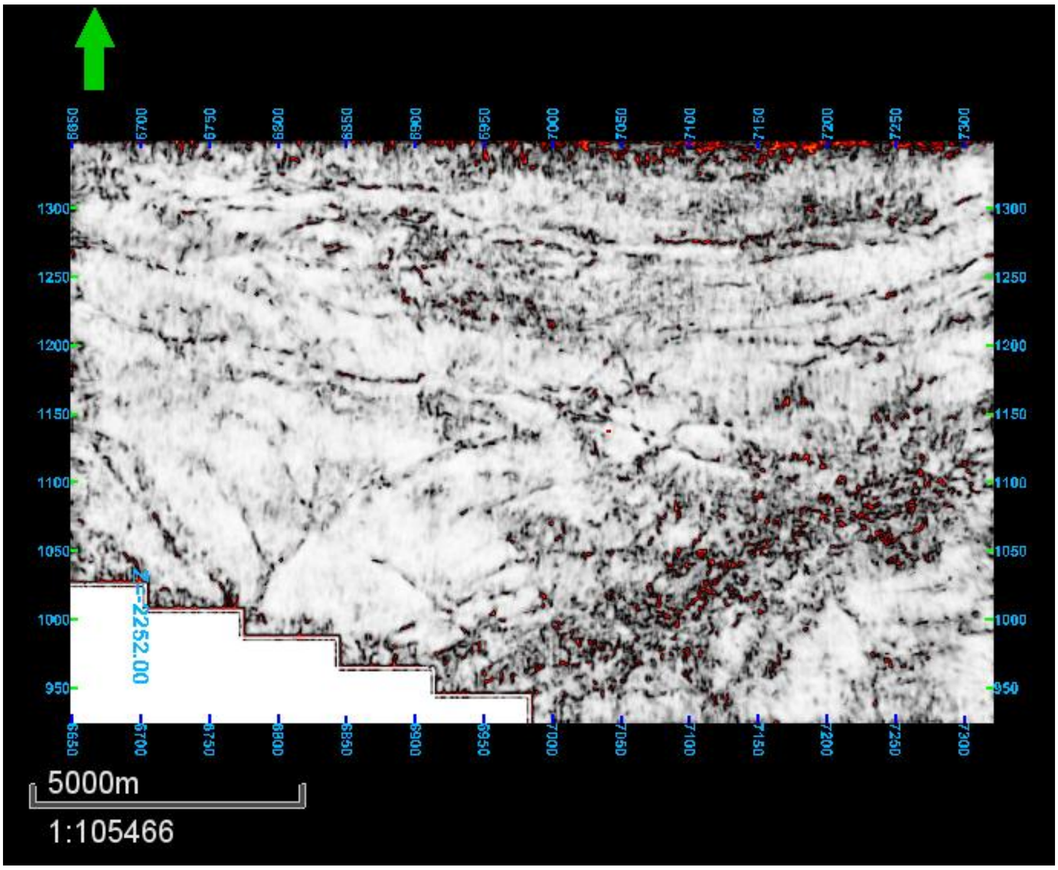


Figure 4.9. Extracted seismic semblance map of the study area (Ikeani Field)

