2-D Seismic Interpretation and Well Logs Interpretation of Badin Area Lower Indus Basin, Pakistan

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CERTIFICATE

It is certified that **Muhammad Mubashir Rana** s/o **Muhammad Yameen** 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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Acknowledgement

First and foremost, all praises to Allah Almighty, the most beneficent and the most merciful. Secondly, my humblest gratitude to the Holy Prophet Muhammad (Peace Be upon Him) whose way of life has been a continuous guidance and knowledge of humanity for me. This thesis appears in its current form due to the assistance and guidance of several people. It gives me great pleasure to express my gratitude to all those who supported me and have contributed in making this thesis possible.

I express my profound sense of reverence to **Dr. Mumtaz Shah** who gave me the opportunity to work under his supervision. His continuous support, motivation and untiring guidance have made this thesis possible. His vast knowledge, calm nature and positive criticism motivated me to starve for pleasant results. Thanks to him for bearing my mistakes and whenever I could not meet the deadlines.

To me, there is nothing better than having good friends, so great pride is with me while thanking M. Ehsan Rafique, Bilal Ahmed, Hassan Sardar, M. Azam , M. Wajahat, Aqeel Nawaz, Sarmad Rameez, Yawer Amin and my all friends. Words are lacking to express my humble obligation for their helping attitude, and Kind Corporation. The time spent with them will remain unforgettable for me.

Last but not least, I would like to acknowledge my **Parents, brothers, sister** and my **family** for their constant support, unceasing prayers and best wishes. They uplifted my morale whenever I needed.

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Muhammad Mubashir Rana

DEDICATION

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ABSTRACT

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Two-dimensional seismic interpretation has been carried out in lower Indus basin, Badin area to confirm the reservoir characteristics of lower Goru formation to delineate promising locations for test drilling. Time and depth contour maps of lower Goru confirm the presence of horst and graben structure with tilted normal fault in the given area.

On the basis of Petrophysical analysis the average porosity values for the promising zone range from 10 to 15% and average values of water saturation range from 75-80%, which cause the failure of Doti-01 well. The average range of volume of shale range 15 to 20%. No major zones can be selected for production due to the high values of water saturation. Cross plots has been generated to confirm the lithologies of the reservoir. Different attributes has been studied to analyses the expected hydrocarbon zone and also to investigate the seismic properly. Coloured inversion shows low acoustic impedence at reservoir level.

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CONTENTS

Chapter 1

Introduction to Study Area

1.1 Introduction to Study Area

Pakistan has high potential of Hydrocarbon in its Southern (Badin, Mari Etc.) And Northern Parts (Potwar, Kohat Plateau). Lower Indus Basin has been serving as a potential zone from which economic amount of Hydrocarbon are recovered. Badin (Study Area) has been famous for its Gas production over the Years. Southern Sindh Monocline is Prolific Hydrocarbon Producing Basin of Pakistan Contributing 28% of The Country's Total Recoverable Oil Reserves and 90% of Sindh total recoverable reserves,(According to Pakistan Energy Year Book 2013, Published by Hydrocarbon Development of Pakistan, Islamabad). Similarly Southern Sindh Contribute 13% of the Country's Total Gas And 24% of Sindh total Gas reserves as of Energy Year Book 2013. Field size distribution in southern Sindh monocline also carried out for more than 100 fields of oil and result shows that most of oil fields are smaller in size. More than 50 % of oil fields in southern Sindh are less than 1 million of barrel (US) as original recoverable size. Lower Goru sands are common reservoir in southern Sindh monocline with proved Sembar Goru play.

1.2 Location

The study area lies in lower Indus basin. Geographically it is located (24.66 N latitude, 69.0 E longitude) shown in figure 1.1, it is approximately 160 km due east of Karachi city. Sukkur rift is dividing between southern and central Indus basin. Southern Indus basin is bounded by Indian shield to the east and marginal zone of Indian plate to west its southward extension is confined by off-shore Murray ridge-oven fracture plate boundary.

1.3 Seismic Lines

Time migrated seismic sections of the lines "PK92-1681, PK92-1686,1694 , PK94-1804 "are Provided for analysis and interpretation. These lines have been processed to get final migrated stacks which have been used for interpretation. Seismic lines show many prominent reflectors which are displayed at different location. The breakage in the reflectors helps in identifying the faults. Basement and other prominent reflectors show high amplitudes, indicating strong reflection coefficients.

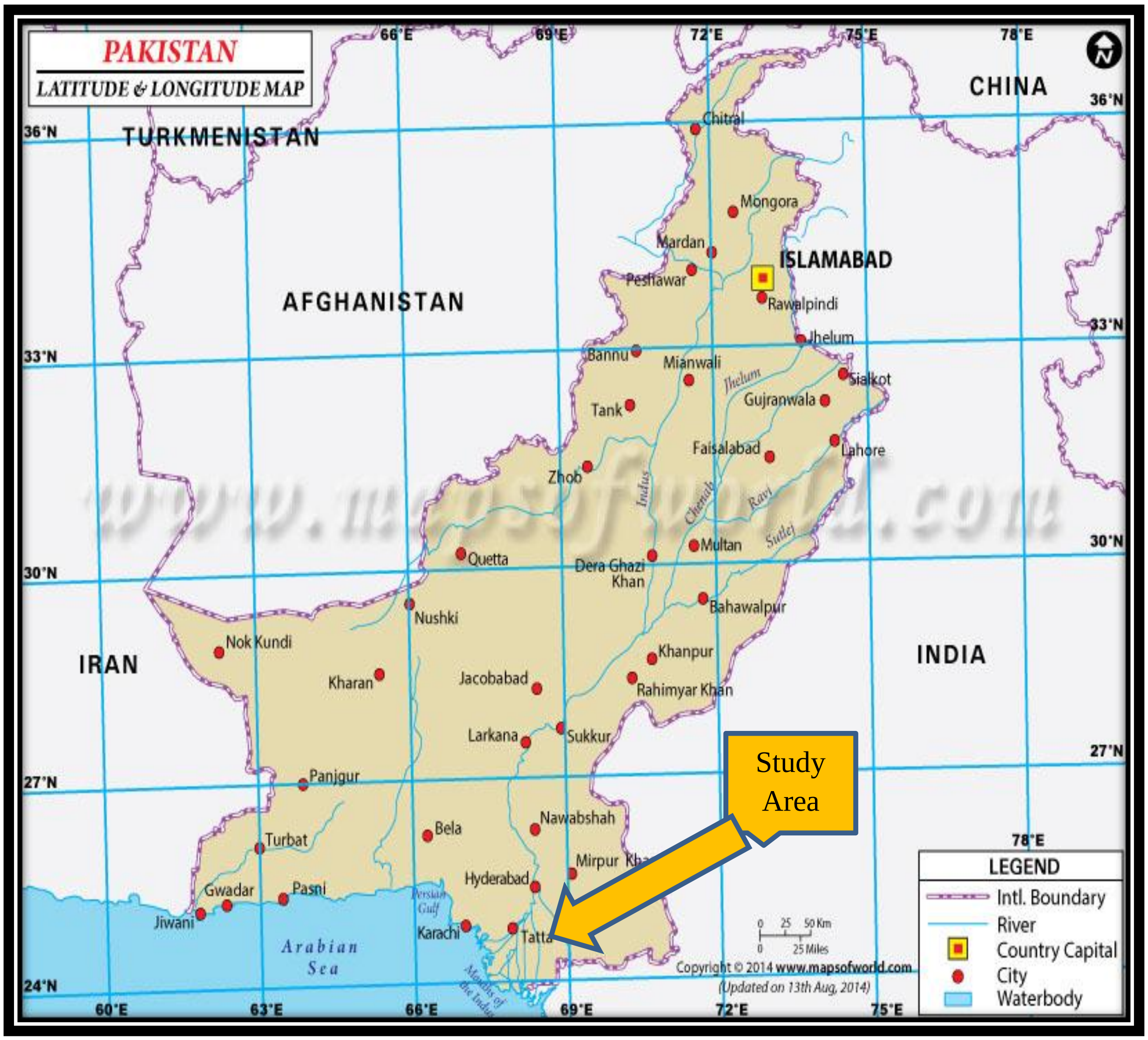

Figure 1.1 Location of Badin block (www.mapsofworld.com).

1.4 Well Data

Doti-01 well is used. This well data contain all information of logs run in the well and well tops. Well tops and other information of well given in table 1.2

1.5 Base Map

A base map is the map on which primary data and interpretations can be plotted. The base map is an important component of interpretation, as it displays the spatial position of each picket of a seismic section. It also shows the spatial Relationship of all seismic sections under consideration, their tie point locations and provides the framework for contouring. The base map of the area is generated by plotting data in Universal Transverse Mercator (UTM, zone 42N) geodetic reference system. The base map given in figure 1.2 shows the orientation of the lines used for study. The lines under study PK92-1681, PK92-1686, 1694, PK94-1804. The Well used for marking the horizons is Doti-01, all information about well is given in table 1.2. The lines used for base map are given in table 1.1.

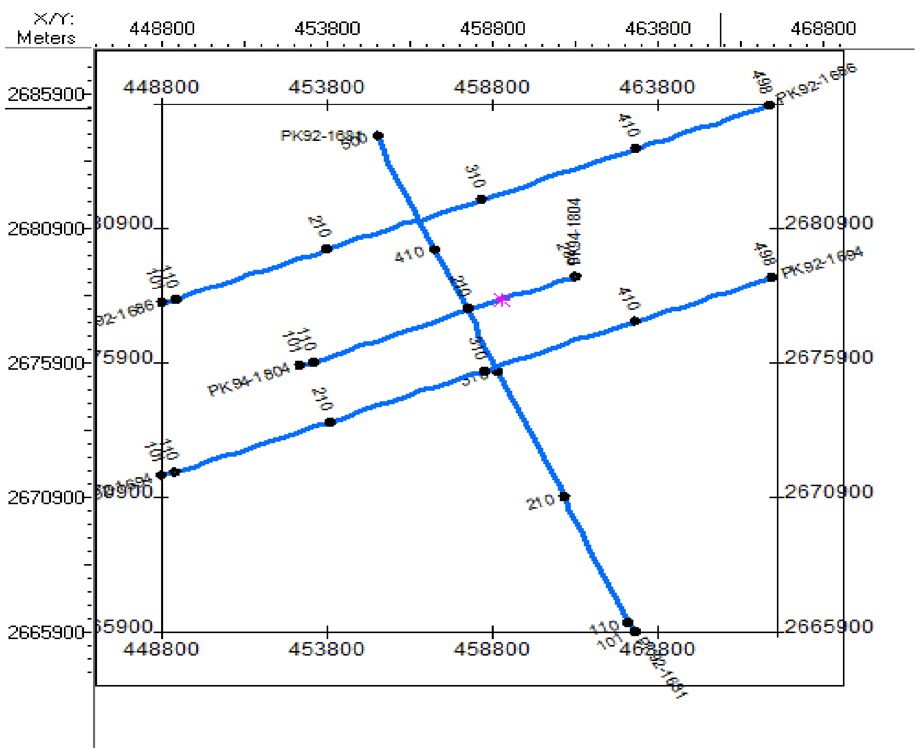

Figure 1.2 Basemap of study area including lines PK92-1681, PK92-1686, PK92-1694, PK94-1804 and Doti-01 well.

Line Name	Orientation	Nature of Line	Well
PK92-1681	NW-SE	STRIKE	
PK92-1686	NE-SW	DIP	
PK92-1694	NE-SW	DIP	
PK94-1804	NE-SW	DIP	DOTI-01

Table 1.1 Seismic lines and well used for base map.

Well Data	
Well Name	DOTI-01
Operator	Union Texas Pakistan (UTP)
Province	Sindh
Status	Abandoned
Latitude	24.219353
Longitude	68.599725
Reference Elevation	8.2300 KB
Total Depth	1830.2
Type	Exploratory
Union Well Identity (UWI)	UWI000963

List Of Formation Tops			
Formations	**Formations Age**	**Tops (M)**	**Thickness (M)**
Alluvium-Gaj-Nari	Late Holocene	15.2	
Kirthar-Laki	Holocene	222.5	207.3
Upper Ranikot	Late Palaeocene	277.4	54.9
Lower Ranikot	Late Palaeocene	461.7	184.3
Khadro	Palaeocene	629.4	167.9
Parh Limestone	Early Palaeocene	739.1	109.7
Upper Goru	Late Cretaceous	771.1	32
Lower Goru	Cretaceous	1537.6	766.5

Table 1.2 Well Tops and Formation Tops of DOTI-01 Well.

1.6 Data Formats

Seismic migrated section along with supporting data and Petrophysical data obtained in following formats.

- Seismic SEG-Y format
- logs LAS format
- Navigation

1.7 Software Used

Various software tools used in the thesis workflow have been summarized below along with their functionality.

SMT kingdom 8.6

- Structural Interpretation
- Stratigraphic Interpretation
- Well correlation
- Seismic attribute analysis
- Rockphysics and Petrophysics

1.8 Objectives of Study

- Structural interpretation using 2D seismic reflection data to understand subsurface geologic framework and its relation with surface geology.
- Generate time and depth contour maps on different levels to find the favourable structure for Hydrocarbon.
- Petrophysical interpretation to find the zone of interest and find the petrophysical properties accociated with that zone.
- Facies analysis to see the type of facies encountered in the well.

Chapter 2

Geology and Stratigraphy

2.1 Introduction

Geology plays an important role for precise seismic interpretation because same velocity affects can be generate from different formations. We must familiar with the geology of adjoining areas and regional geology. It helps us to understand the type of structure present beneath subsurface. As faults are associated with plate boundary we must familiar with type of plate boundaries. So as if we don't know geological formations in area we don't recognize the different reflections appearing in the seismic section. For the exploration of underneath earth surface the geology is of extreme importance. Basin study is very important for geological information. By means of three parameters namely:

- Basin forming tectonics
- Depositional sequences
- Basin modifying tectonics

Pakistan is geologically divided into three main basins Indus, Baluchistan and Kakar Khorasan which are further sub-divided into different sub-basins. Our interested basin Indus is divided into Upper and Lower basins. Upper Indus basin is subdivided into Kohat Sub-Basin and Potawar Basin and Lower Indus basin is divided into Central and Southern Indus Basins. Thar Platform, Karachi Trough, Kirther Foredeep, Kirther Fold Belt and Offshore Indus make up Lower Indus Basin (Kadri, 1995).This chapter contains a brief description of geology, tectonic setting and stratigraphy of area under study.

2.2 Geological Boundaries of Study Area

Geologically southern Sindh monocline is confined **North** by **Sukkur rift**, **South** by **Indus Offshore**, **East** by **Nagar Parker Granite** and **West** by **Kirther and sulaiman ranges**.

2.3 Regional Setting and Tectonic Of Pakistan

The Indo-Pakistan subcontinent separated from Gondwana motherland about 130 million years. The northern most and western regions of Pakistan falls in tethyan domain. Pakistan may be subdivided into the following broad tectonic zones, (kazmi etal, 1997) shown in figure 2.1.

- Indus platform and fore deep
- East Baluchistan and fore deep
- Northwest Himalayan fold and thrust belt.
- Kohistan-ladakh magmatic arc.
- Kakar Khorasan flysch basin and makran accretionary zone.
- Chagai magmatic arc
- Pakistan offshores

2.4 Sedimentary Basins of Pakistan

Basins are the area of regional subsidence and sedimentation occurs for longer periods of time. Sedimentary basins of Pakistan are

- Indus basin
- Baluchistan basin
- Pishin basin

Indus basin is further divided into upper and lower Indus basin. Sargodha high divide the upper Indus basin from lower Indus basin. Lower Indus basin also divided into central and southern Indus basin. Sukkur rift divide the central Indus basin from southern Indus basin. Chamman transform fault separates the Indus basin from Baluchistan basin. Figure 2.2 shows the sedimentary basins of Pakistan.

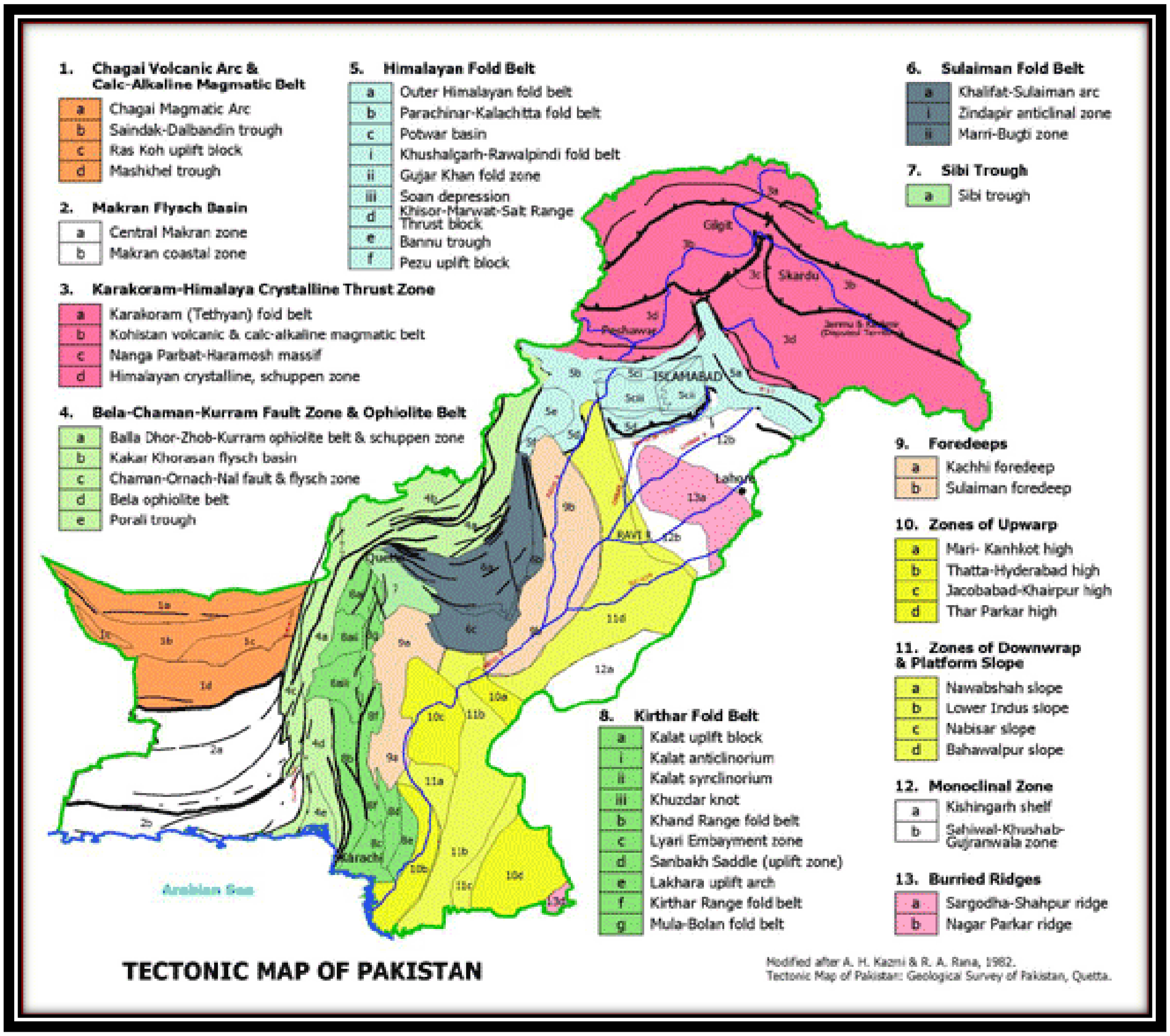

Figure 2.1 Tectonic map of Pakistan modified after, (kazmi etal, 1997) geological survey of Pakistan, Quetta.

