2D SEISMIC REFLECTION DATA INTERPRETATION OF MEYAL AREA, UPPER INDUS BASIN INTEGRATED WITH RESERVOIR CHARACTERIZATION BY USING WIRELINE DATA ALONG WITH POST STACK SEISMIC INVERSION.

DISS
EAR
1694

QUAID-I-AZAM UNIVERSITY
ISLAMABAD

BY

MASHOOD TARIQ CHAUDARY

BS Geophysics

2013-2017

DEPARTMENT OF EARTH SCIENCES,

QUAID-I-AZAM UNIVERSITY

ISLAMABAD

DEDICATION

Every Chalenging work needs self efforts as well as guidance of elders especially those who are very close to our heart.

My humble effort I dedicate to my Sweet and loving parents. Whose effection, love, encouragement and prays of day and night make me able to get such success.

I also want to dedicate my this achievement to a very supporting part of my life TAHIRA BATOOL whose continuous guidance and efforts make me complete my this journey.

ACKNOWLEDGEMENT

*In the name of **Allah**, the most beneficent, the most merciful and all praises to Almighty Allah, the creator of this universe. I bear witness that there is no God but **Allah** and Holy **Prophet Hazrat Muhammad (P.B.U.H)** is the last messenger of **Allah**, whose life is a perfect model for the whole of mankind. All thanks to my **Allah**, who gave me the strength and ability to complete this project successfully. 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 my supervisor **Sir MATLOOB** Assistant Professor Department of Earth Sciences, Quaid-i-Azam University Islamabad who gave me the opportunity to work under his supervision. His vast knowledge and positive criticism motivated me to strive for the required results. I also want to thank **Dr. AAMIR ALI** for his continuous support, motivation and guidance have made this thesis possible.*

Good friends are like heaven on earth. I would like to express my appreciation to all of my friends and class fellows. At the end I specially acknowledge the prayers and efforts of my whole family, specially my parents and brothers for their encouragement, support and sacrifices throughout the study.

MASHOOD TARIQ

ABSTRACT

The main purpose of the study is to interpret seismic data of the Meyal field by evaluating hydrocarbon potential of two wells MEYAL-01 and MEYAL-17, Punjab, Upper Indus Basin, Pakistan. Geographically the Meyal field is located in Punjab province having coordinates Latitude 33° 20'01.1" N and Longitudes 72° 02' 53.2" E. Two-dimensional seismic interpretation has been carried out in upper Indus Basin, Meyal area to confirm the reservoir characteristics of Chorgali and Sakessar Formation to delineate promising locations for test drilling. Time and Depth contour maps of Chorgali and Sakessar help us to confirm the presence of anticlinal structure in the given area. Surface contour maps of both Formations give the real shape of sub-surface structure, which is anticlinal. This anticlinal structure acts as a trap in the area, which is best for hydrocarbon accumulation.

Different attributes has been studied to analyses the expected hydrocarbon zone and also to investigate the seismic properly. Seismic attributes applied on line 97-MYL-01 also confirms the seismic interpretation. On the basis of petrophysical analysis the average porosity values for the promising zone range from 5 to 10% and hydrocarbon saturation ranges from 65-70% confirm that Chorgali and Sakessar formations are the main reservoirs of the Meyal area. Different crossplots has been generated to confirm the lithologies of the rocks. After it seismic inversion has been studied to confirm the seismic interpretation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Introduction:

Hydrocarbons play a vital role in the growth of economy of any country and have wide uses at smaller scales in everyday life as well. Geoscientists are working hard since a long time for the exploration of hydrocarbons from subsurface and are applying different methods in this regard. Geophysical methods are the most widely used methods in the exploration of hydrocarbons, especially Seismic Method and well logging has great importance. Seismic measurements can be used to gain knowledge about geological structures in the ground. The oil industry uses seismic measurements to locate oil-and gas reservoirs. Identification of subsurface structure, petro physical analysis and estimation of rock properties are the most important tools to identify hydrocarbons (Link 1991).

Seismic structural interpretation is the method which tells more about the subsurface structures i.e. orientation of fault, depositional settings and information about horizon. Usually mapping of reflections and faults/unconformities are done and these are supportive in describing the geology and hydrocarbon potential (Badely, 1985). Main elements for interpretation are the identification/mapping of Formation boundaries and faults present on the seismic section (Stewart, 2012).

Seismic attribute is a physical quantity that gives more information about seismic interpretation. They help to mark the faults, to pick the horizons and to recognize the depositional settings (Taner et al., 1994).

In order to know the quantity of hydrocarbon accumulation in reservoir rocks (sandstone, limestone or dolomite), some basic petro physical parameters must be evaluated. These include storage and flow properties (porosity, permeability, fractional flow), fluid identification, fluid phase distribution within gross void space (saturation), interaction of surface forces existing between the rock and contained fluids (capillary pressure), measurements of pressure, stress conditions, electric conductivity of fluid-statured rocks etc. these properties and their relationship are used to recognize and assess hydrocarbon reservoirs, source rock, cap rock, and aquifers (Donaldson 2011).

Facies analysis is the identification of subsurface lithology. Horizontal wells are rarely cored, a method is needed to indirectly derive the facies distributions within the formations penetrated by those wells. There is a material correlation between the behavior of well logs and the lithological 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).

Inversion transforms seismic reflection data into rock and fluid properties. The objective of seismic inversion is to convert reflectivity data (interface properties) to layer properties. To determine elastic parameters, the reflectivity from AVO effects must be inverted. In this research colored inversion of line 97-MYL-07 using well Meyala-17 is performed. Colored Inversion transforms migrated seismic data into a bandlimited acoustic impedance volume by shaping the mean seismic spectrum into the impedance log spectrum.

1.2 Introduction to Study area:

Pakistan has high potential of hydrocarbons in its northern (like Potwar, Kohat) and southern (like Badin, Mari etc.) parts. The Indus basin, including the Kohat-Potwar (study area) depression, belongs to the category of extra-continental downward basins which account for 48% of the world's known petroleum resources. The Potwar sub basin is dominated by the structural traps and mostly seismic data is incorporated for the delineation of these structures. Meyal Field is located in Attock district, near Pindi Gheb, 110 kilometers southwest of Islamabad in an active foreland and thrust belt in the Central Potwar Plateau of the Upper Indus Basin. The study area is bounded by Latitudes 33° 20'01.1" N - 33° 15' 36.1" N and Longitudes 72° 02' 53.2" E - 72° 15' 21.3" E. Meyal Field is one of the major oil and gas producing fields in the Potwar Plateau. The field was discovered by Pakistan Oilfields Limited in 1968. Discovery resulted after 52 years of continuous exploration efforts in the Meyal-Kharpa area. Geographic location of study area is shown in Figure 1.1.

1.2.1 Exploration History of Study Area:

The Burma Oil Company was the first to acquire Meyal concession in 1916, and they drilled three wells, but unfortunately they were all dry, till 1924. Later the area was granted to Attock Oil Company and they drilled their first well during 1942 to 1944 which was abandoned. They drilled second well at the same site and abandoned due to the fact that the well had crossed the thrust entering downthrown block at 8000 ft. Their third well was to be abandoned at 8100 ft due to mechanical problems.

Then Pakistan Oilfields Ltd. entered in concession and acquired 2D seismic data during 1960 to 1961 and 1965 to 1966. Seventeen (17) wells have been drilled till to-date in Meyal Concession area. Oil has been discovered in Eocene (Chorgali / Sakesar Formations), Paleocene (Ranikot/ Lockhart Formations) and Jurassic (Datta Formation). POL wells 6, 8, 12, and 17 are currently producing oil and gas. Well – 6 was drilled down to 13424 ft (Jurassic sandstone), initially completed as dual producer from Paleocene and Jurassic, but production from Jurassic was ceased later in 1982 and currently producing from Paleocene. Well – 12 (W/O) was deepened down to 13622 ft (Triassic) and producing oil/gas from Chorgali/Sakesar. Well – 8 is producing from Eocene/Jurassic. Meyal – 17 was the last well drilled down to 13660 ft in Jurassic and now producing from Paleocene.

1.3. Objectives:

The main objectives of this dissertation based on interpretation of seismic section are:

- To understand the geology of the study area.
- This dissertation is primarily focused on seismic interpretation of study area, which includes marking of horizons, fault picking and construction of time and depth contour maps.
- To study the seismic attributes in order to develop an idea of the petroleum system and confirmation of interpretation.
- Identification of the possible hydrocarbons bearing zones by means of Petrophysical analysis by using available well data.
- Facies analysis to find out the variations in the lithology of the reservoir rock by using well log data.
- Colored inversion which transform seismic reflection data into a quantitative rock property, descriptive of the reservoir.

1.4 Data used:

Data used for this dissertation:

- Seismic data in SEG-Y format
- LAS file(well log data)
- Navigation file

All data sets used were provided by Directorate General of Petroleum concession (DGPC),Government of Pakistan upon the request of Chairperson Department of Earth Sciences, Quaid-e-Azam University Islamabad.

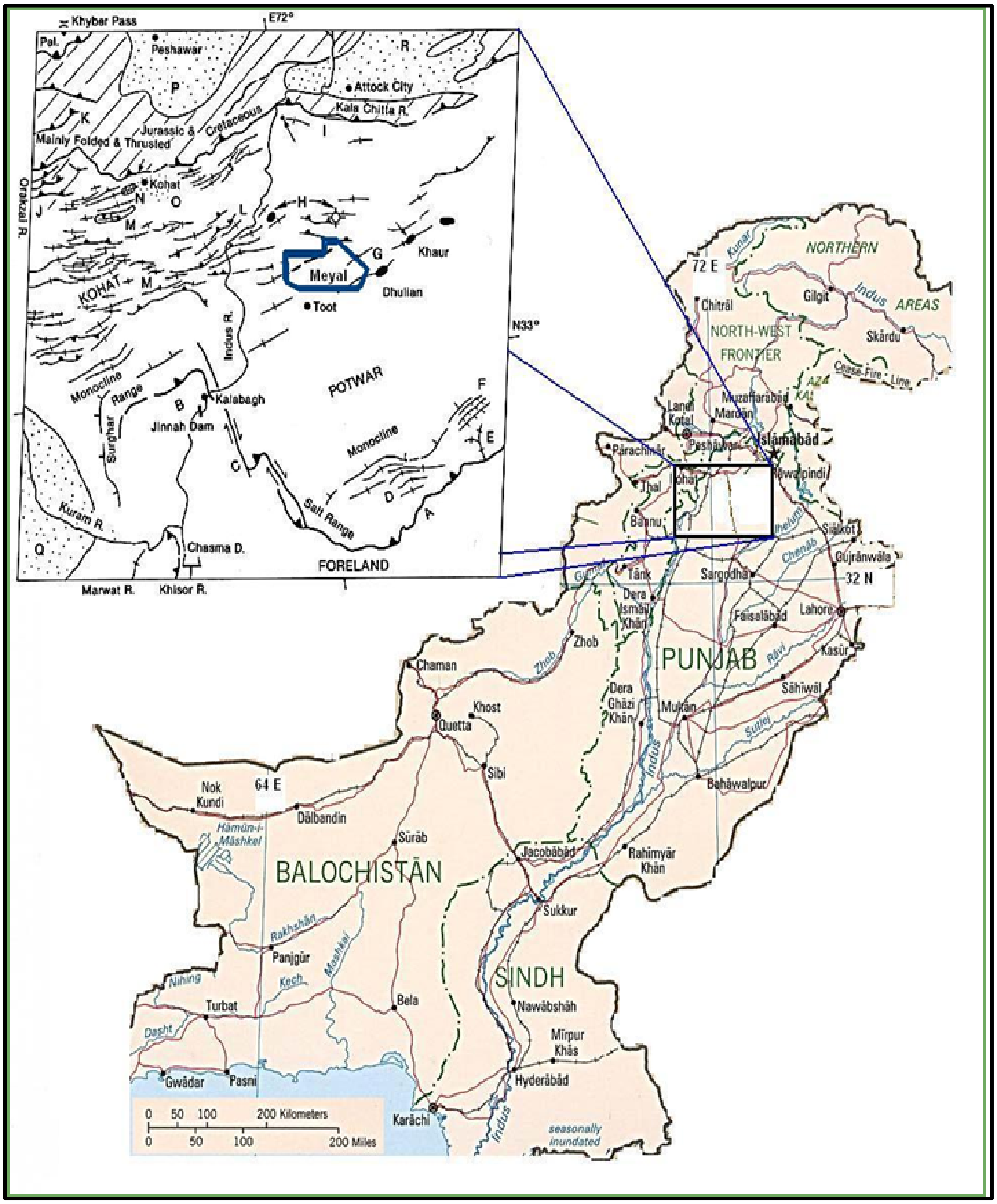

Figure 1.1 Geographic Location Of study area in Potwar Plateau.

1.4.1 Seismic Data:

The seismic reflection data of the study area was obtained by Directorate General of petroleum concession (DGPC) Pakistan in digital format .This data was acquired and processed by POL. The data used for current research includes 9 seismic lines and four wells. The trend of the seismic dip and strike lines in SE-NW and SW-NE respectively. The orientation of seismic lines with the location of wells is listed in the table 1.1. Bold lines and two wells MYl-01 and Myl-17 were assigned to me for the completion of this research work.

1.4.2 Well Data:

The well data includes the following files:

- Meyal-1, Meyal-13 , Meyal-17, Meyal-10.LAS file
- Meyal 1, Meyal-13, Meyal-17, Meyal-10. Txt

These files store all the information about the logs run in the well and well tops. Information about the well used in this research is given below in table 1.2 and 1.3.

Table 1 Data used for research work.

LINE NAME	NATURE	LINE ORIENTATION	WELLS
97-MYL-01	Dip Line	S-N	
97-MYL-02	Dip Line	S-N	
93-MYL-03	Dip Line	S-N	
97-MYL-04	Dip Line	S-N	
97-MYL-05	Dip Line	S-N	MEYAL-10P
97-MYL-07	Dip Line	S-N	MEYAL-01 MEYAL-17
97-MYL-08	Dip Line	S-N	
97-MYL-12	Strike Line	W-E	MEYAL-13
97-MYL-13	Strike Line	W-E	

Table 1.2 Well data of Meyal-01

WELL	**MEYAL-01**
LATITUDE	**033.274444**
LONGITUDE	**072.160278**
KB	**374.71**
TOTAL DEPTH	**3814.10**
STATUS	**Exploratory**
EXPLORATION	**OIL**
COMPANY	**POL, Pakistan**
FORMATION TOPS	**DEPTH (m)**
NAGRI	000000.0
CHINJI	000598.0
KAMLIAL	001920.0
MURREE	002072.0
FATEHJANG	003633.0
KOHAT	003650.0
KULDANA	003688.0
CHORGALI	003732.0
SAKESAR	003798.0

Table 1.3 Well data of Meyal-13

WELL	**MEYAL-17**
LATITUDE	**033.279861**
LONGITUDE	**072.160472**
KB	**436.00**
TOTAL DEPTH	**4164 m**
STATUS	**Development**
EXPLORATION	**OIL**
COMPANY	**POL, Pakistan**
FORMATION TOPS	**DEPTH (m)**
NAGRI	000000.0
CHINJI	430.7927
KAMLIAL	1861.585
MURREE	2077.744
KOHAT	3597.561
KULDANA	3640.244
CHORGALI	3677.134
SAKESAR	3740.244
NAMMAL	3829.268
RANIKOT	3859.146
PATALA	3969.512
LOKHART	3988.415
HANGO	4036.28

1.5 Software Used:

Software's used in this research are;

- IHS Kingdom
- Microsoft Office
- Snagit Editor

1.6 Base Map:

The base map is important component of interpretation, as it shows the spatial position of each picket of seismic section. For a Geophysicist a Base map is that which shows the orientations of seismic lines and specify points at which seismic data were acquired or simply a map which consist of number of dip and strike lines on which seismic survey is being carried out as shown in Figure 1.2. Four lines i.e. two Dip lines MYL-01, MYL-03, MYL-07and one strike MYL-13 and two wells MEYAL-01, MEYAL-17 were assigned to me for this dissertation. Highlighted lines were assigned to me for completion of project.

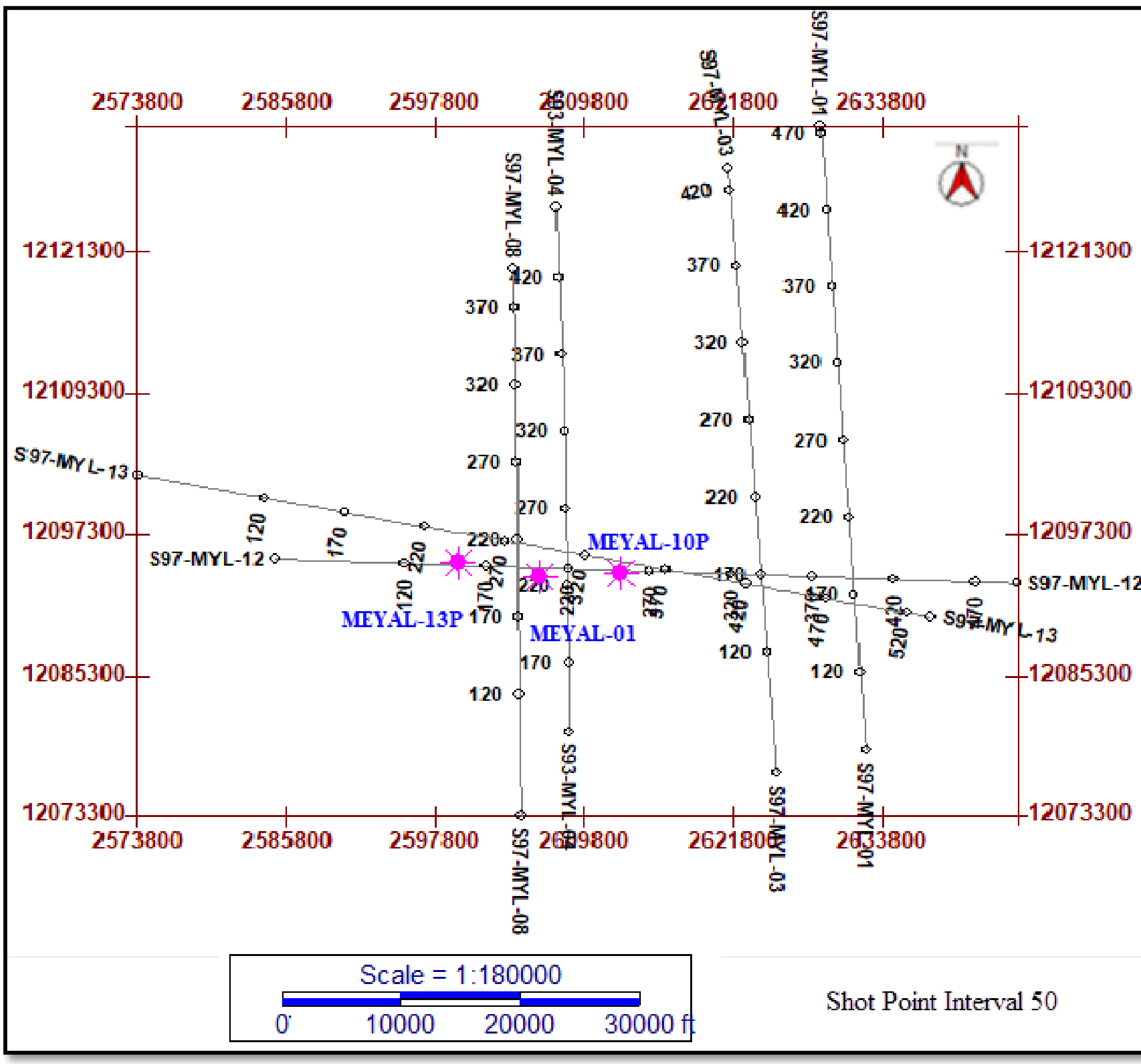

Figure 1.2 Base Map of the study area.

1.7 Work Flow Analysis:

The Interpretation was carried forward using different techniques and steps with each step involve different processes which were performed using the software tools as mentioned above. Simplified workflow used in the dissertation is given in Figure 1.3, which provides the complete picture depicting how the dissertation has been carried.

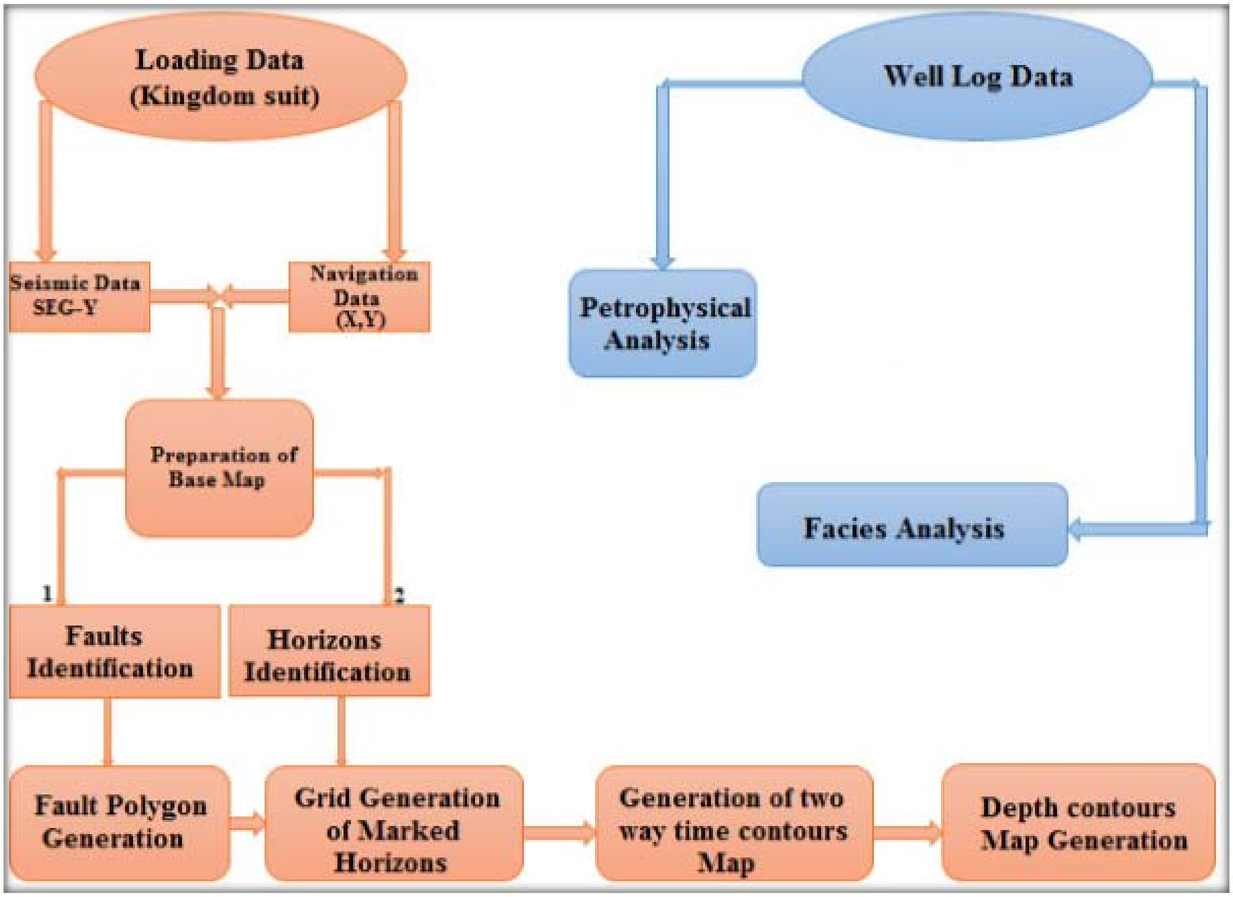

Figure 1.3 Work Flow of dissertation

CHAPTER 2

GEOLOGY AND TECTONICS OF STUDY AREA

2.1 Introduction:

Geology is the science comprising the study of solid Earth, the rocks of which it is composed, and the processes by which it evolves. In modern times for exploration of hydrocarbon general geology and geological history plays a very important role (Kazmi and Jan, 1997).

Information about the geology of the area is very important in seismic survey. As the same velocity effect can be produce from the formations of different lithology and vice versa. Information about the position and penetration of local fault and the presence of the unconformities between the rocks is very important for interpretation point of view. Study area lies in Potwar plateau, Upper Indus Basin and is located in northern Punjab, Pakistan. Area under study is composed of very complex tectonic that is directly related to the regional movement of plates. Since northward movement of Indian plate yield the Mariana type subduction that resulted in the formation of Kohistan Island Arc that accreted with the Eurasian Plate followed by the accretion of Indian Plate along the southern margin (Kazmi & Jan, 1997). Due to the plate movement, tectonic features and structure, Pakistan is divided into following tectonic zones that are shown in Figure 2.1. This chapter deals with a brief description of the tectonics and structural setting.

2.2 Tectonic Basins of Pakistan:

Pakistan comprises of three main sedimentary basins which evolved through different geological episodes and were finally welded together during Cretaceous/Paleocene along Chaman strike slip faults as in Figure 2.1.

