3D SEISMIC INTERPRETATION AND HYDROCARBON PROSPECT IDENTIFICATION OF YEAGER FIELD IN THE NIGER DELTA, NIGERIA

BY

Angel Ogheneyoma ERIYAMREMU
PSC2208051

DEPARTMENT OF GEOLOGY
FACULTY OF PHYSICAL SCIENCES
UNIVERSITY OF BENIN
BENIN CITY

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

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DEDICATION

I dedicate this field report to God Almighty, for his grace and wisdom upon my life, and who has been my help ever since. I also dedicate project to my parents, Mr. and Mrs. Eriyamremu as well as my siblings and friends for their never-ending support and motivation to carry on.

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I hereby acknowledge God who has been my help and source of inspiration and I am grateful to him for bringing me this far.

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To my lovely parents, Prof. George Eriyamremu, and Pst Mrs Enajite Eriyamremu, to my siblings Mrs Carisa Caleb, Mr George Eriyamremu, to Mr. Ezekiel and Mr. Andrew, to my course mates Terra Nova 25, my scholars from the Hotbed of Genius, Miss Favour Okpara, Mr David Akinloye, Mr Armstrong Paul-Osagie, Mr Fortune Betiku, to my friends Miss Pearl Martins, Miss Karen Martins, Miss Jewel and Miss Ella for their unending provision of support, encouragement and prayers.

Finally, to myself for persevering, staying strong and never giving up.

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ABSTRACT

This project presents an integrated 3D seismic interpretation and identification of hydrocarbon prospects of Yeager Field, which is located within the prolific Niger Delta Basin of Nigeria. The research has been performed using high-resolution 3D seismic data, integrated with well-log information provided by the Shell Petroleum Development Company (SPDC) to identify subsurface structural and stratigraphic features that are relevant to hydrocarbon accumulation. A comprehensive fault mapping, horizon interpretation, seismic-to-well tie, velocity modeling, and depth conversion were undertaken and complemented by seismic attribute analysis comprising RMS amplitude, maximum amplitude, average energy, and average magnitude attributes. Thirty-five (35) faults were identified dominated by growth faults, rollover anticlines, and synthetic-antithetic fault systems typical of the extensional regime of the Niger Delta. Several structural closures with trapping potential were identified from the time and depth structure maps, while seismic attributes indicated amplitude anomalies that suggested the presence of hydrocarbon in the reservoir sands of the Agbada Formation. The seismic-to-well tie provided a reliable time-depth relationship that increased the accuracy of horizon correlation by more than forty percent. The results indicate that fault-assisted closures, especially the rollover anticlines resulting from the growth faults, are the primary trapping mechanism in the field. Potential hydrocarbon prospects have been delineated using this integrated approach, providing a robust geological framework for future exploration and development planning in the study area. The importance of advanced 3D seismic interpretation in reducing exploration risk and optimizing hydrocarbon recovery in the complex structural setting of the Niger Delta Basin cannot be overemphasized.

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Hydrocarbon exploration is fundamentally aimed at discovering and producing oil and gas accumulations in the subsurface, and seismic reflection surveying has become the most effective geophysical tool used to achieve this objective. The seismic method relies on the propagation and reflection of acoustic waves to generate images of the Earth's interior, enabling interpreters to recognize variations in lithology, fluid saturation, and structural deformation (Sheriff & Geldart, 1995; Yilmaz, 2001). Over time, technology has advanced from basic 2D seismic profiles, which provide only limited cross-sectional views of the subsurface, to high-resolution 3D seismic datasets that display geological features continuously in three dimensions. This advancement has greatly enhanced geological accuracy and reduced uncertainties associated with hydrocarbon prospect evaluation (Brown, 2011).

Three-dimensional seismic interpretation provides improved visualization of faults, stratigraphic geometries, fluid contacts, and reservoir architecture. It enables more precise mapping of hydrocarbon traps and enhances the characterization of reservoir continuity, compartmentalization, and heterogeneities that often determine production success (Brown, 2011; Yilmaz, 2001). As the petroleum industry continues to explore and develop more complex reservoirs, especially in mature producing basins, 3D seismic interpretation has become pivotal in reducing drilling risks, improving field development decisions, and identifying bypassed hydrocarbons in previously explored areas.

The Niger Delta Basin, one of the world's most prolific hydrocarbon provinces, presents a unique geological setting for the application of 3D seismic interpretation. The basin was formed from extensive deltaic sedimentation derived from the River Niger system from the Late Cretaceous to Recent times (Short & Stauble, 1967). It consists of a tripartite lithostratigraphy, comprising the basal Akata Formation of marine pro-delta shales that serve as the principal hydrocarbon source rock, the overlying Agbada Formation characterized by alternating sandstone and shale sequences that form both reservoirs and seals, and the shallow Benin Formation composed predominantly of continental sands (Avbovbo, 1978; Doust & Omatsola, 1990). The interplay between these formations satisfies the essential petroleum system components necessary for hydrocarbon occurrence: an organic-rich source, porous reservoir units, competent sealing lithologies, effective migration pathways, trap structures, and favourable timing (Magoon & Dow, 1994; Evamy et al., 1978).

Hydrocarbon accumulations in the Niger Delta are commonly trapped within structural configurations formed by syn-sedimentary growth faulting and associated rollover anticlines. Additionally, stratigraphic controls such as channel deposits, pinch-outs, and delta-front depositional features contribute to the trapping and localization of hydrocarbons (Weber & Daukoru, 1975; Corredor et al., 2005). Petroleum migration is facilitated by the expulsion of hydrocarbons from deeply buried over pressured Akata shales, which move upward along fault planes into shallower Agbada reservoirs, and the timing of trap formation and hydrocarbon generation is favorable, ensuring the preservation of commercial quantities of hydrocarbons (Evamy et al., 1978; Doust & Omatsola, 1990). Despite its petroleum richness, the Niger Delta presents interpretation challenges due to structural complexity, shale tectonics, differential compaction, and lateral variations in depositional facies (Corredor et al., 2005).

These complexities can only be appropriately addressed through advanced seismic analysis. Therefore, the detailed 3D seismic interpretation of the study field is necessary to better understand its subsurface architecture, accurately delineate prospects, and enhance hydrocarbon exploration and development strategies. Such interpretation will contribute not only to the identification of new reserves but also to the optimization of existing production potential within the basin.

1.2 Statement of the Problem

Although the Niger Delta Basin is a mature and prolific hydrocarbon province, significant challenges remain in accurately resolving subsurface complexities that influence hydrocarbon exploration and development. The structural complexity of the basin, dominated by syn-sedimentary growth faults, rollover anticlines, shale diapirism, and fault-assisted compartmentalization, continues to create uncertainties in the delineation of hydrocarbon traps and reservoir geometries (Corredor et al., 2005; Doust & Omatsola, 1990). Additionally, the highly variable depositional environments of the Agbada Formation result in lateral and vertical heterogeneities in reservoir quality, continuity, and thickness, which can lead to complexities in predicting reservoir distribution and performance (Weber & Daukoru, 1975).

Traditional 2D seismic interpretation, although valuable, often lacks the spatial resolution required to properly image complex fault networks, subtle stratigraphic features, and small-scale hydrocarbon-bearing intervals (Brown, 2011; Yilmaz, 2001). This limitation may result in misinterpretation of structural closures, inaccurate mapping of reservoir boundaries, and unsuccessful drilling attempts, which increase financial risk and operational uncertainties for exploration companies. Furthermore, fault sealing capacity, fluid migration pathways, and the presence of stratigraphic pinch-outs or channel systems are often inadequately characterized without the aid of advanced 3D seismic interpretation techniques (Evamy et al., 1978; Doust & Omatsola, 1990).

In many fields within the Niger Delta, additional hydrocarbon volumes are suspected to exist in poorly imaged or bypassed zones due to historical reliance on inadequate seismic datasets and simplistic structural models. Therefore, there is a critical need for a more comprehensive 3D seismic interpretation approach that enhances fault and horizon resolution, refines reservoir characterization, and provides improved understanding of trapping mechanisms. Addressing these issues is essential for identifying new prospects, reducing drilling risk, optimizing field development planning, and enhancing ultimate hydrocarbon recovery within the basin.

1.3 Aim and Objectives of the Study

The aim of this study is to use 3D seismic data to interpret subsurface structures and stratigraphic features that influence hydrocarbon accumulation within the study field in the Niger Delta. This will help to improve understanding of reservoir distribution and identify potential hydrocarbon prospects in the area.

The objectives of the study are to:

- Identify key seismic reflectors and correlate them across the field.
- Map major fault trends and understand the structural configuration of the subsurface
- Delineate potential hydrocarbon-bearing reservoirs and evaluate their spatial continuity and reservoir properties
- Apply seismic attribute analysis to enhance reservoir characterization

- Detect possible hydrocarbon indicators using seismic interpretation techniques
- Generate time and depth structure maps for identified horizons
- Improve the understanding of the subsurface of Yeager Field through detailed seismic attribute analysis

1.4 Scope of the Study

This study focuses on the interpretation of 3D seismic data acquired over Yeager Field in the Niger Delta. The work is centered on identifying and mapping key subsurface features that influence hydrocarbon accumulation within the field. It involves picking and correlating major seismic horizons, mapping fault structures, and delineating potential hydrocarbon-bearing reservoir units. The study also includes the generation of time and depth structure maps to define the geometry of identified traps and to improve understanding of the subsurface configuration. Seismic attribute analysis is used to enhance reservoir characterization and highlight possible hydrocarbon indicators.

This research is limited strictly to seismic interpretation and does not extend into drilling operations, petrophysical analysis, reservoir engineering, or economic evaluations. The overall scope is to provide a clearer geological and structural understanding of Yeager Field using available seismic data.

1.5 Limitations of the Study

The interpretation in this study relies entirely on the available 3D seismic dataset. As a result, the accuracy of the findings is limited by the quality, resolution, and coverage of this seismic data. The vertical and lateral resolution may obscure small geological features, especially in areas with complex faults or thin layers that are below seismic resolution. Interpreting seismic data requires the interpreter to decide where to identify horizons and how to trace faults, particularly in areas where reflections are unclear or inconsistent. In the Niger Delta, geological complexity, such as growth faulting, rapid changes in rock types, and uneven compaction, makes it harder to consistently follow seismic reflections. These challenges increase the possibility of bias or mistakes by the interpreter. Differences in experience, assumptions about the structural style, and the choice of seismic attribute parameters can result in variations in the final interpretation. Therefore, the structural and stratigraphic models developed in this work should be viewed as the best estimate of the subsurface based on the available data and may be improved with additional supporting information or more effective interpretation techniques. The accuracy of this study is affected by the performance and capabilities of the software and analysis tools used during seismic processing and interpretation. Any technological limitations may impact the resolution and reliability of the results. Also, environmental and operational conditions during the collection of seismic data can introduce noise and inconsistencies, which can reduce data clarity and interpretive confidence. These factors are beyond the researcher's control. Furthermore, the study has constraints based on the available time and institutional resources, which may limit the depth of investigation and level of detailed analysis possible within the project scope.

1.6 Geology of the Study Area

Yeager’s Field is situated onshore within the Niger Delta region of southern Nigeria, one of the world’s most significant Tertiary clastic sedimentary basins and a major center of hydrocarbon accumulation (Short and Stauble, 1967; Kulke, 1995). The geology of the field reflects the complex depositional and structural framework that defines the Niger Delta petroleum province. Yeager’s field is situated within this context, exhibiting typical characteristics of the Niger Delta, such as extensive growth faults, roll over anticlines, and varied depositional environments. This basin formed during the Late Cretaceous following the rifting and separation of the African and South American continents, which established a passive continental margin along the Gulf of Guinea (Burke et al., 1972). Continuous regional subsidence accompanied by large sediment influx from the Niger River and its distributaries led to the accumulation of more than 9–12 km of sediments, progressively advancing into the Atlantic Ocean (Evamy et al., 1978; Doust and Omatsola, 1990). The subsurface stratigraphy of the Niger Delta is widely recognized to consist of three major formations that describe its progradational development: the Akata, Agbada, and Benin Formations (Doust and Omatsola, 1990). The Akata Formation forms the basal unit and is characterized by deep marine pro-delta shales with minor turbiditic sands and siltstones. These shales are rich in organic matter and serve as the primary petroleum source rocks throughout the basin, generating predominantly gas and light oil at greater burial depths (Ekweozor and Daukoru, 1994).

Superimposed on the Akata is the Agbada Formation, a thick sequence of interbedded sandstones and shales deposited in paralic to delta-front environments. The sand bodies within this formation represent the main hydrocarbon reservoirs due to their good porosity and permeability, while the intercalated marine shales serve as seals that enable the trapping of hydrocarbons (Weber and Daukoru, 1975). Variability in depositional environments such as distributary channels, mouth bars, and tidal channels results in significant lateral and vertical heterogeneity in reservoir architecture (Weber and Bakker, 1981). This heterogeneity presents challenges in seismic interpretation, requiring detailed stratigraphic delineation to accurately define reservoir geometry and connectivity.

The Benin Formation forms the uppermost component of the stratigraphy and is primarily composed of continental, fluvial sands with minor clay interbeds. Although these sands rarely form petroleum traps due to their high permeability and limited sealing capacity, they dominate the shallow subsurface and influence groundwater and surface geologic conditions (Avbovbo, 1978).

Structurally, the study area falls within the extensional zone of the Niger Delta, characterized by syn-sedimentary listric growth faults that sole into the ductile Akata shales (Evamy et al., 1978). Rapid sediment loading during delta progradation triggered gravity-driven deformation, leading to the development of rollover anticlines, fault-assisted closures, collapsed crest structures, and complex trap geometries highly favorable for hydrocarbon entrapment (Corredor et al., 2005). Fault interaction and differential compaction across sediment packages further contribute to reservoir compartmentalization and variable pressure regimes. Additionally, the Niger Delta exhibits substantial stratigraphic complexity associated with channel migration, lobe switching, and rapid facies transitions driven by changing depositional processes (Weber and Bakker, 1981). These features control reservoir distribution and strongly influence hydrocarbon prospectivity, making advanced seismic interpretation essential for reducing uncertainty.

Hydrocarbon accumulation in the area results from the interplay of deeply buried source rocks, high-quality reservoirs, competent intra-formational seals, and well-developed structural traps (Doust and Omatsola, 1990). Fault-controlled migration pathways allow hydrocarbons generated in the Akata Formation to charge reservoirs within the Agbada Formation, producing the prolific accumulations for which the Niger Delta is globally recognized. Overall, the geology of Yeager Field typifies the complex structural and stratigraphic setting of the Niger Delta Basin. Understanding these geological controls provides the necessary foundation for accurate 3D seismic interpretation and hydrocarbon evaluation within the study area.

1.7 Location of the Study Area

The YEAGER's field is a fictitious name given to an area onshore of Niger Delta. The exact location of the field is not given. The Niger Delta region of Nigeria is approximately 85 km towards the Atlantic Ocean.

The figure below shows the map of the survey area.

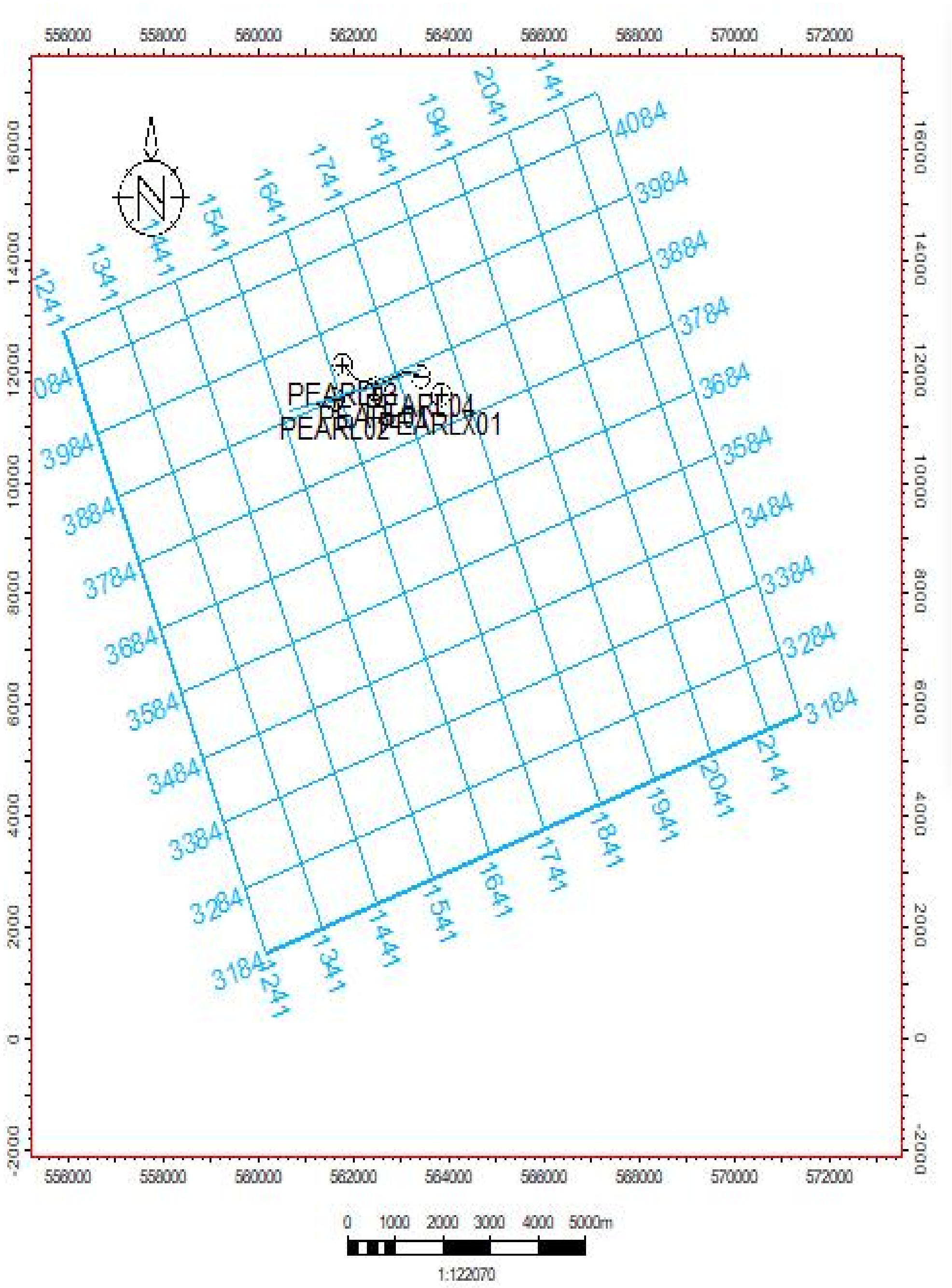

Figure 1.1 : Survey Map

CHAPTER TWO

GEOLOGICAL SETTING AND LITERATURE REVIEW

2.1 Geological Overview of the Niger Delta Basin

The Niger Delta Basin is located along the southern margin of Nigeria, extending into the Gulf of Guinea on the West African passive continental margin. It represents one of the world's most prolific and hydrocarbon-rich Tertiary delta systems, formed primarily as a result of high sediment influx from the Niger River and sustained subsidence over millions of years (Short & Stauble, 1967; Tuttle et al., 1999). The basin covers an estimated area of approximately 300,000 km^2 including its offshore extent, with sediment thickness in the deepest depocenters exceeding 9–12 km (Evamy et al., 1978; Doust & Omatsola, 1990).

