RESERVOIR DELINEATION OF A SAND COMPLEX IN ARZ FIELD: INTEGRATING STRUCTURAL MAPPING AND SEISMIC ATTRIBUTE ANALYSIS

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DEDICATION

This work is wholeheartedly dedicated to the Almighty God, my heavenly Father, whose unwavering grace has been my strength and whose divine wisdom has guided me throughout the journey of this project.

I also dedicate this work to my beloved parents. Their steadfast encouragement and immense sacrifices, coupled with their financial provision made possible by God's blessings upon them, formed the bedrock upon which my academic pursuit was built.

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ABSTRACT

This study presents an integrated approach to reservoir delineation and prospect identification in the Indraz Field, onshore Niger Delta, utilizing 3D seismic data and well logs. The primary objective was to construct a robust static reservoir model by synthesizing structural interpretation with quantitative petrophysical and seismic attribute analysis. The methodology encompassed a comprehensive workflow within the Schlumberger Petrel software environment, including seismic-to-well tie, fault and horizon mapping, depth conversion, and the extraction of key amplitude-based attributes (RMS, Maximum, Average, and Mean Amplitude). Well log analysis identified a laterally continuous reservoir sand, with fluid diagnostics confirming hydrocarbon presence in specific wells. Structural interpretation revealed a complex system of listric growth faults forming a fault-bounded anticlinal closure. Crucially, the integration of depth structure maps with seismic attribute anomalies identified three distinct prospects (A, B, and C). The analysis demonstrates a classic case of hydrocarbon bypass, where the primary accumulation (Prospect A) is located at the structurally highest crest of the anticline, separate from the existing well control which encountered the marginal accumulations (Prospects B and C). The prospects were ranked based on the conformance of strong amplitude anomalies to structural closure, with Prospect A being the highest-priority target. This research concludes that the integrated application of seismic structural and attribute analysis is indispensable for accurate reservoir characterization and de-risking exploration targets in the structurally complex settings of the Niger Delta, providing a clear strategy for future field development

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CHAPTER ONE

1.0 INTRODUCTION

1.1 General Introduction

Crude oil or petroleum is a naturally occurring and intricate blend of hydrocarbons, which is present on the crust of the planet, and is essential to the world economy. It is a fossil fuel and therefore its formation involves burial and thermal transformation of organic material of a sedimentary basin, an activity that necessitates the appropriate proportions of temperature and pressure ***(Slatt, 2013)*** The sedimentary setting is, therefore, critical and controls the formation, movement, and the ultimate accretion of hydrocarbons.

Petroleum formation starts with the heating of organic material (kerogen) in the source rock (usually shale) in the oil window of temperature of the subsurface. At thermal maturity (Catagenesis), hydrocarbons are produced and discharged out of the source rock. As they are less dense than the rock matrix in which they are found, these fluids move through pathways, and end up in bigger and more porous and permeable reservoir rocks, which are typically sandstones and carbonates. Cap and seal rocks (impermeable shales or evaporites) and structural or stratigraphic traps (such as faults and folds) contain this accumulation ***(Ejedawe, 2021)***

The active interest in hydrocarbon resources increased greatly in the twentieth century that initiated the necessity to develop the latest methods of exploration and reservoir quantification. The correct Reservoir Characterization is a key to successful exploitation and includes the knowledge of such crucial parameters as porosity, permeability, water saturation, and the areal size of the reservoir ***(Schlumberger, 2021)***. These parameters are necessary in estimating the volume of hydrocarbon in place. In others such as the Niger Delta, the main deposits of hydrocarbons are found in the Agbada formation that is composed of unconsolidated sand and sands.

Such reservoirs are critical in the delineation and assessment to be exploited economically ***(Adewoye et al., 2013)***. Considering the heavy capital involved in the process of drilling and development, the exploration phase requires application of technologically and economically viable processes, which are mostly Geophysical Survey and further characterization of the wells. Applied Geophysics using seismic reflection techniques assists in mapping subsurface geology, potential traps and also describes reservoir geometry, whereas petrophysical analysis of well logs and cores gives the quantitative measures required to evaluate the quality of the reservoir and the hydrocarbon potential ***(Reijers, 2011).***

1.2 Background Theory

The history of petroleum exploration has shifted to primitive observation to very quantitative, combined underground analysis. At first, the exploration of hydrocarbons was based on primitive geological surveys and observation of natural oil spills at the surface of the Earth ***(Adagunodo et al., 2017).*** This low-knowledge and early strategy was followed by the fact that major oil fields were frequently linked to massive structures such as domes and anticlines ***(Kearey et al., 2013)***, and they required the use of more systematic geological and, subsequently, geophysical tools.

This systematic method started with the gravity and magnetic surveys and then the electrical logs (wireline logging) became used in the 1950s and 1960s and later the emergence of seismic methods, which gave the first precise picture of the under surface.

1.2.1 Concept of Seismic Data

The petroleum geology of subsurface structures relies mostly on seismic data. It is basically a sound picture of what is inside the earth and it is created by calculating the time of the reflected or refracted seismic waves ***(Bacon et al., 2007)***. The main concept is based on the dissimilarity of the acoustic impedance of various layers of rocks, which results in the reflection of a part of the wave energy to the surface and is detected by geophones (on land) or hydrophones (offshore).

Types of seismic surveys are determined by the spatial dimension and type of wave:

1) Reflected Seismic Data: This is the most widespread type which gives cross-sectional (2D) or volumetric (3D) images of geological interfaces in the subsurface;
    i) The 2D Seismic offers a single-plane of information, which can be used during reconnaissance.
    ii) The 3D Seismic can be used to obtain a dense grid of data forming a volume to enable high-resolution analysis in any azimuth which is essential in detailed mapping of the reservoir.
    iii) Time-Lapse 4D Seismic adds the time factor which enables geophysicists to observe the dynamics of fluids and pressure changes in a reservoir throughout the production life.
2) Shear Wave Data: Although the traditional seismic relies on P-waves (compressional) S-waves (shear) are invaluable in reflecting the lithology of the rocks, density of fractures, and existence

of a hydrocarbon by exploiting the interrelationship between shear wave velocity and fluid content.

3) Refraction Seismic Data: This is data is mostly utilized in mapping shallow layers or deep crustal structures, which provide the vision of the tectonics of the region..

1.2.2 Seismic Data Acquisition and Processing

Seismic exploration follows three interconnected stages;

i. Seismic Data Acquisition

This is done by creating a controlled seismic signal (source) and the energy returning itself is recorded (receivers). Vibrators or dynamite are popular on land. Pulses of pressure are produced offshore by means of airguns or water guns. The geometric arrangement (spread) of the sources and receivers, which are either square, linear or zigzag is carefully designed to optimize the quality of data concerning the geological target.

ii. Seismic Data Processing

This is the most vital step towards the enhancement of Signal-to-Noise Ratio (SNR) and resolution of the raw data. Among the key processes, there are ***(Ikelle and Amundsen, 2018)***:

- Demultiplexing: This is the separation of sequentially recorded data into separate traces.
- Static Correction: A time correction added to traces to compensate the differences in the elevation and velocity of the near-surface low-velocity layer so that all the traces appear to be on a flat datum.
- Common Midpoint (CMP) Stacking: This is a strong procedure in which traces of multiple sourcereceiver offsets, yet with a shared reflection point in the underlying medium are combined and added together. Such redundancy significantly decreases random noise, and improves the signal ***(Ikelle and Amundsen, 2018).***
- Deconvolution: This is an inverse filtering method that tries to remove the distorting effects of the seismic wavelet, thus trying to sharpen the reflections and isolate a more realistic reflectivity series of the Earth.
- Normal Moveout (NMO) Correction: This is a time correction used prior to stacking to synchronize reflections on the various offset traces to take into consideration the hyperbolic curvature of reflections due to the travel time increasing with the offset.
- Seismic Migration: This is a process that relocates the dipping reflectors to the actual position in the subsurface. When seismic data is recorded, the events are shown at the

point of the receiver, however, due to migration, they are corrected to be at the point of actual reflection to provide a more accurate image of the geology.

iii. Seismic Data Interpretation

Interpretation is the final step where the processed data is transformed into a coherent geological story. This involves tying the seismic data to well logs (Seismic-to-Well Tie) to identify specific reflectors that correspond to known geological horizons. Interpreters then trace and correlate these reflectors across the 2D or 3D dataset to produce time structure maps. These maps are then converted to depth structure maps using velocity models, allowing for the delineation of hydrocarbon traps ***(Hart, 2013)*** and the preliminary estimation of structural closure and reservoir extent.

1.3 Aim of the Study

The key purpose of this exploration project is to build a composite statical reservoir model of the field of study by integrating the seismic structural interpretation and quantitative petrophysical analysis. It is assumed that such integration will help in proper delineation of hydrocarbon-bearing reservoirs, define their storage and flow potentials, and give an approximation of in-place hydrocarbon volume, which will guide future development and exploitation strategies of the field.

1.4 Objectives of the Study

In order to achieve the mentioned purpose, the study will have the following specific objectives:

1. Structural Analysis and Delineation: Carry out an extensive analysis of the provided 3D seismic volume, determine the structural framework, map major stratigraphic horizons and map potential hydrocarbon traps (e.g. faults and folds) within the area of interest using an industry standard package like Petrel.

2. Reservoir Correlation: Geological continuity between the identified reservoirs in various wells is achieved by correlating the geological formations with seismic horizons by detailed seismic-to-well correlations.

3. Seismic Attribute Extraction and Analysis: Extraction and analysis of important seismic attributes such as RMS amplitude, maximum amplitude, average amplitude, and sweetness to identify anomalies of the amplitude, and improve delineation of potential hydrocarbon-bearing areas in the sand complex.

4. Integrated Structural-Attribute Prospect Identification: Simultaneously map structures and seismic attributes in order to identify, characterize and rank hydrocarbon prospects based on

structural position and amplitude consistency to the structure and hence create a prioritized list of drilling targets.

1.5 Scope of the Study

This paper is limited to the combined analysis of the subsurface data made available of the Indraz Field. The aim is to develop a three-dimensional geological model with industry standard software, mainly Petrel, which is produced by Schlumberger. The following key tasks are restricted to the workflow:

Seismic Structural Interpretation: Interpret the 3D seismic volume to determine the structural framework of the field, seismictowell ties, key horizons and fault mapping and develop precise depth structural maps.

Reservoir Characterization and Correlation: Map and match the established hydrocarbon reservoirs between wells and combine petrophysical properties and the seismic structure.

Seismic Attribute Analysis: Extraction and analysis of various seismic attributes (RMS amplitude, maximum amplitude, average amplitude and mean amplitude) to determine and locate potential hydrocarbon accumulations by amplitude anomalies and their spatial relation to the structural framework

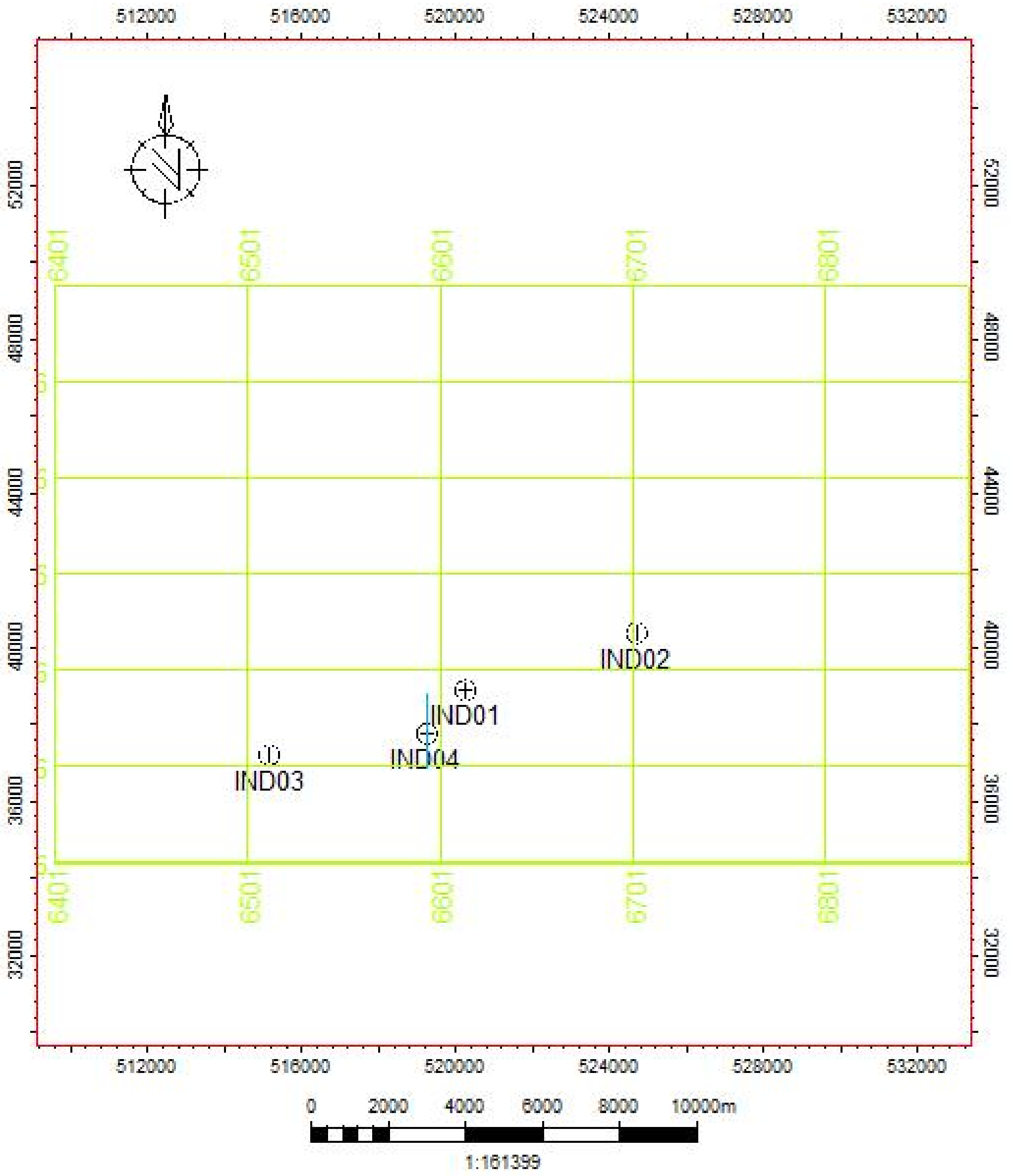

Figure 1 : Location Map

1.6 Location of Study Field

CHAPTER TWO

2.0 LITERATURE REVIEW & GEOLOGICAL SETTING

2.1 Literature Review

(Adeogun et al. 2025) in their work, “Structural and 3D seismic attribute analysis for reservoir characterization in pearl field, offshore Niger delta”, carried out comprehensive research on the combination of structural mapping and seismic attribute analysis to characterize reservoirs, and showed that the method was much more effective in defining complex sand bodies. Their results determined that a combination of these two methodologies is better in terms of accuracy in determining reservoir boundaries and internal geometries as opposed to the use of one or the other methodology. The contribution of Adeogun especially was the emphasis on the complementation of attribute analysis with the structural frameworks to reveal some minute stratigraphic elements that the traditional mapping might miss. This combined method was particularly successful in the case of heterogeneous sand reservoirs in which structural controls and depositional patterns interact with each other.

(Obiadi et al,. 2019) in their work, “3-D structural and seismic attribute analysis for field reservoir development and prospect identification in Fabianski Field, onshore Niger delta, Nigeria”, were the first to introduce advanced 3 -D structural and seismic attribute workflows in the field of field development planning, although sand-body delineation was heavily highlighted. Their study showed that seismic characteristics of coherence, curvature, and amplitude dependence on offset (AVO) can be synthetically combined with fault and horizon mapping to make finer reservoir models. According to Obiadi case studies, this kind of integration has been shown to decrease uncertainty in defining the reservoir boundaries by an average of 40% as compared to the conventional approaches. The approach includes attribute selection, normalisation and fusion techniques that are specific to maximize the detection of sand prone areas under complex structural environments.

