SEISMIC ATTRIBUTES FOR HYDROCARBON PROSPECT EVALUATION – A CASE STUDY OF “STOKED” FIELD NIGER DELTA

A thesis submitted to the Centre of Excellence in Geosciences and Petroleum Engineering, University of Benin for the degree of Master of Science (MSc.) in Integrated Petroleum Exploration and Evaluation Studies (Geophysics option)

By

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CERTIFICATION

This is to certify that this work was carried out by EMEREMGINI, Sharon Chioma (UB/PG/CoE/2021/004) in Halliburton Energy Services, Lagos as a research intern and submitted to the Center of Excellence in Geosciences and Petroleum Engineering, University of Benin, Benin City.

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Prof. Dickson Omorogbe (Deputy Director) **Date**

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Prof. Difference Ogagarue (Director) **Date**

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External examiner **Date**

DEDICATION

I dedicate this project to the Almighty God for His immeasurable guidance, protection and favours in my life. Also to my dad and siblings for their love, care, prayers and moral support throughout my master’s programme.

ACKNOWLEDGEMENT

Many have participated and contributed to the success of this project, and I would like to acknowledge their various efforts.

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The greatest thanks, however, goes to God, the giver of life, knowledge, and every good gifts.

ABSTRACT

The necessity of prospect evaluation is undisputed both to translate geology into figures and to expand the uncertainty implicit in hydrocarbon exploration. In this study, the hydrocarbon potential of STOKED field in offshore coastal swamp Niger delta was evaluated to obtain more information about the structures, stratigraphy and hydrocarbon potential of the field from available seismic and a suite of well logs data. The method adopted involves delineation of lithologies from Gamma ray log, Identification of hydrocarbon bearing reservoirs unit from resistivity log, well to well correlation across the field, fault interpretation and horizon mapping, time to depth conversion, Attribute extraction determination of petrophysical parameters and volumetric estimation. One Major and twelve minor faults were interpreted mapped from the well correlation carried out across the four wells in the NE-SW Direction. Two reservoirs were interpreted, and the seed grids generated three top time structure maps. The attribute maps were used to establish the diagnostic ability of 3D seismic attribute analysis in enhancing seismic interpretation and volumetric estimation. Map based volumetrics was calculated and the stock tank oil initially in place estimated is 85 mmstb for reservoir A while reservoir B was inconclusive as the area extended outside the extent of the seismic. The result from the petrophysical analysis and property modelling has shown that the reservoirs have porosity values that range from 17 - 24%, and water saturation ranges from 11 - 56%. Results from this study have shown that, away from currently producing zone at the central part of the field, additional leads and prospects exist, which could be further evaluated for hydrocarbon production.

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CHAPTER ONE

1.0 INTRODUCTION

As hydrocarbon reserves continue to deplete with major assets near abandonment, cost efficiency has taken over as a driving force in the economics of oil and gas industry. This has highlighted the need to properly evaluate hydrocarbon prospects and bypassed opportunities in matured fields for continuous and optimal production. Hydrocarbon reservoirs of the Niger Delta Basin are among the most challenging targets for both structural and stratigraphic interpretation in petroleum exploration because of the tectono-sedimentological elements involved in their deposition (Smith-Rouch et al., 1996, Tuttle et al., 1999, Dim, 2017, Ogbe et al., 2020).

The Coastal swamp depobelt of Niger Delta, which can be described as a geologically complex area with several transient features is characterized by unknown locations and time extents which generally constitute stratigraphic anomalies in a 3D seismic volume. (Odoh et al., 2014). In addition to seismically mappable fault structures which can ordinarily be mapped using the conventional seismic method, many faults below the limit of seismic resolution also contribute to subsurface deformation (Rubio et al., 2017). These fault structures which have been classified into seismically resolvable and sub-seismic scale (subtle) faults can be interpreted more effectively with the aid of seismic attributes. (Anyiam, 2015, Chukwu, 2016; Oyekan and Issa, 2017). These structural and stratigraphic traps could be very subtle and are, therefore, difficult to map accurately (Adigun and Ayolabi, 2013).

The advancement in 3D seismic refection methodology and borehole geophysics has made it possible to map such structural and stratigraphic configuration with high degree of reliability and precision thus, reducing the risk factor associated with hydrocarbon exploration (Aizebeokhai and Olayinka, 2011; Oyedele et al., 2013). Seismic attributes analysis being an integral part of 3D seismic refection interpretation is one of these advancements. (Chopra and Marfurt, 2006).

In most exploration and reservoir seismic surveys, the main objectives are, first, to correctly image the structure in time and depth and, second, to correctly characterize the amplitudes of the reflections. If all amplitudes are accurately rendered, additional features known as seismic attributes can be derived and used in interpretation (Taner etal., 1979). The simplest attribute, and the one most widely used, is seismic amplitude, and it is usually reported as the maximum (positive or negative) amplitude value at each sample along a horizon picked from a 3D volume. Seismic attribute analysis involves extracting a quantity from seismic data that can be analysed to enhance information that might be more subtle in a traditional seismic image, leading to a better geological or geophysical interpretation of the data, and are used in most seismic exploration and reservoir study to correctly image the subsurface geological structures, correctly characterize the amplitudes of the seismic data and to obtain information on reservoir properties (Abe et al., 2016).

1.1 OVERVIEW OF STUDY AREA

The study field is an onshore brown oil field within the formation in the Coastal swamp Depobelt of Niger Delta region in southern Nigeria (Figure 1.0). Niger Delta is situated within the Gulf of Guinea between longitudes 5° and 8°E and latitude 3° and 6°N. Four wells with a total depth ranging from 2519 ft and 10020 ft have currently been drilled (Figure 1.1).

1.2 STATEMENT OF RESEARCH PROBLEM

Despite the several achievements made in the areas of structural interpretation, reservoir characterization and volumetric estimation from conventional seismic interpretation, a lot of interpretational challenges still exist especially in complex geological settings. These challenges include poor resolution around sub-seismic faults and within stratigraphic features like channels, among others. In a geologically complex hydrocarbon habitat like the Coastal swamp depobelt of Niger Delta, identification of subtle traps and sweet spots can be effectively analysed with the help of seismic attributes in other to quantify how viable a field is and therefore essential for effective prospect evaluation and characterization of complex reservoirs.

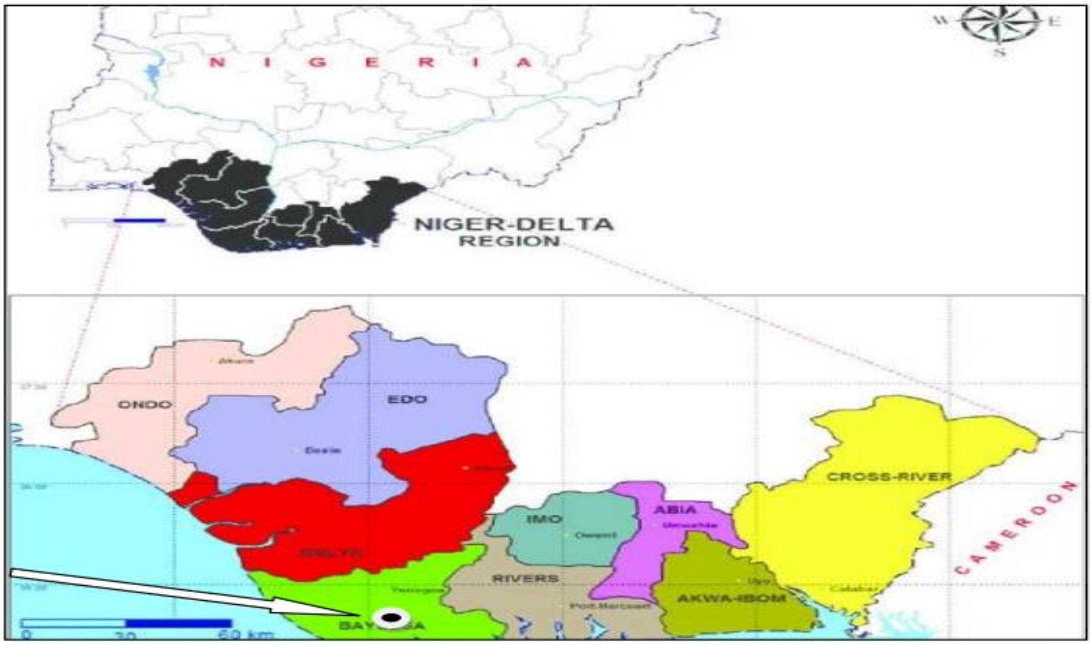


Figure 1.0: Niger Delta basin showing location of study area (After Nzeadibe et al., 2012)

Figure 1.1: Base map of study area showing well positions

1.3 AIM AND OBJECTIVES

The aim of this study, is to apply seismic attributes in re-evaluating the STOKED Field, which could be used as a tool for reservoir management, with the intent to achieve the following objectives:

1.31 TECHNICAL OBJECTIVES

1. To establish the stratigraphic equivalence of reservoirs in the STOKED Field and neighbouring fields through regional correlation.

2. Interpret major and minor faults within the field

3. Generate accurate top structure maps for all reservoirs of interest

4. Identify new prospects that could be matured

5. Evaluate the new reservoir hydrocarbon volumes

1.4 SCOPE OF STUDY

For this study, the scope of work includes:

1. Gathering and QC of all available data.

2. Seismic attribute generation

3. Seismic Interpretation and well to seismic tie (synthetic generation)

4. Well log correlation and geological structures delineation in the reservoirs of interest.

5. Velocity modelling and Time-Depth conversion

6. Volumetric analysis

1.5 SIGNIFICANCE OF STUDY

This study proves helpful in characterizing structural and stratigraphic features important for hydrocarbon exploration using 3D seismic data set by utilizing various seismic attribute to predict regions of high reservoir productivity, which could help in field development planning as well as reducing exploration risk.

1.6 LIMITATION OF STUDY

The limitations experienced on this project includes time constrains, data paucity arising from unavailability of complete log suites, poor seismic resolution, check-shot data available for only well C, and absence of core data for calibration of the petrophysical results in the fields under study. To meet with the project objective with this inherent limitation, analogue data was used where available and other mitigation measures were adopted.

1.7 TOOLS REQUIRED FOR THE STUDY

The tools needed for this project were interpretation software such as:

1. Halliburton's Decision Space Geoscience 10EP for seismic interpretation
2. Open works for project data management

1.8 PROJECT WORKFLOW AND WORK PLAN

The integrated approach adopted in this study is summarized in the multi-disciplinary workflow below.

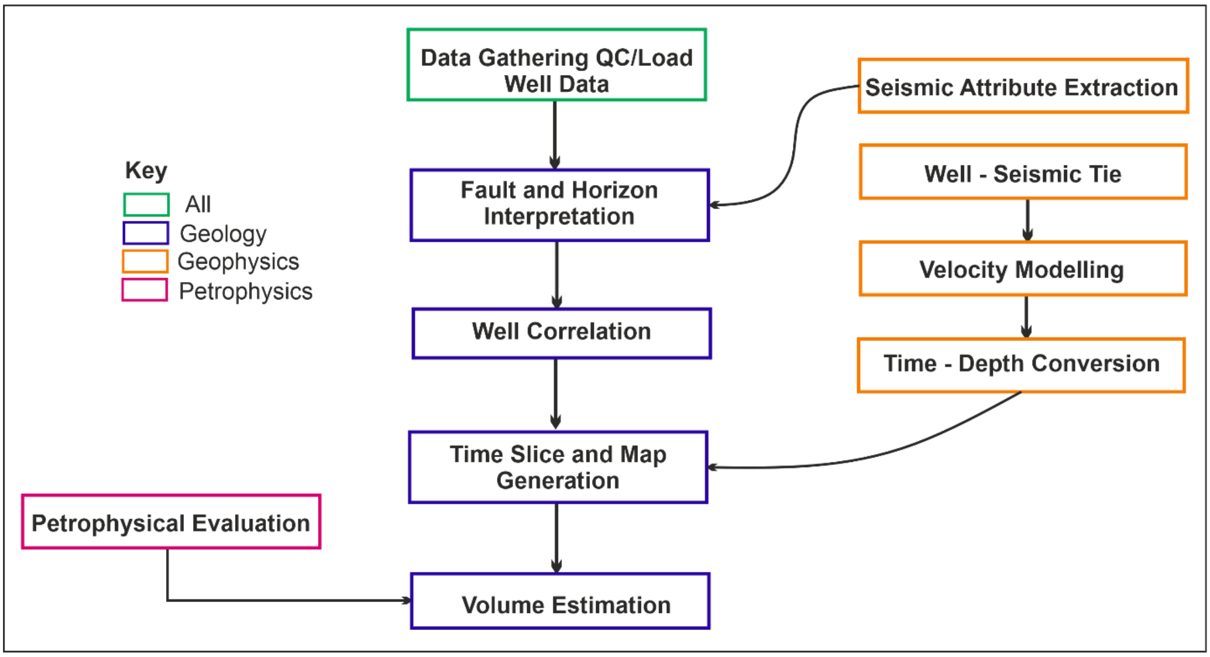


Figure 1.2: Project workflow

CHAPTER TWO
LITERATURE REVIEW

2.0 INTRODUCTION

Several geological investigations have been carried out for hydrocarbon prospecting in the Niger Delta Basin, starting from over fifty years ago (Aizebeokhai and Olayinka, 2011). A lot of authors have worked on the structural geology, the depositional history and sequence stratigraphy of the Niger Delta. Some of the works that are related to this research are briefly highlighted in this chapter.

2.1 GEOLOGY OF NIGER DELTA

The Niger Delta is a Paleocene to Recent and wave dominated delta situated on the Gulf of Guinea on the west coast of Central Africa (Doust and Omatsola 1990; Rouby et al., 2011). It was formed on a triple junction that developed during the breakup of the South American and African plate in the Jurassic (Burke et al., 1972; Whiteman, 1982; Rouby and Cobbold, 1996; Owoyemi and Willis, 2006). It covers an area of 75,000 km^2 and has regressive clastic sediments with a maximum thickness of 12 km (Doust and Omatsola, 1990).

Weber and Doukoru (1975) described the evolution of the tertiary Niger delta basin as resulting from sequential paralic deposition into series of depobelts which succeeded each other in time and space leading to regular step-like southward progression of the Niger, referred to as escalator regression.

Evamy (1997) described the syn-sedimentary tectonics of the tertiary Niger Delta. The sedimentary fill of the delta was derived from the drainage system of River Niger, River Benue and Cross River. However, the present-day delta is a complex fluvio-marine system (Bowen et al., 1994). Short and Stauble (1967) established a tertiary sequence comprising of the Akata shale, Agbada formation and Benin formation.

2.2 REGIONAL TECTONIC SETTINGS

Niger Delta Basin is in the southernmost extremity of elongated intracontinental Benue Trough. To the west, it is separated from the Dahomey Basin by the Okitipupa Basement High, it is bounded at the east by Cameroun Volcanic High. Its northern margin transects the older (Cretaceous) tectonic elements such as the Anambra Basin, Abakaliki Uplift, Afikpo Syncline, Calabar Flank (Figure 2.1).

The evolution of the Niger Delta Basin is controlled by pre- and syn- sedimentary tectonic activities described by Evamy et al. (1978), Ejedawe et al. (1984), Knox and Omatsola (1989) and Stacher (1995). The pre-sedimentary tectonic activities generated Cretaceous Fracture. The tectonic framework of the continental margin is controlled by Cretaceous Fracture zones, expressed as trenches and ridges. The fracture zone ridges subdivide the margin into individual basins, and in Nigeria, form the boundary faults of the Cretaceous Benue-Abakaliki Trough, which cuts far into the West African shield. The Trough represents a failed arm of a rift triple junction associated with the opening of the South Atlantic. Rifting started in the Late Jurassic and persisted into the Middle Cretaceous (Lehner and De Ruiter, 1977). In the Niger Delta region, rifting diminished altogether in the Late Cretaceous. Syn-sedimentary tectonic activities shaped the internal geometry of the Basin and include gravity tectonics which became active after the rifting episode.

After rifting ceased, gravity tectonics became the primary deformational process. Shale mobility induced internal deformation and occurred in response to two processes (Kulke, 1995). First, shale diapirs formed from loading of poorly compacted, over-pressured, pro-delta and delta-slope clays (Akata Formation) by the higher density delta-front sands (Agbada Fm.). Second, slope instability occurred due to a lack of lateral, basinward, support for the under-compacted delta-slope clays (Akata Formation). Gravity tectonics were completed before deposition of the Benin Formation and are expressed in complex structures, including shale diapirs, roll-over anticlines, back-to-back features, and steeply dipping, closely spaced flank faults (Evamy et al., 1978).

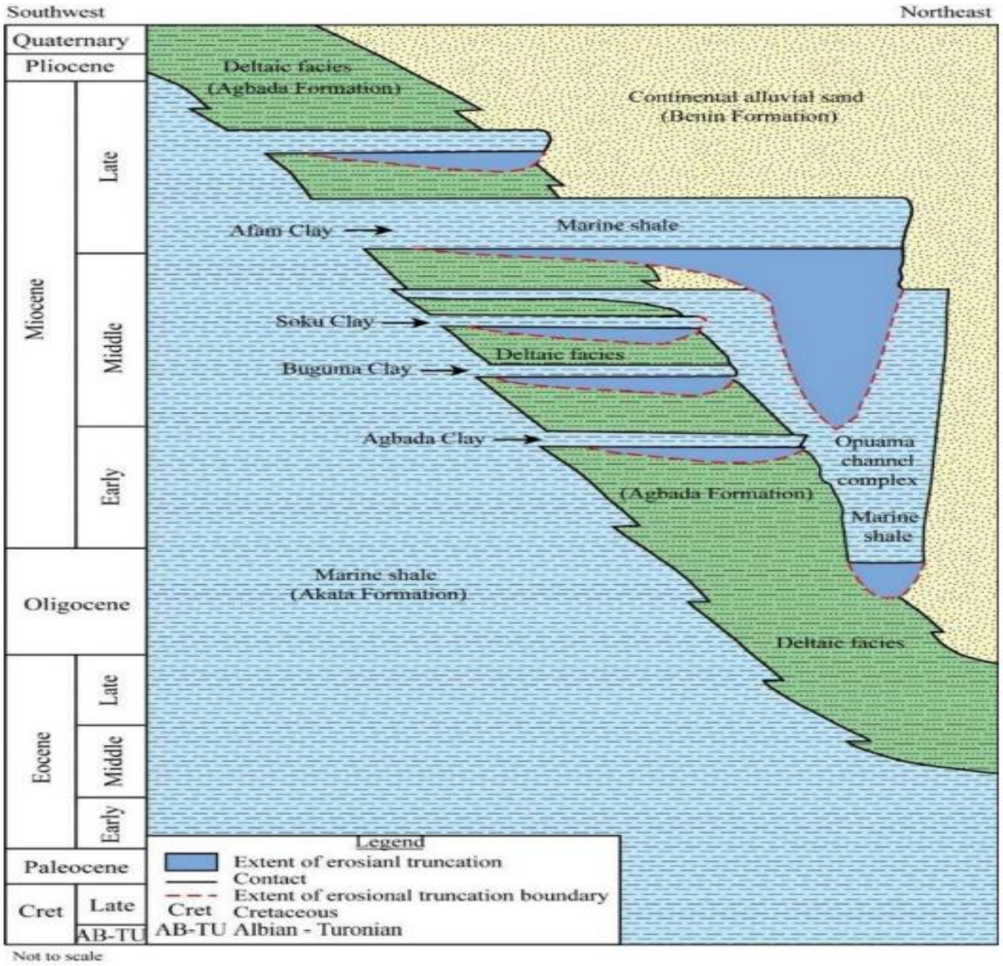


Figure 2.0: Stratigraphic column showing the three formations of the Niger Delta (modified from Lawrence et al., 2002).

