# 2D SEISMIC INTERPRETATION ALONG WITH PETRO-PHYSICAL ANALYSIS,FACIES ANALYSIS AND SEISMIC ATTRIBUTES OF JOYA MAIR,UPPER INDUS BASIN(PAKISTAN)

QUAID-I-AZAM UNIVERSITY

ISLAMABAD

SUBMITTED BY:

**Asif Ullah**

SUPERVISED BY:

**DR.ABBAS ALI NASEEM**

**SESSION (2016-2018)**

**DEPARTMENT OF EARTH SCIENCE QAU ISLAMABAD**

**TABLE OF CONTENT**

**ACKNOWLEDGE**

Foremost, I would like to express my sincere gratitude to my Supervisor **Dr. Abbas Ali Naseem** for the continuous support of my Master Thesis and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better Supervisor and mentor for my Master Thesis.

I whole heartedly thank to department of Earth Science QAU Islamabad and especially to **Prof. Dr. Mona Lisa** (Chairperson).

I am grateful to **Scholar Mr. Mati Ullah,** for his constant hard work to complete my this research.

I am thankful to my **Almighty Allah** for blessing me much more than I deserve. I am highly indebted to my **family** and **friends Babar Ali, Ahmad Saeed, Natasha naem and M. Luqman** for their motivation, guidance and prayer that enabled me to undertake my Master thesis degree.

**Mr. Asif Ullah**

## *ABSTRACT*

The Joya Mair oil field lies in the south-southeast of the Salt Range-Potwar Foreland Basin (SRPFB). It is the result of Tertiary Himalayan collision between the Indian and Eurasian Plates. The SRPFB represents the Precambrian to Recent rocks of the Indian Plate which covers an area of about 2250 Km2. The Himalayan thrusting and folding formed the structural traps in SRPFB. Seismic interpretation has resulted in time and depth contour map, which helps to understand the subsurface structural geometry. Seismic interpretation of the 2D data reveals that the study area has undergone severe deformation illustrated by the development of thrusts and backthrusts which results in the formation of triangle zone in the subsurface. The general trend of these structures is northeast-southwest which is indicative of the fact that the area was subject to southeast northwest compressive stress. The decollement surface is provided by the Salt Range Formation. The reservoir rocks are of Eocene age that occurs at a depth of 2060 m as interpreted from seismic data. The petrophysical analysis of Minwal X-01 well is done on the basis of well logs which gives approximately Vsh 33.3%,PHIA 29%.,PHIE 13%,Sw 40% ,Hs 60% in the reservoirrocks.

# CHAPTER 01

# INTRODUCTION

## 1.1:Introduction to Hydrocarbon Exploration

Global hydrocarbon industry play a vital and irreplaceable role in development and economic of a country especially developing countries like ours ,and act as a major pillar in the future economic and strategic position of the country.As the energy demand increases exploration industry determine to discover and develop new hydrocarbon reserves and enhance production from existing reserves through the application of the best available technologies and expertise.The energy used usually comes from three major sources of hydrocarbons: Coal,Oil and gas.

The hunt for exploration of hydrocarbon in Pakistan initiated in 1868 when the first spud was made at Kundal near Mianwalli, that continue till present day. Most of the Rocks in Pakistan are sedimentary and quite rich in petroliferous material. The exploration companies search for structural and stratigraphic traps where most of the hydrocarbons accumulate. Most of such structures are present in areas where there is intense folding and faulting i-e Potwar area. The possibility of major discoveries, either in on-shore or off-shore areas, is considered quite bright(Sroor, 2010).

Geophysicists have been trying for hydrocarbon exploration since a long time ago and developed many techniques in this regard. Seismic reflection method is used for deep hydrocarbon exploration in petroleum geology.Petroleum geology refers to the specific set of geological disciplines that are used for hydrocarbons exploration. Investigation of the earth's interior using geophysical methods, involves taking measurements at or near the surface of the earth for analysis that can expose both vertical and lateral variations of the physical properties of the earth's subsurface, logs ranging from electrical, nuclear and acoustic have been in use for deriving these parameters (Bust et al., 2013).

## 1.2: Aims and Objectives of Dissertation

The main objectives of this dissertation are lined up as follows:

- Interpretation of the structures present in the study area with the help of satellite images, geology and historical work done in the area.
- Horizon picking at different levels on the seismic sections, marking faults.
- Generating the depth and time contour maps for different formations encountered in the section, also generating 3D models to know the zones of low and high acoustic impedence and pressure.
- Identification of reservoir rock in area by well log data.
- Petrophysical analysis is carried out to characterise the various physical properties of the reservoir .
- Facies analysis is carried out to confirm the dominant lithology of the area acting as reservoir.
- Confirmation of depth section by correlation with Synthetic seismogram & formation tops.
- Applying various attributes to confirm our interpretation.
- Rock physics study to know the behavior of various physical properties at the level of reservoir formation.
- Reserves of reservoir formation are calculated by volumetric analysis to know the economic condition of the well.

## 1.3: Prospectively Zonation of Pakistan

The country has been divided into zones based on their relative prospectivity and geological risk. Onshore areas are sub-divided in three zones;

- **ZONE-I:** high risk - high cost areas
- **ZONE-II:** medium risk - high to medium cost areas
- **ZONE-III:** low risk-low cost areas.

Offshore areas are also sub-divided in three zones; Shallow, Deep and Ultra Deep. Separate incentives have now been provided for the onshore and offshore areas of the country.Joya Mair area lies in zone-II which is medium risk - high to medium cost areas.

### 1.4: Introduction to the Study Area

Joya Mair is an important hydrocarbon production area of the Potwar plateau on the southern flank of Soan syncline in the Himalayan collision regime and part of the upper Indus basin Pakistan. The Kohat-Potwar region, located in the sub-Himalayas, contains a significant amount of hydrocarbons trapped in compresional / transpressional subterranean structures related to the post-Himalayan orogeny (Jaume and Lillie, 1988, Raza et al., 1989, Kadri, 1995, Khawaja and MonaLisa, 2005, Moghal et al., 2007).

