# Reservoir Characterization of Sawan Area using seismic and well data, Pakistan


**BY**

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# CERTIFICATE OF APPROVAL

This dissertation by **Sheeza Nasir** D/o **Nasir Masih Francis** is accepted in its present form by the Department of Earth Sciences, Quaid-i-Azam University Islamabad as satisfying the requirement for the award of degree of **BS Geophysics.**

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**May God bless you all**

**SHEEZA NASIR**

# ABSTRACT

Sawan Field is located in the thar desert, District Khairpur in sindh province of Pakistan. The study area lies in the extensional tectonic regime exhibiting horst and graben structure. The Lower Goru Formation is acting as a potential reservoir which is being charged by shale of sembar formation. The sawan gas field is one of the major gas producing areas with Early-Late Cretaceous Lower Goru Formation acting as the potential reservoir here. During the past two decades these sands have emerged to be a significant hydrocarbon producer from the middle and Lower Indus basin in southern pakistan.

In this study we have utilized seismic and well log interpretation to investigate the reservoir characteristics of Sawan. This includes horizon and fault marking which is marked after a successful cross correlation of synthetic and seismic traces at well location. The marked horizons are Lower Goru and Ranikot formation. The construction of fault polygons, time and depth contour maps of marked horizons were prepared to see the time and depth variations of these reflectors in the study area. The purpose of these contour maps was to understand the spatial geometry of the structure and the nature of geological structure as identified by the seismic study of the area. The general trend of the structure is northwest and south east which indicates that the area lies in extensional regime clearly shown by horst and graben structures which provides the basic component of a profile petroleum play in the area. The petrophysical properties which have been determined include shale volume 38%, total porosity 15%, saturation of water 60% and hydrocarbon saturation 40% was performed to evaluate reservoir properties for the prospect zone. Colored inversion also validates the hydrocarbon potential in reservoir rocks. On the basis of all these delineated petrophysical parameters it has been determined that Sawan field has great potential to produce commercially viable natural gas.

# Contents

# Chapter 01

## INTRODUCTION

Geophysics can be considered as the primary and the most important branch for investigation of the subsurface as it gives us a clue what lying underground and how is its structural and stratigraphy component. There is a broad division of geophysical surveying methods into those that make use of natural fields of the Earth and those that require the input into the ground of artificially generated energy. Generally, natural field methods can provide information on earth properties to significantly greater depths and are logistically simpler to carry out than artificial source methods. The latter, can produce a more detailed and better resolved picture of the subsurface geology (Salama et al., 2019)

The science of geophysics applies the principles of physics to the study of Earth. Geophysical investigations of the interior of the Earth involve taking measurements at or near the Earth's surface that are molded by the internal distribution of physical properties. Analysis of these measurements can give an idea about how the physical properties of the Earth's interior vary vertically and horizontally. Geophysical inspection is used for exploration of hydrocarbons, for metalliferous minerals and environmental applications. Seismic techniques are the most widely used because of its economical application in the exploration of hydrocarbons. Seismic methods are particularly well suited to the investigation of the layered sequences in sedimentary basins that are the primary targets for oil or gas (Kearey et al., 2002)

Pakistan has a high potential of hydrocarbons in its northern (Potwar, Kohat) and southern (Badin, Mari, etc.) parts. The Indus basin, including the Kohat-Potwar depression, accounts for 48% of the world's known petroleum resources. (Hasany and Saleem, 2012).

The objective of this study is using seismic inversion for predicting physical properties of the earth. Seismic inversion is an interpretation technique used to extract physical properties of rocks and fluids from seismic data (Krebs et al., 2009).

### 1.1 The Study Area

The study area (Sawan) is part of the Lower Indus Basin, the main hydrocarbon-producing basin in Pakistan. Sawan Gas Field is situated at latitude 26.98, 27.30 N and longitude 68.54, 68.58 E in lower Indus Basin, Khairpur, Pakistan. The major reservoir rocks are the Cretaceous sandstones (Albian– Cenomanian) of the Lower Goru Member of the Lower Goru Formation. Sawan gas field is one of the major gas producing areas with Lower Goru Formation acting as the potential reservoir here. These sands have been emerged to be a considerable hydrocarbon producer from the Middle and Lower Indus basin in southern pakistan during the past two decades.

This area has thick mesozoic-tertiary sedimentary sequences overlain by quaternary sediments. The area was tectonically stable until the Jurassic and probably early cretaceous, but rifting started to occur during Late Cretaceous and Early Palaeocene, the effects of which can be seen on seismic sections, where the post eocene strata are very less deformed. This area has a NW- trending normal faulting. .There is extensive range of lithological heterogeneity in these rocks, mainly attributed to change in sediment supply and environmental conditions

(Kadri, 1995).

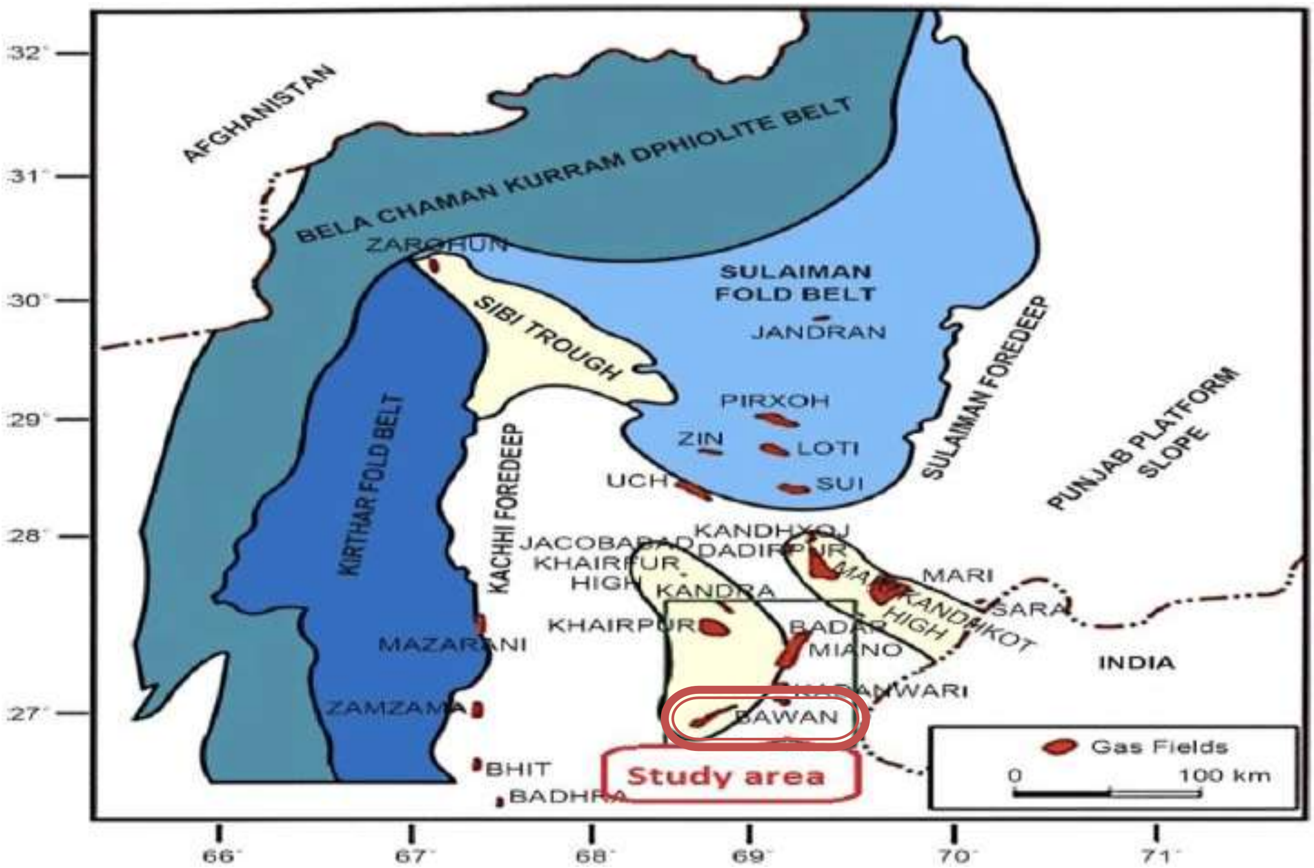


Figure1.1 Regional tectonic map and geological boundaries of the study area (Ahmed et al., 2013)

The Sawan gas field owns total proven reserves of 2–2.5 TCF gas. A total 15 wells have been drilled in Sawan gas field and 14 are providing 270MMSCFD gas to Sui Northern Gas Pipelines and 40MMSCFD to Sui Southern Gas Company.

## 1.2 Data Used

The following data is used for this study;

- Seismic data (SEG-Y lines)
- Navigation data
- LAS file of well
- Sawan-08 well with formation tops
- Velocity data for seismic lines

### 1.2.1 Seismic lines data:

| S. No | Line Number | Nature/ Trend |
|---|---|---|
| **1** | SPSM96-114 | strike |
| **2** | SPSM96-115 | Dip |
| **3** | GPSM98-201 | Dip |
| **4** | SPSM96-129 | Dip |
| **5** | SPSM96-131 | Dip |
| **6** | SPSM96-133 | Dip |
| **7** | SPSM96-135 | Dip |
| **8** | GPSM98-215 | Dip |
| **9** | SPSM98-209 | Dip |
| **10** | SPSM99-302 | Dip |

Table 1.1 Seismic lines data utilized in this study

### 1.2.2Well data:

| Well Name | Latitude | Longitude | Total Depth(m) |
|---|---|---|---|
| Sawan-08 | 26.5957420 | 68.5523940 | 3449.8207 |

Table 1.2 The well data utilized in this study for seismic to well tie and petrophysical analysis

## 1.3 Data Presentation

Seismic lines are in a SEG-Y format which is further used for subsurface structural analysis in the Kingdom Software.

Navigation file (DAT file) is in text format used to attach the navigation to load the seismic lines.

Information about the well location was available in the header of the LAS file of seismic data. Information in the LAS file contains the header that gives basic information about the well and the different types of log values are present below the header.

## 1.4 Base Map

A base map is the graphic representation at a specified scale of selected fundamental map information; used as a framework upon which additional data of a specialized nature may be compiled. It also shows the spatial relationship of all seismic sections under consideration, their tie point locations and provides the framework for contouring.

Using Kingdom software, the navigation data of selected seismic lines and wells in the sawan, taken from Directorate General of Petroleum Concessions (DGPC), are used to design the base map.

## 1.5 Research Objective

- Seismic Interpretation to identify the traps favorable for hydrocarbon accumulation.
- Petrophysical analysis to obtain the important reservoir characterization.
- Seismic colored inversion to investigate the variation of relative acoustic impedance at reservoir level.

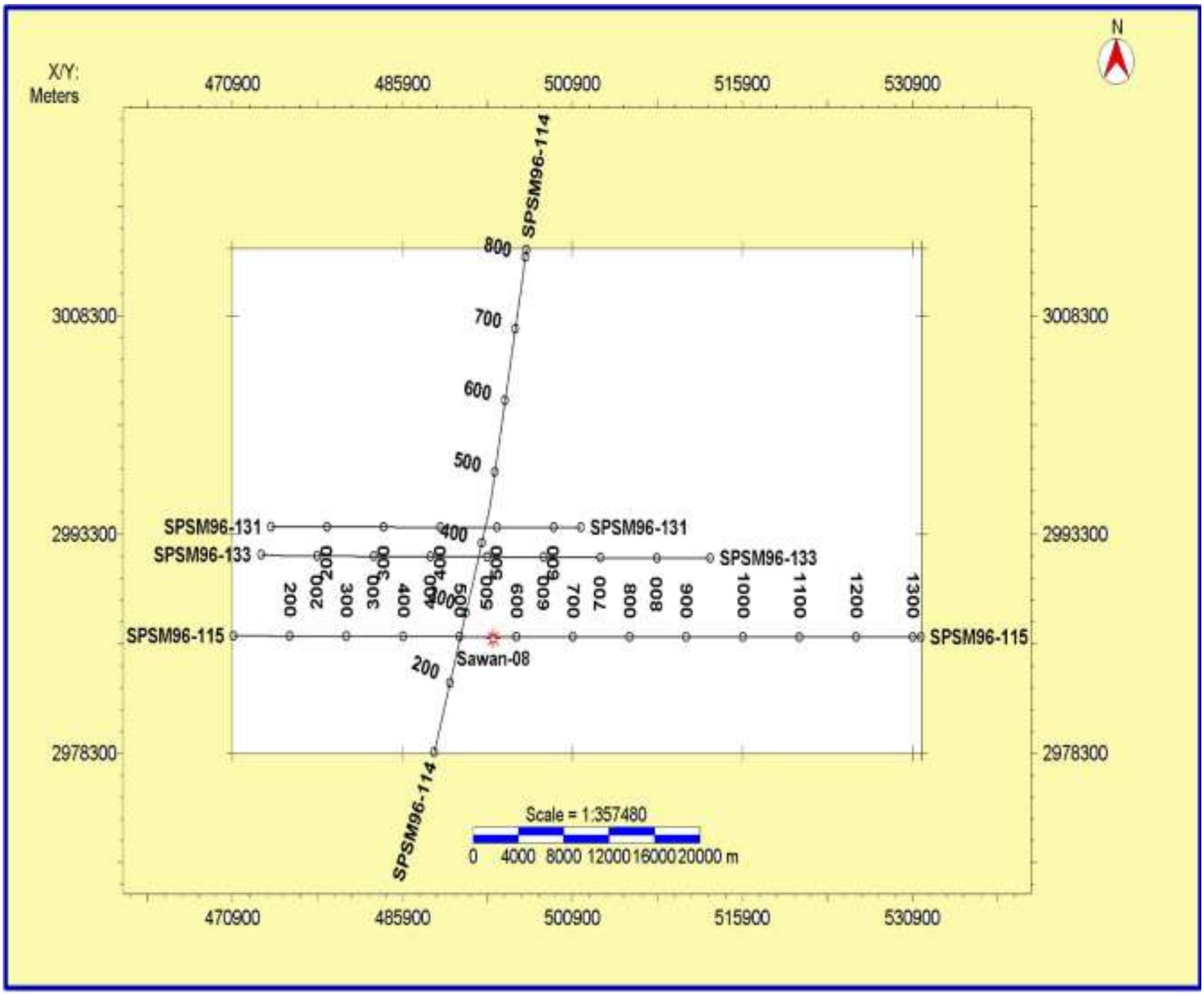



**Figure 1.2 Base Map of the study area.**

## 1.6 Methodology

The general methodology used is as follows,

### 1.6.1 Seismic Interpretation

- Picking Horizons and marking faults
- Time to depth conversion by using empirical relationships
- Creation of Time and depth contour maps
- 1D,2D seismic modelling

### 1.6.2 Petro physical analysis

- Potential Zone Marking
- Volume of shale calculation
- Porosity calculation
- Water Saturation calculation

# Chapter 2

## GEOLOGY OF THE STUDY AREA

Geology plays an important role for the interpretation of seismic data as it gives an idea about how the area is important for doing seismic interpretation