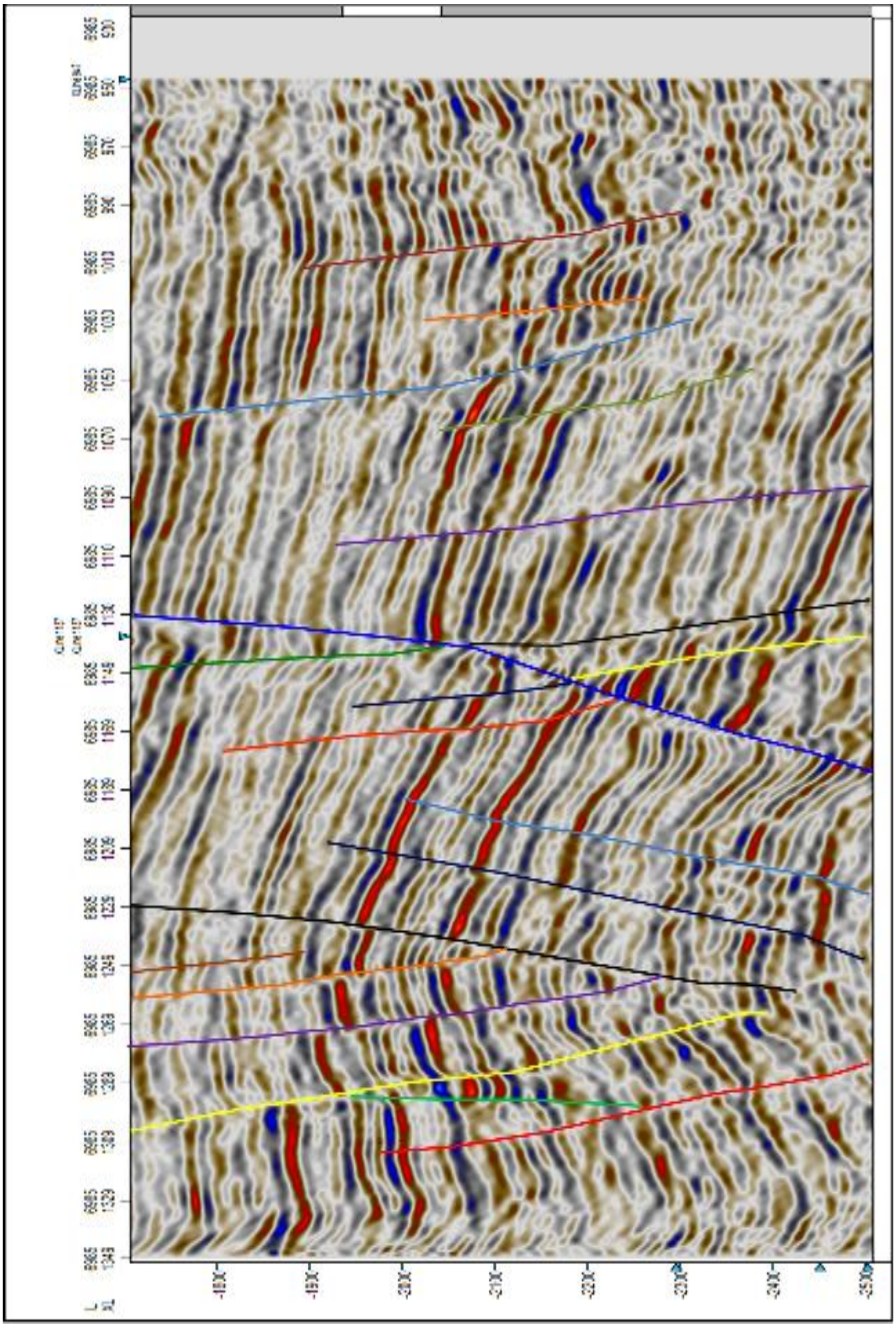


Figure 4.10. Structural interpretation of the study area (Ikeani Field) using inline 6985ms

The 3D geometrical and structural model showing the trends of the faults are shown in (figure 4.11). This however, indicates that faults are major controls which created the accommodation space that caused the influx of the sediments depositions within the mini depo axes. These were also influenced by the relative fluctuations of the sea level causing different stratal stacking patterns as seen earlier in the stratigraphic correlations. Details of the 3D structural framework model is shown in (figure 4.12) faults penetrating a depth surface.

An example of the interpreted depth structural map in the study area showing several faults influence is as shown in (figure 4.12). These however, were incorporated in the study to develop a better understanding of the reservoir fluid distribution. That is virtually all the reservoirs formed closures with the faults (fault dependent reservoirs) unlike fields with four way dip dependent closures.

Typical of the detail approach taken within theinlines, crosslines and time slices to ascertain a good understanding of the reservoir geometrics and faults is as shown in (Figure 4.13). The faults were interpreted in the inlines using structurally enhanced seismic volume complemented with time slices from variance edge volume. The horizons were interpreted both on the inlines and crosslines before translating such to time surfaces and depth surfaces using both synthetic seismogram and velocity model.

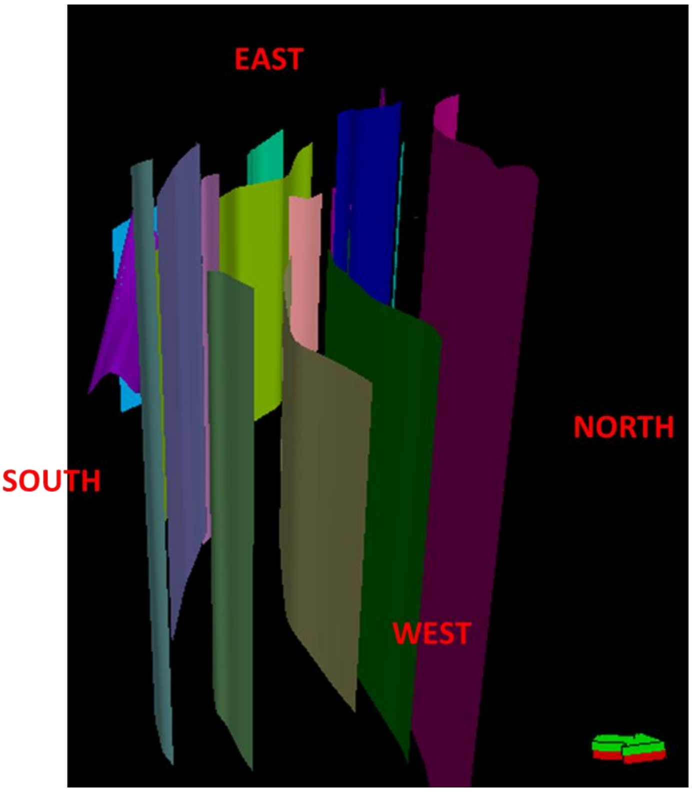


Figure 4.11.Structural interpretation of the study area (Ikeani Field) showing fault styles