#### 1.4.1: Geographical Boundaries

Geographically JoyaMair shares borders with KalarKahar to the south and east with the town of Chakwal and to the west lies the town of Talagang. The area is now easily accessible due to the construction of Lahore Islamabad Highway (M-2). The Kohat-Potwar (study area) belongs to the category of extracontinental watersheds, which account for 48% of the world's known oil resources (Hasany&Saleem, 2001).The area lies in UTM (Universal Transverse Mercator) zone42N in the world GeodeticSystem . Latitude and longitude of the area in decimal degrees: 32.933333-72.65 whereas latitude and longitude in degrees, minutes and seconds: 32º 59′52″N to 72º 82’ 31” "E.

#### 1.4.2: Geological Boundaries of Potwar Basins

The left lateral fault of Jhelum (submitted by Mukherjee) marks the eastern boundary of the plateau; The western margins are delimited by the Kalabagh fault (Gee, 1989). In the south, the plateau is delimited by the thrust of the salt range, while the northern boundary is marked by the main boundary thrust (Rana and Asrarullah, 1982, Jaswal et al., 1997, Kazmi and January 1997).

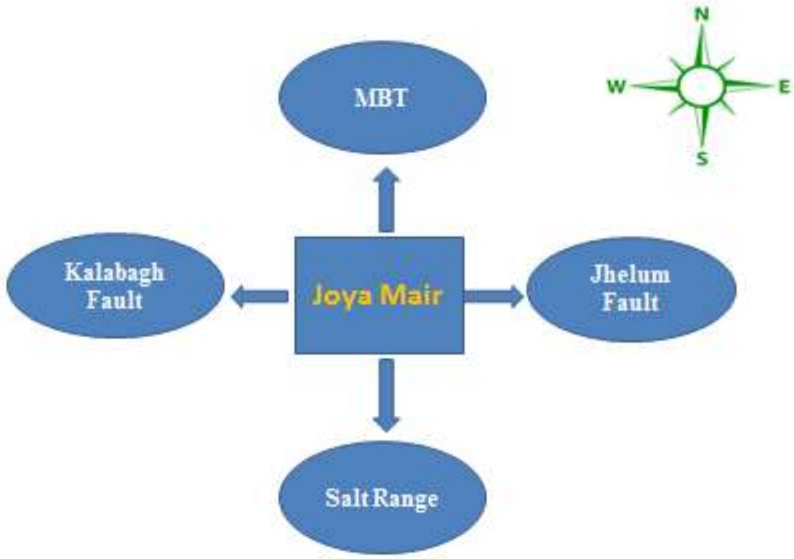



Figure 1.2: Geological Boundaries of Joya Mair Area

Following is the satellite and Google Earth image of JoyaMair given in Figure (1.3) .


Figure 1.3: Location of Balkassar in Satellite image of Pakistan (Khan et al, 2008)

### 1.5: Production History of Potwar Area

The first commercial oil discovery took place in 1914 when Attock Oil Company (AOC) completed a 214-foot well on a thrust faulted anticline near the town of Khaur (Khan et al., 1986). Since the discovery, there have been more than 340 wells drilled in the field. Khaur's production comes from the Sakesar and Chorgalli reservoirs. Drilling from 1920 to 1935 resulted in Dhulian, a structural dome located 17 km southeast of Khaur. Other discoveries followed with JoyaMair in 1944, Balkassar in 1946, Karsal in 1956 and Tut in 1967.

The first commercial gas field Adhi was found in 1979. The Adhi gas field produced from rocks ranging from Cambrian to Eocene. Eighteen oil fields and three gas fields were discovered in the geological province of Kohat-Potwar between 1915 and 1996, and several prospects that were unsuccessfully tested in the 1950s and 1960s are now being re-examined with good results .Production in the geological province of Kohat-Potwar comes mainly from defective anticline traps in Cambrian-Miocene rocks.

The largest oil and gas field to date is the Dhurnal field with an aerial closure of 13.5 $km^2$ and a vertical closure of 500 m. The initial in-place oil estimate for Dhurnal was 102 MMBO (million barrels of oil) (Jaswal and others, 1997).

At the time of independence (1947), Pakistan inherited four productive fields, Khaur, Dhullian, JoyaMair and Balkassar. Since then, four other fields have been discovered: Karsal, Tut, Sarang and Mayal. All this is in the Plateau Potwar. Traces of hydrocarbons occur in several other localities, and exploration continues in Punjab, Sind and Baluchistan by arrangement between various foreign companies and the Oil and Gas Development Corporation (OGDC).

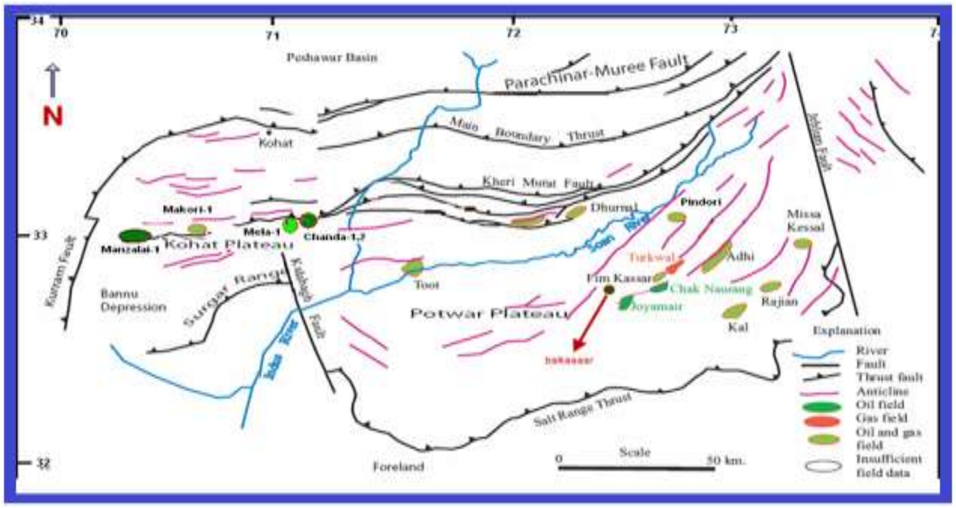



Figure 1.4: Generalizes structure map of Potwar Plateau (Kemal, 1992)