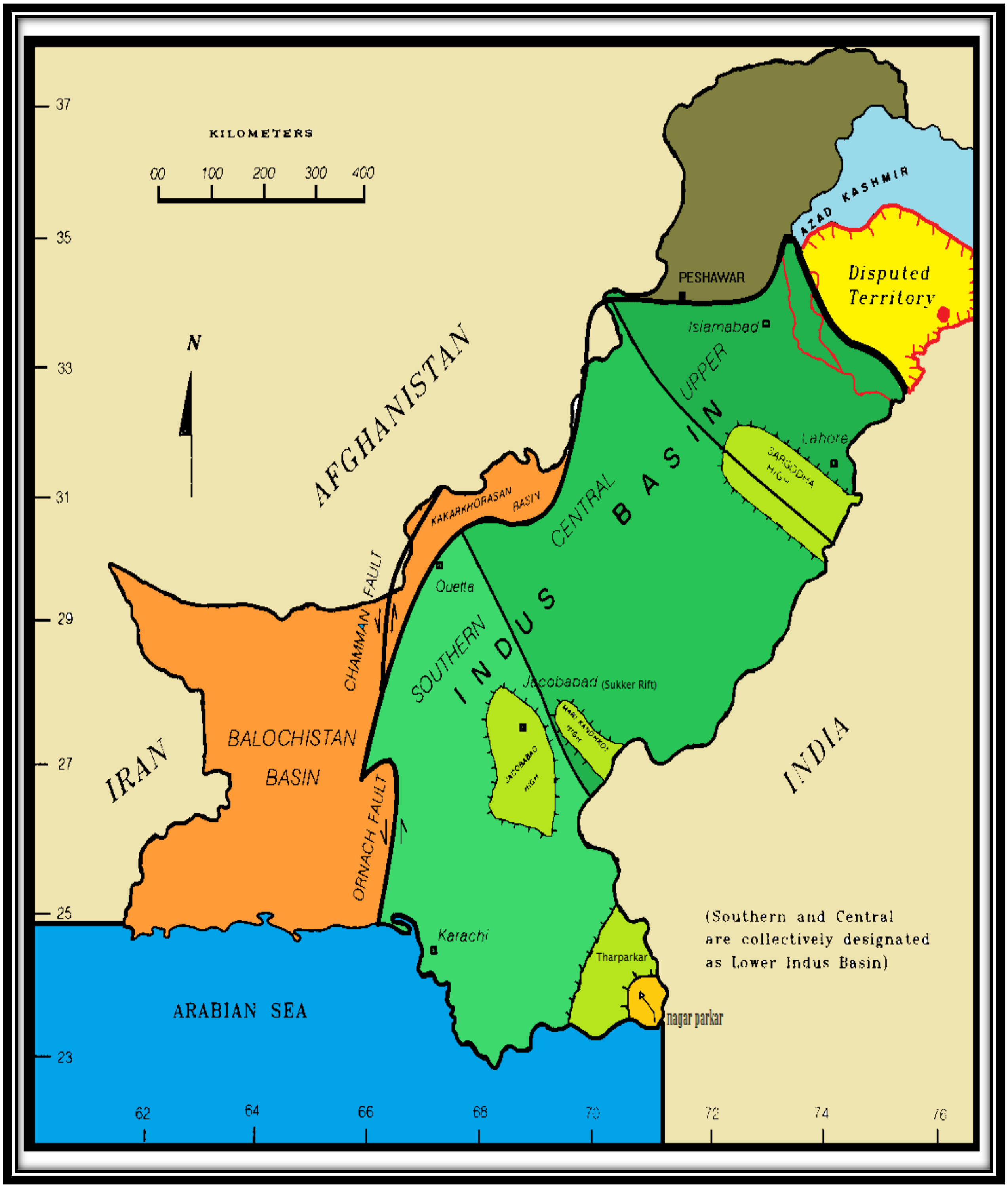

Figure 2.2 The major sedimentary basins of Pakistan, (kadri, 1997) and modified.

2.5 Southern Indus Basin

This basin is located just south of sukkur rift (a divide between central and southern Indus basin). It comprises of following main units.

- Thar platform
- Karachi trough
- Kirther fore deep
- Kirther fore belt
- Offshore Indus

2.6 Thar Platform

It is gently dipping monocline analogous to Punjab platform. Sedimentary wedge thins towards the Indian shield whose surface expression are present in the form of nagger parker high. It is different from Punjab platform because it contains the buried structure of extensional tectonic of late counter-clockwise movement of Indian plate. It is bounded east by Indian shield, merge into Kirther and Karachi trough in the west and bounded north by mari-bugti inner fold zone.

2.7 Stratigraphy

The older rocks encountered in southern Sindh monocline of Triassic age (jhat pat and nabisar wells). Sembar and Goru is most important stratigraphic package in study area. Figure 2.3 shows the stratigraphic column of study area.

2.8 Petroleum Play

A play is a group of geologically related prospects having similar conditions of source, reservoir and trap (kadri, 1997).there are five element of petroleum play;

- Source

- Reservoir
- Seal
- Migration
- Trap

2.8.1 Source

Source is associated both with Sembar and Goru formation, (Siddiqui etal, 2012) discussed source potential in upper shale, lower shale and Talhar shale. Graben are mainly kitchen for generation of hydrocarbon .Excess of overburden pressure and high temperature cause generation of hydrocarbon.

2.8.2 Reservoir

Goru formation act as reservoir in the area. The formation is divided into seven member namely youngest upper sand, upper shale, middle sand ,lower shale, upper basal sand, Talhar shale and lowest basal sand upper sand, middle sand, basal sand and massive sand are proved reservoir of southern Sindh monocline.

2.8.3 Seal

Seal is fine grained sedimentary rock (shale, evaporate) have a tendency to stop hydrocarbon in a trap. Additional seals that may be effective provided by fault, and up-dip facies changes. The thick sequence of shale and marl member of upper Goru formation act as a seal for underlying lower Goru formation. Additional thick shales sequences within the lower Goru provide both vertical and lateral seal across the fault block.

2.8.4 Migration

Migration provides path for movement of hydrocarbon and its upper limit is trap. Two types of migration occur

- Primary migration.

➢ Secondary migration.

Primary migration occurs within the source rock. Secondary migration cause hydrocarbon into specific traps. The tilted normal fault block provides migration path ways for hydrocarbons.

2.8.5 Traps:

Trap is necessary for accumulation of hydrocarbon otherwise it leaks to the surface. Traps in Badin are structural and they are as a result of extensional tectonics. The lower Goru Sand provide the accumulation of hydrocarbon while the upper Goru shaly formation provide a trap. Normal fault provide as excellent seal to hydrocarbon.

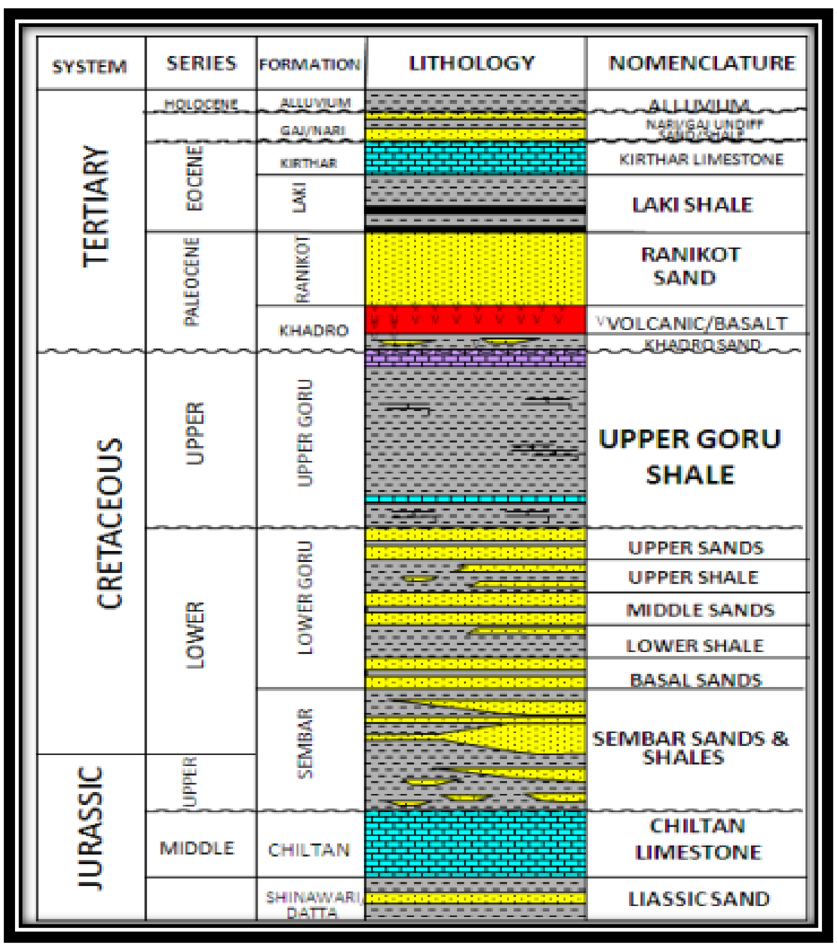

Figure 2.3 Stratigraphic chart of study area, (After Raza etal, 1990).

Chapter 3

Seismic Survey and Data Processing

3.1 Introduction

The seismic survey is one form of geophysical surveys that aims at measuring the earth's geophysical properties by means of physical principles such as magnetic, electric, gravitational, thermal, and elastic theories. It is based on the theory of elasticity and therefore tries to deduce elastic properties of materials by measuring their response to elastic disturbances called seismic (or elastic) waves.

Seismic surveys are used to locate and estimate the size of underground oil and gas reserves. Seismic images are produced by generating, recording and analysing sound waves that travel through the earth. These sound waves are also called seismic waves. The oil and gas exploration industry has deployed this evolving technology for decades to determine the best places to explore for oil and gas.

3.2 Seismic methods

Seismic method is one of the most important geophysical methods in all geophysical methods. This predominance is because of various factors, its high accuracy, high resolution and great penetration. This wide seismic method is mostly used in the exploration of petroleum. This basic technique of seismic exploration is that seismic waves are generated and measured the time required for waves to travel from source to the geophones which are arranged in specific pattern. There are two types of seismic methods i.e.

1. **Seismic reflection method.**
2. **Seismic refraction method**

The seismic reflection method is based on the study to map subsurface geological structures. Measurements are made of the arrival time of events attributed to seismic waves which have been reflected from interfaces where the acoustic impedance changes. The objective usually is to map variations in the depth and attitude of the interfaces which usually are parallel to the bedding. Seismic refraction method is based on the study of elastic waves refracted along geological layers. This method is generally used to map low velocity zone. This method is used as supplement with reflection method.

3.3 Seismic data acquisition

Seismic investigation starts in the field with the acquisition of data. The purpose of seismic data acquisition is to record the effects produced by mechanical disturbance at the surface of earth, and its effects are observed at number of locations along the surface. The instruments so adopted to acquire seismic data now-a day's differ from those used in past, but essential principle for all instruments is same. The seismic data acquisition starts with, field by few organization divided as if it is land organization or marine organization. Seismic acquisition system consists of three basic subsystems:

- Energy sources (explosives)
- Energy receiving units (geophones)
- Recording system

Explosives or vibrating plates generate the waves and a line or grid of geophones records them. Density changes between rock or soil layers reflect the waves back to the surface and the speed and strength that the waves are reflected back indicates what geological features lie below.

3.4 Seismic data processing

The process of data processing includes the sequence of operations. According to predefined program these operations are carried out to convert set of raw data into useful information. Advancement of technology/electronic computers in last two decades brought the digital revolution in seismic prospecting for oil and gas. After the introduction of computers seismic data processing attained new shape. The rationale behind the seismic data processing is to convert the recorded information of field into a form that allows geological interpretation, the reflections presentation with maximum possible resolution on the seismic section and the reduction or elimination of different noises. The main objectives of the seismic data processing are summarized as below.

•Signal to noise ratio.

•Representation of geology in seismic cross-section.

•Acquire the target provided by client.

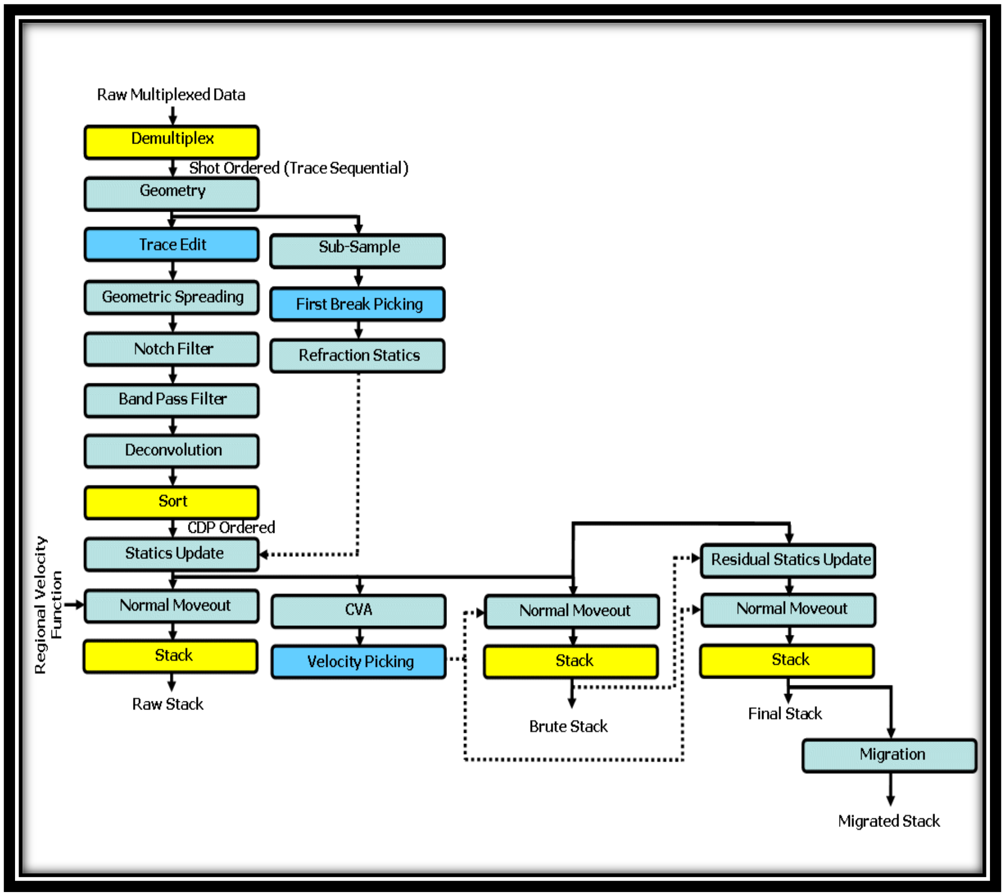

Figure 3.1 Seismic data processing flow chart. (Khan etal, 2009)

3.5 Survey parameters of study area

In this section survey parameters, acquisition parameters and processing parameters, are displayed.

3.5.1 Acquisition parameters

Acquisition parameters of study area are enlisted in table 3.1

<table>
<tr><th colspan="2">Recorded By</th><th>CGG</th></tr>
<tr><td colspan="2">Source</td><td>Dynamite</td></tr>
<tr><td colspan="2">Cable Type</td><td>Split Spread</td></tr>
<tr><td colspan="2">Shoot Depth</td><td>6m</td></tr>
<tr><td colspan="2">Number Of Groups</td><td>96</td></tr>
<tr><td colspan="2">Group Interval</td><td>50m</td></tr>
<tr><td colspan="2">Shoot Interval</td><td>100m</td></tr>
<tr><td colspan="2">Recording System</td><td>Myriaseis</td></tr>
<tr><td colspan="2">Recording Length</td><td>6s</td></tr>
<tr><td colspan="2">Recording Fold</td><td>24</td></tr>
<tr><td colspan="2">Sampling Rate</td><td>2ms</td></tr>
<tr><td colspan="2">Format</td><td>SEG=D DE multiplex</td></tr>
<tr><td rowspan="2">Recording Filter</td><td>High Cut</td><td>150 Hz 54 DB/Oct</td></tr>
<tr><td>Low Cut</td><td>2 HZ 18 DB/Oct</td></tr>
</table>

3.5.2 Display parameters

Display parameters enlisted in table 3.2

Gain	0.0
Bias	10%
Polarity	Normal
Trough	White
Crust	Black
Horizontal Scale	1:20,000
Vertical Scale	10cm/Sec

3.5.3 Processing parameters

Instruments, filters and processing parameters used in the processing of the data of study area are enlisted in table 3.3

Processed By	GECO-Prakla, Abu Dhabi
Processed Date	Sep 1992-May1993
Processing Records Length	6s
Processing Sample Interval	4ms
Input SEG-D	2ms Sample Rate
Out SEG-Y	4ms Sample Rate
Deconvolution	
Type	Predictive
Operator Length	16 Ms
Predictive Gap	16ms
Derivation Window	Near 400-400ms.Far 3000-4500 Ms
Application Window	Near 0-2400ms, Far 2600-6000ms
Pre-Whitening	2%
Initial Velocity Analysis	Analysis Every 3km
Velocity Analysis	Every 1km
NMO Correction	
Floating Datum To M.S.L	
FK Filter	Polygon Pass
Time Variant Band Pass Filtering	
Finite Difference Migration	95% Staking Velocities
Array Length	50m

Chapter 4

Seismic Data Interpretation

4.1 Introduction

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 delineate hydrocarbon accumulation and their extent and also calculate their volumes. Exploration seismic methods involve measuring seismic waves traveling through the Earth. Explosives and other energy sources are used to generate the seismic waves, and arrays of seismometers or geophones are used to detect the resulting motion of the Earth. The data are usually recorded in digital form on magnetic tape so that computer processing can be used to enhance the signals with respect to the noise, extract the significant information, and display the data in such a form that a geological interpretation can be carried out readily (Kearey et al, 2002).