The geological evolution of the basin is tied to the rifting and subsequent opening of the South Atlantic during the Late Jurassic–Cretaceous, resulting in a passive margin setting favorable for long-term sediment accumulation (Burke, 1972). The progressive seaward progradation of the delta during the Paleogene and Neogene led to the development of a thick wedge of clastic sediments dominated by delta-front, delta-plain, and pro-delta depositional environments (Doust & Omatsola, 1990).

Lithostratigraphically, the Niger Delta is defined by a three-unit succession comprising the Akata, Agbada, and Benin Formations (Evamy et al., 1978). The Akata Formation consists essentially of deep marine shales and turbidites that serve as the primary source rocks for hydrocarbons in the basin. Above this lies the Agbada Formation, a paralic sequence of interbedded sandstones and shales that forms both the major reservoirs and regional seals. The succession is capped by the Benin Formation, composed chiefly of continental sands deposited by fluvial systems and acting predominantly as an aquifer.

The basin's structural architecture is distinguished by extensive syn-sedimentary growth faults, rollover anticlines, shale diapirs, and fault-dependent closures, which were formed as a result of gravitational deformation linked to rapid sediment loading on the ductile Akata shale (Tuttle et al., 1999; Doust & Omatsola, 1990). These deformational structures significantly influence hydrocarbon accumulation by providing favorable trapping mechanisms.

The spatial and temporal variability of depositional environments has resulted in highly heterogeneous reservoir characteristics, with lateral and vertical facies transitions affecting reservoir continuity and quality. These geological complexities make the Niger Delta both an attractive and challenging region for hydrocarbon exploration and 3D seismic interpretation (Nyantakyi et al., 2013).

The figure below shows the location of the Delta Field Within the Niger Delta and the cross section across the Niger Delta

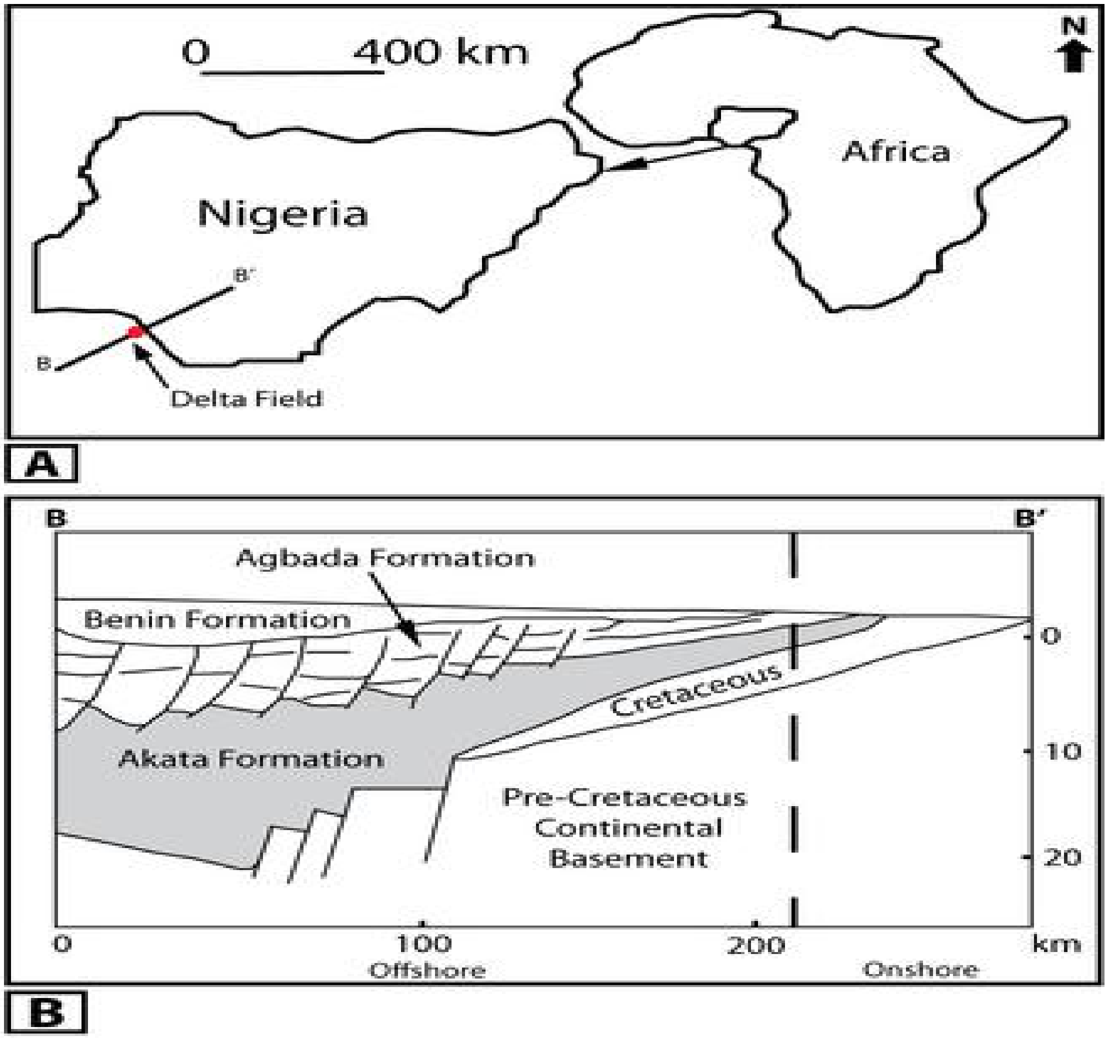

Figure 2.1 : (A) Location of the Delta Field within the Niger Delta (B) Cross section across the Niger Delta (Stacher, 1995)

2.1.1 Tectonic Framework and Evolution of the Niger Delta

The tectonic framework of the Niger Delta is fundamentally linked to the rifting and subsequent separation of the African and South American plates during the opening of the South Atlantic in the Late Jurassic to Early Cretaceous (Burke, 1972; Whiteman, 1982). As spreading progressed, a passive margin was established along the West African coastline, creating accommodation space for extensive sediment accumulation. This transition from a rift to a drift setting marked the beginning of regional subsidence and the formation of the proto–Niger Delta depocenter.

During the Paleocene, clastic sediments delivered by the Niger River began to build outward into the Atlantic Ocean, producing large-scale progradation of deltaic sequences (Short & Stauble, 1967; Doust & Omatsola, 1990). Continuous subsidence, coupled with extremely high sediment input rates, led to the rapid vertical and lateral expansion of the delta throughout the Eocene to Recent times. This sustained development generated a thick clastic wedge characterized by increasing sediment thickness basinward, reaching over 12 km in the offshore region (Evamy et al., 1978).

A key process shaping the tectonic evolution of the basin is gravitational instability caused by dense sediment overburden resting atop the relatively ductile Akata Formation shale. This # in mechanical behavior facilitated detachment and gravity-driven deformation, giving rise to extensive listric growth fault systems that dip basinward and sole into the underlying shales (d et al., 1999). The resulting structural configuration is dominated by extensional tectonics in the northern onshore area and compressional toe-thrust zones in the deeper offshore region, forming a classic growth-fault province (Corredor et al., 2005).

Sediment loading also induced shale diapirism and mud volcanism, especially in areas where overpressured shales mobilized vertically to create piercement structures that disrupt stratigraphy and alter fluid migration pathways (Doust & Omatsola, 1990). These processes play a crucial role in the creation of hydrocarbon traps and compartmentalized reservoirs. As the delta continued to advance southward, the structural complexity intensified due to syn-depositional deformation, leading to spatial variability in trap types and reservoir geometry.

2.1.2 Stratigraphy and Sedimentary Fill of the Niger Delta: Youngest to Oldest

The Niger Delta Basin is a classic example of a wave-dominated, passive margin delta, the product of prograding large volumes of clastic sediments into the Gulf of Guinea over the last 60 million years. Its stratigraphic architecture reflects the interaction of tectonic subsidence, sediment supply from the Niger River system, and eustatic sea-level fluctuations to produce a thick, diachronous sedimentary wedge extending from the onshore coastal plain to the deep offshore depocenters Short & Stauble, 1967; Tuttle et al., 1999. The sedimentary fill contains a continuous transition from continental through paralic into deep marine depositional environments, recording the evolution of the delta from the earliest Paleocene phase to the present day.

An understanding of the stratigraphy and sedimentary fill of the Niger Delta is fundamental to hydrocarbon exploration because it determines the distribution and quality of reservoirs, source rocks, and sealing intervals, plus the structural framework controlling hydrocarbon entrapment. The sedimentary sequence of the delta is typified by vertical and lateral facies heterogeneities arising from channel migration, lobate deposition, progradation cycles, and differential compaction, all factors affecting the geometry and connectivity of hydrocarbon-bearing formations.

The stratigraphic succession is classically subdivided into three major formations-arranged here from youngest to oldest-to facilitate the interpretation of both depositional history and hydrocarbon potential:

1. **Benin Formation**

   The Benin Formation is the youngest stratigraphic unit, deposited from Oligocene to Recent in continental fluvial and alluvial environments. It consists mainly of coarse to medium-grained sands, sandy gravels, and minor clay interbeds that are generally poorly consolidated and highly porous (20–35%), with a permeability of 500–1500 mD (Avbovbo, 1978). The thickness of the Benin Formation varies from approximately 2 km in the onshore depocenter to thinner landward sections as a consequence of topographic relief and delta progradation patterns. Due to its high permeability, it acts regionally as an aquifer, and with a lack of potential for hydrocarbons generated laterally due to the absence of lateral seals and trap structures, it can act as a migration pathway. The formation also marks the transition from marine-influenced deposition below to dominantly continental sedimentation above. This reflects the progradation of the delta over time.

2. **Agbada Formation**

   Underlying the Benin Formation, the Agbada Formation ranges in age from Eocene to Recent and forms the principal hydrocarbon-bearing interval of the Niger Delta, Evamy et al., 1978. It is composed of interbedded sandstones and shales that were deposited within delta-front, delta-plain and paralic environments as a paralic paralellel sequence.

The sandstone intervals form the principal reservoirs while the interbedded shales form intra-formational seals, allowing the development of stacked hydrocarbon traps. Sandstone beds are between 5 m to in excess of 50 m thick and may be up to several kilometres laterally continuous or pinch out due to the channel migration and lobate deposition. The petrophysical properties of the Agbada Formation are highly variable: porosity ranges between 15–30% and permeability is between 100–500 mD, reflecting facies changes and compaction trends.

Some of the depositional controls, including river channel migration, tidal reworking, delta-lobe switching, and relative sea-level changes, have produced complex lateral heterogeneity in both the quality of sandstone reservoirs and the integrity of shale seals. Evidence of syndepositional faulting also occurs in the Agbada Formation, where growth faults generated rollover anticlines and compartmentalized reservoirs critical to hydrocarbon accumulation and 3D seismic interpretation (Nyantakyi et al., 2013). This formation is hence one providing producible hydrocarbons in its reservoirs while serving as the seal to deeper accumulations in the Akata Formation.

3. Akata Formation

The Akata Formation is the basal unit of the Tertiary Niger Delta, deposited in deep marine pro-delta to turbiditic environments during the Paleocene. It consists predominantly of clay-rich shales, silts, and minor turbiditic sandstones, with thicknesses ranging from 2 km onshore to more than 7 km offshore (Doust & Omatsola, 1990). Rich in Type II and III kerogen, the Akata shales are the main source rock for both oil and gas in the Niger Delta. Deep burial has led to overpressure development and ductile rheology, which allows for gravity-driven deformation, listric growth faulting, and shale diapirism responsible for the complex structural traps found throughout the basin (Tuttle et al., 1999; Nyantakyi et al., 2013).

Occasional turbiditic sand layers within the Akata Formation can act as secondary reservoirs; however, they are mostly thin and laterally discontinuous. The formation also acts as a detachment layer, facilitating deformation in the overlying Agbada Formation. The interaction of sedimentation, subsidence, and tectonics in the Akata Formation underpins the structural complexity observed in seismic data and has a direct impact on hydrocarbon migration pathways and trap formation.

The figure below shows the stratigraphic colum of the Niger Delta.

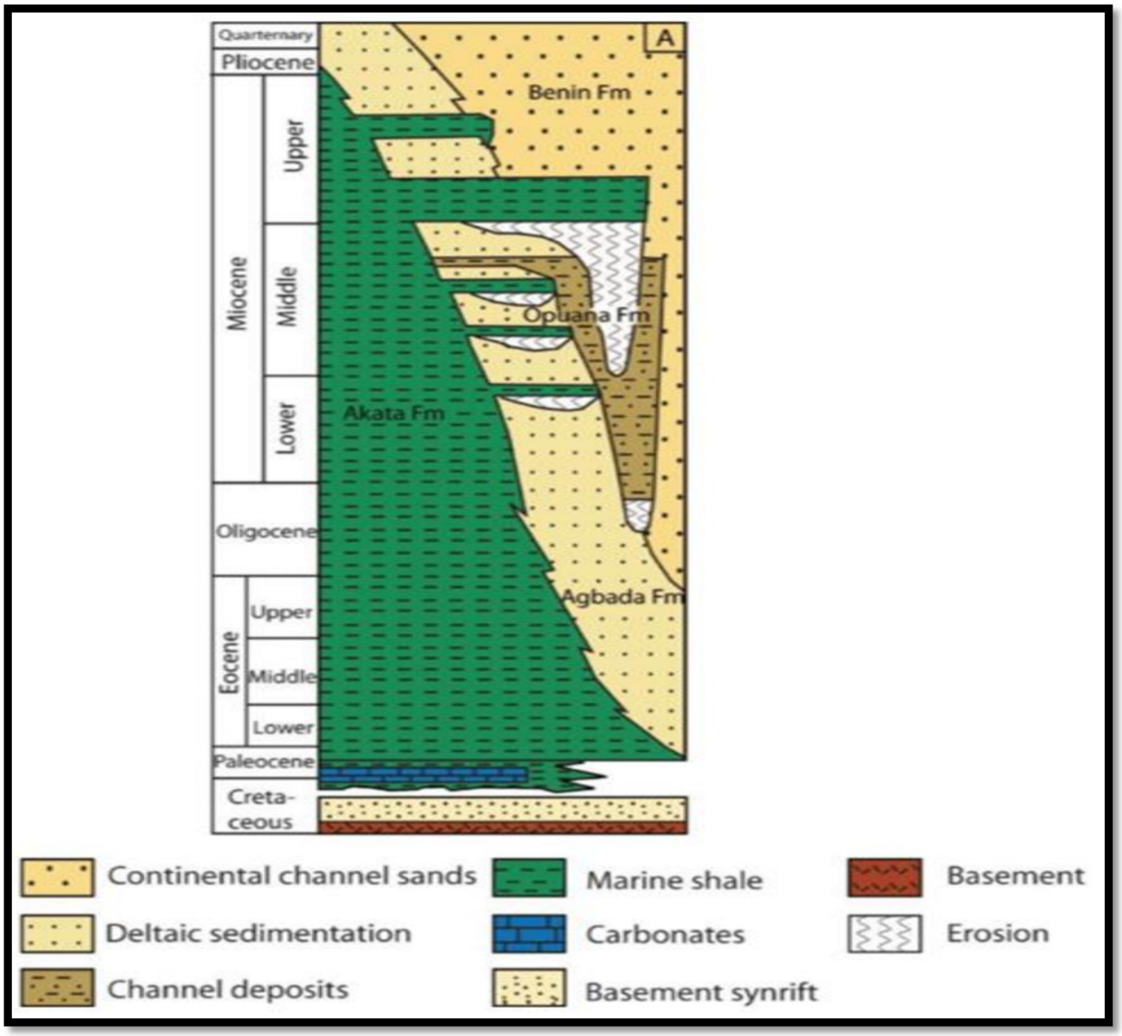

Figure 2.2 : Stratigraphic column of the Niger Delta (Shannon and Naylor, 1989; Doust and Omatsola, 1990)

2.1.3 Tectonic Structures and Structural Styles in the Niger Delta

The Niger Delta Basin is structurally complex, with syn-depositional extensional features dominated by high sedimentation rates, subsidence, and the mechanical properties of the underlying ductile Akata shales (Tuttle et al., 1999; Doust & Omatsola, 1990). Its structural framework is a direct result of gravitational instability within the thick, rapidly deposited clastic wedge. Understanding such structures is of vital importance for hydrocarbon exploration and 3D seismic interpretation. The most characteristic structural features are Growth Faults, which are generally listric, dipping basinward into the ductile Akata Formation and flattening at depth. They develop contemporaneously with sediment deposition, resulting in variable displacement along their length and creating rollover anticlines and associated accommodation zones (Evamy et al., 1978).