### 2.1 Geology of Sawan Area

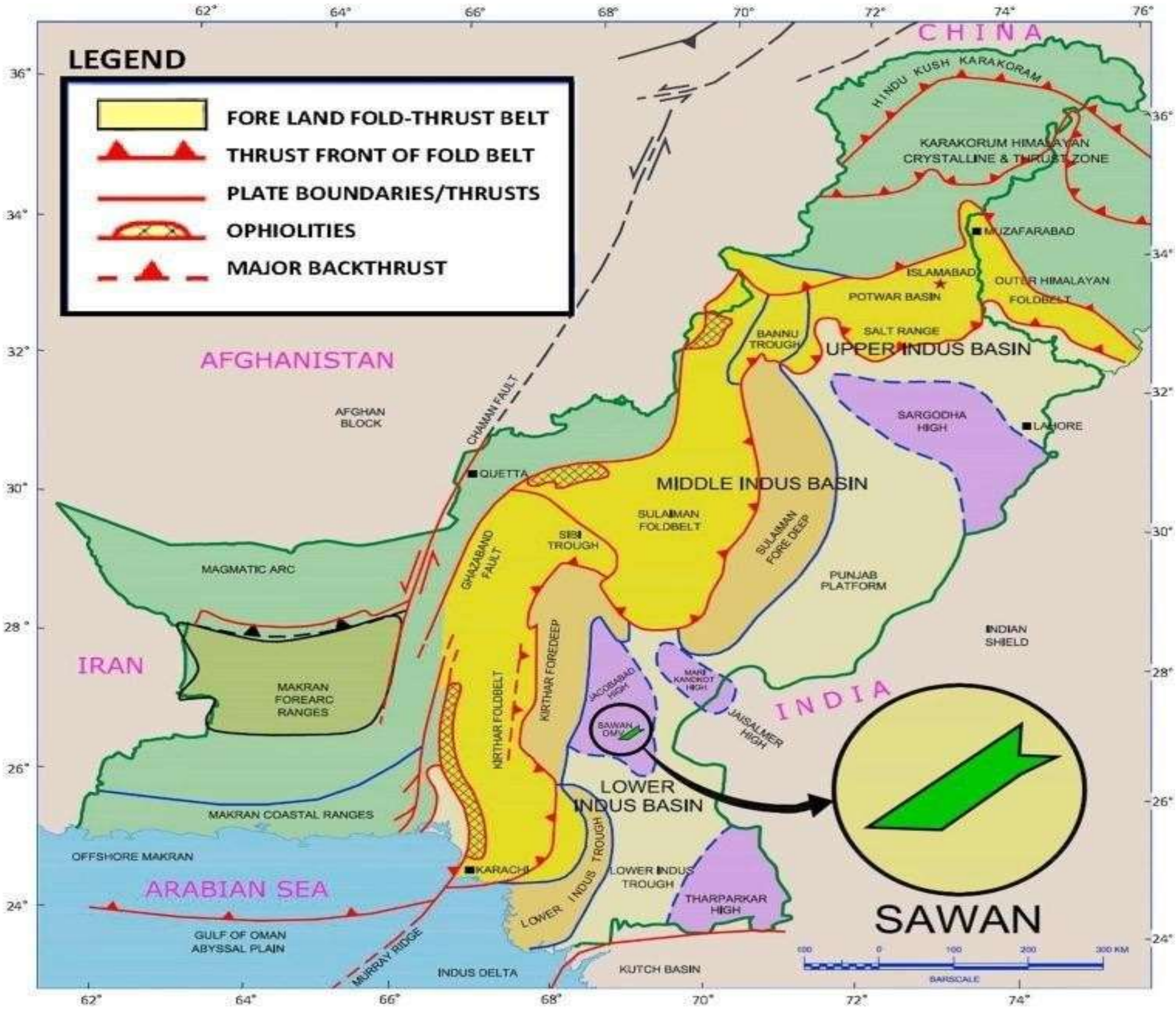



Figure 2.1: Geological map of Pakistan showing the study area (Anwar et al.,2017)

The Sawan gas field lies in the Middle Indus basin, in the eastern border of Pakistan. The study area is bounded by the Sargodha High to the north and by the Jacobabad and Mari-Kandkot Highs to the south (Figure2.1). The Indian Shield bounds the eastern side of the study area, whereas the Kirthar suleiman fold and thrust belt mark its western boundary (Figure 2.1)

Regional geological data indicate that the structural evolution of the Sawan gas field was closely controlled by three post-rift tectonic events:

- Late Cretaceous uplift and erosion
- NW–trending thick skinned wrench faulting
- Late Tertiary to present-day tectonic uplift of the jacobabad and khairpur highs .

These latter structural highs played an important role in the formation of structural and stratigraphic traps, not only in the sawan area, but also in multiple oil and gas fields in the middle Indus basin.

## 2.2 Geological Framework of Lower Indus Basin

The lower indus platform basin is bounded to the north by the central indus basin, to the northwest by the sulaiman foldbelt basin and the kirthar fold belt basin in the south west. The lower indus platform basin is bounded to the north by the central indus basin, to the northwest by the sulaiman foldbelt basin and the kirthar fold belt basin in the south west. The main tectonic events which have controlled the structures and sedimentology of the lower indus basin are rifting of the indian plate from gondwanaland (Jurassic or Early Cretaceous) which probably created NE-SW to N-S rift systems, isostatic uplift or ridge-push at the margins of the newly developed ocean probably caused uplift and eastwards tilting at the start of the cretaceous. The separation of the Madagascar and Indian plates in the Mid to Late Cretaceous which may have caused some sinistral strike-slip faulting in the region, hotspot activity and thermal doming at the boundary. This in turn caused uplift, erosion, extrusion of the deccan flood basalts and probably the NNW-striking normal faults.

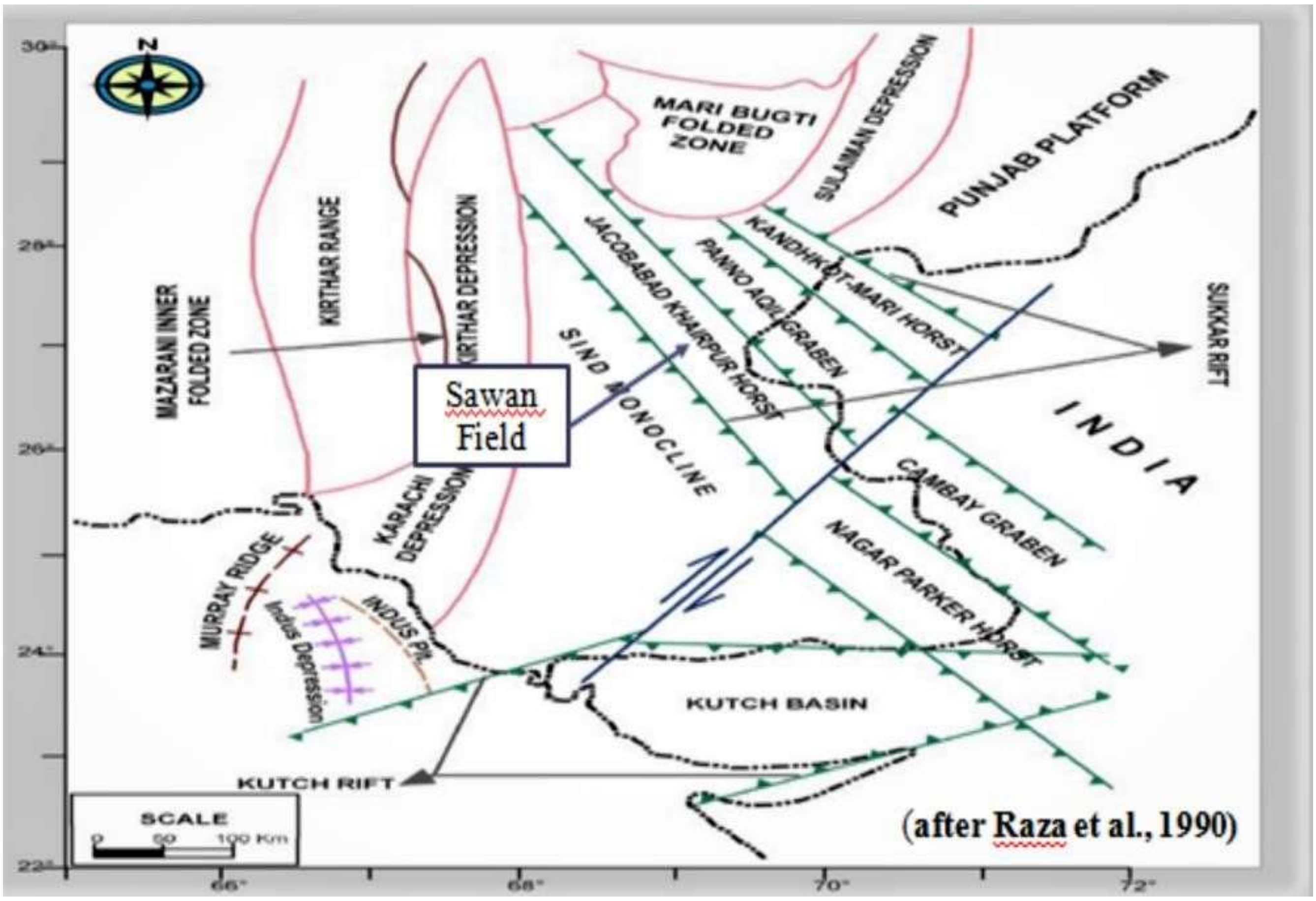


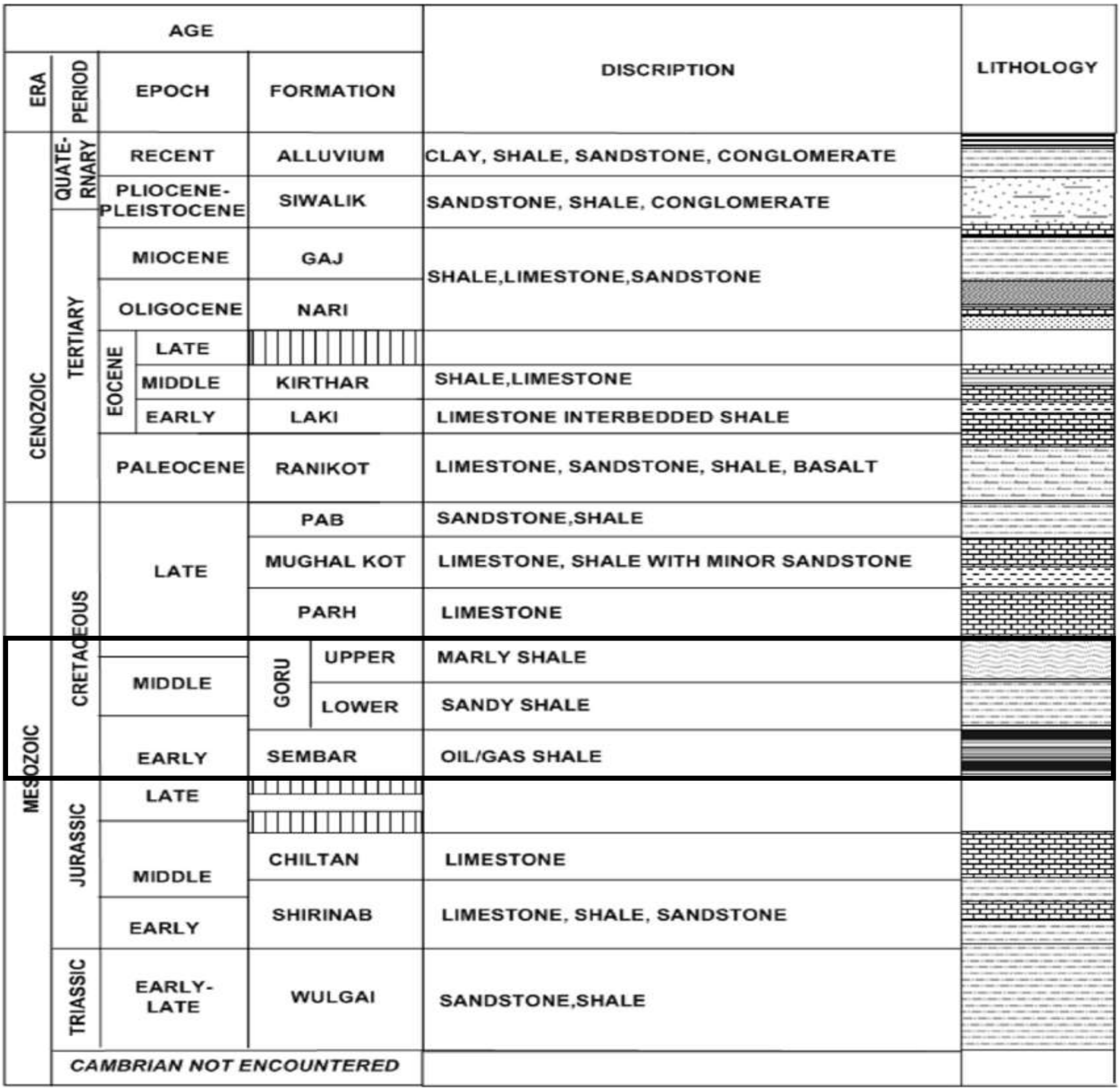

Figure 2.2 Divisions of lower Indus basin (after Raza et al.,1990)

## 2.3 Geological Configuration of Area

Sawan field is situated in the lower indus basin between 240 -280 north latitude and 660 east to eastern territory of pakistan. The study area lies tectonically in an extensional regime. Lower goru formation and sembar formation act as a reservoir and source respectively. The geologic signatures were dominantly spotted by paleocene indian-eurasian collision and additionally by translation between indian plate and afghan craton in north-west and convergence between the arabian plate and afghan craton. The effects of west rift margin induced several subsurface expressions among which normal faults and horst and grabens are the evidence of subsurface expressions and sibbi-jackobabad, khairpur-mari kandkot high are the manifestation of surface expressions

## 2.3 Stratigraphy of Lower Indus Basin

The stratigraphic succession changes from east to west. precambrian basement is exposed in the southeastern corner of the basin. The thickness of the sediments increases westward. Important unconformities occur at base permian and base tertiary. In the eastern part of the basin, Tertiary has direct contact with the Jurassic sequence.



| ERA | PERIOD | EPOCH | FORMATION | DISCRIPTION |
|---|---|---|---|---|
| CENOZOIC | QUATE-RNARY | RECENT | ALLUVIUM | CLAY, SHALE, SANDSTONE, CONGLOMERATE |
| | | PLIOCENE-PLEISTOCENE | SIWALIK | SANDSTONE, SHALE, CONGLOMERATE |
| | TERTIARY | MIOCENE | GAJ | SHALE,LIMESTONE,SANDSTONE |
| | | OLIGOCENE | NARI | |
| | | EOCENE LATE | | |
| | | EOCENE MIDDLE | KIRTHAR | SHALE,LIMESTONE |
| | | EOCENE EARLY | LAKI | LIMESTONE INTERBEDDED SHALE |
| | | PALEOCENE | RANIKOT | LIMESTONE, SANDSTONE, SHALE, BASALT |
| MESOZOIC | CRETACEOUS | LATE | PAB | SANDSTONE,SHALE |
| | | | MUGHAL KOT | LIMESTONE, SHALE WITH MINOR SANDSTONE |
| | | | PARH | LIMESTONE |
| | | MIDDLE | GORU UPPER | MARLY SHALE |
| | | | GORU LOWER | SANDY SHALE |
| | | EARLY | SEMBAR | OIL/GAS SHALE |
| | JURASSIC | LATE | | |
| | | MIDDLE | CHILTAN | LIMESTONE |
| | | EARLY | SHIRINAB | LIMESTONE, SHALE, SANDSTONE |
| | TRIASSIC | EARLY-LATE | WULGAI | SANDSTONE,SHALE |
| | CAMBRIAN NOT ENCOUNTERED | | | |

Figure 2.3 Stratigraphic Column of lower Indus basin (Zaidi et al.,2012).

## 2.4 Petroleum Play of Area

### 2.5.1. Source Rocks

The Lower Cretaceous shale of Sembar Formation is proven source for oil and gas discovered in the area because of its organic richness and thermal maturity. The organic matter in the Sembar formation is mainly type-iii kerogen, capable of generating gas. Shales of Sembar and lower goru formations have been established as main source rocks lower and middle Indus Basin (Raza et al, 1989 & 1990). Carbonates and shales of deeper horizon may also act as source.