2.3 STRATIGRAPHY OF THE NIGER DELTA BASIN

The Niger Delta Basin covers an area of about 300,000 km^2 and is composed of an overall regressive clastic sequence that reaches a maximum thickness of 9,000 to 12,000 m (29,500 to 539,400 ft). The Niger Delta is divided into three formations, representing prograding depositional facies that are distinguished mostly based on sand-shale ratios (Figure 2.0).

1. **Akata Formation:** The Akata Formation at the base of the delta is of marine origin and is composed of thick shale sequence (potential source rock), turbidite sand (potential reservoirs in deep water), and minor amounts of clay and silt. Beginning in the Paleocene and through the Recent, the Akata Formation formed during low stands when terrestrial organic matter and clays were transported to deep water areas characterized by low energy conditions and oxygen deficiency (Stacher, 1995).

The formation underlies the entire delta and is typically over pressured. The approximate range of the thickness is about 6,000m (Paul, 2003).

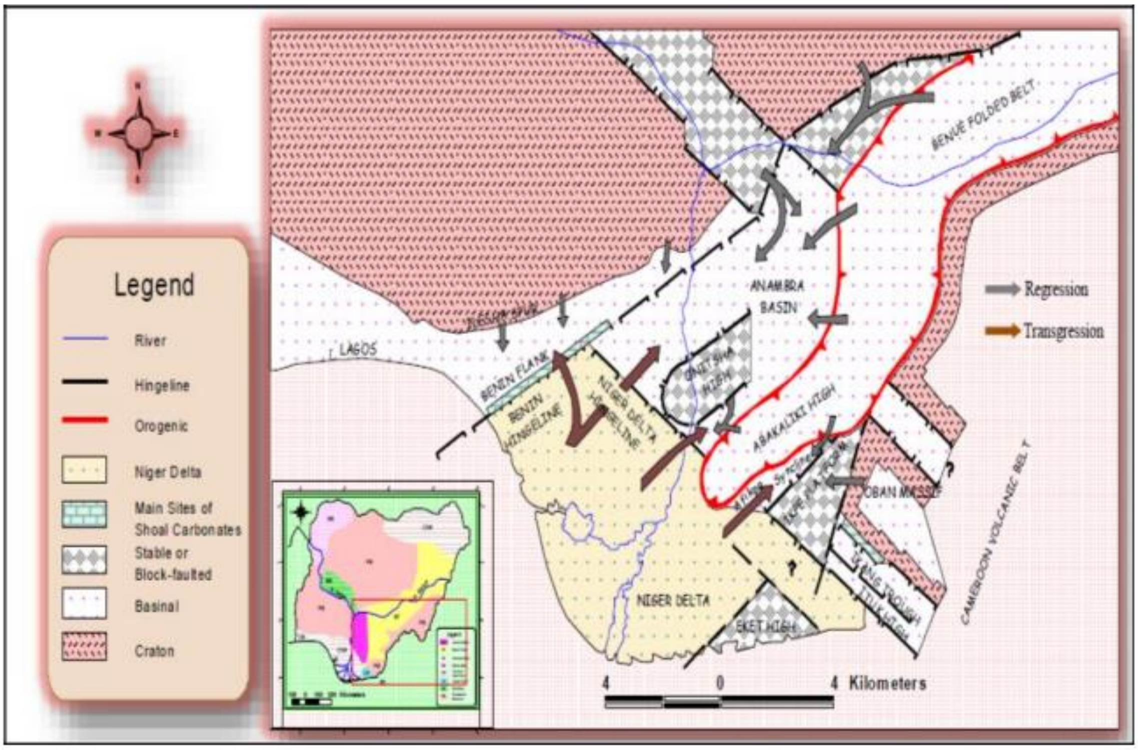


Figure 2.1: Tectonic Map showing the Niger Delta (modified after Kogbe, 1989)

2. **Agbada Formation:** The overlying Agbada Formation, the major petroleum-bearing unit, began in the Eocene and continues into the Recent. The formation consists mostly of shoreface sands and channel sands with minor shales in the upper part, and alternation of sands and shales in equal proportion in the lower part. The thickness of the formation is over 3,700 meters thick.

3. **Benin Formation:** The Agbada Formation is overlain by the third formation, the Benin Formation, a continental latest Eocene to recent deposit of alluvial and upper coastal plain sands that are up to 2,000m thick, (Avbovbo, 1978). It is the uppermost part of the sedimentary sequence in the basin, and it is composed almost entirely of continental sands of alluvial coastal plain origin with local thin shale inter-beds considered to be of braided stream origin. It also contains pebbly member which are believed to be deposited by braided stream as channels on natural levees. The

thickness of this formation is up to 2000 m (Avbovbo, 1978). It is Miocene to Recent in age.

2.4 DEPOBELTS

From the Eocene to the present, the delta has prograded south-westwards, forming depobelts that represent the most active portions of the delta at each stage of its development, (Doust and Omatsola, 1990). Deposition of the three formations (Akata, Agbada, and Benin Fm.) occurred in each of the five off-lapping siliciclastic sedimentation cycles that comprise the Niger Delta. Each cycles (depobelts) ranges from 30 - 60 km in width, and prograde south-westward 250 km over oceanic crust into the Gulf of Guinea (Stacher, 1995).

According to Doust and Omatsola (1990), they are defined by syn-sedimentary faulting that occurred in response to variable rates of subsidence and sediment supply. The interplay of subsidence and supply rates resulted in deposition of discrete depobelts when further crustal subsidence of the Basin could no longer be accommodated, the focus of sediment deposition shifted seaward, forming a new depobelt (Evamy et al., 1978). Doust and Omatsola (1990) described each depobelt as a separate unit that corresponds to a break in regional dip of the delta and is bounded landward by growth faults and seaward by large counter-regional faults or the growth fault of the next seaward belt. Five major depobelts are generally recognized, each with its own sedimentation, deformation, and petroleum history. This depobelts include the Northern delta, Great Ughelli, Central swamp I and II, Coastal swamp and offshore depobelts (Figure 2.2).

Doust and Omatsola (1990) described three depobelt provinces based on structure. The northern delta province, which overlies relatively shallow basement, has the oldest growth faults that are generally rotational, evenly spaced, and increase their steepness seaward. The central delta province has depobelts with well-defined structures such as successively deeper rollover crests that shift seaward for any given growth fault. The distal delta province is the most structurally complex due to internal gravity tectonics on the modern continental slope.

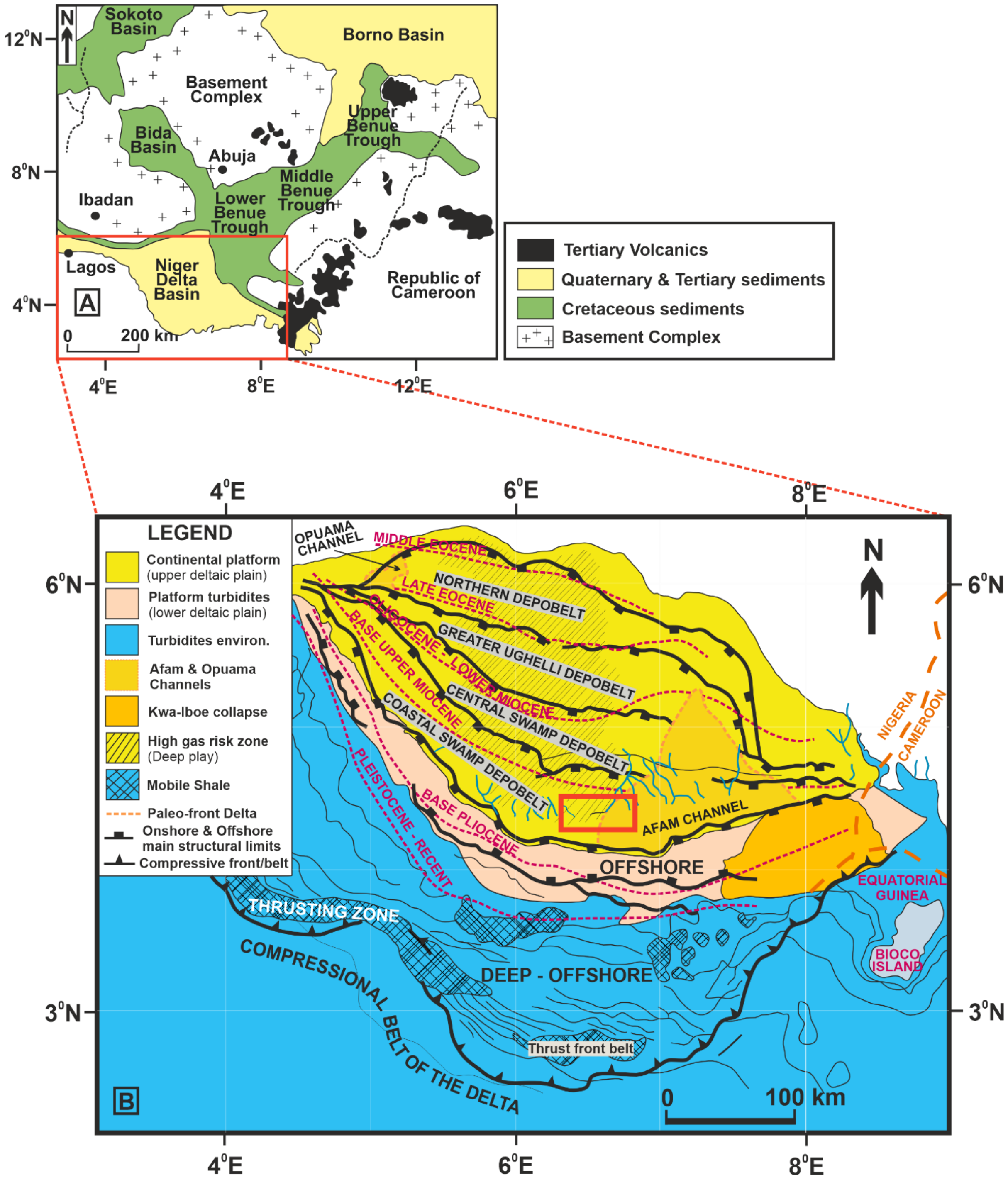


Figure 2.2: (a) Geological map of Nigeria showing the location of the Niger Delta Basin. (b) Map showing the distribution of depobelts and structural elements in the Niger Delta Basin The approximate location of the study area is shown by the red box (redrawn and modified from Ebong et al., 2020).

2.5 STRUCTURAL SETTING OF THE NIGER DELTA

Originally the Niger Delta was divided into three structural zones: an extensional zone I beneath the outer continental shelf and upper slope; an intermediate translational zone II beneath the continental slope; and a compressional zone III beneath the lower continental slope and uppermost rise according to (Damuth, 1994). Subsequently, Connors et al. (1998) subdivided the Niger Delta into five major structural provinces or zones making his inference from structural styles imaged in seismic data and high-resolution bathymetry. These structural zones include

1) An extensional province beneath the continental shelf, characterized by basinward-dipping (Roho-type) and counter regional growth normal faults and associated rollover anticlines and depocenters.

2) A mud diapir zone located beneath the upper continental slope, which is characterized by passive, active, and reactive mud diapirs (Morley and Guerin, 1996), including shale ridges and massifs, shale overhangs, vertical mud diapirs that form mud volcanoes at the seafloor (Graue, 2000), and inter diapir depocenters.

3) The inner fold and thrust belt, which is characterized by basin ward verging thrust faults (typically imbricated) and associated folds, including some detachment folds.

4) A transitional detachment fold zone beneath the lower continental slope that is characterized by large areas of little or no deformation interspersed with broad detachment anticlines that accommodate relatively small amounts of shortening (Bilotti et al., 2005)

5) The outer fold and thrust belt characterized by both basin ward- and hinterland verging thrust faults and associated folds.

The contractional portion of the delta in the deep-water consists of the major zones (3, 4 & 5) aforementioned (Connors et al., 1998; Corredor et al., 2005): the inner fold and thrust belt, the outer fold and thrust belt, and the detachment fold province, with the deformation within these zones being driven by up dip, gravitational collapse of shelf sediments.

2.6 TRAPPING STYLES IN THE NIGER DELTA BASIN

The trapping styles in the Niger Delta are mostly structural although stratigraphic traps are not uncommon. Weber and Daukoru (1975) described three main structural trapping elements. These trapping styles which may form components of more complex structures like collapsed crests can be distinguished as anticlinal dip closures, upthrown fault of footwall closures, down thrown faults or hanging wall closures and dip fault closures. In anticlinal dip closures, trapping is largely by means of simple closure independent of faults. The three types of this trapping are

a). Simple anticlinal or pure dip closure,

b). Dip-assisted fault closure where apparent fault dependent element of closure is less than 50 ft,

c). Dissected anticlinal dip closure: a pure dip closure dissected by non-sealing synthetic and antithetic faults. About 50 % of hydrocarbon bearing reserves in Nigeria appears to be dip closed.

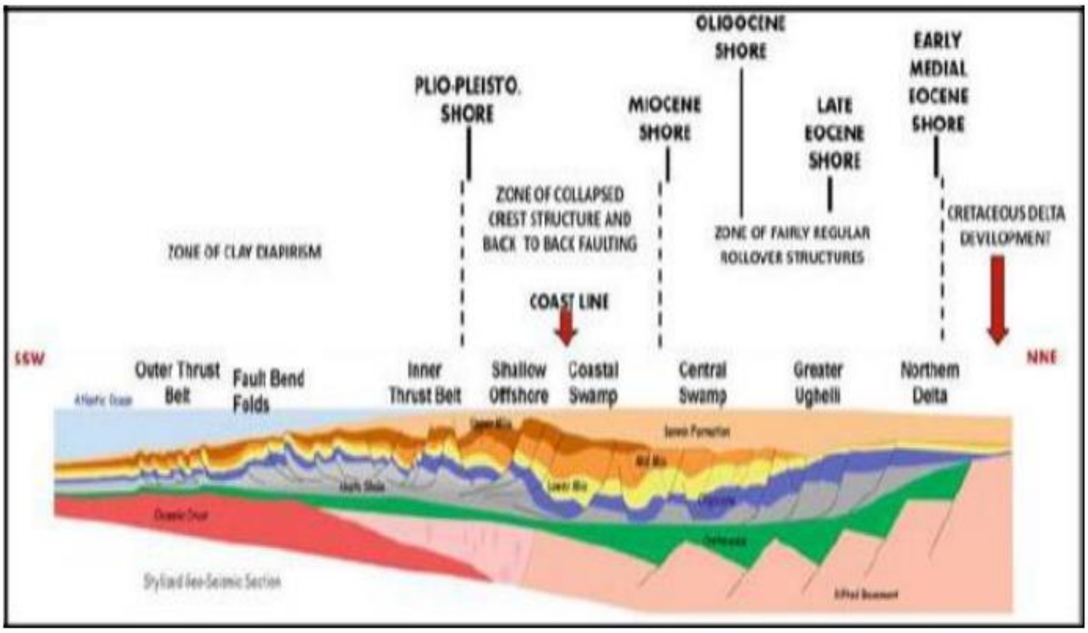
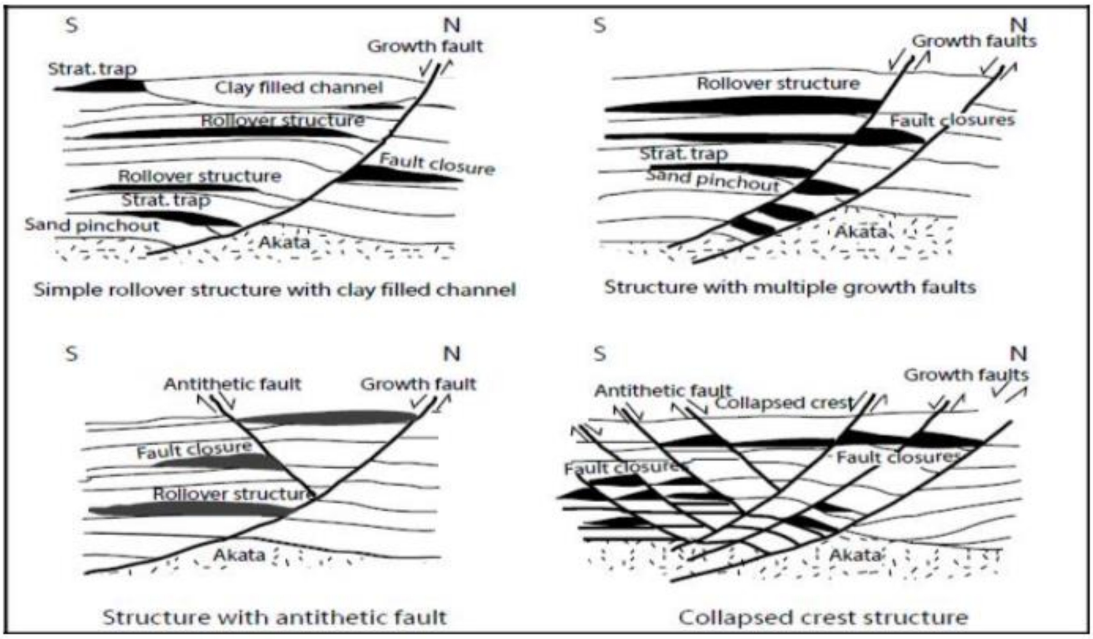


Figure 2.3: Schematic Dip section of the Niger Delta (After Shell 2007; Weber and Daukoru 1975)



Simple rollover structure with clay filled channel

Structure with multiple growth faults

Structure with antithetic fault

Collapsed crest structure

Figure 2.4: Structural styles and associated hydrocarbon traps in the Niger Delta (After Doust and Omatsola, 1990).

CHAPTER THREE

METHODOLOGY

3.0 INTRODUCTION

This section of the report provides detailed insight as to how the data used for this study were acquired or generated and how they were analysed. It also gives in-depth account of the various processes and steps carried out to obtain the results, establish deductions and achieve project objectives.

3.1 PROJECT WORKFLOW

This aspect of the project was executed with the workflow as shown in Figure 3.0 below. It captures the steps carried out and each of the steps are explained in detail.