### 1.6: Exploration Historyof the Joya Mair Oil Field

Joya Mair is located about 105 km south-west of Islamabad in the Chakwal district. Field was discovered in 1946 by Attock Oil Company, establishing the potential of fractured Eocene limestone. The Chorgali (Bhadrar) and Sakesar formations are the main reservoirs of oil production in the field.

In total, 15 wells were drilled in the D & P Lease Joya Mair, one of which was off-structure, two wells could not reach T.D and 12 wells cut the tank. Some wells were abandoned prematurely and some were plugged due to mechanical problems after a small production, whereas only six wells (A-3, A-5, A-7, P-2, POL-1, A-6 And MinwalX-01) currently produce. Wells A-3, A-5, A-7 and B-2 (P-2) are in regular production while A-6, POL-1 and Minwal X-1 are intermittent producers. All regular producers and A-6 are located in the northwestern compartment of the field, while POL-1 is located in the southeast compartment.

The maximum output was about 3700 BOPD in 1965 which has since dropped to about 420 BOPD and 0.05 MMSCFD of gas. The field produced on natural reservoir pressures until 1961, and then it was converted to the gas lift and produced until 1974. The average depth of the wells targeting the Eocene reservoir is about 9000 ft. Most wells are drilled in the western compartment which is structurally lower than east. While three wells are in the eastern compartments that are all non-producing, only POL-1 contributes with minor rates.

The fractured carbonates of the Sakesar and Chorgali formations of the Eocene age are the main producing reservoirs of Joya Mair. Minor oil production comes from Paleocene Lockhart Formation. The OIIP calculated internally is estimated at 174 MMSTB. The recoverable oil reserves are estimated at 38.37 MMstb and the gas at 234.86 MMscfd. Cumulative oil productions at 31 March 2015 is approximately 35.56 MMstb

**Exploration and production Information:**

Following is the production and exploration information of Joya Mair oilfiels.

Table 1.1: Production information of Joya Mair oilfield

| Recoverable Reserves | Oil=38.37 MMstb , gas =234.86 MMscfd |
|---|---|
| PPL Working Interest | 100 percent |
| Operator | POL |
| peak production | 3700 BOPD in 1965 |
| OIIP | 174 MMSTB |
| License Area | 149.13 Sq Km |
| Average depth of wells | 9000 ft |

## 1.7: Data formats

Data for dessertation consist of :

- SEG-Y (Seismic)
- LAS (Well data)
- Navigation

That was provided by Directorate General Petroleum concession (DGPC),Government of pakistan upon the request of Chairperson of Earth sceinces,Quaid-e-Azam Universty Islamabad.

### 1.8: Data description

To carry out this dissertation, seismic reflection data, which consists of ten 2D seismic reflection lines, was provided by the permission of Directorate General of Petroleum Concessions Government of Pakistan (DGPC).

The seismic reflection data was acquired and processed by OGDCL.

The Data for subsurface interpretation of the study area is obtained from LMKR Company.

The data includes: The seismic lines (PBJ - 01 to PBJ – 11 except PJB- 07).

#### 1.8.1: Seismic Reflection Data

The seismic reflection data of the study area was obtained from theDirectorate General of Petroleum Concession (DGPC) Pakistan in digital format .This data was acquired and processed by OGDCL.

The trend of the seismic dip and strike lines in SE-NW and SW-NE respectively.

Table 1.2: Seismic lines along with their orientations.

| Line Name | Nature And Orientation | Well Location |
|---|---|---|
| POL-MN-93-05 | Dip Line, NE-SW | |
| POL-MN-93-06 | Dip Line, NE-SW | |
| POL-MN-93-08 | Dip Line, NE-SW | MINWAL-X-01 |
| POL-MN-93-09 | Dip Line, NE-SW | |
| POL-MN-93-10 | Strike Line, NW-SE | |
| POL-MN-93-11 | Strike Line,NW-SE | |

### 1.8.2: Well Data

The well data includes the following files:

LAS files

Navigation files

These files store all the information about the logs run in the well and well tops. Following is brief details of Well Joya Mair Minwal X-01.

## 1.9: SeismicAcquisition and Processing Parameters

Following are the seismic acquisition and processing parameters of LineLine POL-MN-93-08,POL-MN-93-05andPOL-MN-93-11.

### 1.9.1: Geophone Spread

Table 1.3: Geophone spread of the area

| **Geophone Spread** | |
|---|---|
| Spread geometry | |
| No of Geophones | 48 |
| Group interval | 100 m |
| Group length | 159 m |

### 1.9.2: Pre-Processing Parameters

Table 1.4: InstrumentUsed In Aquisition

| **Pre-Processing Parameters** |
|---|

| | |
|---|---|
| Sampling interval | 4 MS |
| Record length | 25000ms |
| Pre Amplifier Gain | 2 |
| Main Amplifier Gain | I.F.P |
| Summing | Diversity Average |
| Format | SEG-C |
| Density Notch filter | 1600 BPI |
| No. of channels | 62 |

### 1.9.3: Source Information

Table 1.5: Source Information Of The Data

| SOURCE INFORMATION | |
|---|---|
| Energy source | Vibroseis |
| Number of Vibrators | 2 to 3 |
| Number of Sweeps per $V_P$ | 42 |
| Source Pattern | Inline |
| Type of Vibrator | Mertz Model SHV-100 |
| Vibration length | 100m |
| Sweep frequency | 7-42Hz |
| Sweep Duration | 20000ms |