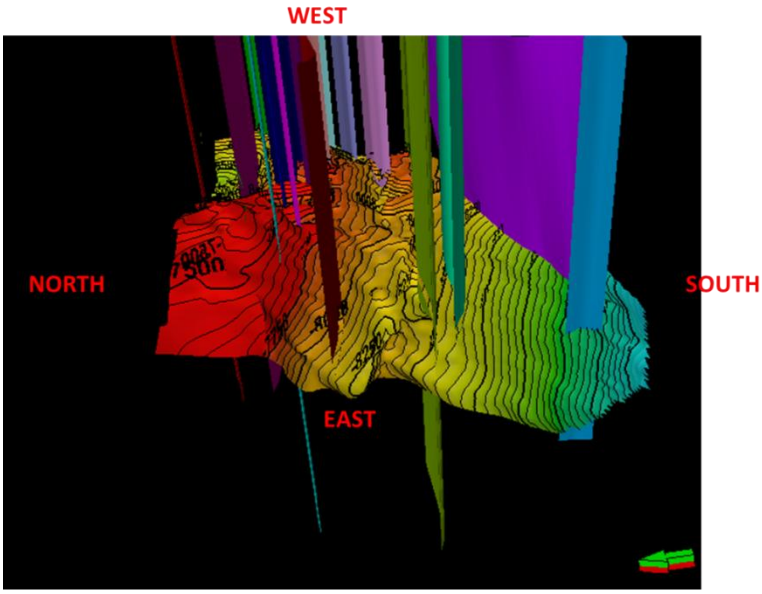


Figure 4.12. Structural interpretation of the study area (Ikeani Field) showing both faults and depth surfaces

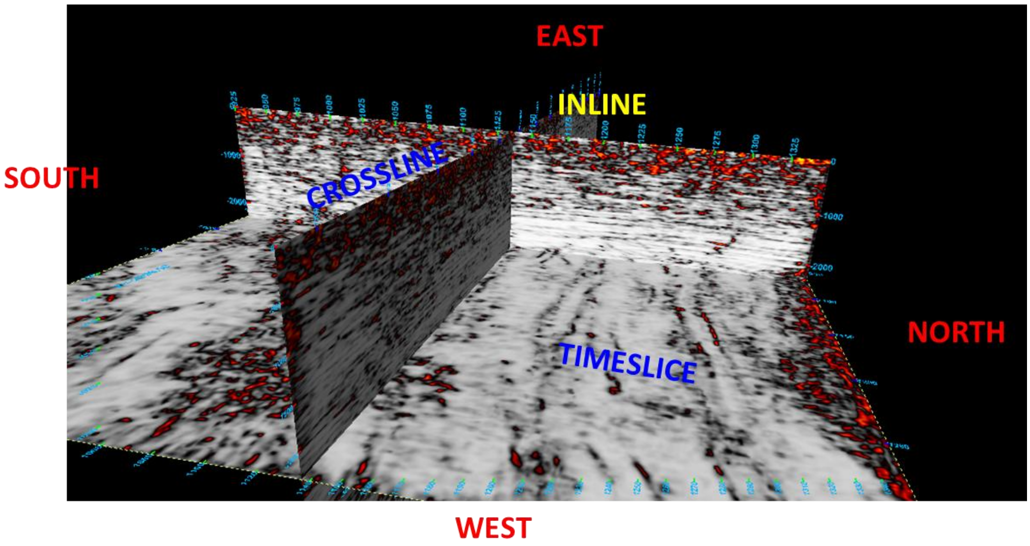


Figure 4.13. Structural interpretation of the study area (Ikeani Field)

4.2.4 Seismic Stratigraphic Interpretation

Transects taken from dip axis were used to ascertain the actual geometries, configurations and patterns of the stratal sequences. Typical of such is as shown in (figures 4.14 to 4.16) which represents sub-parallel reflection configuration transcending to divergent reflection configuration (subtle deposition in a near quiet environment to increasing depositional energy).

Typical of the divergent reflection configurations are shown in (figures 4.16) indicative of the predominance of high energy depositional settings.

However, arbitrary transverse indicates that within the dips (AB & CD) the actual stratal patterns are represented with respect to the present and paleo coastline migration. Also, the strikes here are not the true representation of the stratigraphic patterns and configuration since they are not in dip with paleo shore line migration but simply represents stratigraphic thickening or thinning as can be seen in (figure 4.17).