### 2.5.2 Reservoir Rocks

Reservoirs rocks of the lower indus basin include carbonates of eocene and lower goru sands of cretaceous age. The principal reservoirs are deltaic and shallow-marine sandstones in the lower part of the Lower Goru Formation in the area (Ahmad et al, 2002) , informally divided into A, B, C and D intervals in figure 2.4. Out of which the top part of the C-interval is reservoir in Sawan field. petrographically A and B intervals are typically quartz arenites while C unit is the altered volcanic rock fragments and pore lining iron chlorite cement, leading to lithic arenites. B and C unit contributes to the main reservoir portion. The recent major discoveries are from Lower Goru Sands.

### 2.5.3. Cap Rocks

The known seals in the system are of shales, which are interbedded with sands and overlying the reservoirs. In producing fields, thin shale beds of variable thickness are found to be effective seals. The other additional seals that may be effective include impermeable seals above truncation traps, faults, and updip facies changes. The Upper Goru shale and interbedded shales of Sui Main Limestone are acting as a seal in study area. Shale of Lower Goru Formation also has the same properties.

### 2.5.4 Trapping Mechanism

The traps formed in study area are both structural and stratigraphic. These provide the significant trapping system along tilted fault blocks and negative flower structures. The variety of structural traps includes anticlines, thrust-faulted anticlines, faulted gentle role-overs and tilted fault blocks. Such combination of source, reservoir, seal and traping mechanism made Lower Indus Basin the more potential basin in the context of petroleum accumulation.

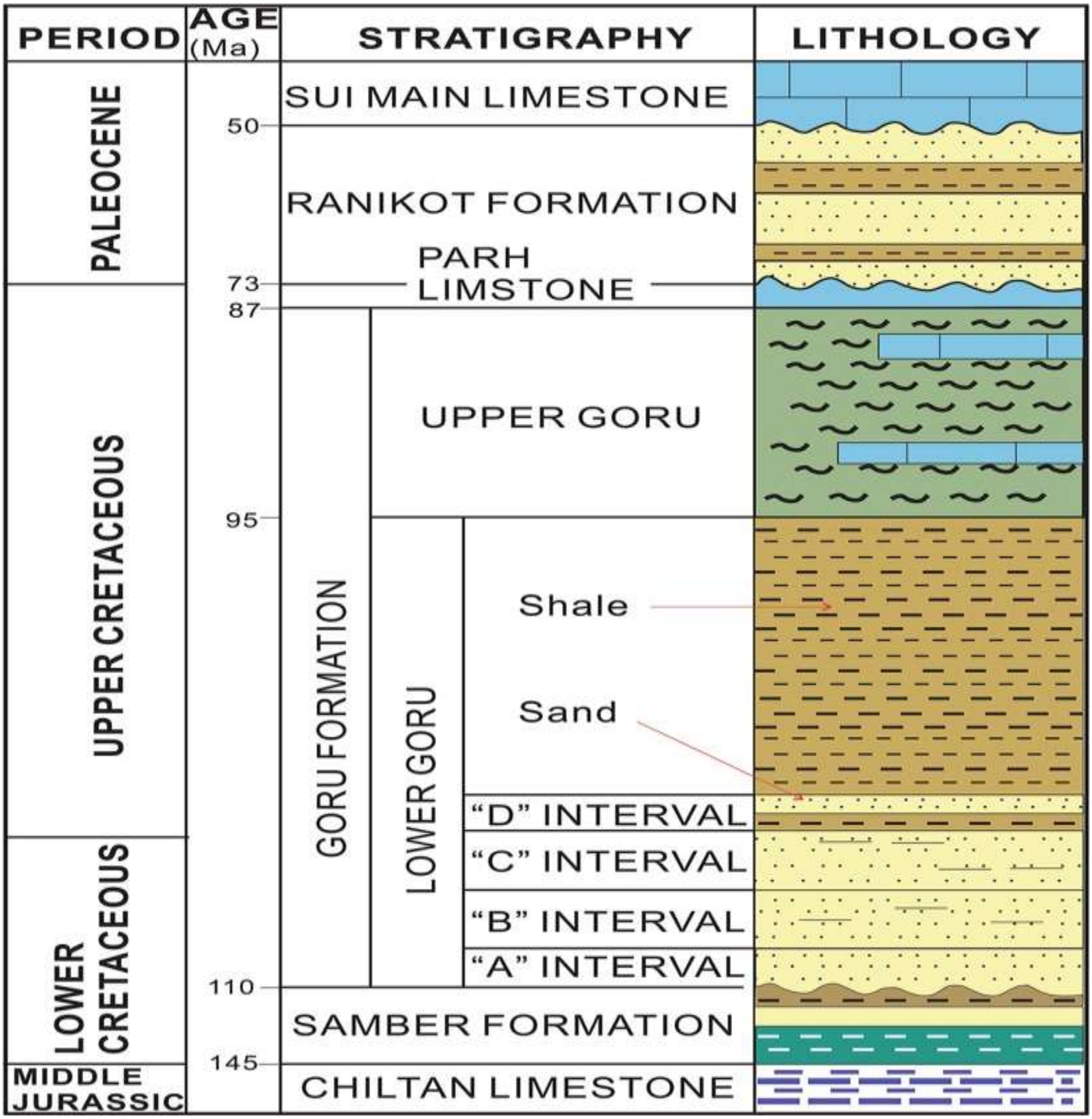



Figure 2.4: Stratigraphic column representing the shale and sand intervals (A, B, C and D sand intervals) of Lower Goru formation (modified after Krois et al.,1998)

# CHAPTER 3

## SEISMIC INTERPRETATION

### 3.1. Introduction

Seismic interpretation, whether for hydrocarbon exploration or geotechnical studies, is the determination of the geological significance of seismic data. it is rare that the correctness (or incorrectness) of an interpretation can be ascertained, because the actual geology is rarely known in enough detail. Instead, the test of a good interpretation is consistency with all the available data. in oil and gas exploration, emphasis is placed on finding an interpretation that is most favorable for hydrocarbon accumulation. As with many scientific investigations, interpretations are almost always non-unique.

### 3.2 Seismic Interpretation

Seismic interpretation is the transformation of seismic reflection data into a structural picture by the application of correlation of seismic reflectors with geological boundaries and their time-depth conversion. An interpreter of seismic data may have a good hold in both geology and geophysics. it is the ingenuity and in-depth understanding of an interpreter to extract geologic significance from the aggregate of many minor observations. for example, down dip thinning of the reflection might result from standard increase velocity with depth or thinning of the sediments or flow of the shale or salt may develop illusory structure in the deeper horizon (Sheriff, 1999).main approaches for the interpretation of the seismic section are

- Structural analysis
- Stratigraphic analysis

#### 3.2.1 Structural Analysis

The structural interpretation will lead to search some important structural traps and then will give a way to find hydrocarbon bearing zones. Structural interpretation is the study of reflector geometry on the basis of reflection times. Most structural interpretation use two-way reflection time rather depth and time. Structural maps are constructed to display the geometry of selected reflection events. Tectonic setting usually governs which types of the structure are present and how the structural features are correlated with each other, so tectonics of the area is helpful in determining the architectural style of the area and to locate the traps.

### 3.2.2 Stratigraphic Analysis

Stratigraphic analysis greatly enhances the chances of successfully locating hydrocarbon traps in sedimentary basin environment. The stratigraphic interpretation is the analysis of reflection sequences as the seismic expression of lithological-distinct depositional sequences. stratigraphy analysis involves the demarcating of seismic sequences, which present the different depositional units, identifying the seismic facies characteristic with suggesting depositional environment and study the reflection characteristic variation locate the both stratigraphy change and hydrocarbon depositional environment. Hydrocarbon accumulation is indicated by the amplitude, velocity, frequency or the change in a wave shape. Variation of the amplitude with the offset is also an important hydrocarbon indicator. Unconformities are marked by drainage pattern that helps to develop the depositional environment. Reef, lenses, unconformity are an example of stratigraphy traps.

## 3.3 Interpretation

The interpretation is carried on the basis of available geological information of the area. Analysis started with horizons picking. Horizons are picked with the help of well tops and synthetic seismogram. Horizons picked are Ranikot Formation and Lower Goru. Interpretation workflow is given in figure 3.1

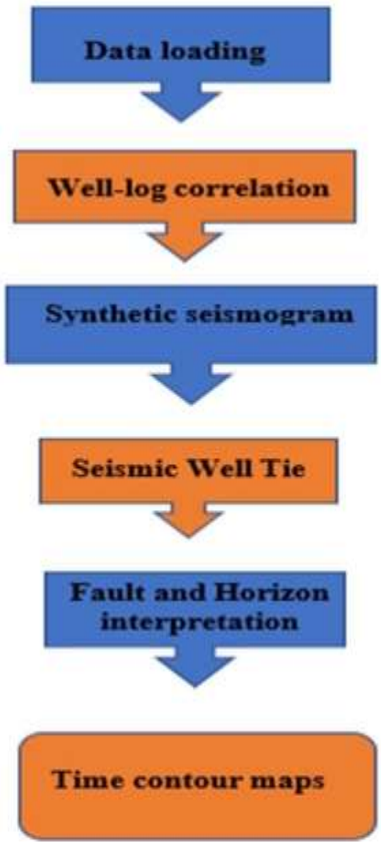



Figure 3.1 General Interpretation Workflow

## 3.4 Generation of Synthetic Seismogram

Synthetic seismogram is basically a 1-d modeling of acoustic energy that is travelling through the earth. To a first approximation, we can calculate the expected seismic response of the rock sequence encountered in the well by treating it as a one-dimensional problem. The synthetic seismogram is generated by convolving the reflectivity derived from digitized acoustic and density logs with the wavelet derived from seismic data. Synthetic seismograms for layered medium examine the effects of varying the model parameters in the form of the resulting seismograms. Synthetic seismic sections are compared with observed data, and models can be manipulated in order to simulate the observed data which leads to valuable insights into the subsurface geology responsible for a particular seismic section.

A synthetic seismogram $x(t)$ may be considered as the convolution of the assumed source wavelet $s(t)$ with a reflectivity function $r(t)$ representing the acoustic impedance contrasts in the layered model:

$$x(t) = s(t) * r(t) \tag{3.1}$$

For the generation of synthetic seismogram two way time for each well top is required. Two way time for each well top or reflector is calculated by using depth, sonic log data of well and replacement velocity of the area. By using two way time against each well top time depth chart is prepared and then finally synthetic seismogram is generated shown in figure 3.2. The purpose of generation of synthetic is to find two way travel time against each depth for marking of horizons.

The synthetic seismogram not only helps to recognize individual reflection but can also give significant guide to investigative reflection character. This synthetic seismogram is match with seismic section at a well point to correlate the reflectors and used to calibrate the seismic velocities. A density and sonic log of Sawam-08 has been used in figure 3.2 for generation of synthetic seismogram.

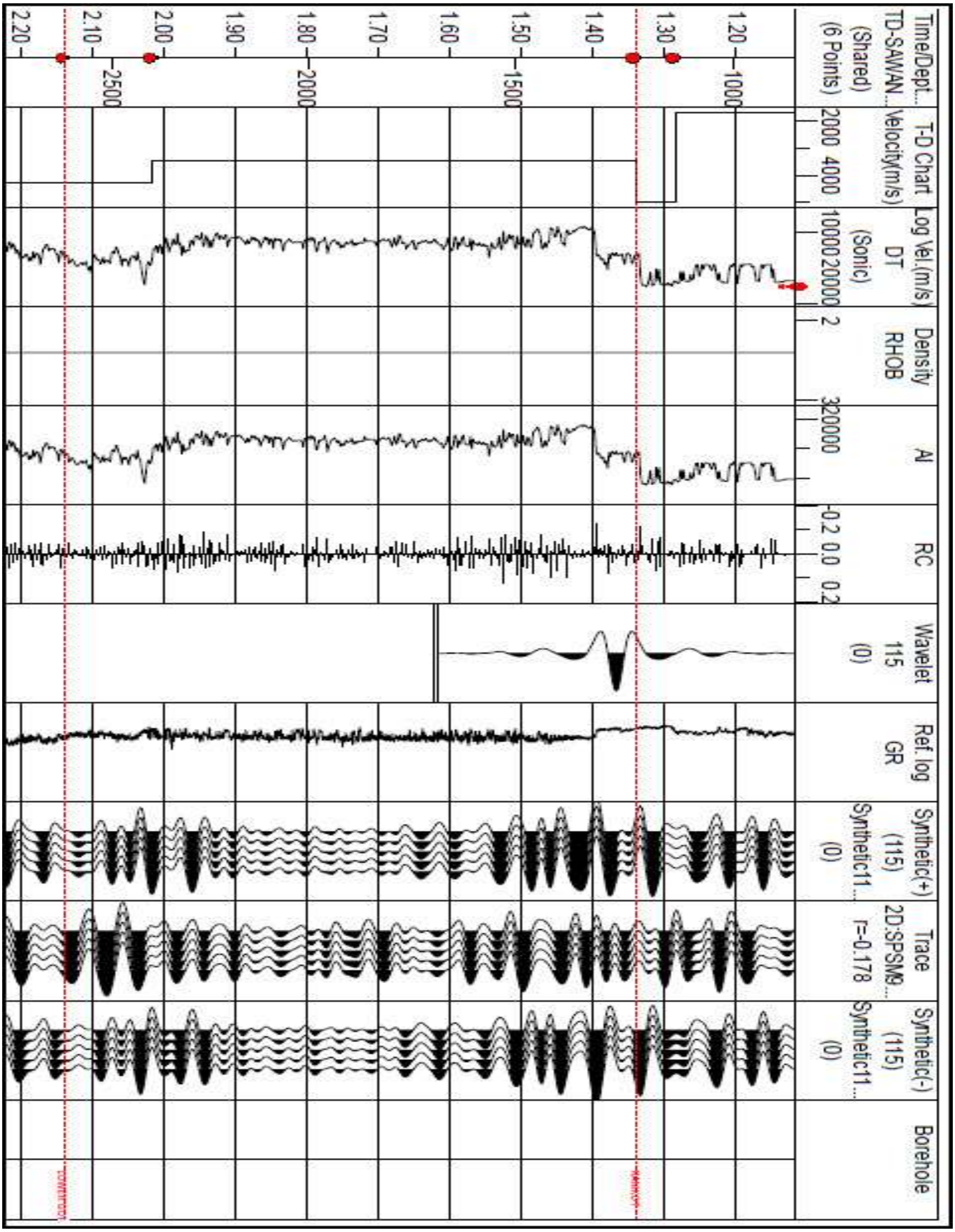



Figure 3.2 Synthetic seismogram used for the Interpretation of SPSM96-115 using Well Sawan-08

## 3.5 Seismic Section

The time section provides the position and configuration of reflectors in the time domain. two reflectors are marked on seismic line PSM96-114 (figure 3.3) by using Sawan-08, which is named based on stratigraphic column encountered in well sawan-08. Each reflector is characterized by different color