### 1.9.4: Processing Parameters

Table 1.6: Processing Parameters Of the Seismic Data

| PROCESSING PARAMETERS | |
|---|---|
| Processing Sample rate | 4ms |
| Edit- demuxed | WGC code-4 format |
| Preprocessor | CDP sorted |
| Replacement velocity | 2500m/s |
| Datum plane elevation | 350m |
| Type | Early mute |
| Mute velocity | 2200m/s |
| Constant start time | 350ms |
| Min Distance for start time | 550m |
| Deconvoulution | |
| Type | Predictive D-Convolution |
| No of windows | One |
| Auto correlation stop time | 3500ms |
| Auto correlation delay | 200ms |
| Minimum prediction distance | Time of 2nd zero crossing |
| Operator length | 140ms |
| Pre filter | 10-40 Hz |

| | |
|---|---|
| Vel analysis | On gather of 3 cdps |
| Finite diff migration filter | 10-40 Hz |
| Horizontal scale | 8 Traces/inch |
| Vertical Scale | 5Inchs/sec |
| Gain | 15 DB |
| Processed in | Jul-81 |

### 1.10: Base map

The base map is an important component of interpretation. For a geophysicist a basemap is the one that shows the orientations of the seismic lines and specifies the points where the seismic data were acquired or simply a map that consists of number of dip and strike lines on which seismic prospecting is carried out.

A base map generally includes the location of concession and concession boundaries, wells, seismic survey points, and other cultural data such as buildings and roads with geological reference such as latitude and longitude.

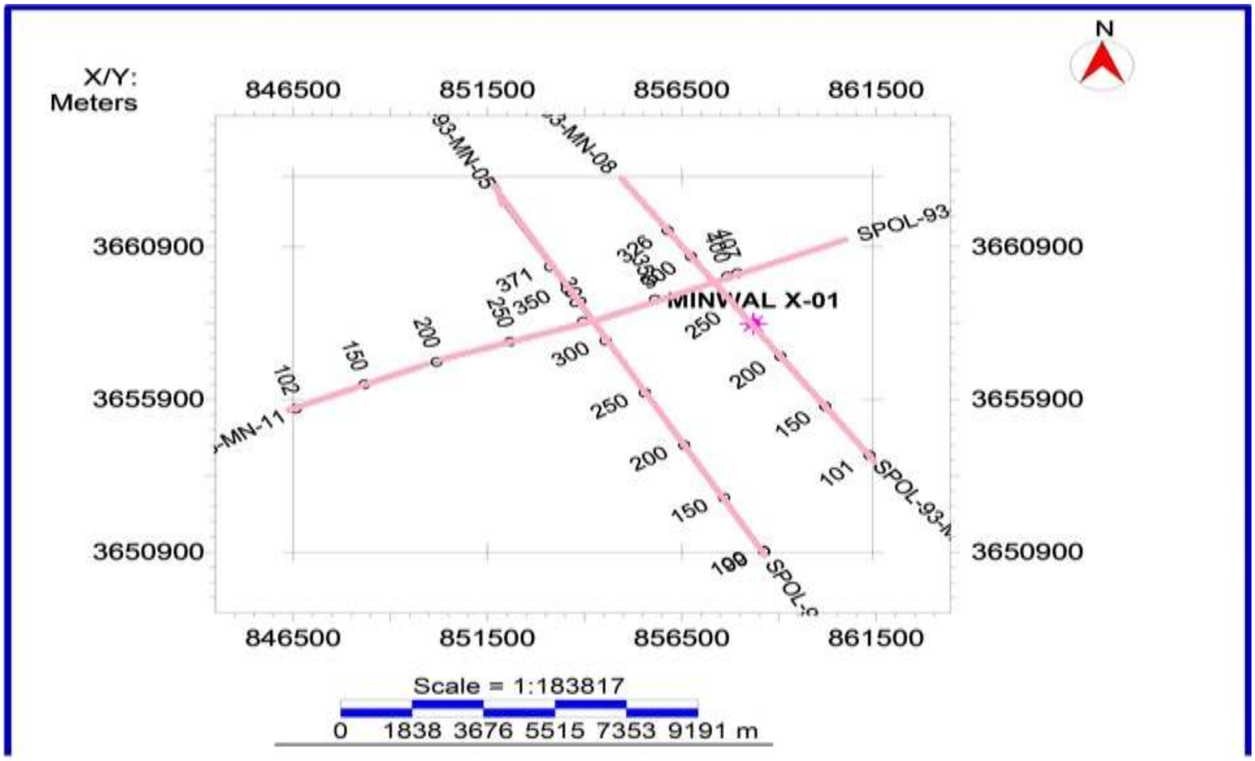



Figure 1.5: Base map of the Joya Mair Area comprising of my lines

## 1.11: Synthetic Seismogram

Synthetic seismograms are artificial seismic traces used to establish correlations between local stratigraphy and seismic reflections. To produce a synthetic seismogram, a sonic log is required. Ideally, a density log should also be used, but these are not always available, so we can also use constant density for this area.

A narrower definition used by seismic interpreters is that a synthetic seismogram is a direct one-dimensional model of acoustic energy traveling through the Earth's layers. The synthetic seismogram is generated by convolution of the reflectivity derived from the acoustic and density records digitized with the wavelet derived from seismic data. By comparing marker beds or other correlated points collected on well logs with major reflections on the seismic section, interpretations of the data can be improved. The quality of the correspondence between a synthetic seismogram depends on the quality of the well log, the quality of seismic data processing and the ability to extract a representative wavelet from seismic data among other factors.

The following steps are adopted when generating the synthetic seismogram in the Kingdom software.

