# INTEGRATED SEISMIC INTERPEPTATION, WELL LOGGING ALONG WITH SEISMIC ATTRIBUTE ANALYSIS OF BADIN BLOCK-4, PAKISTAN

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## CERTIFICATE OF APPROVAL

This dissertation by **Bilal ahmed** s/o **Mushtaq Ahmed** is accepted in its present form by the Department of Earth Sciences, Quaid-i-Azam University Islamabad as satisfying the requirement for the award of degree of BS Geophysics.

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# DEDICATION

**My whole work is dedicated to my Parents and my respected teachers,**

## 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.

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Last but not least, I would like to acknowledge my family for their constant support, unceasing prayers and best wishes. They uplifted my morale whenever I needed. I do thank all those who have helped me directly or indirectly in the Successful completion of my thesis. Anyone missed in this acknowledgement are also Thanked.

**Bilal Ahmed**

# ABSTRACT

The present study pertains to the structural and stratigraphy interpretation using SEG –Y data and well logs data. Badin area is prominent in the Lower Indus Basin for its hydrocarbon (oil and gas) structural traps.

For interpretation of these seismic lines two reflectors and normal faults were marked by using the interactive tools of Kingdom software, polygon construction, two way time contour and depth contour are also the part of the seismic data interpretation. The marked horizons were identified using formation tops from wells and their depths were confirmed through correlation with synthetic seismogram. From time and depth contour maps of the horizons that are marked were generated to understand the spatial geometry of the structures and the nature of geological structures as identified by the seismic section of the area. Normal faulting as identified on seismic sections confirmed that study area lies in extensional tectonic regime. The resulted seismic interpretation of these lines confirmed Horst and Grabben structures by normal faulting. Horsts or the elevated portions in the structure are suitable place for the accumulation of hydrocarbon.

Petrophysical results by using statistical analysis and facies modelling indicates the dryness of well Doti-01.Coloured inversion shows low acoustic impedence at reservoir level.

Contents

Chapter 1 **Introduction**

## 1.1 Introduction to the Area

Hydrocarbons are among the earth's most important natural resources and hydrocarbons are the main constituents of petroleum (literally, "rock oil"), also called "oil," and natural oil. They are commonly found in and extracted from the Earth´s subsurface. Petroleum is a mixture of liquid hydrocarbons, while natural gas is mainly constituted of methane gas.

The extraction of liquid hydrocarbon fuel from a number of sedimentary basins has been integral to modern energy development. Hydrocarbon are mined from tar sands and oil shale. These reserves require distillation and upgrading to produce synthetic crude and petroleum. A future source of methane may be methane hydrates found on ocean floors.

The area of research is located in East of Badin district in Sindh province of Pakistan. It is located in Lower Indus basin(Southern) bounded by Sargodha high in the north, Indian Shield in the east, Kirthar and Suleiman ranges in the west and Indus Offshore in the south. The basin is separated from Upper Indus Basin by Sargodha High and Pezu uplift in the north. The geographical coordinates of the area are:

- **Latitude**: 24° 5’N to 25° 25’N
- **Longitude:** 68° 21’ E to 69° 20’ E

The geographic boundary and the location of the study area is shown in Fig 1.1.


**Fig: 1.1 Satellite Image of Pakistan showing Badin Area (Khan et al, 2008).**

## 1.2 Base Map

A base map typically includes locations of concession boundaries, wells, seismic survey points and other cultural data such as buildings and roads, with a geographic reference such as latitude and longitude or Universal Transverse Mercator (UTM) grid information. Geologists use topographic maps as base maps for construction of surface geologic maps. Geophysicists typically use shot point maps, which show the orientations of seismic lines and the specific points at which seismic data were acquired, to display interpretations of seismic data. Base Map of interest is given below in Fig 1.2:

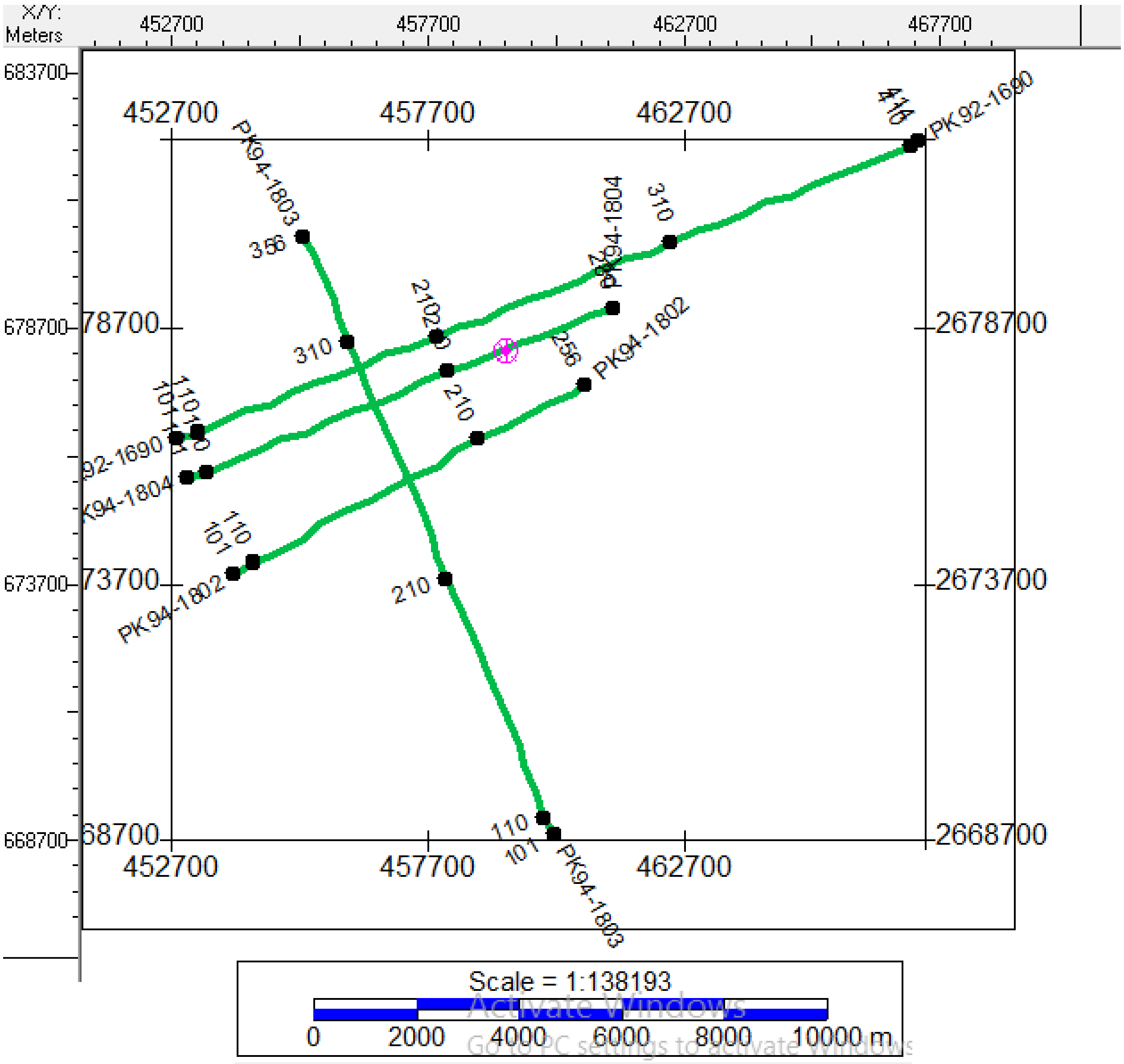


**Fig 1.2 Base Map of the Area, showing location & orientation of seismic lines**

## 1.3 Seismic Data

2D seismic reflection & well data is obtained from Landmark Resources (LMKR) by permission of Directorate General Petroleum Concessions (DGPC) of Pakistan. Seismic data is acquired by Union Texas Pakistan (UTP). The orientation and direction of seismic lines under study are shown in Table 1.1

| Sr. No | Line No | Line Orientation |
|---|---|---|
| 1 | PK92-1690 | NE-SW(DIP) |
| 2 | PK94-1803 | NW-ES(STRIKE) |
| 3 | , PK94-1802 | NE-SW(DIP) |
| 4 | PK94-1804 | NW-ES(STRIKE) |

**Table 1.1 The line number under study** PK92-169, PK94-1803, PK94-1802, PK94-1804

### 1.4 Well data:

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

- Doti-01

### 1.5 Software Purposes

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

**1. Kingdom suite**

- ❖ Base map generation
- ❖ Basic Interpretation
- ❖ DEM contours

**2. X-Works** .

- ❖ Integrated depth surfaces. ❖ 2D seismic Modeling.
- ❖ Velocity Model Building.

**3. Visual Oil**

- ❖ Velocity inversion/ Rock physics.

**4. Wavelets**

- ❖ Petro physics.

❖ Rock physics and Engineering properties.

**5. Kingdom SMT**

❖ Seismic Attributes Analysis.

**6. Surfer**

❖ Horizon velocity contour maps.

❖ Rock physics parameters cross-section.

## 1.6 Analysis of Workflow

The Interpretation was carried forward using different software tools and techniques with each involve different processes.The simplified workflow used in the dissertation is given in Fig 1.5 which provides the complete picture depicting how the dissertation has been carried forward from the initial phase till its completion.

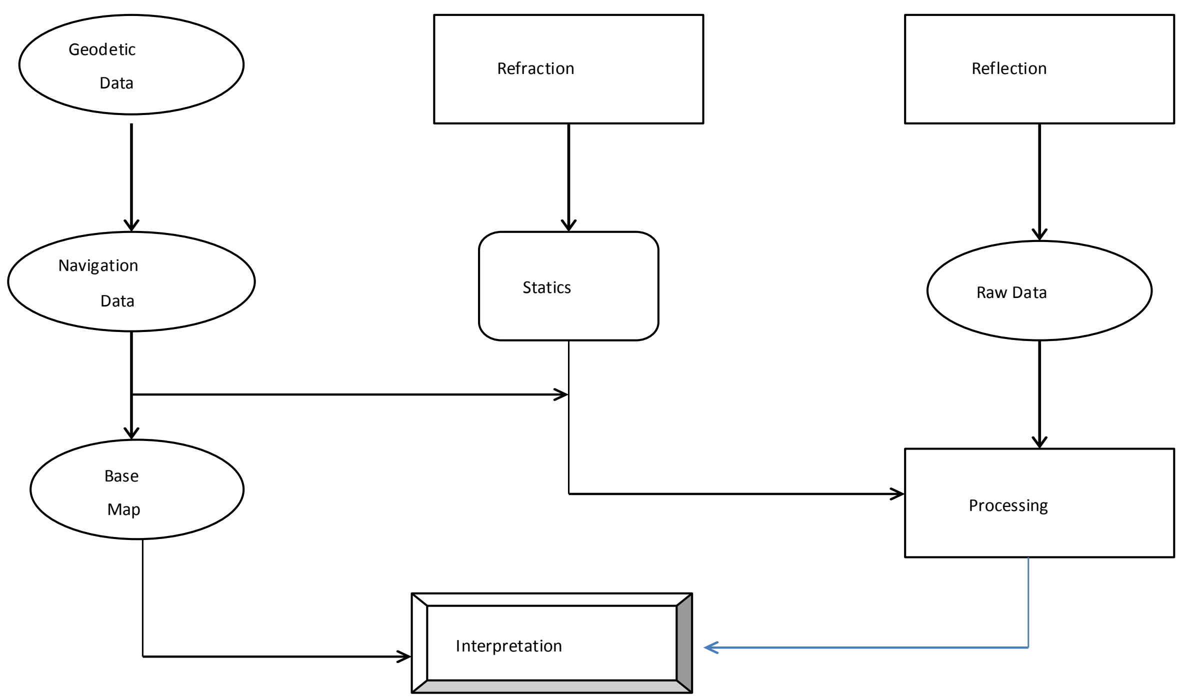


**Fig 1.5 Generalized flow chart of seismic interpretation.**

## 1.7 Aims and Objectives

The following are the objectives of this study:

- This dissertation is primarily focused on seismic interpretation of the study area, which includes marking of horizons, fault picking and construction of time and depth contour maps.
- To find the petro physical properties of reservoir zone by using statistical analysis.
- Identification of reservoir lithology .
- Seismic Attribute Analysis for the confirmation of the horizon marking.

Chapter 2

# 2 Geological setting of the Area

## 2.1 Introduction

The information about the geology of an area plays an important role for precise interpretation of seismic data, because some velocity effects can be generated from formation of different ideologies and also different velocity facts can be generated some lithological horizons. 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)

**Table 2.1 shows the boundaries of Badin Block-IV**

| **Direction** | **Boundaries** |
|---|---|
| East | Indian shield |
| West | Kirthar and Sulaiman Ranges |
| North | Sargodha High |

| | |
|---|---|
| S0uth | Offshore |

Study area lies in the East of district Badin (Latitude 24$^o$ 5′ N to 25$^o$ 25′ N: longitude 68$^o$ 21′ E to 69$^o$ 20′ E) in Sindh province of Pakistan. To the North of Badin is Hyderabad, Arabian Sea and Run of Kutch are in the South, Mirpurkhas and Tharparker are in the East and districts Thatta and Hyderabad are in the West (Munir et al, 2014).

## 2.2 Structural Setting of Badin Area:

A series of horst and graben structures are present in study area almost below the base of Paleocene 5 within the Crateceous in lower indus basin (Shuaib, 1982).

0n west indus plain as a result of normal faulting, these faults performed as a major migrating paths for hydrocarbon from fundamental shaly source sequence (kadri, 1995). The complex type structure and a passive back thrust along kirthar foldbelt (Fig 2.1)

Tectonic instability occurred in Cretaceous time when rifting rate was high about 20-30 cm/a in 80-53 Million years (Farah et al, 1984; Mohoney, 1988; Gnos et al, 1997). Badin Rift exists in Thar Platform vicinity which is in fact Sargodha High that divides Indus Basin into Upper and lower Indus Basins (Kadri I.B, 1995). Mostly horst and graben structures can be seen in Badin Rift (Alam etal, 2002).

Most prominent structure are rifting and doming in study area. The area was away from the main tectonic zone therefore degree of deformation was relatively low. The rate of deformation increases from East to West. Over a large area of Eastern Lower Indus Sub-Basin tilted faults are produced due to extensional tectonic in the time of Cretaceous. Cretaceous and older strata are broken by system of faults with normal dip separation that can be seen on seismic reflectors. Strike of Cretace ous faults is between N 30$^o$ W & N 50$^o$ W.