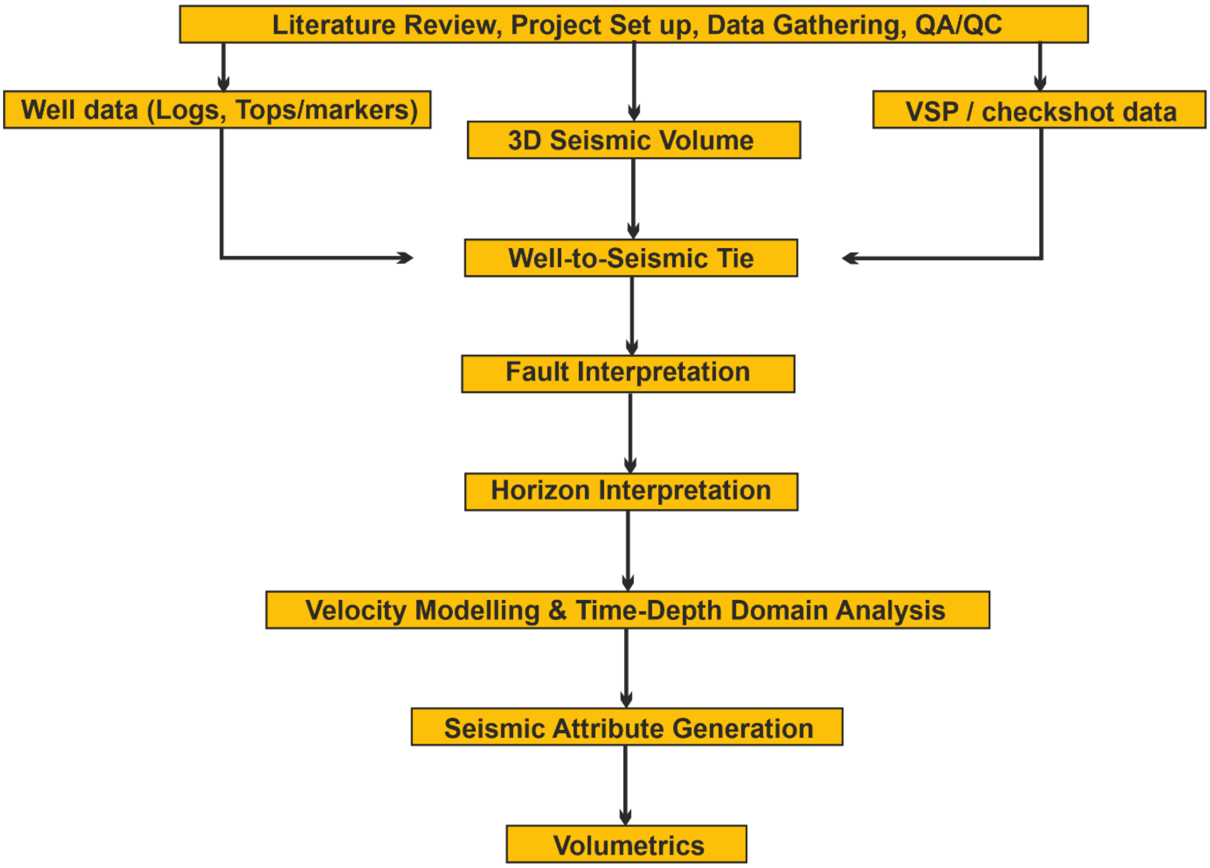


Figure 3.0: Project workflow

3.2 DATA INVENTORY

The data set available and utilized for this study include:

1. 3D Seismic Data

2. Well data: This includes the well header, deviation, well logs and Time-Depth data (for WELL C)

Table 1: Data inventory table

WELL	CHECK-SHOT	CAL	GR	RES	NEU	DENS	SON	POR	SW
Well A	NO	NO	YES	YES	NO	YES	YES	YES	YES
Well B	NO	NO	YES	YES	NO	YES	YES	YES	YES
Well C	YES	NO	YES	YES	NO	YES	YES	YES	YES
Well D	NO	NO	YES	YES	NO	YES	YES	YES	YES

3.3 PROJECT SET UP

A new project was created on Decision Space Geoscience software and the appropriate Coordinate Reference System (CRS) and unit system specified to suit the field data. This was done before data loading to avoid errors with the location and units of the project.

3.4 DATA GATHERING, IMPORT AND QC

The gathered data sets were quality checked for errors before being imported into the software. Seismic data was imported in SEG-Y format and well data imported in LAS format. The imported data sets were checked for errors before interpretation started. Industry best practice requires that the data be quality checked before and after loading to ensure that the data is fit for purpose and avoid errors from being carried into the interpretation.

3.5 WELL LOG CORRELATION

The purpose of performing well log correlation is to identify the stratigraphic tops and bases of the reservoirs in each well. Lithostratigraphic approach was adopted using shale markers as the basis for correlating. This helps to give an understanding of how the reservoir is developed across the area of interest.

Gamma ray log was used to identify lithology. From the log, the ash colour indicates sand while black colour indicates shale (Figure 3.1). This region is highly dominated by sand bodies which indicate the reservoir potential of the formation. It was observed that there was continuity of events of deposition of the sand sediments across the wells.

3.6 FAULT INTERPRETATION

An integral part of reservoir characterization is the definition of the reservoir fault system and structural control. This is done to determine the fault framework and identify the types of faults present (sealing or non-sealing) in the reservoir. It aids in understanding the reservoir's trapping mechanism and how it affects the accumulation and flow of hydrocarbons. A fault is a planar surface or fracture on a rock where there has been an appreciable displacement of the rock units caused by tectonic activities, sedimentation, or a combination of both.

On seismic, faults are identified as discontinuities or reflection cut-offs while picking and mapping the faults from line to line. A good geological knowledge of the structural setting of the study area is necessary to correctly interpret the faults based on the expected orientation. Faults have great impact on fluid flow and affects reservoir dynamics which strongly affects field performance. For this study, fault mapping was done on the crossline of the 3D seismic display across the seismic volume as shown in Figure 3.2.

The structural interpretation revealed mainly synthetic and a few antithetic faults and are very visible on the seismic data. The faults were interpreted at every tenth crossline for consistency. The interpreted faults were quality checked using discontinuity attribute generated from the seismic cube which aided a thorough interpretation of the faults.

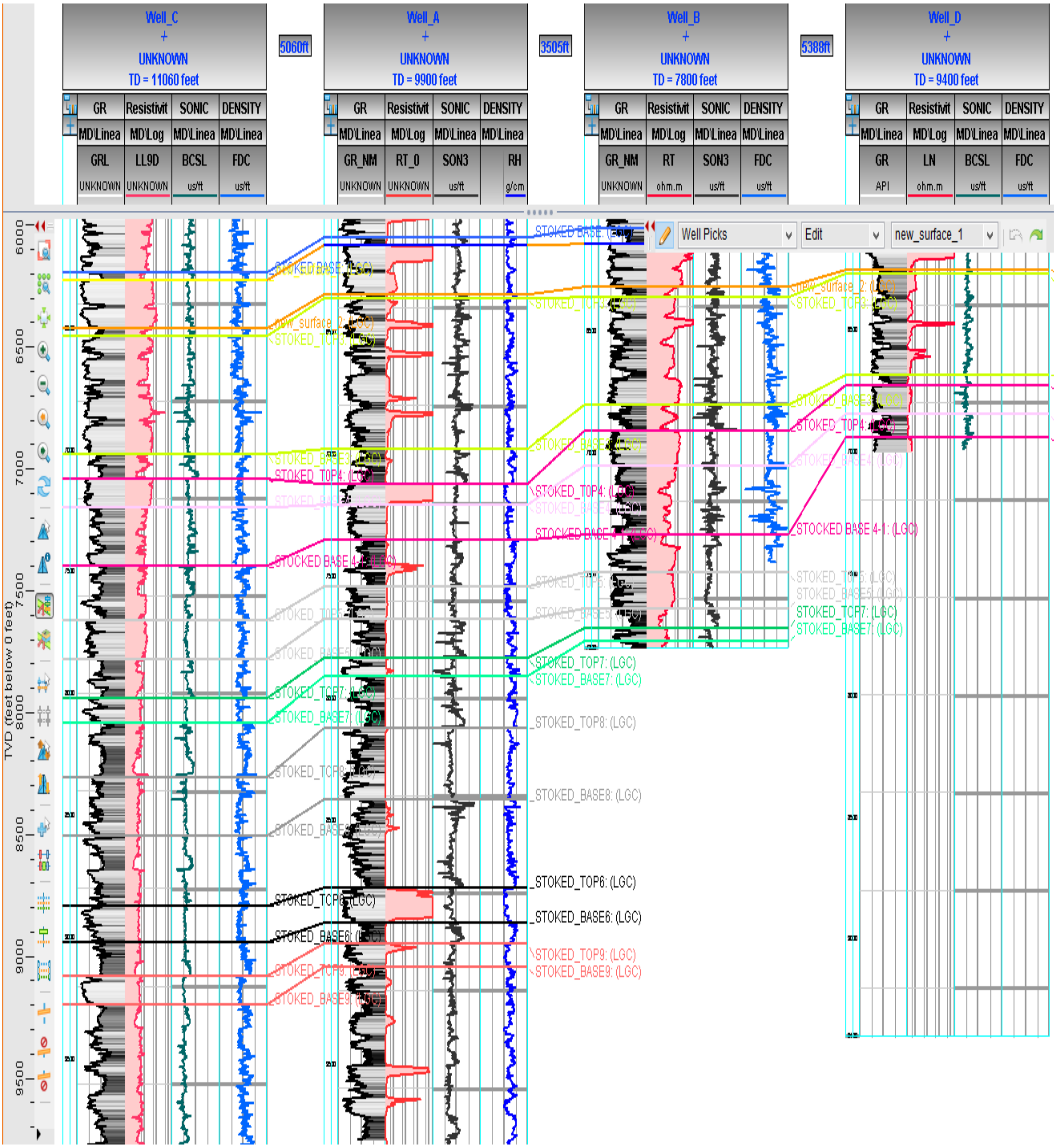


Figure 3.1: Correlation of the reservoirs in STOKED Field (Well A to D)

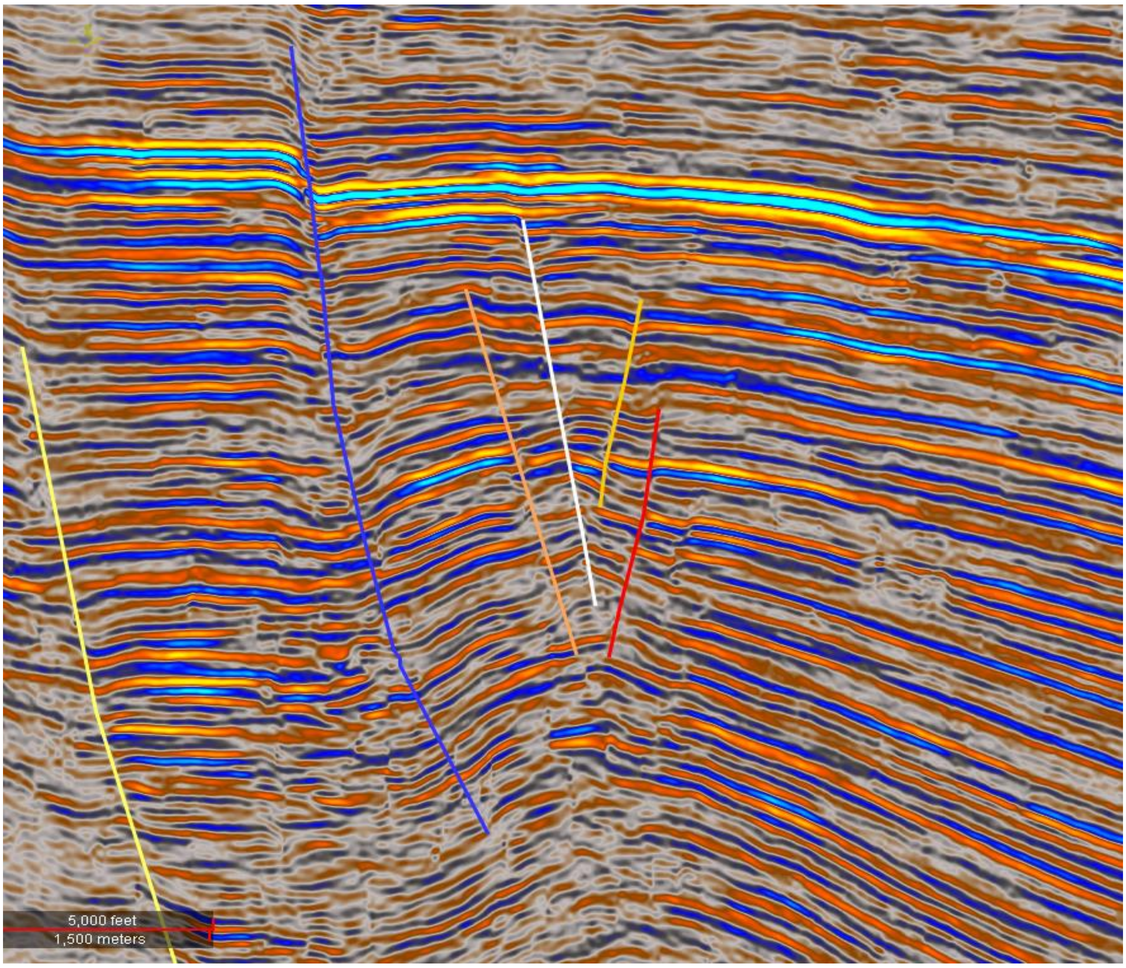


Figure 3.2: Crossline 5237 showing interpreted fault across the field.

3.7 WELL TO SEISMIC TIE

Well to seismic tie is the process of establishing the relationship between geological information (well data in depth) and geophysical information (seismic data in time) by matching the seismic reflection with the well log curves. Without this process, it is not possible to identify which seismic reflection corresponds to a particular horizon top as interpreted on the logs. This process involves a series of steps that culminate in the generation of a synthetic seismogram at a particular well location to enable the comparison with the seismic data. The inputs required are seismic data, sonic and density logs, formation tops, check shots and seismic wavelet. For this study, only one well to seismic tie was performed because there is only one well in the field with complete data for the process (WELL C).

The check shot from WELL C was used to calibrate the sonic log, which was subsequently used together with the density log to create the reflective coefficient. The reflective coefficient was convolved with a wavelet to generate a synthetic seismogram for the well tie.

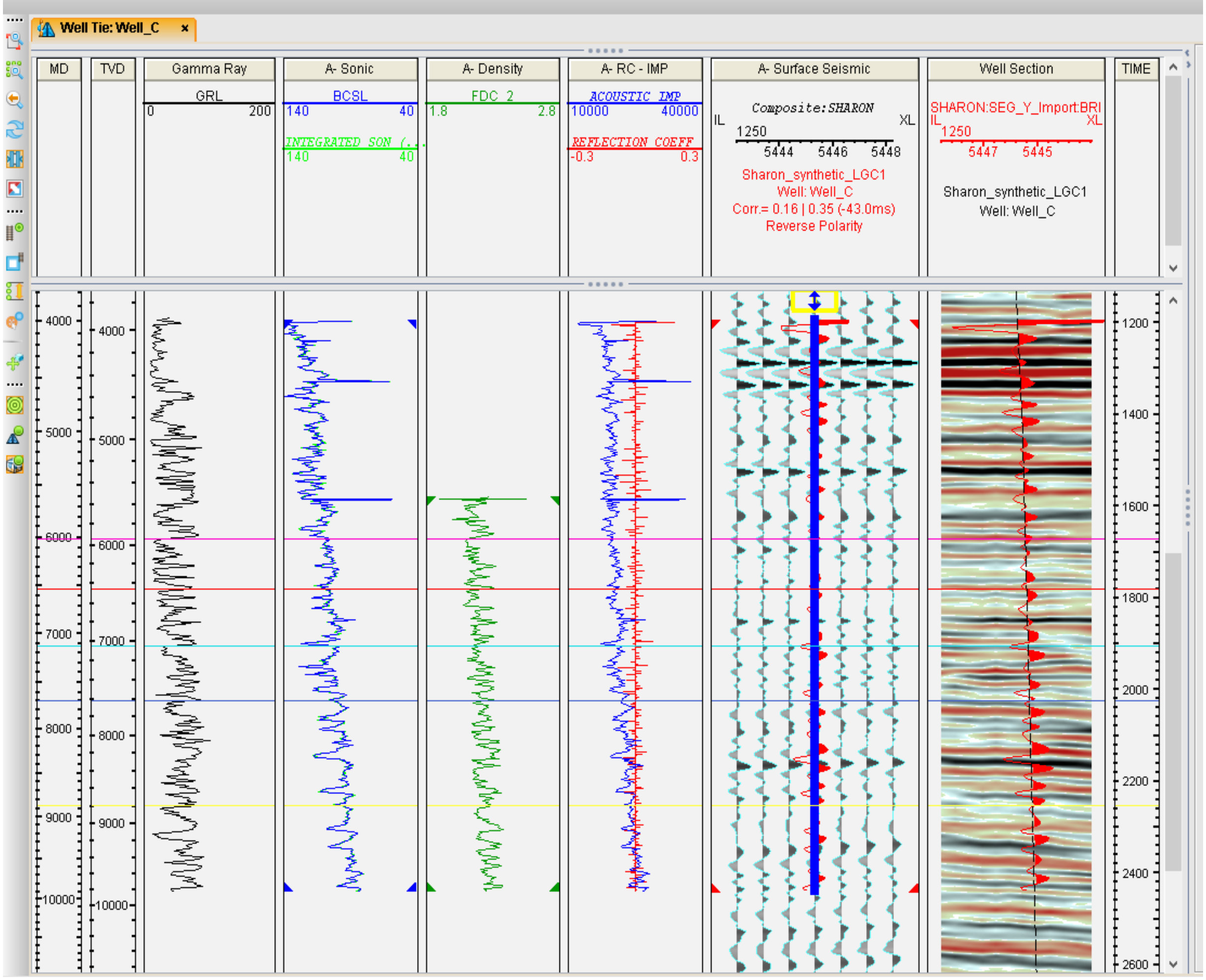


Figure 3.3: Synthetic seismogram tying seismic wiggles in time to formation tops in depth

3.8 HORIZON INTERPRETATION

Horizons are the loops on seismic sections that represent changes in geological events. These changes can be from hard to soft formations and vice versa or in the case of the Niger Delta reservoir system, from sand to shale. Horizon interpretation is usually done after fault interpretation and well to seismic tie. Geological knowledge of the field, together with the interpreted faults helps to guide horizon interpretation, while the results of the well to seismic tie aids in identifying the seismic loops that correspond with the reservoirs correlated in the wells.

For this study, two key horizons of interest were interpreted using well tops and synthetic seismogram as a guide. The synthetic seismogram generated from seismic to well tie process was displayed in the well location on the seismic volume. Identified loops were mapped on the seismic volume from well location. The horizons were mapped manually on every tenth line on both inlines and crosslines. The interpreted seeds for the reservoirs were then gridded, smoothened and a time map was generated.

