2D SEISMIC DATA INTERPRETATION, PETROPHYSICAL ANALYSIS AND VOLUMETRIC RESERVES ESTIMATION OF SHAHDADPUR GAS FIELD, LOWER INDUS BASIN, PAKISTAN

By

MUHAMMAD HARIS (01-166201-010)

MURSALEEN QADEER (01-166201-011)

DEPARTMENT OF EARTH AND ENVIRONMENTAL SCIENCES

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A thesis submitted to Bahria University, Islamabad in partial fulfillment of the requirement for the degree of BS in Geophysics

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ABSTRACT

The research was conducted to reveal the subsurface geology of the Shahdadpur area by using the seismic interpretation technique and the hydrocarbon saturation was estimated to find the potential reserves by using petrophysical techniques. Seismic data interpretation plays a crucial role in exploring hydrocarbons and understanding the geology beneath the earth's surface. The study area has an extensional basin regime followed by normal faults that are marked in interpreted seismic sections F1, F2, F3, F4, and F5. By observing these faults, the area has horst and graben structures which helps in hydrocarbon accumulation. Sembar Formation was the major source rock in the study area and the reservoir Formation was Lower Goru and Chiltan, and Upper Goru acts as seal rock that completes the petroleum system. In this research, two horizons were marked on a seismic section named Lower Goru of the Cretaceous age and Chiltan Limestone of the Jurassic age and then the time and depth contour maps were generated for both marked horizons. Petrophysical analysis was performed on the Lower Goru Formation in which three hydrocarbon-bearing zones were identified that was based on log trends. Overall, the average values of the volume of shale, a saturation of hydrocarbon, and effective porosity in these zones were 49.9%,40.4%, and 9.1% respectively. By using seismic results of the depth contours map of the Lower Goru Formation and petrophysical analysis that was done on the Lower Goru Formation, volumetric reserves estimation was computed to identify the maximum hydrocarbon extent which indicates the more presence of hydrocarbon availability while proceeding toward the advanced seismic interpretation.

ACKNOWLEDGEMENT

We extend our heartfelt gratitude to the Almighty for blessing us with the strength and opportunity to achieve this milestone. Our sincere thanks go to our parents, whose unwavering support and trust have been pivotal in reaching this point in our careers. Special appreciation is due to our mentor, Dr. Urooj Shakir, Senior Lecturer in the Department of Earth and Environmental Sciences at Bahria University, Islamabad. Her invaluable guidance and steadfast support have been crucial throughout the research and composition of our thesis. Our supervisor's mentorship has significantly shaped our academic journey, and we are deeply thankful for her expertise and wisdom. We are also immensely grateful to Dr. Fahad Mehmood and Dr. Muhammad Raiees Amjad, Senior Lecturer in the Department of Earth and Environmental Sciences at Bahria University, Islamabad. His readiness to assist and effectively address our queries has greatly contributed to our learning and the successful completion of our thesis. Their guidance has not only helped us complete our thesis but also equipped us with new skills and knowledge.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Seismic data interpretation plays a crucial role in exploring hydrocarbons and understanding the geology beneath the earth's surface. The reflection seismic technique offers an effective and non-intrusive method to investigate underground structures. In this method, seismic waves are projected into the ground. As these waves, whose characteristics are known before, encounter various subsurface structures, they reflect with signal’s notating subsurface image data. These changes in the waves provide insights into the diversity and composition of the subsurface formations. These reflected waves, once recorded, become valuable tools in identifying potential oil and gas reservoirs located beneath the surface. Petrophysical analysis is another key aspect of hydrocarbon exploration. It involves examining the physical and chemical properties of rocks and formations that contain oil and gas. Petrophysical evaluations yield crucial information about the types of fluids and minerals, the nature of porosity, and the volumes of these elements in flush, transition, and uninvaded zones with the help of log curves/data (Nester et al., 2022).

1.2 Location of the study area

Shahdadpur is a town located in the Nawabshah District in the Sindh province of Pakistan. Its boundary meets with five other districts of Sindh i.e. Sanghar, Jamshoro, Dadu, Naushashro Firoz, and Khairpur. The town lies in a region known for agricultural activities and is surrounded by fertile land used for farming purposes. The study area is approximately 240 kilometers northeast of Karachi. Tectonically this district is to the east of Kirthar Foldbelt and Axial Belt and on the west bank of the river Indus. The Shahdadpur-01 well is located at a latitude of **26°9'37.53''N** and a longitude of **68°31'57''E** on the Asian Continent with an elevation of about 350m above sea level (Map Carta, 2003).

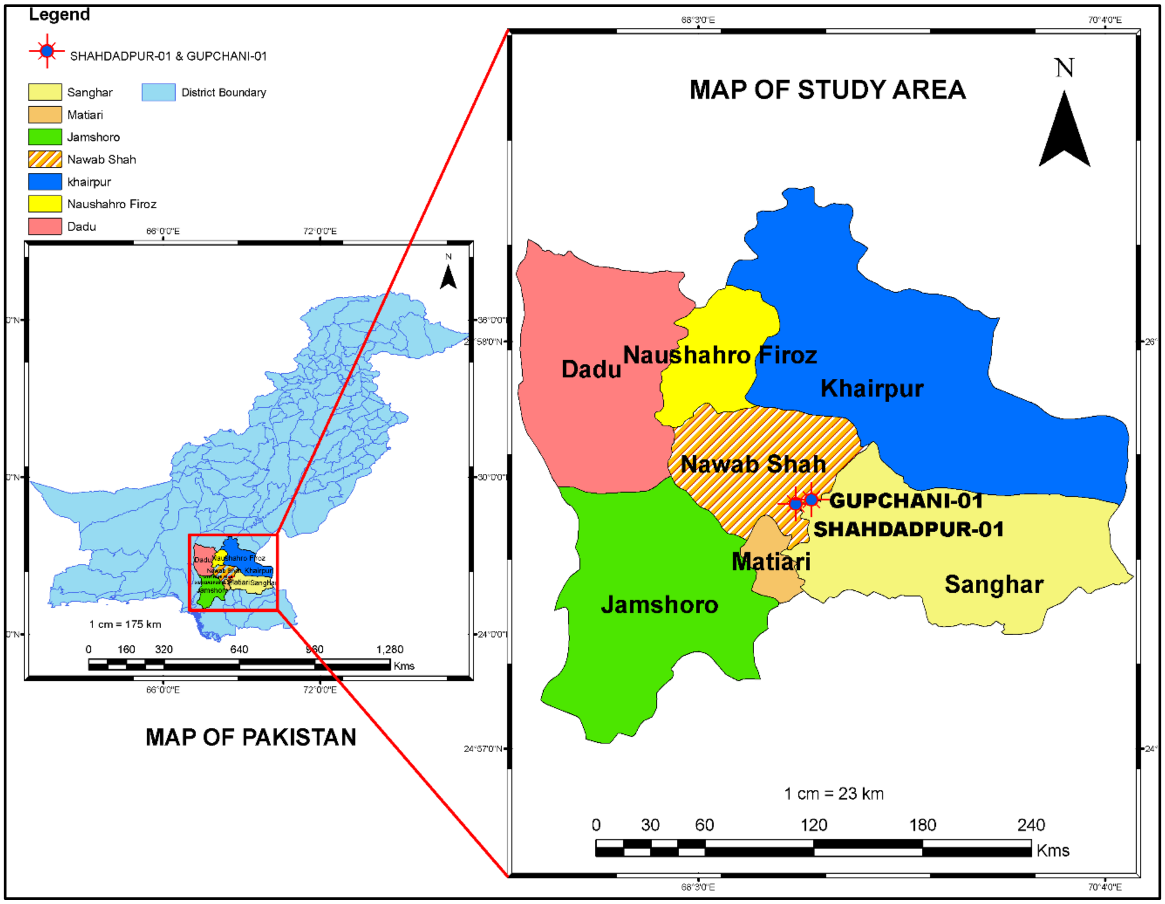

Figure 1.1 Location Map of Study Area (Created on ArcMap 10.7.1).

1.3 Climate

Shahdadpur is a region characterized by its distinct climatic patterns. The district's yearly temperature is 31.46ºC (88.63ºF) and it is 10.57% higher than Pakistan's averages. Located at an elevation of zero feet above sea level. Shahdadpur typically receives about 15.45 millimeters (0.61 inches) of precipitation and has 19.33 rainy days (5.3% of the time) annually.

1.4 Exploration history

Shahdadpur which is situated in the Sindh province of Pakistan has assembled attention as a promising site for oil and gas exploration. This area has witnessed a series of seismic surveys and drilling operations conducted by different oil and gas corporations such as OGDCL & PPL. These efforts are directed towards uncovering potential hydrocarbon reserves in the region.

The Shahdadpur region, specifically the Gambat South Block in Sindh, Pakistan, has witnessed significant exploration activities by Pakistan Petroleum Limited (PPL), particularly focusing on discovering hydrocarbon reserves. In 2013, PPL made its second discovery in the block with the Shahdad X-1 well. This well was drilled to test the hydrocarbon potential of the massive sand formations within the Lower Goru Formation. Subsequently, commercial production at the Shahdadpur West Gas Field commenced on September 9, 2015, maintaining an average daily output of approximately 9 MMscfd of gas and 95 bpd of condensate between July 2022 and March 2023. Another significant well, Sharf X-1, was drilled in 2014 to assess the Lower Goru formation. It showed a substantial gas flow of 42 MMscfd and 210 bpd of condensate during testing. The field, including Sharf X-1, Sharf-2, Sharf-3, and Nasr X-1, reported a daily production rate of 113 MMscfd gas, 1,027 bpd condensate, and 11.4 tons per day (TPD) of Liquefied Petroleum Gas (LPG) in 2022-23. The Government of Pakistan acknowledged the commercial viability of the Shahdadpur Field and approved the Field Development Plan on March 21, 2017. Since August 9, 2016, Sharf X-1 has been in production. The Shahdadpur region, with its discoveries and productive wells like Shahdad X-1, Sharf X-1, and Kinza X-1, has become a notable area for hydrocarbon exploration and production, contributing significantly to the energy sector in Pakistan (Courtesy PPL,2013).

1.5 Objective

Our main aim of the research is to interpret the subsurface geology of the area by the use of seismic method and petrophysical analysis through which the hydrocarbon potential was calculated of Shahdadpur area of the Lower Indus Basin.

Following are the stages to accomplishing the goals:

1. Delineation of sub-surface structure with the help of seismic data interpretation.
2. Hydrocarbon potential evaluation based on petrophysical analysis of Shahdadpur-01 Well.
3. Volumetric Reserve estimation of the reservoir interval to calculate the remaining potential of that reservoir (Imran , 2003).

1.6 Data required

The given data was obtained from LMKR (Landmark Resources Pakistan) with approval from the DGPC (Director General Petroleum Concessions).

Dataset includes:

1. Navigation file
2. Seismic lines
3. Well tops, well logs (Las File)

Table 1.1 List of the Seismic Lines (Orientation and Type) and Wells (Log Data)

<table>
<tr><th colspan="3">Seismic</th><th colspan="2">Well</th></tr>
<tr><th>Line Name</th><th>Line Type</th><th>Line Orientation</th><th>Well Name</th><th>Log Type</th></tr>
<tr><td>GO-741-SH-4</td><td>Dip Line</td><td>EW Trending</td><td rowspan="4">Shahdadpur-01</td><td rowspan="7">Gamma-ray Log
Spontaneous Potential
Caliper Log
Density Log
Neutron Log
Sonic Log
PEF
Resistivity Log</td></tr>
<tr><td>GO-741-SH-6</td><td>Strike Line</td><td>EW Trending</td></tr>
<tr><td>GO-741-SH-7</td><td>Strike Line</td><td>NS Trending</td></tr>
<tr><td>GO-741-SH-8</td><td>Strike Line</td><td>NS Trending</td></tr>
<tr><td>GO-741-SH-9</td><td>Dip Line</td><td>EW Trending</td><td rowspan="3">Gupchani-01</td></tr>
<tr><td>GO-741-SH-11</td><td>Dip Line</td><td>EW Trending</td></tr>
<tr><td>GO-851-SGR-212</td><td>Dip Line</td><td>EW Trending</td></tr>
</table>

1.7 Methodology

Seismic Interpretation and petrophysical analysis have been done side by side. The methodology that is used in seismic interpretation is generally based upon the marking of horizons and faults, then afterward is the making of time-depth charts, time contour maps, and depth contour maps. While petrophysical analysis includes conventional rock evaluation such as lithology identification, porosity estimation, and fluid saturation using log curves. Both need software for the interpretation of seismic and petrophysics. Kingdom 2017 for seismic interpretation was used and for petrophysical analysis, Gverse Geographix 2022.1 was used.

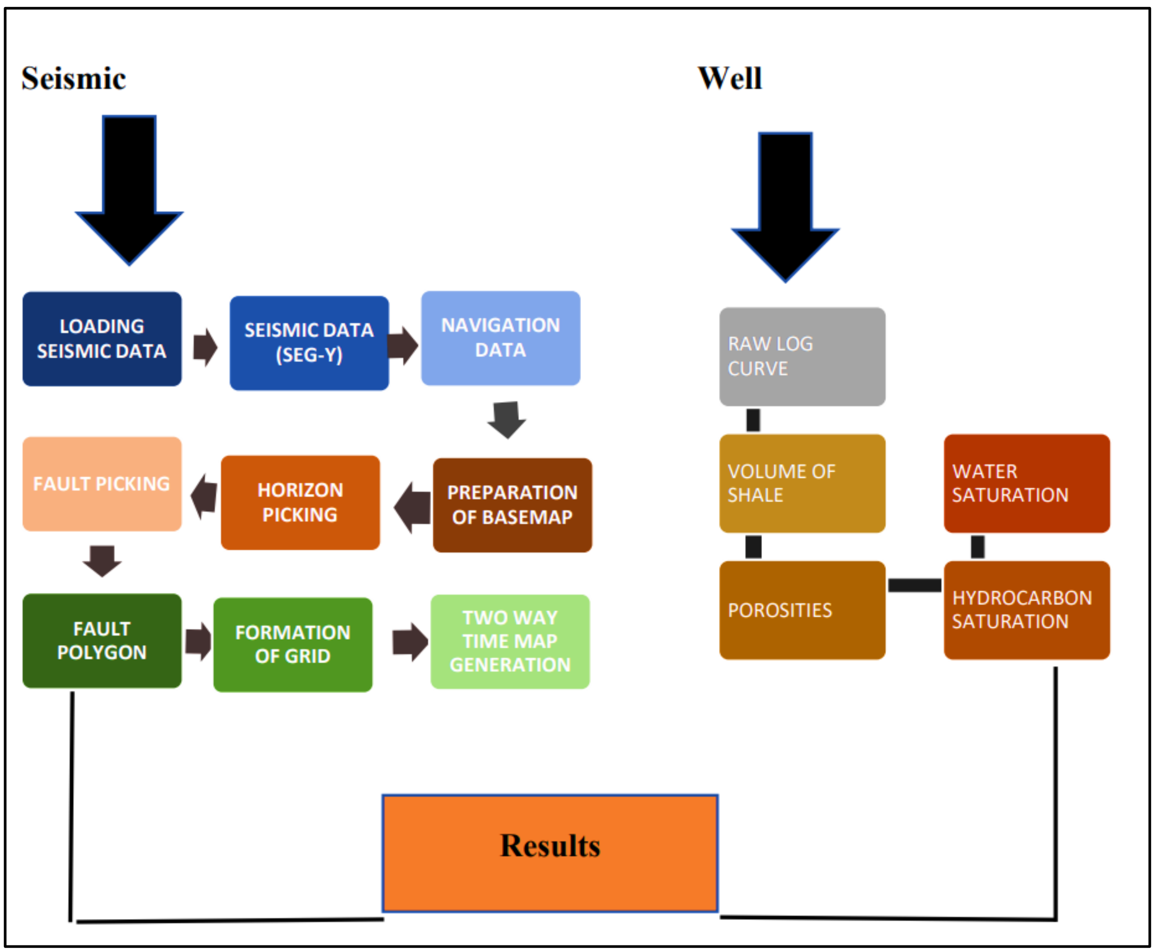

Figure 1.2 Complete methodology followed for the seismic data interpretation and petrophysical analysis.

CHAPTER 2

GEOLOGY & TECTONICS

2.1 Introduction

Pakistan is part of a tertiary converging zone between greater India and Eurasia, straddling the subduction margin of the Arabian plate under the Makran coastline. Before the Triassic age, Greater India was part of the continental mass of Gondwana. After the break-up of Gondwana, India separated from other continental masses around 210 Ma and later from Madagascar around 84 Ma. It continued its north-eastern drift with varying velocities. The geologic history of the basin development is divided into cycles using three parameters basin forming, depositional sequence, and basin modifying tectonics. These three parameters play a role in the basin assessment of Pakistan. The sedimentary sequences reflect the paleo-geographical environments of the basins. Pakistan has two main sedimentary basins the Indus Basin and the Baluchistan Basin. The Indus Basin is divided into the following basins:

Table 2.1 Divisions of Indus Basin

Division of Indus Basin			
Upper Indus Basin		**Lower Indus Basin**	
Potwar Basin	**Kohat Basin**	**Central Indus Basin**	**Southern Indus Basin**
Eastern Potwar Sub Basin	Northern Kohat Sub Basin	Punjab Platform	Lower Indus Platform
Central Potwar Sub Basin	Eastern Kohat Sub Basin	Sulaiman Foredeep	Karachi Trough
Western Potwar Sub Basin	Central Kohat Sub Basin	Sulaiman Fore belt	Kirthar Foredeep
	Western Kohat Sub Basin		Kirthar Fore belt
			Indus Offshore

The Lower Indus Basin part of Pakistan is the most studied and studied sedimentary basin in the country. The main factor that influences the structure and sedimentology is the rifting of Indian plates. The study area I am working on is also part of the lower Indus

Basin, which is part of an extensional regime where the main geometrical features are the graben geometry and horst geometry found in the subsurface. Various seismic techniques and petrophysical methods are used to fully understand the geologically and structurally important zones in each area. The Shahdadpur area of Pakistan is part of this extensional regime and is home to a wide range of sedimentary rocks including recent alluvium, Tertiary formations, and a variety of depositional environments ranging from fluvial to deltaic and marine. Tectonologically, the area is affected by the collision of Indian plates and Eurasian plates which has been going on since the last Cenozoic age. The impact of this collision has led to the formation of important structural formations in the basin, such as a major fault system and fold belt. The dominant structure in Shahdadpur lies in the extension of the Kirthar fold belt, which is composed of several anticline and syncline structures. These structures play a major role in trapping and accumulating hydrocarbons in the basin. The region has also gone through several tectonic stages, which have reactivated older faults and created new fault system formations. This tectonic activity has played a major role in the distribution and conservation of reservoir and source rocks. The Shahdadpur area plays an important role in the development and exploration of oil and gas resources in the Lower Indus basin. The unique geology of the area and the presence of dynamic tectonics play an important role in determining the potential of the area as a hydrocarbon province (Kazmi and Jan,1997).

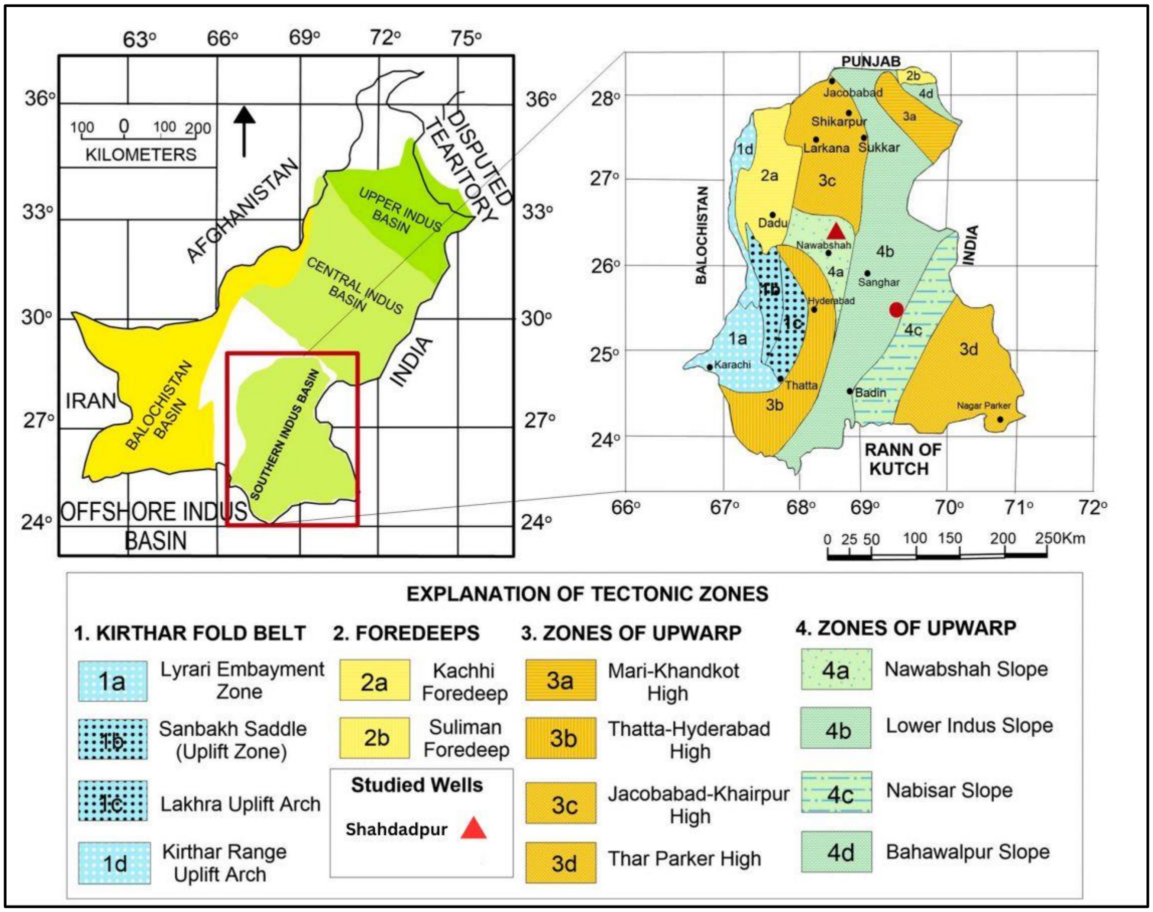

Figure 2.1 Maps showing sedimentary basins and tectonic features of Southern Indus Basin, Pakistan as well as the location of the study wells (Ehsan et al., 2023).