When hydrocarbons generated then block of tilted faults traps were in existence. In Badin block the faults related traps are responsible for trapping hydrocarbons in Lower Goru Sandston (Kemal, 1991). Fig 2.1 shows the tectonic framework of the Pakistan in which Badin area is highlighted using coordinates.

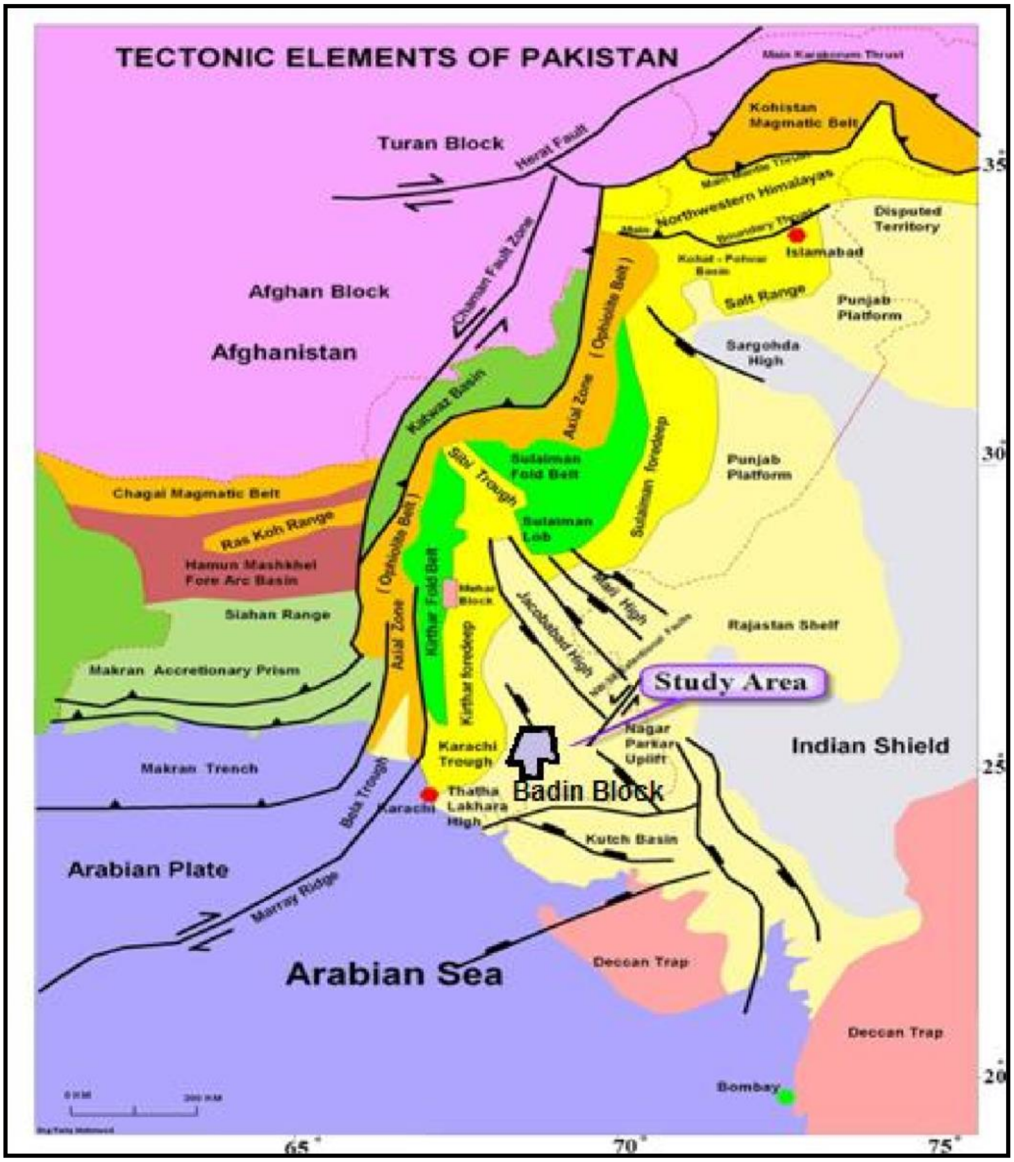


**Fig 2.1 The tectonic and geological setting of the Pakistan including Greater Indus Basin and Study Area in Lower Indus Basin (modified after Kazmi & Snee, 1989).**

## 2.3 Stratigraphy of the Area:

Generalized stratigraphy chart of the area is shown in the Fig 2.2 in which the age of the rocks ranges from Jurassic to Tertiary. In Badin block Chiltan limestone of Jurassic age overlies Triassic sequence. About 610 m thick shale of Sembar formation overlies the Chiltan limestone. On the top of Sembar formation is Lower Goru which is consider as major source rock in the area. Lower

Goru is further divided into five units such as Basal sand overlies Sembar formation, Lower shale overlies Basal sand, Middle sand overlies Lower shale, Upper shale lies between Middle and Upper sand which is 5$^{th}$ unit of the Lower Goru as shown in Fig 2.2. Depositional environment of the Upper sand is shallow marine to deltaic and consider as good reservoir in the Lower Indus Basin (Alam et al, 2002).

Stratigraphically, the shale series of the Early Cretaceous Sember formation and interbedded shale layer of Lower Goru formation are the main document petroleum source rock units in the southern Indus basin. Upper Paleocene marine transgressive shale acts as secondary source rock, deeply buried in the western half of the southern Indus Basin (Zaigham and Mallick, 2000).

The basal sand of Lower Goru Formation is target formation in the area. Massive Sand is another interesting producing reservoir from its various sand sheets of multiple thickness. The possibility of reservoir in lower Goru overlain on Basal sand could not be ruled out,however thet have not yet proved to be such up till now ( Kadri I.B, 1995).

In general, the transgressive shales of the Cretaceous (Sember formation) and Tertiary (Bara-lakhlra, Laki-Gazij and Kirthar formation) acts as a seal in Southern Indus Basin (Zaigham and Mallick, 2000). Intra-formation shale of Lower Goru formation provides effective vertical and lateral seal. The shale units also provides cross fault seal. Fault may also acts a seal. Upper Goru shale, Lower Goru and Talhar shale are the primary seal for Lower Goru reservoir sands (Kadri etal, 1995).

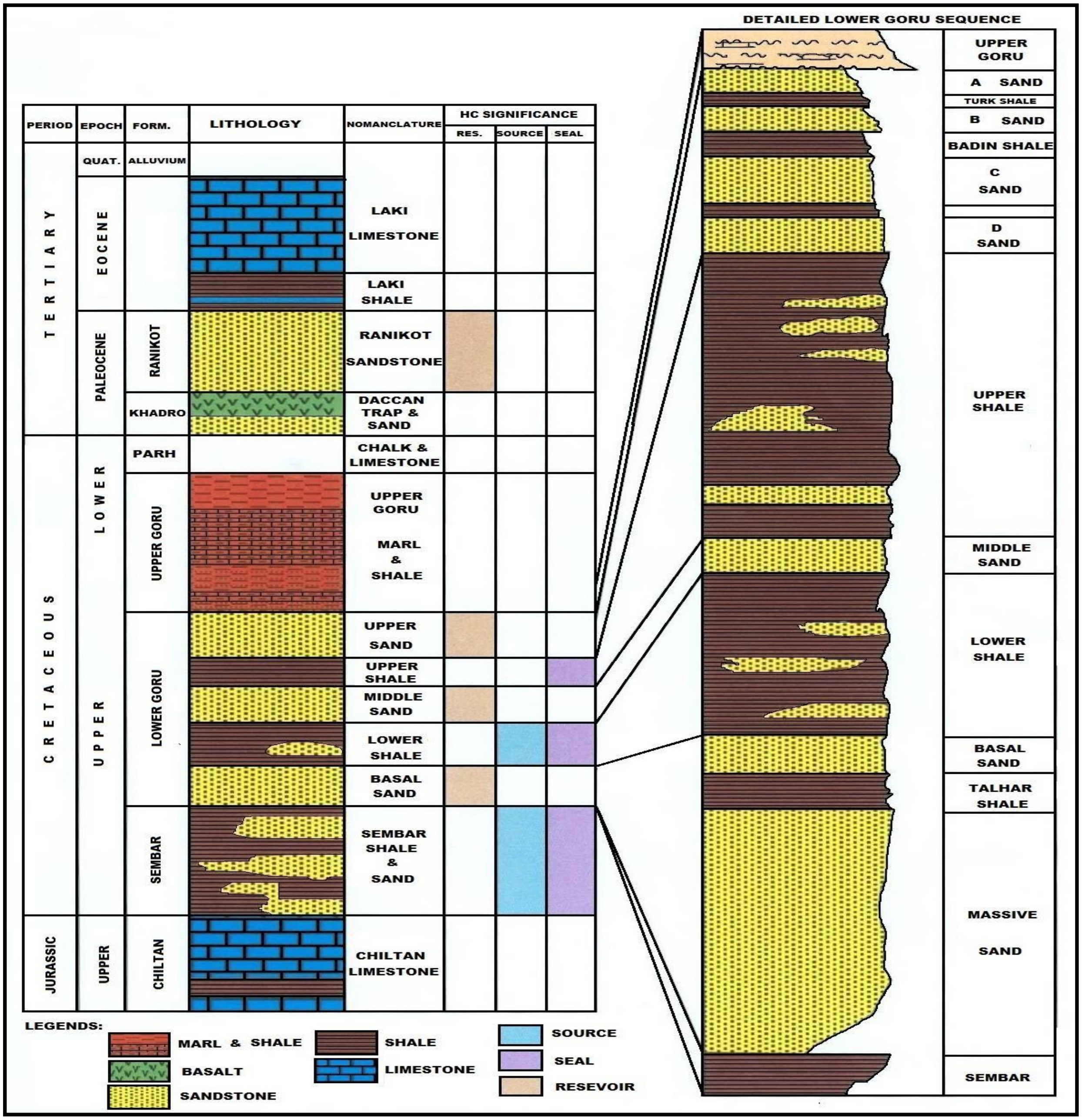


**Fig 2.2 General stratigraphy chart of the Lower Indus Basin and study area inwhich Lower Goru is further subdivided into different units (modified after Saleem et al., 2011; Alam et al., 2002; courtesy MPCL).**

## 2.4 Petroleum Play In The Study Area:

- Source Rock : Sember shale
- Reservoir Rock : Basal sand
- Cap Rock : Upper Goru marl

### 2.4.1 Reservoir Rocks:

The Basal Sand of Lower Goru formation is target formation in the area. Massive Sand is another interesting producing reservoir from its various sand sheets of multiple thicknesses. The possibility of reservoir in Lower Goru overlain on Basal Sand could not be ignored although they have not proved as reservoirs still now (Kadri, 1995). Hydrocarbon targets may also exist in the Jurassic Chiltan Limestone, Paleocene and Eocene formations (Zaigham and Mallick, 2000).

### 2.4.2 Seal Rocks:

Sember Formation, Bara-Lakhra, Laki-Ghazij and Kirthar Formations act as seal in Southern Indus basin (Zaigham & Mallick, 2000). Inter-bedded Shales (Upper, Lower and Talhar) of Lower Goru formation provides effective vertical and lateral seal and act as a primary seals. The Upper Goru forms the top and lateral seals for the Upper Sand units of Lower Goru formation. (Kadri, 1995).

### 2.4.3 Source Rock:

Sembar is considered as source rock in the lower and middle Indus basins that has high vertical and lateral extension throughout the basins. Source rock in the study area is of early cretaceous. 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.

### 2.4.4 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 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 method 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 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 in a way that its relation with initial disturbance can be interpreted. It includes all those steps which yield final output to be processed and interpreted. 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. Then the whole work starts with field equipment and methods to be adopted for the acquisition of seismic data. 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 shows the generalized processing flow chart

### 3.5 Survey parameters of study area

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

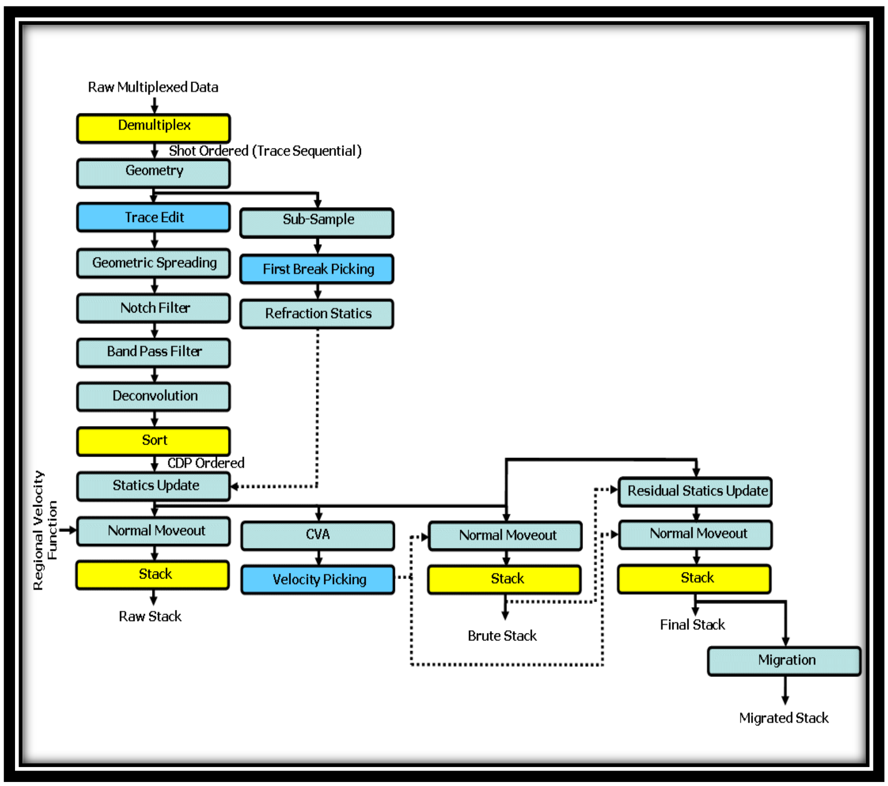


Figure 3.1 Seismic data processing flow chart. (Khan etal, 2009)

### 3.5.1 Acquisition parameters

Acquisition parameters are shown in table 3.1

| Recorded By | CGG |
|---|---|
| **Source** | Dynamite |
| **Cable Type** | Split Spread |
| **Shoot Depth** | 6m |
| **Number Of Groups** | 96 |
| **Group Interval** | 50m |
| **Shoot Interval** | 100m |
| **Recording System** | Myriaseis |
| **Recording Length** | 6s |
| **Recording Fold** | 24 |
| **Sampling Rate** | 2ms |
| **Format** | SEG=D DE multiplex |

| | | |
|---|---|---|
| **Recording Filter** | High Cut | 150 Hz  54 Db/Oct |
| | Low Cut | 2 HZ   18 DB/Oct |

### 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

# 4 SEISMIC INTERPRETATION

## 4.1 INTRODUCTION

Seismic interpretation is the process of determining information about the subsurface of the earth from seismic data. Seismic interpretation implies picking and tracking laterally consistent seismic reflector for the purpose of mapping geologic structures, stratigraphic and reservoir detection. Seismic Methods deal with the use of artificially generated elastic waves to locate hydrocarbon deposits, geothermal reservoirs, groundwater, archaeological sites, and to obtain geological information for engineering. It provides data that, when used in conjunction with other geophysical, borehole and geological data, and with concepts of physics and geology, can provide information about the structure and distribution of rock types.

