Study of Geological Interpretation using Petro-physical Analysis, Facies Analysis and Colored Inversion of Bitrism Area Southern Indus Basin, Pakistan

BY

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CERTIFICATE

It is certified that Mr. Yawar Amin carried out the work contained in this dissertation under my supervision and accepted, in its present form by department of Earth Sciences, as satisfying the requirements for BS degree in Geophysics.

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To the man I look up to and the woman I love from the bottom of my heart, my Father and my Mother.

To my siblings.

To my old friends Aayat, Ammar, Moeez and Yasin.

ACKNOWLEDGEMENT

In the name of the Creator, the Merciful the All-knowing and with the blessings of His Last Prophet (peace be upon him), I thank Allah as his humble servant for He has given me opportunity, strength, knowledge, creativity and will to make me who I am today.

I am indebted to my honorable supervisor and teacher Dr. M. Gulraiz Akhter for taking me under his supervision. I am thankful and blessed to have had the opportunity to work under such an experienced and patient teacher.

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ABSTRACT

Interpretation of two dimensional Seismic lines obtained from a survey conducted in the Bitrism block, Southern Indus Basin by means of Time and Depth contour maps and fault polygon maps for the Upper and the Lower Goru Formations portrays presence of extensional regime as major normal faults form Horst and Graben structures with probable hydrocarbon saturation. The shales present in the Lower Goru formation acts as a source while the sand present in the Lower Goru formation acts as a reservoir. Interpretation shows that the Upper Goru formation acts as a seal rock

Cross plot between GR log, NPHI log and RHOB log shows presence of major shale lithologies with interbedded sand lithologies. This has been confirmed using various other cross plots like a cross plot between GR log, LLD log and RHOB log as well as DT log, RHOB log and GR log as reference log.

Rock physics shows saturation of the target zone. Petro-physical analysis of the Lower Goru formation shows 60% volume of shale. The Petro-physical analysis of the reservoir zone shows 29% shale presence with hydrocarbon saturation of 81%, water saturation of 19% and effective porosity of 27.5%.

Colored inversion shows low Acoustic Impedance present in the zone of interest referring to presence of hydrocarbons as velocity and density values are low.

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Chapter 1

INTRODUCTION

1.1 Hydrocarbon and Petroleum Play

For many years, geophysicists and other scientists have made efforts and prevailed at extracting the material form the subsurface of the earth called hydrocarbons. Hydrocarbons are generated in the subsurface as a result of maturation of the buried organic matter. Organic matter (organic carbon) in sediments underlying the oceans is derived from different sources (Emeis and Kvenvolden, 1986), including marine phytoplankton, Phytobentos in shallow water with sufficient light, Bacteria, and Allochtonous (i.e., land derived) material. The composition of the organic matter is changed with burial depth and temperature. Three major steps in the conversion of organic matter to hydrocarbons include diagenesis, catagenesis and metagenesis. C1-C4 hydrocarbons are found excessively in the gaseous phase at surface conditions. Methane (C1) may be generated in significant quantities, either in near surface conditions by bacterial action or at greater depths by thermochemical action. C5 and heavier hydrocarbons (predominantly oil) are generated thermal cooking of hydrogen-rich organic matter for chronologically larger periods of time.

In order to explore the subsurface hydrocarbons, geophysical methods are used. These methods utilize the motion of artificially generated seismic waves which travel through the earth, reflected back and stored in receivers via devices called geophones.

1.2 Study Area

The study area is bounded by 26°16´ - 26°29´ N Latitude and 68°54´ - 69°0´ Longitude, located in the Sindh province, Pakistan. Geologically Bitrism area is situated within Southern Indus Basin to the south of the Sukkur Rift. Geologically, Bitrism area is situated within Jacobabad Khairpur high in lower Indus Basin of Pakistan. Until today, several wells have been drilled in Lower Goru formation of Cretaceous age, but without any commercial hydrocarbon discovery. The present study is based on of 2D seismic survey, Carried out by Oil and Gas Development Corporation Limited (OGDCL) in 1996, 1997, 2001.

A satellite image of Pakistan is given in Fig 1.1 highlighting the Bitrism area. The imagery has been obtained from the Image Base databank which was developed using the Projection Independent Multi-Resolution Imagery Tiles Architecture (PIMRITA) *Khan et al in (2008).*

Figure 1.1: Satellite image of Pakistan showing Bitrism area

1.3 Objectives

The purpose of this dissertation is to interpret the stratigraphic and structural traps of the area by the help of time and depth contour maps and fault polygons.

- Structural interpretation to find out structural traps favorable for hydrocarbons accumulation present in the study area.
- To generate time and depth contour map from seismic section to understand trend of horizon as well as the structure present in the subsurface.
- Facies analysis to confirm lithologies in the zone of interest.
- Petrophysical properties for confirmation of reservoir zone by means of petrophysical analysis.
- Colored inversion of Strike Line 20017-BTM-02 to confirm the lead of hydrocarbon presence.

1.4. Survey Information

The survey was done by OGDCL Company in the years 1996, 1997 and the year 2001. The survey consist of many lines out of which some have been used in this thesis. After the processing and interpretation of the area, two wells were drilled which produced certain amount of oil but were later abandoned because of low reservoir quantity. These wells were named as Fateh-01 and Ichhri-01. The main focus of the wells was to extract the oil reserves present in the Upper and the Lower Goru formations.

1.4.1 Base Map

This map shows the orientation and spatial extent of seismic lines (Figure 1.2). For present study, 8 seismic lines have been used. One of the lines is a strike line in NW-SE orientation while the rest of the seismic lines are dip lines with NE- SW orientation. The software used for making the base map is SMT Kingdom 8.8 (HIS). The file used for making the base map was a navigation file with .DBO format. This file contained information about the orientation of the seismic lines, their coordinates and their lateral extent. Names of the lines and their decimal degree latitude and the longitude coordinates were selected manually for the software to read them. SEG-Y files which contains the information about the seismic lines were then imported through the browser and pickets containing seismic data were therefore imported.

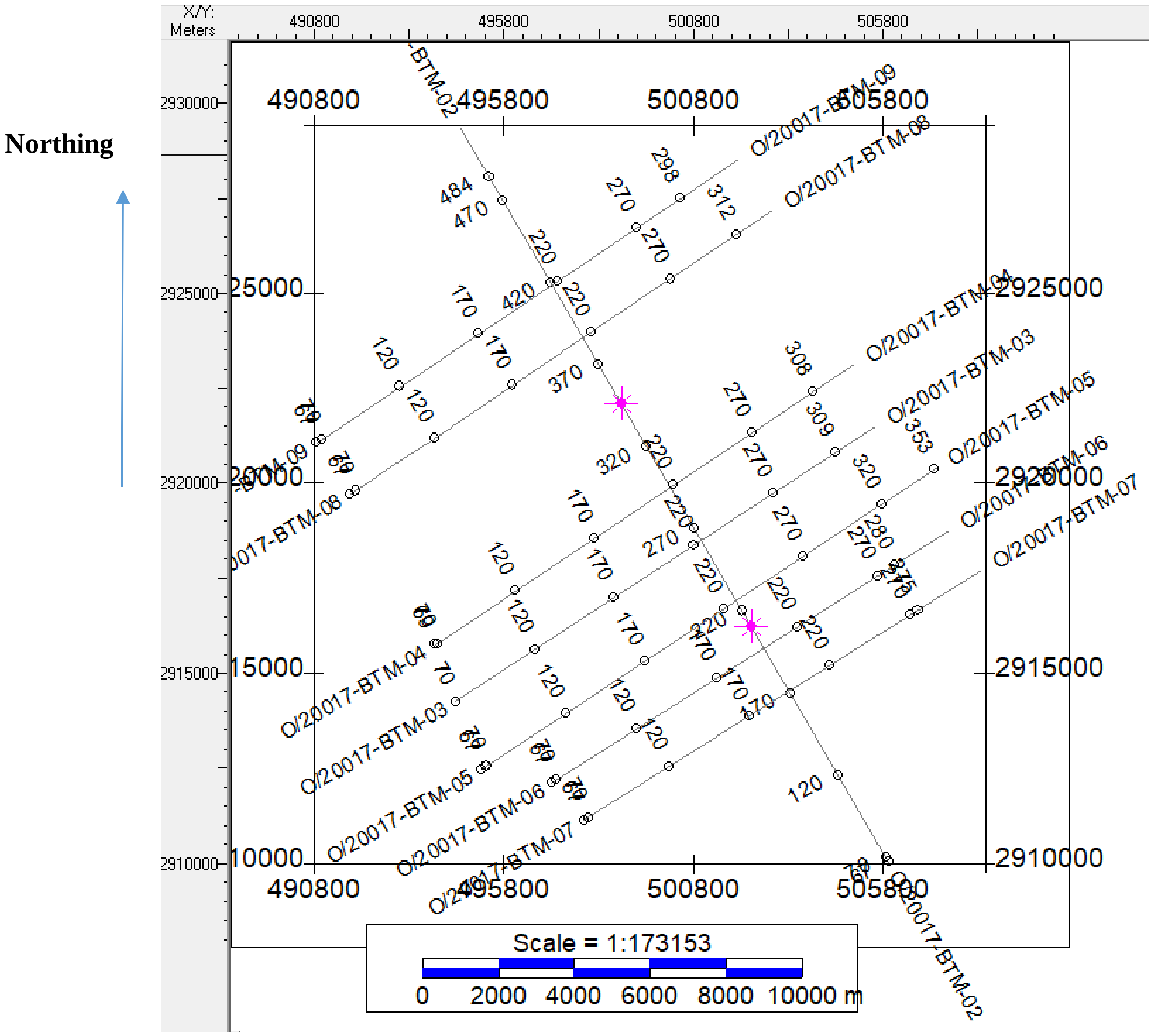


Figure 1.2: Base map of Bitrism Area showing orientation of seismic lines.

Table 1.1: Seismic lines with orientation and well data used in the base map.

Sr. No.	Line No.	Line Orientation
1	20017-BTM-02	Strike (NW-SE)
2	20017-BTM-03	Dip (NE-SW)
3	20017-BTM-04	Dip (NE-SW)
4	20017-BTM-05	Dip (NE-SW)
5	20017-BTM-06	Dip (NE-SW)
6	20017-BTM-07	Dip (NE-SW)
7	20017-BTM-08	Dip (NE-SW)
8	20017-BTM-09	Dip (NE-SW)

Wells used are Fateh-01 and Ichhri-01.

The thesis will focus mainly on the sections of the lines 017 BTM-02 (strike line), line 017 BTM-06 and line 017 BTM-07. These sections will include seismic section for amplitude (time), depth and other Seismic attributes.

1.4.2 Data Formats

Data set was obtained from Directorate General Petroleum Concession (DGPC) Pakistan. The data set used extensively in preparing this dissertation contained data regarding.

- SEG Y of the Seismic Lines mentioned in Table 1.
- Navigation data for Generation of Base map.
- LAS data of Fateh-01 and Ichhri-01

1.5 Seismic Acquisition Parameters

The seismic acquisition and processing parameters are presented in this segment. Seismic acquisition is an important aspect in the industry and needs to be carefully monitored and handled as there are many practical problems that arise during acquiring data from the field. While technical problems are in their own way hard to handle and manage, environmental problem can also be a headache. These environmental problems include access to the area, locomotive issues, politics, explosive issues, local problems etc. Seismic acquisition requires proper information about the locality, man handling capabilities, proper resources, a reliable crew, exasperating effort and adventurous nature.

Table 1.2: instruments

Summing computer	**SN-388**
Low cut filter	Out
Notch filter	In (50 Hz)
High Cut filter	125 Hz -72DB/OCT
Sample rate	2 MSEC
Record length	1700 MSEC
Summing	Diversity Average
Format	SEG-D
Density Notch filter	1600 BPI
No. of channels	120

Table 1.3: Source

Energy Source	Dynamite
Charge Pattern	1 hole
Avg. Shot Depth	30 meter
S.P Interval	50 meters

Table 1.4: Cable

Spread	3075-125-*-125-3075
Group Interval	50 meters
Type Of Geophones	SM4
Geophone Code	0312
Group length	97.30 meters
Geophone Interval	2.78 Eters

1.6 Processing

After the raw data has been collected from field, the data passes through the whole processing sequence that includes different data processing techniques which are used to suppress the noise and enhance the quality of the data for better interpretation. The raw seismic data is processed to enhance the signal to noise ratio and get the final seismic sections. Processing can be challenging as it requires technical ability and intuition. Filtering is one of the aspects of processing. The noise in the data not only includes randomly added noise by means of technical glitches, rather removing the coherent noise can be challenging. The coherent noise can be due to continuously produced noise from sources like rivers flowing nearby or electric wire lines in the vicinity. We acquire data by means of geophones. Waves travel in the subsurface and arrive at the geophones at different time depending upon the offset. This technical problem cause's parabolic pattern in the arrival time of waves coming from same lithology and stored at different geophones. In order to remove this problem, an acquisition technique called Normal Move-out Correction is used. In this technique, velocities are assigned to the waves on the basis of their depth and intuition, the constant velocity removes the parabolic effects. Common Mid-Point and Common Depth Point techniques are used for stacking of the data. Migration is used to enhance horizontal resolution by removing seismic miss-ties and vertical resolution is enhanced by means of Deconvolution technique. The generalized processing sequence flow chart (Khan, 2009) is given in Fig 1.3

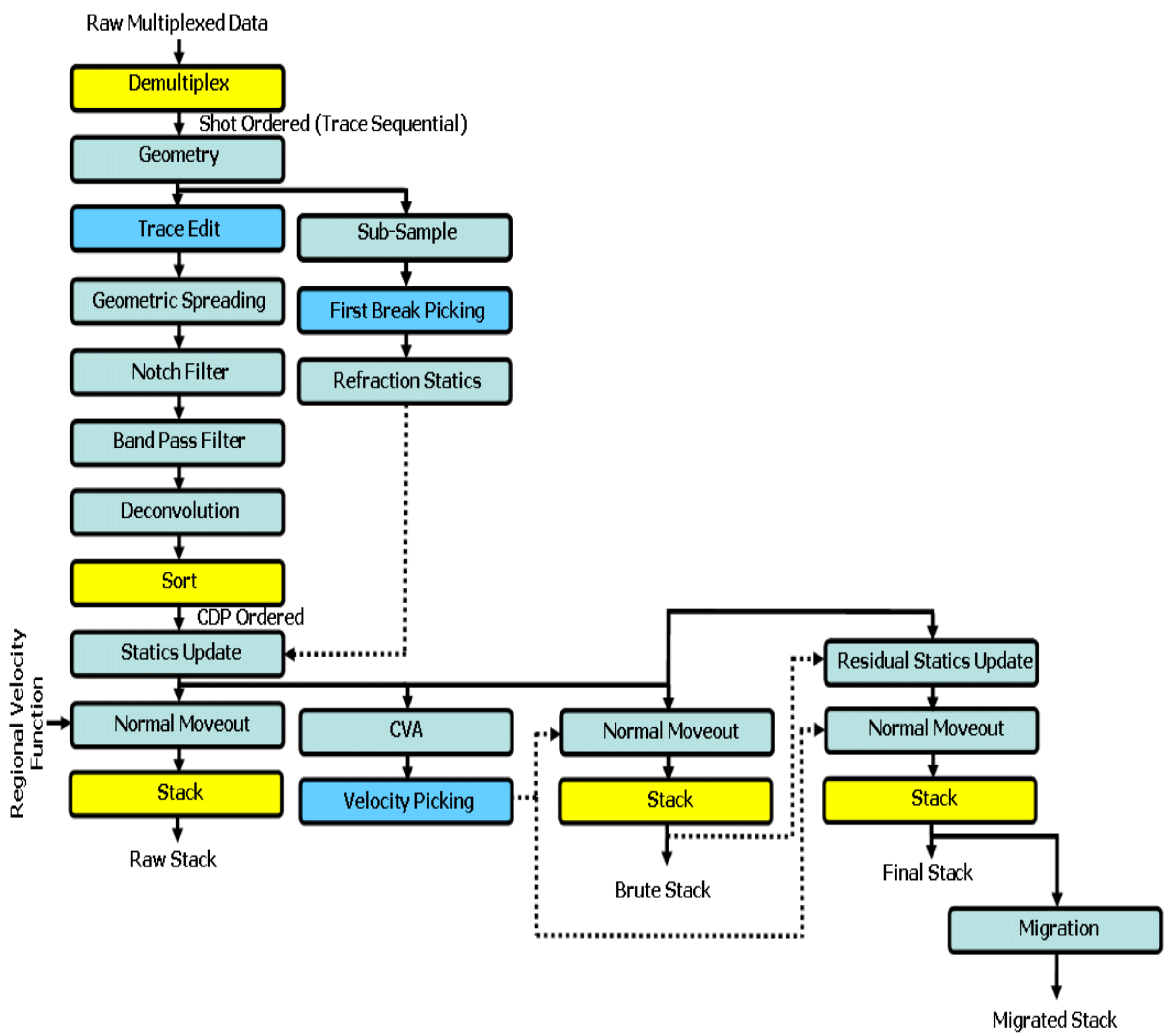


Figure 1.3: Seismic data processing flow chart. (Khan, 2009)

1.7 Interpretation and Analysis Methodology

1.7.1 Critical steps involved in Interpretation

The complete interpretation was possible after only identifying the key milestones. The work on these key milestones was very critical, keeping in view the overall scope of dissertation.
Kingdom Suite was the main software tool that was in performing interpretation of the seismic lines mentioned in Table 1. Steps taken in the conversion of raw data into process- able and beneficial information consist up of following.