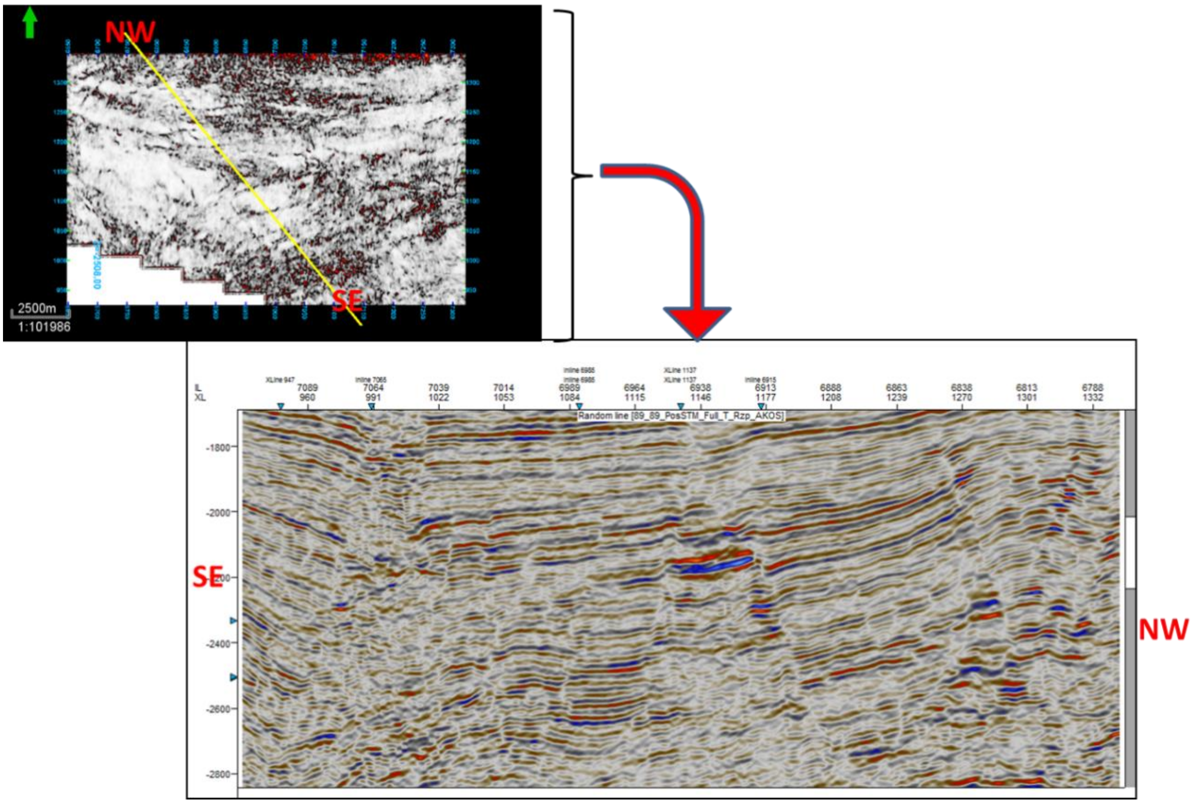


Figure 4.14. Seismic stratigraphic interpretation of the study area (Ikeani Field) using NE-SW arbitrary transect

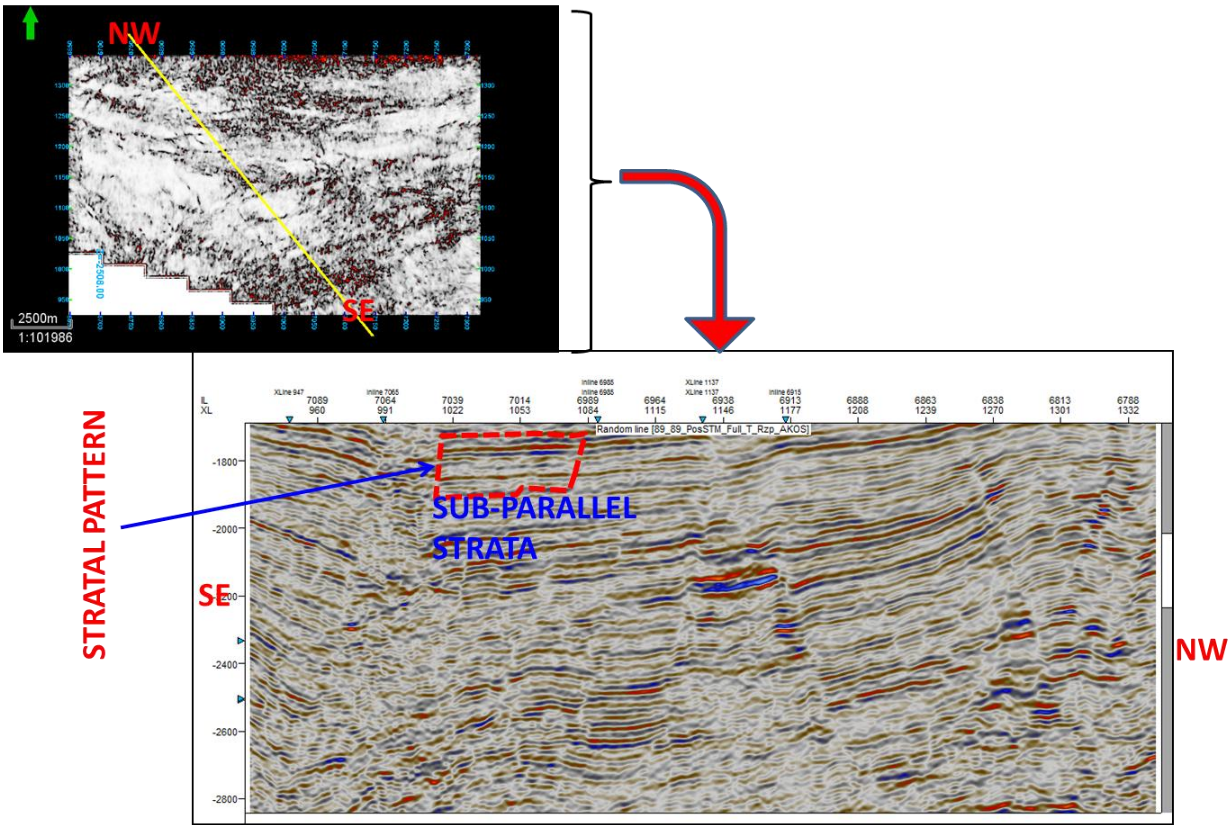


Figure 4.15. Seismic stratigraphic interpretation of the study area (Ikeani Field) using NE-SW arbitrary transect showing sub-parallel reflection configuration