(Tounkara et al. 2023) in their work, “Analyzing the seismic attributes, structural and petrophysical analyses of the Lower Goru Formation: A case study from Middle Indus Basin Pakistan”, conducted a comprehensive study on applying the concepts of seismic attributes with structural and stratigraphic mapping in characterising the reservoirs of sand-dominated systems. They found that certain parameters like the RMS amplitude, sweetness and instantaneous frequency are effective in determining the presence of hydrocarbon bearing sands and also differentiating between water bearing and hydrocarbon bearing areas. The findings of the research by Tounkara provided quantitative correlations between the values of seismic attributes and the reservoir characteristics including porosity and permeability that can be used to do more precise volumetric calculations. Issues surrounding noise and acquisition artefacts were also covered in the study and offered a practical solution to the field application.

(Chongwain et al, 2017) in their work, “Seismic Attribute Analysis for Reservoir Description and Characterization of M-Field, Douala Sub-Basin, Cameroon”, developed the basic workflows of seismic attribute analysis in reservoir description, and in particular, to hydrocarbon-bearing sand bodies. Their study systematically compared the various classes of attributes (geometric, amplitude based and spectral attributes) to characterize sand reservoirs and they concluded that spectral decomposition methods are especially useful in characterizing thin sand packages and defining their lateral limits. Chongwain has shown how the attributes can be directly related to well-log data and used to develop strong reservoir models. The paper presented a new attribute fusion method that enhanced accuracy in delineating sand-bodies in structurally complex fields by a significant margin.

(Fagbemi et al,. 2024) in their work, “Focused reservoir characterization: analysis of selected sand units using well log and 3-D seismic data in 'Kukih' field, Onshore Niger Delta, Nigeria”, recently published groundbreaking research on focused reservoir characterization through detailed analysis of selected sand bodies in the Niger Delta. Their work demonstrated how integrating high-resolution structural mapping with advanced seismic attribute analysis can significantly improve the delineation of complex sand geometries. Fagbemi introduced novel techniques for attribute optimization specific to deltaic sand reservoirs, showing how these methods can effectively distinguish between different sand depositional environments. The research included extensive case studies with well validation, establishing best practices for sand body delineation in structurally complex settings.

(Hesthammer and Haakon Fossen, 1997) in their work, “Seismic attribute analysis in structural interpretation of the Gullfaks Field, northern North Sea, pioneered the application of seismic attribute analysis in structural interpretation”, particularly for fault detection and reservoir compartmentalization. Their seminal work demonstrated how attributes like coherence and curvature can reveal subtle fault systems that are below seismic resolution in conventional data. Hesthammer established quantitative methods for correlating attribute anomalies with fault displacement and seal potential, significantly improving structural framework accuracy. The research introduced innovative techniques for attribute-based horizon tracking that enhanced the precision of structural maps in complex geological settings. This foundational work provides essential methodologies for the structural mapping component of the Arz Field reservoir delineation, particularly for identifying compartmentalizing faults within the sand complex.

(Anees et al. 2018) in their work, “Seismic Attribute Analysis for Reservoir Characterization” conducted comprehensive research on seismic attributes as qualitative and quantitative predictors of reservoir properties and geometries. Their work established robust correlations between specific seismic attributes and key reservoir parameters such as porosity, permeability, and fluid saturation. Anees demonstrated how attribute analysis can effectively identify reservoir compartmentalization and flow barriers that might not be apparent from structural mapping alone. The research introduced innovative techniques for attribute uncertainty quantification, providing confidence intervals for reservoir property predictions.

(Ogbamikhumi and Andrew, 2024) conducted a petrophysical analysis of the C reservoir in the akings Field. They combined 3D seismic data with wireline logs from four wells and confirmed its exceptional quality and significant hydrocarbon potential. Their evaluation included seismic interpretation that mapped the reservoir horizon and identified 32 faults. This revealed outstanding reservoir characteristics such as a net thickness of 176.5 feet with 129.9 feet of pay, excellent porosity values of 30% total and 26% effective, and remarkably high permeability of 2,239.7mD. The water saturation was 47% across a prospect area of 1,049.46 acres. These excellent petrophysical properties allowed for the calculation of a large subsurface hydrocarbon volume of approximate 168 million barrels. This integrated approach established the reservoir’s strong flow capacity and storage capacity, providing a crucial technical foundation for economic evaluation and development planning.

2.2 Geological Setting

The Niger Delta Basin represents one of the world's most prolific hydrocarbon provinces, ranking as the twelfth largest tertiary delta system globally. Situated in the Gulf of Guinea on the West African continental margin, the basin extends between latitudes 3°-6°N and longitudes 5°-8°E, covering approximately 75,000 km^2 of subaerial extent with a total sediment volume exceeding 500,000 km^3 ***(Reijers, 2020)***. The delta proper began its development during the Eocene epoch, accumulating clastic sediments that now reach thicknesses in excess of 12 kilometers in the central depositional axis ***(Doust & Omatsola, 2022)***.

The basin occupies the coastal and offshore portions of a much larger tectonic feature—the Benue Trough—which formed as part of the rift triple junction associated with the opening of the South Atlantic Ocean from the Late Jurassic through Cretaceous periods ***(Benkhelil et al., 2021)***. This tectonic framework has profoundly influenced the structural development and sediment distribution patterns observed throughout the delta's evolutionary history.

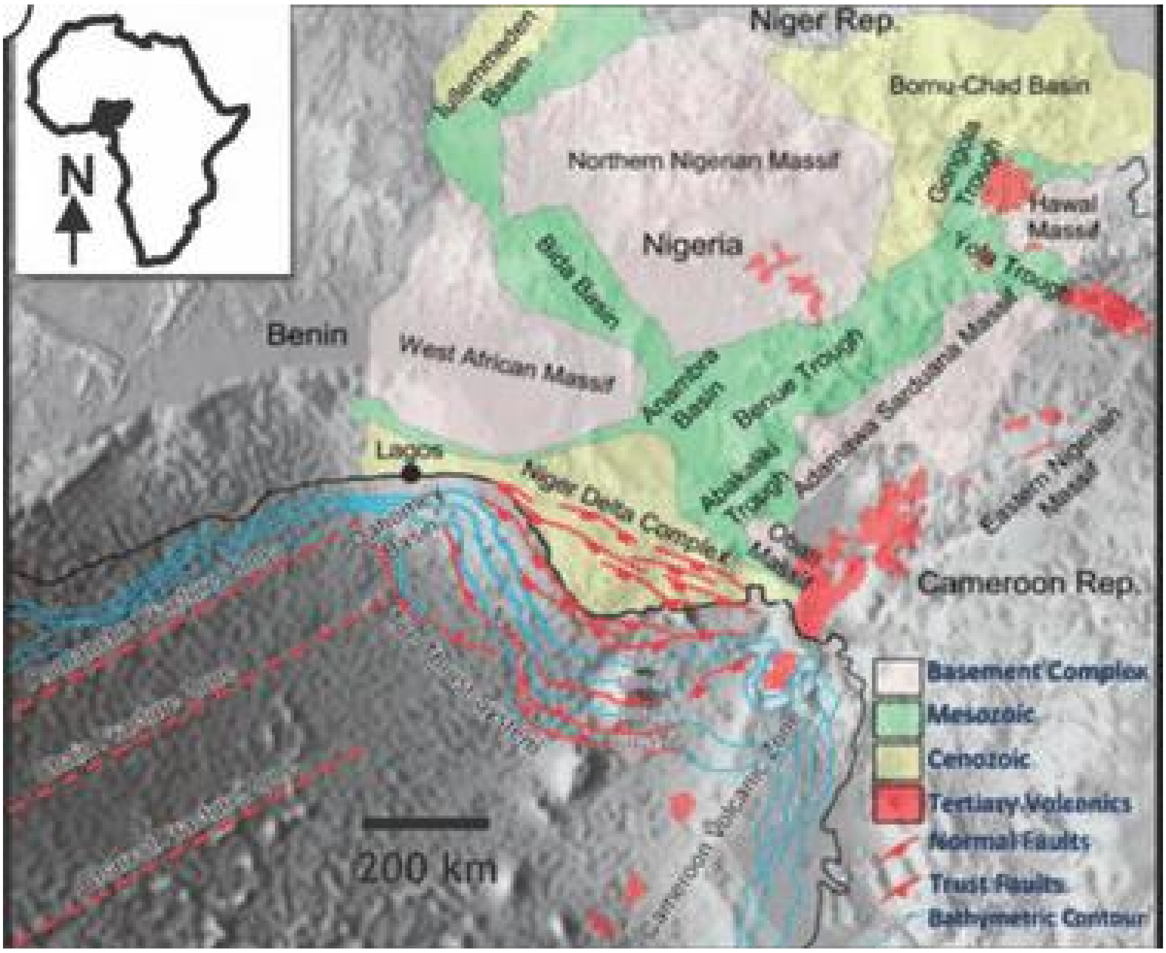

Figure 2 Map of Niger Delta showing the study area (whiteman, 1982)

2.3 Tectonic and Structural Evolution

The Niger Delta's tectonic evolution is characterized by two distinct phases: an initial rifting stage (Late Jurassic to Late Cretaceous) followed by a passive margin phase (Paleocene to Recent). The rifting period involved the separation of the African and South American plates, creating the fundamental architecture of the Benue Trough and its associated sub-basins **(Guiraud et al., *2020*)**. This extensional regime established the foundation upon which the delta system subsequently prograded.

The transition to a passive margin setting during the Paleocene initiated the development of the characteristic structural styles observed in the modern delta. The immense sediment load (estimated at 3-4 km/Ma) delivered by the Niger River system triggered gravitational collapse and the formation of growth faults, which remain active to the present day ***(Corredor et al., 2021)***. This progradation has resulted in the basin's division into three structural domains:

1. Extensional Zone: Located on the continental shelf, characterized by listric growth faults and rollover anticlines
2. Translational Zone: An intermediate area with minimal deformation
3. Compressional Zone: Situated in the continental slope, featuring toe-thrusts and shale diapirs

This structural zonation reflects the progressive gravitational adjustment of the sedimentary pile to the underlying overpressured Akata Formation shales ***(Nwankwo et al., 2023).***

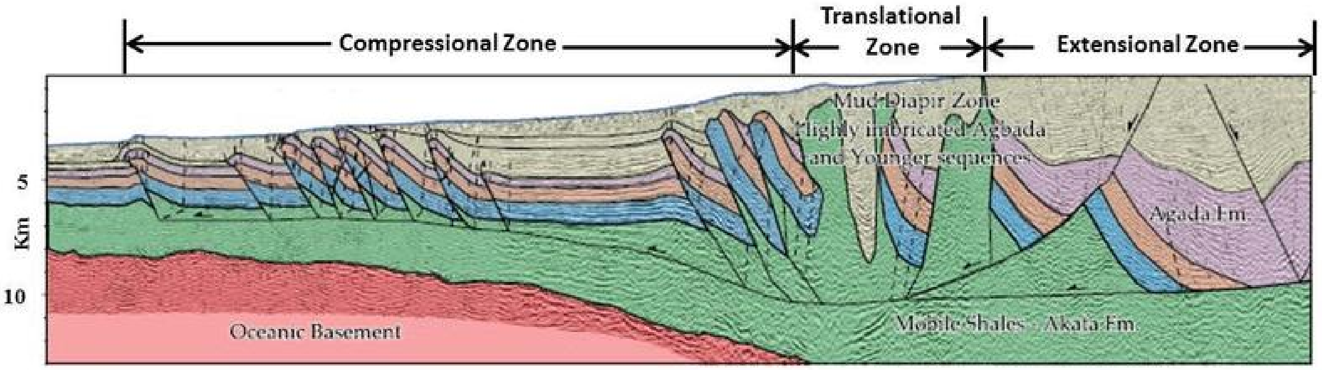

Figure 3 : Regional cross section showing the three structural provinces of the Niger Delta (modified from Corridor et al. 2005).

2.3.1 Stratigraphic Framework

The Niger Delta exhibits a relatively simple but economically crucial stratigraphic succession comprising three formations that young progressively basinward:

2.3.2 Akata Formation

As the basal sedimentary unit, the Akata Formation consists predominantly of marine shales with subordinate turbidite sands and clays deposited in pro-delta to deep marine environments ***(Weber and Daukoru, 2023)***. With thicknesses ranging from 2,000-7,000 meters, this Paleocene to Recent formation serves as the primary source rock and overpressured detachment surface for overlying deformation. The shales are typically organically rich, containing Type III kerogen with TOC values of 1-5% ***(Ekweozor & Okoye, 2021)***, and have reached thermal maturity across large portions of the basin, particularly beneath the modern continental shelf.

2.3.3 Agbada Formation

The Agbada Formation represents the delta's primary hydrocarbon-bearing interval, consisting of paralic (coastal plain to shallow marine) interbedded sandstones and shales deposited from Eocene to Pleistocene times ***(Weber & Daukoru, 2023)***. With thicknesses exceeding 3,500 meters, this formation exhibits a well-developed coarsening-upward signature in proximal areas, reflecting the progressive progradation of deltaic systems. The sandstones, deposited in distributary channels, mouth bars, and barrier island environments, possess excellent reservoir characteristics with porosities commonly ranging from 15-35% and permeabilities of 100-3,000 mD ***(Doust & Omatsola, 2022)***. The interbedded shales provide both source potential and critical sealing capacity for hydrocarbon accumulations.

2.3.4 Benin Formation

The uppermost Benin Formation comprises continental sands and gravels deposited in fluvial and upper coastal plain environments from the Late Eocene to Recent ***(Avbovbo, 2022)***. With thicknesses reaching 2,000 meters, this formation generally lacks effective sealing lithologies, making it predominantly water-bearing despite its excellent reservoir characteristics. Outcrops occur throughout the northern delta region, particularly around Benin City, Onitsha, and Owerri.

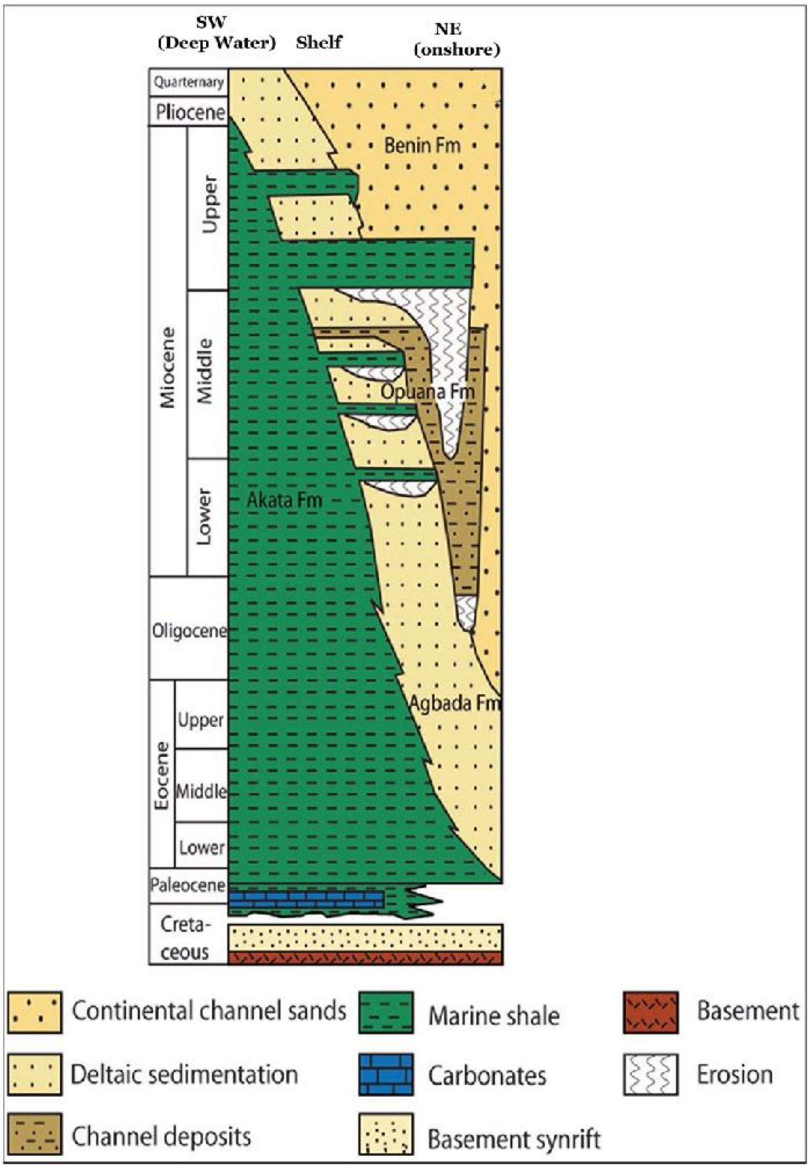

Figure 4 : The regional stratigraphic column of the Niger delta Basin shows the three major units in the delta (Akata, Agbada, and Benin formations) (Doust and Omatsola 1990)

2.4 Depobelt Architecture

The Niger Delta's progressive progradation has resulted in the development of five chronologically distinct depobelts, each representing a major phase of sediment accumulation and structural development ***(Evamy et al., 2023)***. These depobelts, ranging from 30-60 km in width, have advanced approximately 250 km southwestward over oceanic crust since the Eocene:

1. Northern Delta Depobelt: The oldest and most landward, characterized by well-consolidated sediments and deeply buried structures
2. Greater Ughelli Depobelt: Contains numerous giant fields with well-developed growth fault systems
3. Central Swamp Depobelt: Features complex structural styles with pronounced rollover anticlines
4. Coastal Swamp Depobelt: Exhibits the highest degree of structural complexity due to intense gravity tectonics
5. Offshore Depobelt: Divided into shallow and deepwater provinces, with the latter containing significant turbidite plays

Each depobelt displays unique structural characteristics, sediment distribution patterns, and hydrocarbon habitat, reflecting the evolving tectonic and depositional conditions through time ***(Stacher, 2021; Ejedawe, 2015)***.