- Marking of Horizons for 2-Dimensional Structural interpretation of Seismic Data using Kingdom software.
- Preparation of Time and Depth sections and study their differences using Kingdom software.
- Study of Rock Physics parameters by means of digitizing section through well and calculation of various secondary logs and then comparison of various logs.
- Facies analysis of the lower Goru Formation.

1.7.2 Analytic Workflow

The Interpretation was carried forward using different techniques and steps with each step involve different processes which were performed using the software tools as mentioned above. As it's said that a picture is worth a thousand words, similarly the simplified workflow used in the dissertation is given in Fig 1.4 which provides the complete picture depicting how the dissertation has been carried forward from the initial phase till its completion

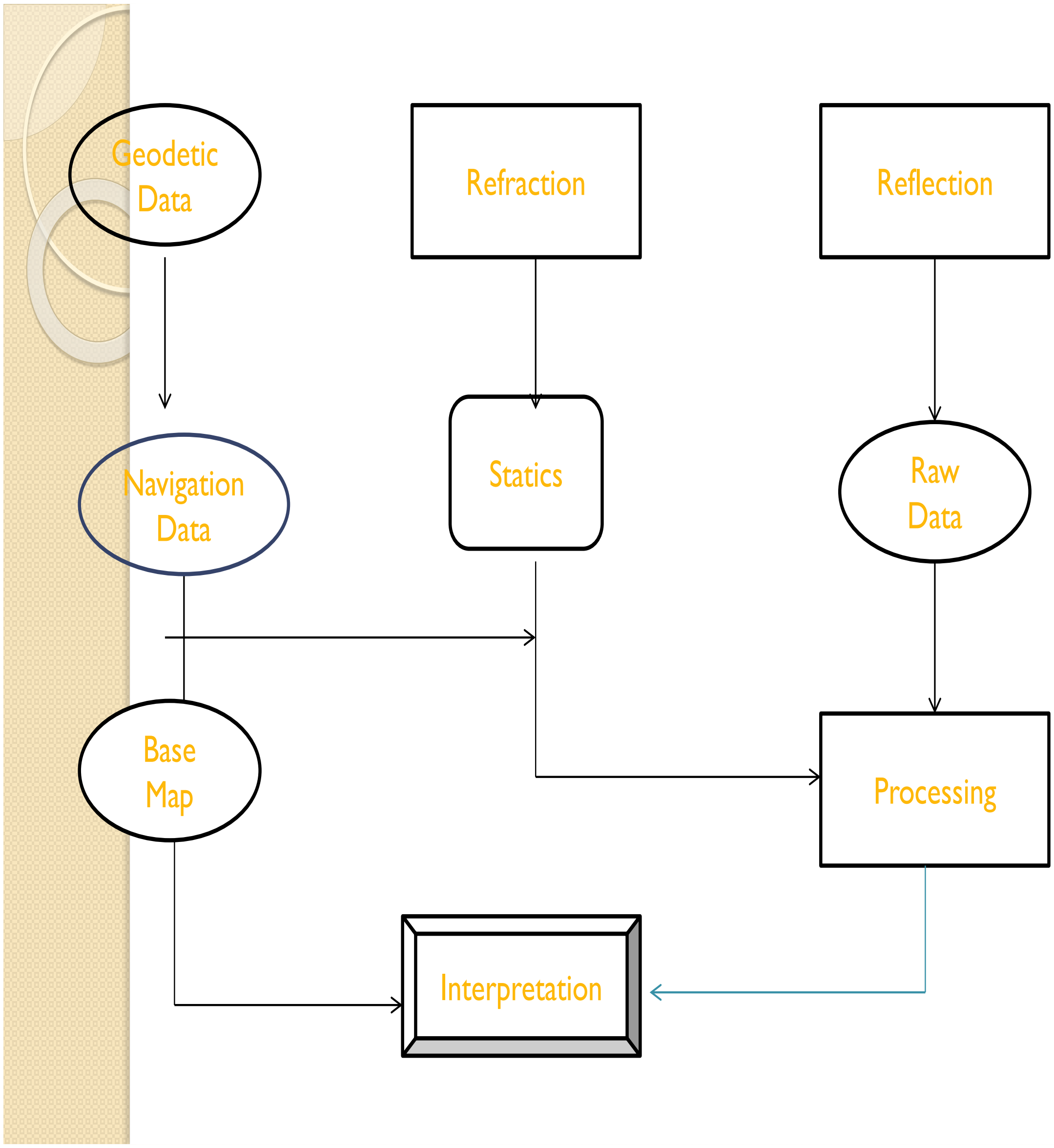


Figure 1.4: Work flow carried out using different software tools (Abbas, 2012)

1.8 Software Applications

The major software used in this thesis and there uses have been stated below:

SMT Kingdom Suite 8.8

- To generate the base map
- To draw Wells on the base map
- To pick horizons
- To mark faults
- To make grids for horizons
- To make contours for horizons
- For time to depth conversion of the seismic sections
- For synthetic seismogram development
- For interpretation of possible structural and stratigraphic traps
- For 3D view of the seismic lines and horizons
- For inversion method
- For petro-physical analysis
- For facies analysis

Microsoft Excel

- For petro-physical results
- For taking averages
- In log depth measurement
- For creating TD charts

Chapter 2

GENERAL GEOLOGY AND STRATIGRAPHY

2.1 Introduction

Pakistan has a high potential of hydrocarbons and consists of three major sedimentary basins (covering more than 2/3rd of its area) namely, Indus Basin in the east, Baluchistan Basin in the west and Pishin basin in the northwest. The Indus Basin covers an area of about 533,500 Km^2 and contains more than 15,000m thick sediments ranging in age from the Precambrain to recent. This giant basin has been divided into three compartments based on structural highs namely, The Jacobabad Khairpur High, Mari Khandkot High (Sukkur Rift) and the Sargodha High (Kazmi & Jan, 1997). Indus basin is divided into Upper Indus Basin, Middle Indus or Central Indus Basin and Lower Indus or Southern Indus Basin. There are extensional traps in the southern indus basin and it has been a site for many successful wells over the past few years. Some wells however have failed to produce any large amount of hydrocarbons due to various reasons despite the stratigraphic potential in the respective areas. This thesis looks into a case study of one of such examples of a well using seismic section interpretation as well as logs from the well in Bitrism Area in Khairpur District, Sindh Province, Pakistan.

2.2 Local Tectonics of the Area

The regional regime of the bitrism area is extensional in nature. Horst and Graben structures are therefore most prominent in the region which have been developed due to normal faulting. Major as well as minor faults are present.

2.3 Petroleum Geology of the Area

The oldest lithology penetrated in the study area is the Jurassic Chiltan Limestone. It is overlain by the Lower Cretaceous Sembar and Goru formations. The Goru Formation has conformable contact with overlying Parh Limestone of Late Cretaceous age which is capped unconformably by the Ranikot Group. The Lower Goru is mostly composed of interbedded sandstone and shale in different proportions and is the main reservoir rock in the area. The Lower Goru horizon has been divided into five parts based on lithology; the Basal Sand unit, lower Shale, Massive Sand unit, Upper Shale and Upper Sand. The Ranikot Group is capped unconformable by the Laki Formation of the Eocene age. During Oligocene the Proto-Indus River began to deposit Nari/Gaj sediments from the north into shallow embayment in the Karachi area. At the end of the Gaj depositional cycle, the eastward movement of the Afghan Plate along the Murray Ridge began and the Indus course was shifted eastward by the compressional uplift in the Karachi area.

2.4 Basin Architecture of Pakistan

In terms of genesis and different geological histories, Pakistan comprises two main sedimentary basins namely Indus Basin and Baluchistan Basin. Both the basins evolved through different geological episodes and were finally, welded together during Cretaceous/Paleocene along Ornach Nal/Chaman strike slip faults. The geological history of the Indus Basin goes back to Precambrian age. The Paleotopographic features influenced, to a large extent, the depositional processes throughout the basin development. These features also marked the limit of the basin and its divisions (Kadri, 1995). Different Basins of Pakistan includes:

- Upper Indus Basin.
- Middle Indus Basin.
- Lower Indus Basin.
- Baluchistan Basin.
- Kakar Khorasan Basin.
- Pishin Basin.

2.5 Stratigraphy of the Study Area

The stratigraphic succession changes from east to west. Precambrian basement is elevated in the south-eastern corner of the basin. The thickness of the sediments increases westward. In the eastern part of the basin tertiary sequence has direct contact/ Interaction with Jurassic sequence.

2.5.1 Cretaceous Stratigraphy

Goru Formation

Age: Age of the Lower Goru formation is Lower Cretaceous while the age of Upper Goru formation in Lower Cretaceous.

Lithology: Sequences of shale with interbedded sand is present.

2.5.2 Paleocene Stratigraphy

Ranikot Formation

Age: Age of Ranikot Formation is early Paleocene.

Lithology: Basal marine sequence of sand stone and shale with inter-beds of limestone (Raza 2003). Ranikot Formation is mainly comprises of grey limestone with some brown sandstone and shale in the upper part while sandstone with shale and limestone inter-beds are found in lower part.

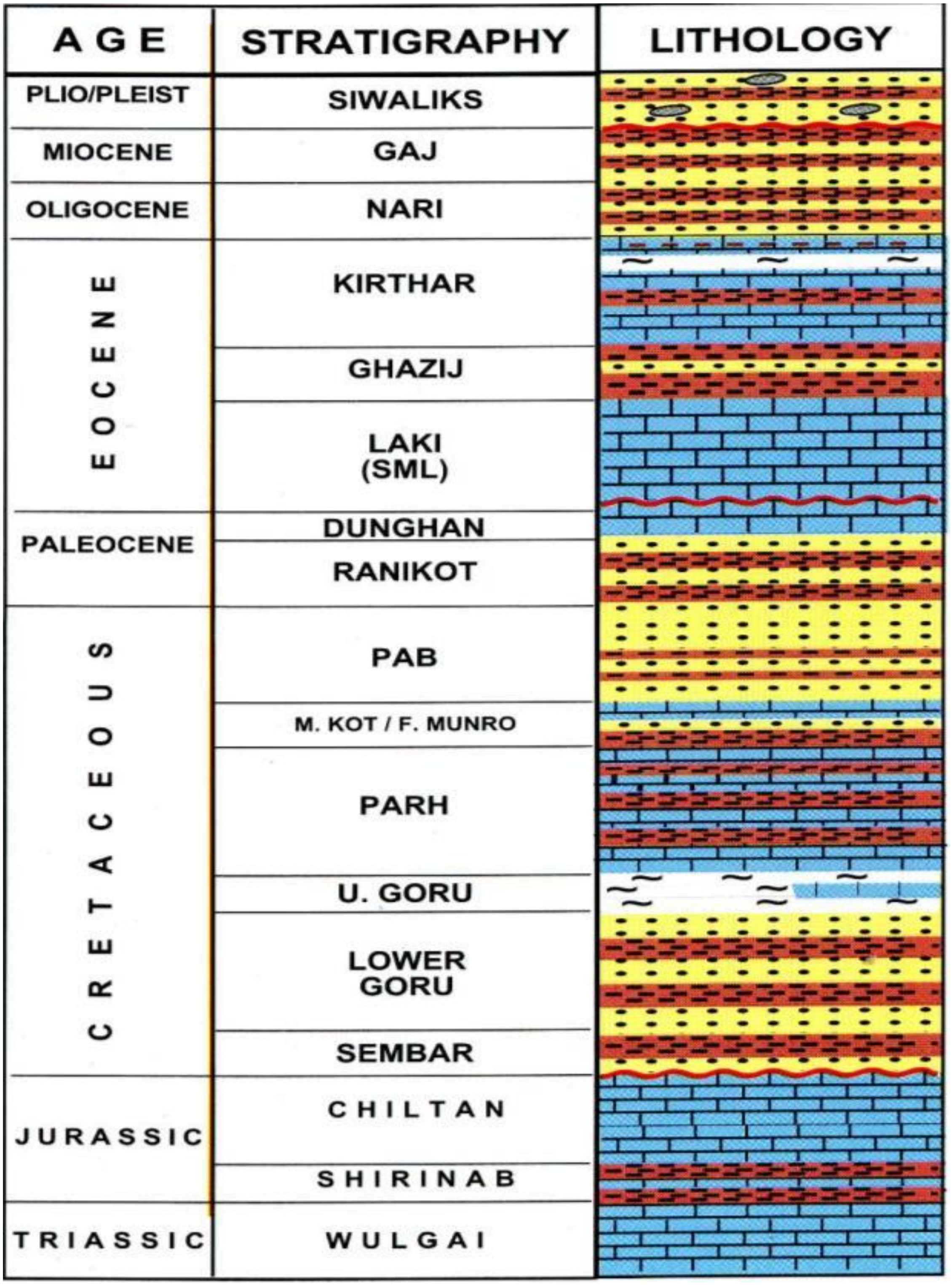


Figure 2.1: Stratigraphic Chart of the Study Area (after *S. A. Abbasi et al. (2016))*

2.6 Sequence stratigraphy of Area

The Lower Cretaceous series consist of Sembar formation and some part of Lower Goru member. The Lower Goru member has A, B, C and D intervals and a major shale bed. Three of the intervals lie in the lower cretaceous series while interval D and major shale bed on top lies in the Upper Cretaceous series. Upper Goru member also lies in the Upper Cretaceous series. Parh formation of the Upper Cretaceous series have an un-confirmable boundary with the Ranikot formation of the Paleocene series which has an un-confirmable upper boundary with the lower boundary of the Sui Main Limestone.

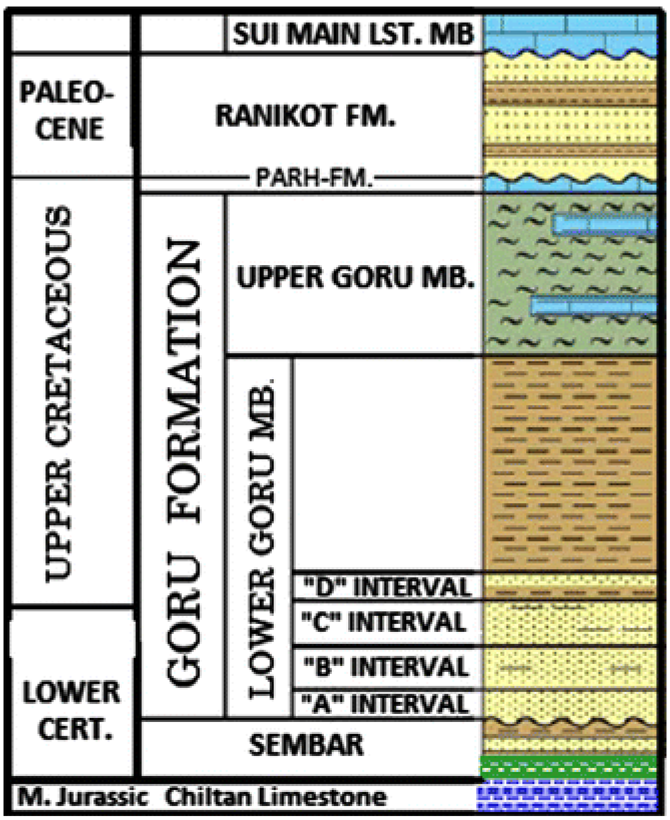


Figure 2.2: The stratigraphic column showing the subdivisions of Lower Goru Formation into Sand intervals A, B, C and D after Ahmed et al. 2004

2.7 Petroleum Play of Area

2.7.1 Source Rocks

While the Sembar has been identified as the primary source rock for much of the Greater Indus Basin, there are other known and potential source rocks. Rock units containing known or potential source rocks include the Salt Range Formation "Eocambrian" shales, Permian Dandot and Tredian Formations, Triassic Wulgai Formation, Jurassic Datta Formation, Paleocene Patala Formation, Eocene Ghazij formation, and lower Miocene shales. Of all the possible source rocks in the Indus Basin, however, the Sembar is the most likely source for the largest portion of the produced oil and gas in the Indus foreland. The Lower Cretaceous Sembar Formation consists mainly of shale with subordinate amounts of siltstone and sandstone. The Sembar was deposited over most of the Greater Indus Basin in marine environments and ranges in thickness from 0 to more than 260 m.