Seismic interpretation is the process of determining the subsurface information of the earth from seismic data, (coffeen, 1986). It may determine general information about an area, locate prospects for drilling exploratory wells, or guide development of an already-discovered field.

4.2 Types of 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.

Main approaches for the interpretation of the seismic section are;

- **Structural analysis**
- **Stratigraphic analysis**

4.2.1 Structural Analysis

This type of analysis is very suitable 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 fault sand undulating reflection several folded beds, (Telford etal, 1990).

4.2.2 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. We want to distinguish the features that are not marked by the sharp boundaries. Geologists ordinarily group the sequence of sedimentary rocks into units called “formations”. These formations can be described in term of age, thickness, and lithology of the constituent layer. To distinguish different formations on the basis of seismic reflections is an important question in interpreting seismic data that may be structural, stratigraphic or lithological, (Robinson, 1988).

4.3 Work Flow

For data interpretation base map is prepared by loading Navigation data and SEGY in software. Horizons of interest are marked manually. In this process faults are identified and marked. Faults polygons are generated and horizons are contoured to find out structural highs and lows. Then time and depth contours are plotted. Figure 4.1 shows the step used for seismic interpretation.

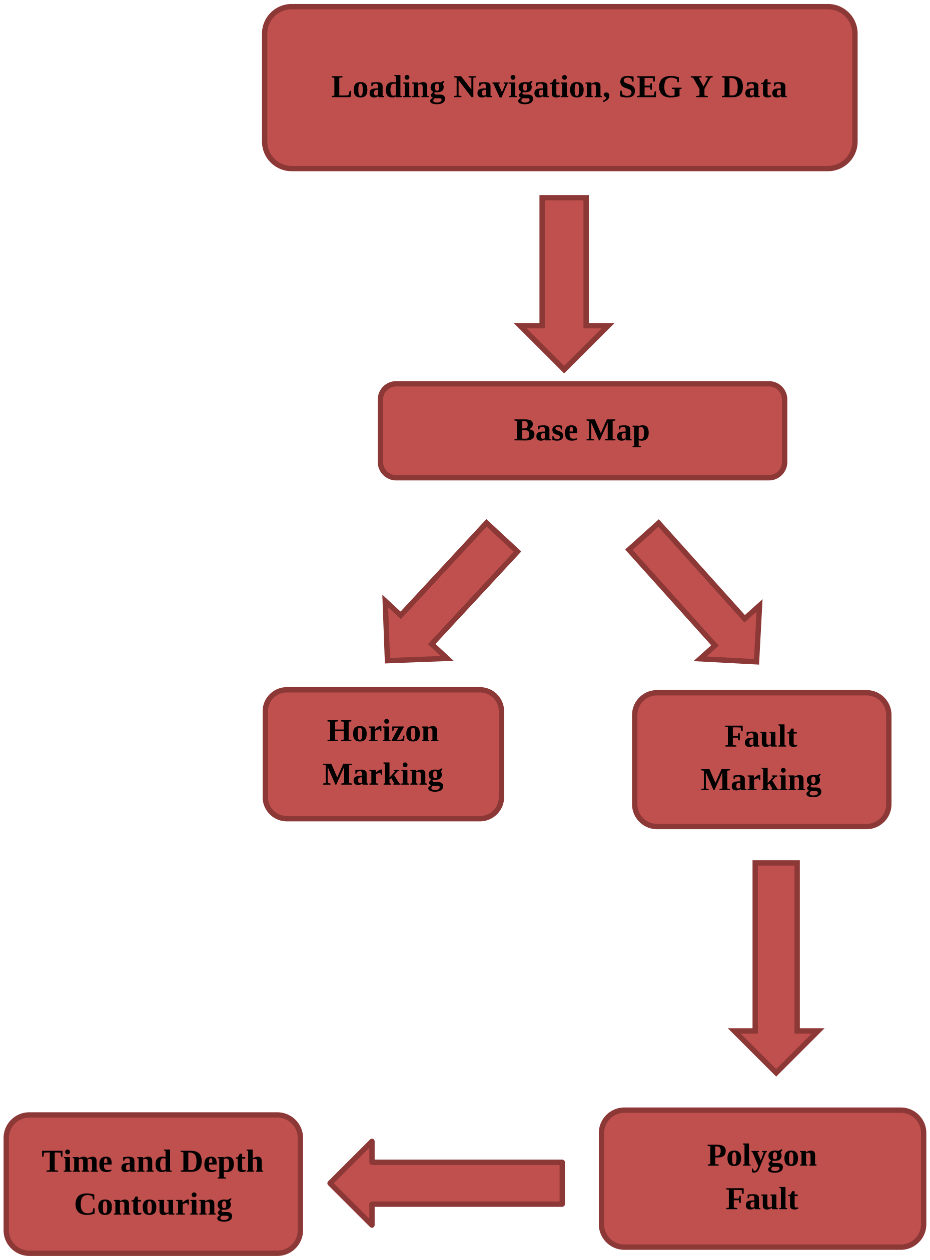

Figure 4.1 Steps for seismic data interpretation

4.4 Synthetic Seismogram Generation

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 4.2. Match this synthetic seismogram with seismic line PK94-1804 on which Doti-01 well is located. Actually seismic data is provided in time scale and well tops are given in depth so we cannot mark horizons. The purpose of generation of synthetic is to find two way travel time against each depth for marking of horizons. With the help of this synthetic seismogram two horizon were marked (upper Ranikot, Lower Goru) on line PK94-1804. Tie this marked seismic section with other lines and horizons are marked on these lines.

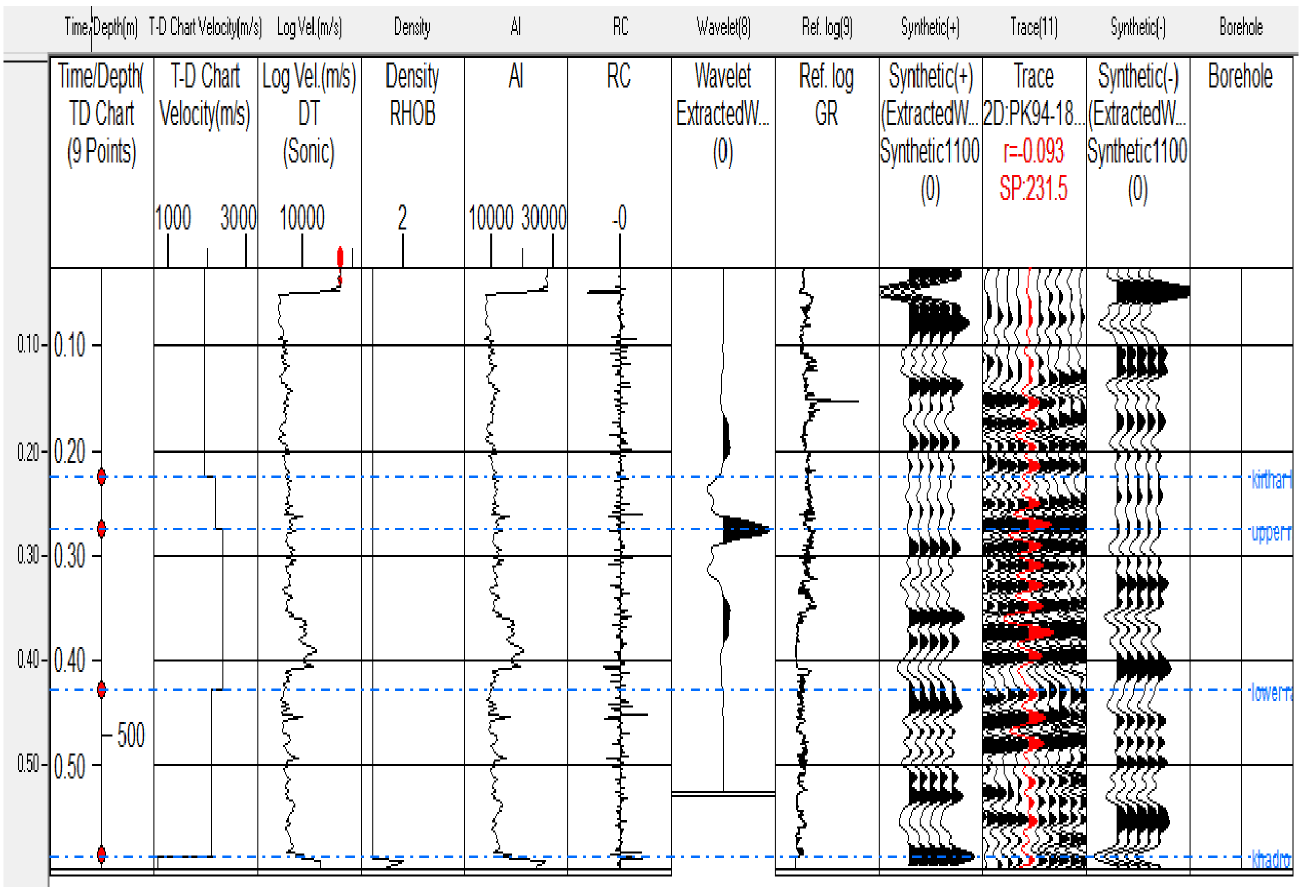

Figure 4.2 Synthetic Seismogram of Doti-01well

4.5 Marked Seismic Sections

Two seismic horizons Parh limestone and lower Goru (of early cretaceous age) are marked. Interpreted seismic section are shown in figure 4.3, 4.4, 4.5.These seismic sections show horst and graben structure except line PK92-1681 which is a strike line. Structures are not clear in strike line therefore faults are not marked. These horst and graben structures is associated with normal faulting which shows the study area is lies in extensional regime. Below lower Goru strata is highly disturbed by cretaceous faulting. The Khadro formation (recent deposition) unaffected by cretaceous tectonic activity.

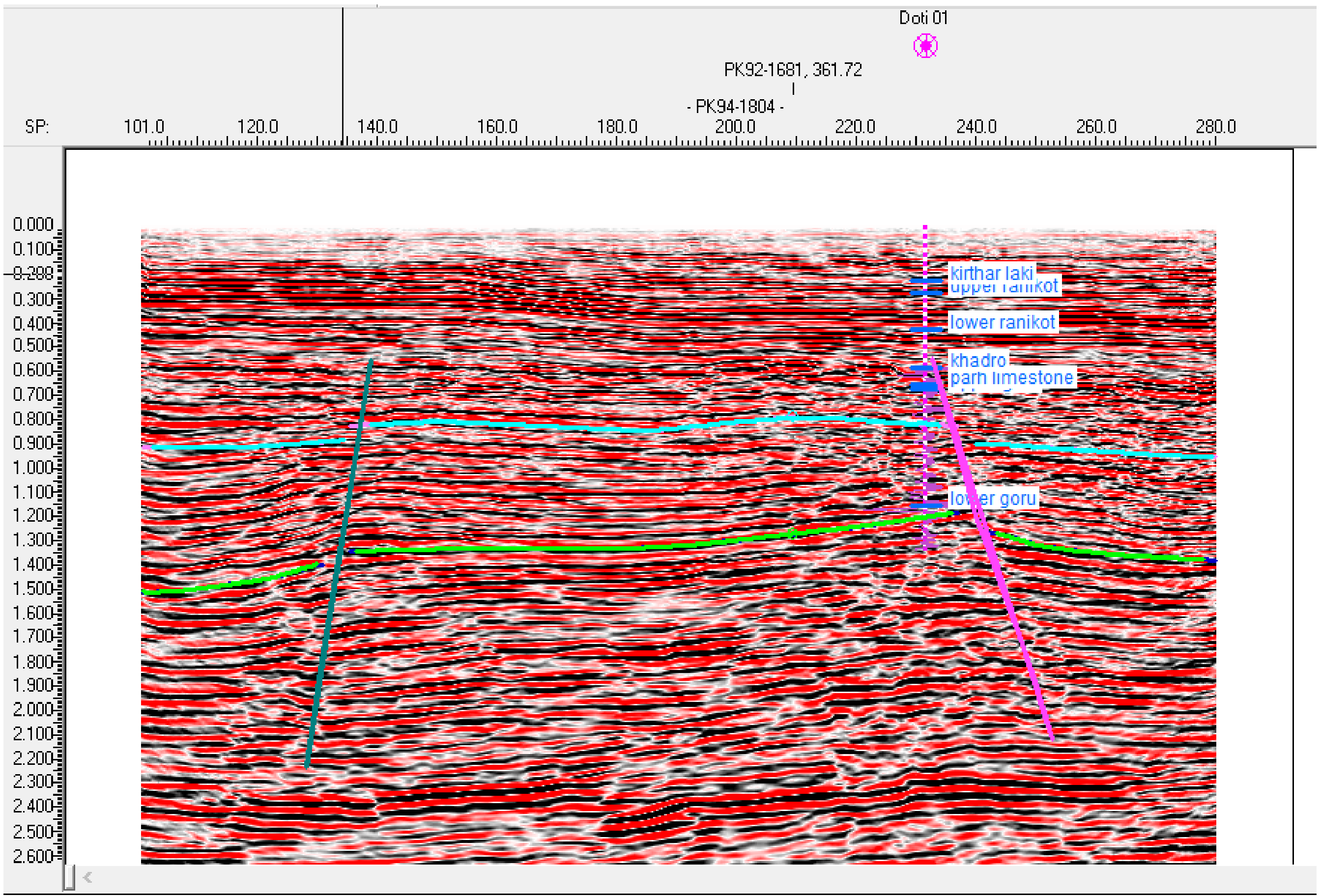

Figure 4.3 Interpretation of PK94-1804 show normal faults with horst and graban geometry.

Here is the Seismic line shown on which 3 - 4 faults are marked on the basis of continuity of reflectors and two formation Upper Goru and Lower Goru is marked with the help of synthetic seismogram. After marking Horizons and faults, we got good horst and graben geometry structures, which with matches our previous geological information.

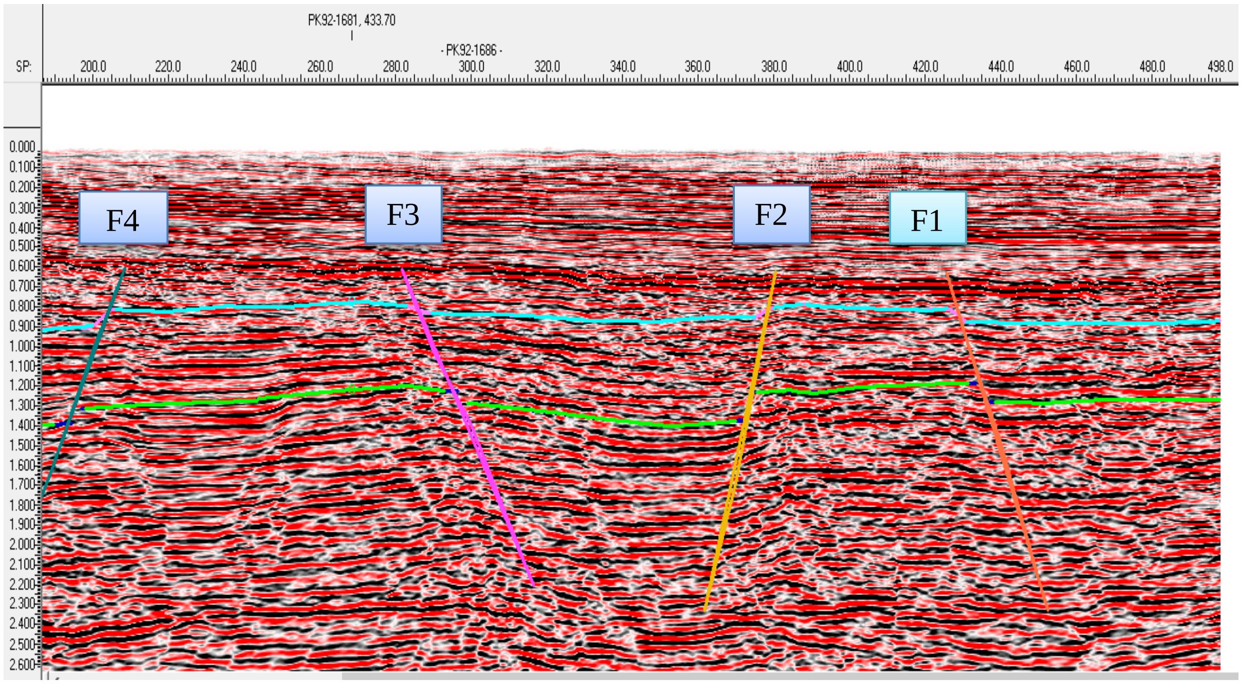

Figure 4.4 Showing Normal faulting on Interpreted Seismic Dip Line PK 92-1686.