The region lies in the structural zone of the Indus plate structure and front profound which contains numerous underlying zones. Tilted fault blocks, thrust-faulted anticlines, and anticlines are the structural features in this region. The review district of Shahdadpur is in the Southern Indus Basin, initially a segment of the more extensive Lower Indus Basin. This Lower Indus Basin is fundamentally parted into two unmistakable regions: both the Central and Southern Indus Basins. Quiet, the Southern Indus Basin itself is partitioned into five chief fragments. The Thar Platform, Karachi Trough, Kirthar Foredeep, Kirthar Fold Belt, and the Offshore Indus region are all examples of these (Kazmi and Jan.,1997).

2.2 Southern Indus Basin

The Southern Indus Basin is arranged between the Indian Shield to its east and the external edge of the Indian Plate to its west. The presence of older rifts in the earth's crust that are now covered by thick layers of sediment has resulted in the formation of this basin, which is recognized as an extensional basin. The primary elements of the Indus Basin are impacted by patterns in magmatic abnormalities that are set apart as horst and graben structures, separately. The Jacobabad, and Mari-Kandhkot all resemble horst hinders and are framed by the extensional structural style of the lower basin. (Kadri.,1995)

2.2.1 Thar Platform

It is a gently sloping monocline that is governed by basement topography, much like the Punjab Platform. The Indian Shield, whose surface manifestations take the shape of Nagar Parkar high, is where the sedimentary wedge thins. Its boundaries are the Indian shield to the east, the Kirthar and Karachi trough to the west, and the Mari-Bugti inner folded zone to the north. The Early/Middle Cretaceous sands (Goru), the reservoirs for all the oil and gas plays in this area, show excellent growth along the Platform (Nayyer., 2000).

2.3 Stratigraphy of the study area

General stratigraphy of the Lower Indus Basin is referenced; however, the arrangements are not present in the Shahdadpur region. Lower Goru and the Sembar Formation are the most well-known petroleum system formations in this region. Sembar development is a territorial source of rock and a lower sand individual from Goru development is a general repository. The Upper Goru individuals go about as seal and of Lower Goru intra shale likewise goes about as a source in certain areas (PAPG.,2002).

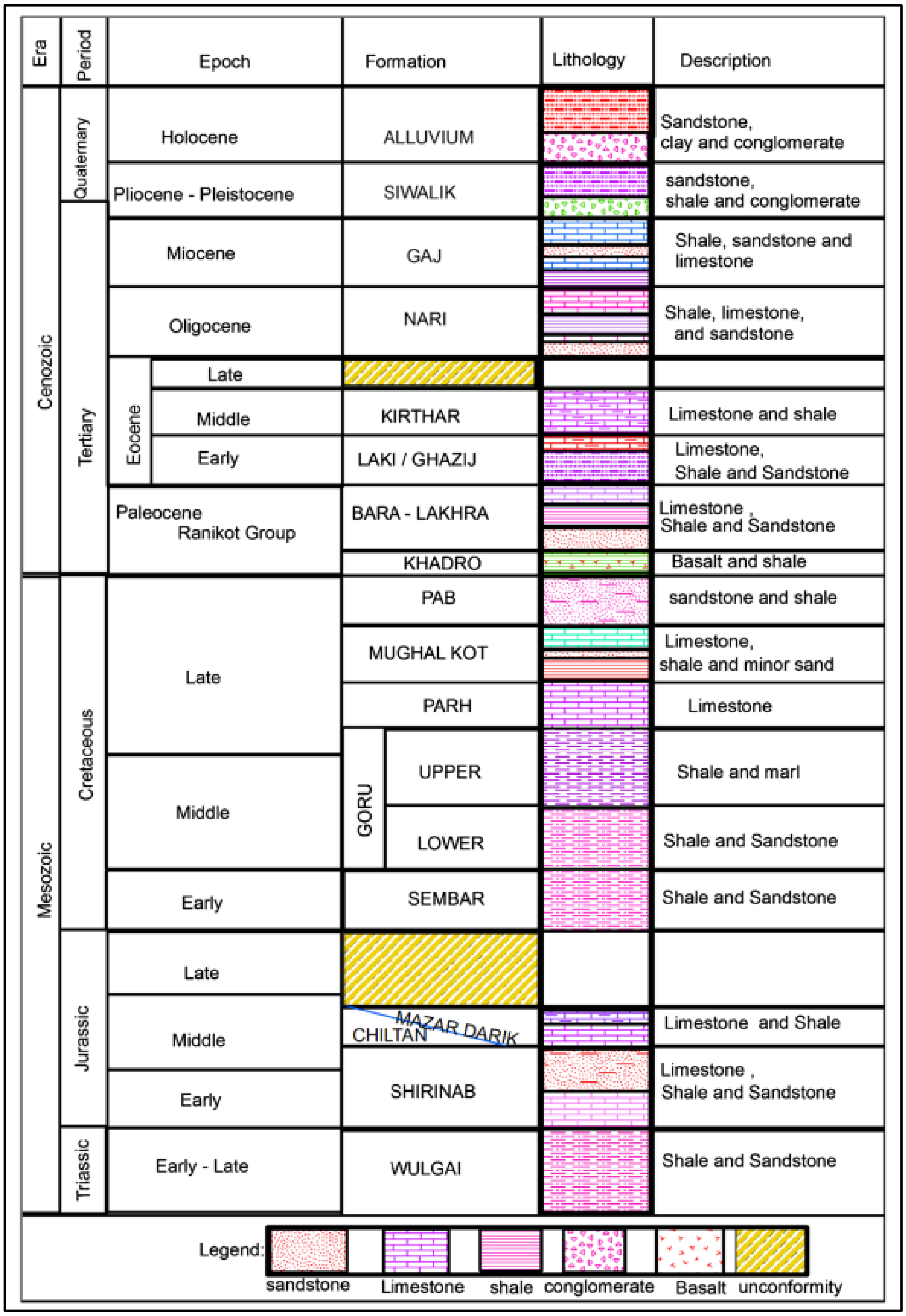

Figure 2.2 Generalized stratigraphy of Southern Indus Basin, Pakistan. The stratigraphic sequence covers the lithostratigraphic units from the Triassic to Recent (Hussain Asghar., 2021).

In the study area, the well contains the formations from the Middle Jurassic to Quaternary ages, which contains Chiltan limestone that is of the middle Jurassic, Sembar consists of shale and limestone of the early Cretaceous that is the main source, Lower Goru sand and shale of Middle Cretaceous age that act as our reservoir, Upper Goru shale of Cretaceous age that act as our seal, then the formation Parh limestone, Mughal kot (Limestone, shale, and sand) and Pab (Sandstone and shale) is of Late Cretaceous age, khadro limestone and Ranikot of Paleocene age, Laki (limestone, shale, marl) and Kirthar limestone formation of Eocene age and Alluvium of Quaternary age (Shah., 1977).

2.4 Borehole stratigraphy

A borehole stratigraphy of our study area Shahdadpur 01 well.

Table 2.2 List of Formation, Formation thicknesses, depth and ages.

Formations	Ages	Formation Tops (m)	Thickness (m)
Alluvium	Holocene	0	**489**
Kirthar	Eocene	489	**148**
Laki	Eocene	637	**442**
Ranikot	Paleocene	1079	**501**
Khadro	Paleocene	1580	**76**
Pab	Cretaceous	1656	**44**
Mughal Kot	Cretaceous	1700	**27**
Parh	Cretaceous	1727	**253**
Upper Goru	Cretaceous	1980	**970**
Lower Goru	Cretaceous	2950	**752**
Sembar	Cretaceous	3702	**227**
Chiltan	Jurassic	3929	**195**

2.5 Petroleum play of the study area

The Lower Indus Basin has the highest rate of hydrocarbon discovery success. The hydrocarbons in this space are put away in rock layers from the Cretaceous time frame. These layers were formed by source rocks that contained a variety of organic materials, mostly decomposition products from land plants and animals. This combination was protected in conditions with a lot of oxygen which is shown by unambiguous compound proportions in the stones. It is known that the Lower Goru Formation, which dates to the Early Cretaceous period, has excellent reservoirs. The best spots for these supplies are in sure layers inside the Lower Goru Formation, arrangement that are known as third request low stand framework plots. Maps that show the thickness and porosity of these layers alongside maps that represent how the stones were stored and cross areas of the development uncover the most likely areas for top-notch sandstone repositories. These guides likewise give signs about the shapes and sizes of these sandstone bodies (AAPG, 2015).

The study area Shahdadpur scenario is that it became an abundant oil and gas well because of more water found which is explained in terms of Sw (saturation of water) that causes the well to be less productive. These are the six proven and viable plays identified in the Lower Indus Platform Basin, where the perfect petroleum system exists. Operational fields are Sui Field, Tando Alam Field, Bari Oil Field, Kadanwari Field, Pasakhi Field, Khaskeli Field, etc (Nayyer, 2000).

2.5.1 Source rock

A Sembar Formation shale with some amount of siltstone and sandstone of the lower cretaceous age acts as source rock in the lower Indus basin of our area as mentioned before. It has a marine environment of deposition. The shale in the Lower Goru also acts as a probable source rock. Sembar formation is considered gas-prone as it mainly contains type-3 kerogen (Iqbal & Shah,1980).

2.5.2 Reservoir rock

From Cretaceous to Eocene clastics and carbonates are the proven reservoirs in the basin. The Lower Goru sand is the main reservoir for oil and gas production, The sand reservoir is further divided into sand intervals A, B, C, and D. While Chiltan Limestone, Kirthar, Pab Sandstone, and Khadro Formation also act as secondary reservoirs.

2.5.3 Seal rock

A seal rock in the basin is composed of the shales that are interbedded and overlying the reservoir that may be Lower Goru but our main seal in this area was Upper Goru formation thick shale.

2.5.4 Trapping mechanism

The region is notable for its diverse geological features including both horst and graben formations, as well as termination or pinch-out traps. This combination of stratigraphic and structural traps enhances the area's potential for hydrocarbon presence (Kadri,1995).

Table 2.3 Petroleum play of Shahdadpur area.

Petroleum play	Formations	Ages
Seal	Upper Goru	Cretaceous
Reservoir	Lower Goru	Cretaceous
Source	Sembar	Cretaceous

CHAPTER 3

SEISMIC DATA INTERPRETATION

3.1 Introduction

Seismic interpretation is a scientific process used to figure out underground geological structures and layers by analyzing seismic data. It involves turning seismic information into models that show the earth's structure or layers. The main methods include marking different horizons, identifying faults, and creating grids and contours in both time and depth measurements. In seismic interpretation, reflectors were marked on time-based using a synthetic seismogram, which is created from log data. This helps in correlating the information with the seismic sections. First, identify the layers in the synthetic seismogram and then apply this information to all the seismic sections (Tnacheri & Bearnth, 2009).

Technique which is used to reach hydrocarbons and to get information about subsurface geology. The reflection seismic method gives a convenient way to examine subsurface structures without harming the subsurface geology. Seismic waves are sent to the earth’s surface. The nature of the sent waves is already known, hence when the waves strike subsurface structures and bounce back. The change in the nature of the wave has been observed which represents the heterogeneity of subsurface and structures beneath the earth. The recorded waves are then used to learn about the presence of oil and gas reservoirs in the subsurface (Tucker.,1988).

3.2 Objective

1. Delineation of sub surface structure with the help of seismic data interpretation.
2. Lead and Prospect Identification of Hydrocarbon zones using Depth Contour Map of Lower Goru and Chiltan Limestone of Shahdadpur area.

3.3 Types of seismic interpretation

Seismic interpretation process is subdivided into two types:

1. Structural
2. Stratigraphic

3.3.1 Structural interpretation

The Structural seismic interpretation is directed toward the creation of structural maps of the subsurface from the observed three-dimensional configuration of arrival times.

3.3.2 Seismic interpretation

The Seismic sequence stratigraphic interpretation relates the pattern of reflections observed to a model of cyclic episodes of deposition. The aim is to develop a chronostratigraphic framework of cyclic, genetically related strata (Tayyeb et al., 2017).

3.4 Methodology

Firstly, to start project the data on the kingdom software was loaded that consist of Navigation and SEG-Y for base map generation and applying other interpretation steps that are as follows:

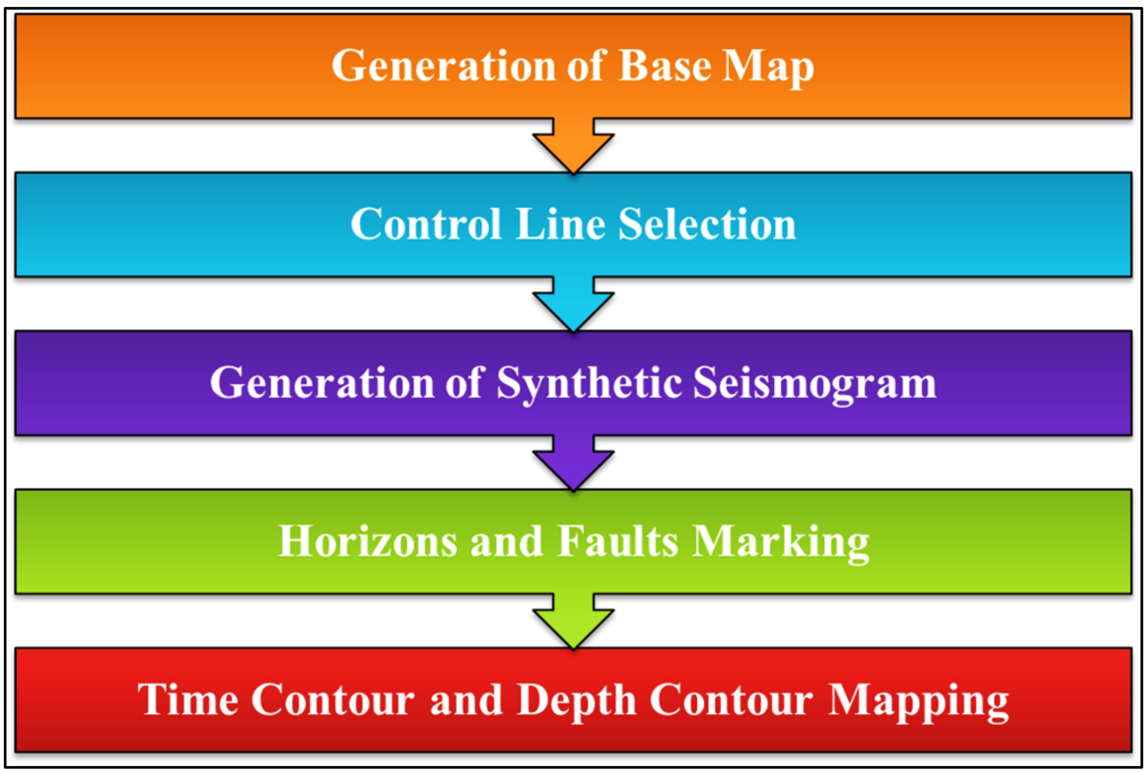

Figure 3.1 Complete workflow of seismic interpretation.

3.4.1 Generation of base map

The base map is used to represent the information about the orientation and location of seismic lines, it also gives knowledge about their extension, well position, concession boundaries and other geophysical information about data of study area. The base map is generated by uploading the Navigation's and SEGY's files including the information in software. The base map shown in figures represents the orientation of the seismic lines that are used for seismic interpretation of our research work. The seismic base map includes four dip lines, three strike lines and three wells shown in the base map (Schlumberger, 2009).

For the generation of base map, software Kingdom 2017 was used by using navigation files from the data given by LMKR. There are three strike lines and 4 dip lines using this line information regarding shot points and well location was obtained. For the determination of well location, well log coordinates mentioned on the log header was used, and the software generated the corresponding well points to serve as control lines. The resulting base map was created on a scale of 1:169932. To analyze subsurface structure and to get information about the structural trends the 2D seismic data collected from the Shahdadpur area was used. For the determination of the depth of horizons Shahdapur-01 log data was used as reference point (Amir, 2006).

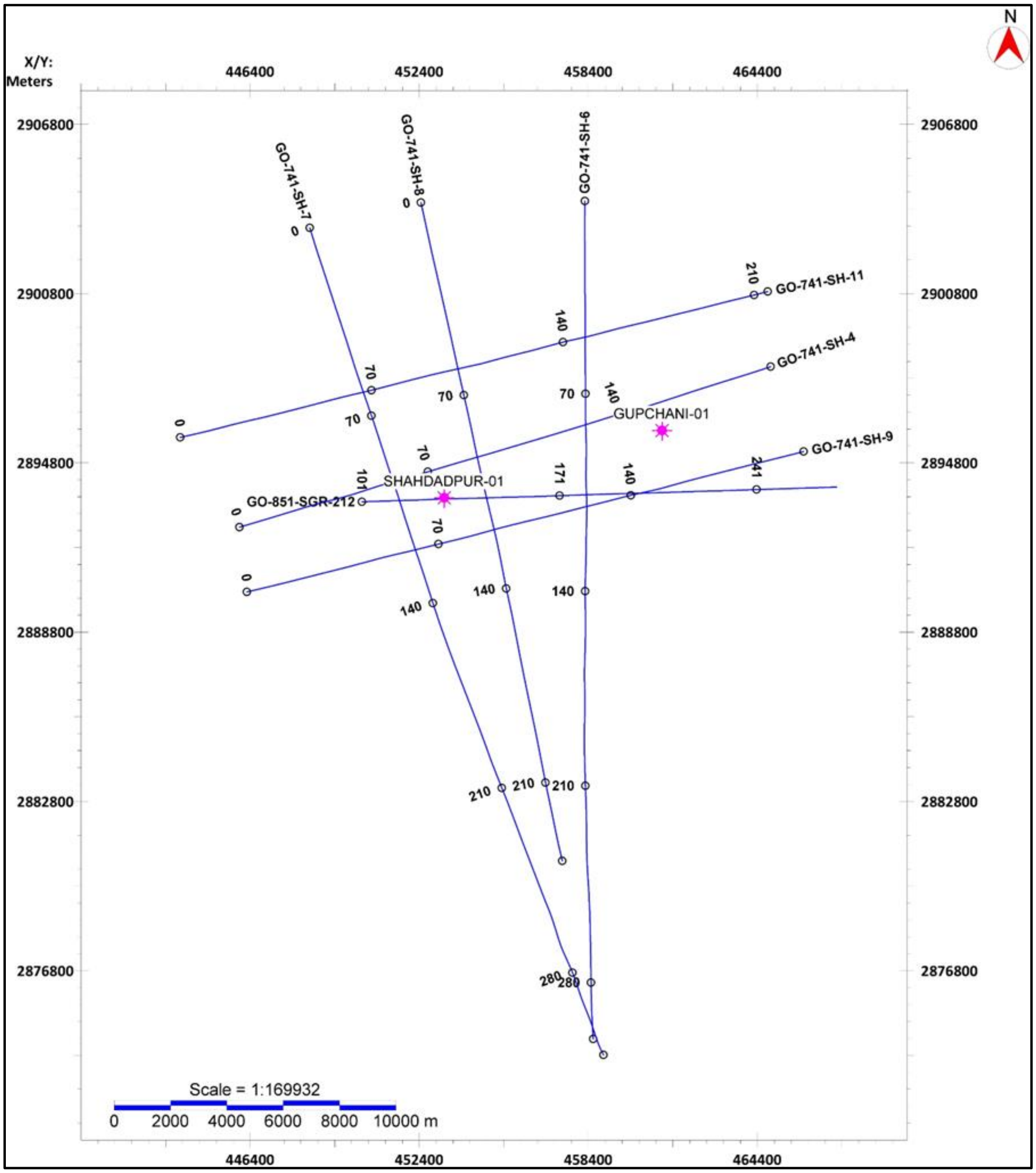

Figure 3.2 Base map showing seismic lines and wells generated on kingdom 2017.

3.4.2 Data quality

A good interpretation requires data quality (that is having good resolution) mostly for our focused area. A good data quality is done by good processing. Data quality is crucial for accurately interpreting data, especially in specific areas we're focusing on. To ensure high data quality, effective processing methods are required. Data Quality Control (DQC) is essential to find any vital information that might be missing. It is also helpful to identify any mistakes that occurred during data transfer or when changing the data format and to spot any repeated data.

In the context of seismic data, which is used to study and map underground structures, quality control is vital to make sure the data is reliable before begin analyzing it. This can be done by using navigation files to create a basic map of the area. This helps us understand where the seismic surveys were conducted. Make sure all-important details like the location of seismic shots, line names, well locations, and receiver points are correctly marked. Here in Shahdadpur block, no miss ties were observed on any of the seismic lines. Recording length of the seismic lines is also checked. In the end verify the duration of the seismic recordings. All these steps are necessary to ensure the seismic data is accurate and trustworthy for further interpretation.

3.4.3 Selection of control line

Location of Shahdapur well is nearly at control line **GO-851-SGR-212** which is a Dip Line. **GO-851-SGR-212** is selected as a control line to correctly mark the horizons, faults and for correcting the miss-ties in other lines. In the next step seismic to well tie is performed by using the control line SGR-212.

3.4.4 Generation of synthetic seismogram

It is important to generate the synthetic seismogram before beginning any seismic interpretation project. The main purpose of generating synthetic seismogram is to identify seismic horizons and the rectification of seismic events is done in time and amplitude data. It has also been used for the correlation of geological data with well logs data for the adjustment of seismic trace (Naeem et al., 2015).