2.7.2 Reservoir Rocks

The principal reservoirs are deltaic and shallow-marine sandstones in the lower part of the Goru in the Lower Indus Basin and the Lumshiwal Formation in the Middle Indus Basin and limestone in the Eocene Ghazij and equivalent stratigraphic units. Potential reservoirs are as thick as 400 m. Sandstone porosities are as high as 30 percent, but more commonly range from about 12 to 16 % and limestone porosities range from 9 to 16 percent. The permeability of these reservoirs ranges from 1 to > 2,000 milli darcies. Reservoir quality generally diminishes in a westward direction but reservoir thickness increases. Because of the progressive eastward erosion and truncation of Cretaceous rocks, the Cretaceous reservoirs all have erosional up dip limits, whereas Tertiary reservoirs extend farther east overlying progressively older rocks.

2.7.3 Seal Rock

The known seals in the system are composed of shales that are interbedded with and overlying the reservoirs. In producing fields, thin shale beds of variable thickness are effective seals. Additional seals that may be effective include impermeable seals above truncation traps, faults, and up dip facies changes. The thick sequence of shale and marl of upper Goru Formation serves as cap rock for underlying Lower Goru reservoir.

2.7.4 Traps

All production in the study area is from structural traps. The tilted fault traps in the Lower Indus Basin are a product of extension related to rifting and the formation of horst and graben structures. The temporal relationships among trap formation and hydrocarbon generation, expulsion, migration, and entrapment are variable- throughout the Indus Basin. These provide the significant trapping system along tilted fault blocks and negative flower structure.

Chapter 3

SEISMIC INTERPRETATION AND MODELING

3.1 Introduction

Seismic interpretation is the progression of determining information about the subsurface of the earth from seismic data. It may resolve general information about an area, locate prospects for drilling exploratory wells, or guide development of an already-discovered field (Coffeen, 1986). Conventional seismic interpretation implies picking and tracking laterally consistent seismic reflectors for the purpose of mapping geologic structures, stratigraphy and reservoir architecture. The ultimate goal is to detect hydrocarbon accumulations delineate their extent, and calculate their volumes. Conventional seismic interpretation is an art that requires skill and thorough experience in geology and geophysics. To meet the challenges of exploring ever increasingly complex targets, there have been tremendous advancements in data acquisition equipment, computer hardware and seismic processing algorithms in the last three decades (Khan, 1995).

3.2. Types of Seismic Interpretation

The main approach of the stratigraphy is as follows:

3.2.1 Structural Analysis

This type of analysis is very suitable in case of Pakistan, as most of the hydrocarbon is being extracted from the structural traps. It is study of reflector geometry on the basis of reflection time. The main application of the structural analysis of seismic section is in the search for structural traps containing hydrocarbon. Most structural interpretation use two way reflection time rather depth and time structural maps are constructed to display the geometry of selected reflection events. Discontinue reflections clearly indicate faults and undulating reflections reveal folded beds (Telford et al., 1990).

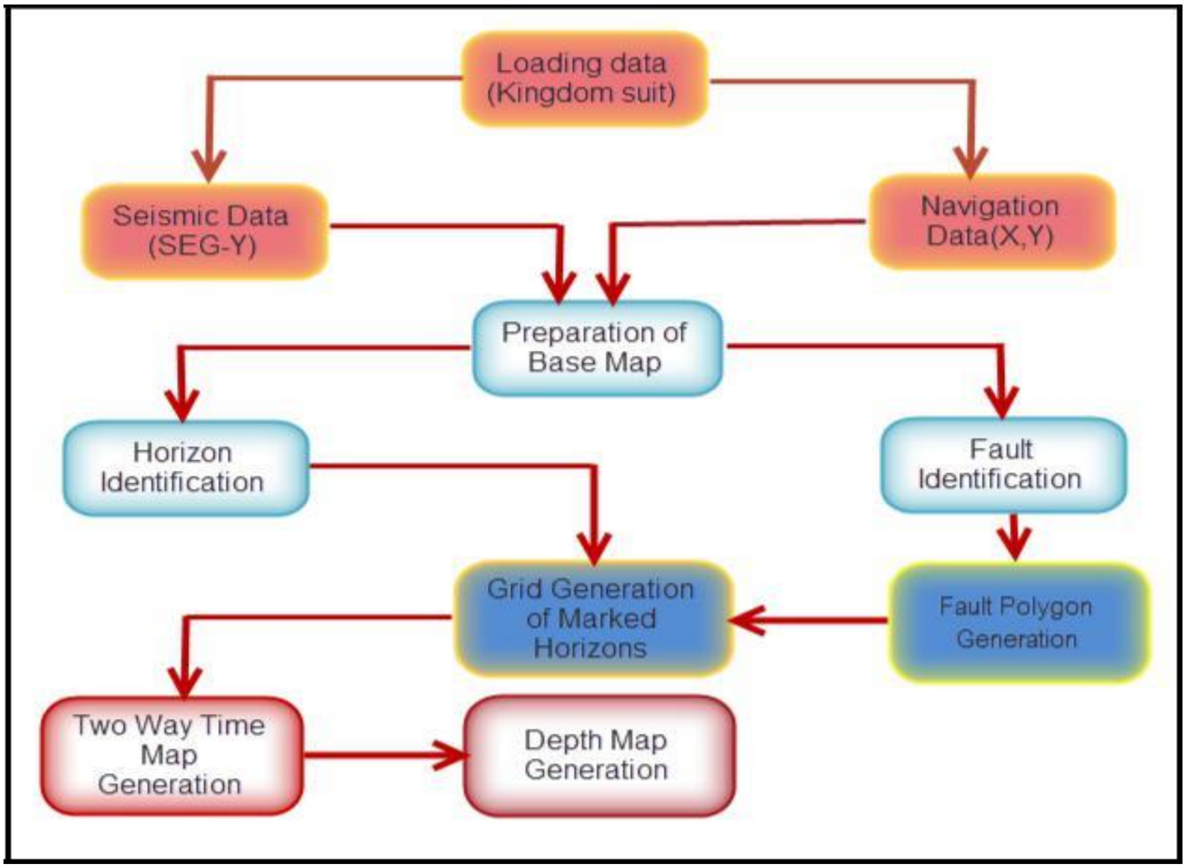
3.2.2 Stratigraphic analysis

Stratigraphic analysis greatly enhances the chances of successfully locating hydrocarbon traps in sedimentary basin environment. Seismic stratigraphy is used to find out the depositional processes and environmental settings, because genetically related sedimentary sequence normally consists of concordant strata that show discordance with sequence above and below it.

3.3 Work Procedure

For the past 50 years, seismic methods have evolved to a great extent. Data is stored, displayed, processed and interpreted in computational form. The data used for the base map generation in this thesis was Navigation file in .DBO format. This data was loaded in to the SMT Kingdom Suite 8.8 software. 2D SGY lines were then fed into the software. The coordination system was changed to UTM 42˚N (66˚E to 77˚W).

Formation tops were loaded into the software. The well tops information was used to define the depths of the formation tops. A synthetic seismogram was generated using a TD chart which was extracted by using DT log with respect to depth and by the use of replacement velocity on MS Excel. Correlation of the tops between the synthetic seismogram and seismic section was done. Major faults were marked on the dip lines on the basis of knowledge of the area i.e. extensional regime and intuition. Horizons of Lower Goru Formation and Upper Goru Formation were picked after correlation. Misties were checked and Fault polygons were generated. Grids and contours of the Lower Goru fm. and Upper Goru fm. were generated. Colored Inversion was applied and the results were checked.



Flow Chart 1: work flow of seismic interpretation

3.4 Seismic Horizons

Seismic interpretation focuses on the picking of seismic horizons and therefore marking out the interfaces between different lithologies. In order to do so, the structural and stratigraphic understanding of the area is necessary. The seismic data was provided in digital SEGY format; this data was loaded in the Kingdom Suite software and the horizons were marked on the seismic sections with the help of formation tops and synthetic seismogram. The well tops information was as follows:

Table 3.1: Formation tops

WW FATEH-01	**Depth (m)**
ALLUVIUM	**000000.0**
KIRTHAR	**000654.0**
LAKI	**000885.0**
SUI MAIN LIMESTONE	**001085.0**
UPPER RANIKOT	**001196.0**
LOWER RANIKOT	**001365.0**
UPPER GORU	**001810.0**
LOWER GORU	**002083.0**

3.5 Synthetic Seismogram

A synthetic seismogram is a 1D forward model generated from the logs run in a well in order to correlate it with the whole seismic section. In order to generate a synthetic seismogram, sonic log and density logs are used whose product gives the Acoustic Impedance log. The formula is given below:

$$AI = \rho v$$

Where,

AI= Acoustic impedance,

p = Density form density log

v = Velocity form sonic log

Sometimes density log is not available and therefore constant value for density and the sonic log values are used to generate impedance log. The following formula is used to create reflection coefficient series from the AI log:

$$RC = \frac{AI2 - AI1}{AI2 + AI1}$$

Where,

RC = Reflection coefficient series

AI2 = Acoustic impedance of below lying layer

AI1= Acoustic impedance of above lying layer

The following steps are adopted during the Generation of the synthetic seismogram using the IHS kingdom.

- Open 1D forward modeling Project and select the well logs.

- Load all the information of the well in the software.
- Load UWI, Elevation, Total Depth, Latitude and Longitude of the well.
- Load the Las file of the well.

- Create a TD chart for the well from the velocity logs

  - Load the TD chart of the well.
  - Load the formation tops of the well.

The following process of synthetic seismogram is done by Software automatically:

- Integrate the sonic log to rescale from depth in meters to two-way travel time in seconds.
- Compute Acoustic impedance log using velocity and density log.
- Compute the reflection coefficients from the time-scaled velocity log.
- Compute a first-order Ricker wavelet as a digital filter with two millisecond increments.
- Two-way travel time; using a frequency in Hertz.
- Convolve the reflection coefficient log with the Ricker wavelet to generate the amplitudes of the synthetic seismogram.

The synthetic after its generation is used to confirm the formation tops by means of correlation.

In the data, logs from the Fateh-01 well were used to generate synthetic on kingdom suite. The results were as follows:

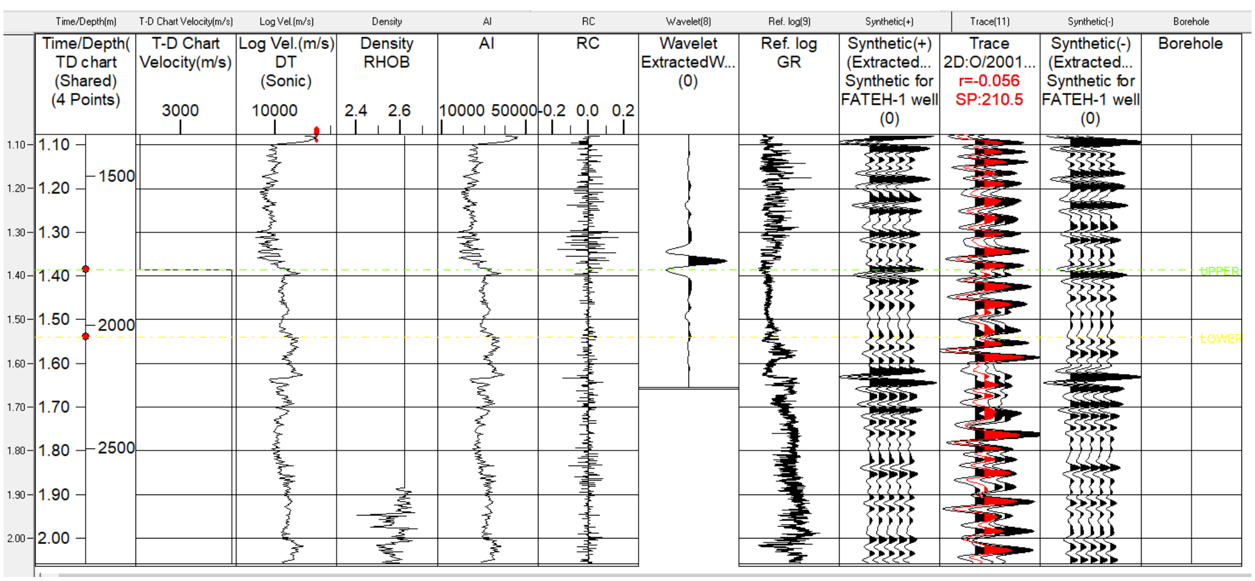


Figure 3.2: Synthetic seismogram of Fateh-01 Well.

3.6 Seismic Sections and their Interpretation

Primary task of interpretation was to identify the lower and the upper Goru formations which are geologically suitable for petroleum play. Thus, the upper and the lower Goru horizons on the seismic line 20017-BTM-06 and the well line 20017-BTM-02 were marked. The major faults on the seismic section were also marked.

3.6.1 Seismic Time Section Interpretation

The seismic section was given in time values. The lower and upper Goru formation tops have been interpreted. The major faults on the sections have been marked. The stratigraphy shows an extensional regime with horst and graben structures as a result of normal faulting caused by extensional forces in the region.

3.6.1.1 Strike line Time Section interpretation

The strike line in my data has been interpreted in terms of time section as follows:

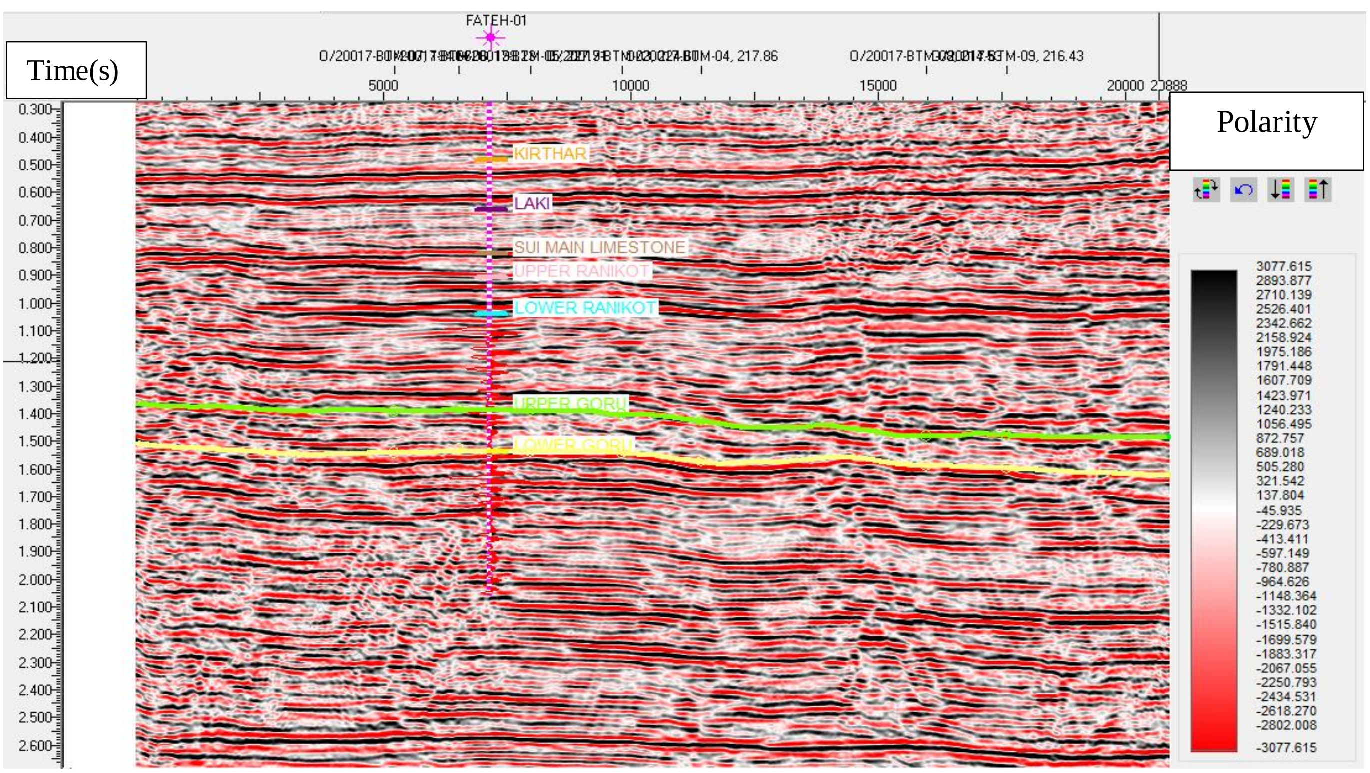


Figure 3.3: interpreted time section of well line 20017-BTM-02.