- IndusBasin
- Baluchistan Basin
- Pishin Basin

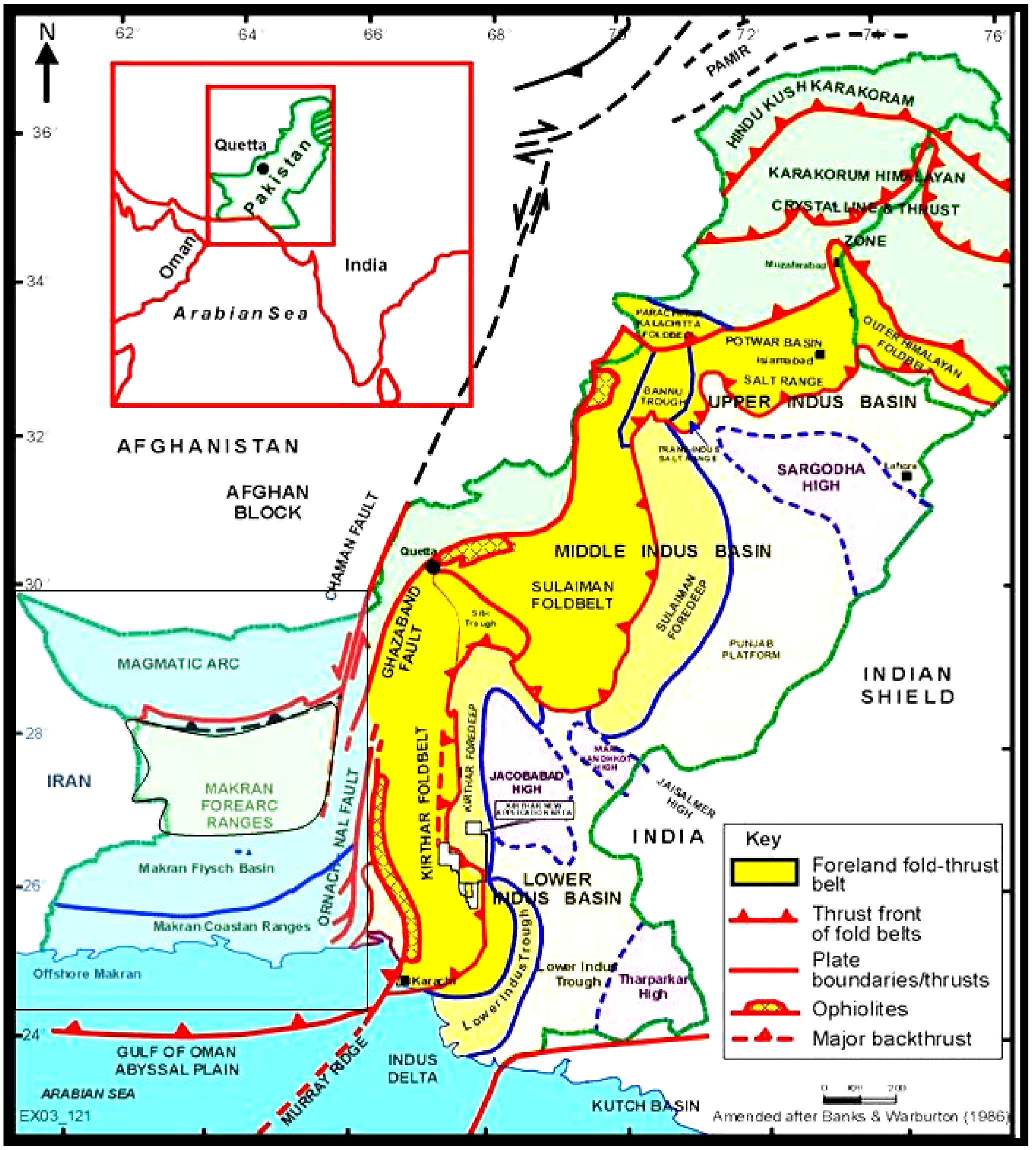

Figure 2.1 Tectonic Map of Pakistan

2.2.1 Indus Basin:

The basin has elongated shape and is oriented in the northeast and southwest direction. The main tectonic features of Indus basin are the Platform, the Foredeep comprising depressions, inner folded zone and outer folded zone (Kazmi &Jan, 1997). Indus basin is divided into compression regime in upper Indus basin, basement uplift in central Indus basin and extensional regime in lower Indus basin. On the basis of structure Indus basin is subdivided into three parts as shown in Figure 2.2.

- Upper Indus Basin
- Lower Indus Basin

• Central Indus Basin

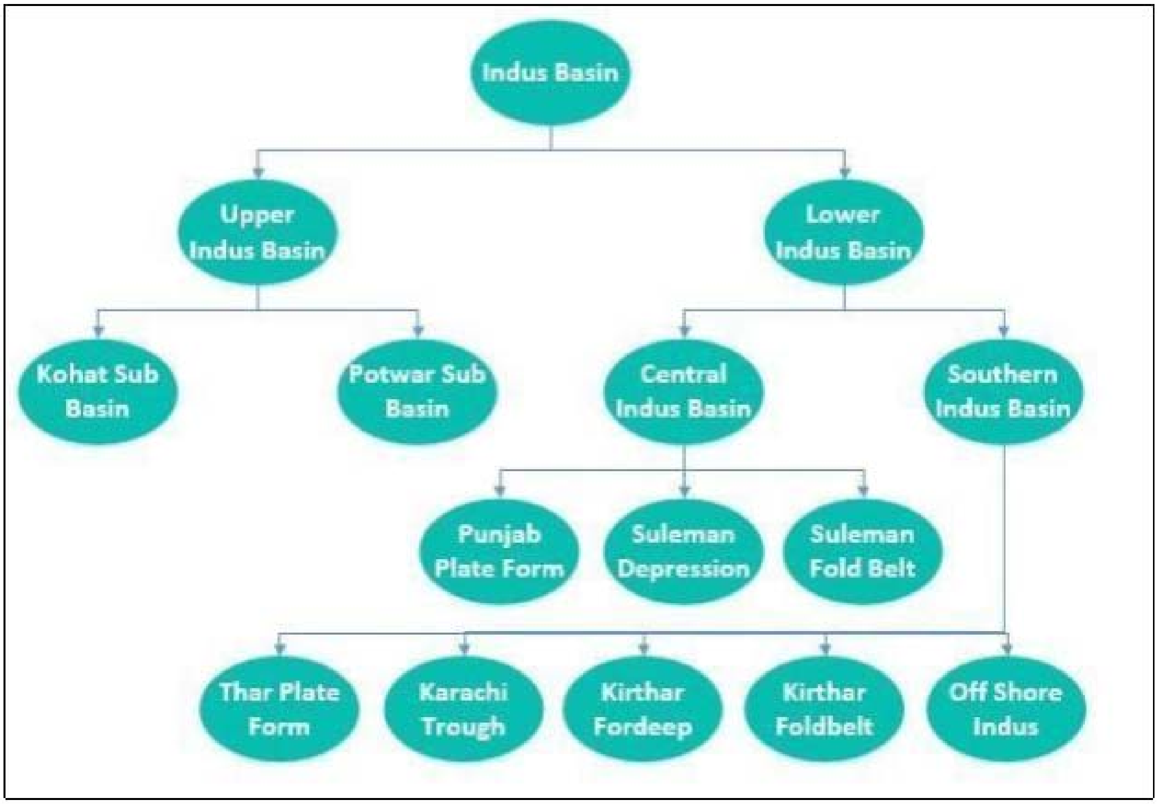

Figure 2.2 Division of Indus Basin

2.3. Regional Setting and Tectonics of Study Area (Meyal):

The Himalayan collision system represents an active collision orogen between the Indian and Eurasian subcontinents shown in Figure 2.3. The collision was active since about 55 Ma (Jadoon et al., 1999; Powell, 1979) and involves continuous uplifting, erosion and deposition of sediments. Meyal concession is situated in Potwar Plateau. The plateau is bounded in east by Jhelum strike – slip fault (JF) and in the west by Kalabagh strike – slip fault (KF). And the plateau is a part of Upper Indus Basin, situated in the lesser Himalayas of Pakistan, a zone of deformed meta-sedimentary and sedimentary rocks originally deposited on the northern Indian continental margin and in the Indo-Gangetic foreland basin Figure 2.4. It extends south about 130 Km from the Main Boundary Thrust (MBT) in the north to Salt Range Thrust in the south. This zone is south of the high crystalline Himalayas, which contain, from north to south, meta-sedimentary and igneous rocks of the northern Asian continental margins; meta-volcanic, igneous and meta-sedimentary rocks of the Kohistan Island arc terrain; and igneous and high grade metamorphic rocks of the intensely deformed northern margin of the Indian Plate. Thrust faults have been traditionally assigned for the fault contacts between these zones (Sercombe et al., 1998).

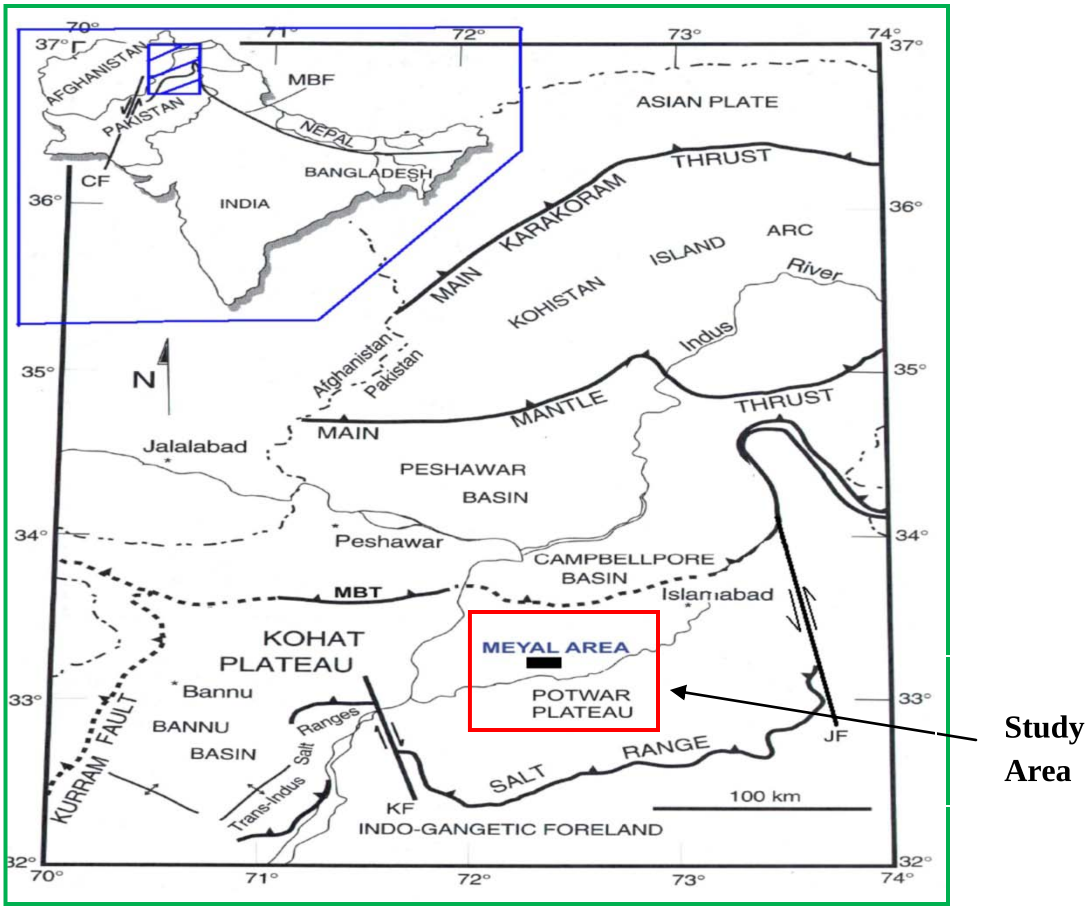

Figure 2.3 Regional Tectonic Framework map with reference to Meyal area (After W. J. Sercombe et.,al)

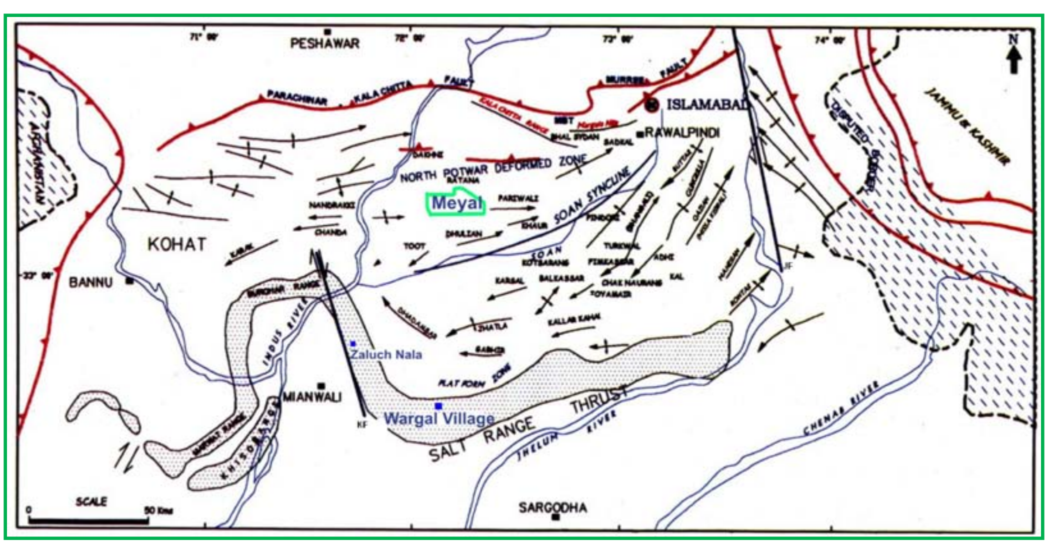

Figure 2.4 Tectonic map of Kohat – Potwar area, showing local structural orientations.

2.4 Stratigraphy of the Study Area:

Rocks from Precambrian to Quaternary age are present in the Potwar Plateau. These rocks, with a total thickness of more than 26,000 feet, were deposited in a variety of environments ranging from marine to fluvial. Periods of uplift and erosion were quite extensive, as indicated by several major unconformities Figure 2.5. The oldest rocks penetrated in the Meyal Field are the Permian clays, encountered at 14,360 feet in Meyal No. 13 well. In the Meyal area, Mesozoic sediments comprise a thin sequence of Triassic and Jurassic sands and shales (Mianwali and Datta formations) overlain unconformably by Paleocene strata. The upper Jurassic strata Samana Suk Formation and entire Cretaceous strata, however, are missing over the field, as the NE-SW directed wedge outs run in just west of the field, and as a consequence, Hangu Formation (Dhak Pass) directly overlies the Datta Formation. During the Eocene, shallow marine sedimentation resumed with deposition of a mainly calcareous/argillaceous sequence of the Nammal, Sakesar and Chorgali formations. The overlying Kuldana Formation, which consists of red claystones and shales, was deposited in open marine to partially restricted environments. While the youngest of Eocene rocks in the area, i.e. Kohat Formation, was deposited in more open marine conditions.

2.5 Structure of the Area:

Meyal-Kharpa surface structure is an east-west trending narrow, steep, faulted anticline with two major thrusts cutting the structure longitudinally. The subsurface structure does not lie directly underneath the surface structure. There is a southwest shift of subsurface structure to the surface structure. This shift is likely due to relatively younger transpressional movement of the blocks. Previous exploratory attempts were mainly based on the surface geological mapping. Seismic data acquisition during 1965-1966 had helped identify the subsurface structure configuration.

2.6 Petroleum Play:

In geology a petroleum play is a group of oil fields or prospects present in the same region that are controlled by the same set of geological circumstances (Stoneley, 1995). Lower Indus is the main hydrocarbons producing basin of the Pakistan 37% hydrocarbons of the Pakistan are extract from the lower Indus basin (Kadri, 1995). Within a basin the presence of play elements plays important role in hydrocarbon accumulation.

- Mature Source rock

- Migration pathway
- Reservoir rock
- Trap
- Seal or Cap rock
- Appropriate timing

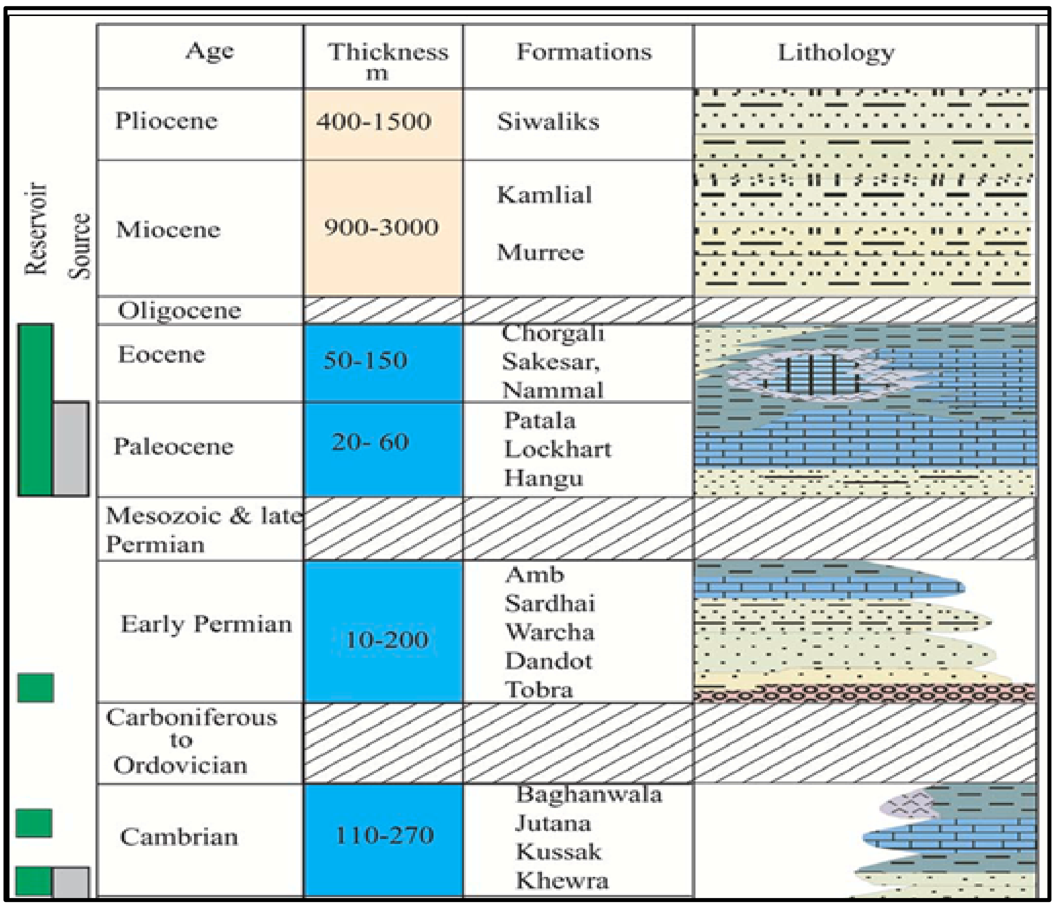

Figure 2.5 Stratigraphic column of Meyal (study area) (Amir et al., 2006)

2.6.1 Hydrocarbon Potential:

The Salt Range Potwar-Foreland Basin (SRPFB) belongs to the category of extra continental down warp basins, which accounts for 48% of the world known petroleum (Riva, 1983). Presence of continental margin, thick marine sedimentary sequence, potential source, and reservoir and cap rocks make this region suitable for suitable for hydrocarbon accumulation. It contains a thick overburden (about 3000 m) of fluvial sediments, which provide the burial depth and optimum geothermal gradient for seeps found in this area (Moghal et al., 2003).The (Salt range-Potwar foreland basin with an average geothermal gradient of 2 °C/100 m is producing oil from the depth of 2750-5200m (Shami & Baig, 2003)

2.6.2 Source Rock:

The possibility of the occurrence of two source rocks in the Potwar Basin, Nammal shales interpreted to be the major contributor of the oils to the reservoirs of Dhulian (Chorgali-Sakesrar), Joya Mair (Sakesar), Khaur (Murree sandstone) and Balkassar fields (Sakesar). Another potential source rock considered actively participating generation of oil is the Jurassic Variegated series. This unit provided oil to the Meyal (Lockhart and Jurassic and Sakesar) and Dhulian fields (Variegated beds and Lockhart). However, the Eocene Chorgali-Sakesar carbonates and shales of Paleocene Patala black marine shales are also considered as the potential source rocks.

2.6.3 Reservoir Rock:

- **Ecocene:**

The oil and gas was discovered in the known oil bearing horizons of the Chorgali and Sakesar limestones of Eocene age. The top 50 to 100 feet of this sequence overlies the Main Oil Horizon, which comprise interbedded limestone and turquoise shale and marl. The Sakesar limestone is light yellow gray, massive and partly dolomitized and locally contains chert concretions. The Chorgali Formation is creamy yellow to yellow gray, silty, partly dolomitic and thin bedded limestone. The Datta Formation is dominantly sandstone.

Water resistivity (Rw) of the Eocene reservoirs is estimated to be 0.314 to 0.464 ohm/m, having Total Dissolved Solids (TDS) of 12,759 to 19,585 ppm (NaCl equivalent).

- **Paleocene**

The lower unit of the Paleocene section is the Lockhart Formation (Khairabad Limestone), which is a massive, argillaceous limestone. The regular production from the Paleocene started in March, 1976 and continued until 1998. Water resistivity (Rw) of the Paleocene reservoirs is estimated to be 0.05 to 0.060 ohm/m having TDS 133,475 to 137,451 ppm (NaCl equivalent)

- **Jurassic**

The Jurassic Datta Sandstone in the Potwar Basin was first established as an oil and gas producer in the Dhulian Field. The Jurassic reservoir in Meyal Oil Field has produced oil but due to lack of substantial reservoir potential the total oi1 production does not exceed 2 million barrels as yet.

2.6.4 Seal Rock:

Seals act as a barrier for the flow of hydrocarbons. Usually three formations are considered as seal rocks in Meyal Field.

- **Kuldana Formation**

The Kuldana Formation is mainly composed of multi-colored shale (red, reddish brown and purple), usually silty and brittle but occasionally clayey and soft. The thickness of this formation is 120 to 192 feet in the Meyal Field. Due to its impermeable and argillaceous character the Kuldana Formation forms an effective seal over the Eocene reservoirs of the Meyal Field.

- **Nammal Formation**

The Nammal Formation is predominantly shale with marl and soft argillaceous chalky limestone. Shales of the Nammal are developed all over the Meyal Field. A 45 to 108 feet thick unit provides a top seal to trap oil in the Paleocene reservoirs.

- **Datta Formation**

The top part of the Datta Formation consists of varicolored shales, siltstone, mudstone and claystone with thin sands bed (Variegated Beds). These beds overlie the "Main Oil Sand" of the Datta Formation and are considered to be the top seal for the Jurassic reservoirs. It is 217 to 277 feet thick in the Meyal Field.

2.6.5 Traps:

In Potwarbasin faulted anticline structure act as trap which are mostly Salt cored, occasionally highly asymmetrical to overturned fault propagation fold and pop-up structures are common deformation style in that area. Secondary traps may also be present within major thrust sheets, particularly at the leading edge of the thrust sheet and above footwall ramp.

2.7 Oil and Gas Fields in Upper Indus Basin:

The table 2.1 display oil and gas fields of Upper Indus basin with their productive formations and production. Figure 2.6 is the structural map of Kohat-Potwar Pleatue depicting oil and gas fields of area and boundaries of Potwar.

Table 2.1 Hydrocarbon significance of different rock units in the study area (modified after Kadri, 1995)

Age	Formations	Lithology	Oil & Gas Field	Production
Eocene/Paleocene	Lockhart/Sakessar/ Chorgali	Limestone	Dhurnal, Dakhni,Balkasser & chak Naurang	Oil
Jurassic	Data & Samanasuk	Sandstone & limestone	Dhulian, Toot & Meyal	Oil
Permian	Tobra, Nilawahan & Zaluch	Conglomerate & Limestone	Adhi & Dhurnal	Oil
Cambrian	Khewra sandstone	Sandstone	Adhi & Missa keswal	Gas

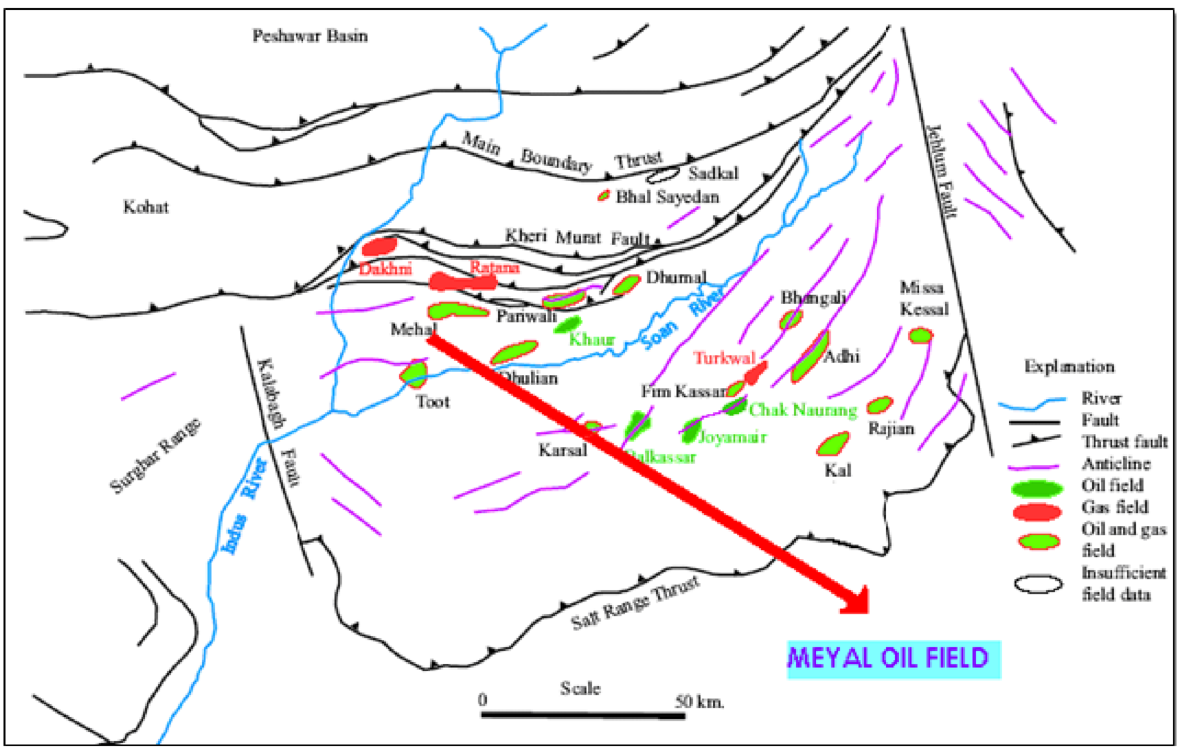

Figure 2.6 Show the oil gas field of Potwar Paleatu (Shah et al., 2004).