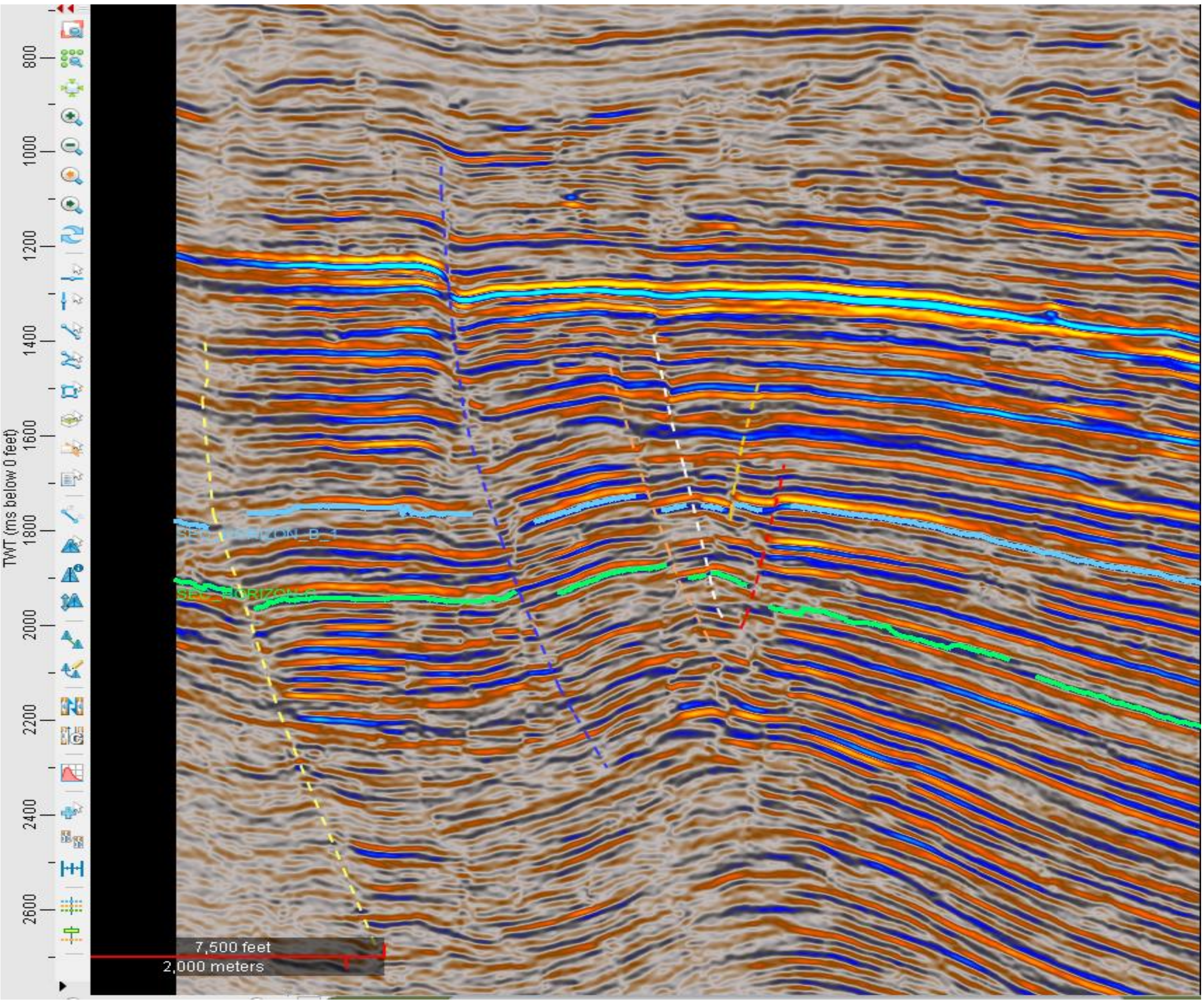


Figure 3.4: Crossline 5240 showing interpreted horizons across the field.

3.9 TIME-TO-DEPTH CONVERSION

The purpose for Time – Depth conversion is to position structural data correctly in depth (reflectors) from data recorded in the time domain (reflections). It is also used in making maps of reservoirs in depth, to calculate volumes, and for well planning. The interpreted maps in time domain were depth-converted using Velocity Modelling approach.

3.9.1 Velocity Modelling

The velocity modelling approach was employed using well velocity data (check-shot). Velocity model was generated from well velocity data using time-depth relationship (TDR) as input. Velocity can be modelled in three different deterministic methods which include:

3.9.1.1 TD curve Based Models:

Time-depth (T-D) curves provide a quick and easy approach to velocity modelling. T-D curves are interpolated and extrapolated into a velocity volume. The accuracy of the velocity model can be improved by integrating sparse well data with the dense velocity information extracted from seismic data.

3.9.1.2 Well Pick Based Models:

Well picks are accurate depth data. If properly correlated to a seismic horizon, they become a reliable source of velocity information for the interpreter. Therefore, well picks play an especially important role in depth conversion, model calibration, and uncertainty estimation. Well depth picks are associated with seismic time horizons to create pseudo-velocities. Well picks associated with time horizons can also be used to calibrate other velocity information, such as that provided by seismic velocity functions or T-D curves. The resulting calibrated models tie the well picks and incorporate the other information between the picks.

3.9.1.3 Structurally Controlled Models:

Surfaces are used for several tasks, such as building well-based pseudo-velocities, constraining velocity function interpolation, and creating analytic velocity models. Small holes in the input surfaces will automatically be interpolated, yet large holes should probably be gridded or constructed as part of a framework. Below are some guidelines when deciding whether to grid or interpolate incomplete horizons.

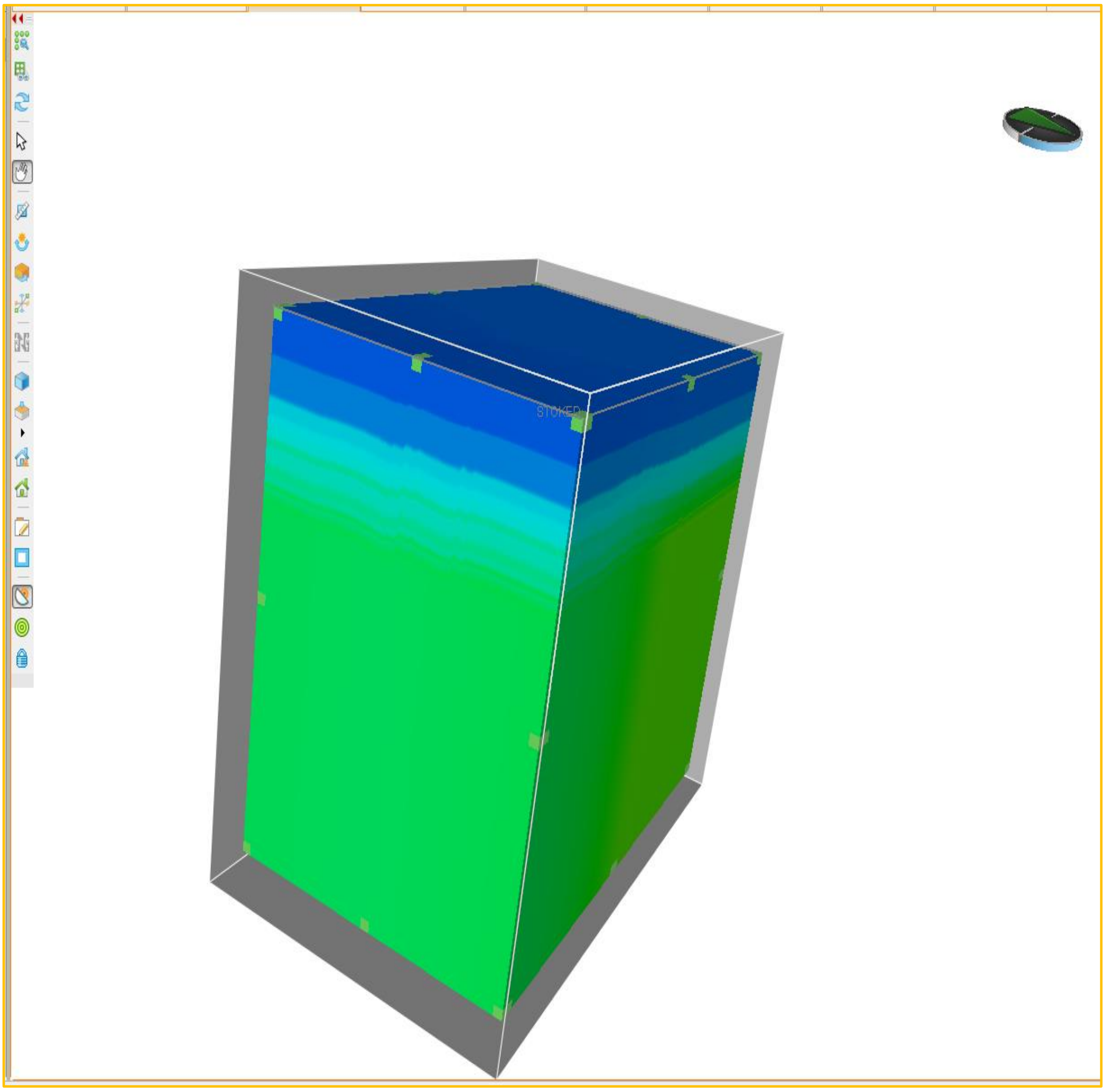


Figure 3.5: Velocity model built with structurally controlled model.

3.10 DEPTH MAP GENERATION

The velocity models generated from the previous section were then used to convert the time maps to the depth maps. The depth maps (i.e., depth horizons) were calibrated to their correct well picks using well tops. By comparing the results obtained from both techniques described above, the depth maps having structural features conformable with those on the time maps, showed the maps were correct.

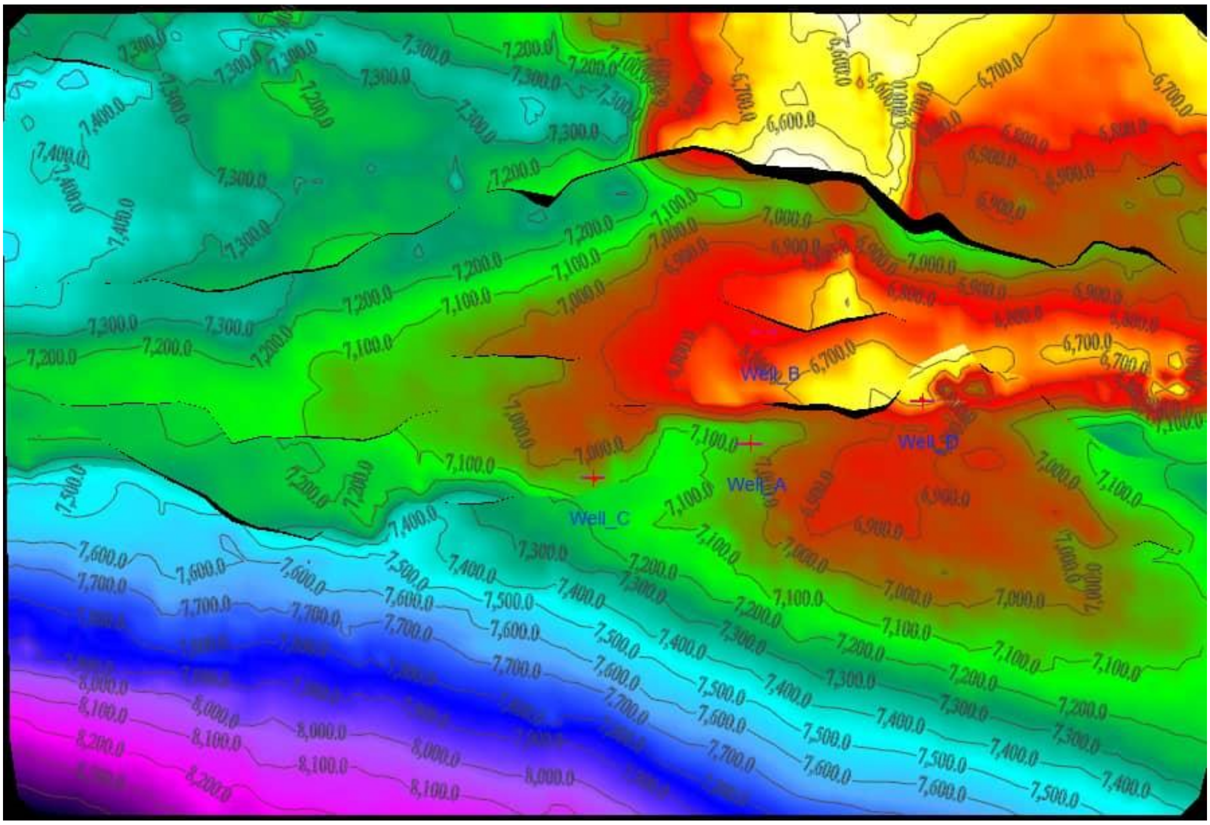


Figure 3.6: Depth map for Top of Reservoir A

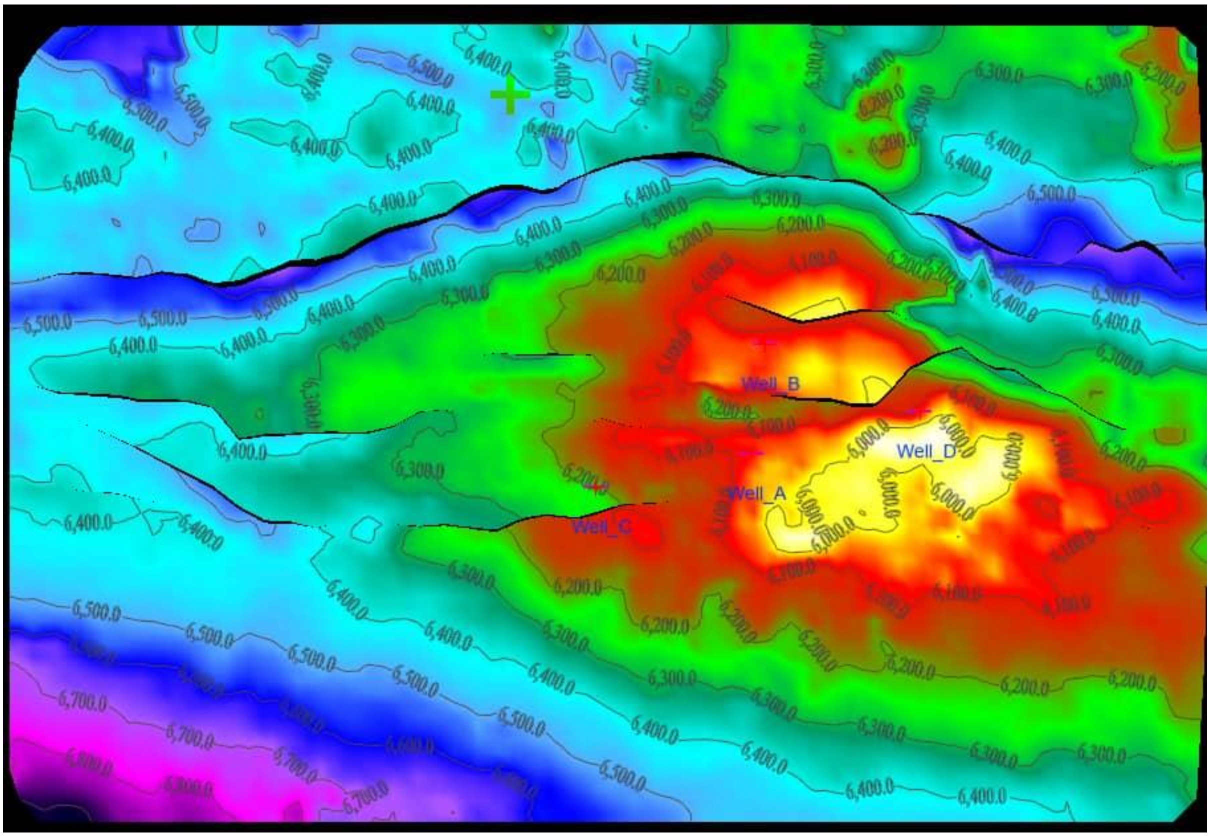


Figure 3.7: Depth map for Top of Reservoir B

3.11 SEISMIC ATTRIBUTE GENERATION

A series of seismic volume attributes such as discontinuity, sweetness, relative acoustic impedance, and RMS amplitude were generated in Decision Space Geoscience software interface to investigate potential structural and stratigraphic controls within the study area. One of the results of this interpretation was a seismic amplitude map that, along with other documents would guide the selection of new oil well locations. The new locations are close to existent oil-producer wells, and over a high-amplitude seismic anomaly.

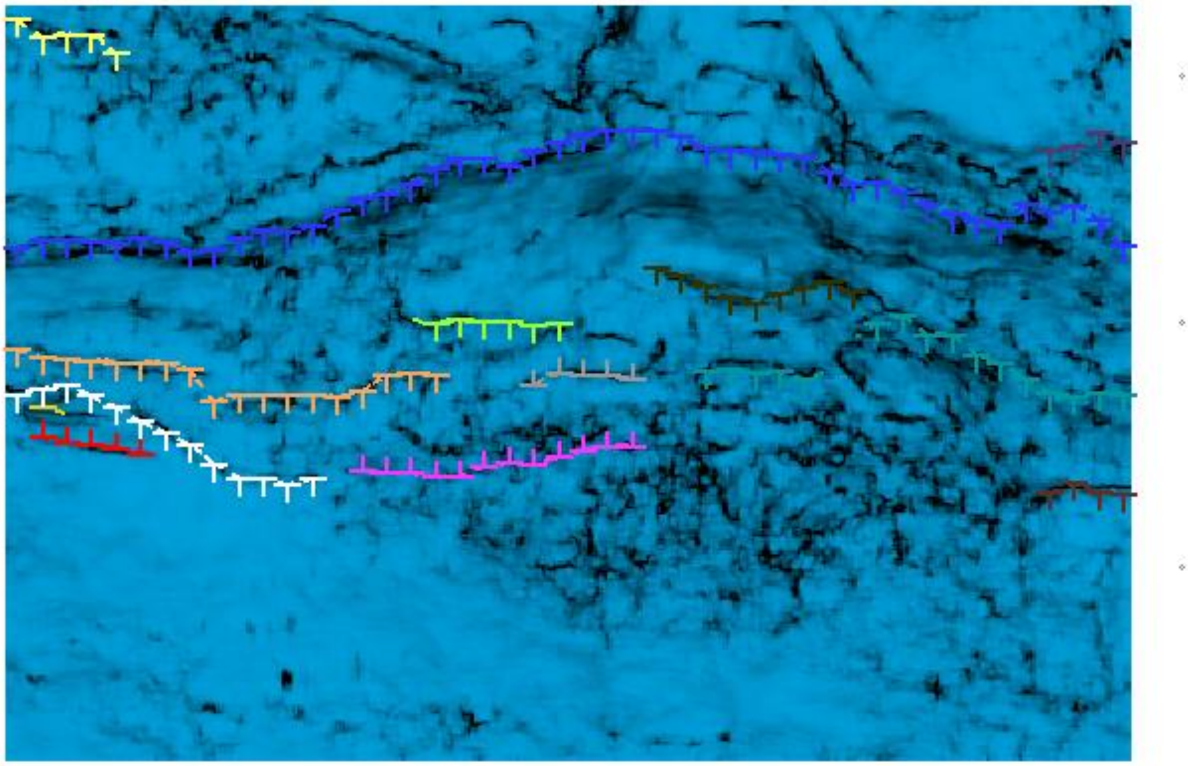


Figure 3.8: Discontinuity attribute extracted over the seismic volume

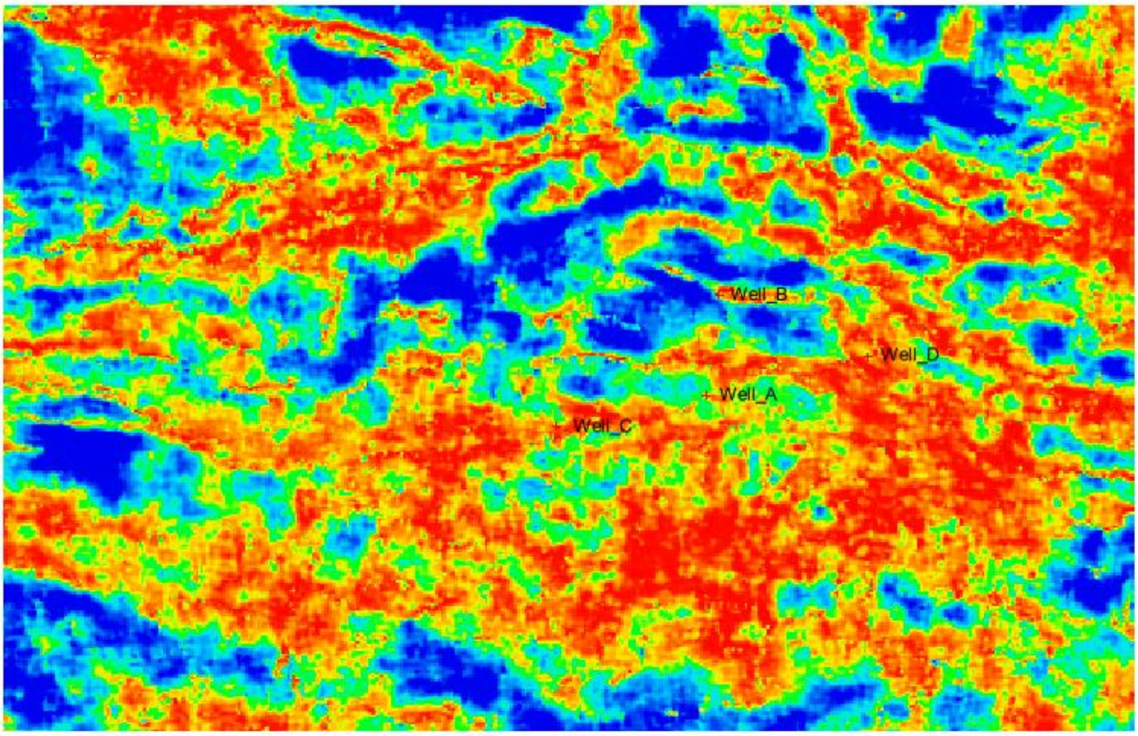


Figure 3.9: Sweetness attribute extracted over seismic volume

CHAPTER FOUR
ANALYSIS OF RESULTS

4.1 INTRODUCTION

The chapter focuses on the analysis of the outcomes from the project work and the general observations.