The Fateh well-01 is located on the strike line 20017-BTM-02. Synthetic seismogram developed from the logs run in the well and the formation tops data was used to mark the upper and the lower Goru formations in the seismic section of the strike line.

3.6.1.2 Dip line time section interpretation

One of the dip line 20017-BTM-06 has been interpreted as follows:

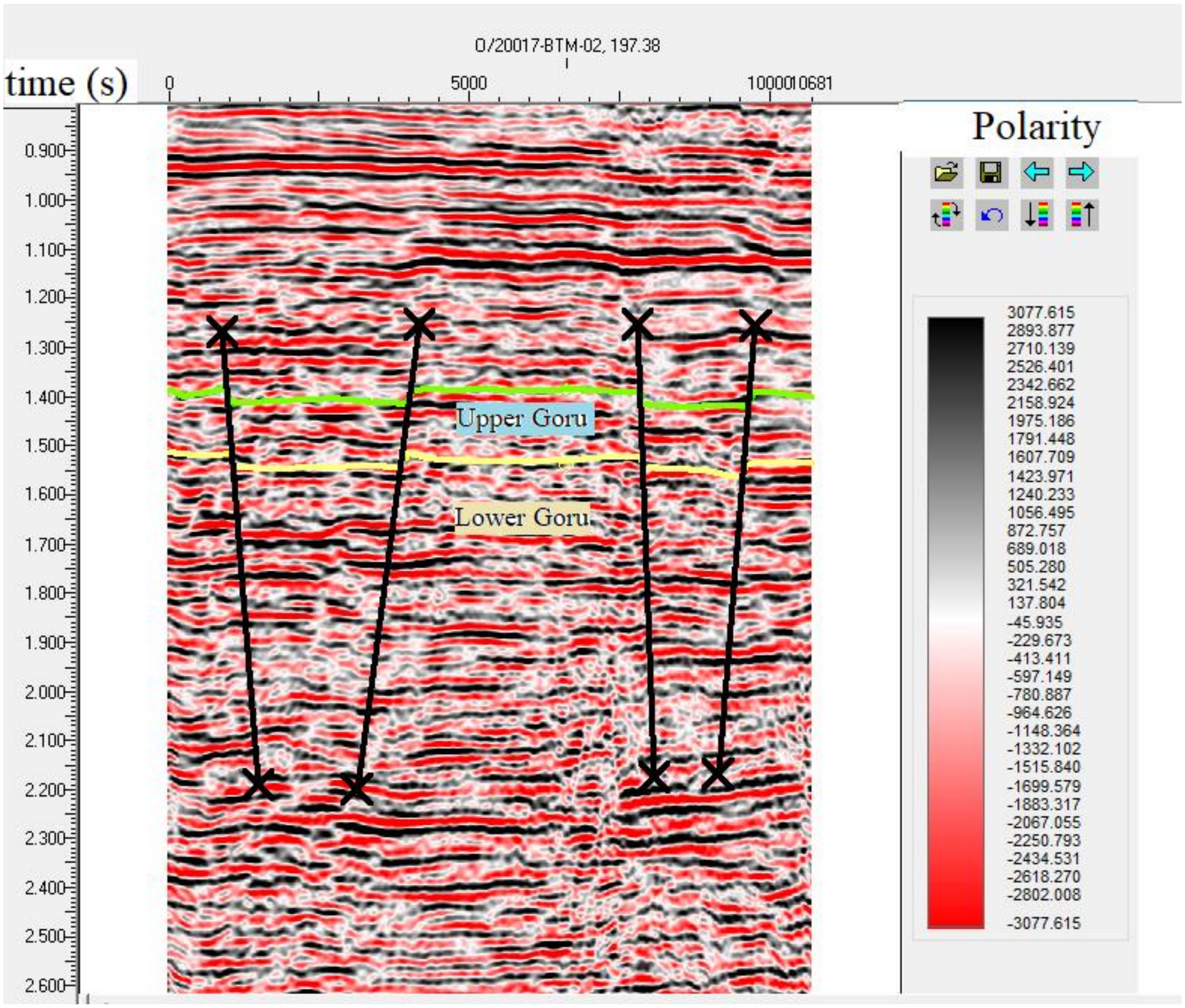


Figure 3.4: Interpretation of Seismic line 20017-BTM-06.

Horizons were marked on the seismic dip line 20017-BTM-06 by using the strike line intersecting this dip line. Faults were marked where there is a break in the continuity of the horizons. Horst and Graben structures can be seen on the seismic section.

3.7 Generation of Fault Polygons

Once the faults have been marked, the generation of fault polygons over the base map with respect to the horizons marked on the seismic lines is an important procedure as it ensures the proper interpretation of the subsurface continuity of any fault. This continuity is confirmed and marked by looking at the pattern of the faults marked on each seismic line and joining them by means of fault polygon digitization method in which points (represented by a “+” or “x” signs by Kingdom software) can be manually joined to make a polygon. Construction of fault polygons are very important as far as time and depth contouring of a particular horizon is concerned.

Any mapping software needs all faults to be converted in to polygons prior to contouring. The reason is that if a fault is not converted into a polygon, the software doesn’t recognize it as a barrier or discontinuities, thus making any possible closures against faults represent a false picture of the subsurface. After construction of fault polygons, the high and low areas on a particular horizon become obvious.

The fault polygons with regards to the time and depth sections of the Lower Goru and the Upper Goru formations are given as follows:

3.7.1 Upper Goru Time Section Fault Polygons

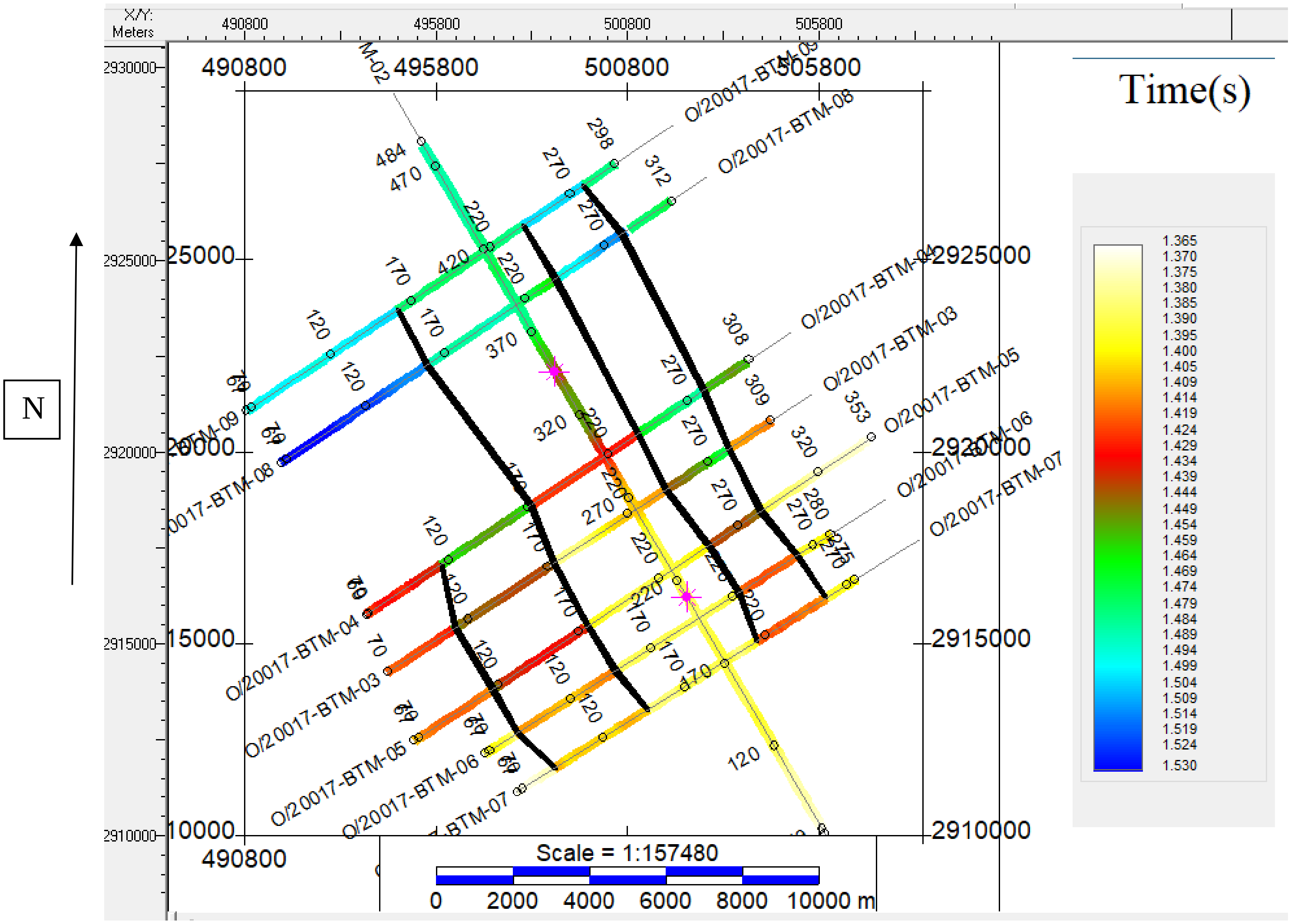


Figure 3.5: Fault polygons of Upper Goru w.r.t time section.

The upper Goru time section fault polygon shows the subsurface continuity of the fault plane. Fault polygons creates a discontinuity in the horizons and therefore helps in contouring and gridding to find subsurface structures.

3.7.2 Lower Goru Time Section Fault Polygons

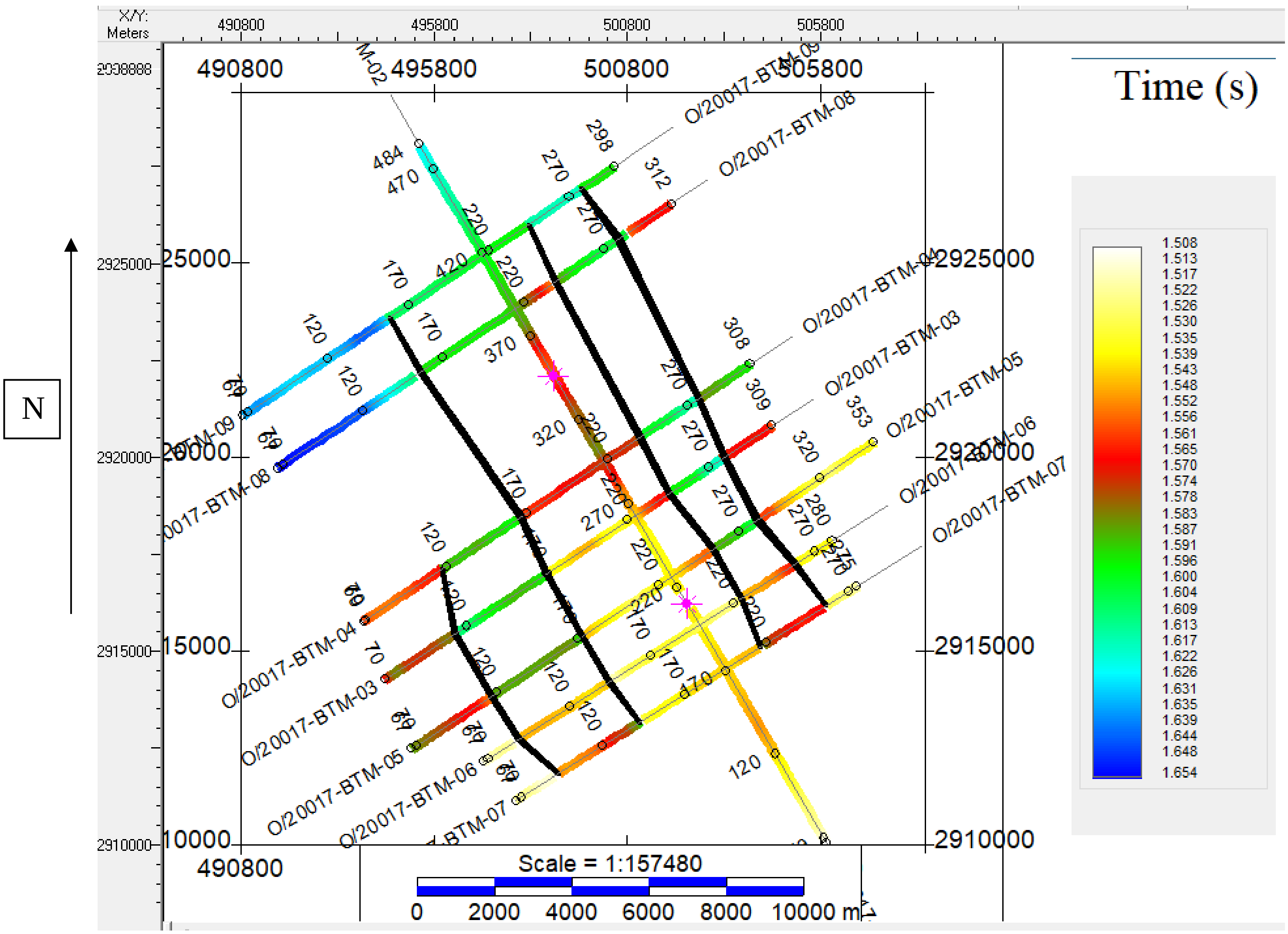


Figure 3.6: Fault polygons of Lower Goru w.r.t time section.

The Fault polygons for Lower Goru formation shows the same trend as the Upper Goru formation since the same fault planes are disturbing both the horizons therefore similar structures are being formed for both the horizons.

As shown in all the sections, the fault polygons are confirmed to be oriented in NW-SE direction. The results show that the region between the central two fault polygons seems to be the ideal position of accumulation of hydrocarbons in this case as this structure represents a Horst structure with faults on both sides. This assumption is backed by the fact that the horst structure is complimented by Graben structures on both sides making a possible case of migration and trap phenomena. This knowledge however cannot alone be used to interpret the presence of hydrocarbons as many other probabilities can exist based on the tectonic history (burial and uplift), un-conformities, hydrocarbon maturation time, fractures, total organic content etc.

3.8 Gridded Contour Maps

Marking the fault polygons paves the way to creating Grids of the respective horizons. These grids show the variation of time, throughout the base map, in time section of any horizon and depth in depth section of any horizon by using color representation. These Grids are then contoured using the software application to show contours of time or depth in respective case.

Contours are lines of equal value. The final products of all the seismic exploration are the contour maps, time or depth. Contour is a line joining points of same elevation (Coffeen. 1986). A structure contour map is one of the most important tools for structural interpretation because it represents the two-dimensional form of a map horizon. These contour maps represent the structural relief of the formation, any faulting and folding including dip of the strata.