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).

The importance of the seismic methods over other geophysical methods as mentioned by Robinson & Coruth (1988) and Kearey & Brooks (1996) is due to its accuracy, resolution and presentation. In addition to oil and gas prospecting, the seismic methods are also employed for the:

- Measurement of the bedrock depth
- Ground water investigation
- Geotechnical purpose

Followings are the main seismic methods:

- **Seismic Reflection Method**

- **Seismic Refraction Method**

### 4.2 Method for the Interpretation of Seismic Data

There are two main approaches for the interpretation of seismic section

- Stratigraphic Analysis
- Structure Analysis

#### 4.2.1 Stratigraphic Analysis

Stratigraphy analysis involves the delineating the seismic sequences which present the different depositional units recognizing the seismic facies characteristic with suggest depositional environment and analysis the reflection characteristic variation to locate the stratigraphic change and hydrocarbon depositional environment 3-D works is especially important recognizing the stratigraphic feature with distinct shape. The amplitude velocity and frequency or the change in the wave shape are the indicative of the hydrocarbon accumulation. Variation of the amplitude with the offset is also important hydrocarbon indicator. Unconformities ae mark by the change in the drainage basin but that helps developed the depositional environment. Reef, lenses, unconformities are the example of the stratigraphic (Sheriff, 1999**).**

#### 4.2.2 Structural Analysis

This type of analysis is very suitable in case of Pakistan, as most of the hydrocarbon are being extracted from the structural traps. It is study of reflector geometry on the basis of reflection time. The main purpose of structural analysis on seismic section is in the search for the structural traps containing hydrocarbon. Most seismic interpretation used two way times rather depth and time structural maps are constructed to display the geometry of selected reflections events. Some seismic sections contain images that can be interpreted without difficulty. Discontinue reflections clearly indicate faults and undulating reveal folded beds (Sheriff, 1973).

Some of the parameters used in seismic stratigraphic interpretation are:

- Reflection Configuration
- Reflection Continuity

- ➢ Reflection Amplitude
- ➢ Reflection Frequency
- ➢ Interval velocity
- ➢ External form

### 4.2.3 Working Procedure

The following steps were followed for interpretation purpose.

- Preparation of base map
- Generation of synthetic seismogram.
- Fault identification and marking
- Horizon marking

All digital maps along with geo-referenced imagery were produced by using Kingdom Suite. The interpretation was done on Kingdom which provides an interactive interface for marking horizons and faults, exporting horizon's time, velocity and depth data for contouring and for further analysis

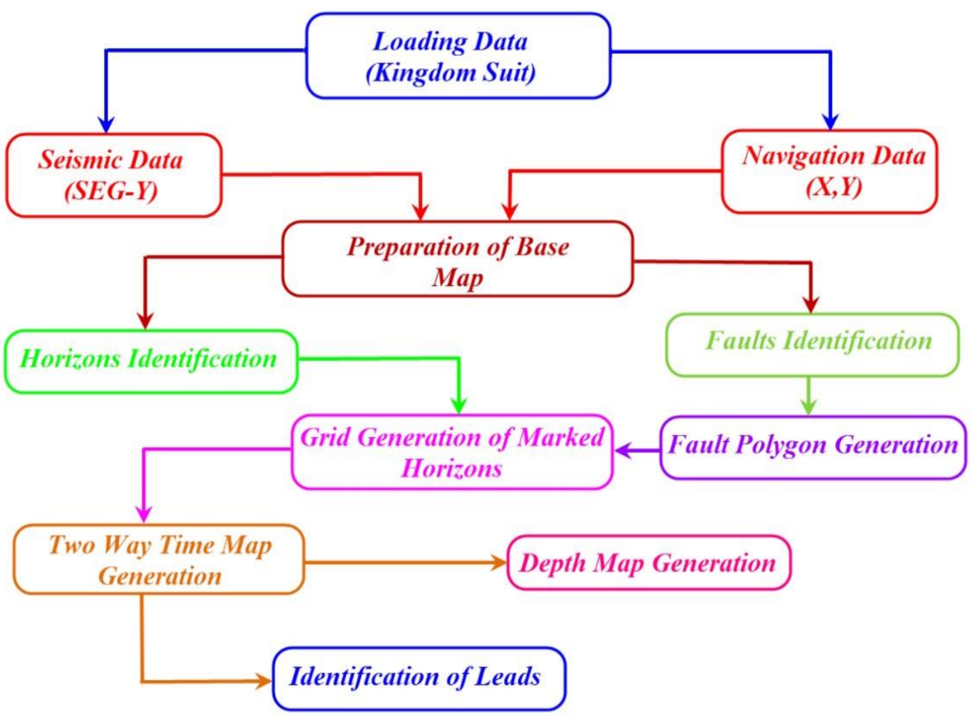


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**Fig 4.1. Interpretation work flow**

### 4.2.4 Generation of Synthetic Seismogram

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 depth time depth chart is prepared. And then finally synthetic seismogram is generated Fig 4.2. Tie this synthetic seismogram with the Seismic line, on which well is located (PK94-1804). Actually seismic data is provided in time scale and well tops are given in depth so we cannot mark horizons in time form. So, 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 on this line. Tie marked Seismic with other lines and horizons are marked on these lines. During tie lines mistie shift is applied.

TWO Seismic lines assigned are interpreted in following sections.

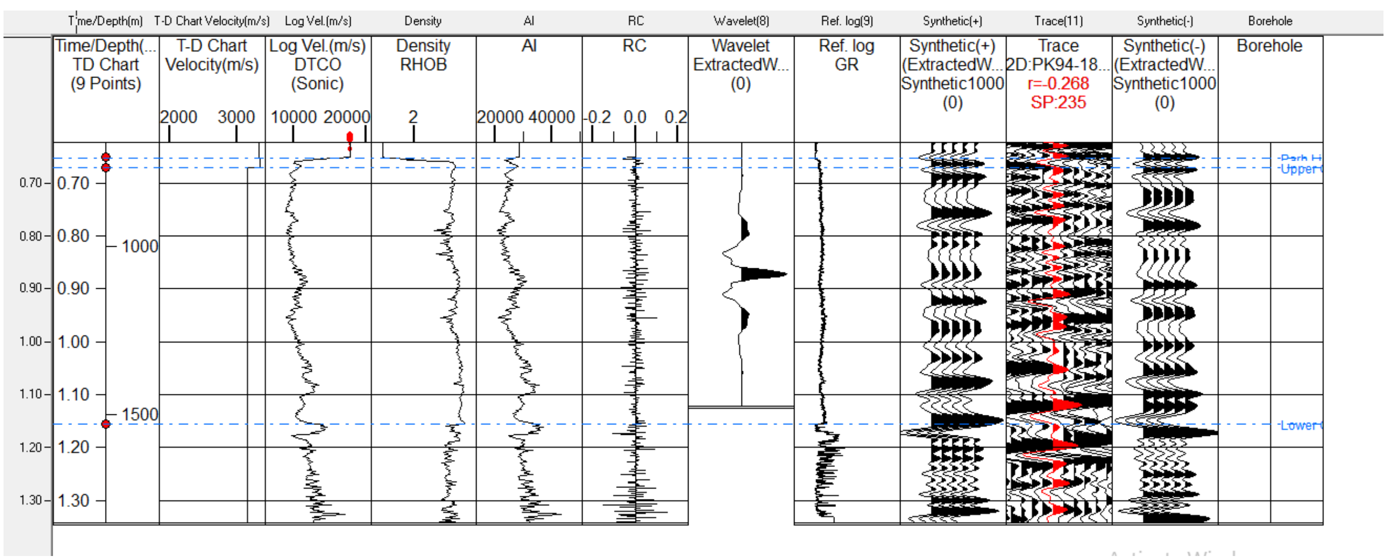



**Fig 4.2 Synthetic Seismogram of Doti-01**

### 4.2.5 Marking of Seismic Horizons

Primary task of interpretation is the identification of various horizons as an interface between geological formations. For this purpose, good structural as well as stratigraphic knowledge of the area is required. Thus during interpretation process, I mark both, the horizons and faults on the seismic section (McQuillin *et al*, 1984). Three horizons are picked on the basis of available information. The horizons are named on basis of well tops of the well Doti-01. The Kadro, Upper Ranikot and Lower Goru formations, Fig 4.3 which are showing high reflections on a seismic section making it easier to be picked.

#### 4.2.6 Fault Identification

Following steps should be followed to interpret the faults on the seismic data.

1. Geology of the area

2. Marking faults on seismic sections

3. Correlation of the faults

#### 4.2.7 Interpreted Seismic Sections

The interpreted seismic section of the line PK92-1690,PK94-1804,PK94-1802 and PK94-1803 is shown in Fig 4.3. Fig 4.4,Fig 4.5 and Fig 4.6 Total Two seismic horizons namely Chiltan and Lower Goru are marked. Along these seismic horizons, faults are also picked shown in Fig 4.3.

