UNIVERSITY OF GHANA
DEPARTMENT OF EARTH SCIENCE

HYDROCARBON POTENTIAL EVALUATION OF SHALLOW WATERS WEST OF ACCRA BASIN

BY

BLESS ARKU (10357989)
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DECLARATION

We certify that this thesis is the result of the candidate's own research work in the department of earth science, university of Ghana.

Signature………………………..

Prof. D. Asiedu

(Principal Supervisor)

Signature ………………………

Dr. Thomas Armah

(Supervisor)

Signature………………….

Bless Arku

(Student)

DEDICATION

This work is dedicated to the almighty God for giving me the strength, my father Mr. Christian Arku for being the pillar behind my formal education and Faustina Ampadu for Her support.

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ABSTRACT

Exploration activities have intensified in the Tano basin following the discovery of oil and gas in commercial quantities at the Jubilee fields. The analogue Accra-Keta Basin is still under explored but found to be highly prospective. In this context, this research utilized a twenty (20) two dimensional (2D) seismic line and well data comprising of gamma ray log, density log, sonic log, spontaneous potential and resistivity logs. These data sets were used to evaluate the hydrocarbon potential of shallow waters west of Accra-Keta Basin and the results are in three folds. Firstly, it was clear from the well data that there is a gross reservoir thickness of 744.23m, Net of 531.73m and an average porosity of 15.5%. Secondly, from attribute analysis and geophysical interpretation, it was found that, though the area is structurally controlled leading to the compartmentalization, there exist also channels which serve as a very good source of quality sand. Diapiric structures which could serve as trapping mechanism for hydrocarbon were found in addition to gas chimney which is an indication of a working petroleum system. The final volume was calculated based on monte-carlo simulation approach which resulted in a minimum volume 150 million barrel of oil and 309.3 million cubic feet of gas.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Hydrocarbon explorations have been in existence for many years and major discoveries have been made in many parts of the world. However, it is becoming increasingly likely that future finds would be smaller and more complex.

The oil and gas industry, has become an" elephant hunt" off West Africa that is the Gulf of Guinea province. The search for giant offshore oil fields is focused on geologic sweet spots in the gulf of guinea and is most active in the offshore sectors of Nigeria. The prospectivity of the transform margin which includes Ghana has been established. There are well known oil and gas productions from this area for example, the Espoir, Lionpanthere, Foxtrot and Baobab fields, all in Cote d'ivoire. There are also well known discoveries that are either being developed or waiting to be developed such as the West, North and the South Tano fields in Ghana, and the Ibex and Kudu fields in la Cote d'ivoire.

Ghana is famous for its gold but oil exploration dates back to the end of the 19th Century. Ghana has two Cretaceous sedimentary basins (Tano and Keta) and two Paleozoic Basins (Saltpond and Voltaian) which have all been explored to some extent. The existence of oil seepages onshore and oil slicks offshore which have been found to be associated with subsea seepage are all indications of a working mature source. Numerous studies commissioned and non –

commissioned have proved beyond doubt that there is a very good oil and gas potential in Ghana.

Exploration works on Ghana's territorial waters started as far back as 1896 (Mohsin, 1963) and although commercial quantities of offshore oil reserves were discovered in the 1970s, by 1990 production was still negligible.

Fortunately, the development of new exploration techniques have improved the geologist understanding and increased the efficiency of exploration. Although targets are getting smaller, exploration and appraisal wells can be sited more accurately and with a greater chance of success. Thus, with the advent of extremely advanced, ingenious technology such as modern seismic sections which often bear a striking resemblance to stratigraphic cross sections, many individuals are tempted to interpret them directly without making the special corrections they require. Seismic sections show the response of the earth to seismic waves, and the position of geologic bedding planes is only one of several factors which affect the response. Because most seismic reflections are interference composites, there is no one to one correspondence between seismic events and interfaces within the earth. However, with today's processing power, geophysicists can often convert subtle changes of wave shapes into stratigraphic terms.

In 1983, the government established the Ghana National Petroleum Corporation (GNPC) to promote exploration and production, and the company reached agreements with a number of foreign firms. The most important of these permitted companies were the US based Amoco to prospect in ten offshore blocks between Ada and the eastern border with Togo, Petro Canada International had prospected in the Tano River Basin, and Diamond Shamrock in the Keta Basin

(GNPC). These previous exploration activities in these areas were focused on the shallow water and onshore area, mainly targeting tertiary plays and were unsuccessful due to several reasons. There has been some shift from the shallow water areas to the deepwater areas of the offshore basins. Four deepwater wells drilled in Ghana between 1999 and 2003 have proven the existence of an active petroleum system in the deepwater. Significant analogues are the Jubilee and Odum discoveries in the west of the country. Only two exploratory wells were drilled, offshore Keta deep water in 2003 known as Tarpon 1X and also in 2008 known as Cuda 1X.

Exploration offshore Ghana received a tremendous boost with a number of large discoveries recently made in Cape Three points West and Deep Water Tano. Offshore exploration is progressing, both on the continental shelf and in ultra-deep waters.

1.2 Problem Statement

The Gulf of Guinea province has had a lot of exploration and evaluation works done especially in waters within the borders of Ghana. This led to the discovery of oil and gas in commercial quantities in the offshore Tano Basin. Accra-Keta and part of the Central Basins have also seen oil shows in some of the exploratory wells in addition to other surface indicators such as oil seepages which are evident in these areas are indicators of a working petroleum system. Currently, GNPC has licensed blocks to companies which are working extensively on these finds. However, the shallow waters (water depth less than 200 m) of Accra west which forms part of the western end of Accra-Keta Basin is unlicensed and has had two dimensional (2D) seismic exploration coverage by Japan in 1987 and a well drilled in 1975 by Amoco Exploration Company to test for hydrocarbon potential have been lying dormant. This research seeks to reprocess these available data sets using modern technology in order to appropriately evaluate and establish the hydrocarbon potential traps of this unlicensed area and as well estimate total reserve in this area which hitherto was not considered as a bright prospect for hydrocarbon exploration.

1.3 Aims and Objectives

This research seeks to use sophisticated software, Petrel, to process seismic and well log data of the unlicensed area, shallow waters (water depth less than 200 m), of Accra west for the following specific objectives:

1. To look for potential hydrocarbon traps and estimate total reservoir if there is any.
2. To study the stratigraphy of the area using seismic and existing well data from GNPC
3. To use the well data to estimate porosity, water saturation and permeability from the study well
4. To establish a tie between seismic and well data for the estimation of volume of shale and thickness of hydrocarbon zone in the area.
5. To use seismic data to identify pay horizon and the structures associated with it.

1.4 Study Area

The existence of the Gulf of Guinea Province is directly linked with the breakup of the South American and the African continents along the transform margin between the St. Paul and the Romanche Fracture Zones during the Early Cretaceous (Baik et al., 2000). The study area, shallow water west of Accra, is located on the Accra-Keta Basin offshore in the gulf of guinea and it has the dimensions of 2 km by 4 km. The lithology is the Accraian which is considered Mid–Devonian in age and consists predominantly of sandstone and shales, as shown in Figure. 1.1.

This offshore block is situated in the eastern portion of the larger Saltpond Basin, which has historically been considered primarily a Paleozoic Frontier Basin. Across the shelf (less than 200 m), the Lower Cretaceous and Paleozoic sequences are encountered at relatively shallow depths north of the Romanche fault zone (Baik et al., 2000). This fault zone separates the deformed shallow water platform to the north from a gradually subsiding deepwater basin to the south. Significant right lateral displacement along the Romanche fault zone has resulted in an entirely different sedimentary regime from that found shoreward (Baik et al., 2000).

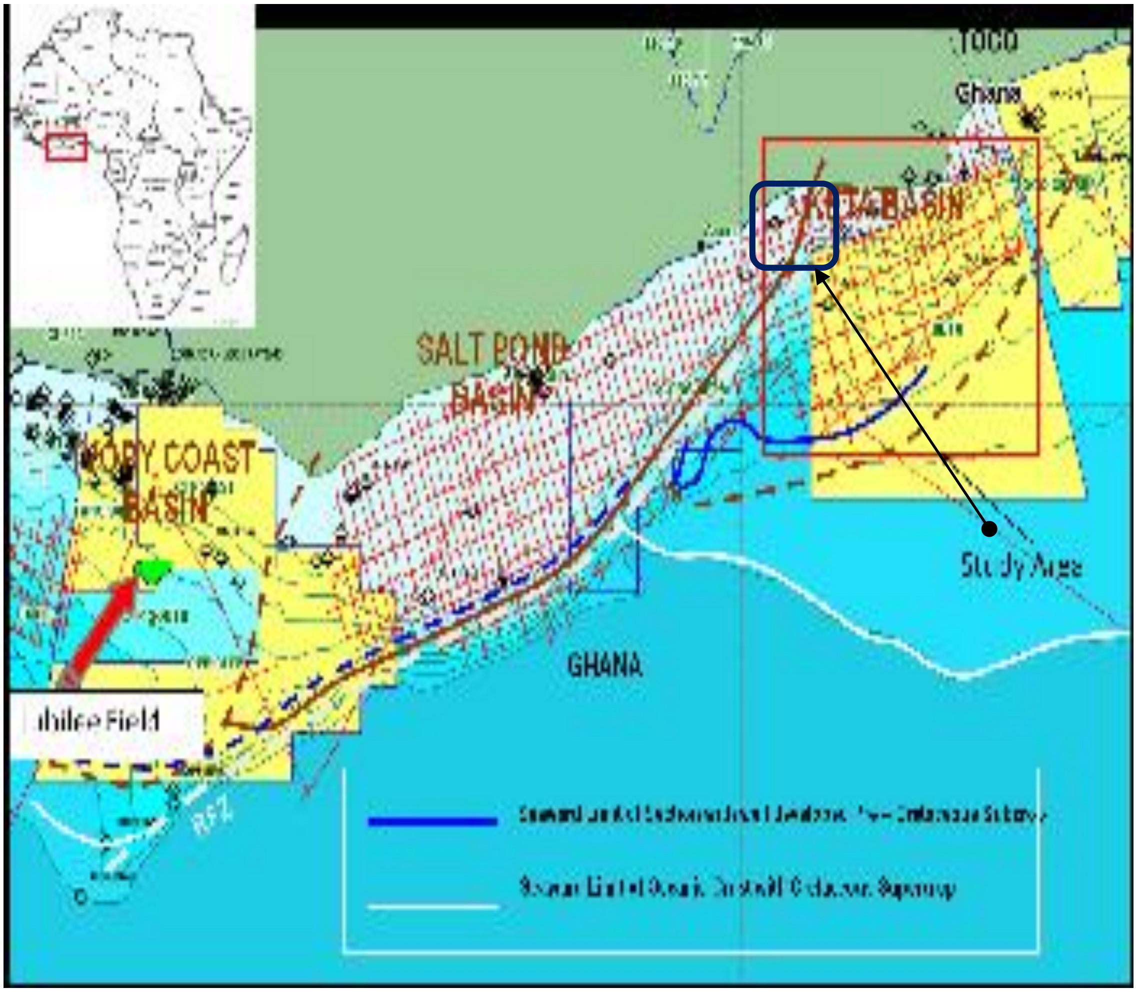


Fig.1.1 Location map of the study area, wells and proximity to other fields in the Gulf of Guinea (source western Geco)

1.5 Scope of Work

This study involves several aspects of hydrocarbon exploration which deals with the processing, interpretation and evaluation of the available data.

The processing aspect deals with editing the data to remove errors and re-arranging these data sets to suit the format which is easily accepted by this sophisticated software called Petrel. This software is used for processing of these data sets to generate structural and attribute maps. The processing also includes modeling of the reservoir and the creation of Stock Tank Oil Originally in place (STOOIP) maps.

The seismic interpretation will be divided into two major parts. Thus, seismic stratigraphy and structural interpretation. The stratigraphic interpretation will be considering the behaviour and the resolution of the reflection amplitudes and frequencies in order to make inferences. While the structural interpretation will deal with picking of horizons, trapping mechanisms like faults and diapiric structures. Furthermore, direct hydrocarbon indicators will also be looked for.

The third aspect is formation evaluation. The formation will be evaluated in other to delineate possible reservoir zone using suite of logs available. These logs will also be used to estimate porosity, water saturation, hydrocarbon saturation and net to gross ratio.

1.6 Justification

In August 2007, Kosmos Energy announced that the Mahogany-1 exploration well offshore Ghana on the West Cape Three Points Block contained a significant oil accumulation based on the results of drilling and wireline logs and sample of the reservoir fluid. The well has encountered to date, a gross hydrocarbon column of 270 m with 95 m of net stacked pay. This success is grossly achieved due to the enhanced data acquisition and processing techniques in finding potential source and reservoir rocks and traps which hitherto were not visible due to poor data processing, visualization and interpretation activities (GNPC, unpublished report). Therefore this study has the tendency to enhance or establish this area as commercially viable for hydrocarbon exploitation since the goal of hydrocarbon exploration is to identify and delineate structural and stratigraphic traps suitable for economically exploitable accumulation (Aizebeokhai and Olayinka, 2010).

1.7 Expected Results

It is envisaged that at the end of this research the following outcomes will be realized.

1. The realized seismic volume will help determine some geological structures
2. Best well ties will be used for mapping the horizons.
3. Structural and grid map of each horizon will be created
4. Bulk volume will be calculated for the mapped zones
5. In each case, distribution of porosity, water saturation, reservoir thickness, permeability will be determined with the help of wire line logs.

CHAPTER TWO

LITERATURE REVIEW

2.1 Geology

Ghana has four sedimentary basins. These are Tano, Accra- Keta, Saltpond and the Voltaian Basins. The source rocks for petroleum and natural gas are mainly sedimentary rocks. It is therefore essential to know exactly where these sedimentary rocks occur within Ghana as they receive first consideration in any evaluation of the possibilities of oil and gas presence within any hitherto unproductive region.

Relatively minor outcrops of sedimentary rocks along the coast from Keta and Accra in the east to Half Assini in the west constitute remnants of rocks of the Phanerozoic coastal basins as shown in Figure. 2.1. From east to west, these rocks occur in the Keta, Accra, Sekondi and Tano basins.

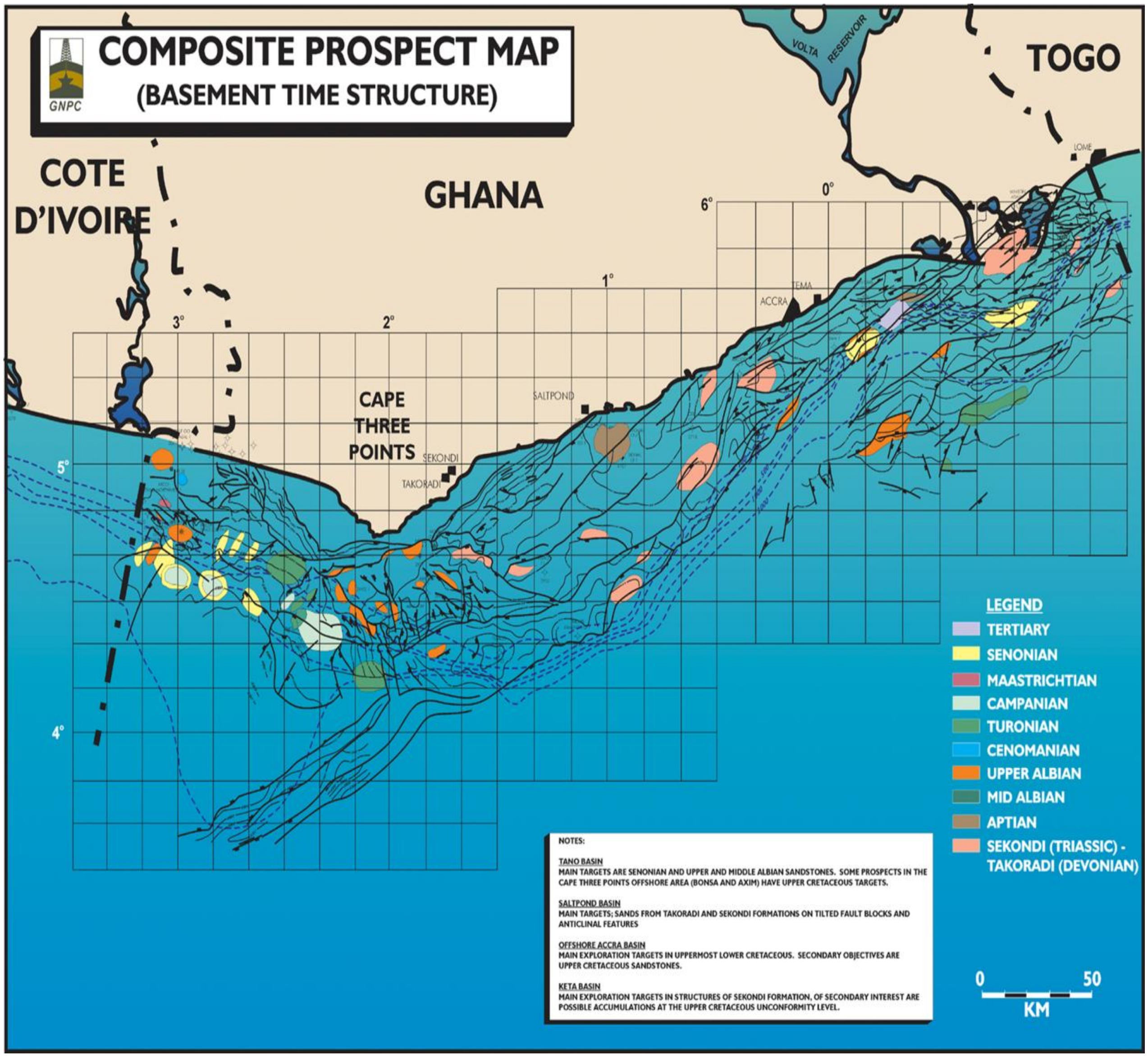
Fortunately, nearly half of Ghana's total area, about 135000 sq. km is covered by sedimentary rocks which are found mainly in four different parts of the country as follow

Table 2.1 Showing area of sedimentary rock coverage in Ghana.

Area	sq. mile	sq. km
Tano basin	450	1165
Accra keta	850	2200
Voltaian basin	10000	103600
Continental shelf	10.642	27562
Total	51942	134527

Rocks of the Accra-Keta basin are of Palaeozoic to recent in age and consist of sandstones, siltstone, shales, claystone and fossiliferous limestone beds (Kesse, 1985). The Accraian is considered mid-Devonian in age and consists predominantly of sandstones and shales which have been folded and faulted (McCallien, 1962). The Sekondian strata is made up of sandstones, shales, silts and beds of chalcedony, sands and pebbly beds and range in age from Devonian to Cretaceous. The Tano Basin is located in the extreme southwestern corner of Ghana. It is made up of Cretaceous-Tertiary sediments consisting of limestones, shales and sands which have a large off-shore extension.

The general spatial alignment between the onshore Precambrian structural fabric and the geometry of the major structural features of the Ghana margin shows that pre-existing zones of weakness were rejuvenated and exploited for the segmentation of the margin during the initial rifting process (Antobreh et al., 2008). Also, it is pointed out that the structural development of the gulf of guinea province may have given rise to the development of a number of important petroleum systems along the margin (Antobreh et al., 2008).



NOTES:

TANO BASIN
MAIN TARGETS ARE SENONIAN AND UPPER AND MIDDLE ALBIAN SANDSTONES. SOME PROSPECTS IN THE CAPE THREE POINTS OFFSHORE AREA (BONSA AND AXIM) HAVE UPPER CRETACEOUS TARGETS.

SALTPOND BASIN
MAIN TARGETS; SANDS FROM TAKORADI AND SEKONDI FORMATIONS ON TILTED FAULT BLOCKS AND ANTICLINAL FEATURES

OFFSHORE ACCRA BASIN
MAIN EXPLORATION TARGETS IN UPPERMOST LOWER CRETACEOUS. SECONDARY OBJECTIVES ARE UPPER CRETACEOUS SANDSTONES.

KETA BASIN
MAIN EXPLORATION TARGETS IN STRUCTURES OF SEKONDI FORMATION, OF SECONDARY INTEREST ARE POSSIBLE ACCUMULATIONS AT THE UPPER CRETACEOUS UNCONFORMITY LEVEL.

Fig. 2.1 Composite prospect map showing minor outcrop of rocks exposed along the coast of Ghana (from GNPC).

2.1.1 Geologic Setting of the Accra-Keta Basin

The Accra-Keta Basin covers an area of about 3755.50 square kilometers, of which 2201.50 sq. km are onshore and the remainder offshore. It is believed that this forms part of the larger Benin Embayment.

The geology of this basin can be divided into 3 major sequences; the pre-rift section, the rift stage of the south Atlantic and the drift stage along the romanche.

In the Accra-Keta, and Saltpond Basins of Eastern and Central Ghana, the pre-transform rocks range in age from Ordovician to Triassic (Kjemperud et al., 1992). The Ordovician to Silurian lacustrine Ajua Formation consists of laminated shales; it is overlain by the fluvial and lacustrine Elmina Formation, composed of feldspathic sandstone and minor conglomerate. Both formations are present only in the Saltpond Basins (Kjemperud et al., 1992). The offshore Accra-Keta Basin, a sub-basin of the Larger Ghana Coast Basin, developed as a part of the transform margin along the Romanche Fracture Zone as Africa separated from South America beginning in the Early Cretaceous. This offshore block is situated in the eastern portion of the Larger Saltpond Basin, which has historically been considered primarily a Paleozoic Frontier Basin. Across the shelf (less than 200 m), the Lower Cretaceous and Paleozoic sequences are encountered at relatively shallow depths north of the Romanche fault zone (Baik et al., 2000). This fault zone separates the deformed shallow water platform to the north from a gradually subsiding deep-water basin to the south (Baik et al., 2000). Significant right lateral displacement along the Romanche fault zone has resulted in an entirely different sedimentary regime from that found shoreward. The orientation and morphology of the Upper Cretaceous deepwater canyons identified in the concession were predominantly influenced by the combination of active strike-slip movement of the Romanche fracture zone and the distribution of the Upper Cretaceous drainage system along the eastern Ghana shelf (Baik et al., 2000).

2.1.2 The Accraian Formation

The Accraian series covers an area of about 11.7 sq. km in vicinity of Accra and unconformably overlies the Dahomeyan basement complex.

The Sedimentary Rocks of Accra are exposed on the beaches and cliffs and existed in the Devonian period of over 350 million years ago. The Accraian can be sub-divided into three formations; with the oldest at the bottom:

1. Upper Sandstone Shale Formation
2. Middle Shale Formation
3. Lower Sandstone Formation

2.1.2.1 Lower Sandstone Formation

This formation extends from the headland near the Osu Fisheries in the east to the end of the rocky shore. These rocks are essentially sandstones with subordinate amount of coarser materials such as grits, breccias and pebble beds, as well as finer grained shales. Many beds show conspicuous current bedding and some of the bedding surfaces are marked by good fossil ripple marks. The sandstone beds can either be massive or thinly bedded. These sandstones dip to the south southwest at 30^0 and lying unconformably on the Dahomeyan rocks.

2.1.2.2 Middle shale formation

The shales have yielded fossils which consist almost exclusively of trilobites and lamellibranchs and are represented by casts, impressions or limonitic films. Trilobites are numerous but belong to two main species. One of these is the well-known Diploura (Homalonotus) Dekayi Green, while the other may be smaller species of the same genus or the young of the same species.

The lamellibranchs belong to the genera nuculites, palaeoneilo, glyptodesma, leiopteria, leptodesma, lunulicardkum, all (except the last named) being closely comparable with North American Middle Devonian species. A hyolithes (probably h. aclis, hall), a pleurotomaria and a lingual complete the list.

2.1.2.3 Upper Sandstone Shale Formation

This interbedded formation consists of thin, fine grained quartzitic sandstones alternating with argillaceous shales. The individual beds are never more than 30 cm in thickness. Thickness of this formation cannot be determined. The beds pass downwards conformably into the underlying shales. The Accraian series is of a lower to middle Devonian in age.

2.2 Petroleum System Development

The structural development of the gulf of guinea has resulted in the development of a number of potentially important petroleum systems in the area (Antobreh et al., 2008). Primary controls for these systems would be the Early Cretaceous phase of rifting and the subsequent wide spread basin development (Antobreh et al., 2008). The syn-rift phase of the opening of the gulf of guinea was characterized by the development of several pull-apart basins both in the shelf areas and the deep-sea provinces (Antobreh et al., 2008). These basins were rapidly in filled by organic rich fluvial and deltaic sediments (Mascle et al., 1988). Preservation of the sediments within the basins therefore constitutes important structural and stratigraphic control for potential exploratory plays in the shelf areas as well as the deep-water provinces (Antobreh et al., 2008). The dominant structural characteristics of these rocks are the northeast-southwest shear zones (Muff and Effa, 2006). The coastal boundary fault defines the contact between Jurassic and Tertiary sedimentary units (Blundell and Banson, 1975). These numerous interconnecting faults along the margin provide the path ways for hydrocarbon migration. The hydrocarbon accumulation occurs mostly in structural traps afforded by the widespread rotated fault blocks associated with the rifted basins and half-grabens (Anthobreh et al., 2008).

2.3 History of Hydrocarbon Exploration

Exploration for hydrocarbons (oil, gas, and condensate) is commonly acknowledged to have begun with the discovery at Oil Creek, Pennsylvania, by "Colonel" Edwin Drake in 1859 (Gale, 2005). Traditionally, oil exploration was conducted by recognizing seeps of hydrocarbons at the surface. Drake's well, the first to intentionally look for oil in the subsurface, was based on direct identification of seeped hydrocarbons at the surface. However, this was only the start of the modern global era of technology-driven advances in exploration. Initially, the oil produced was used to provide kerosene for lamps, but the later invention of automobiles drove up demand and ushered in modern methods of oil exploration.

In the mid-1800s, William Logan, first Director of the Geological Survey of Canada, recognized oil seeps associated with the crests of convex-upward folded rocks and employed a geologist, Thomas Hunt, to formalize his anticlinal theory (Gale, 2005). This idea however, was only recognized as a viable tool for exploration when Spindle top was discovered on the Gulf Coast of Texas in 1901 (Gale, 2005). In the 1920s explorers realized that hydrocarbons could occur in situations where no anticline was preserved. For example, it was noted as far back as 1880 that oil was trapped in the Venango Sands of Pennsylvania, not in the form of an anticlinal structure, but by the lithologies occurring in a moving palaeoshoreline. In fact, oil trapped by stratigraphy was discovered more often by chance rather than design even until the 1970s (Gale, 2005).

By the 1920s, mapping of surface features was complimented by the development of seismic refraction, gravity, and magnetic geophysical methods (Gale, 2005). At this time, another significant advance in exploration of the subsurface took place with the application of geophysical techniques by the Schlumberger brothers to measuring properties of rocks and fluids encountered whilst drilling for hydrocarbons (Gale, 2005).

In France in 1927, they initially measured the resistivity of the rocks in shallow wells (drilled primarily for water distribution), but later went on to add other electric, sonic, and radioactive logging tools (Schlumberger, 1991). It is now even possible to log porosity**,** permeability**,** mineralogy, and fluids and image the structures and rock type’s downhole.

2.4 Seismic Method

The theory of seismic wave propagation in acoustic, elastic and anisotropic media was developed to allow seismic waves to be modeled in complex, realistic three-dimensional Earth models.

1D and 2D basin modeling tools have been used within oil companies for exploration purposes for approximately ten years (Doligez et al., 1986). In this method, elastic waves are sent into the subsurface, and subsequently the energy is recorded that arrives back at the surface. This recorded energy is due to reflection, diffraction and refraction at subsurface boundaries. These boundaries are interfaces between layers of the earth that have different acoustic and elastic properties (Kearey et al., 2002).

Much of the seismic theory was developed prior to the availability of instruments that were capable of sufficient sensitivity to permit significant measurement. In 1845, Mallet tried to measure the velocities in an experiment using artificial earthquakes (Telford et al., 1990). In

1889, Knott developed the theory of reflection and refraction and in 1907 the wave theory was published by Zoeppritz and Wiechert. In the early 1920's karcher developed a reflection seismograph that saw field use in Oklahoma (Telford et al., 1990). The application of the seismic method to the search for petroleum began in the US Gulf Coast in 1924, when Orchard Salt Dome Field (Texas) was discovered (Telford et al. 1990). Here, a refraction seismic survey method was used. It exploits the property whereby much seismic energy travels along the interface between lithologies that have different acoustic properties. Three years later (1927), a reflection seismic survey was employed to aid definition of the Maud Field (Oklahoma) (Telford et al., 1990). Today, reflection seismic survey methods, which are suited to relatively low dipping strata, are used most commonly in the search for petroleum. Reflection survey methods remain the favored method for those Earth Scientists who are studying the deep structure of the Earth.

The seismic data are combined with any available geological information and well data to determine as accurately as possible the subsurface structure and the material properties of the subsurface layers. The seismic methods, involving the application of various advanced data processing techniques, had developed into one of the most valuable tools for finding accumulations of oil and gas.

2.4.1 Seismic Survey

In seismic surveying, seismic waves are created by a controlled source and propagate through the subsurface. Some waves will return to the surface after refraction or reflection at geological boundaries within the subsurface. Instruments (geophones) distributed along the surface detect the ground motion caused by these returning waves and hence measure the arrival times of the waves at different ranges from the source (Kearey et al., 2002).

2.4.2 Seismic Waves

Seismic waves are parcels of elastic strain energy that propagate outwards from a seismic source such as an earthquake or an explosion. Sources suitable for seismic surveying usually generate short-lived wave trains, known as pulses that typically contain a wide range of frequencies. Except in the immediate vicinity of the source, the strains associated with the passage of a seismic pulse are minute and may be assumed to be elastic. On this assumption the propagation velocities of seismic pulses are determined by the elastic moduli and densities of the materials through which they pass (Kearey et al., 2002).

There are two groups of seismic waves;

1. Body waves and
2. Surface waves.

2.4.2.1 Body Waves

Body waves can propagate through the internal volume of an elastic solid and are of two types; primary and shear waves. Compressional waves (the longitudinal, primary or P-waves of earthquake seismology) propagate by compressional and dilational uniaxial strains in the direction of wave travel. Particle motion associated with the passage of a compressional wave involves oscillation, about a fixed point, in the direction of wave propagation. Shear waves (the transverse, secondary or *S*-waves of earthquake seismology) propagate by a pure shear strain in a direction perpendicular to the direction of wave travel as shown in figure 2.2. Individual particle motions involve oscillation, about a fixed point, in a plane at right angles to the direction of wave propagation. If all the particle oscillations are confined to a plane, the shear wave is said to be plane-polarized (Kearey et al., 2002).

Historically, most seismic surveying involve only compressional waves, since this simplifies the survey technique in two ways (Kearey et al., 2002). Firstly, seismic detectors which record only the vertical ground motion can be used, and these are insensitive to the horizontal motion of S-waves. Secondly, the higher velocity of P-waves ensures that they always reach a detector before any related S-waves, and hence are easier to recognize (Kearey et al., 2002). Recording S-waves, and to a lesser extent surface waves, gives greater information about the subsurface, but at a greater cost of data acquisition. As technology advances multicomponent surveys are becoming more commonplace (Kearey et al., 2002).

2.4.2.2 Surface Waves

In a bounded elastic solid, seismic waves known as surface waves can propagate along the boundary of the solid. Rayleigh and love waves propagate along a free surface, or along the boundary between two dissimilar solid media, the associated particle motions being elliptical in a plane perpendicular to the surface and containing the direction of propagation (Kearey et al., 2002). The orbital particle motion is in the opposite sense to the circular particle motion associated with an oscillatory water wave, and is therefore sometimes described as retrograde. A further major difference between Rayleigh waves and oscillatory water waves is that the former involve a shear strain and are thus restricted to solid media (Kearey et al., 2002). The amplitude of Rayleigh waves decreases exponentially with distance below the surface as shown in figure 2.2. They have a propagation velocity lower than that of shear body waves and in a homogeneous half-space they would be non-dispersive (Kearey et al., 2002). In practice, Rayleigh waves travelling round the surface of the Earth are observed to be dispersive, their waveform undergoing progressive change during propagation as a result of the different frequency components travelling at different velocities (Kearey et al., 2002). This dispersion is directly attributable to velocity variation with depth in the Earth's interior. Analysis of the observed pattern of dispersion of earthquake waves is a powerful method of studying the velocity structure of the lithosphere and asthenosphere (Knopoff, 1983). The same methodology, applied to the surface waves generated by a sledgehammer, can be used to examine the strength of near-surface materials for civil engineering investigations.

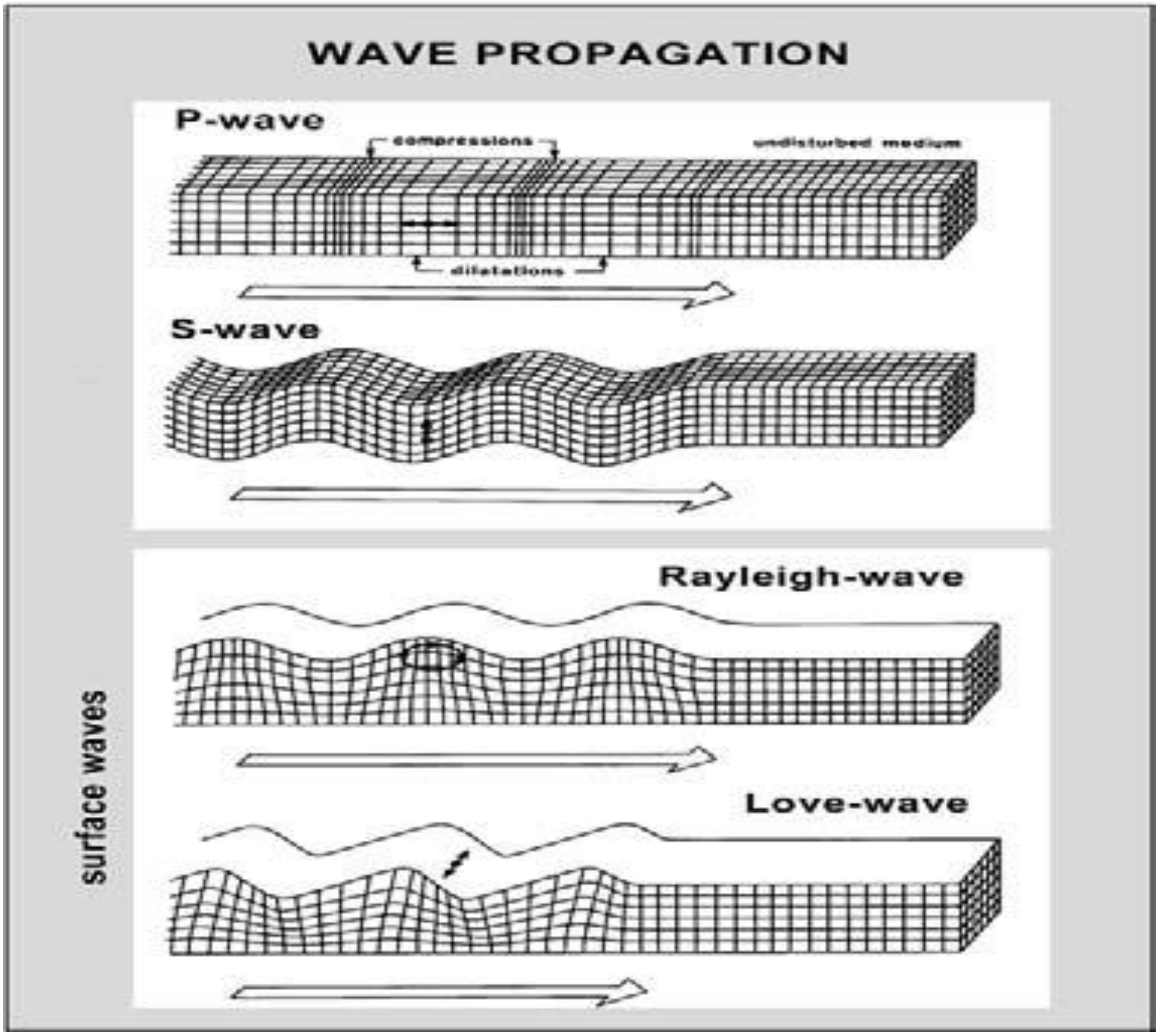


Fig. 2.2 P-waves S-wave, Love and Raleigh waves (modified after Kearey and Brooks, 1991).