3.9 Time Contour Maps

A time contour map shows the variation of time throughout the base map by means of contours. The pattern of Time Contour map confirms the shape of the subsurface structure. Time contour maps of these formations show 2D-variations with respect to time and the hydrocarbons probably accumulate at those places where contour values are low. The time contour maps of the horizons picked in this thesis are given as follows

3.9.1 Time contour map of Upper Goru

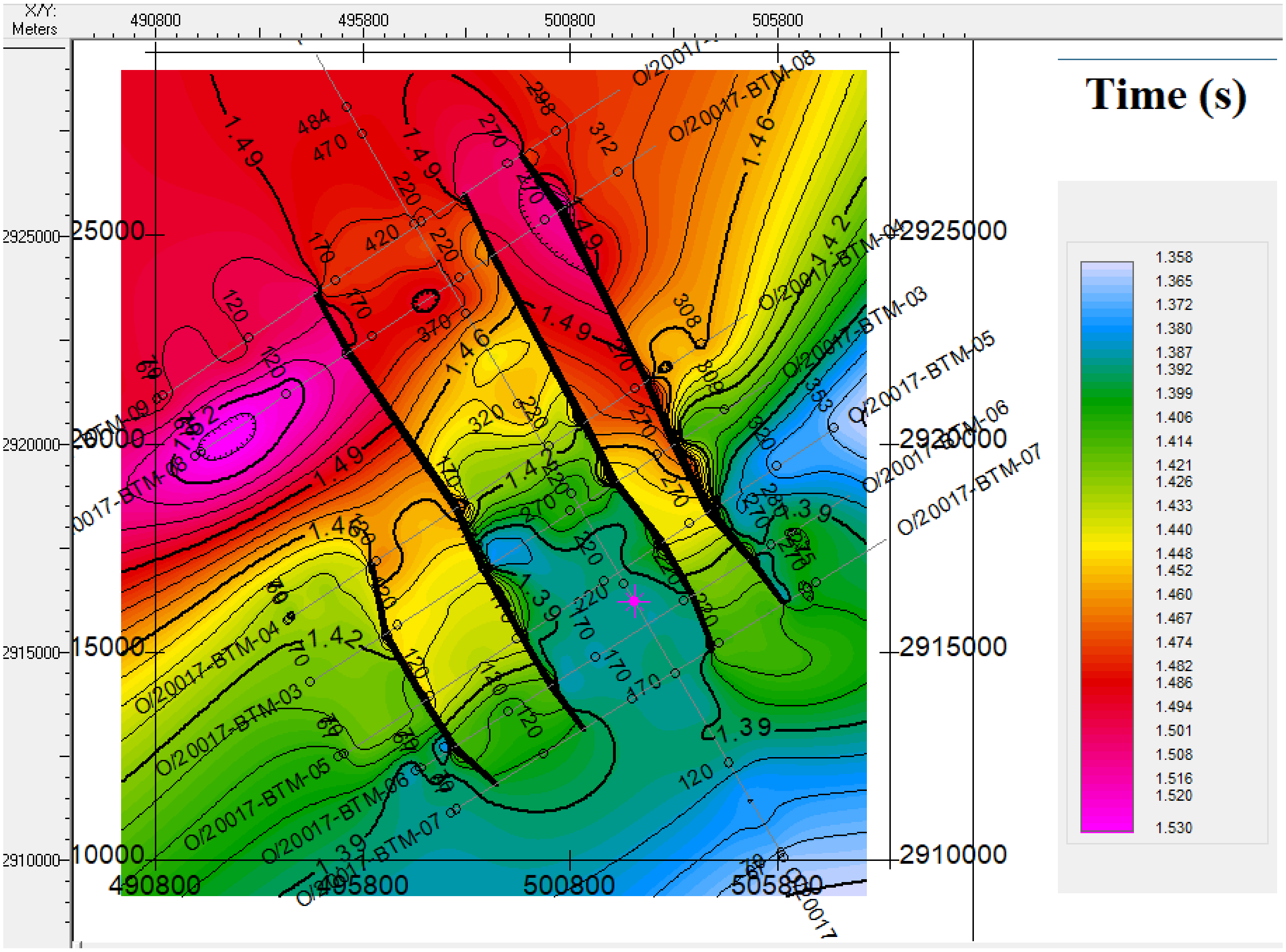


Figure 3.7: Time contour map of Upper Goru Fm. showing variation of time on base map.

The time contour map of the Upper Goru formation with a contour interval of 0.008s shows that the favorable petroleum play exist in the horst structure as shown by lower time values for the upper Goru horizon. The central fault polygons show horst structure which is surrounded by graben structures with larger time values.

3.9.2 Time contour map of Lower Goru

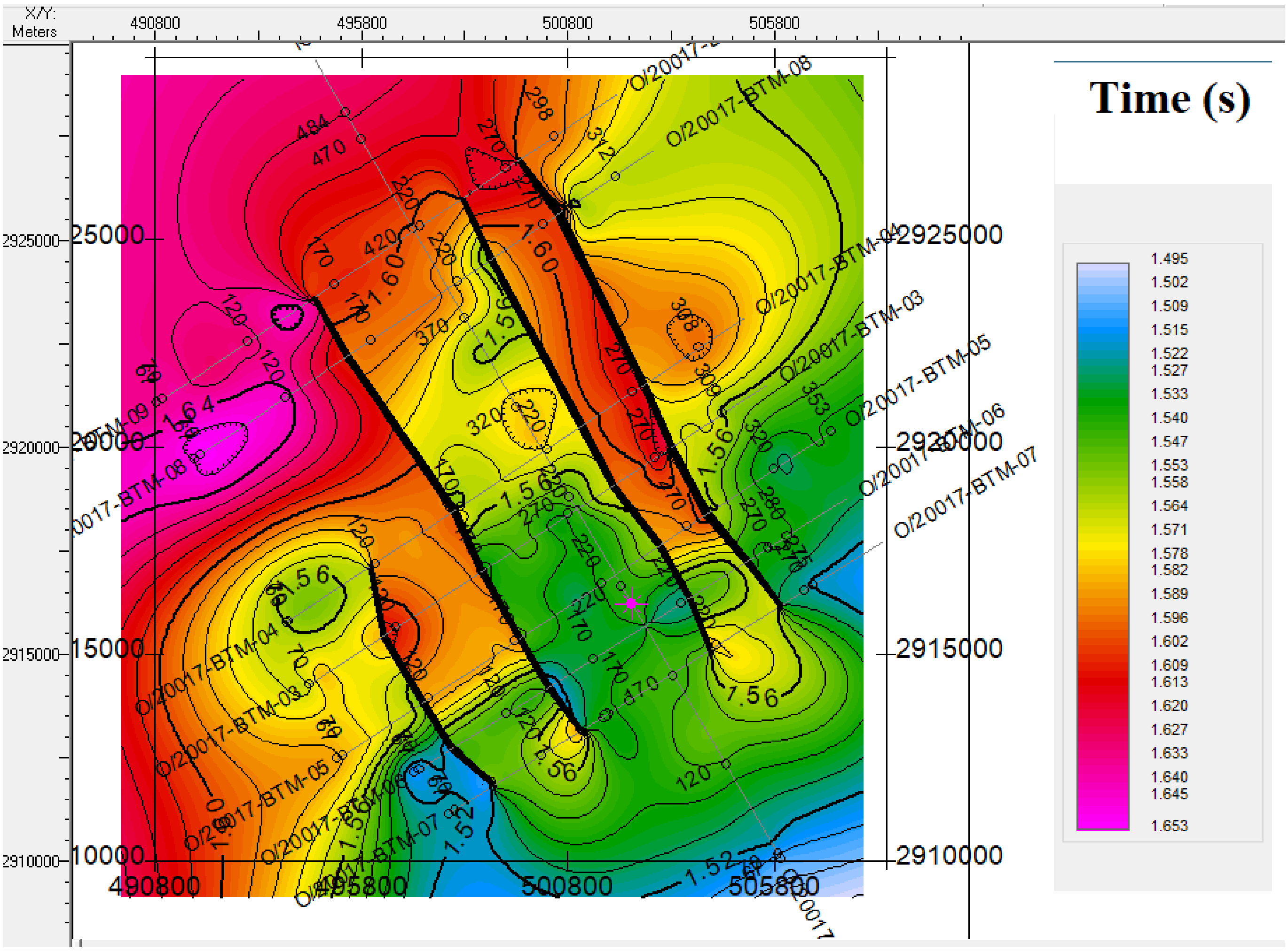


Figure 3.8: Time contour map of Lower Goru Fm. showing variation of time on base map.

Time contour map for lower Goru formation shows the same result as that of upper Goru formation since the same fault planes are passing through them therefore giving rise to the same structures.

3.10 Depth Contour Maps

Time contours tend to show the variation of time of the waves which are recorded on the geophones which would logically be greater for greater depths. These contours however do not show the real subsurface image. The depth contour maps depicts the real image of the lithologies the way they are present in the subsurface. In order to make the depth contour maps, we first convert the time values into the depth values which have been discussed in the previous section.

3.10.1 Seismic Depth Section Generation

The depth section interpretation required conversion of the time sections into depth sections. This was done by using the TD chart. The rest of the conversion can be done by two methods:

1) By using the tool for Depth conversion. The algorithm for such conversion is present in the Kingdom Suite software tools.
2) By using extended math tool which is a part of calculator present in Kingdom Suite.

3.10.2 Depth contour map of Upper Goru

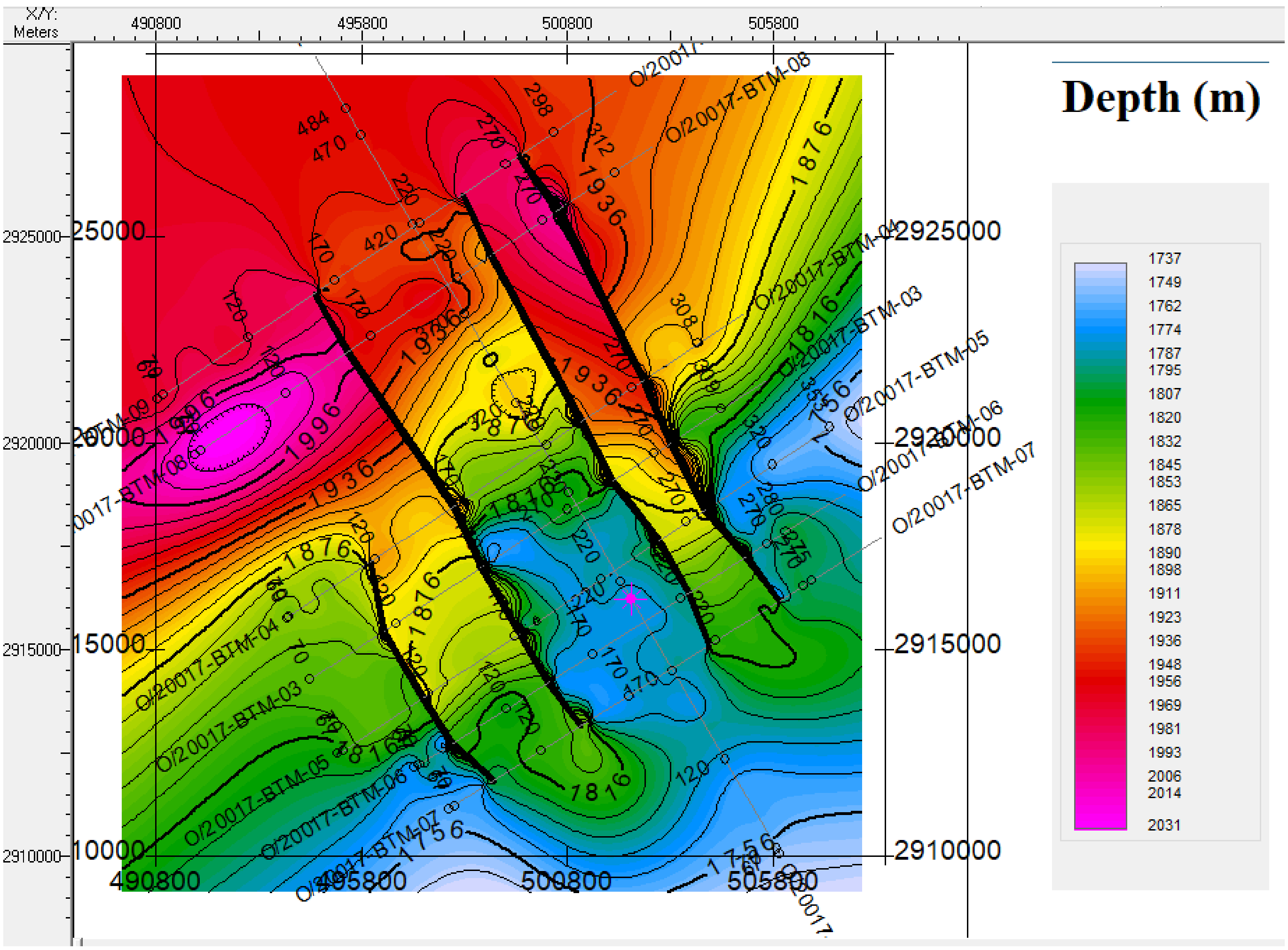


Figure 3.9: Depth contour map of Upper Goru

The contour map of Upper Goru with respect to depth confirms the pattern of the lithology in which it exists in the subsurface. The trend matches our previous interpretation of presence of horst and graben structures and a possible hydrocarbon migration and trapping mechanism. The reason for the coherence between the depth and time contour map for the upper Goru formation is because average velocity was used to develop the depth section hence the time and depth values are directly proportional to each other.

3.10.3 Depth contour map of Lower Goru

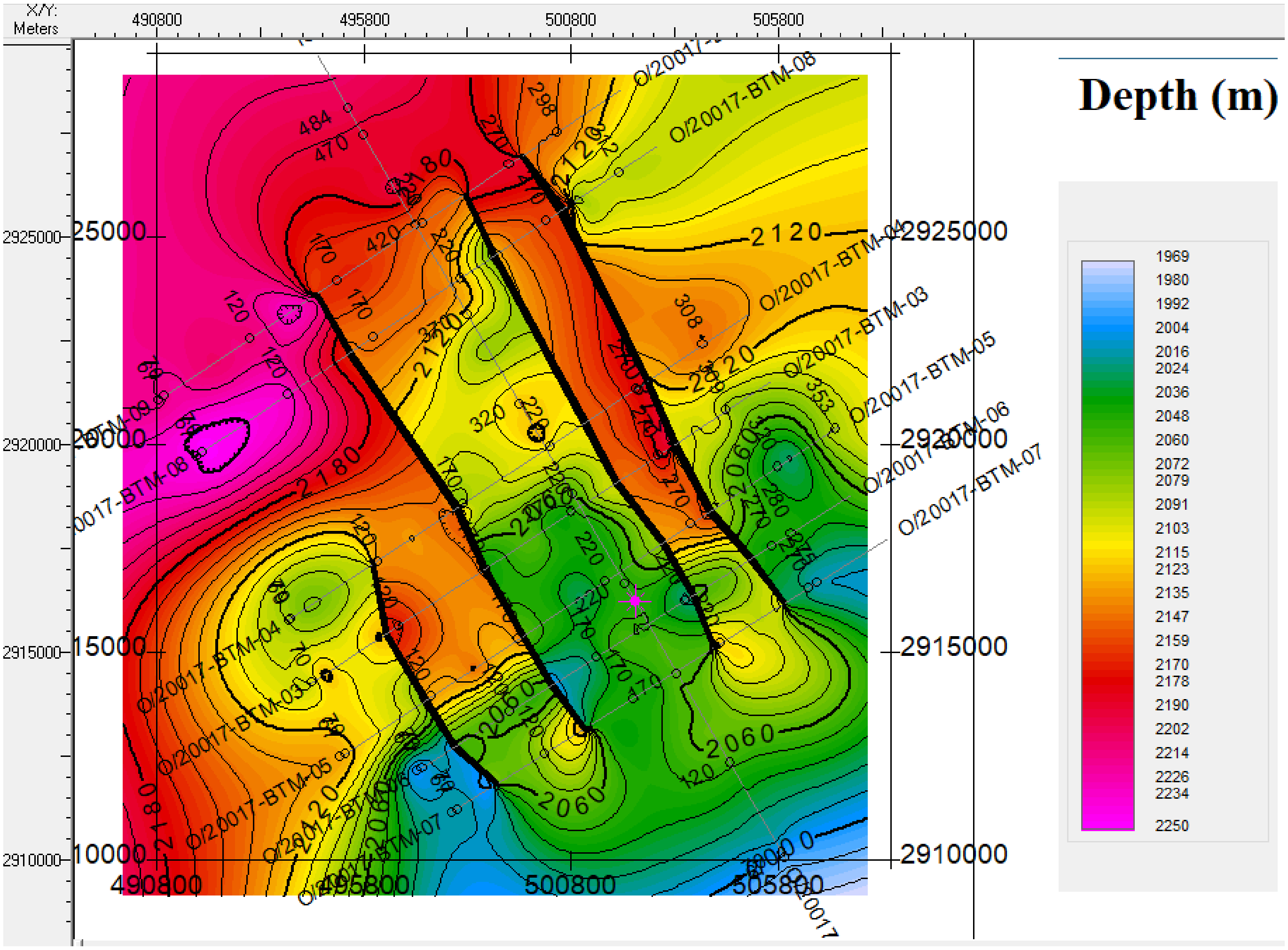


Figure 3.10: Depth contour map of Lower Goru

Lower Goru contour map with regards to depth follows, as it should, the same pattern as of Upper Goru with horst and graben structure confirmation complimenting the normal faulting system in response to the extension regime present in the locality.

Chapter 4

PETRO-PHYSICS

4.1 Introduction

Petro-physics (petro is Latin for "rock" and physics is the study of nature) is the study of the physical and chemical properties that describe the occurrence and behavior of rocks, soils and fluids. Petro-physicists evaluate the reservoir rock properties by employing well log measurements, core measurements, and sometimes seismic measurements, and combining them with geology and geophysics.

It is mainly used in the hydrocarbon industry to study the behavior of different kinds of reservoirs. It also explains about the chemistry of pores of the subsurface and how they are connected. It helps in controlling the migration and accumulation of hydrocarbons. While explaining the chemical and physical properties, petro-physics also explains many other related terms such as lithology, water saturation, density, Irreducible water saturation, Hydrocarbon saturation, Net pay thickness, permeability and porosity and many more.

The key role of petro-physics is to evaluate the rock properties by placing measurement tools in the bore hole. It is classified into three major parts namely

- Rock mechanical properties
- Ore quality
- Conventional Petro-physical properties

These properties provide complete description about the rock, for instance, they provide information about the size of the grains present, composition of the rock and the texture of the rock.