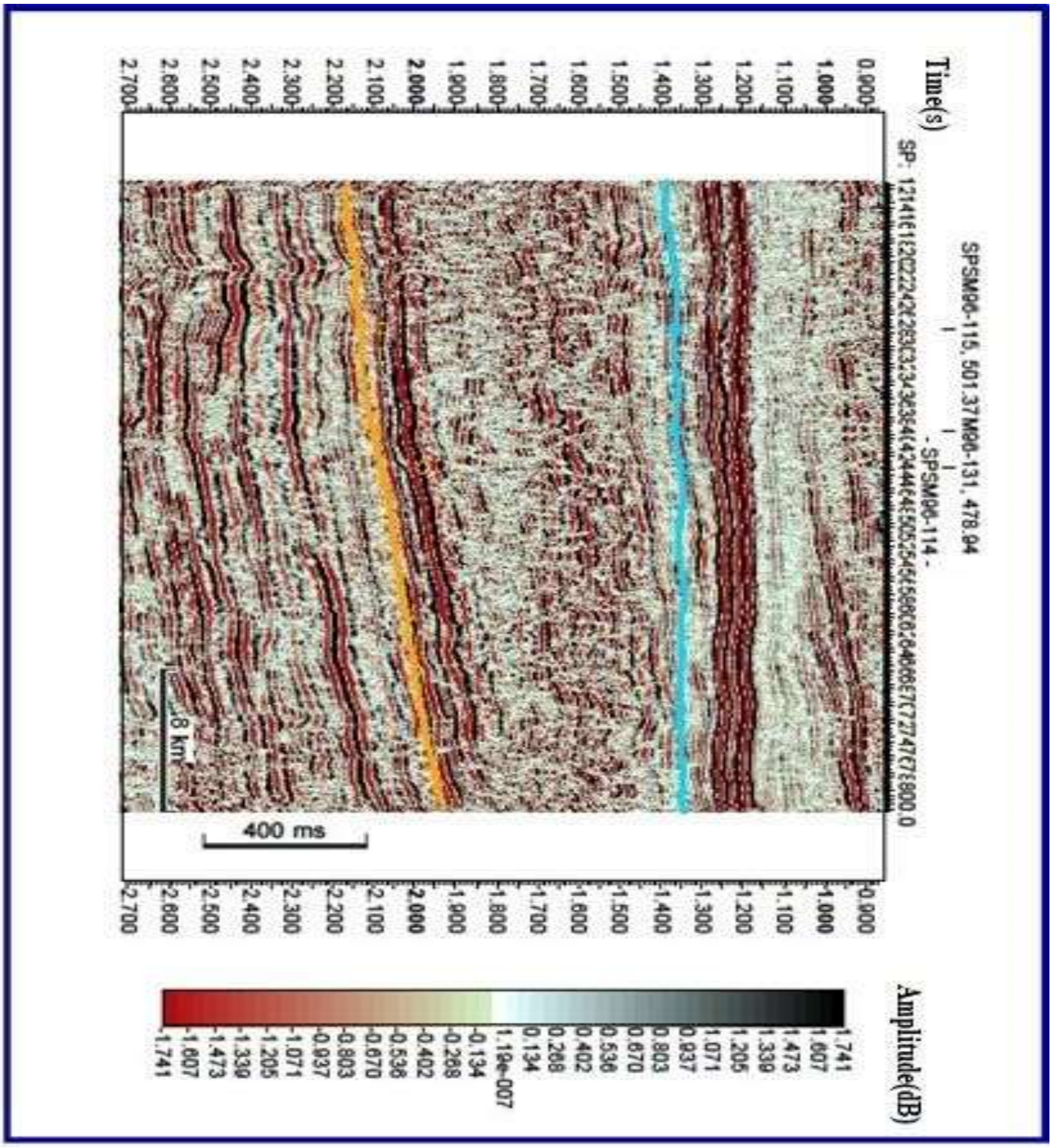


Figure 3.3: Interpreted seismic section of PSM96-114 (orange-Lower Goru, blue- Ranikot formation).

so that they can be readily distinguished. These horizons are then moved to the other lines.

After processing these lines misties are eliminated. Figure 3.3-3.6 shows the time section of PSM96-114, PSM96-115, PSM96-133, PSM96-1.

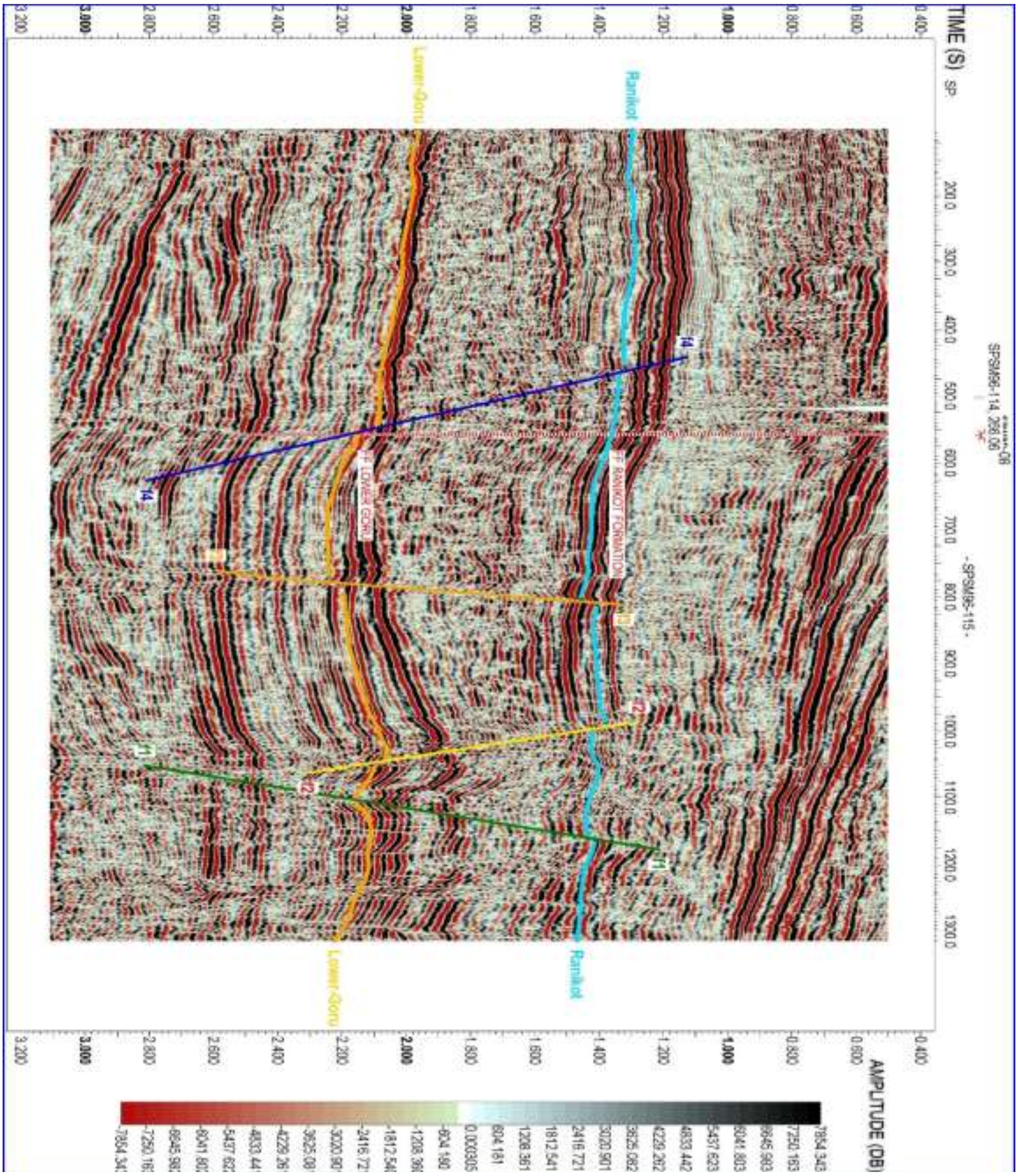



Figure 3.4 Interpreted seismic section of PSM96-115 (orange-Lower Goru, blue- Ranikot formation)

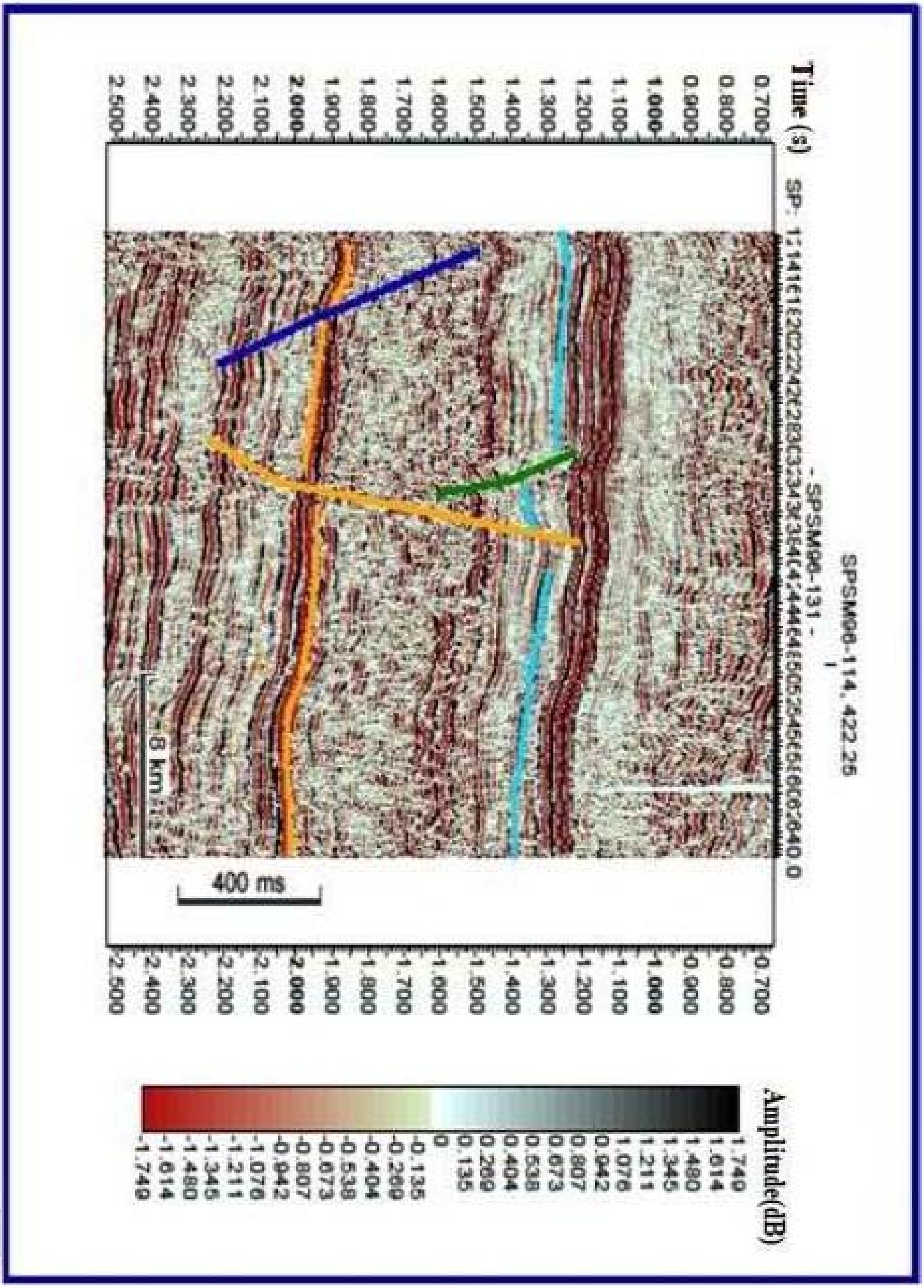



Figure 3.5 Interpreted seismic section of PSM96-131 (orange-Lower Goru, blue- Ranikot formation)

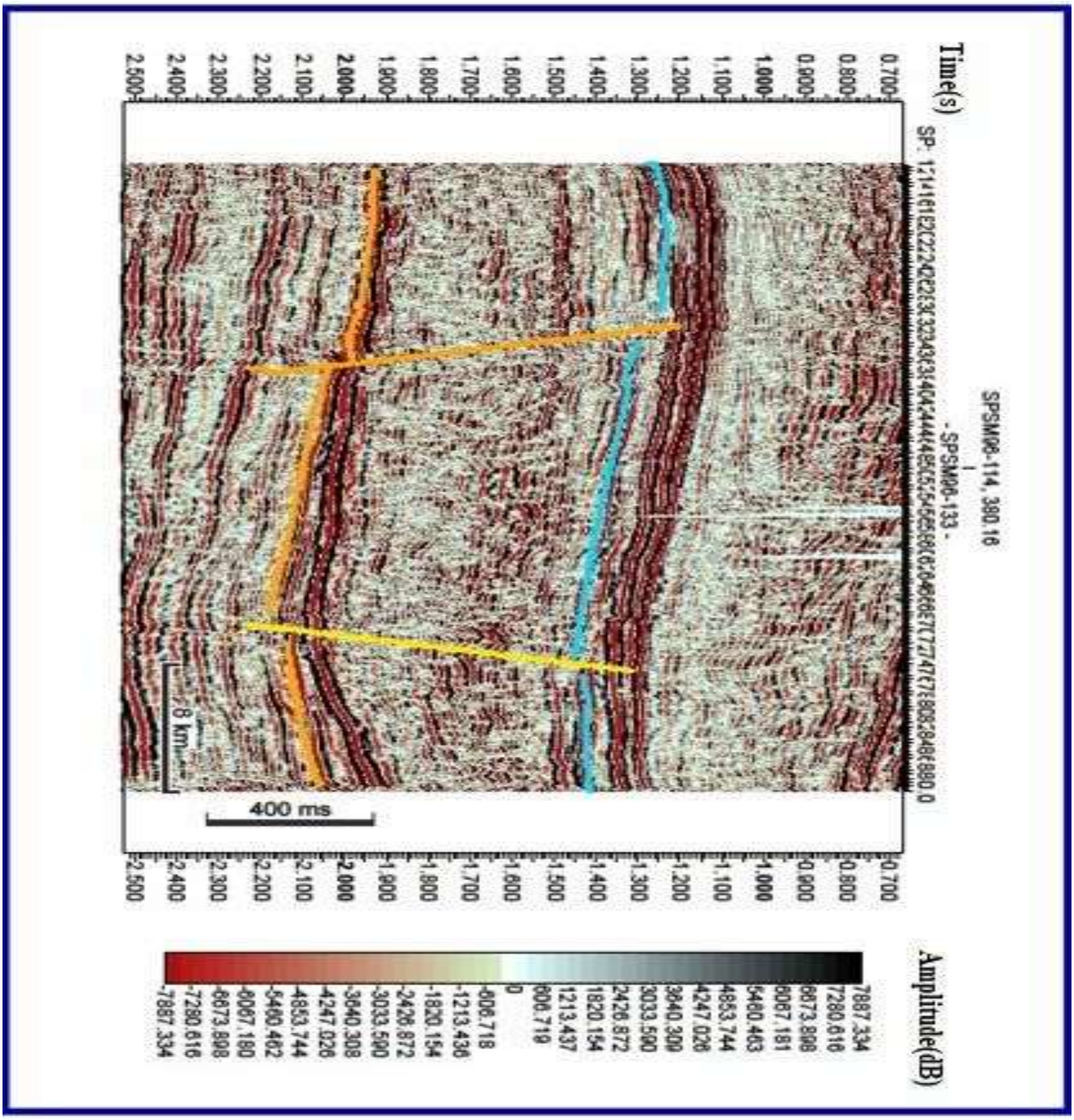


Figure 3.6 Interpreted seismic section of PSM96-133 (orange-Lower Goru, blue- Ranikot formation.

## 3.6 Time to Depth Conversion

As we know that the true subsurface structures are in depth domain, but the seismic time sections are in time domain, so we need to convert these seismic time sections into depth sections. For this we need to use seismic velocity data. For time to depth conversion, average velocities are used. The maps of two-way-time to various horizons and of the average velocities between the formations are used to generate a depth contour map (Paturet, 1971).