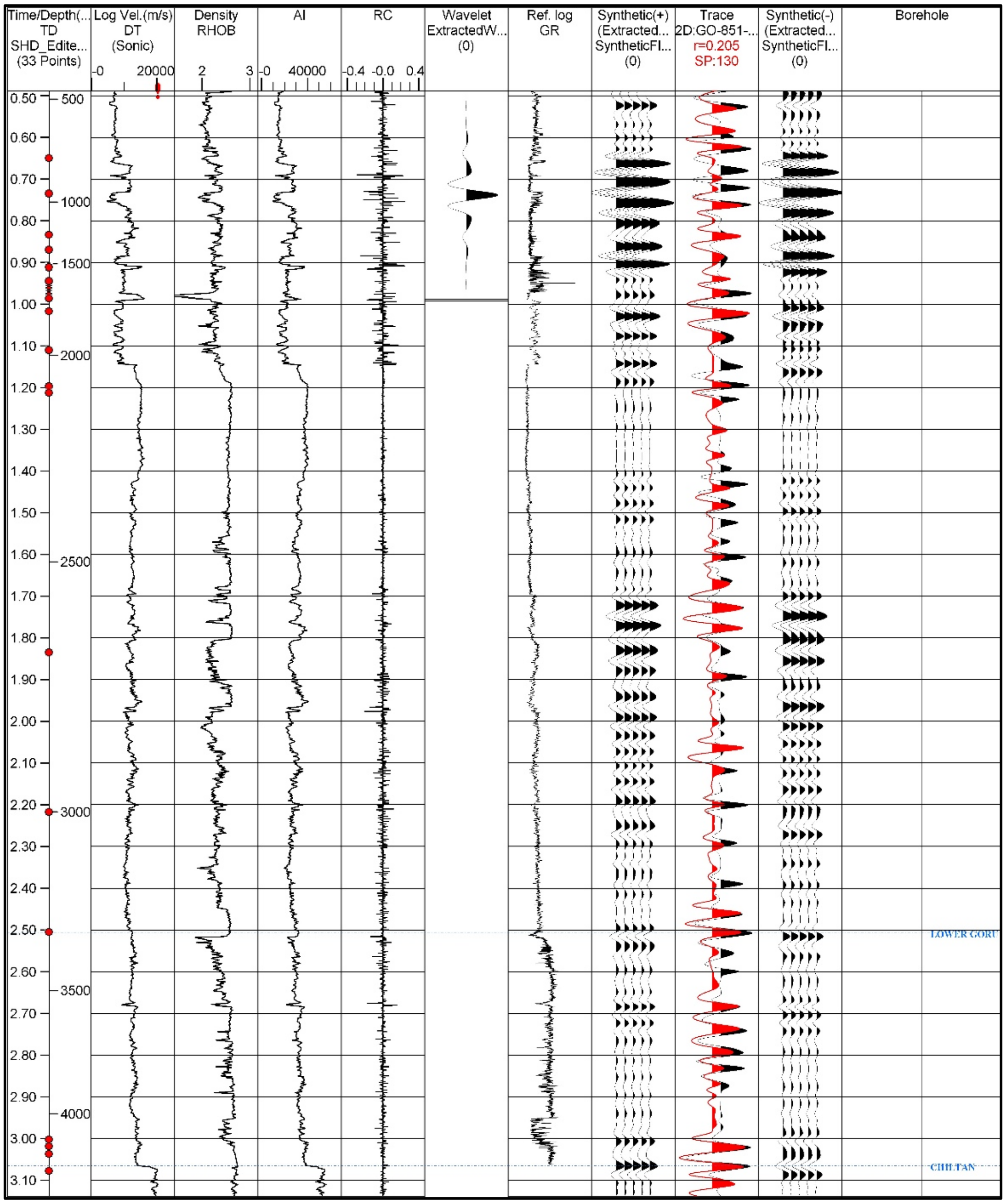

Figure 3.3 Synthetic seismogram of Shahdadpur-01 well.

A synthetic seismogram for the well Shahdapur-01 that lies on the seismic line GO-851-SGR-212 has also been generated by using kingdom 2017 software. Synthetic seismogram is generated by using a time-depth chart which was created by using the velocity header. Acoustic impedance was calculated by convolving the sonic log and density log from well. The Acoustic Impedance was then used to generate Reflection coefficient and reflectivity series, and the gamma ray log was considered as the reference log. Now generate the wavelet by using seismic trace (traces near the well) this wavelet was then combined with the reflectivity series to form synthetic seismogram. Theoretical wavelets include Ormsby, Ricker, Minimum phase and Butterworth etc. can be used for synthetic generation. The seismic data is given in time domain while the well tops are in the depth domain. In this manner both data having different domains it's difficult to mark the horizons so for marking the horizons generate the synthetic seismogram first to calculate two-way time with respect to depth (Amir,2006).

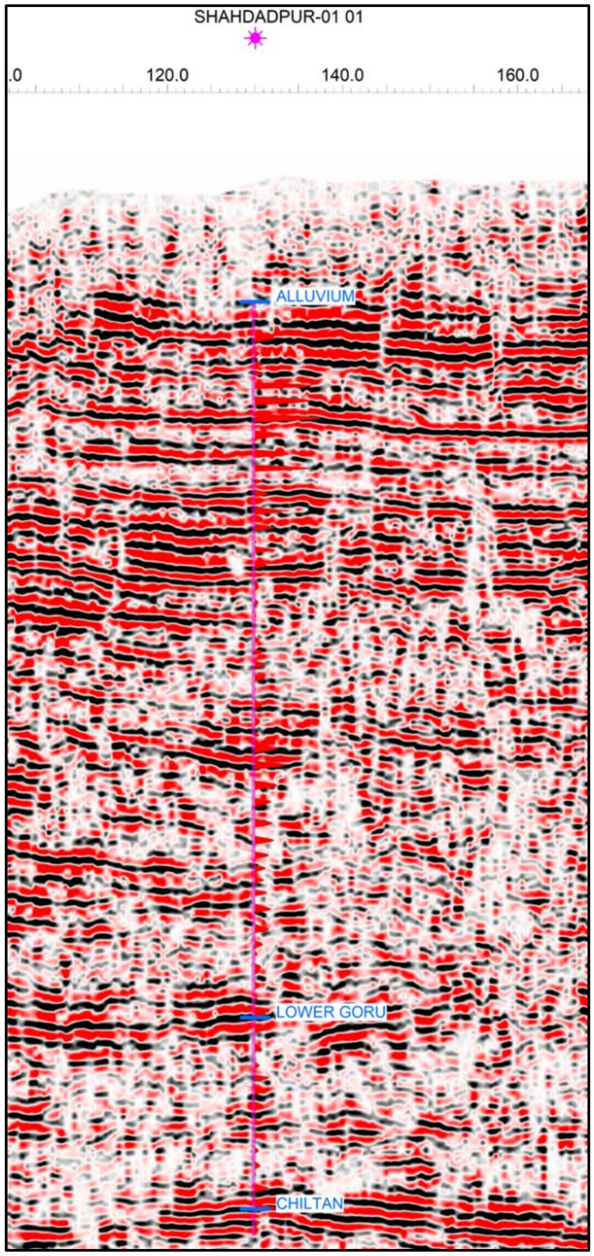

Figure 3.4 Synthetic seismogram of Shahdadpur-01 well overlayed on seismic line showing marked formations (Lower Goru and Chiltan Limestone).

3.4.5 Horizon picking and fault identification

Seismic interpretation involves analyzing seismic sections, which are images showing the underground layers of the earth. The next important step in this process is marking horizons, which are distinct layers within these sections. In our case, we've identified two main horizons which are Lower Goru marked in yellow, and the Chiltan Limestone marked in blue. To accurately identify these horizons across multiple seismic lines, two methods were used. The first method is Loop tying. This method helps us match up similar horizons and faults (breaks in the earth's layers) across different seismic lines. It's like drawing a continuous line across a grid to connect similar features. And the second method is Jump correlation. This technique is used when there's a gap or discontinuity between parallel seismic lines. It helps us bridge these gaps to maintain a consistent interpretation.

Faults, which are breaks in the layers, are also identified during this process. They are usually easier to spot when there's a large vertical shift in the layers. This shift can be seen when the layers on one side of the fault move significantly compared to the other side. Identifying these features and problems is crucial and can usually be clearly seen in the seismic section records (Oriol Ferrer, 2019).

3.4.6 Interpretation of seismic lines

It is done on Less explored areas, structural interpretation is done by marking faults and generate maps.

3.4.6.1 Interpretation of seismic line GO-851-SGR-212

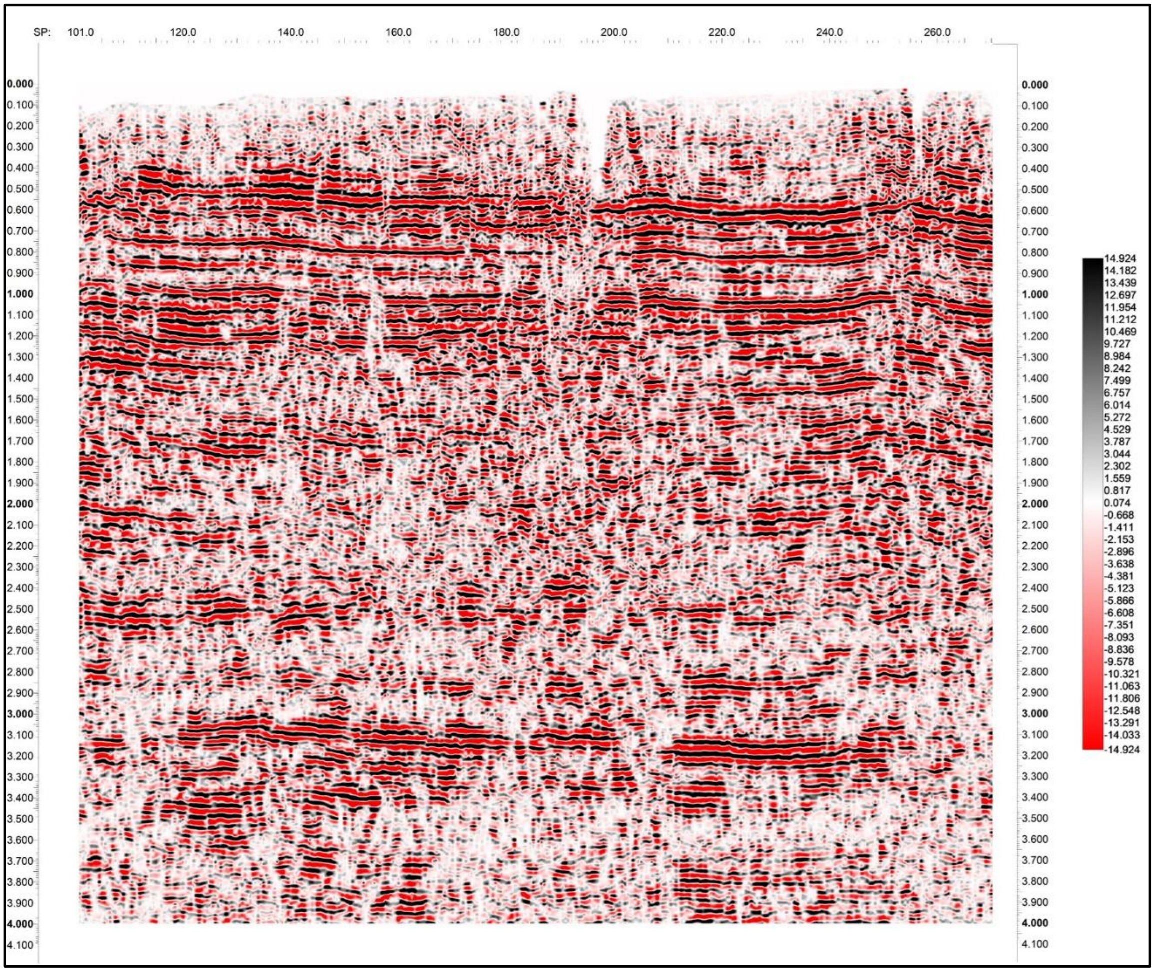

Figure 3.5 Uninterpreted seismic line GO-851-SGR-212.

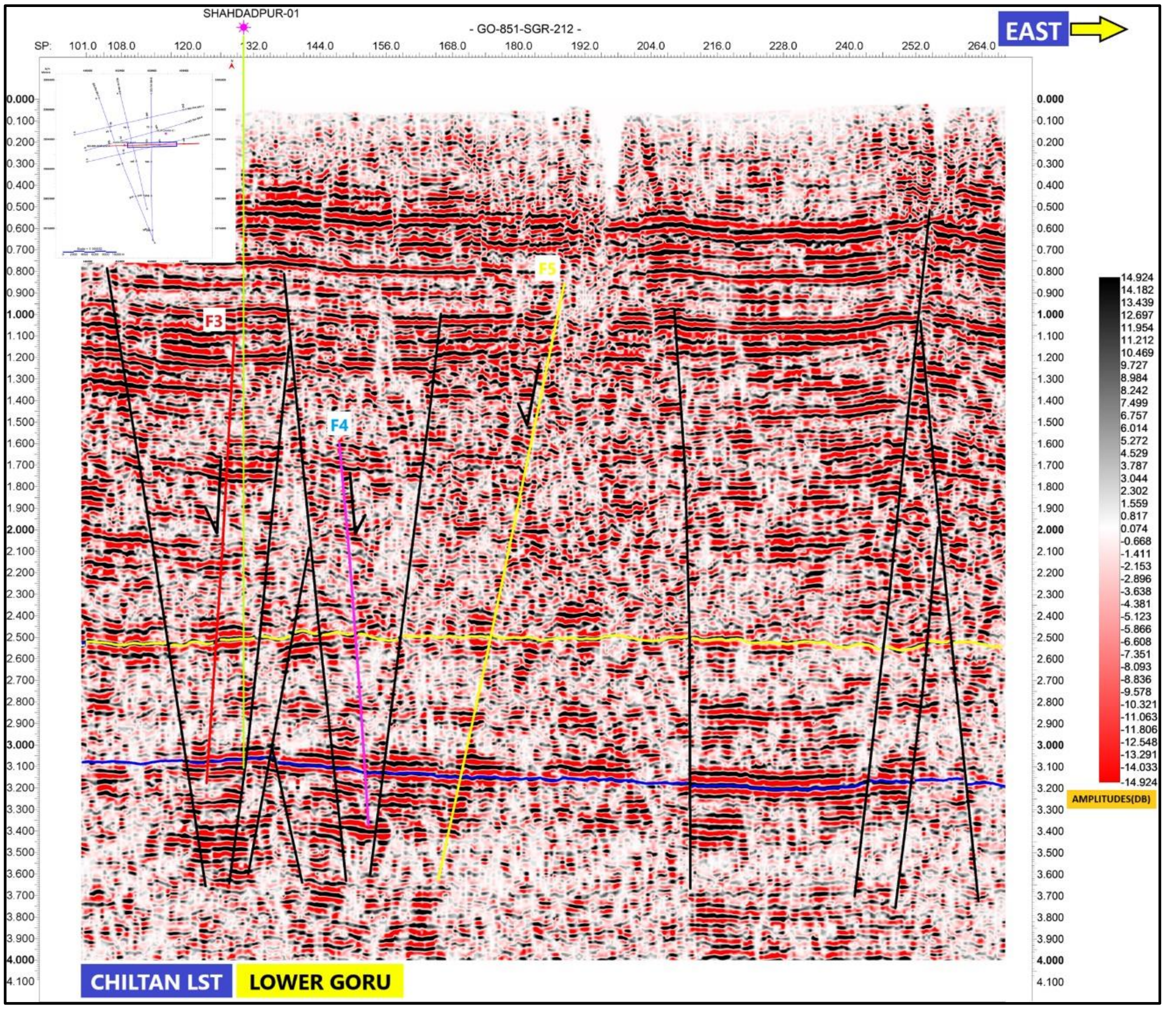

Figure 3.6 Seismic interpreted line GO-851-SGR-212.

The Shahdadpur well is located on seismic line named GO-851-SGR-212, which has an east-west direction. This line is crucial for accurately identifying formations, faults and for correcting the miss-ties in other lines. It's 38km long and reveals specific geological structures called horst and graben. Chiltan Limestone and Lower Goru Formation are identified on this line. There are five notable faults, labeled F1 through F5. Fault F1 forms a half-graben structure, while faults F2 and F3 form full graben structures. Faults F4 and F5 also show graben structures, but there is a horst structure located between F3 and F4.

3.4.6.2 Interpretation of seismic line SH-11

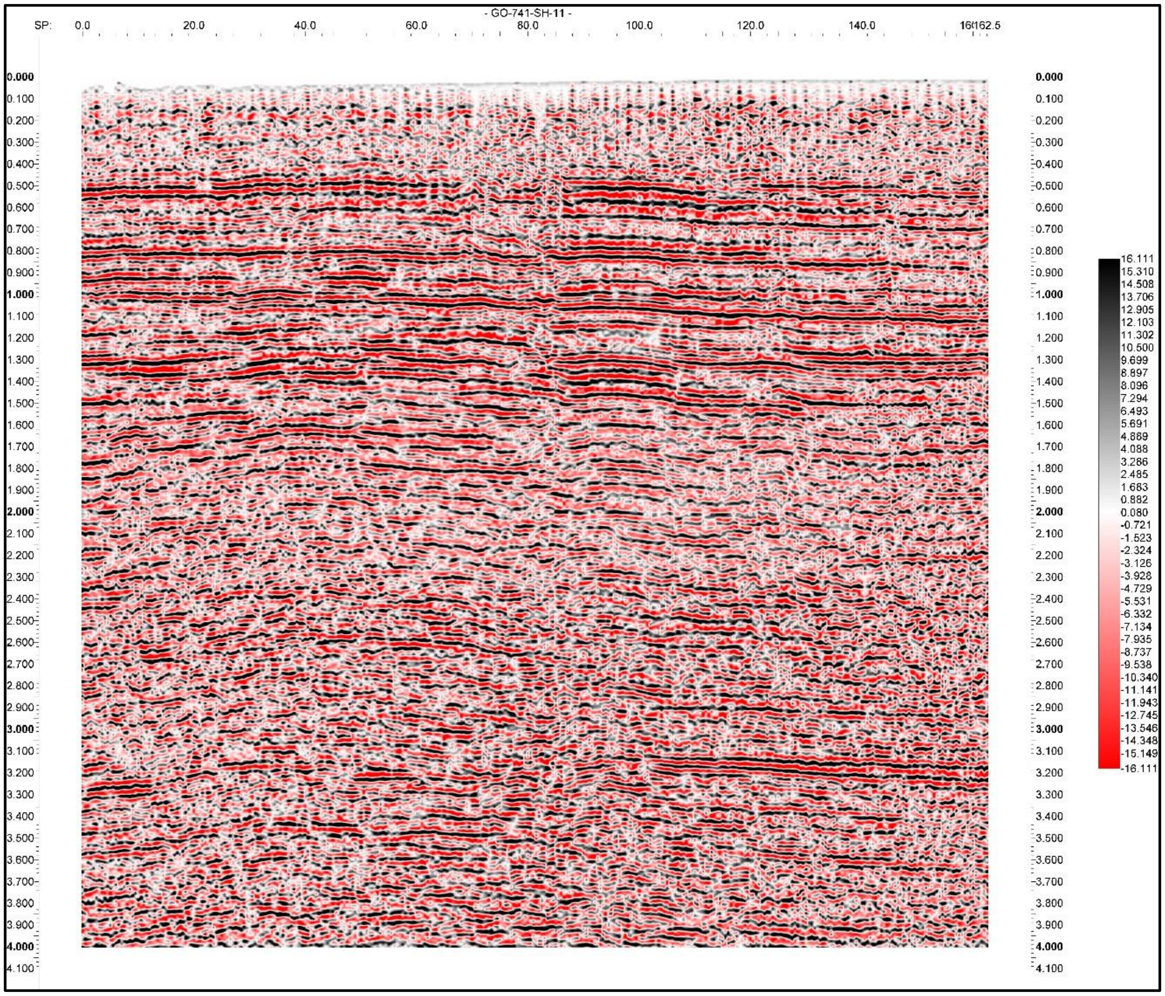

Figure 3.7 Uninterpreted seismic line SH-11.

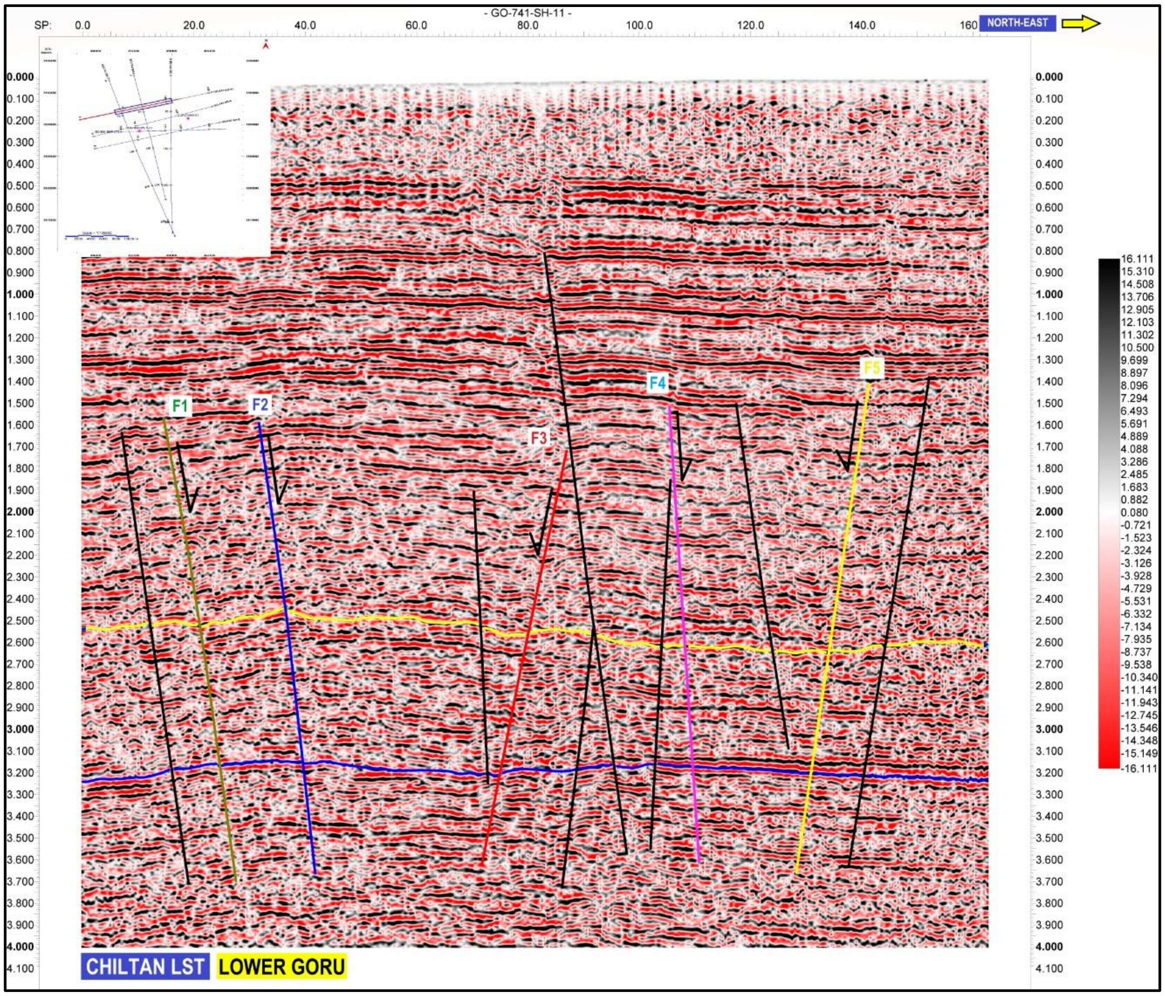

Figure 3.8 Seismic interpreted line SH-11.