• Load the file Las from the well into the software.

• Open the 1D modeling project and select the well logs.

• Integrate the sonic log to a new scale from depth in meters to bi-directional travel in seconds.

• Calculate the speed from the sonic log for P and S waves.

• Create a TD diagram for the well from the sonic log.

• Calculate the acoustic impedance log using velocity and density log.

• Calculate the reflection coefficients from the time scale velocity log.

• Calculate a first order Ricker wavelet extracted from the seismic.

• Convolution of the reflection coefficient with the Ricker wavelet to generate the amplitudes of the synthetic seismogram.

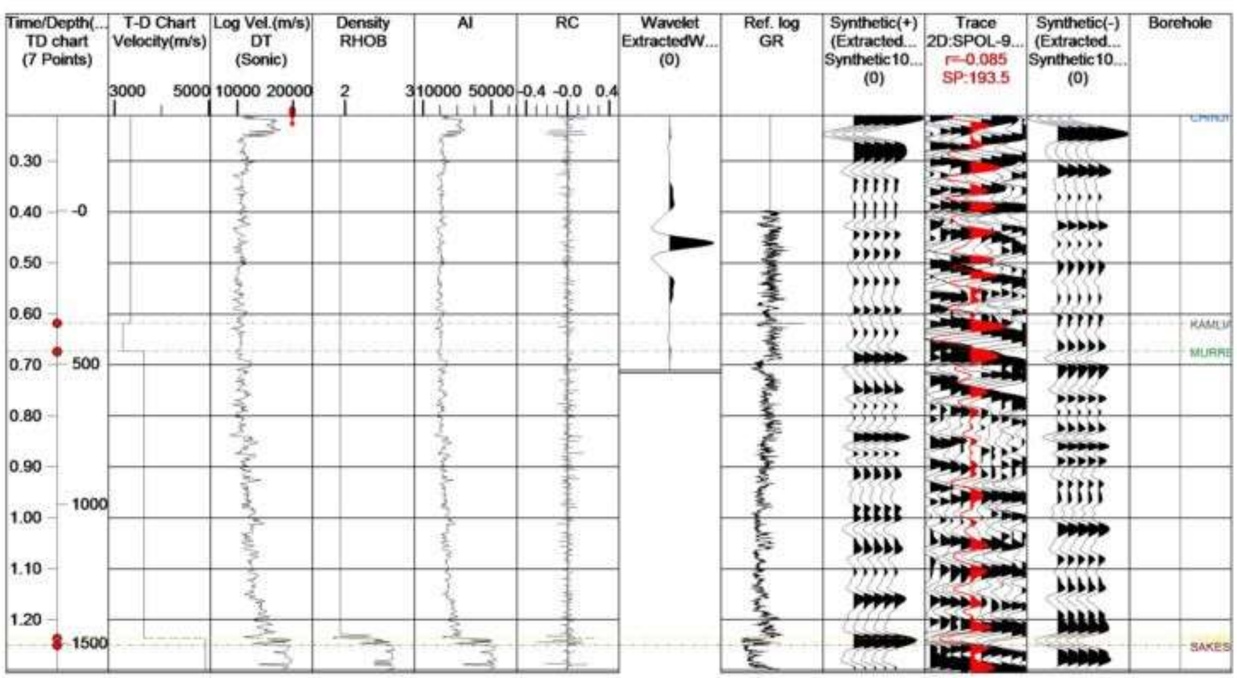


Figure 1.6: Synthetic Seismogram of the well

## 1.12:Processing sequence

After the data has been acquired, it passes through the whole processing sequence that includes different data processing techniques that are used to enhance the quality of the data. The raw seismic data is processed to enhance the signal to noise ratio and get the final seismic sections. The seismic data is interpreted in the following sequence.

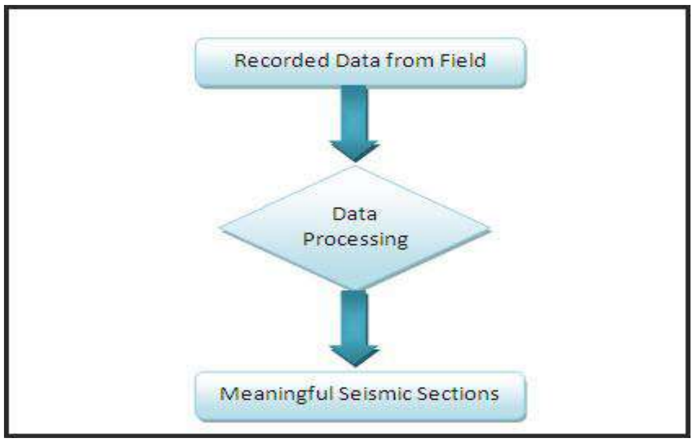



Figure 1.7: The processing sequence flow chart

The data acquired in the field zone are the sum of the signal which carries significant information and the noise which does not contain any significant information. These data are transmitted through various processes to extract the signal from the noise and improve the signal-to-noise ratio. The processed signal is then interpreted in such a way as to obtain significant results and to delimit the structural and stratigraphic traps of the subsoil.