4.2 Reservoir Petro-physical Properties

Most petro physicists are employed to compute what are commonly called reservoir Petro-physical properties. These properties are used in lithological interpretation and saturation in the subsurface rocks. These are given as follows:

4.2.1 Lithology

What type of rock is it? When combined with local geology and core study, geoscientist can use log measurements such as natural gamma, neutron, density, Photoelectric, resistivity or their combination to determine the lithology downhole.

4.2.2 Porosity ϕ

The amount of pore (or fluid occupied) space in the rock. This is typically measured using an instrument that measures the reaction of the rock to bombardment by neutrons or by gamma rays. Sonic wave speed and NMR logs are also measured to derive rock porosity.

Nuclear magnetic resonance (NMR) logging, including porosity, saturation, hydrocarbon identification, facies prediction, and permeability.

4.2.3 Water saturation (SW)

The fraction of the pore space occupied by water. This is typically measured using an instrument that measures the resistivity of the rock.

4.2.4 Hydrocarbon saturation (H.C.S)

The fraction of the pore space occupied by hydrocarbon. This is typically measured by subtracting the water saturation from 1.

4.2.5 Net Pay

Thickness of rock that can deliver hydrocarbons to the well bore at a profitable rate.

4.3 Given Data

- Gamma Ray (GR)
- Spontaneous Potential (SP)
- Calliper Log (CALI)
- Velocity (DT)
- Density (RHOB)
- Neutron Porosity (NPHI)

- Deep Latero-log (LLD)
- Shallow Latero-log (LLS).

4.4 Tracks

Log is a record. Well log is a profile showing different properties of formation that is measured through wells. Every log give some information about subsurface. Some logs are correlated with other log to assure our prediction of lithologies. Interpretation of well log data is given below.

4.5 Lithology Track

4.5.1 GR log

GR logging tool detect the natural Gamma radiations across the formation. These radiations comes from radioactive element like Potassium, Uranium and Thorium etc. GR show maximum deflection for dirty lithologies (Shale) and minimum against clean lithologies. A clean lithology (Sandstone) have smaller quantity of clay minerals while a dirty lithology is enrich in clay minerals (Shale). From GR log we not only interpret lithologies but we can also find Volume of shale.

4.5.2 Spontaneous potential log

The spontaneous potential log (SP) measures the natural or spontaneous potential difference (sometimes called self-potential) that exists between the borehole and the surface in the absence of any artificially applied current. It is a very simple log that requires only an electrode in the borehole and a reference electrode at the surface. These spontaneous potentials arise from the different access that different formations provide for charge carriers in the borehole and formation fluids, which lead to a spontaneous current flow, and hence to a spontaneous potential difference. The SP log has four main uses: The detection of permeable beds, determination of Rw. The indication of the shaliness of a formation and for Correlation.

4.5.3 Caliper log

Caliper log tell us about borehole diameter. Borehole diameter is actually equal to the bit size. A line is drawn on the Caliper log which shows the size of borehole. A simple mechanical measures a vertical profile of borehole diameters. Any deflection from this line show the variation of borehole diameter and it actually gives us clue of the lithology. It is run in track 1 with Sp and GR log. Its variation effects the GR log values as variation in borehole size leads to replacement of lithology with brine. The brine can either have potassium ions which increases GR values or can have a negative effect on the GR values.

Increase of borehole diameter indicates Caving and Washouts and similarly decrease in borehole diameter indicates that Mud Cake has formed on the wall of borehole. Mud cake is formed when fluids pass from the borehole into the lithology and the particles from the brine are filtered out. Caliper log showing the decrease in bore-size indicates that mud cake is formed on the walls of bore hole, which is a good indicator of Permeable lithology because mud Cake only forms when rock is permeable. Caving and washouts show loose lithology, i.e. Shale, so increase of bore hole diameter is an indication of shale.

4.6 Resistivity Track

4.6.1 Resistivity logs

A log of the resistivity of the formation is expressed in ohm-m. The resistivity can take a wide range of values, and, therefore, for convenience is usually presented on a logarithmic scale from, for example, 0.2 to 2000 ohm-m. The resistivity log is fundamental in formation evaluation because hydrocarbons do not conduct electricity while all formation waters do. Therefore a large difference exists between the resistivity of rocks filled with hydrocarbons and those filled with formation water. Clay minerals and a few other minerals, such as pyrite, also conduct electricity, and reduce the difference. Resistivity logs are of various types these are described below

LLD

(Deep Latero-log) Latero-log deep also measures the true formation resistivity beyond the outer boundary of invaded zone.

LLS

Shallow Latero-log deep measures the resistivity in the invaded zone

MSFL

Micro spherically focused log measures the resistivity of the flushed zone (R-xo).

4.7 Porosity Track

4.7.1 Density Log

Density porosity log (RHOB) displays the electron density of formation in contact by detecting the scattered gamma rays. It gives an indication of porosity, lithology and can assist to detect gas bearing zone. Cross over of Neutron and density log is an indicator of Gas/hydrocarbons called Gas Effect. The overlapping curves indicate the presence of water.

4.7.2 Sonic log

Sonic log is a porosity log that measures interval transit time of compressional sound waves. It displays travel time of P-waves versus depth. Sonic logs are typically recorded by pulling a tool on a Wireline up the wellbore. The tool emits a sound wave that travels from the source to the formation and back to a receiver. (1).the interval transit time is dependent upon both lithology and porosity. For porous rock the travel time increases and hence the larger deflection occurs on the log display and for denser and nonporous material the traveling velocity increases and hence the travel time decreases.

4.7.3 Porosity log

Neutron log, density logs and sonic logs are the porosity logs. None of these logs gives direct porosity values. We can find the porosity of the formation by analyzing these logs.

4.7.4 Neutron log

Neutron log is based on effect of the lithology on fast neutrons emitted by a source. Hydrogen has the largest effects on these neutrons in slowing down and absorbing them. Since hydrogen is found in with water and hydrocarbons. This is found mainly in pores, so neutron is direct indicator of porosity

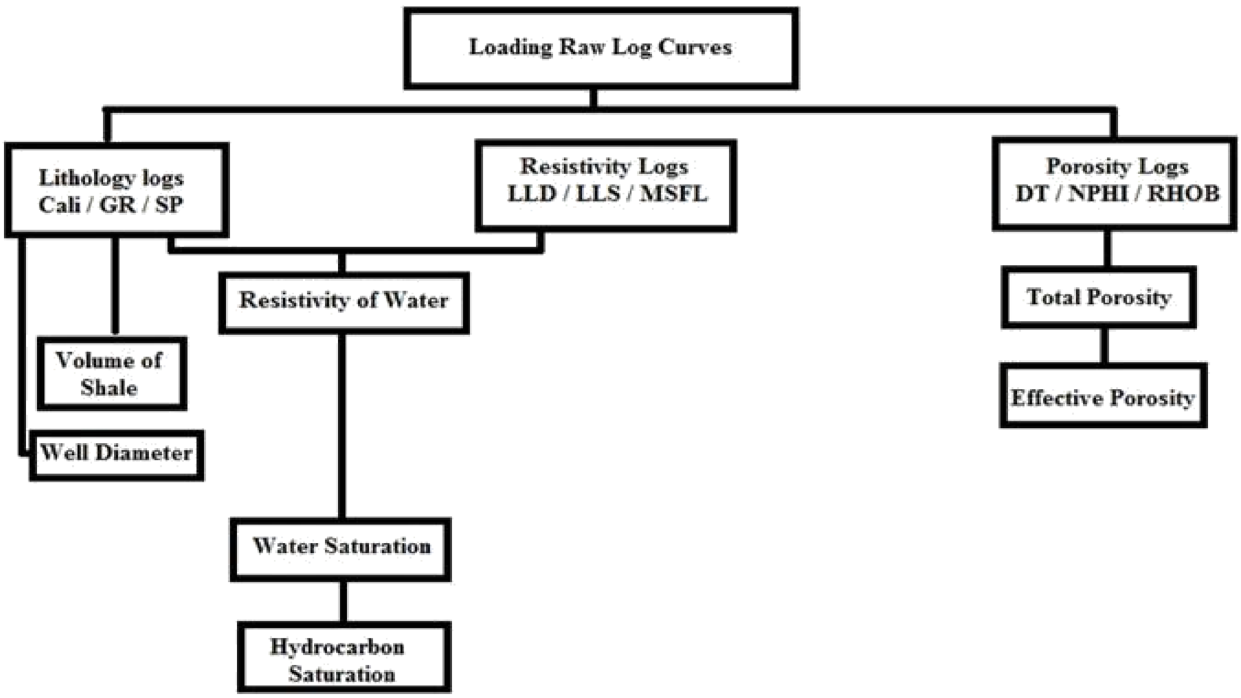


Figure 4.1 Petro-physics workflow

Volume of Shale

$$I_{gr} = \frac{(GR_{log} - GR_{min})}{GR_{max} - GR_{min}}$$

Sonic Porosity

$$\emptyset_s = \frac{(\Delta t - \Delta t_{mat})}{(\Delta t_f - \Delta t_{mat})}$$

Density Porosity

$$\emptyset_D = \frac{(\rho_{mat} - \rho_b)}{(\rho_{mat} - \rho_f)}$$

Average Porosity

$$\emptyset_{AVG} = \frac{(\emptyset_N + \emptyset_D)}{2}$$

Static Spontaneous Potential

$$SSP = SP(clean) - SP(shale)$$

Formation Temperature

$$FT = ST + \frac{(BHT - ST)}{(TD \times FD)}$$

Resistivity of Mud Filtrate

$$R_{mf2} = R_{mf1} \times \left(\frac{ST + 6.77}{FT + 6.77}\right)$$

Water & Hydrocarbon Saturation

$$Sw(\%) = (A \times Rw/RT \times \emptyset^{M})^{\frac{1}{N}}$$

$$S_h(\%) = 100 - S_w\,(\%)$$

Figure 4.2: Formulae used in Petro-physics

4.8 Petro-physics of Lower Goru Formation

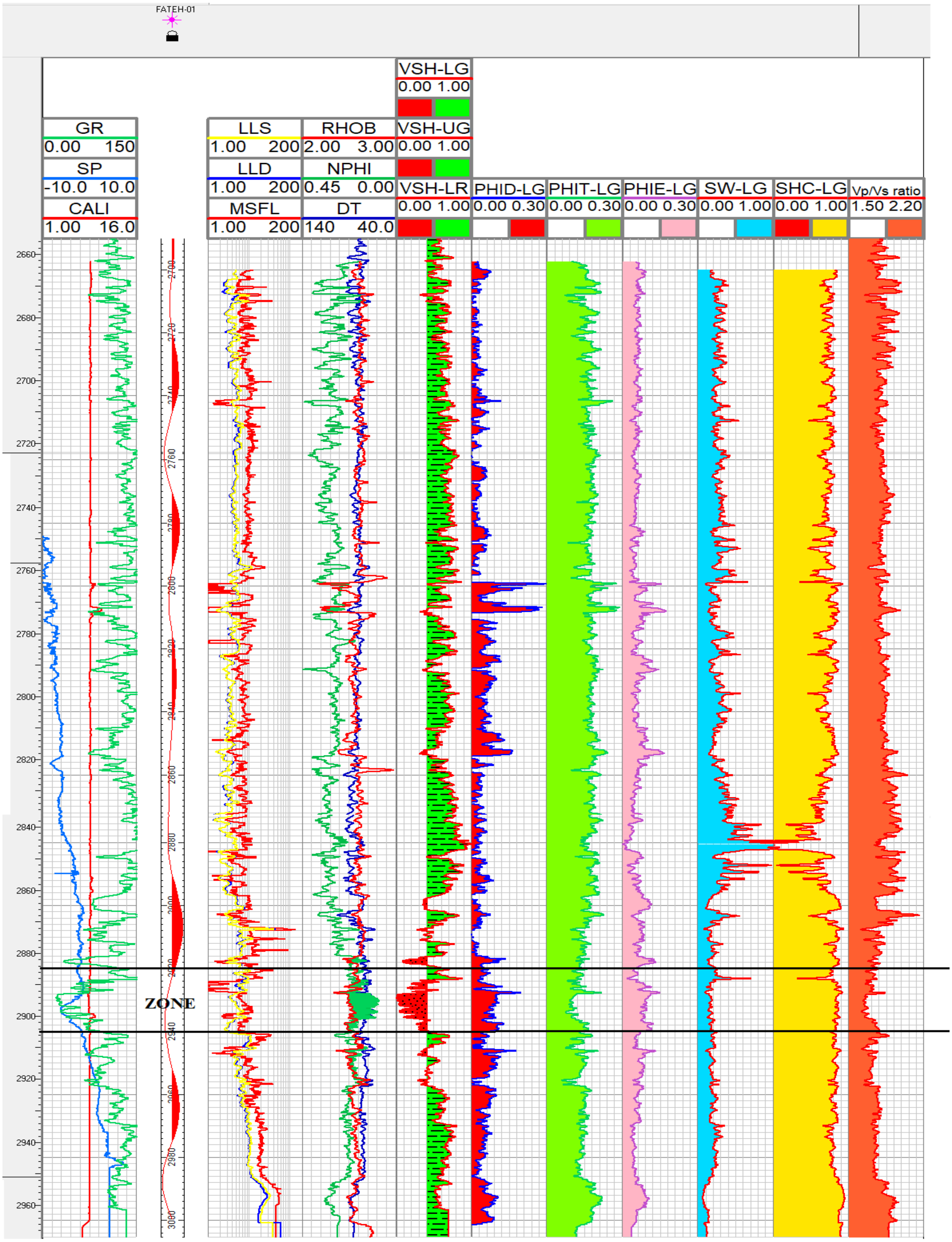


Figure 4.3: Petro-physical logs analysis of Lower Goru formation

The petro-physical analysis of the Goru formation present in the Bitrism area through the logs run in Fateh-01 Well indicates the presence of shale in a greater amount. The logs show variation as as the subsurface lithology varies. In this locality, Lower Goru mostly consist of shale beds with interbedded sands. These sands can act as potential gas- sand reservoirs. The results of petro-physical analysis of Lower Goru Formation in terms of percentage are given as follows

4.8.1 Lower Goru Petro-Physical Results

Table 4.1: Petro-physical results of Lower Goru Formation

Lower Goru Petro-Physics Results						
Log	**PHID LG**	**PHIE LG**	**PHIT LG**	**SHC LG**	**SW LG**	**VSH LG**
Range	0 - 0.3	0 - 0.3	0 - 0.3	0 - 1	0 - 1	0 - 1
Average	0.04	0.06	0.16	0.707	0.29	0.60
Avg. in %age	13.3	20.8	53.8	70.8	29.2	60

Table 4.2: Petro-physical results of Reservoir in Lower Goru Formation

Petro-Physics Results of Reservoir with in Lower Goru (2920-2940m)						
Log	**PHID LG**	**PHIE LG**	**PHIT LG**	**SHC LG**	**SW LG**	**VSH LG**
Range	0 - 0.3	0 - 0.3	0 - 0.3	0 – 1	0 - 1	0 - 1
Average	0.07	0.08	0.16	0.707	0.29	0.60
Avg. in %age	26	27	40	81	19	29

Where,

PHID is Porosity density

PHIE is Effective porosity

PHIT is Average porosity

SHC is Hydrocarbon saturation

SW is Water saturation

VSH is Volume of shale

4.9 Compressional and Shear Wave Velocities

Compressional waves are primary waves which are longitudinal in nature and are denoted as VP. Shear waves are secondary waves with transverse motion of particle mechanism and are denoted by VS.