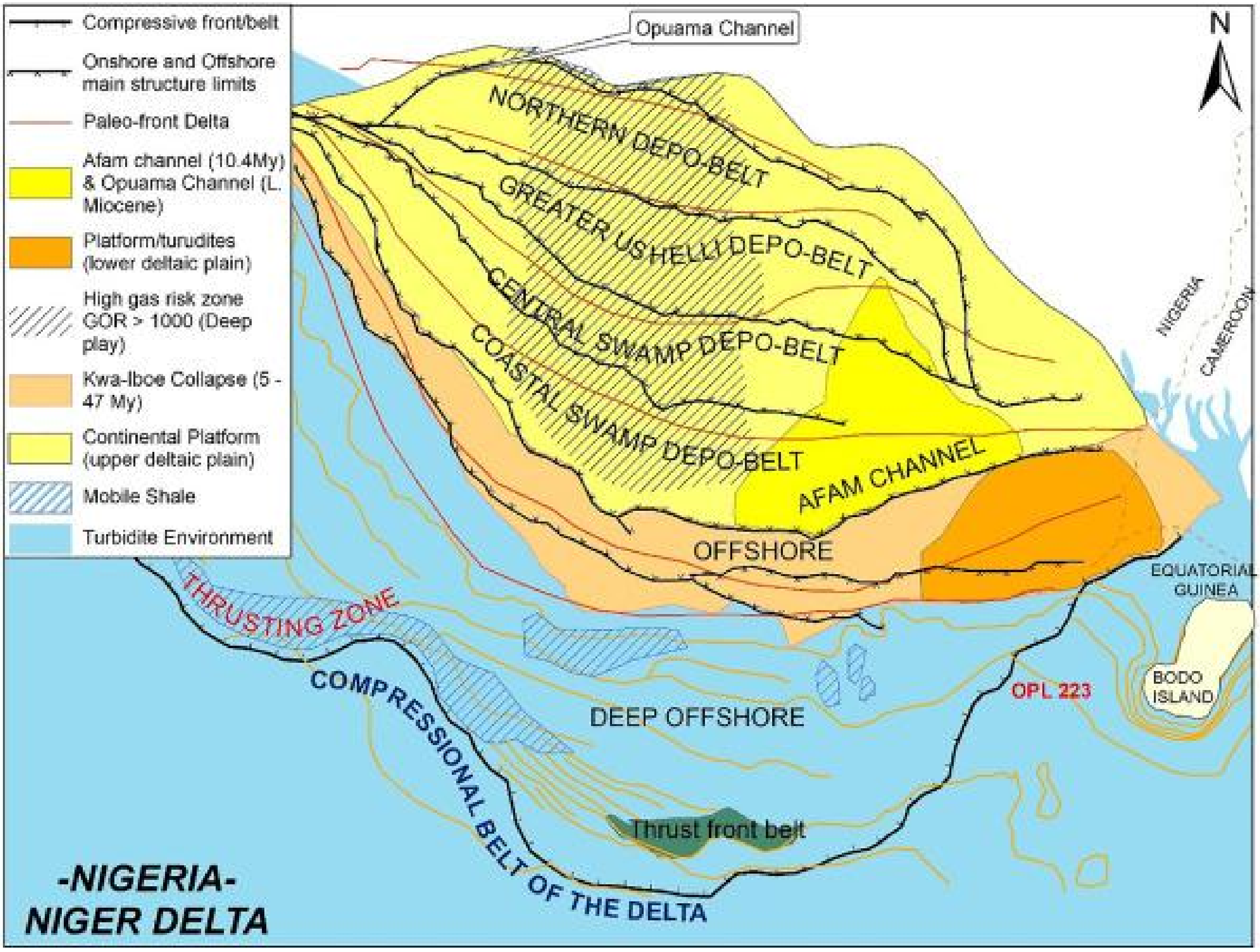

Figure 5 : Geologic map of the Niger Delta Basin showing depo-belts and structural elements (Adapted from Obiadi and Obiadi, 2016).

2.5 Structural Styles and Trap Mechanisms

The Niger Delta's structural inventory is dominated by gravity-driven features resulting from sediment loading on undercompacted, overpressured shales of the Akata Formation. The primary structural elements include:

2.5.1 Growth Faults

These syndepositional normal faults display listric geometries, soling out into the overpressured Akata shales ***(Weber, 2021)***. They typically display increasing throw with depth and are associated with expanded stratigraphic sections in their hanging walls. Both synthetic (dipping basinward) and antithetic (dipping landward) varieties create structural closures critical for hydrocarbon accumulation.

2.5.2 Rollover Anticlines

Formed through the bending of strata into the space created by movement along listric growth faults, these structures represent the most prolific trap type in the Niger Delta ***(Doust & Omatsola, 2022)***. Their geometry is controlled by fault curvature, with steeper faults generating tighter folds.

2.5.3 Shale Diapirs and Mud Volcanoes

Mobile Akata shales pierce overlying strata in response to unequal loading, creating both structural closures and sealing barriers ***(Morley, 2023)***. These features are particularly common in the offshore and deepwater domains.

2.5.4 Toe-Thrust Belts

In the compressional domain, basinward-vergent thrust faults accommodate the gravitational spreading of the deltaic wedge (Corredor et al., 2005). These structures have gained increasing importance with deepwater exploration.

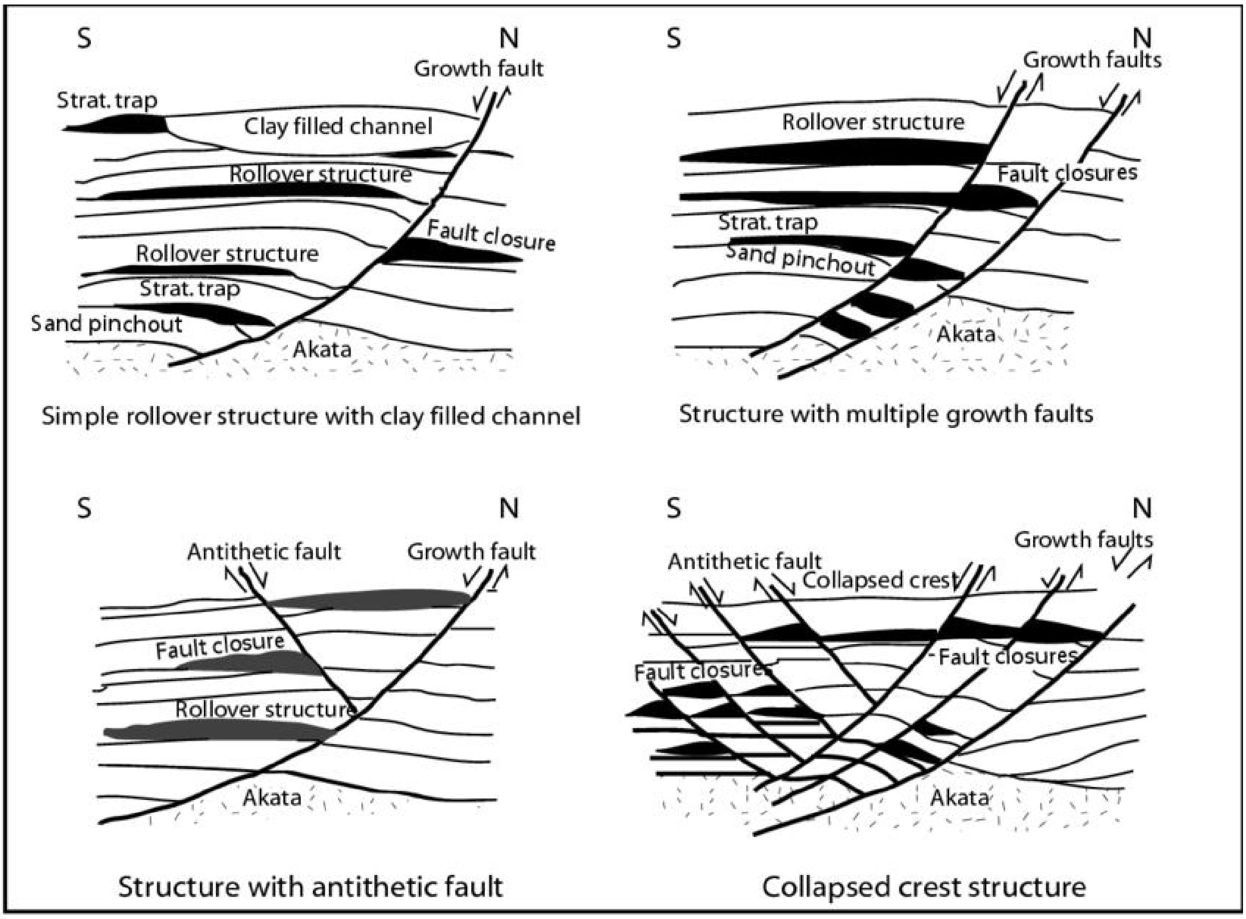

Figure 6 : Examples of Niger Delta oil field structures and associated trap types. Modified from Doust and Omatsola (1990) and Stacher (1995).

2.6 Petroleum System

The Niger Delta contains a single, vertically extensive petroleum system encompassing the Akata and Agbada Formations ***(Tuttle et al., 2022)***. The system's effectiveness derives from the intimate association of source, reservoir, and seal lithologies within a structurally dynamic setting.

2.6.1 Source Rocks and Hydrocarbon Generation

The Akata Formation shales represent the primary source rock, generating both oil and gas at maturity depths of 2,700-4,000 meters ***(Ekweozor & Okoye, 1980)***. Thermal modeling indicates peak oil generation occurs between 90-120°C, with gas generation dominating at higher temperatures ***(Haack et al., 2022)***. Hydrocarbon generation commenced in the Northern Delta during the Oligocene and has progressively migrated basinward with continued subsidence and sedimentation.

2.6.2 Migration Pathways

Vertical migration along growth faults represents the primary conduit from Akata source rocks to Agbada reservoirs ***(Stacher, 2021)***. Episodic fluid release from overpressured zones creates fracture networks that facilitate efficient primary migration. Secondary migration occurs both vertically along fault planes and laterally within continuous sandstone bodies.

2.6.3 Reservoir Characteristics

Agbada Formation sandstones display exceptional reservoir quality, with porosities of 15-35% and permeabilities commonly exceeding 1,000 mD (Weber & Daukoru, 1975). Reservoir distribution reflects the complex interaction of depositional environment and structural modification, with the highest-quality sands typically occurring in channel and bar complexes within the Central Swamp and Coastal Swamp depobelts.

2.6.4 Trap Styles and Seal Integrity

Structural traps dominate the Niger Delta, accounting for approximately 90% of known accumulations ***(Doust & Omatsola, 2022)***. Growth fault-associated rollover anticlines represent the most common configuration, complemented by fault-dependent closures and diapir-related structures. The interbedded shales of the Agbada Formation provide effective top and lateral seals, with seal integrity largely maintained despite intense faulting due to the shale-smearing process along fault planes ***(Weber et al., 2023)***.

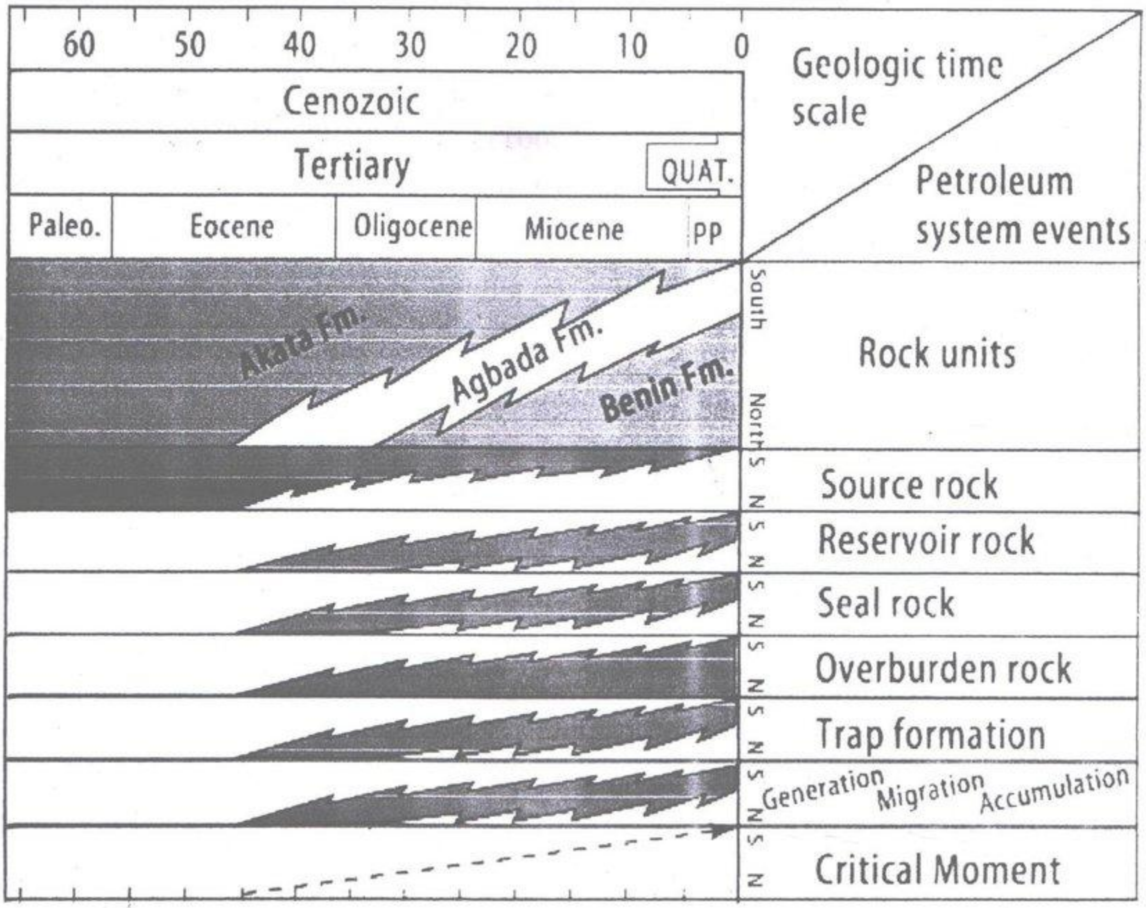

Figure 7 : Events chart for the Niger Delta (Akata/Agbada) Petroleum system (Modified from Tuttle et. al., 1999)

CHAPTER THREE

3.0 MATERIALS AND METHODOLOGY

This chapter details the materials, datasets, and methodological workflow employed to achieve the aim of reservoir delineation in the INDARZ Field. The integrated approach combined structural mapping and seismic attribute analysis within the Schlumberger Petrel software environment.