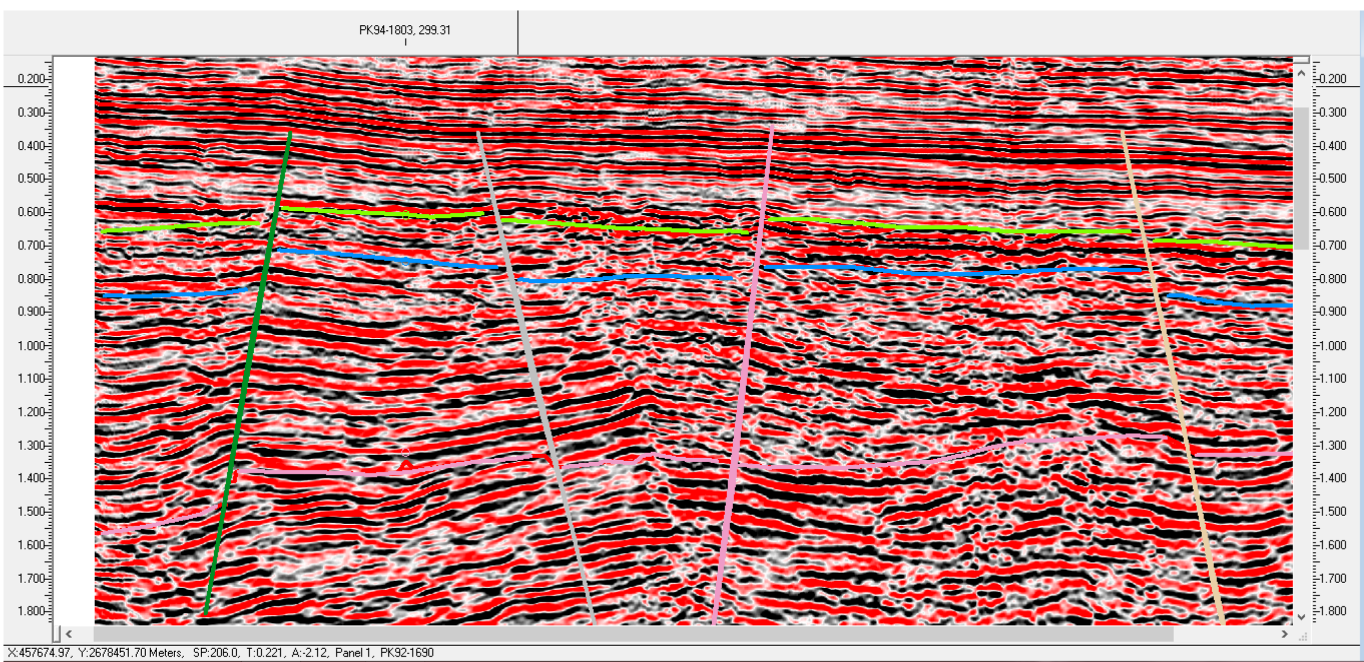


**Fig 4.3 Interpretation of the line PK92-1690(Dip)**

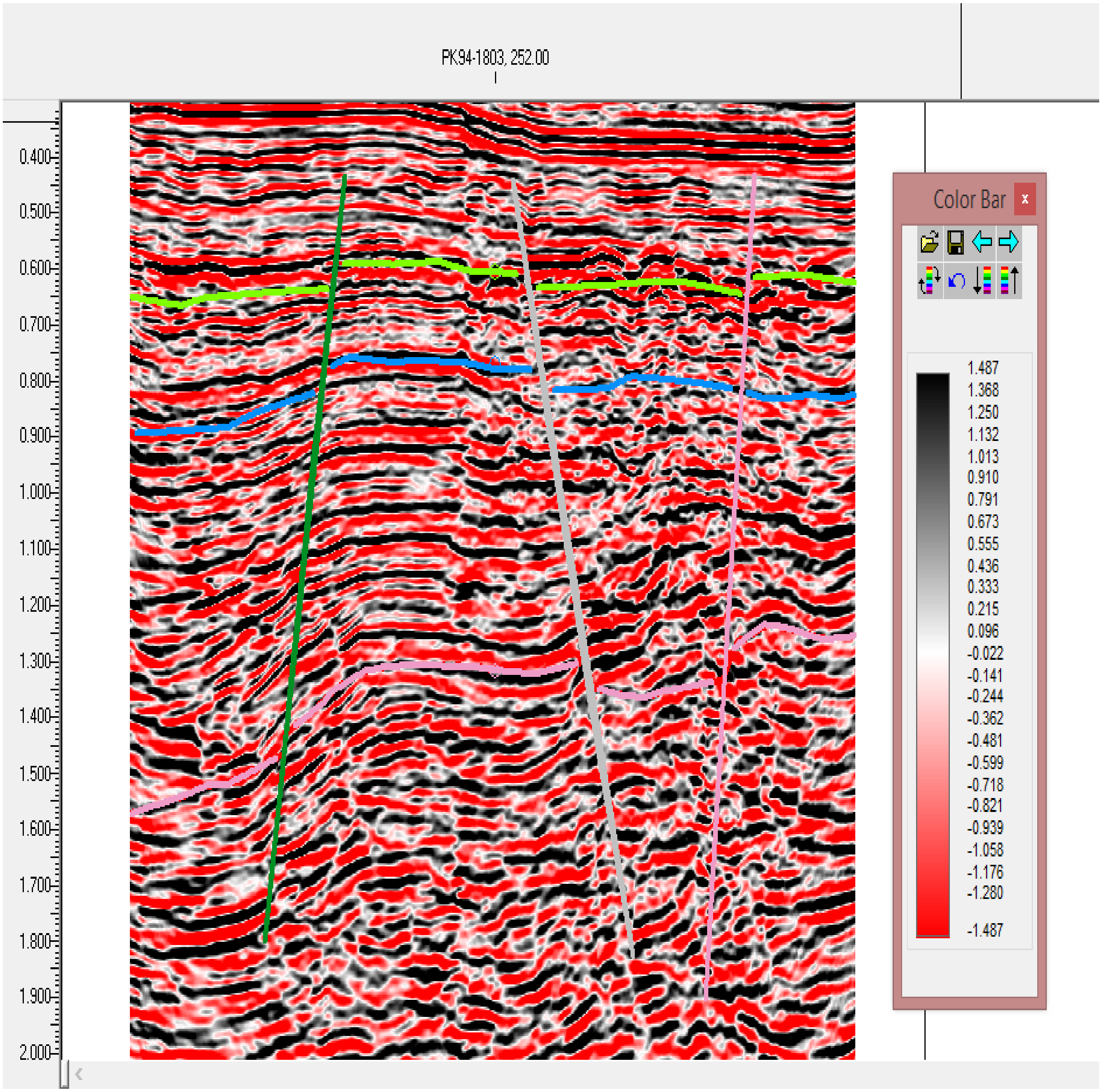



**Fig 4.4 Interpretation of line PK94-1802(dip)**

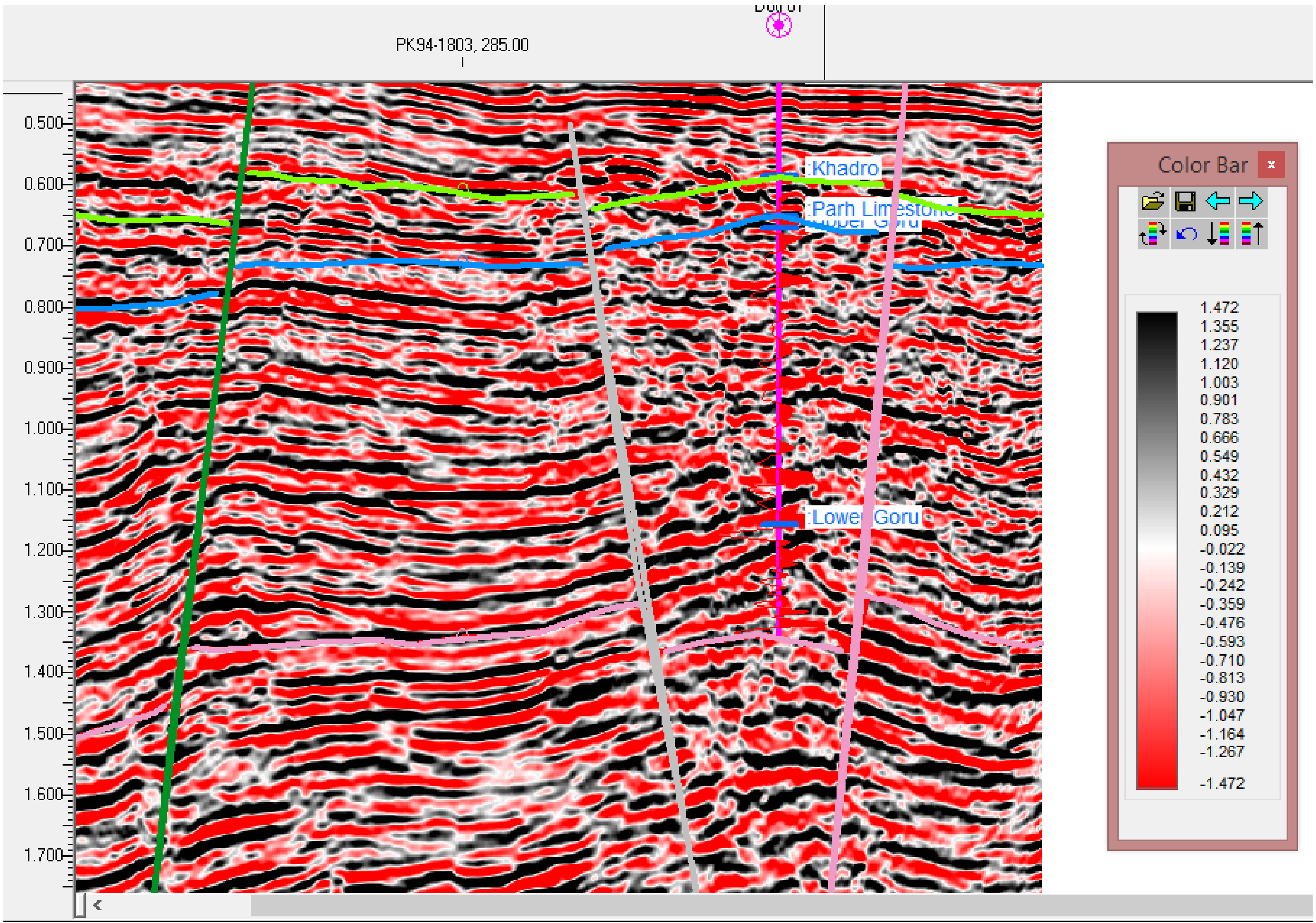



**Fig 4.5 Interpretation of line PK94-1804(dip)**

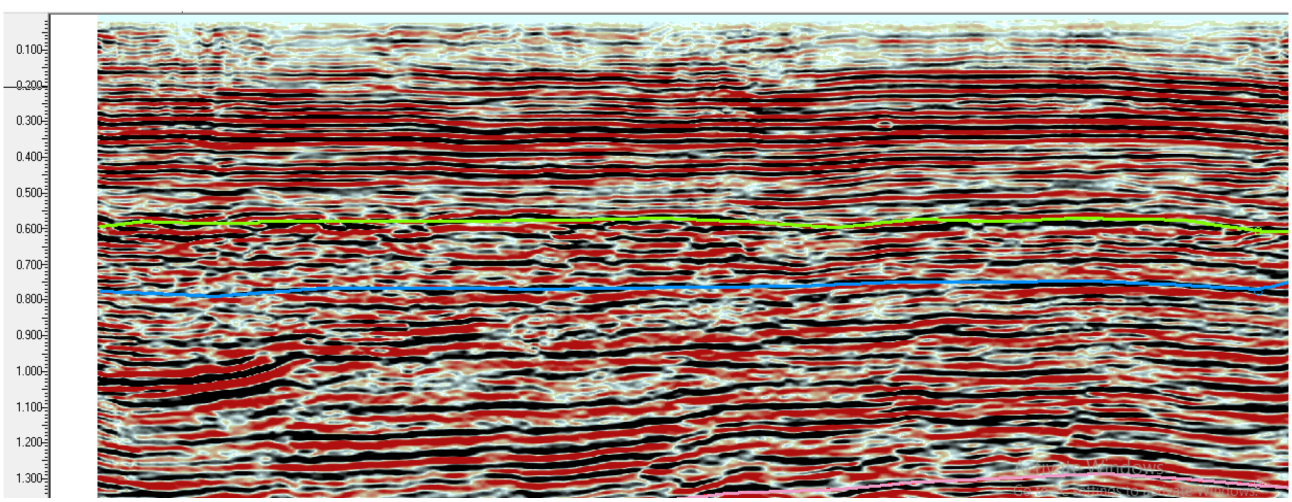



**Fig 4.6Interpretation of line PK94-1803(strike)**

### 4.2.8 Fault Polygons Generation

Before generation of fault polygons it is necessary to identify the faults and their lateral extent by looking at the available seismic data. If one finds that the same fault is present on all the dip lines, then all points (represented by a “+” or a “x” sign 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. Fig 4.5 formed at Lower Goru level 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 all marked horizons and these are oriented in NW-SE direction.

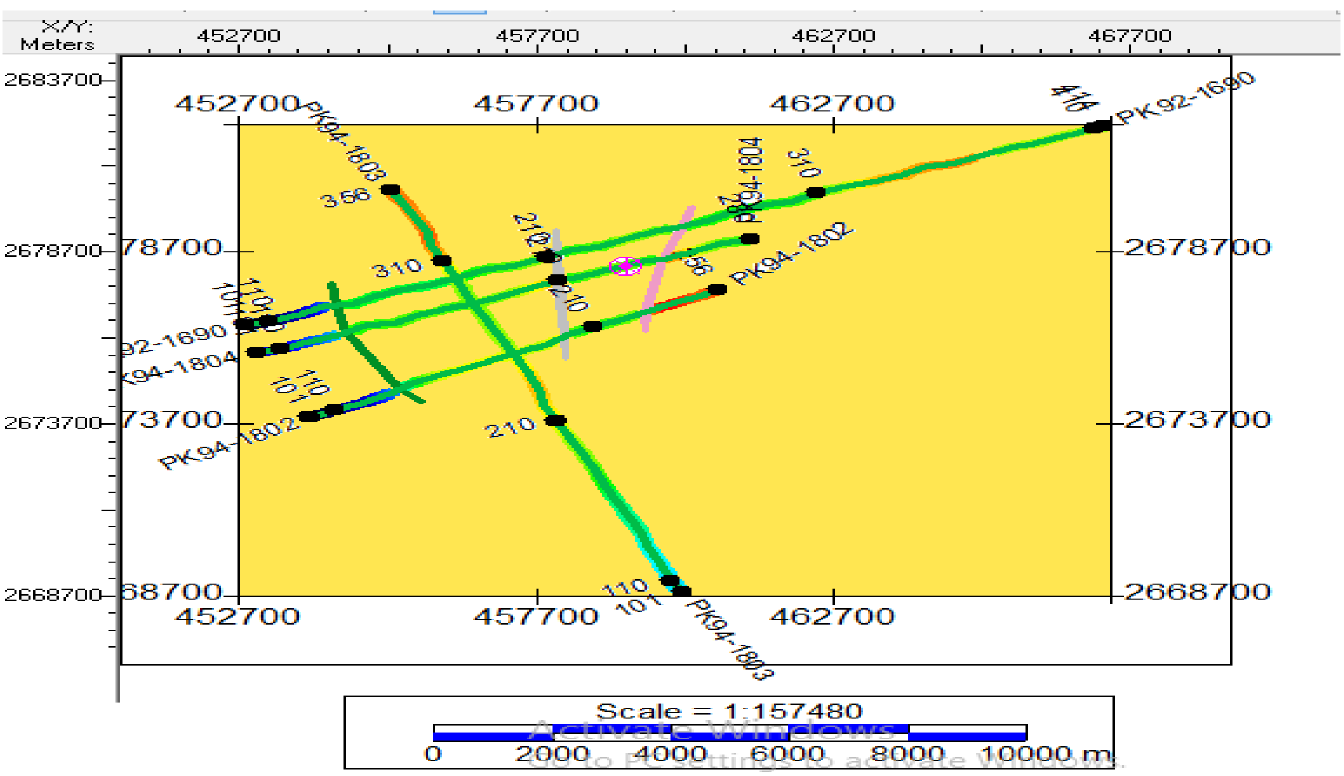



**Fig 4.5 Showing set of fault polygons of an arbitrary prominent horizon marked on Seismic section**

## 4.3 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. The contours are the lines of equal time or depth wandering around the map as dictated by the data (Coffeen, 1986). 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).

### 4.3.1 Time Contour Maps of Marked Horizons

Time contour maps at the level of marked horizon are posted in the following figures i.e. Fig 4.6. In these time contour maps the central parts indicating Graben trending NW-SE shows deepest part on the color scale while the shallowest parts indicating horst. As our well is lying away from the highs, so this well is going to be non-producing well.

Time contour maps of the Lower Goru formation is shown below:

### 4.3.2 Time Contour Map of Lower Goru Reservoir

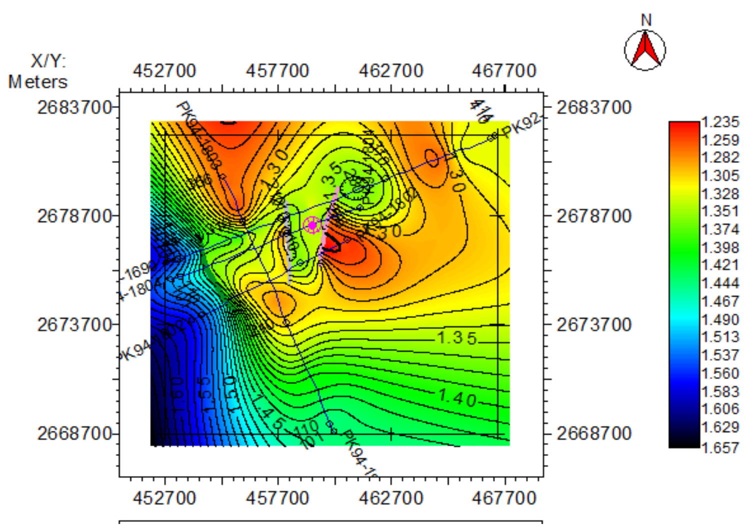



**Fig 4.6 Time Contour Of Lower Goru Formation**

### 4.3.3 Depth Contour Map of Marked Horizons

The depth contour maps show the horizon depth variation, from the Fig 4.7. It can easily be interpreted that horizon is forming a horst and graben structures, as from the scale the central portion between fault polygons is deepest in depth than the surrounding area. Some ambiguous portion is also seen in map which may be the poverty or unavailability of the data. It also be noted that that there is no change in pattern of time and depth contours because variation is same either with time or with depth.