### 3.6.1 Seismic Depth Section

For field development and exploration only a good seismic image is not sufficient. We need subsurface picture in depth domain and well ties are also required.

Time migrated images can be converted into depth domain either by migrating the original data with a prestack depth migration algorithm, or by depth migration of post-stack data after time migration (Kim et al., 1997), or by direct mapping from time to depth. Each of these options utilizes the time migration velocity to a velocity model in depth. In the case of a laterally homogeneous medium, the conversion from time to depth is provided by the classic Dix method (Dix, 1955). By using the appropriate values of velocity and time, the depth of each interface can be easily calculated using following equation.

$$Depth = \boldsymbol{V_{av}} * \frac{\boldsymbol{T}}{\boldsymbol{2}} \qquad (3.2)$$

The time is divided by two because the time in time-velocity pairs is two-way time. Time to depth conversion is performed using Kingdom software.

## 3.7 Contour Maps

We display the results of our seismic interpretation in the form of map. Mapping is very important part of seismic interpretation. The ultimate product of seismic exploration is structural seismic map and worth of whole seismic operation depends on it. Lines of equal time or depth wandering around the map are called contours. Subsurface maps are generated in order to gain a deeper insight of results of interpretation. In the past, these maps used to be produced manually, but modern era provided us with more robust computer operators to do this job automatically, although the nomenclature remains unaltered. The final product of seismic exploration is the seismic structure map, the one on which the entire operation depends on its usefulness.

A reference datum is first selected to construct a subsurface map from seismic data which can be sea level or any other depth above or below sea level. Generally, another datum above sea level is chosen in order to image a shallow marker on the seismic cross-section, which may have a great impact on the interpretation of the zone of interest.

Contouring technique is used to symbolize the three-dimensional Earth on a two-dimensional surface. The contour spacing quantifies of the steepness of the slope; the closer the spacing the steeper the slope. A subsurface structural map exhibits relief on a subsurface horizon with contour lines that employ the information of equal depth below a reference datum or two-way time from the surface. These contour maps bring out the slope of the formation, structural relief of the formation, its dip and any faulting and folding encountered in the area.

### 3.7.1 Time Contour Maps

Time contour maps represent the time variation for a single horizon. The contours of time contour maps show in two-way time. The interpreted seismic data is contoured for producing seismic maps which provide a three-dimensional picture of the various layers within the area which is circumscribed by decussated shooting lines. The picked times for each reflector along with the navigation data are exported in the form of an XYZ file and are used for contouring. The kingdom software is used to bring forth all the contour maps

### 3.7.2 Depth Contour Maps

It is usually better to map in time rather than in depth, but in particular cases, in spite of all the problems, depth imaging is preferred. In the development stage of a field, depth maps are more valuable than time maps.

### 3.7.3 Time and Depth Contour Maps of Lower Goru Formation

Lower goru formation is the main interest for geophysicists and oil and gas experts for it has the potential to produce hydrocarbons due to its lithological features and minerals packing. Specifically, it consists of sandstones and is divided into three main categories i.e. A, B and C sands. Above it lies the upper goru formation which consists of shaly texture, while below it lies the sembar formation which serves as the main source rock for these sands. The contour interval in Time & Depth Contour maps of Lower Goru is set as 0.02 sec and 25 meters and of ranikot formation is 0.008 sec and 6.25 meters respectively