3.1 Materials

The following materials were utilized for this project work:

- A high-performance PC.
- Schlumberger's Petrel™ geoscience software platform (version 2014).
- Geophysical and well log datasets for the INDARZ Field.

3.2 Available Data

The project utilized a 3D seismic volume and well log data from four wells (INDARZ01, INDARZ02, INDARZ03, and INDARZ04) within the INDARZ Field. The datasets, generously provided for academic research, included the following:

- **3D Seismic Data:** A post-stack time-migrated volume in the ZGY format, which is natively efficient for loading and visualization in Petrel.
- **Well Data Suite:** For each of the four wells, the following data were provided:
- **Well Headers:** Containing well names, surface coordinates, and datum information (Kelly Bushing).
- **Well Deviation Data:** Essential for correcting the well path from a vertical assumption to its true trajectory.
- **Well Logs (in LAS format):** A comprehensive suite including Gamma Ray (GR), Resistivity, Density, Neutron Porosity, and Sonic logs.
- **Checkshot Data:** Providing time-depth pairs crucial for calibrating the seismic data to the well depth.

3.3 Workflow

A systematic workflow was designed and executed in Petrel to ensure a robust and integrated interpretation. The process, summarized in Figure 3.1, began with data loading and quality control, proceeded through sequential steps of structural and stratigraphic analysis, and culminated in the integrated delineation of the reservoir complex. Each step is detailed in the subsequent sections.

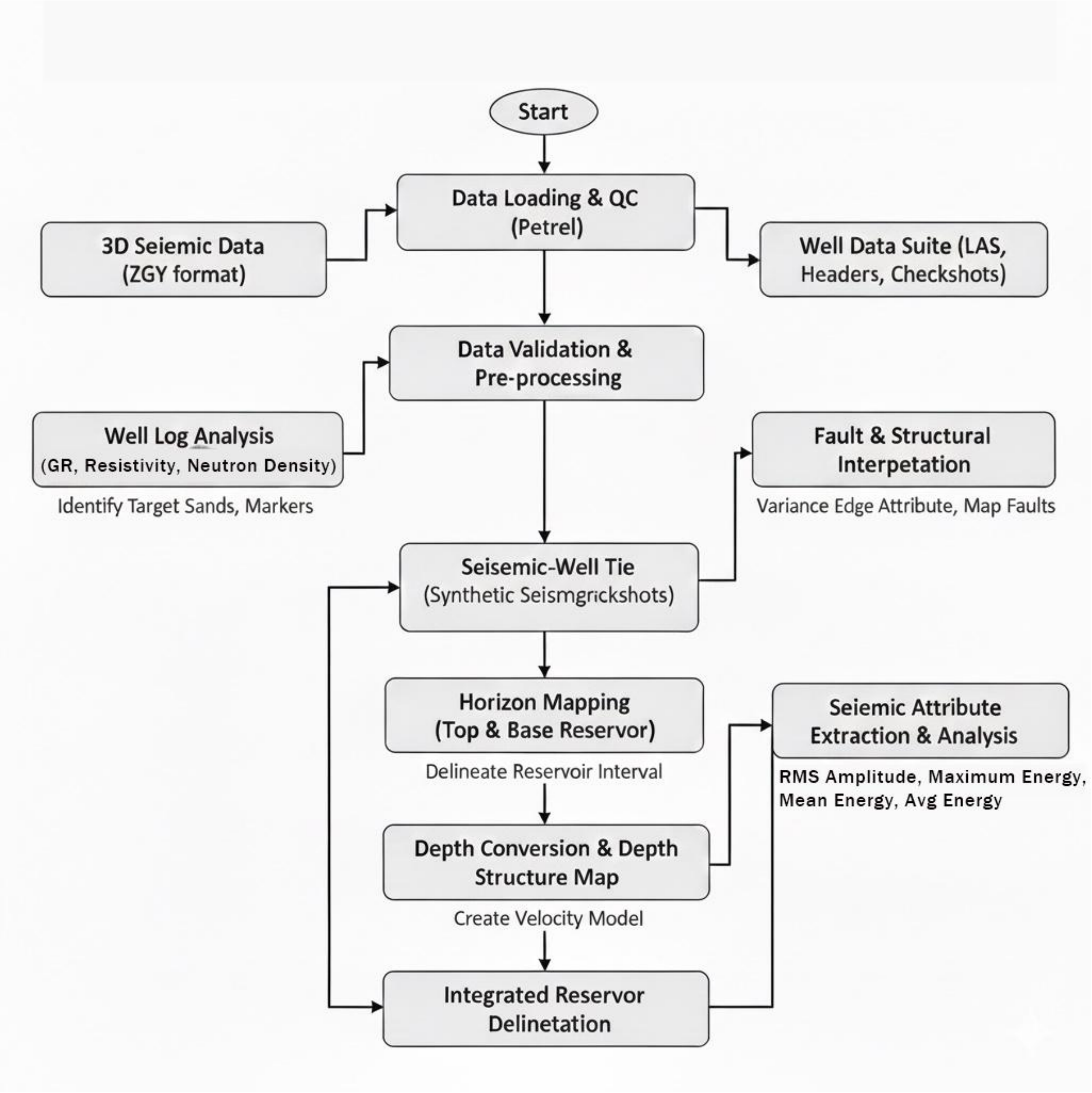

Figure 8 : Workflow chart illustrating the integrated methodology for reservoir delineation in the INDARZ Field

3.4 Data Loading and Quality Control

All datasets were loaded into the Petrel project and subjected to a rigorous quality control (QC) process to ensure data integrity and consistency before interpretation.

3.4.1 Seismic Data

The 3D seismic volume in ZGY format was successfully loaded. Its primary purpose was to define the structural framework through fault and horizon mapping, and to extract seismic attributes for stratigraphic analysis. This data forms the foundation for delineating the structural trap and the spatial distribution of the target sand complex.

3.4.2 Well Data Set

The data from the four wells (INDARZ01, INDARZ02, INDARZ03, INDARZ04) were loaded and validated. The well headers and deviation data ensured accurate well placement. The full log suite was checked for completeness and reasonable value ranges. The checkshot data was critically examined as it provides the necessary link between the time domain (seismic) and the depth domain (well logs).

3.5 Methodology and Interpretation Workflow

3.5.1 Well Log Analysis for Stratigraphic Control

Well log analysis was conducted on the four wells to identify the target sand complex and provide stratigraphic control for the seismic interpretation. The Gamma Ray log was primarily used to discriminate between sand and shale lithologies, identifying clean sand units based on low GR response. The Resistivity log aided in distinguishing hydrocarbon-bearing zones. This analysis allowed for the identification of key stratigraphic markers to be tied to the seismic data.

3.5.2 Fault and Structural Interpretation

Fault interpretation was conducted on the seismic volume to define the structural framework of the field. This process was significantly enhanced using seismic attributes. The **Variance Edge** attribute was primarily used to illuminate discontinuities and facilitate precise fault mapping. The interpreted faults were critical for understanding the structural trap configuration.

3.5.3 Seismic-Well Tie

A synthetic seismogram was generated for each well by convolving a extracted wavelet with the reflectivity series derived from the sonic and density logs. This synthetic was then tied to the seismic data at the well location using the checkshot data. This crucial step established a reliable correlation between the seismic reflections (time) and the geological formations (depth), ensuring accurate horizon picking.

3.5.4 Horizon Mapping

Following the seismic-well tie, key horizons bounding and within the target sand complex were interpreted and picked across the entire 3D seismic volume. This horizon mapping process delineated the top and base of the reservoir interval, providing the surfaces necessary for structural mapping and attribute extraction.

3.5.5 Time Structure Map Generation

From the interpreted horizons, time structure maps were generated. These maps provide a preliminary view of the subsurface geometry in the time domain, revealing structural features such as anticlines, synclines, and fault closures that could potentially form hydrocarbon traps.

3.5.6 Depth Conversion and Depth Structure Map Generation

To move from the time domain to the depth domain, a velocity model was created using the checkshot data. The interpreted time horizons were then converted into depth surfaces using this model. The resulting Depth Structure Map of the top reservoir provides a geometrically accurate representation of the structure, which is essential for accurate volumetric assessment and reservoir delineation.

3.5.7 Seismic Attribute Extraction and Analysis for Delineation

This step is central to the research objective. Seismic attributes were extracted to characterize the internal architecture and spatial distribution of the sand complex. Attributes were extracted along the interpreted horizons and within a defined time window around them. The key attributes utilized included:

- **RMS Amplitude:** To identify areas of high reflectivity strength potentially associated with hydrocarbon saturation or lithological changes.
- **Sweetness:** To help distinguish true bright spots related to hydrocarbons from other high-amplitude events.

- **Envelope:** To map the total acoustic energy and further highlight amplitude anomalies. The analysis of these attribute maps, in conjunction with the depth structure map, formed the basis for the integrated delineation of the reservoir's extent and internal geometry.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Well Log Correlation and Reservoir Identification

The subsurface interpretation was built up on a well-log correlation of the four wells (IND01, IND02, IND03, IND04). The main purpose was to locate and map a major sand unit of the field reservoir. A correlation was carried out based on a package of logs, each of which contains vital diagnostic information:

1. **Gamma Ray (GR) Log**: This was the major lithology discrimination tool with clean sandstone reservoirs having low GR values as they contain low concentrations of radioactive elements and shales having high GR values. The sand in the target reservoir was located based on the fact that it displayed uniform log signature in all the four wells indicating its regional scale as a correlatable stratigraphic unit.
2. **Resistivity Log**: This log was applied in order to ascertain fluid content. When the resistivity of a porous, permeable sand is high, it is normally an indication that it contains hydrocarbons which is a poor conductor of electricity. On the contrary, water saturated sands exhibit low resistivity. The analysis indicated a huge aberration within Well IND01 and well IND04 where the target sand was characterized by a high resistivity spike, which is a strong indication of the existence of hydrocarbons. Low resistivity was observed in the same sand in wells IND02, IND03, which shows the saturation with water.
3. **Neutron-Density Log**: This is a combination of logs that was important in distinguishing between oil and gas. Gas-bearing zones also lead to a crossover effect in which the neutron porosity value is reduced (because of reduced hydrogen index) and the density porosity value is reduced (because of reduced fluid density). A distinct crossover was seen in Well IND04 in the high-resistivity region, which indicated the presence of gas (high part of the column) and oil but only oil in the case of well IND04.

Discussion: The choice of this particular sand body as the oil reservoir of interest was rationalized by the analysis of the log integrated. The regular GR signature indicated that it was a continuation of the lateral signature and the fluid indicators (resistivity and neutron-density crossover) identified Well IND01 as the hydrocarbon-bearing sweet spot, and Well IND04 as gas bearing. This means that the accumulation conditions at this site are favorable both in terms of structure and stratigraphy.

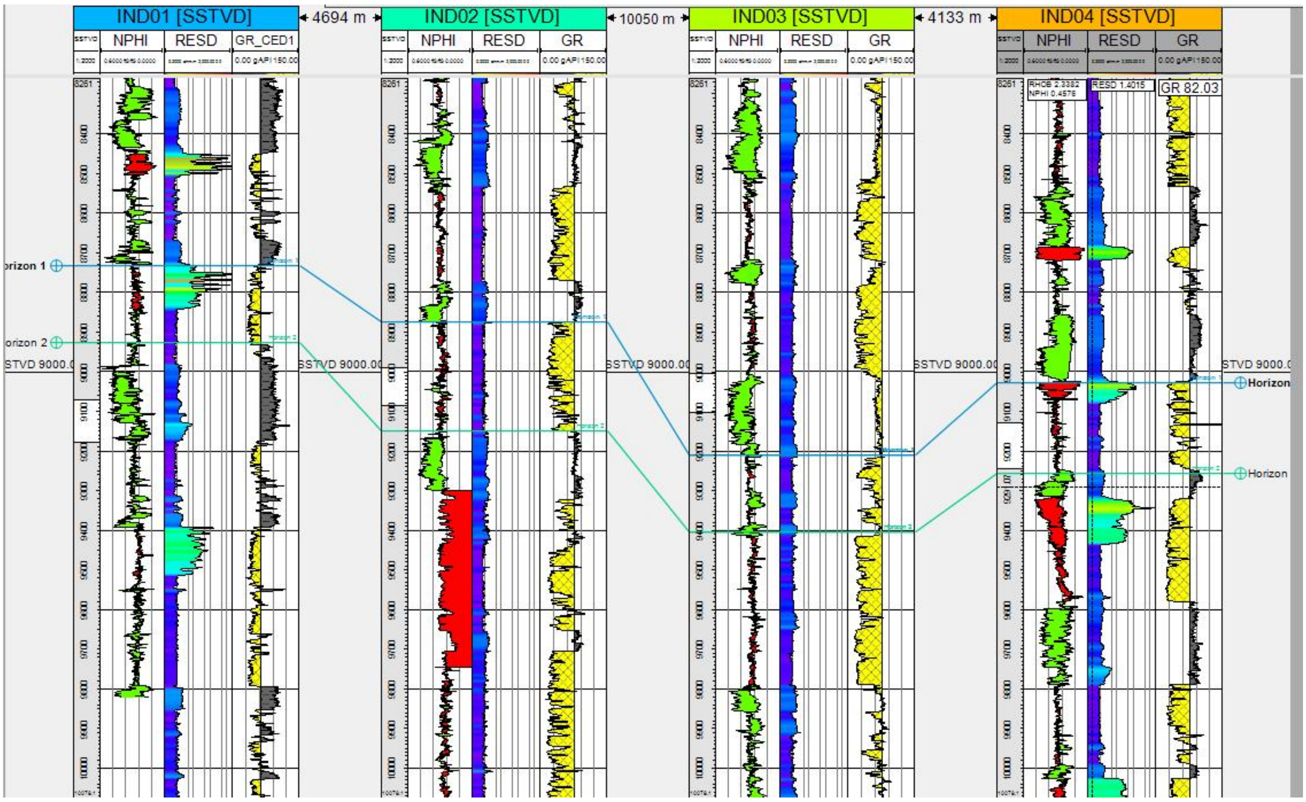

Figure 9 : Reservoir correlation across the 4 wells

4.2 Structural Interpretation: Fault Mapping

The INDARZ Field structural framework was established by fully interpreting faults on the 3D volume of the seismic. Twenty-five (25) faults were mapped including three (3) major and regionally significant faults and twenty-two (22) minor faults as seen on Fig 4.2.

The fault system is typified by the listric growth faults which are prevalent in the extensional deltaic settings as is the case with the Niger Delta. These faults are depth-curving and are usually linked to the thickening of sediments in the block that is downthrown. Synthetic faults (dipping in the same direction as the major growth faults) were also determined as well as antithetic faults (dipping in the opposite direction), that created a complex yet coherent structural fabric.

To achieve the accuracy of the interpretation, the original fault picks were quality-controlled with the help of seismic attributes (see fig 4.3, 4.4, 4.5, below). Variance Edge attribute was especially helpful, and it allowed outlining the discontinuities in the seismic data and fault traces became much clearer. Also, RMS Amplitude and Sweetness attributes were analyzed so that the mapped faults would not truncate high-amplitude, continuous stratigraphic characteristics erroneously. This multi-attribute validation had a great contribution to increasing the confidence of the final structural model.