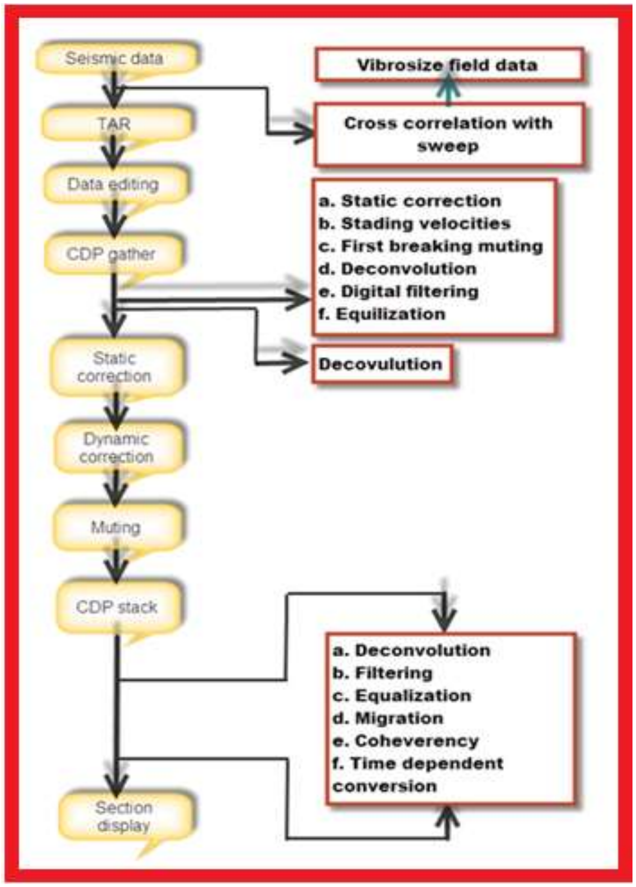



Figure 1.8: Generalized flow chart of Seismic processing (Al-Sadi, 198

## CHAPTER 02

# GEOLOGY AND TECTONIC

### 2.1: General geology of Joya Mair Oil field

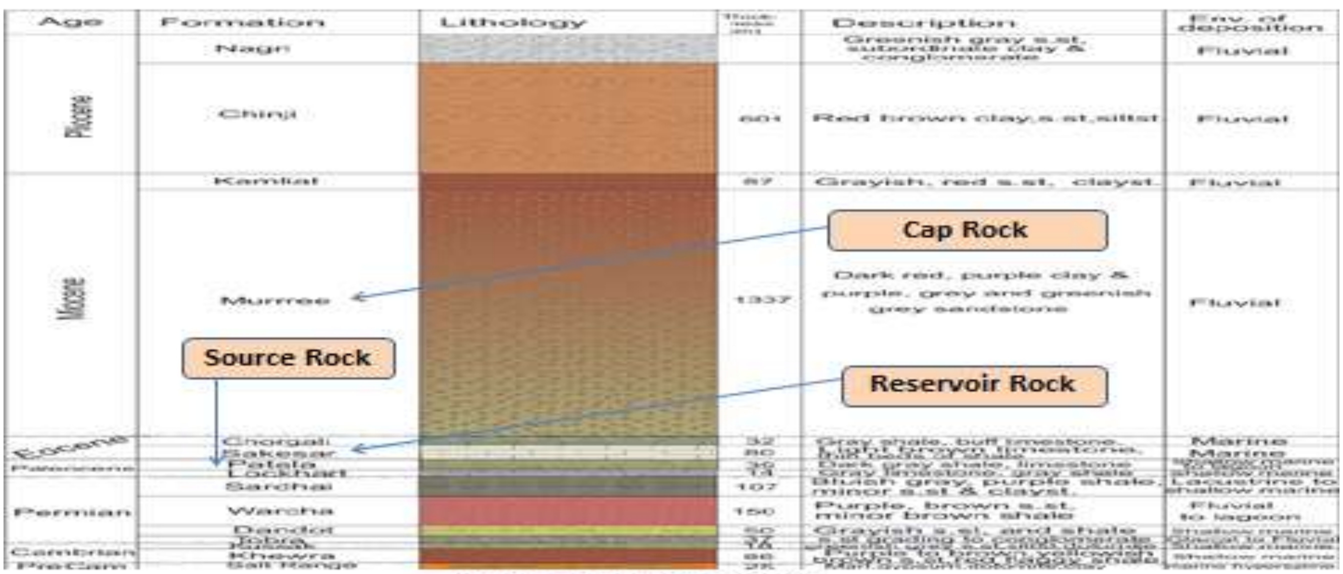
Following is the formations encounter in the wells of Joya Mair field.

Table 2.1: Generalized stratigraphy of Joya Mair field

| AGE | FORMATION | ENVIRONMENT |
|---|---|---|
| Pliocene | Nagri | Fluvial Channel |
| | Chinji | Fluvial Stream Channels |
| Miocene | Kamlial | Fluvial |
| | Murree | Fluvial |
| Oligocene | Unconformity | |
| Eocene | Chorgali | Shallow Marine SupratidalLagoonal |
| | Sakessar | Shallow Marine SupratidalLagoonal |
| | Nammal | Shallow Marine Restricted Anoxic |
| Paleocene | Patala | Shallow Marine |
| | Lockhart | Shallow Marine (Distal to Proximal) |
| | Hangu | Shallow Marine (Littoral to Paludal) |
| Cretaceous<br>Jurassic<br>Triassic Late Permian | Unconformity | |

| | | |
|---|---|---|
| Early Permian | Sardhai | Very Shallow Marine to Estuarine |
| | Warcha | Fluvial Sub Aerial PaludalLagoonal |
| | Dandot | Shallow Marine Lagoonal |
| | Tobra | Glacial to Fluvial |
| Late Cambrian | Unconformity | |
| Cambrian | Khewra | Shallow Marine Sub Littoral to Littoral |
| Pre-Cambrian | Basement | Restricted Marine Hyper saline |

## 2.2: Generalized stratigraphy of Joya Mair field




(Aamir and Siddiqui, 2006)

Figure 2.1: Generalized Stratigraphy of Potwar area (Aamir and Siddiqui,2006)

**FORMATIONS ENCOUNTERED IN WELL Minwal X-01 THEIR AGE,AND THICKNESS:**

Following is the formation encountered in well Minwal x-01 their age,and thickness.