### 4.3.4 Depth Contour Map of Lower Goru

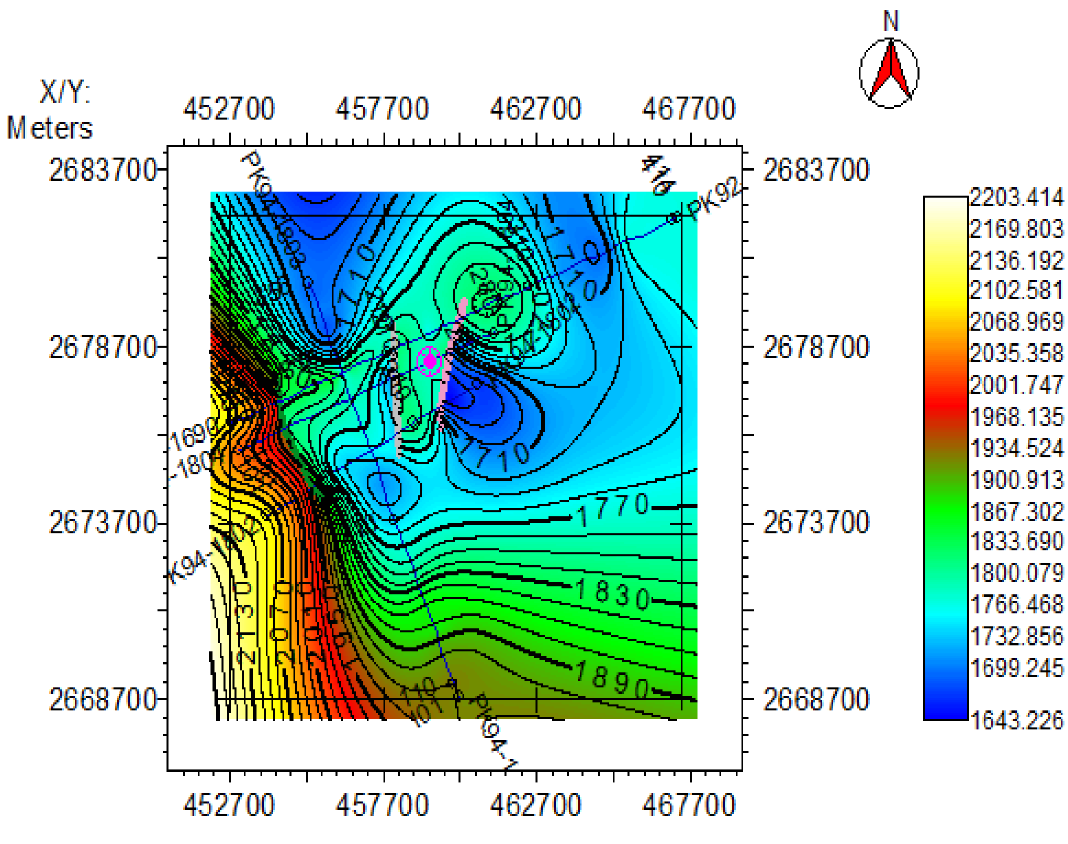



**Fig 4.7 The depth Contour Map of Lower Goru**

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 1D 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.

## 35.2 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.

### 5.4 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;

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

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.

### 5.4.1 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.

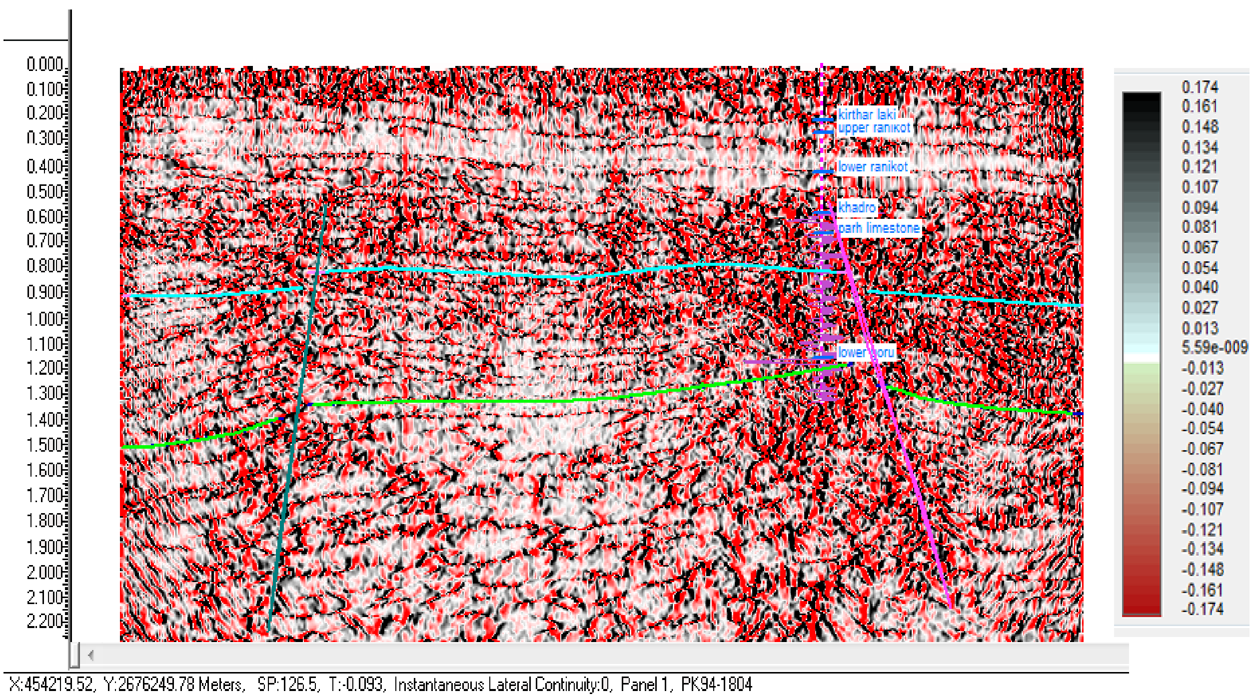



Figure 5.1 Instantaneous phase attribute on seismic line PK92-1804.

### 5.5 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 5.3 shows the trace envelope attribute applied on line PK94-1804.

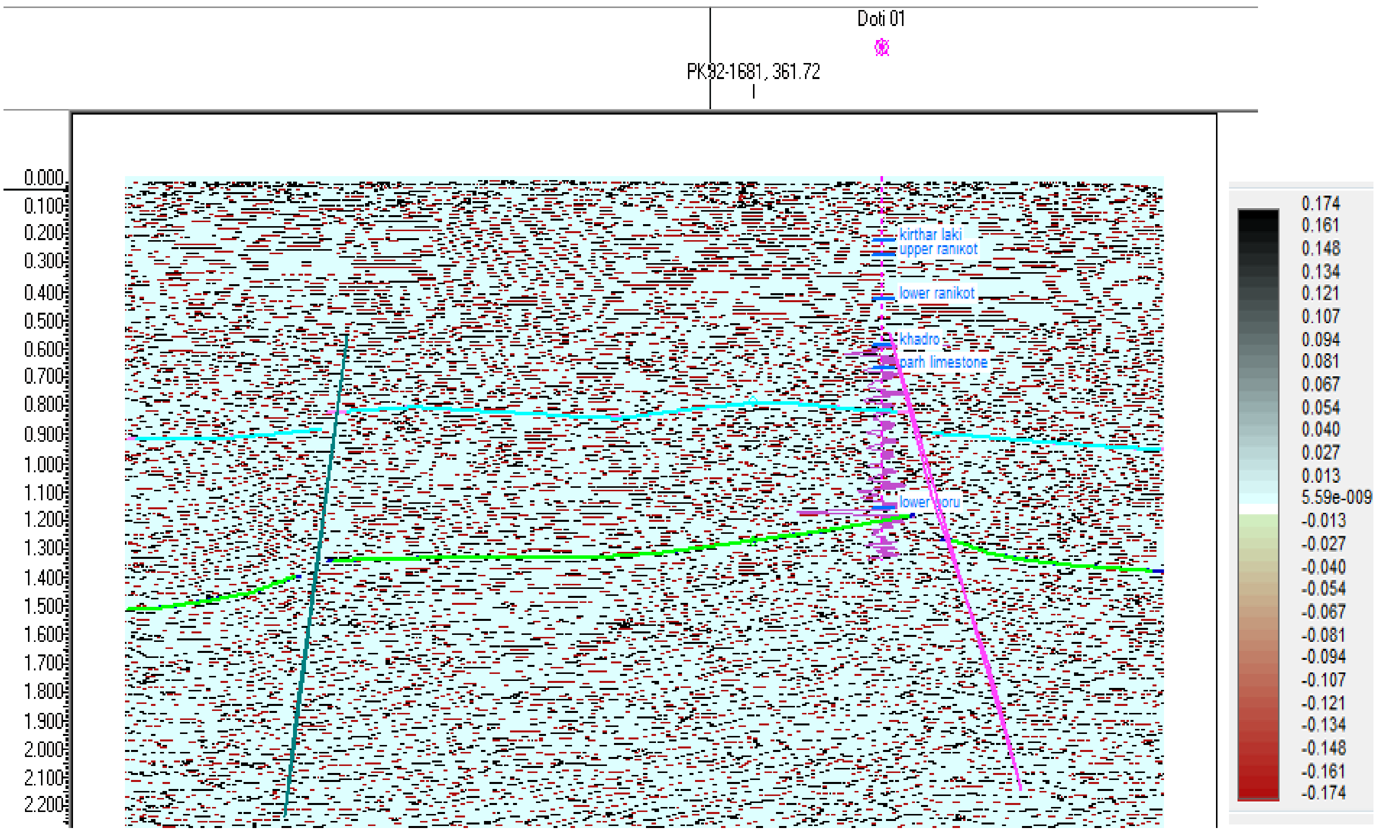



Figure 5.3 Trace envelope attribute applied on PK94-1804

Chapter 6

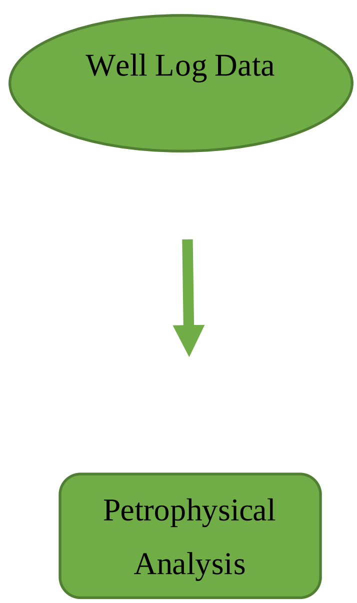
# Well Logging Interpretation

## 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



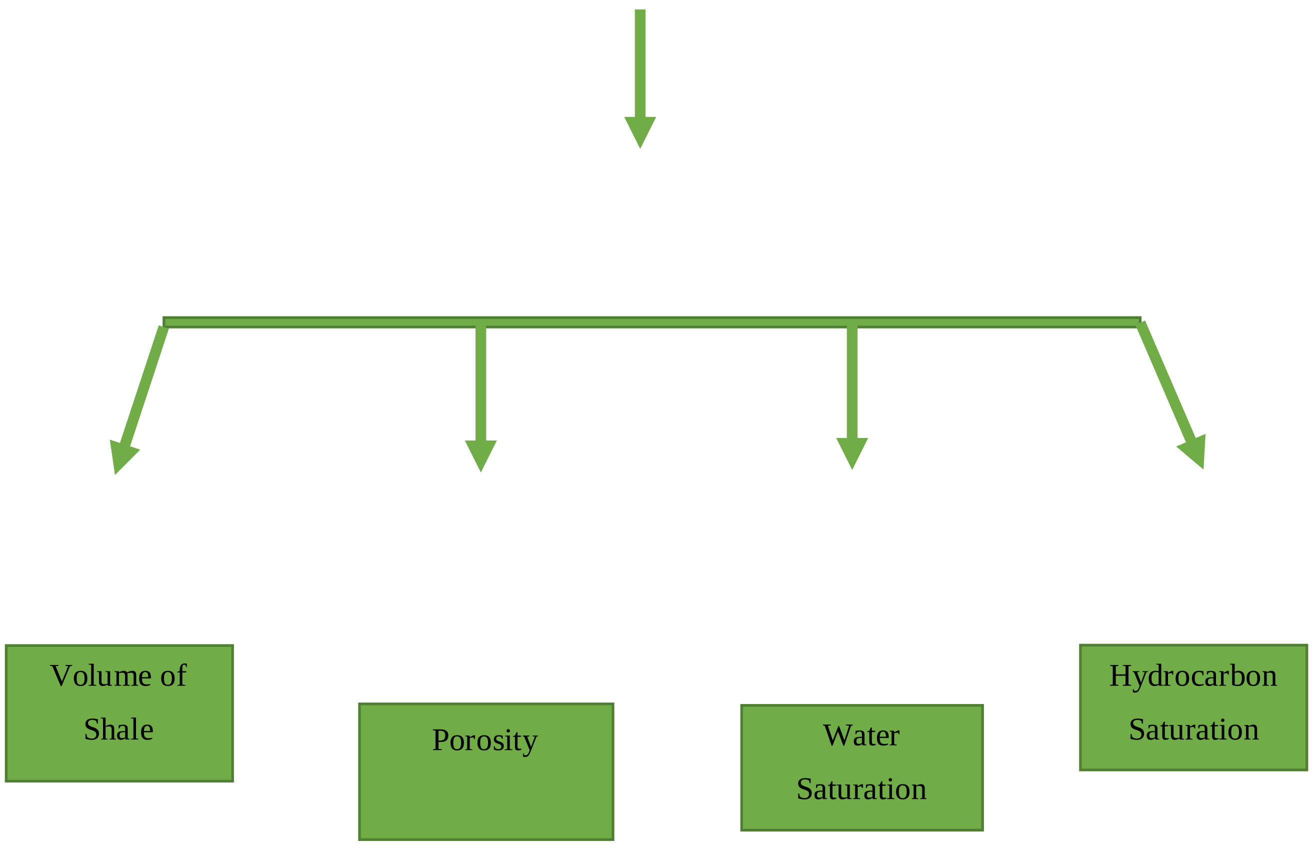



Figure 6.1 work flow for well data interpretation.