2.4.3 The Seismic Reflection Method

Reflection seismology (or seismic reflection) is a geophysical method that uses the principles of seismology to estimate the properties of the Earth's subsurface from seismic waves. The method requires a controlled seismic source of energy, such as dynamite/ Tovex, a specialized air gun or a seismic vibrator, commonly known by the trademark name Vibroseis.

In simple terms and for all of the exploration environments, the general principle is to send sound energy waves (using an energy source like dynamite or Vibroseis) into the Earth, where the different layers within the Earth's crust reflect back this energy. These reflected energy waves are recorded over a predetermined time period (called the record length) by using hydrophones in water and geophones on land. The reflected signals are output onto a storage medium, which is usually a magnetic tape. The general principle is similar to recording voice data using a microphone onto a tape recorder for a set period of time. Once the data is recorded onto a tape, it can then be processed using specialist software which will result in processed seismic profiles being produced. These profiles or data sets can then be interpreted for possible hydrocarbon reserves.

The time it takes for a reflection from a particular boundary to arrive at the geophone is called the one way travel time. If the seismic wave velocity in the rock is known, then the travel time may be used to estimate the depth to the reflector. For example a single horizontal reflector lying at a depth z beneath a homogeneous top layer of velocity V. The equation for the travel time t of the reflected ray from a shot point to a detector at a horizontal offset, or shot–detector separation, x is given by the ratio of the travel path length to the velocity (Kearey et al., 2002)

$t = (x^2 + 4z^2)^{1/2} / V$……………………(2.0) (Kearey et al., 2002)

Where Z is the depth to the reflector surface

X is offset distance and

V is the wave velocity in the rock.

A series of apparently related reflections on several seismograms is often referred to as a reflection event. By correlating reflection events, a seismologist can create an estimated cross-section of the geologic structure that generated the reflections. Interpretation of large surveys is usually performed with programs using high-end three dimensional computer graphics.

2.5 Borehole Logging

Wireline logging refers to the practice within the oil and gas industry of lowering a logging device attached to a wireline into a borehole or oil well to measure the properties of the rock and fluids of the formation. The measurements obtained are then interpreted and used to determine the depths and zones where oil and gas can be found. The continuous recording of a geophysical parameter along a borehole produces a geophysical well log. The value of the measurement is plotted continuously against depth in the well (Ryder, 2002).

In 1931, Henri George Doll and G. Dechatre, working for Schlumberger, discovered that the galvanometer wiggled even when no current was being passed through the logging cables down in the well. This led to the discovery of the spontaneous potential (SP) which was as important as the ability to measure resistivity. The SP effect was produced naturally by the borehole mud at the boundaries of permeable beds. By simultaneously recording SP and resistivity, loggers could distinguish between permeable oil-bearing beds and impermeable nonproducing beds (Telford et al., 1990).

In 1940, Schlumberger invented the spontaneous potential dipmeter; this instrument allowed the calculation of the dip and direction of the dip of a layer. The basic dipmeter was later enhanced by the resistivity dipmeter in 1947 and the continuous resistivity dipmeter in 1952 (Schlumberger, 1991).

Oil-based mud (OBM) was first used in Rangely Field, Colorado in 1948. Normal electric logs require a conductive or water-based mud, but Oil-based muds are nonconductive. The solution to this problem was the induction log, developed in the early 1950s (Schlumberger, 1991).

The introduction of the transistor and integrated circuits in the 1960s made electric logs vastly more reliable. Computerization allowed much faster log processing, and dramatically expanded log data-gathering capacity. The 1970s brought more logs and computers. These included combo type logs where resistivity logs and porosity logs were recorded in one pass in the borehole.

The two types of porosity logs (acoustic logs and nuclear logs) date originally from the 1940s. Sonic logs grew out of technology developed during World War II. Nuclear logging has supplemented acoustic logging, but acoustic or sonic logs are still run on some combination logging tools (Telford et al., 1990).

Nuclear logging was initially developed to measure the natural gamma radiation emitted by underground formations. However, the industry quickly moved to logs that actively bombard rocks with nuclear particles. The gamma ray log, measuring the natural radioactivity, was introduced by Well Surveys Inc. in 1939, and the Well Survey Incorporation neutron log came in 1941 (Telford et al., 1990). The gamma ray log is particularly useful as shale beds which often provide a relatively low permeability cap over hydrocarbon reservoirs usually display a higher level of gamma radiation. These logs were important because they can be used in cased wells (wells with production casing) (Schlumberger, 1991). Many modern oil and gas wells are drilled directionally. At first, loggers had to run their tools somehow attached to the drill pipe if the well was not vertical. Modern techniques now permit continuous information at the surface. This is known as logging while drilling (LWD) or measurement-while-drilling (MWD). Measurement while drilling logs use mud pulse technology to transmit data from the tools on the bottom of the drillstring to the processors at the surface (Schlumberger, 1991).

2.6 Exploration History Of Ghana Margin

Exploration in the Accra-Keta Basin area has been minimal as compared to the Jubilee Fields in the deep water Sub-Tano Basin. Exploration began in the early sixties and the initial work was basically gravimetric surveys onshore. Subsequent drilling of 2 onshore wells encountered some hydrocarbon shows and these Wells provided evidence of enough sedimentary cover and rock types to spur on further exploration. More exploration work followed with more onshore and offshore wells have been drilled as shown on table 2 (GNPC).

Although exploration has been undertaken in Ghana for decades, it wasn't until recently that adequate capital has been invested into the exploration of Ghana's oil and gas potential. Ghana has four off-shore sedimentary basins known to hold oil and gas:

1. Tano Basin,
2. Saltpond Basin,
3. Accra/Keta Basin, and
4. Cape Three Points Basin.

These four have been well explored in recent years. The Voltaian Basin, which is on-shore, has yet to be fully explored. The Ghanaian government has put in a request to expand its continental shelf, which is currently being reviewed by the United Nation's Convention on the Law of the Sea (UNCLOS). It is likely to be approved and would open up further opportunities for exploration off Ghana's shores.

The site of the initial commercial oil and gas find is now known as Jubilee Field, and is located in the Tano and Cape Three Points Basins. It is estimated to hold oil reserves of between 800 million and 3 billion barrels. It is also believed to hold substantial natural gas reserves. Countrywide, Ghana is estimated to have gas reserves between 1.5 and 1.7 Trillion Cubic Fit (Tcf). Since the Jubilee Field discovery in 2007, additional substantial discoveries have been made. In September 2010, Tullow Oil announced its discovery of between 70 million and 550 million barrels in the Owo field, located nearby the Jubilee Field. Exploration continues to intensify and it is expected that more discoveries will be made both on and off-shore. This budding upstream oil and gas industry holds great opportunity (Source, GNPC).

Table 2.2 Showing Exploration History – Wells Drilled in Basin up to 2003 (GNPC)

Well Name	Year Drilled	TD (ft)	Location	Remarks
Atiavi-1	1966	5152	Onshore	Permanently Abandoned (P&A)
Anloga-2	1967	6995	Onshore	P & A
UC 19-1A	1970	7075	Offshore	P & A
Keta-1	1970	9143	Offshore	P & A Shows in L. Cret
UC 19-2A	1970	9079	Offshore	P & A
Dzita-1	1973	13448	Onshore	P & A Shows in Devonian
Amoco 16-1	1975	11527	Offshore	P & A Live oil in ZASZAS L. Cret
Sevilla-1	1986	6130	Onshore	P & A
Tema-1	1990	11855	Offshore	P & A
Dolphin-1	2000	9010	Offshore	P & A
NAK-1X	2001	10100	Offshore	P & A
Tarpon-1	2003	11457	Offshore	P & A

CHAPTER THREE

METHODOLOGY

This research seeks to evaluate the hydrocarbon potential in the shallow waters west of Accra basin using 2D seismic data with a well located within the area of the seismic coverage. The 2D seismic data was acquired by Japan in 1987 and the Well by Amoco Company in 1975.

Hydrocarbon potential exploration may be classified into three major stages.

1) Gathering of relevant information to establish the viability of the area; this is known as the desk top study.
2) The second stage is the data acquisition stage which deals with procedures used during data acquisition and it also involves processing of the data to remove error and finally filtering the data to smoothen it.
3) The third stage is the post data acquisition which involves the quality controlling and uploading the data into software for processing, analyzing and developing models.

This work revolves around the third aspect of the methods in hydrocarbon exploration. The software used for processing, interpretation and modeling in this work is petrel 2010.1 from Schlumberger.

The approach to this work can be divided into three major parts:

1) Stratigraphic analysis

2) Geophysics

3) Modeling

The data for this work was acquired from GNPC and it includes 20 lines of 2D seismic data comprising of 14 North to South sail line seismic section and 6 East to West sail line sections in addition to data from a well located within the area covered by the 2D seismic survey lines as shown in figure 3.1. These data were loaded into petrel software to begin the processing and building a model for the area.

First of all, the data was quality checked in order to remove errors that came with it. Since quality controlling data during processing and interpretation should never be compromised (Dasilva et al., 2004). Also, rearrangement of the data was done to suit petrel format after which the data was loaded into petrel 2010.1 in their respective format.

The process began by first loading the well header, well deviation, and then followed by the well log and then well tops. The check shots were also loaded and finally the SEGY data which is the 2D seismic was also loaded. Volume rendering was a technique applied on this seismic volume to bring out features (structures) which might be hidden on the original seismic volume for easy identification of hydrocarbon indicators and fracture patterns.

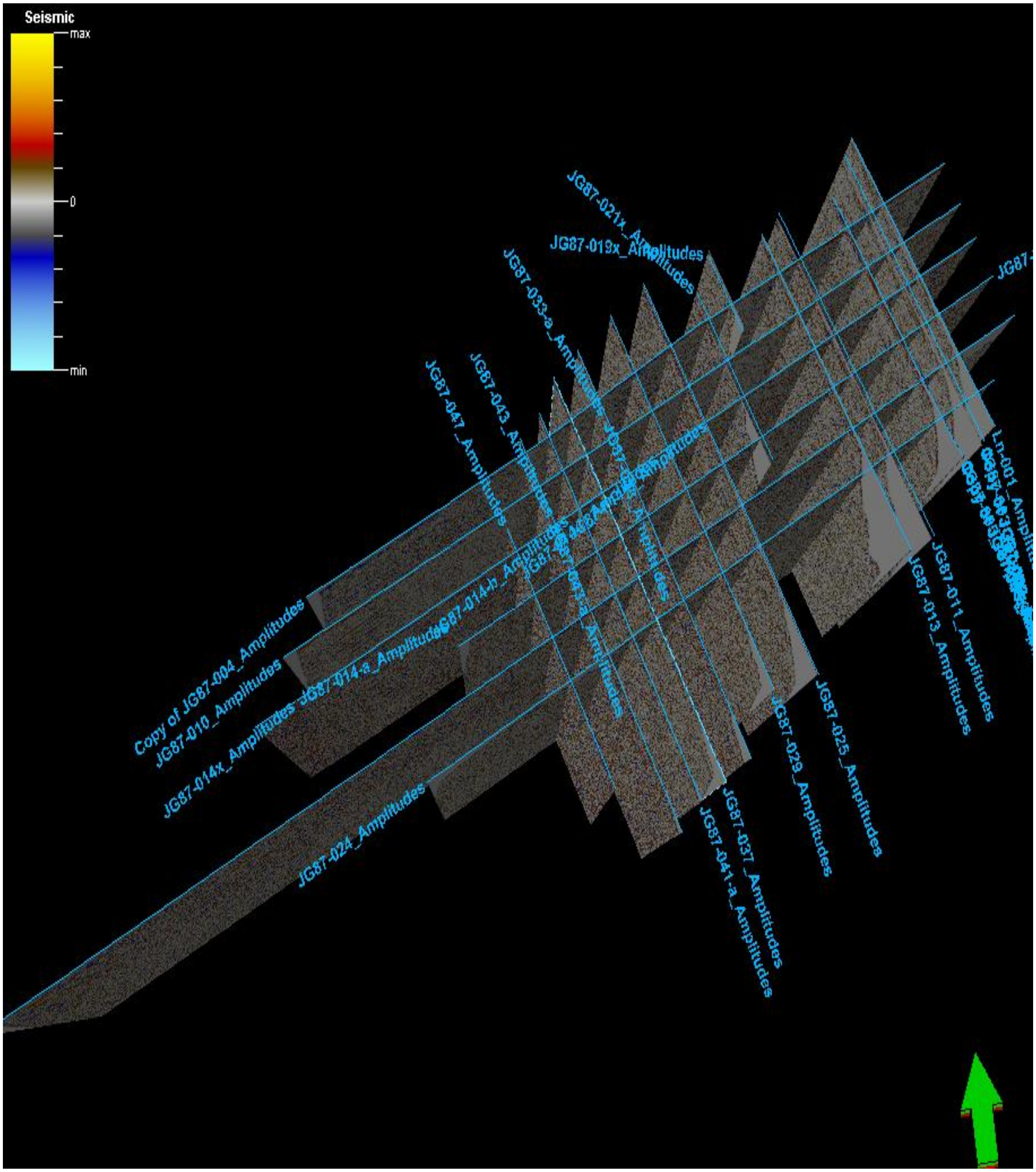


Fig. 3.1 Showing 2D seismic lines

3.1 Stratigraphic Analysis

During the stratigraphic modeling process the formation was evaluated to better understand the subsurface geology at well location. The signatures of the logs were used to infer the type of lithology. The SP and the GR log were used to differentiate potentially porous and water permeable reservoir rocks (sandstone, limestone, and dolomite) from non-permeable Clays and Shales. The log signatures were also used to calculate certain parameters such as Vsh (volume of shale), net to gross, porosity, Sw (water saturation) and Sh (hydrocarbon saturation).

3.1.1 Reservoir Rock Delineation

Gamma ray log in conjunction with the SP log were used to delineate permeable reservoir rocks (sandstone, dolomite and limestone) from the non-permeable rocks such as the clays and shales. This is because the spontaneous potential (SP) curve and the natural gamma ray (GR) log are recordings of naturally occurring physical phenomena in in-situ rocks. The SP curve records the electrical potential (voltage) produced by the interaction of formation connate water, conductive drilling fluid and certain ion-selective rocks (shale). The GR log indicates the natural radioactivity of the formations.

3.1.2 The Spontaneous Potential (SP)

Opposite shales the SP curve usually defines a more or less straight line on the log, called the shale baseline as shown in figure 3.2. Opposite permeable formations, the curve shows excursions from the shale baseline; in thick beds, these excursions (deflections) tend to reach an essentially constant deflection defining a sand line (Ryder, 2002). The deflection may be either to the left (negative) or to the right (positive), depending primarily on the relative salinities of the formation water and of the mud filtrate. If the formation water salinity is greater than the mud filtrate salinity, the deflection is to the left. For the reversed salinity contrast, the deflection is to the right.

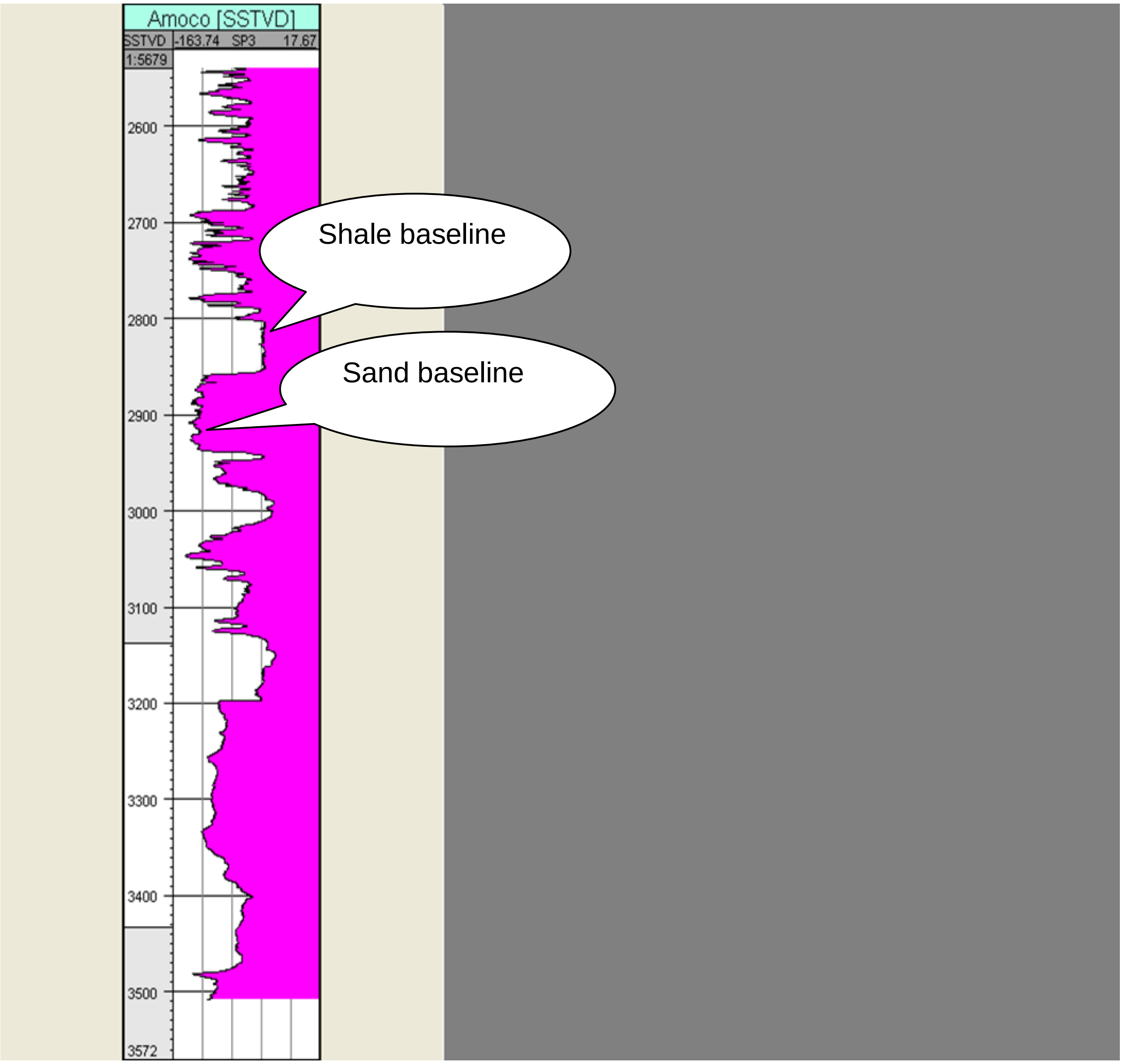


Fig. 3.2 Showing shale baseline and sand line

3.1.3 The Gamma Ray (GR) Log

The GR log is a measurement of the natural radioactivity of the formations. In sedimentary formations the log normally reflects the shale content of the formations. This is because the radioactive elements tend to concentrate in clays and shales as shown in **figure. 3.3**. Clean sand formations usually have a very low level of radioactivity, unless radioactive contaminant such as volcanic ash or granite wash is present or the formation waters contain dissolved radioactive salts.

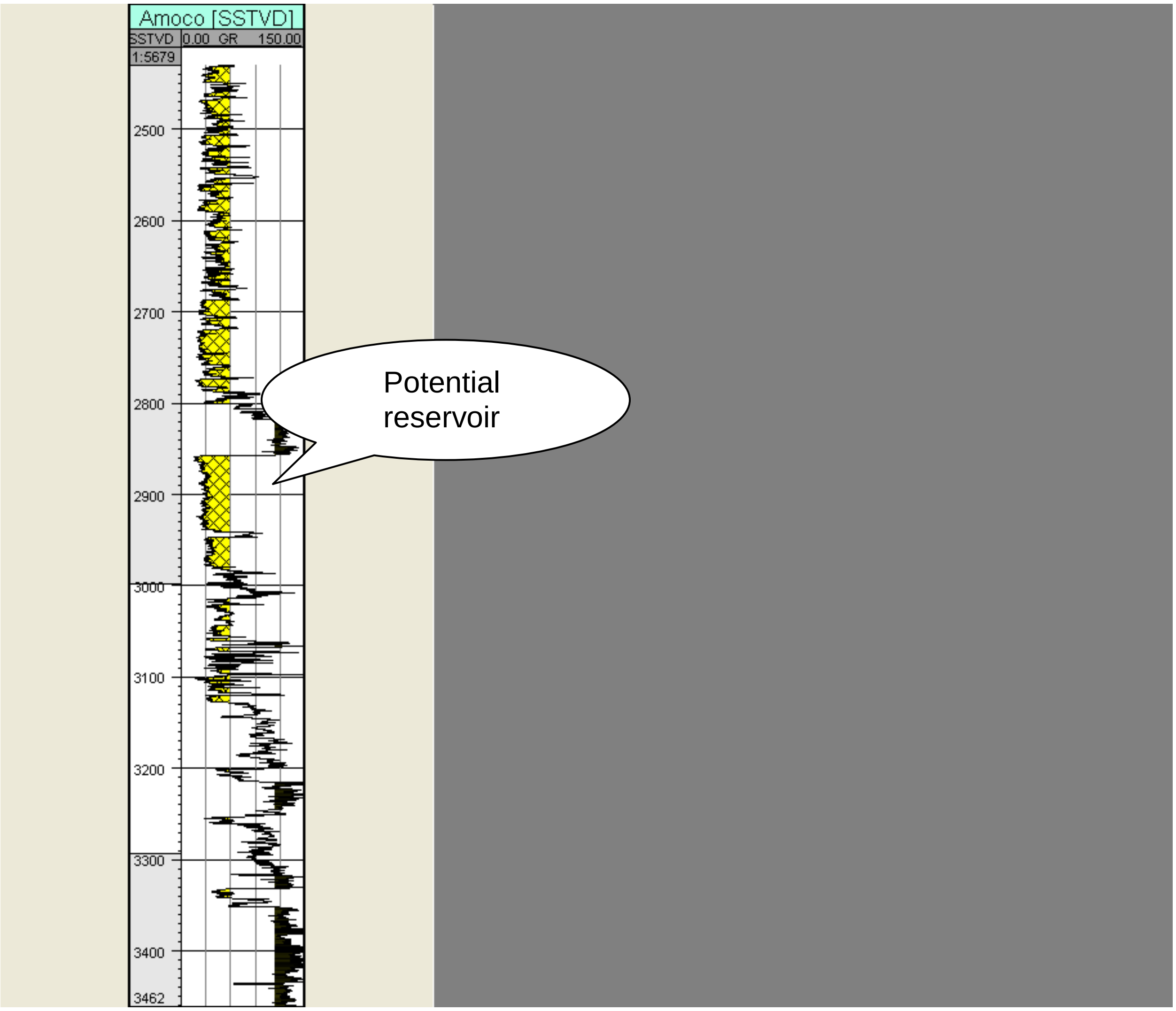


Fig. 3.3 Showing gamma ray log indicating porous formation (Yellow)

3.1.4 Facies

Facies was created using the Gamma ray log. This was done for easy identification of reservoir areas from non-reservoir areas.

A facies was created using the gamma ray log and an API (American Petroleum Association) unit of 60. This value was settled on after experimenting with API values of 45 and 50 which gave results indicating that the formation was lacking porous and permeable zone (sandstone, limestone, and dolomite). The API unit to 70 was used and the whole formation became sandy. API unit of 60 which is the standard value for the Gulf of Guinea was finally used because; it gave a good balance between the lithology and it also corresponds to the SP log signature as shown in figure 3.4. The theoretical maximum deflection of the SP opposite permeable beds is called the static spontaneous potential (SSP) which corresponds with the zones or the sand units within the facies. This SSP represents the SP value that would have been observed in an ideal case with the permeable bed isolated electrically (Sclumberger, 1991). Where Gr. is indicating to be sand clearly corresponds with Sp deflection to the left towards the sand line.

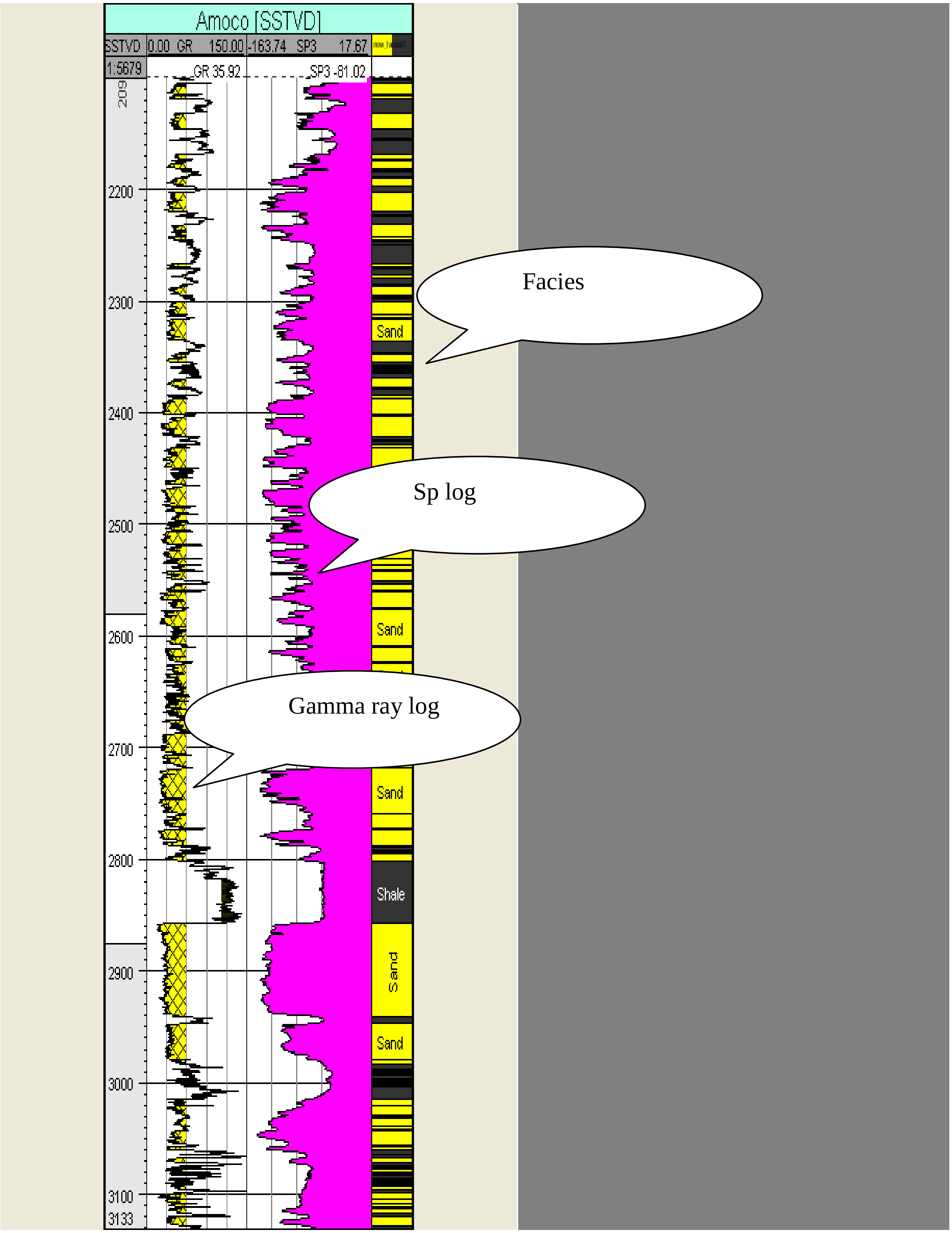


Fig. 3.4 Showing gamma, spontaneous potential and facies logs

3.1.5 Hydrocarbon Delineation

Almost all oil and gas produced today come from accumulations in the pore spaces of reservoir rocks usually sandstones, limestones, or dolomites. The amount of oil or gas contained in a unit volume of the reservoir is the product of its porosity by the hydrocarbon saturation. In addition to the porosity and the hydrocarbon saturation, the volume of the formation containing hydrocarbons is needed in order to estimate total reserves and to determine if the accumulation is commercially viable. Knowledge of the thickness and the area of the reservoir are needed for computation of its volume.

To evaluate the producibility of a reservoir, it is necessary to know how easily fluid can flow through the pore system. This property of the formation rock, which depends on the manner in which the pores are interconnected, is its permeability (Desbrandes, 1985). The main petrophysical parameters needed to evaluate a reservoir, then, are its porosity, hydrocarbon saturation, thickness, area, and permeability. In addition, the reservoir geometry, formation temperature and pressure, and lithology can play important roles in the evaluation, completion, and production of a reservoir.

3.1.6 Porosity

Rock porosity can be obtained from the sonic log, density and neutron logs. Since there is no neutron log for this study, sonic and density cross plot was used to determine the lithology and porosity of the reservoir formation. Crossplots are a convenient way of demonstrating how various combinations of logs respond to lithology and porosity. They also provide visual insight into the type of mixtures that the combination is most useful in unraveling that is they are useful for determining some evaporates such as rock salt and anhydrites (Schlumberger, 1991). This was done by plotting an average reading of the density log and the sonic log of the zone of interest on the density –sonic crossplot as shown in appendix C2 (AP. C2).

3.1.7 Volume of Shale

The volume of shale (Vsh) in the reservoir zone was determined using the SP logs. This was done by reading the SP value at zones where the SP indicates to be clean, porous sand and where these signatures also indicate as pure shale. The SP readings for the zones of interest were also read and these values were put into the formula bellow.

$$Vsh = PSP - SSP / SPsh - SSP \qquad (3.1)$$

Vsh: Volume of shale

SSP: Maximum deflection over porous clean sand

PSP: SP reading when shale is present (Pseudo static sp)

SP: SP response due to the presence of thin beds.

3.1.8 Water Saturation Determination

Saturation of a formation is a fraction of its pore space occupied by fluids. Water saturation is the portion or fraction of the pore volume being occupied by water. It is generally assumed, unless otherwise known that the pore volume not filled with water is filled with hydrocarbons.

The resistivity of a formation is a very good indicator of the type of fluid present in the pore space of that formation. Hydrocarbons do not conduct or are poor conductors of electrical current but water is a very good conductor of electrical current. Generally, there is some level of water saturation Sw in all formations though formations without water exist. The amount of water and hydrocarbon present in the pore space of a formation is generally determined by the log signature of the resistivity log. The existence of a water saturation less than 100% generally implies that a hydrocarbon saturation equal to 100% less than the water saturation (1-Sw).

All water saturation determinations from resistivity logs in clean (non-shaly) formation with homogeneous intergranualar porosities are based on Achie's equation.

- $S_w = [\ (a / \Phi^m)*(R_w / R_t)\ ]^{(1/n)}$
- S_w: water saturation
- Φ: porosity
- R_w: formation water resistivity
- R_t: observed bulk resistivity
- a: a constant (often taken to be 1)
- m: cementation factor (varies around 2)
- n: saturation exponent (generally 2)

3.2 Geophysics

Before any geophysical interpretation was done, the logs signatures in the borehole were used to delineate areas of interest or possible reservoir areas. A carefully chosen suit of logs such as gamma log, resistivity and density were also used to delineate areas of possible hydrocarbon accumulation. These logs were chosen because

1) The gamma log helps to differentiate between possible reservoir rock (porous and permeable) from non-reservoir rocks.
2) The resistivity log was used to differentiate between formation water and possible hydrocarbon accumulation since water turns to conduct electricity thereby giving low resistivity whiles in the case of hydrocarbons high resistivity is observed due to their poor conduction.

3) Finally, the bulk density was used to quality check areas which have low gamma and high resistivity because bulk density drops when there are fluid within these areas but if bulk density is also still high then it is not possible it is hydrocarbon but rather lithology.

3.2.1 Cropping

The 2D seismic data was cropped to remove or cut off unwanted areas of the seismic volume. This can also be thought of as an action of defining a region of interest and it makes the seismic volume smaller that is usually faster and convenient to work with.

3.2.2 Realize

This is a process of creating a copy of the seismic volume of 2D lines. A realized seismic file is created in petrel's internal binary format (2D lines); it is usually noticeably faster in use compared to using the original SGY data format. This also helps in seismic visualization as shown in figure 3.5.