4.9.1 Compressional Velocity to Shear Velocity Conversion

The compressional Velocity determined through the sonic can be converted into the shear wave velocity by using the following formula:

$$VS = \frac{VP - 1.36}{1.16}$$

Where, VP is compressional velocity in Km/s

VS is shear velocity in Km/s

4.9.2 VP/Vs ratio vs Compressional Velocity (VP)

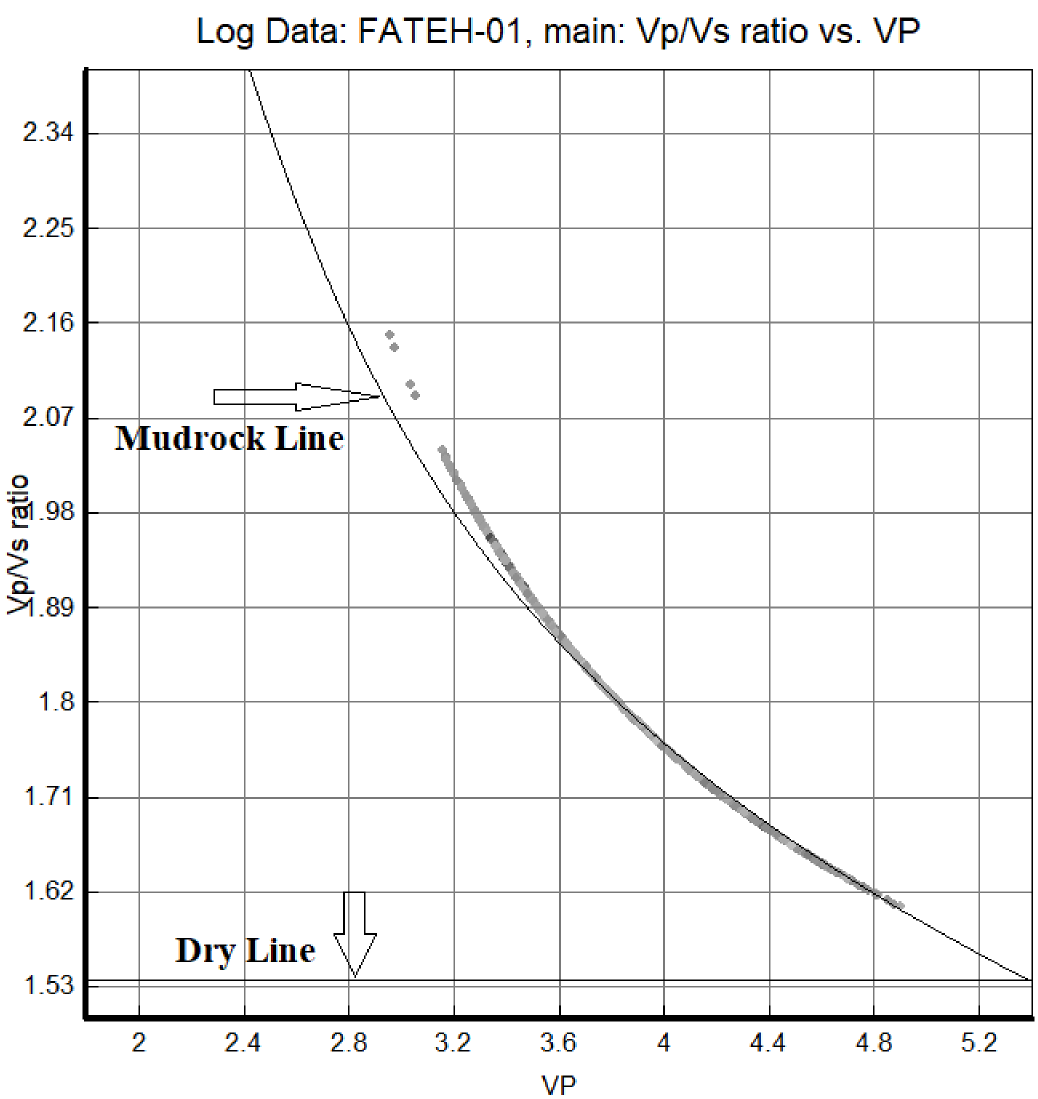


Figure 4.4: plotting VP/VS against VP results

The comparison with the ultrasonic measurement of VP/VS vs VP of the Berea sandstone (J.P Castagna, et al., 1985) shows the variation presence of mudrock (shale) interbedded with sand and probable saturation.

4.9.3 Poisson's Ratio vs Compressional Velocity (VP)

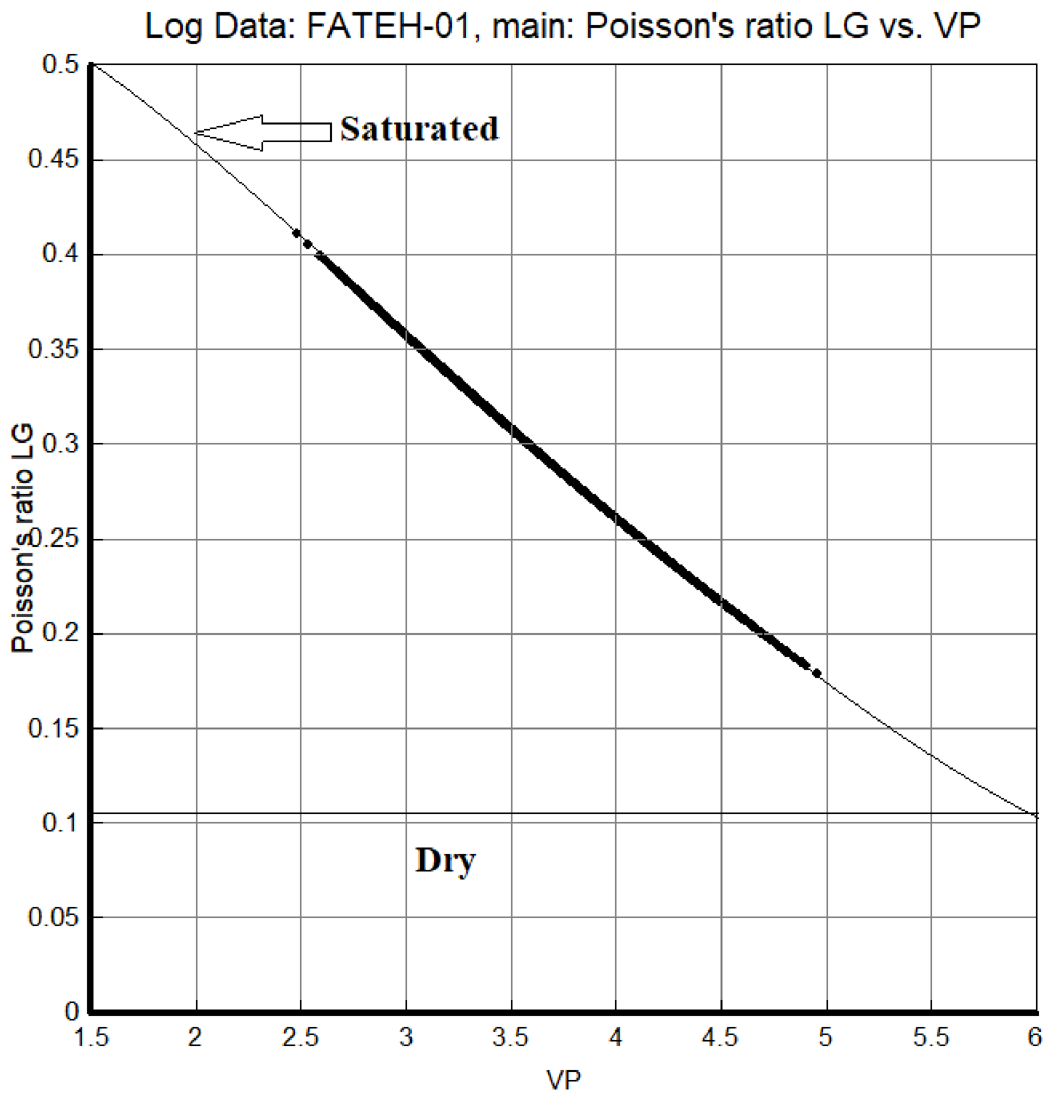


Figure 4.5: Poisson's Ratio values vs compressional velocity values

The Poisson's ratio has been calculated by using the formula as given below:

$$v = \frac{1}{2}\frac{(Vp/Vs)^2 - 2}{(Vp/Vs)^2 - 1}$$

The comparison of the results and that of the computed relationships between Poisson's ratio and the compressional velocity (J.P. Castagna et al., 1985) shows that our lithologies are on the margin of saturation line. Thus there is a probability of saturation.

Chapter 5

FACIES MODELING

5.1 Introduction

In geology, a facies is a body of rock with specified characteristics. Generally the facies is distinctive rock unit that form under certain condition of the sedimentation that reveals the environmental process.

The differentiation between the shale and sand has been constantly challenged for the geoscientist. In this process the key challenge is identifying the facies, from logging and core data, and degree to which the shale content effect the reservoir properties. This gives the main indication about the productive zone in the reservoir (Kurniawan, 2005).This problem leads us towards the cross plots which provides us the relationship between the reservoir properties and log response (Naji et al., 2010).

These facies are related to the certain depositional environment. Basically the depositional environment is specific type of place where the facies are deposited. Such as the Glaciers. Lakes, Abyssal plain, Sea bottom. Stream, Delta etc. The different types of the environment are shown in the below figure 6.1.

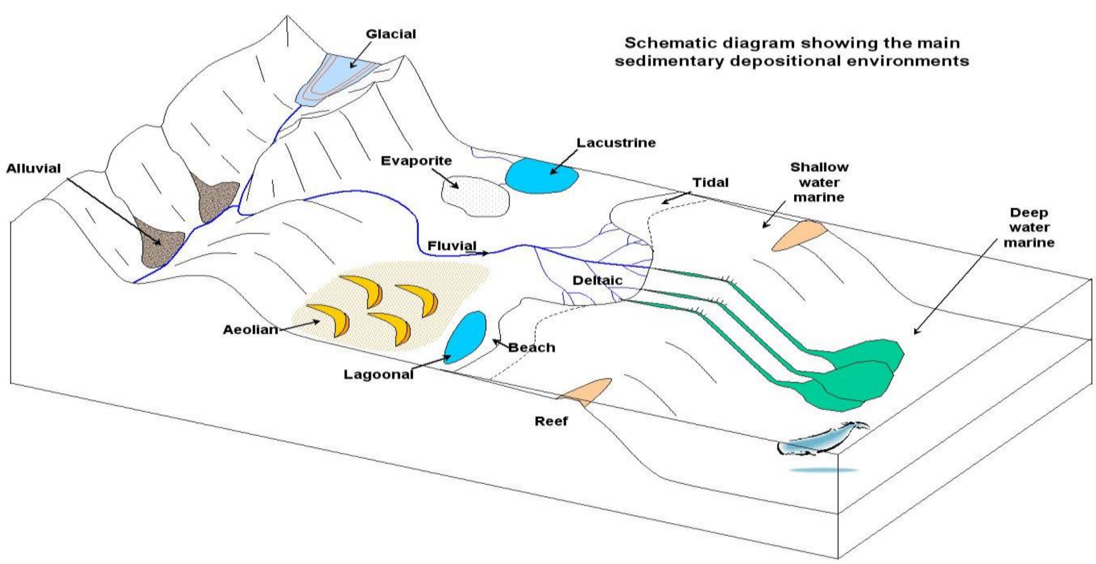


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Figure 5.1: different depositional environments and their associated deposition *Mike norton, (2008).*

5.2 Walther's Law of Facies

Walther's Law of Facies, or simply Walther's Law, states that the vertical succession of facies reflects lateral changes in environment. Conversely, it states that when a depositional environment "migrates" laterally, sediments of one depositional environment come to lie on top of another. A classic example of this law is the vertical stratigraphic succession that typifies marine transgressions and regressions. However, the law is not applicable where the contact between different lithologies is non-conformable (Lucia 1995)

5.2.1 Transgression

A marine transgression is a geologic event during which sea level rises relative to the land and the shoreline moves toward higher ground, resulting in flooding. During this period retro-gradation takes place which is movement of facies deposition towards the landward side. Maximum flooding surface is related to the extent of transgression phenomena.

5.2.2 Regression

A marine regression is a geologic event during which sea level falls relative to the land and the shoreline moves toward lower ground and exposes former sea bottom. During this period, pro-gradation takes place that is movement of facies deposition towards the seaward side.

5.3 Facies Analysis

The identification of a bed's lithology is fundamental to all reservoir characterization because the physical and chemical properties of the rock that holds hydrocarbon affect the response of every tool used to measure formation properties. Understanding reservoir lithology is the foundation from which all other Petro-physical calculations are made. To make accurate Petro-physical calculations of porosity, water saturation (Sw) and permeability, various lithologies of the reservoir interval must be identified and their implications understood. Lithology means the composition or type of rock such as sandstone or limestone.

5.4 Facies Analysis of Lower Goru

An effort has been made in this thesis to plot various logs and by means of geophysical knowledge of the logs, to mark the facies present in the subsurface. Facies analysis of only Lower Goru Formation has been done. The results were as follows:

5.4.1 Cross plot of LLD and RHOB Logs

A cross plot between the resistivity log LLD and the density log RHOB has been shown for Lower Goru. It consists of LLD log on Y axis, RHOB log on X axis and GR log as a reference log on Z axis.

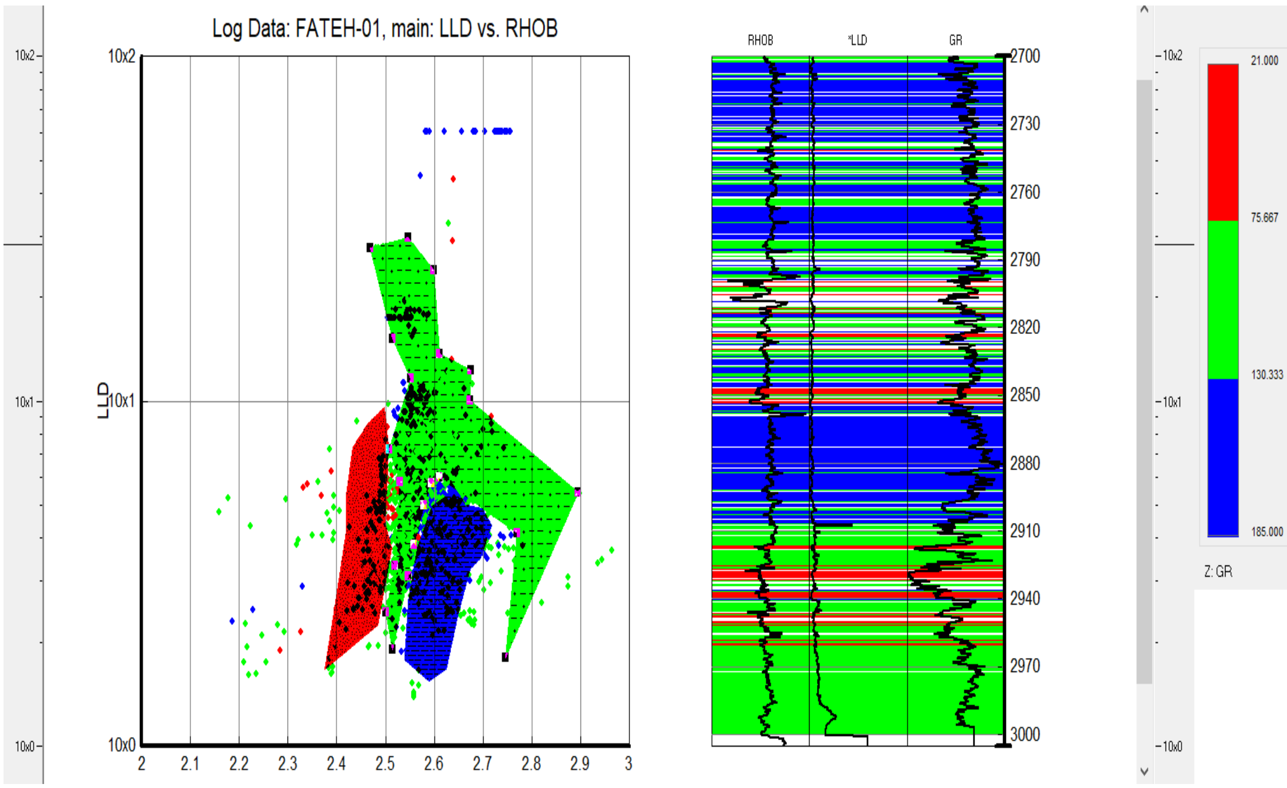

Figure 5.3: Cross Plot of LLD vs RHOB showing different facies

5.4.2 Results

The zone shaded by blue shows high GR values witch comparatively high density values. Thus indicating presence of shale.

Red zone shows low GR values with comparatively lower density hence depicting sand beds which are present in minute quantity in the Lower Goru Formation of the Bitrism area.

Green zone displays sand particles intermixed with the shales with shales being in major proportion. Thus showing average GR and density values.