This dip line has EW direction, it is 16km long and makes horst graben structures. Chiltan Limestone and Lower Goru horizons are marked in this line. The faults show horst and graben structure, the faults that are marked in our sections are F1, F2, F3, F4 and F5. Faults are shown F1 that is half graben, whereas F2 and F3 shows graben structure, and the F4 and F5 also shows graben structure, but the horst structure also shown between F3 and F4.

3.4.6.3 Interpretation of seismic line SH-04

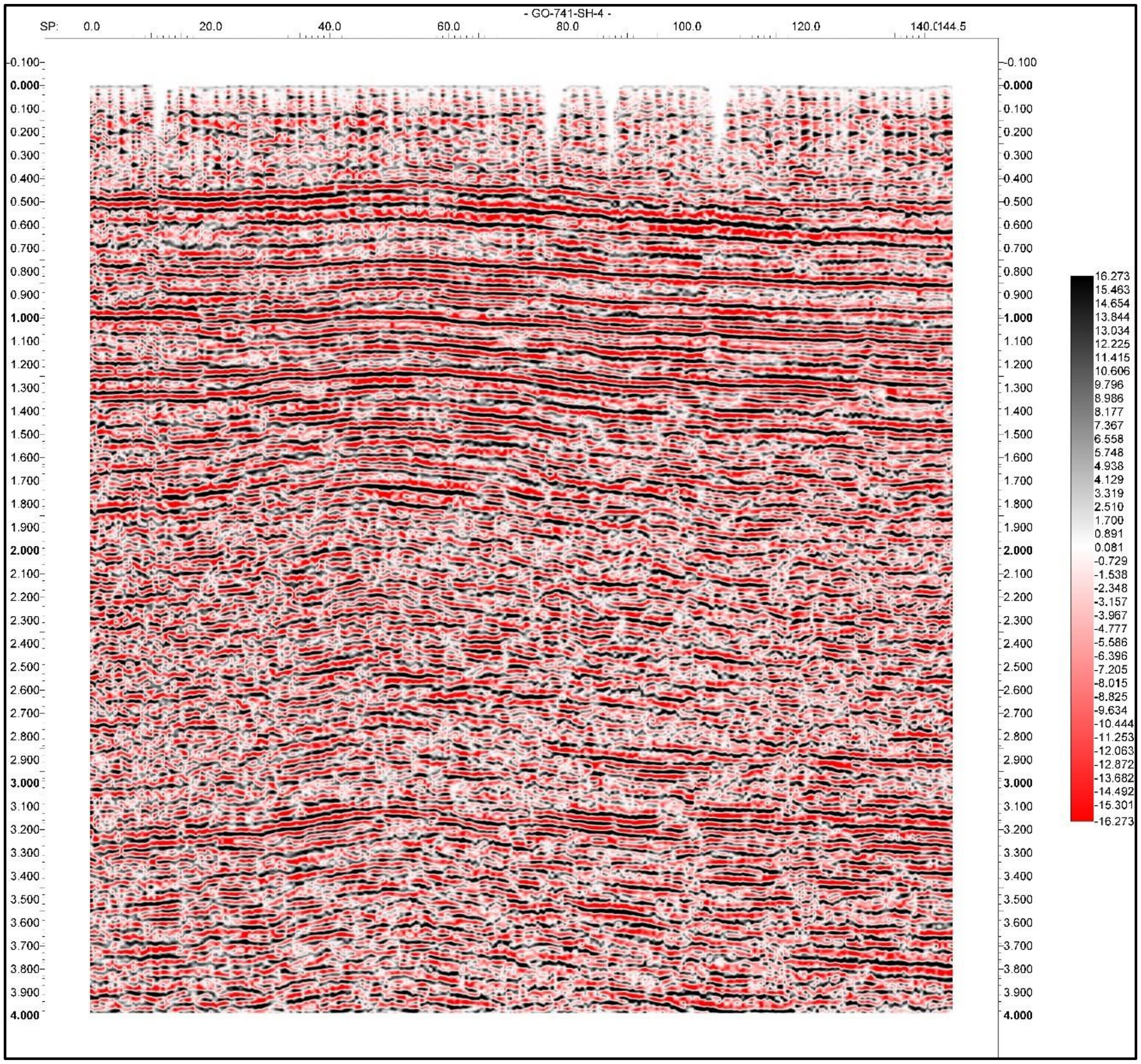

Figure 3.9 Uninterpreted seismic line SH-04.

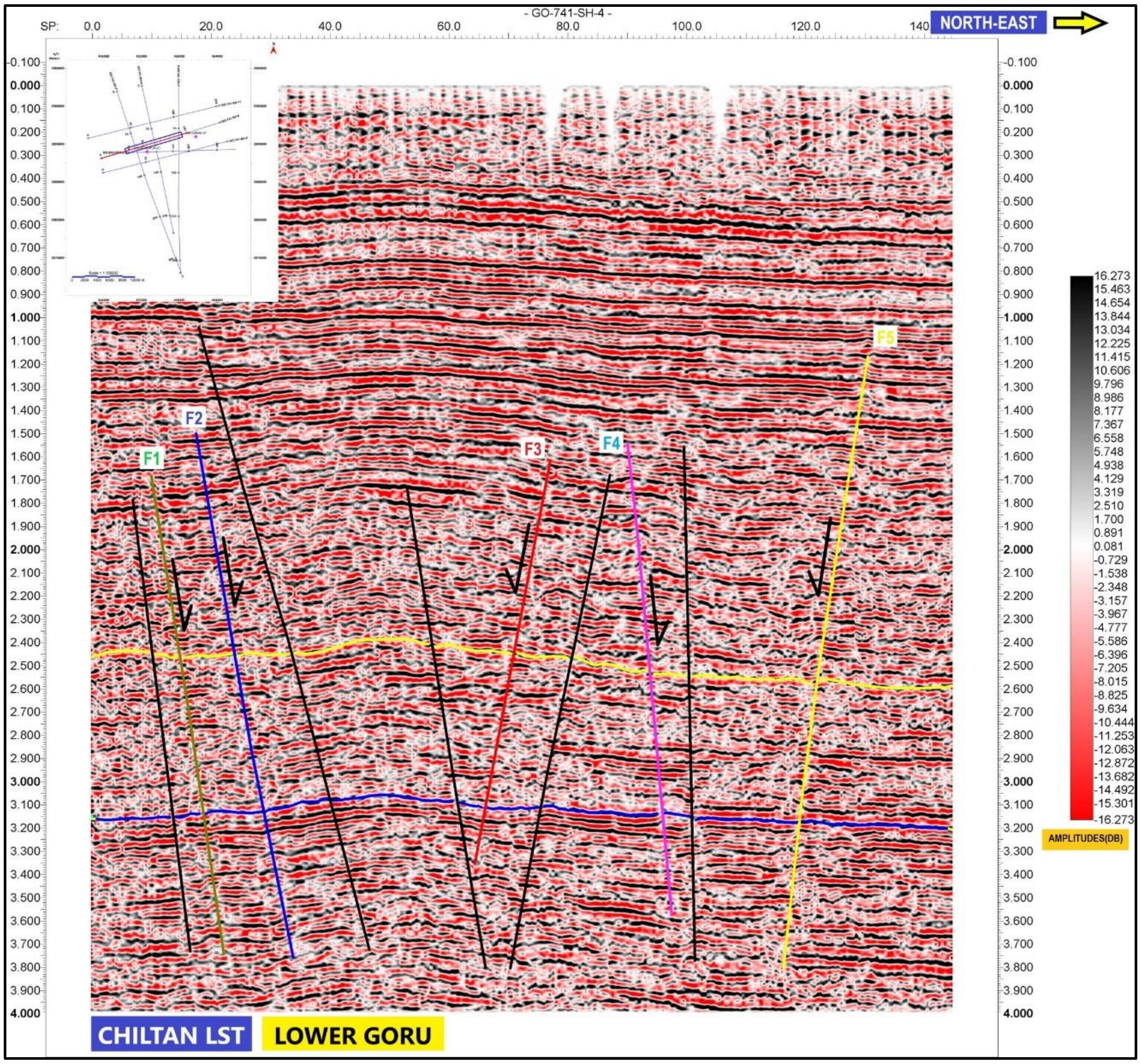

Figure 3.10 Seismic interpreted line SH-04.

This dip line has EW direction, it is 15km long and makes horst graben structures. Chiltan Limestone and Lower Goru horizons are marked in this line. The faults show horst and graben structure, the faults that are marked in our sections are F1, F2, F3, F4 and F5. Faults are shown F1 that is half graben, whereas F2 and F3 show a graben structure, and the F4 and F5 also show graben structure, but the horst structure also shown between F3 and F4.

3.4.6.4 Interpretation of seismic line SH-09

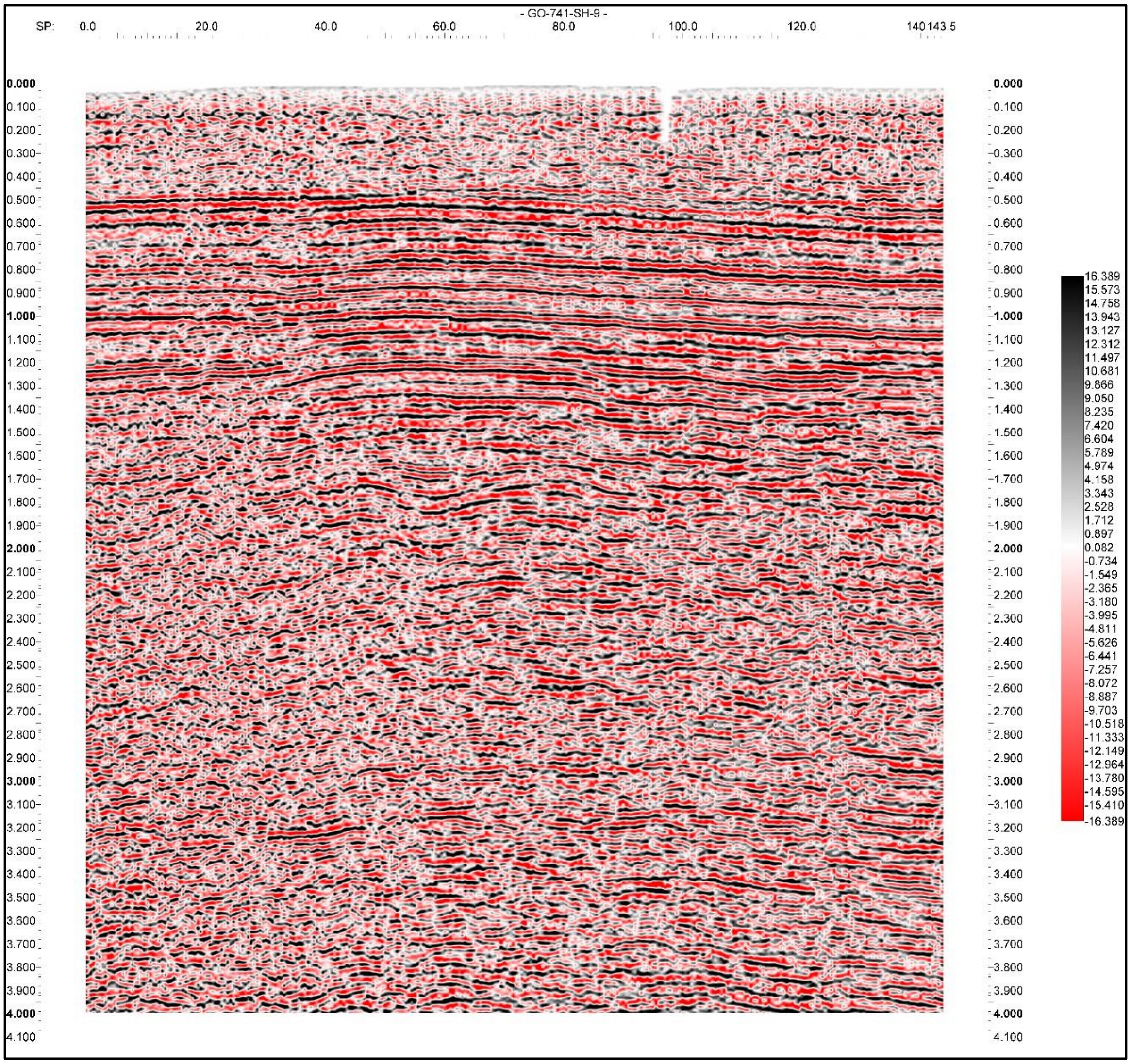

Figure 3.11 Uninterpreted seismic line SH-09.

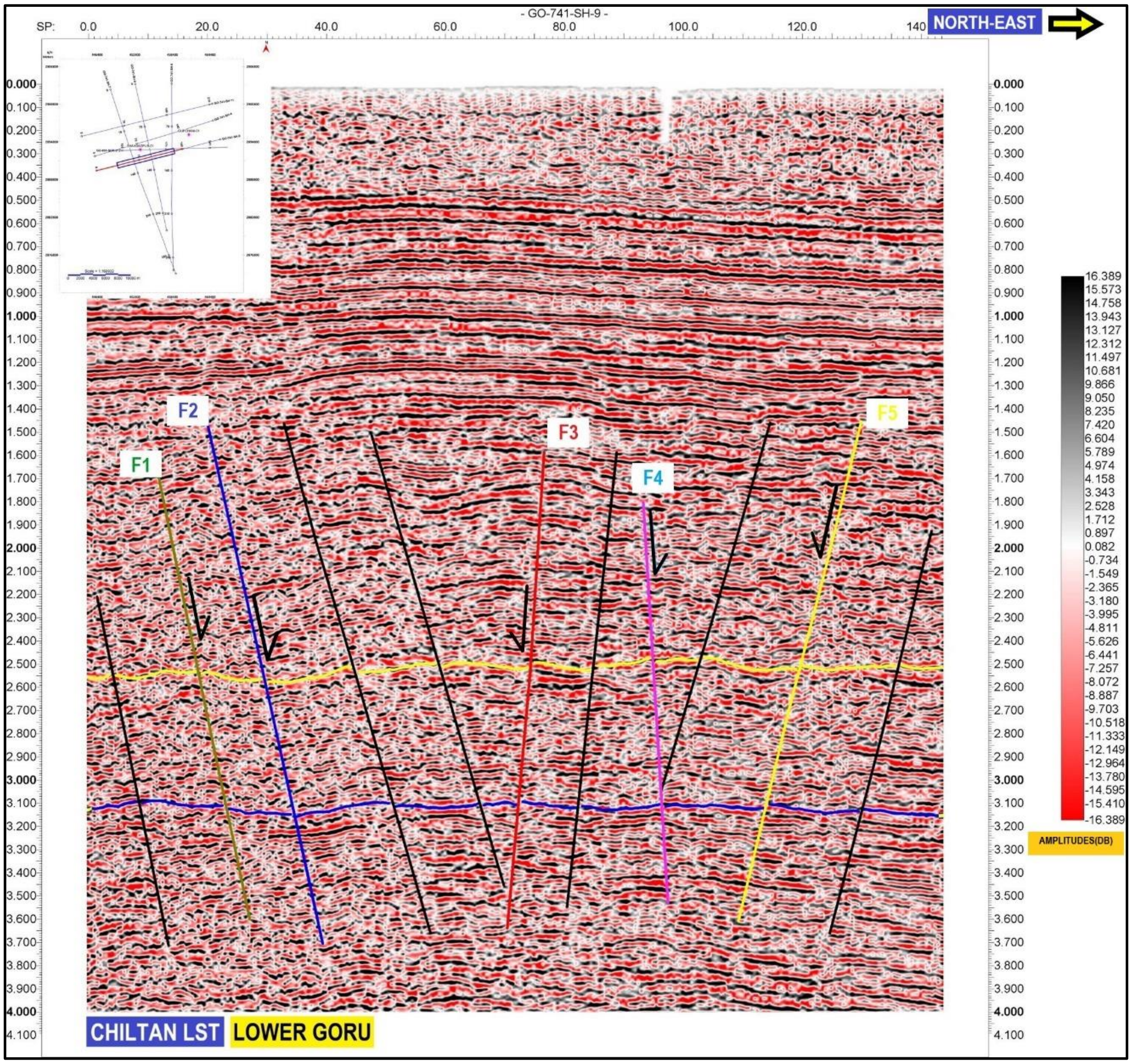

Figure 3.12 Seismic interpreted line SH-09.

This dip line has EW direction, it is 14.5 km long and makes horst graben structures. Chiltan Limestone and Lower Goru horizons are marked in this line. The faults show horst and graben structure, the faults that are marked in our sections are F1, F2, F3, F4 and F5. Faults are shown in which F1 that is half graben, whereas F2 and F3 show a graben structure, and the F4 and F5 also show graben structure, but the horst structure also shown between F3 and F4.

3.4.6.5 Interpretation of seismic line SH-07

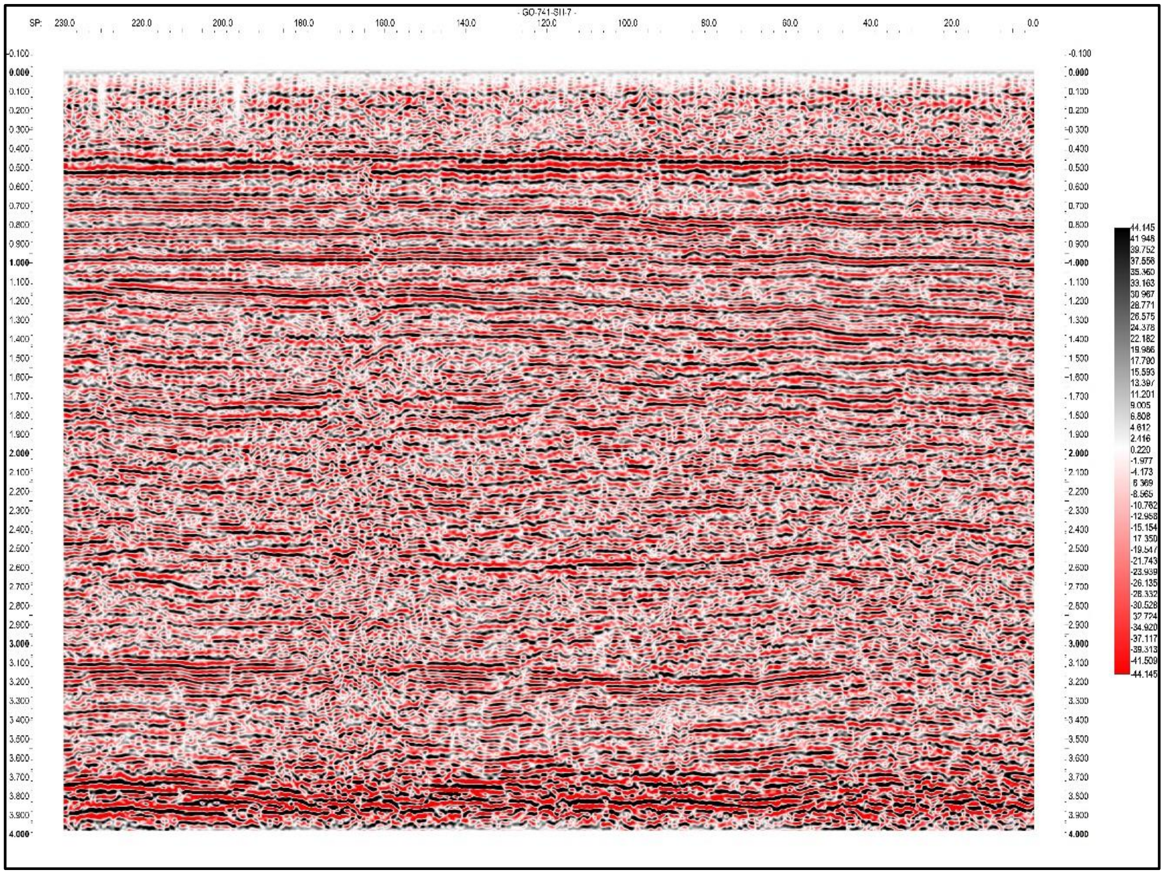

Figure 3.13 Uninterpreted seismic line SH-07.

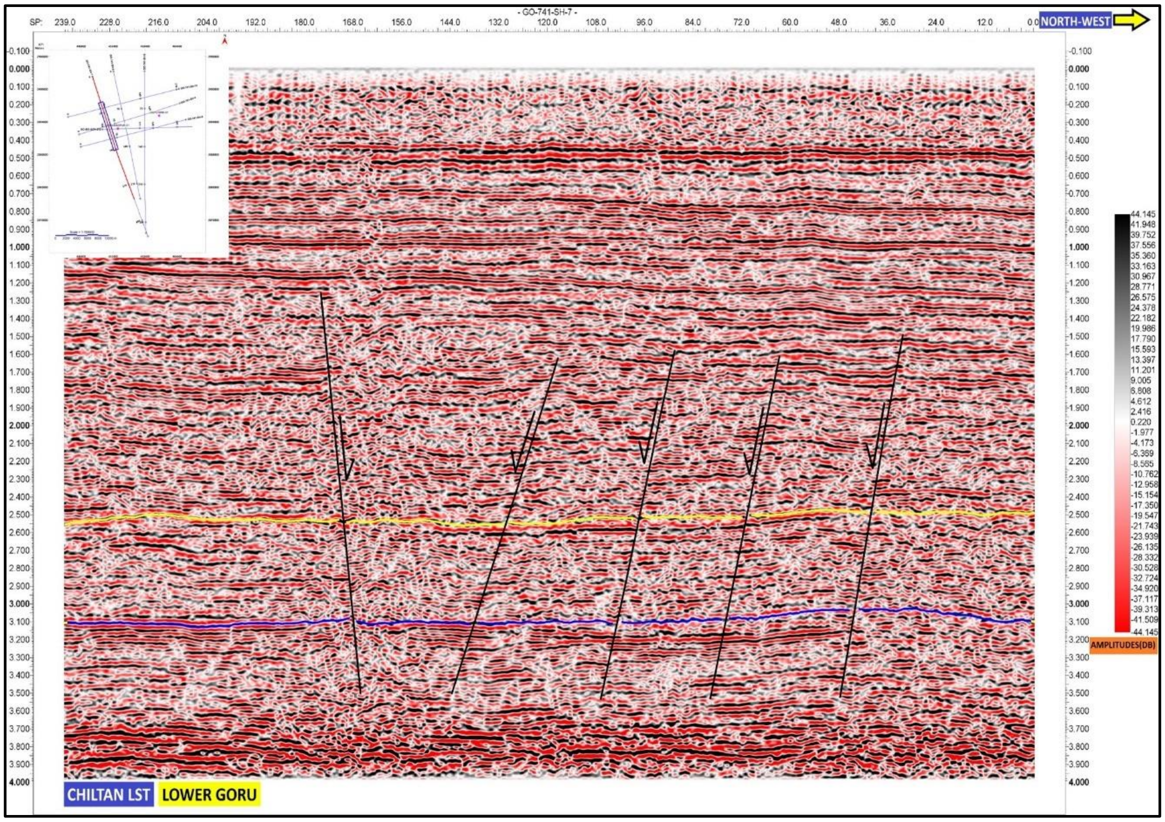

Figure 3.14 Seismic interpreted line SH-07.