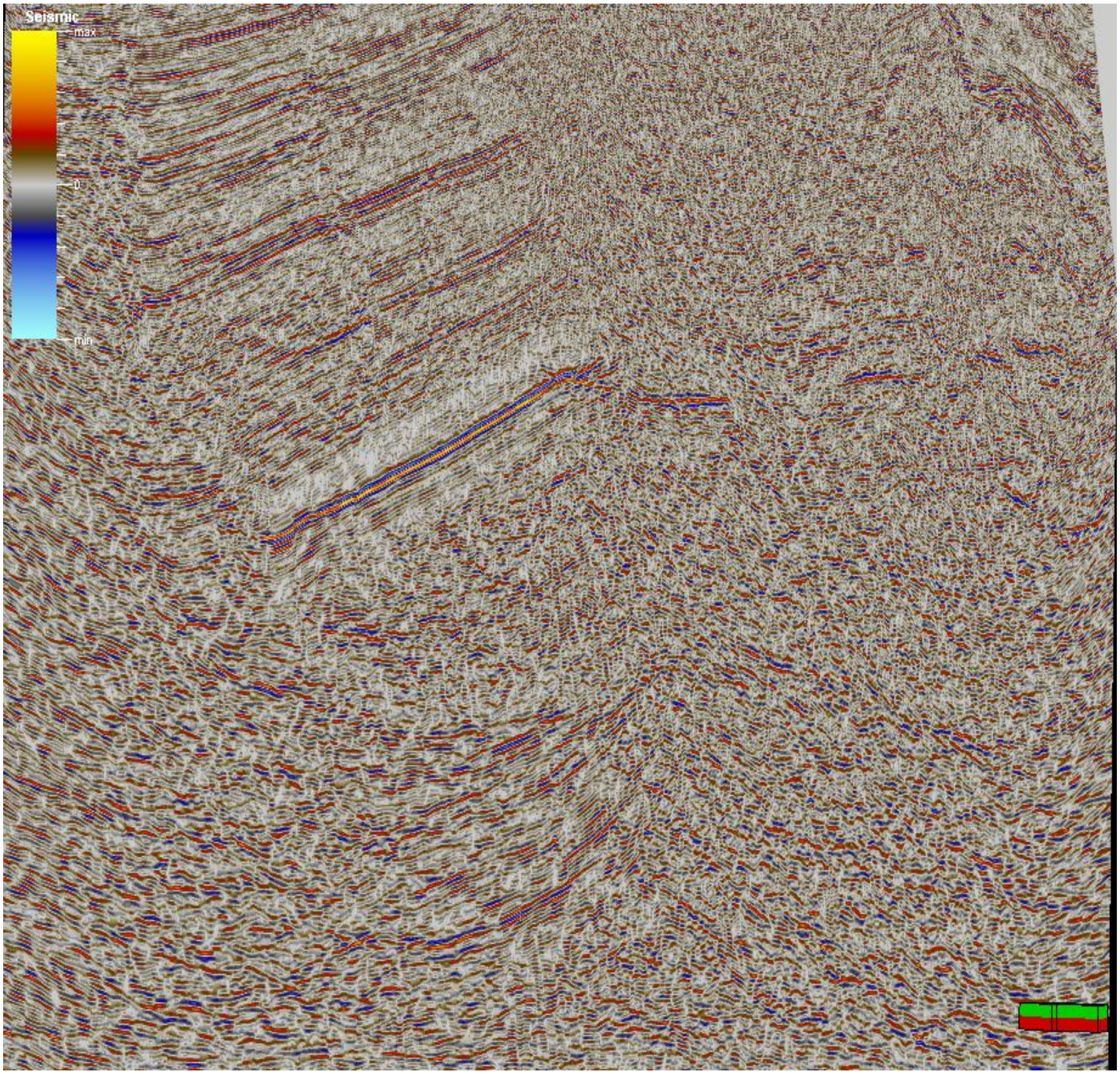


Fig. 3.5showing the realized seismic section

3.2.3 Volume Rendering

Volume rendering is by making the seismic volume partly opaque and partly transparent for easy identification of hidden structural and depositional features. This process was performed on the cropped seismic volume.

3.2.4 Seismic Volume Attribute Analysis

Since the 2D seismic is not of high quality, there is so much noise in the data that after realizing the data, high reflectance were not clearly outstanding hence Several volume attribute generation process were performed on the 2D seismic which helped to enhance visualization as shown in figure 3.6. This brought out information that might be subtle in traditional seismic, and it led to a better interpretation of the seismic data.

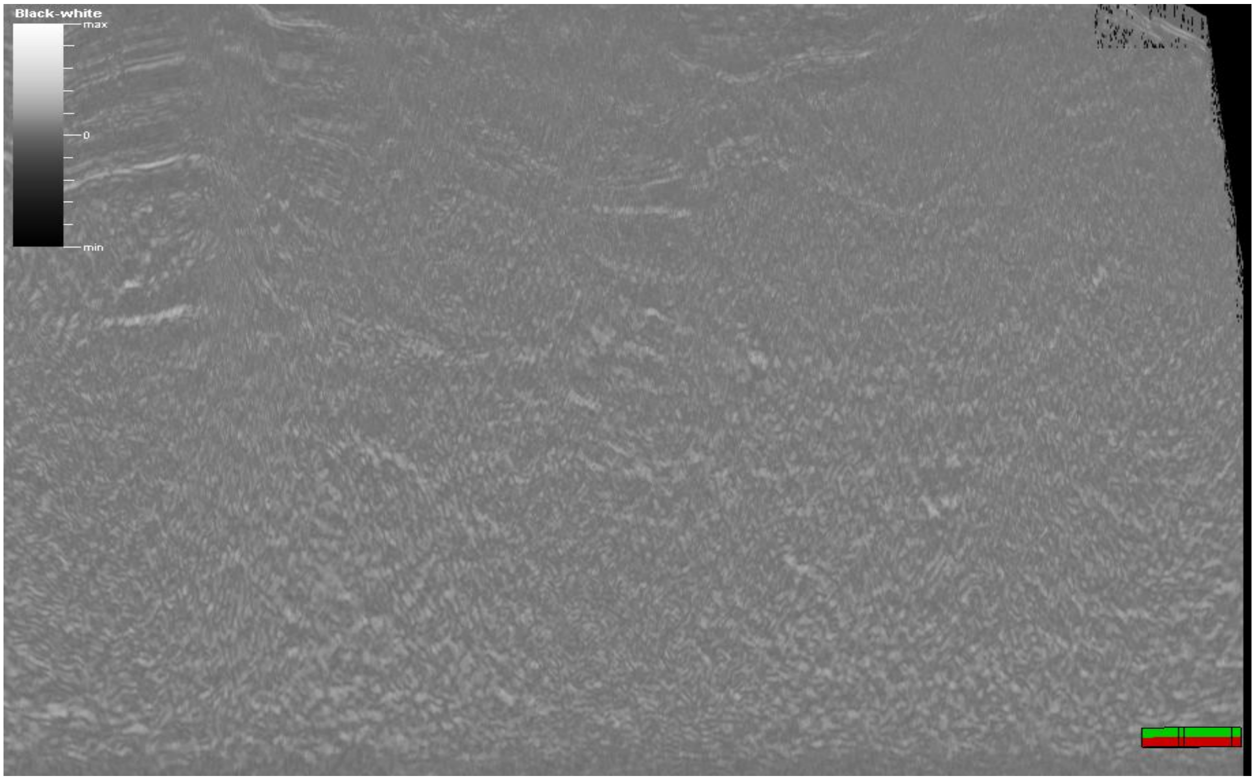


Fig. 3.6 Showing volume Attribute (structural smooth)

3.2.5 Seismic to Well Tie

Seismic to well tie process found under geophysics in the process pane, was the approach used to generate synthetic seismogram.

This serves as the bridge between time and depth where a synthetic seismogram is created. Synthetic seismogram is the bridge between geological information (well data in depth) and geophysical information (seismic in time). This essentially involves a two-step process.

1) Time converting the wells by means of check shot data and sonic logs, establishing time-depth relationships for the wells
2) Generating synthetic seismogram from density log, sonic log and seismic wavelet by calculating acoustic impedance and reflection coefficient, which were convolved using a wavelet (Schlumberger, 2010).

Changes to the time–depth relationship can be made and seismic horizon can be correlated with the stratigraphic boundaries identified in the well logs (AP.A).

This generated synthetic seismogram is used as the starting point for seismic interpretation as shown in figure 3.7 and figure 3.8.

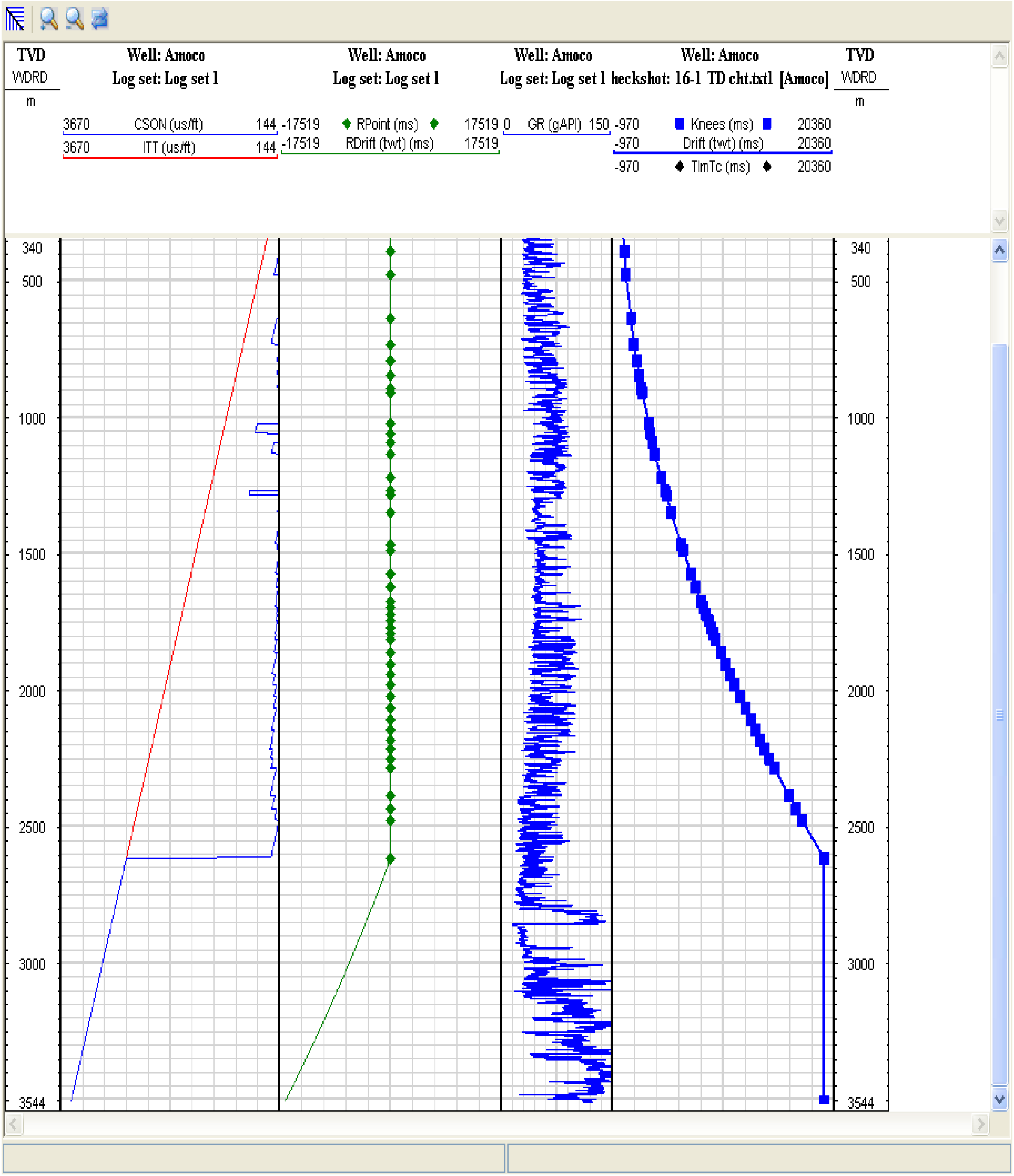


Fig. 3.7 showing sonic calibration.

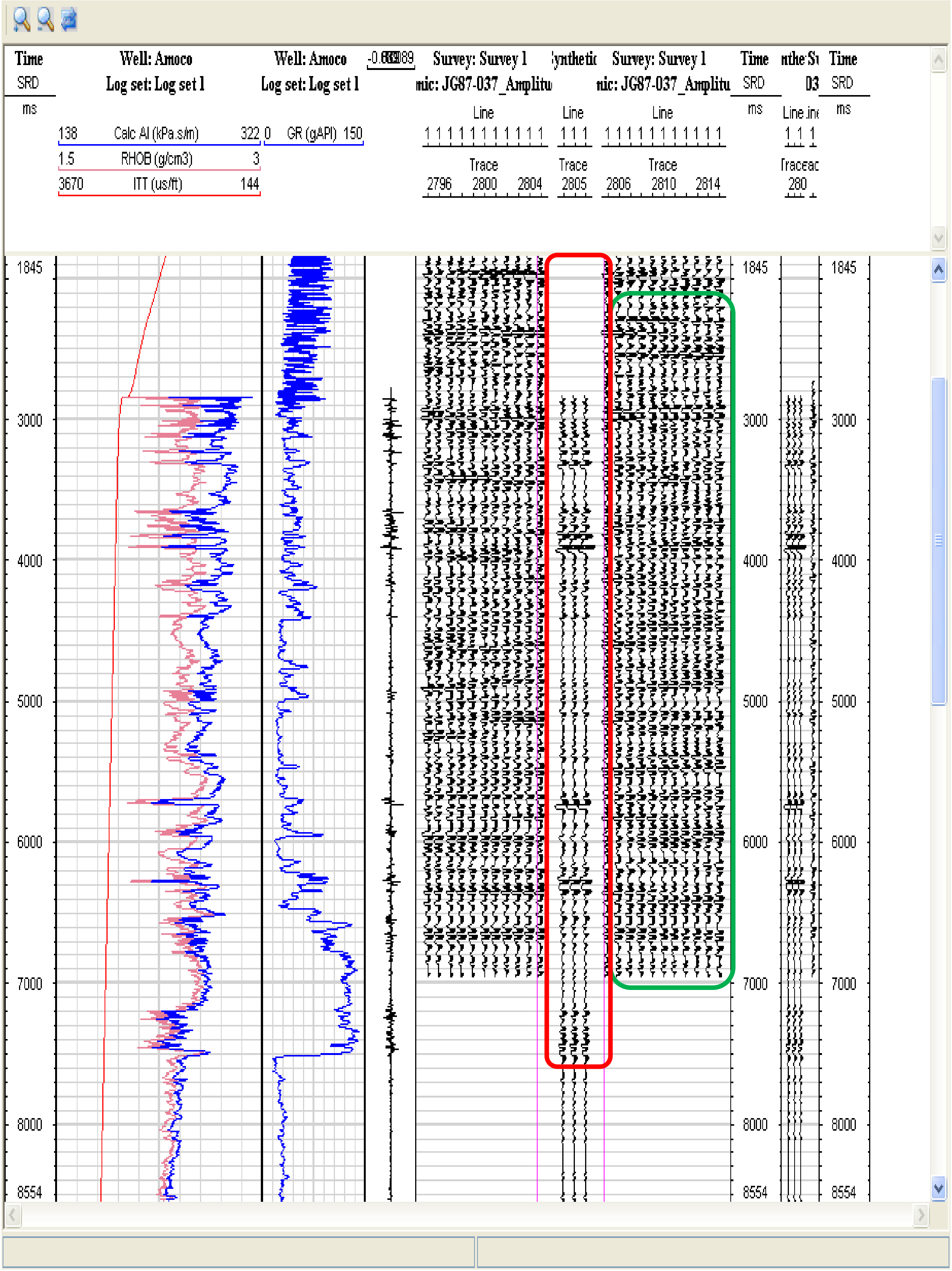


Fig. 3.8 Synthetic seismogram (Red boundary) and seismic section (Green boundary)

3.2.6 Seismic Horizon Interpretation

Horizons interpretation was done based on the signature of the logs from the well and best ties were interpreted as shown in figure 3.9. These interpreted horizons were then named horizon H1, horizon H2 and horizon H3 also shown in figure .3.10.

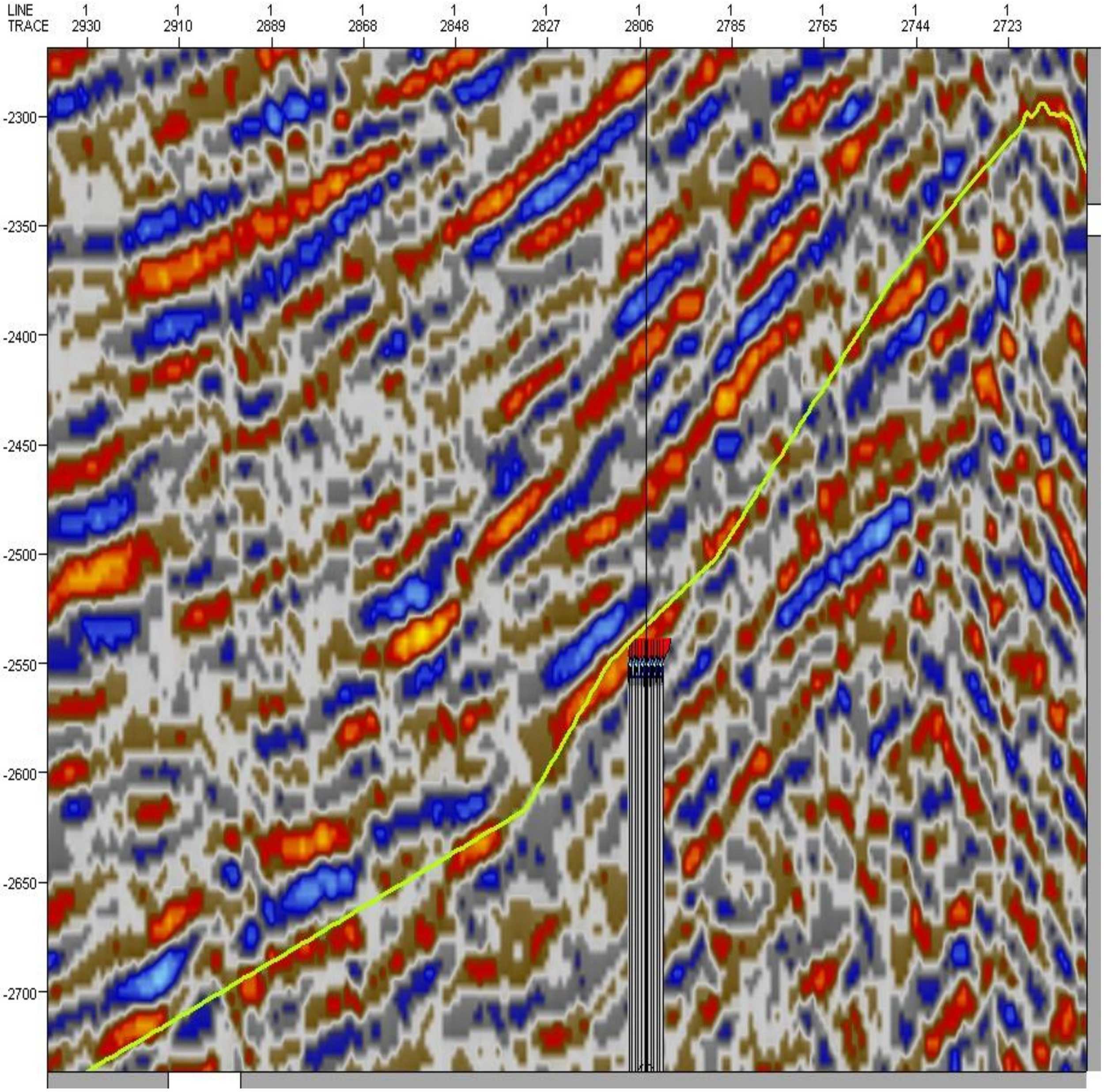


Fig. 3.9 Horizon interpretation

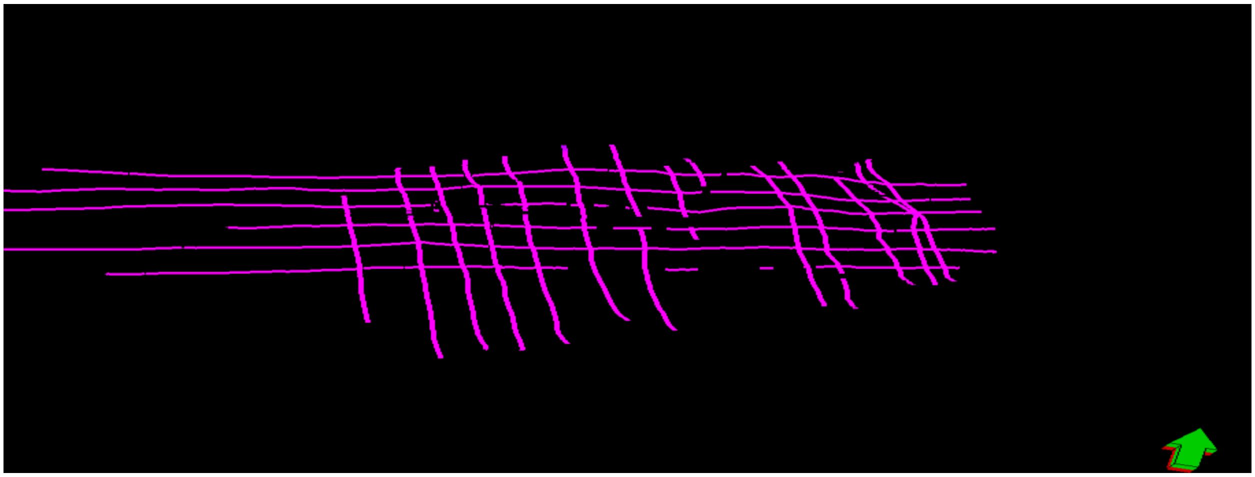


Fig. 3.10 (a) interpreted horizon H1

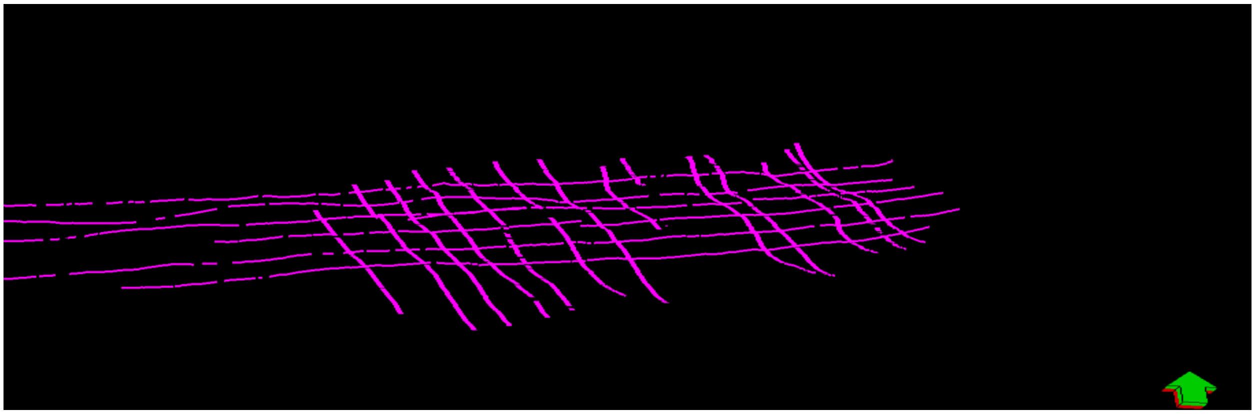


Fig. 3.10 (b) showing interpreted horizon H2

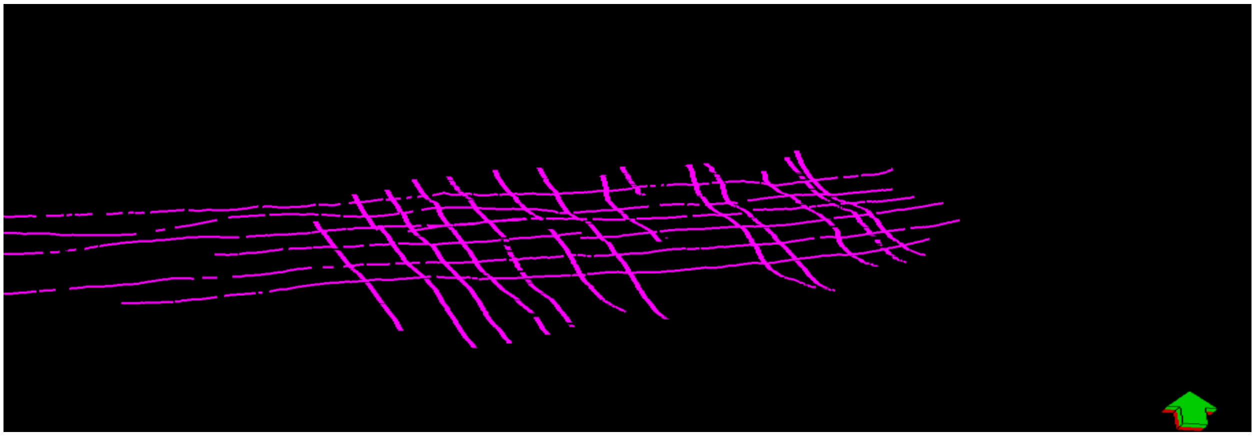


Fig. 3.10 (c) interpreted horizon H3

3.2.7 Fault Interpretation

Faults were interpreted or picked on the Seismic sections when there is a break in the horizon and there has been displacement on the horizon as shown in figure 3.11. These faults were picked on both the east to west and north-south sail line seismic sections as shown in figure 3.12.

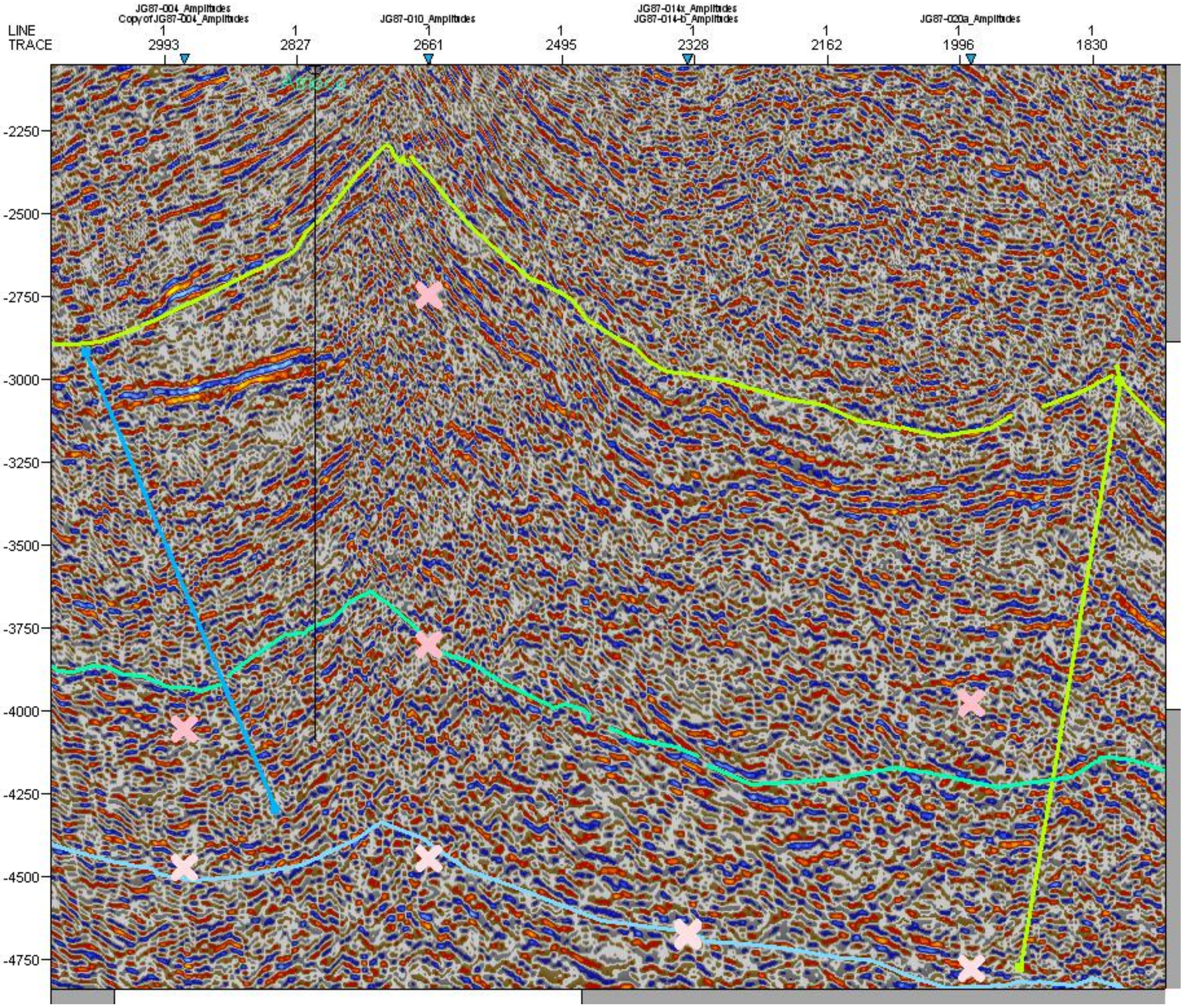


Fig. 3.11 Showing major fault and horizons interpreted

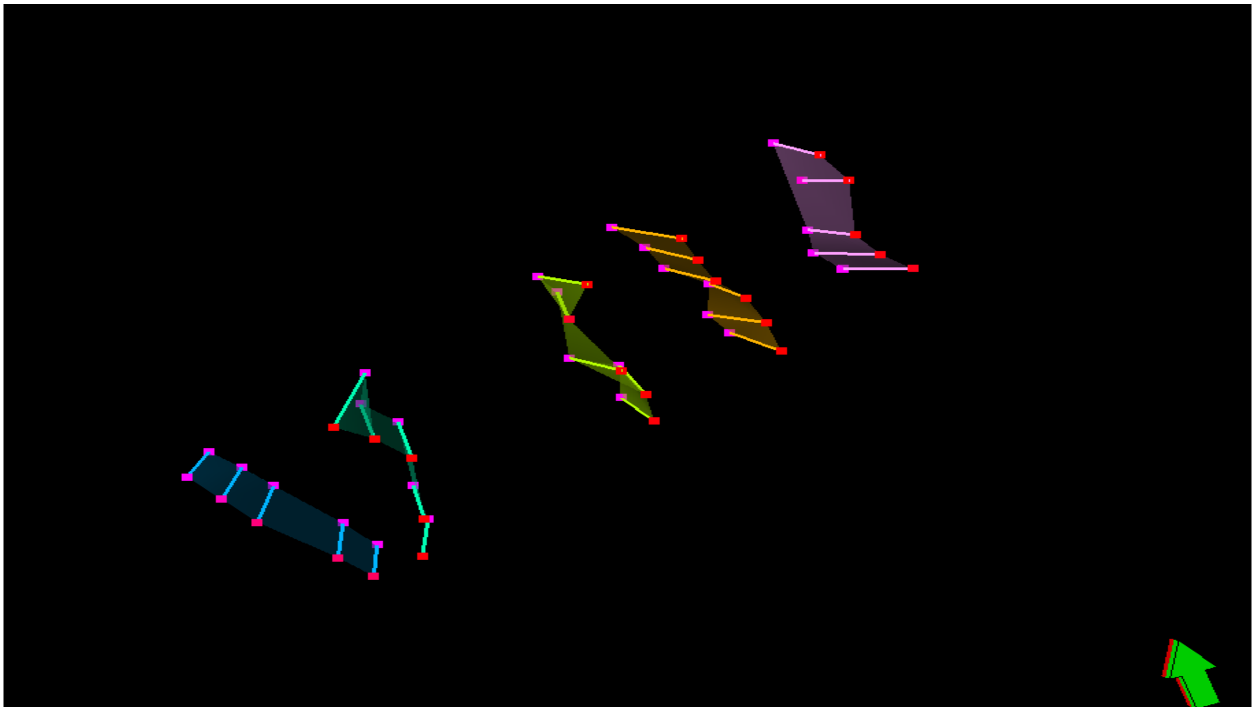


Fig. 3.12 (a) Showing interpreted fault on west to east sail line seismic volume

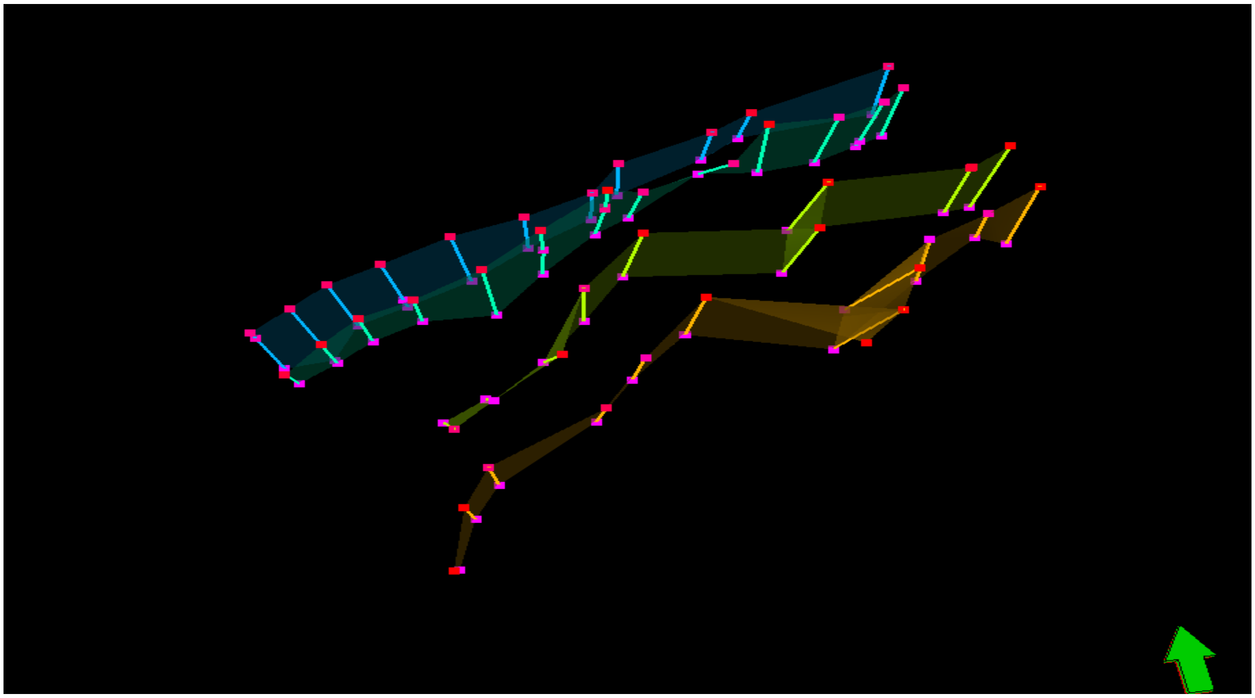


Fig. 3.12 (b) Showing interpreted faults on north -south sail line seismic volume.

3.3 Surfaces

Time structural maps were generated from the horizons interpreted through Make/Edit surfaces under utility in the process pane (AP.B1). This process generates a regular 2D grid surface as shown in figure 3.13.