Growth faults enable structural traps where hydrocarbons can accumulate in the hanging wall, whereas the footwall often remains tight and under-compacted. The rollover anticlines form in the hanging wall of listric faults due to differential extension and sediment loading. These structures are commonly hosts to commercial hydrocarbon accumulations, and their geometry has been influenced by sedimentation rates, fault displacement, and compaction of underlying shales. These anticlines may also interact with other faults or minor folds, creating trap segmentation that must be carefully assessed in seismic interpretation. Nyantakyi et al., 2013 Where overpressured Akata shales intrude into overlying formations, shale diapirs and piercement structures are generated. The diapirs may pierce through the Agbada Formation, deforming the reservoir sands and creating localized traps, but they also complicate seismic imaging because of chaotic reflections and velocity anomalies. Their presence is particularly important with regard to the identification of fault-seal relationships and predictions concerning reservoir continuity in the subsurface. In addition to these primary structures, the delta displays a range of minor extensional features such as rollover faults, synthetic and antithetic splays, and minor folds that influence the compartmentalization of the reservoir. These structures define the organization of the delta into a series of depo-belts, each related to a particular phase of deltaic progradation and thereby associated with an individual structural style. In general, simple, moderately dipping listric faults dominate the shallower northern onshore area of the delta while complex toe-thrust zones, shale-cored anticlines, and interacting arrays of multiple faults characterize the deeper offshore depocenters (Doust & Omatsola, 1990; Tuttle et al., 1999).

The structural style in the Niger Delta has a direct impact on hydrocarbon exploration because it predetermines the conditions of trap development, migration paths, and reservoir compartmentalization. Growth faults and related rollover anticlines create the bulk of the structural traps, and shale diapirs and minor faults add heterogeneity that can either promote or inhibit hydrocarbon accumulation. Resolved in 3D seismic data, these features can be mapped with much better accuracy than in 2D data to predict the geometry of the reservoir, connectivity of faults, and trap integrity.

The figure below shows the location of the Niger Delta on the continental margin of the Gulf of Guinea in equatorial West Africa

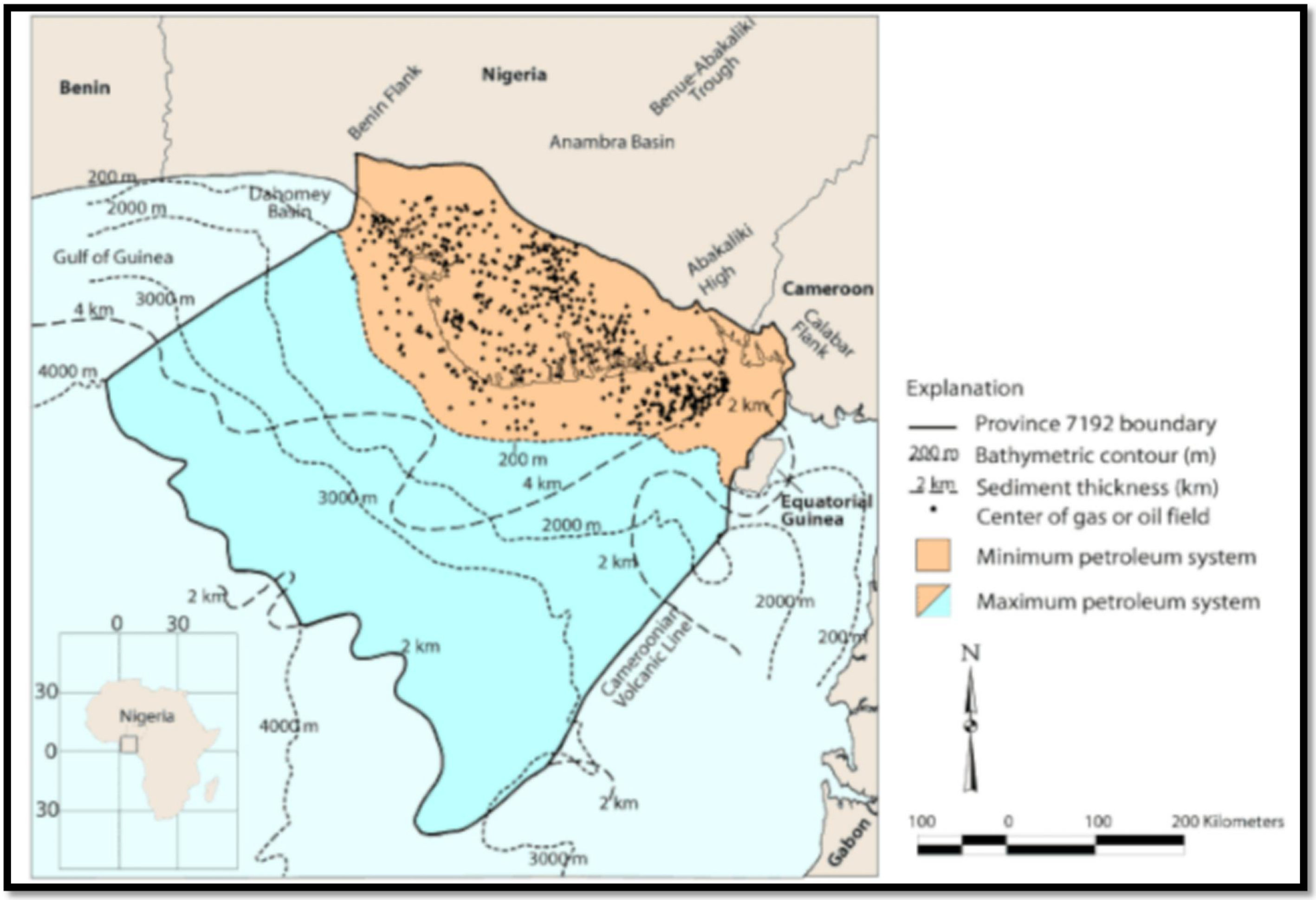

Figure 2.3 : Location of the Niger Delta on the continental margin of the Gulf of Guinea in equatorial West Africa (Tuttle *et al.*, 1999)

2.1.4 Depobelts of the Niger Delta

The The Niger Delta is a wave-dominated, passive margin delta whose sedimentary fill is organized into distinct depositional belts, or "depo-belts", reflecting the progressive progradation of clastic sediments from the onshore Niger River system into the Gulf of Guinea over the past ~60 million years (Short & Stauble, 1967; Doust & Omatsola, 1990). These belts are defined not only by their geographic position and distance from the shoreline but also by sediment thickness, lithofacies characteristics, structural style, and depositional age. This understanding of depo-belts is important in hydrocarbon exploration because they determine the reservoir distribution, facies heterogeneity, trap types, and hydrocarbon migration pathways.

Each depo-belt represents a different stage of deltaic growth, reflecting chronology and spatial sediment distribution. Commonly identified are the Northern or Frontal, Central or Main, Southern or Distal, Offshore Toe-Thrust, and minor lateral belts. Each of these has specific depositional and structural features affecting petroleum prospectivity.

The definition of depobelts is based on various criteria: the thickness of the sedimentary accumulations, the dominant lithology and facies, structural style, including growth faults and rollover anticlines, and the relative age of deposition. Younger sediments occur towards the toe-thrust belt, while the northern onshore belt consists of older, shallow deposits. Each belt also shows characteristic reservoir and seal architecture, reflecting the interaction of sedimentation with subsidence and syn-depositional tectonics.

1. **Northern Delta Depo-Belt**

   The Northern Delta Belt is the oldest and most landward depositional belt, forming the northern fringe of the delta. Sediment thickness ranges from 2–5 km where deposits are dominated by Benin Formation continental sands and minor paralic Agbada Formation sequences. Structurally, this belt is rather simple with moderate-displacement listric growth faults and gentle rollover anticlines. Hydrocarbon traps are essentially structural and related to growth faults, whereas the reservoirs are generally shallow and laterally continuous. This belt is defined by its onshore position, thin sedimentary cover, and continental depositional facies.

2. **Greater Ughelli Depo-Belt**

   The Greater Ughelli Belt represents the main productive belt of the delta and is defined by thick Agbada Formation sequences ranging from 5–9 km. Deposits consist of alternating sandstones and shales, forming the primary reservoir–seal pairs of the basin. Large-displacement listric faults, rollover anticlines, and accommodation zones define the belt structurally and generate stacked and compartmentalized traps. Channel migration, lobe switching, and tidal reworking are the typical deltaic processes which create major facies heterogeneity. This belt is thus critical in hydrocarbon exploration, as it is home to most oil fields in the Niger Delta.

3. **Central Swamp Depo-Belt**

   The Central Swamp Belt is more distal compared to Greater Ughelli and represents a deepening phase of delta progradation. Sediment thickness varies from 7 to 10 km, with deposition dominated by Agbada paralic sand-shale sequences and turbiditic sands. Structural complexity increases with listric growth faults, minor shale diapirs, and folded closures, which produce highly compartmentalized reservoirs. Lateral facies changes result in variable continuity within the reservoirs. Hydrocarbon traps are both structural and stratigraphic. The belt is defined by its intermediate offshore position, increased sediment thickness, and complex structural style.

4. **Coastal Swamp Depo-Belt**

   The Coastal Swamp Belt is situated between the Central Swamp and offshore environments. Here, sediments are younger and thinner, averaging 5-8 km; deposition occurs in delta-front and shallow marine paralic environments. It is less structurally complex in comparison with the Central Swamp but possesses moderate-displacement growth faults with smaller rollover anticlines, although there are minor shale diapirs. Reservoirs tend to be laterally continuous, although often compartmentalized due to channelized sand bodies. The belt is defined based on its position along the coastal swamp, paralic depositional facies, and intermediate structural complexity. Offshore Depo-Belt

5. **The Offshore Depo-Belt**

   This represents the most distal and deepwater part of the delta and includes the toe-thrust zone of the clastic wedge. Agbada turbiditic sands are interbedded with overpressured Akata shales to thicknesses exceeding 10-12 km. Toe-thrusts, shale-cored anticlines, and chaotic growth faulting are characteristic structural features that are responsible for highly compartmentalized traps. Hydrocarbon exploration is difficult because of complex structural deformation and overpressure besides deep-water conditions. Offshore position, thick sediment accumulation, distal depositional facies, and compressional structural style define this belt.

   The figure below shows the structural and depositional framework of the Niger Delta Depo-belts, structural provinces and limits

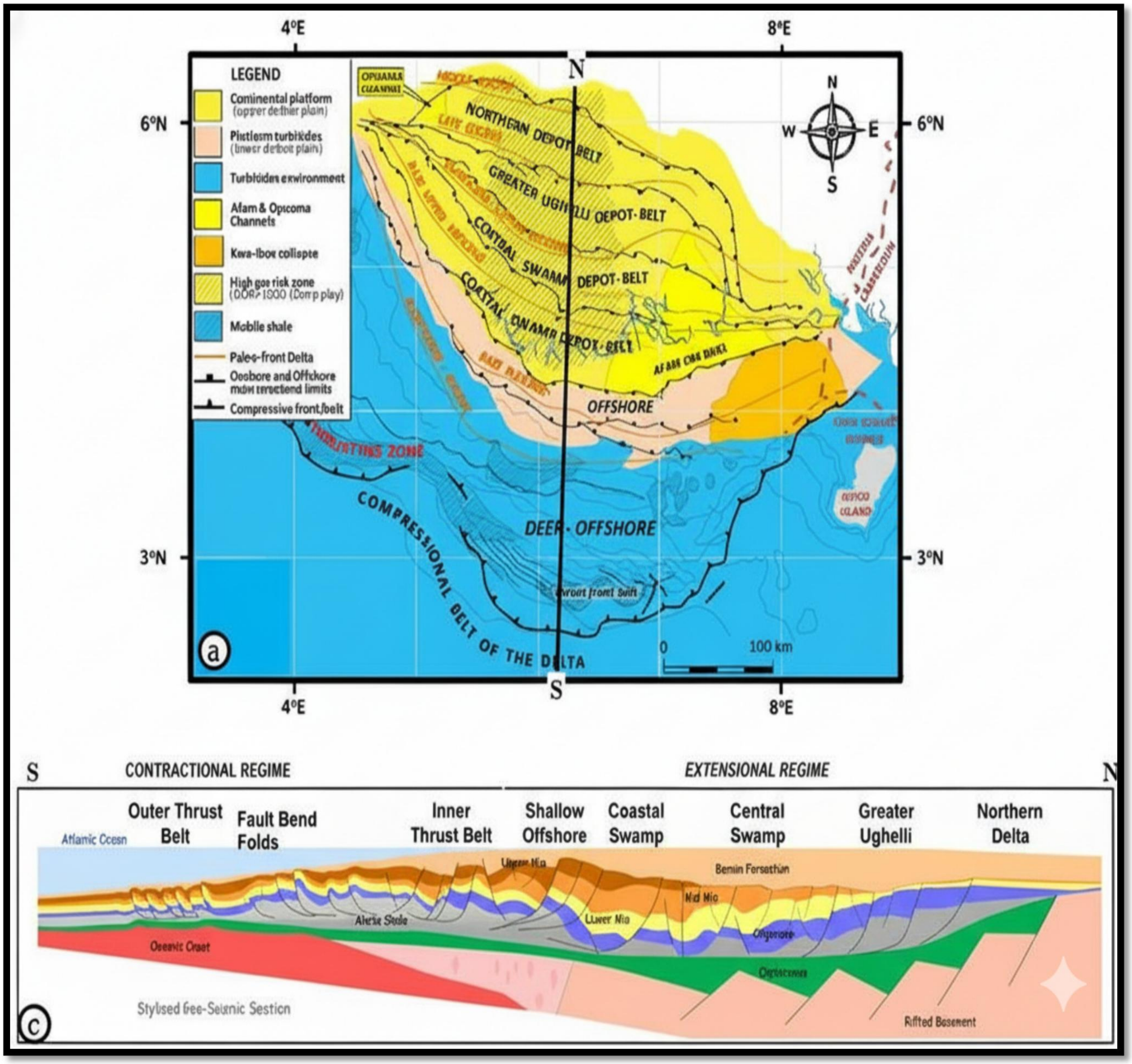

Figure 2.4 : The structural and depositional framework of the Niger Delta Depo-belts, structural provinces and limits (Doust and Omatsola 1990)

2.1.5 Structural Geology of the Niger Delta

The structural geology of the Niger Delta is a direct consequence of the interplay between rapid sedimentation, gravitational forces, and the rheological behavior of underlying ductile shales, particularly the Akata Formation. Over millions of years, the enormous sediment load of the deltaic clastic wedge has induced syn-depositional extensional tectonics, gravitational sliding, and localized compressional deformation, producing a diverse range of structural features. These structures vary across the delta's five depositional belts; Northern Delta, Greater Ughelli, Central Swamp, Coastal Swamp, and Offshore, and critically influence trap formation, reservoir compartmentalization, hydrocarbon migration, and the overall petroleum prospectivity of the basin. The study of these features, especially through 3D seismic interpretation, provides the foundation for understanding the complex subsurface architecture of the Niger Delta.

I. **Listric Growth Faults**

Listric growth faults are the principal extensional structures in the delta, characterized by a concave-downward geometry that flattens into the ductile Akata Formation at depth. These faults develop contemporaneously with sediment deposition, accommodating differential subsidence and high sedimentation rates. The hanging walls of listric faults typically form rollover anticlines, while the footwalls develop mini-basins that influence sediment distribution and reservoir development. In the Northern Delta and Greater Ughelli belts, these faults display moderate displacement and relatively simple geometries. By contrast, the Central Swamp and Coastal Swamp belts exhibit larger-displacement growth faults that produce highly compartmentalized reservoirs. In the Offshore belt, growth faults overlap and interact with toe-thrust structures, resulting in complex deformation patterns.

II. Rollover Anticlines

Rollover anticlines form in the hanging walls of listric growth faults due to differential extension and sediment loading. They are critical as structural traps, with their geometry influenced by fault displacement, sediment thickness, and compaction trends. In the Central Swamp and Coastal Swamp belts, rollover anticlines are often segmented by minor faults, creating discrete compartments that can affect hydrocarbon distribution. Offshore, these anticlines interact with shale diapirs and toe-thrusts, increasing structural complexity and presenting challenges for reservoir prediction.

III. Shale Diapirs and Piercement Structures

Shale diapirs arise when overpressured Akata shales pierce overlying Agbada sequences, deforming reservoirs and forming localized closures. They are prominent in the Central Swamp, Coastal Swamp, and Offshore belts. While diapirs can act as effective hydrocarbon seals, they may also disrupt reservoir continuity and complicate fluid flow pathways, requiring careful analysis during seismic interpretation.

IV. Toe-Thrusts and Compressional Features

Toe-thrusts develop at the distal edge of the clastic wedge due to gravitational loading exceeding the critical threshold, producing compressional structures. These include shale-cored anticlines, imbricate thrusts, and complex folds, particularly in the Offshore belt. Toe-thrusts form traps that are structurally distinct from extensional rollover anticlines and are often highly compartmentalized, necessitating detailed seismic mapping for accurate delineation.

V. Synthetic and Antithetic Faults

Secondary faulting within deltaic lobes produces synthetic and antithetic faults. Synthetic faults dip in the same direction as the main growth fault and often bound rollover anticlines, while antithetic faults dip in the opposite direction, segmenting reservoirs and impacting hydrocarbon continuity. These minor faults are especially prevalent in the Central Swamp and Coastal Swamp belts, where they influence reservoir connectivity and fluid migration patterns.