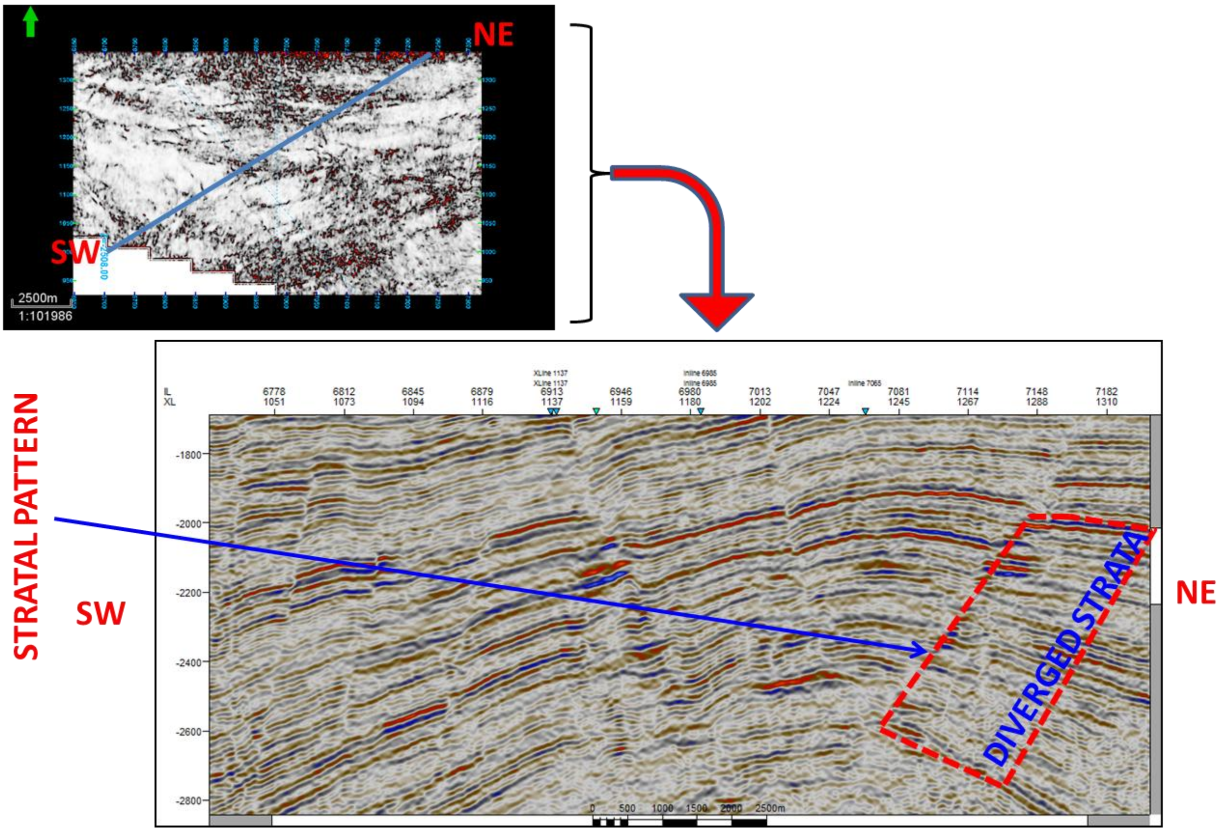


Figure 4.16. Seismic stratigraphic interpretation of the study area (Ikeani Field) using NE-SW arbitrary transect