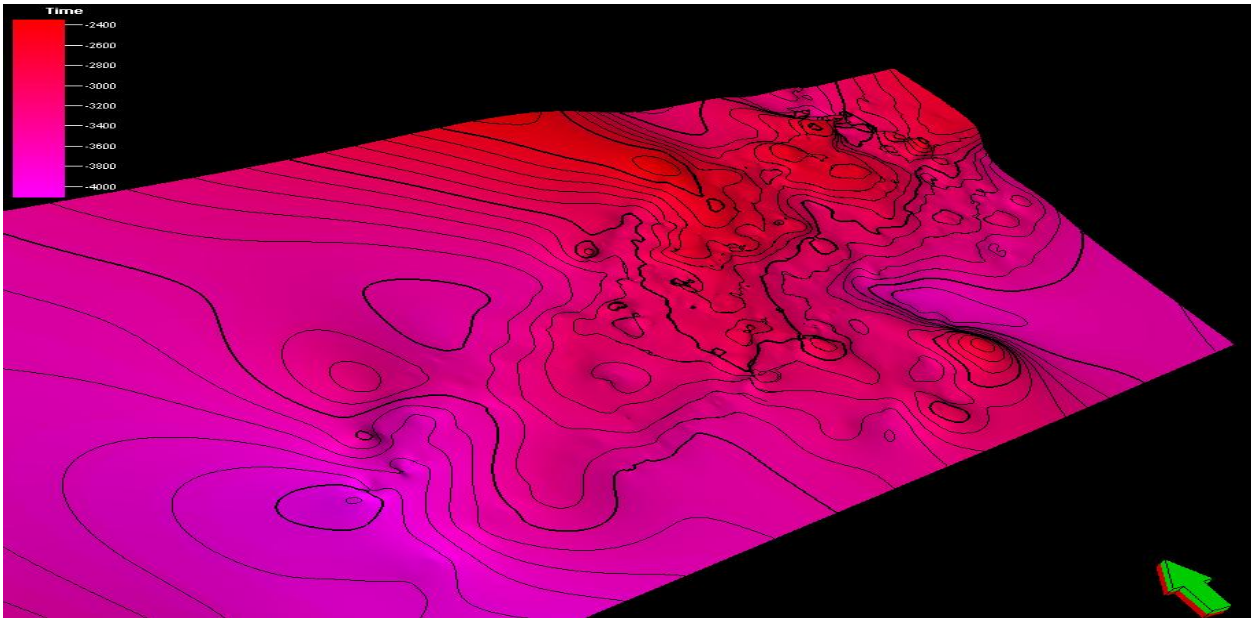


Fig. 3.13 (a) Showing top of reservoir surface generated from horizon H1

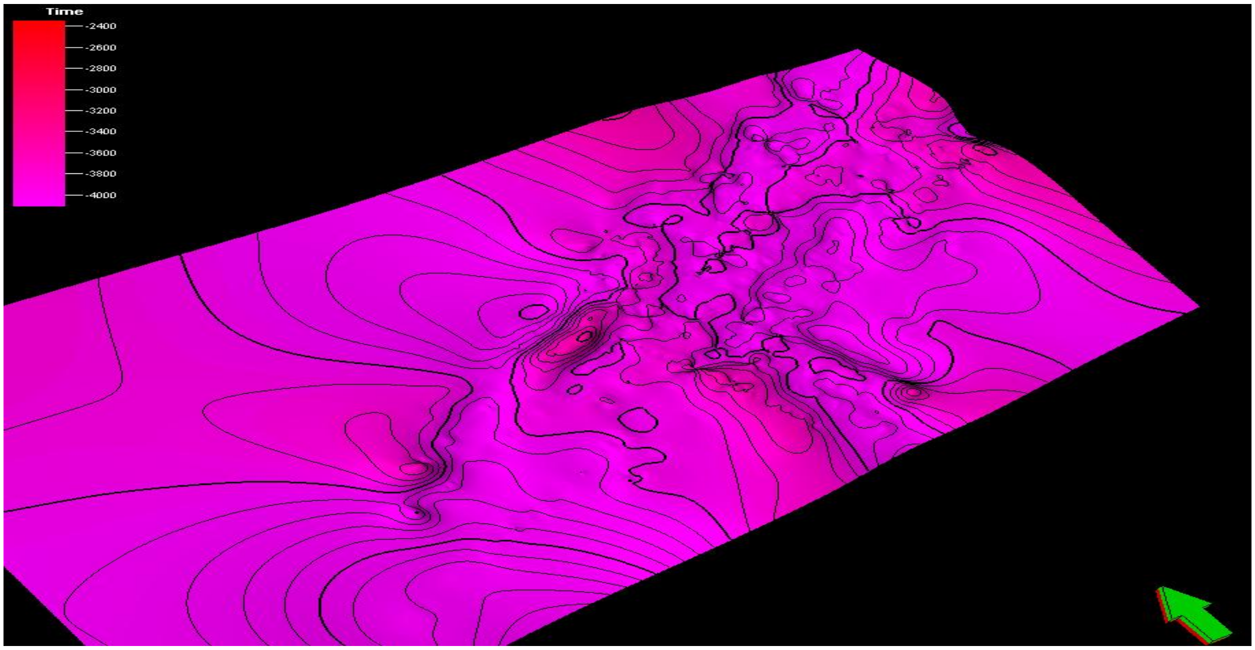


Fig.3.13(b) Showing time surface generated from horizon H2

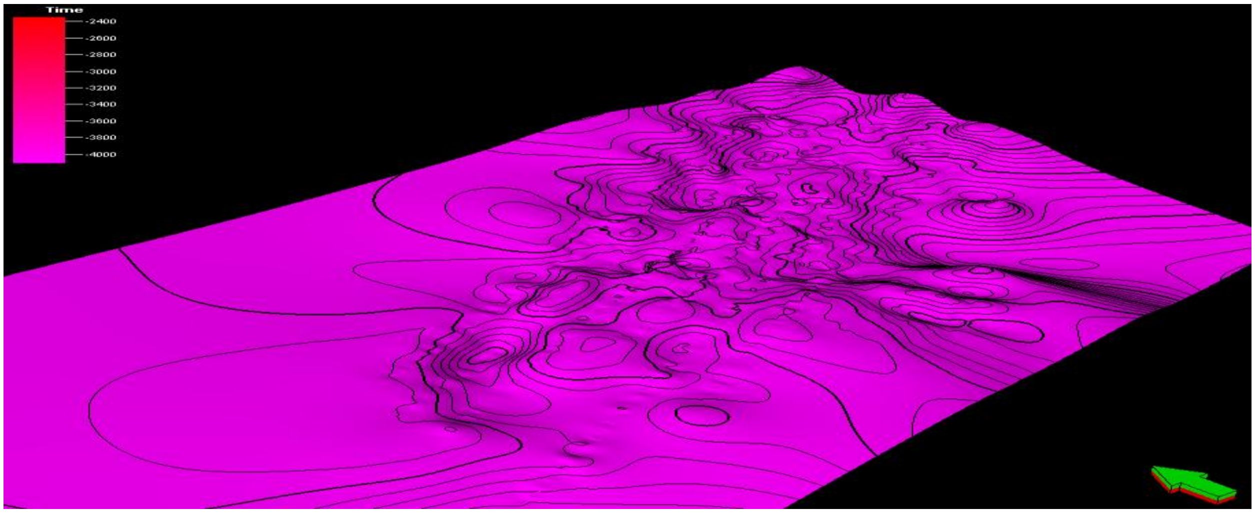


Fig. 3.13(c) Showing time surface generated from horizon H3

3.3.1 Boundary Polygon

A boundary polygon was created around the zone of interest as shown in figure 3.14. This is done through Make/Edit polygon surface process and it helps by saving time during modeling.

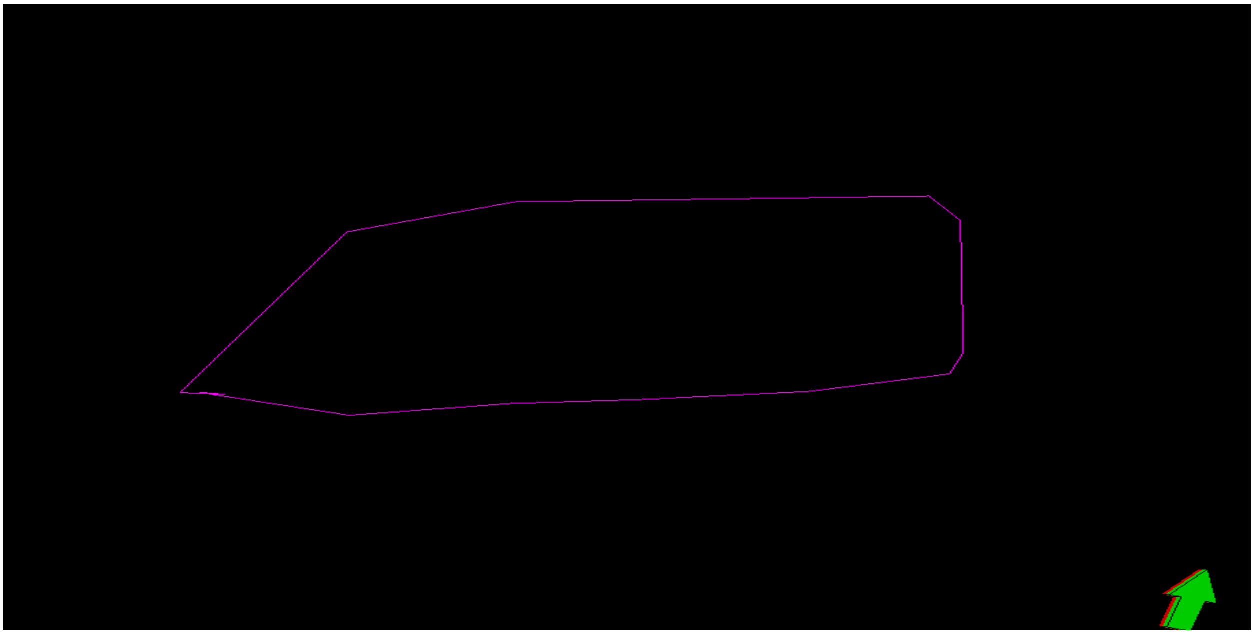


Fig. 3.14 showing boundary polygon

3.4 Look Up Function

A velocity look up function was generated to convert these surfaces created and faults interpreted from time to depth. Figure 3.15 shows the look up function generated by using checkshots.

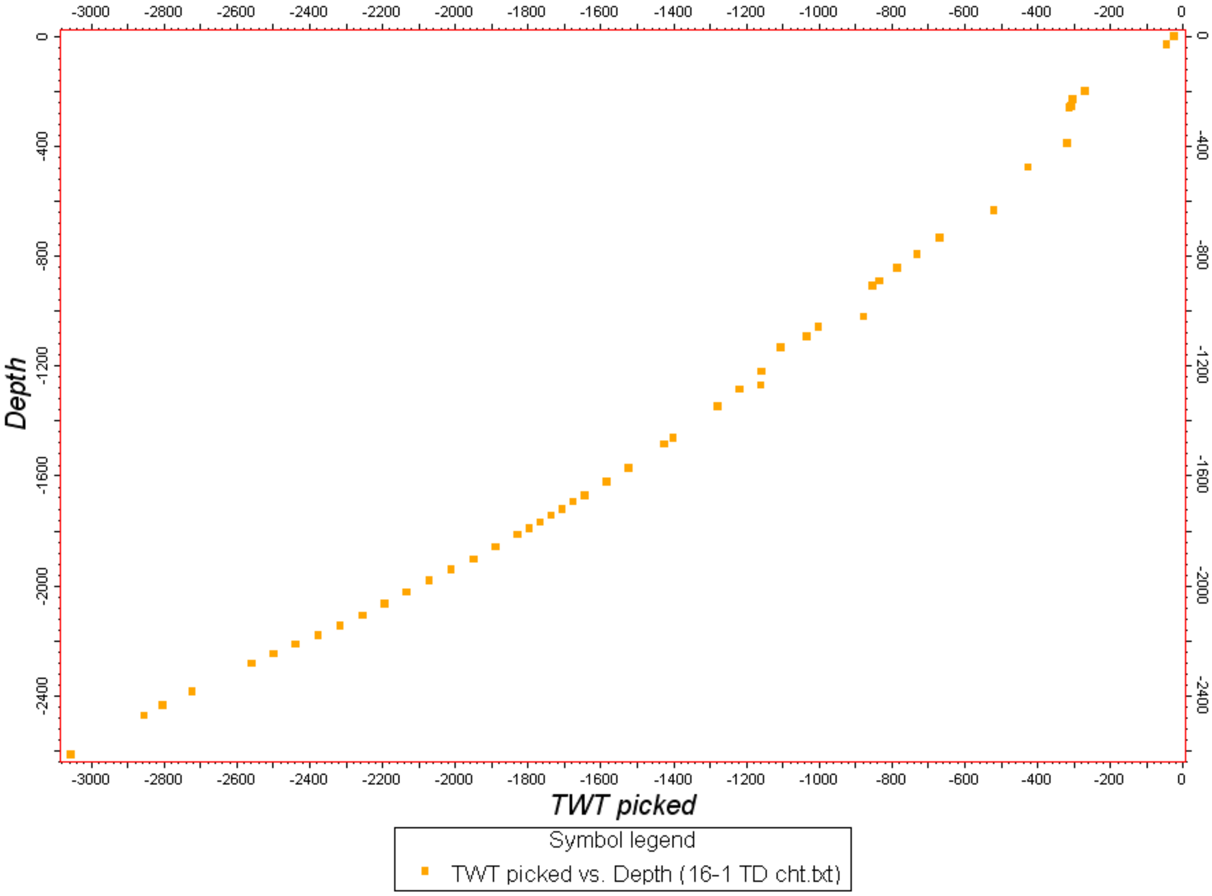


Fig. 3.15 showing a velocity function.

3.4.1 Depth Maps

The time surface maps created above were depth converted by using this velocity function which was also generated from the checkshots (AP.B2). The depth maps show structural highs and lows with colour gradation as shown in figure 3.16.

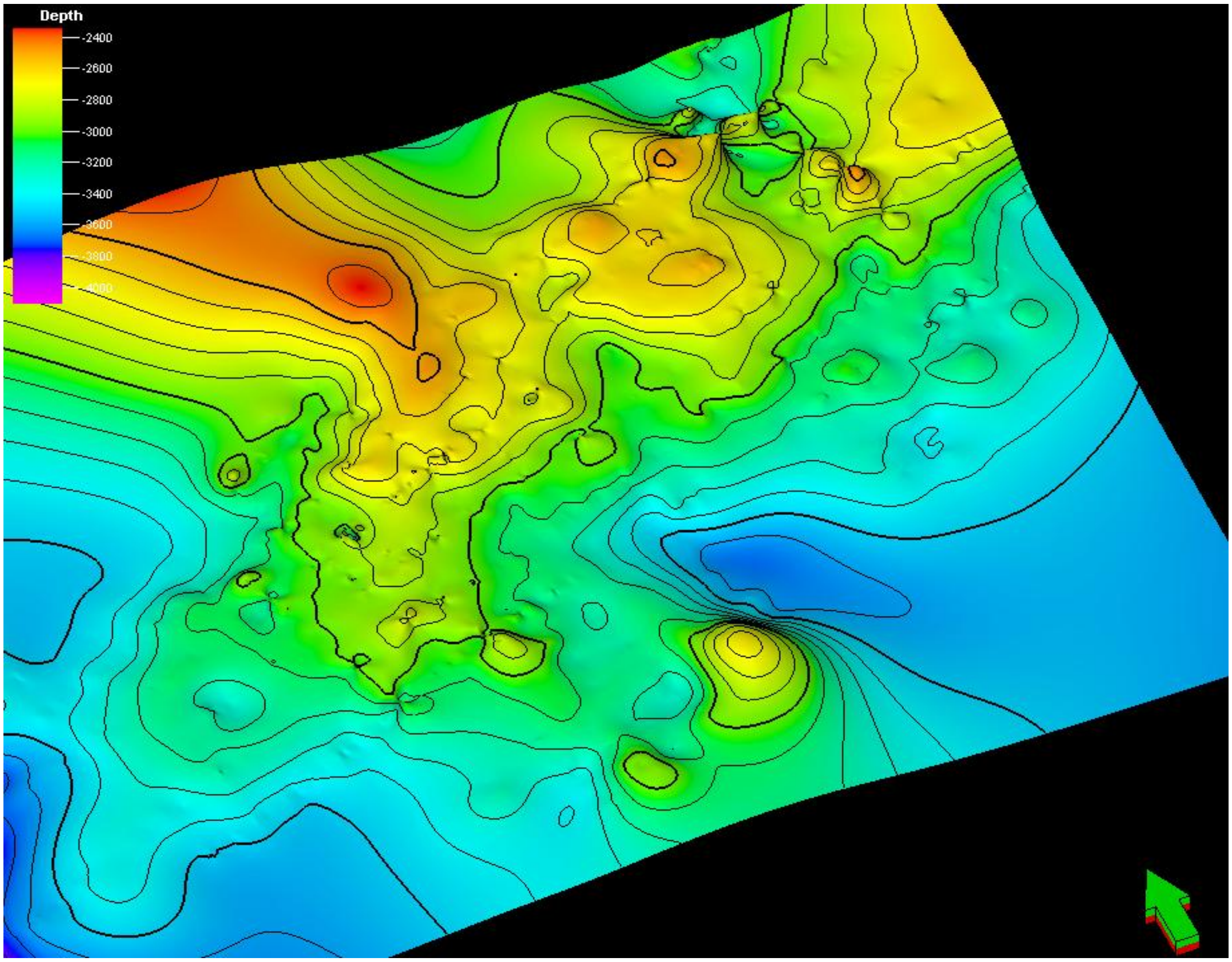


Fig. 3.16 (a) Showing depth converted map of surface H1

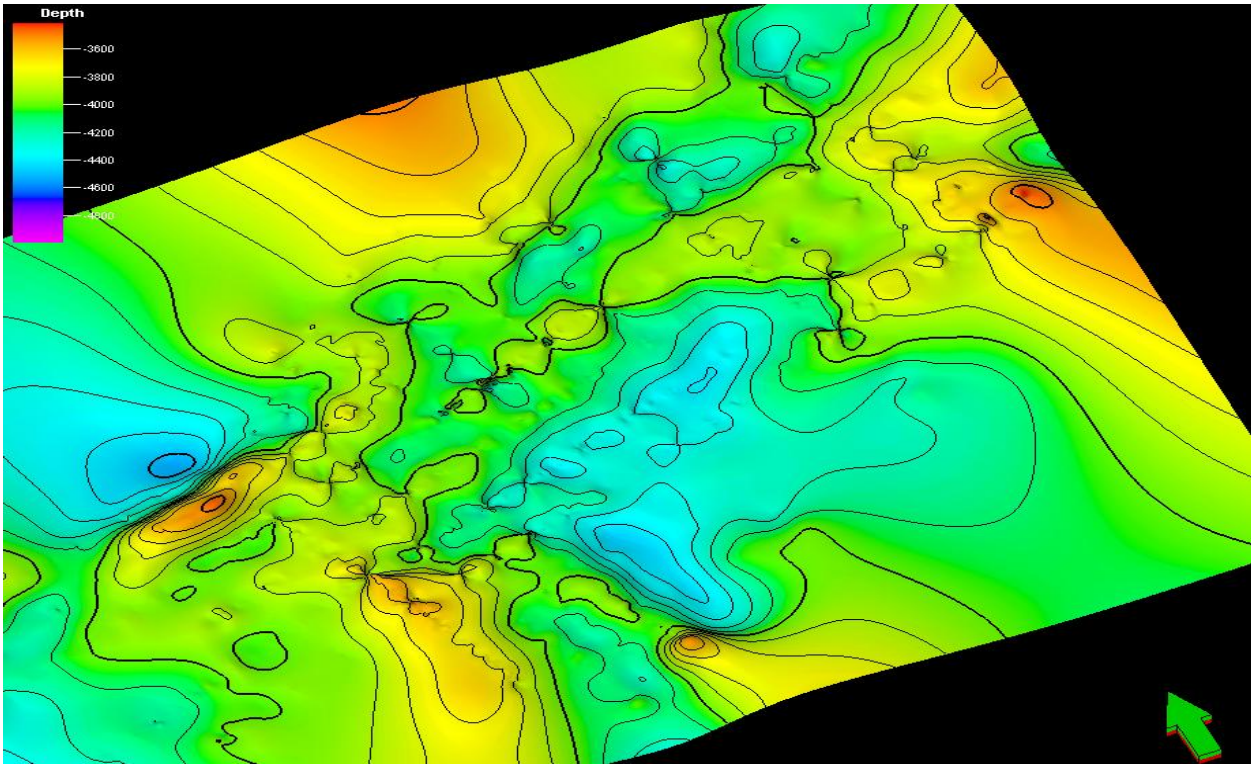


Fig. 3.16 (b) Showing depth converted map of surface H2

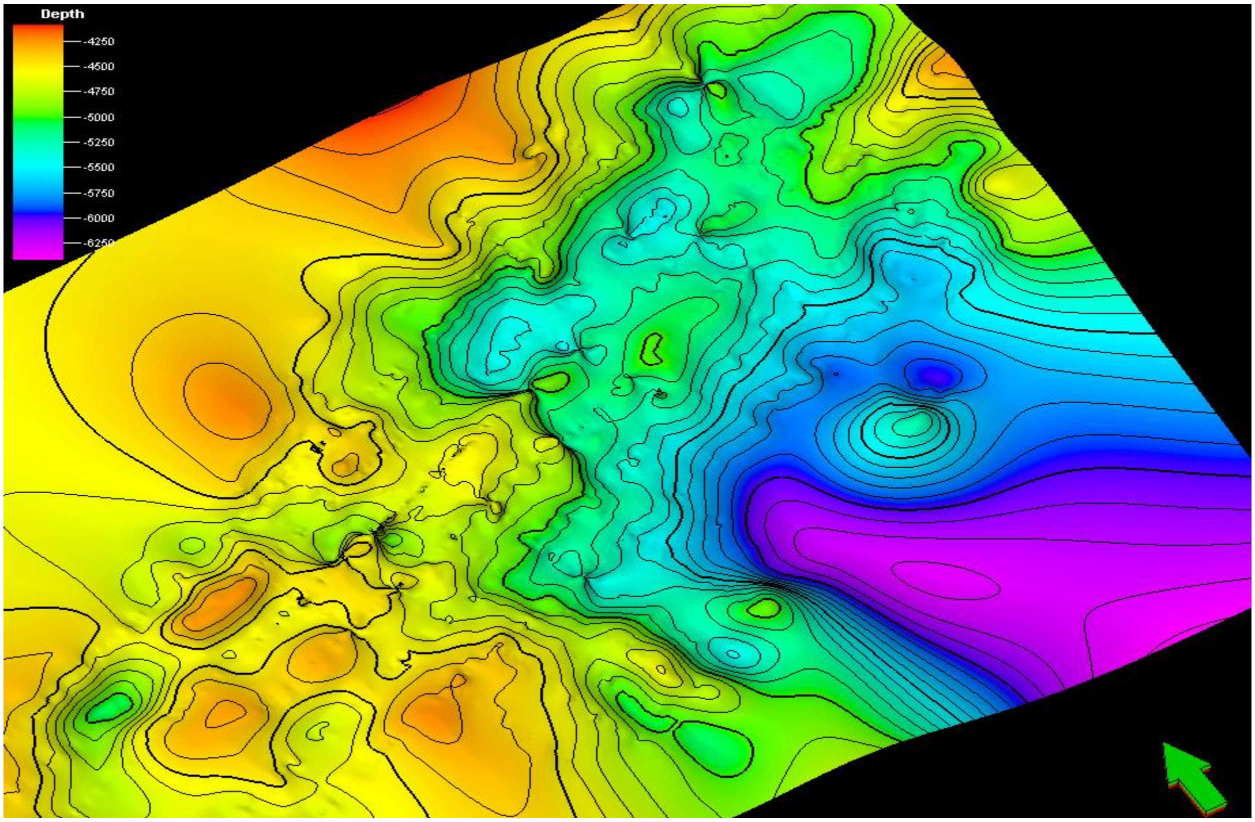


Fig. 3.16 (c) Showing depth converted map of surfaceH3

3.5 Modeling

In building the structural 3D grid for this project, interpreted horizons coupled with the faults that were interpreted from the 2D seismic data were used. There are three major ways of building the structural model. These are the Simple 3D Grid, Corner Point Gridding, and Structural Frame work.

3.5.1 Simple 3D Grid

The first one is when surfaces generated from horizon interpretation were used only to create a simple grid which was then used to make zone and layer. This gives the general overview of the reservoir without inputting fault or the fault model as shown in figure 3.17.

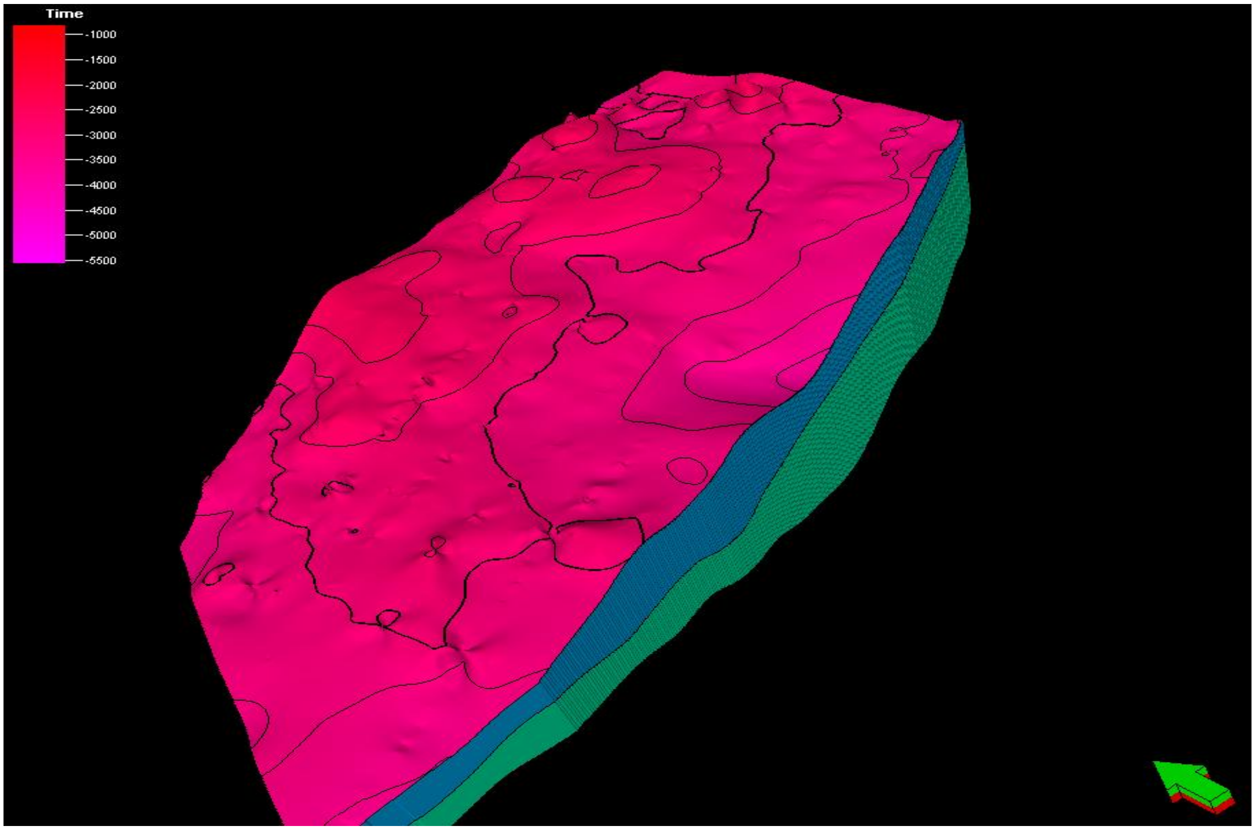


Fig. 3.17 Showing a simple 3D grid

3.5.2 Corner Point Gridding

The second method is by using faults modeled from seismic interpretation in addition to surfaces created from same seismic interpretation. This process is referred to as corner point gridding; this was then used as input for making zone and layers as shown in figure 3.18.

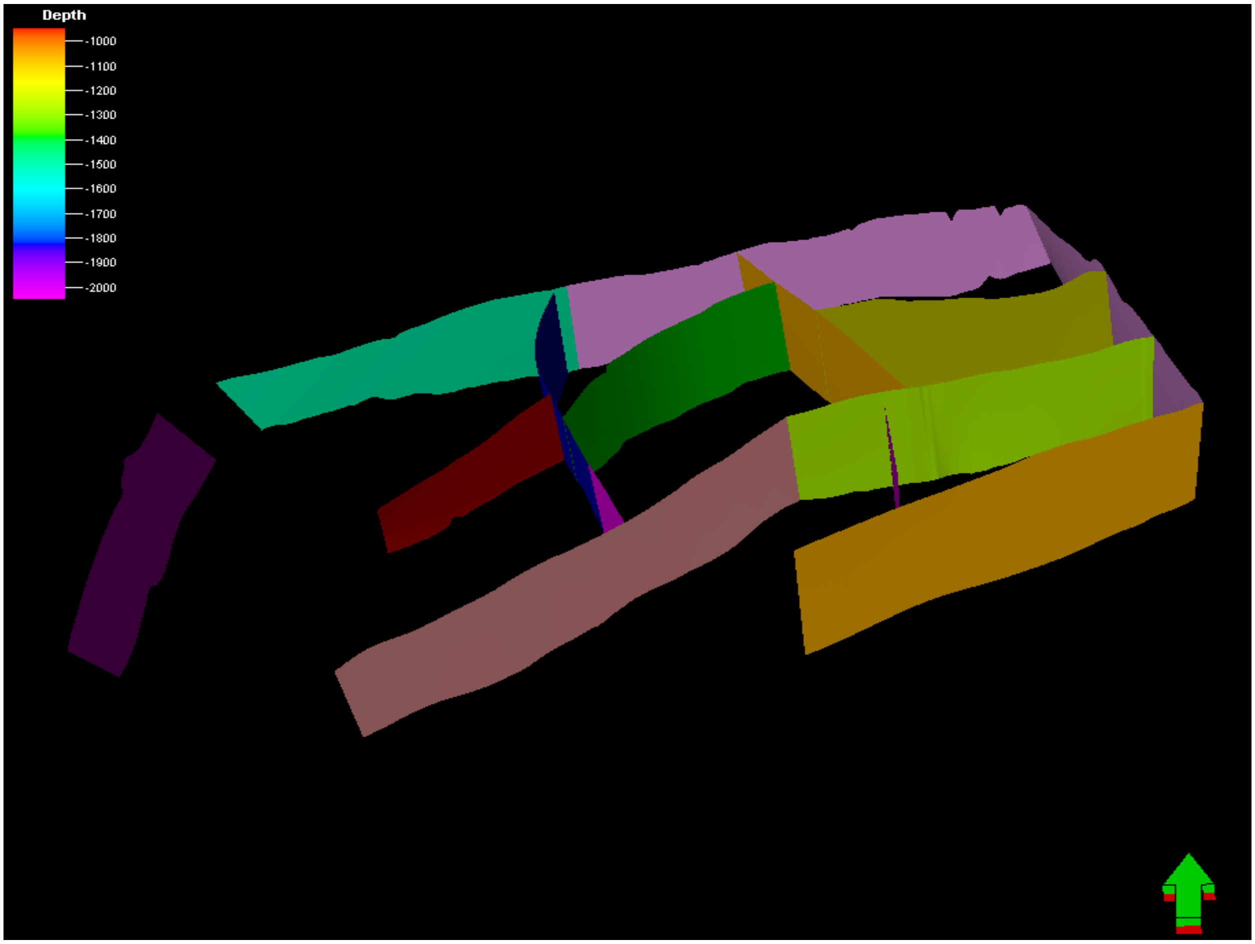


Fig. 3.18 Showing modeled Faults

The final method is by using structural framework which allows complex fault relationships but this project made use of the first two methods only for its structural modeling.

3.5.3 Pillar Gridding

Pillar gridding process is more concern about defining mid of the pillars though the top and the base of the skeletal framework was also defined. During pillar gridding process Trend and Direction were set in addition to the creation of segments as shown in figure 3.19, (AP.B4).

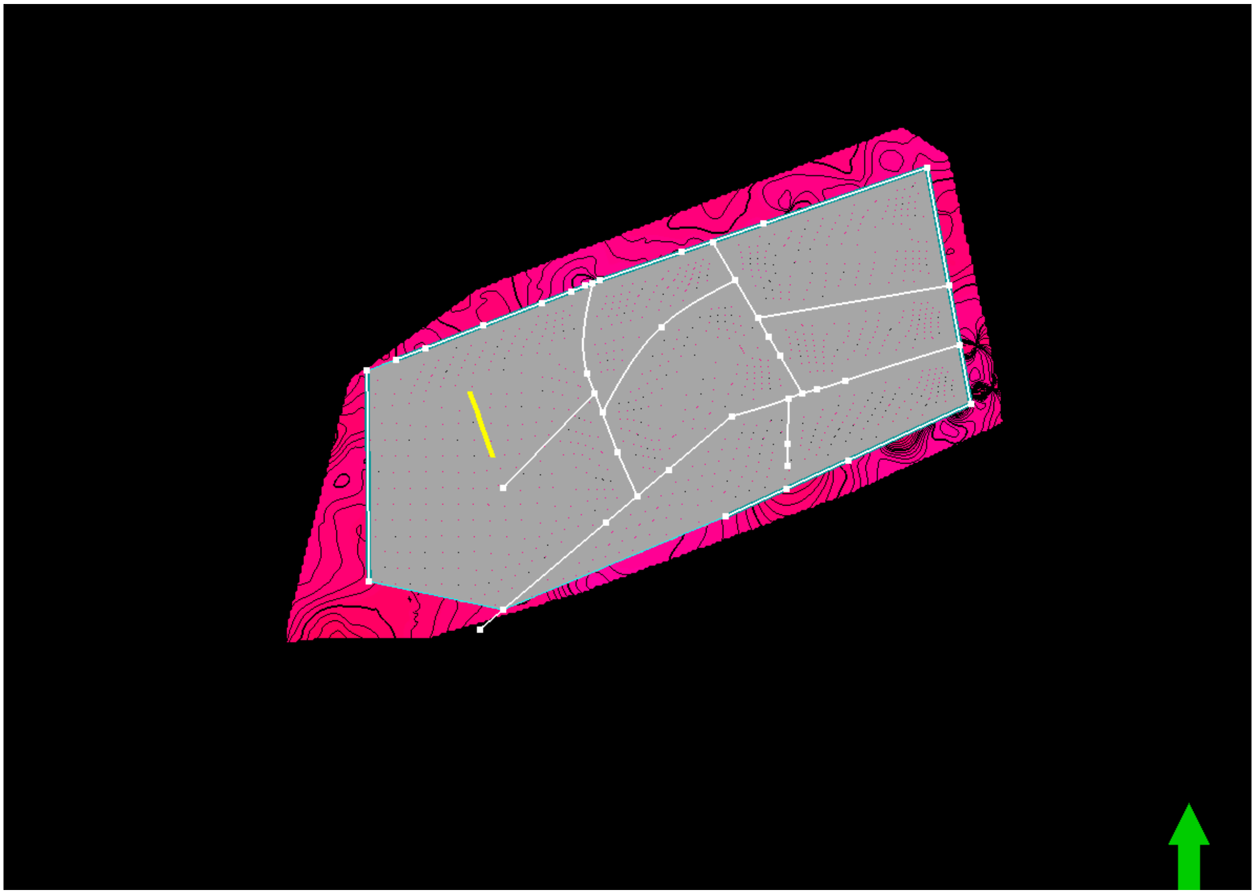


Fig. 3.19 Showing pillar gridding process

3.5.4 Velocity model

The subsurface rocks exist in depth and seismic reflections portray this subsurface in recorded time (Edward et al., 2001). Hence in order to bridge the gap between time and depth a velocity model is created. This is a way of removing structural ambiguity inherent in time and verifies structures.

3.5.5 Zones creation

Before zones were made thickness maps or isochore map which is thickness between two horizons measured vertically were created using the formation or well tops as shown in figure 3.20. Zones were created using make zones in the process pane. The number of zones created using this process is based on the number of zones identified from the reservoir area. These zones were further divided into layers as shown in figure 3.21.