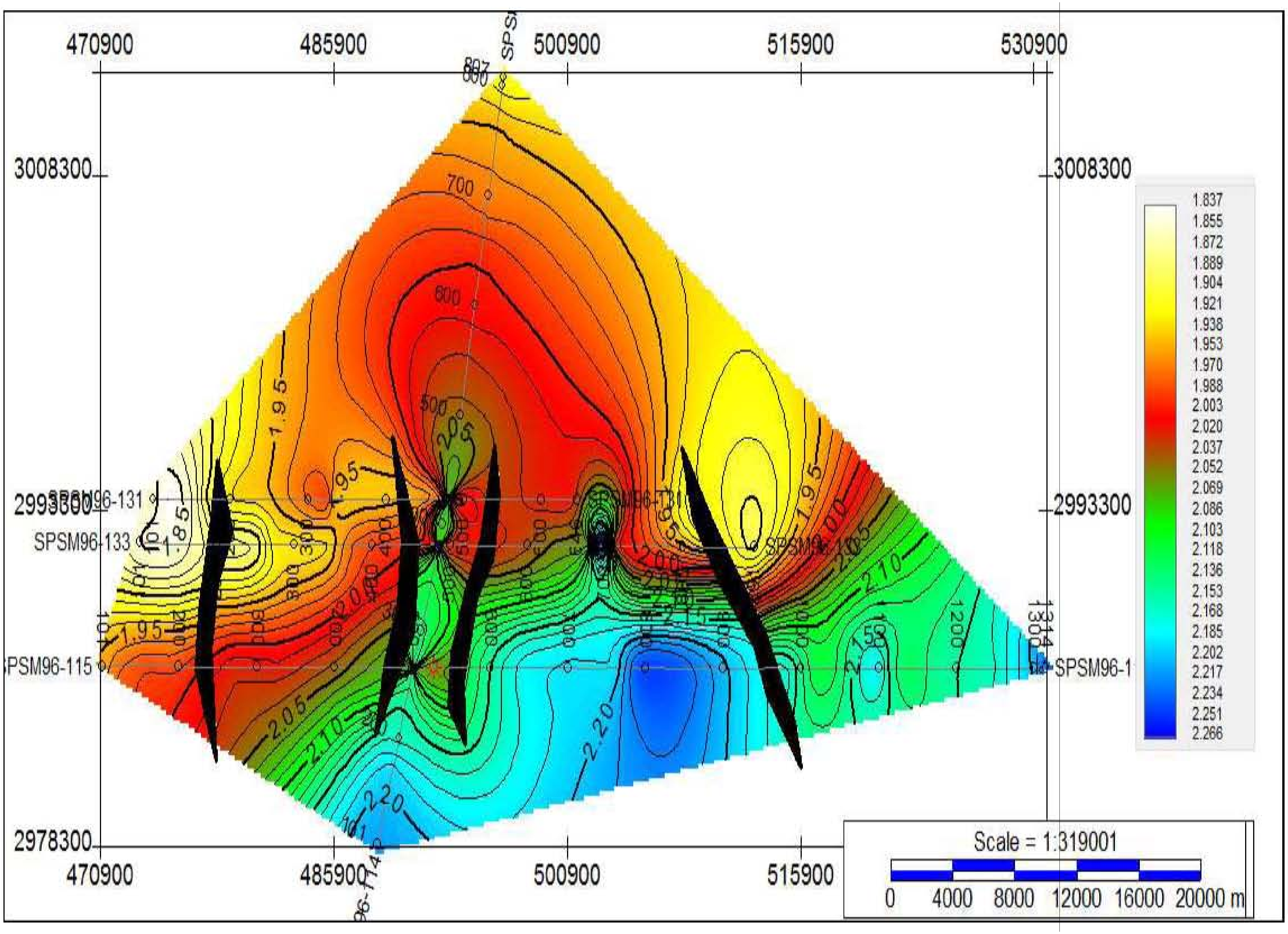



Figure 3.7 Lower Goru Time contour map

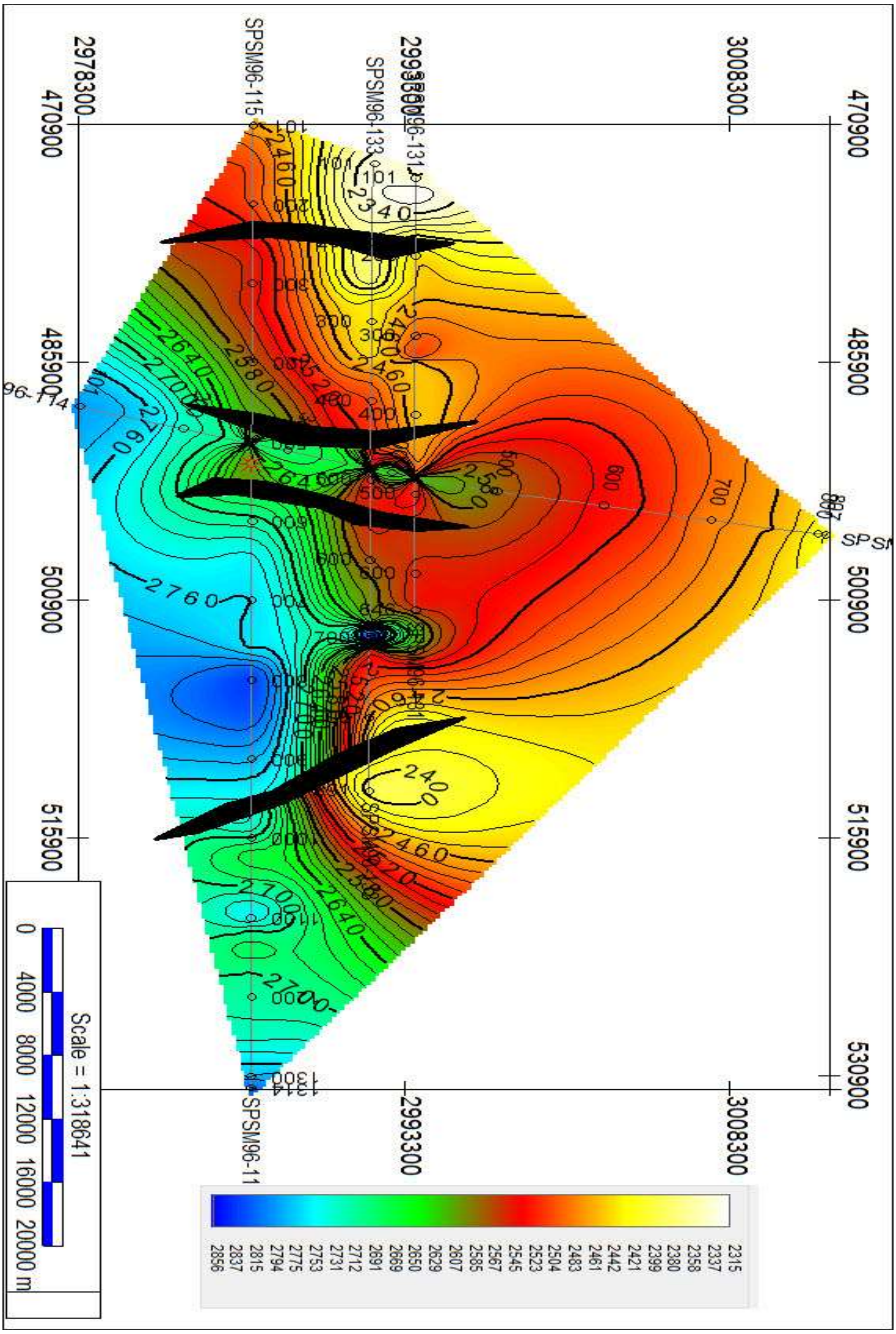



Figure 3.8 Lower Goru Depth contour map

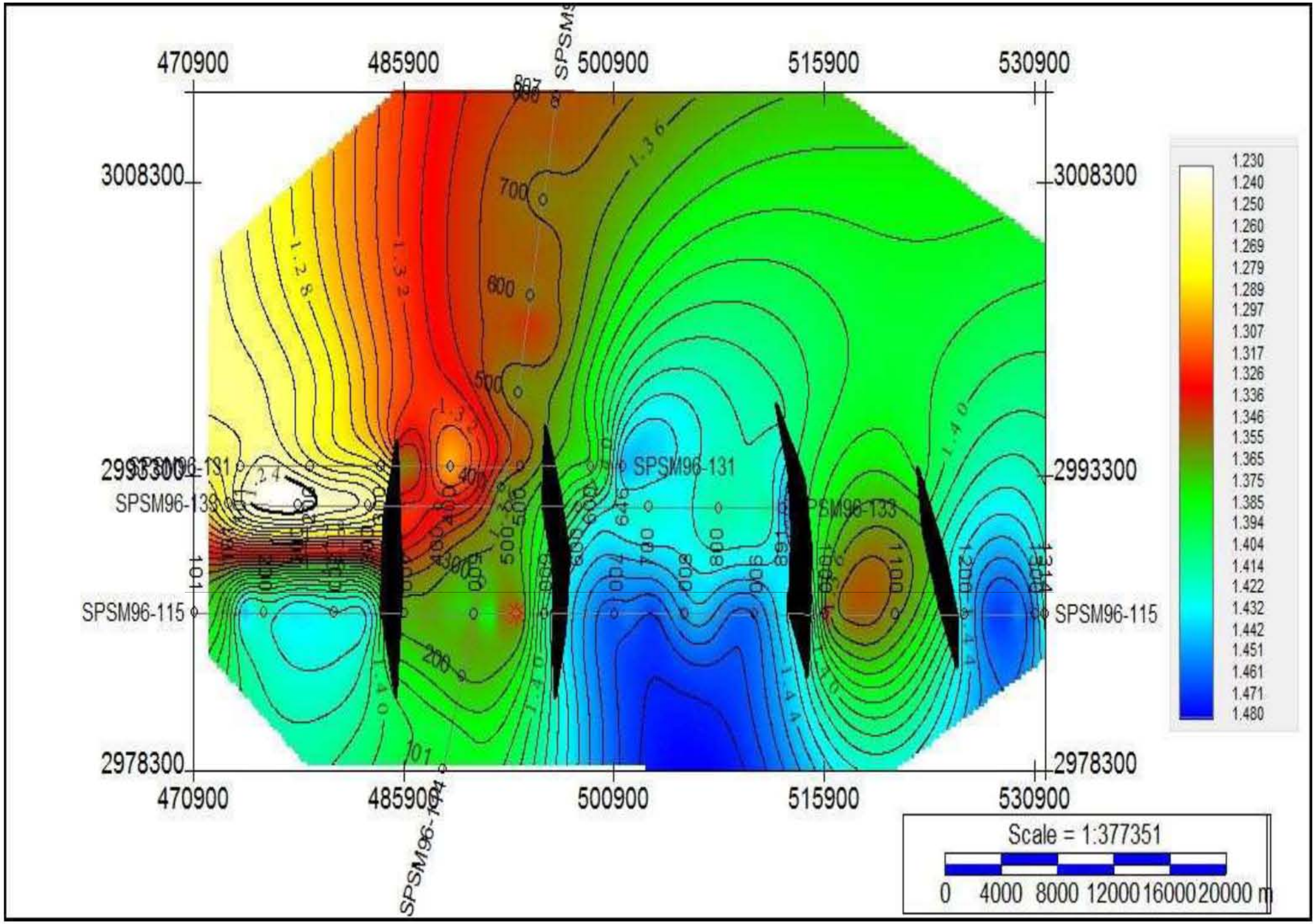



Figure 3.9 Ranikot formation Time contour map

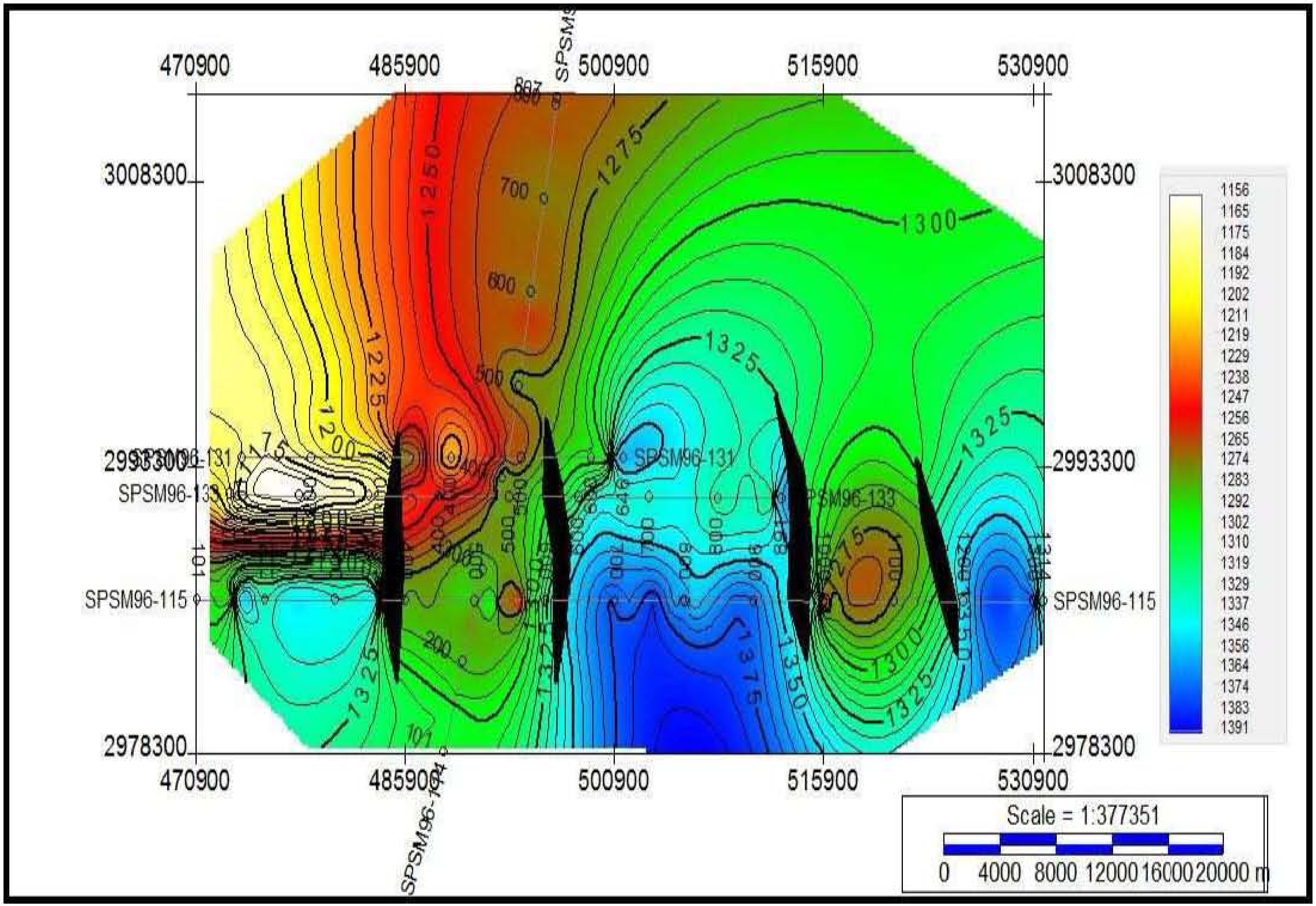



Figure 3.10 Ranikot formation Depth contour map

# Chapter no 4

## PETROPHYSICAL INTERPRETATION

### 4.1 Introduction

Petrophysics is the study of the physical and chemical properties that describe the occurrence and behaviour of rocks, soils and fluids. The major goal of petrophysical well log analysis is to transform well log measurements into reservoir properties like porosity, permeability, oil saturation, etc. Formation evaluation is generally carried out as the practice of determining the physical properties of rocks and the fluids that they contain. The objective of formation evaluation is to define, locate and help to produce a given reservoir and also quantitatively the thickness of the reservoir, effective porosity, water saturation and permeability.

The two primary parameters determined from well logs measurement are porosity, and the fraction of pore spaces filled with hydrocarbons. The parameters of log interpretation are determined either directly or indirectly and are measured by one of three general types of logs:

(1) electrical

(2) Nuclear

(3) Acoustic log

### 4.2 Objective

The main objective of petrophysical interpretation is to evaluate the reserves for Sawan area. To attain this goal, following procedure is followed,

- Interpretation of Well Sawan-08
- To calculate the petrophysical parameters using formulas and with the help of interpreted well log to evaluate a zone
- To confirm the hydrocarbon zone with Sand-Shale analysis

### 4.3 Petrophysical Analysis of study area

The petrophysical analysis is carried out for Sawan-08 well.

#### 4.3.1 Log Interpretation Workflow

Log interpretation workflow in figure 4.1

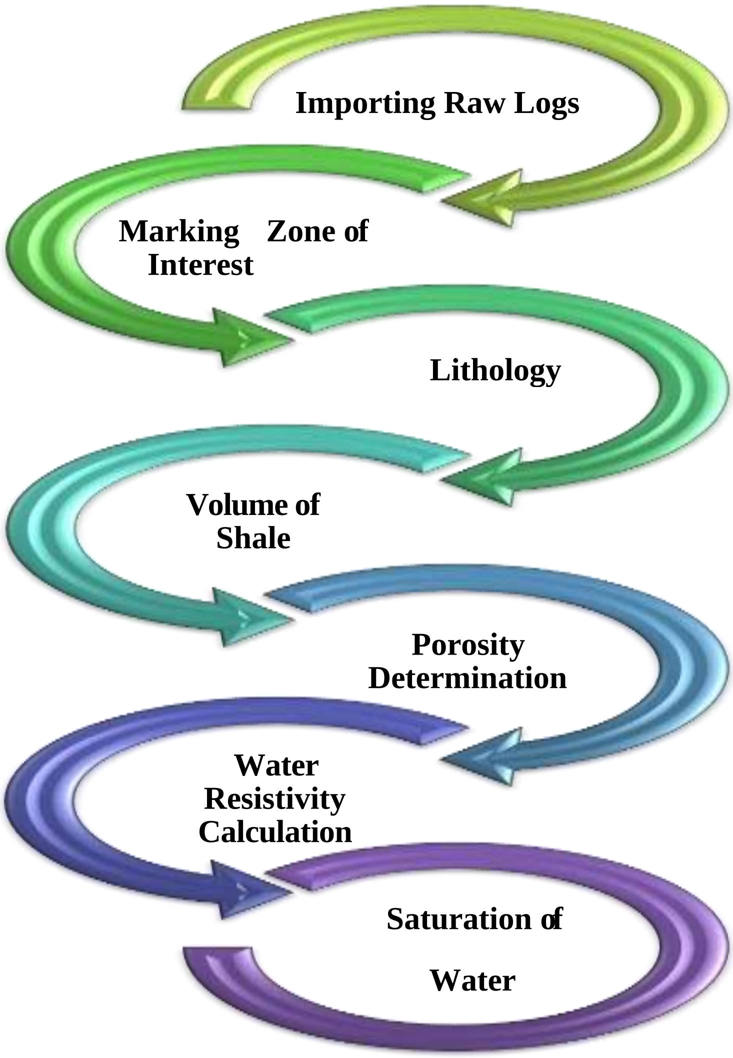



Figure 4.1 General workflow adopted for the petrophysical study

### 4.3.2 Petrophysical Parameters

The following parameters are found during petrophysical interpretation.

- Shale volume
- Porosity and Permeability
- Lithology Estimation
- Water saturation
- Hydrocarbon

The interpretation of gamma ray logs shows clearly that the intervals are dominated by sand and shale sequences, the shale occurring more frequently at the top of the log whereas the sand occurs more frequently as the logging deepens. This is based on integrated use of well-log signatures and upshot of computed porosity cross plots from log analogues available. Furthermore the careful study of porosity log (NPHI) and density log (RHOB) shows these TWO curves follow the cross over at the whole reservoir level which is a clue to the presence of hydrocarbons.

## 4.4 Shale Volume

Shales generally contain small quantities of radioactive elements, in particular, $^{40}K$ which occurs in mica, alkali feldspars and clay minerals, and trace amounts of $^{238}U$ and $^{232}Th$. These produce detectable gamma radiation from which the source can be detected by spectrometry; that is, energy emission in selected energy bands. The natural gamma radiation log consequently detects shale horizons and thus calculates c lay content of other sedimentary rocks.

The volume of shale is calculated as a decimal fraction or percentage is called $Vshale$. The volume of shale can be calculated from Gamma ray log using formula $Volume\ of Shale$

$$Volume\ of Shale\ (Vsh) = GRlog - GRmin / GRmax - GRmin \qquad (4.1)$$

From the figures, it is evident that reservoir lies in the depth range of *3270-3335m*

## 4.5 Porosity Calculation

Porosity is the very important attribute analyzed in reservoir characterization. It quantifies void or empty spaces within a rock body and is expressed as a function of fraction or percentage of the bulk volume of that rock. Two kinds of porosity are found in rocks, the primary porosity and secondary porosity, the first is developed between the grains at the time of deposition, and the second is due to fracturing and dissolution the pore spaces become void thus contributing to secondary porosity. Secondary porosity is mainly observed in limestone. Porosity plays very important role in production regulation of the well. If the porosity (Φ) range is greater than 6%, the formation can be reckoned as productive formation. The porosity of each meter is averaged out to calculate total reservoir pore volume.

This study utilizes the concept of calculation of porosity from density and neutron log, although there are several methods available for the calculation of porosity using different logs e.g. sonic log, density log or neutron log.

Density Porosity is derived from density log using the following equation

Density Porosity = (Density Matrix - Density Log) / (Density Matrix- Density Fluid) (4.2)

Neutron Porosity is directly obtained from Neutron log values. The Average Porosity is obtained by taking the mean of the above two;

Average Porosity = (Density Porosity + Neutron Porosity) (4.3)

Finally, Effective Porosity is given by;

Effective Porosity = Average Porosity * Vmatrix (4.4)

Where Vmatrix is Volume of Matrix given by

Vmatrix =1- Vshale (4.5)

## 4.6 Calculation of Water Saturation (Sw)

Porosity is the measure of holding fluids. Water saturation is the fraction or percentage of the storage capacity of a rock inhabited by water. The spatial distribution of water saturation (Sw) within a reservoir is dependent on many factors e.g. pore throat-size distribution, the height above free water, hydrocarbon type and pore geometry. Mapping Sw distribution in a reservoir helps us assign trap limits. Water saturation is usually calculated by Archie's Law which is given by

$$S_w = \{R_w/(R_t * \phi m)\}1/n \quad (4.6)$$

Where

- Rw Resistivity of Water,
- Rt is True Resistivity (obtained from LLD log),
- Φ is Porosity,
- m is Cementation factor (with a constant value 01),
- n is Wettability factor (with a constant value 02).

Since Archie's law involve the usage of Rw, so we will explain the calculation procedure for Rw.

$$Rw = \frac{(RT*Rmf)}{Rxo} \quad (4.7)$$

## 4.7 Results of Petrophysics

The petrophysical properties of the zone is delineated from available wireline logs in Sawan-08.

| Formation | Total porosity(v/v) | Volume of Shale(v/v) | Water Saturation(v/v) | Hydrocarbon Saturation(v/v) | Thickness m |
|---|---|---|---|---|---|
| **zone** | 15% | 38% | 60% | 40% | 65 |

Table 1: shows the average values of the marked zone of interest.

In the Sawan-08 well, the Zone is encountered at a depth of 3270 m. Based on our petrophysical analysis a 65 m thick net pay zone of clean sand, at a depth range from 3270 to 3335 m, can be delineated. This sandy zone exhibits total porosity (15%), hydrocarbon saturation (40%).

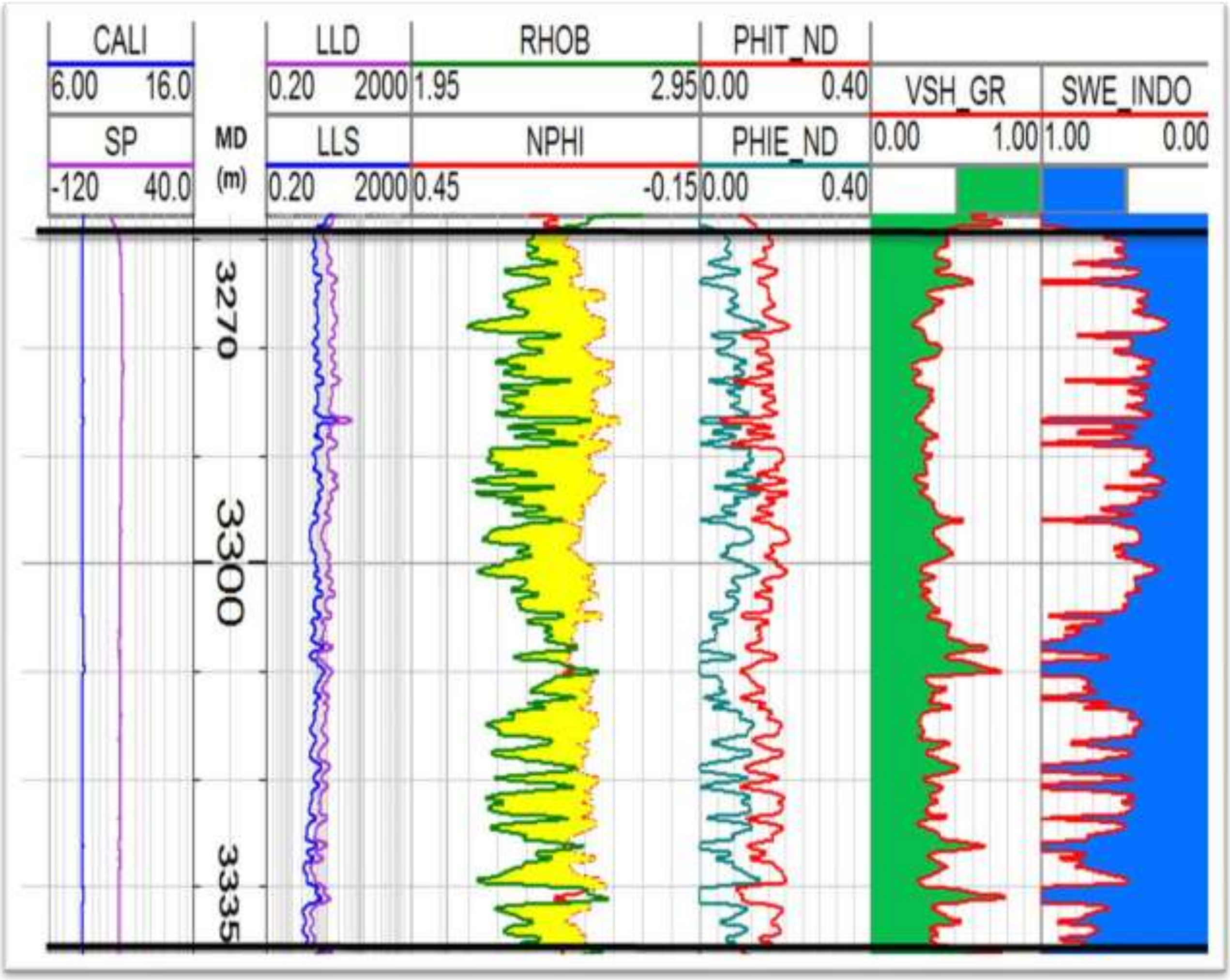



Figure 4.2The petrophysical results of sawan-08

Kingdom petrophysics tool is used for petrophysical analysis of well Sawan-08. With the help of caliper log from track 1 borehole conditions are marked. From the resistivity track water saturation is calculated. Track 03 is the RHOB and NPHI track, from which total porosity is calculated. Petrophysical interpretation of well Sawan-08 is shown in figure 4.2

**4.7.1 Interpretation**

Using Kingdom Software 8.8, in well Sawan-08 the probable producing zone strata is at depth of 3270m to 3335m. At this depth, the marked zone shows a good reservoir specification as shown by different wireline log signatures. At this portion of reservoir, the lithology package is sand as the shale volume here is 38.38%. A well- defined separation can be seen in Later log deep and later log shallow. furthermore, a clear cross over of neutron-density log in figure 4.2 can be seen which is clear identification of gas present at that interval as density decreases abruptly and neutron logs shows higher readings. Caliper log is not deviated in our marked zone which shows there is no bad borehole conditions exists.