**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.

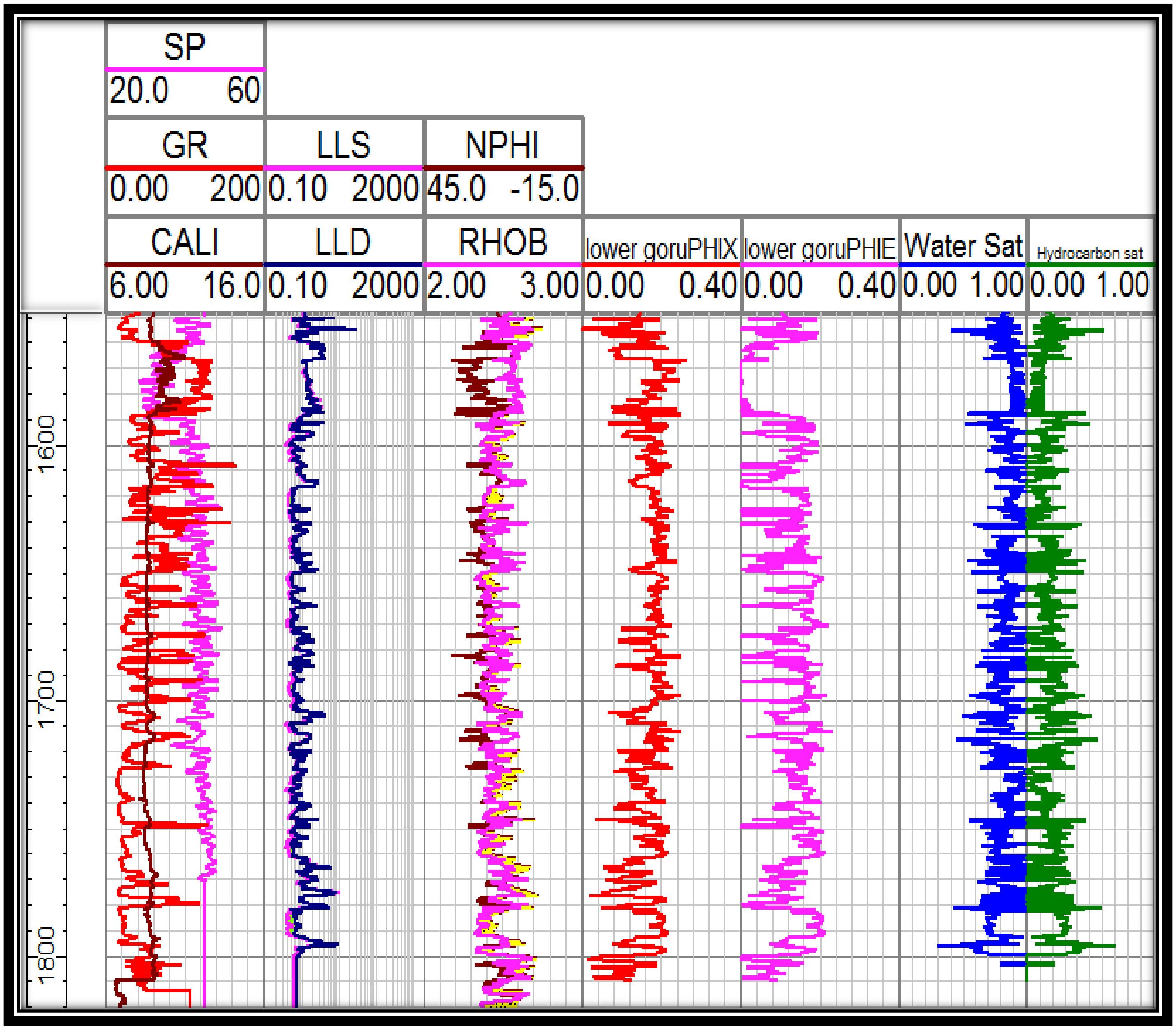
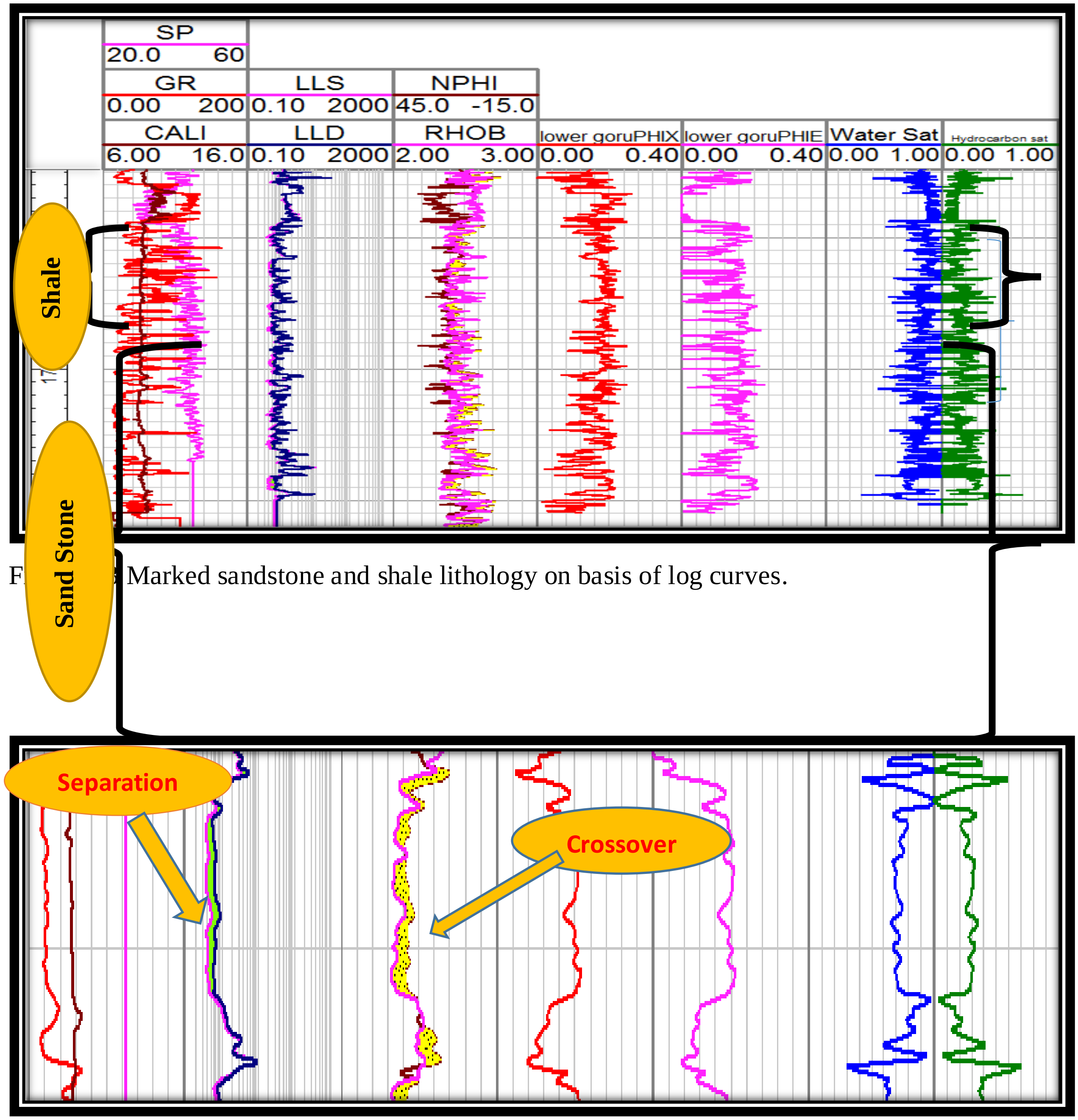



Figure 6.2 Logs curves in Reservoir Zone of Doti-01 Well.




F 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

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

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

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

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

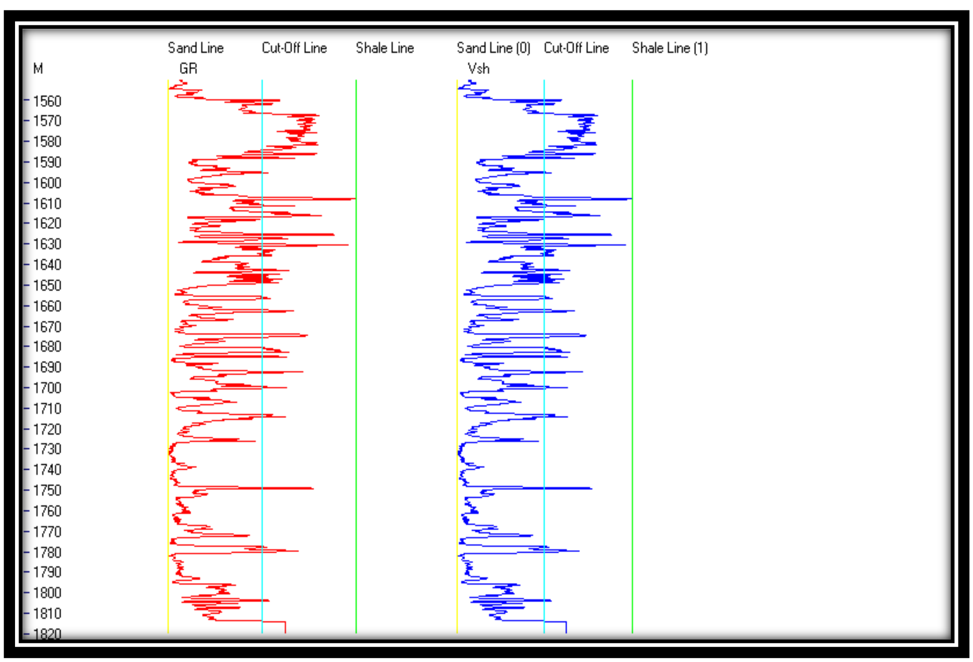


Figure 6.5 variation in volume of shale in Reservoir.

### 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 (ɸ).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

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

Where

$\Phi_{S} =$ Sonic porosity

$\Delta T$= Log response

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

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

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

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

$\Phi$ = 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

Table 6.1 shows the end results.

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

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.