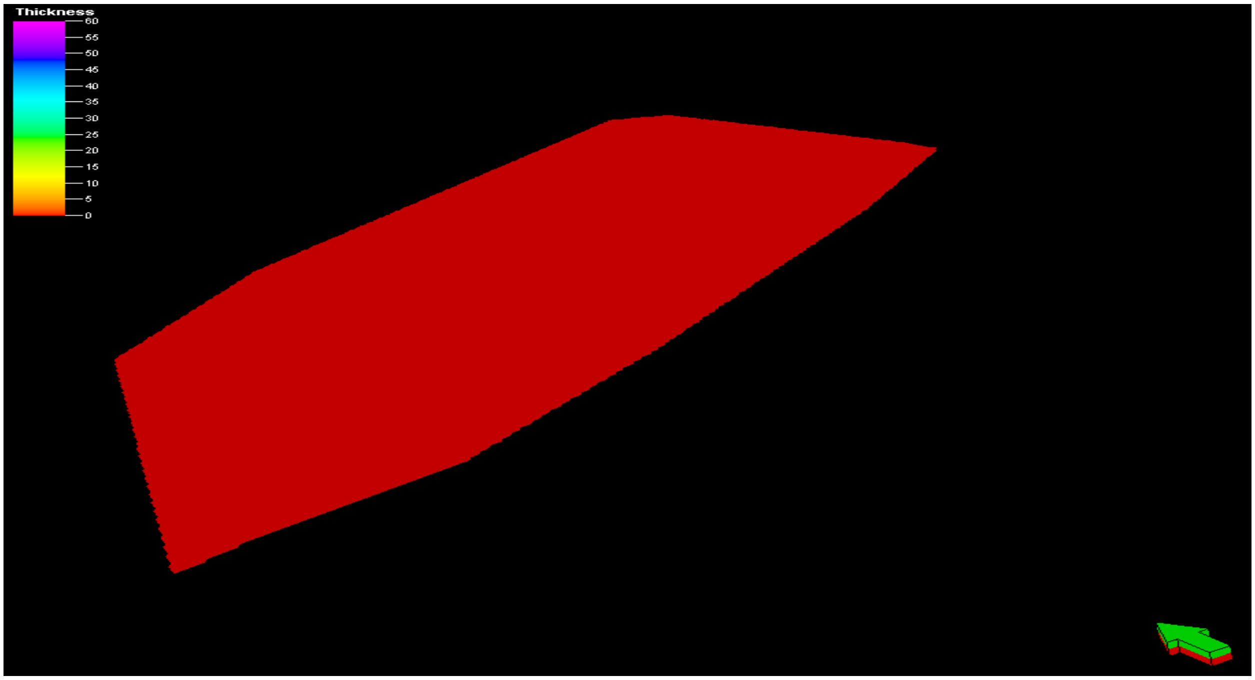


Fig. 3.20 Showing Isochore or thickness map

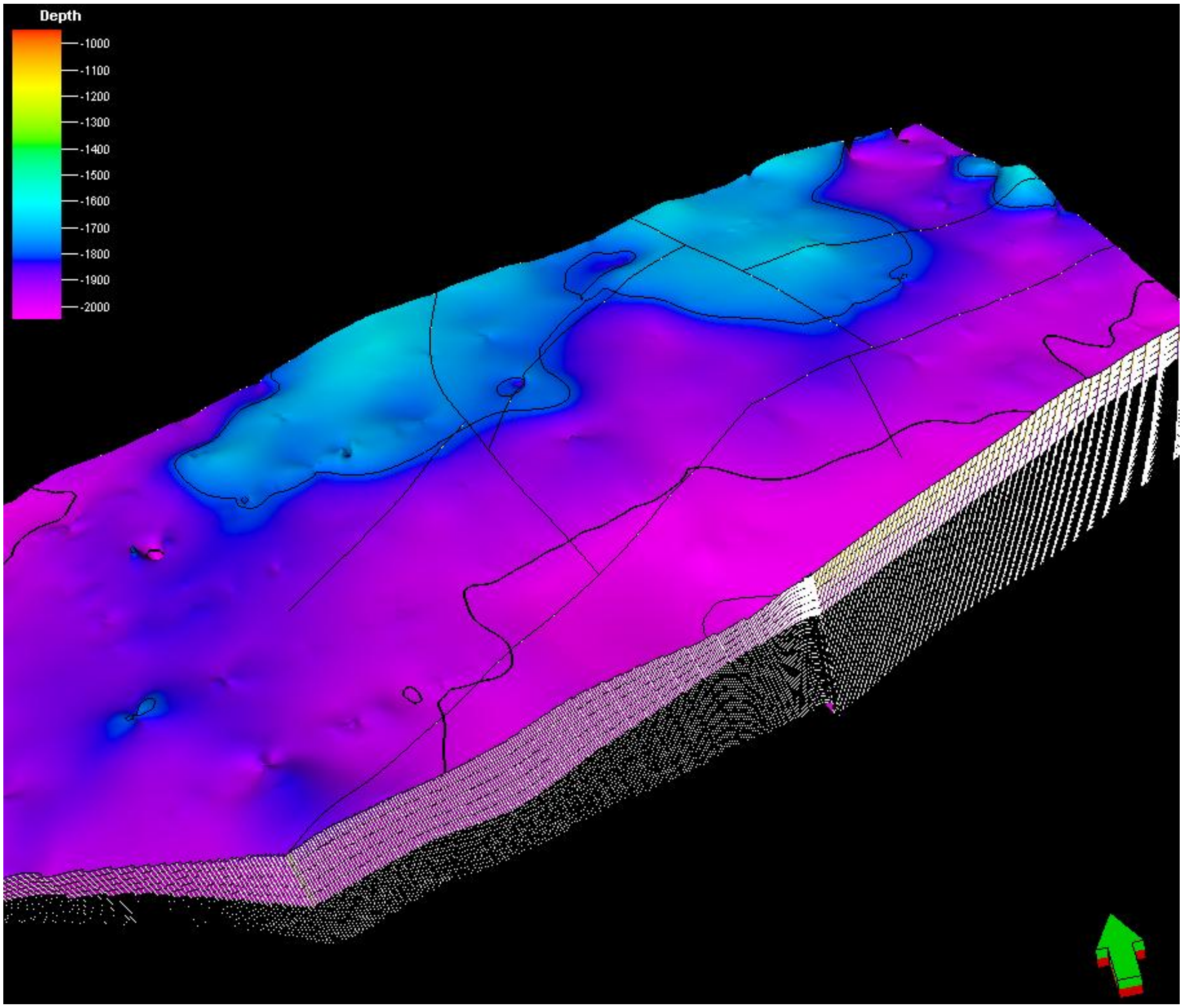


Fig. 3.21 3D model showing zone and layers

3.5.6 Property modeling

Property modeling helps distribute properties between the available wells so it realistically preserves the reservoir heterogeneity and the well data, available, together with other input data (Schlumberger, 2010). This process includes facies, petrophysical and geometrical modeling.

3.5.7 Geometrical modeling

These are 3D properties created by using pre-defined system variables such as cell angle which is used to quality check the orthogonality of the cell created during structural modeling as shown in figure 3.22; bulk volume is used for finding negative cells when filtered. This is done by assigning each cell a numerical value corresponding to the selected system variable.

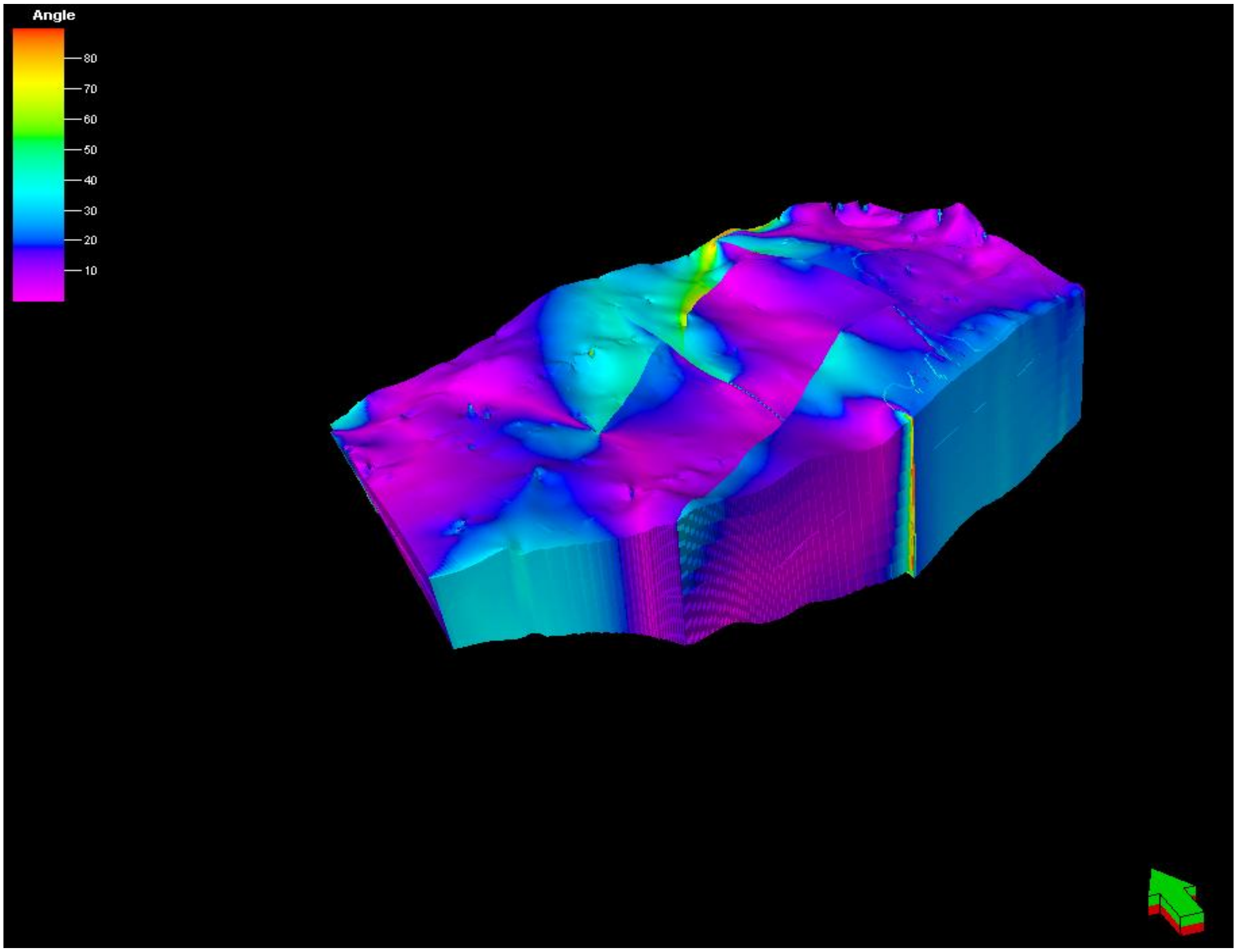


Fig. 3.22 Showing Cell Angle

3.5.8 Make Contacts

This is the process where contacts were defined to be used in volume calculation; the various contacts were defined in the Make Contacts process as shown in figure 3.23. Several sets of contacts were defined and each Contact Set contains a number of different contact types (AP.B5).

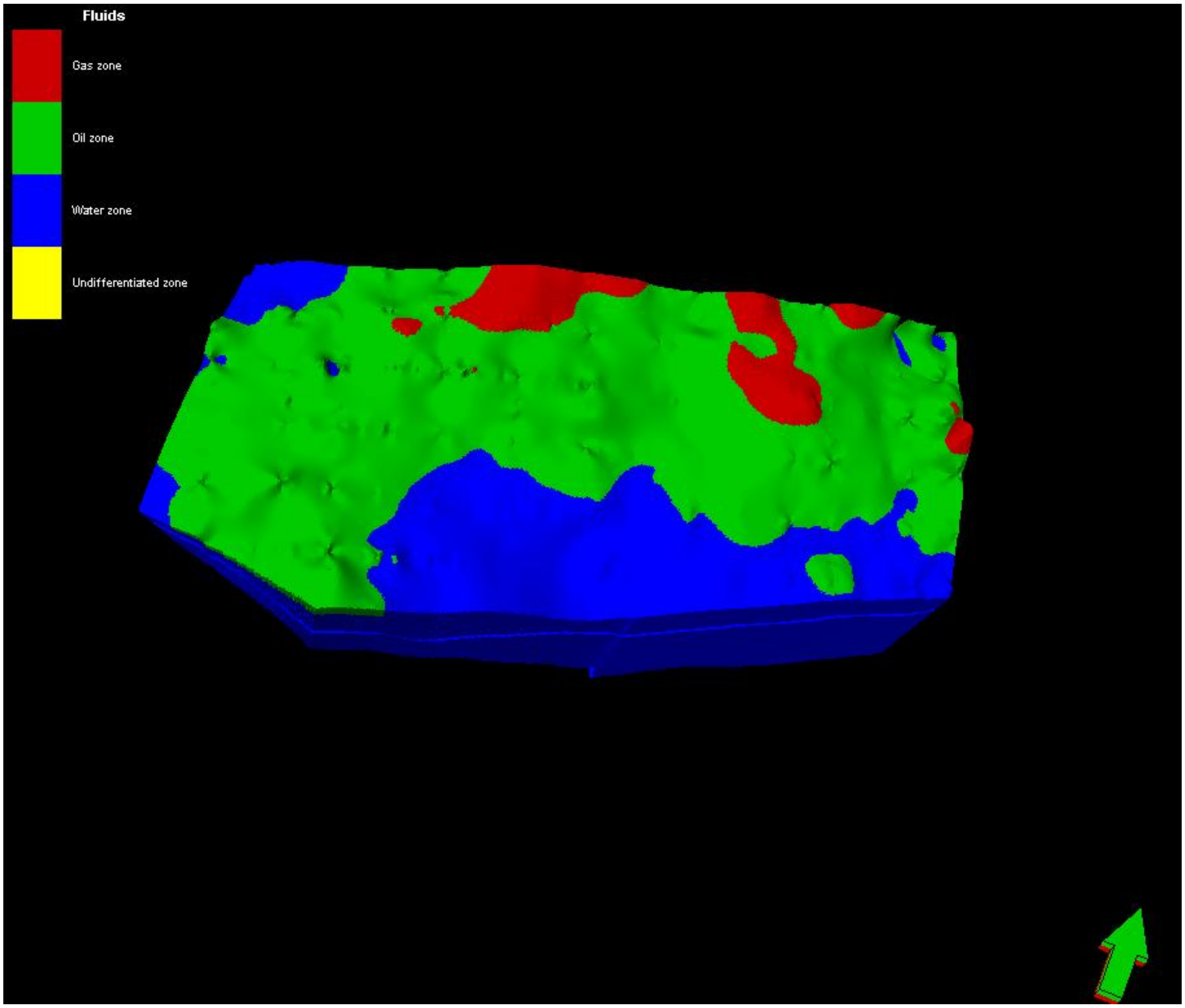


Fig. 3.23 Showing contacts modeled into the 3D grid

3.5.9 Upscaling of well logs

Well logs were upscaled to an average value since cells in the 3D model which were penetrated by these well logs were given single value each. In other words it is the process of resampling well logs into the cells as they are defined by the 3D grid. This Upscaled well log is shown in figure 3.24

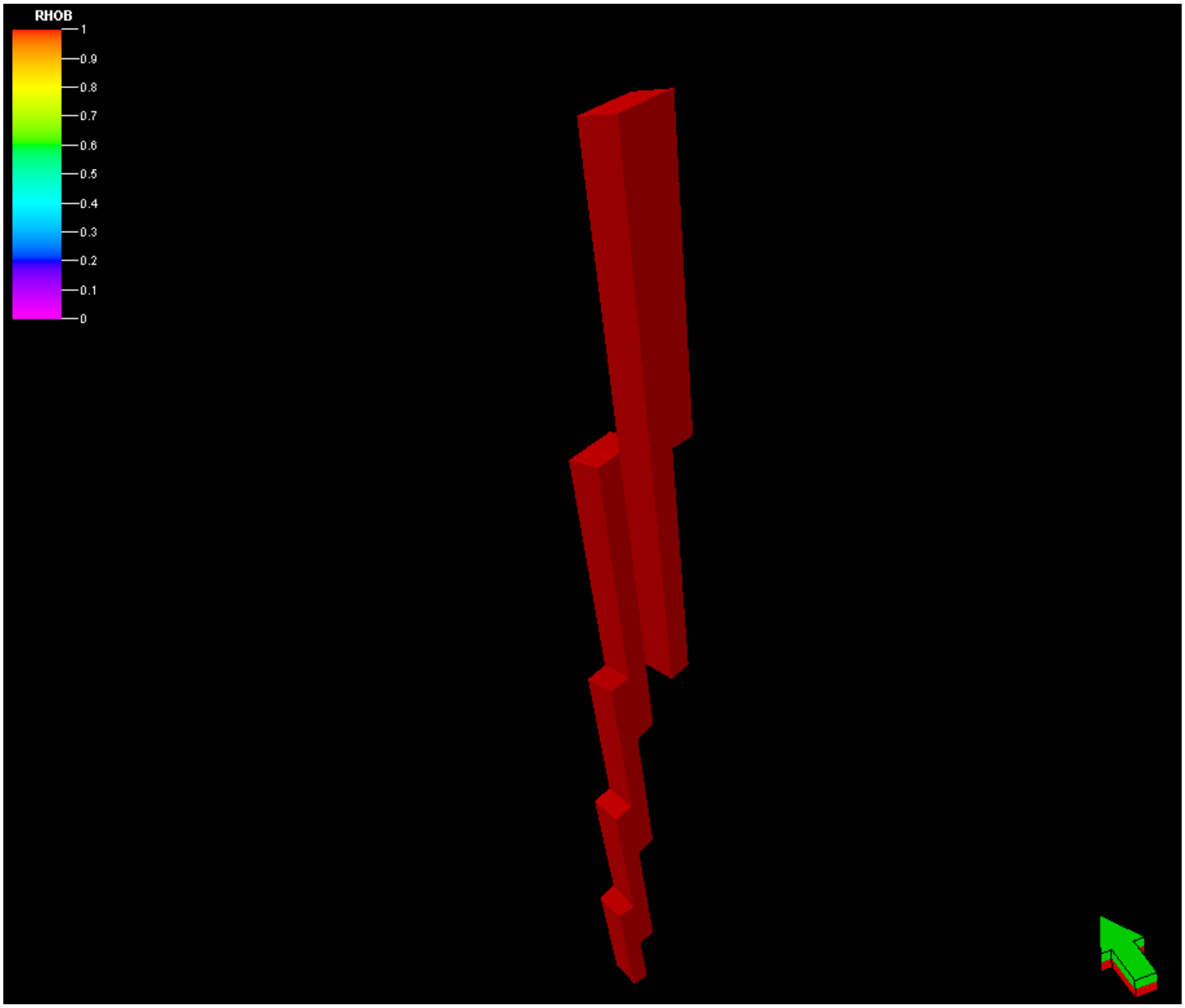


Fig. 3.24 Upscaled Density log

CHAPTER FOUR

RESULTS AND DISCUSSION

Hydrocarbon accumulations and prospectivity are established in most sedimentary basins along the coast of the Gulf of Guinea. In Ghana, to date, all oil and gas production have been from the Jubilee fields of the Tano Basin and Saltpond in the Central Basin.

It is believed that the rest of the under explored basins have potential for commercial hydrocarbon discoveries. Although numerous gas and oil seeps have been documented, the Accra-Keta Basin remains one of the least explored areas in Ghana (GNPC, unpublished).

The results and discussion of the study area which forms part of the larger underexplored Accra Keta basin follow a systematic approach in which the work was done in the previous chapter. But within each of the three major categories, position of sub process may be interchanged or even merged (combine).

4.1 Stratigraphy

Facies was created by using an API unit of 1/150 which is the difference between two radioactivities was used (Belknap et al, 1959) and for a tested Gamma ray tool, the API unit is the difference between the low and high values (Ryder, 2002).

The acceptable API unit of 60 for areas within the Gulf of Guinea was used and it corresponds to the SP log deflection; since SP log was the first log to permit correlation in sand – shale sequences principally because certain interval had typical log shapes (Ryder, 2002). Thus, the theoretical maximum deflection of the SP opposite permeable beds is called the static SP or SSP. It represents the SP value that would have been observed in an ideal case with the permeable bed isolated electrically (Sclumberger, 1991). Where Gr. is indicating to be sand clearly corresponds with SP deflection to the left towards the sand line as shown in figure 4.1.

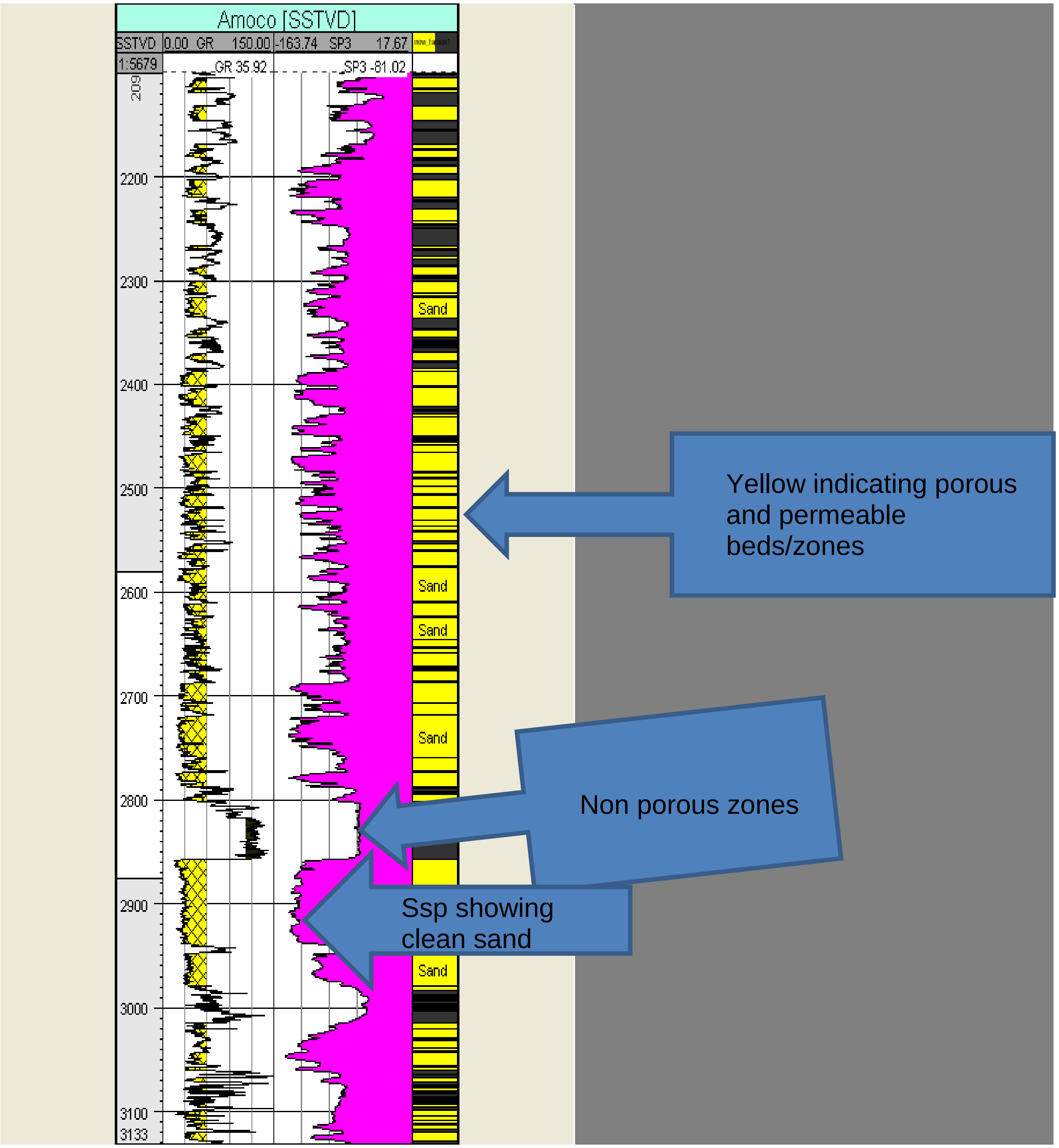


Fig. 4.1 Showing the facies displayed with SP and Gamma ray logs.

Analysis of the facies could not be done because there was no additional well to correlate with. Furthermore, where the reservoir was thickening or thinning to in addition to, whether there is a change in facies could not be determined. Hence the logs from this well were only used to delineate possible reservoir zones and for evaluation of the formation.

4.1.1 Formation Evaluation

During the formation evaluation process, the suit of logs were correlated to ensure that the petrophysical measurements made on a particular zone within the formation by the sonde are all represented at the same depth. These suits of logs were then analyzed for determination of lithology, porosity, net to gross and water saturation.

Since the subsurface is inhomogeneous and formations are made up different composition of minerals, a combination of logs was used to obtain a better indication of the lithology within the formation. For reservoir rock characterization, the Gamma ray log and spontaneous potential (SP) were used and these gave an indication of a total reservoir thickness (Gross) of **744.33 m** thus from depth of **2385.77 m** to **3130 m** and a Net of **541.73 m**. Part of this reservoir which was about **470 m** is the poorly dated late Carboniferous to Triassic preserved Paleozoic series which in some places can reach thickness **1000** to **1200** meters includes continental sandstone which overlaid the marine carboniferous consisting of sandstones shales, carboniferous shales, and limestones (basil et al, 2005) as shown in appendix C.

4.1.2 Lithology

In order to determine the lithology of the reservoir rocks, density and sonic logs were used. First of all average reading of density and sonic velocity of each zone within the reservoir was crossplotted to determine the porosity which was used to determine the lithology. Thus, the average porosity values within the reservoir range from 11% to 21% which gave an indication of a lithology between 2385.77 and 2800 meters as sandstone intercalating with dolomite. Also, from the porosity calculated for depth of 2860 to 2932 meters gave an indication of thick clean sandstone. Finally, a qualitative analysis of log signatures from depth of 2980 to 3130 meters show sandy-shale formation and upon calculating porosity for each individual small zone, it came out clearly as sandstone intercalating with limestone.

4.1.3 Hydrocarbon Delineation

The induction log (ILD) was developed to measure formation resistivity and to detect hydrocarbon zones within the formation. Practically, the induction log is used to distinguish between conductive areas consisting of either water or mud filtrate and nonconductive areas consisting of hydrocarbons. Hence a combination of gamma ray log with the resistivity (ILD) log and bulk density log were used to delineate these areas of possible hydrocarbon bearing and are mapped out as shown in **figure. 4.2.**

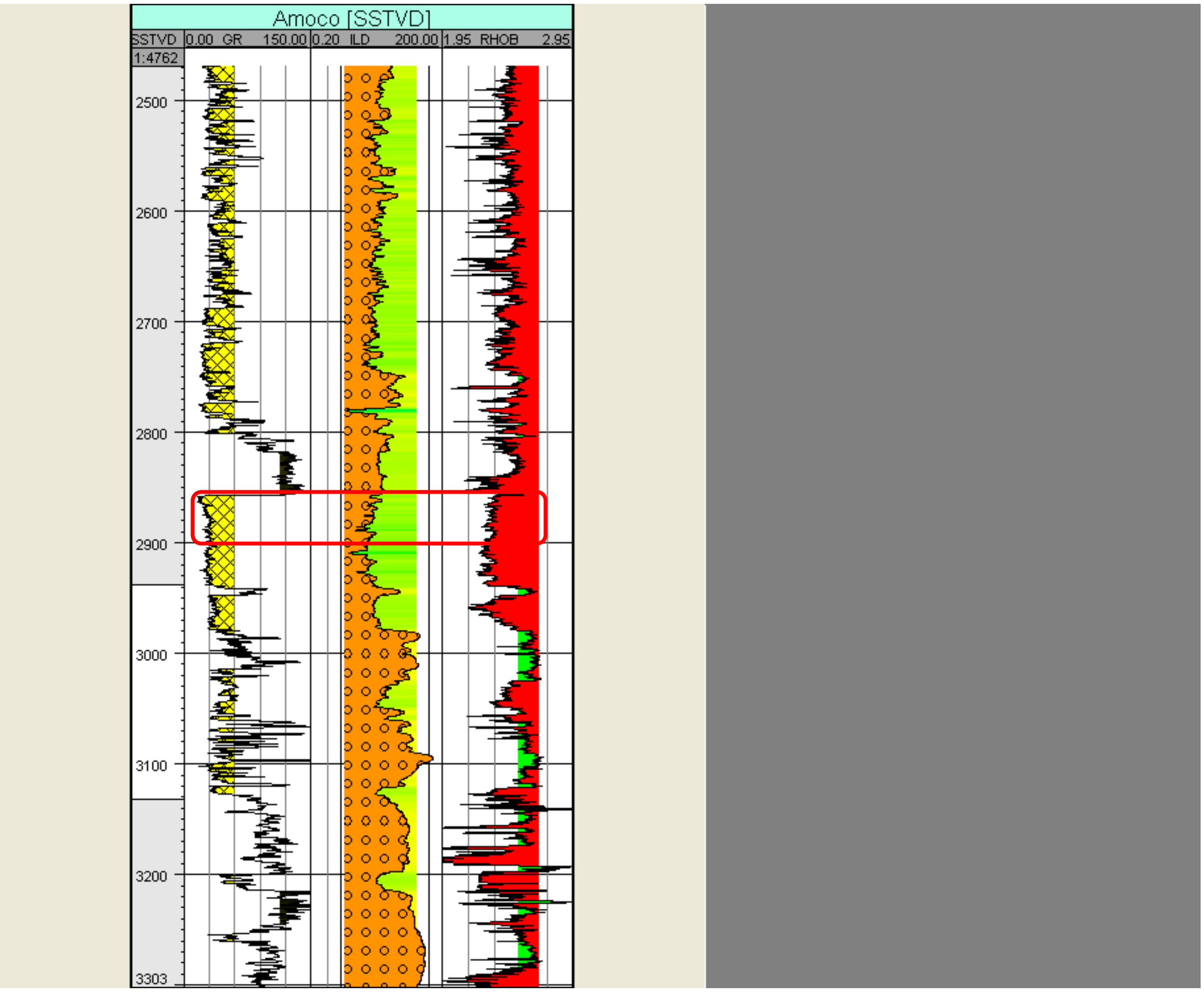


Fig. 4.2 Showing gamma ray log, density and resistivity logs.

It is also necessary to know if there are voids within the formation and how easily fluid can flow through these voids or pore spaces. This property of the formation rock, which depends on the manner in which the pores are interconnected, is its permeability. The main petrophysical parameters needed to evaluate reservoir producibility, then, are its porosity, hydrocarbon saturation, thickness, area, and permeability (Ryder, 2002). These parameters however, are determined and presented in the table 4.1

Table 4.1 Showing petrophysical results

Net/Gross	Porosity	Vshale	Sw	Net	Gross	Hydrocarbon saturation
0.72	15.5%	0.12	0.59	541.73m	744.23m	0.41

From the table, an average porosity was presented though the reservoir formation comprises of different lithology leading to different porosity values. This average value shows that the porosity in the formation is good and the dominant lithology is sandstone. The permeability which determines how fluids can flow within the formation is good from the qualitative analysis of the logs. Similarly hydrocarbon saturation which is 1-Sw (water saturation) is low meaning there is high concentration of water in the formation.

During formation evaluation it was realized that the caliper log shows a lot of spikes which is an indication of caverns or vugs as shown in figure. 4.3. Vugy formation is an indication of secondary porosity and since sonic logging tools respond to only intergranular porosity, crossplot involving sonic log are affected by these porosities and displaces the plotted point from correct lithology line (Sclumberger, 1991). During lithology identification, dolomites were identified as part of the reservoir rock and secondary porosity normally exists within formation of limestone or dolomite which has been dissolved by ground water (Sclumberger, 1991).