CHAPTER 3
SEISMIC INTERPRETATION

3.1 Seismic Data Interpretation:

Interpretation is a technique or tool by which we try to transform the whole seismic information into structural or stratigraphical model of the earth. Since the seismic section is the representative of the geological model of the earth, by interpretation, we try to locate the zone of final anomaly (Sheriff, 1999). The Seismic data interpretation is the method of determining information about the subsurface of earth from seismic data. It may determine general information about an area, locate prospects for drilling exploratory wells or guide development of an already discovered field (Coffeen, 1986). According to Badley (1985), such reflections and unconformities are to be mapped on seismic section, which fully describe the geology and hydrocarbon potential of the area. If the horizon of interest is not prominent and it is difficult in tracing it over the whole area, it is advisable to pick additional horizons above and/or below the target horizon. This helps in understanding the trend and behavior of the target horizon in the zones where its quality is not good enough to be picked with confidence. Final objective of interpretation is conversion of seismic section into a geological section which provides a somewhat realistic subsurface picture of that area, both structurally as well as stratigraphically (Badley, 1985).

There are two main approaches for the interpretations of a seismic section are:

- Stratigraphical Analysis
- Structural Analysis

3.1.1 Stratigraphical 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 both stratigraphy change and hydrocarbon depositional environment . The amplitude, velocity, frequency or the change in wave shape indicates hydrocarbon accumulation. Unconformities are marked by drainage pattern that help to develop the depositional environment. Reef, lenses, unconformity are example of stratigraphy traps (Sheriff, 1999).

3.1.2 Structural Analysis:

In structural analysis main emphases is on the structural traps in which tectonic play an important role. Tectonic setting usually governs which types of the structure are present and how the structural features are correlated with each other's, so tectonic of the area is helpful in determining the structural style of the area and to locate the traps. Structural traps include the faults, folds anticline, pop up, duplex, etc. (Sheriff, 1999).

3.2 Workflow for Seismic Interpretation

Procedure adapted for interpretation is given in Figure 3.1. Base map is prepared by loading navigation and Seg-Y data. The software used for this purpose is HIS kingdom. After preparing base map faults are identified on the basis of the geology of the area and interested horizons are also marked on the seismic section then by synthetic seismogram marked horizon are confirmed. Faults polygons are generated to see the structure present in the study area and horizons are contoured.

3.3 Fault Marking

Conventional seismic interpretations are the arts that require skills and thorough experience in Geology and Geophysics to be precise (Mc. Quill in et al., 1984). Fault marking on real time domain seismic section is quite a hard work to do without knowing tectonic history of area (Sroor, 2010).

3.4 Horizon Picking

Interpreting seismic sections, marking horizons, producing time and depth maps is a task which depends on interpreter's ability to pick and follow reflecting horizons (reflectors) across the area of study (Mc.Quillin et al., 1984). Reflectors usually correspond to horizon marking the boundary between rocks of markedly different lithology but it does not always occur exactly at geological boundary of horizon which is sometimes important problem in seismic interpretations (Kemal et al., 1991).

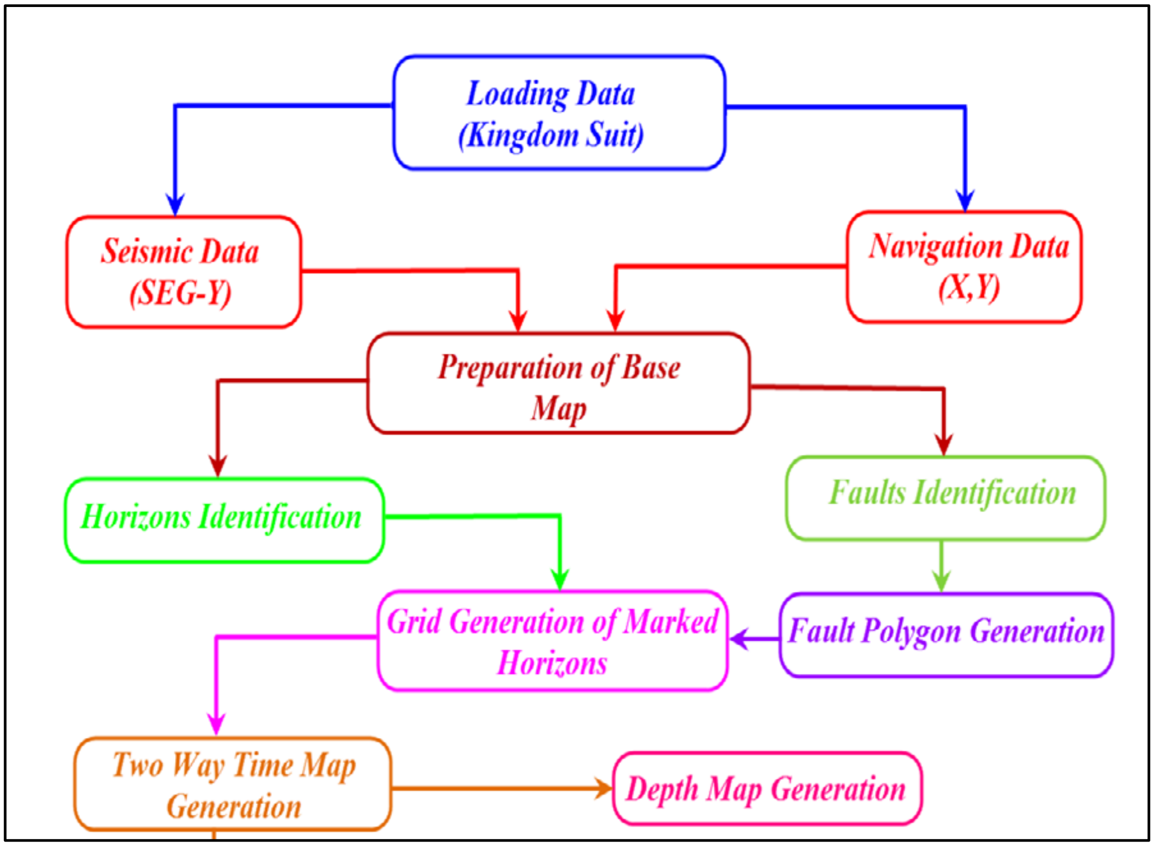

Figure 3.1 work flow of seismic interpretation.

3.5 Interpretated Seismic Sections:

Four lines were assigned to me for the completion of this dissertation i.e., 97-MYL-01, -97-MYL-03, 97MYL-13 and 97MYL-07. 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 Meyal-01 and Meyal-17. Three horizons are marked and their time is given below:

Table 3.1 Time of the marked horizon

HORIZON	TIME(s)	DISPLAY COLOR
Chorgali	2.87	Pink
Sakessar	2.94	Purple
Nammal	3.3	Green

The interpreted seismic section of the line 97-MYL-07 is shown in Figure 3.2. Total three seismic horizons namely, Chorgali, Sakesar and Nammal of Eocene age and two faults are marked. Three seismic horizons, five faults are picked on line 01 and 03 are shown in Figure 3.3 and Figure 3.4. This seismic section shows two pop-up structures bounded by thrust faulting. These pop-up structures are suitable place for the accumulation of the hydrocabons. Thurst faulting and pop-up structures show that the study area is dominated by compressional forces. Interpreted Strike line in shown in Figure 3.5.

Whereas time section of dip lines are also incorporated which clearly shows the fault movement and displacement across faults. All interpreted Seismic sections are shown below in Figures, 3.6, 3.7, 3.8, 3.9.

- **Dip line 97-MYL-07**

Well Meyal-17 lies on this line and this line is the reference line for picking the horizons. Three horizon are marked on the basis of TD chart of Meyal-17 and Pop-up structure confirms the location of the well and suitable place for hydrocarbon accumulation.

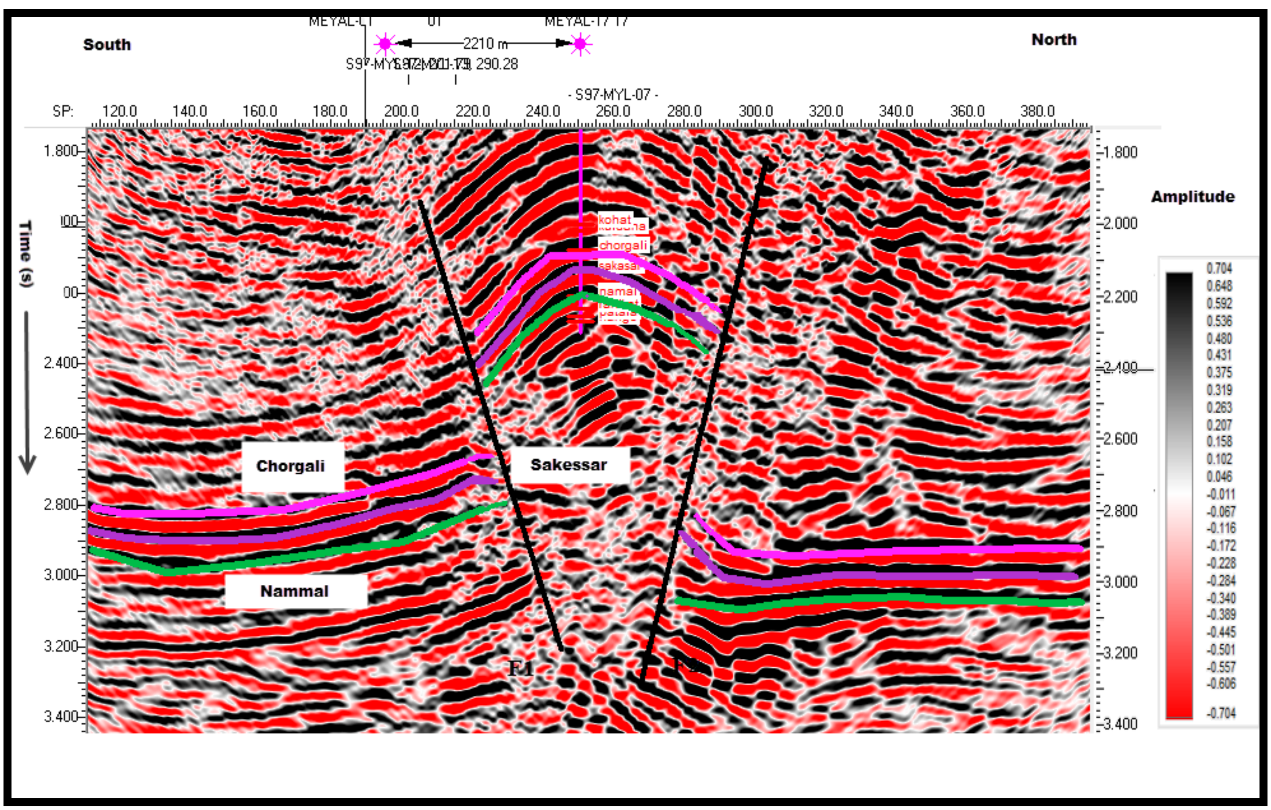

Figure 3.2 Interpreted Seismic line 97 MYL-07.

- **Dip line 97-MYL-01**

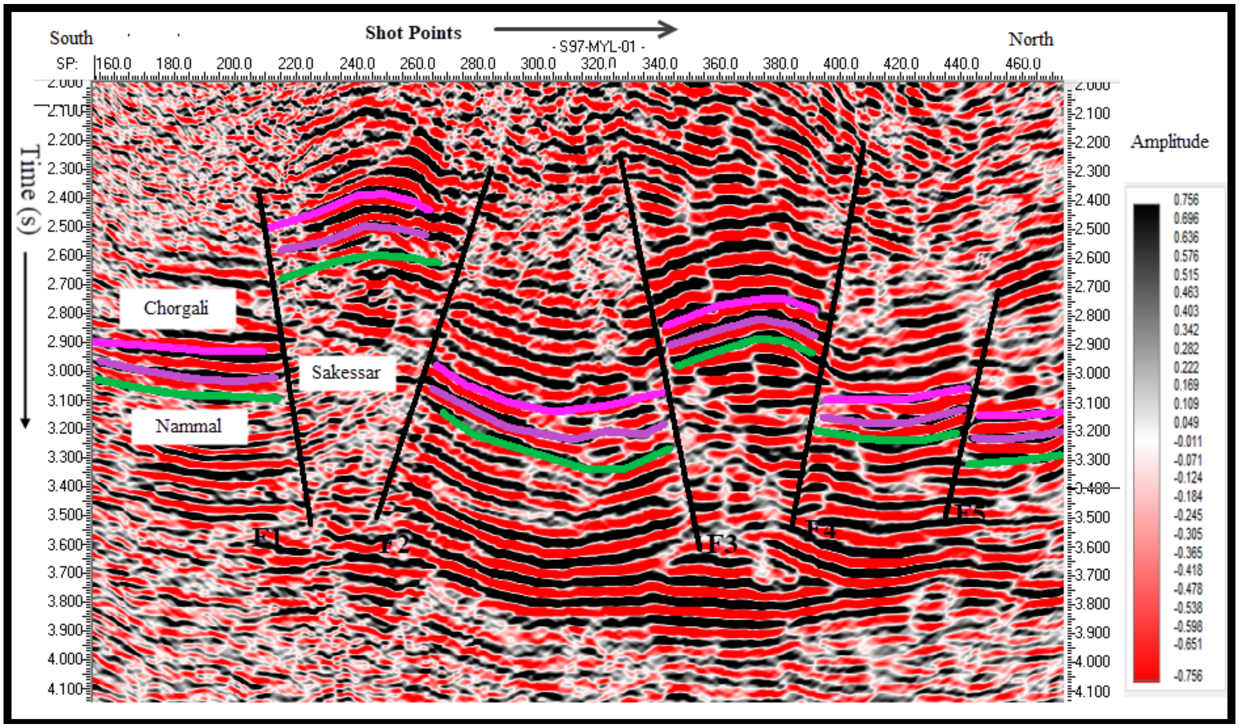

Figure 3.3 Interpreted seismic section of line 97-MYL-01 showing horizons and faults.

- **Dip line 97-MYL-03**

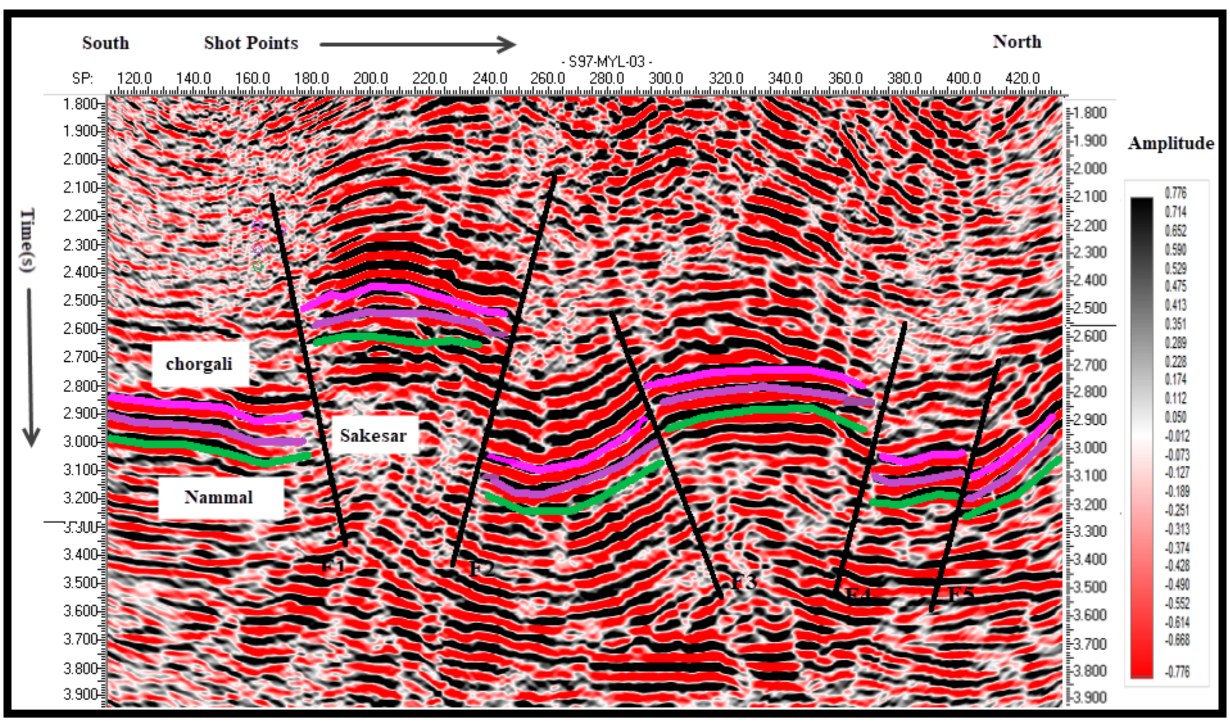

Figure3.4 Interpreted seismic section of line 97-MYL-03 showing horizons and faults.

- **Strike Line 97-MYL-13:**

The interpreted seismic section of the line 97-MYL-13 is shown in Figure 3.5. Total three seismic horizons namely, Chorgali, Sakesar and Nammal of Eocene age are marked. This seismic section shows a gentle anticlinal fold. It is a strike line so faults are not clearly shown on this line.

After this interpretation Synthetic seismogram is generated to confirm the marked horizon. Synthetic seismogram of Meyal-17 well is generated which lies on line 97-MYL-07 and it confirms the marked horizons.

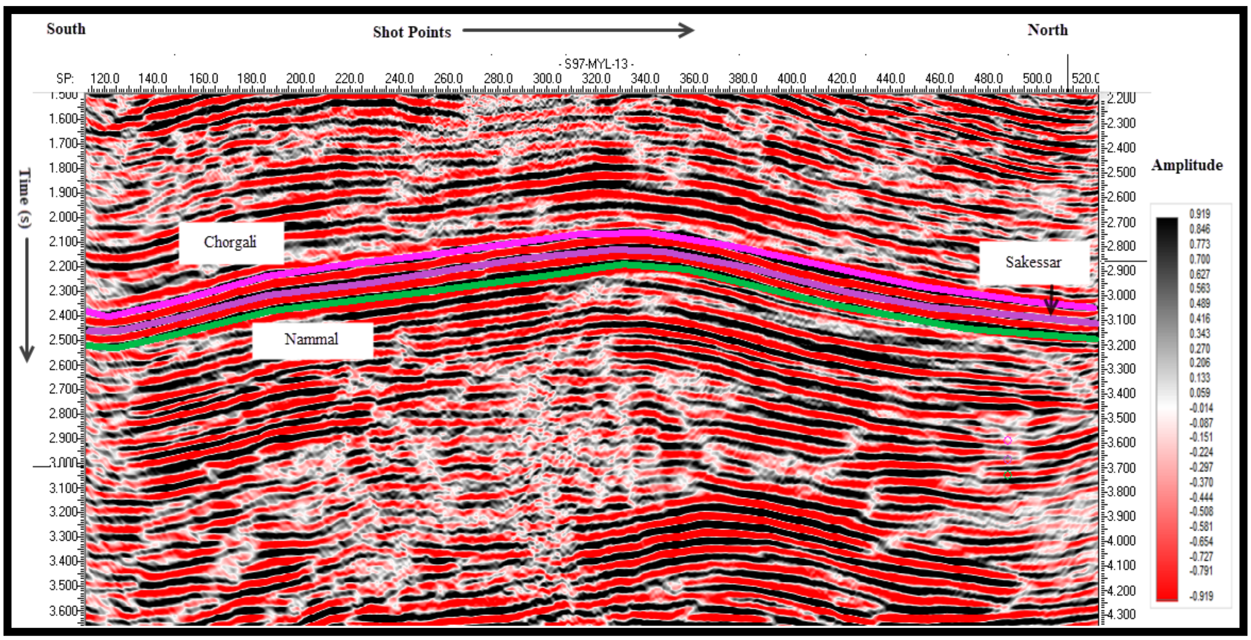

Figure 3.5 Interpreted seismic section of line 97-MYL-13 showing horizon.

➢ **Interpreted Time Sections:**

Whereas time section of dip lines are also incorporated which clearly shows the fault movement and displacement across faults. All interpreted Seismic sections are shown below in Figures, 3.6, 3.7, 3.8, 3.9.

- **Time Section of Line 97-MYL-07**

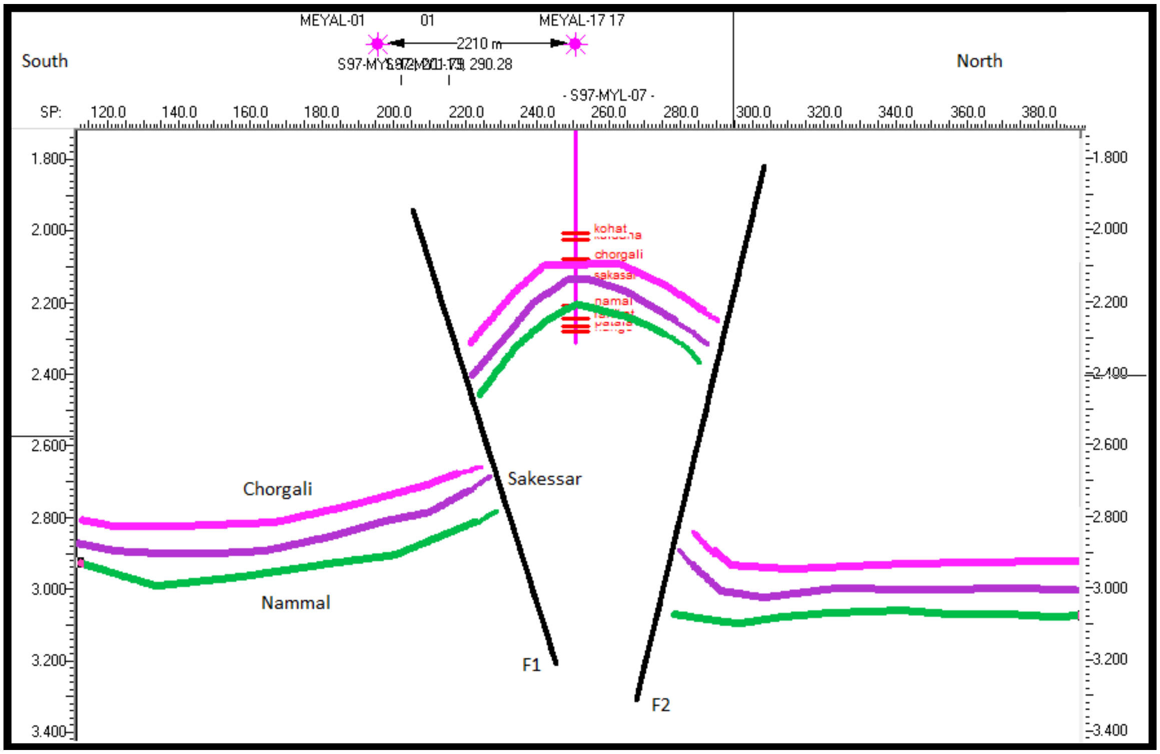

Figure 3.6 Time section of line 97-MYL-07.