4.2 WELL CORRELATION

From the correlation carried out using gamma ray, resistivity, sonic and density logs, tops, and bases of two reservoirs of interests were mapped. The occurrence and distribution of the lithostratigraphic units reflects influence of basin morphology and sea level variation (Figure 4.0). The reservoirs appeared to be continuous across the wells

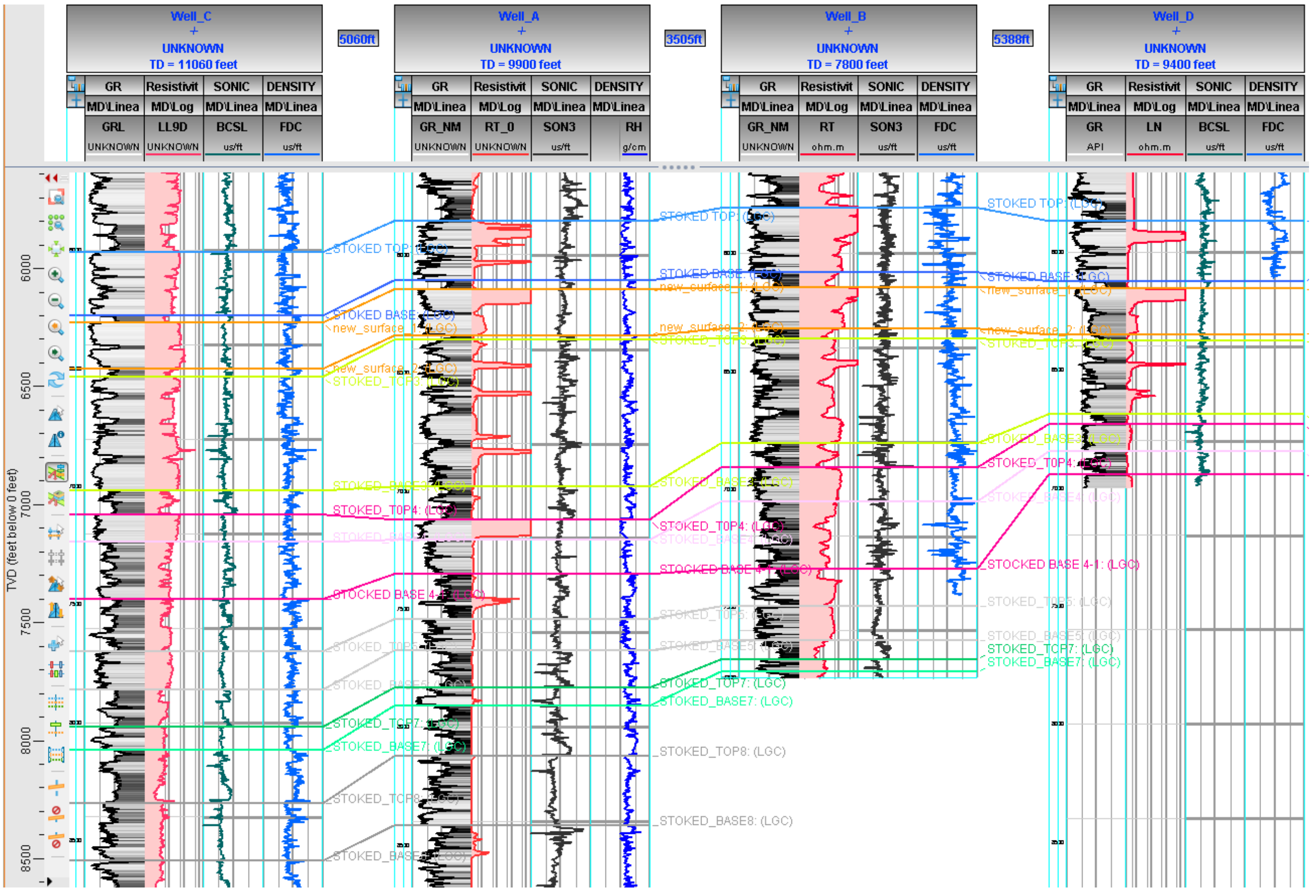


Figure 4.0: Well correlation across the STOKED field

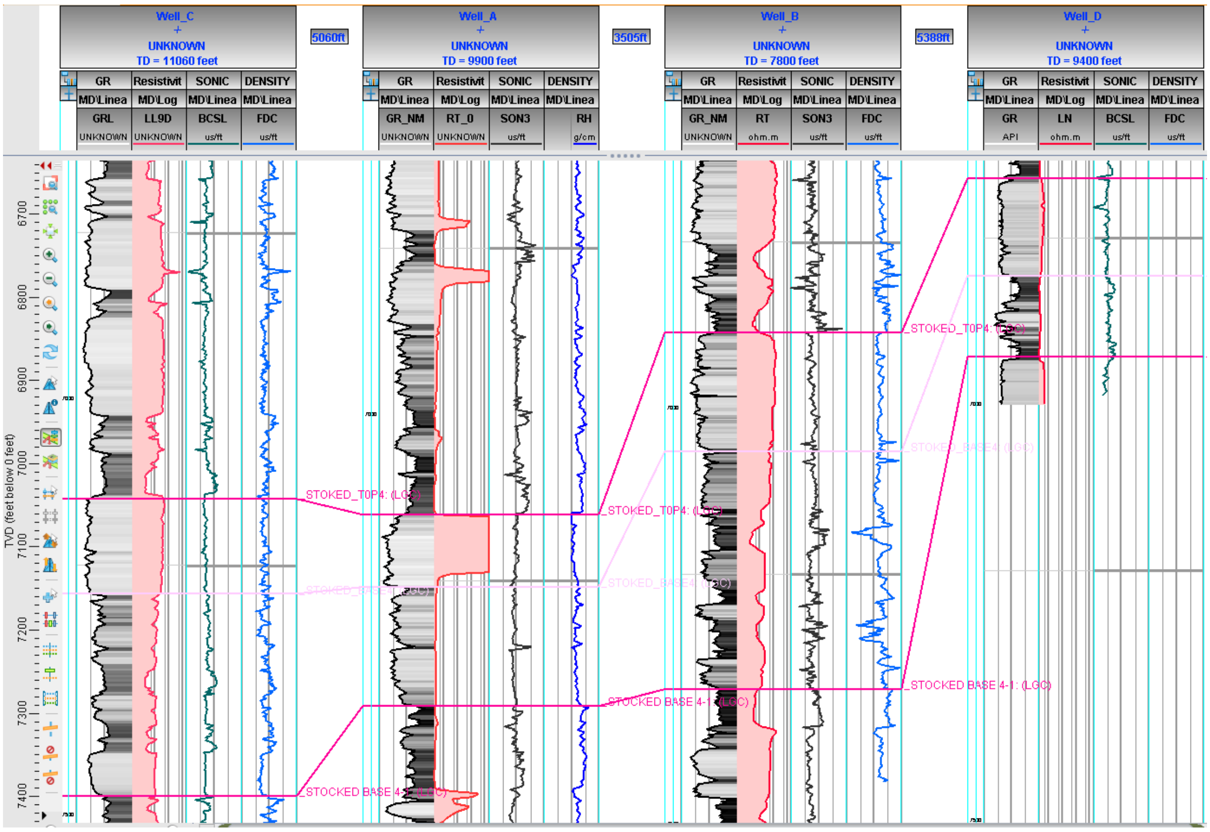


Figure 4.1: Correlation of RESERVIOR A (see Figure 4.0 for interval representing Reservoir A)

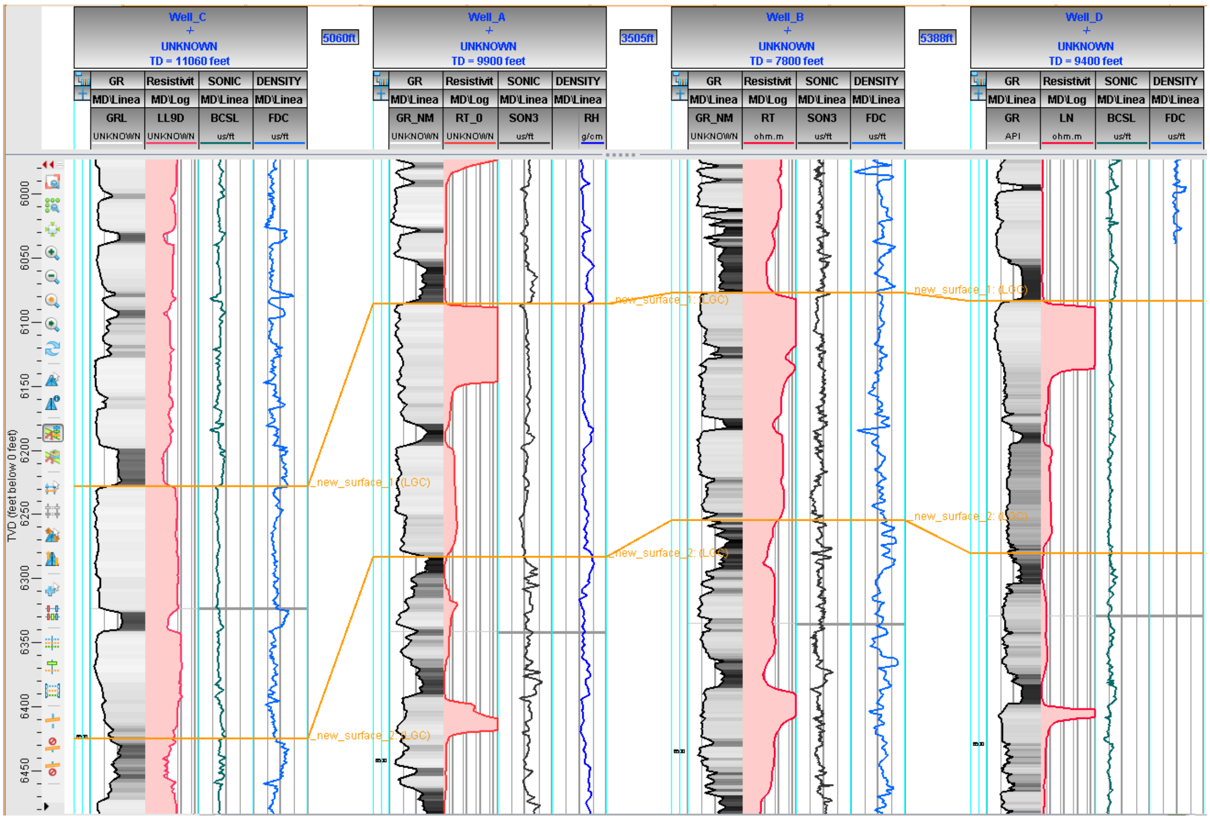


Figure 4.2: Correlation of RESERVOIR B (see Figure 4.0 for interval representing Reservoir B)

4.3 STRATIGRAPHIC AND STRUCTURAL ANALYSIS

A network of several normal faults was interpreted in the crossline direction because it had a better imaging of the fault trends. The faults were mapped at every 10th line. Thirteen of these faults were mapped, one major fault and several minor faults across the field trending NW-SE (Figure 4.5). Seismic attribute such discontinuity attribute was used to check the continuity of events (Figure 4.4). which helped QC the fault interpretation. Figure 4.5 shows the crossline 5237 with interpreted faults. The presence of these faults in the study area is an indication that there is a possibility of hydrocarbon accumulation.

Potential hydrocarbon trap types identified in the field are both structural and stratigraphic traps and typical examples that were identified includes collapsed crest, major growth fault, synthetic and antithetic fault. Interpreting the fault plane geometry was quite challenging in most areas due to poor seismic acquisition and processing artefact that resulted in difficulty in interpreting reflection characteristics around fault. Also mapping faults detachments at depth was difficult and sometimes impossible as data quality deteriorates greatly with depth.

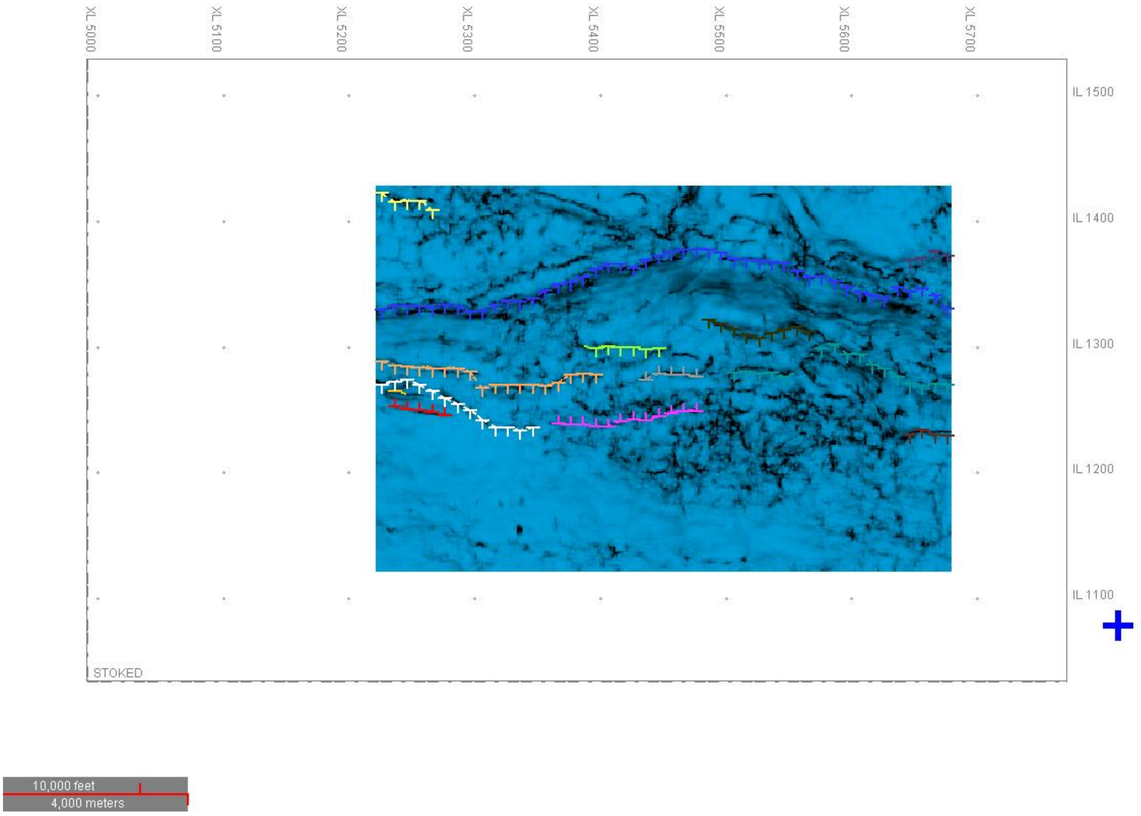


Figure 4.4: Discontinuity attribute aiding fault interpretation across the field

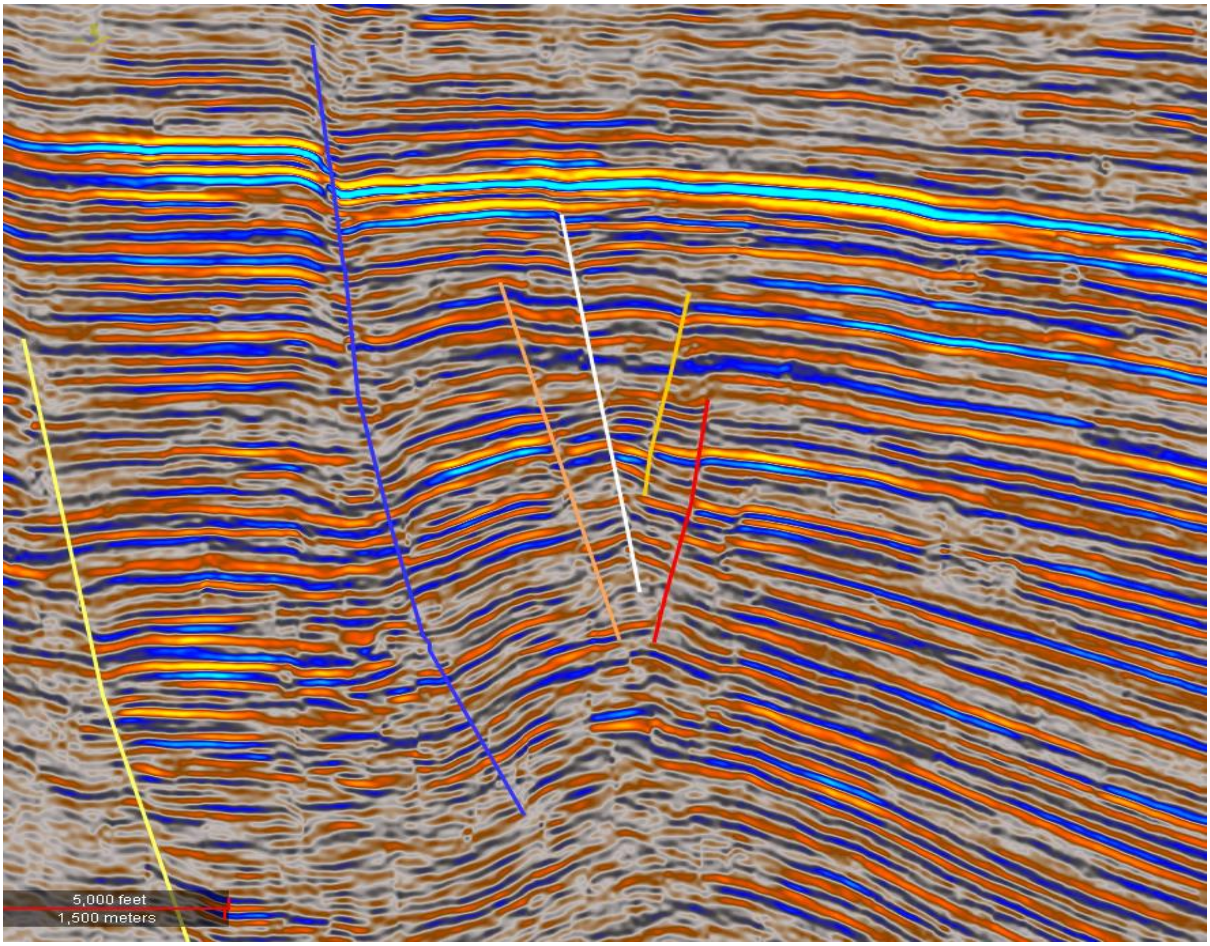


Figure 4.5: Fault interpretation across crossline 5237

4.4 FAULT INTERPRETATION

The structural pattern of the field was observed, and the faults interpreted on the 3-D seismic data. The interpreted faults reveal that the STOKED field is a collapsed crest structure with major NW-SE trending bounding faults. Minor N-S and NE-SW trending cross-cutting faults bound some of the blocks to the east and west and may likely influence lateral accumulation and flow of the hydrocarbons in the reservoirs. The faults are mainly synthetic, with a few antithetic faults. The reservoir trapping mechanism is a fault-dependent three-way dip closure and four-way dip closure. Further studies on the sealing capacity of the faults needs to be carried out to determine if the fault blocks in the field are compartmentalized or not.