# Chapter 5

## COLORED INVERSION

### 5.1 Introduction

Seismic inversion is an interpretation technique used to extract physical properties of rocks and fluids from seismic data (Krebs et al.). Inversion converts reflectivity data to physical properties of the earth, such as acoustic impedance (AI) the product of seismic velocity and bulk density. This is crucial because while reflectivity informs us about boundaries, impedance can be converted to useful earth properties such as porosity and fluid content via known petrophysical relationships.

### 5.2 Colored Inversion

Colored inversion is designed to approximately match the average spectrum of inverted seismic data with the average spectrum observed impedance (Lancaster and Whitcombe, 2000). The earth's reflectivity can be considered fractal, and the resulting amplitude spectrum favors high frequencies. If there was no preferred frequency, then you would have a "white spectrum", but as there are some frequencies with more energy, then it is called "colored".

Colored inversion include preparation of the well logs, investigating relationship between impedance and reservoir properties and tying the well logs to the seismic. After tying to the seismic, the well log data is used to estimate a seismic wavelet. By application of zero phase deconvolution a broad-band zero phase dataset is obtained which forms the input to colored inversion (Lancaster and Whitcombe, 2000).

Before doing the color inversion, we have to find the inverse wavelet and convolve it with all seismic traces to find acoustic impedance is called relative impedance because in processing we mute different frequencies by limited filter. On the other hand absolute acoustic impedance recovers the missing frequencies by generating low frequency model which is generated by calculating impedance from well log and using interpolation model on the whole area. This low frequency model will be added to impedance.

The advantages of the colored inversion are the speed of calculation and avoidance of artefacts that may be introduced by model.it enhances the seismic signal and adds the auto-picker. Often it can enhance features such as bed resolution, minor faulting, fracture zones and discontinuities due to channels and possibly the presence of hydrocarbons. Colored inversion whether acoustic or elastic impedance (Connolly, 1999), is an excellent interpretation tool.

### 5.2.1 Workflow

The workflow of colored inversion is shown below;

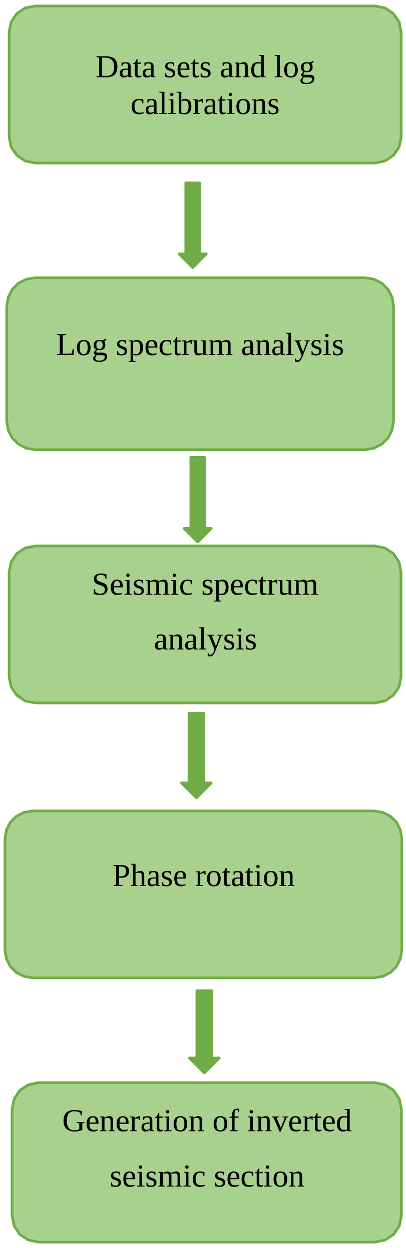



Figure 5.1 General colored inversion workflow

## 5.3 Wavelet Extraction

Using Kingdom Software 8.8 the wavelet is extracted on the basis of the well log data that provides the true reflectivity series (compressional wave velocity and density computed into acoustic impedance logs which are mapped into normal incidence reflectivity series). An initial guess of wavelet convolved with reflectivity series and synthetic normal incidence trace is generated. The difference between the observed and synthetic trace is minimized using a suitable chosen norm with smoothness constraints

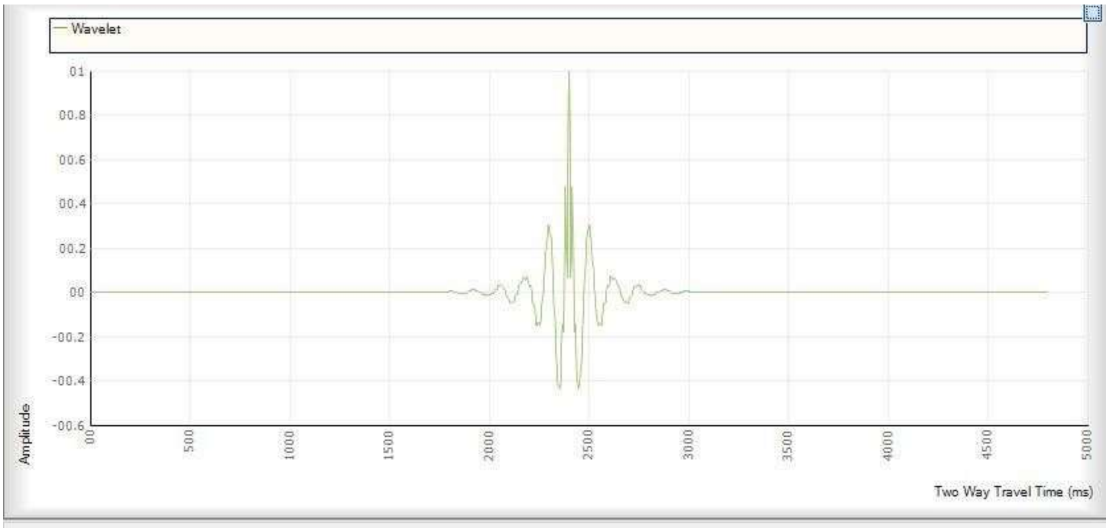



Figure 5.2 extracted wavelet

## 5.4 log Spectrum Analysis

The impedance spectrum of the log is generated on the log log paper by passing the best fit line in seismic frequency range. At the beginning the researcher have almost the same impedance but as the amplitude spectrum trend gently rises with frequency, the impedance log tends to decay with frequency, have effectively undergone the process of integration relative of the data in figure 5.3 by using Kingdom Software8.8

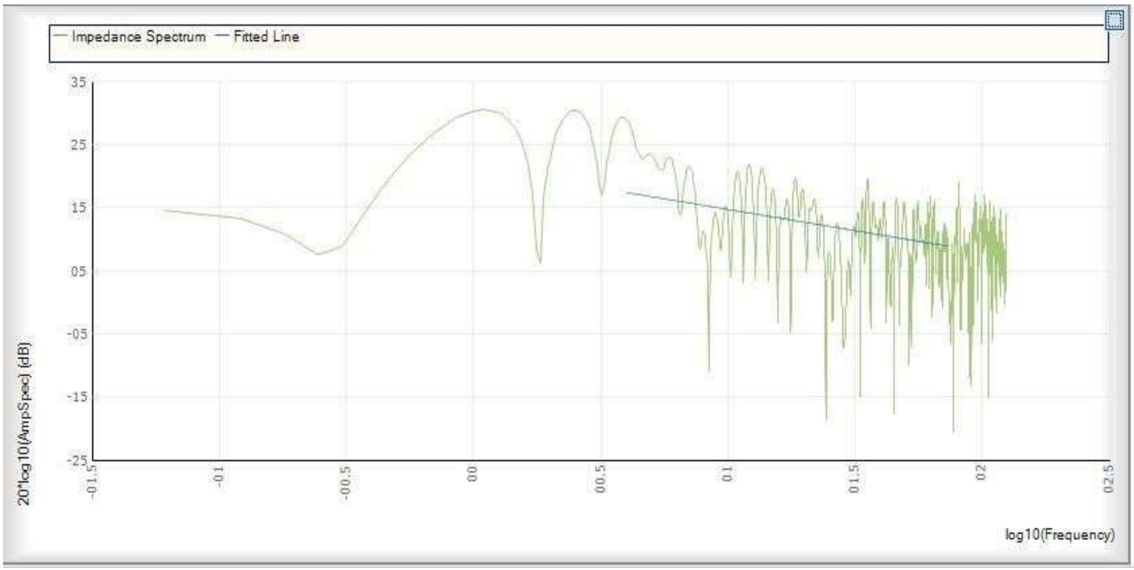



Figure 5.3 Impedance spectrum log with best fit line

## 5.5 Butterworth Filter

The Butterworth filter is used to smooth and constraints the impedance log spectrum. The butterworth filter is a type of signal processing filter designed to have a flat frequency response as possible in the pass band. It is also referred to as maximally flat magnitude filter. A butterworth filter needs to be defined by low and high cut frequencies and their corresponding slopes. This filter shown in figure 5.4 is used here for the convolution of wavelet and reflectivity series for formulation of seismogram by using Kingdom Software 8.8.

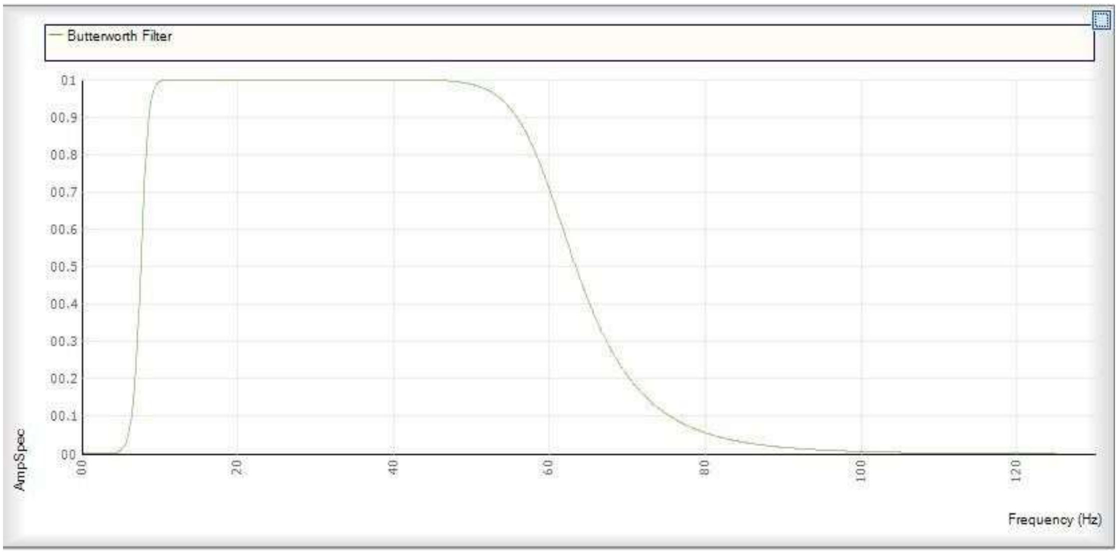



Figure 5.4 Butterworth filter

## 5.6 Desired Spectrum

By using the Kingdom Software 8.8 the modelled spectrum is computed from the logs which is impedance spectrum and it is smoothed and constraint by the butterworth filter in order to proceed towards the seismic spectrum and match it with the desired spectrum which is shown in blue color in figure 5.5.

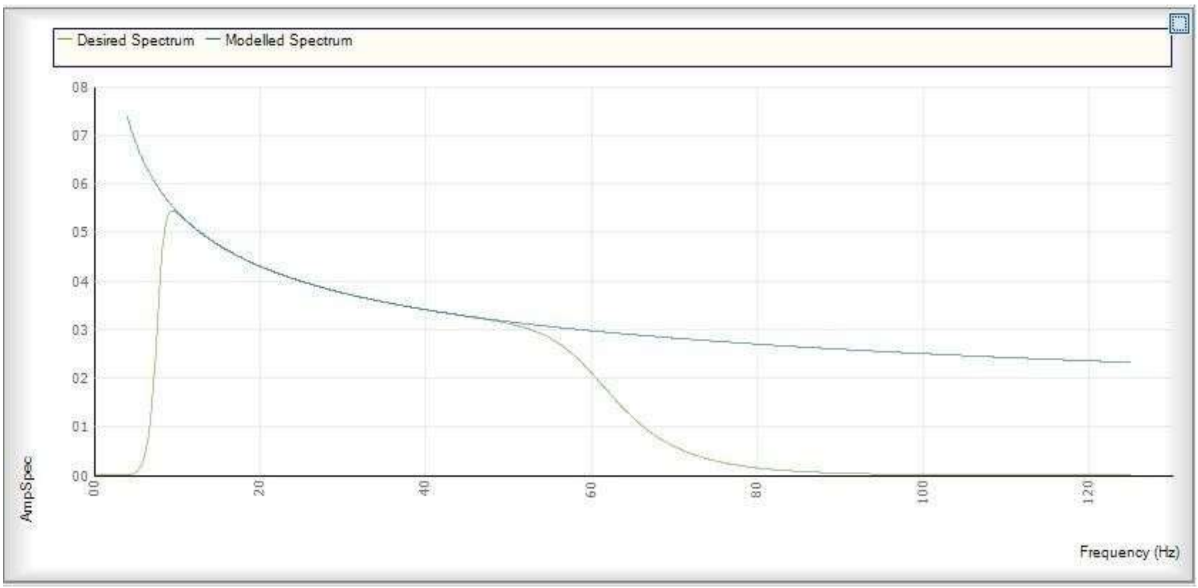



Figure 5.5 Desired spectrum

## 5.7 Phase Rotation

When the input seismic trace have been accurately zero-phased relative to the reflectivity sequence at wells, the colored inversion process requires a phase shift of -90 degrees to complete the match with the impedance log as well as the estimate amplitude spectral trend. There is an opportunity in the inversion package to apply a phase shift that will optimize the tie with impedance log trace, or the program can be requested to calculate the phase. The program estimates the phase rotation angle by comparing band pass filtered impedance logs with the shaped seismic data assuming that well ties are reasonably good. This phase value will be used to rotate the shaped seismic data to complete the colored inversion process. This acquire by using Kingdom Software 8.8.