VI. Flexural Folds

Flexural folds form due to differential subsidence, sediment loading, or interactions between adjacent growth faults. They produce minor structural traps, predominantly in the Northern Delta and Greater Ughelli belts. Although less prominent than major growth faults, these folds contribute to reservoir compartmentalization and may host small hydrocarbon accumulations.

VII. Collapse Structures and Gravitational Sliding

Rapid sedimentation over ductile Akata shales can trigger gravitational sliding and collapse structures, particularly along steep delta slopes. These features are most common in the Coastal Swamp and Offshore belts and produce chaotic seismic facies. Collapse structures affect reservoir predictability and trap integrity, requiring careful interpretation to avoid exploration risk.

VIII. Minor Thrusts and Reverse Faults

Localized compressional stresses, especially near the toe of the clastic wedge, generate minor thrusts and reverse faults. These structures are prevalent in the Offshore belt, modifying pre-existing extensional traps and creating hybrid traps that combine structural and stratigraphic elements. Such features further complicate the subsurface architecture and must be integrated into 3D seismic models for accurate reservoir characterization.

The figure below shows the Examples of Niger Delta oil field structures and associated trap types .

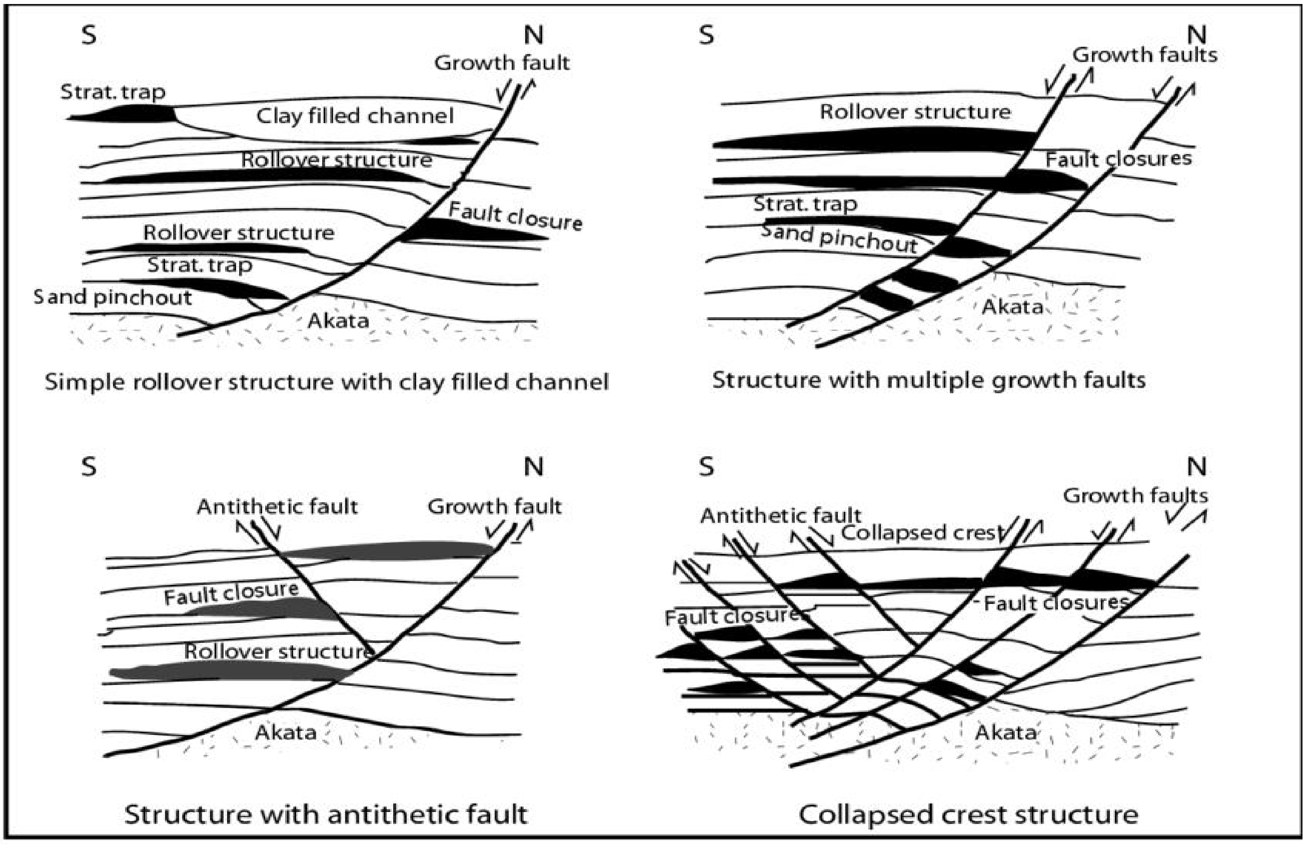

Figure 2.5 : Examples of Niger Delta oil field structures and associated trap types (Doust and Omatsola (1990) and Stacher (1995))

2.1.6 Petroleum Potential of the Niger Delta

The Niger Delta Basin represents one of the most prolific hydrocarbon provinces in the world, characterized by a thick, rapidly deposited clastic wedge, extensive deltaic systems, and a structurally complex subsurface framework. Its petroleum potential arises from the combination of high sedimentation rates, diverse depositional environments, and dynamic tectonic activity, which together have created a range of hydrocarbon accumulations across the five major depositional belts: Northern Delta, Greater Ughelli, Central Swamp, Coastal Swamp, and Offshore.

2.1.7 Source Rock

The source rocks of the Niger Delta are fundamental to the basin's prolific hydrocarbon generation. The primary source rock is the Akata Formation, which consists predominantly of organic-rich marine shales, silty shales, and turbiditic deposits. These sediments were deposited in prodelta to deepwater environments, providing conditions favorable for the accumulation of high-quality organic matter. The Akata shales are generally overpressured, which enhances hydrocarbon expulsion into overlying reservoir units, and contain Type II and Type III kerogen, capable of generating both oil and gas depending on depth and thermal maturity (Short & Stauble, 1967; Weber & Daukoru, 1975).

The Agbada Formation also contributes as a minor source rock in the proximal parts of the delta, particularly in the Northern Delta and Greater Ughelli belts, where interbedded shales with moderate TOC values are present. Hydrocarbon generation from the Akata Formation is depth-dependent: oil generation typically occurs at burial depths of 2–3 km, whereas gas generation dominates at greater depths, often in the Offshore belt where sediment thickness and overpressure are highest.

The effectiveness of these source rocks is controlled not only by organic richness and kerogen type, but also by burial history, geothermal gradient, and overpressure development, which influence the timing and efficiency of hydrocarbon generation. Migration pathways are generally vertical, driven by buoyancy, and lateral migration is often guided along growth faults and syn-depositional channels. The interplay between source rock maturation, structural architecture, and depositional facies is crucial for determining the spatial distribution of hydrocarbons across the Northern Delta, Greater Ughelli, Central Swamp, Coastal Swamp, and Offshore belts.

2.1.8 Reservoir Rocks

The reservoirs of the Niger Delta are predominantly composed of sandstones within the Agbada Formation, deposited in a range of deltaic, fluvial, and shallow marine environments. These sandstones exhibit significant variability in thickness, lateral continuity, porosity, and permeability, reflecting the heterogeneity of depositional processes and subsequent structural modification. Reservoir quality is influenced by grain size, sorting, cementation, diagenetic processes, and structural deformation, including growth faults, rollover anticlines, and shale diapirs (Doust & Omatsola, 1990; Weber & Daukoru, 1975).

Reservoir sandstones range from laterally extensive channel sands to stacked delta-front sand bodies, creating multiple intervals with complex vertical and lateral heterogeneity. Structural deformation, such as listric faulting and diapiric intrusions, can segment reservoirs into isolated compartments, affecting fluid flow and hydrocarbon recovery (Evamy et al., 1978). Fine-grained interbeds within the sandstones can reduce porosity and permeability locally, introducing additional heterogeneity (Short & Stauble, 1967).

In deeper settings, reservoirs may consist of turbiditic and deepwater sandstones interbedded with thick shale sequences, producing discontinuous and structurally complex hydrocarbon-bearing units. These reservoirs are often highly compartmentalized due to collapse structures, toe-thrusts, and diapiric activity, requiring careful seismic interpretation to map geometry and connectivity accurately (Doust & Omatsola, 1990).

2.1.9 Traps and Seals

Hydrocarbon accumulation in the Niger Delta is fundamentally controlled by the presence and effectiveness of traps and seals, which together determine whether generated hydrocarbons are preserved or lost through leakage. The delta exhibits a variety of trap types, formed through both structural deformation and stratigraphic processes, while seals are primarily provided by shale intervals capable of preventing vertical and lateral hydrocarbon migration (Doust & Omatsola, 1990; Evamy et al., 1978).

I. Structural Traps

Structural traps dominate hydrocarbon entrapment and are primarily associated with growth faults, rollover anticlines, shale diapirs, and toe-thrust anticlines. Growth faults, which developed contemporaneously with sedimentation, create rollover anticlines on their downthrown sides. These anticlines act as effective traps where reservoir sands are juxtaposed against sealing shales. Shale diapirs, formed through differential loading and overpressure in the Akata Formation, generate shale-cored anticlines, providing structural closures for hydrocarbon accumulation. Toe-thrust anticlines, commonly observed in distal offshore areas, form due to gravitational sliding of deltaic sediments into deeper basins and represent structurally complex traps that often require detailed seismic interpretation for delineation (Weber & Daukoru, 1975).

II. Stratigraphic Traps

Stratigraphic traps arise from lateral facies variations, pinch-outs of sand bodies, and deltaic channel terminations. Isolated sandstones that terminate against shales, as well as sand-filled incised valleys and deltaic lobes, create conditions for hydrocarbon accumulation without significant structural deformation. These traps are often subtle and require careful seismic and well correlation to identify (Short & Stauble, 1967).

III. Combination Traps

Combination traps result from the interaction of structural deformation and depositional heterogeneity, producing closures where faults or folds coincide with sand pinch-outs or facies changes. Examples include segmented rollover anticlines or sand bodies draped over diapirs. Their effectiveness depends on the timing of sedimentation, faulting, and hydrocarbon migration, and they are often highly compartmentalized (Doust & Omatsola, 1990).

IV. Seals

Seals in the Niger Delta are primarily provided by Agbada Formation shales, with the Akata Formation shales acting as a regional basal seal. Seal effectiveness depends on shale thickness, ductility, lateral continuity, and degree of compaction. Structural deformation can enhance sealing by juxtaposing sands against shales or compromise it through fault planes and diapiric piercing. In deeper offshore settings, thick overpressured prodelta shales form particularly effective seals, preserving hydrocarbons in structurally complex reservoirs (Evamy et al., 1978; Weber & Daukoru, 1975).

2.2 Literature Review

Aizebeokhai (2018) remains one of the landmark studies in Niger Delta reservoir characterization, presenting a strong multidisciplinary approach that merged well-log analysis and 3D seismic interpretation. The study was conducted in an offshore field in which Aizebeokhai identified and characterized four key reservoir units, R1–R4, using petrophysical analysis to determine critical parameters such as porosity (21–30%), hydrocarbon saturation (80–96%), and net-to-gross ratios from log data, indicative of the presence of high-quality Agbada Formation sands. Among the key strengths in his work is the orderly application of seismic attributes-RMS amplitude, coloured inversion, and amplitude anomalies-that were used in mapping the geometry of the reservoirs and for the identification of DHI-anomalies such as bright spots, flat spots, and fluid contacts (GOC/OWC). Aizebeokhai also computed neural network-based chimney attributes to analyze seal integrity and migration pathways, showing a forward-looking approach in the integration of machine learning into traditional seismic interpretation. In this paper, the use of common contour binning to correlate seismic responses with well log data from petrophysics enhanced net-pay prediction and facies discrimination. In summary, Aizebeokhai (2011) serves to illustrate how the integration of petrophysics, seismic, and emerging computation methods can significantly increase confidence in the subsurface of the geologically complex Niger Delta and remains a benchmark for integrated studies in this basin.

Avbovbo (1978) represents one of the foundational works in Niger Delta geology and indeed provides the first comprehensive stratigraphic and structural model of the basin, which continues to underpin both academic and industry workflows to date. Drawing on extensive well-log and drilling data, Avbovbo established the now-standard tripartite Tertiary sequence-Akata, Agbada, and Benin Formations-and linked their lithofacies to distinct depositional environments: deep marine prodelta shales (Akata), delta-front to distributary-channel sand-shale complexes (Agbada), and continental fluvial sands (Benin). The work demonstrated the role of the Agbada Formation as the main reservoir-seal system and positioned the Akata as the main source rock. Beyond the stratigraphy, Avbovbo explained the typical structural style of the delta and attributed growth faults, listric faulting, and rollover anticlines to gravity-driven deformation above overpressured shales. Avbovbo's model illustrates well the dominant trap types in this basin. By integrating the lithologic, stratigraphic, and tectonic insight, Avbovbo provided the essential geological framework that informs seismic interpretation, reservoir modeling, and exploration strategies in the Niger Delta to this day, offering it as a cornerstone reference in the field.

Larue and Legarre (2004) document a case study in the wave-dominated, middle Miocene delta-front deposit Meren E-01 reservoir, Agbada Formation, Niger Delta, that illustrates how sequence stratigraphy is essential for capturing reservoir heterogeneity and making reliable predictions of fluid flow. Core analysis and correlation of eight flooding surfaces defined a complex architecture of progradational and retrogradational shoreface clinoforms, while sedimentary features (e.g., hummocky cross-stratification, slumps, turbidites) indicated high-energy, wave-influenced deposition. Three 3D geological modeling approaches were compared, including a simple geostatistical model, a facies-enhanced model using sandstone-quality trends, and a fully integrated sequence-stratigraphic model incorporating mudstonequality trends and flooding surfaces. Only the sequence-stratigraphic model identified vertical compartmentalization due to laterally extensive, tortuous mudstone layers responsible for significant unswept oil zones omitted by the more simplistic approaches. Flow simulations and history matching demonstrated this approach provided not only better predictions of reservoir connectivity but also highlighted economically viable infill drilling opportunities. Larue and Legarre (2004) demonstrate that high-resolution sequencestratigraphic frameworks are an integral part of good reservoir management in heterogeneous wave-influenced deltaic systems, capturing the flowcontrolling heterogeneities significantly better than conventional geostatistical approaches.

Okechukwu & Nnabuique (2025) give an example of an increasing practical application of multi-attribute seismic analysis to the improvement of reservoir characterization in structurally complicated offshore Niger Delta. The Authors analyzed an "X" Field using amplitude, RMS amplitude, variance edge, phase, frequency, and reflector continuity attributes to improve the resolution of geometry, fault network, and fluid-related anomalies not so clear in conventional seismic data. It is shown that the RMS amplitude clearly outlined the bright spots and fluid contacts, while the variance-edge attributes allowed for better mapping of growth faults and synthetic–antithetic fault systems, the major structural traps in the delta. In addition, seismic attributes-driven structural smoothing and 3D fault modeling substantially improve the interpretation of the faulting and help optimize well placement. General industry interest in the adoption of attribute-driven workflows is supported by the results of Okechukwu & Nnabuique (2025) which tell about the role of such attributes in a joint reduction of subsurface uncertainty and identification of strengths in hydrocarbon prospect evaluation.

Kalu et al. (2020) conducted a detailed re-evaluation of the Emerald Field in the Niger Delta Basin using 3D seismic data and four wells to construct an updated structural model of the field.

Their study integrated well-log analysis, seismic facies classification, petrophysical evaluation, and seismic attribute interpretation to determine reservoir quality and hydrocarbon distribution. Through combined analysis of Gamma Ray, Resistivity, Neutron, and Density logs, three hydrocarbon-bearing reservoirs, Emy A, B, and C, were identified across the wells. Petrophysical results revealed porosity values ranging from 10–29%, hydrocarbon saturation between 0.75–0.84, and water saturation from 0.16–0.25. The shale content varied between 0.24–0.33, while net-to-gross ratios ranged from 0.72–0.93. Five seismic facies were recognized and interpreted as distributary channel fills, over bank deposits, and floodplain sediments, characteristic of a paralic depositional environment. The study ultimately delineated two prospects and one lead, recommending Emerald Prospect B as the most promising target for further drilling and production testing.

Doust and Omatsola (1990) offered a comprehensive chronostratigraphic and structural interpretation of the Niger Delta Basin, focusing on the structural styles that define trap formation. Their work emphasized the influence of syn-sedimentary faulting on sand body distribution and reservoir geometry. By organizing the delta into structural and depositional frameworks, they provided interpretive guidelines that continue to support seismic-based reservoir and trap analysis across the basin.

Ogbamikhumi and Ighodalo 2021 combined model-based inversion analysis and rock-physics workflows with artificial neural networks to locate and evaluate probable prospect zones in an undrilled portion of the basin. Employing available well penetrations, the authors developed amplitude and structural maps that pointed to interesting reservoir responses indicating hydrocarbon accumulation. Rock-physics crossplot analyses, especially Poisson's ratio, Lambda-Rho, and Lambda/Mu-Rho, were the most useful as fluid and lithology indicators. The inversion results are portrayed as attribute maps, which were further analyzed in order to confirm the presence of hydrocarbon-bearing intervals. The PNN prediction generally showed values ranging between 25–30%, indicating good-quality reservoir zones within the prospect area.

CHAPTER THREE

METHODOLOGY

Seismic data interpretation involves the extraction of comprehensive subsurface information from processed seismic datasets. This process encompasses several aspects, including the identification of geological structures, analysis of stratigraphic compositions, evaluation of subsurface rock properties, velocity modeling, stress assessment, and, where applicable, monitoring changes in reservoir fluids over time and space. The primary interpretation objectives in this study include fault analysis, seismic horizon interpretation, and the generation of both time and depth structure maps to delineate structural and stratigraphic frameworks relevant to hydrocarbon accumulation.