It is a strike line having North-South direction and it is 24km long. The horizons Chiltan Limestone and lower Goru marked in this line are same that are on dip lines by tying this line with our control line **GO-851-SGR-212**. In this line multiples unassigned faults have been marked that are making a horst and graben structures.

3.4.6.6 Interpretation of seismic line SH-06

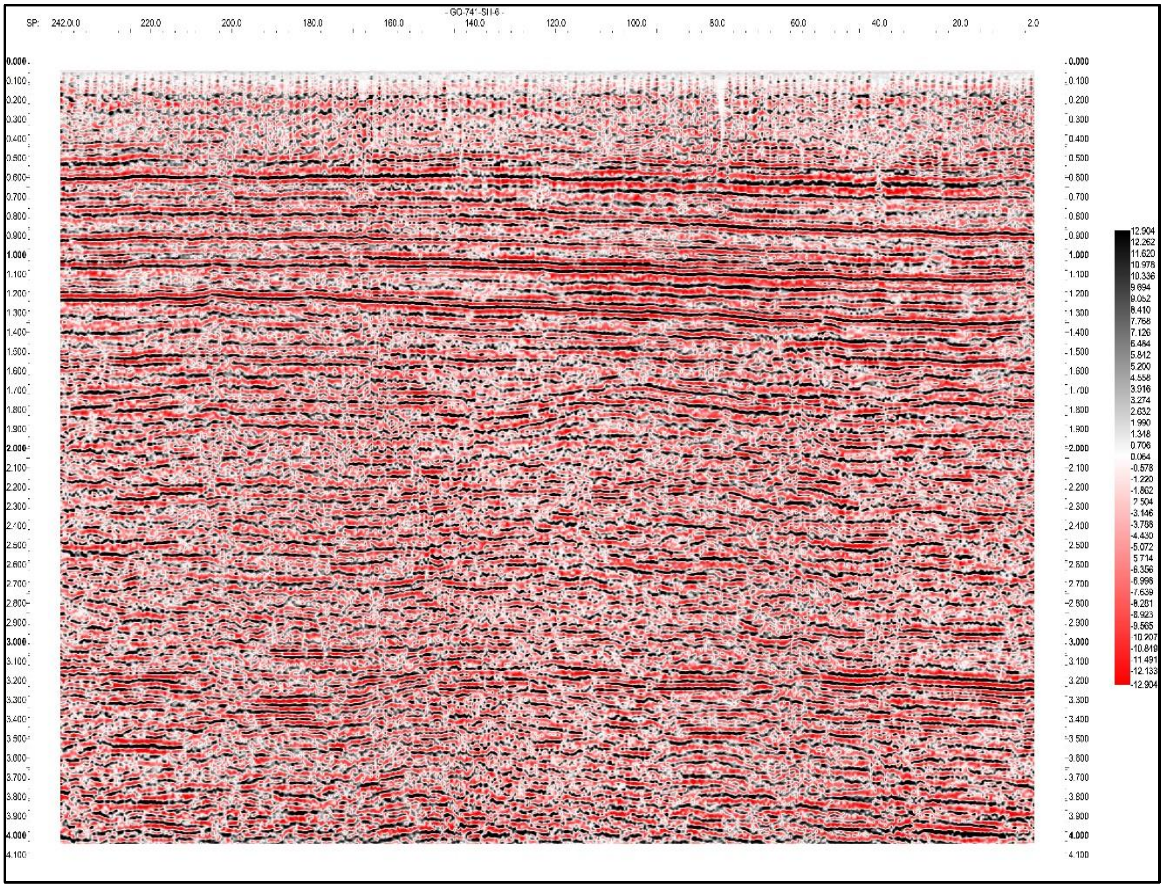

Figure 3.15 Uninterpreted seismic line SH-06.

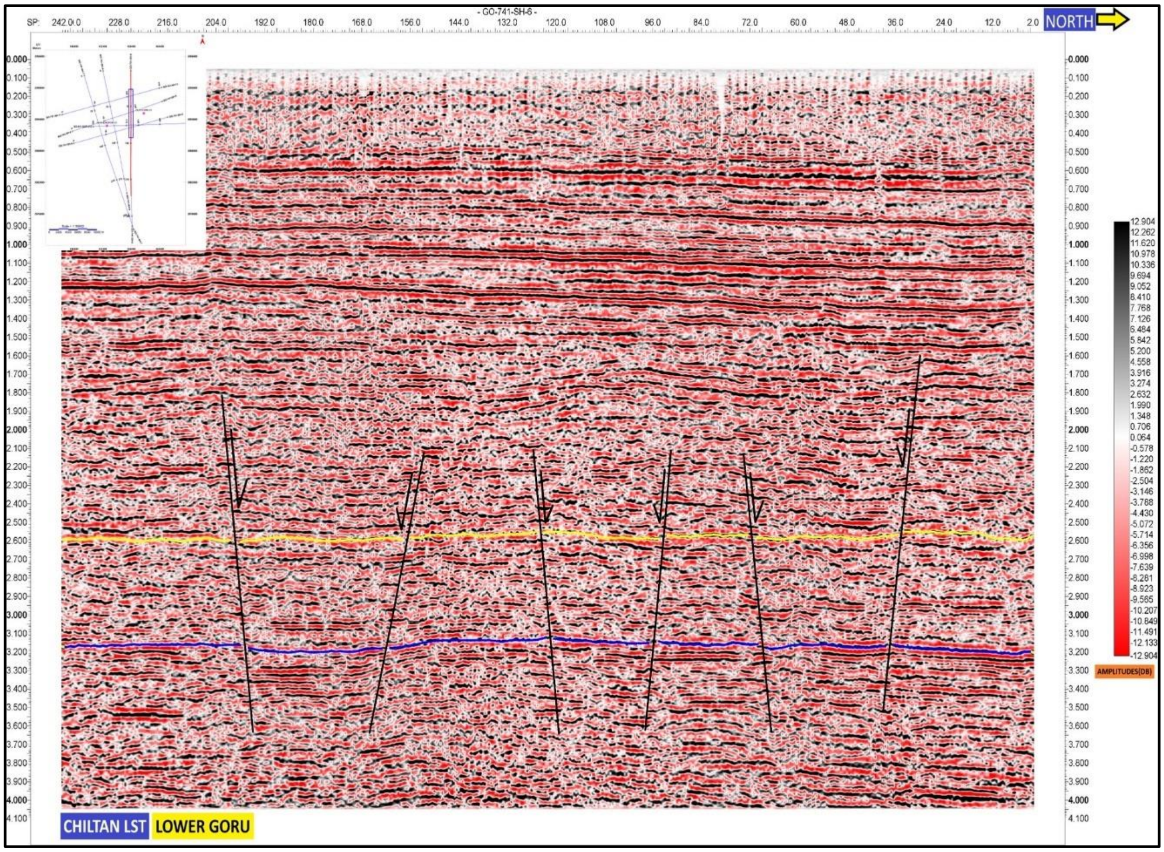

Figure 3.16 Seismic interpreted line SH-06.

It is a strike line having North-South direction and it is 24km long. The horizons Chiltan Limestone and Lower Goru marked in this line are same that are on dip lines by tying this line with our control line **GO-851-SGR-212**. In this line multiples unassigned faults have been marked that are making a horst and graben structures.

3.4.6.7 Interpretation of seismic line SH-08

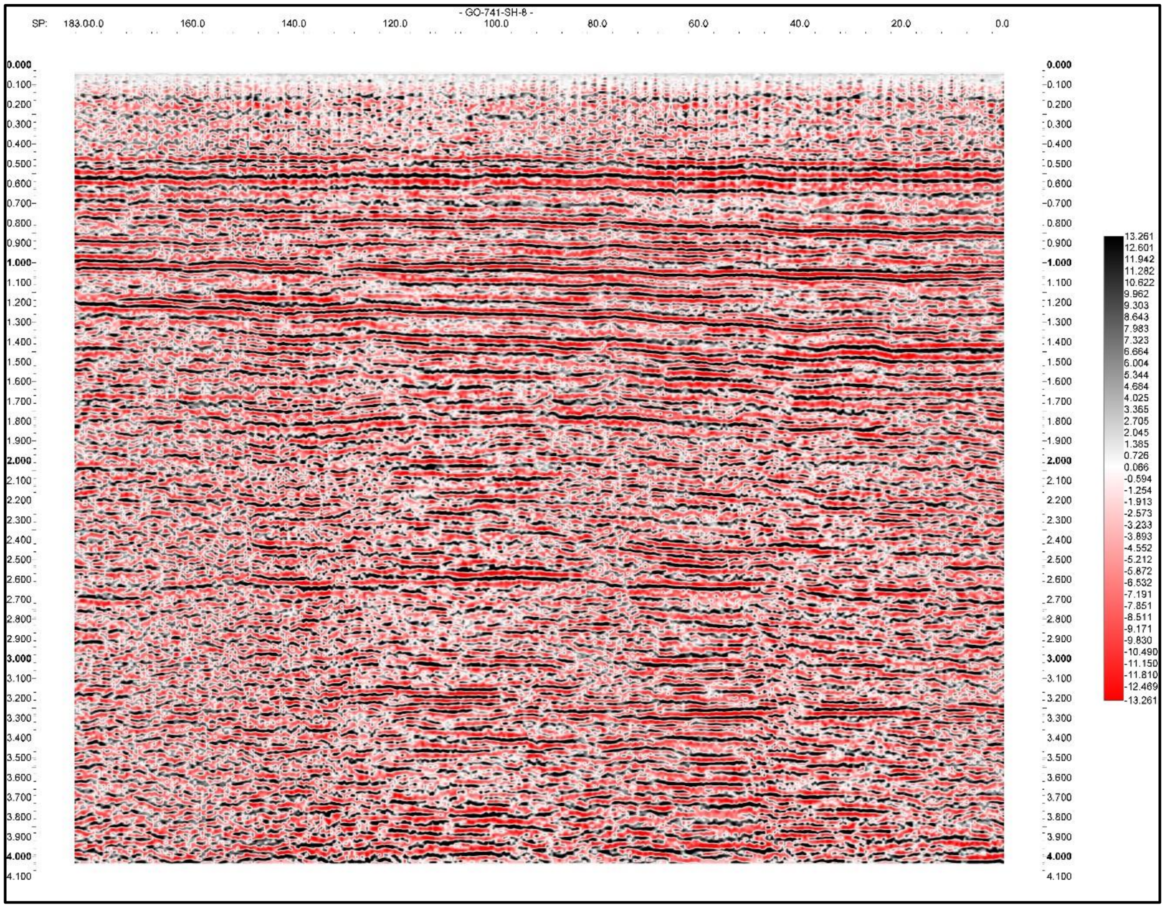

Figure 3.17 Uninterpreted seismic line SH-08.

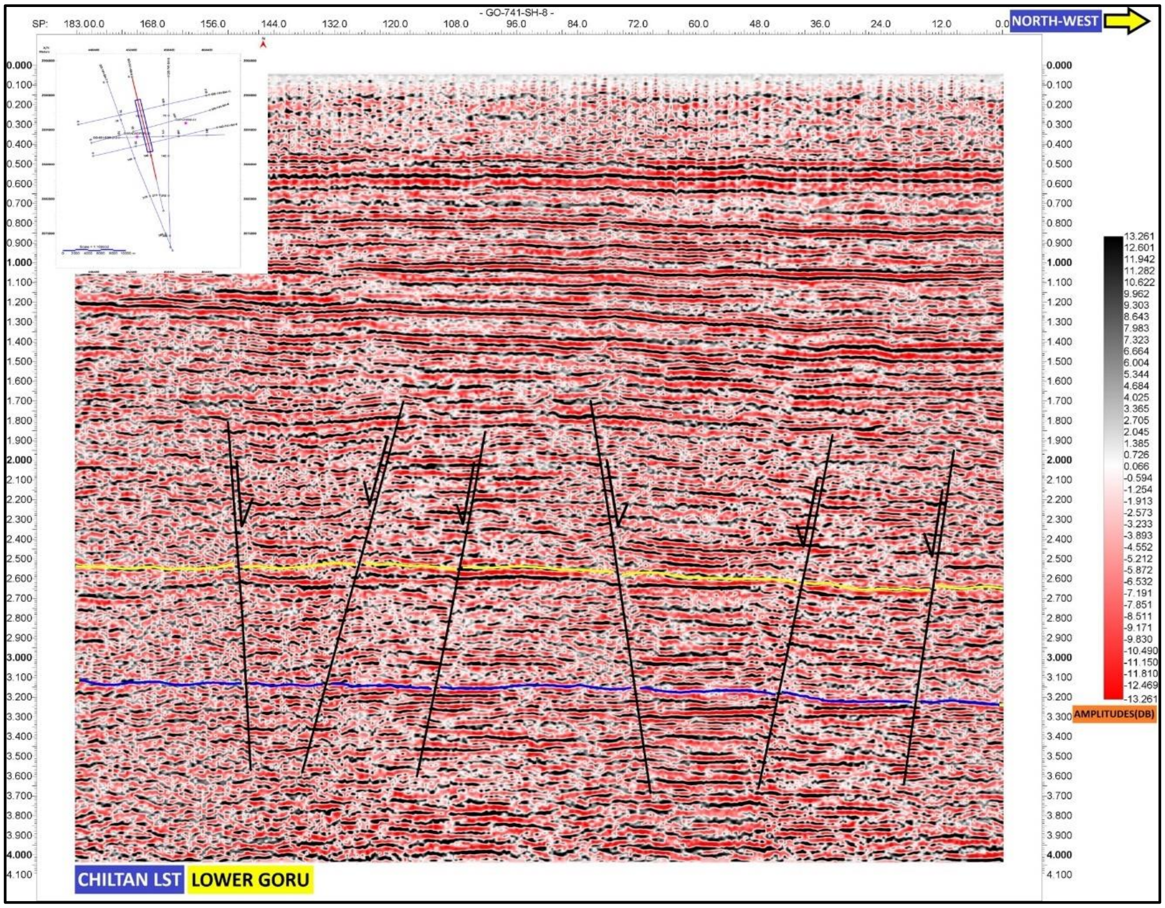

Figure 3.18 Seismic interpreted line SH-08.

It is a strike line having North-South direction and it is 18 km long. The horizons Chiltan Limestone and Lower Goru marked in this line are same that are on dip lines by tying this line with our control line **GO-851-SGR-212**. In this line, multiple unassigned faults have been marked that are making a horst and graben structures.

3.4.7 Seismic contouring

Seismic contouring is a method used to correlate the different nature of seismic signals with the contrasting structural styles of rock deformation. Using a computer makes it easy to generate suites of maps quickly (Tucker, 1988).

The study and observation of seismic countering is a distinctive method in the field of geophysics and geology exploration. This method has been broadly explored and acknowledged by numerous researchers over the years. This method includes the examination of the seismic waves reflected off various geological layers to image the structures in the subsurface (Smith & Jones 2017).

3.4.7.1 Time contour map of Lower Goru Formation

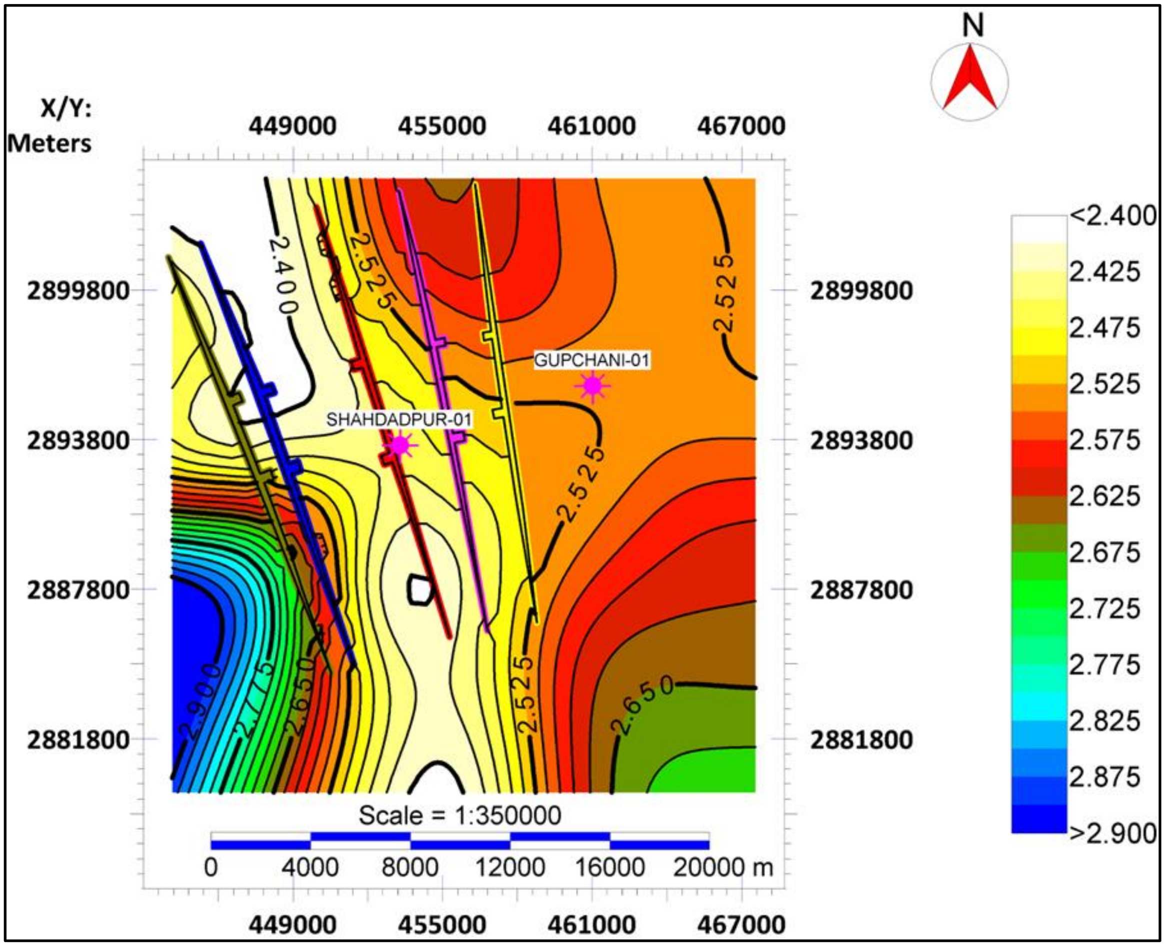

Figure 3.19 Time contour map of Lower Goru Formation.

To represent the time of a specific horizon, generate two-way travel time (TWT) maps. By using TWT maps relief features and faults can be identified. The higher values of the time represent the deeper level while the lower value of time represents the shallow level in the subsurface. A time map was created for the Top Lower Goru.

The time contour map for the Lower Goru Formation was created by selecting times from the seismic horizon (Lower Goru) in contrast with each shot point and by using a contouring module they were contoured in Kingdom Software. On the time is also contour map of Lower Goru Formation the faults show horst and graben structure five faults are shown F1 that is half-graben, whereas F2 and F3 show graben structure, and the F4 and F5 also show graben structure, but the horst structure also shown between F3 and F4. The contour interval of Lower Goru time is 0.025s. The minimum contour value is 2.4s and the maximum contour value is 2.9s.

3.4.7.2 Time contour map of Chiltan Limestone

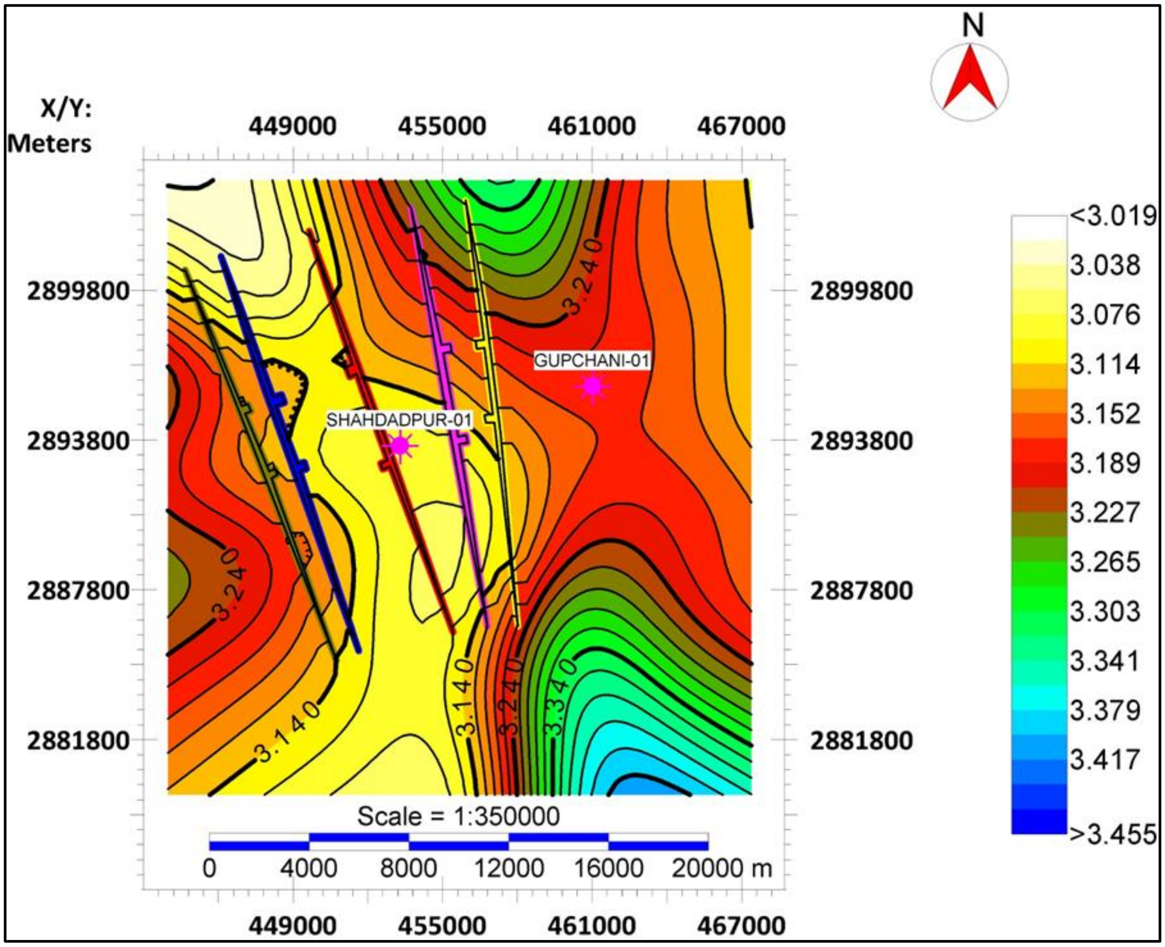

Figure 3.20 Time contour map of Chiltan Limestone.