Table 2.2: Formation encountered in wellMinwal x -1 their age,and thickness

**List of Well Tops**

| Formation Top | Formation Top Age | Formation Top Value | Thickness |
|---|---|---|---|
| NAGRI | PLIOCENE | 0.00 | 231.64 |
| CHINJI | MIOCENE | 231.64 | 680.89 |
| KAMALIAL | MIOCENE | 912.53 | 87.47 |
| MURREE | MIOCENE | 1,000.00 | 1,020.42 |
| BHADRAR | EOCENE | 2,020.42 | 33.83 |
| SAKESAR | EOCENE | 2,054.25 | 124.75 |

## 2.3: Techtonics of Pakistan

The Indian Ocean and the Himalayas, two of the most pronounced global features surrounding the Indo-Pakistani subcontinent, have a common origin. Both are the product of the geodynamic processes of seabed spreading, continental drift and collision tectonics. A plate of the earth's crust carrying the Indo-Pakistani landmass has moved away from the Gondwana super-continent, followed by expansion of the seabed and opening of the Indian Ocean.

Propelled by geodynamic forces, the Indian plate traveled 5000 km to the north and eventually struck Eurasia. The subduction of the northern margin of the Indian plate finally closed the ocean of Neo-Tythes. This collision formed the Himalayas and the adjacent mountain ranges. The north suture is called Main Karakoram Thrust (MKT) while the southern suture that separates the land from the Indian plate is known as the Main Mantle Thrust (MMT). The MBT is more or less EW trends in the center of the Himalayas. The south margin of the Himalayan collision zone in Pakistan is represented by the salt range, the Potwar Plateau and the Kohat Plateau. This is an active thrust belt that is limited by MBT in North and SRT in the south. In the complex domain of northwestern Himalayan tectonics, Main Mantle Thrust (MMT), Main Boundary Thrust (MBT) and Himalayan Frontal Thrust (HFT) delimit the major tectonic zones (Figure 2.2, Tahirkheli et al., 1979 ;Ghazanfar, 1993).

The presence of three lithospheric plates in the northern area of Pakistan, namely India, Eurasia and Arabia and their interaction with the boundaries of the active plate resulted in the development of spectacular mountain belts including Himalayas, Karakorum and Hindukush. Precambrian to Recent rock units of these belts records the tectonic history of the region. Permo-Triassic time is supposed to be the initiation of the Gondwana rifting and the development of the Atlantic passive continental margin.

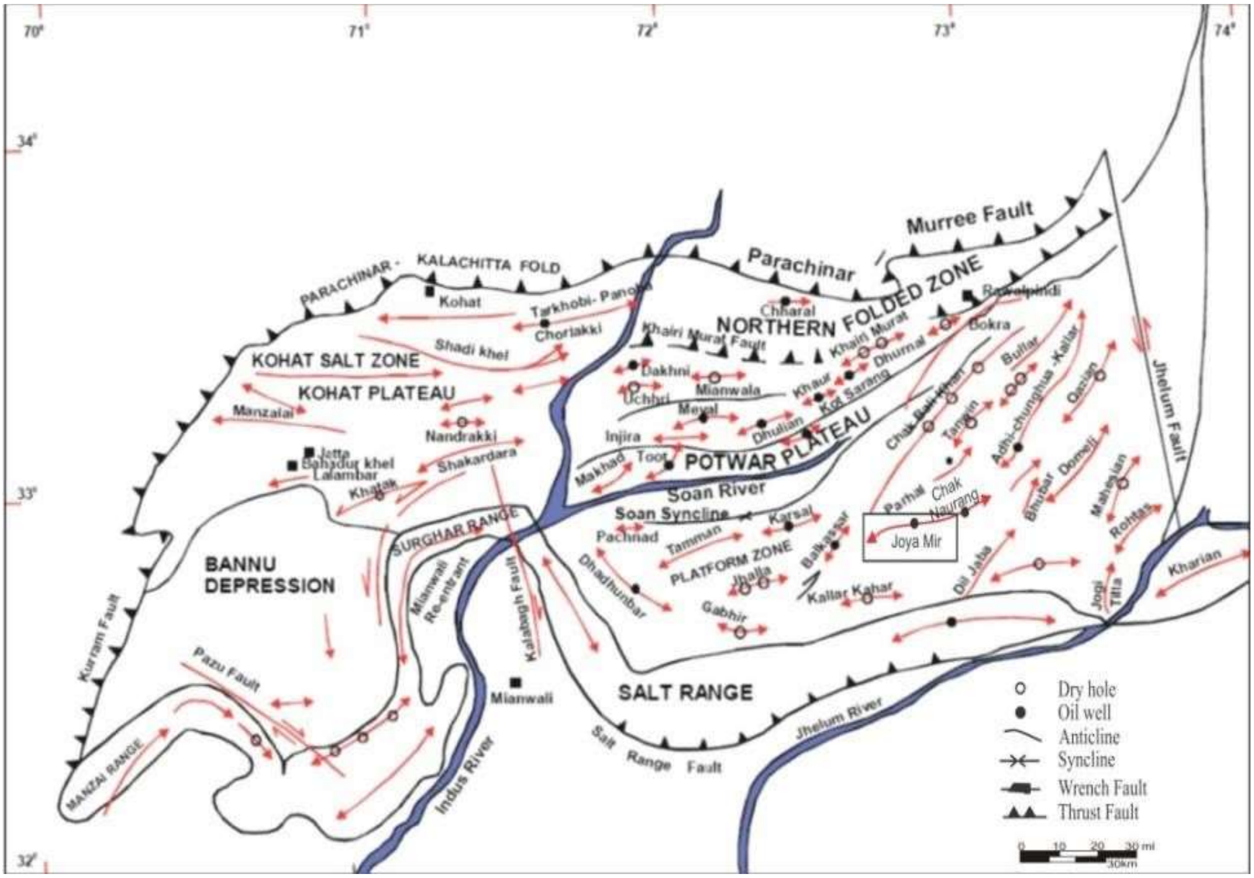



Figure 2.2: Tectonic map of Pakistan (after Shami,1998)

Thrust, where deformation as young as 0.4 Ma has been documented. In the Lesser Himalaya of northern Pakistan (Hill Ranges), detachments at upper crustal levels occur along a series of south-verging thrust.