5.4.3 Cross plot of DT and RHOB Logs

A cross plot between the sonic and the density log again verifies the type of lithologies present in the subsurface Lower Goru Formation. DT log has been taken on Y axis with RHOB log on X axis and GR log as a reference log

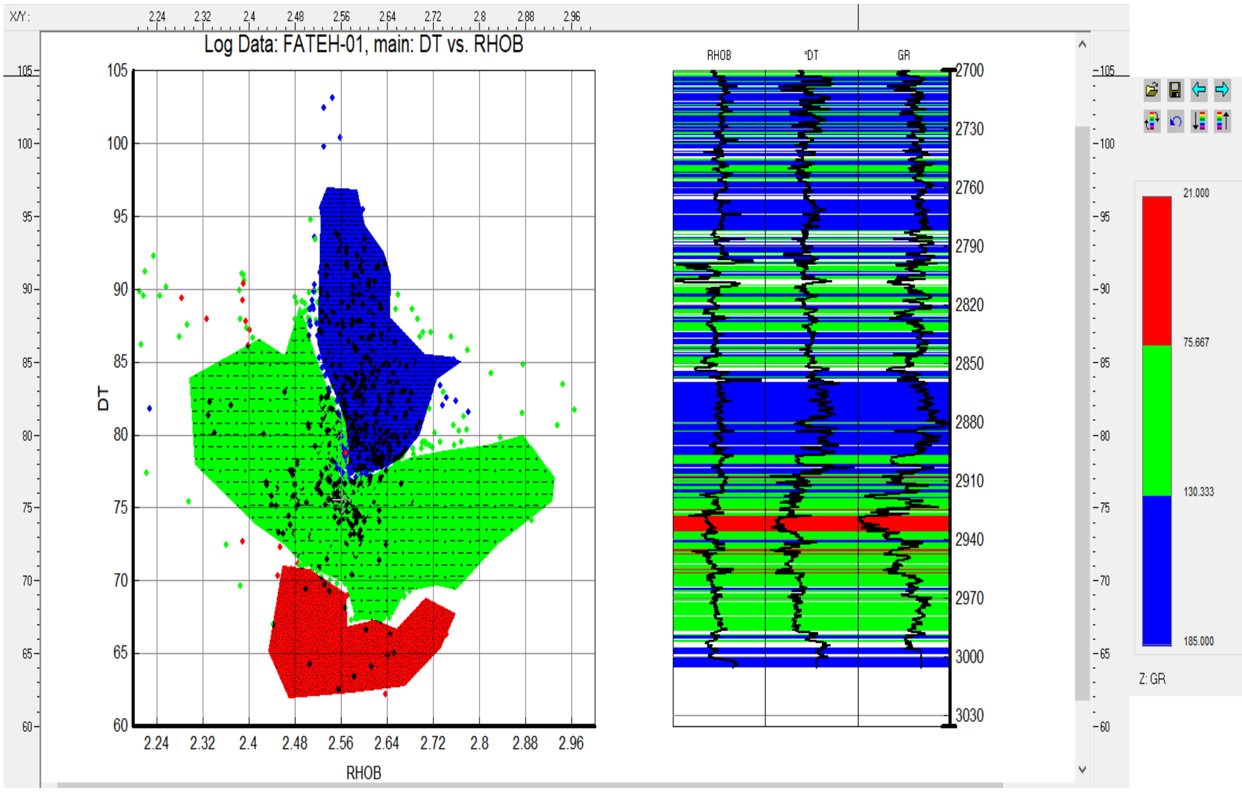

Figure 5.4: Cross plot of DT and RHOB log showing facies variation

5.4.4 Results

The results show similar pattern to that of the LLD vs RHOB log confirming the presence of the respective lithologies shown in the previous cross plot.

The Red zone shows low GR values and lower density but the sonic values are low hence depicting absence of hydrocarbons in the sand beds.

Green zone expresses minor sand particles present in major proportion of shales making shaley sand beds. This in confirmed by average GR values with average RHOB values and high sonic figures due to saturation of the shales.

Blue zone is attributed by high GR values and high density and complimented by high DT values. Hence depicting presence of shale beds in major proportion of all the three facies with probable chance of saturation.

5.4.5 Cross plot of NPHI and RHOB Logs

The cross plot of NPHI and RHOB logs from depth 2700m to 3005m will be done to show the facies variation in the Lower Goru Formation of the Bitrism Area. NPHI log has been placed on Y axis with RHOB on X axis and GR as a Reference log.

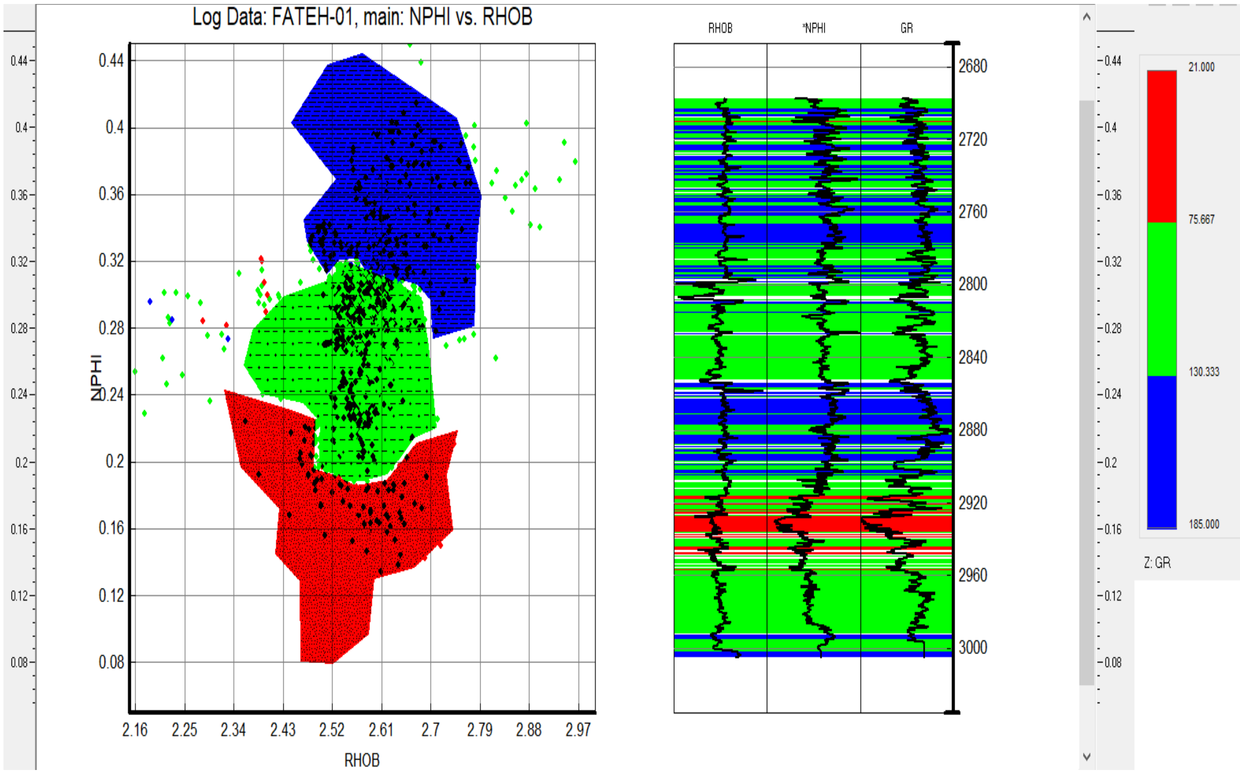

Figure 5.5: Cross plot of NPHI and RHOB log showing facies variation

5.4.6 Results

The results of the NPHI vs RHOB logs confirm the presence of shale in major proportion interbedded with sand and a few sand beds

The sand bed depicted by the red shows low GR, low RHOB and low NPHI values.

The shales have high GR values, high RHOB and high NPHI values as shown by blue colored zones.

The sandy shales show average values of the respective logs.

Chapter 6

COLORED INVERSION

6.1 Seismic Inversion:

Geophysical inversion involves mapping the physical structure and properties of the subsurface of earth using measurements made on the surface of earth. Another way to look at seismic inversion is to consider it as the technique for creating a model of the earth using the seismic data as input. As such, it can be considered as the opposite of the forward modelling technique, which involves creating a synthetic seismic section based on a model of the earth (or, in the simplest case, using a sonic log as a one-dimensional model).

6.2 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 (spectral blueing). 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 relationships 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).

Colored inversion converts the seismic data to a relative impedance data set. The advantages of colored inversion are the speed of calculation and avoidance of artifacts that may be introduced by a model. Colored inversion, whether acoustic or elastic impedance (Connolly, 1999), is an excellent qualitative interpretation too.

A method was developed by Lancaster and Whitcombe (2000) which called Colored Inversion (CI). The CI method is a simple and fast technique to invert the band-limited seismic data to relative impedance and can be done by generating a single operator to match the average seismic spectrum to the shape of the well log impedance spectrum.

Colored Inversion 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.

6.3 Work Flow Adopted

Below is work flow which I have followed for performing colored inversion on my data.

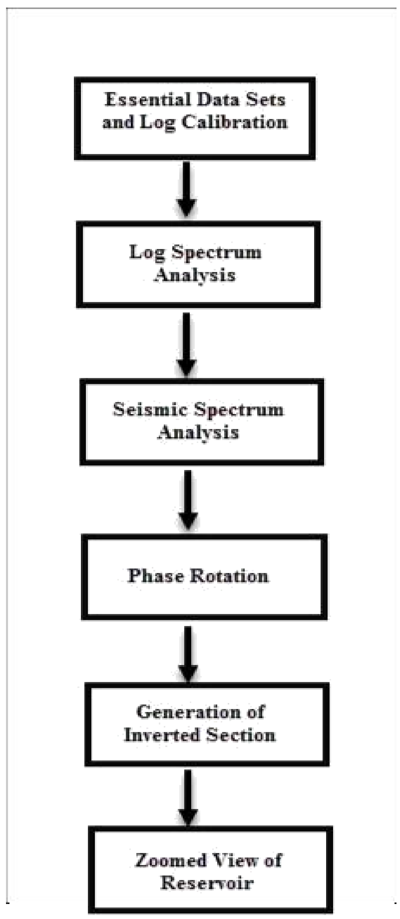

Figure 6.1: Workflow for colored inversion

6.4 Colored Inversion Computation

The colored inversion computation requires the following as input:

- DT log
- RHOB log
- Formation tops
- TD chart

The amplitude spectra of the impedance logs (velocity * density) derived for the window of interest can be calculated and displayed on a log-log graph from which a linear spectral slope can be estimated. The fitted line can be expressed as the exponential α in the equivalent representation of the spectral trend in the form A*fα.

Butterworth filter is used to smooth and constrain the impedance log spectrum. The Butterworth filter is a type of signal processing filter designed to have as a flat frequency response as possible in the pass band.

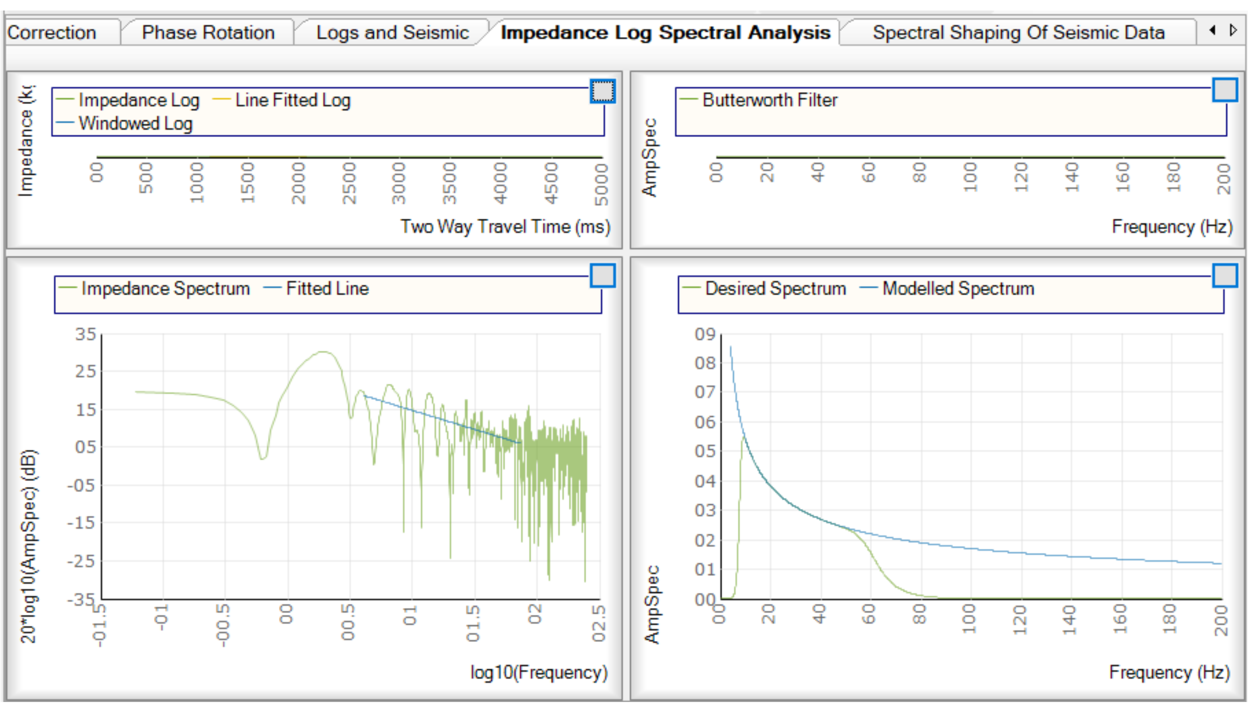

Figure 6.2: smoothing of impedance spectrum using Butterworth filter

The amplitude spectra are averaged and smoothed – to enable a smooth spectral shaping operator to be derived to operate on the data.

The phase of the operator is a constant -90° which is in agreement with the simplistic view of inversion to integration, and the concept of a zero-phase reflection spike being transformed to a step AI interface, provided the data are zero-phase.

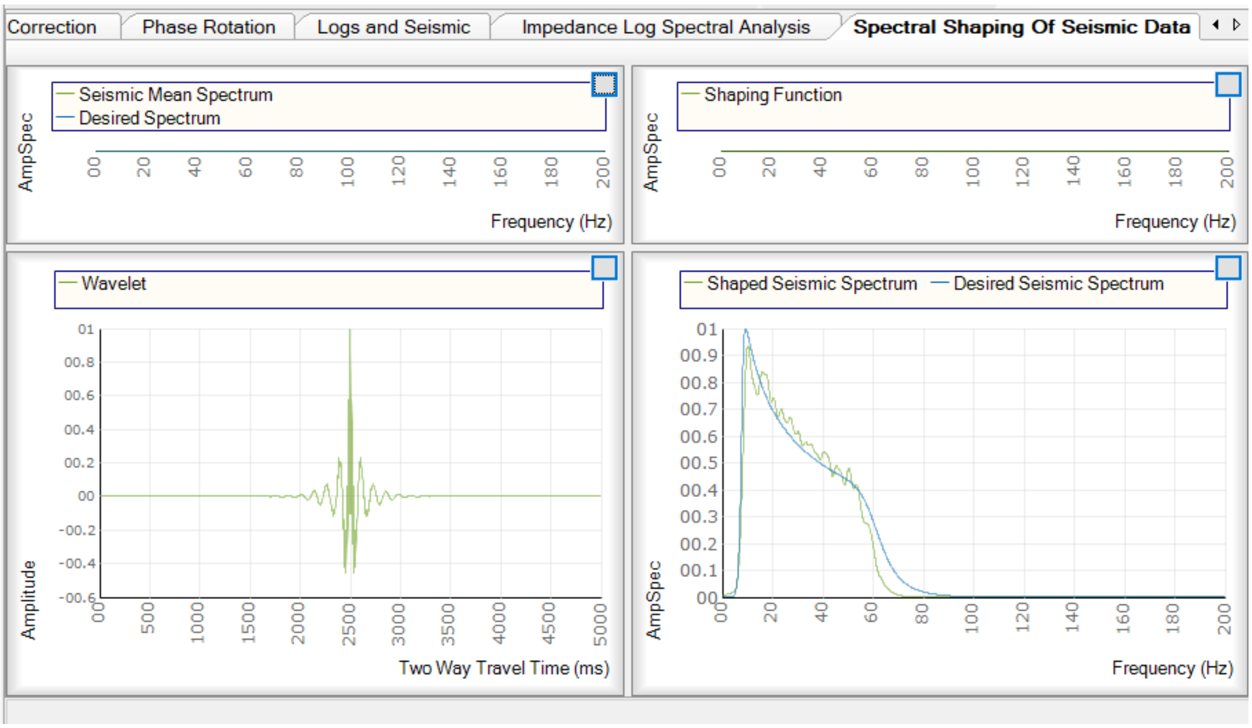

Figure 6.3: Spectral shaping and extraction of wavelet

6.5 Colored Inversion of 20017-BTM-02

The colored inversion applied to the strike line 20017-BTM-02 of my data gave the following results.

Figure 6.4: Colored inversion of 20017-BTM-02 line.

The results show the decrease in acoustic impedance shown by RED in some portion of Lower Goru depicting presence of hydrocarbons. A major bed in the Ranikot Formation also show low Acoustic impedance values.

Conclusion

- Time and depth contour map indicates presence of horst and graben structures forming a favorable petroleum play.
- Rock physical properties also show probable hydrocarbon saturation.
- Facies analysis confirms presence of shale lithologies interbedded with sand beds.
- Petro-physical analysis confirms presence of sand reservoir with hydrocarbon saturation of 81% and water saturation of 19 % with an effective porosity of 27.5%.
- Colored inversion confirms the lead for the presence of hydrocarbons in the zone of interest.

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