To represent the time of a specific horizon two-way travel time (TWT) maps are generated. By using TWT maps relief features and faults can be identified. The higher values of the time represent the deeper level while the lower value of time represents the shallow level in the subsurface. A time map was created for the Top Chiltan Limestone. The time contour map for Chiltan Limestone was created by selecting times from the seismic horizon (Chiltan Limestone) in contrast with each shot point and by using a contouring module they were contoured in Kingdom Software.

On the time contour map of Chiltan Limestone, the faults show horst and graben structure five Faults are shown F1 is half graben, whereas F2 and F3 shows graben structure, and the F4 and F5 also shows graben structure, but the horst structure is also shown between F3 and F4. The contour interval of Chiltan Limestone is 0.02s. The minimum contour value of contour is 3.04s and the maximum is 3.5s.

3.4.7.3 Depth contour map of Lower Goru Formation

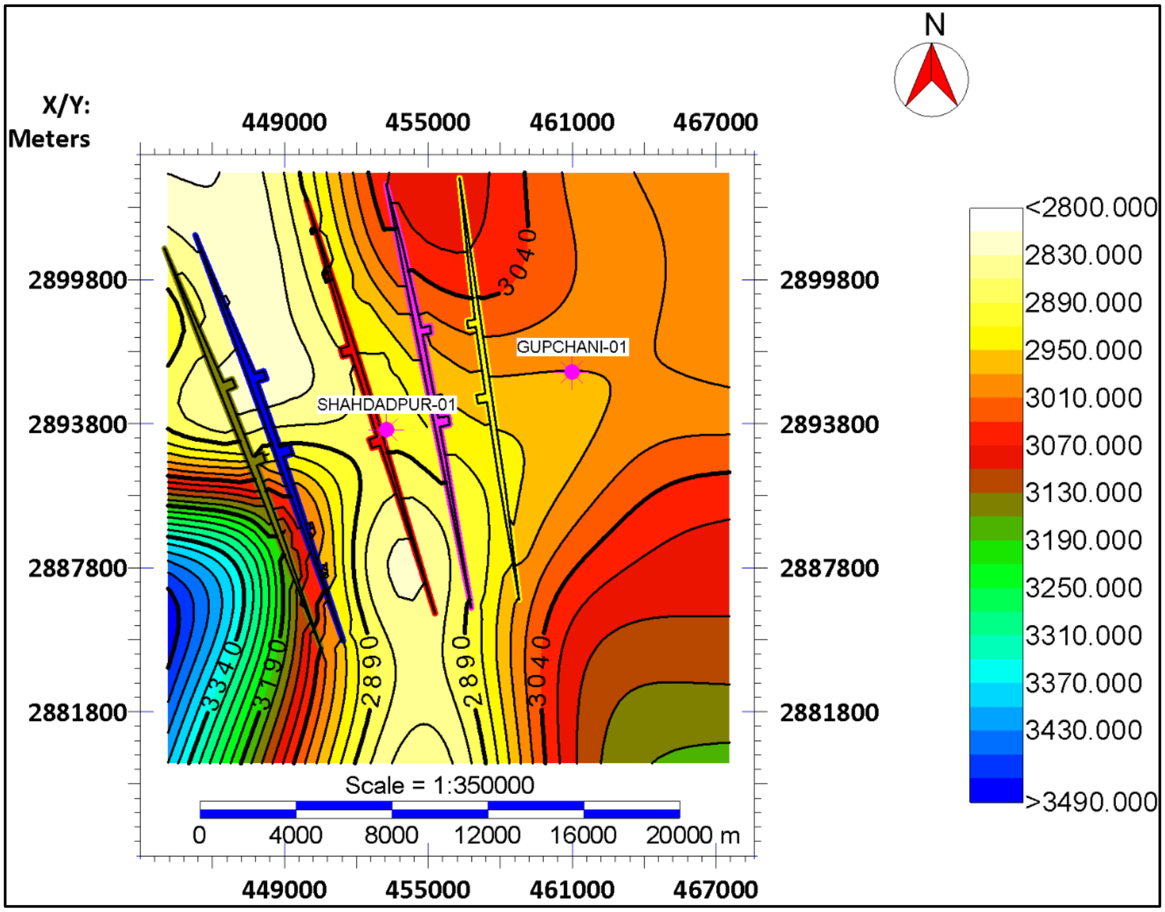

Figure 3.21 Depth contour map of Lower Goru Formation.

A time map is converted into a depth map by using the formula.

$$S = \frac{V * T}{2} \tag{3.1}$$

The contour value on the well matches with the value of synthetic seismogram that justifies the structural interpretation. The contour interval of Lower Goru depth is 30m, the minimum contour value is 2800m and maximum contour value is 3550m. And the horizon of the contour is of seismic interpreted section. On the depth contour map of Lower Goru Formation the faults show horst and graben structure five Faults are shown F1 that is half graben, whereas F2 and F3 shows graben structure, and the F4 and F5 also shows graben structure, but the horst structure also shown between F3 and F4.

3.4.7.4 Depth Contour Map of Chiltan Limestone

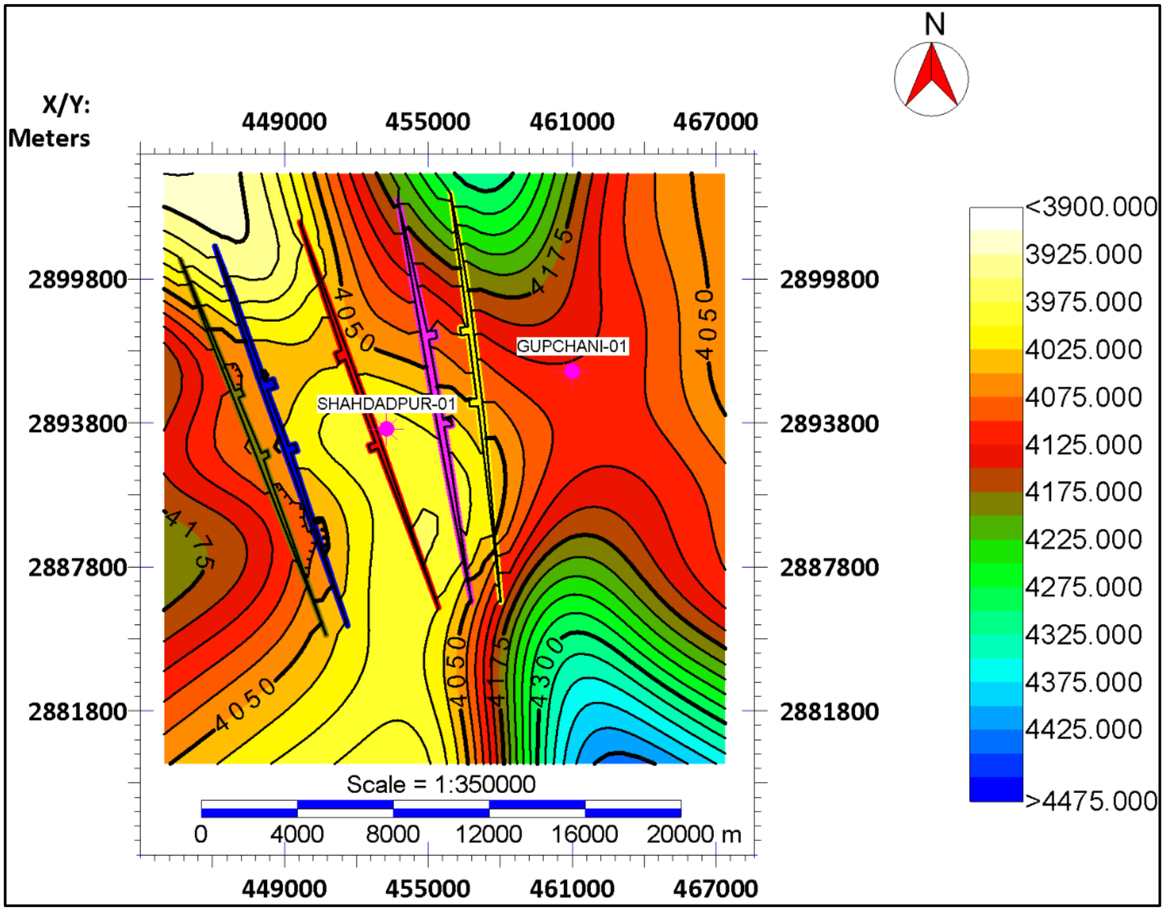

Figure 3.22 Depth contour map of Chiltan Limestone.

A time map is converted into depth map by using the formula.

$$S = \frac{V*T}{2} \tag{3.2}$$

The contour value on the well matches with the value of synthetic seismogram that justifies the structural interpretation. The contour interval of Chiltan Limestone Formation is 25m, the minimum color value of contour is 3900m and maximum is 4475m. And the horizon of the contour is of seismic interpreted section. On the depth contour map of

Chiltan Limestone the faults show horst and graben structure five Faults are shown F1 that is half graben, whereas F2 and F3 shows graben structure, and the F4 and F5 also shows graben structure, but the horst structure is also shown between F3 and F4.

CHAPTER 4

PETROPHYSICAL ANALYSIS

4.1 Introduction

The petrophysical study deals with the physiochemical properties of rock and their interaction with fluids. The petrophysical well log's primary goal is to convert well log measurement into reservoir attributes such as lithology, volume of shale, porosity, water saturation, and permeability (Shah, 2017).

4.2 Objectives

Petrophysics aims to deeply understand the earth's structure, especially where oil and gas are found. This knowledge helps experts like geologists, geophysicists, and reservoir engineers locate and use oil and gas resources more effectively and get the most out of existing oil and gas fields (Baig, 2002).

To give an understanding of the fundamental wireline logging strategies used to infer petrophysical properties for hydrocarbon investigation, well logs give continuous in situ estimations of boundaries connected with porosity, lithology, presence of hydrocarbons, and other related rock properties of interest.

1. Identification of potential and hydrocarbon-bearing zones.
2. Differentiation of hydrocarbon-bearing zones with non-bearing zones.
3. For the calculations of reserves present in a reservoir.

4.3 Methodology

By using the following methodology in our research area to compute the necessary parameters needed for performing petrophysical analysis.

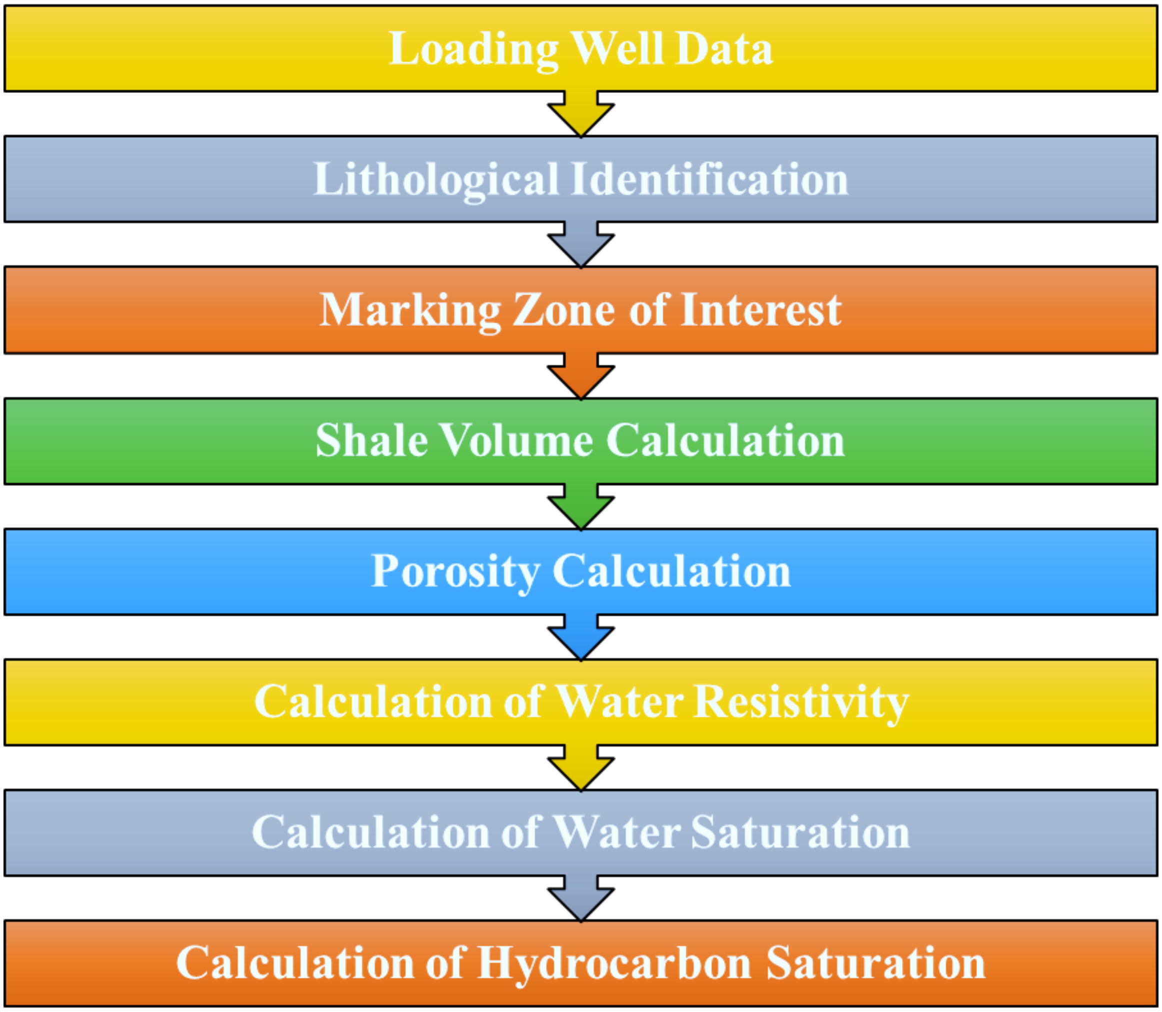

Figure 4.1 Complete workflow of petrophysical analysis.

Petrophysical analysis is a process used in the oil and gas industry to understand underground rock Formations and find out where oil or gas might be. To perform petrophysical analysis follow certain steps. Initially, load the log data in which we have to gather and properly organize data from well logs. These logs are records of the geological Formations encountered when drilling a well. Now by using the data from the log identify the various types of rocks present in the subsurface, like sandstone or shale. After identifying the types of rocks now calculate certain properties like the volume of shale, porosity, the resistivity of water, water saturation, and hydrocarbon saturation. Before moving towards the next step check the data to make sure it's accurate and adjust the data to standard scale units. Now perform a Formation evaluation which involves identifying the most promising rock layers that might contain oil or gas. This is done by looking for certain signs in the log data, like low responses on gamma-ray logs (which could indicate less shale), differences in resistivity readings, and other key indicators. All these steps can be performed on specific geological layers, like the Lower Goru Interval in the study area, to understand their potential for oil or gas production.

In general, petrophysical analysis is about using data from well logs to study underground rocks and find out where oil or gas might be hidden. This involves a lot of calculations and careful examination of the data to identify the most promising areas for exploration (Ellis & Singer, 2007).

4.4 Petrophysical analysis of Shahdadpur-01 well

Petrophysical Analysis is carried out on the Lower Goru Formation of the Lower Indus Basin which is drilled in Shahdadpur-01 well. Initially calculating the two volumes, the volume of shale and the volume of clean. After which several porosity parameters which are density-porosity, neutron-porosity, average-porosity, and effective-porosity. At last, fluid saturation is concluded. All these parameters are calculated with the use of different well log curves which are used to perform this analysis. In our work, I have selected Lower Goru of Cretaceous age for the petrophysical analysis to evaluate its hydrocarbon potential.

4.5 Logs used in petrophysical analysis

The petrophysical analysis was conducted using the logs (GR, DT, CALI, SFLU, ILD, RHOB, PHIN, SP,) obtained from the Shahdadpur-01 well.

4.6 Calculated parameters

4.6.1 Determination of volume of shale

The reservoir's potential is highly dependent on the amount of shale that is contained in it. GR log is used to calculate the amount of shale inside the reservoirs. The following formula is used to determine the volume of shale (Rider, 2002).

$$V_{Shale} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (4.1)$$

4.6.2 Porosity calculation

Porosity refers to the volume of void spaces, or pores, within a material compared to its total volume.

4.6.2.1 Density porosity

Density porosity is effective where there is no caving and washout and the bore hole conditions are normal, if these conditions do not exist then density porosity cannot be used, and results are not accurate and reliable for interpretation. So, to overcome this use sonic porosity and based on it compute average porosity. The formula for calculating density porosity is typically used when the conditions inside a borehole are normal, without any issues like caving or washouts (Ellis & Singer, 2007).

The following formula is used to calculate density porosity:

$$\boldsymbol{\varphi_D = \frac{\rho m - \rho_b}{\rho m - \rho_f}} \qquad \textbf{(4.2)}$$

$\boldsymbol{\varphi_D}$ = Density porosity of the rock, ρma = Density of the rock matrix (2.65 g/cm3), ρb = Bulk density of the formation (log response in zthe one of interest), ρf = Density of the fluid occupying the pores (1.1 g/cm^3).

4.6.2.2 Neutron porosity

Neutron porosity can be estimated by using the neutron log data for the depth of interest. The neutron log directly represents porosity (Asquith & Gibson, 2004).

4.6.2.3 Sonic porosity

Sonic porosity is another method of measuring the porosity of a rock formation in petrophysics. It is based on the measurement of the travel time of acoustic waves through the rock (Serra, 1984).

$$\boldsymbol{\varphi_s = \left(\frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}\right)} \qquad \textbf{(4.3)}$$

$\boldsymbol{\varphi_s}$ = Sonic porosity, $\boldsymbol{\Delta t_{log}}$ = Transit time in the formation of interest, $\boldsymbol{\Delta t_{ma}}$ = Transit time through 100% of the rock matrix, $\boldsymbol{\Delta t_f}$ = Transit time through 100% of the pore fluid.

4.6.2.4 Average porosity

Average porosity is the average of density and neutron porosity and the formula used is written below:

$$\boldsymbol{\varphi_A = \left(\frac{\varphi_D + \varphi_N}{2}\right)} \tag{4.4}$$

$\boldsymbol{\varphi_A}$= Average Porosity, $\boldsymbol{\varphi}_D$= Density Porosity, $\boldsymbol{\varphi}_N$= Neutron Porosity.

4.6.2.5 Effective porosity

Effective porosity is calculated using the Sonic Porosity Log. It is a measurement of the total amount of porous material's unfilled spaces that can transmit fluid.

$$\boldsymbol{\varphi_E = \varphi_A * (1 - V_{Shale})} \tag{4.5}$$

4.6.3 Resistivity of water (Rw)

To determine the fluid saturation, the value of resistivity of water should be known. Methods that are used to calculate **the** resistivity of water are computed directly from the equation, SP method, or picket plot method.

Here Pickett plot is used which was generated from Gverse Geographix 2022.1 software.

4.6.3.1 Picket plot creation

A Picket plot is a type of graph used in the oil and gas industry to understand water content in different areas of an underground reservoir, usually based on data from one or more wells. It visually represents the Archie equation, which is a formula used to estimate the amount of water in a reservoir. The plot shows a relationship between two key factors which are porosity and resistivity (Muhammad et al., 2019).

On a Pickett plot, you'll see a series of lines, typically colored red, which indicate different levels of water saturation (Sw) - essentially, how much of the pore space in the rock is filled with water. These lines are marked with values that decrease by increments of 25, starting from 100 and going down to 25. This means you can look at the plot and quickly see areas with high water content (near 100) and those with less water (closer to 25).

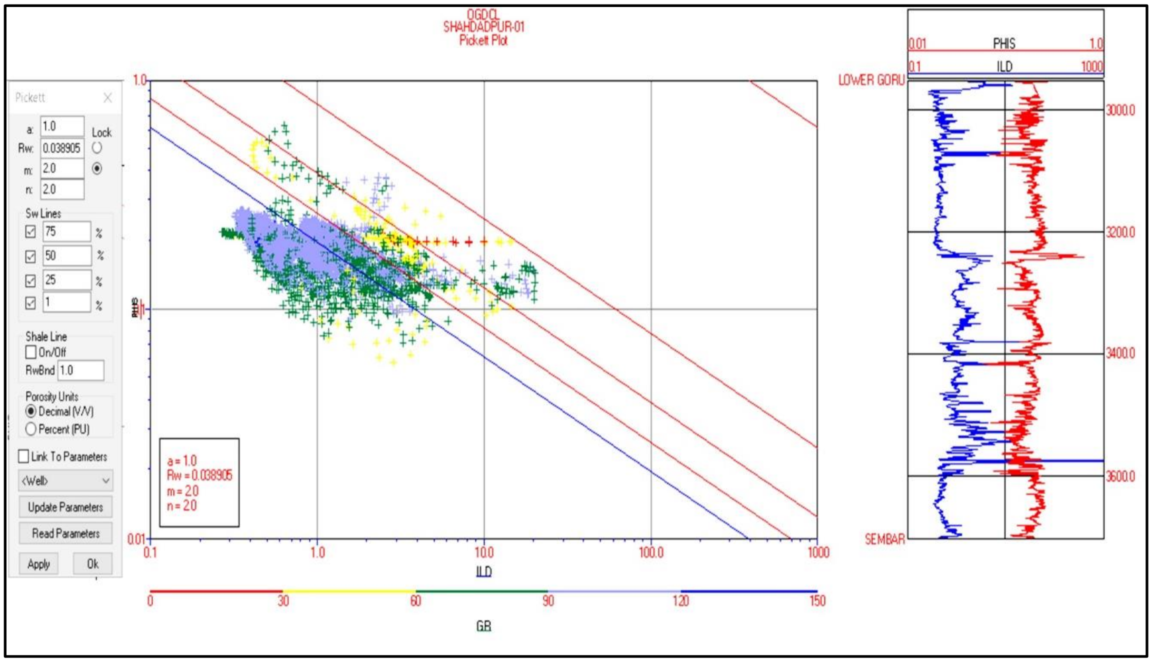

Figure 4.2 Showing picket plot of Shahdadpur-01 well.