- **Time section of lIne 97-MYL-01**

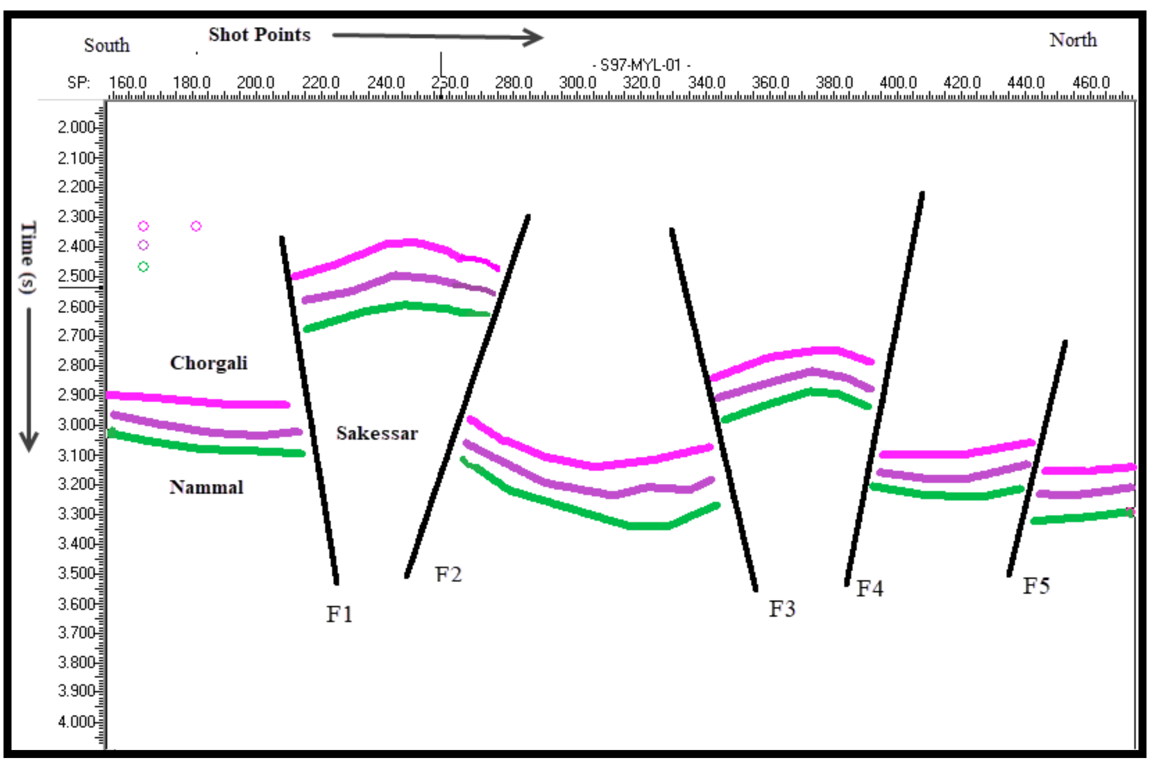

Figure 3.7 Time Section of Line 97-MYL-01.

- **Time Section of Line 97-MYL-03**

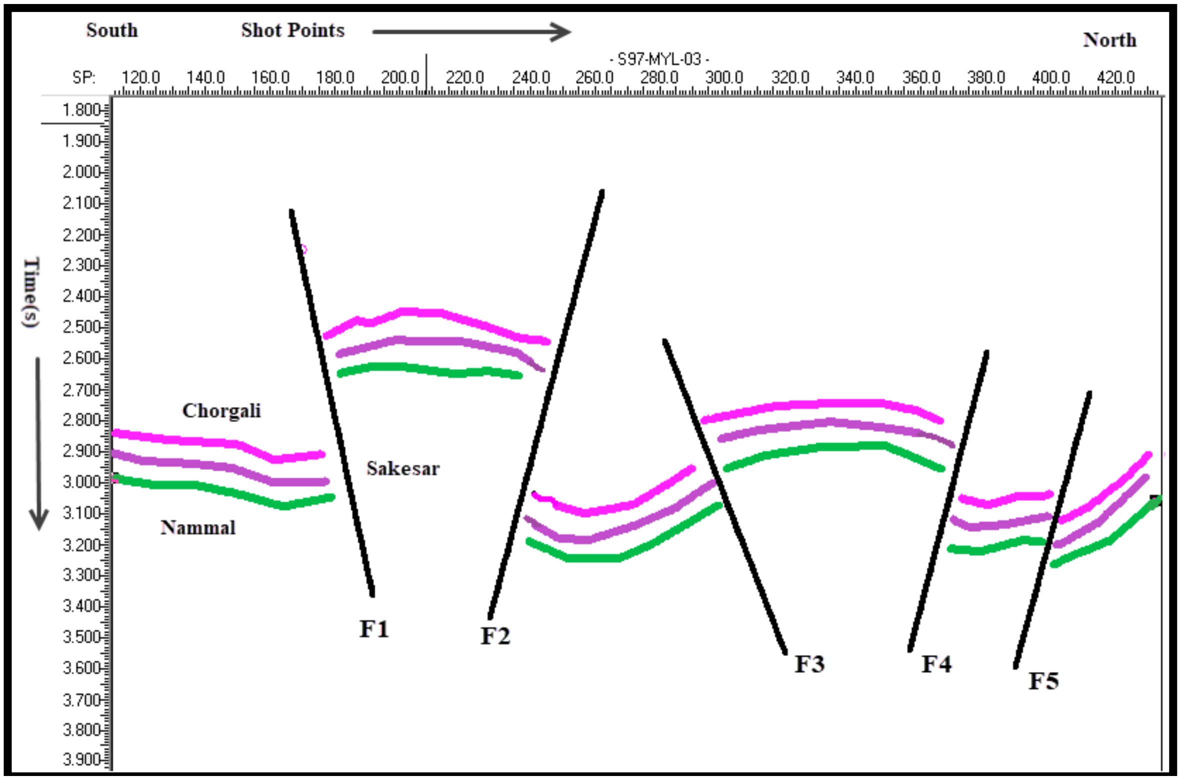

Figure 3.8 Time section of Line 97-MYL-03

- **Time Section of Line 97-MYL-13**

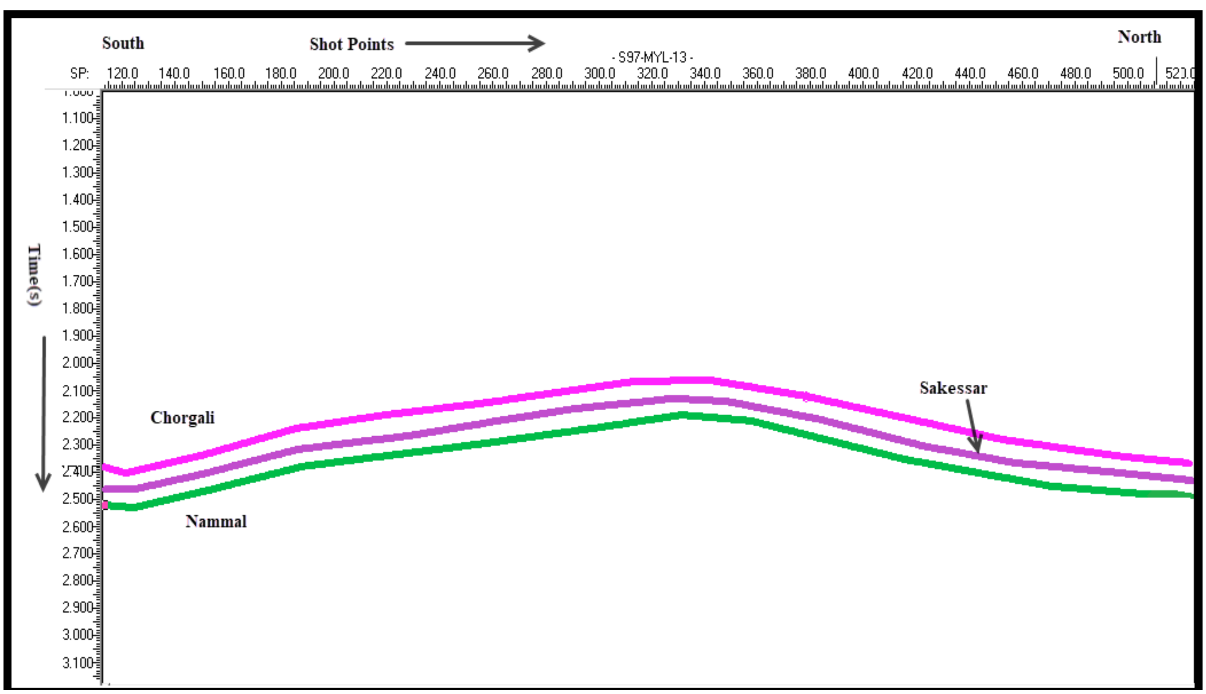

Figure 3.9 Time section of Line 97-MYL-13

3.6 Synthetic Seismogram Generation:

For 1-D forward modeling or synthetic seismogram generation, TWT (two way time) for each well top/reflector is required. From the well data, the depths of the formations are known, by plotting values of depths & times which came from the check-shot survey, we can extract the time value for certain depth (to mark that depth on seismic section). However check-shot surveys are expensive and are not available for research purposes. Another way to find TWT is using Sonic Log Data. Impedance log can be generated by multiplying digital data of Sonic and density logs point by point, equation (01). From LAS files of wells available, Reflection Coefficient (RC) Series is calculated using this acoustic impedance (AI) log by using formula given in equation (2), after this a source wavelet(Ricker Wavelet or may be extracted) is generated and then this source wavelet is convolved with reflection coefficient series to generate a synthetic seismic trace, equation (3). Following are some basic information should be pointed out, carried during preparation of synthetic trace:

• Kelly Bushing was reference datum of survey
• The Check-shot time is two way time determined from well log data
• The type of well depth was MD (Measured Depth from KB)

Convolution of wavelets with RC series means the combination of both, source wavelet and reflection coefficient series shown in figure 3.8 and mathematically can be written as following:

- **Acoustic Impedence (I)= Vp(Sonic log)*Density(Rhob)= ρυ** (1)
- **Reflection Coefficient =** $(\rho_{2V2} - \rho_{1V1})/(\rho_{2V2} + \rho_{1V1})$ (2)
- **Seismic Reflection = Seismic source wavelet * Earth reflectivity** (3)
- **Synthetic Seismogram = Artificial source wavelet * RC-Series** (4)

Synthetic seismogram of Meyal-13 is generated and it confirms the marked horizons. Synthetic seismogram of Meyal-13 is shown below in Figure 3.9 which lies on line S97-MYL-12 .

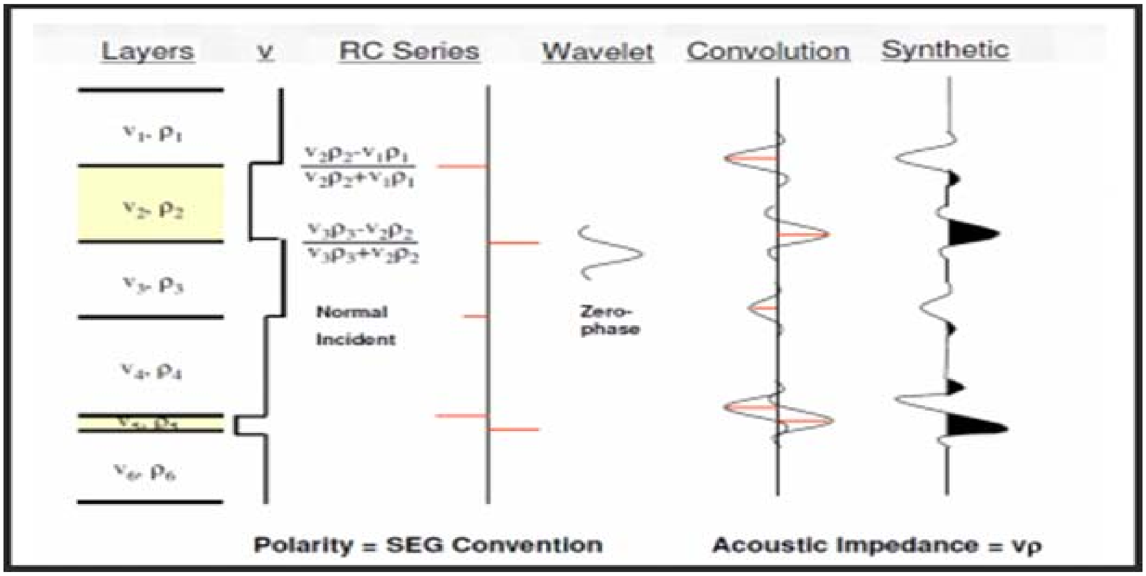

Figure 3.10Process of convolution and making of synthetic seismogram (Courtesy IHS)

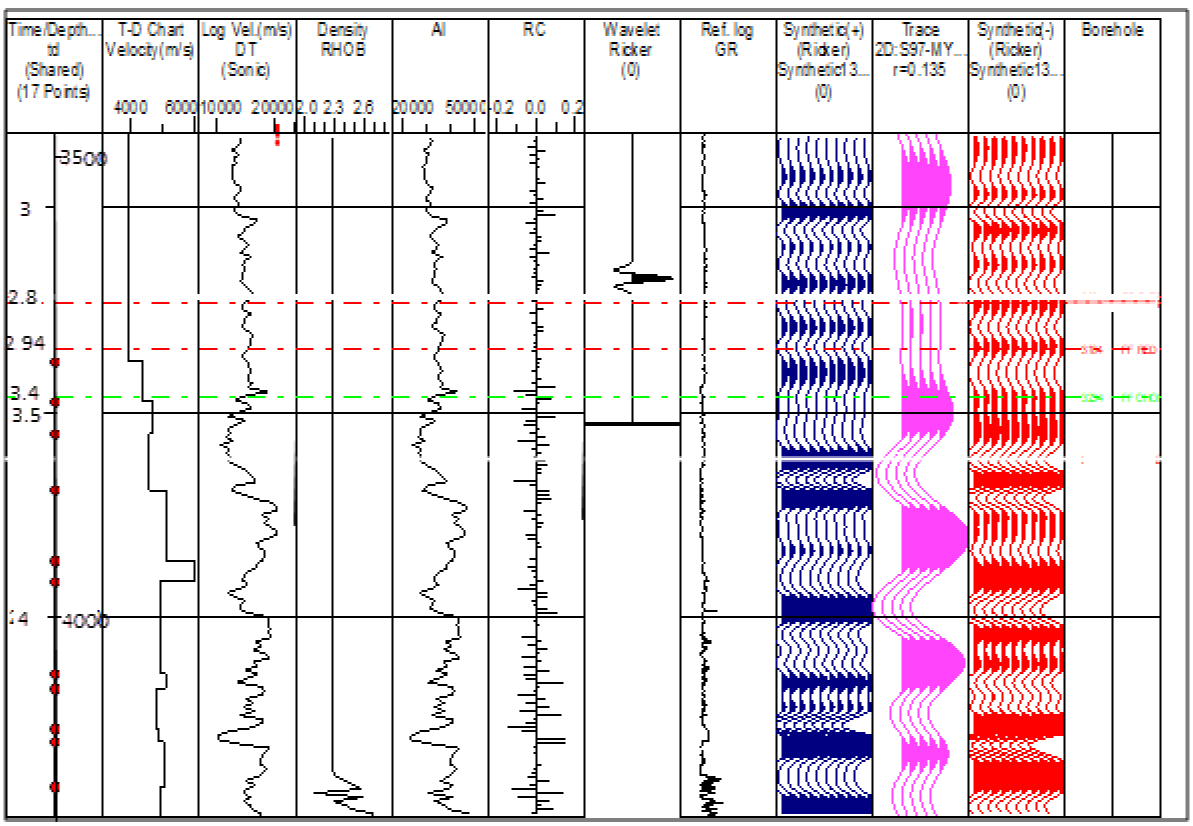

Figure 3.11 Synthetic Seismogram of MEYAL-17

Synthetic seismogram is generated to know the exact location of the formation tops Picking in time domain, then, to tie it with the seismic section. In Figure above Synthetic seismogram is shown which confirms the top of the marked formations. All assigned lines are interpreted and next step is to generate Fault polygon and contours.

3.7 Generation of Fault Polygon:

A fault polygon represents the lateral extent of dip faults or strike faults having same trend. Fault polygons show the sub-surface discontinuities by displacing the contours. To generate 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 on base map can be manually joined to make a polygon. Figure 3.12 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. Figure 3.12 shows polygon of Chorgali formation. At Chorgali level five fault polygons are generated. Figure 3.13 shows fault polygon of Sakessar formation and it confirms that all the wells lies in low values of time.

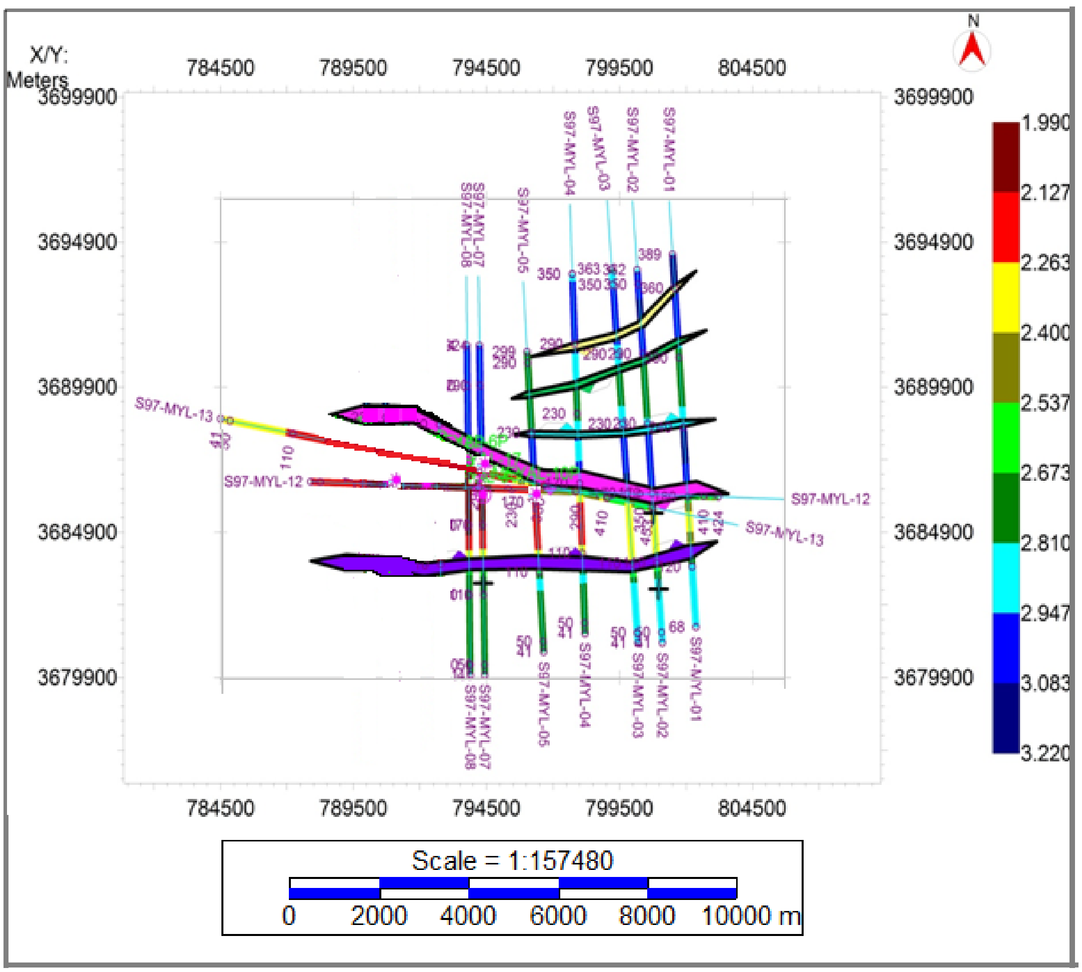

Figure 3.12 Fault polygon of Chorgali Formation.

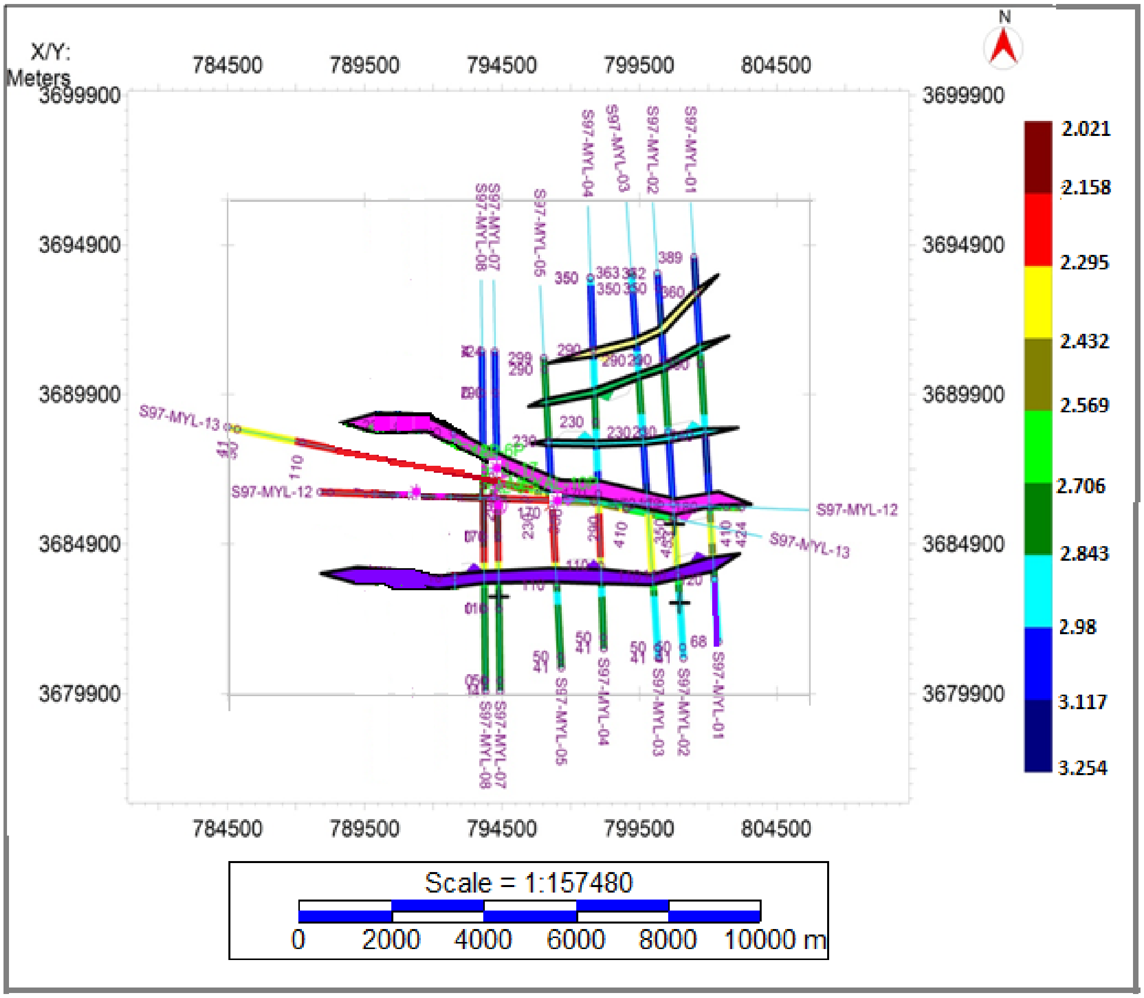

Figure 3.13 Fault polygon Of Sakessar formation.

3.8 Contour Map

In seismic interpretation contouring is used to identify the structure forming a particular horizon. For the purpose of constructing subsurface contour maps from the seismic data formation and reference datum is selected first. The reference datum may be above or below sea level (Gadallah & Fisher, 2009). In constructing a subsurface map from seismic data, a reference datum must first be selected. The datum may be sea level or any other depth above or below sea level. Frequently, another datum above sea level is selected in order to image a shallow marker on the seismic cross- section, which may have a great impact on the interpretation of the zone of interest (Gadallah & Fisher, 2009).

Contouring represents the 3D earth on a 2D surface. The spacing of the contour lines is a measure of the steepness of the slope i.e. closer the spacing, steeper the slope. A subsurface structural map shows relief on a subsurface horizon with contour lines that represent equal depth below a reference datum or two way time (TWT) from the surface. These contour maps reveal the slope of the formation, structural relief of the formation, its dip, and any faulting or folding.

The spacing of the contour lines is a measure of the steepness of the slope; the closer the spacing the steeper the slope. A subsurface structural map shows relief on a subsurface horizon with contour lines that represent equal depth below a reference datum or two way time from the 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. The picked times for each reflector are exported along with the navigation data in the form of an XYZ file to be used for contouring. The Kingdom software is used to generate the contour maps.

3.8.1 Time Contour Map of Chorgali and Sakessar formation:

Chorgali formation is one of the reservoir formations in Meyal area. This formation has both Oil & Gas content and is mainly composed of limestone with some shaly content. Chorgali time contours map shown in Figures 3.14 plotted on the seismic base map along with well locations and fault polygons.

Two way time contour map of Chorgali formation is shown in Figure 3.14. Time variation is mentioned through the color bar . Dark red color from 1.942 to 2.092 sec is showing highest (peak) point and it is the most favorable area for hydrocarbon extraction. The pop-up structures are bounded by two major faults.

Sakessar formation is also one of the main reservoir formations in Meyal area. Sakasser formation lies below Chorgali formation in all seismic sections. Fault polygons of Sakasser formation are similar to Chorgali formation which indicates the presence of same faults on both formations. Contour interval in time & depth contour maps is 30 milliseconds and 50 meters respectively. Dark red color from 2.051 to 2.190 sec shows highest point known as pop up structure and it is the most favorable area for hydrocarbon extraction from Sakessar formation.

Two way time contour map of sakessar formation is shown in Figure 3.15.

3.9.2 Depth Contour Map of Chorgali and Sakessar formation:

Depth contour map of Chorgali and sakessar formation is shown in Figure 3.16 and Figure 3.17. Depth variation is shown by the color bar Dark red colored portion is showing the shallowest part while blue color is showing deepest part of the formation. Dark red color is showing highest point. This highest point is the pop up structure and it is the most favorable area for hydrocarbon extraction from Chorgali and sakessar formation.