The available 3D seismic and well log data were carefully checked for quality assurance, validated for consistency, and subsequently loaded into Petrel™ 2014 interpretation software for processing and interpretation. The workflow was designed to ensure precision in correlating well data with seismic reflectors and in accurately mapping subsurface structures and reservoirs.

3.1 Workflow

The processes involved in the completion of this project work are shown by the flowchart below and further discussed in detail.

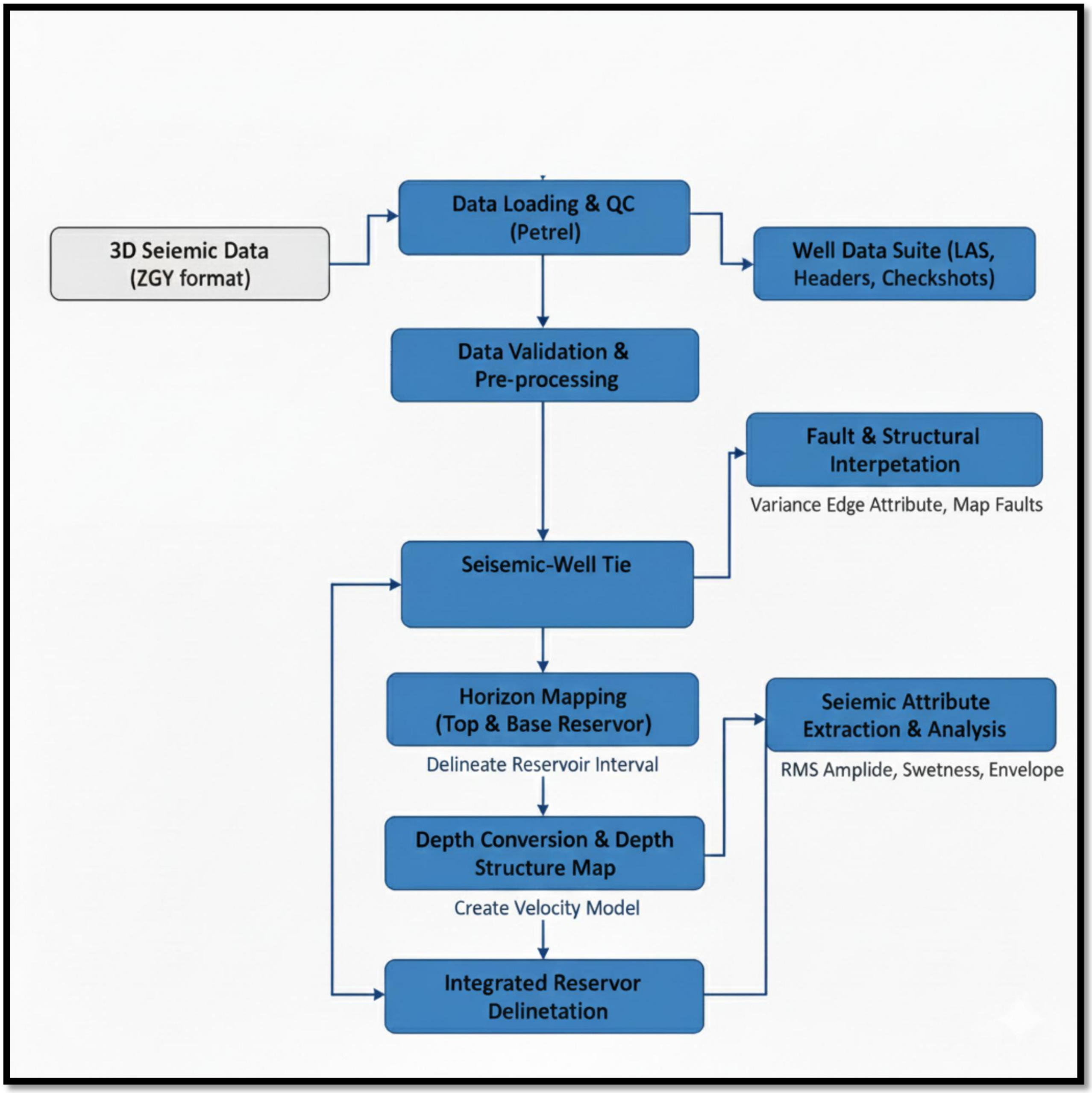

Figure 3.1 : Workflow

3.2 Seismic Data Source

The seismic data utilized for this study were provided by the Shell Petroleum Development Company (SPDC) through authorization obtained from the Department of Petroleum Resources (DPR). These data formed the foundation for all subsequent analyses and interpretations carried out during the course of this research.

To effectively handle, visualize, and interpret the seismic data, the researchers employed Petrel™ 2014 software, a robust platform widely used in the oil and gas industry for seismic and well data integration, interpretation, and modeling. The dataset comprises three-dimensional (3D) seismic data, which provides a detailed representation of the subsurface architecture, enabling accurate mapping of structural and stratigraphic features.

The primary objective of seismic data interpretation is to extract comprehensive subsurface information from the processed seismic data. This involves identifying and delineating geological structures such as faults, folds, and horizons, as well as characterizing stratigraphic patterns, correlating wells, and potential hydrocarbon-bearing zones. The interpretation process ultimately leads to the generation of structural time and depth maps, which are essential for understanding the geometry and extent of the subsurface formations and for evaluating potential hydrocarbon traps within the study area.

3.3 Data Importation

The process of data importation involved systematically loading all available seismic and well datasets into the Petrel™ 2014 interpretation software environment for analysis. This step was critical to ensure seamless integration between the seismic data and the corresponding well information, forming the basis for accurate interpretation and modeling.

Prior to importation, the datasets were carefully reviewed to verify their formats, coordinate systems, and consistency. The seismic volume, provided in ZGY format, was imported into Petrel along its respective inline and crossline orientation, ensuring that the spatial relationships within the 3D dataset were preserved. Each inline and crossline was checked for continuity and data quality to confirm that the seismic cube was properly referenced in both time and space domains.

The figure below shows the 3D view of study field when data was loaded

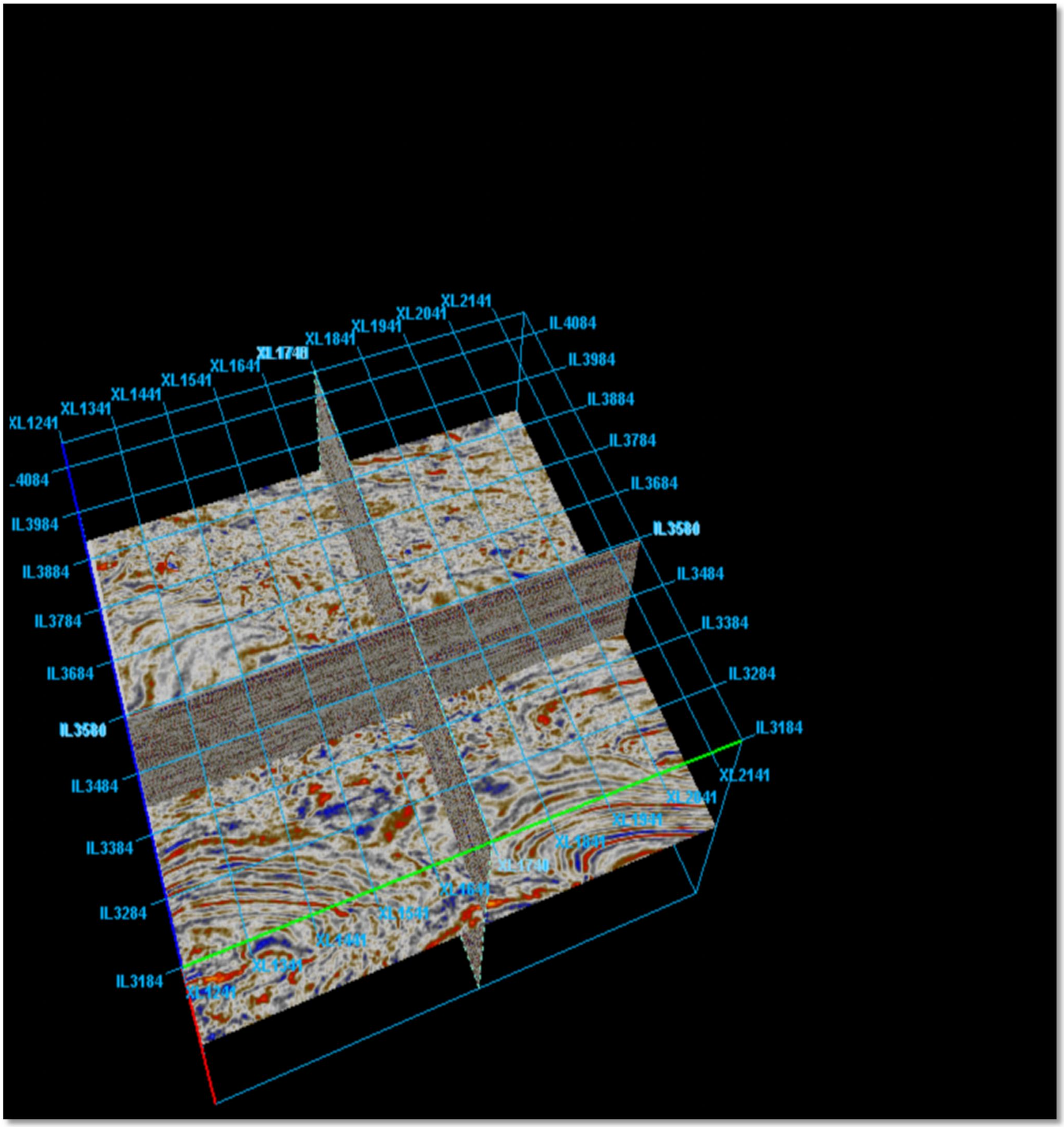

Figure 3.2 : 3D view of study field when data was loaded

The well log data, on the other hand, were imported in LAS format, which contained essential log curves such as gamma ray, resistivity, density, and neutron logs. These logs were depth-matched and quality-checked to ensure accurate alignment with the seismic data. Checkshots were used to establish a time–depth relationship (TDR) that facilitated subsequent correlation between seismic reflections and geological formations observed in the wells.

3.4 Seismic Volume, Attribute Realization, and Fault Mapping

The imported 3D seismic volume served as the fundamental dataset for interpreting the subsurface architecture of the study area. The seismic cube provided a continuous spatial and temporal representation of subsurface reflectors, allowing for the identification and delineation of geological structures such as faults, folds, and stratigraphic boundaries. Attribute extraction and fault mapping were subsequently performed to enhance the interpretation accuracy and reveal subtle structural features that might not be easily visible on conventional amplitude displays. The attribute realization process involved the generation of the variance attribute, which are particularly effective in highlighting discontinuities within the seismic volume. These discontinuities often correspond to fault planes or structural boundaries. The variance attribute was extensively utilized to delineate fault trends and orientations by enhancing lateral changes in seismic amplitude. Time-slice visualization and 3D volume rendering were also employed to trace fault geometries throughout the dataset.

Fault interpretation was carried out systematically across selected inlines and crosslines using both manual and semi-automated techniques. Cursor tracking on the attribute-enhanced maps facilitated the accurate picking of fault planes. Through this process, a total of thirty-five (35) faults were identified and mapped across the study area. These faults include growth faults, rollover anticlines, synthetic and antithetic faults, back-to-back structures, and conjugate faults, all of which are characteristic of the extensional tectonic regime of the Niger Delta Basin.

3.5 Seismic-to-Well Tie

The seismic-to-well tie represents a critical stage in the seismic interpretation workflow, serving as the bridge between the well data (measured in depth) and the seismic data (recorded in time). This process ensures that the seismic reflections correspond accurately to the geological formations penetrated by the wells, thereby improving the reliability of structural and stratigraphic interpretations.

In this study, the seismic-to-well tie was carried out, which allows for the integration of checkshot, sonic, and density logs to create synthetic seismograms. The synthetic seismogram replicates the seismic response at the well location and was generated by convolving the reflection coefficient series, derived from the sonic and density logs with an extracted seismic wavelet from the seismic volume.

This synthetic seismogram was then visually correlated with the actual seismic trace at the well location to ensure alignment between key seismic reflectors and known geological markers. Minor adjustments to the wavelet and log data were made to optimize the correlation, producing a reliable time–depth relationship (TDR) for the study area.

The resulting TDR was subsequently applied to other wells within the field to achieve consistent depth-to-time conversion across the dataset. This relationship also provided the foundation for velocity modeling and depth conversion, both of which are vital for constructing accurate depth maps.

3.6 Horizon Mapping

Horizon mapping is a key step in seismic interpretation aimed at identifying and correlating significant reflection events that represent geological boundaries within the subsurface. The process began with the identification of prominent, continuous reflection events on in lines and crosslines, which were carefully tracked throughout the seismic section to ensure spatial consistency.

3.7 Time Structural Map

The time structural map represents the spatial configuration of subsurface reflectors in terms of two-way travel time (TWT). The mapped horizons from the 3D seismic interpretation were converted into grid surfaces that displayed the variation in travel time across the study area. The fault planes identified during the fault interpretation stage were also superimposed on the time structure maps to visualize their spatial relationship with the mapped horizons and to understand the fault-controlled deformation pattern.

3.8 Velocity Modelling

In this study, velocity modelling was performed using the Time–Depth Relationship (TDR) developed during the seismic-to-well tie process. The TDR curve was derived from check shot and sonic log data, ensuring a reliable correlation between the recorded two-way travel time and the corresponding true depth. This relationship was modeled using a second-order polynomial function, which best represented the velocity trend of the subsurface layers within the study area.

3.9 Depth Structural Mapping

In this study, the depth structural maps were generated from the time-structure maps using the velocity model derived from the Time–Depth Relationship (TDR). The applied second-order polynomial velocity function provided a reliable basis for depth conversion, capturing both vertical and lateral velocity variations within the stratigraphic intervals of interest. The resulting depth maps effectively illustrated the subsurface configuration of the interpreted horizons, highlighting fault trends, structural highs, and closures that may serve as potential hydrocarbon traps.

3.10 Seismic Attribute Analysis

Seismic attribute analysis was conducted to enhance the interpretation and characterization of the identified reservoir zones within the study area. The seismic attributes applied include the Root Mean Square (RMS) amplitude, maximum amplitude, average energy, and average magnitude. These attributes were utilized to highlight zones of possible hydrocarbon accumulation, delineate reservoir boundaries, and improve the understanding of subsurface continuity and lithologic variations.

3.11 Hydrocarbon Prospect Identification

Prospect identification is the last step of the seismic interpretation workflow, which integrates all the interpreted results, faults, horizons, seismic attributes, and depth structure maps to identify Prospects that offer the maximum hydrocarbon potential.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Fault Interpretation

The main objective of this interpretation is to detect and map fault structures that can serve as potential traps for hydrocarbon accumulation within the Yeager Field. Detailed interpretation was carried out on the 3D seismic dataset using an integrated approach that combines structural visualization and seismic attribute analysis.

A total of thirty-five (35) faults were identified and mapped across the field. The interpretation process utilized a 3D visualization window in conjunction with an interpretation window, aided by a cursor tracker on the semblance map displayed within the 3D view. The variance attribute was effectively employed to delineate fault planes and improve fault trace continuity, as clearly observed in the time-slice representations. The faults identified were Growth faults, Rollover anticlines, Synthetic faults, Antithetic faults, Back-to-back fault structures and Conjugate faults

These fault systems define the primary structural framework of the Yeager Field and are consistent with the extensional tectonic regime of the Niger Delta Basin. The configuration of these structures indicates significant fault interaction and compartmentalization, which are typical characteristics of onshore Niger Delta fields.