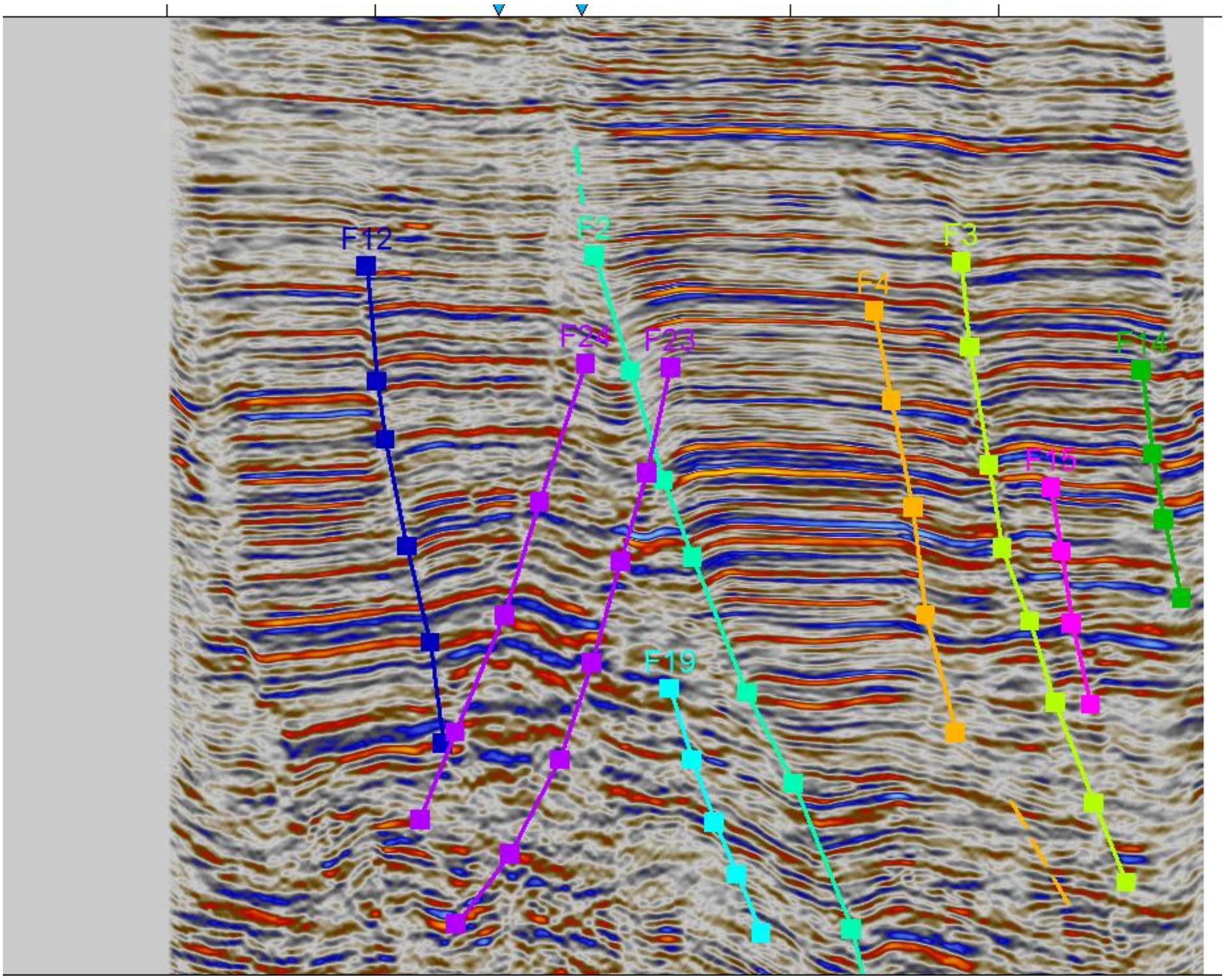

Figure 10 : Mapped Faults on inline section

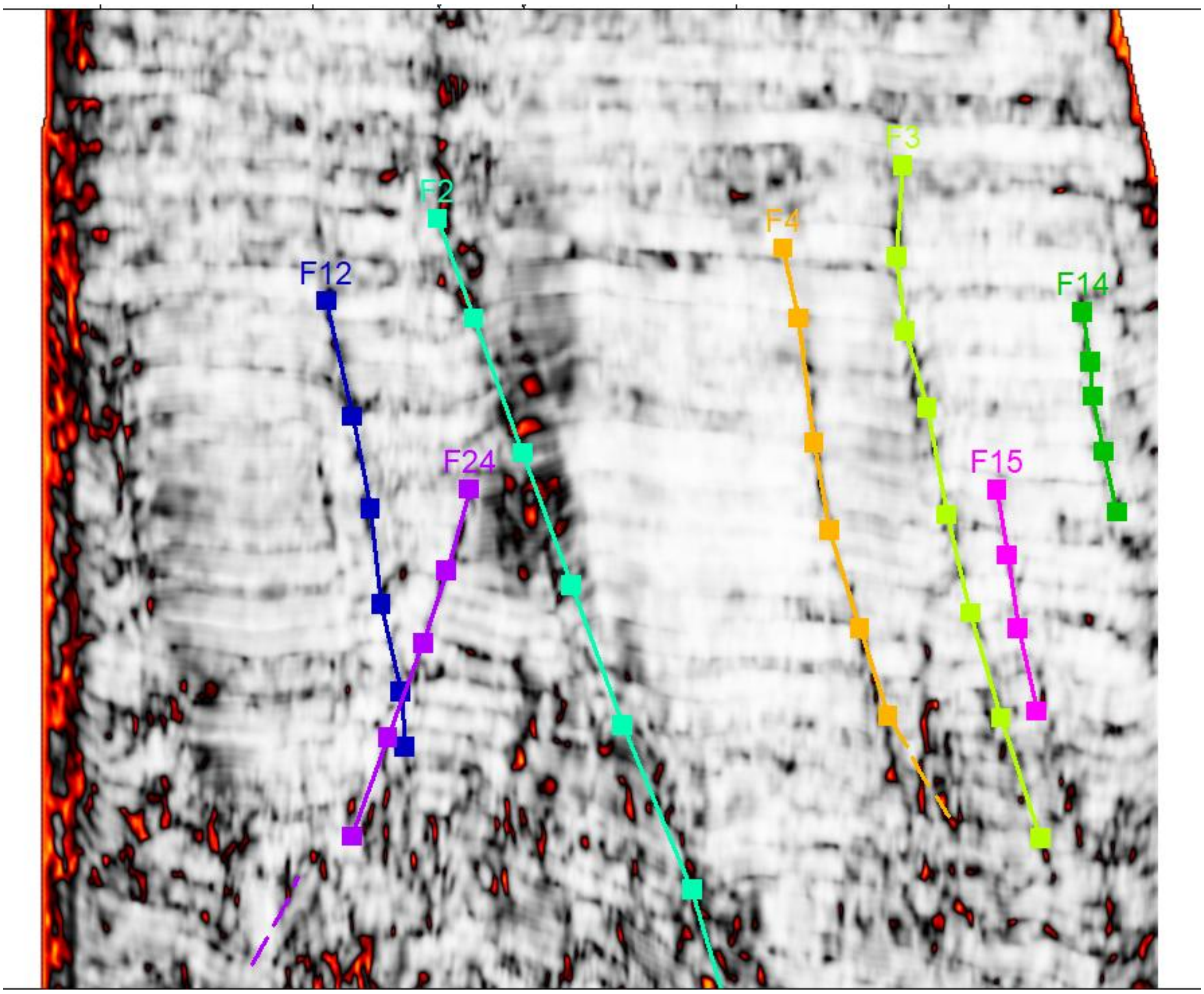

Figure 11 : Envelop Attribute

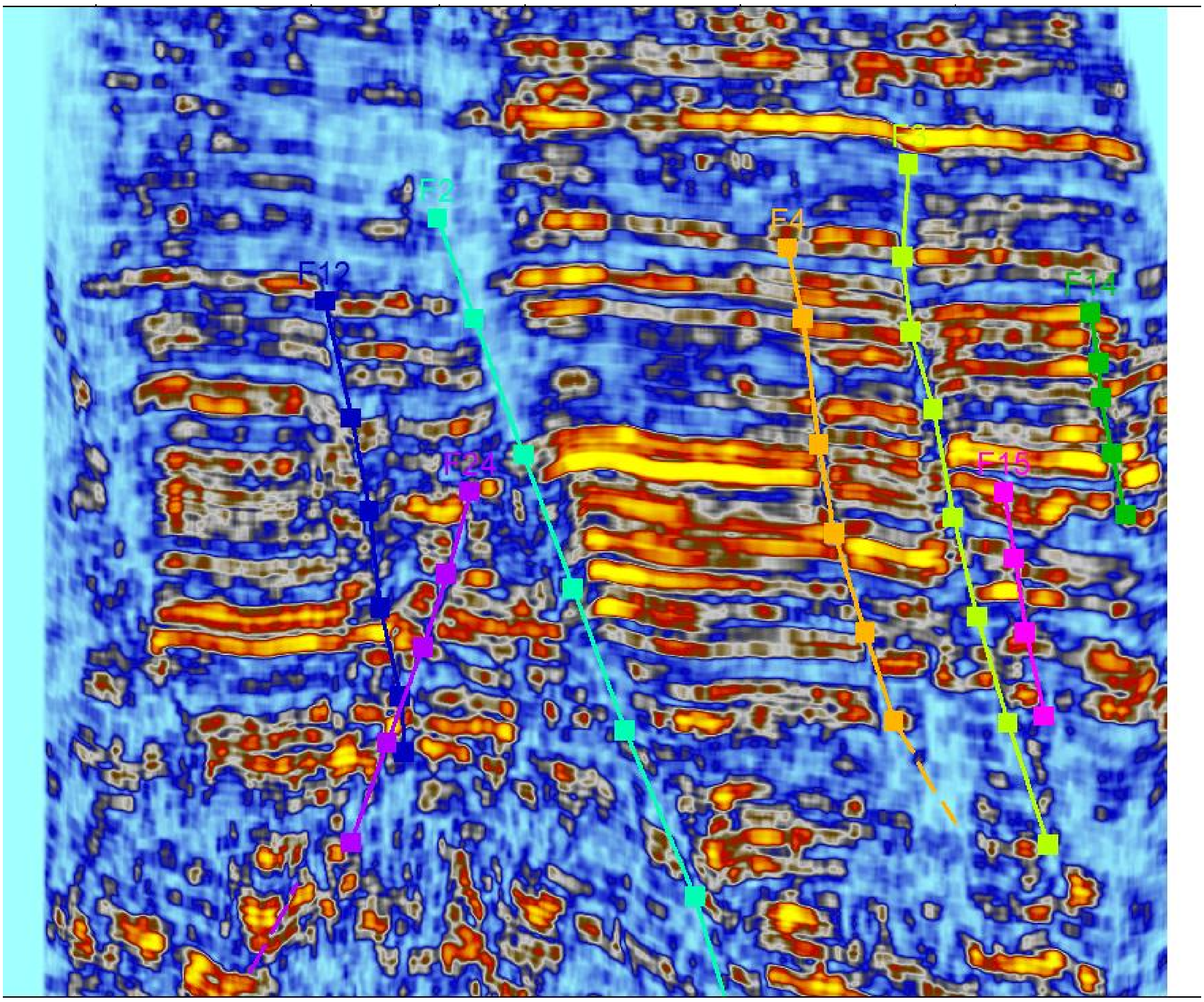

Figure 12 : RMS Amplitude Attribute

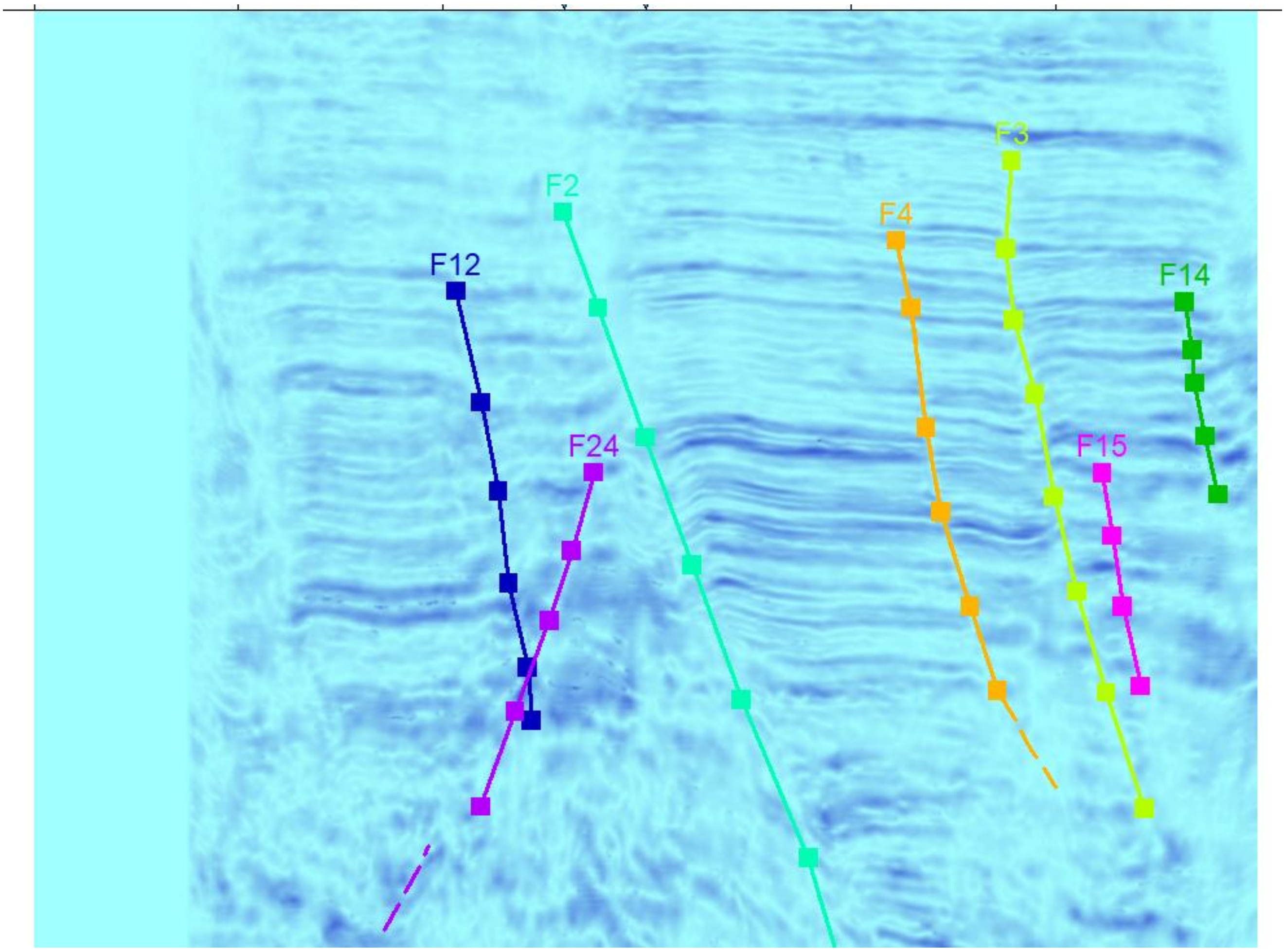

Figure 13 : Sweetness Attribute

4.3 Seismic-to-Well Tie

An association between the well-based depth domain and the seismic time domain was made. This has been accomplished in the seismic-to-well tie process which can be subdivided into two important steps:

1. Velocity Calibration using Checkshot Data: The initial step was to calibrate the continuous velocity using the checkshot survey sonic log data with discrete and high-fidelity time-depth pairs of the checkshot survey. This calibration is used to correct any drift or inaccuracy in the sonic log to provide the correct Time-Depth Relationship (TDR) of the well.
2. Synthetic Seismogram Generation: This step entailed the generation of a synthetic seismic trace that was in the area of the well. This was done by:
   - Deriving a reflectivity series based on the sonic and density calibrated logs.
   - Convolution of this reflectivity series with a statistical wavelet recovered out of the seismic data around the well site.
   - The resultant synthetic seismogram is a simulated seismic trace which approximates how the seismic response would be at the well (see fig 4.6).