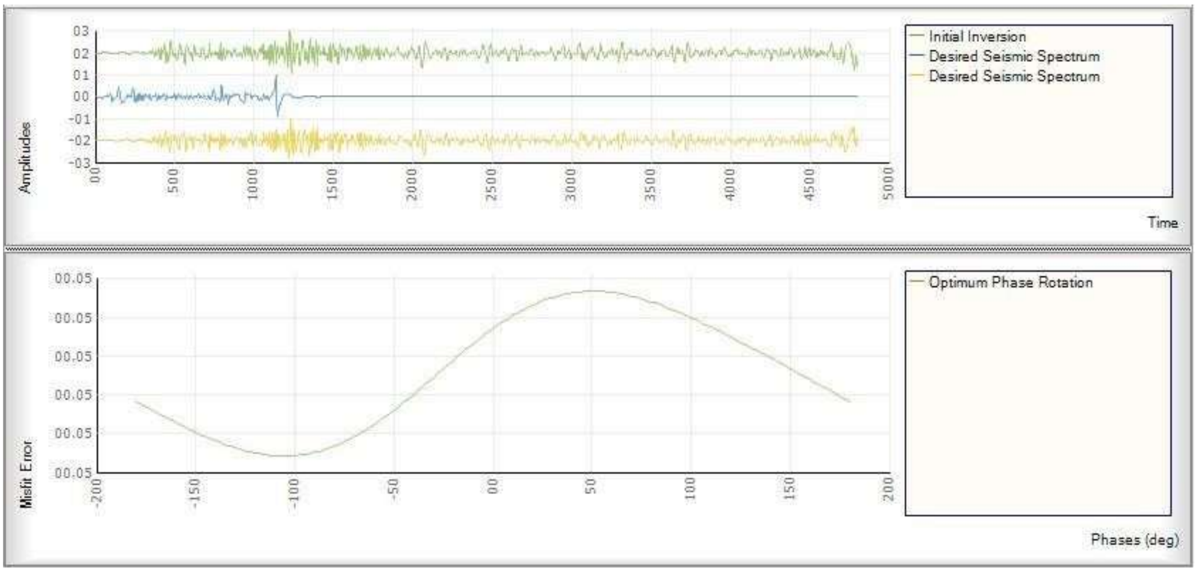



Figure 5.6 Optimum phase rotate

## 5.8 Generation of the Inverted Section

The operator is applied on the well Sawan-08 to get the inverted seismic section shown in figure 5.7. The inverted log is applied on the whole section. The optimum result will only be available at the well location, the control will be lost if locate far away from the well. The seismic section is displayed with respect to relative acoustic impedance shown in figure 5.7 giving the inverted seismic section.

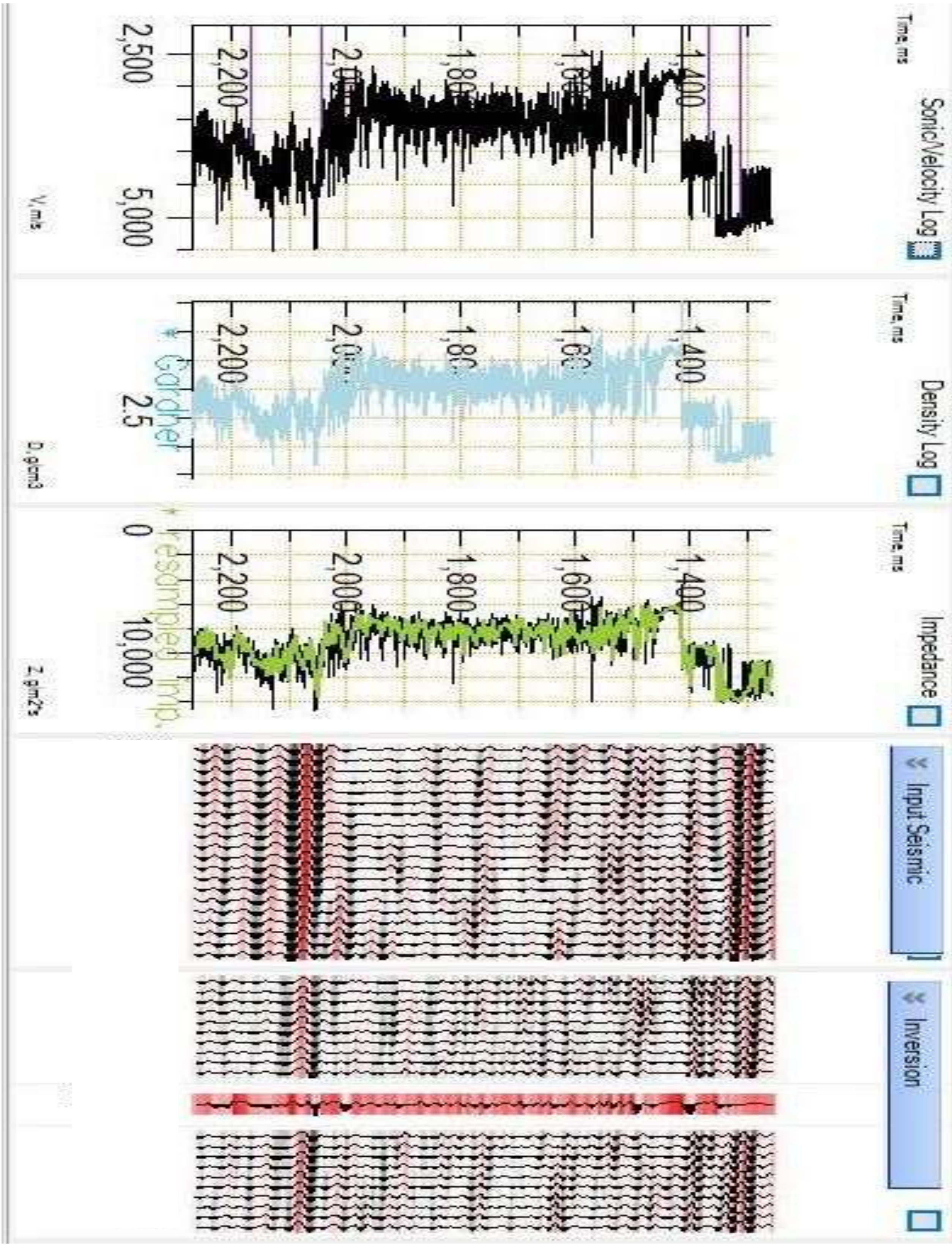



Figure 5.7 the inverted seismic section

## 5.9 Interpretation of Inverted Section

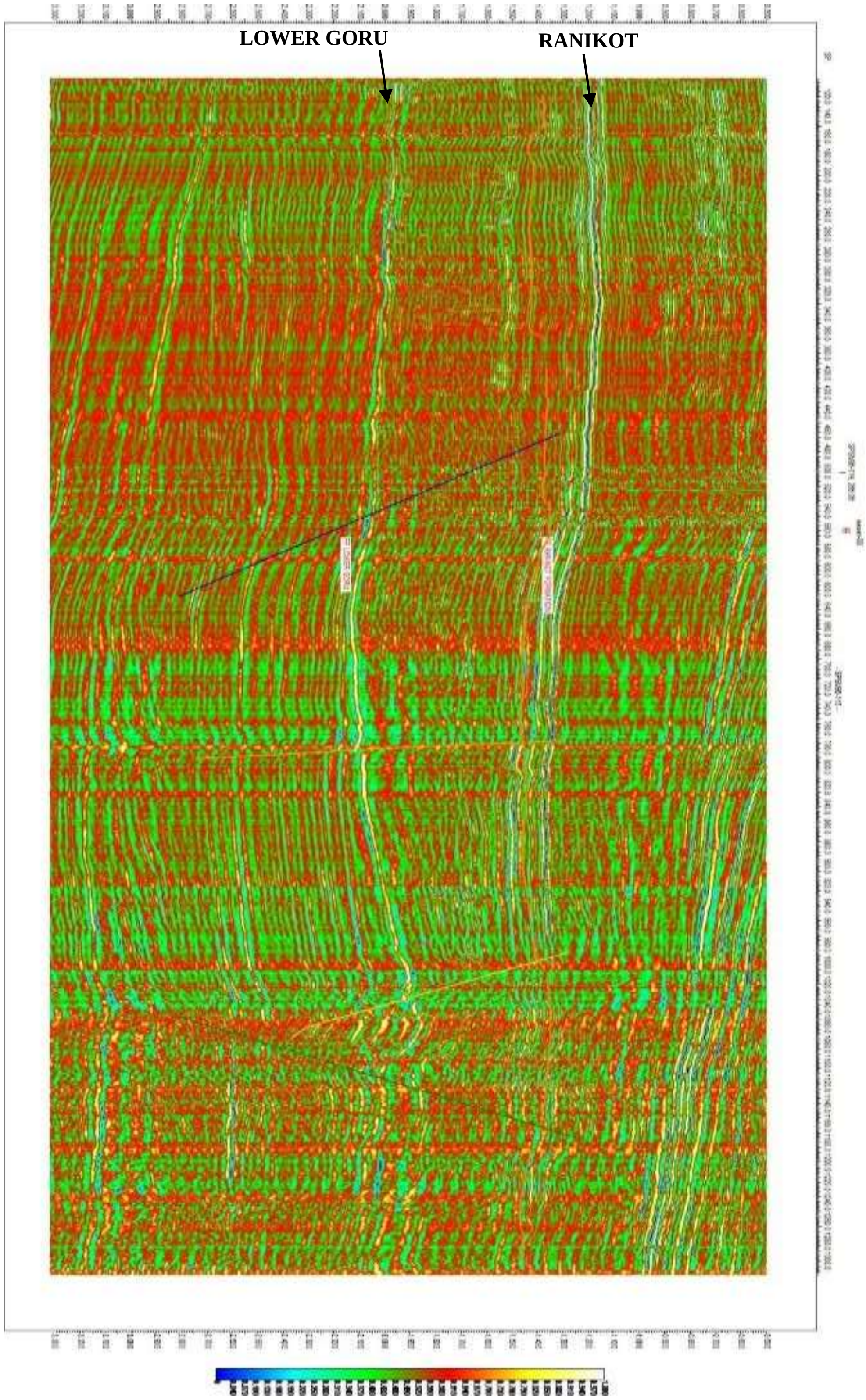



Figure 5.8: The inversion of the well sawan-08.

The result of inversion is shown in figure 5.8. The inverted section can be interpreted using a color bar as shown in figure. The white to yellow color shows high values of acoustic impedance and blue to green shows low values of acoustic impedance. The hydrocarbon accumulation is associated with low acoustic impedance as blue color in figure. The inverted section shows formations as well because TD chart is used. The low acoustic impedance values Lower Goru Formation and the structure formed are the indication of the possible hydrocarbon potential zone.

## Discussion and Conclusions

The Area of study lies in southern side of Sawan block. The whole interpretation is based on the seismic and well data available for the dissertation. Sawan block is in the area where there is influence of both structure and stratigraphy which make the interpretation more interesting, complex and challenging. Based on seismic and well data, reflectors are marked i.e Lower Goru and Ranikot Formation. The Lower Goru is acting as a reservoir in this area. The sub surface seismic interpretation revealed horst and graben structures in Sawan area having a faults with orientation NW-SE. This whole tectonic scenario was a result of trans-tensional tectonics of the first docking of the India- Eurasian plates and counterclockwise rotation of the Indian plate (Ibrahim, 2007)

Contour maps were prepared, and 2D seismic reflection data reflect that overall strata are dipping towards east and as area lies in extensional regime so normal faulting prevails in the study area.

Petrophysical analysis of Sawan-08 shows zone of interest which can be prospect zone for hydrocarbons by calculating various physical properties. This sandy zone exhibits effective porosity (7%), an economic percentage of pores filled with hydrocarbons (40%) and water saturation (60%)

According to seismic inversion analysis, Lower Goru shows the low value of impedance which is a strong indicator of hydrocarbon potential zone.

**REFERENCE:**


- Aamir Ali, Tiago M. Alves, Farhad Aslam Saad, Matee Ullah, Muhammad Toqeer, Matloob Hussain, (2018), Resource potential of gas reservoirs in South subcontinent revealed by post-stack inversion techniques Pakistan and adjacent Indian subcontinent revealed by post-stack inversion techniques
- Abdellatief, A. A. (2009). The Geological Interpretation of Reflection Seismic Data (Doctoral dissertation, Al-Azhar University)
- Ahmad, N., Fink, P., Sturrock, S., Mahmood, T., & Ibrahim, M. (2004). Sequence Stratigraphy as Predictive Tool in Lower Goru Fairway, Lower and Middle Indus Platform, Pakistan. PAPG, ATC.
- Anna Berger, Susanne Gier, and Peter Krois (2009) Porosity-preserving chlorite cements in shallow- marine volcaniclastic sandstones: Evidence from Cretaceous sandstones of the Sawan gas field, Pakistan
- Anwer, H. M., Alves, T. M., & Ali, A. (2017). Effects of sand-shale anisotropy on amplitude variation with angle (AVA) modelling: The Sawan gas field (Pakistan) as a key case-study for South Asia's sedimentary basins. *Journal of Asian Earth Sciences*, *147*, 516-531.
- Asquith, G. B., Krygowski, D., & Gibson, C. R. (2004). Basic well log analysis (Vol. 16). Tulsa: American association of petroleum geologists
- Asquith, G., and D. Krygowski, (2004), Basic Well Log Analysis. American Association of Petroleum Geologist, pp.244.
- Azeem, T., Chun, W. Y., Khalid, P., Qing, L. X., Ehsan, M. I., Munawar, M. J., & Wei, X. (2017). An integrated petrophysical and rock physics analysis to improve reservoir characterization of Cretaceous sand intervals in Middle Indus Basin, Pakistan. Journal of Geophysics and Engineering, 14(2), 212-225.

- Badley, M. E. (1985). Practical seismic interpretation
- Bakker, P. (2002). Image structure analysis for seismic interpretation. Delft University of Technology
- Benedicuts, T. (2007). Determination of petrophysical properties from well logs of the offshore Terschelling Basin and southern Central North Sea Graben region (NCP-2A) of the Netherlands: TNO report
- Cooke, D., & Cant, J. (2010). Model-based Seismic Inversion: Comparing deterministic and probabilistic approaches. CSEG Recorder, 28-39.
- Donaldson, E. C., & Tiab, D. (2004). Petrophysics: Theory and Practice of measuring reservoir rock and fluid transport properties. Gulf Professional Publishing.
- Gavotti, P. E. (2014). Model-based inversion of broadband seismic data.
- Hasany, S. T., & Saleem, U. (2012). An integrated subsurface geological and engineering study of Meyal Field, Potwar Plateau, Pakistan. In Annual Technical Conference, Islamabad, Pakistan (pp. 205-234).
- Ibrahim, M., (2007). Seismic inversion Data, A tool for reservoir characterization/Modeling Sawan Gas Field - A case study, PAPG, ATC
- Kazmi A.H. & Jan M.Q., 1997 ―Geology and Tectonic of Pakistan‖
- Kearey, P., Brooks, M., & Hill, I. (2002). An introduction to geophysical exploration (Vol. 4). John Wiley&Sons.
- Krebs, J. R., Anderson, J. E., Hinkley, D., Neelamani, R., Lee, S., Baumstein, A., & Lacasse, M. D. (2009). Fast full-wavefield seismic inversion using encoded sources. Geophysics, 74(6), WCC177-WCC188.
- Lines, L. R., & Newrick, R. T. (2004). Fundamentals of geophysical interpretation. Society of Exploration Geophysicists.
- Mahmoud Salma Tawfik, (2019), Hydrocarbon exploration: Geological and Geophysical surveys.
- Oldenburg, D. W., Scheuer, T., and Levy, S., 1983, Recovery of the acoustic impedance from reflection seismograms: Geophysics, Vol. 48, No. 10.
- Ontiveros, T., Herrera, V., & Meza, R. (2014). Seismic Inversion Applied To Geological And Operational Monitoring Of Drilling Horizontal Wells In The Carabobo 5 Area Of The Faja Petrolífera Del Orinoco.
- Sheriff, R.E., 2002, Encyclopedic Dictionary of Applied Geophysics: SEG, 4th edition.
- Tian, C. S., Hsieh, B. Z., and Lin, Z. S., (2001). Development of permeability calculation

models by genetic algorithms: Journal of Petroleum, vol.37, No.4, pp1-8.

- Veeken, P. C. H., & Da Silva, M. (2004). Seismic inversion methods and some of their constraints. First break, 22(6), 47-70.
- Worthington, P. F., & Cosentino, L. (2005). The role of cut-offs in integrated reservoir studies. SPE Reservoir Evaluation & Engineering, 8(04), 276-290
- Ziolkowski, A., Underhill, J. R., & Johnston, R. G. (1998). Wavelets, well ties, and the search for subtle stratigraphic traps. Geophysics, 63(1), 297-313.