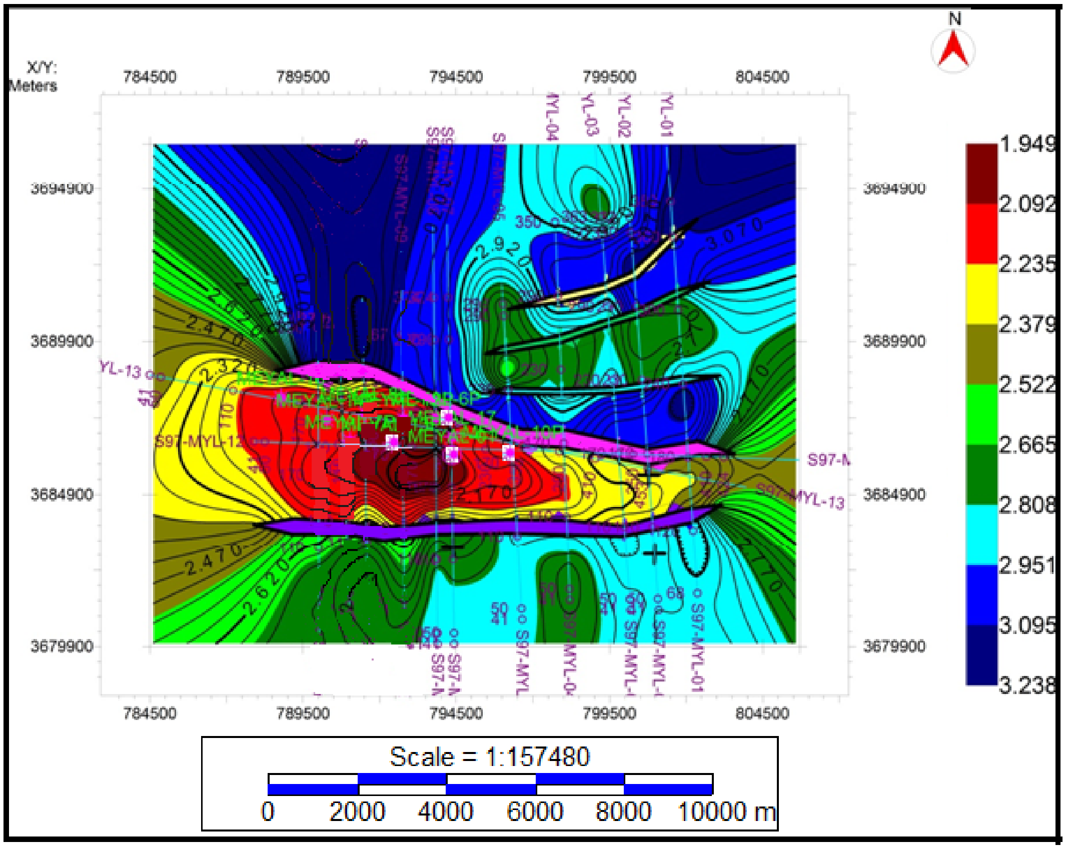

Figure 3.14 Time Contour map of Chorgali formation at Eocene level.

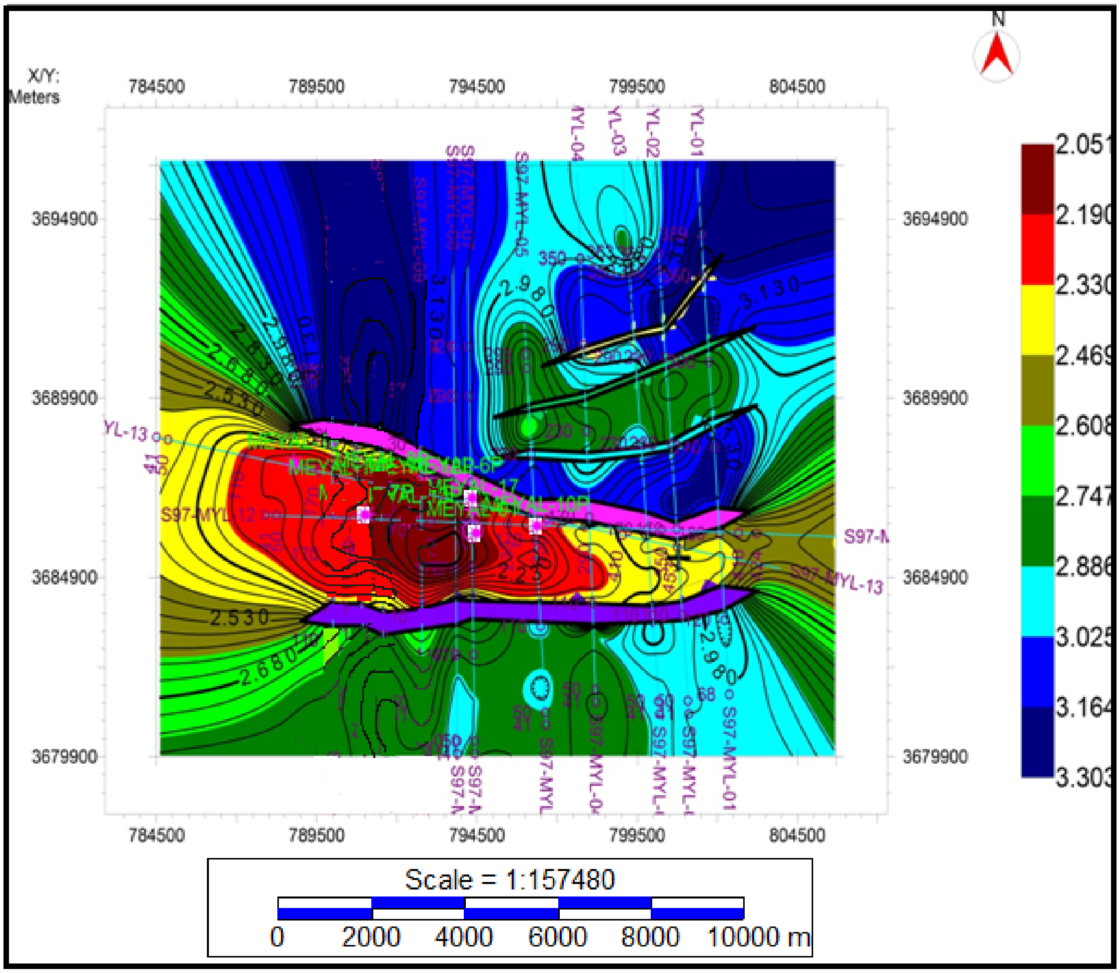

Figure 3.15 Time contour map of Sakessar formation

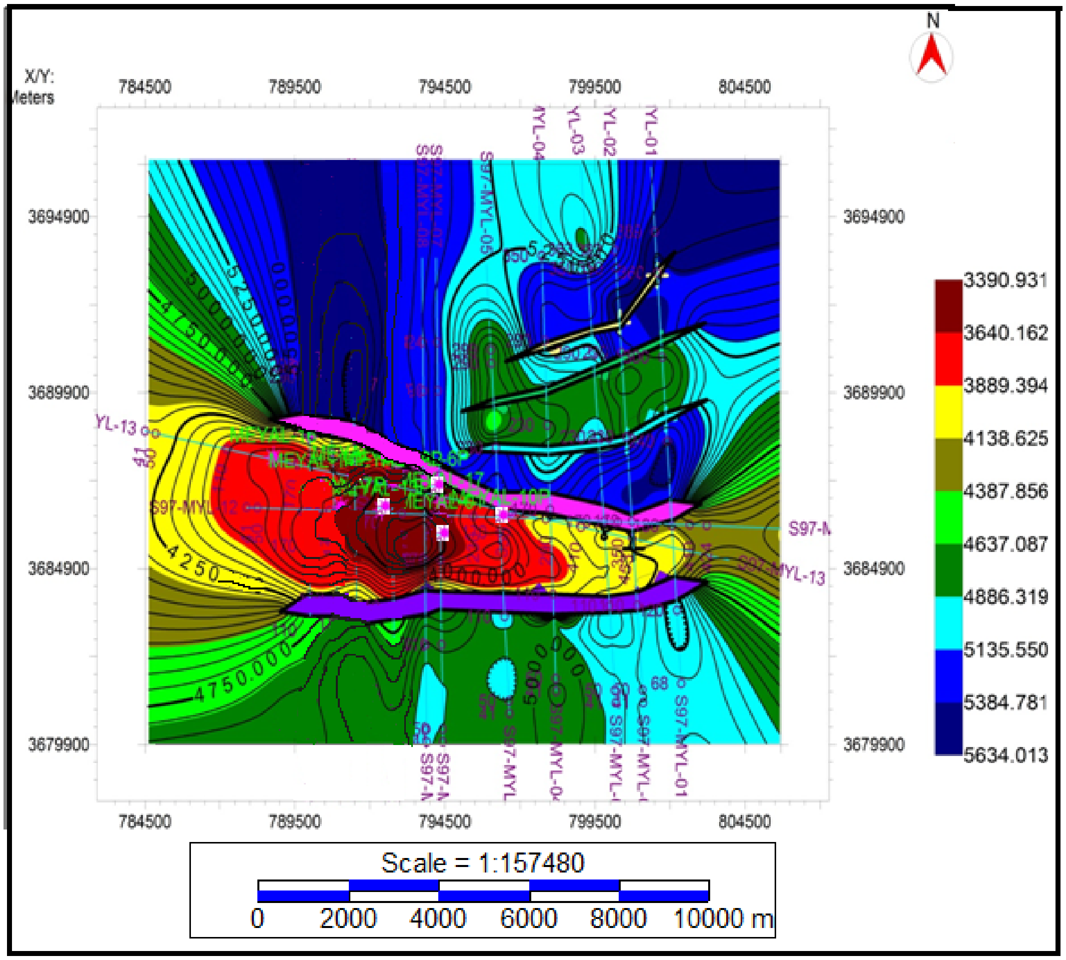

Figure 3.16 Depth contour map of Chorgali Formation.

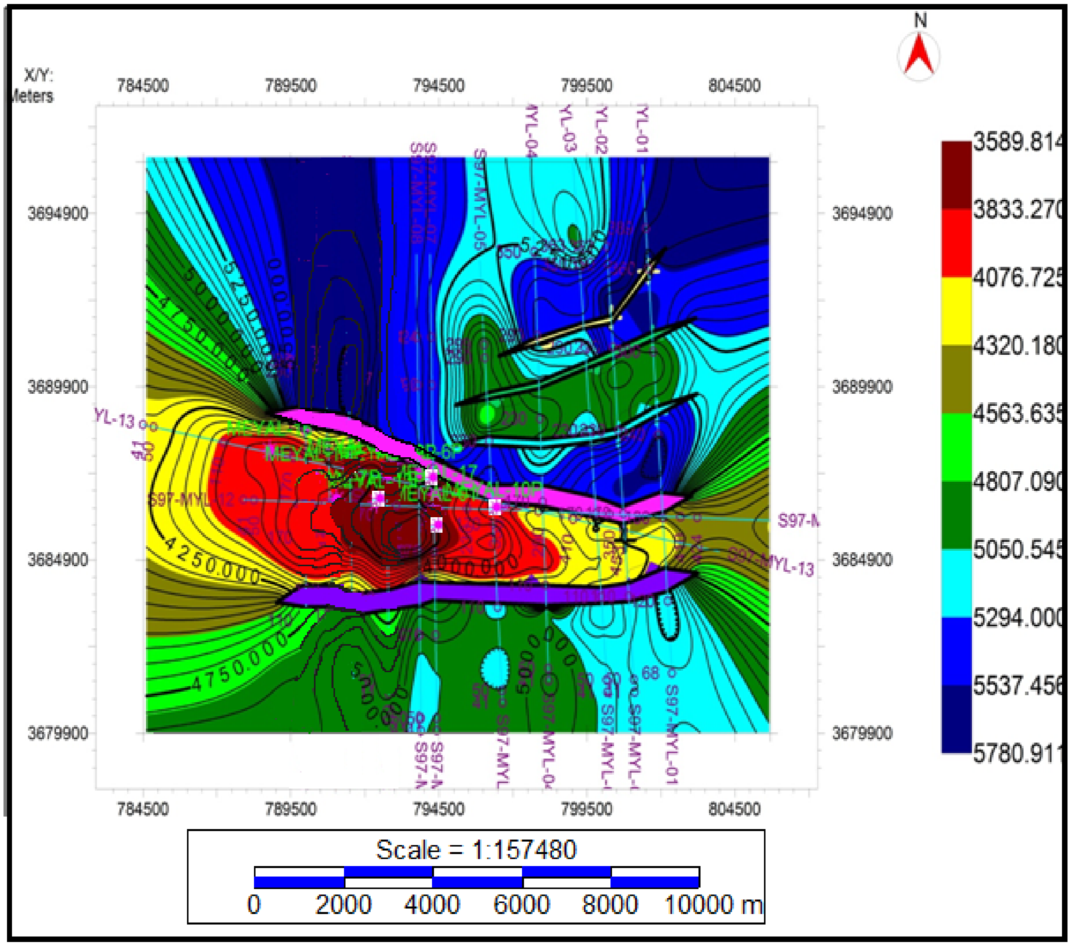

Figure 3.17 Depth Contour map of Sakessar formation at Eocene level.

CHAPTER 4
SEISMIC ATTRIBUTES

4.1 Introduction:

Seismic attribute is defined by as a measurement derived from seismic data. It can be obtained either by direct measurements or by logical or experience based reasoning. Seismic attributes have come a long way since their introduction in the early 1970's and have become an integral part of seismic interpretation projects. Today, they are being used widely for lithological and petrophysical prediction of reservoirs. Various methodologies have been developed for their application to broader hydrocarbon exploration and development decision making (Chopra and Marfurt, 2006).

Many of these attributes play an exceptionally important role in interpreting and analyzing seismic data (Chopra et al, 2005). Some particular attribute applications are considered i.e. Amplitude, Frequency, 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.

4.2 Classification of Seismic Attributes:

The default attribute of Seismic data is Amplitude. From the early days of seismic prospecting, Geoscientists used to draw conclusions about subsurface geology and drilling locations primarily from this single seismic data attribute. Attribute computations decompose seismic data into constituent attributes. There are no rules governing how attributes are computed. Any quantity calculated from seismic data can be considered an attribute. Seismic Attributes can be classified in a number of ways as discussed below.

a. Seismic Data Domain based Classification

- Pre-Stack Attributes
- Post-Stack Attributes

b. Computational Characteristics based Classification

- Instantaneous Attributes
- Interval/ Window Attributes

- Trace to Trace Attributes

c. Information Characteristics based Classification

- Time-derived attributes
- Amplitude-derived attributes
- Frequency-derived attributes
- Attenuation

4.3 Attribute Analysis:

The following attributes were applied to line 97-MYL-01 and the results are interpreted.

- Envelope of trace
- Instantaneous Frequency
- Average Energy
- Instantaneous Phase

4.3.1 Envelope of Trace (reflection strength)

Envelop of a trace, also called as reflection strength, represents the total instantaneous energy of the complex trace which is independent of the phase and is computed as the modulus of the complex trace. The Hilbert Transform of the real seismic trace is generates an imaginary trace and using both these traces the envelope trace is computed.

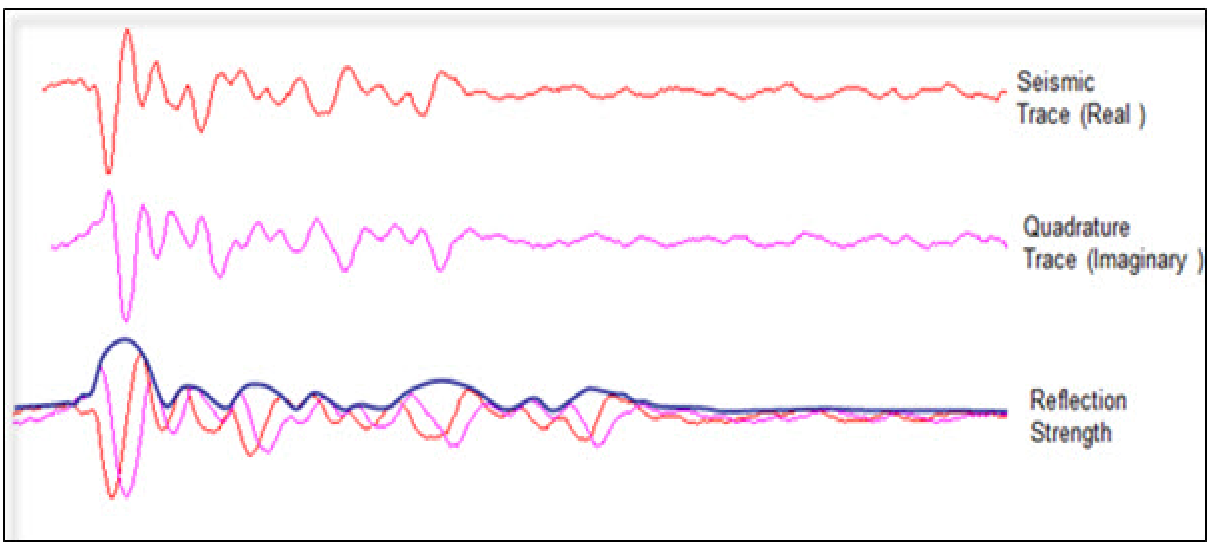

Figure 4.2: Envelope traces attribute for real seismic trace.

The Trace Envelope is a physical attribute and it can be used as an effective discriminator for the following characteristics.

- Mainly represents the acoustic impedance contrast, hence reflectivity.
- Bright spots, possible gas accumulation.
- Sequence boundaries
- Thin-bed tuning effects
- Major changes in depositional environment
- Unconformities
- Major changes of lithology
- Spatial correlation to porosity and other lithological variations
- Indicates the group, rather than phase component of the seismic wave propagation (Subrahmanyam 2008).

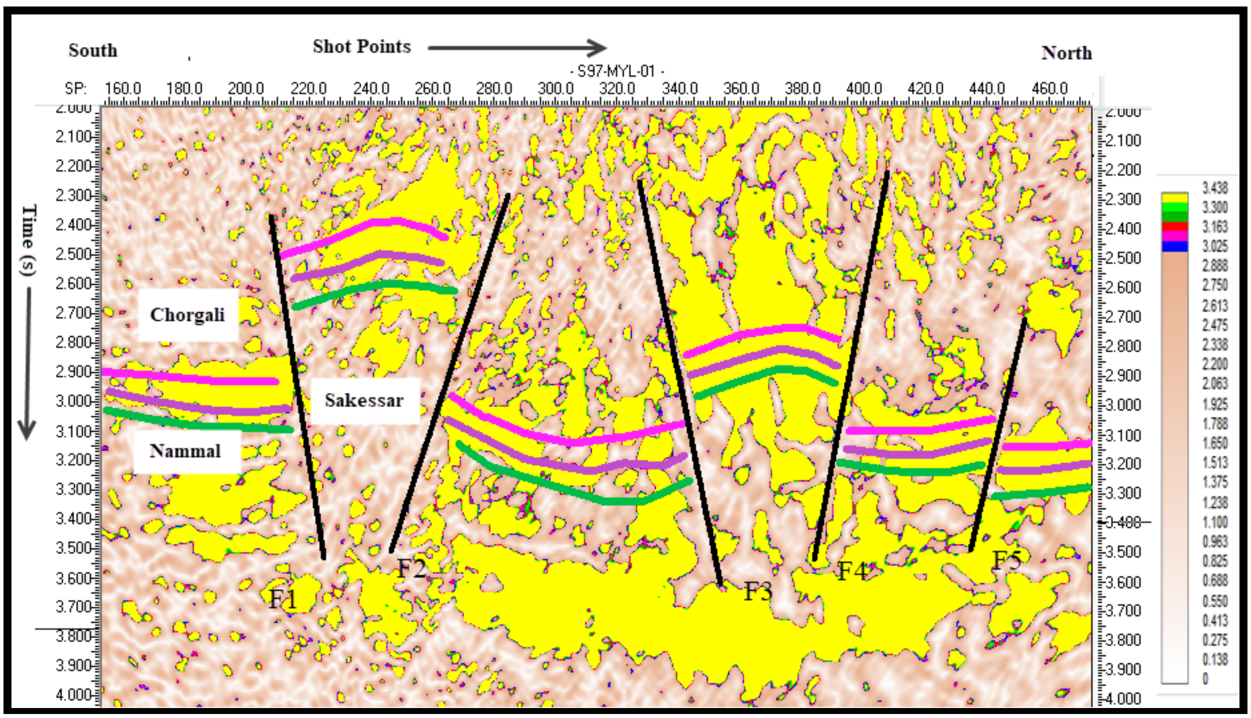

Figure 4.2 Envelope Attribute on line 97-MYL-01

This attribute is computed for seismic line 97-MYL-01 shown in Figure 4.2, to see the major changes in lithologies. Even negative reflection coefficients such as limestone formation overlaid on clayey formation would generate a positive response in this attribute. A thick (yellow) package indicates the maximum reflection strength corresponding to the source, reservoir and seal rocks. It also shows spatial patterns representing changes in the limestone thickness and breakage due to the faults.

4.3.2 Average Energy Attribute :

Average energy is a post stack wavelet attribute, in which, within a specified window the square root of the sum of squared amplitudes is calculated and divided by their number of samples. The wavelet attributes are computed at the peak of the envelope, which represent the attributes of the wavelets within a zone defined by the trace envelope minima. These attributes indicate spatial variation of the wavelets and therefore relate to the response of the composite group of individual interfaces below the seismic resolution. The attribute has a blocky response and individually highlights the seal, reservoir and source rocks as shown in Figure 4.3.

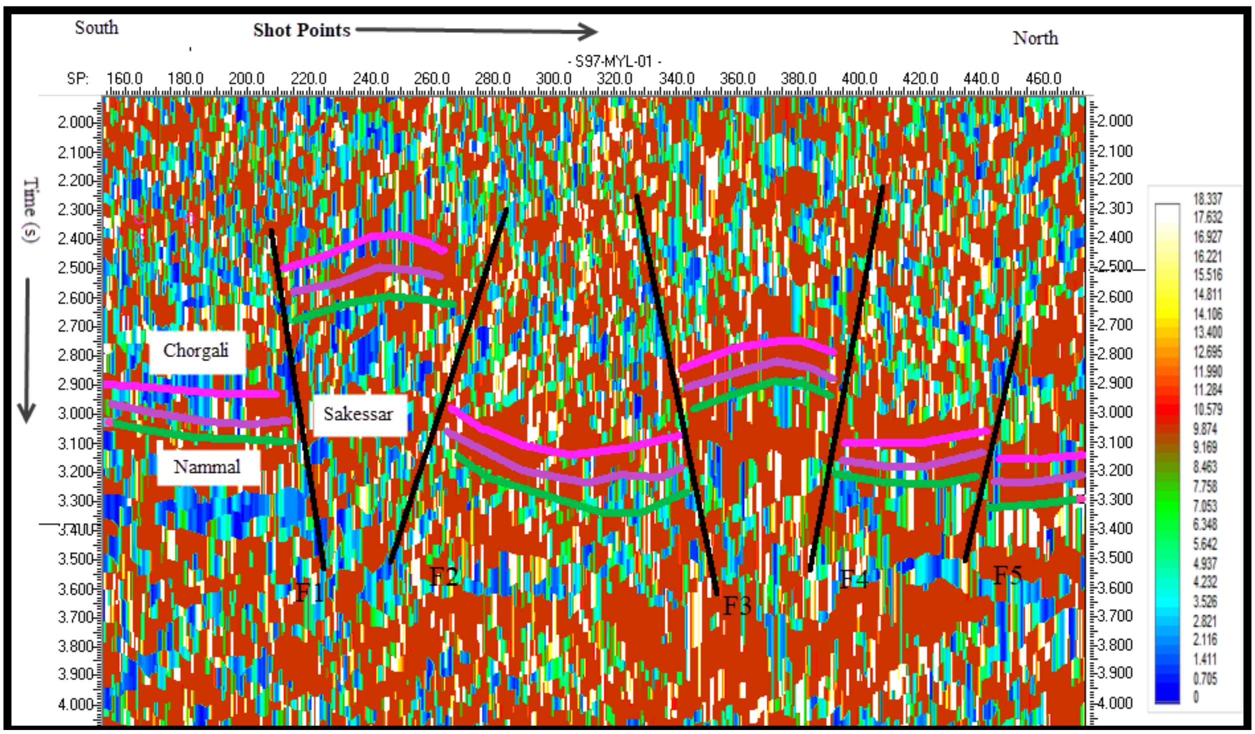

Figure 4.4 Average Energy attribute on line 97-MYL-01

4.3.4 Instantaneous Phase Attribute:

Phase attribute is also a physical attribute and can be effectively used as a discriminator for geometrical shape classifications. The phase information is independent of trace amplitudes and relates to the propagation of phase of the seismic wave front.

- Instantaneous phase is the best indicator of lateral continuity
- 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
- Shows discontinuities

- Detailed visualization of bedding configuration (Subrahmanyam 2008).