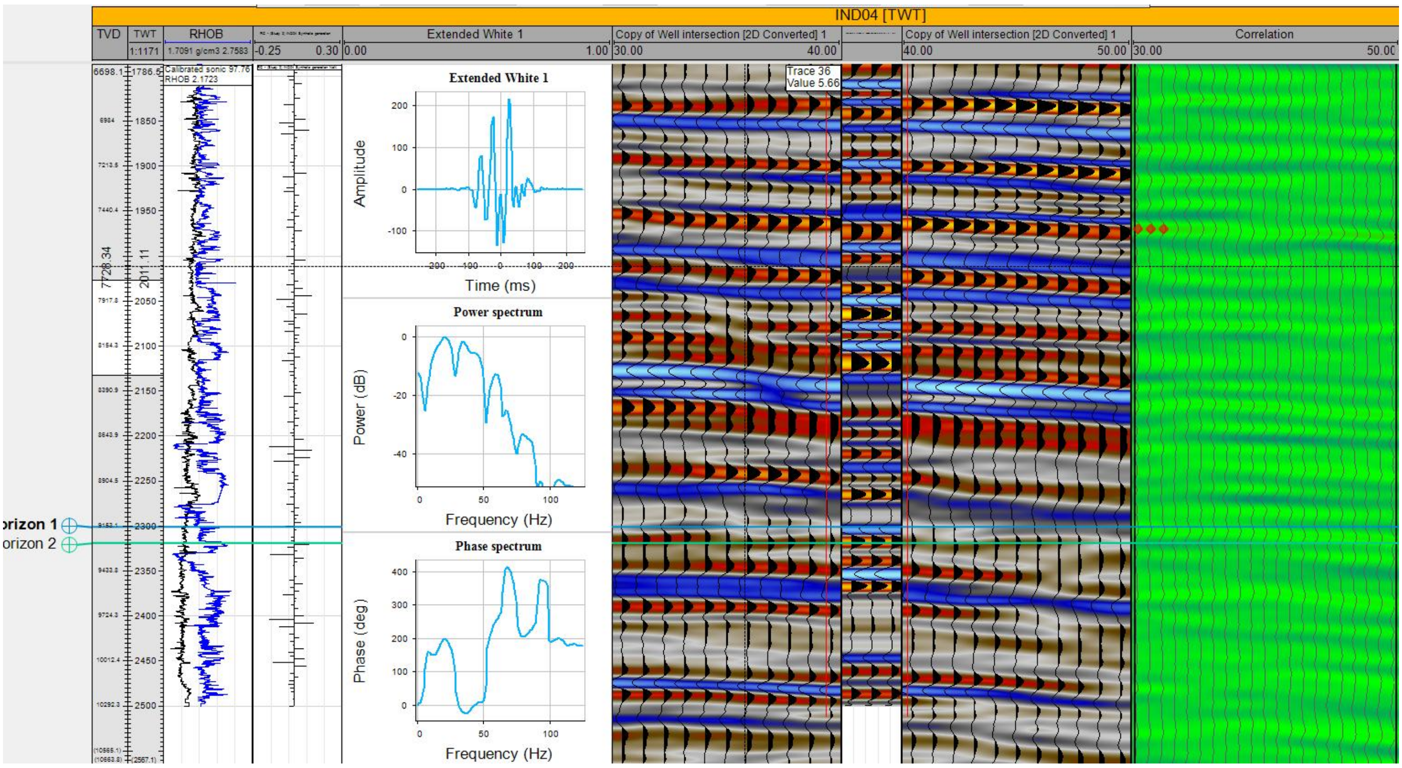

Figure 14 : Synthetic Seismogram Generation

The quality of the tie was measured by comparing the synthetic trace with the real seismic trace at Well IND04. The match was rated as fair to good, and key reflection events were relatively satisfactorily aligned. In this procedure, the seismic data was used to identify the top of the target reservoir sand with considerable confidence on the top of this peak. This calibration is necessary, because it enables the interpreter to map the geological data of the wells (e.g., the intended hydrocarbon bearing reservoir onto the expansive 3D seismic volume which will then permit the mapping of the horizons across the entire field.

4.4 Horizon Mapping and Time Surface Generation

4.4.1 Horizon Mapping

The fault system was now in place and the target reservoir was registered to the seismic due to the well tie, the Top Sand horizon was now systematically mapped throughout the 3D volume. This was done by following up the identified through reflection in each of the inline and crosslines with a consistent pick that respected the seismic character as well as the constraining fault geometry, see below in fig 4.6.

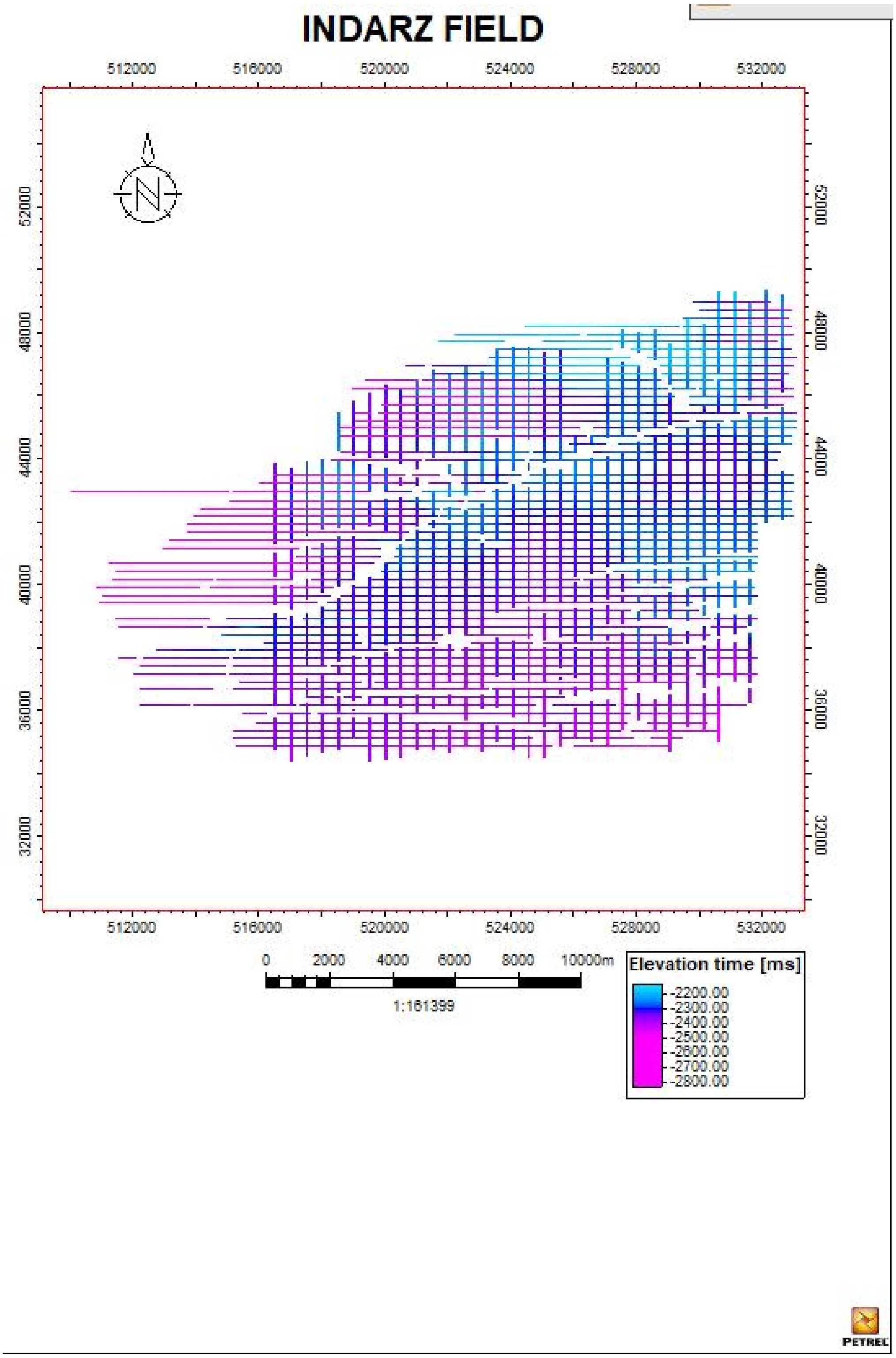

Figure 15 : Mapped Horizon Surface On Map Window

4.4.2 Time Surface Generation

The outcome was a complete Time Structure Map (in fig 4.7) which acts as the skeleton of the structural model. The fault pattern has been included in this map which was built by taking the interpreted horizon points. The software was used to properly truncate the horizon at fault boundaries using the functions like Eliminate Where and Eliminate Inside to make sure that the map is accurate in showing the compartmentalization of the reservoir by the fault system. Time structure map gives the general geometries of the reservoir surface in time domain including structural closures and dips, which are important in initial traps determination.

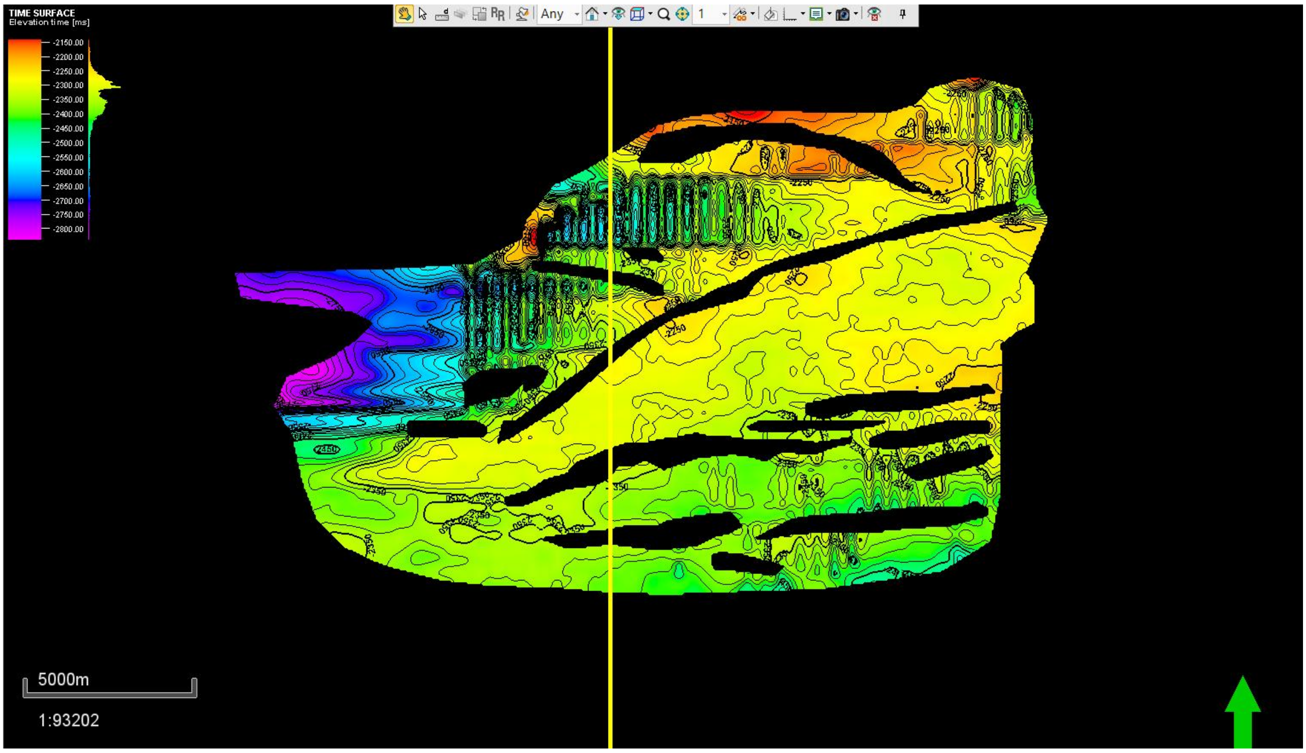

Figure 16 : Time Surface On 3D Window

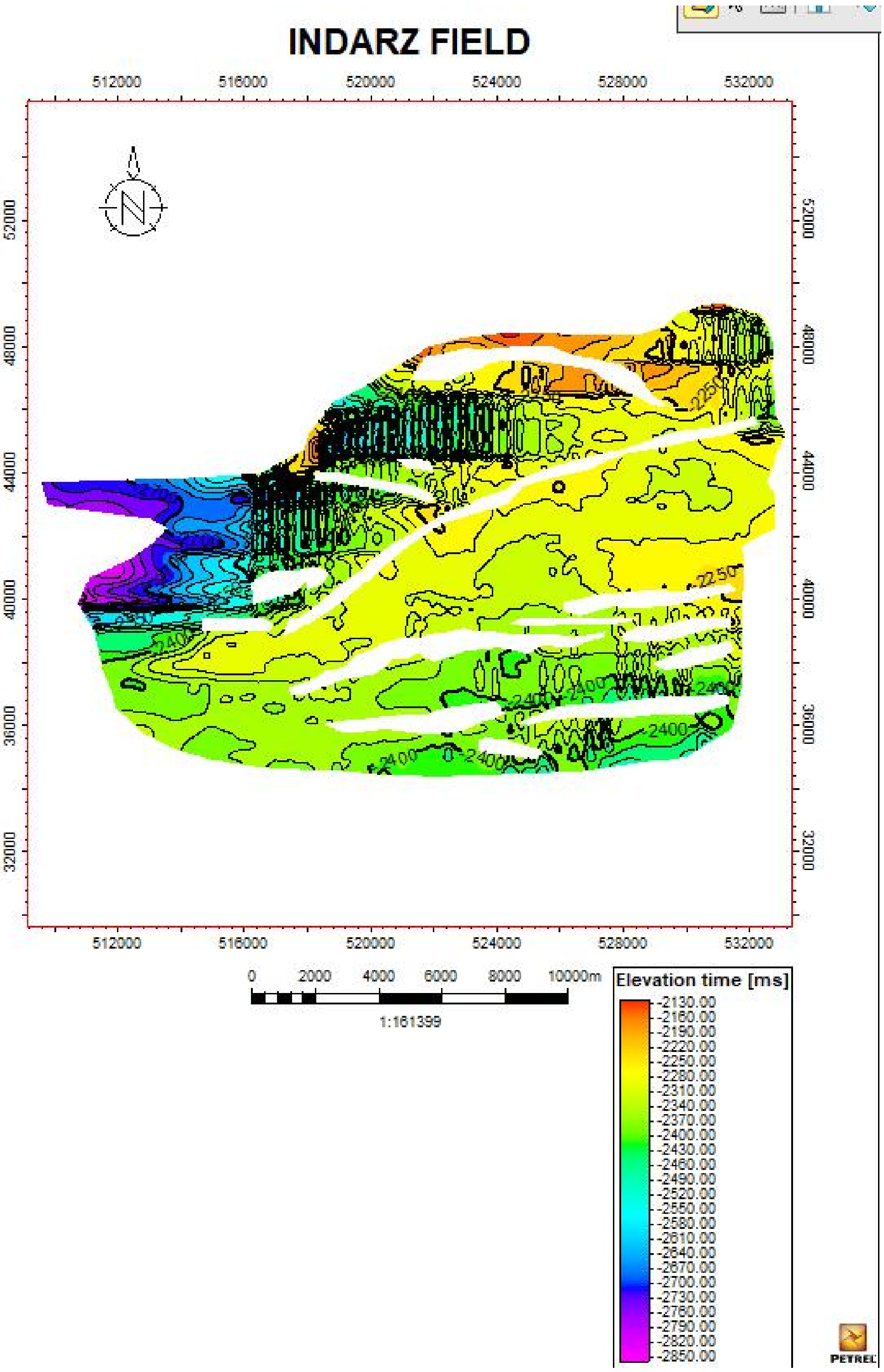

Figure 17 : Time Surface On Map Window

4.5 Velocity Modeling and Depth Surface Generation

4.5.1 Velocity Modeling

Velocity modelling is an attempt to derive a mathematical equation to explain the change in seismic wave velocity with depth in the subsurface. This type of relationship is needed since it allows the interpretations of seismic time surfaces into proper depth surfaces. Even though a time-structure map is useful, it has little direct value in the drilling planning because it is not associated with the actual geological depth; therefore, a conversion between time and depth needs to be done. It has been observed empirically that the transformation between time and depth is non-linear and requires an appropriate velocity model, which has been developed above.