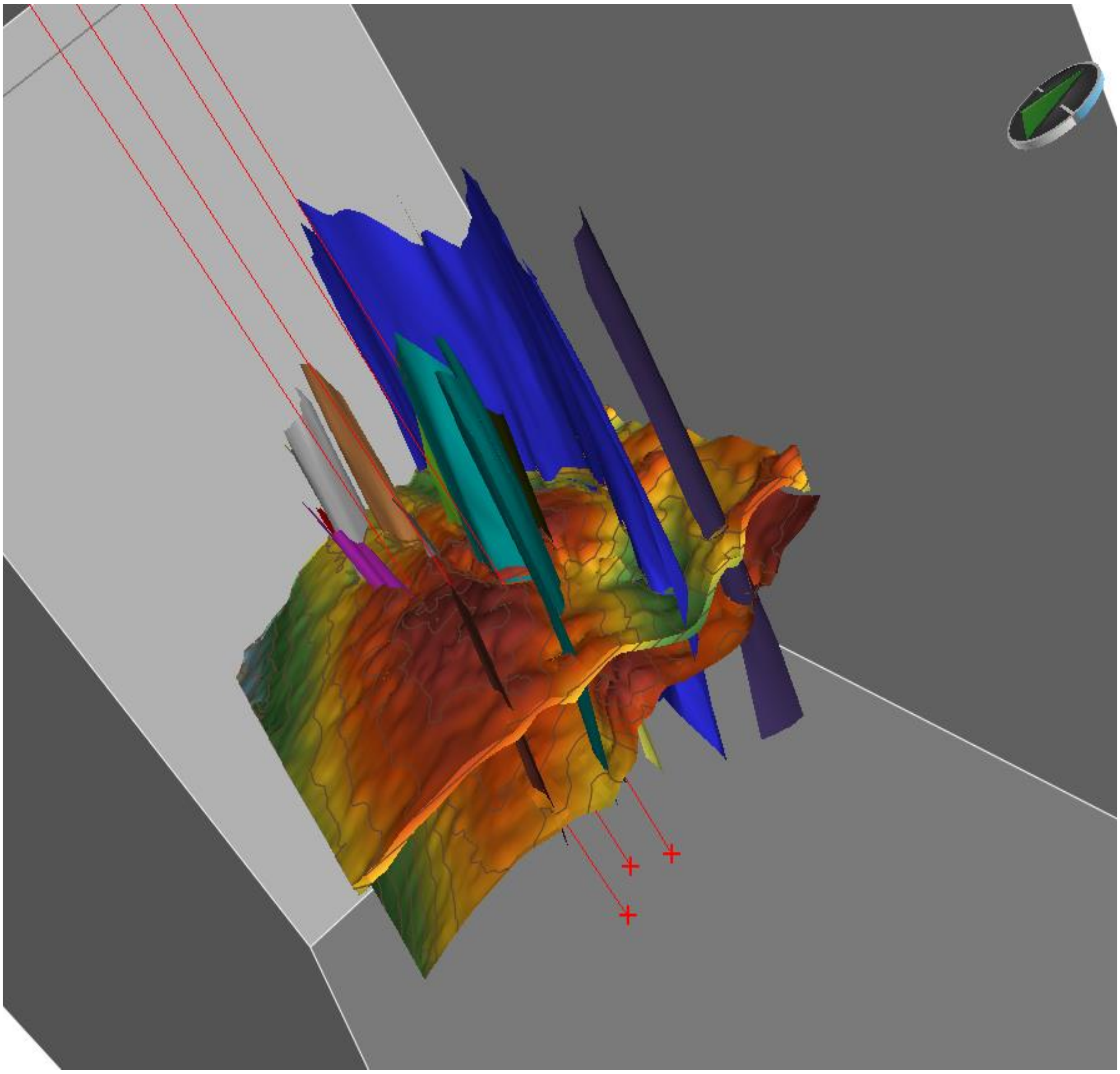


Figure 4.6: Fault interpretation across reservoirs A and B

4.5 WELL TO SEISMIC TIE

A well to seismic tie was done using the synthetic seismogram built from WELL C (Figure 3.3). The seismogram was compared with the seismic data for the field and adjusted to fit. A time shift of 12 ms was applied to achieve a good seismic to well match and a correlation coefficient of 0.60 was achieved.

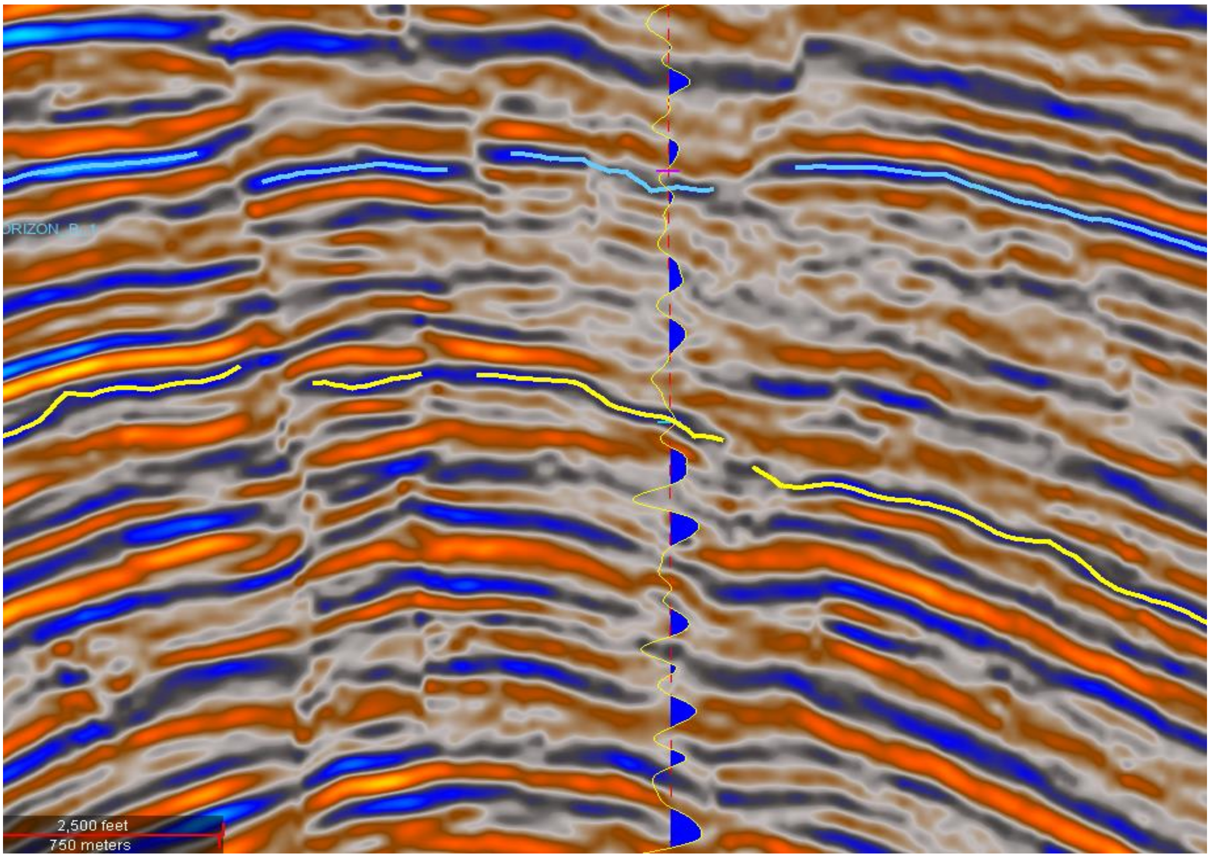


Figure 4.7: Section view showing synthetic seismogram at WELL C

4.6 HORIZON INTERPRETATION

The synthetic seismogram was displayed on the seismic section and the horizon corresponding to the A and B reservoirs was interpreted at every 10th inline and crossline. The interpreted seeds (see Figure 4.8 and 4.9) for the reservoirs of interest were then gridded, smoothened and a time map was generated.

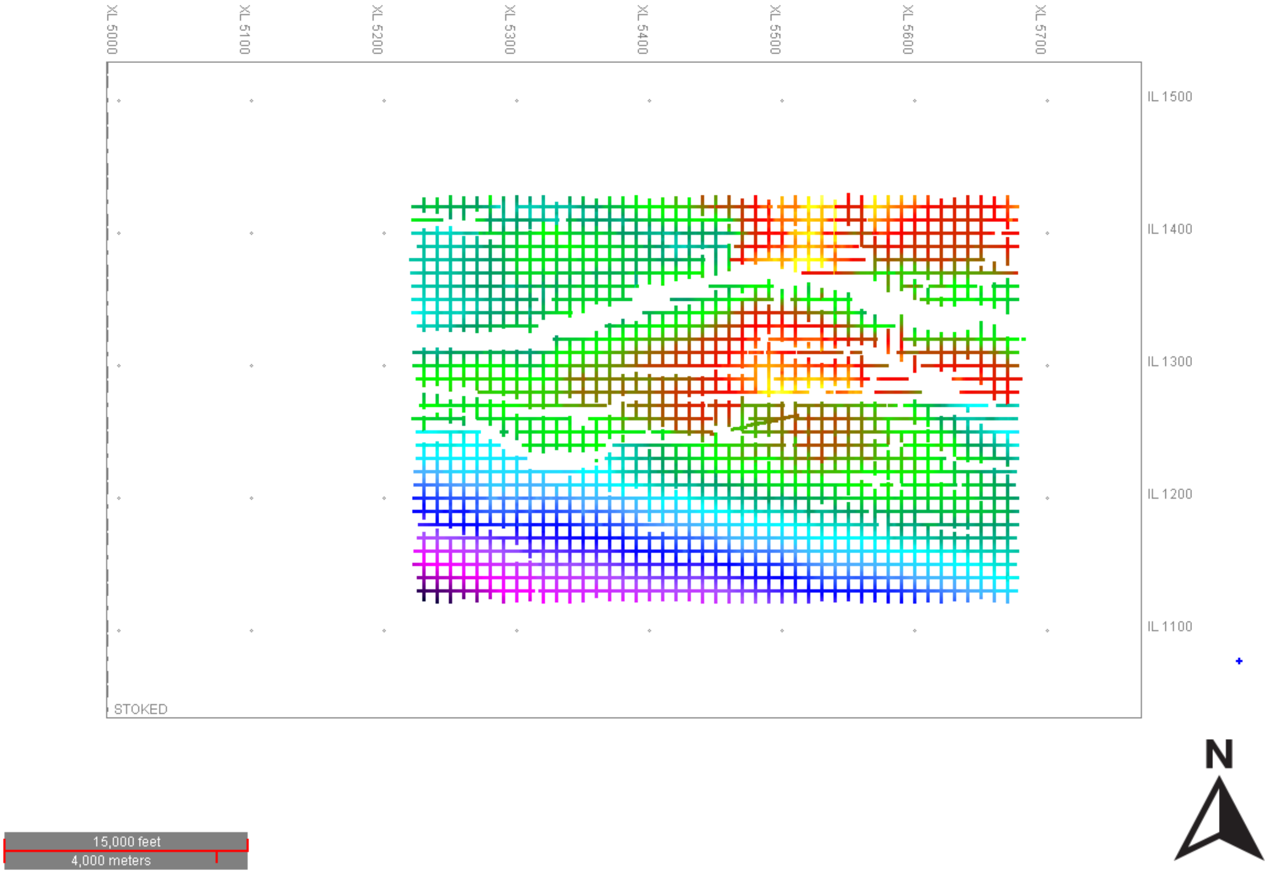


Figure 4.8: Interpreted seed grids showing top of Reservoir A

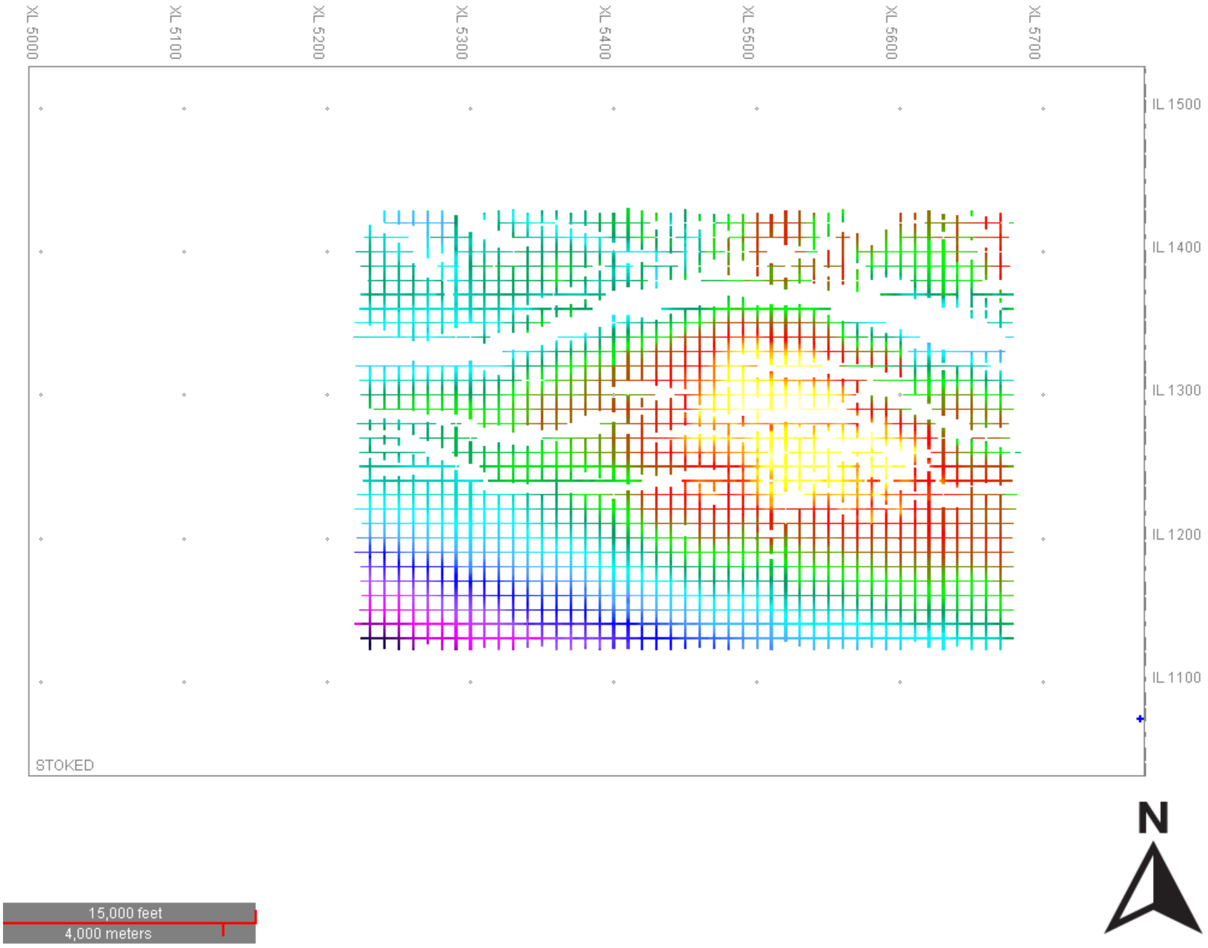


Figure 4.9: Interpreted seed grids showing top of Reservoir B

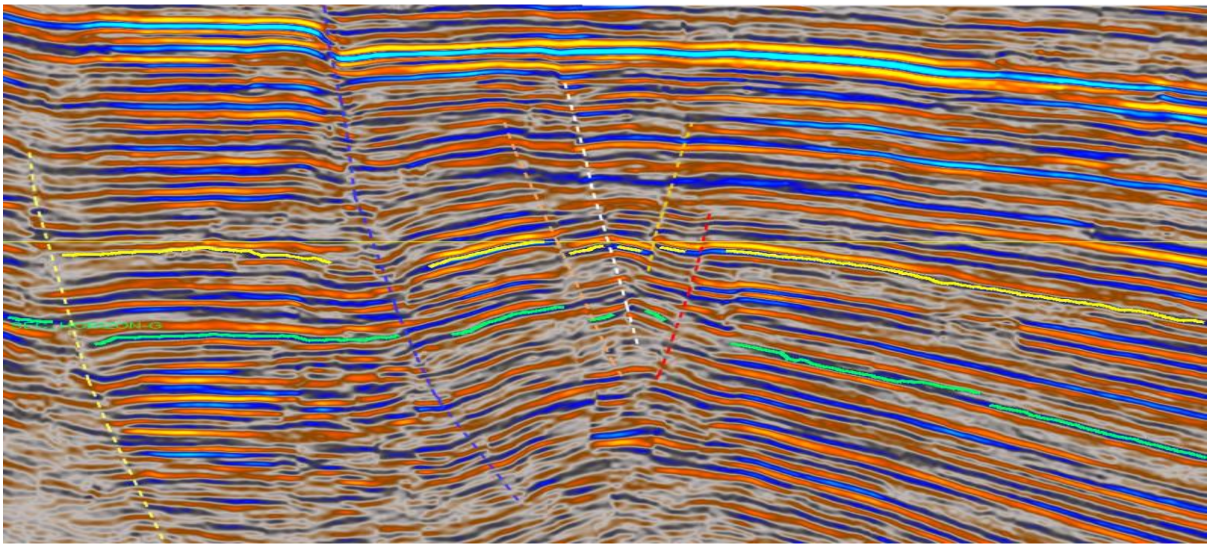


Figure 4.10: Section view showing horizons across both reservoirs

4.7 VELOCITY MODEL AND DEPTH CONVERSION

The updated Time Depth relationship (TDR) from the well to seismic tie was used as input for the velocity model. Depth Conversion is an especially important aspect of seismic data interpretation as it helps to get a representative depth image of the subsurface interpreted from seismic data that is recorded in two-way travel time. The model was used to convert both reservoir top maps from time to depth.