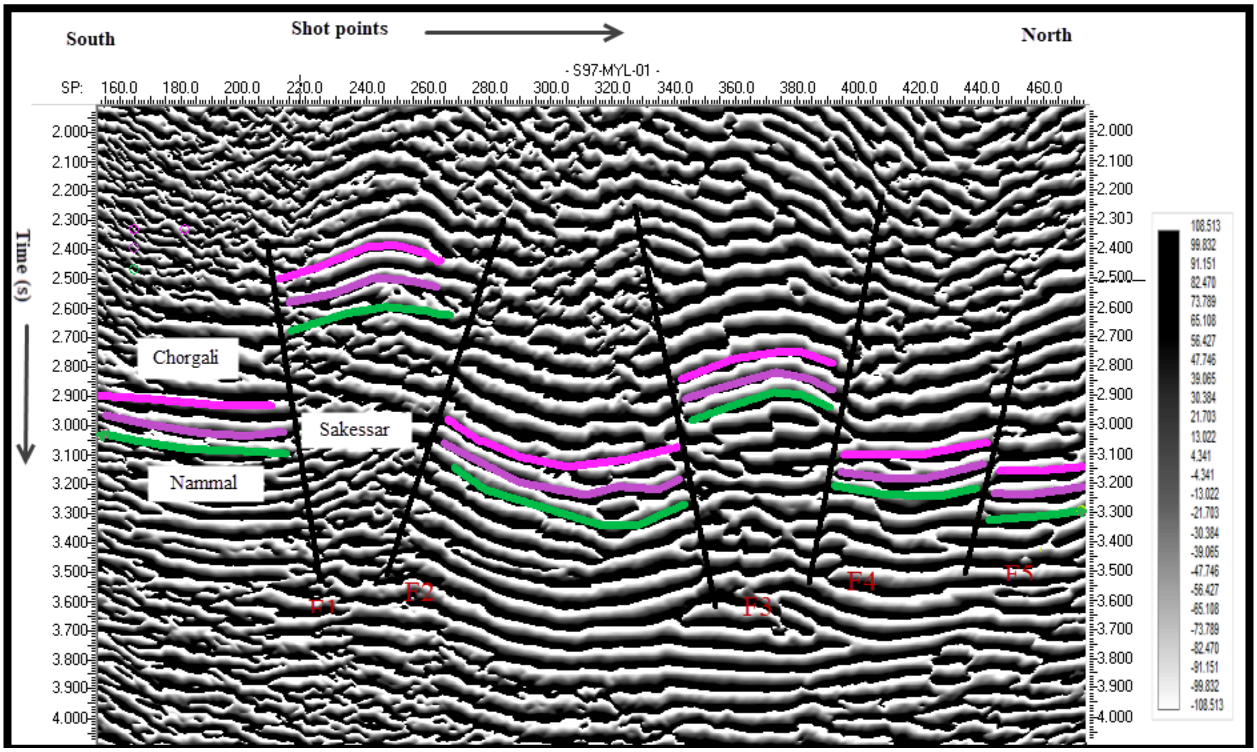

Figure 4.5 Instantaneous Phase Attribute on line 97-MYL-01.

The interpreted horizons lie over the zero phase regions indicated by white color. This attribute further confirms the interpretation as the input data is zero phase. It can be observed in comparison to amplitude based sections that the instantaneous phase shows much deeper horizons. The phase attribute in Figure 4.5 shows the lateral continuity.

4.3.5 Instantaneous Frequency Attribute:

Instantaneous frequency attribute relates to the centroid of the power spectrum of the seismic wavelet. The instantaneous frequency attribute responds to both wave propagation effects and depositional characteristics, hence it is a physical attribute and can be used as an effective discriminator (Subrahmanyam 2008). Its uses include:

- Hydrocarbon indicator by low frequency anomaly. This effect is sometimes accentuated by unconsolidated sands due to the oil content of the pores
- Fracture zone indicator, since fractures may appear as lower frequency zones.
- Bed thickness indicator. Higher frequencies indicate sharp interfaces such as exhibited by thinly laminated shale, lower frequencies are indicative of more massive bedding geometries, e.g. sand-prone lithology

- Instantaneous frequency can indicate bed thickness and also lithology parameters

Another piece of information we can extract from the seismic data are the locations where instantaneous frequencies jump or exhibit a negative sign. These sign reversals are caused by closely-arriving reflected wavelets. Therefore, the time derivative of the phase function will contain the indicators for thin beds, in the form of large variations of instantaneous frequency. Its smooth variation will relate to bedding characteristics (Subrahmanyam 2008). Figure 4.6 shows Instantaneous frequency attribute calculated for seismic line 97-MYL-01.

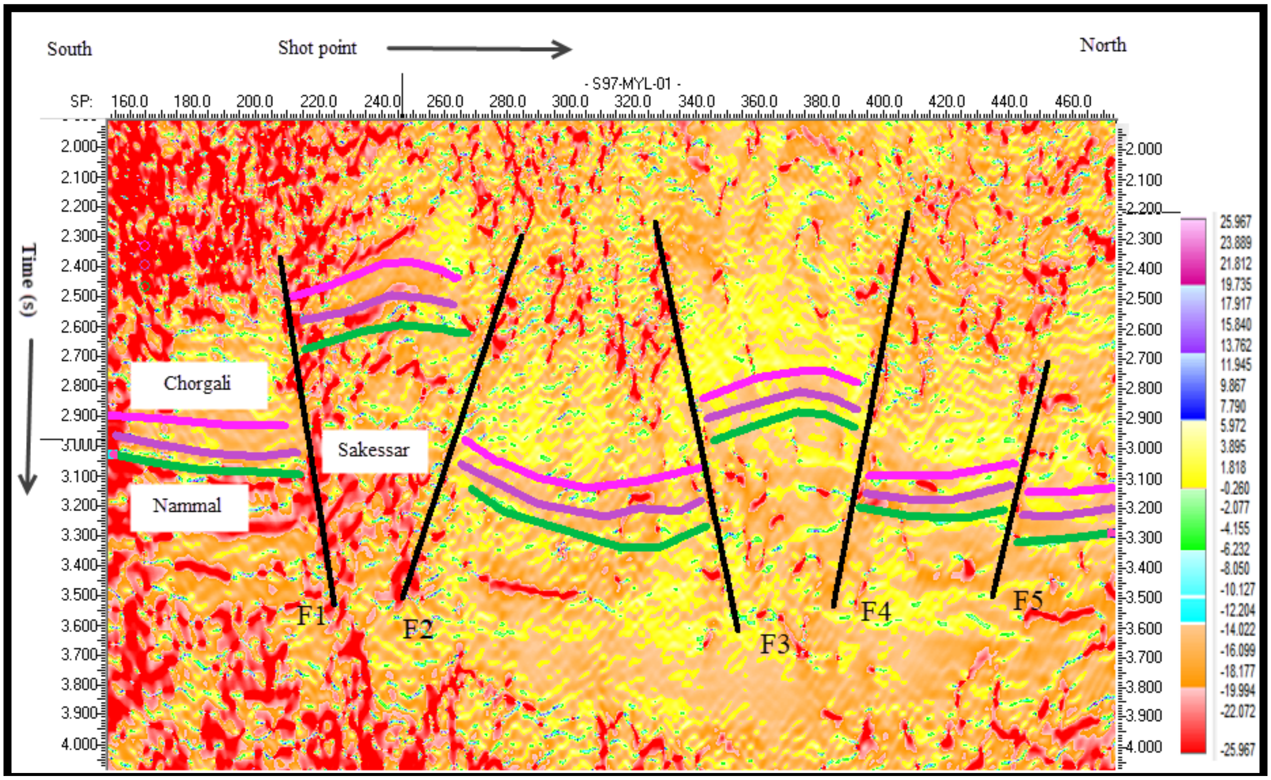

Figure 4.6 Instantaneous Frequency on line 97-MYL-01

CHAPTER 5
PETROPHYSICAL ANALYSIS

5.1 Introduction:

Petrophysics is suggested as the term pertaining to the physics of particular rock types. It is the study of the physical properties of rock which are related to pore and fluid distribution. When physical measurements of the rocks like core analysis is combined with log analysis then the work done is called petrophysical analysis. To accurately characterize oil or gas in a reservoir, measurements such as resistivity, porosity and density are made, from which volume of shale, average porosity water saturation and hydrocarbon saturation can be quantified (Dewar 2001).

- Petro physics uses all kinds of logs, core data and production data; and integrates all pertinent information
- Petro physics aims at obtaining the physical properties such as porosity, saturation and permeability, which are related to production parameters.
- Petro physics is generally less concerned with seismic, and more concerned with using wellbore measurements to contribute to reservoir description.
- Petrophysics can provide things like porosity, saturation, permeability, net pay, fluid contacts, shale volume, and reservoir zonation.
- Petrophysics is the interest of Petroleum Engineers, Well Log Analysts, Core Analysts, Geologists and Geophysicists (Dewar 2001).

5.2 Principle of Log Interpretation:

The first step of log interpretation is to locate the reservoir zone by log patterns, then detecting hydrocarbon zone. After that distinguish between oil and gas bearing zones. Finally computing effective porosity, water saturation and hydrocarbon saturation. Figure 5.1 shows basic steps of log interpretation.

5.3 Types of Well Logging:

Well logging is classified into three broad categories:

- Open hole logging.
- Cased hole logging.
- Production logging.

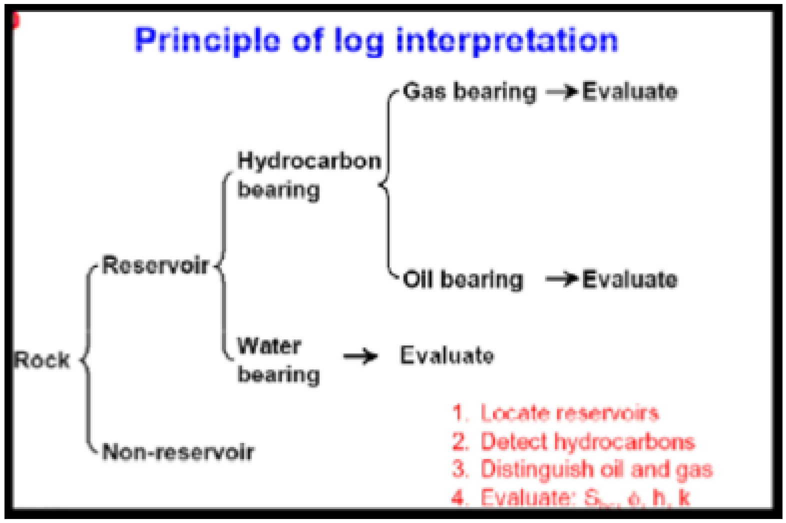

Figure 5.1 Basic Steps in Well log Interpretation

5.4 Raw Log Curve

The Petrophysical analysis for reservoir characterization of Meyal area has been carried out. For this purpose well data of MEYAL-01 is used for the prospect, reservoir generation and data was issued by DGPC (Directorate General of Petroleum Concessions). For Petrophysical analysis Caliper log, Gamma Ray log (GR), Spontaneous potential log (SP), Resistivity log and porosity logs are used.

Using these logs different rock properties can be measured which is the main objective of this chapter. These logs are identified or displayed in the Figure 5.2.

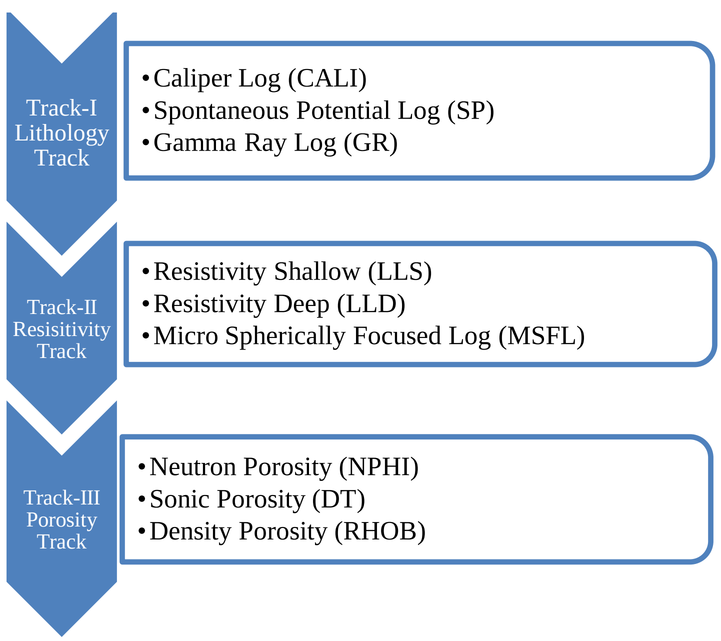

Figure 5.2 Basic three log Tracks

- **Lithology Track**

Gama ray log, SP log and Caliper log is included in this track against the depth. GR log reads the radioactivity of rocks in API units. Caliper log measures size and shape of borehole diameter. The SP is useful tool for the detection of permeable beds, marking bed boundaries and shale indicator (Schlumberger, 1974).

- **Resistivity Track**

It includes MSFL, Latero log deep (LLD) and Latero log shallow (LLS). All of these logs are plotted on logarithmic scale due to more variations in resistivity (1-1000ohm) with depth.

- **Porosity Track**

This track is also called track 3 and it includes the Sonic (DT), Density (RHOB) and Neutron log. These logs give us the porosity of the formation or rock present in the well.

5.5 Work Flow for Petrophysical Interpretation

The log data of MEYAL-01 is available in Logging ASCII Standard (LAS) format. The log curves parameters given in the LAS file header are used to calculate all basic and advance parameters. The methodology adopted for this work is given in Figure 5.3 and each analysis step is discussed in the proceeding sub-sections. For calculating rock properties IHS kingdom software is used.

5.6 Calculating Rock Properties of well MEYAL-01:

IHS kingdom software is used for calculation of rock properties of wells. As through Petrophysics we estimate the properties of reservoir so in Meyal-01 properties of Chorgali and Sakessar formations are calculated and depth of Meyal-01 is 3815.

Depth Ranges of Formations

Table 5.1 Shows depth ranges of formations

FORMATIONS	DEPTH (m)
Chorgali	3738-3778
Sakessar	3778-3813

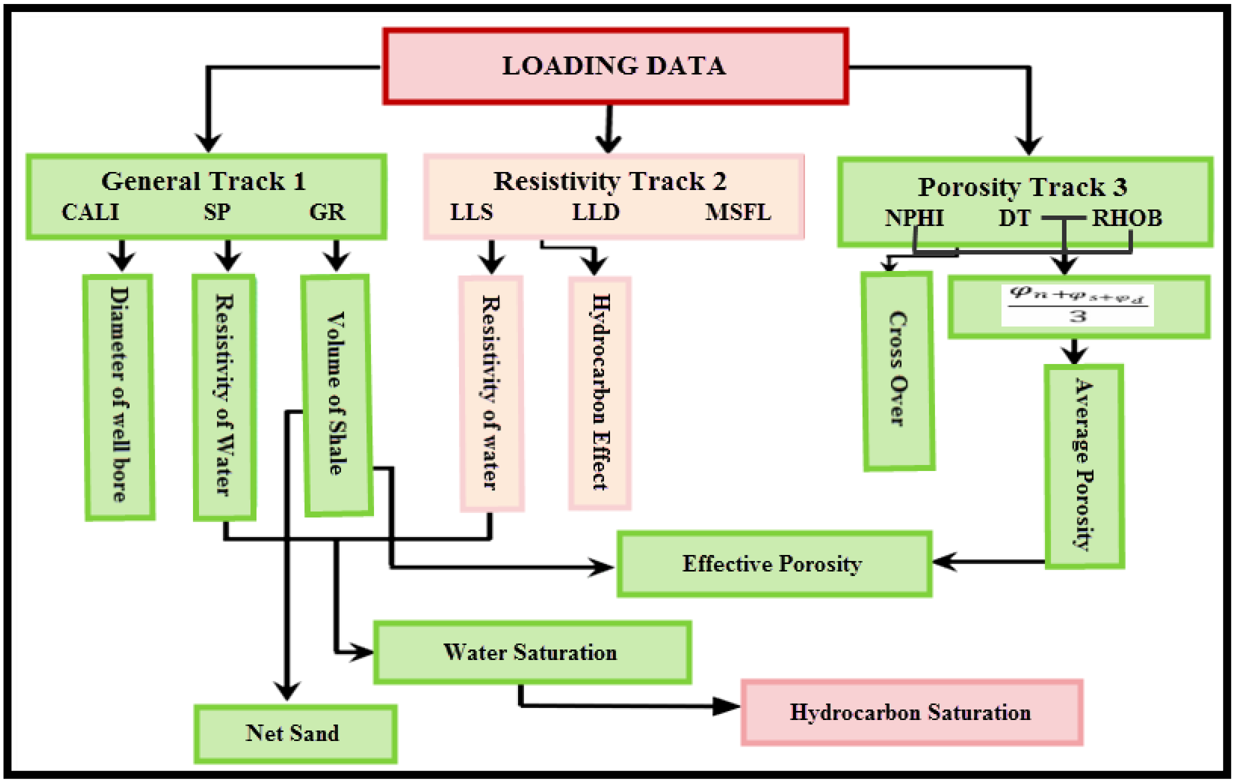

Figure 5.3 Work flow for petro physical analysis.

5.6.1 Volume of Shale

GR log basically used to find the Volume of shale (VSH). Shale content reads high GR value whereas; sandstone or limestone shows lower value of GR (schlumberger, 1989).

$$\mathbf{VSH} = \frac{(\mathbf{GR\ log} - \mathbf{GR\ min})}{(\mathbf{GR\ max} - \mathbf{GR\ min})}, \qquad (1)$$

where,

VSH = Volume of shale

GR min = Minimum value of GR log in particular zone of interest

GR max = Maximum value of GR log in particular zone of interest

GR log = Value of GR log at given point in zone of interest.

Plot/log cure of volume of shale (VSH) of reservoir formations is shown in is shown in Figure 5.4 and 5.5 in track-5.

5.6.2 Porosity Calculation

- **Sonic Porosity**

The porosity reservoir zone can be calculated using all porosity logs. Sonic log is useful technique which uses transit time to evaluate porosity of the formationSonic porosity has been calculated by using this formula (Wylie et al., 1958).

$$\Phi S = \frac{(\Delta T - \Delta T\ mat)}{(\Delta Tf - \Delta T\ mat)}, \quad (2)$$

where,

ΦS=Sonic porosity µs/ft

ΔT =Log response

ΔT mat = Transit time in matrix

ΔTf= Transit time in fluids.

According to Wyllie interval transit time (ΔT) increased due to the presence of hydrocarbon (i.e. hydrocarbon effect). In order to correct this Hilchie suggested the following empirical correction equation 3 and 4 for hydrocarbon effect. (Hilchi., 1978).

$$\Phi = \Phi s \times 0.7 \text{ (for gas)}, \quad (3)$$

$$\Phi = \Phi s \times 0.9 \text{ (for oil)}, \quad (4)$$

- **Neutron Log**

Neutron log gives the direct measurement of porosity. It is considered the concentration of hydrogen ions (HI) and pores filled within that formation (Asquith and Gibson, 2004).

- **Total Porosity**

Total porosity can be calculated by the help of following formula. Sonic porosity and neutron porosity is used for calculating total porosity.

$$\Phi_t = \frac{\varphi s}{2\varphi n}, \quad (5)$$

where,

Φ_t = Total Porosity

Φn= Neutron porosity

ΦS= Sonic Porosity.

Plot of Total porosity is shown in Figure 5.4 and Figure 5.5 in track 7.

- **Effective porosity**

The number of inter-connected pores is known as effective porosity.

$$\mathbf{\Phi_e = \Phi_t \times (1 - V_{sh})}, \quad (6)$$

where, in equation 6:

Φe = Effective porosity

Φ_t = Total Porosity

Vsh = Shale volume.

Plot of effective porosity of Meyal-01 is shown in Figure 5.4 and Figure 5.5 in track 8.

5.6.3 Water Saturation:

Percentage of water in the volume of rock which is highly porous is called saturation of water. As it reads the percent so it has no unit whereas, it has a symbol S_w.

Archie's Experiment explains that the water filled formation's resistivity (R_o) and resistivity of water R_w can be related through formation resistivity factor (F):

$$\mathbf{R_o = F \times R_w} \quad (7)$$

Formation factors can also be related with porosity as:

$$\mathbf{F = a/\Phi^m} \quad (8)$$

Where, m is a concentration exponent whose value varies with grain's size, its distribution, and tortuosity factor. Whereas, a is being taken as 1 called a tortuosity factor. Following relationship helps to determine water saturation from water filled resistivity (R_o) and formation (without water) resistivity (R_t).

$$\mathbf{S_w = (R_o/R_t)^{1/n}} \quad (9)$$

Where n is the exponent of saturation which ranges from 1.8 to 2.5 but is most commonly 2. By combining the equations (5.7) and (5.9), we have:

$$\mathbf{S_w = (F \times R_w / R_t)^{1/n}} \quad (10)$$

To calculate water saturation of Meyal-01 we have to find Rw which is nearly equal to 0.033. Thus by putting this value in above equations one can easily calculate saturation of water. Sw of Meyal-01 is shown in Figure 5.4 and Figure 5.5 of Chorgali and Sakessar formation.

5.6.4 Hydrocarbon Saturation

The fraction of porous rock which is filled with hydrocarbons is called saturation of hydrocarbons. Which is being taken by subtracting water saturation from one.

$$S_h = 1 - S_w \tag{11}$$

5.7 Well Interpretation of Chorgali formation (MEYAL-01):

Petrophysical properties of Chorgali formation were calculated by using the well data of Meyal-01 well shown in Figure 5.4. Calliper log and gamma ray log are used for correlation purpose. These two logs are common lithologies indicator. At some part of depth high value of calliper log indicates the shaly material. It is also confirmed by the gamma ray log. The main zone of interest for hydrocarbon extraction of Chorgali formation ranges from 3740-3767m In this zone high resistivity values show the presence of hydrocarbons. Volume of shale is very low. All these Petrophysical properties confirm that Chorgali formation having mostly limestone lithology is a good reservoir rock in upper Indus basin.

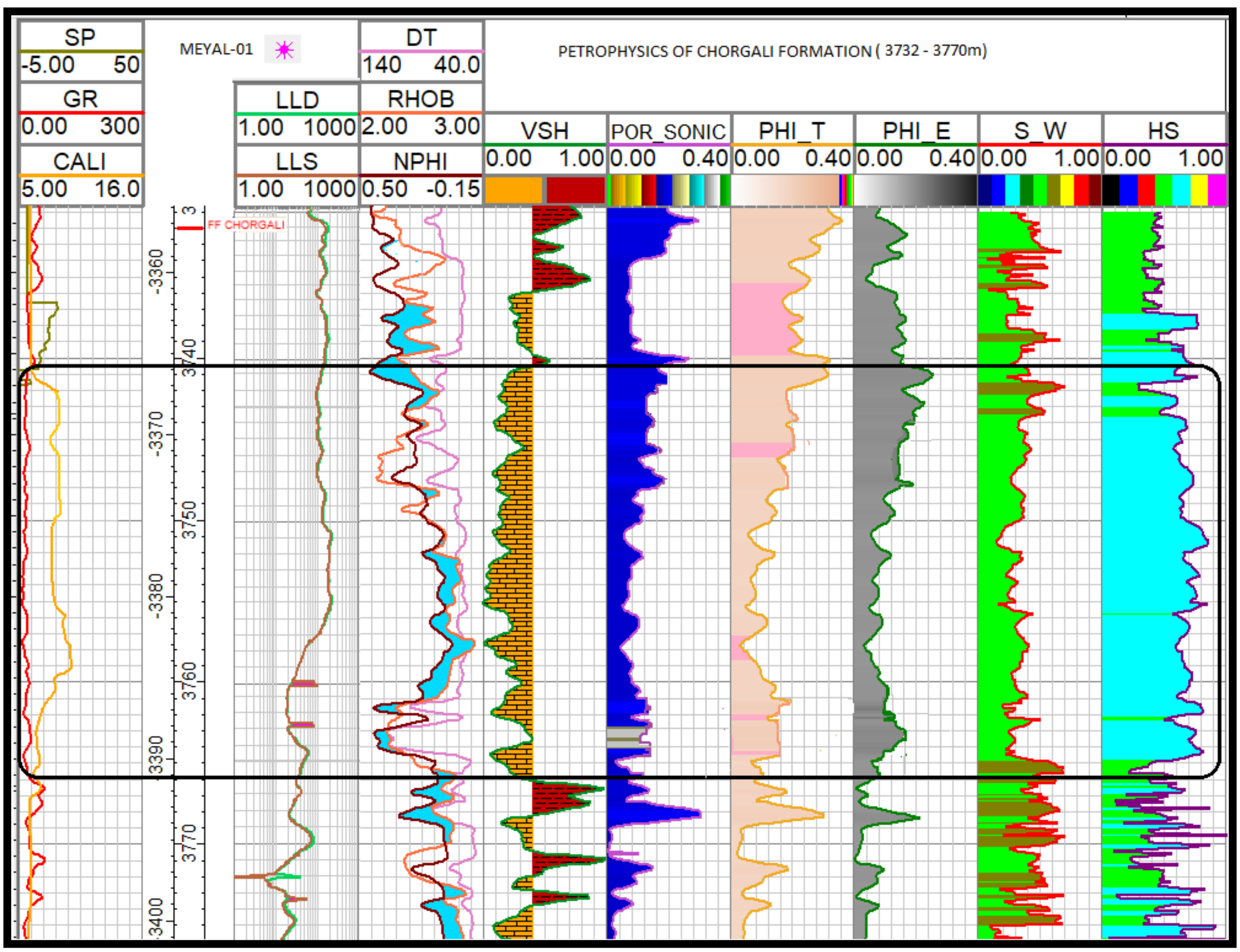

Figure 5.4 Petrophysics of Chorgali formation where the marked zone is pay zone (3740-3767).

Table 5.2. Petrophysical interpretation results for Pay zone Meyal-01

Well Meyal-01	
Calculated parameters	**Pay Zone**
Effective Porosity	8%
Average Porosity	10%
Volume of Shale	20%
Water Saturation	33%
Hydrocarbon Saturation	67%

5.8 Well Interpretation of sakessar Formation (Meyal-01):

Petrophysical properties of Sakasser formation were calculated by using the well data of Meyal-01well. Depth range from 3798-3814m All these Petrophysical properties shown in Figure 5.5 confirm that Sakasser formation having mostly limestone lithology and it is a good reservoir rock in upper Indus basin.