4.6.4 Saturation of water (S_W)

Water saturation refers to water that is present in pore spaces. It aids in determining whether hydrocarbons are present in a reservoir. If $\mathbf{S_W}$ is low, it indicates a significant amount of hydrocarbon, whereas a high value of $\mathbf{S_W}$ shows a very low amount of hydrocarbon in the reservoir. Different methods including Archie's equation, Indonesian equation, and Modified Simandoux Equation are used to calculate the saturation of water.

Saturation of water by Archie's

$$\mathbf{S_W} = \left[\frac{(a*R_W)}{(R_t*\varphi_E{}^m)}\right]^{\frac{1}{n}} \tag{4.6}$$

Saturation of water by Indonesian

$$\mathbf{S_{W_{Indonesian}}} = \left\{\frac{\sqrt{\frac{1}{R_t}}}{\left(\frac{V_{sh}{}^{(1-0.5*V_{sh})}}{\sqrt{R_{sh}}}\right)+\sqrt{\frac{\varphi_E{}^m}{a*R_W}}}\right\} \tag{4.7}$$

Saturation of water by Simandoux

$$S_{W_{\text{Modified Simandoux}}} = \frac{a*R_W}{2*\varphi_E{}^m}\left[\sqrt{\left(\frac{V_{sh}}{R_{sh}}\right)^2 + \frac{4*\varphi_E{}^m}{a*R_W*R_t}} - \frac{V_{sh}}{R_{sh}}\right] \quad \textbf{(4.8)}$$

$\mathbf{S_W}$ = Saturation of Water, $\mathbf{R_W}$= Resistivity of Water, $\mathbf{R_t}$= True resistivity from Lateral Log Deep (LLD), $\boldsymbol{\varphi_E}$= Effective Porosity, m = 2, n = 2, a = 1

Here in Petrophysical analysis of our well, **Indonesian** as well as **Modified Simandoux** Equation for the computation of water saturation was used.

4.6.5 Saturation of hydrocarbon (S_H)

The following equation was used to determine the hydrocarbon saturation at a given temperature:

$$S_H = 1 - S_W \quad \textbf{(9)}$$

$\mathbf{S_H}$ = Saturation of hydrocarbons, $\mathbf{S_W}$ = Saturation of Water

Criteria of zone of interest

1. There must be separation in MSFL, LLS & LLD logs.
2. Gamma ray values must be less.
3. Caliper Log must be stable which shows that the bore hole condition is good.
4. Crossover between Density and Neutron Logs (Both Log values tend to be decreasing)

Raw log curves

The raw log curves are presented in three sections, known as tracks. Each track displays different types of measurements taken from a borehole. Track-01 (Lithological Logs) shows the geological characteristics of the rocks. It includes GR, SP, CALI. The GR (Gamma Ray) Log that is represented by a solid black line, measures natural radioactivity, with values ranging from 0 to 150 API units. The SP (Spontaneous potential) Log is represented as a green line, it measures natural electrical potentials in the earth with values between -100 to 50 millivolts. The CALI (Caliper) Log is displayed with a dark blue dashed line, it measures the borehole diameter, ranging from 6 to 16 inches. Additionally, the borehole diameter is also shown with a black dotted line within the same range. Track-02 (Resistivity and Induction logs) focuses on the electrical resistivity of the rock formations, it includes SFLU with a solid black line and ILD with a dashed blue line. Track-03 (Porosity logs) provides information about the porosity of the rocks, which is their ability to contain fluids. It comprises NPHI (Neutron porosity log) represented by a solid blue line and RHOB (Density log) represented by a solid black line. Track-04 which contains Sonic log represented by a solid black line.

These logs are used in the analysis of Lower Goru Formation and are particularly useful in identifying oil and gas reserves. Each log type is represented by specific line styles and colors for easy identification.

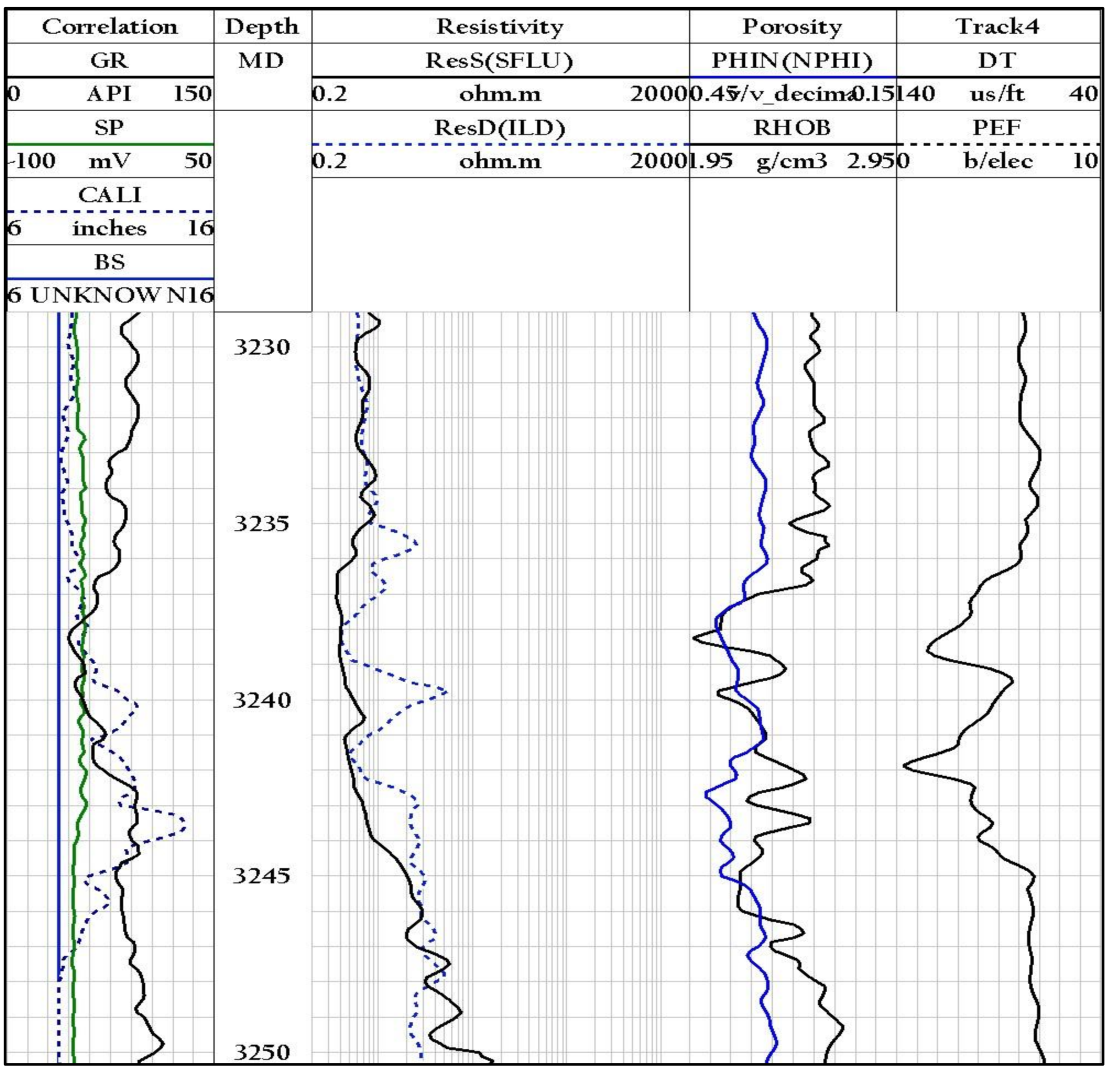

Figure 4.3 Raw log of Lower Goru Formation with given depth in meters

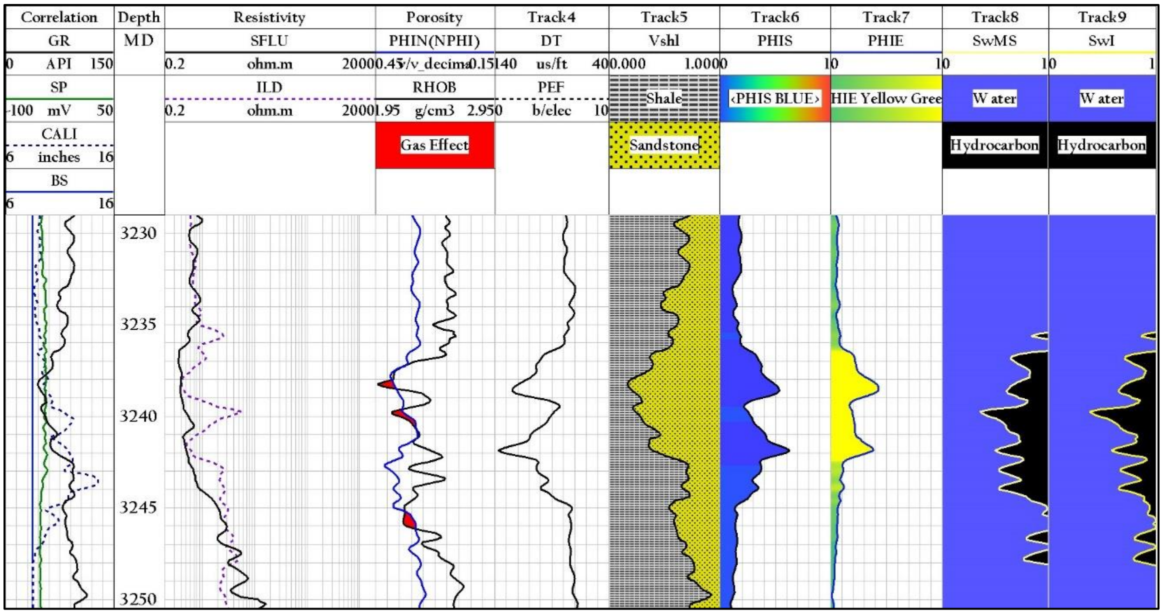

Figure 4.4 Petrophysical analysis of Lower Goru Formation having depth starting from 3239.63 m to 3240.63m and 3245.25m to 3245.75m of zone thickness of about 1.5m.

Table 4.1 Calculated parameters of zone 1.

ZONE 1 (3239.63m - 3240.63m) & (3245.25m-3245.75m)						
Depth	V_{sh}	**PHIS**	**PHIE**	S_{w_I}	$S_{w_{MS}}$	$S_{H_{MS}}$
3239.63	**0.218**	**0.235**	**0.184**	**0.49**	**0.467**	**0.533**
3240.13	**0.292**	**0.29**	**0.205**	**0.552**	**0.516**	**0.484**
3240.63	**0.386**	**0.353**	**0.217**	**0.678**	**0.613**	**0.387**
3245.25	**0.576**	**0.148**	**0.063**	**0.932**	**0.968**	**0.032**
3245.5	**0.601**	**0.152**	**0.061**	**0.989**	**1.037**	**-0.037**
3245.75	**0.585**	**0.143**	**0.059**	**1.007**	**1.07**	**-0.07**
Average	**0.443**	**0.220**	**0.1315**	**0.775**	**0.779**	**0.222**
Average (%)	**44.30**	**22.02**	**13.15**	**77.47**	**77.85**	**22.15**

The Formation Lower Goru was discovered at 2950m. In the beginning of Zone 1 which is from depth (3239.63m-3240.63m), (3245.25m-3245.75m) which has 44.30% of V_{Sh}. The amount of shale grows from 0.218% to 0.601% from 3239.63m to 3245.5m depth. Since shale eliminates porosity, the volume of shale must be calculated to compute porosities. Conversely, however with depth comes an increase in clean volume. At the beginning of the dive, at 3239.63 meters, the volume of clean was 53%. Figures representing curves of porosities also show saturation of water at the start of the reservoir zone at 3239.63m which is 0.467% and at 3245.75m depth it was highest in this zone. 1.07%. The saturation of hydrocarbon was 0.533% at the starting depth and it is the maximum percentage of hydrocarbon saturation at this point.

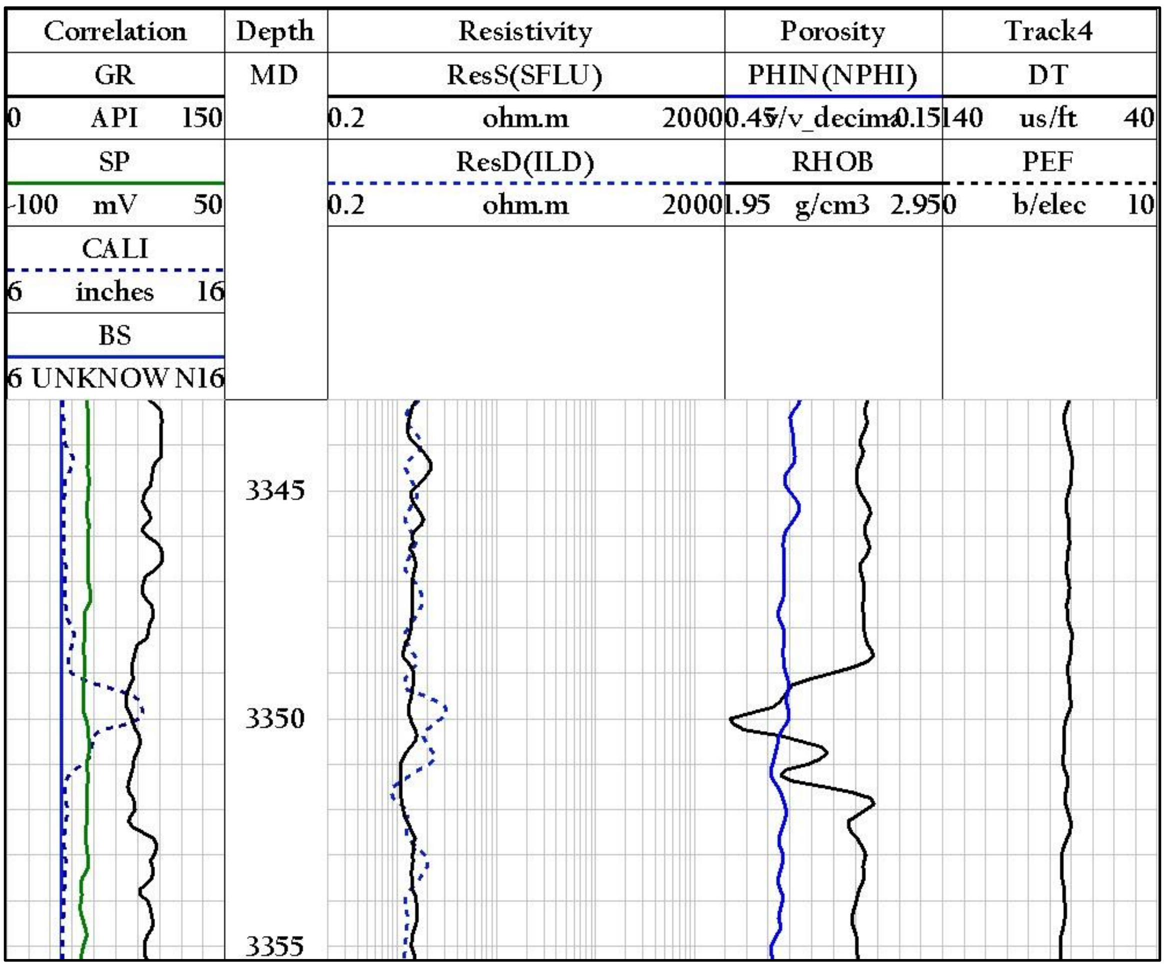

Figure 4.5 Raw log of Lower Goru Formation with given depth in meters

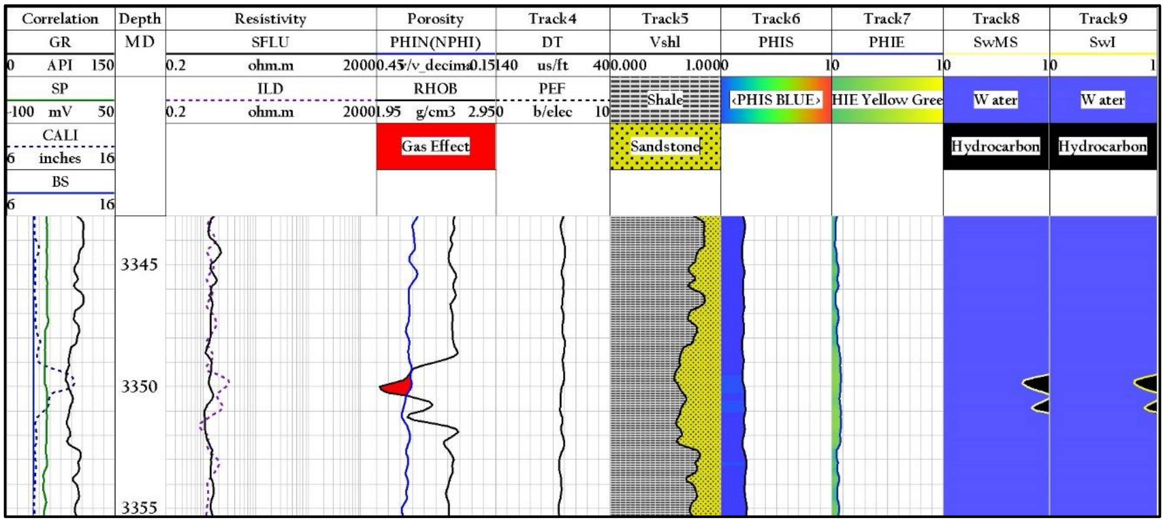

Figure 4.6 Petrophysical analysis of Lower Goru Formation having depth starting from 3245.25 - 3250.25 m of zone thickness of about 0.75m.

Table 4.2 Calculated parameters of zone 2.

ZONE 2 (3249.25m - 3250.25m)						
Depth	V_{sh}	**PHIS**	**PHIE**	S_{w_I}	$S_{w_{MS}}$	$S_{H_{MS}}$
3249.25	**0.576**	**0.148**	**0.063**	**0.932**	**0.968**	**0.032**
3249.5	**0.601**	**0.152**	**0.061**	**0.989**	**1.037**	**-0.037**
3249.75	**0.58**	**0.194**	**0.082**	**0.8**	**0.77**	**0.23**
3250	**0.621**	**0.209**	**0.079**	**0.84**	**0.799**	**0.201**
3250.25	**0.656**	**0.217**	**0.075**	**0.999**	**0.965**	**0.035**
Average	**0.607**	**0.184**	**0.072**	**0.912**	**0.908**	**0.092**
Average (%)	**60.68**	**18.4**	**7.2**	**91.2**	**90.78**	**9.22**

At the beginning of Zone 2, is about 3249.25m - 3250.25m. At a depth of 3249.75 meters, the lowest recorded volume of shale is 0.58%. Following 3249.75 meters of depth shale volume rises from 0.58% to 0.621% (depth: 3249.75 m to 3250 m). Since shale eliminates porosity, the volume of shale must be calculated to compute porosities. Conversely, however with depth comes an increase in clean volume. In addition to displaying porosity curves, the figures also show the saturation of water at the beginning of the reservoir zone at 3249.25m, which is 0.968% and at the highest depth of this nine, at 3249.5m, which is 1.037%. Following this depth, the saturation of water shows a decreasing trend, ranging from 0.77% to 0.799% till 3250m, at which point it again increases in trend, 0.965% at 3250.25m. The hydrocarbon saturation was 0.23%, and at 3249.75 meters. At this stage, it represents the greatest percentage of hydrocarbon saturation.

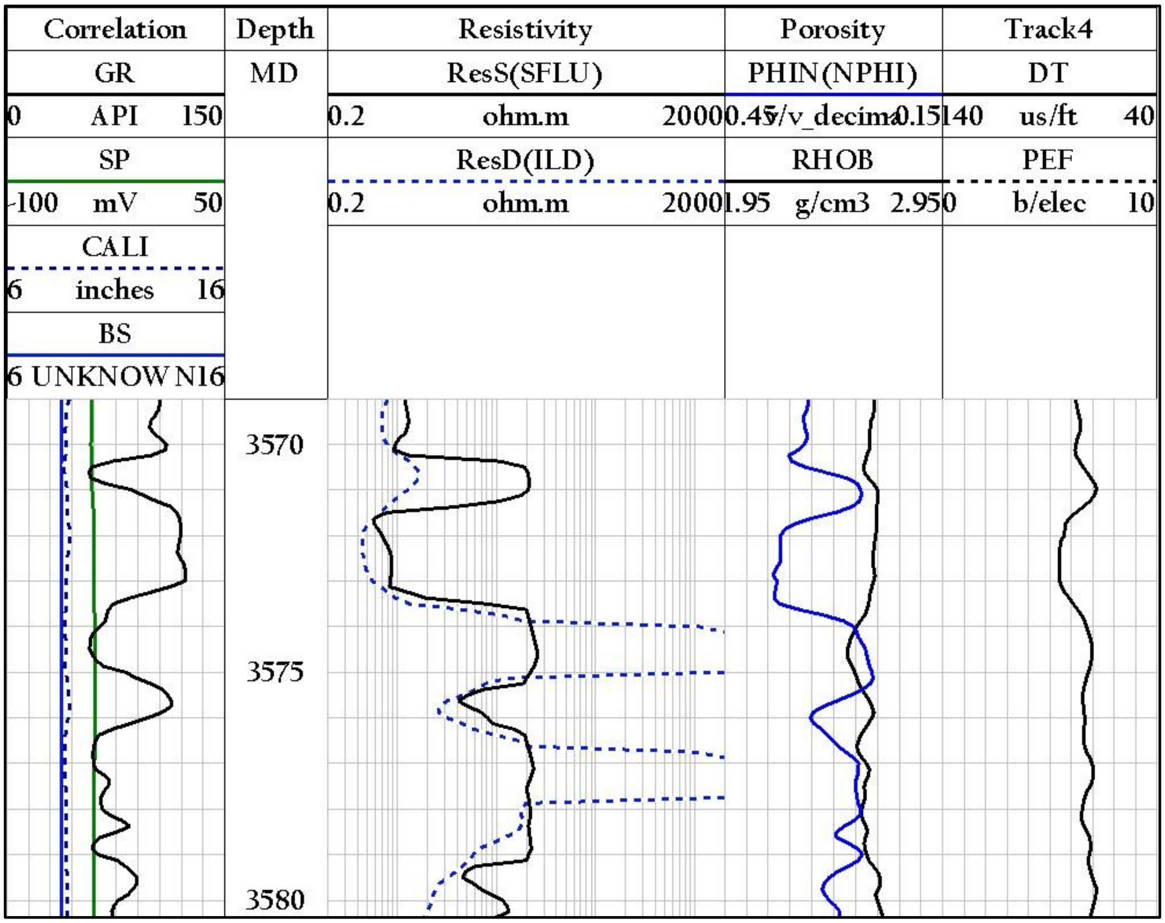

Figure 4.7 Raw log of Lower Goru Formation with given depth in meters.