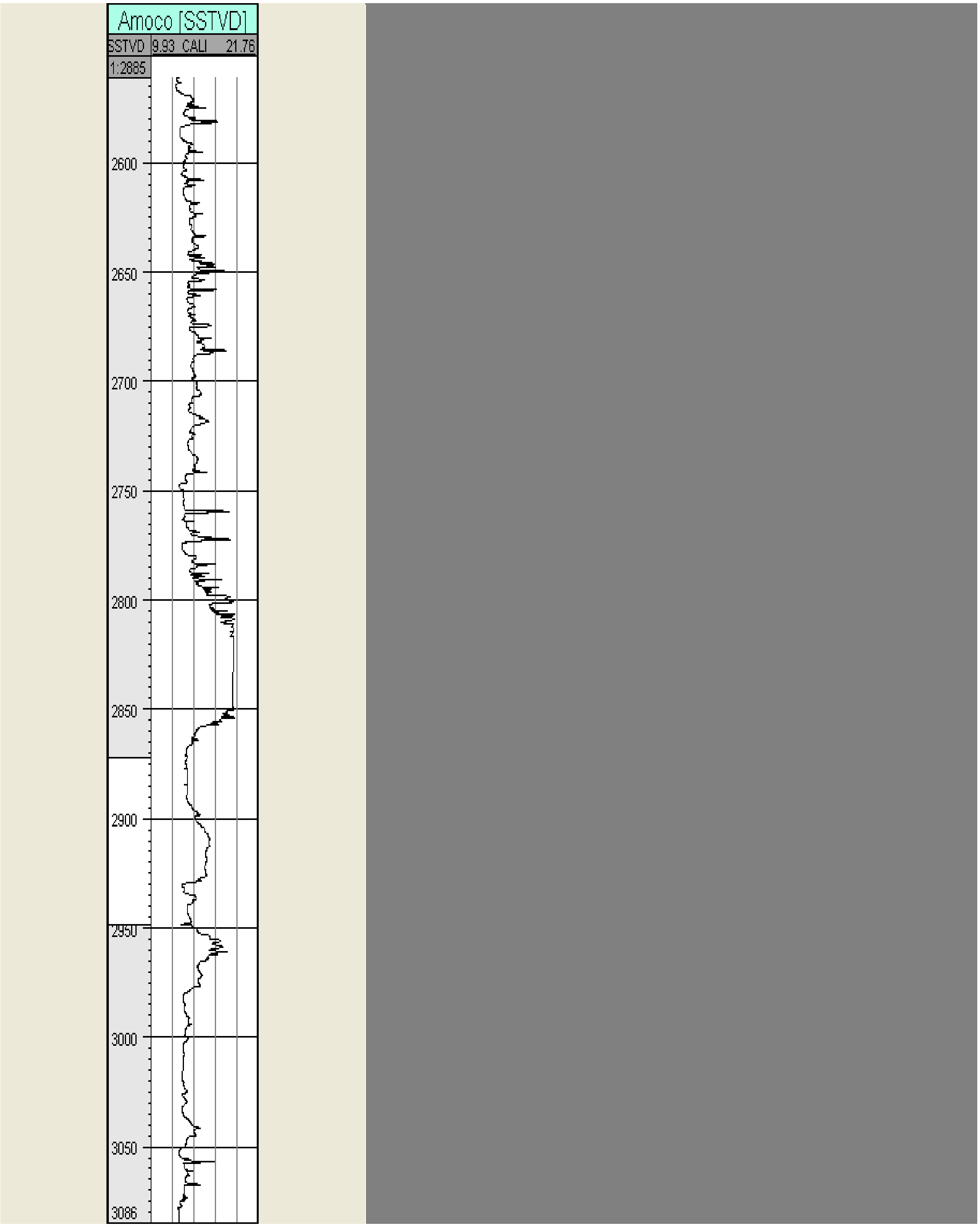


Fig. 4.3 Showing spikes on caliper log

4.1.4 Abnormal Pressures

Subsurface formation compaction increases with depth. Sonic velocity gradually increases with depth, due to compaction of sediments and with more overburden. In a normal compaction trend a gradual increase in sonic velocities is observed with depth. In under compacted sediments there is a drop in sonic velocity and increase in travel time (Goud, 2010). Departures from this normal trend towards higher values of interval transit times suggest an abnormal pressured section (Dullien, 1992). Hence by evaluating the ITT log which is a sonic acoustic log, there is a deviation from the normal trend. There is a reduction in interval velocity at some point indicating that there is an abnormal pressure as shown in figure.4.4

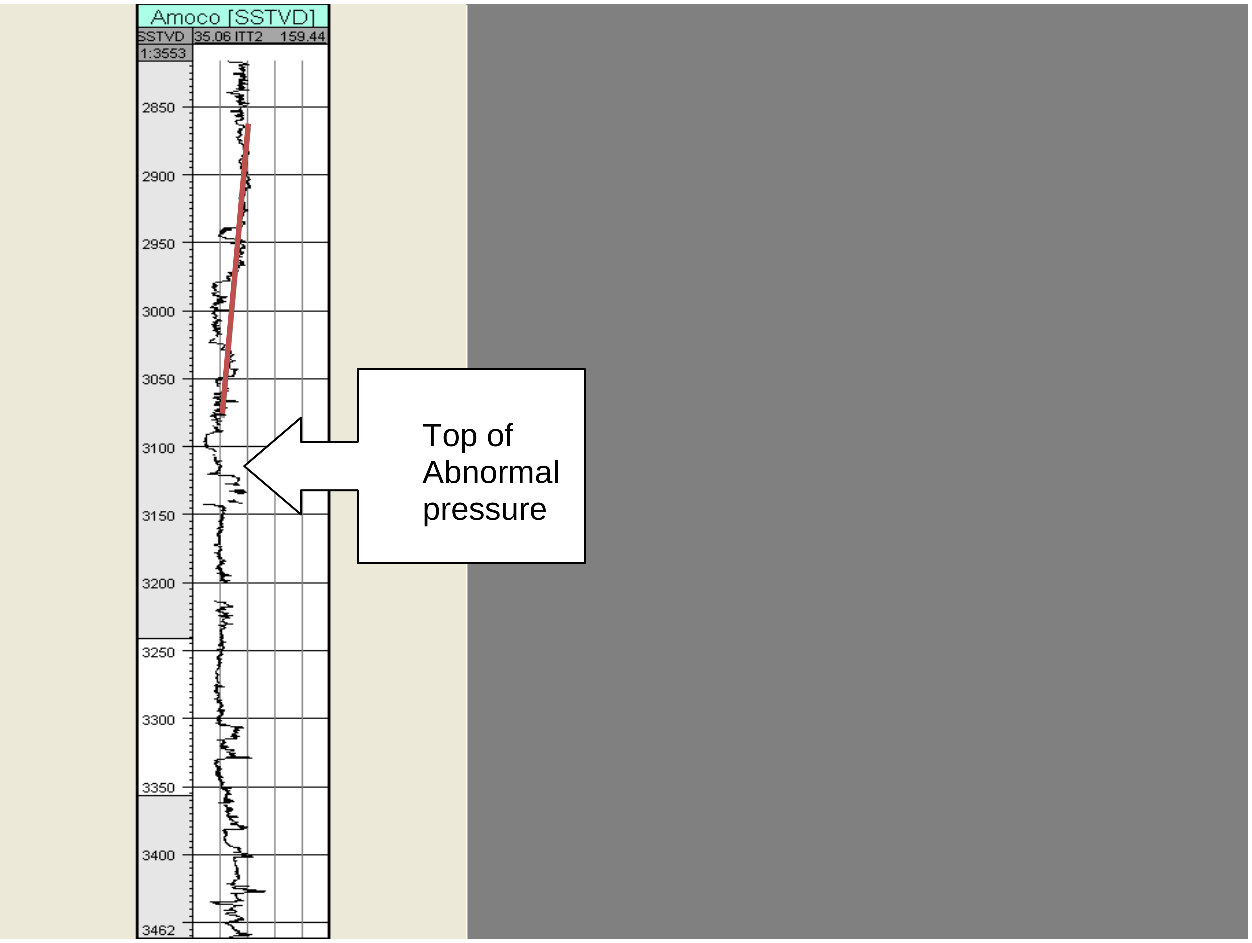


Fig. 4.4 Sonic log indicating deviation from increasing velocity (abnormal pressure)

4.2 Geophysics

Realization: this process helps to a create a physical copy of the 2D seismic line and the output or the result of this process are noticeable faster in use compared to the original data and also helps in visualization.

4.2.1 Seismic to well tie and depth conversion

This serves as the bridge between time and depth where a synthetic seismogram is created. Much emphasis was placed on obtaining a synthetic seismogram which is the bridge between geological information (well data in depth) and geophysical information (seismic in time) as shown in **figure 4.5**. This generated synthetic seismogram is used as the starting point for seismic interpretation because a good seismic reflection image of the subsurface is not enough for an exploration and field development interpretation (Schlumberger, 2010). A good seismic to well tie and reliable depth conversion are also required because a thick zone of high velocity material can masquerade in the time domain as an evenly layer of rock and structures can also be concealed by the overburden, a good depth conversion can show structures where none were thought to exist, revealing potentially bypassed reserves (Edward et al, 2001).

From the well tie, it was realized that the seismic did not go down through to the end of the well so, much of the reservoir zone mapped out from the logs fell below the depth of seismic coverage. This limited the extent of the reservoir for this analysis from the late Jurassic to early cretaceous reservoir of sand intercalating with shales as shown in **figure 4.6**.

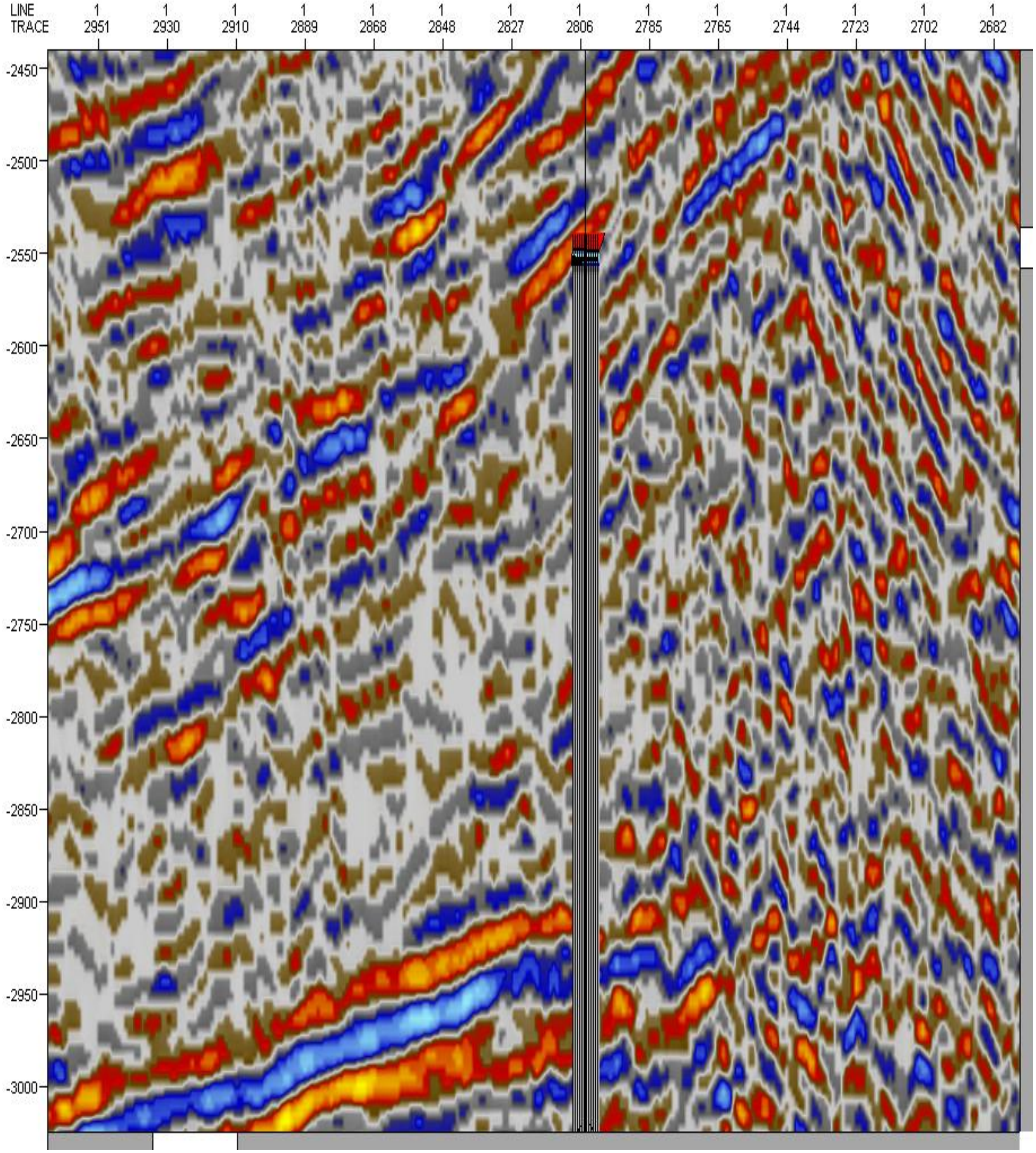


Fig. 4.5 Synthetic seismogram displayed on seismic section showing the tie.

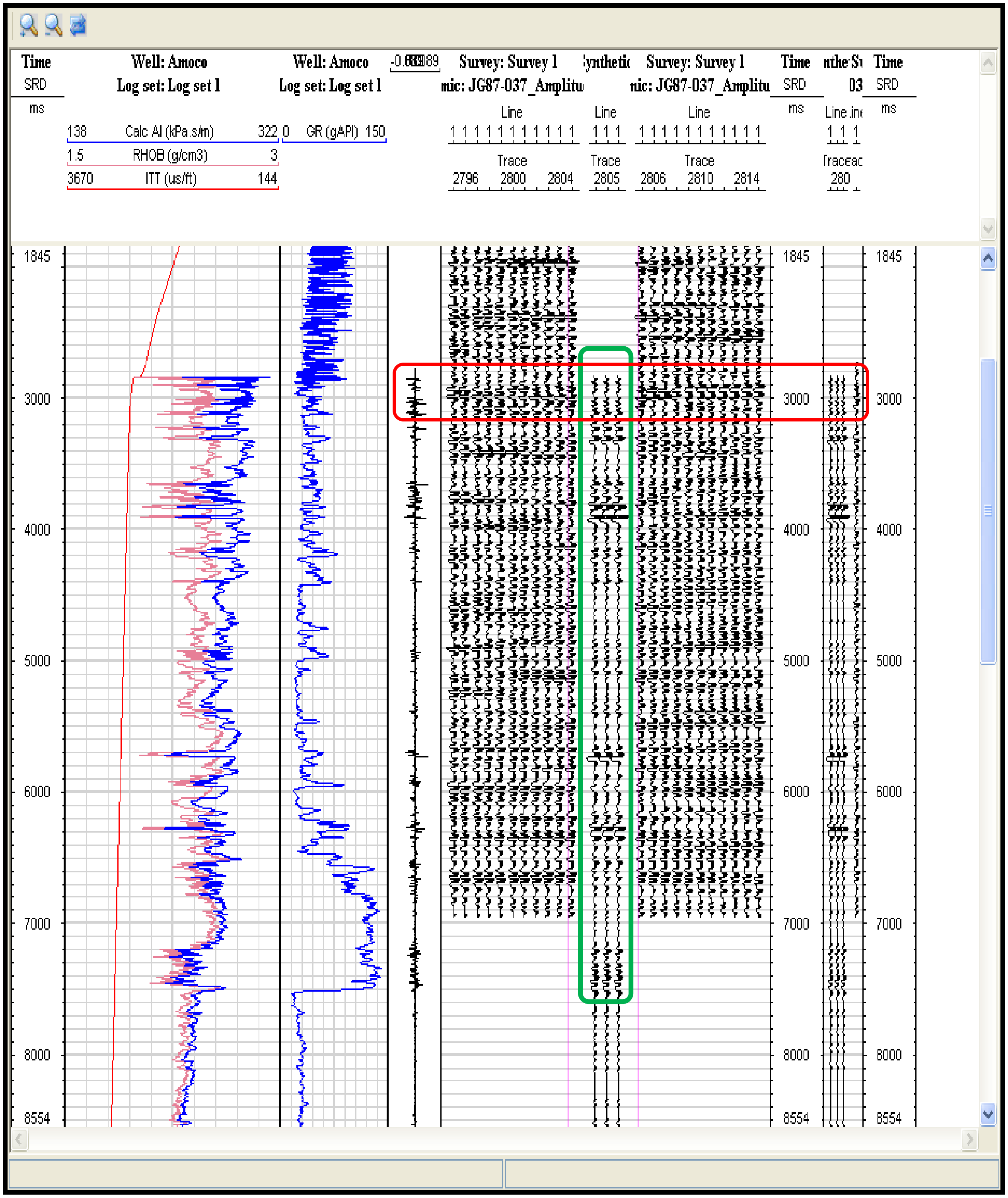


Fig. 4.6 Result of seismic well tie with the generated synthetic seismogram in green and best tie in red

4.2.2 Seismic Interpretation And Mapping

The identification of lithofacies on the seismic section was done based on the tie between the well and the seismic section and also the amplitude of reflection events (Aizebeokhai and Olayinka, 2010), where high amplitude and continuous reflections were found to correspond with the sand units, whereas low amplitude reflections were found to correspond to shale units as shown in **figure 4.7**.

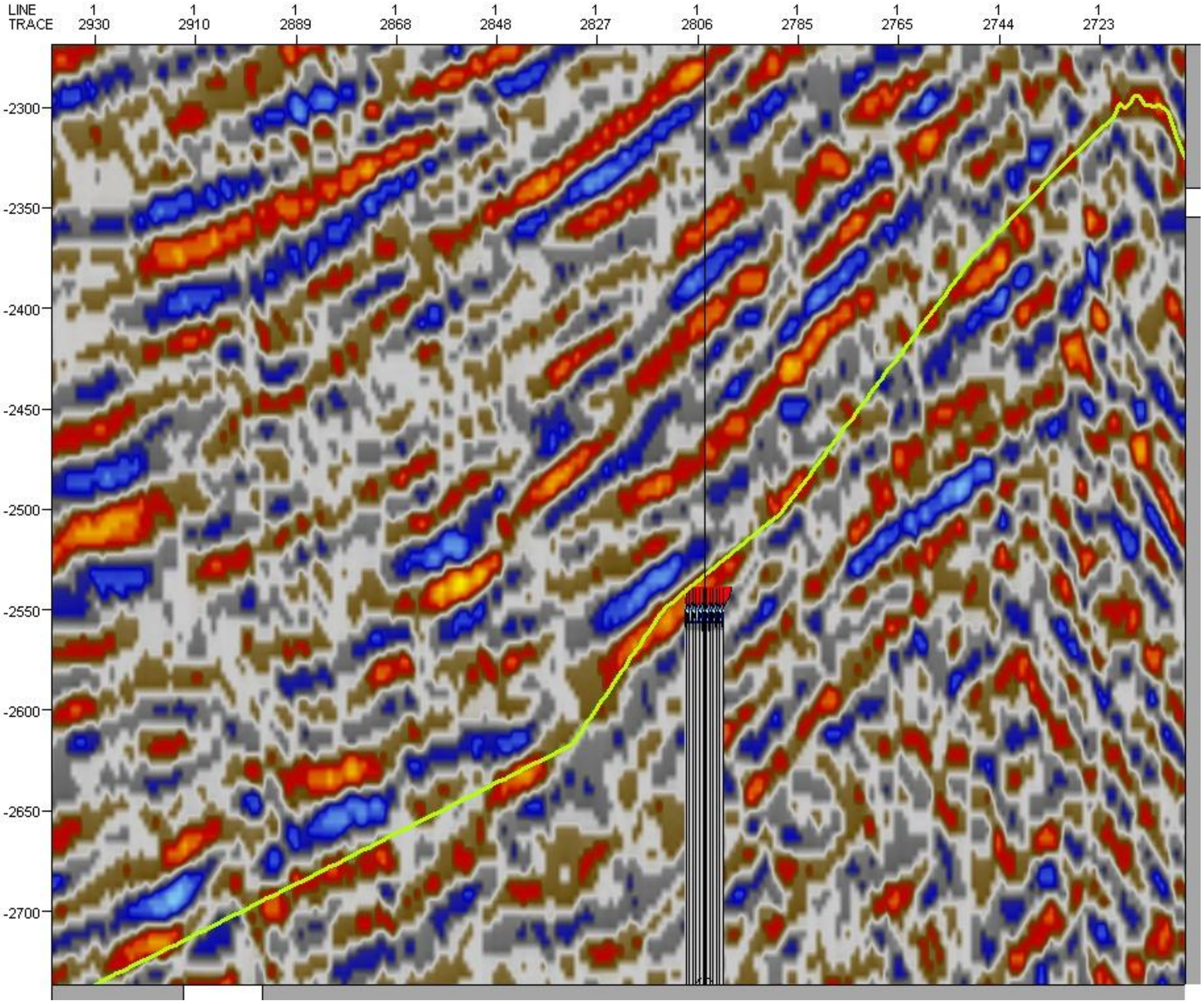


Fig. 4.7 (a) Showing synthetic ties with horizon picked H1

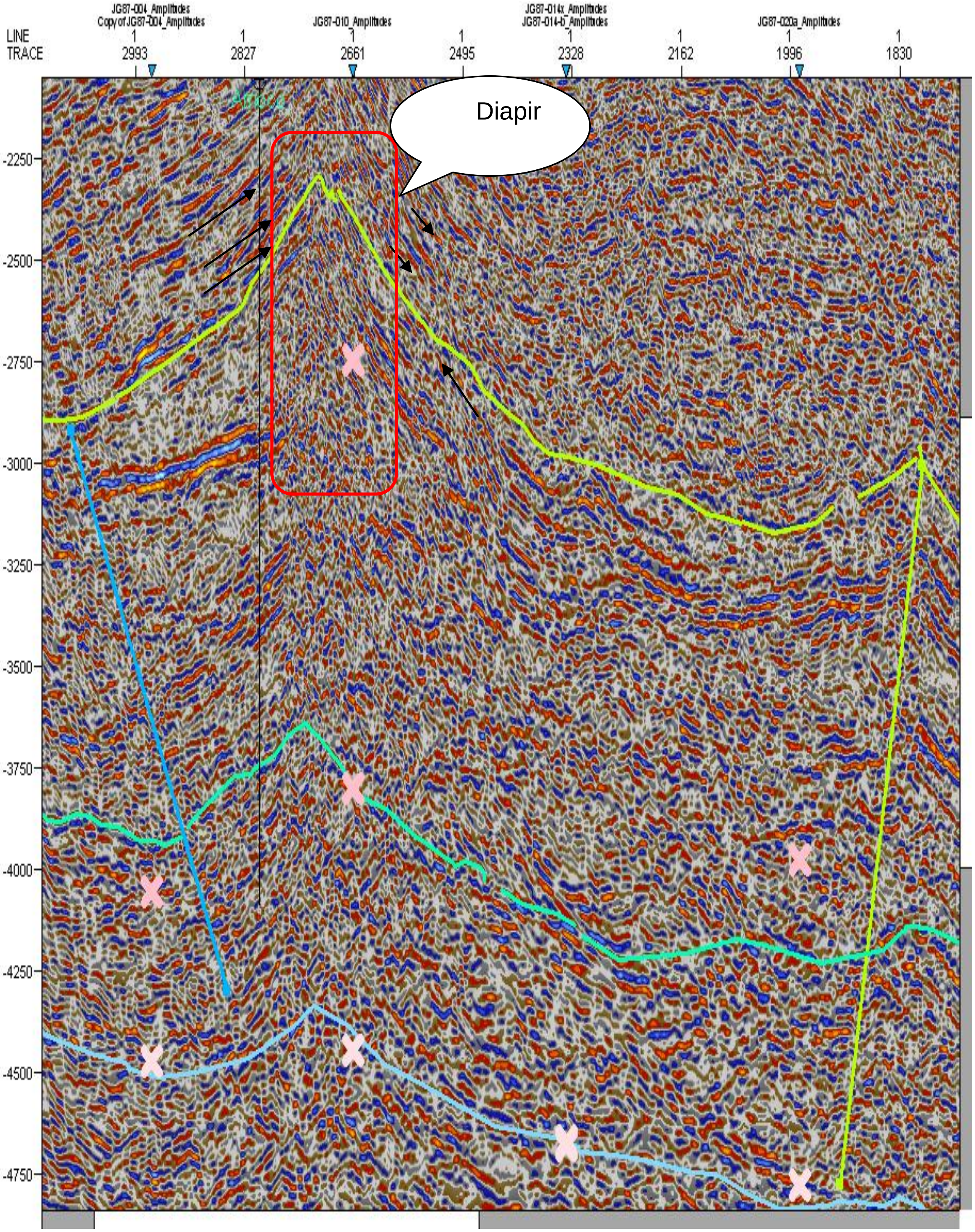


Fig. 4.7 (b) Seismic Interpretation

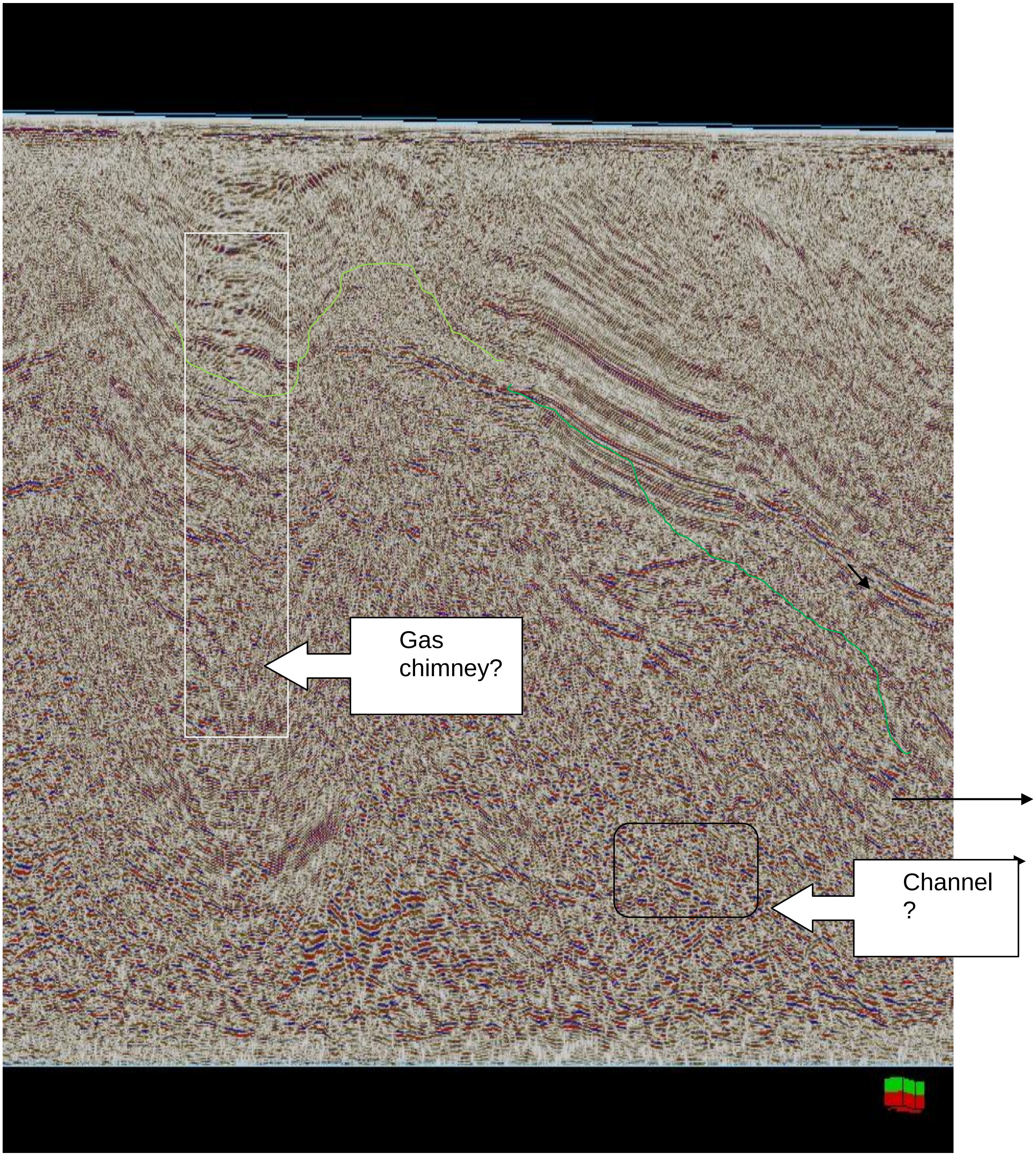


Fig 4.7(c) Sseismic Interpretation b

4.2.3 Stratigraphic Interpretation

Horizon A is where the seismic ties with the well and this occurs in the early cretaceous. Below this horizon, there has been no outstanding reflectance on the seismic section meaning the vertical and lateral resolution are poor (amplitudes are noisy) and juxtaposing to the well information it was realized that the zone represent an event of thin beds of sand and shale intercalating up to late Jurassic horizon C which lies on a thick bed of shale within the Jurassic (light blue) as shown in **figure 4.7 b.** This also means that there is change in facies because the reflectance from top through to the Neocomian has high amplitudes than from the Neocomian down to the late Jurassic.

4.2.4 Structural Interpretation

Normal faults are seen to cut across the horizons and at the eastern and western ends of the seismic section. Dome shaped structures are observed at the central portion of the seismic section. The draping nature of the reflectors in this zone suggests that the doming of the horizons is as a result of salt diapirism as shown in **figure 4.7 b.**

During the seismic interpretation, structures like Gas chimney and channels system were also observed on some of the seismic sections. It seems that the gas is being emitted from a deeper source (may be Jurassic or Permian) and migrating vertically into the cretaceous.

The presence of good quality porous and clean sands can be expected within these channels too.

4.2.5 Petroleum Play Types

Many types of structures which may have hydrocarbon potential have been identified in the study area. They include fault block, channel features, trap due to salt dome and stratigraphic trapping mechanisms.

4.2.6 Time Thickness Maps

Vertical time thickness maps of various intervals have been generated and displayed together as shown in **figure 3.13** in previous chapter. To understand the relationship of various sediment packages, these time surfaces were depth converted. It was found that the highs and lows follow a similar pattern between H2 and H3 surfaces which revealed that the sediments show a similar depositional geometry.

4.2.7 Seismic Attributes Analysis

Attribute analysis process was used in this work to enhance visualization and also quantify features of interpretation interest. Seismic attribute analysis can be divided into two major categories:

1) Seismic attributes that are used to quantify morphological components of the seismic data example coherence. These attributes help us to extract important information on the reflector such as faults truncation and diapirs.
2) Surface attribute also referred to as seismic attributes maps is an extraction of data from a seismic volume across a surface within an interval or where interpretation intersects the volume as shown on Figure 4.8. Although these generated maps such as maximum amplitude reviled the lows on H3 are gradually disappearing on H2 and finally could be

seen on H1 as a high meaning formations of H2 and H3 might be deposited during the same geologic time. In addition to that, the high on maximum amplitude attribute surface means the presence of good quality sand that can serve as reservoir for hydrocarbon accumulation. These analysis and interpretations were done carefully not to over emphasis surface attribute since it could be misleading because the area of interest is full of thin beds (Wayne et al, 2002) (AP.B3).

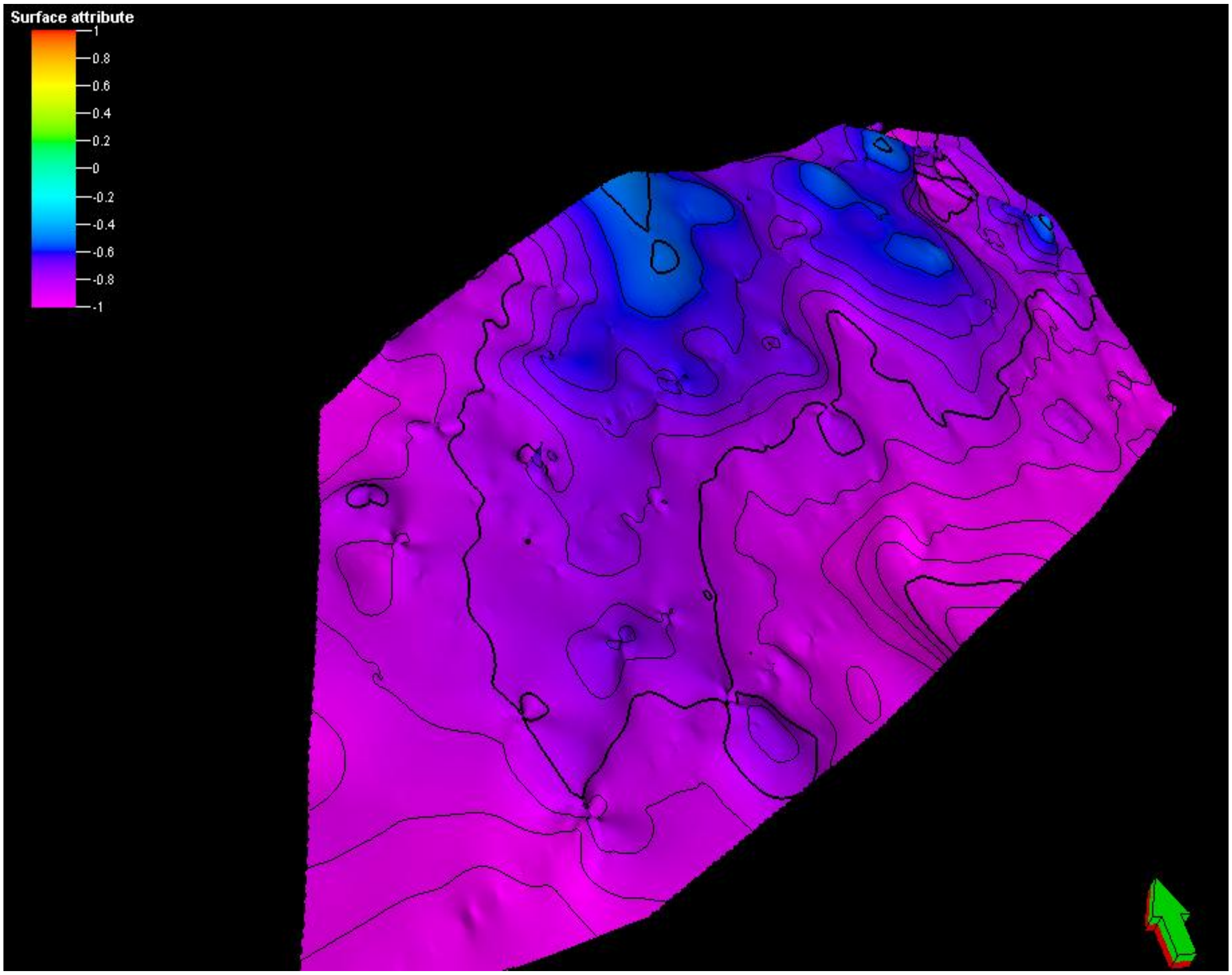


Fig. 4.8 (a) Maximum Amplitude for surface H1

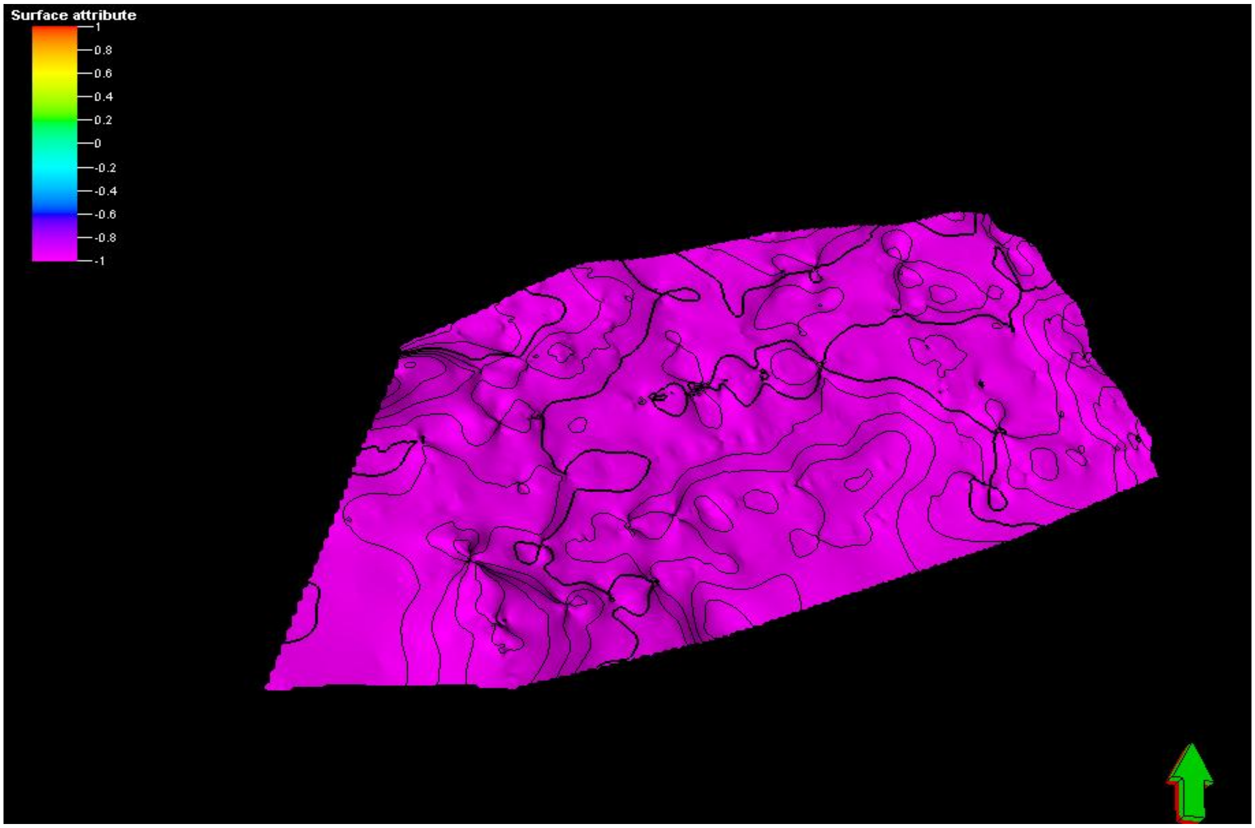


Fig. 4.8 (b) Maximum Amplitude for surface H2

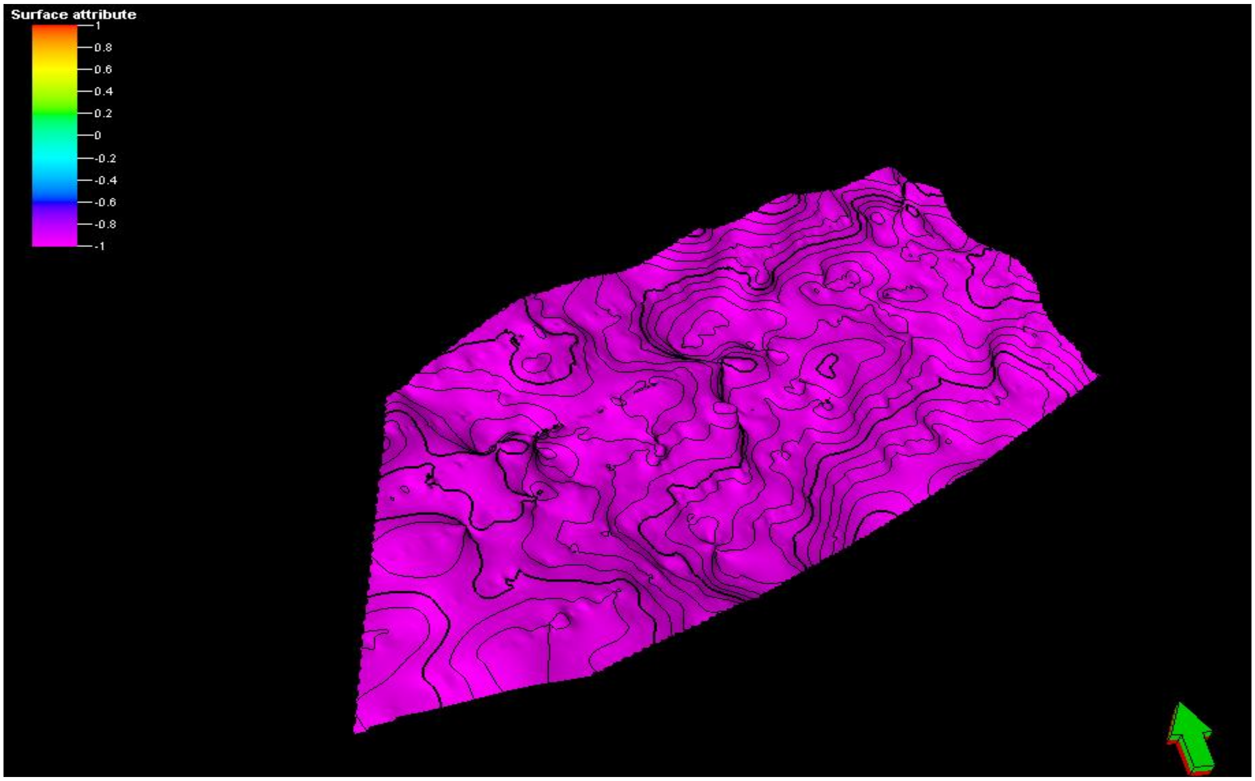


Fig.4.8 (c) Maximum Amplitude on surface H3

4.3 Modeling

In order to show the details of the hydrocarbon system of the Accra Basin, a model was built based on the horizon and faults interpreted with the petrophysical properties used to populate it. Contacts such as Oil/Gas and Oil/water were also defined within the 3D grid model using depth level approach. These constants' depth values used in the model were arrived at after analysis of the resistivity log coupled with gamma and the bulk density logs.