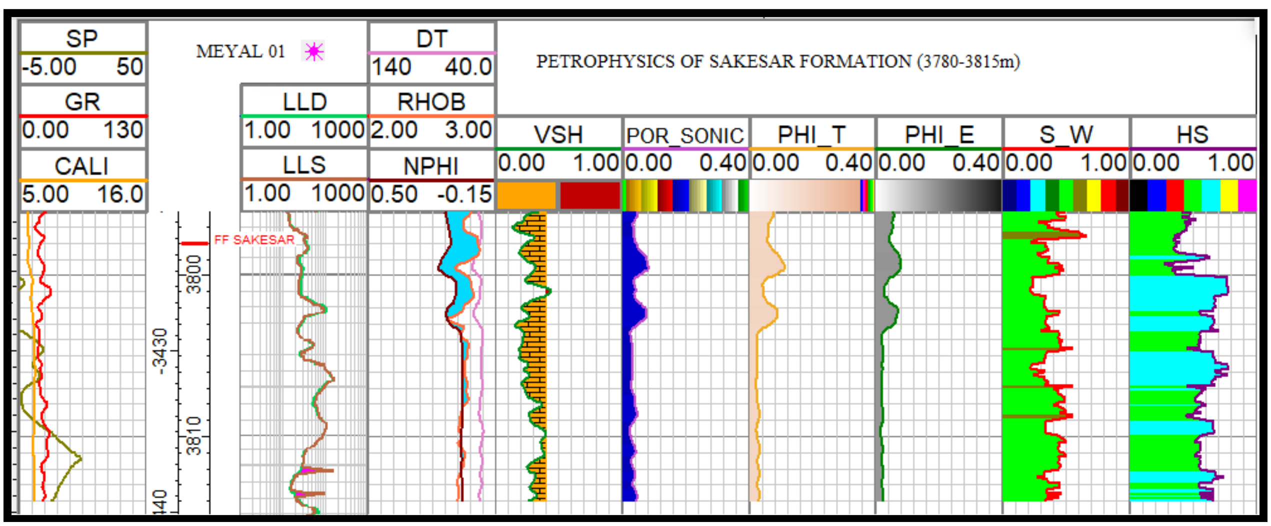

Figure 5.5 Petrophysics of Sakessar formation of Meyal-01

Table 5.3. Petrophysical interpretation results of sakessar formation.

Well Meyal-01	
Calculated parameters	**Pay Zone**
Effective Porosity	4%
Average Porosity	7%
Volume of Shale	15%
Water Saturation	30%
Hydrocarbon Saturation	70%

CHAPTER 6
FACIES MODELING

6.1 Introduction

Facies are generally considered as bodies of rocks that show some specific characters but ideally these are rock units that form under certain conditions of sedimentation, displaying a particular process or environment of deposition (Staton, 1987). Facies models provide additional aid to the understanding of sedimentary environments and the origin of old sedimentary rocks (Johnson, 2004).

In linked with petro graphical and lithological variation different kinds of facies are identified on the basis of structure, composition and sedimentary texture (Ahmad et al., 2002).

6.2 Facies Modeling:

Rock facies define the internal architecture of the reservoir rock. To understand the reservoir quality and behavior in a better way it is better to predict and model the distribution of facies accurately because, an accurate facies-model would be a good predictor of in-place volumes and fluid flow (Lau, 1990). \

6.2.1 Methods of Facies Analysis

There are different approaches used for performing facies analysis, (Saggaf and Nebrija, 2000). These are listed as:

- Supervised analysis
- Unsupervised analysis
- Semi supervised analysis

6.2.1.1 Supervised Analysis

Supervised analysis is used to identify the facies types which are present in a certain well (by using facies that are identified from cores in a nearby well). The method is suitable for analyzing lithologies and depositional facies of horizontal wells, which are almost never cored, especially if core data is available for nearby vertical wells. This mode is often called guided or directed classification (Saggaf and Nebrija, 2000).

6.2.1.2 Unsupervised Analysis

The objective of the unsupervised mode of analysis is to segregate the well into distinct facies classes based on their log behavior. This process emulates of what a petrophysicist would execute by performing a cautious examination of the log characteristics at various intervals in the well. This mode of analysis is implemented by a single-layer competitive neural network that takes the various well logs as an input and classifies each depth interval into its corresponding facies category. As it performs clustering, or quantization of the input space, this mode is also called a feature discovery or "let-the data-talk" scheme (Saggaf and Nebrija, 2000).

6.3.1.3 Semi supervised Analysis

Semi supervised analysis is a hybrid between the two modes mentioned above. Instead of using the core facies and logs of specific wells, regional log response averages for each facies (calculated or estimated qualitatively from experience may be used). Unsupervised analysis is run, and allows the resulting classes to automatically label with the facies names by comparing their class representatives with the regional averages (Saggaf and Nebrija, 2000). All modes of analysis can be applied to classify and identify not only depositional facies, but also lithologic facies. In fact, identification of lithologies is most often more facile, since the relation between lithology and log response is stronger.

The **Methodology adopted** in this research is **unsupervised analysis**. Log data of Meyal-01 is input in SMT kingdom 8.6 different cross plot is prepared and then compared with standard plots to identify the lithologies in well.

6.4 Use of Acoustic Logs

Acoustic velocity is primarily a function of the rock matrix and can be used to identify different lithologies and for stratigraphic correlations (Clavier et al., 1976). A variety of cross plot techniques, using acoustic measurements alone, or in combination with other porosity logs (neutron and density) have been devised to assist in lithologic identification (Bruke et al., 1969). Behavior of acoustic log and porosity log with respect to depth is shown in Figure 6.2. By comparing this response from the response of logs in Figure 6.1. This comparison shows that the Major lithology of reservoir zone is limestone.

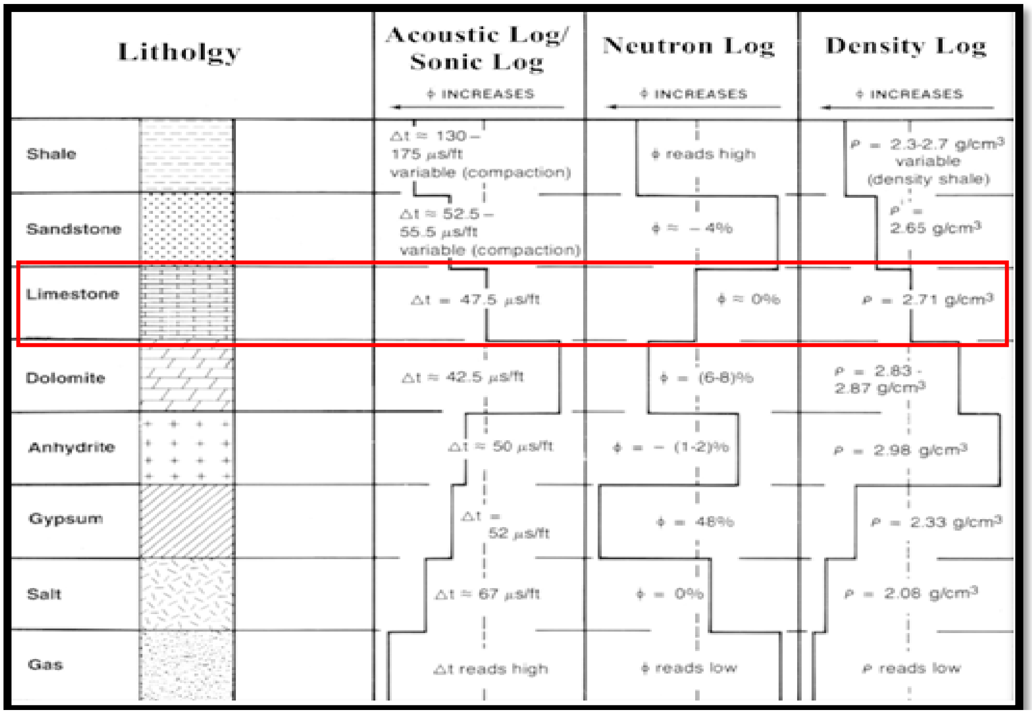

Figure 6.1 Generalized comparison of acoustic-, neutron-, and density-log responses in common reservoir lithologies (courtesy of Baker Atlas).

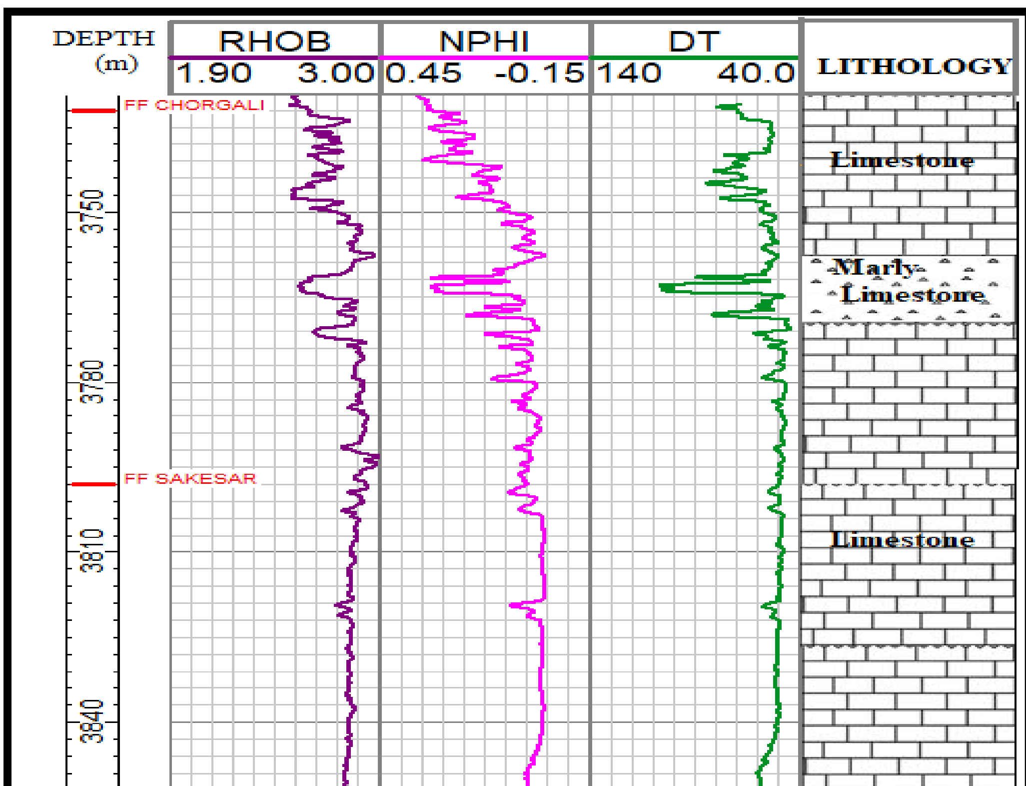

Figure 6.2 Density, Sonic and Neutron log response of well Meyal-01 shows 47µsec/ft sonic porosity, 0.04 Neutron Porosity and 2.7g/cubic cm density porosity, which yields Limestone as major lithology.

6.5 Facies Modeling of Meyal-01:

Facies analysis of Meyal-01 of reservoir zone has been done. Reservoir depth ranges from 3740-3810m. Different cross plots are obtained by assigning different log data to the axis(X, Y and Z).

6.5.1 Crossplot between Density log and Sonic log:

Crossplot, in the depth range of reservoir rocks, between sonic log and density log is prepared by using software, Figure 6.4. A standard crossplot between these two logs is shown in Figure 6.3 (www.welllog.com).

In the Figure 6.4 lime stone located in the range of axes marked with blue. By the comparison of prepared crossplot it is vivid that cluster of points lies in the same axes range which is marked in standard crossplot Figure 6.4. So the major lithology in the depth range of main reservoir is limestone.

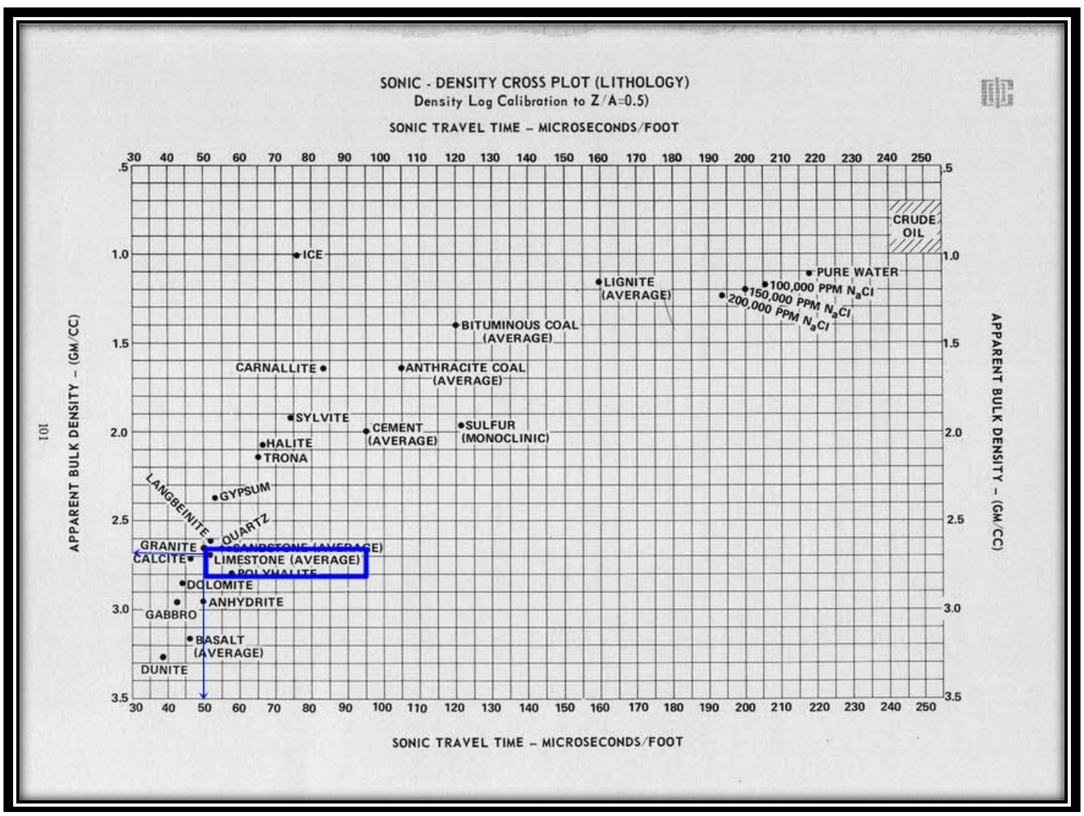

Figure 6.3 Standard crossplot between RHOB and DT(www.welllog.com)

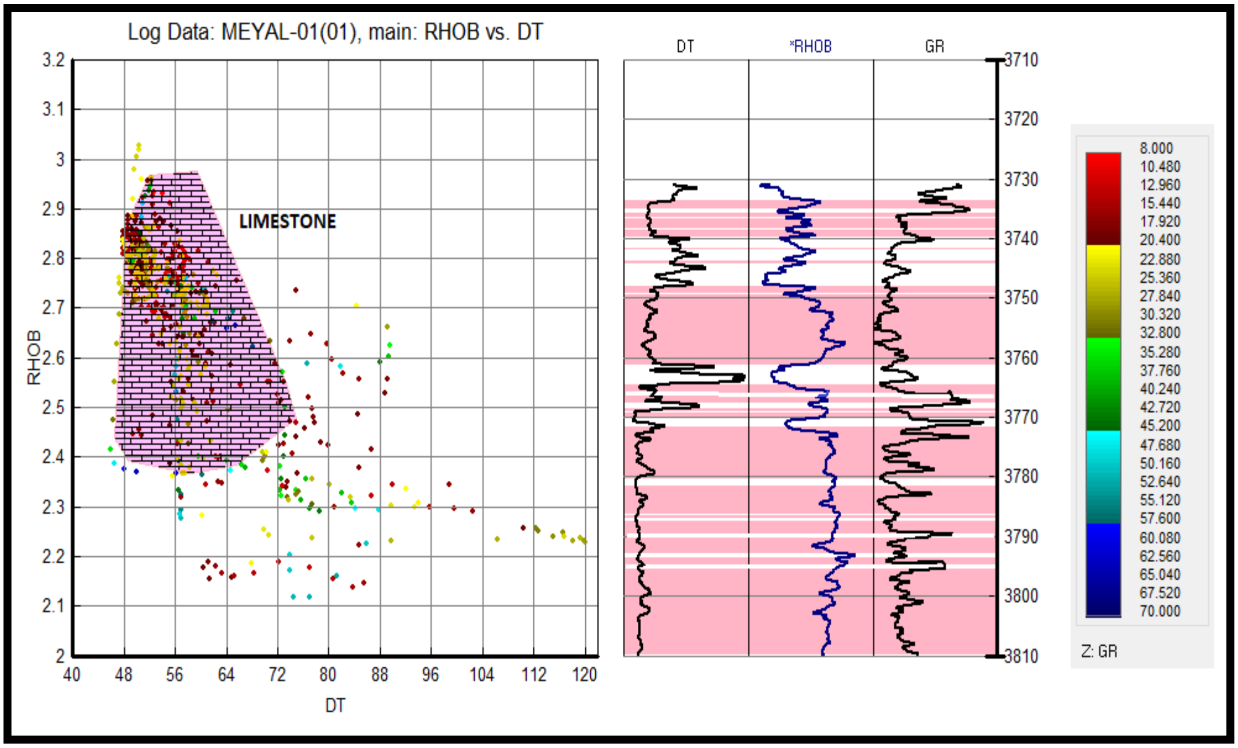

Figure 6.4 Crossplot between RHOB and DT.

6.5.2 Crossplot between Density log and Neutron log:

A standard crossplot between neutron log **(NPHI**) and density log **(RHOB)** is given in Figure 6.5 (www.wellog.com). Same crossplot is prepared with log data of Meyal-01, with Gamma ray log as reference log at z axis, Figure 6.6. The depth range selected for this crossplot is 3740-3810 meters because major reservoir rocks(Chorgali and Sakesser) lies between this depths.

By comparison of Figure 6.5 and 6.6 different polygons are drawn and labeled according to the standard crossplots. Cluster of dots is thick in the limestone polygon. So it is interpreted that the reservoir is mainly comprises of limestone.

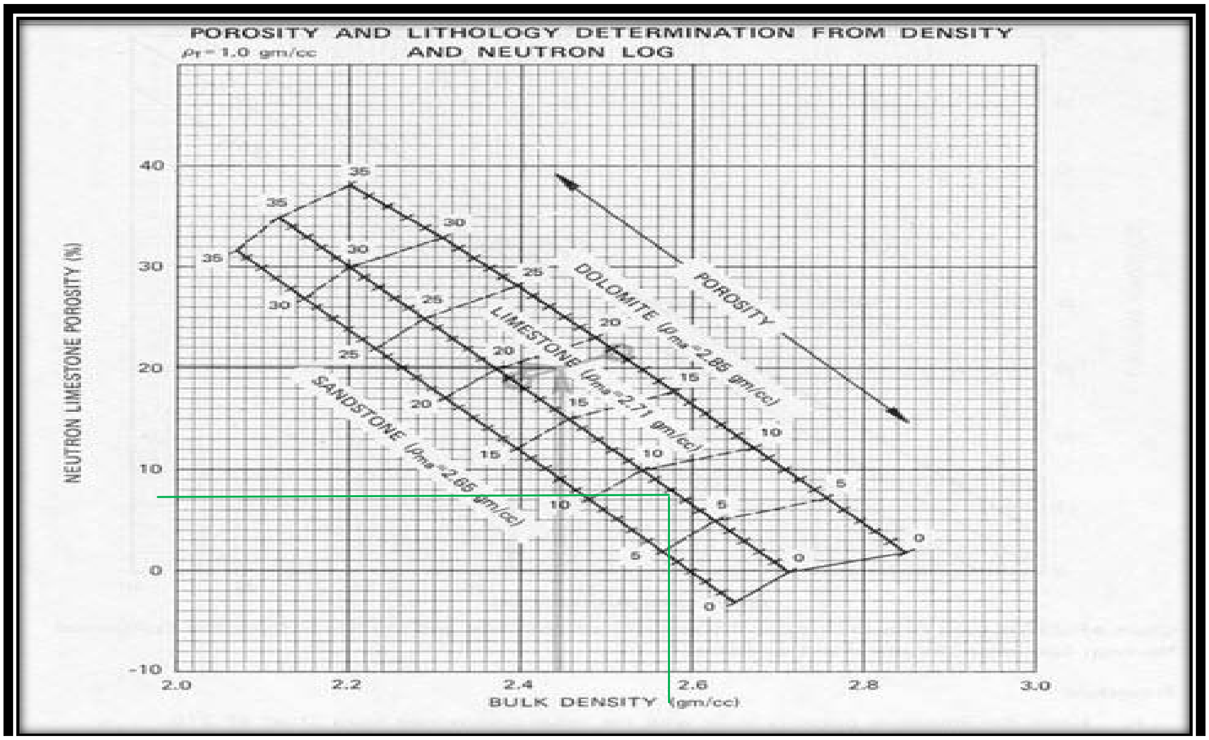

Figure 6.5 Standard crossplot between NPHI and RHOB (www welllog.com)

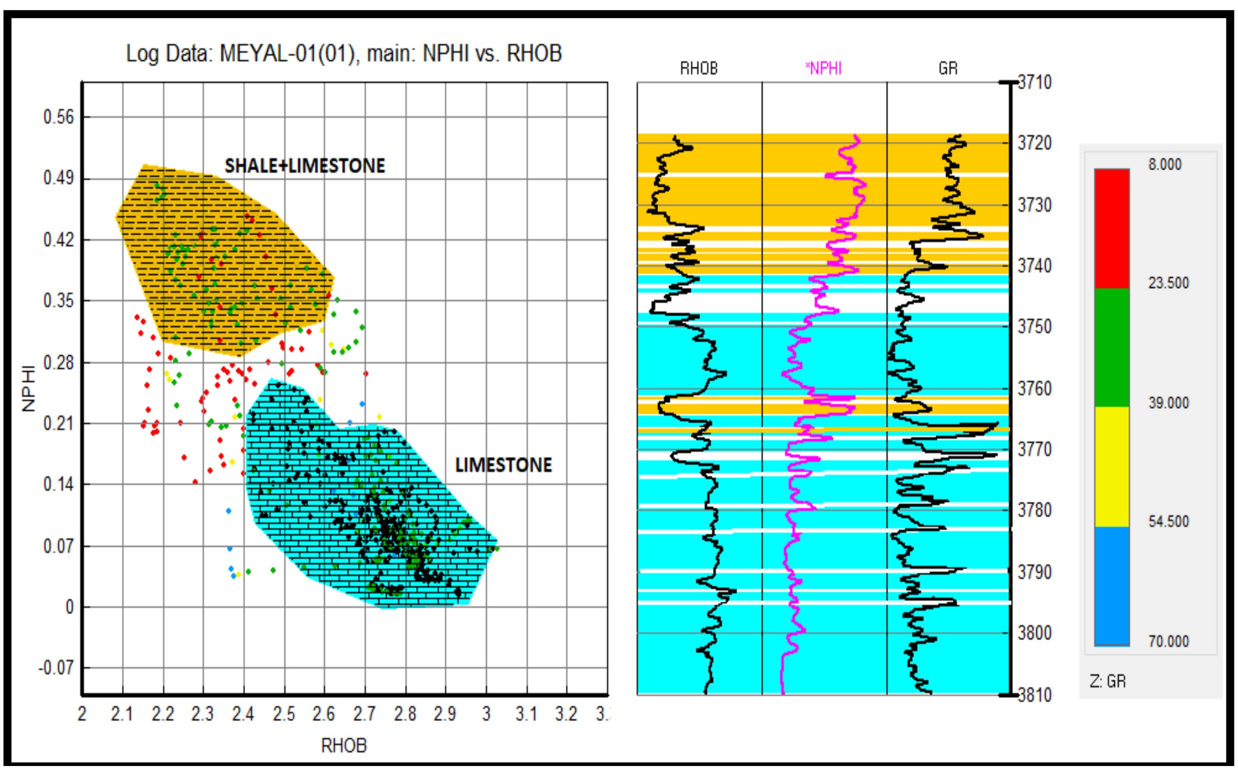

Figure 6.6 Crossplot between NPHI and RHOB.

6.6 Conclusion:

Unsupervised analysis has been approached to analyses the reservoir lithology. Acoustic log and porosity logs has been studied and different lithologies marked on the basis of some standard values. To confirm this different crossplots is prepared by the combination of acoustic and porosity logs. From these plots we get exactly the same results which confirms the interpretation that reservoir lithology is dominantly composed of limestone

CHAPTER 7
COLOURED INVERSION

7.1 Introduction:

Inversion transforms seismic reflection data into rock and fluid properties. The objective of seismic inversion is to convert reflectivity data (interface properties) to layer properties. To determine elastic parameters, the reflectivity from AVO effects must be inverted. The most basic inversion calculates acoustic impedance (density X velocity) of layers from which predictions about lithologyand porosity can be made. The more advanced inversion methods attempt to discriminate specifically between lithology, porosity, and fluid effects. Inversion is the “flip side” of forward modeling shown in Figure 7.1. Forward Modeling takes well logs, combines with wavelet to produce synthetic seismic trace while Inversion takes seismic trace, removes effects of estimated wavelet and creates acoustic impedance values.