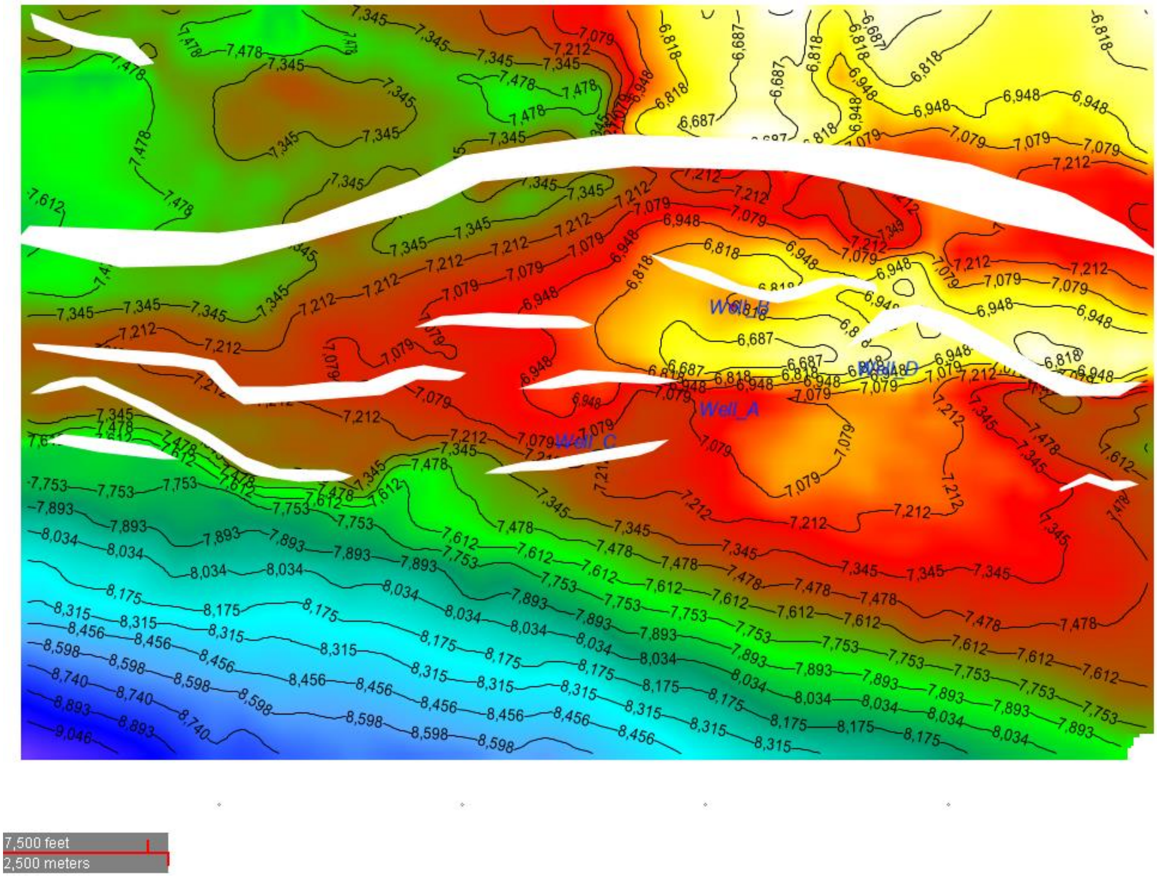


Figure 4.11a: Time Map for top of Reservoir A

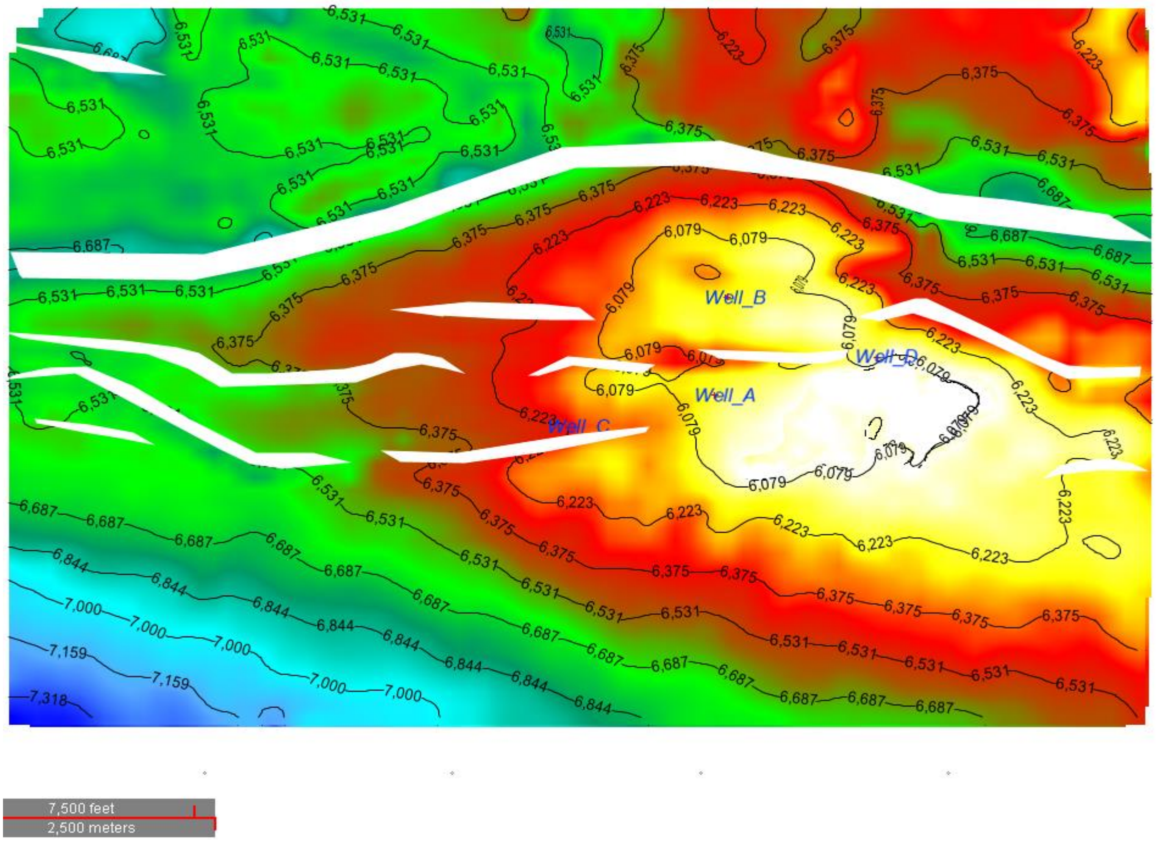


Figure 4.11b: Time map for top of Reservoir B

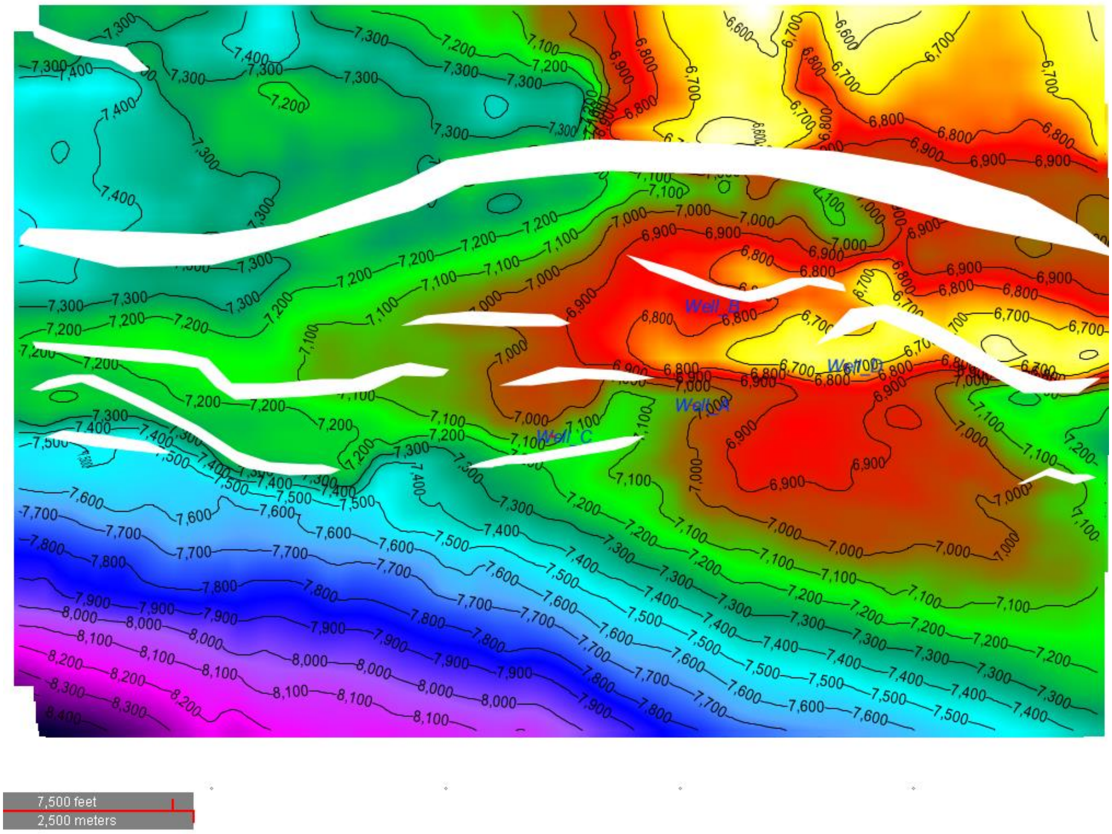


Figure 4.12a: Depth map for top of Reservoir A

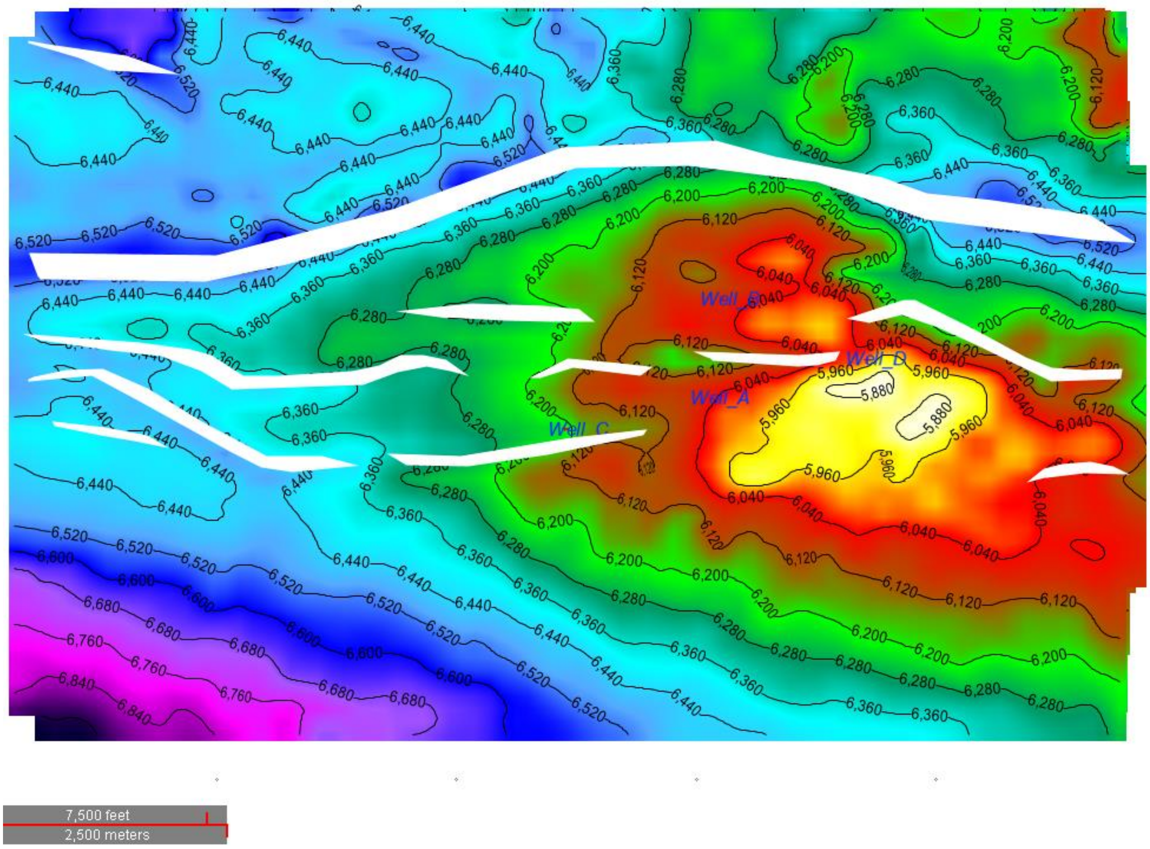


Figure 4.12b: Depth map for top of Reservoir B

4.8 SEISMIC ATTRIBUTE ANALYSIS

Seismic attributes analysis carried out within the study area revealed prospective zones where the drilled wells did not penetrate. RMS amplitude, Instantaneous frequency, Maximum peak and maximum positive amplitude attributes were selected and used in this study because of their application as Direct Hydrocarbon Indicators (HDI). The attributes extracted was checked for conformability with structure. Sweetness attribute which is a good hydrocarbon indicator was extracted as shown in Figure 4.13 The map showed that the region with anticlinal structure on the structural high is associated with high sweetness and amplitude which suggest that there is the possibility of the presence of hydrocarbon in it.