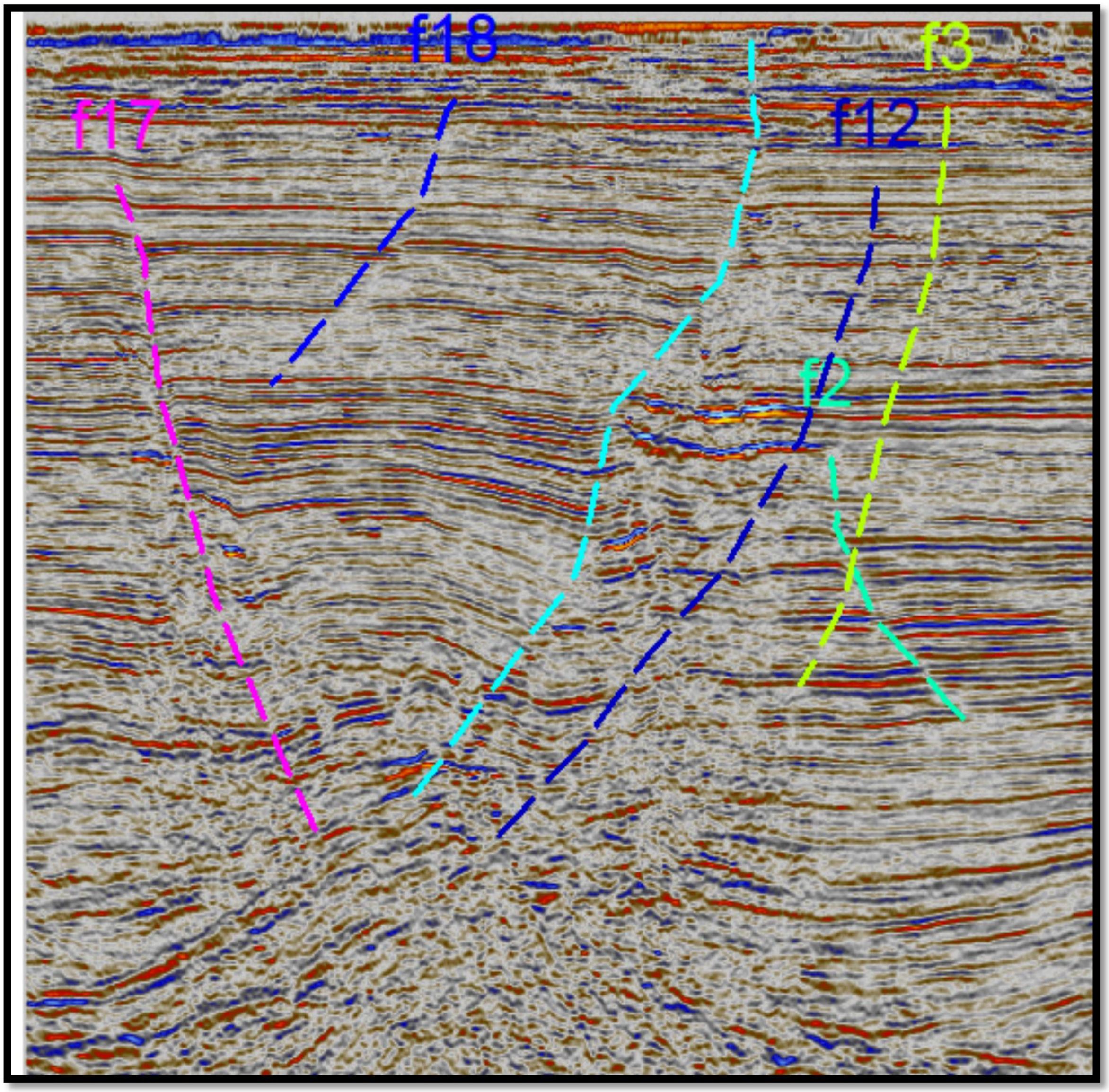

Figure 4.1 : Mapped faults on inline

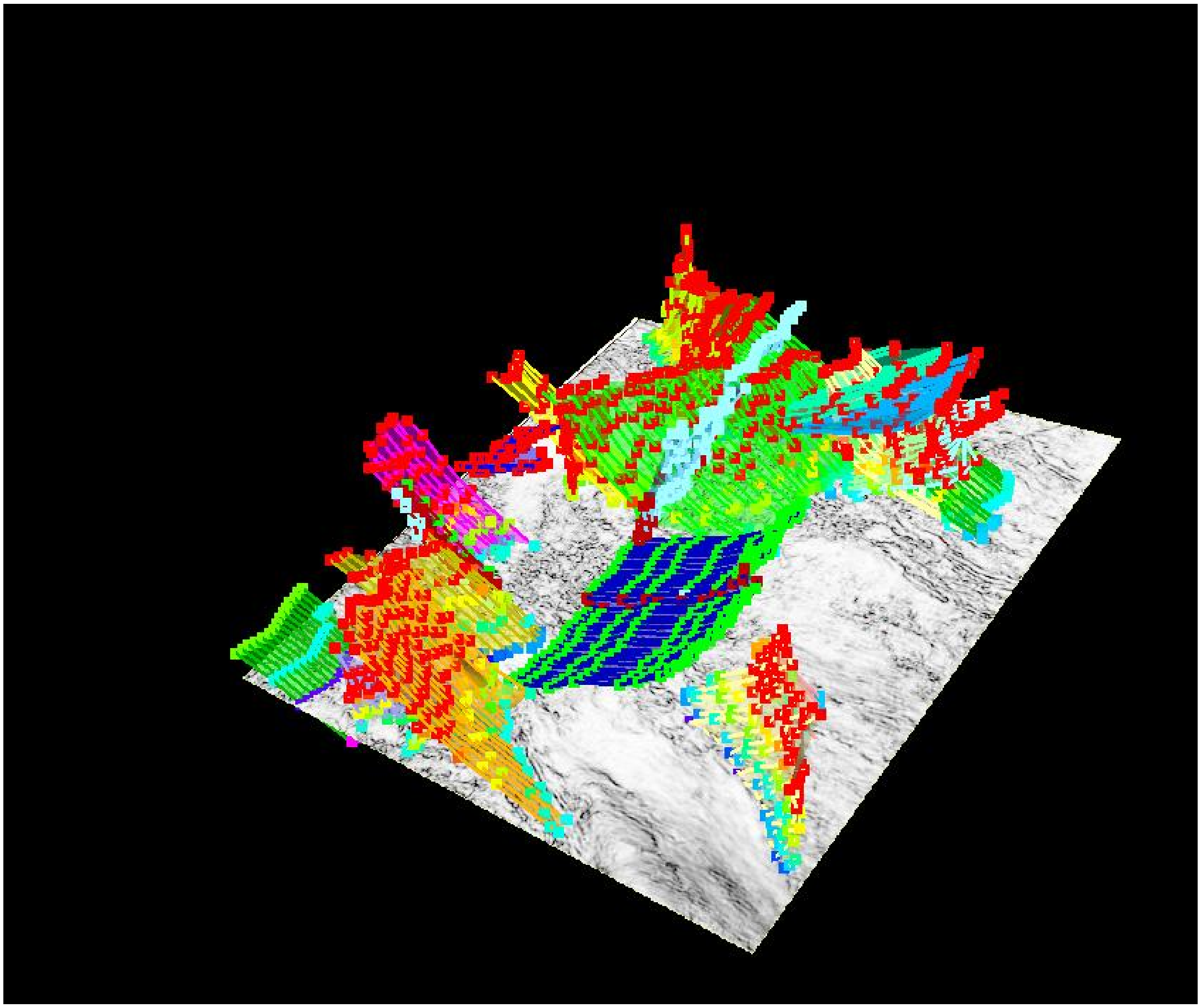

Figure 4.2 : Faults on time slice direction (variance attribute)

4.1.1 Stratigraphy, Lithology, and Reservoir Distribution

The subsurface stratigraphy of the Yeager Field, as interpreted from well log and seismic data, reflects the typical depositional characteristics of the Niger Delta Basin, which is composed of alternating sandstone and shale sequences.

Lithological identification and stratigraphic delineation were achieved primarily through the gamma ray (GR) logs, which effectively distinguish between sand and shale units based on variations in natural radioactivity. Low gamma ray readings correspond to clean sandstone intervals, while high readings represent shale-dominated zones. This interpretation provided the basis for reservoir identification and correlation across the study area.

From the well log analysis, two distinct reservoir units were identified within the available well data. However, the reservoir interval between 6,400 ft and 6,600 ft in Well 1 was selected as the primary target for detailed analysis and correlation across all wells. The choice of this reservoir was based on its consistent thickness, favorable log responses, and presence of hydrocarbons, which make it the most prospective zone for further evaluation.

Correlation across all wells revealed that oil was present only in Wells 1, 3, and 4, while Wells 2 and 5 showed water-bearing responses within the same stratigraphic interval. The hydrocarbon-bearing wells exhibited clear separation between the neutron and density log curves, indicating the presence of hydrocarbons within the pore spaces. The density-neutron cross plot showed a reduced density and a corresponding neutron response consistent with oil saturation, while the water-bearing intervals showed overlapping curves typical of fluid-filled formations.

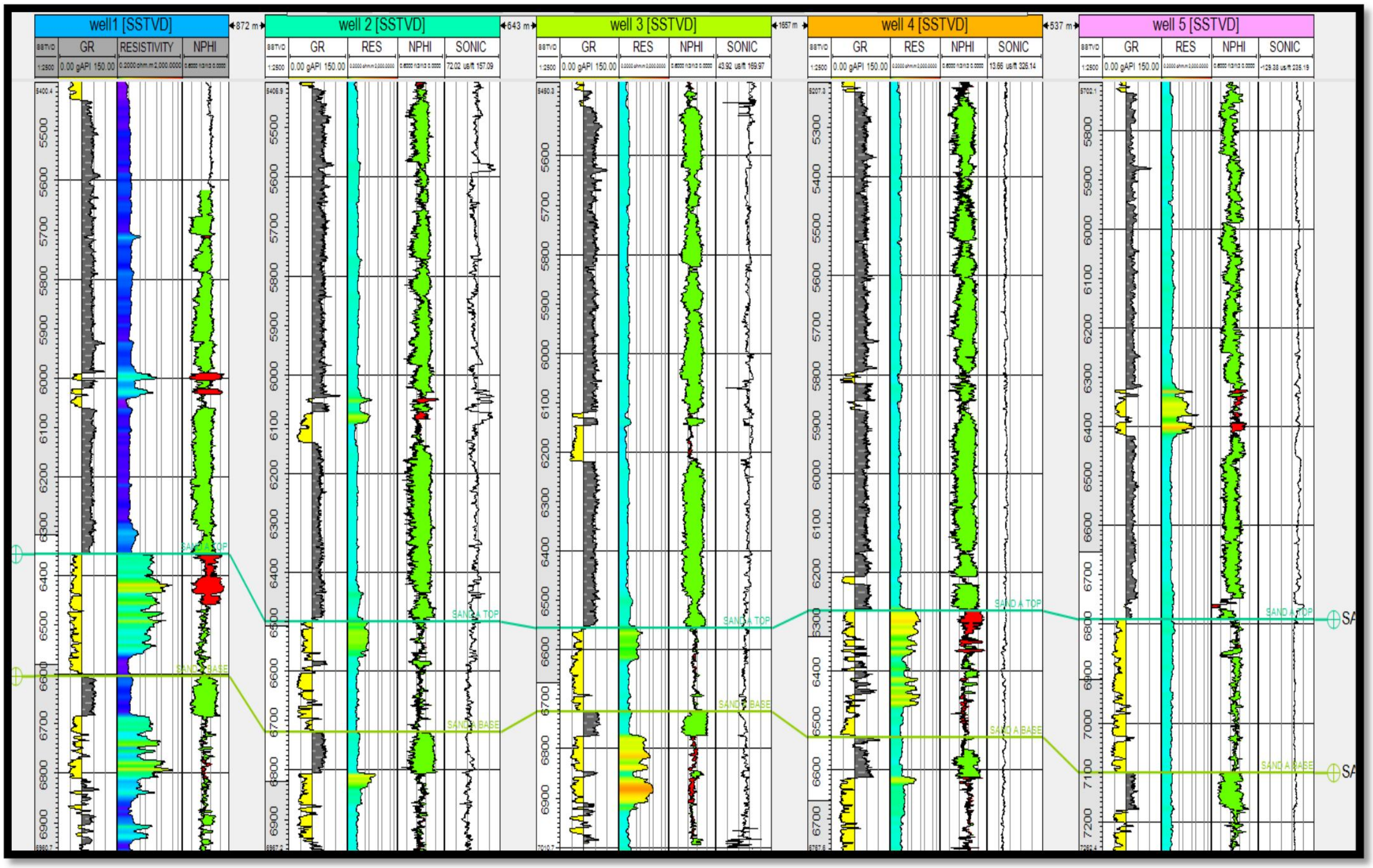

Figure 4.3 : Correlated well logs indicating reservoir

4.1.2 Seismic-to-Well Tie

The seismic-to-well tie process was performed to establish a reliable relationship between the time-domain seismic reflections and the depth-domain well log data, ensuring accurate horizon identification and interpretation. The procedure involved the integration of check-shot data and well-log information to create a synthetic seismogram that replicates the seismic response at the well location. The key logs used in this process included the sonic (DT) log and the density (RHOB) log, which together were used to compute the acoustic impedance (AI) profile. This impedance log was then convolved with an extracted seismic wavelet to generate the synthetic trace.

The synthetic seismogram was correlated with the actual seismic trace at the well location to achieve the best possible match between the seismic reflectors and lithological boundaries identified in the well.

The correlation showed a good alignment between key reflection events on the seismic section and lithologic boundaries interpreted from the well logs; The top of the reservoir (sand A top) is a peak event on the seismic data (seg y normal). This confirmed the accuracy of the time–depth relationship and validated the subsequent horizon interpretation and mapping. The correlation between the seismic data and the synthetic seismogram was greater than forty percent because of this process

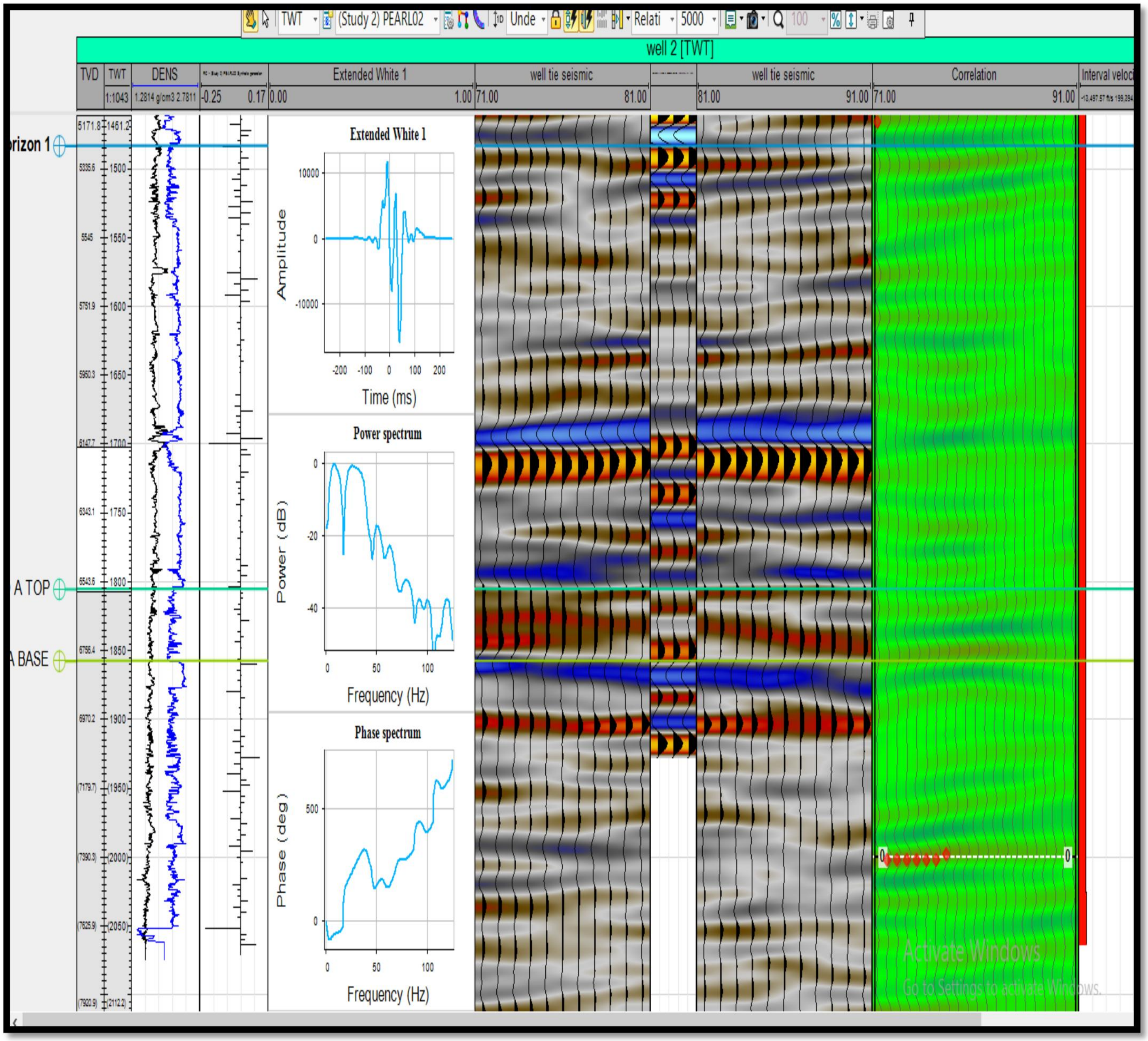

Figure 4.4 : Seismic well tie showing the indicated reservoir

4.1.3 Horizon Mapping

Horizon mapping was conducted to delineate reflections that are continuous and correlated with major stratigraphic boundaries or hydrocarbon-bearing zones after performing the seismic-to-well tie. The primary aim of this step is to trace the identified reservoir horizon and correlate it within the seismic volume in a way that is geologically consistent with the well data. Mapping was conducted on both the strike lines (cross-lines) and the dip lines (in-lines) across the seismic volume. The seismic interpretation software was used in carefully tracking each of the identified horizons across adjacent traces, ensuring consistency and geological correlation along the section. The mapped horizons were followed laterally across the survey area until they terminated against faults or lost continuity.