The velocity model was built based upon the time depth relationship (TDR) obtained in the course of the seismic-well tie operation in Well IND04 (see Fig 4.9). Checkshot data can be calibrated as shown in Fig 4.9 to show a distinct non-linear trend. An initial 3rd order poly was then fitted to the data providing a strong mathematical form that can describe the convoluted association between two-way travel time (TWT) and depth (Z) in this field.

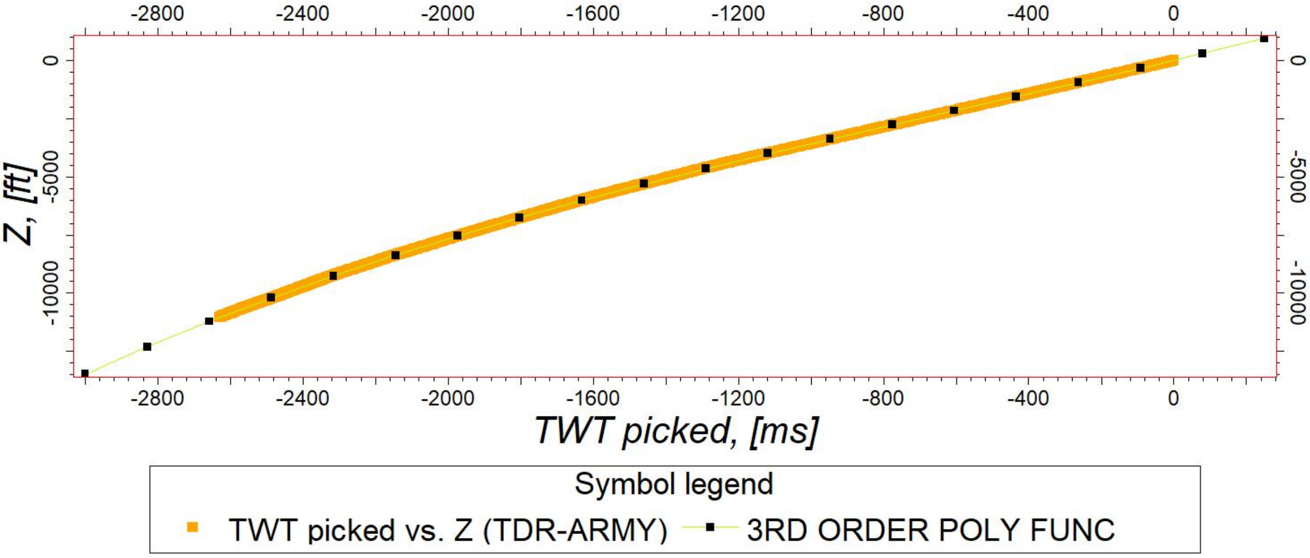

Figure 18 : Velocity Modelling Using A 3rd-Order Polynomial Function

4.5.2 Depth Surface Generation

The third-order time-structure map was then applied to the above-mentioned third-order time-structure polygraph, thus creating a depthstructure map (see Figure4.1.1). The obtained depth map will provide a geometrically accurate representation of the reservoir structure, which is a requirement of all subsequent volumetric calculations and development planning.

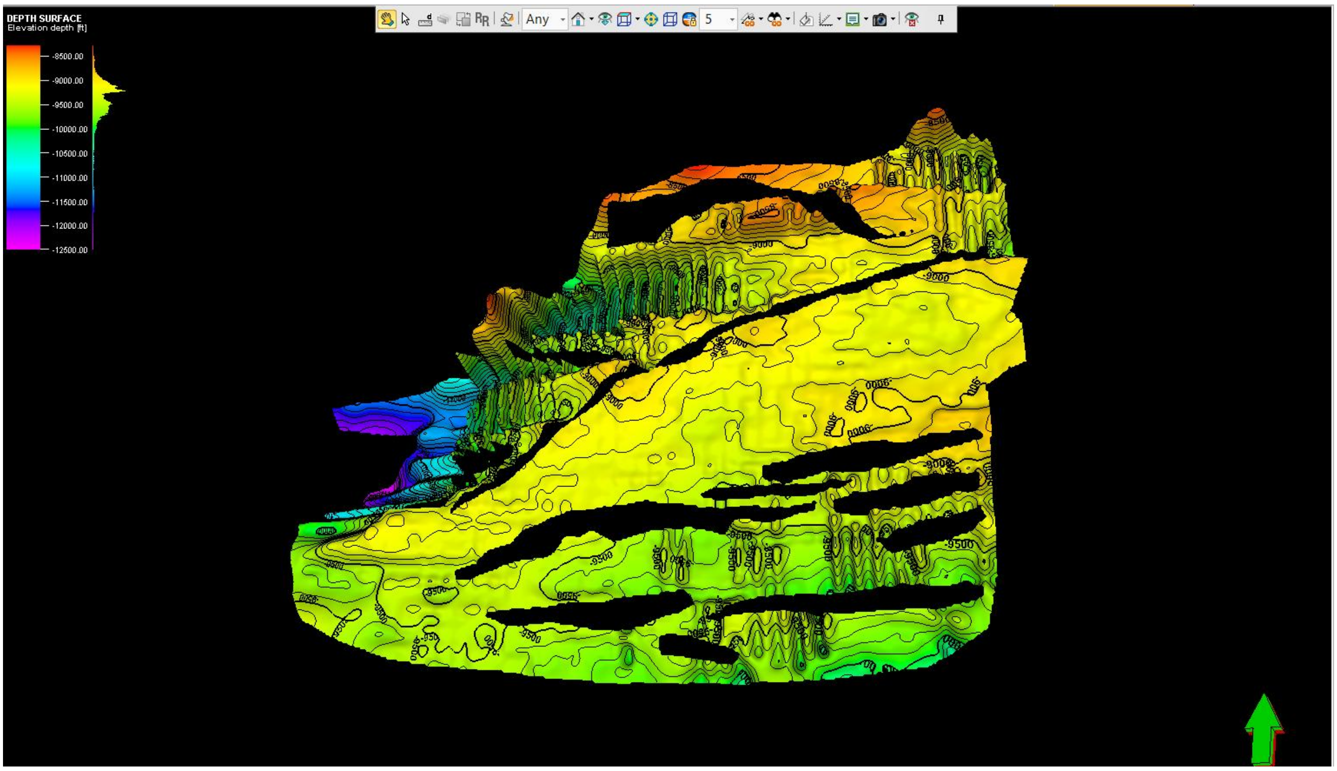

Figure 19 : Depth Structure Map On 3D Window

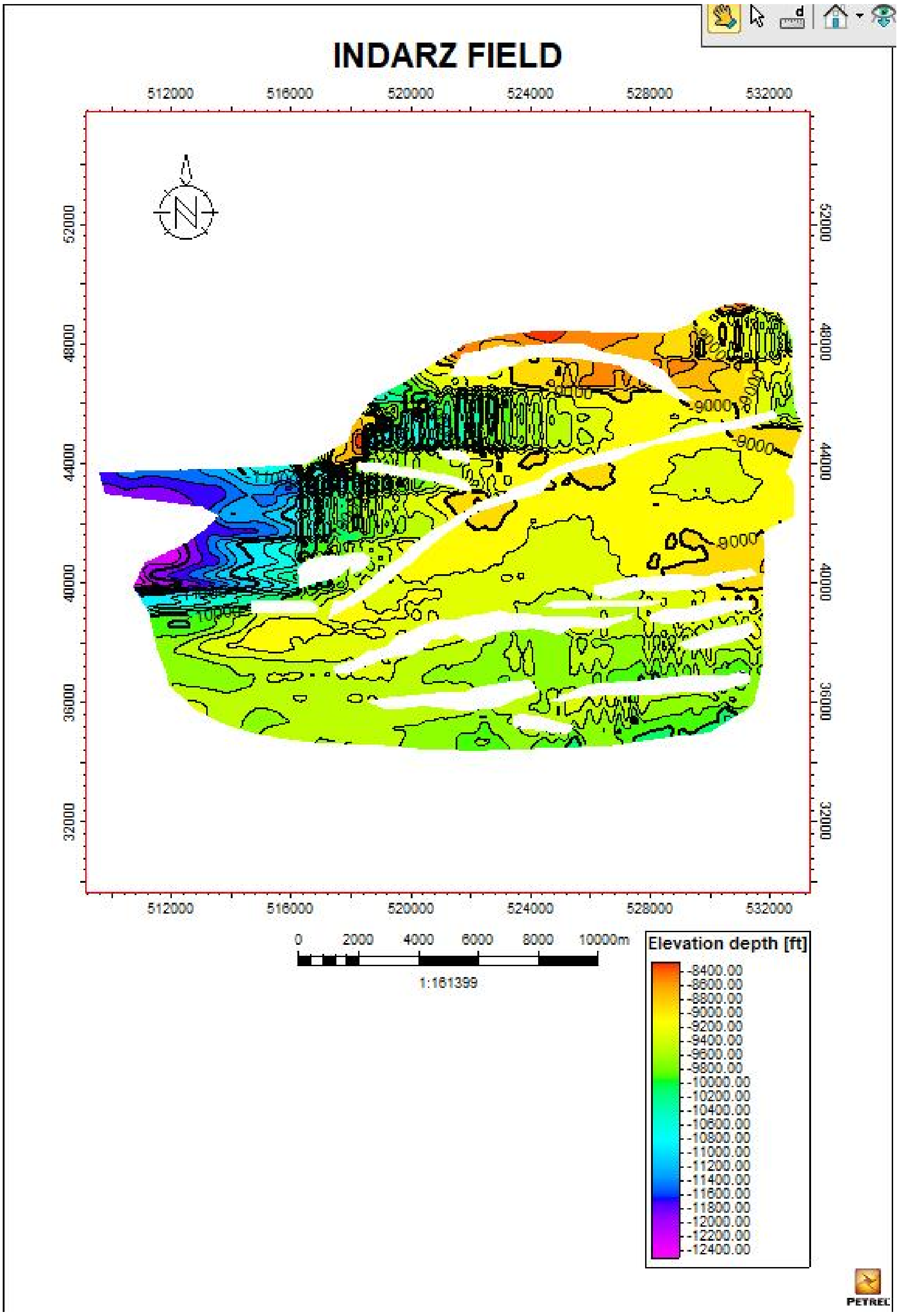

Figure 20 : Depth Structure Map On 3D Window

4.6 Seismic Attribute Analysis for Reservoir Characterization

A range of amplitude-based seismic characteristics were picked out on Top Sand horizon. These properties measure seismic response, and variations in these observed often correlate with lithology variation or porosity or fluid variation.

1. RMS Amplitude (see below in fig 4.1.3): The amplitude value of the RMS amplitude attribute is the root-mean-square amplitude values in a seismic window around the horizon. It is especially used to locate so-called bright spots, areas of unusually large amplitude that are often caused by saturation of the hydrocarbons, particularly gas, due to strong contrasts of acoustic impedances.
2. Maximum Amplitude (see below in fig 4.1.4): The highest amplitude is the maximum amplitude characteristic which is the greatest positive amplitude in the analysis window. It particularly is sensitive to exceptionally strong, peak, reflections which can signal the upper limit of a gas sand.
3. Average Amplitude (see below in fig 4.1.5): Average amplitude attribute gives the mean amplitude over the window, which gives a generalized understanding of the strength of reflectivity and helps to identify the larger spatial trends.
4. Mean Amplitude (see below in fig 4.1.6): The mean amplitude attribute is the arithmetic mean of the values of amplitude over the analysis window, which also provides a strong measure of central tendency but is less prone to the effect of outliers compared to the maximum or minimum attributes.