4.3.1 Reserve Estimation

The final volume calculated for the model was based on Monte-Carlo simulation approach. Under society for petroleum engineers SPE guidelines, for proved reserves, there should be at least a 90% probability that the quantities actually recovered will equal or exceed the estimate. For P90, minimum values of 0.1 porosity, 0.5 Net/Gross, and 0.4 water saturation were used as input which resulted in stock tank of oil initially in place (STOIIP) of 148 million barrel of oil and Gas initial in place (GIIP) of 309.3 million cubic feet. For probable reserves, there should be at least a 50% probability that the quantities actually recovered will equal or exceed the sum of estimated proved plus probable reserves. This P50 also resulted in STOIIP of 334 million barrel and GIIP of 695 million cubic feet when a mean values such as 0.15 for porosity. 0.6 Net/Gross and 0.5 water saturation were used. Likewise, for possible reserves, there should be at least a 10% probability that the quantities actually recovered will equal or exceed the sum of estimated proved plus probable reserves. For this 10% probability, maximum values such 0.2 for porosity, 0.7 Net/Gross, and 0.6 water saturation were used which resulted in a STOIIP of 495 million barrel and GIIP of 1.08 billion cubic feet as shown in appendix B6).

STOOIP map for various probabilities were generated draped on horizon H2 are displayed below in figure 4.9.

During the volume calculation formation volume factor Bo value of 1.1 was used for oil and 0.0009 for Gas because the expansion and reduction in volume undergone by oil and gas as its temperature and pressure conditions change from that in the reservoir to that in the stock tank depends upon the changes in pressure and temperature and the composition of oil or gas. This is expressed by the formation volume factor.

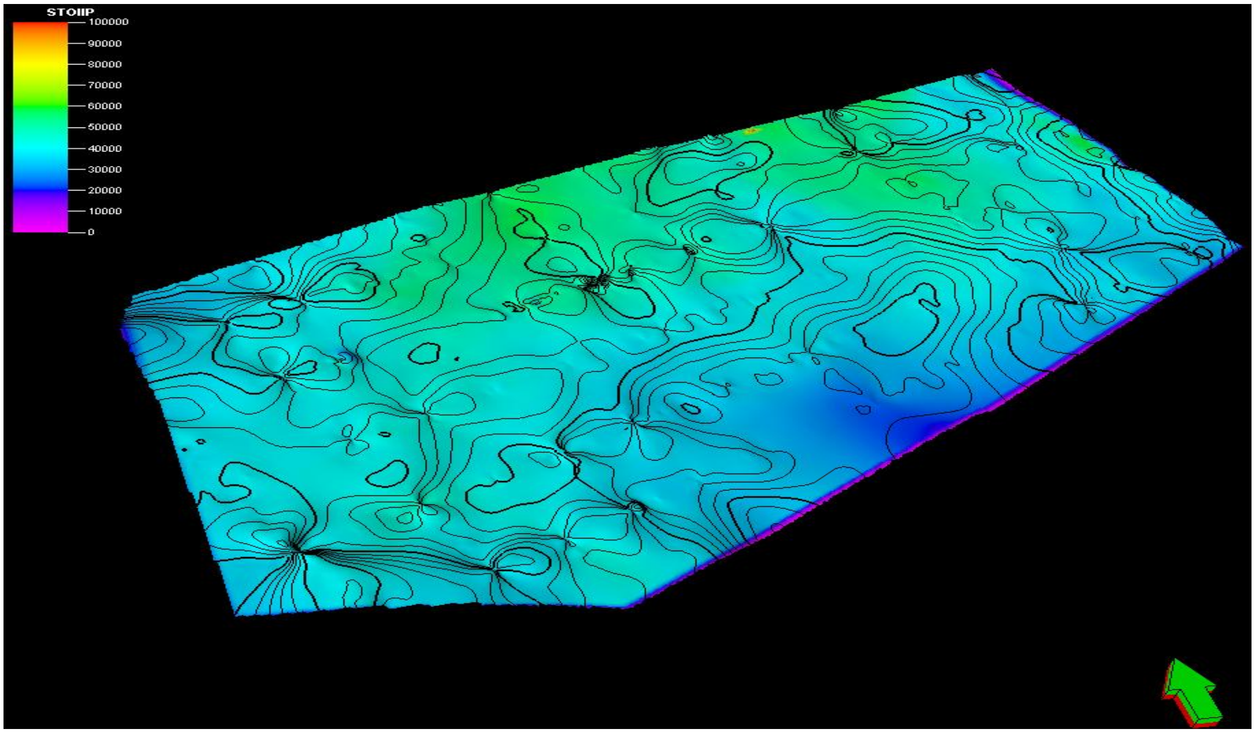


Fig. 4.9 (a) Showing case1(90% probability)

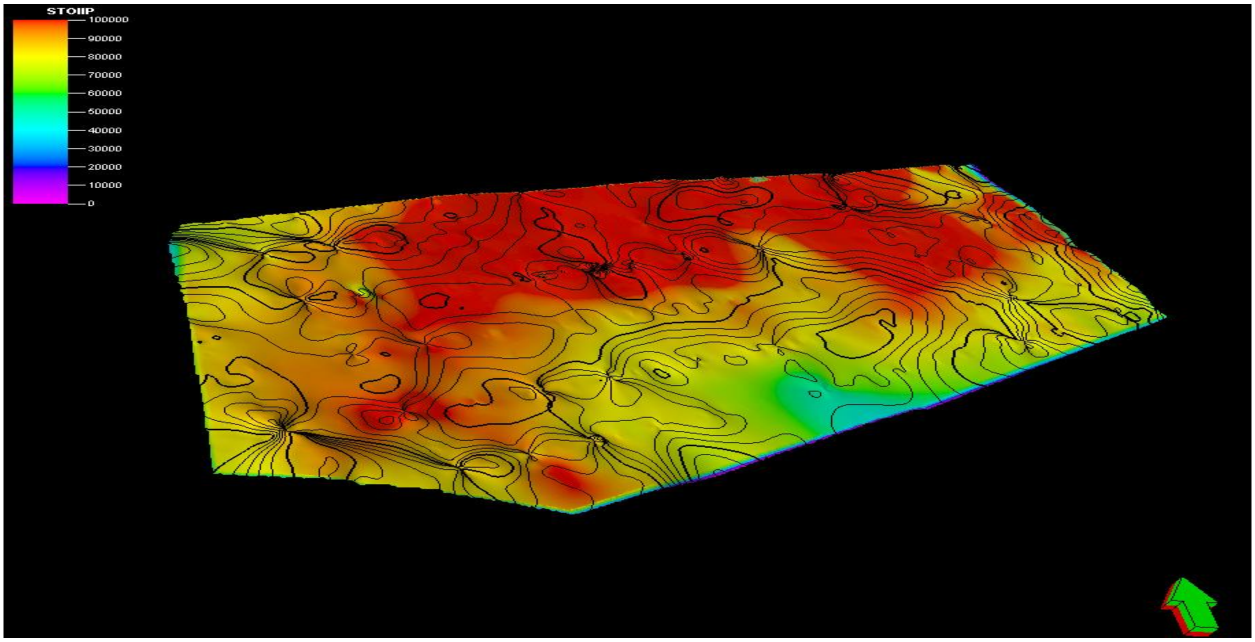


Fig.4.9 (b) Case 2 (50% probability)

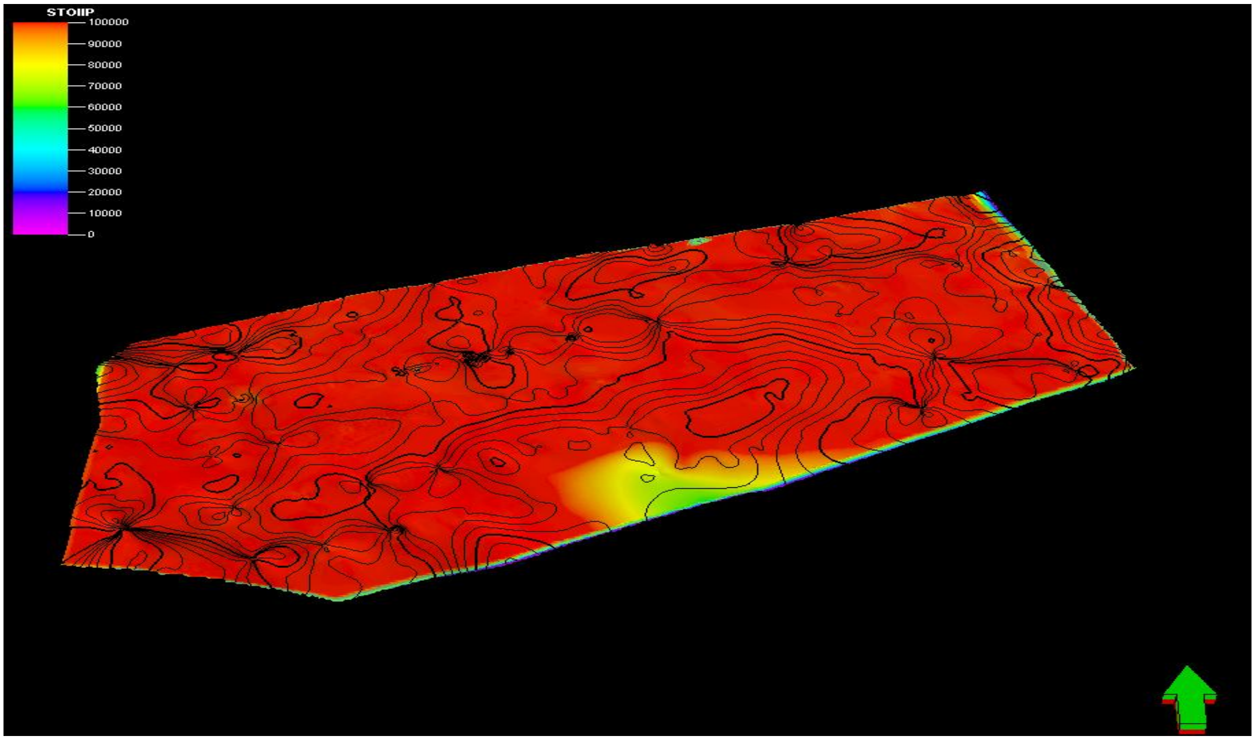


Fig. 4.9 (c) Case3 (10-% probability)

CHAPTER FIVE

CONCLUSION, RECOMMENDATION AND LIMITATION

5.1 Conclusion

The integration of seismic data with well data was successful in defining the subsurface geometry and hydrocarbon trapping potential of the study area. Based on this, it was seen from corner point gridding that the offshore Accra west of the Accra – keta basin is structurally controlled and most of these faults have normal separation leading to compartmentalization of the study area.

From the seismic interpretation it was observed that there were multiple play types in the study area. Thus, within the upper cretaceous, anticlinal features were identified which was an indication of stratigraphic trapping, and within the Neocomian there was a Diapiric structure and the faults which serve as migration path ways for hydrocarbon.

From the integration of seismic data and the well data it was found out that the seismic did not penetrate through the classtic sands deposited within the Jurassic to late Permian. Also the seismic reflections amplitudes below the Neocomian are very chaotic and noisy although it is the mapped out area from the well which gave all the necessary indications that the area contained porous and permeable formation capable of serving as reservoir rock for hydrocarbon accumulation.

The well data was used to delineate the reservoir zone and in the calculation of petrophysical properties. It also serves as a guide during the seismic interpretation.

The stratigraphy of the area could not be analyzed well due to the nature of the resolution of the seismic data.

A final model was created and depth converted and used to calculate volume after contacts were determined. The volume calculated based on monte-carlo simulation approach gave a stock thank initially in place (STOIIP) of 150 million barrel of oil (mmbo) and Gas initially in place (GIIP) of 309.3 million cubic feet (mcft).

5.2 Recommendation

After reviewing and reprocessing the data relating to the study area, the following are suggestions which need to be carried out in the future.

1. A new 3D seismic survey should be conducted within the area targeting the Jurassic to late Permian classtic sand reservoirs.
2. Since the study area is highly segmented by fault blocks more wells should be drilled in the area through these compartments.
3. Amplitude variation with offset (AVO), analysis and seismic inversion should be carried out in the study area to better understand the stratigraphy and characterize the reservoirs.

5.3 Limitations

The well log data was not adequate for better assessment of the study area. The determination of hydrocarbon type could not be done because there was no neutron log. Also there was only one induction log hence the permeability could not be calculated quantitatively.

Finally the resolution of the seismic is very poor making the interpretation very difficult because high reflectance amplitudes are not clearly defined. Thus, the seismic sections are noisy (both lateral and vertical resolution are poor).

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Telford W.M., Geldart L.P., and Sheriff R.E., 1990, Applied Geophysics 2nd Edition, Cambridge University press, P137, 644-646

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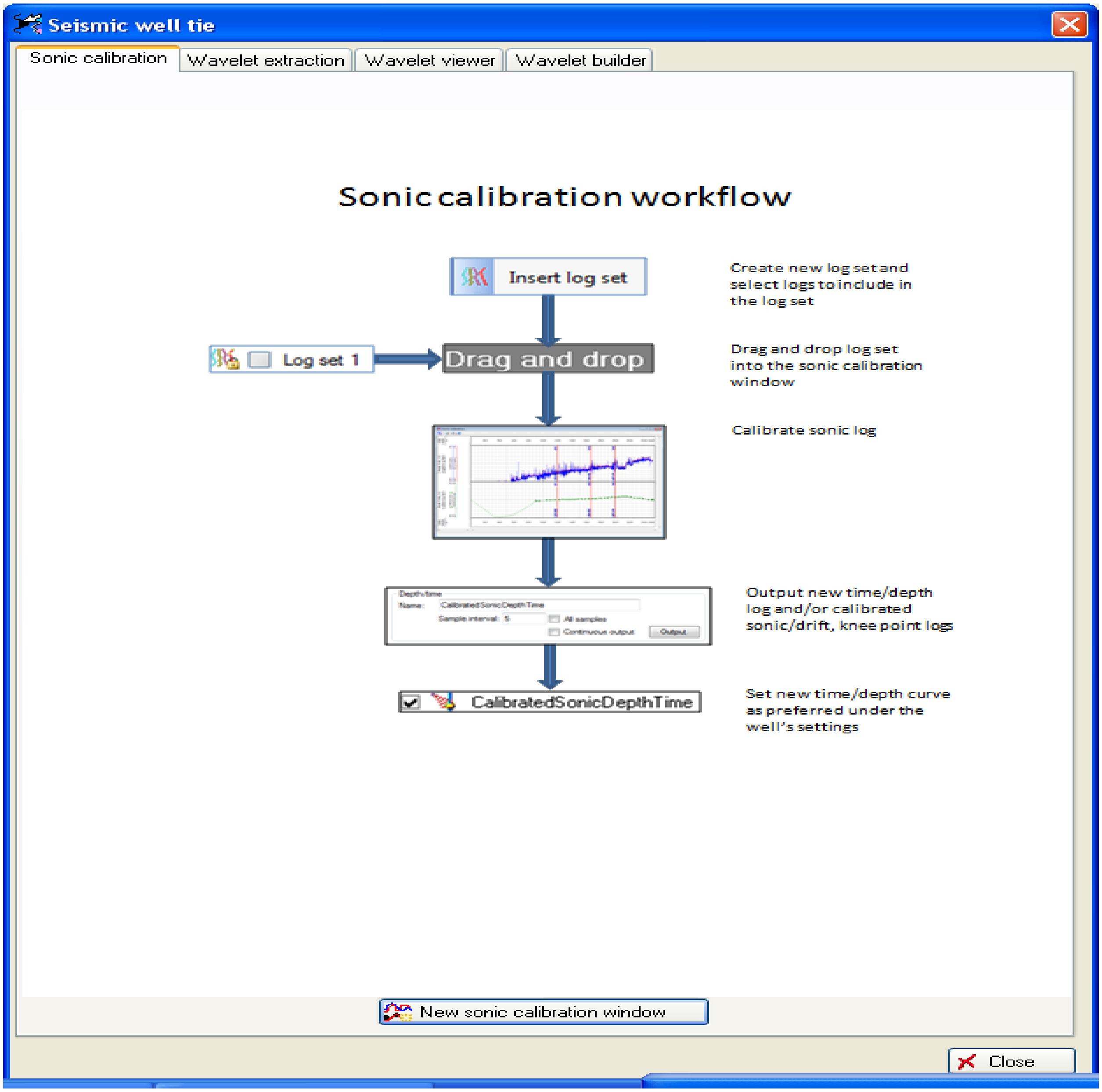
Appendices

Appendix A



Sonic calibration workflow

Create new log set and select logs to include in the log set

Drag and drop log set into the sonic calibration window

Calibrate sonic log

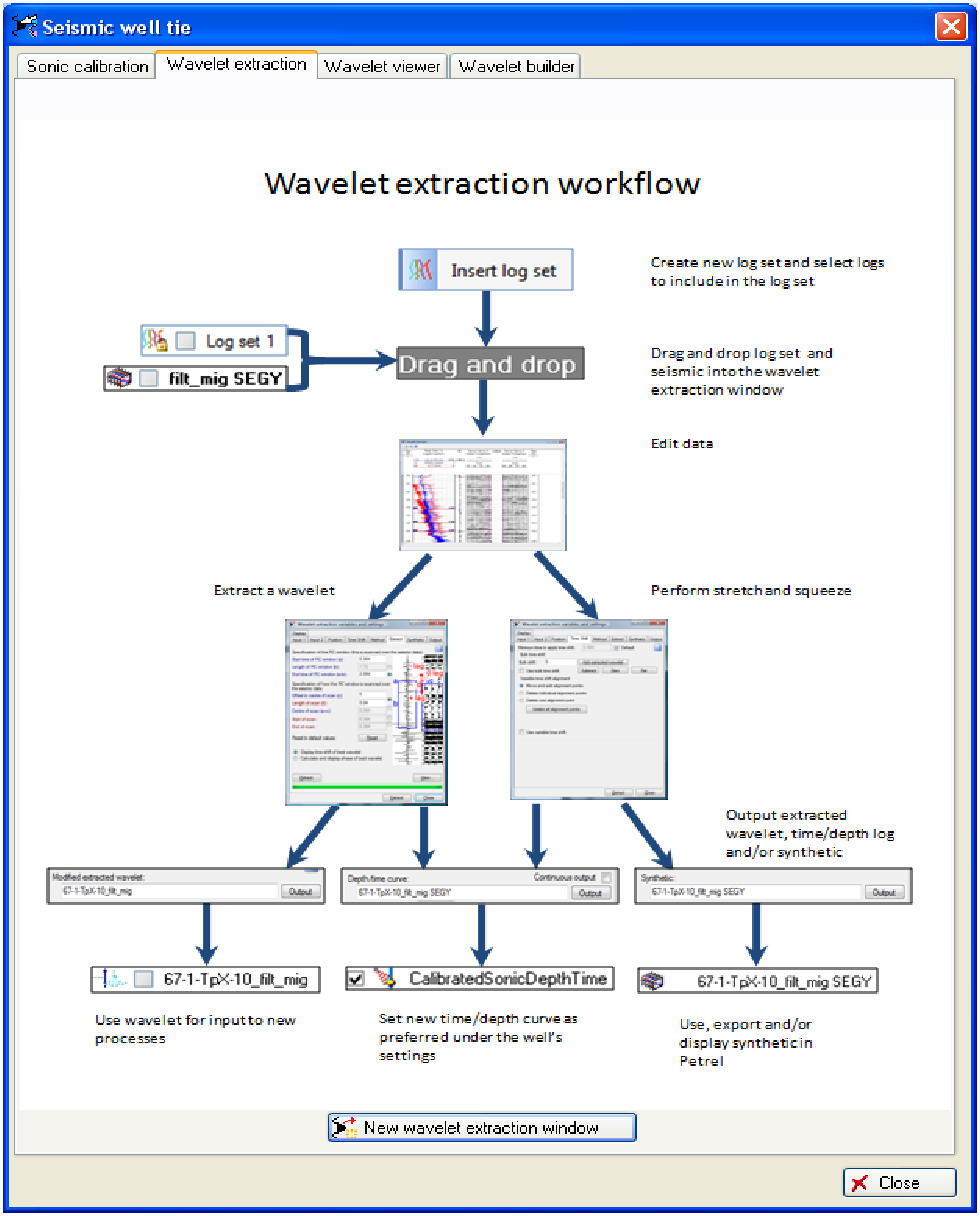
Name: CalibratedSonicDepthTime

Sample interval: 5

Output new time/depth log and/or calibrated sonic/drift, knee point logs

Set new time/depth curve as preferred under the well's settings

AP.A1 Showing Sonic Calibration window



Wavelet extraction workflow

Create new log set and select logs to include in the log set

Drag and drop log set and seismic into the wavelet extraction window

Edit data

Extract a wavelet

Perform stretch and squeeze

Output extracted wavelet, time/depth log and/or synthetic

Modified extracted wavelet: 67-1-TpX-10_filt_mig Output

Depth/time curve: 67-1-TpX-10_filt_mig SEGY Continuous output ☐ Output

Synthetic: 67-1-TpX-10_filt_mig SEGY Output

☐ 67-1-TpX-10_filt_mig

☑ CalibratedSonicDepthTime

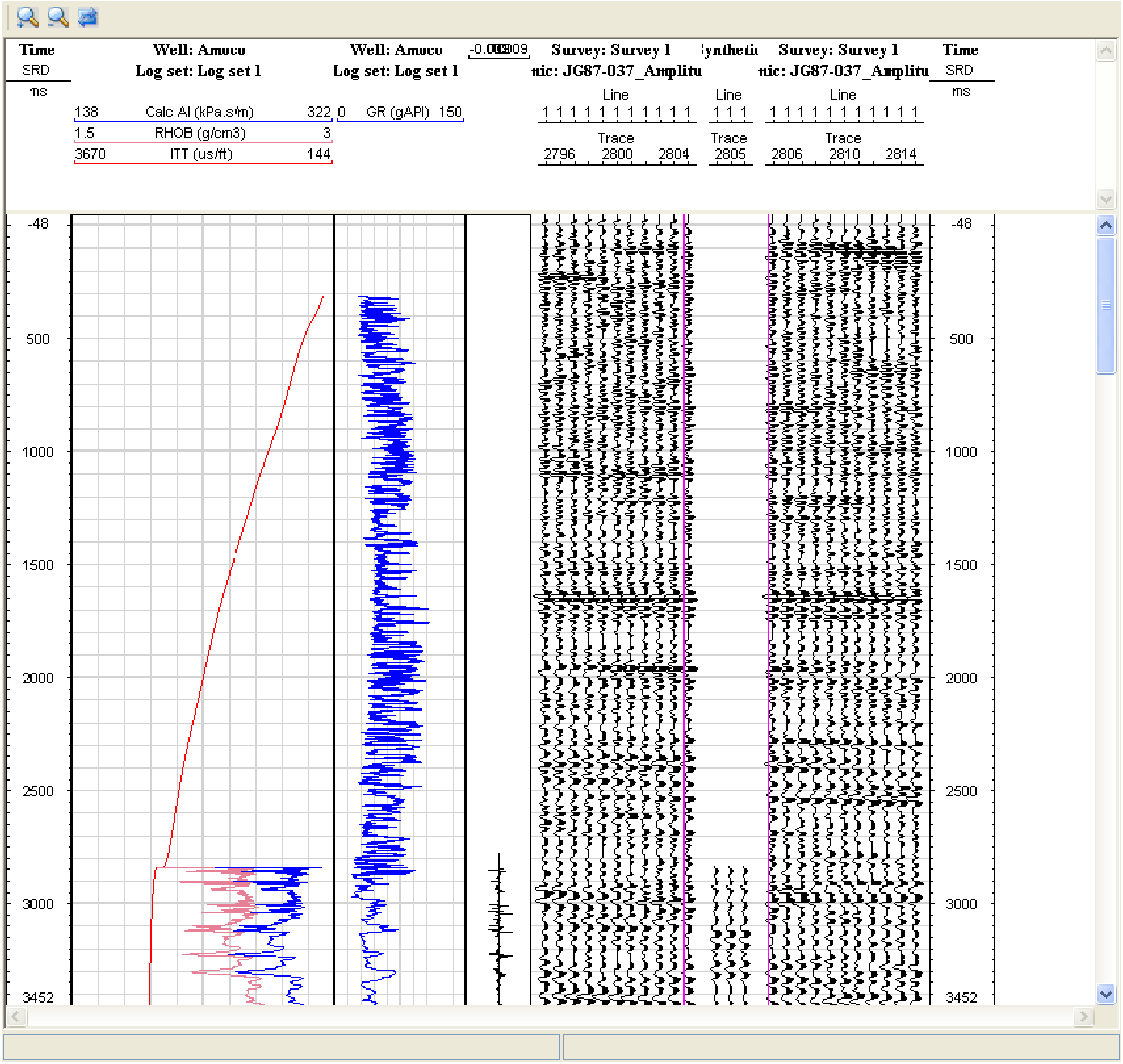
67-1-TpX-10_filt_mig SEGY

Use wavelet for input to new processes

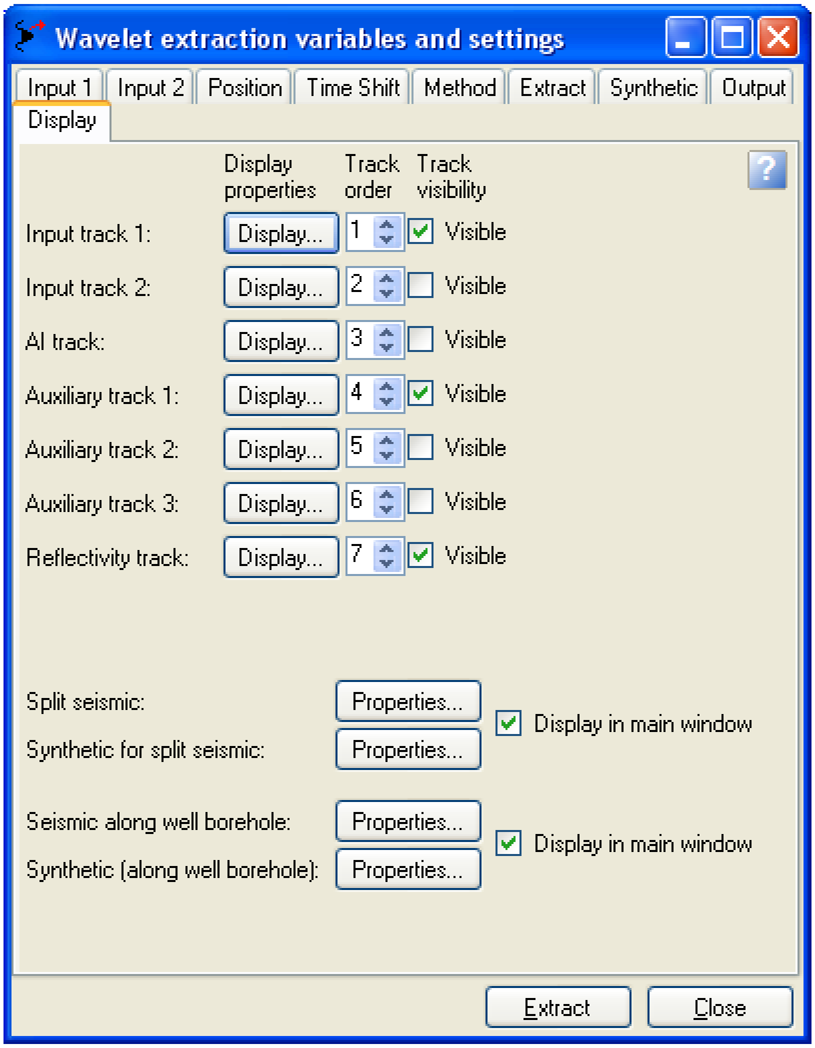
Set new time/depth curve as preferred under the well's settings

Use, export and/or display synthetic in Petrel

AP.A2 Showing wavelet extraction window



AP.A4 Showing seismic well tie result

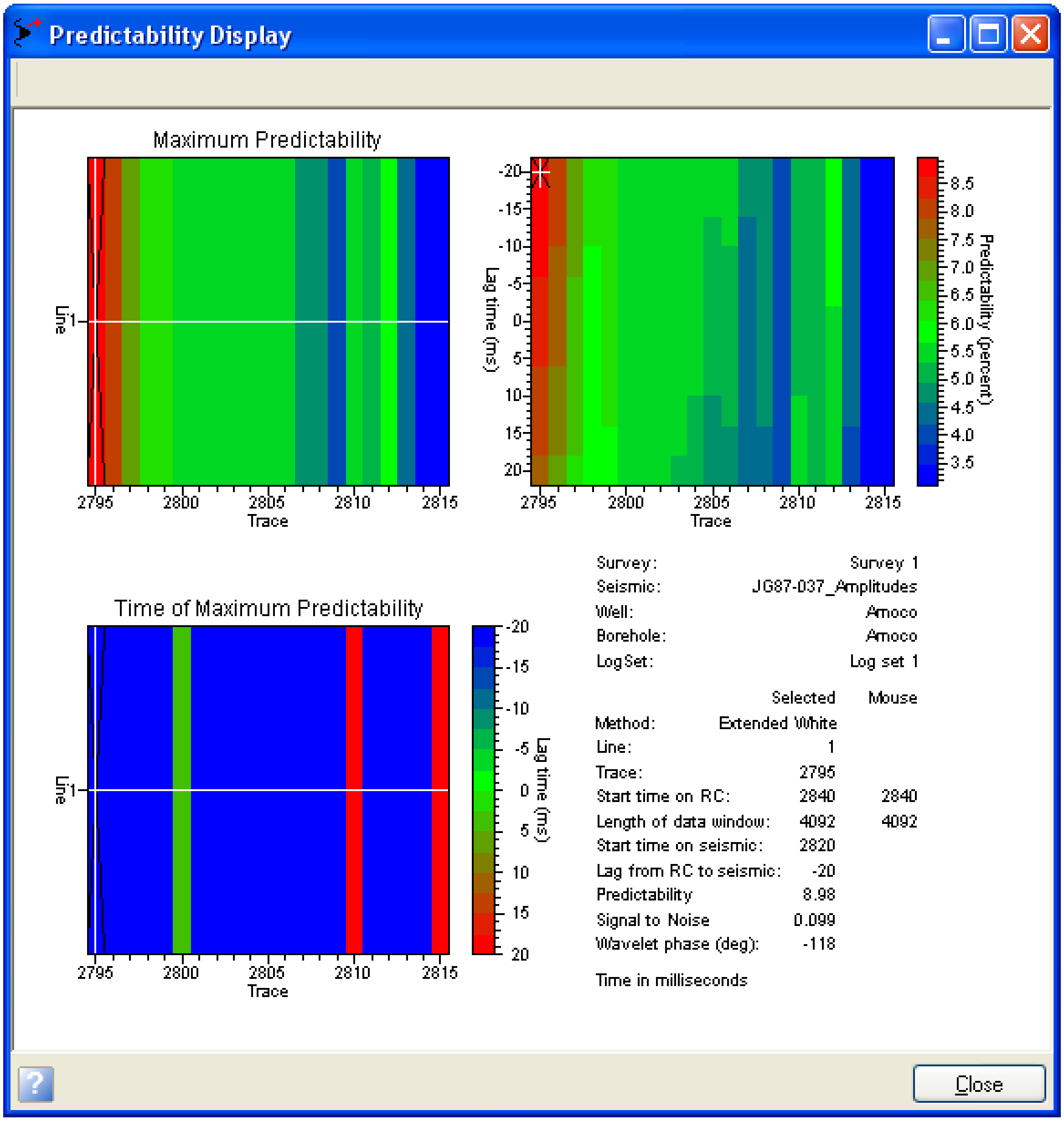


	Display properties	Track order	Track visibility
Input track 1:	Display...	1	☑ Visible
Input track 2:	Display...	2	☐ Visible
AI track:	Display...	3	☐ Visible
Auxiliary track 1:	Display...	4	☑ Visible
Auxiliary track 2:	Display...	5	☐ Visible
Auxiliary track 3:	Display...	6	☐ Visible
Reflectivity track:	Display...	7	☑ Visible