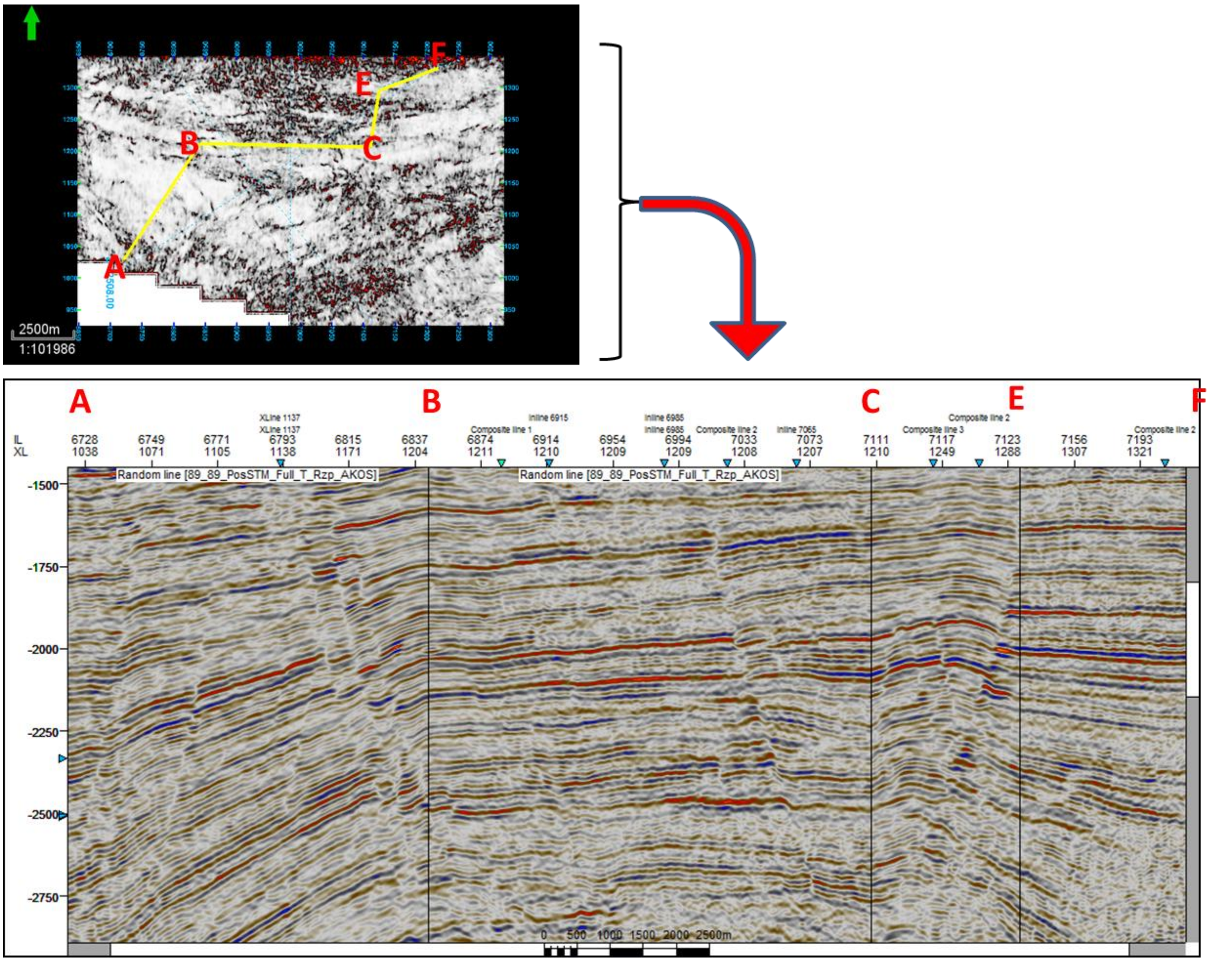


Figure 4.17. Seismic stratigraphic interpretation of the study area (Ikeani Field) using NE-SW arbitrary transect

4.2.5 Depositional Environment Interpretation

An interpretation of the depo environment utilized the Root Mean Square (RMS) amplitude. The depositional environment in the study field varies and these include channels and barrier deposits (Figures 4.18 and 4.19).These however ranges in sizes and directions depending on the type of depo energy influence on the deposits.

A good example of the hydrocarbon accumulation in one of the reservoirs in this study is as shown in (Figure 4.20). That is accumulation of hydrocarbon (oil) with water contact (hydrodynamic drive). The distribution of the hydrocarbon is controlled by both depofacies and faults.

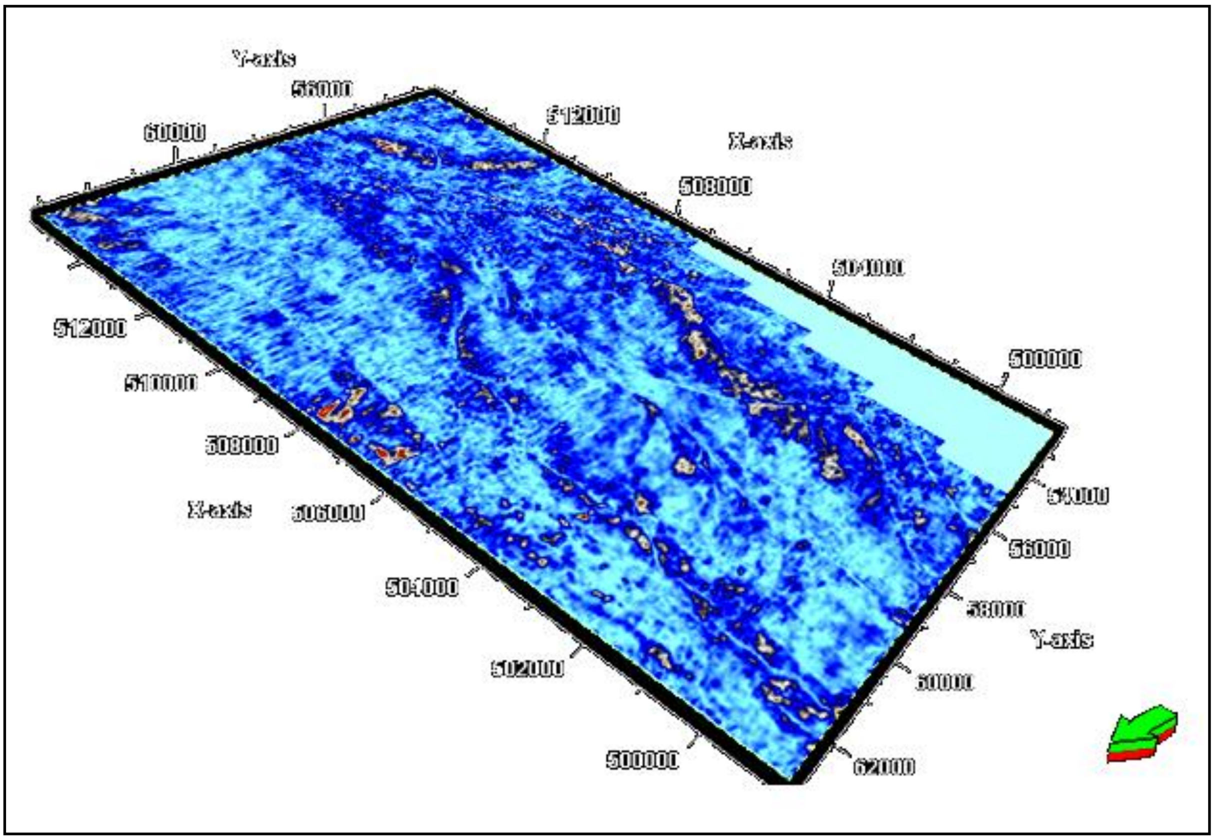


Figure 4.18.Typical depo environment interpretation in the study area (Ikeani Field) using RMS time slice 1828ms revealing major and minor channels and barrier deposits