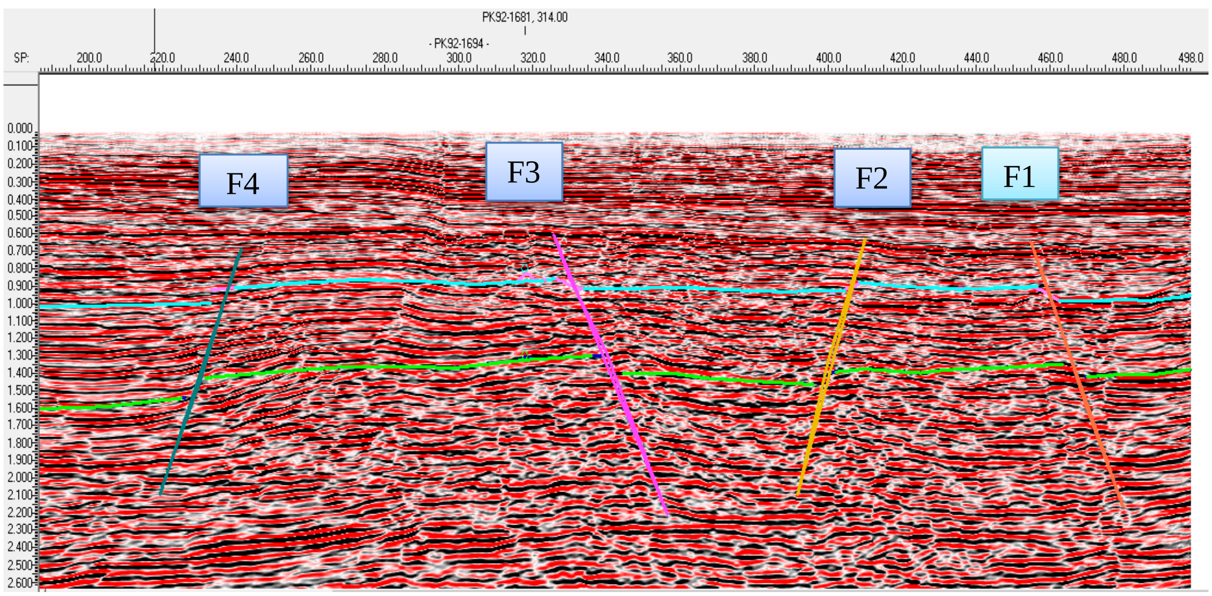

Figure 4.5 Showing Normal faulting on Interpreted Seismic Dip Line PK 92-1694.

4.6 Construction of Fault 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. Figure 4.8 shows fault polygons at lower Goru level. It clearly shows that after construction of fault polygons the high and low areas on a particular horizon become obvious. Moreover, the associated color bar helps in giving information about the dip directions on a fault polygon if dip symbols are not drawn. Fault polygons are constructed for Lower Goru formation and these are oriented in NW-SE direction.

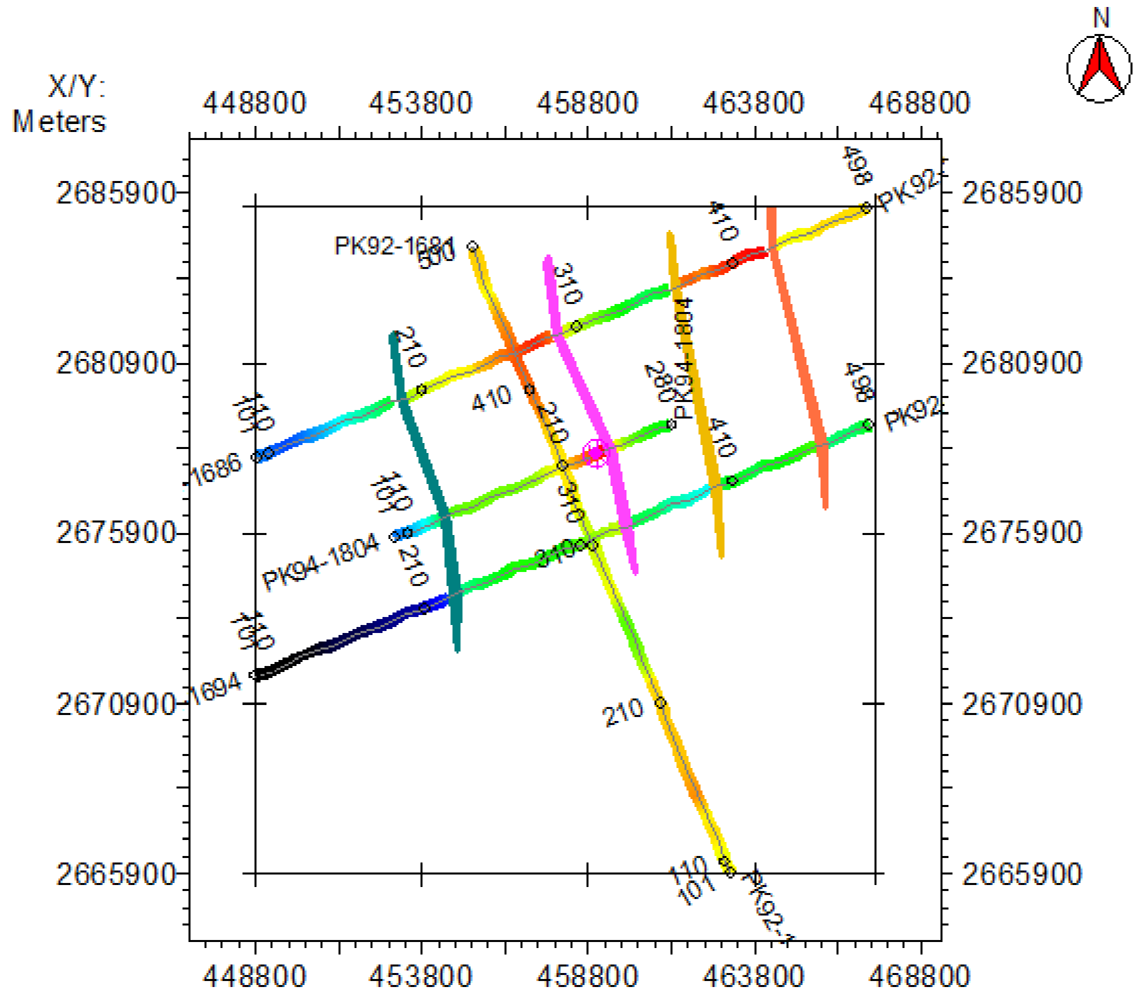

Figure 4.6 Fault polygon of lower Goru formation

4.7 Contour Maps

The final products of all the seismic exploration are the contour maps, time or depth. Mapping is part of the interpretation of the data the one on which the entire operation depends for its usefulness. Contouring represents the three-dimensional earth on a two dimensional surface. These contour maps reveal the slope of the formation, structural relief of the formation, its dip and any faulting and folding. The interpreted seismic data is contoured for producing seismic maps which provide a three-dimensional picture of the various layers within an area which is circumscribed by intersecting shooting lines. These time and depth contour maps have been generated with the help of seismic micro technology SMT (kingdom 8.6).

4.8 Time and depth contour map of lower Goru formation

Figure 4.7 and 4.8 shows the time contour map and depth contour map of lower Goru formation. The horsts are at smaller time values and Grabens are marked by greater time values. Grabens are at greater depth so top of lower Goru is deeper in graben. Graben accounts greater pressure and temperature condition then horst and it act as a place where hydrocarbon mature.

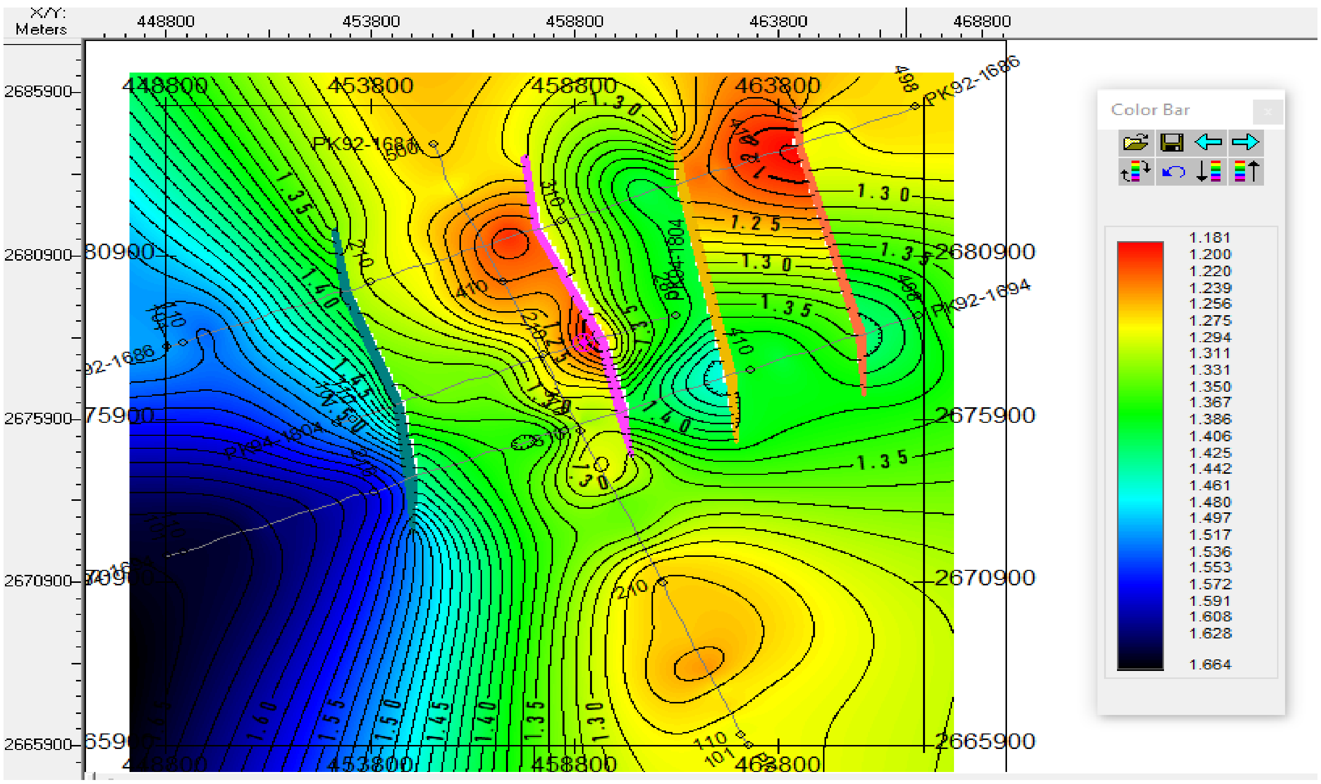

Figure 4.7 Time contour at Lower Goru level showing change in time on the base map.

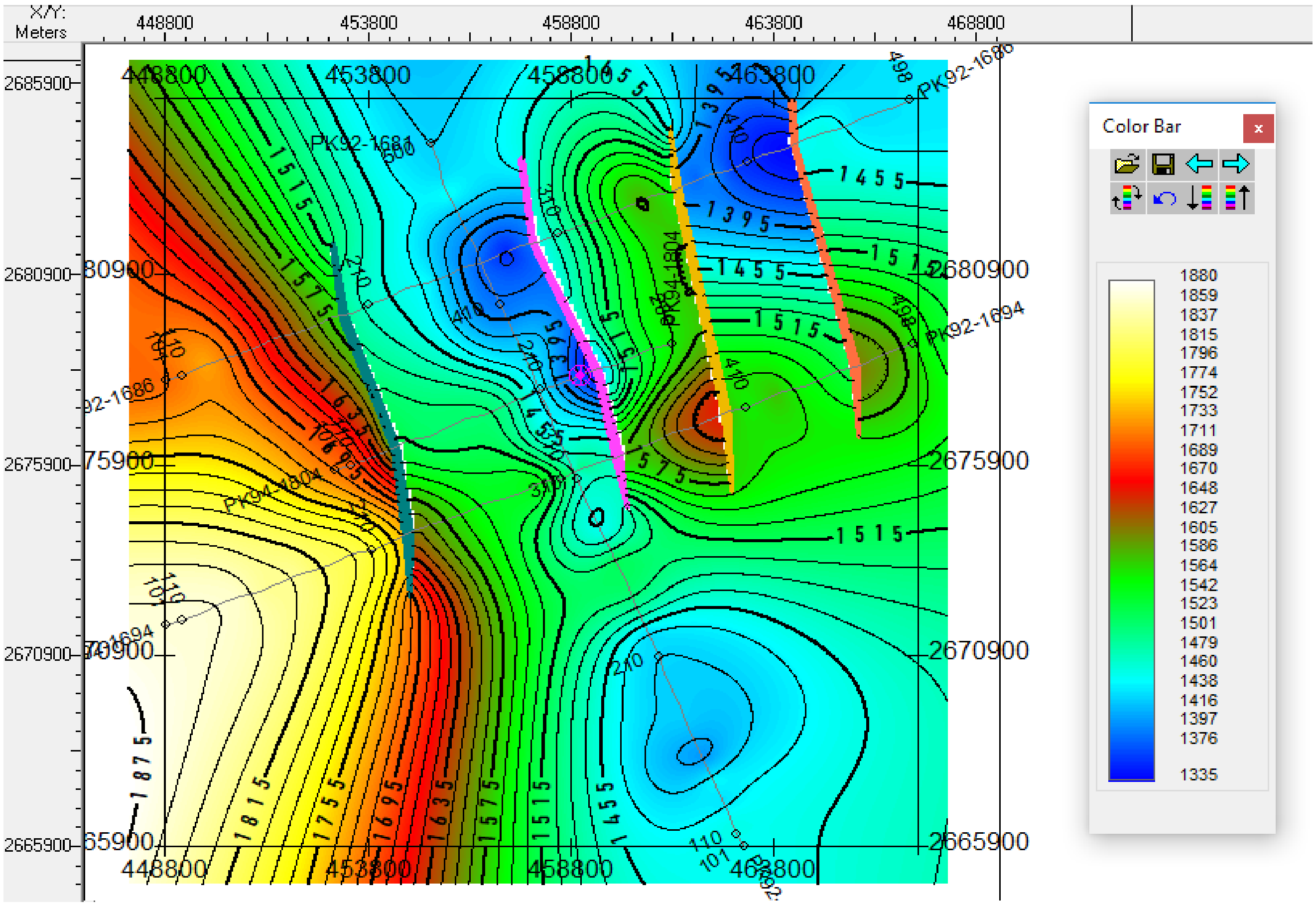

Figure 4.8 Depth contours of Lower Goru

Chapter 5

SEISMIC ATTRIBUTES

5.1 Seismic Attributes

Seismic attribute is defined by as a measurement derived from seismic data. Such a broad definition allows for many uses and abuses of the term. Countless attributes have been introduced in the practice of seismic exploration. Many of these attributes play an exceptionally important role in interpreting and analysing seismic data. Some particular attribute applications are considered i.e. amplitude, frequency, phase and energy, etc. A seismic attribute is any quantity derived from seismic data using measured time, amplitude, frequency, attenuation or any combination of these. It intends to output a subset of the data that quantifies rock and fluid properties and/or allows the recognition of geologic patterns and features. Almost all seismic attributes are post-stack but there are few pre-stack ones. They can be measured along a single seismic trace or throughout various seismic trace. The first attributes developed were related to the 1-D complex seismic trace and included envelope amplitude, instantaneous phase, instantaneous frequency, and apparent polarity. Acoustic impedance obtained from seismic inversion can also be considered an attribute and was among the first developed. In this research attribute analysis for major reservoir in the area i.e. Lower Goru formation has been calculated.

5.2 Classification of Seismic Attributes

The seismic attributes are classified basically into two categories.

- Physical attributes
- Geometric attributes

5.2.1 Physical Attributes

Physical attributes are defined as those attributes which are directly related to the wave propagation, lithology and other parameters. These physical attributes can be further classified as pre-stack and post-stack attributes. Each of these has sub-classes as instantaneous and wavelet attributes. Instantaneous attributes are computed sample by sample and indicate continuous change of attributes along the time and space axis. The wavelet attributes, on the other hand represent characteristics of wavelet and their amplitude spectrum. Post stack attributes are derived from the stacked data. The attribute is a result of the properties derived from the complex seismic signal.

5.2.2 Geometrical Attributes

The geometrical attributes are dip, azimuth and discontinuity. The dip attribute or amplitude of the data corresponds to the dip of the seismic events. Dip is useful in that it makes faults more discernible. The amplitude of the data on the azimuth attribute corresponds to the azimuth of the maximum dip direction of the seismic feature.

5.3 Instantaneous Phase

The phase information is independent of trace amplitudes and relates to the propagation of phase of the seismic wave front. Since, most of the time, wave fronts are defined as lines of constant phase, the phase attribute is also a physical attribute and can be effectively used as a discriminator for geometrical shape classifications. It is computed from real and imaginary traces as given below;

$$\Theta (T) = \tan^{-1} [H (T) / F (T)]$$

Instantaneous phase is the best indicator of lateral continuity, relates to the phase component of the wave propagation and has no amplitude information, hence all events are represented. It can be used to highlight interface in sections with high decay of amplitudes and even highlight deeper horizons which are not visible in the normal amplitude sections.It is a physical attribute and describe phase angle at any instant.

- Best indicator of lateral continuity.
- Relate the phase component of wave propagation.
- Has no amplitude information so all the events are represented.
- It better shows continuous events.

- Detailed visualization of bedding configuration.

- It is used to find deposition pattern.

5.3.1 Instantaneous Phase on Seismic Line PK94-1804

Khadro formation is unaffected by cretaceous faulting. It shows continuity on applying attribute. Chilton and lower Goru formation do not show continuity due to faulting. This attribute satisfied the piking of horizons. Figure 5.1 show instantaneous phase attribute applied on seismic line PK94-1804.