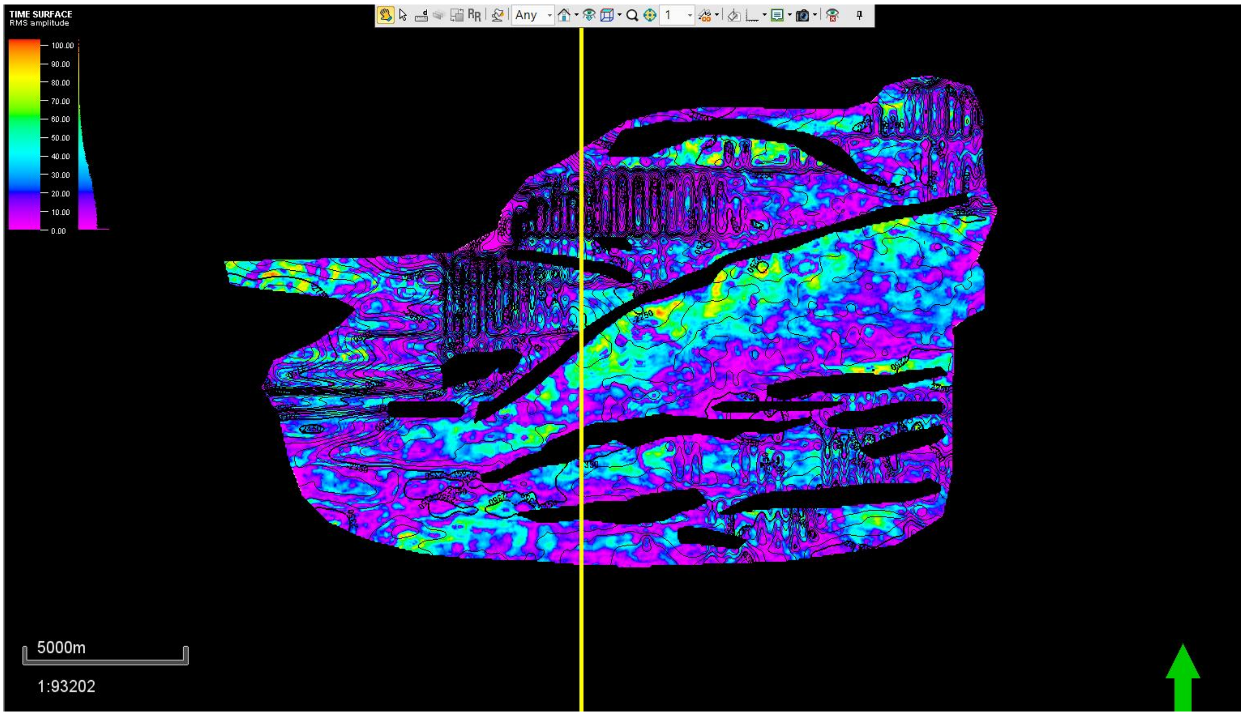

Figure 21 : Time Structure Map With RMS Amplitude

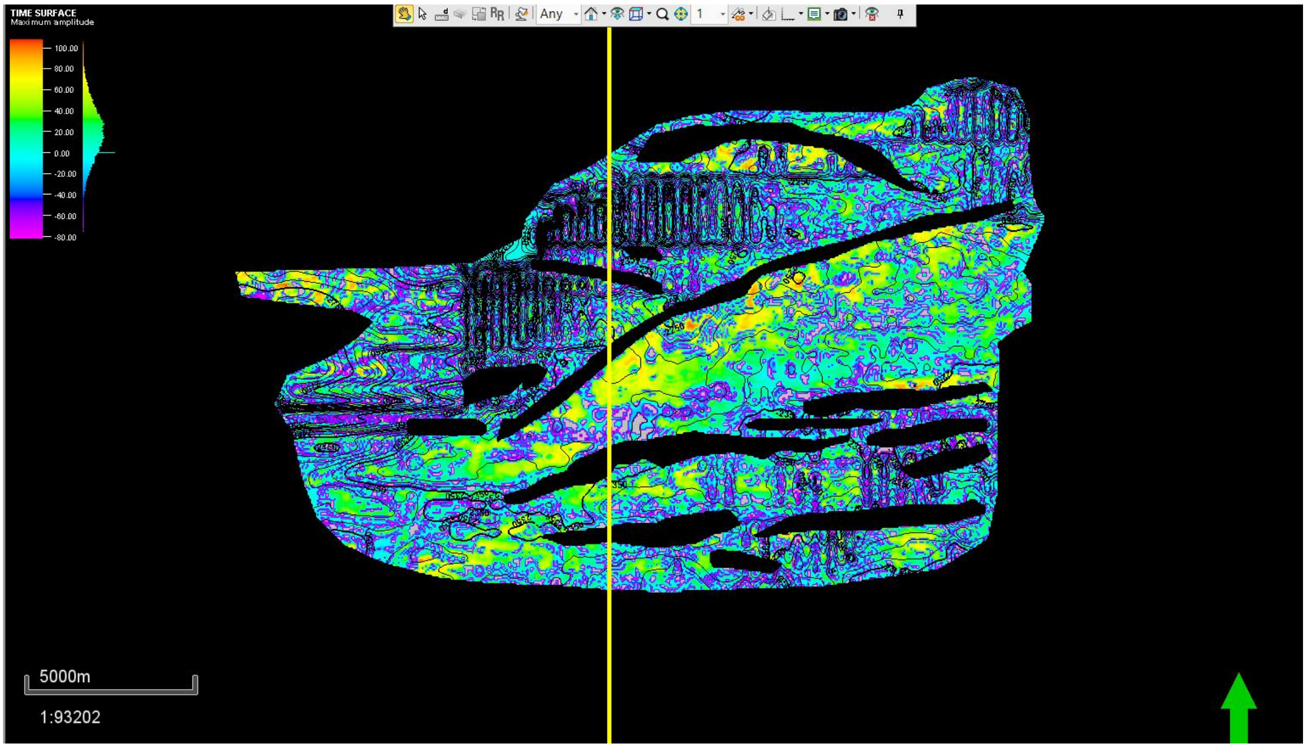

Figure 22 : Time Structure Map with Maximum Amplitude

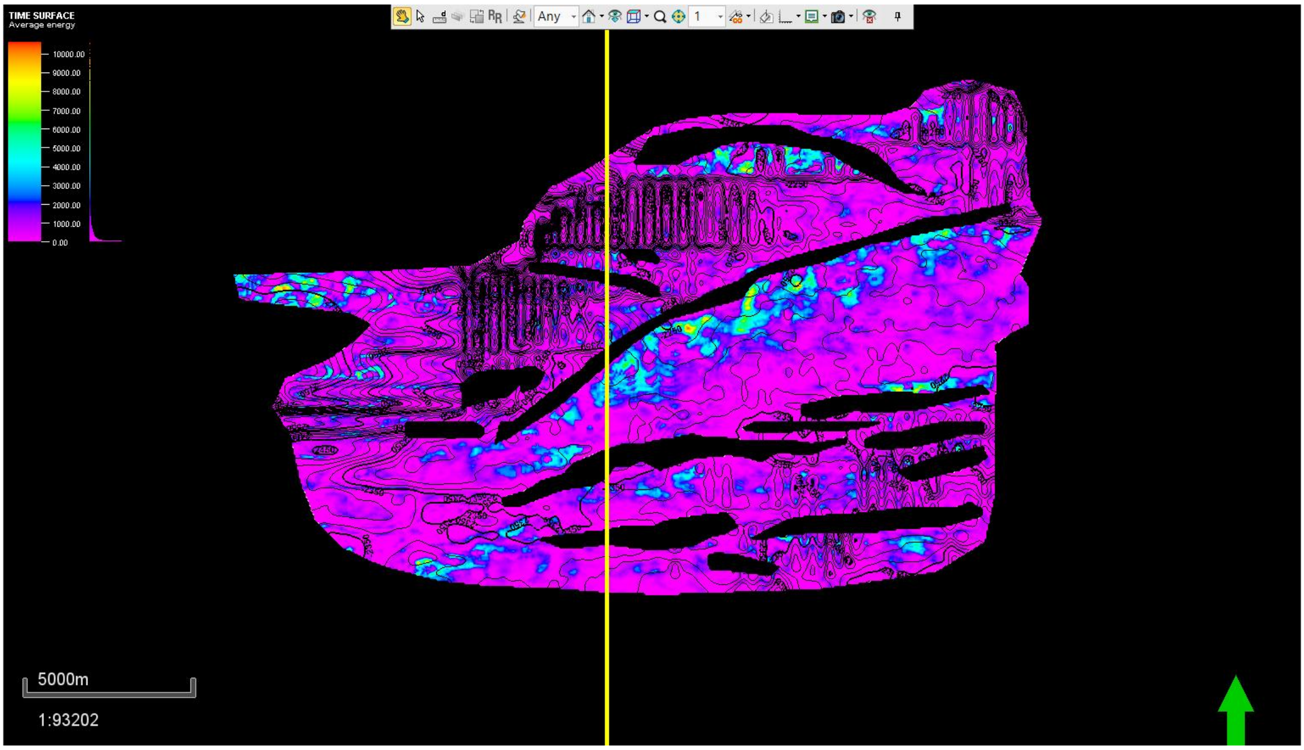

Figure 23 : Time Structure Map With Average Energy

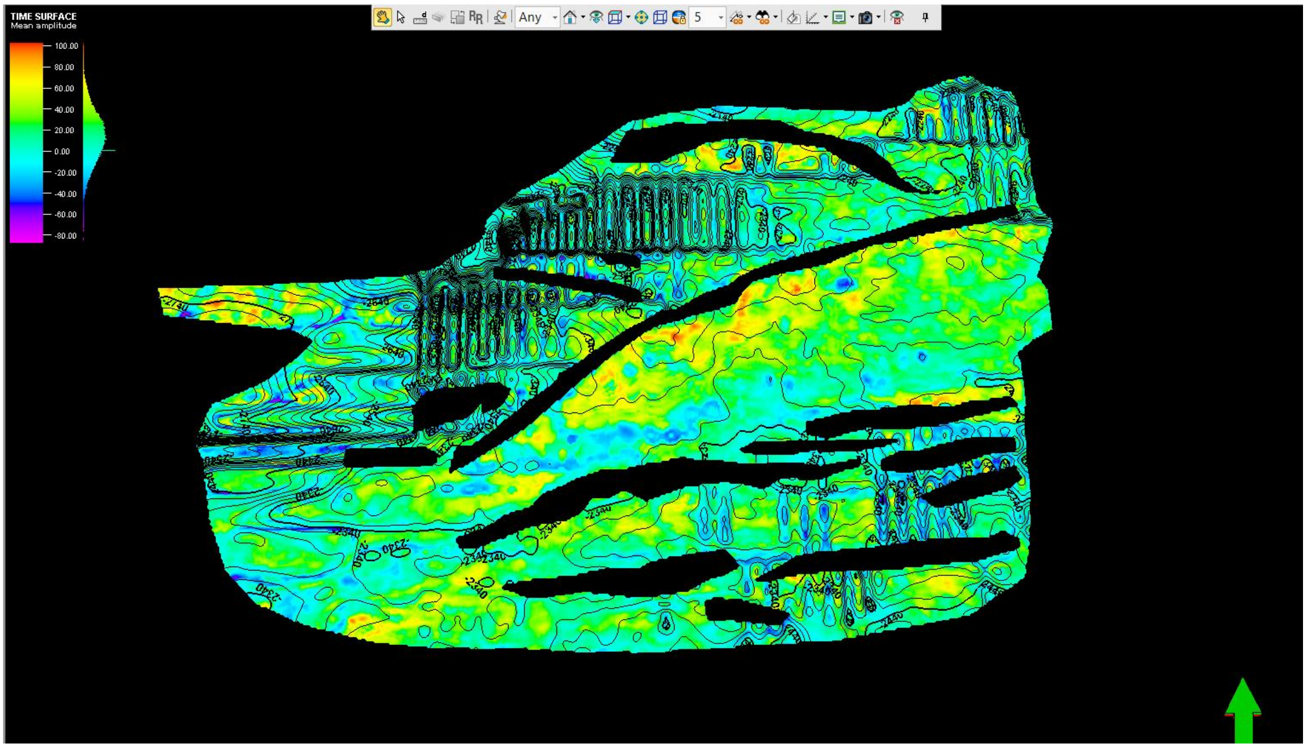

Figure 24 : Time Structure Map with Mean

4.7 Integrated Analysis and Prospect Delineation

The overall analysis of all interpreted datasets gave a comprehensive evaluation of the hydrocarbon potential of the INDARZ Field which produced three distinct prospects (see Figure 4.1.7). The time-surface map of the RMS amplitude analysis showed significant spatial relationship between amplitude anomalies and the structural features.

Structural and Attribute Integration:

1. The depth-structure map indicates a valid structural trap arrangement that is typified by a fault-bound anticlinal closure, which is in line with the established Niger Delta trap styles
2. The three separate high-amplitude bright-spot anomalies that are identified by seismic attribute analysis as seen below in Figure 4.1.7, most notably RMS and maximum amplitude, represent three separate potential hydrocarbon accumulations

Prospect Characterization and Grading:

Prospect A (Primary Target):

1. As shown in Figure 4.1.7 and in the other three surface attributes, Prospect A has the strongest amplitude response in the RMS attributes
2. It is positioned on the structurally highest location on the anticlinal crest
3. It is laterally confined on a regional scale by a major fault, therefore, making it an ideal lateral seal

The strong amplitude indicates high saturation of the gas in the column with a thick hydrocarbon column that generates a strong acoustic impedance difference. Its crest-top position is thus the most favourable accumulation point with the buoyancy forces concentrated and hydrocarbons are concentrated.

Prospect B (Secondary Target):

1. Prospect B is of moderate amplitude response compared with Prospect A and is located around the current well control (see Figure 4.1.7)
2. It illustrates verified presence of hydrocarbons by means of well-log calibration
3. It is in a good structural position within the fault-bounded closure

This lower amplitude strength could be due to a thinner pay thickness or a decreased saturation; however, the fact that it is considered a prospect not a lead is supported by the confirmed evidence of hydrocarbons through well data and the fact that it is in line with the verified structural trap..

Prospect C (Tertiary Target):

- Prospect C has a smaller but clear aberration of amplitude that is downdip of Prospect A (see Figure 4.1.7)
- It has an amplitude variation with the structural geometry
- It has structural closure in the fault-bounded compartment

The smaller amplitude response can be a sign of a thinner reservoir unit or other fluid properties, which can include increased oil saturation and decrease acoustic contrast. Its prospect position is supported by the indisputable structural closure and amplitude anomaly that are in line with the presence of hydrocarbons**.**

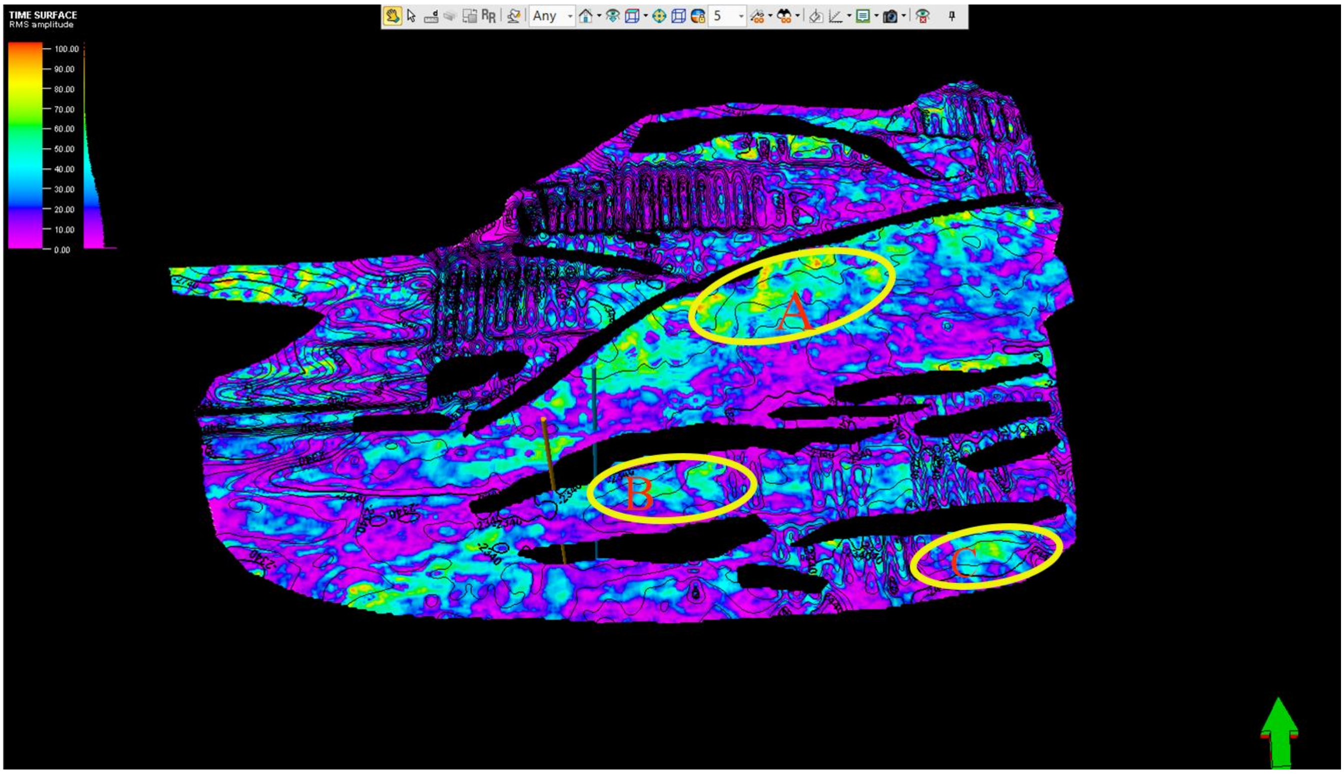

Figure 25 : RMS Time Surface Showing The 3 Prospects and Well Position

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study, anthropomorphic delineation of the reservoir of INDARZ Field was successfully accomplished by means of combination of three-dimensional seismic interpretation and attribute analysis. The workflow involved full fault mapping, horizon interpretation, seismic- well tie calibration, depth conversion and amplitude attribute analysis, thus bringing out a complex structural trap that contains several potential accumulations.

The main result of this study is that by combining structural mapping and the use of seismic attributes, three different perspectives are identified: A, B, and C. This is a classic case of hydrocarbon bypass, where the main accumulation (Prospect A) is found at the highest point of the structures of the anticlinal crest instead of encircling the existing wells. The available wells only intersected the peripheral part of the accumulation (Prospects B and C) thus justifying the reason why the full potential of the field had not been realized until now with the detailed analysis of seismic attributes.

All three features qualify as prospects rather than leads due to the convergence of valid structural traps with clear amplitude anomalies that conform to structure, supported by well-based proof of hydrocarbon presence in the reservoir interval. The graded prospect ranking (A, B, C) reflects decreasing confidence based on amplitude strength and structural position, providing a clear exploration priority for future drilling campaigns.

5.2 Recommendation

Based on the findings of this study, the following recommendations are proposed:

1. **Drilling Priority:** Prospect A should be prioritized for immediate drilling as it represents the most significant accumulation with the strongest amplitude anomaly and optimal structural position.
2. **Appraisal Strategy:** Following successful drilling of Prospect A, Prospects B and C should be appraised as secondary targets to fully evaluate the field's potential.

3. **Further Studies:** Additional seismic attribute analysis including AVO (Amplitude Versus Offset) studies and spectral decomposition is recommended to further de-risk the prospects and better characterize the reservoir distribution.
4. **Data Acquisition:** Future drilling programs should include comprehensive data acquisition (including modern logging suites and fluid samples) to validate the seismic interpretations and optimize field development planning.

The integrated approach demonstrated in this study provides a robust template for exploration in similar structurally complex settings within the Niger Delta basin.

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