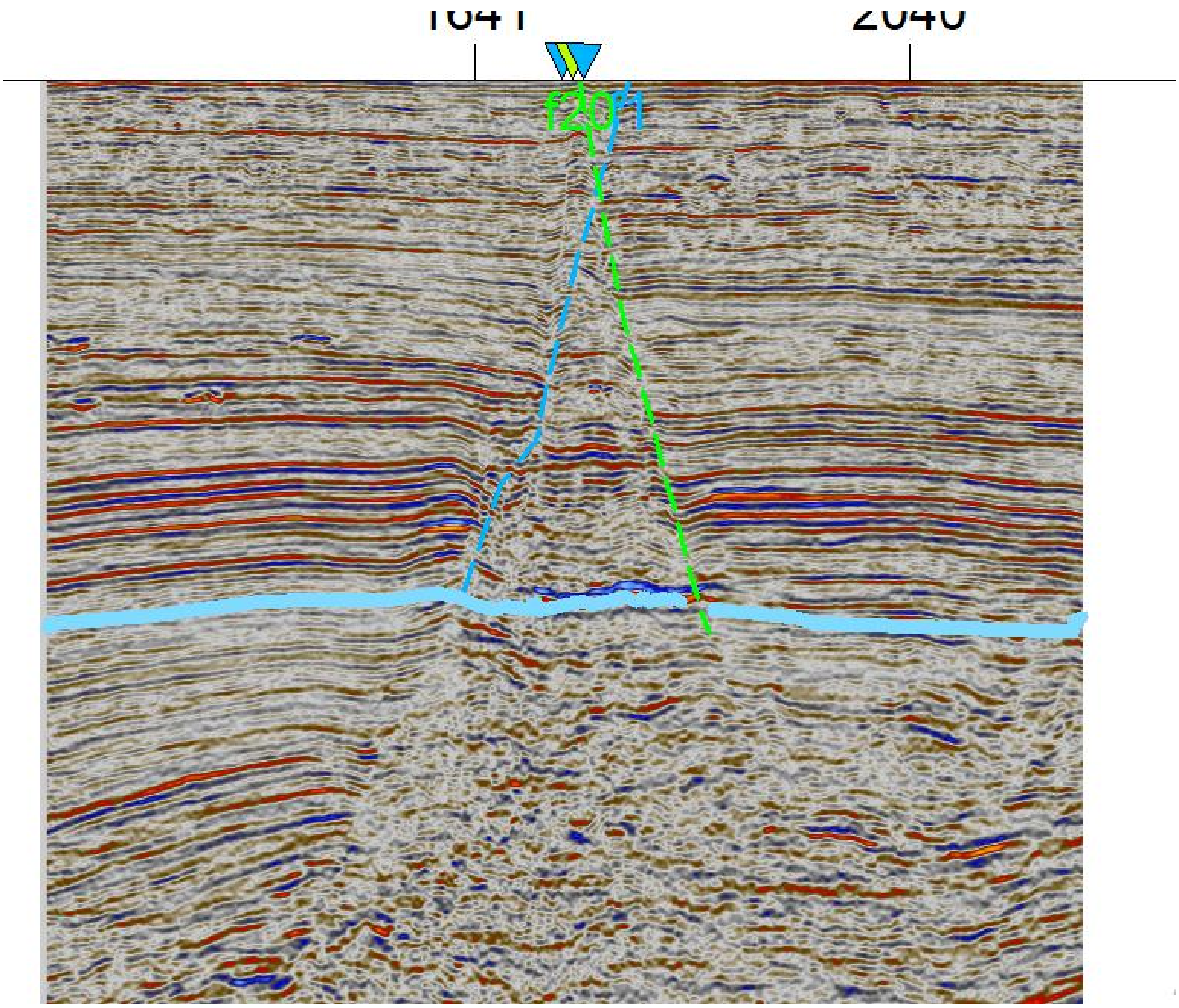

Figure 4.5 : Mapping of the reservoir top to generate the horizon

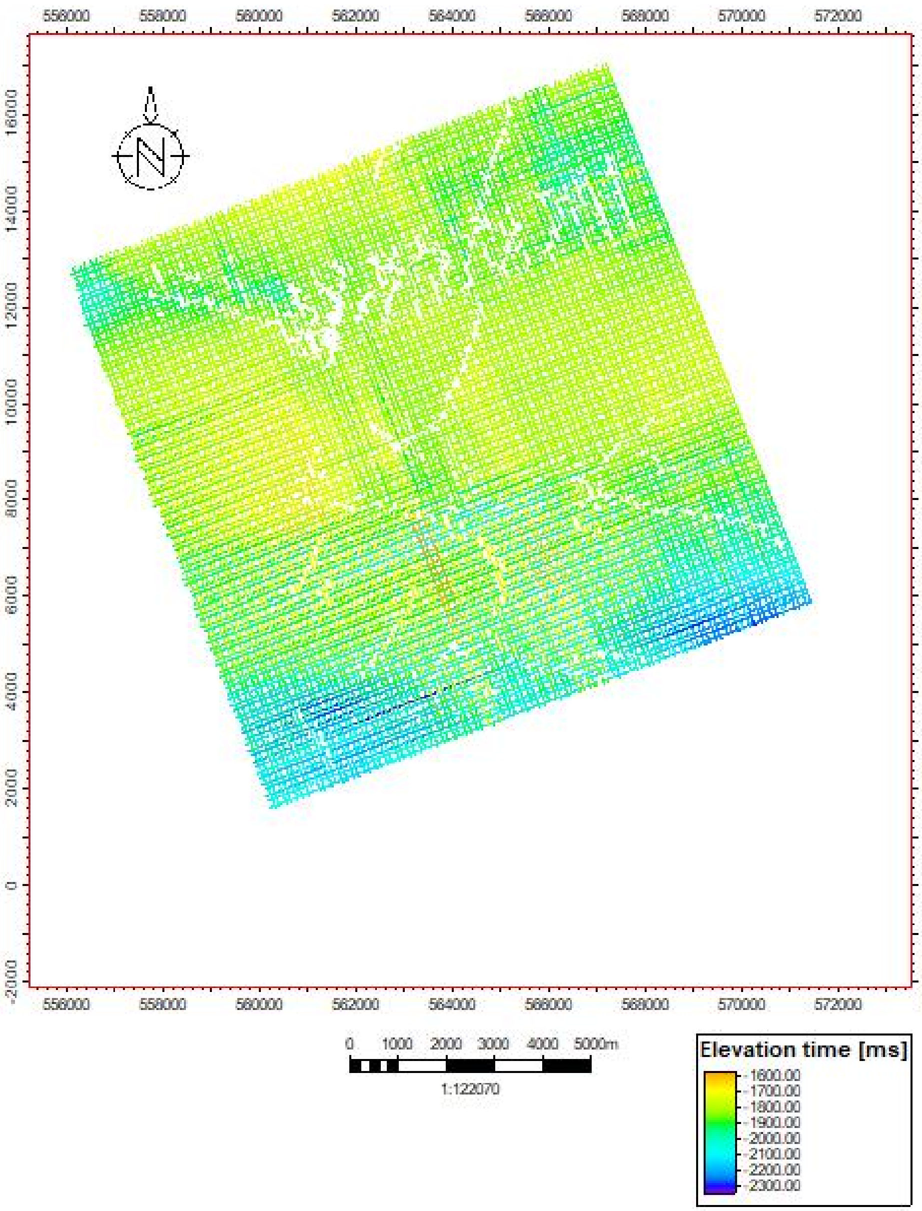

Figure 4.6 : Mapping of the reservoir top to generate the horizon

4.1.4 Time Surface Generation

These mapped horizons, or seed grids, were used to produce time surface maps, which express the structural configuration of the subsurface in terms of two-way travel time. Time surfaces were generated by using special tools to create continuous surfaces from the interpreted horizons. Initially, faults were mapped on the horizon maps, and the Polygon Editing Tool was carefully used to trace fault boundaries. Once these structural elements were well defined, time surfaces were constructed within the defined polygons for consistency and geological accuracy. This map formed the basis for identifying potential hydrocarbon traps and visualizing the overall tectonostratigraphic framework of the study area.

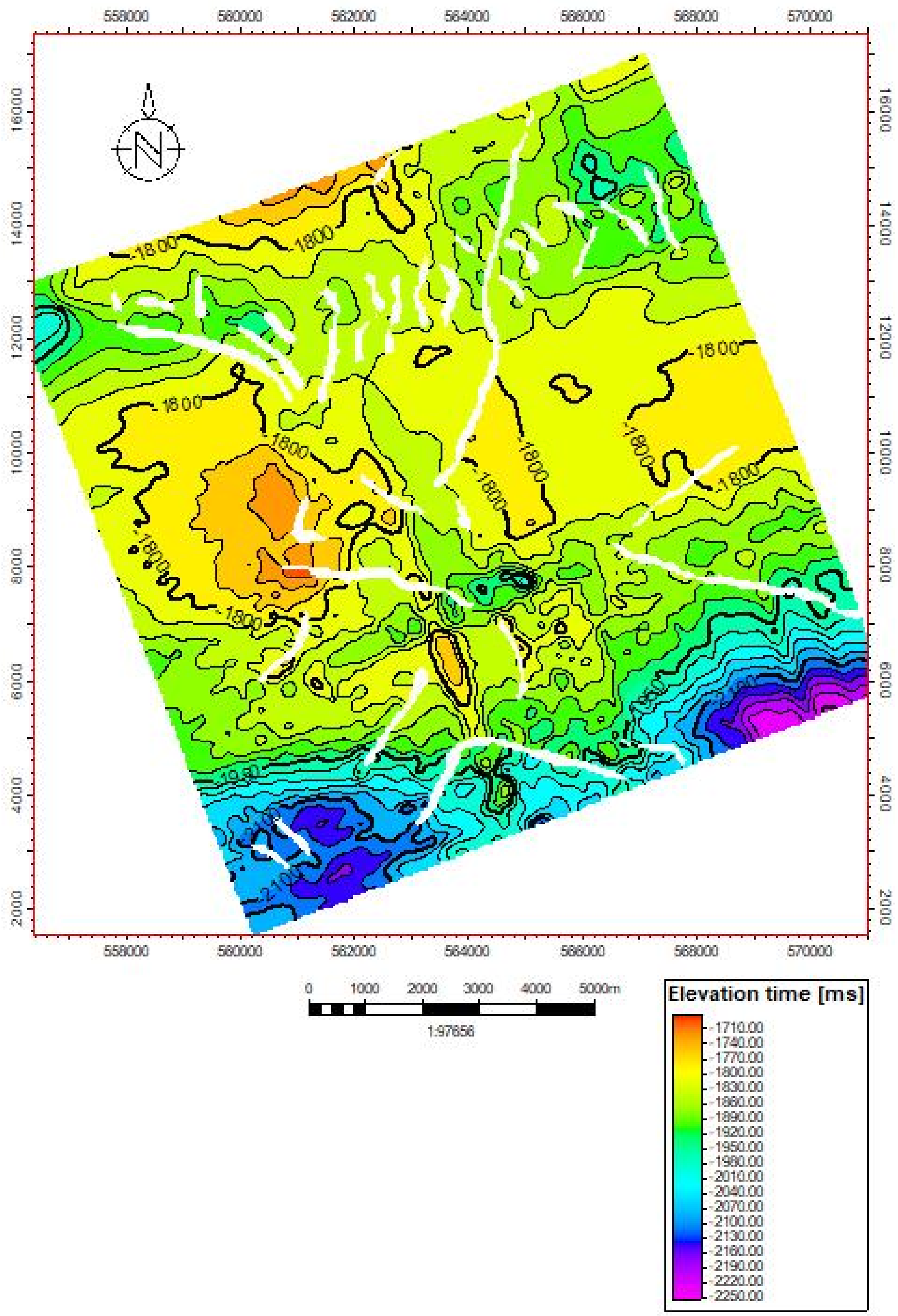

Figure 4.7 : Map of the reservoir top with contour in milliseconds (time)

4.1.5 Velocity Modelling

Velocity modeling was carried out to accurately establish the relationship between seismic two-way travel time (TWT) and true subsurface depth, which is critical for reliable time-to-depth conversion and the generation of depth structure maps. Since seismic data are recorded in time, the velocity model provides the necessary calibration for translating seismic reflections into their corresponding geological depths.

The time–depth relationship (TDR) developed during the seismic-to-well tie served as the foundation for constructing the velocity model. This relationship ensures consistency between the seismic data and the well information, minimizing interpretation errors and improving the accuracy of subsurface mapping. The model was generated using a second-order polynomial function, which provided the best mathematical fit for modeling the relationship between time and depth across the studied interval. This approach effectively accounted for the nonlinear variation of seismic velocities with depth due to compaction and lithologic changes within the stratigraphic column.

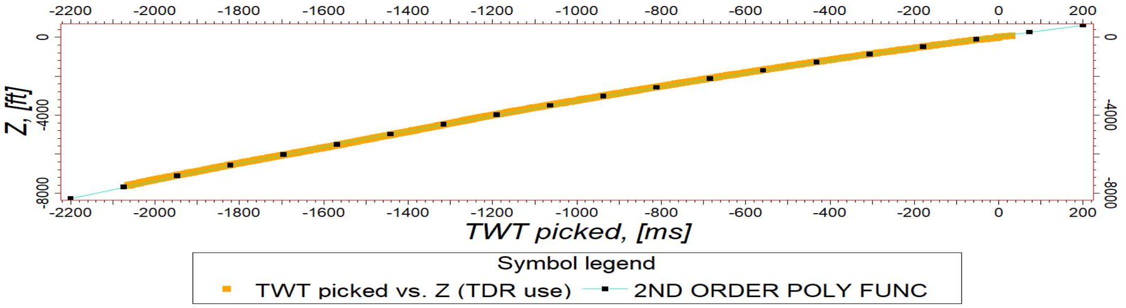

Figure 4.8 : Velocity modelling with the use of second order polynomial fuction

4.1.6 Depth Structure Map

The depth structure map was generated from the converted time surface map to represent the true subsurface configuration of the horizon of interest in depth units (feet or meters). This map provides a clearer geological understanding of the structural framework of the field, especially in identifying possible hydrocarbon traps and reservoir geometries.

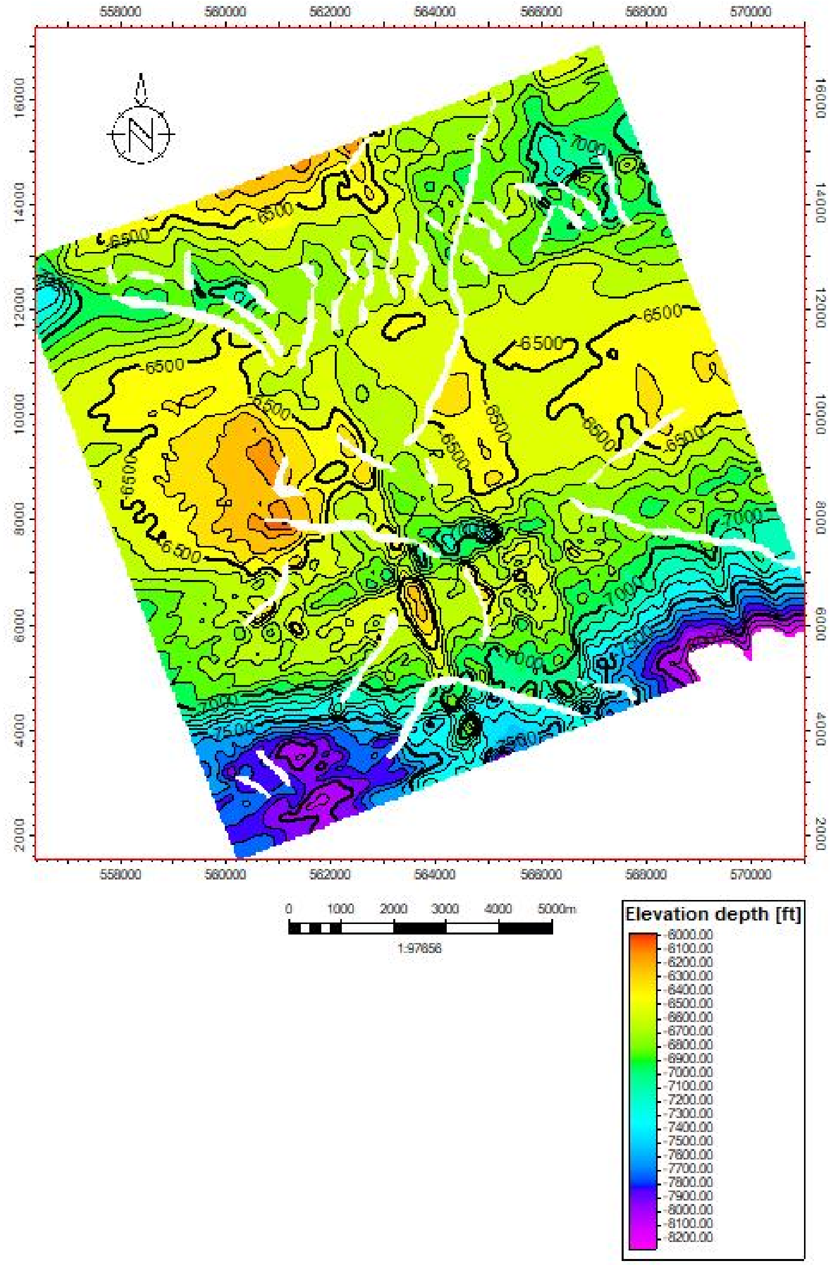

Figure 4.9 : Map of reservoir top with contours in ft (depth)

4.1.7 Use of Surface Attributes for Reservoir Characterization

Seismic attribute analysis was carried out to enhance the understanding of the reservoir geometry, continuity, and hydrocarbon distribution within the study area. A variety of amplitude-based attributes were extracted from the interpreted horizons, including Root Mean Square (RMS) Amplitude, Maximum Amplitude, Average Energy and Average Magnitude.

The RMS Amplitude attribute provided a measure of the energy of reflected seismic signals over a given window, effectively highlighting zones with high reflection strength that could be associated with hydrocarbon saturation.