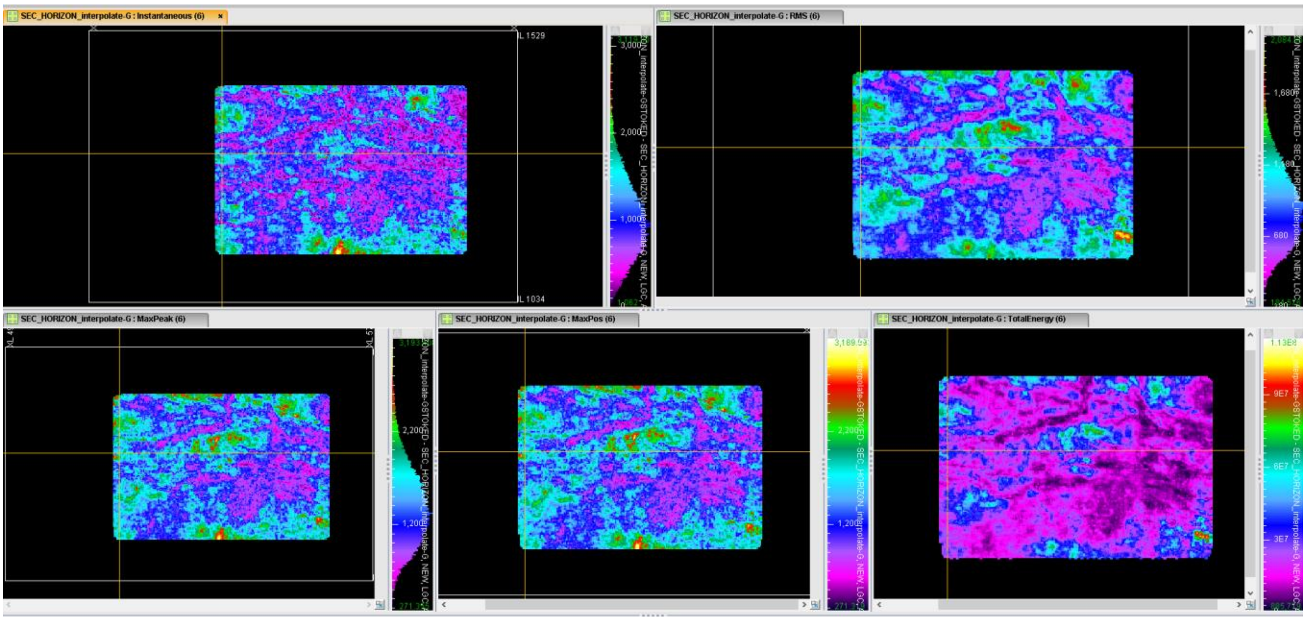


Figure 4.13: Reflection strength attribute for reservoir A

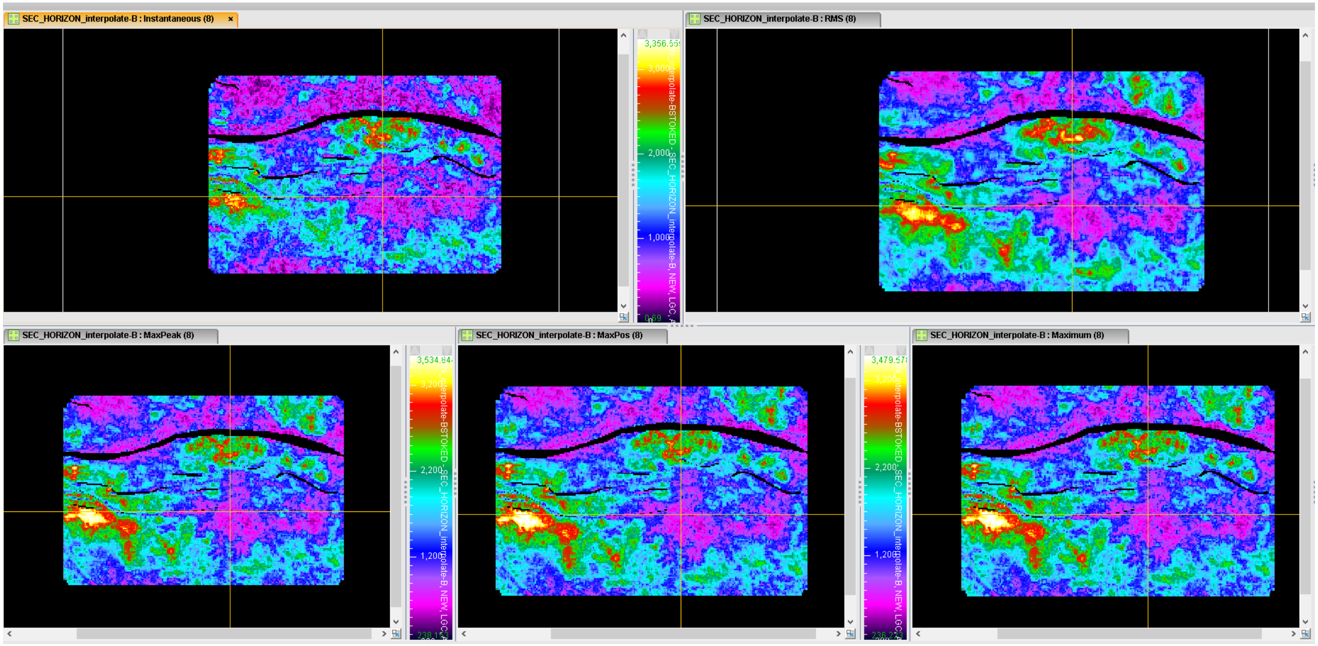


Figure 4.14: Reflection strength attribute for reservoir B

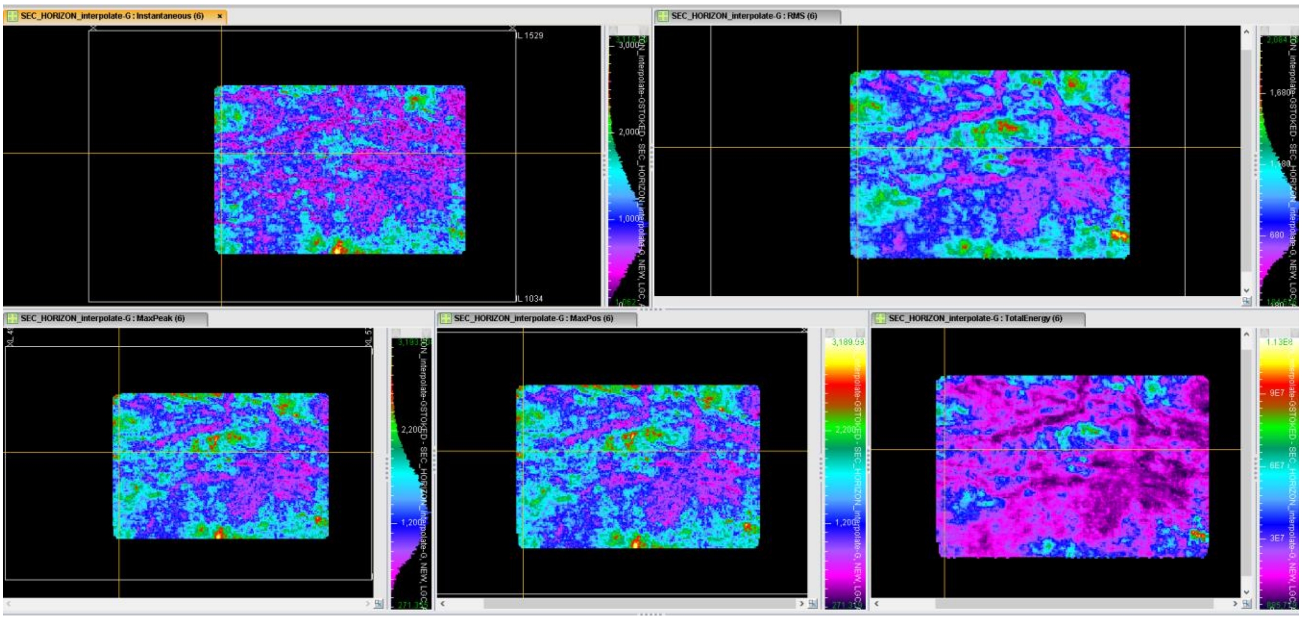


Figure 4.15: Sweetness attribute for reservoir A

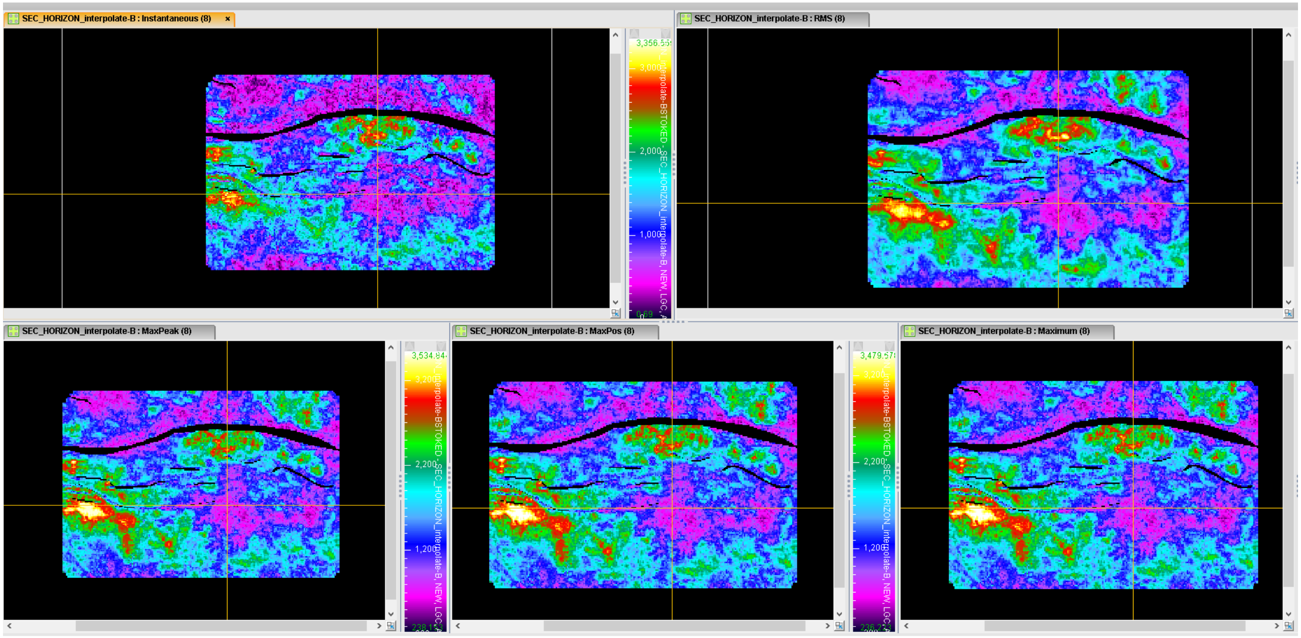


Figure 4.16: Sweetness attribute for reservoir B

4.9 VOLUMETRIC ESTIMATION

The oil in place was determined using the volumetric method from data generated from geological and petrophysical evaluation (gross rock volumes, porosity, saturation, net-to-gross and formation volume factor).

The governing equation for the volumetric estimation of oil in place is given as:

$$\mathbf{N} = \frac{7758\, Ah\emptyset\, (1 - S_{wc})}{B_{oi}}$$

Recoverable Reserves = N * RF

Where;

N *= STOIIP (barrels)*

Ah *= Bulk (rock) volume (acre-feet or cubic meters)*

Ø *= Fluid-filled porosity of the rock (fraction)*

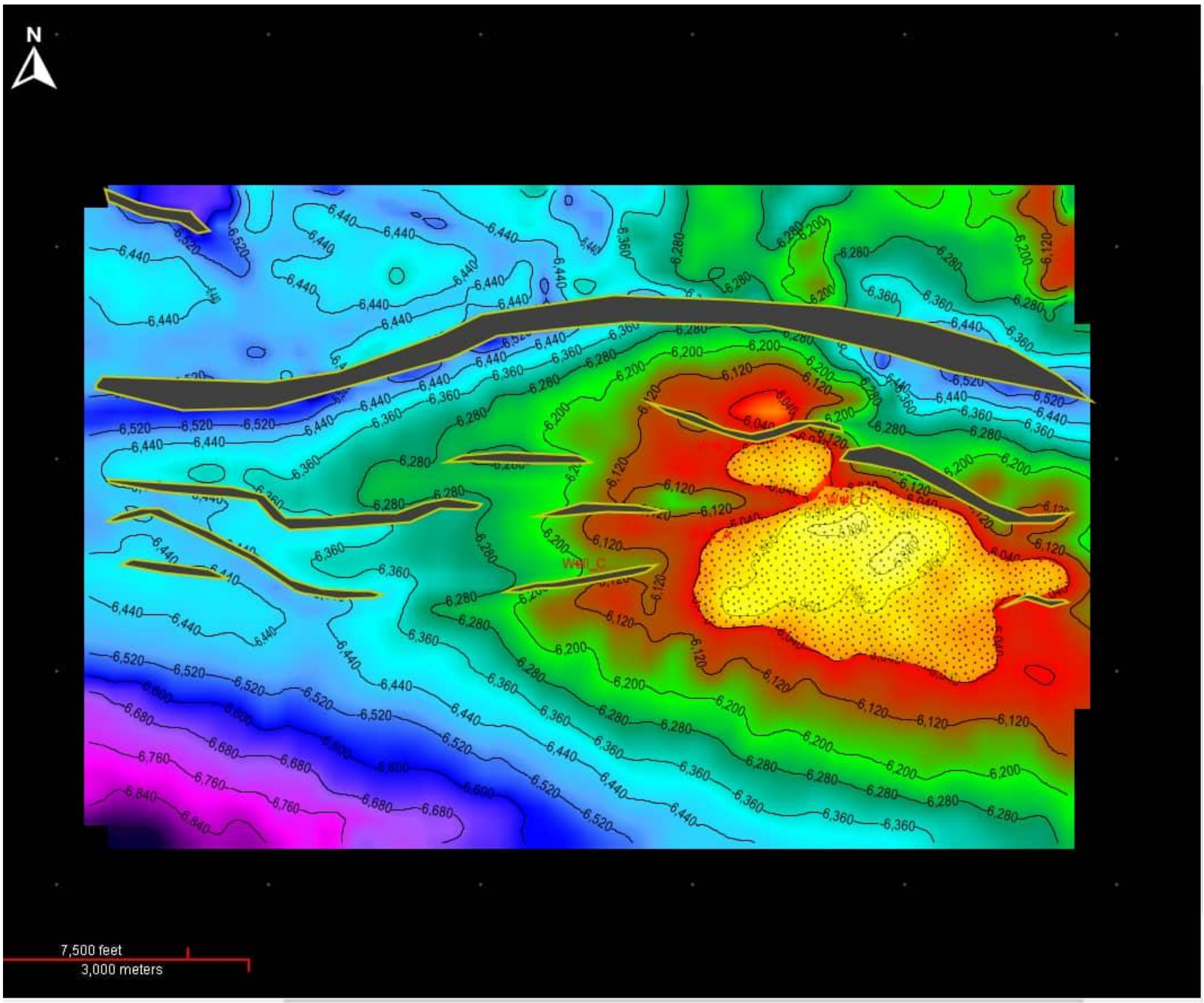
S_{wc} *= Water saturation - water-filled portion of this porosity (fraction)*

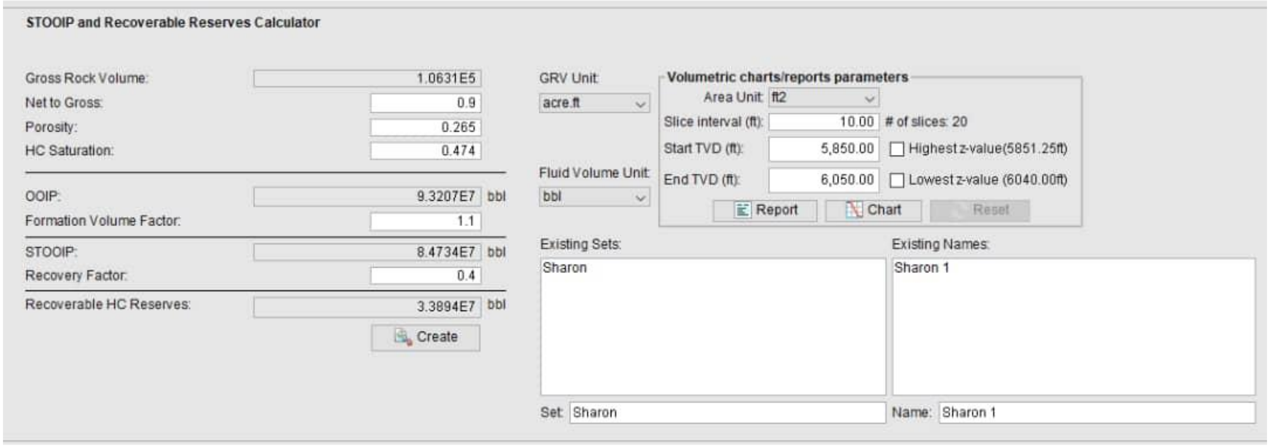
B_{oi} *= Formation volume factor (dimensionless factor for the change in volume between reservoir and standard conditions at surface)*

RF *= Recovery Factor*

Table 2: STOIIP and Recoverable Reserves estimate for Reservoir A

Average Petrophysical Properties		**STOIIP (bbl)**	**Recovery Factor (RF)**	**Recoverable Reserves (bbl)**
Gross Rock Volume (GRV)	106310	**84734000**	**0.4**	**33894000**
Net to Gross (NTG)	0.9			
Porosity (Ø)	0.27			
Hydrocarbon Saturation (1 - S_{wc})	0.47			
Formation Volume Factor (B_{io})	1.1			





STOOIP and Recoverable Reserves Calculator

Gross Rock Volume: 1.0631E5

Net to Gross: 0.9

Porosity: 0.265

HC Saturation: 0.474

OOIP: 9.3207E7 bbl

Formation Volume Factor: 1.1

STOOIP: 8.4734E7 bbl

Recovery Factor: 0.4

Recoverable HC Reserves: 3.3894E7 bbl

GRV Unit: acre.ft

Fluid Volume Unit: bbl

Volumetric charts/reports parameters

Area Unit: ft2

Slice interval (ft): 10.00 # of slices: 20

Start TVD (ft): 5,850.00 ☐ Highest z-value(5851.25ft)

End TVD (ft): 6,050.00 ☐ Lowest z-value (6040.00ft)

Existing Sets: Sharon

Existing Names: Sharon 1

Set: Sharon

Name: Sharon 1

Figure 4.17: Volume estimation from Decision Space for Reservoir A

4.10 DISCUSSION

By revisiting the work related to the application of seismic attributes in the characterization of reservoirs, it appears that each attribute gives a particular function and explanation for the understanding of geological structures and hydrocarbon potentials. This contribution of the attributes is manifested by the quality of the results obtained. The Identification of hydrocarbon prospects using seismic attributes is an interesting technique that provides quality results which allows firstly to locate the accumulation zones, then to analyse the characteristics of reservoirs, and finally to determine the distribution of hydrocarbons. The use of seismic attributes to characterize reservoirs provides information on reservoir characteristics such as porosity, thickness, lithology, direct hydrocarbon indicators (bright spot, flat spot, and dim spot), and traps (faults, anticlines, synclines, and salt domes). It should be emphasized that this approach can be improved by combining it with other methods such as log analysis, seismic sampling, neural networks, and statistical analysis. It becomes very easy to interpolate the well data with the seismic attributes to know the distribution of the properties over the whole extent of the reservoir. In addition, gamma ray and resistivity logs provide valuable information on reservoir characteristics (Eshimokhai and Akhirevbulu 2012). The integration of good logs with seismic data provides more accurate seismic attributes in the analysis of hydrocarbon reservoir characteristics. The statistical approach to reservoir characterization is an important tool in the analysis of the petrophysical properties of reservoirs in that it allows the values of each characteristic to be calculated. As this approach provides local information, it is important to use the seismic attributes derived from the integration of statistical data with seismic data. This leads to a joint analysis of several attributes called multiattribute (MA). To do this, the multiattribute analysis highlights possible approaches, such as the co-kriging technique, the neural networks (Aminzadeha et al., 2000), and the co-variance matrix. These three statistical methods make it possible to predict a property by using several attributes in order to improve the results obtained with a seismic attribute.

CHAPTER FIVE
SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY

In this study, the hydrocarbon potential of STOKED field in offshore coastal swamp Niger delta was evaluated. The method adopted involves delineation of lithologies from Gamma ray log, Identification of hydrocarbon bearing reservoirs unit from resistivity log, well to well correlation across the field, fault interpretation and horizon mapping, time to depth conversion, determination of petrophysical parameters and volumetric estimation. The geological consistency of this model required an integrated approach, using seismic data, well log data and subsurface knowledge across the various subsurface disciplines namely, Geology, Geophysics, and Petrophysics. Geologic structures observed and interpreted includes growth faults, roll-over anticlines, antithetic and synthetic faults in a paralic sequence (Agbada Formation). One Major and twelve minor faults were 11-56% interpreted mapped from the well correlation carried out across the four wells in the NE-SW Direction. Two reservoirs were interpreted, and the seed grids generated three top time structure maps. The result from the petrophysical analysis and property modelling has shown that the reservoirs have porosity values that range from 17-24%, and water saturation ranges from for various Reservoir Intervals. Trapping configuration is a fault assisted closure in the shallow reservoirs and a four-way dip closure in the deeper reservoir. The closures are products of rollovers anticlines related to growth faults antithetic and synthetic faults in a paralic sequence (Agbada Formation). Map based volumetrics was calculated and the stock tank oil initially in place estimated is 84mmstb for reservoir A while reservoir B was inconclusive as the area extended outside the extent of the seismic. Root mean square (RMS) amplitude, instantaneous frequency and reflection strength maps were extracted on seismic events with pronounced bright spots. These maps were used to establish the diagnostic ability of 3D seismic attribute analysis in enhancing seismic interpretation and volumetric estimation. Results from this study have shown that, away from currently producing zone at the central part of the field, additional leads and prospects exist, which could be further evaluated for hydrocarbon production.

5.2 CONCLUSION

In this study, Decision Space Geoscience software has been used to generate and interpret seismic attributes and well logs. The structural style of the field is a collapsed crest structure with a series of synthetic and antithetic faults. Hydrocarbon accumulation in the field is observed to be mainly structurally controlled. It has been demonstrated that seismic attributes are complementary to the information derived through traditional methods of seismic interpretation and hydrocarbon exploration, and development risks can be reduced greatly with the outcome of seismic attributes extraction and analysis. Having carried out amplitude extraction, structural and stratigraphic interpretation, from an integrated view, the following conclusions were reached:

1. The regional faults, growth-faults, collapsed crest, synthetic and antithetic faults identified during seismic interpretation were typical of Niger Delta structural style.

2. Reservoir B is a fault bounded 3-way dip structure with intra-reservoir fault while Reservoir A is a 4-way dip closure

3. The discontinuity attribute revealed the subtle structures and faults in the seismic section while the RMS amplitude, Instantaneous frequency, Maximum peak and maximum positive amplitude results highlighted the hydrocarbon zones

4. Reservoir B contours closed outside the extent of the seismic hence the volumetrics were inconclusive

5. The seismic attribute analysis in this study has helped in increasing the understanding of the delineated reservoirs and geological structures in the study area towards a better delineation of hydrocarbon potential and improved reservoir characterization.

5.3 RECOMMENDATIONS

The following recommendations are made based on our findings:

1. The seismic data should be reprocessed to solve the problem of chaotic reflections and reduce the noise in the seismic data.

2. Fault seal analysis should be carried out on the STOKED Field to determine if the reservoir blocks are in communication.

3. Acquisition of new seismic to delineate the lateral extent of the reservoir and to better characterize the reservoirs inherent in the field.

4. All generated Depth maps to be used for Static Modelling

5. Drill more wells to further develop the field.

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