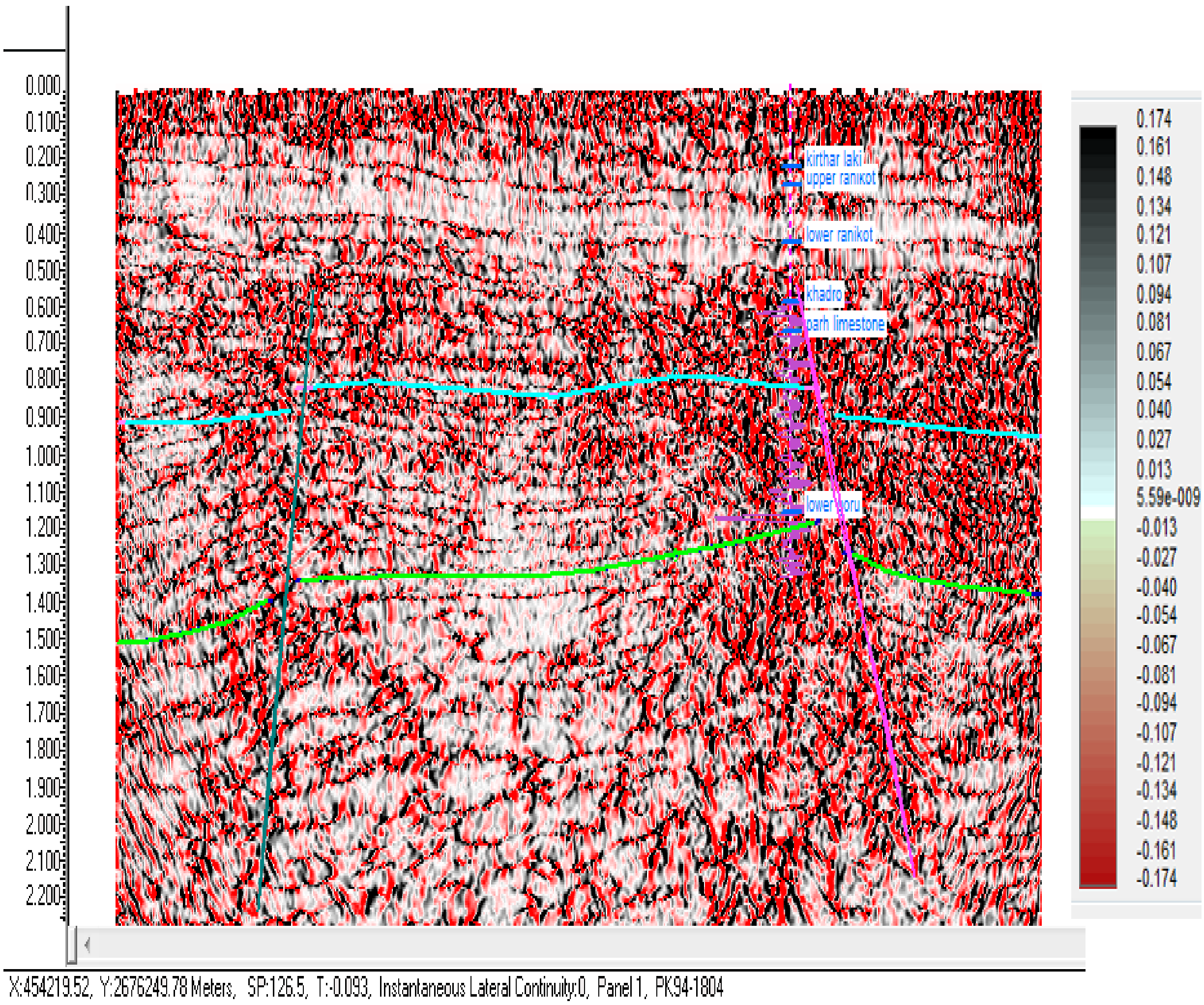

Figure 5.1 Instantaneous phase attribute on seismic line PK92-1804.

5.4 Trace envelope attribute applied on PK94-1804

Strata above Parh limestone shows no breakage on applying that attribute so cretaceous faulting do not affect them. Chilton limestone shows positive acoustic impedance contrast (black color). Changing in Chilton limestone thickness and faulting clearly seen on applying that attribute. Figure 5.2 shows the trace envelope attribute applied on line PK94-1804.

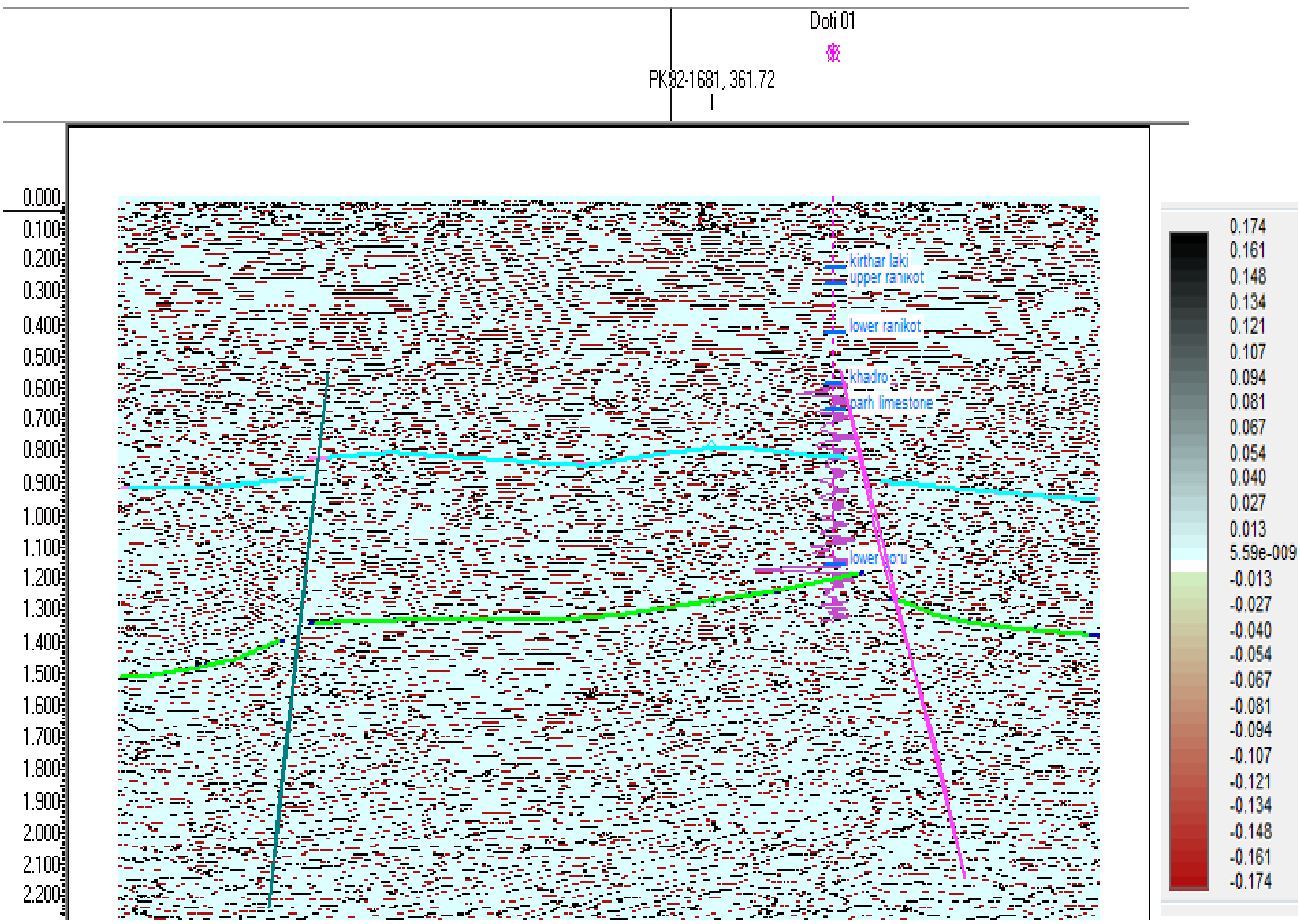

Figure 5.2 Trace envelope attribute applied on PK94-1804

Chapter 6

Well Logging Interpretation

6.1 Introduction

When seismic interpretation completed next step is well logging. Seismic tells us site of drilling. Seismic conform our structure. Well logging tell us true depth of formations so reservoir boundaries are marked. After marking the reservoir boundaries Petrophysical properties (porosity, permeability, water saturation, hydrocarbon saturation and volume of shale) are calculated. For computing these properties different logs are used given below;

- Neutron
- Sonic
- Density
- Resistivity (LLD,LLS,MSFL)
- Gamma Ray
- SP Log

6.2 Work Flow for Well Data Interpretation

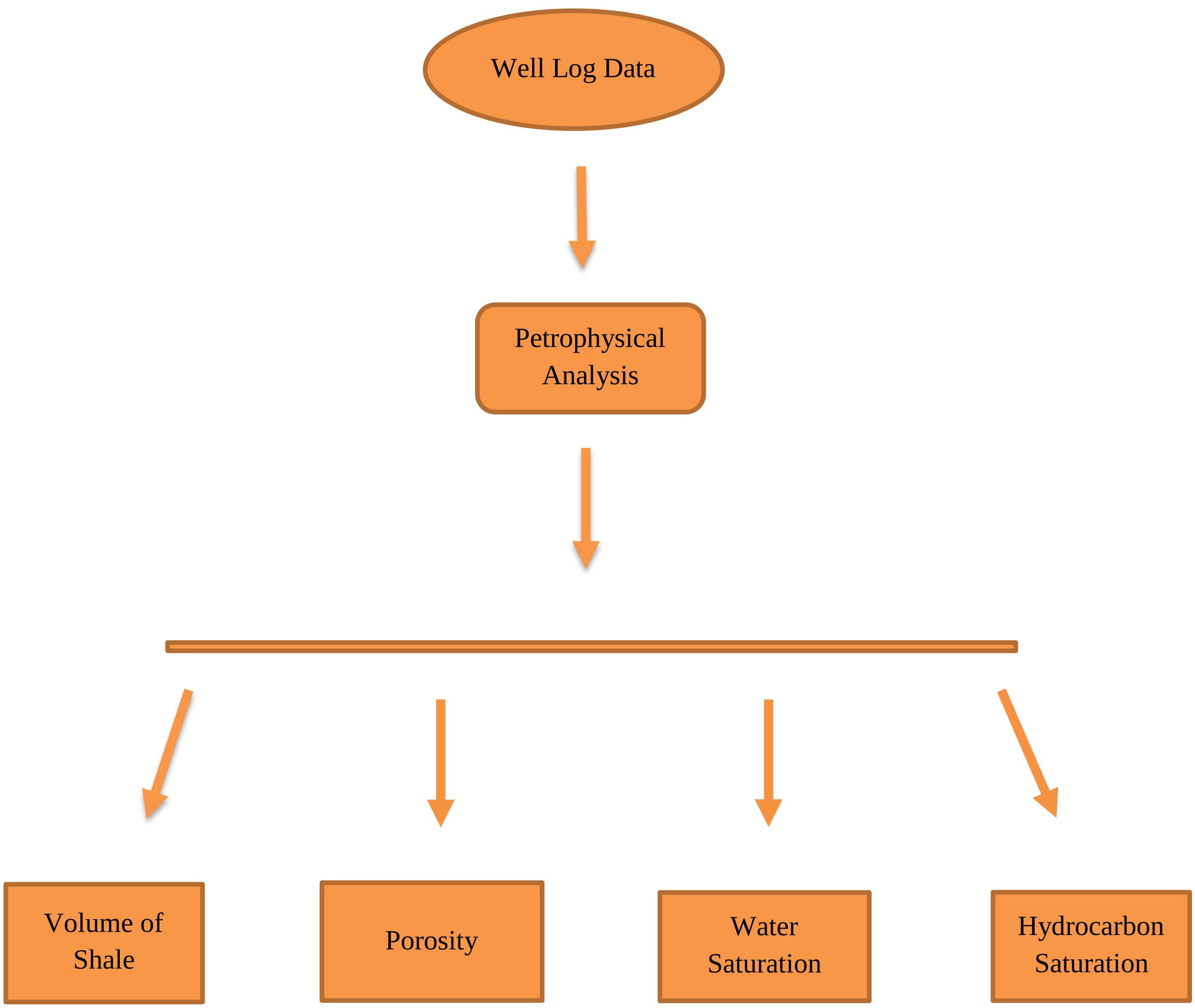

Figure 6.1 work flow for well data interpretation.

6.3 Petrophysical Analysis

Petrophysical analysis is carried out by using wireline logs. Some of the Petrophysical properties for Doti-01well is given below. Figure 6.2 shows wireline logs behaviour in Doti-01 well. In reservoir zone shale is marked on the basis of high gamma ray response log show deflection, calliper log show washouts(increase in diameter) also LLD and LLS not show any separation and density and neutron log do not show any crossover so this is the marked shaly package in the reservoir. Below this the gamma ray response decreases ,calliper log stable(hard lithology) .In sand stone where hydrocarbon is present LLD and LLS shows separation due to difference in resistivity , neutron and density log show crossover(hydrocarbon effect). Figure 6.4 shows separation and crossover effects.

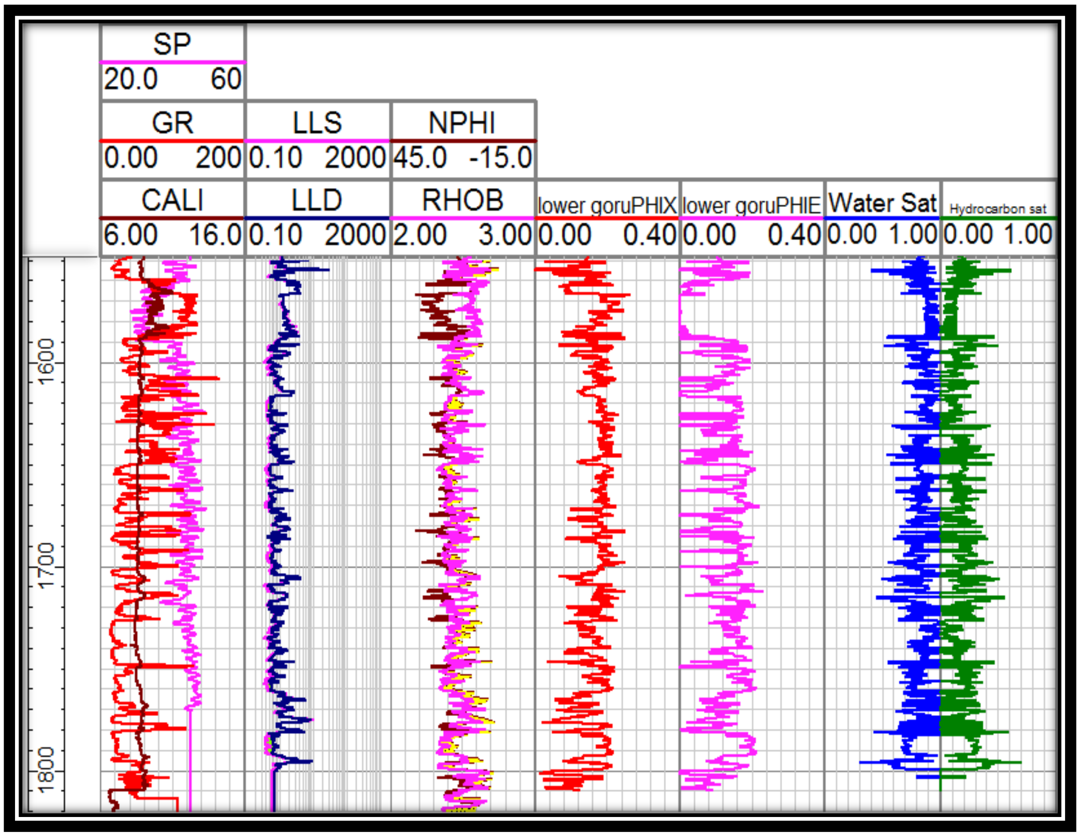

Figure 6.2 Logs curves in Reservoir Zone of Doti-01 W

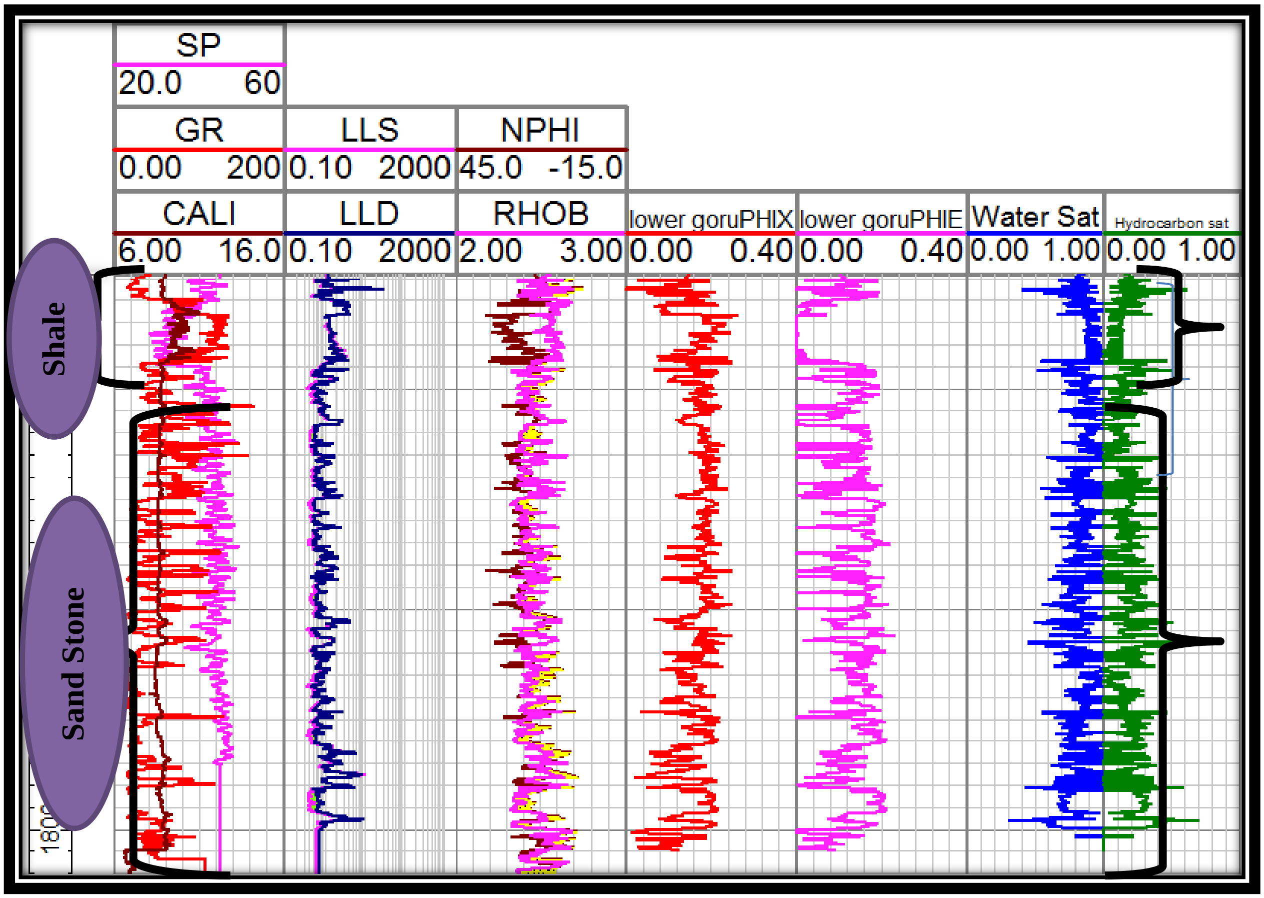

Figure 6.3 Marked sandstone and shale lithology on basis of log curves.