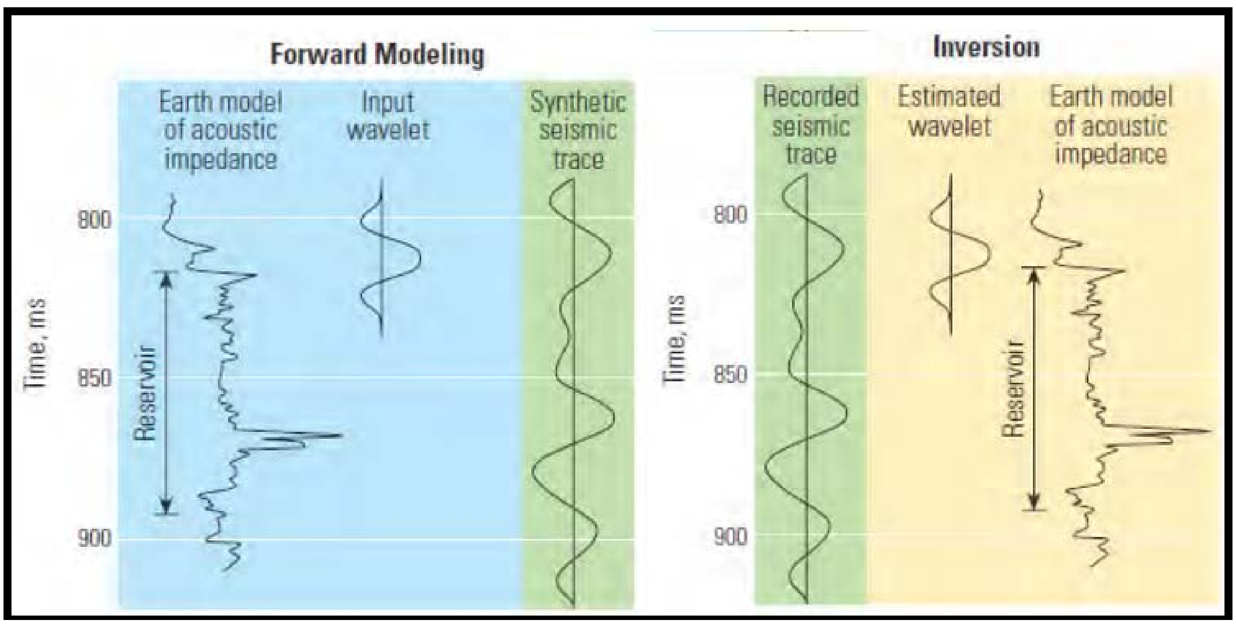

Figure 7.1 Steps involved in Seismic Inversion.

7.2 Data Considerations for Inversion:

- Pre-stack and/or post-stack time migrated seismic data.
- Well data
- Wavelet estimation–required for all modern inversion approaches
    - Deterministic
    - Statistical

- Low Frequency Trend –absolute acoustic impedance contains a low frequency trend that must be obtained usually from well control or stacking velocities.

7.3 Methods of Seismic Inversion:

Inversions can be grouped into categories:

- pre-stack vs. post-stack,
- deterministic vs. geostatistical,
- relative vs. absolute.

Figure 7.2 shows flowchart of seismic inversion methods.

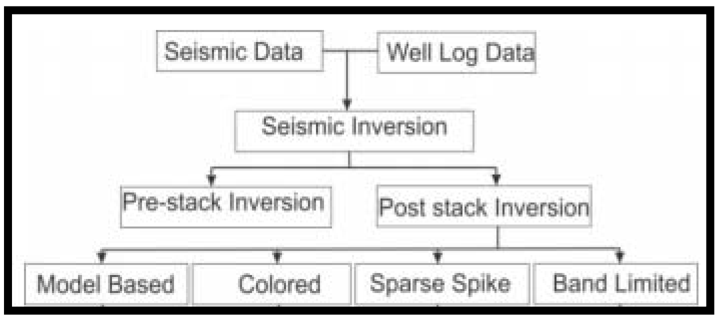

Figure 7.2 Flowchart of Seismic inversion methods.

This research based on coloured inversion using well Meyal-17 which lies on line 97-MYL-07.

7.4 Post Stack Inversion:

This is the most commonly used inversion where the effect of the wavelet is removed from the seismic data and a high-resolution image of the subsurface is produced. The post stack time-migrated data is input for the inversion algorithm. It is important to have clean seismic data as input and that proper data conditioning is done (Da Silva et al.,2004).

Post Stack Inversion includes:

- Model based
- Coloured Inversion
- Sparse Spike Inversion
- Band Limited Inversion

7.4.1 Coloured Inversion:

Coloured Inversion transforms migrated seismic data into a bandlimited acoustic impedance volume by shaping the mean seismic spectrum into the impedance log spectrum. This approach only gives a relative acoustic impedance which does not contain any low frequency components. This inversion method can make it simpler to interpret the variations in thickness related to various lithologic packages, properties of thin beds, and changes in acoustic impedance associated with fluid effects and rock property variations. The colored inversion technique is a process where the spectra of the acoustic impedance derived from log data are used to compute the spectrum of the operator (Berteussen, K et l., 1983). Coloured Inversion was first introduced by Lancaster and Whitcombe (2000) and involves deriving an operator that transforms the seismic amplitude spectrum to the acoustic impedance spectrum from well logs with a -90°phase change. Work flow for Coloured inversion is shown in Figure 7.3.

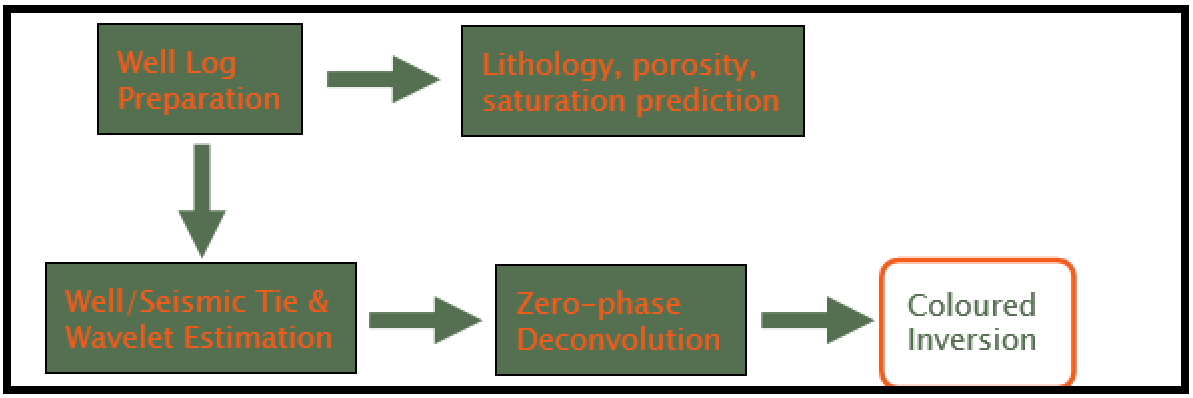

Figure 7.3 Workflow for Coloured Inversion.

7.4.1.1 Coloured Inversion of Well Meyal-17

Coloured Inversion is Post-stack Seismic Inversion and in this research Meyal-17 is used for the inversion. Meyal-17 lies on line 97-MYL-07. Seismic Inversion is still the best technique for reservoir characterization. Coloured Inversion performs significantly better than traditional fast-track routes such as recursive inversion, and benchmarks well against unconstrained sparse-spike inversion. It is applied on 2D seismic data and results of Coloured Inversion is shown in Figure 7.4.

Variation of Sonic velocity with depth is also shown in Figure 7.5 it is integrated with Drift curve.

A crossplot between amplitude and frequency is made and the logarithm of the frequency to compute the operator. Figure 7.6 shows the variation of amplitude versus frequency and the difference between desired spectrum and seismic mean spectrum. By changing the low frequency unit from 8 to 14 Hz the following results are obtained. Wavelet is also extracted from the seismic data and in Figure 7.7 line 97-MYL-07 with amplitude colored inversion is shown.

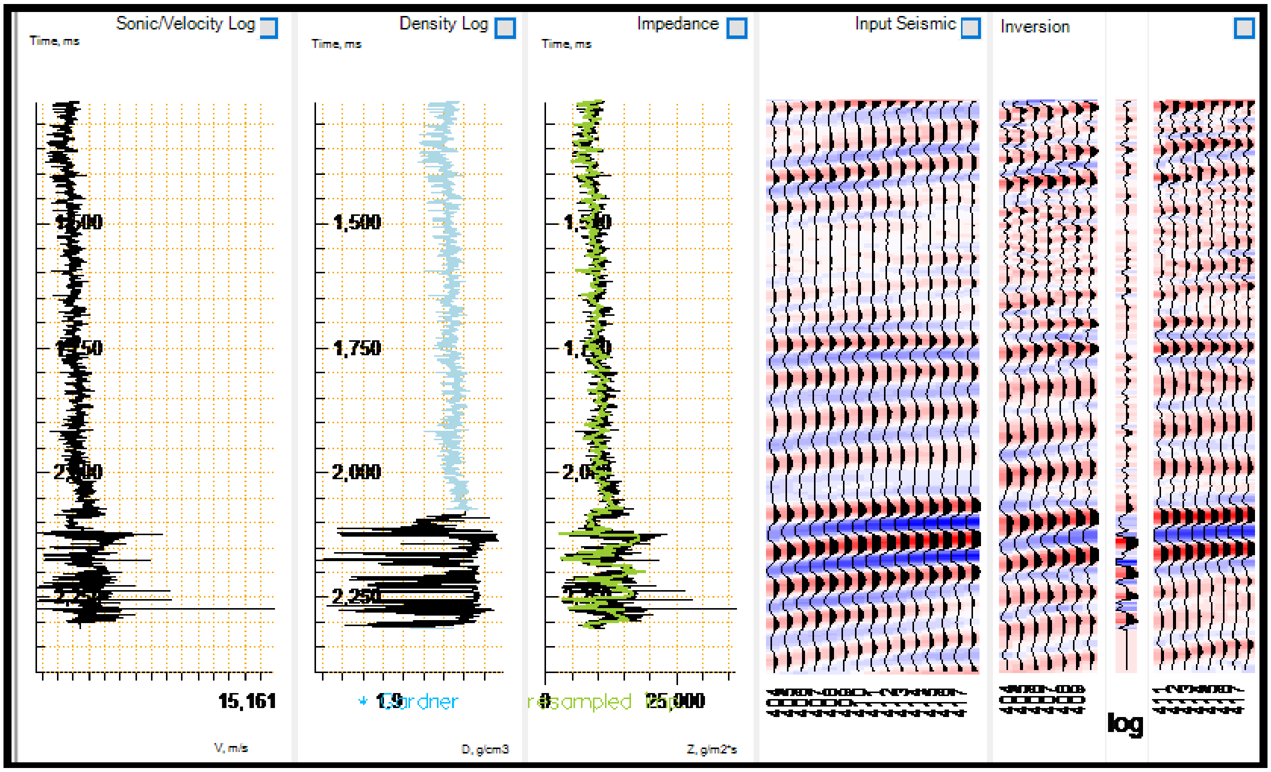

Figure 7.4 Coloured Inversion using Meyal-17 and 97-MYL-07

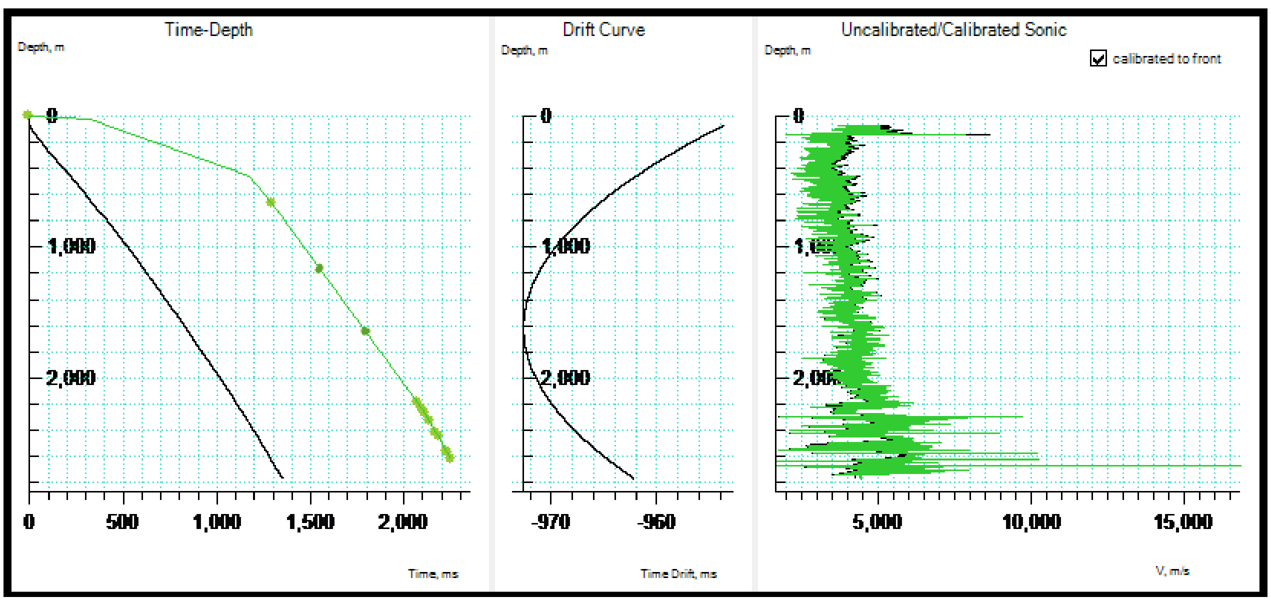

Figure 7.5 Variation of sonic with depth is shown.

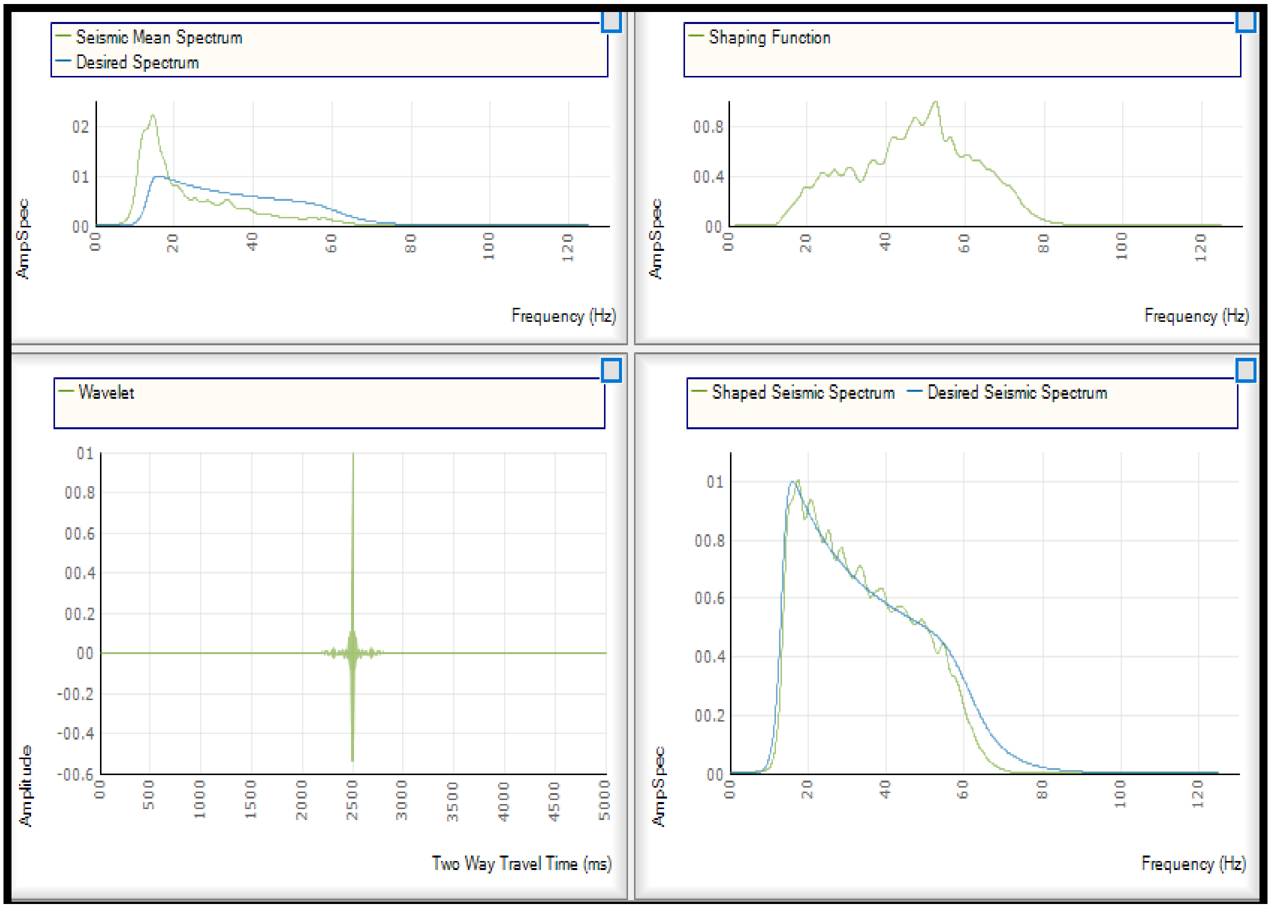

Figure 7.6 Shows spectral Shaping of Seismic data.

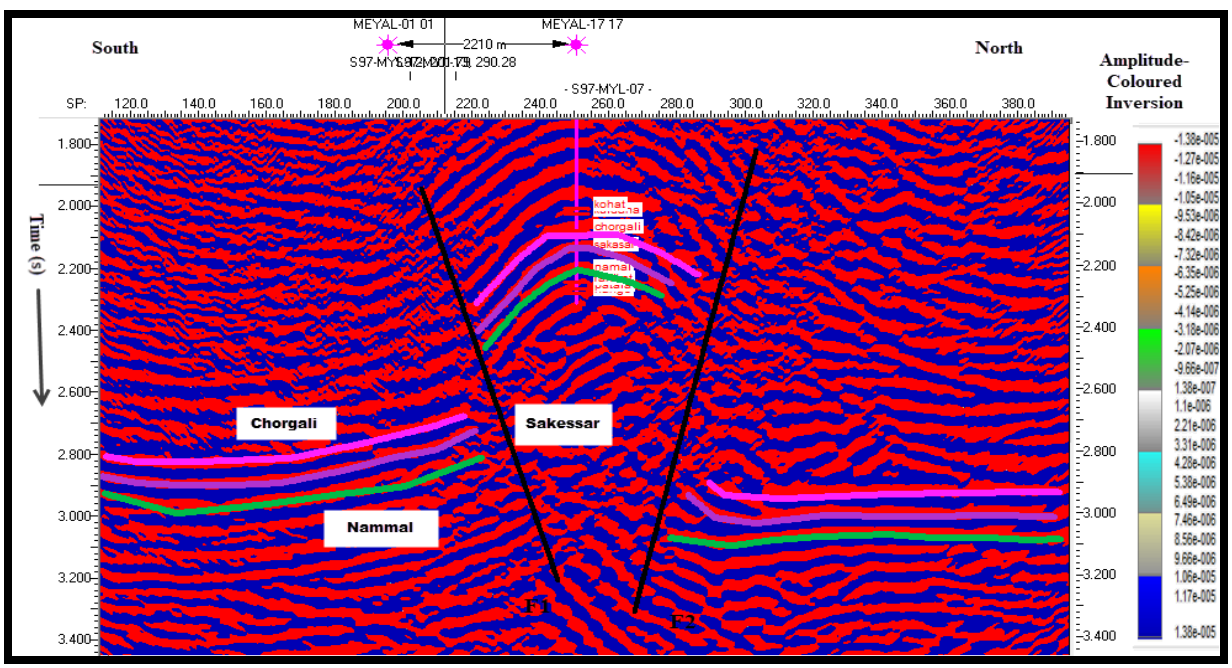

Figure 7.7 Amplitude coloured Inversion on line 97-MYL-07.

Discussions and Conclusions

Basically major sections of this research work are: Structure interpretation of seismic data, seismic attribute analysis, Petrophysical analysis, facies analysis and Coloured Inversion using Meyal-17 which lies on line 97-MYL-07. From seismic data and well log data on the basis of general stratigraphic column present in the area three reflectors were marked which are shown in Figures 3.2, 3.3, 3.4 and 3.5 respectively. The marked horizons were named as Chorgali, Sakessar and Nammal formation. Horizons were being confirmed afterward by synthetic seismogram of Well Meyal-17 see Figure 3.6 and 3.7 respectively. Five normal faults were also marked on seismic sections; see Figure 3.2, 3.3, 3.4 and 3.5 respectively. Pop-up structures are found in Meyal region and it confirmed the compressional regime in the study area. Faults polygon of Chorgali and Sakessar are constructed to show the extension of the faults. Time and depth contour maps of chorgali and Sakessar formations are formed which confirms that all wells lies in pop-up structure which is favourable zone for hydrocarbon accumulation. After the structural interpretation of the seismic data seismic attribute were calculated for the confirmation of the structural interpretation. Four seismic attribute were calculated from the seismic data by using kingdom software on North-south oriented dip line 97-MYL-01 which are trace envelop, instantaneous phase, instantaneous frequency and energy attribute shown in figure 4.2, 4.3, 4.4 and Figure 4.4 respectively.

In petrophysical analysis the volume of shale, porosity, water saturation and hydrocarbon saturation of well Meyal-01 are calculated in reservoir zone (Chorgali and Skaessar) to identify the zone of accumulation of hydrocarbons within the reservoir zone are shown in Figure 5.4 and 5.5. Quantitative results shows the 5-10% porosity which is fair for the reservoir rock, 20-25% volume of shale, 30-35% water saturation and 65-70% hydrocarbons saturation. These results show that the reservoir zone would be effective for the accumulation of the hydrocarbons.

Facies analysis is also performed by using well log data of meyal-01 well within the reservoir zone, which shows the reservoir zone is mainly comprises of Limestone and shaly Limestone.

Seismic Inversion of well Meyal-17 is done. This approach only gives a relative acoustic impedance which does not contain any low frequency components.

REFRENCES

-
- Sercombe, W.J, D.A. Pivnik, W.P. Wilson, M.L. Albertin, R.A. Beck, and M.A. Stratton, 1998, Wrench faulting in the northern Pakistan foreland: AAPG Bulletin, v. 82/11, p. 2003-2030.
- Amigun, J.O., & Odole, O. A. (2013). Petrophysical Properties Evaluation for Reservoir Characterisation of SEYI Oil Field (Niger-Delta).International Journal of Innovation and Applied Studies, 3(3), 765-773.
- Asquith, G. B., Krygowski, D., and Gibson, C. R. (2004). Basic well log analysis (p. 39). American Association of Petroleum Geologists.
- Badley, M. E. (1985). Practical seismic interpretation.
- Bender. (1995). Geology of Pakistan. Berlin: Gerbruder Borntraeger.
- Chopra, Satinder, and Kurt J.Marfurt. "Seismic attributes, A historical perspective." Geophysics 70.5 (2005): 3SO-28SO.
- Coffeen, J.A., 1986, Seismic Exploration Fundamentals, PennWell Publishing Co.408.
- Djebbar, T. I. A. B., & Donaldson, E. C. (2004). Petrophysics.
- Dobrin, M. B., & Savit, C. H. (1988). Introduction to geophysical prospecting.
- Esentials of Geology, 3rd Edition, Stephen Marshak.
- Eskola, Pentti Eelis, 1920: "The mineral facies of rocks".
- Hasany, S.T., and Saleem, U., (2001), An Integrated Subsurface, Geological and Engineering Study of Meyal Field, Potwar Plateau, Pakistan.
- Hynes, N.J. 1991. Dictionary of Petroleum Exploration, Drilling, and Production. Tulsa, Oklahoma: PennWell.
-
-
- Amir, M., and Siddiqui, M.M., 2006 Interpretation and visualization of thrust sheets in triangular zone in eastern Potwar, OGDCL, Islamabad, Pakistan.
- Riva, J.P, 1983. World Petroleum resources and reserves, Colorado: Boulder.
- Moghal, M. A., Saqi, M. I., Hameed, A., & Bugti, M. N. (2003). Subsurface Geometry of Potwar Sub-Basin in Relation to Structuration and Entrapment.,in SPE-Annual Technical Conference and Oil show 2003-Islamabad, Pakistan.

- Kearey, P & Brooks M.1984, an Introduction to Geophysical Exploration", Blackwell Scientific Publications, Oxford, 1-98p.
- McQuillin, R., Bacon, M., and Barcaly, W., 1984 An introduction to seismic interpretation, Graham & Trotman Limited Sterling House, 66 Wilton Road London SW1V 1DE.
- Schlumberger. (1974). Log Interpretation Volume I Principles. Schlumberger, New York London. p. 113.
- Clavier, C. and Rust, D.H. 1976. MID Plot: A New Lithology Technique. The Log Analyst **17** (6): 16–24.
- Burke, J.A., Campbell Jr., R.L., and Schmidt, A.W. 1969. The Litho-Porosity Cross Plot a Method of Determining Rock Characteristics for Computation of Log Data. Presented at the SPE Illinois Basin Regional Meeting, Evansville, India, 30-31 October. SPE-2771-MS