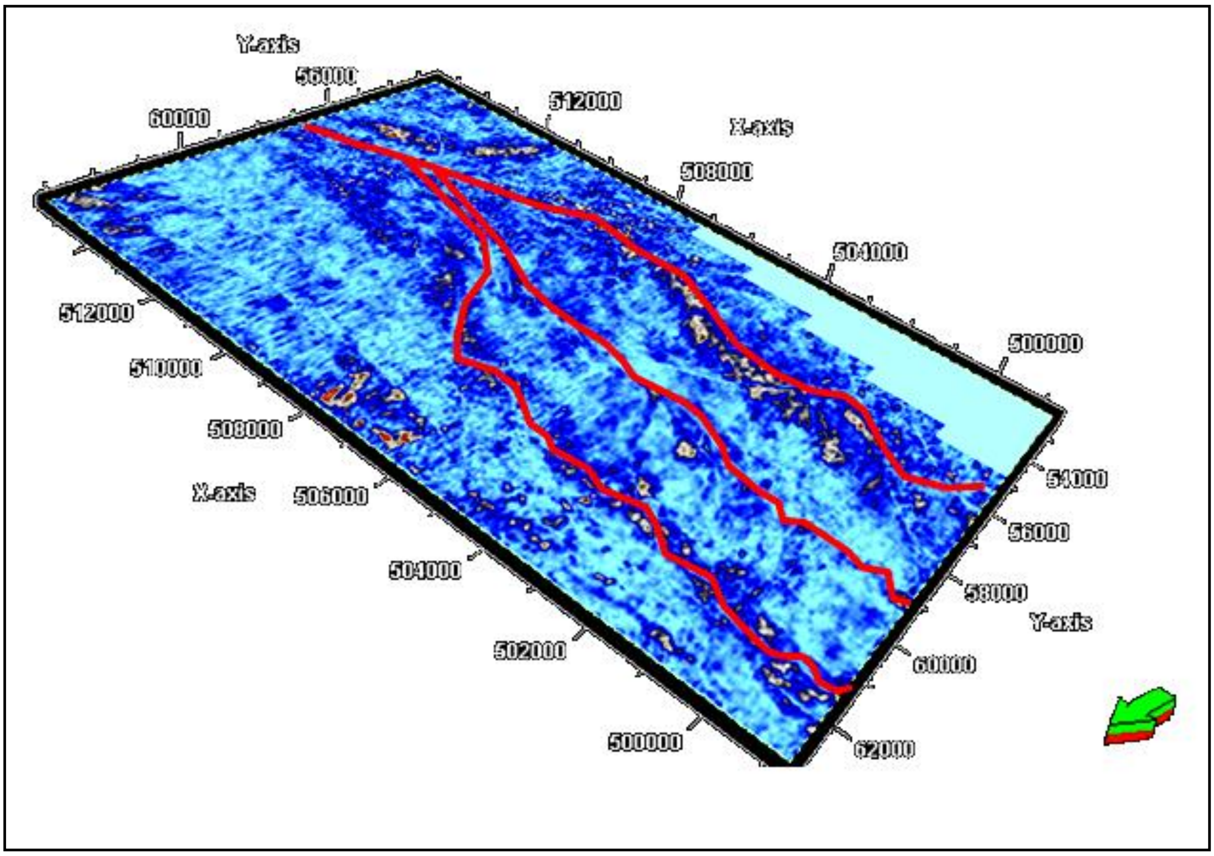


Figure 4.19. Depositional environment interpretation of the study area (Ikeani Field) using RMS time slice 1828ms with major channel disclosed