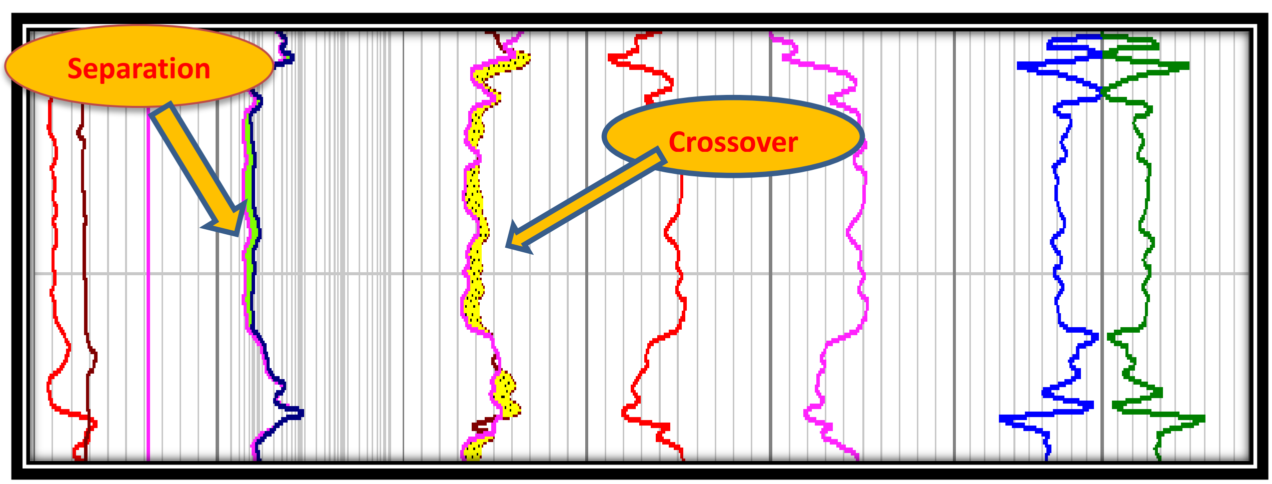

Figure 6.4 Separation and crossover affects in lower Goru sands.

6.3.1 Volume of Shale

Gamma ray log used to calculate the volume of shale and marking of reservoir boundaries. It computed as

$$\mathbf{I.GR} = \frac{\mathbf{GRlog - GRmin}}{\mathbf{GRmax - GRmin}} \qquad \text{(Crain's Petrophysics, 2000)}$$

Where

I_{gr}= Gamma ray index,

GR_{log} = Gamma ray log reading of the formation,

GR_{max} = maximum gamma ray log reading,

GR_{min} = minimum gamma ray log reading

Then by using the following formula volume of shale is computed

$$\mathbf{V_{sh} = 0.0883[2(3.7*I_{gr}) - 1]} \qquad \text{(Crain's Petrophysics, 2000)}$$

The average volume of shale in reservoir is (25-30) % .Figure 6.5 shows the variation in volume of shale with depth.

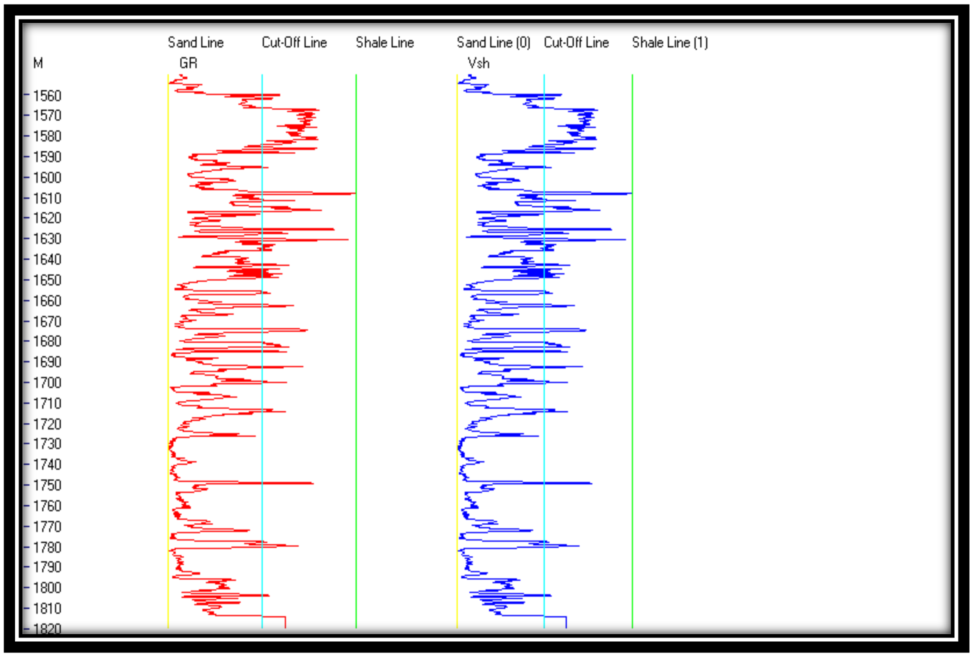

Figure 6.5 variation in volume of shale in Reservoir.

6.3.2 Porosity

Porosity is defined as the ratio of the volume of void spaces to the total volume of the rock. Velocities have an inverse relation with the porosity, so that for small values of velocities the porosity value is high. The porosity is represented by (ϕ).Porosity is calculated by averaging the sonic and density porosity. Sonic and density porosity is computed by using sonic log and density log with the help of following Formula;

$$\Phi S = \frac{\Delta T - \Delta Tmat}{\Delta Tf - \Delta Tmat}$$

Where

Φ_S = Sonic porosity

ΔT= Log response

$\Delta t_{mat=}$ Transit time in matrix

$\Delta t_{f=}$ Transit time in fluids

$$\mathbf{\Phi D = \frac{\rho m - \rho b}{\rho m - \rho f}}$$

Where

Pm = Density of matrix (gm/cm^3)

Pf = Density of fluid (Gm/Cm^3)

Pb = Log response in zone of interest.

After computing sonic and density porosity the total porosity calculated as

$$\mathbf{\Phi_T = \frac{1}{2}\,(\Phi_S + \Phi_D)}$$

Where

$\mathbf{\Phi_T}$=Total Porosity

$\mathbf{\Phi_D}$=Density Porosity

$\mathbf{\Phi_S}$=Sonic Porosity

The average porosity in reservoir zone is (10-15) %.

6.3.3 Water Saturation

After computing porosity next target is amount of water and hydrocarbon in pores. Archie's equation can be used to calculate the water saturation.

$$\mathbf{Sw = \frac{a}{\Phi m} X \frac{Rw}{Rt}} \quad \text{(Archie's, 1950)}$$

Where

Sw = Water saturation

Rw = Water resistivity (formation)

Φ= Porosity,

M is (cementation factor) = 0.81,

a (constant) = 1

Rt = LLD Log Response

Rw has been calculated with help of the following formula, (Crain's Petrophysics,2000)

$$\mathbf{Rw=\Phi^2 \times Rt}$$

Where

Φ = Porosity in clean zone

Rt = Observed LLD curve in clean zone.

The average water saturation in productive zone is (75-80) %.

6.3.4 Hydrocarbon Saturation

The hydrocarbon saturation calculated as

$$\mathbf{H.C= (1-Sw)}$$

Average water saturation in productive zone is (20-25) %

6.4 Petrophysical Results

Petrophysical Property	**Lower Goru**
Volume of shale	(15-20)%
Porosity	(10-15)%
Water saturation	(75-80)%
Hydrocarbon saturation	(20-25)%

Table 6.1 shows the end results.

6.5 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 and/or water affect the response of every tool used to measure formation properties. Understanding reservoir lithology is the foundation from which all other Petrophysical calculations are made. To make accurate Petrophysical calculations of porosity, water saturation (S_w), and permeability, the 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. There is a material correlation between the behaviour of well logs and the lithologic and depositional facies of penetrated formations, since modern logs are sensitive to factors that vary with the makeup of those formations, (Saggaf and Nebrija, 2000). In geology, facies the observable attributes of a sedimentary rock body that reflect the depositional processes or environments that formed it. These depositional environments are classified as terrestrial, continental slope, slope, and basin floor shown in figure 6.6

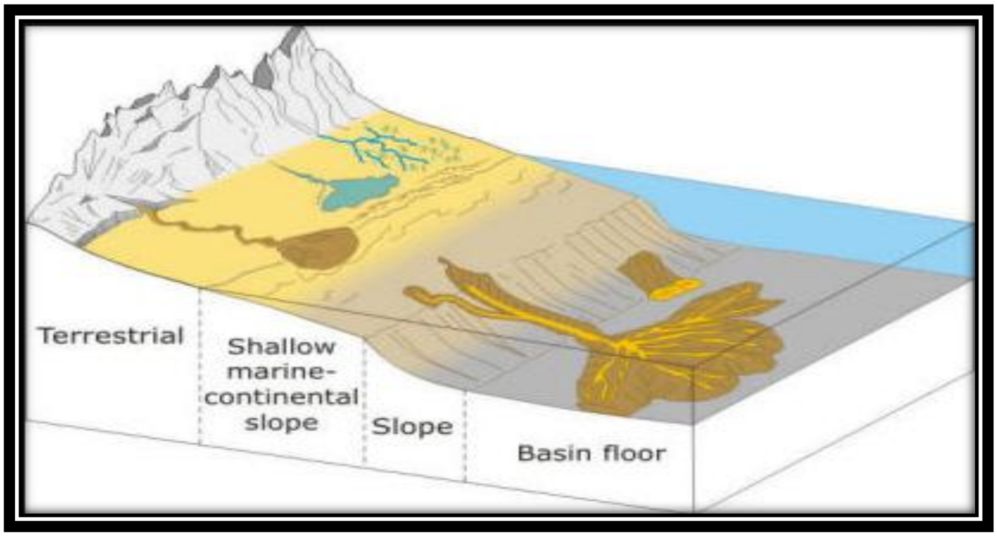

Figure 6.6 Diagram of major depositional environments, (Rais etal, 2012).

6.6 Cross Plot of NPHI and Gamma Ray

Using unsupervised approach the cross plot between density and neutron porosity is obtained. Figure 6.7 shows the standard cross plot between NPHI and RHOB. Gamma ray used as reference log. The neutron log is measuring the hydrogen population of the formation.

Therefore, it records a nearly constant response through sands and increases in shales. Since the population of hydrogen is nearly the same in water, oil, and wet clay, the neutron log cannot distinguish between them. Hydrogen population is therefore no longer controlled by the pore distribution. The neutron log then measures increased hydrogen as the clay volume increases.

High gamma ray log and neutron porosity log indicate the shale while the low response of both logs shows the existence of clean sand. Moderate gamma ray log indicates the shaly sand around the shale sand boundary. Figure 6.8 and 6.9 shows the lithology model for Doti-o1 well.

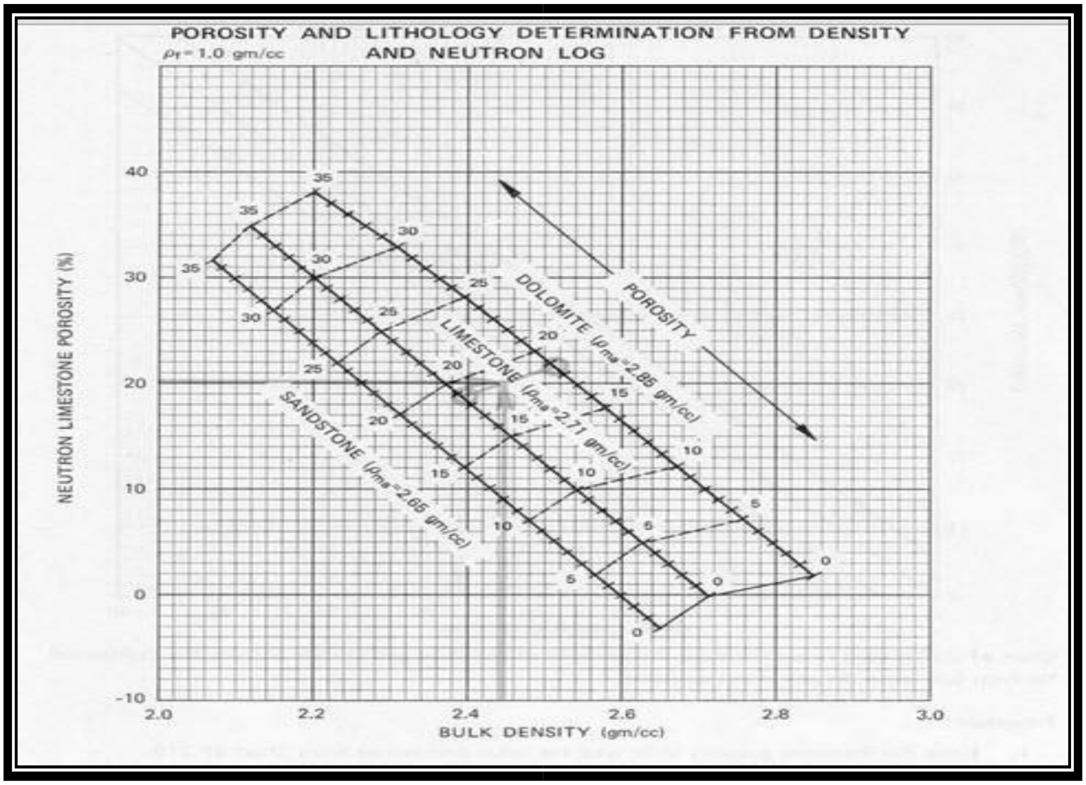

Figure 6.7 Standard crossplot between NPHI And RHOB.

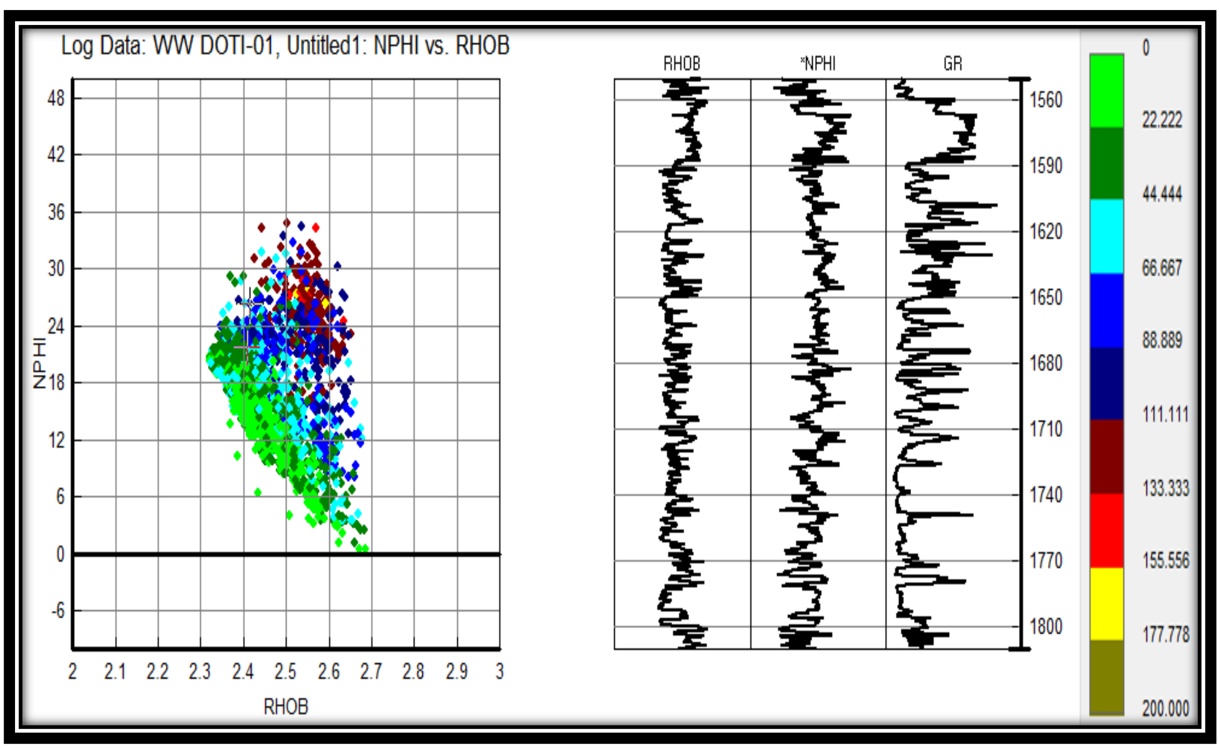

Figure 6.8 Facies model showing clustered points of different lithologies.