## 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 (7.2) 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).

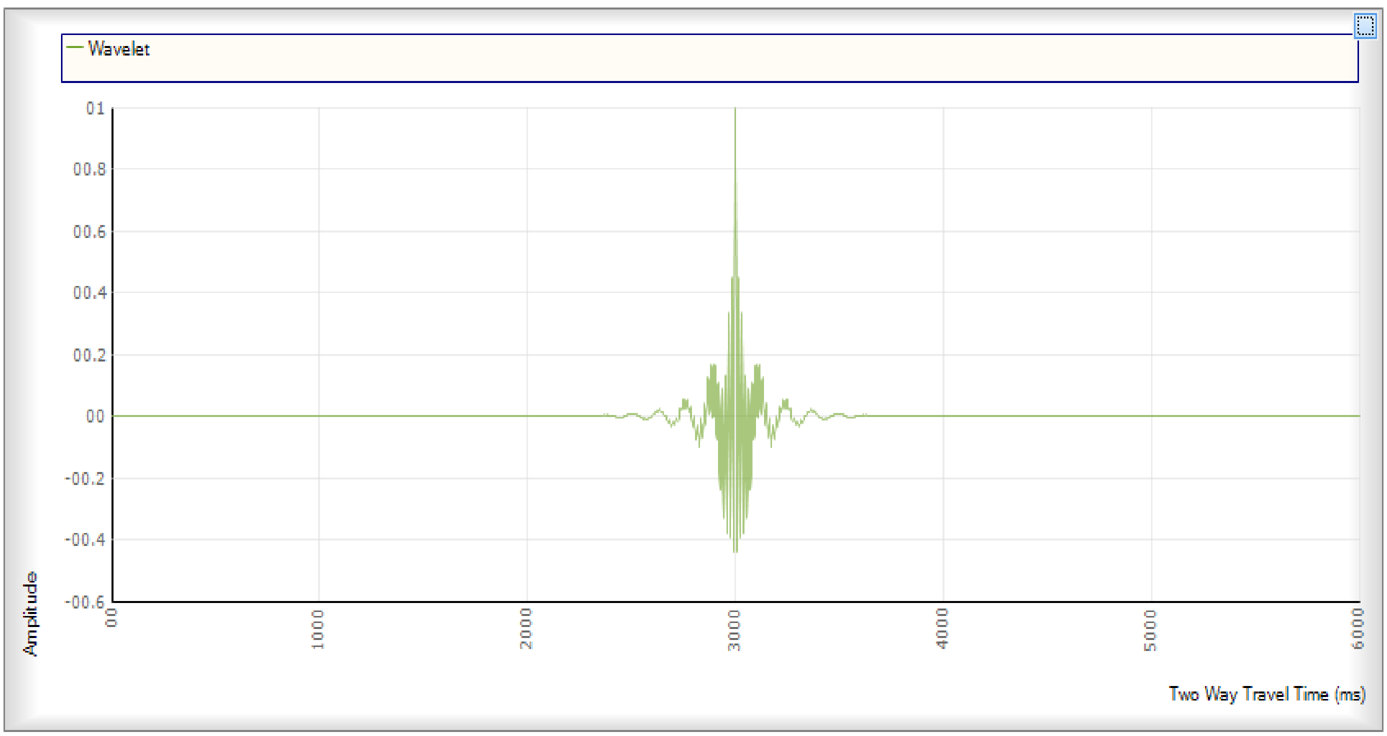



**Figure (7.2): Extracted Wavelet**

### 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).

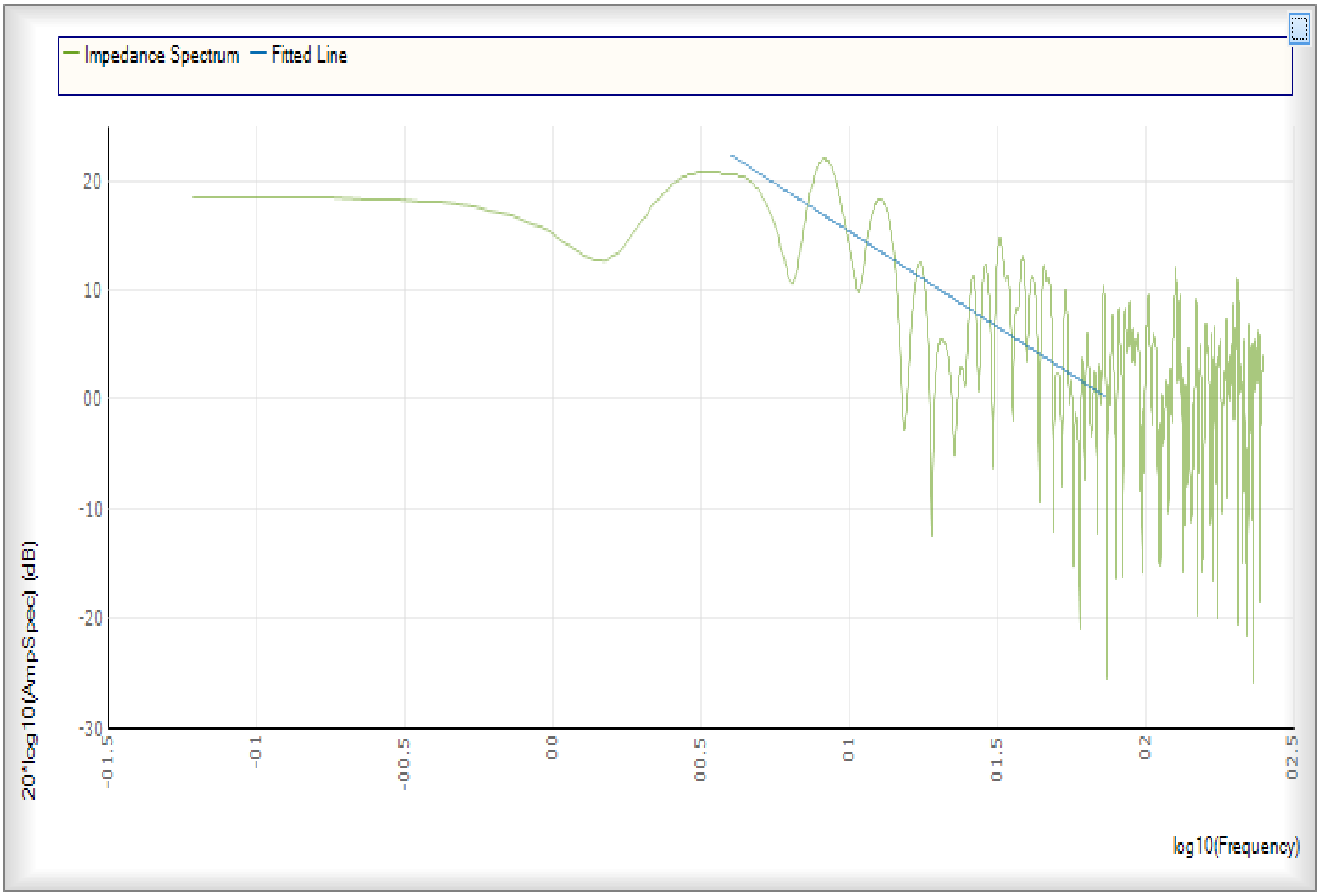



**Figure (7.3): Impedance spectrum with fitted line.**

## 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 (7.4).

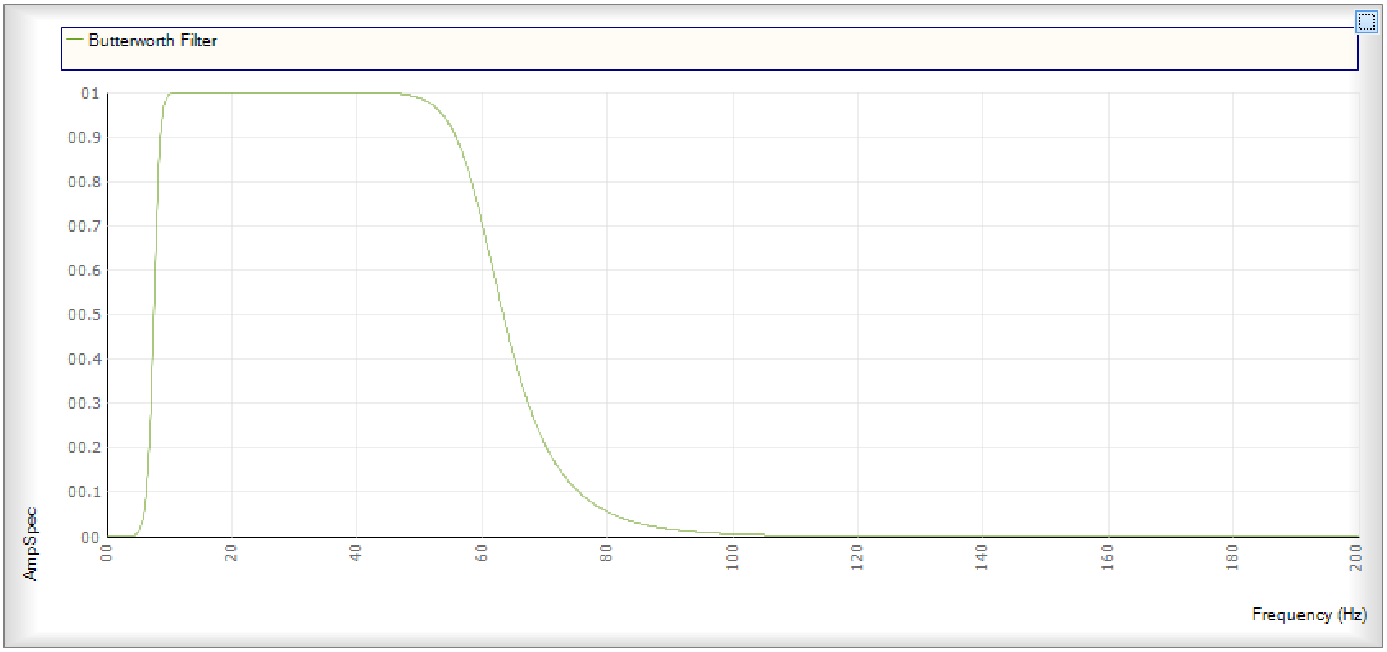



**Figure (7.4): Butterworth filter. After the process of convolution is performed we get the seismogram (operator). There is a vast difference between the seismogram of our desire and the seismogram we obtained from the convolution.**

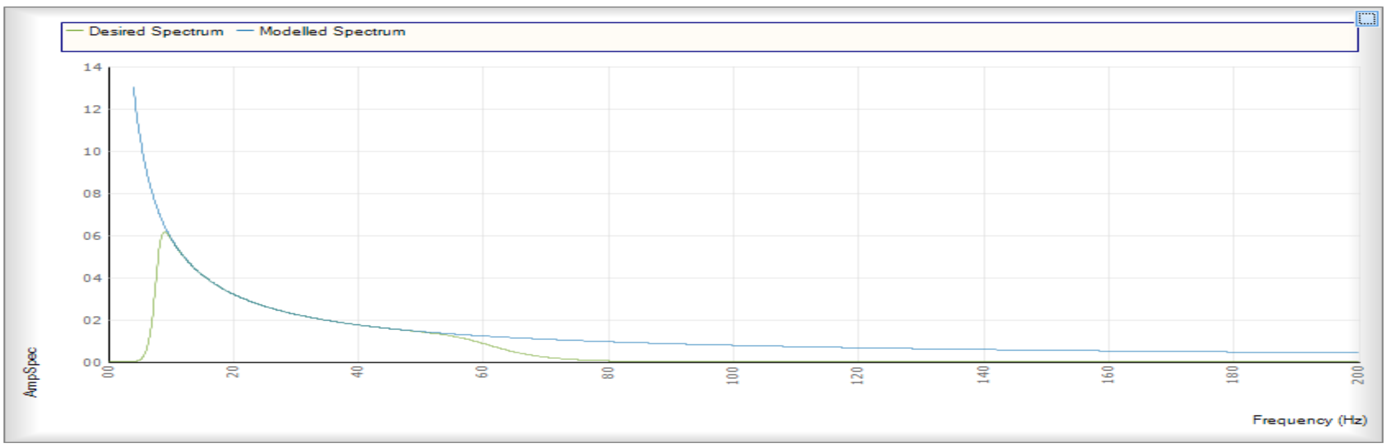



**Figure (7.5): Desired and modeled spectrum.**

There are two spectrums shown in figure (7.5) 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 (7.6).

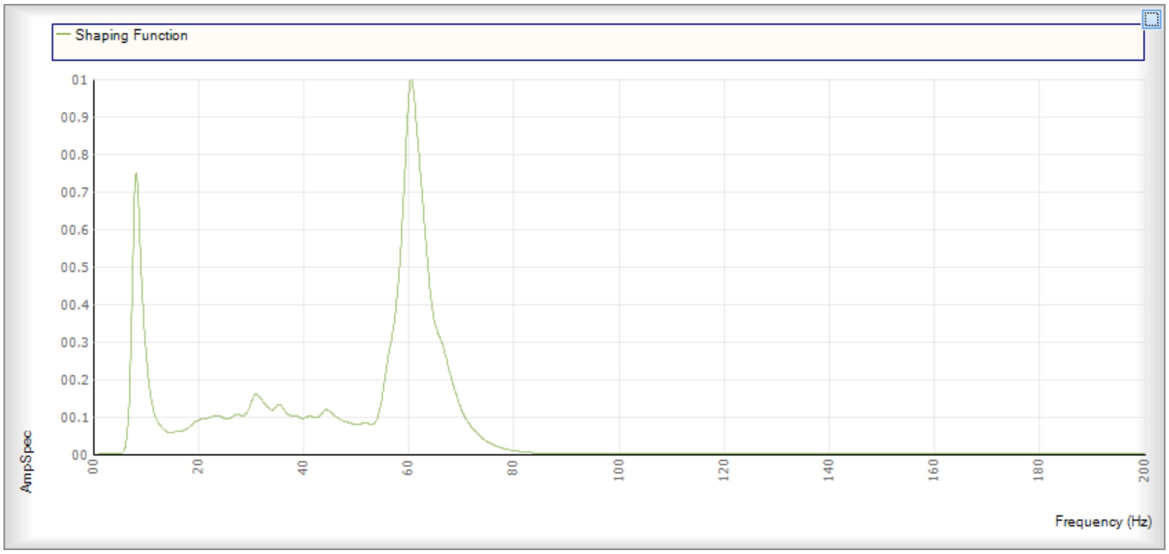



**Figure (7.6): Shaping spectrum. The figure (7.6) shows us the shaped seismic spectrum and desired seismic spectrum**.

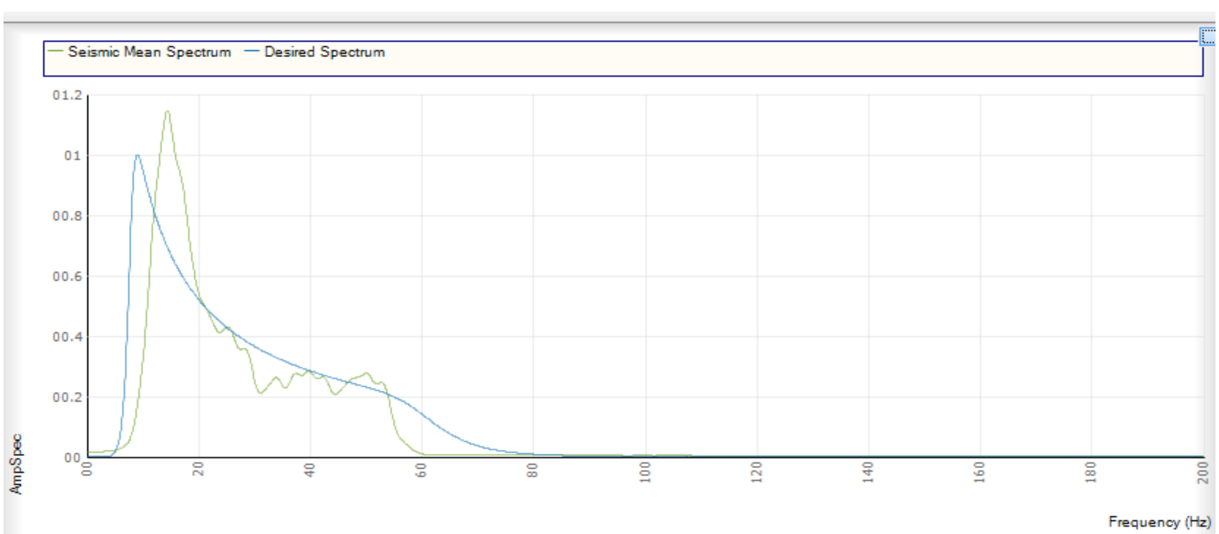



**Figure (7.7): Convolution of shaped seismic spectrum and desired spectrum**.

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 7.8 shows seismic mean spectrum and desired spectrum.