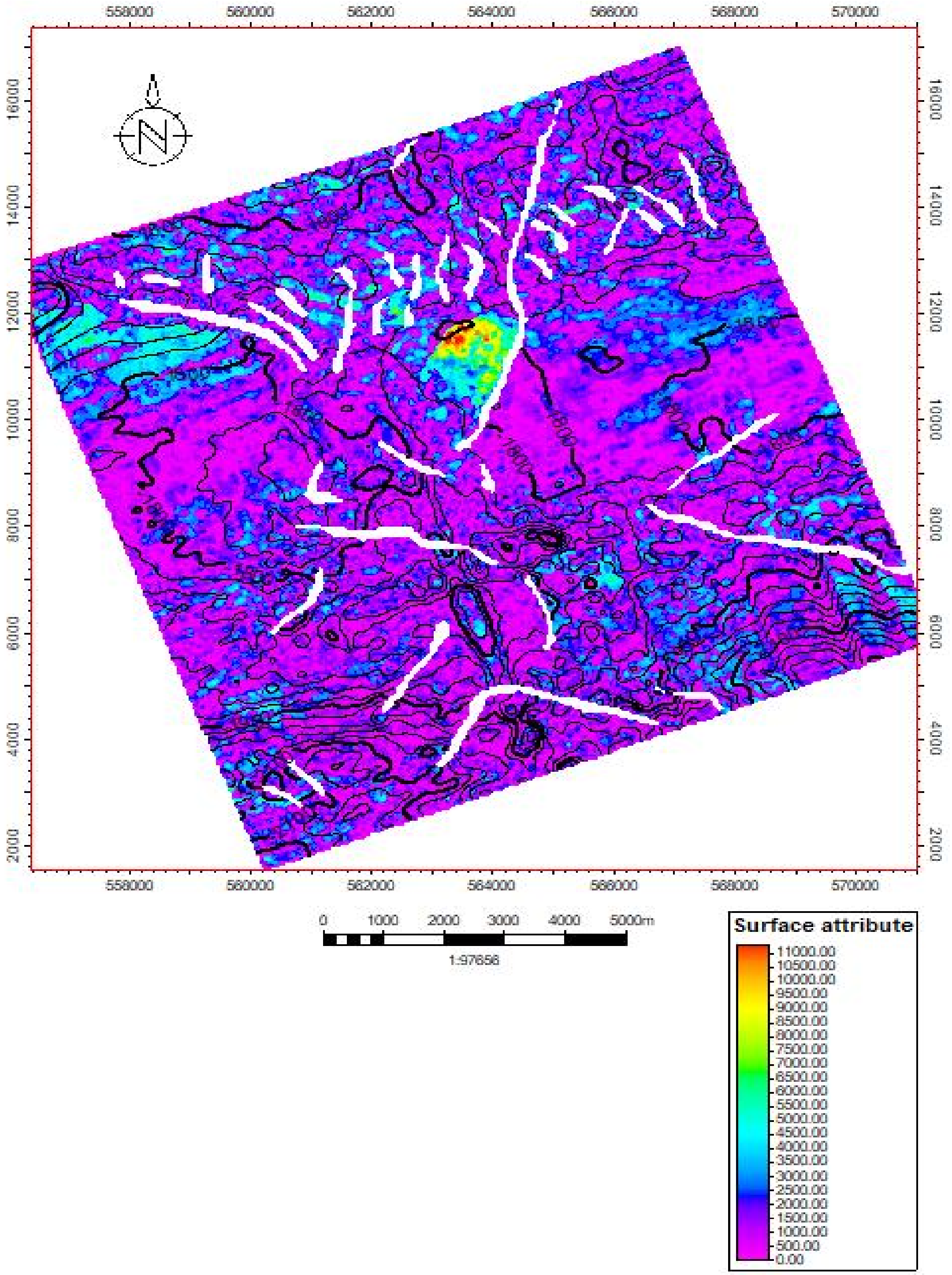

Figure 4.10 : RMS amplitude attribute on the reservoir top

The Maximum Amplitude attribute emphasized the strongest reflection events, which are typically linked to interfaces with significant impedance contrast, such as sand–shale boundaries. These amplitude maxima delineated the lateral extent of the reservoir and aided in confirming structural closures identified earlier in the depth structure maps.

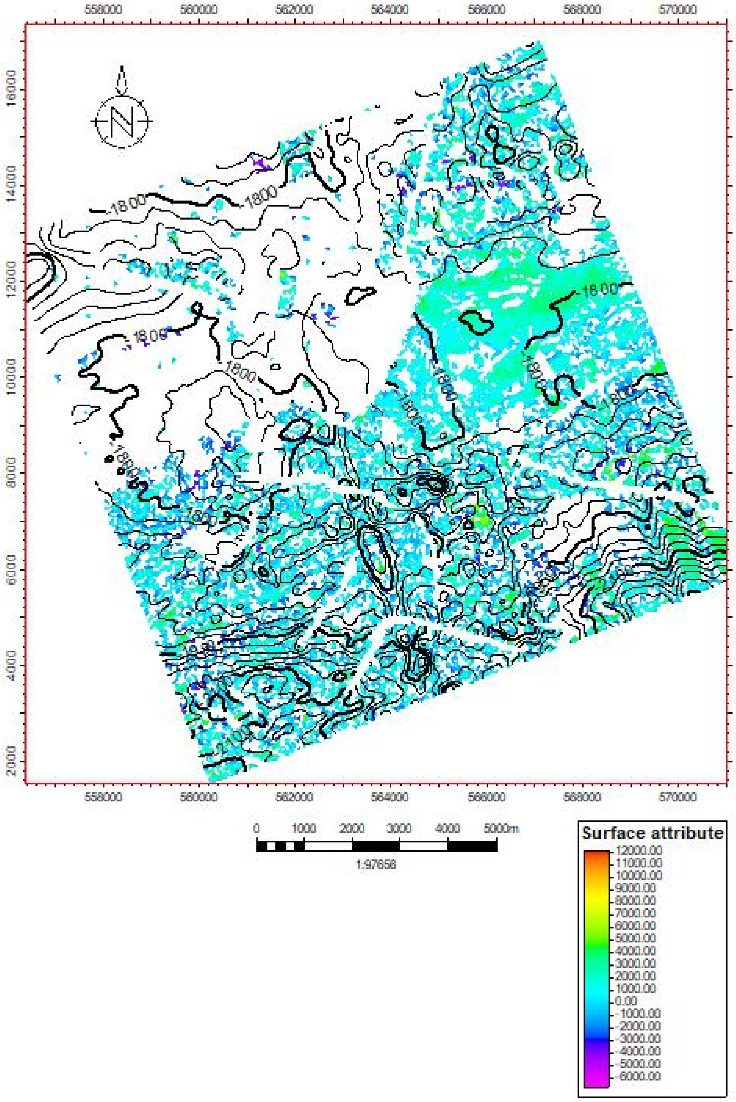

Figure 4.11 : Maximum amplitude attribute on the reservoir map

The Average Energy and Average Magnitude attributes were utilized to evaluate the overall signal strength and reflectivity distribution within the reservoir zone. These attributes provided insights into lithological uniformity and helped in differentiating between clean sands and shaly intercalations.

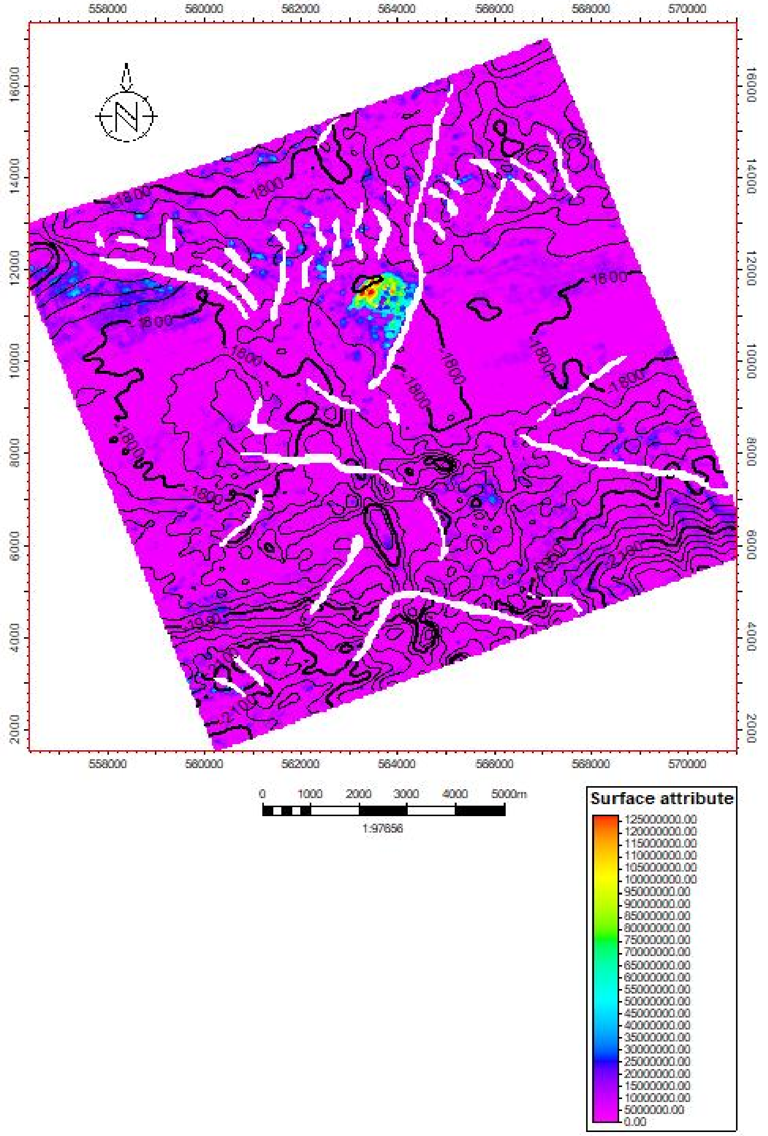

Figure 4.12 : Average energy attribute on the reservoir map

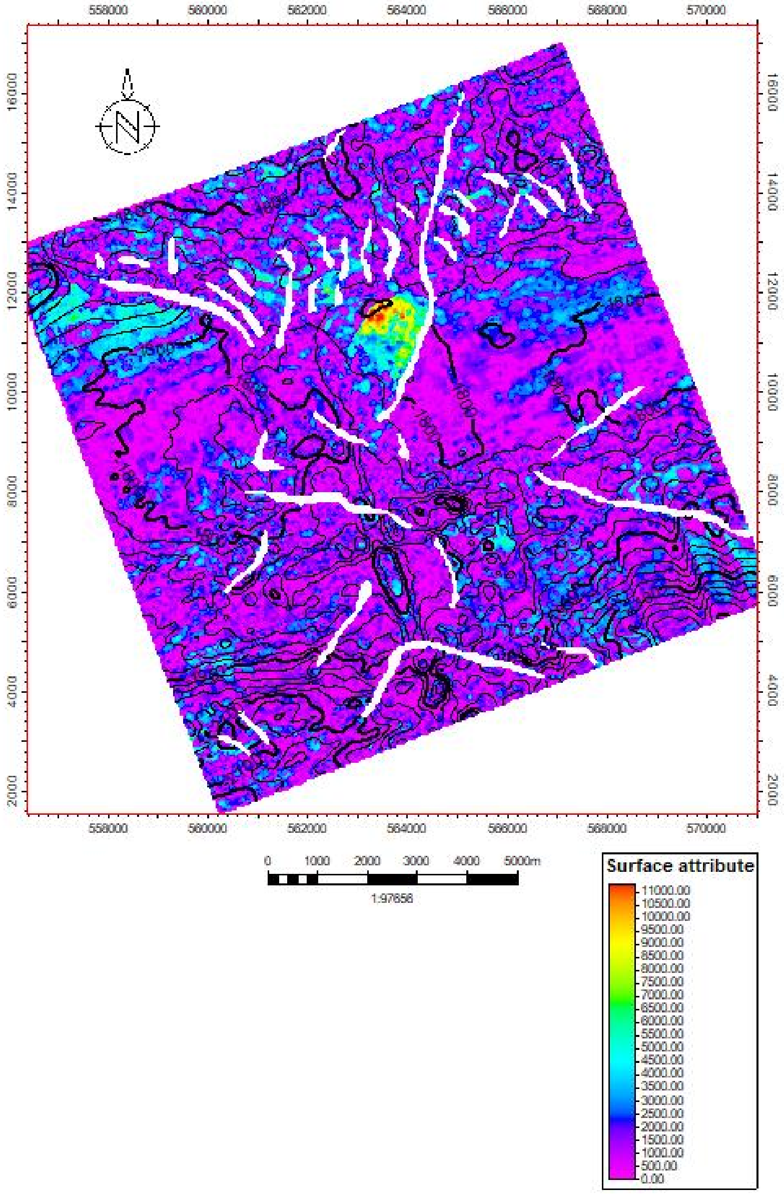

Figure 4.13 : Average magnitude attribute on the reservoir map

4.1.8 Prospect Identification

Detailed inspection of the depth structure maps and fault configurations derived from the 3D seismic data was a key element of the identification process. Attention focused primarily on areas with structural highs, especially fault-bounded closures, as being hydrocarbon prospective. Normally, these closures have formed as a result of synthetic and antithetic growth faults; both are characteristic structural features of the Niger Delta Basin. The mapped rollover anticlines and related back-to-back fault systems presented further evidence of trap development suitable for hydrocarbon entrapment.

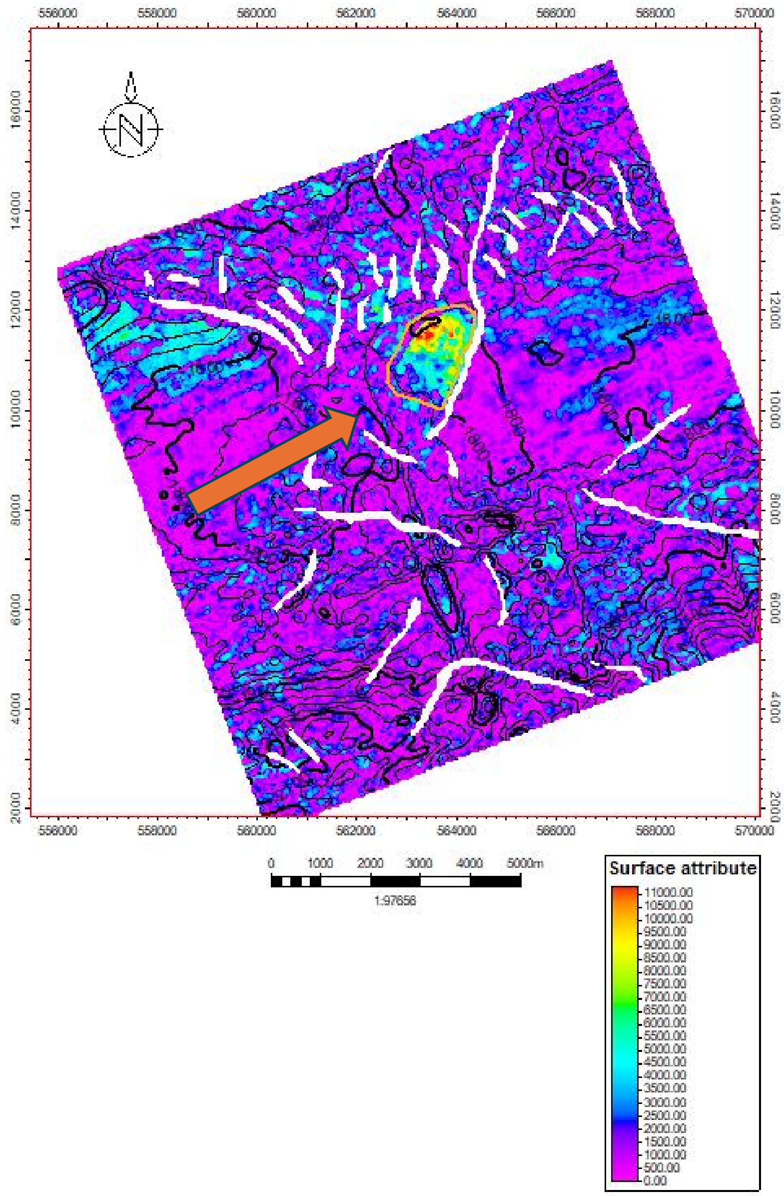

Figure 4.14 : Reservoir map showing the prospect area

CHAPTER FIVE

CONCLUSION, SUMMARY AND RECOMMENDATION

5.1 Conclusion

This study successfully integrated well log analysis and 3D seismic interpretation to evaluate the structural and stratigraphic framework of the study area within the Niger Delta Basin. The main objective was to identify potential hydrocarbon-bearing zones and understand the trapping mechanisms responsible for their accumulation. Through detailed fault interpretation, the trapping mechanism was identified as a rollover anticline, synthetic and antithetic faults, as well. These structural features are consistent with the tectonic setting of the Niger Delta. The seismic-to-well tie enhanced the accuracy of horizon interpretation by ensuring consistency between seismic reflectors and subsurface lithologic interfaces. Horizon and depth mapping further delineated the spatial extent and structural closure of the reservoir. Additionally, surface seismic attributes such as RMS amplitude, maximum amplitude, average magnitude and average energy were used to characterize the reservoir. These attributes provided insights into amplitude anomalies, which are potential indicators of hydrocarbon saturation and sand distribution within the identified traps.

5.2 Summary

This project presents a comprehensive 3D seismic interpretation of the Yeager Field, a fictitious onshore location within the prolific Niger Delta Basin of Nigeria. The study integrated high-resolution 3D seismic data with well logs to delineate the subsurface structural and stratigraphic framework for identifying potential hydrocarbon prospects. The methodology involved detailed fault mapping, which identified 35 faults typical of the Niger Delta's extensional regime, including growth faults and rollover anticlines. A reliable seismic-to-well tie was established, enhancing horizon correlation accuracy by over 40%, and this was followed by the generation of time and depth structure maps. Seismic attribute analysis, including RMS and maximum amplitude, revealed significant anomalies indicative of hydrocarbon saturation within the primary Agbada Formation reservoir sands. The results successfully identified a promising prospect area characterized by structural closures formed by fault-assisted traps. The study concludes that these integrated techniques are crucial for reducing exploration risk in the complex Niger Delta.

5.3 Recommendations

It is recommended that a new seismic acquisition survey be carried out over the field to obtain clearer and higher-resolution data. Improved imaging will enhance fault definition, horizon continuity, and overall structural and stratigraphic interpretation. This will reduce subsurface uncertainty and lead to more reliable hydrocarbon prospect evaluation. Also improve the accuracy and reliability of future interpretations within the study area, it is recommended that further seismic attribute analyses be undertaken, such as seismic inversion. Additionally, parameters such as coherence, sweetness, and impedance inversion to refine the understanding of lithologic variations and fluid distribution. A more detailed petrophysical evaluation should also be carried out to better quantify key reservoir properties such as porosity, permeability, and hydrocarbon saturation within the identified reservoir.

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