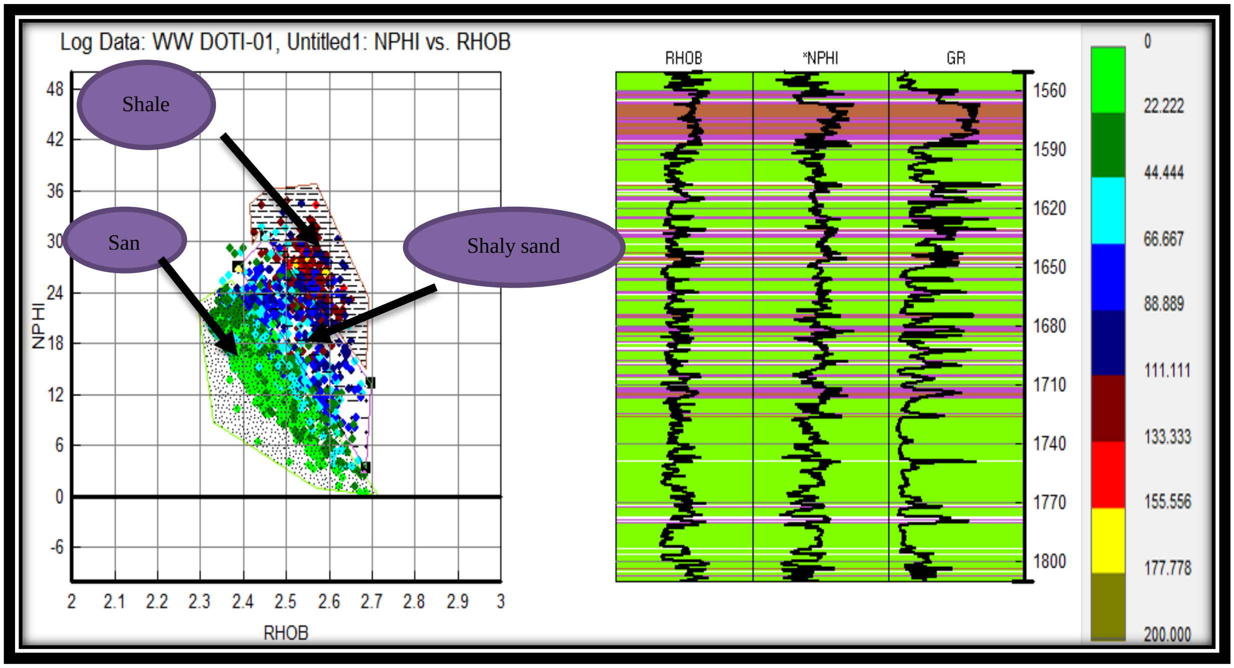

Figure 6.9 Facies model showing the sandstone, Shaly sand and shale

Chapter 7

COLORED INVERSION OF POST STACK DATA

7.1 Wavelet and acoustic impedance

For many seismic processing applications, it becomes necessary to derive an estimate of the seismic wavelet. Because the character of wavelet is imprinted on seismic traces, it is important to understand its shape in order to decipher the properties of earth's interior from seismic traces. In spite of the fact the wavelet is time varying and is expected to be spatially varying, an overall knowledge of wavelet is crucial to enhancing resolution for better imaging of structure and predicting lithology and fluid content. The most common practice is to invert post-stack seismic data for wavelets. A post-stack trace emulates a zero-offset or normal-incidence seismogram, which can be simulated using convolution model assuming 1D earth model. Most seismic data contain noise this problem must be compensated. In frequency domain, the convolution operation is replaced by a multiplication. Three inverse problems are identified.

- Estimation of the wavelet when the reflection co-efficient is known.
- Estimation of reflection co-efficient or acoustic impedances when the wavelet is known.
- Simultaneous inversion for acoustic impedance of wavelet.

Inversion of seismic data to Acoustic Impedance is usually seen as a specialist activity, so despite the publicized benefits, inverted data are only used in a minority of cases. To help overcome this obstacle we aimed to develop a new algorithm which would not necessarily be best in class, but would be quick and easy to use and increase the use of inversion products with in BPA. This new technique, Colored Inversion', performs significantly better than traditional fast-track routes such as recursive inversion, and benchmarks well against unconstrained sparse-spike inversion.

Once the Colored Inversion operator has been derived it can be simply applied to the data on the interpretation workstation as a _user-defined filter‘. In this way inversion can be achieved within hours since the volume data do not have to be exported to another package, and no explicit wavelet is required. The inversion is understood simply by this flow chart.

7.2 Methodology

The well data and information of logs is required for the performing the colored inversion in Kingdom Software.

- The velocity is obtained from sonic log and density is obtained from density log and values of densities are obtained from density log by convolving these values.
- We get acoustic impedance by cross-matching these impedance data with the input reflection data.
- We derive a single optimal matching filter Figure (5.8). Convolving this filter with the input data we see in figure (5.7) that the result is very much similar, everywhere.
- This Empirical observation indicates that inversion can be approximated with a simple filter and that it may be valid over a sizeable region.

The phase of the operator is a constant -90o which is in agreement with the simplistic view of inversion being akin to integration, and the concept of a zero-phase reflection spike being transformed to a step AI interface, provided the data are zero-phase. Walden & Hoskins‘s (1984) empirical observation tells us that earth reflection coefficient series have spectra that exhibit a similar trend that can be simply described as constant function. The term is a positive constant and is frequency arrives at a similar observation theoretically may vary from one field to another but tends to remain reasonably constant with in any one field (Velzeboer 1981). It therefore follows that if our seismic data are inverted correctly they too should show the same spectral trend as logs in the same area.

7.3 Non uniqueness and convolution

The process of convolution for constructing a seismogram using a wavelet and acoustic impedance is performed to generate an operator. Note that wavelet is smoothly varying function, while the reflectivity is a series of delta functions placed at two-way normal time of each reflector (Cooke and Schneider 1983). The spectra of the wavelet and reflectivity series for synthetic are also shown in figure. We observe that wavelet is a band-limited, while reflectivity series is a broad-band. Because the convolution is equivalent to multiplication in frequency domain the spectrum of resulting seismogram is band-limited as well. We can imagine the complexity of the problem further we can take into account the loss of high frequencies of wavelet caused by attenuation. In other words series cannot be assumed to be stationary. Even under stationary conditions the data does not contain all the frequencies. The most common approach to deriving the wavelet is based on well-log data that produce a true reflectivity series**.**

7.4 Wavelet extraction

The wavelet is shown in figure (7.1) is extracted on the basis of the well log data that provides the true reflectivity series (i.e. compressional wave velocity and density computed into acoustic impedance logs, which are mapped into normal incidence reflectivity series). An initial guess of wavelet is convolved with reflectivity series and synthetic normal incidence trace is generated. The difference between the observed and synthetic traced is minimized using a suitable chosen norm with smoothness constraints (Mrinal K. Sen).

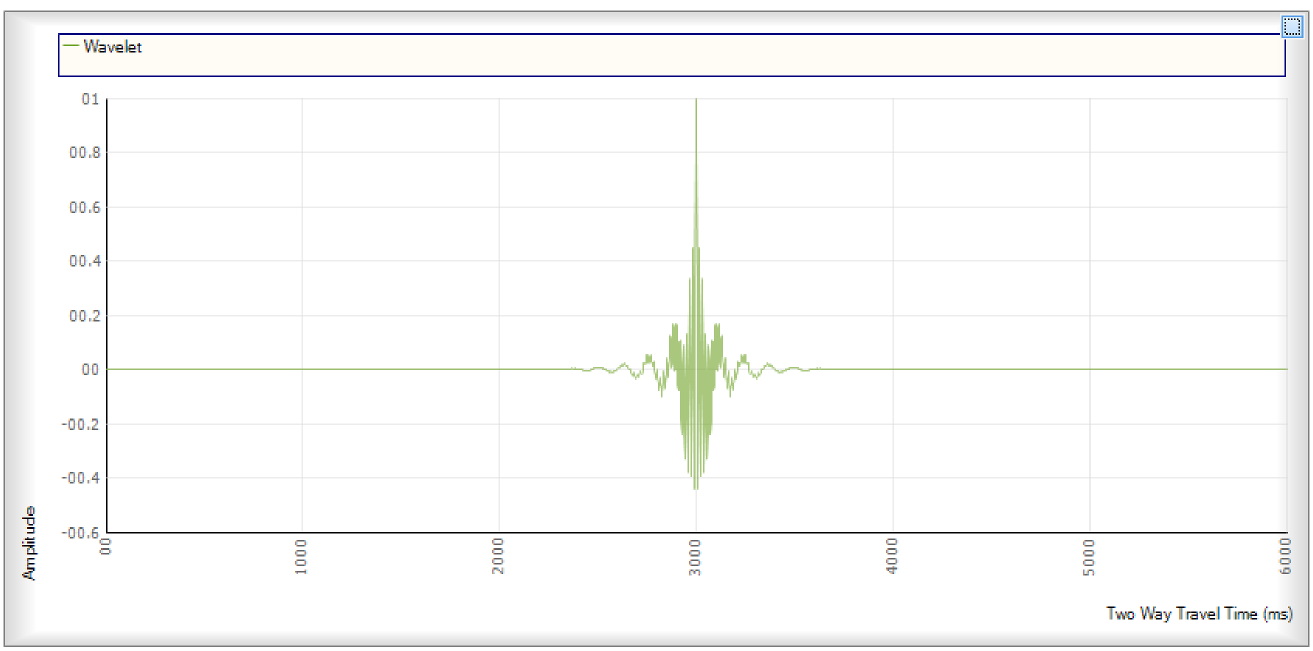

Figure (7.1): Extracted Wavelet

7.5 Impedance estimation

Now our approach is to convolve this wavelet with acoustic impedance (reflectivity series). The acoustic impedance is also computed from well log data as described previously. The impedance spectrum is shown in figure (5.3) is estimated after removing source wavelet; noise must be absent; all multiple reflections must be removed; spherical spreading including all plane reflections (Ghosh 2000).

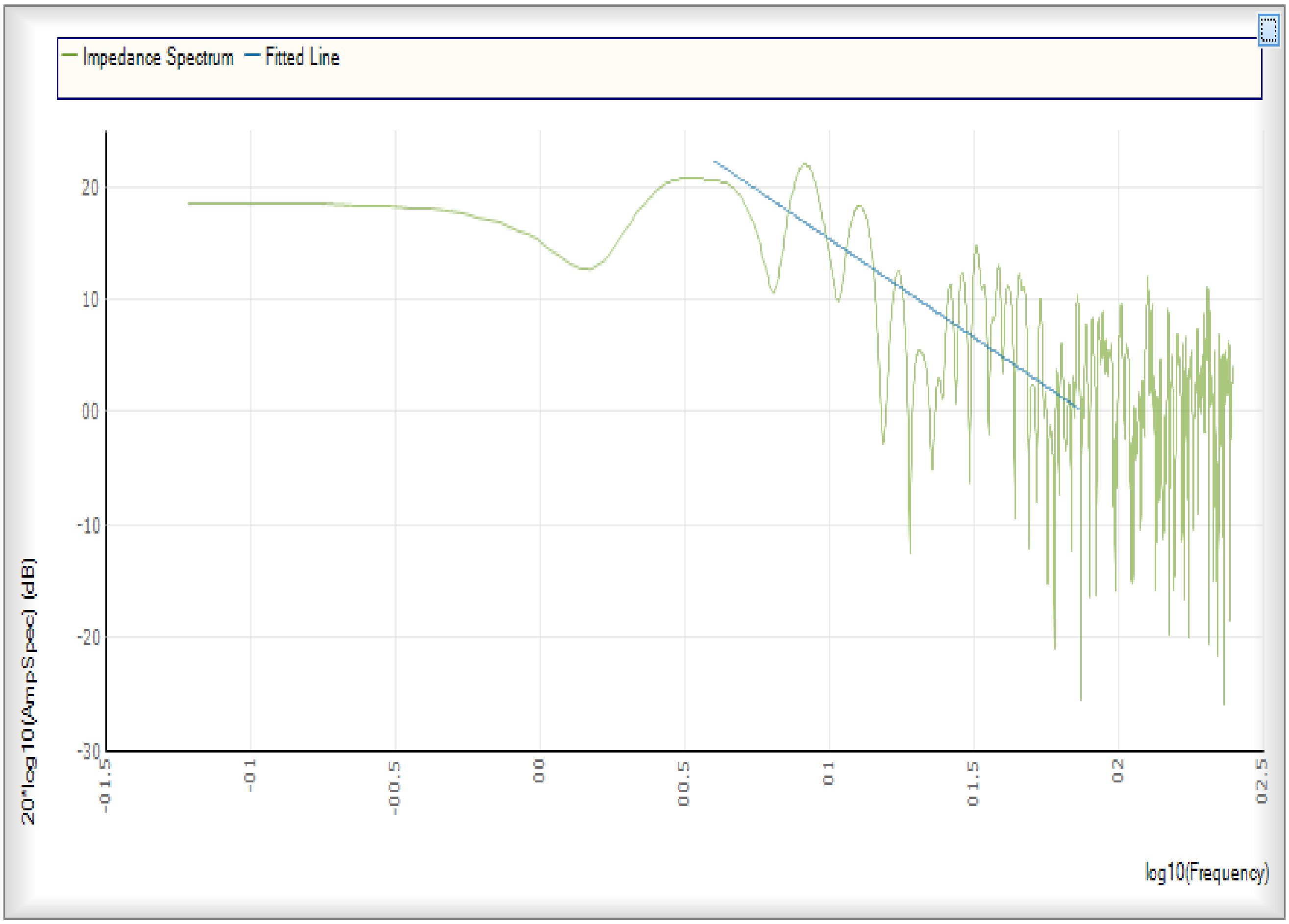

Figure (7.2): Impedance spectrum with fitted line.

7.6 Butterworth filter

The Butterworth filter is a type of signal processing filter designed to have as flat a frequency response as possible in the pass band. It is also referred to as a maximally flat magnitude filter. It was first described in 1930 by the British engineer and physicist Stephen Butterworth in his paper entitled "On the Theory of Filter Amplifiers. An ideal electrical filter should not only completely reject the unwanted frequencies but should also have uniform sensitivity for the wanted frequencies. This filter is used here for convolution of the wavelet and reflectivity series for formulation of seismogram. The Butterworth filter is shown in figure (7.3).

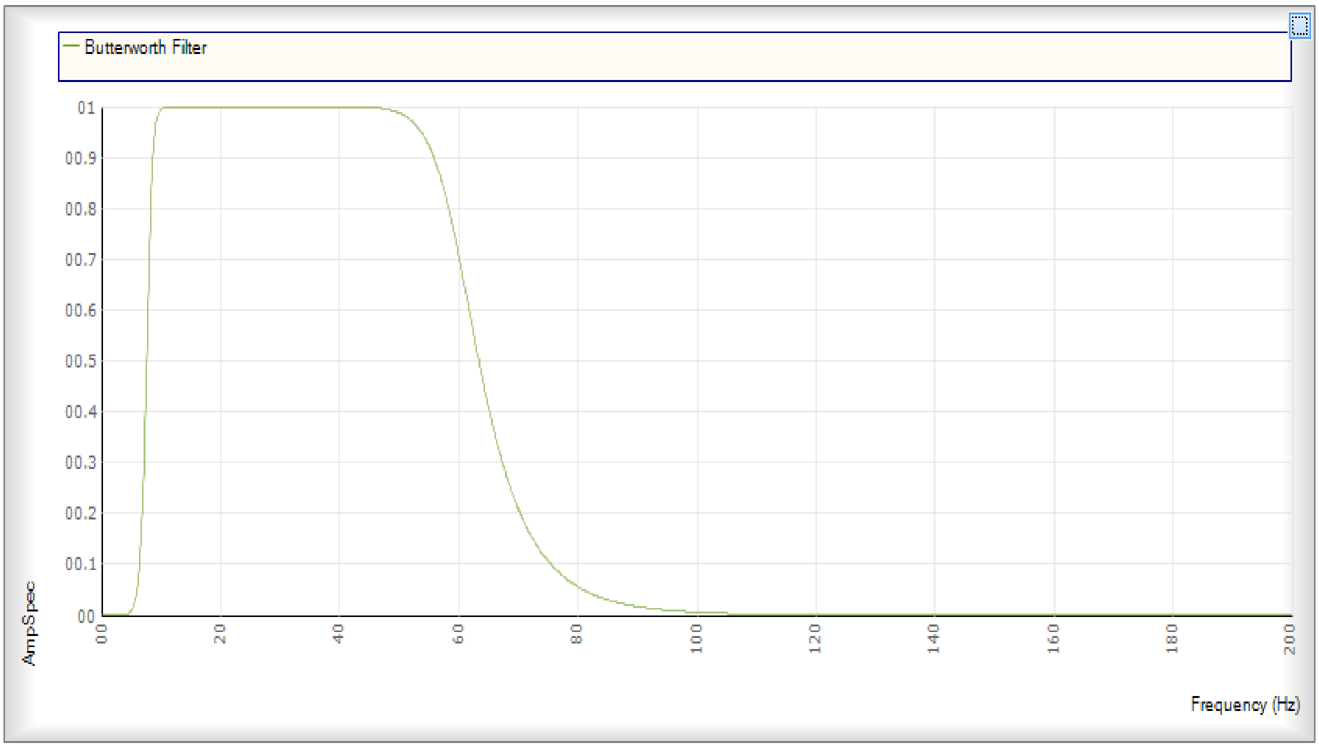

Figure (7.3): Butterworth filter. After the process of convolution is performed we get the seismogram (operator). There is a vast difference between the seismogram of our desire and the seismogram we obtained from the convolution.

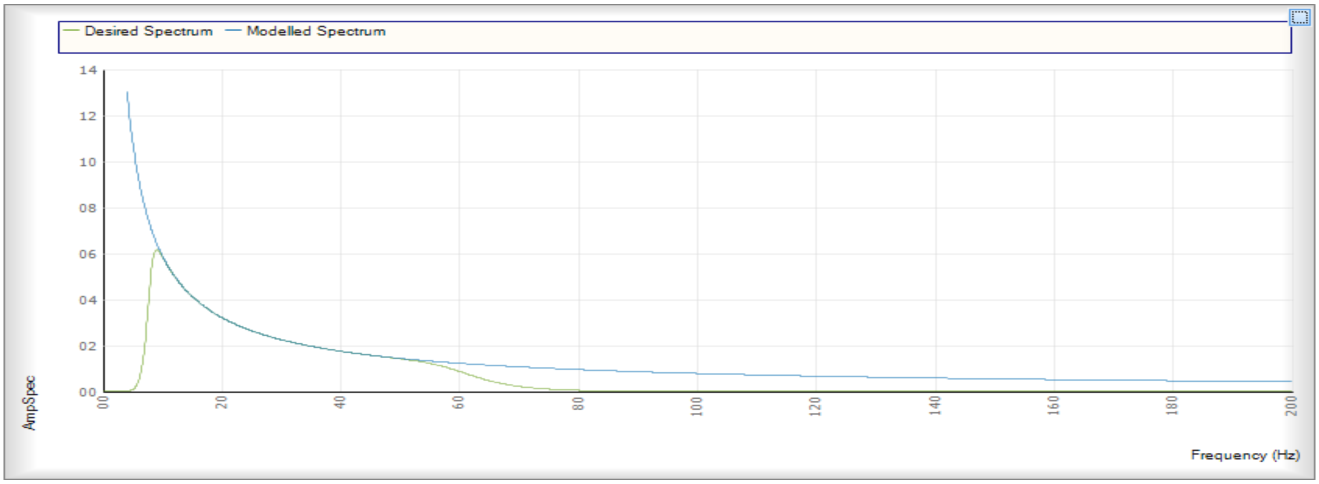

Figure (7.4): Desired and modeled spectrum.