Split seismic: Properties...
Synthetic for split seismic: Properties...
☑ Display in main window

Seismic along well borehole: Properties...
Synthetic (along well borehole): Properties...
☑ Display in main window

AP.A5Showing wavelet extraction variable settings

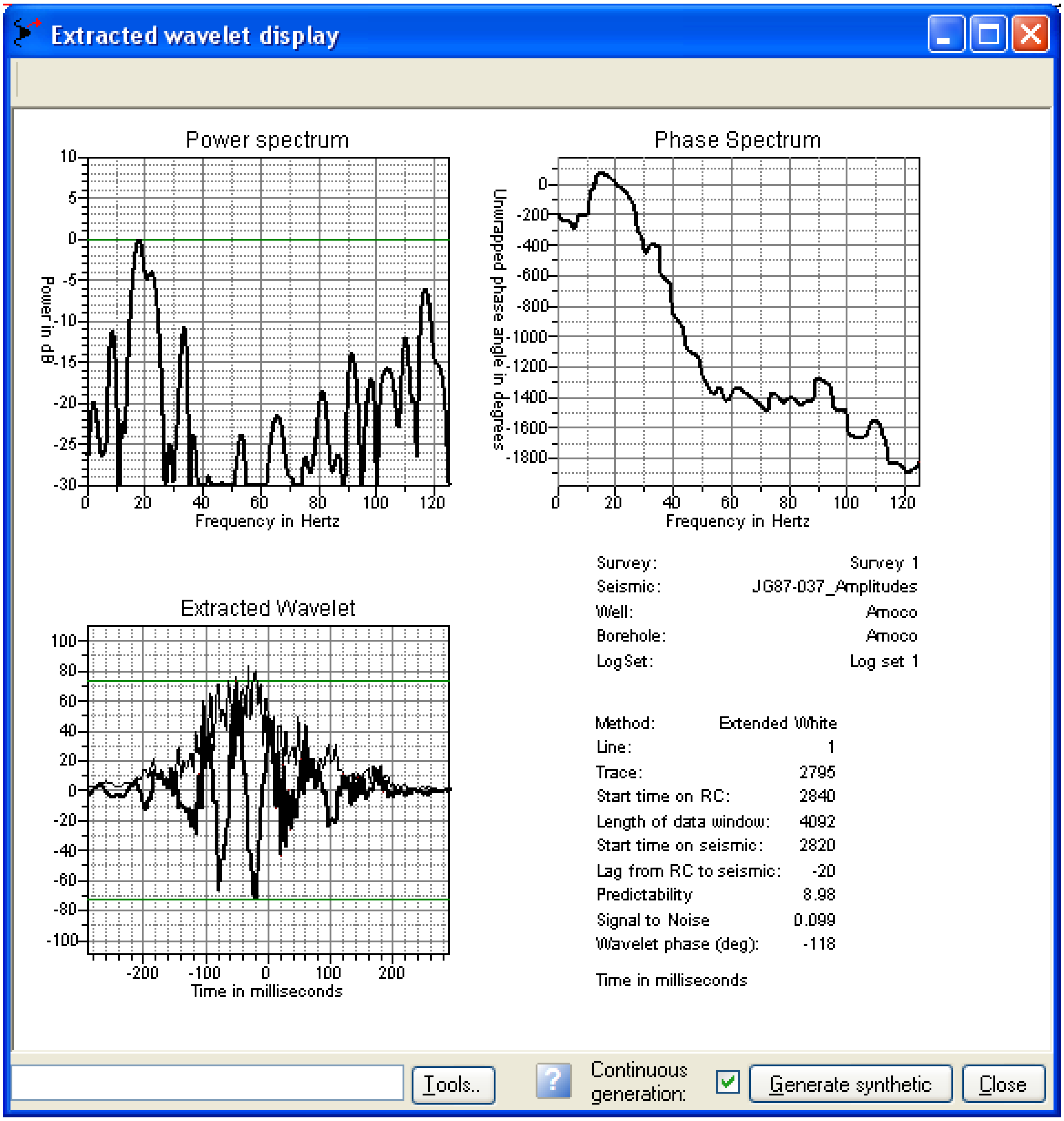


Survey: Survey 1
Seismic: JG87-037_Amplitudes
Well: Amoco
Borehole: Amoco
Log Set: Log set 1

	Selected	Mouse
Method:	Extended White	
Line:	1	
Trace:	2795	
Start time on RC:	2840	2840
Length of data window:	4092	4092
Start time on seismic:	2820	
Lag from RC to seismic:	-20	
Predictability	8.98	
Signal to Noise	0.099	
Wavelet phase (deg):	-118	

Time in milliseconds

AP.A5 Showing maximum predictability



Survey: Survey 1
Seismic: JG87-037_Amplitudes
Well: Amoco
Borehole: Amoco
Log Set: Log set 1

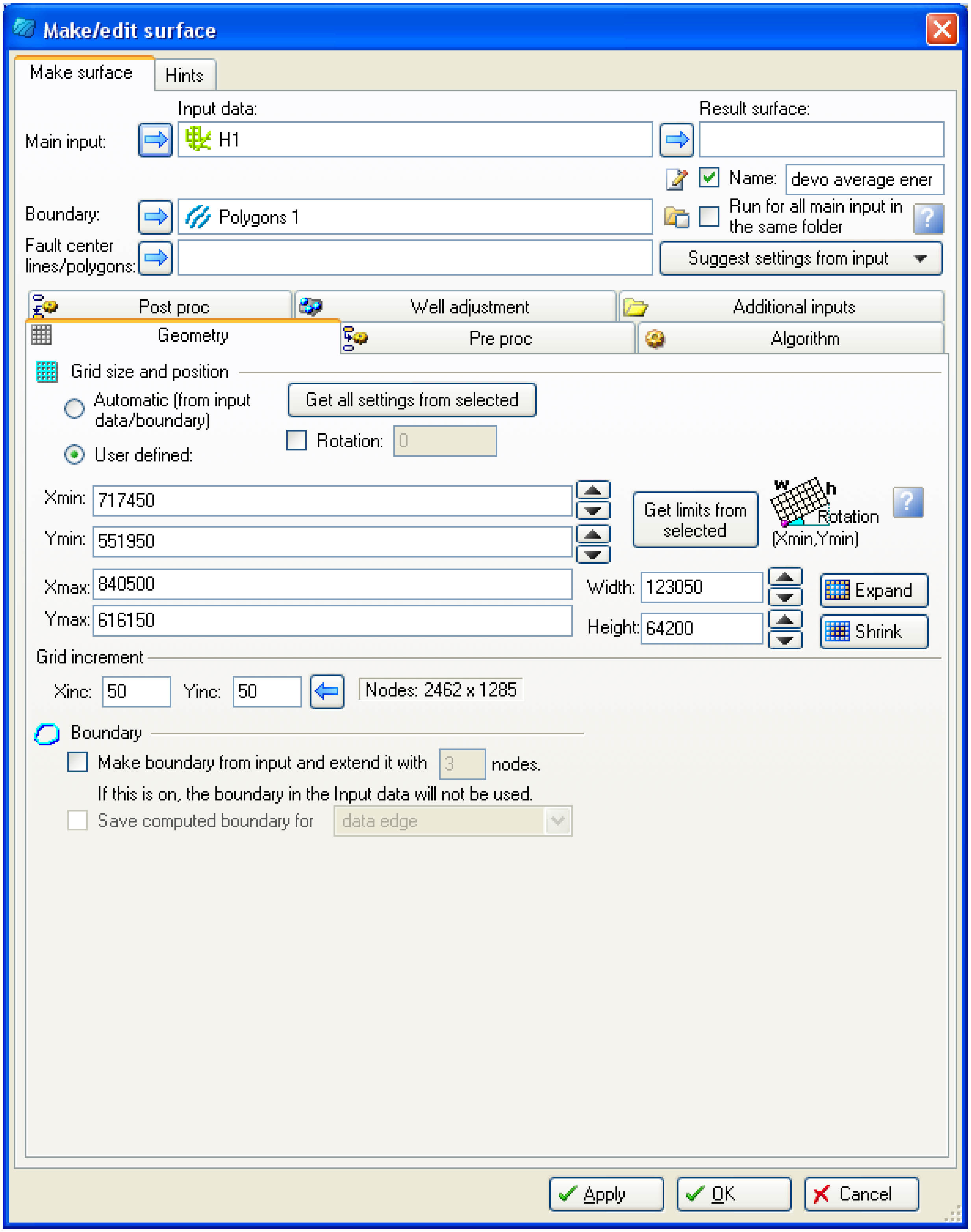
Method: Extended White
Line: 1
Trace: 2795
Start time on RC: 2840
Length of data window: 4092
Start time on seismic: 2820
Lag from RC to seismic: -20
Predictability 8.98
Signal to Noise 0.099
Wavelet phase (deg): -118

Time in milliseconds

Continuous generation: ☑

AP.A6 Showing extracted wavelet window

Appendix B



Make/edit surface

Main input: Input data: H1

Result surface:

☑ Name: devo average ener

Boundary: Polygons 1

Fault center lines/polygons:

☐ Run for all main input in the same folder

Grid size and position

○ Automatic (from input data/boundary)

● User defined:

☐ Rotation: 0

Xmin: 717450

Ymin: 551950

Xmax: 840500

Ymax: 616150

Width: 123050

Height: 64200

Grid increment

Xinc: 50 Yinc: 50 Nodes: 2462 x 1285

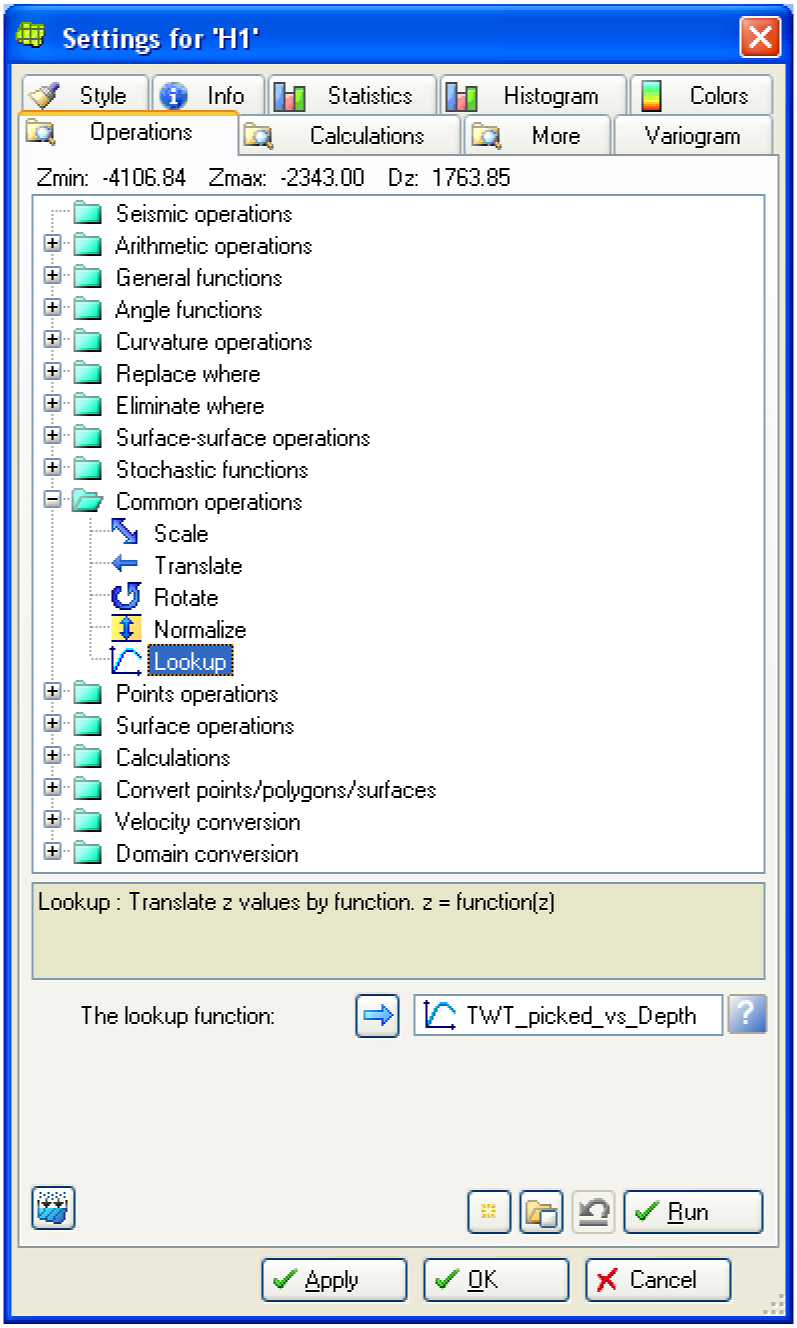
Boundary

☐ Make boundary from input and extend it with 3 nodes.

If this is on, the boundary in the Input data will not be used.

☐ Save computed boundary for data edge

APB1 Showing make/edit surface window

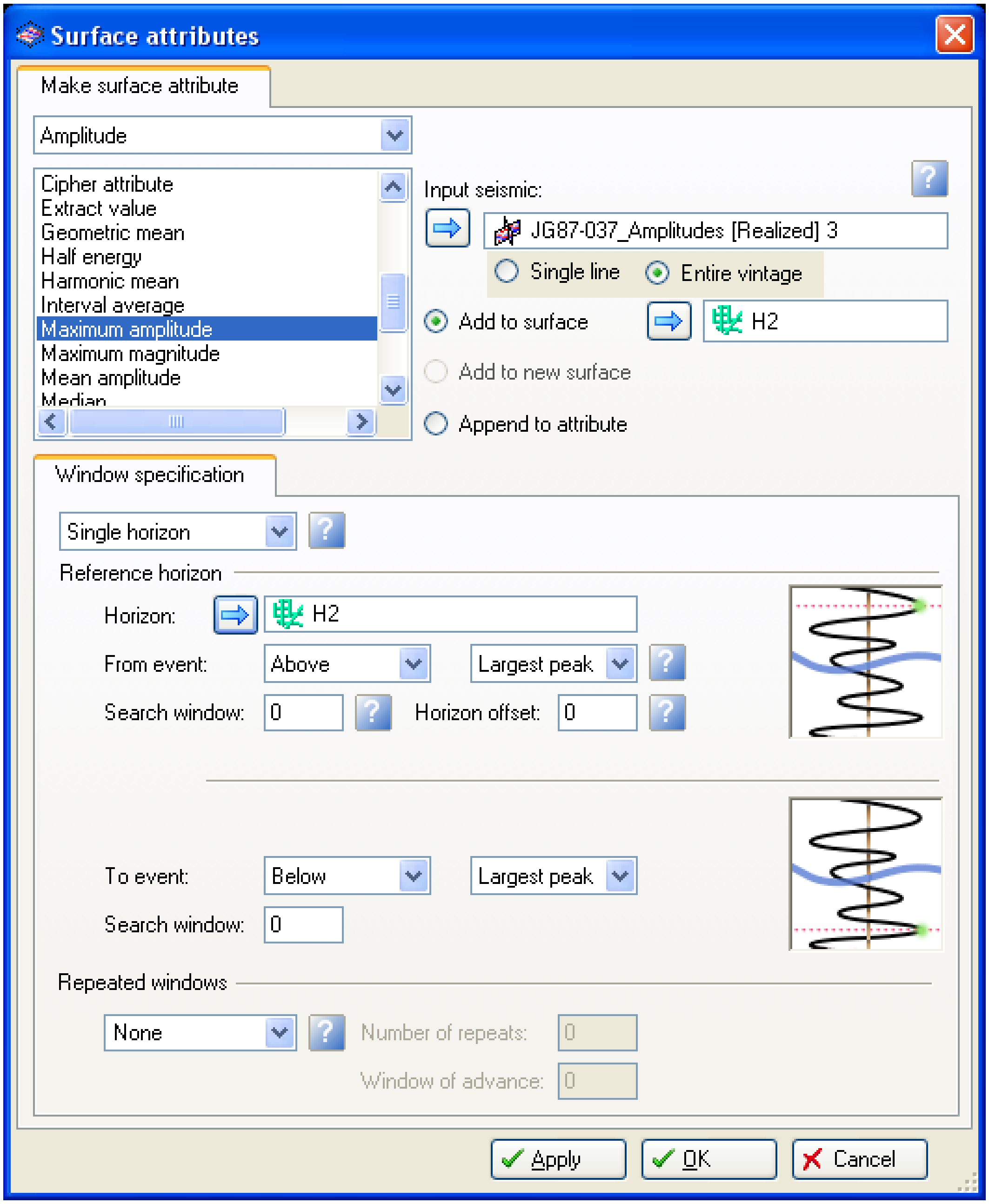


Zmin: -4106.84 Zmax: -2343.00 Dz: 1763.85

Lookup : Translate z values by function. z = function(z)

The lookup function: TWT_picked_vs_Depth

AP.B2 Showing a depth converting window of H1



Surface attributes

Make surface attribute

Amplitude

Maximum amplitude

Input seismic: JG87-037_Amplitudes [Realized] 3

○ Single line ● Entire vintage

● Add to surface H2

○ Add to new surface

○ Append to attribute

Window specification

Single horizon

Reference horizon

Horizon: H2

From event: Above Largest peak

Search window: 0 Horizon offset: 0

To event: Below Largest peak

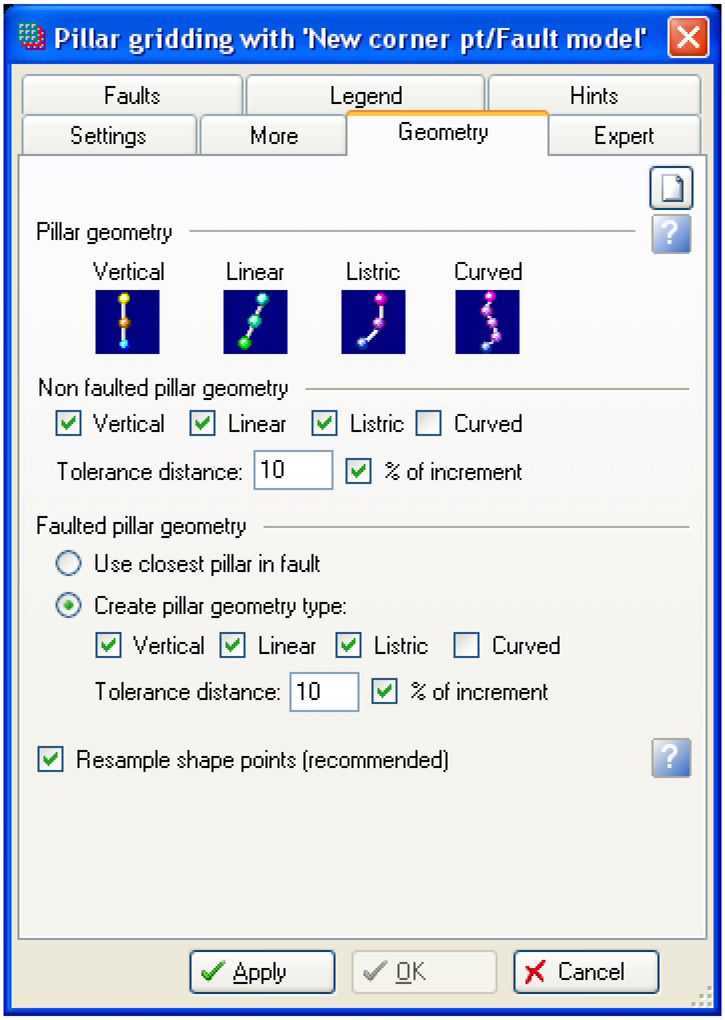
Search window: 0

Repeated windows

None Number of repeats: 0

Window of advance: 0

AP.B3 Showing surface attribute generating window



Non faulted pillar geometry

☑ Vertical ☑ Linear ☑ Listric ☐ Curved

Tolerance distance: 10 ☑ % of increment

Faulted pillar geometry

○ Use closest pillar in fault

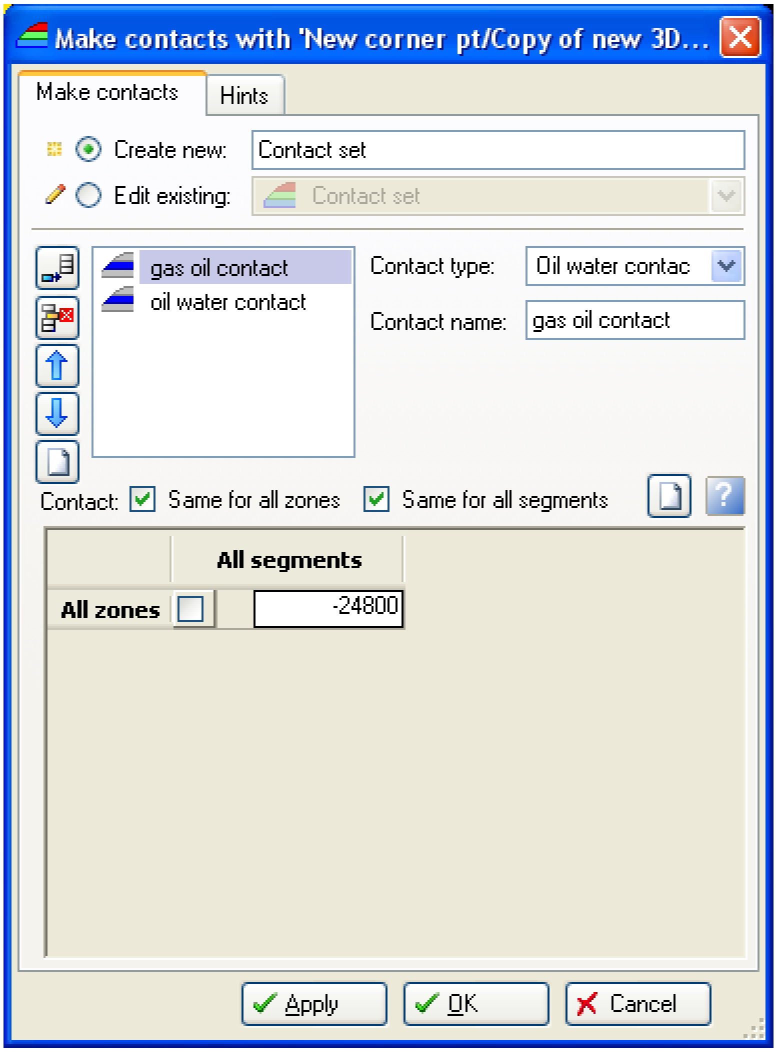
● Create pillar geometry type:

☑ Vertical ☑ Linear ☑ Listric ☐ Curved

Tolerance distance: 10 ☑ % of increment

☑ Resample shape points (recommended)

AP.B4 Showing pillar gridding process window



Make contacts with 'New corner pt/Copy of new 3D...

● Create new: Contact set

○ Edit existing: Contact set

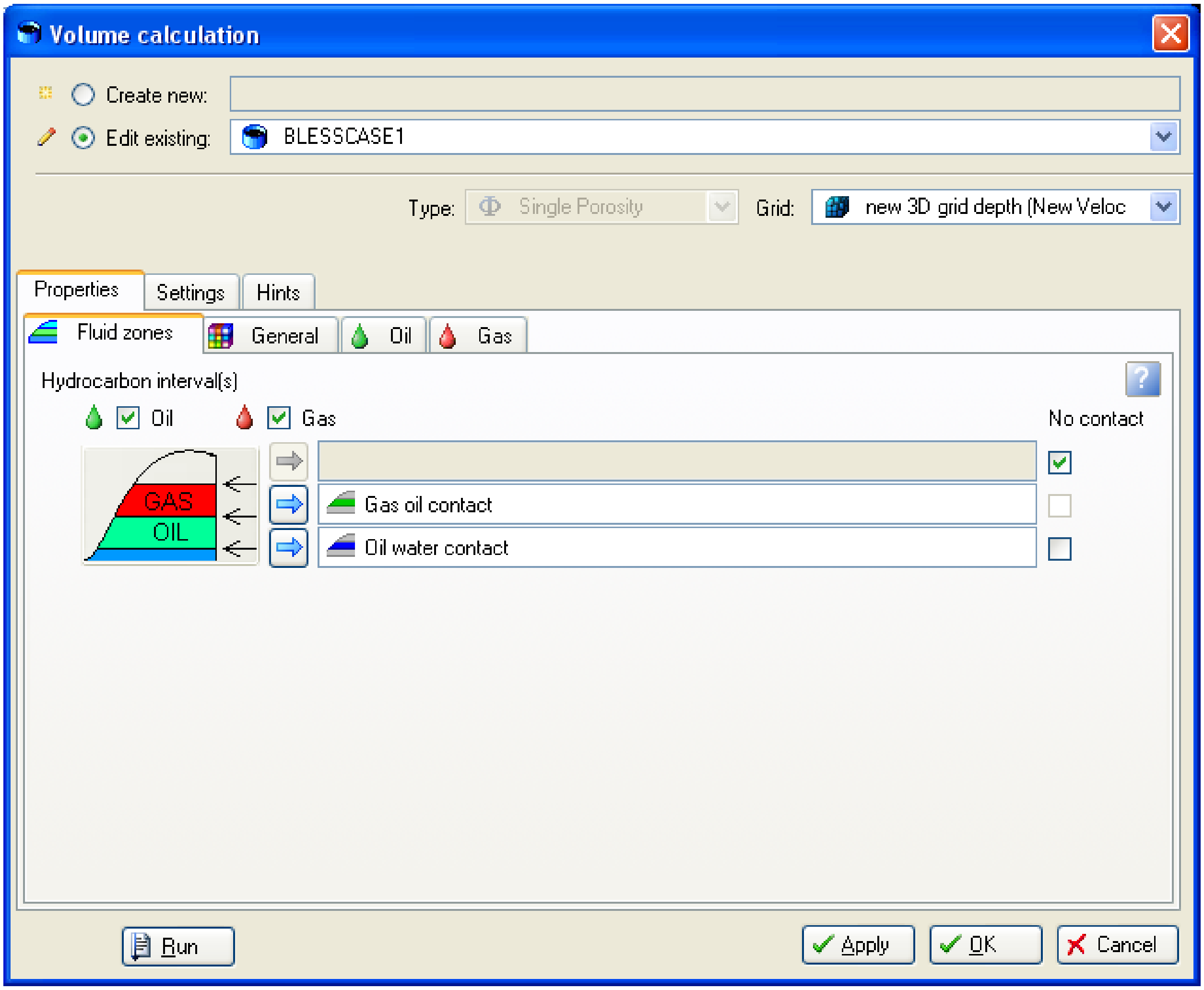
Contact type: Oil water contac

Contact name: gas oil contact

Contact: ☑ Same for all zones ☑ Same for all segments

	All segments
All zones ☐	-24800

AP.B5 Showing generation window



Volume calculation

○ Create new:

● Edit existing: BLESSCASE1

Type: Single Porosity

Grid: new 3D grid depth (New Veloc

Hydrocarbon interval(s)

☑ Oil ☑ Gas

No contact

☑

Gas oil contact ☐

Oil water contact ☐

AP.B6 Showing volume generation window.

Appendix C

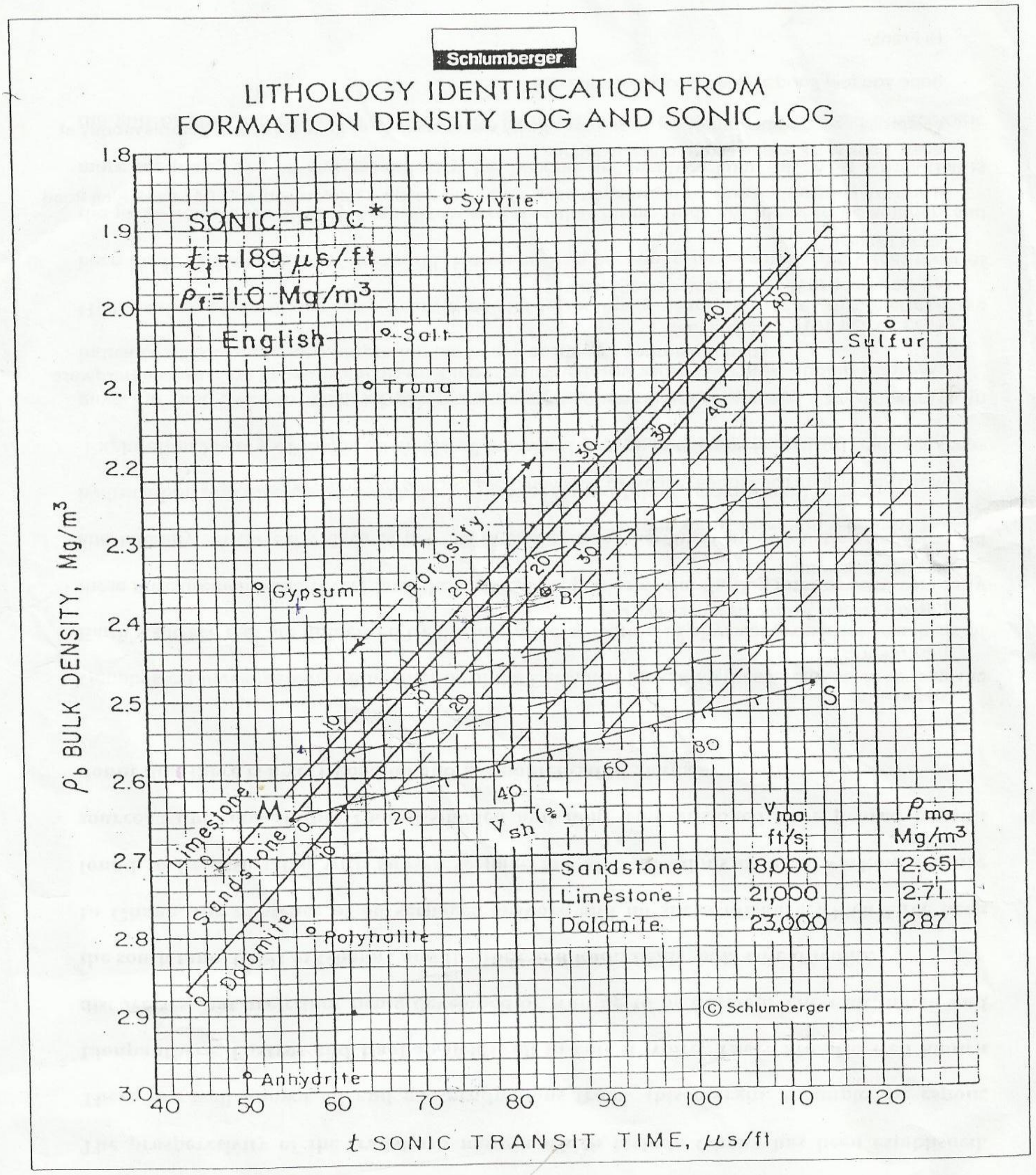
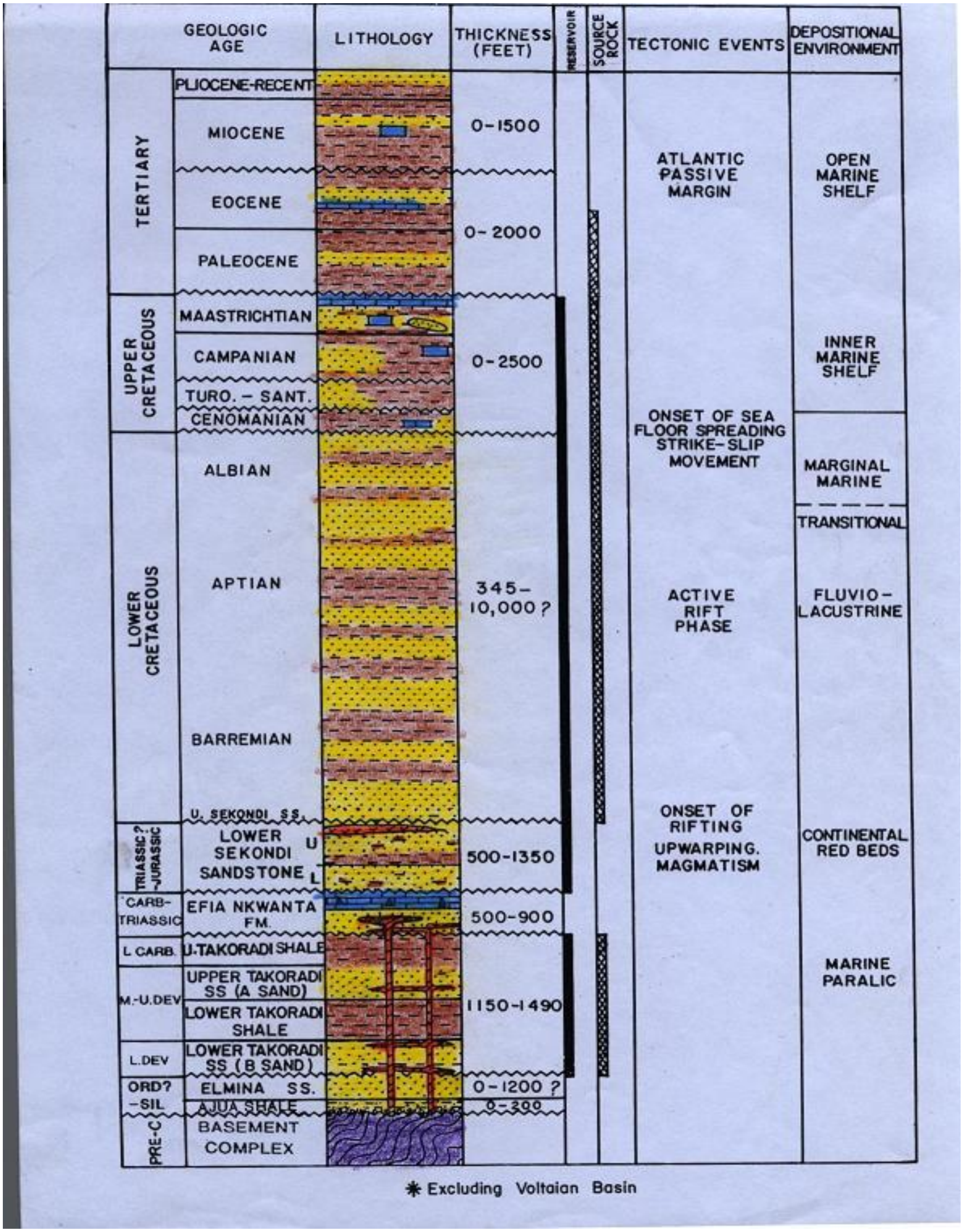


Figure 9.14 V_{sh} and ø Determination in a Shaly Sandstone by the Sonic-Density Crossplot

AP.C1 Showing density sonic crossplot.



AP.C2 Showing regional stratigraphy column of the Accra-Keta basin