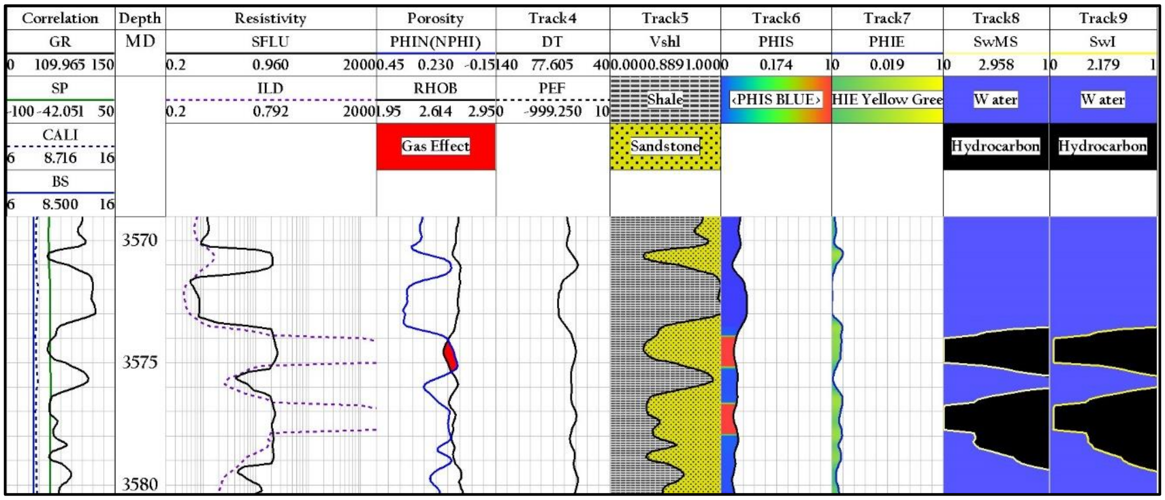

Figure 4.8 Petrophysical analysis of Lower Goru Formation having depth starting from 3574m to 3575.25m of zone thickness of about 1.25m.

Table 4.3 Calculated parameters of zone 3.

ZONE 3 (3574m – 3575.25m)						
Depth	**V_{sh}**	**PHIS**	**PHIE**	**S_{w_I}**	**$S_{w_{MS}}$**	**$S_{H_{MS}}$**
3574	**0.381**	**0.137**	**0.085**	**0.048**	**0.011**	**0.989**
3574.25	**0.31**	**0.124**	**0.085**	**0.036**	**0.007**	**0.993**
3574.5	**0.3**	**0.115**	**0.081**	**0.038**	**0.007**	**0.993**
3574.75	**0.354**	**0.119**	**0.077**	**0.037**	**0.006**	**0.994**
3575	**0.574**	**0.13**	**0.055**	**0.039**	**0.004**	**0.996**
3575.25	**0.767**	**0.142**	**0.033**	**0.657**	**0.58**	**0.42**
Average	**0.448**	**0.128**	**0.069**	**0.143**	**0.103**	**0.898**
Average (%)	**44.77**	**12.78**	**6.93**	**14.25**	**10.25**	**89.75**

Zone 3 designates a depth range of 3574m– 3575.25m. The composition of the rock in this zone provides important information. Zone 3 has variable shale volume V_{Sh} averaging 44.77%. Interestingly, the average porosity PHIS, which measures the pore space in the rock, is 12.78%. The average value of linked pore spaces, or effective porosity (PHIE), is 6.93%. The percentage of water in the rock is represented by the water saturation calculated from Simandoux which averages 10.25%, and the water saturation index, which averages 14.25%. Zone 3 offers a quick overview of the subsurface features, which is essential for comprehending reservoir characteristics and fluid behavior.

Petrophysical results of Lower Goru

Table 4.4 Shows the starting and ending depth, net thickness, and gross thickness of the Lower Goru Formation.

Formation	Starting Depth(m)	Ending Depth(m)	Thickness
Lower Goru	2950m	3702	752m
Zone 1	3239.63m	3240.63m	1m
	3245.25m	3245.75m	0.5 m
Zone 2	3249.25m	3250.25m	1m
Zone 3	3574m	3575.25m	1.25m
Net pay			3.75m

According to the literature, Lower Goru is the primary reservoir in this area and Chiltan Limestone, Khadro, Kirthar Formation is the secondary reservoir. The top of the lower Goru Formation starts from a depth of 2950. After observing the log trends, the following results for the volume of shale, different porosities, water saturation, and hydrocarbon saturation of Lower Goru have been calculated. There were multiple zones with a total net pay thickness of 3.75m which are feasible for Hydrocarbon Exploration. Following are the overall results in the percentage of all the reservoir zones that are present in the Lower Goru Formation.

Table 4.5 List of zones average in percentage.

ZONES (AVERAGE IN %)						
ZONES %	V_{sh}	PHIS	PHIE	S_{W_I}	$S_{W_{MS}}$	$S_{H_{MS}}$
ZONE 1	44.30	22.02	13.15	77.47	77.85	22.15
ZONE 2	60.68	18.4	7.2	91.2	90.78	9.22
ZONE 3	44.77	12.78	6.93	14.25	10.25	89.75
Average in %	49.9	17.7	9.1	61.0	59.6	40.4

This table is a useful overview that offers a clear illustration of significant reservoir features found in several Lower Goru Formation zones. Geoscientists and reservoir engineers use the data to help them make well-informed judgments about how best to explore for and produce oil and gas.

CHAPTER 5

VOLUMETRIC RESERVE ESTIMATION

5.1 Introduction

A distinct calculation of hydrocarbon reserves has an important role in achieving success in field development and remains critical at some point in the field's lifespan. Quantitative assessment is done to evaluate the economically recoverable hydrocarbons inside a field, area, or region. Various strategies exist for estimating hydrocarbon reserves, which include analogy, volumetric, decline analysis, material balance, and reservoir simulation. The reliability of those techniques is based completely on the nature, amount, and reliability of the geological, geophysical, engineering, and financial information at hand (Dandekar, 2013).

5.2 Reserves

The part of hydrocarbons that can be economically extracted is known as "reserves." For reserves to be classified as such, they have to meet four criteria: discovery, recoverability, commercial viability, and final potential, all primarily based totally on the selected development approach.

5.3 Oil volume in place

In reservoir engineering, the quantity of hydrocarbons found in a reservoir is called the "Oil quantity in place". The valuation of oil and gas volumes in place, in conjunction with the determination of their recoverable reserves, is a critical level in the numerous activities concerned with the improvement of oil and gas fields (Ahmed & Ihonor,2006).

5.4 Types of reserve estimation

Reserve estimation techniques can be classified into three primary types: analogy, volumetric, and performance methods. Volumetric and performance methods are broader techniques, with the key difference existing in the data applied for the pre-and post-production stages (Dake, 2000).

5.4.1 Volumetric method

The volumetric method includes estimating the reservoir's volume using maps and petrophysical data from drilled wells. This technique is usually employed during the initial exploration phases to decide the entire quantity of oil and gas in place, in addition to the corresponding reserves (Paul, 1993).

5.4.2 Material balance method

The Material stability technique is implemented at some point of the intermediate stages of exploration and production to analyze and estimate the production of oil and gas.

5.4.3 Decline curve analysis

In the past due life of the field, while a large part of the oil and gas has already been obtained and the production rate is decreasing, a decline curve evaluation is employed. This method offers a forecast of production that can be obtained in future, allowing the estimation of reserves (Skinner & David, 1946).

Reserves estimation using the volumetric method

To evaluate the reserves by utilizing the volumetric technique, petro physical data of the well is required. Here we need to discover the total volume of oil reserves (Hawkins et al., 1959).

Formula

$$N = 7758 * GRV * \frac{N}{G} * \varphi_A * S_W * \frac{1}{B_O} \quad (1)$$

Where **7758** is a Conversion factor, **N** is Total Recoverable Hydrocarbons**, GRV** is Gross Rock Volume (acre-ft)**, N/G** is Net to Gross Ratio (Net pay), φ_A is the Average Porosity**,** S_w is the Saturation of water and B_o is the Formation Volume Factor.

All the required data values from petrophysical calculation have been calculated but here we've an unknown GRV, calculate GRV using the planimetry device to get the digitized value of region P90, P50 and P10 in acre-ft. Here P90 represents the region where there is a 90% chance of locating hydrocarbons. P50 denotes the zone with a 50% probability while P10 shows the zone with a 10% probability of hydrocarbon presence**.**

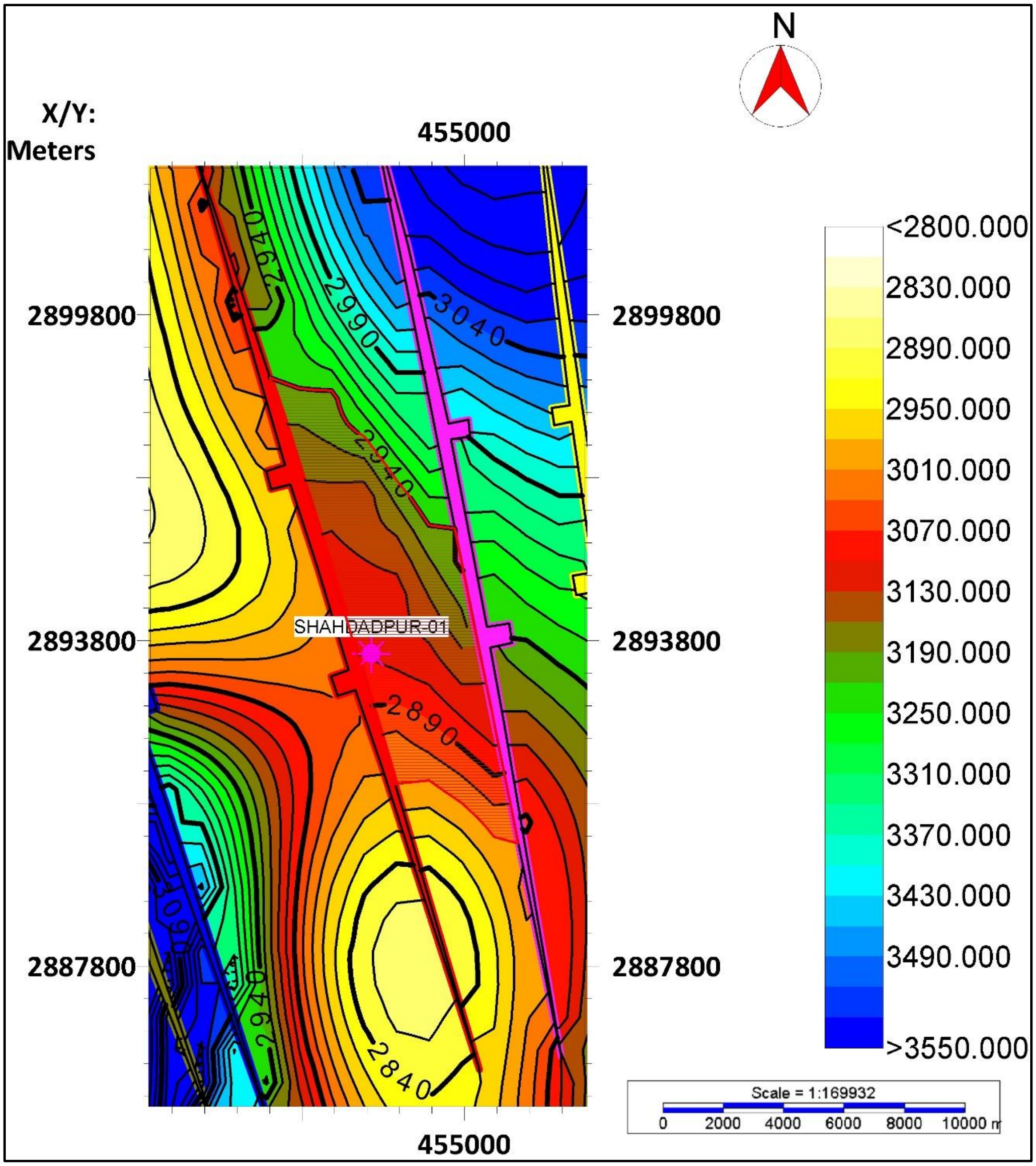

Figure 5.1 Shows 10% Probability of hydrocarbon presence.

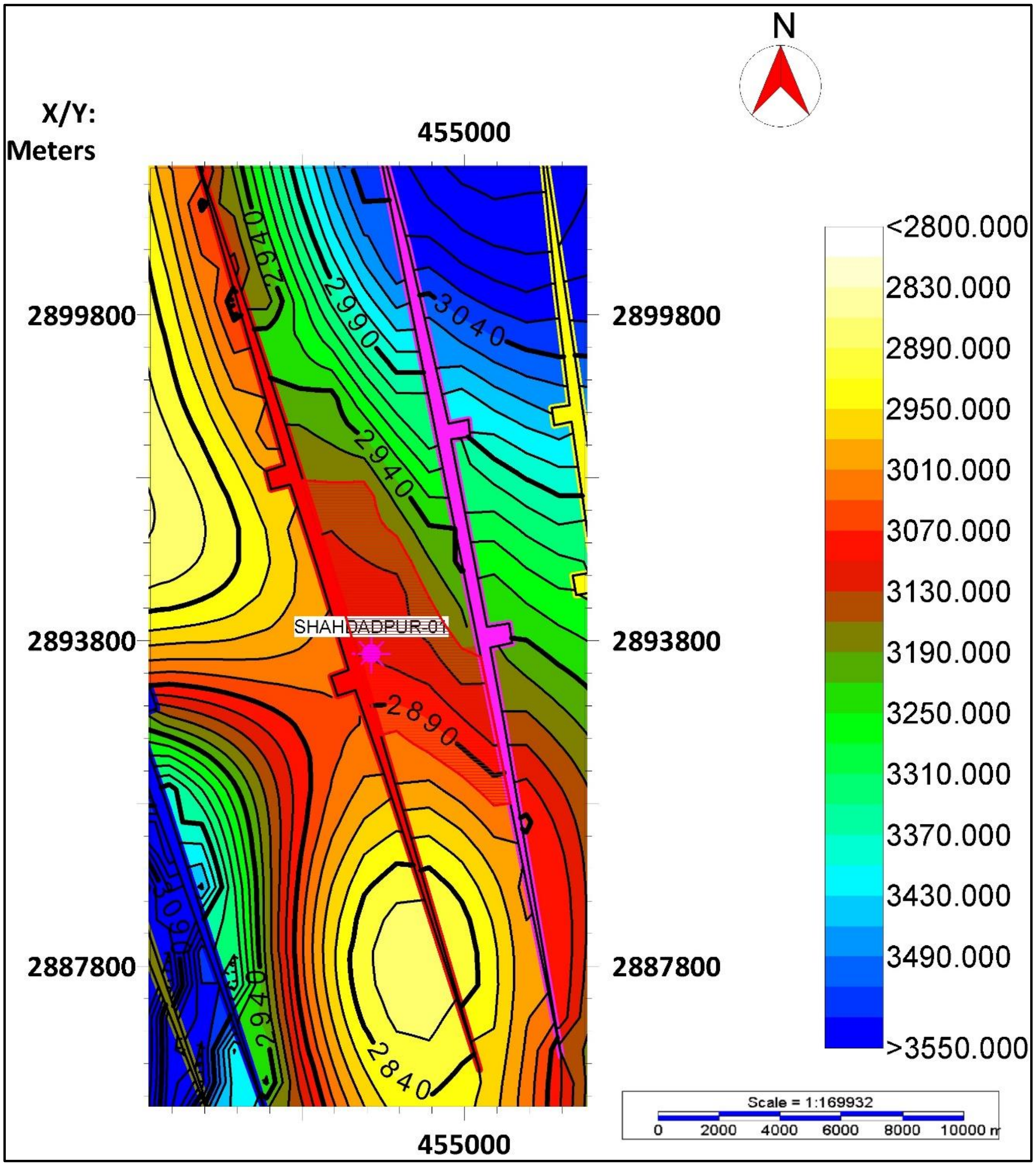

Figure 5.2 Shows 50% probability of hydrocarbon presence.

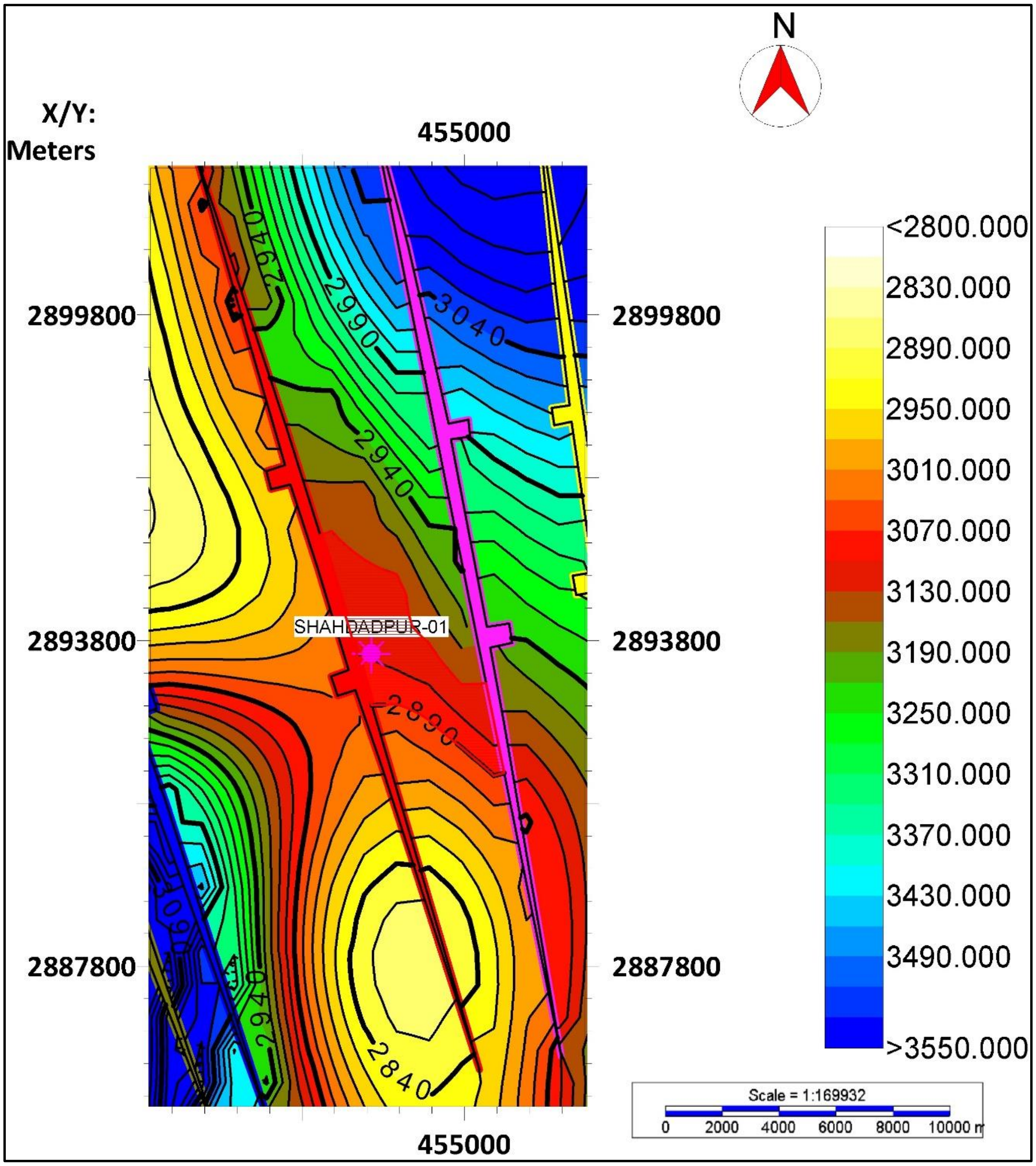

Figure 5.3 Shows 90% probability of hydrocarbon presence.

5.5 Results

Table 5.1 Shows volumetric reserves estimation of Lower Goru Formation.

Case	Contour	Area (Acre)	Net Pay (ft)	Average Porosity (fraction)	S_{WMS} (fraction)	Bo	Recoverable HC's (bbl)	Recoverable HC's (Mbbl)
P90	2890	1268.15	12.30	0.1773	0.596	1.6	7,994,067.44	7.9940
P50	2915	2317.77	12.30	0.1773	0.596	1.6	14,610,548.6	14.61
P10	2940	3846.47	12.30	0.1773	0.596	1.6	24,246,995.7	24.24

CONCLUSION

1. An integrated seismic and well-based study for evaluating the Lower Goru Formation in the study area of Shahdadpur. We conclude that, according to seismic data interpretation of the Shahdadpur area there are normal faults with minor throw which indicates the involvement of extensional tectonics in the area. The normal faults were quite difficult to identify on the seismic sections due to the lower fold coverage (resolution) of the acquired seismic data, the normal faults that are marked in interpreted seismic sections are F1, F2, F3, F4, and F5. By observing these faults, it concludes that the area has horst and graben structures which helps in hydrocarbon accumulation. In the research, two horizons have been marked two on a seismic line named Lower Goru Formation of the Cretaceous age and Chiltan Limestone of the Jurassic age, and then the time and depth contour maps have been generated for these horizons to further validate the structure identified on the seismic section.
2. The Lower Goru Formation was subjected to a comprehensive examination of its petrophysical characteristics. The results indicate that the formation can be segregated into two distinct facies, which are sand and shale. In the petrophysical analysis it has been identified that the zones fulfil all the four criteria of zone of interest. The net pay thickness of the zones is total 3.75m (12.303 ft). In zone 1the percentage of volume shale, saturation of hydrocarbon, and effective porosity are 44.30%, 22.15%, and 13.15% respectively, whereas in zone 2 the percentage of volume shale, saturation of hydrocarbon, and effective porosity are 60.68%, 9.22%, and 7.2% respectively whereas in zone 3 the percentage of volume shale, saturation of hydrocarbon, and effective porosity are 44.77%, 89.75%, and 6.93% respectively. Overall analysis showed that zone 3 is a more hydrocarbon bearing zone than the other two zones (1,2).
3. Here in the research volumetric reserves estimation has also been carried out through the depth contour of Lower Goru Formation in which 3Ps have been marked on that contour map named as P10, P50, and P90 zones.

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