There are two spectrums shown in figure (7.4) both are of different colors. The blue color shows the spectrum obtained from convolution of wavelet and acoustic impedance and the spectrum in blue color shows a desired spectrum. Now we need to obtain a spectrum of our desire for this purpose we have to convolve this spectrum with another spectrum known as shaping spectrum which is obtained by applying Fourier transformation on desired spectrum. The shaping spectrum is shown in figure (7.5).

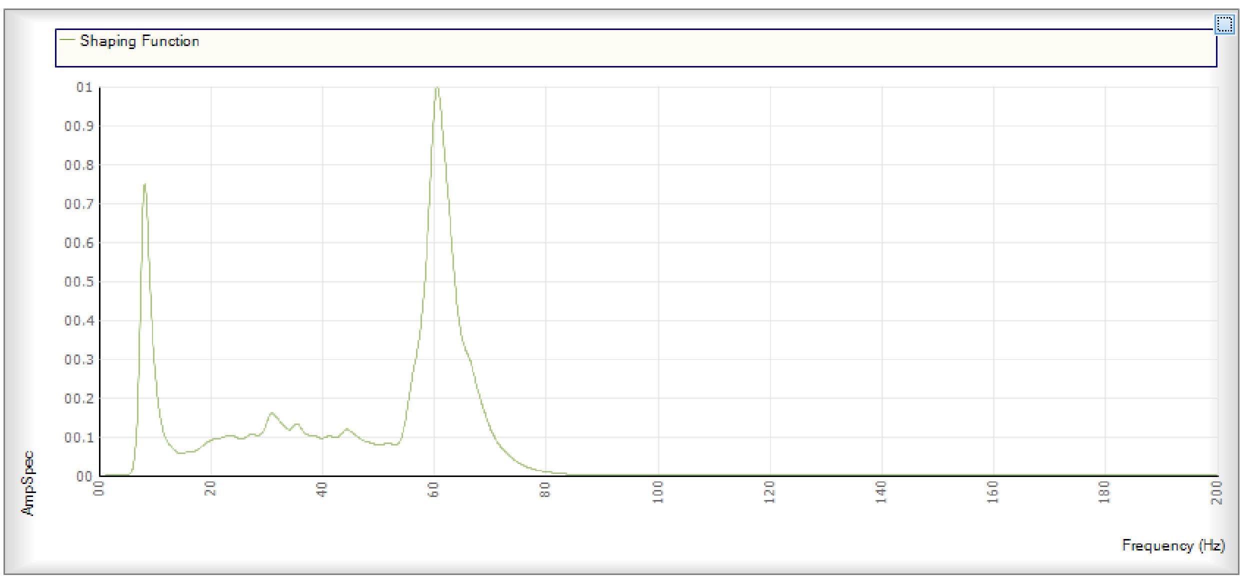

Figure (7.5): Shaping spectrum. The figure (7.5) shows us the shaped seismic spectrum and desired seismic spectrum.

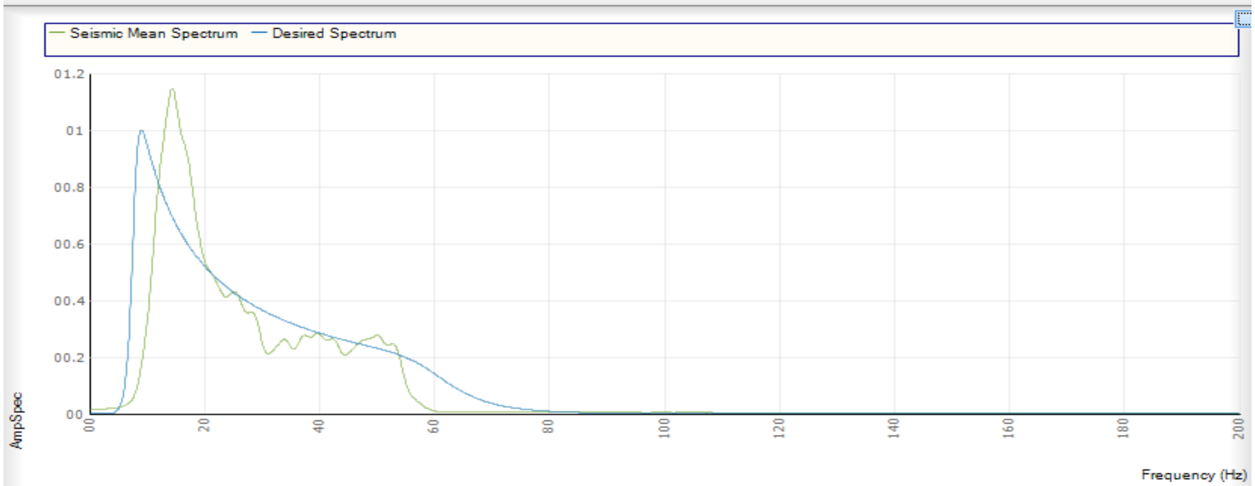

Figure (7.6): Convolution of shaped seismic spectrum and desired spectrum.

A seismogram for specific window (as values of acoustic impedance is obtained from well data) is developed now we develop a seismogram to invert whole section. After convolving seismogram with seismic mean spectrum we are able to apply it on whole seismic section. The figure 7.7 shows seismic mean spectrum and desired spectrum.

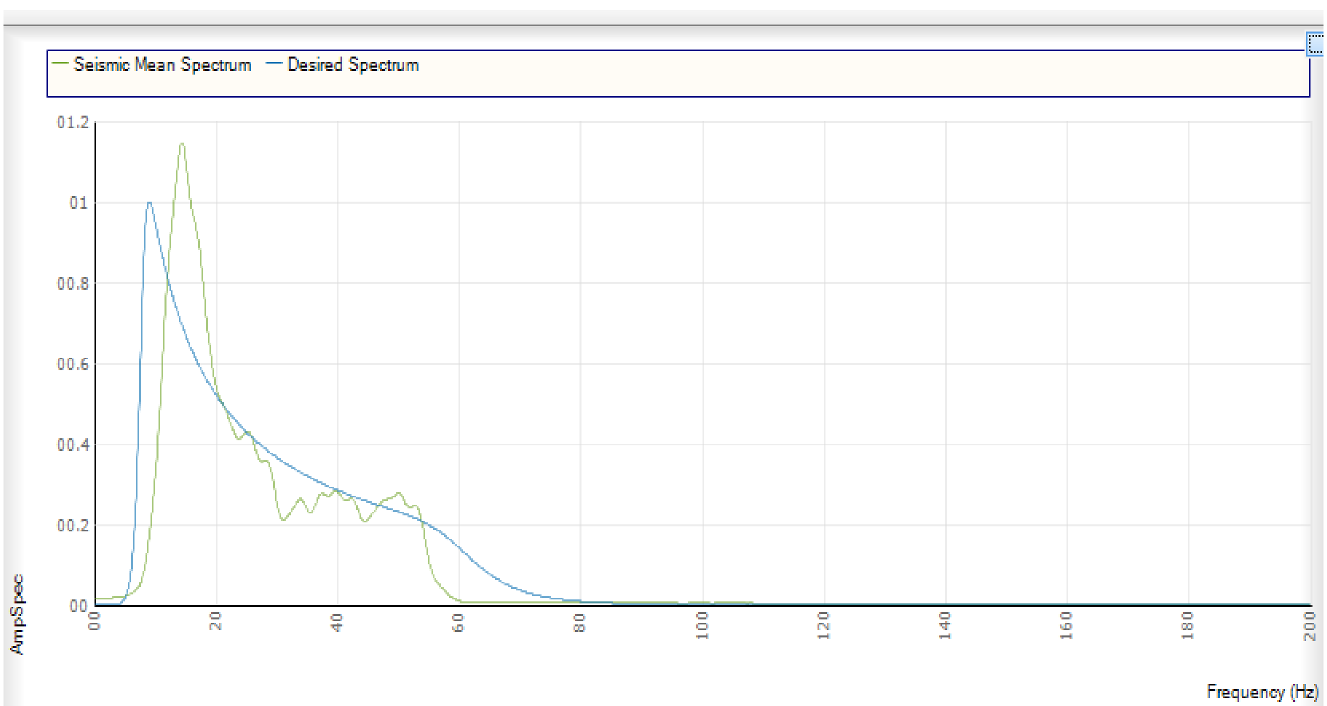

Figure (7.7): Convolution of seismic mean spectrum and desired spectrum.

After completion of the process of generating synthetic seismogram, the section is inverted an acoustic impedance is shown on section instead of amplitude as shown in figure (7.8).

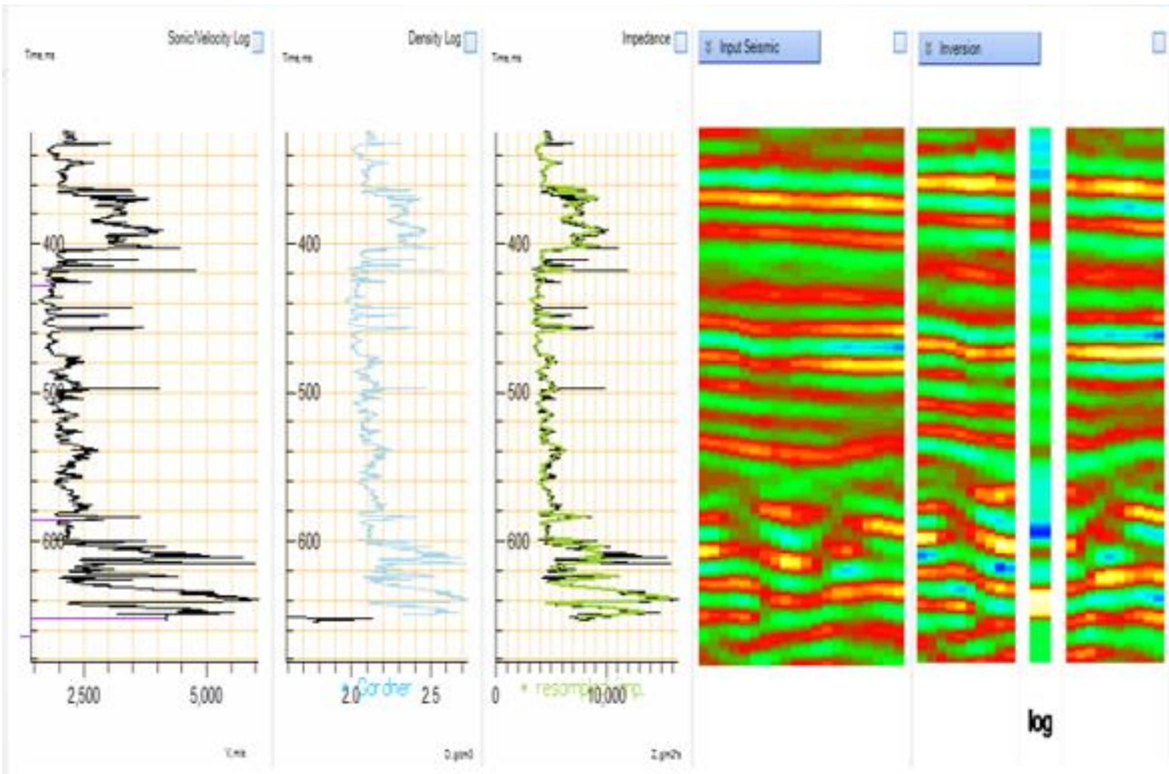

Figure (7.8): Input seismic section and inverted section along with logs

Figure (7.8): Input seismic section and inverted section along with logs. This window displays sonic log and density logs. These logs are used to compute the acoustic impedance. If values of density log are missing then Gardner equation is used to estimate these densities. This equation is very popular in petroleum exploration because it can provide information about the lithology from interval velocities obtained from data these values are calibrated from sonic and density well log information but in the absence of these, Gardner's constants are a good approximation for density. At the right corner of the window input seismic section is shown on left side and inverted section is shown on the right hand side. The inverted section is shown on the both sides of logs sides of the well the log is inverted to invert the seismic section. The zoomed picture of inverted section is shown in the figure (7.9) given below;

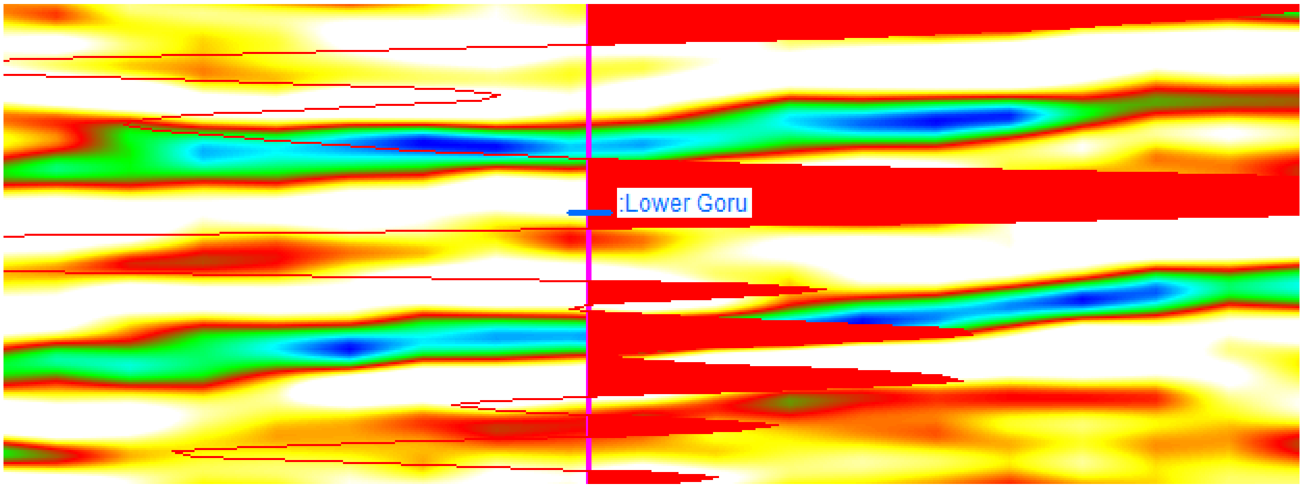

Figure (7.9): Inverted section with inverted logs .Now inversion is applied to the whole section shown in figure 7.10.

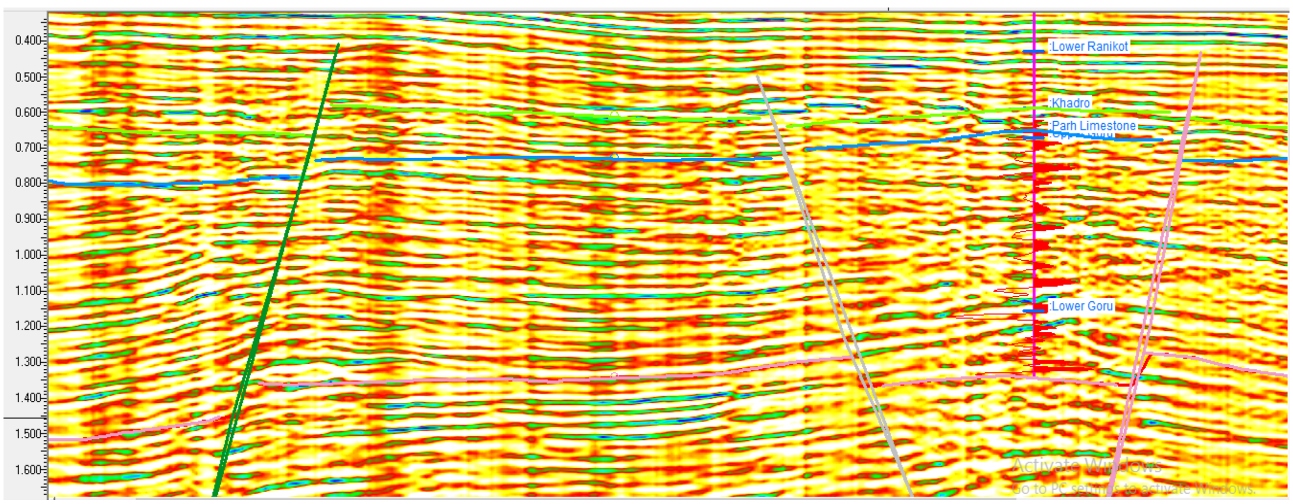

Figure (7.10): Inverted seismic section.

7.7 Interpretation of inverted section

It gives value of low acoustic impedence around the well which gives the indication of hydrocarbons. In the above inverted seismic section there are blue spots which mean there is low acoustic impedence. In the above section low acoustic impedence is represented by blue spots which give the indication of hydrocarbon.

Chapter 8

Conclusions

The thesis work ends with following conclusions:

- The seimic interpretation indicates horst and grabben structure in the area.
- Time to Depth conversion of seismic section gives us the true picture of sub-surface structure.
- Time and depth contours show that horst and graben structure formed in study area.
- Petrophysical analysis show good porosity, major fluid is water (75-80) %.
- Facies analysis show that Dominant lithology in reservoir is sandstone with small shale packages.
- Attribute analysis is worked out for better structural interpretation and result confirmation, seismic attributes also indicates the zones of interest.
- Results of well logs confirm the failure of Doti-01 well.
- Coloured inversion shows low impedence at reservoir level.

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