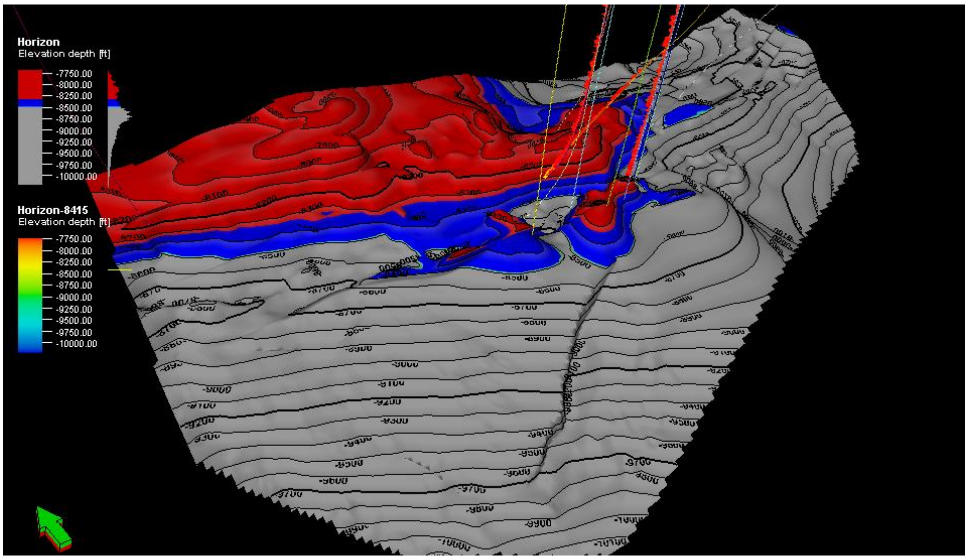
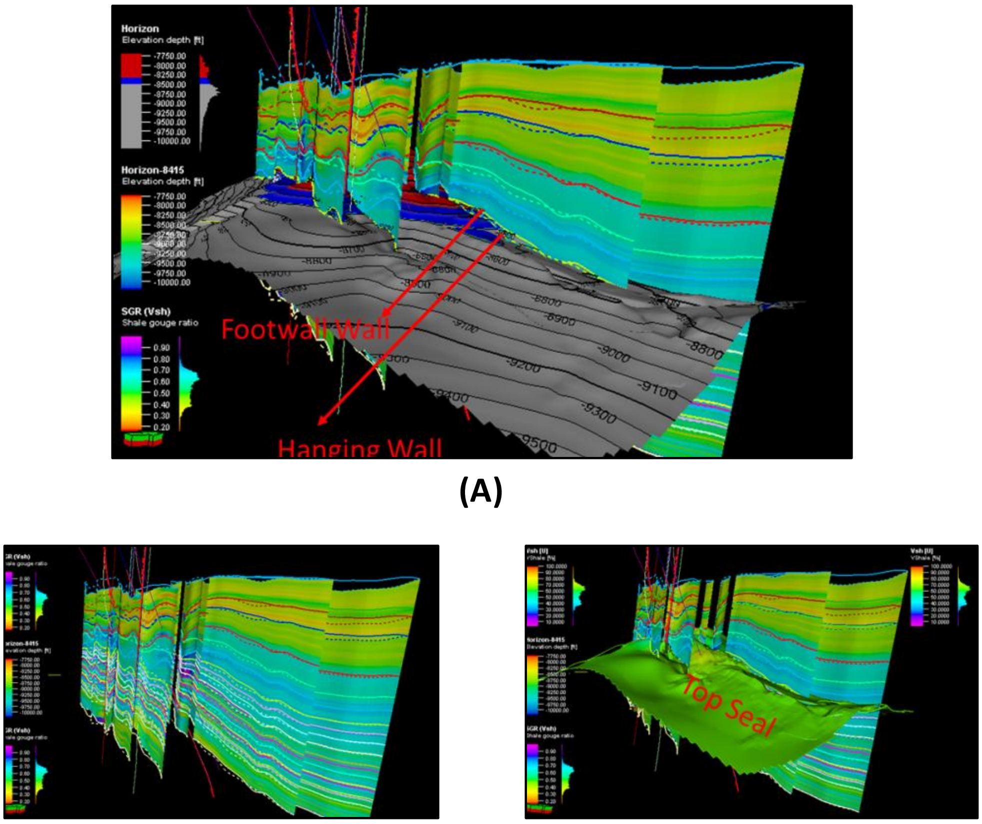


Figure 4.20. Typical depth structural map interpretation in the study area showing oil accumulation

4.2.6 Fault Seal Analysis

The sealing capacity of the faults is demonstrated in this study using the C6000 fault dependent reservoir. The faulting is influenced by stratigraphic juxtapositions of different strata along the fault surfaces with associated mechanical grain crushing (cataclasis) causing high capillary entry pressure in the faults as dependent by the reservoir. The fault throws analysis both in the dip and strike axes, volume of shales and thicknesses of the various strata units influencing the faults are translated to Shale Gouge Ratio (SGR). The SGR indicates that over 60% SGR caused good sealing in C6000 reservoir by impeding further oil migration as well as being supported and capped with over 70% Volume of Shale as the top seal rock.



(A)

(B)

(C)

Figure 4.21. Typical depth structural map interpreted in Ikeani Field (a) showing footwall and hanging wall (b) Fault justaposition (c) top seal (example with C6000)

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

Various data (well logs, biostratigraphy data, seismic volume and check shot data) were used to evaluate reservoir quality using integrated approach as well as delineating the sealing efficiency of the faults and the top seal. The reservoir quality assessments were anchored on sequence stratigraphic and seismic stratigraphic evaluations, structural interpretations and depositional environment assessment. It is evident from this research that reservoir qualities varies by virtue of their stacking patterns causing different sequences due to fluctuations of sea level leading to different systems tract such as HST, TST and LST. These systems tract are used in the description and understanding of the grain, matrix and cement textural gradients. These were applied in defining the reservoir quality and characterization as well as the lateral extent of the reservoir. The structural interpretations were used to ascertain any structural connotations and implication to the hydrocarbon accumulation. These include the structural closures and fault styles in relationship to the stratal patterns. Also, the seismic reflection configuration, patterns and terminations were utilized in the seismic stratigraphic interpretation to complement the RMs amplitude extraction in defining the depositions environment. Good fault seals are interpreted in the faults at C6000 level with over 60% SGR and over 70% V-shale top seal causing oil accumulation at this level.

5.2 Recommendations

i. Reservoir modeling and geochemical analysis of the field should be carried out to enable high resolution of reservoir rock properties in term of quartz, feldspar and rock fragment content.
ii. 4-Dimension exploration should also be carried out to enable re-examination of subsurface structures with respect to time to note if secondary porosity (mechanical and/or chemical rock fracturing) due to drilling activities occurs. This can encourage transmisivity of fluid within one reservoir and another thereby encouraging productivity.

5.3 Contributions to Knowledge

This work has been able to substantially reduce the uncertainties associated with hydrocarbon exploration in the study area by identifying quantitatively good fault seals at C6000 level with over 60% SGR and over 70% V-shale top seal causing oil accumulation at this level.

With these results better informed decisions can be made concerning well planning and field development as well as give credence to reserves estimation of hydrocarbons in a field.

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