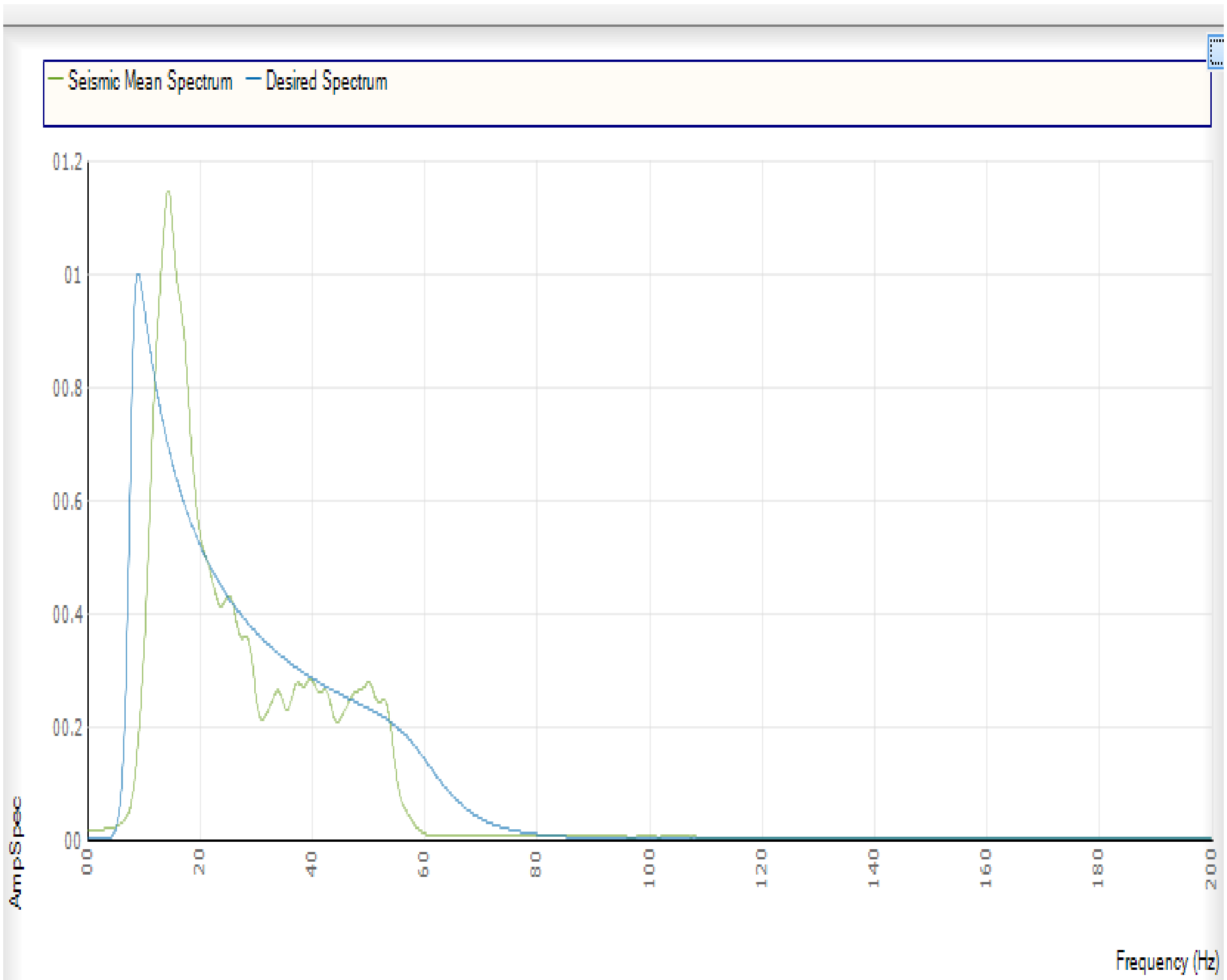



**Figure (7.8): Convolution of seismic mean spectrum and desired spectrum.**

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 (7.9).

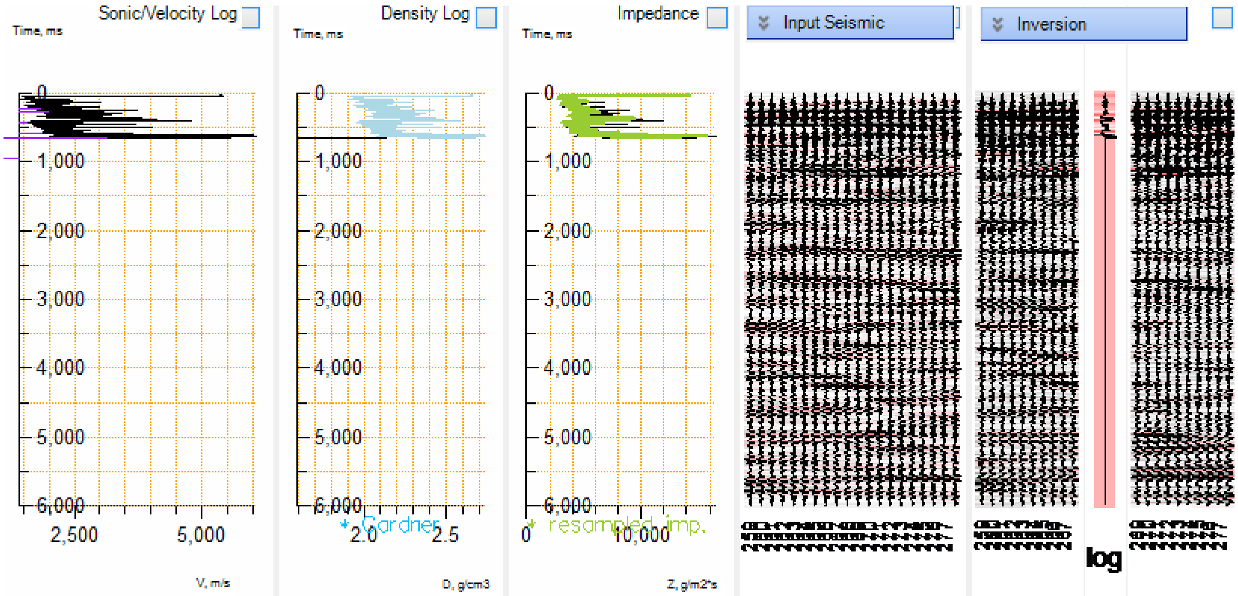



**Figure (7.9): Input seismic section and inverted section along with logs**

Figure (7.9): 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 (7.10) given below

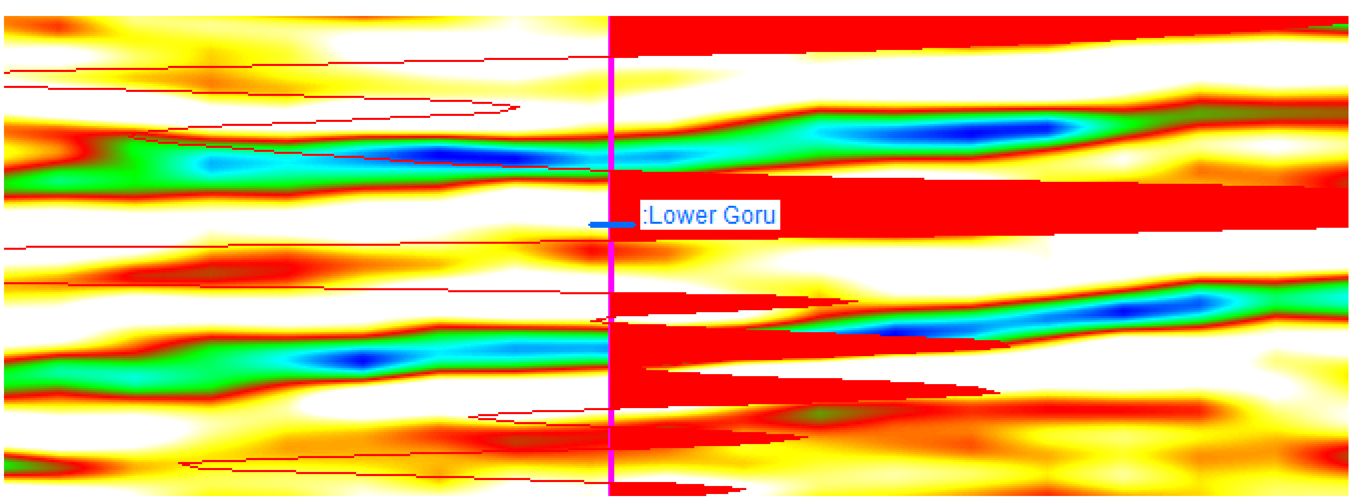


Figure (7.10): Inverted section with inverted logs Now inversion is applied to the whole section shown in figure 7.11.

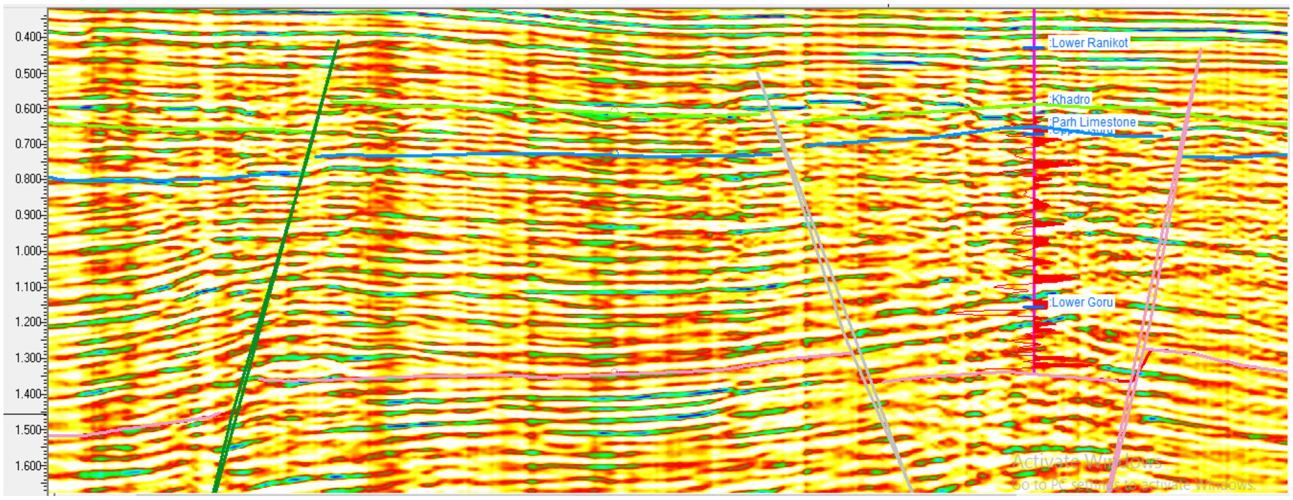



**Figure (7.11): Inverted seismic section.**

## 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 means there is low acoustic impedence.In the above section low acoustic impedence is represented by blue spots.which gives the indication of hydrocarbon

# CONCLUSION

- . The thesis work ends with following conclusions:
- The seismic 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 contour maps of Lower Goru and Upper Goru help us to confirm the presence of horst and grabben structure in the given area.. This structure acts as a trap in the area, which is best for hydrocarbon
- Petro physical analysis of the reservoir shows a high water saturation.
- Seismic attributes analysis of line PK94-1804 help us to find the zones and Formations of interest.
- Attribute analysis is worked out for better structural interpretation and result confirmation, seismic attributes also indicates the zones of interest.
- Coloured inversion shows low impedence at reservoir level.

**References**

Aadil, N., Tayyab, M., and Naji, A., (2014). Source rock evaluation with interpretation of wirelinelogs: A case study of Lower Indus Basin, Pakistan. Nucleus, 51 (1), 139-145..

Ahmad, N., Meteen, J., Ch, S.K., Mahmood, N., and Arif, F., (2012 & 2013). Shale Gas Potential of Lower Cretaceous Sembar Formation in Middle and Lower Indus Basin, Pakistan. Pakistan Journal of hydrocarbon Research. vol. 22 & 23, p. 51-62.

Ahmad, R., Ali, A.S., (1992). Structural styles and hydrocarbon prospects of Sibi Foreland Basin, HDIP journal.

Alam, M.S.M., Wasimuddin, M., and Ahmad, S.S.M., (2002). Zaur structure, a complex traps in poor seismic data area, BP Pakistan Exploration and Production inc. AAPG Search and Discovery Article # 90149 © 2012 PAPG/SPE ATC. 2-4 November 2002. Islamabad, Pakistan. p. 1-3.

Archie, G.E., (1942). The electrical resistivity logs as an aid in determining some reservoir characteristics: Society of Petroleum Engineers of AIME Transaction, v. 146, p. 54-62..

Barker, C.E., and Pawlewics, M.J., (1994. Calculation of vitrinite reflectance from thermal histories and peak temperature: A comparision of method, in Mukhopadhhay, P.K., and Dow, W., eds., Vitrinite reflectance as a Maturity Parameter: Aplication and Limitation, American Chemical Society Symposium Series 570.

Carpentier, B., Huc, A.Y., Bessereau, G., (1991). Wireline logging and source rocks – Estimations of organic carbon content by CARBOLOG method [J]. Log Anal, 1991, 32(3):279-297.

Coffeen, J.A., (1978). Seismic exploration fundamentals.

Coffeen, J.A., 1986. Seismic exploration fundamentals, Penn Well Publishing Company, Tulsa, Oklahoma

Dewar, J., and Pickford, S. (2001). Rock Physics for the Rest of Us –An Informal Discussion. Cseg Recorder

Dow, W.G., (1977). Kerogen studies and geological interpretation. Journal of Geochemical Exploration 7, 79–99.
Gadallah, J., and Fisher, I., 2009. Exploration Geophysics, Springer-Verlag Berlin Heidelberg. DOI: 10.1007/978-540-85160-8.

Gardner, G.H.F., Gardner, L.W., and Gregory, A.R., 1974, Formation velocity and density – the diagnostic basics for stratigraphic traps: Geophysics, 39, 770-780.

Hasany, S.T., and Khan, A.F., 1997. Case history of Eight oil and gas fields in Pakistan, proceedings of Pakistan petroleum convention, pp.2-20.

Hasany, S., and Saleem, U. (2001). An Integrated Subsurface, Geological & Engineering Study of Meyal Field, Potwar Plateau, Pakistan.

McQuillin, R., Bacon, M., and Barcaly, W., 1984. An introduction to seismic interpretation, Graham & Trotman Limited Sterling House, 66 Wilton Road LondonSW1V1DE.

Peterson, R.A., Fillipone, W.R., and Coker, F.B., 1955. The synthesis of seismograms from well log data, Geophysics. Vol.20, pp. 516-538.

Robinson, E.S., and Coruh, C., 1988, Basic Exploration Geophysics, John Wiley & Sons, Inc Newyork.
Siddiqui, S.U., Elahi, N., and Siddiqui, A.J., 1998. Published in proceedings of Pakistan petroleum convention, Case histories of Eight oil and gas fields in Pakistan.

Taner, M.T., and Koehler, F., 1969.Velocity spectra – digital computer derivation and applications of velocity functions, Geophysics, Vol.34, pp.859-881.

Telford, W. M., Sheriff, R. E., and Geldart, L. P. (1990).Applied geophysics. Cambridge University Press.

Van Hise, C.R., 1898. Estimates and causes of crustal shortening, Journal of geology, Vol.6, pp.29-31.

Wandrey, C. J., Milici, R., and Ben, E. L. (2001).Region 8 Assessment Summary—South Asia.U.S. Geological Survey Digital Data Series 6.0.

Khan (2009) has compiled a complete set of equations linking seismic velocities and rock physics parameters.

Shales, Encylopedia Britannica. (http://www.britannica.com/science/shale).

www.mapzones.com