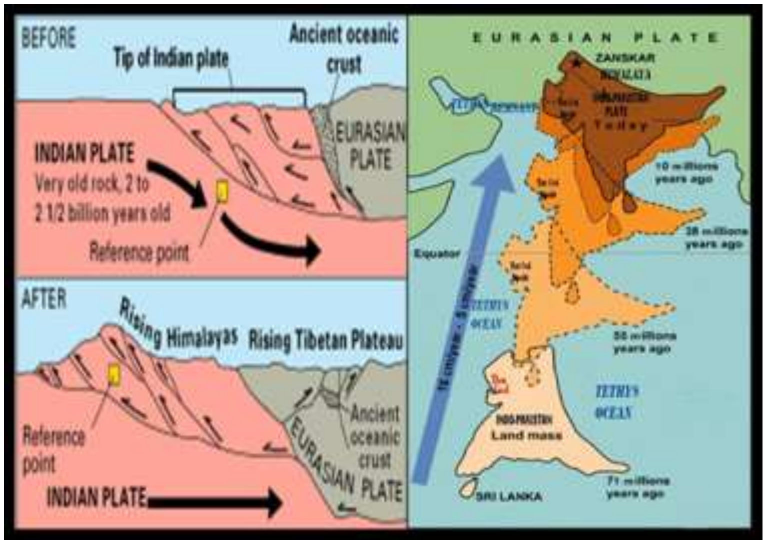



Figure 2.3: Formation of Himalaya (Kazmi& Jan, 1997)

## 2.4: Sedimentary basins

The basin is an area characterized by regional subsidence and in which the sediments are conserved for longer periods of time. In a basin a receptacle or container, which is the basin's substratum is called the Basement.The container is filled or contained, which is the accumulation of sediments resting on the basement, is called sedimentary cover. The progressive settlement of the basin is called subsidence. The point of maximum sedimentary accumulation is called the Depocenter. The detachment may not correspond to the maximum subsidence .Pakistan includes three sedimentary basins.


Figure 2.4: Basin Architecture of Pakistan, (Raza ,A.H. 1990)

Geographically upper Indus basin is located from MBT in the north to Sargodha High in the South, central Indus basin from Sargodha high to Mari Kankot High and lower Indus basin from Mari Kankot High to Nagar Parker High.Following are the basins classification of Pakistan.

- Upper Indus Basin
- Southern Indus Basin
- Central Indus Basin
- Lower Indus Basin
- Baluchistan Basin
- KakarKhorasaan Basin or Pishin Basin
- Indus offshore basin

### 2.4.1: Indus Basin

Indus Basin includes the 25000 square Km of South-East of Pakistan. It includes the Thar-Cholistan desert and Indus Plain. It has 80% of Pakistan population. Tectonically it is much stable area as compare to other tectonic zone of Pakistan. It comprises of buried ridges, platform slop, zone of up warp and dawn warp. (Kazmi&Jan, 1997) .

Structurally Indus Basin divided into two main parts;

- Upper Indus Basin (in north)
- Southern Indus Basin (in south)

Upper Indus Basin is further divided into two sub basin.

- Potwar sub-Basin.
- Kohat sub-Basin.

Lower Indus Basin is also divided into two Basins.

- Central Indus Basin (in north)
- Lower Indus Basin ( in south)

### 2.4.2: Upper Indus Basin

It is located in northern Pakistan and separated from the lower Indus basin by the Sargodha High. In its northern MBT, while in the east and west strike slip faults Jhelum and Kalabaugh is located, the upper Indus basin is subdivided into the Potwar and Kohat basins along the Indus River. (Kazmi& Jan, 1997).

In the the Upper Indus Basin Deposition began from the Pre-Cambrian. It is the only Pakistan basin that receives deposition from Precambrian times. The General Stratigraphy of the Upper Indus Basin is shown in the stratigraphic column, which shows two main unconformities and some small unconformities.

### 2.4.3: Potwar Sub-Basin

The Potwar sub-basin is about 130 to 150 km from Precambrian to recent rocks. The MBT (Main Boundary Thrust), active since 15 million years, and the Salt Range have bounded respectively the Potwar sub-basin to the north and south. Left lateral Jhelum and right lateral Kala Bagh strike slip faults delineate the basin on east and west (Kadri, 1995; Jadoon et al., 2003), respectively.

The Potwar Sub-Basin represents a deformed thrust sheet including the North Potwar Deformed Zone(NPDZ) and the South Potwar Platform Zone (SPPZ) separated by the Asymmetric Soan Syncline (Jaswal et al., 1997; Jadoon et al., 2003) .

In the High Indus basin of Pakistan have generated multiple oil prospects. These structures result from compression tectonics at the foreland margin, subsoil uplift in platform areas and extensional tectonics.Soanwide and broad syncline divides the Potwar Plateau in the deformed area of North PotwarZone (NPDZ) and the South Potwar Platform Area (SPPZ).

The NPDZ is more strongly deformed than the southern part. It is a neogenedeformation belt, extending southward from the main boundary thrust (MBT) to the Soan Synclinal. Outcrops and faults in shape are generally east-northeast trends, approximately perpendicular to the direction of tectonic transport. The strongly dissected NPDZ is an area of broad synclines, compressed folds and closely spaced imbricate thrusts. The deformation style of NPDZ changes abruptly from east to west (Figure 2.5).

The eastern NPDZ represents a buried thrust front with the development of foreland syncline on the back of Dhurnal Fault, passive roof duplex (triangle zone) and hinterland dipping imbricate stack farther north while the western NPDZ which is characterized by compressed and faulted anticlines separated by large synclines, representing the emergent thrust. The horizontal shortening for the zone between the Soan syncline and a point near MBT is calculated as about 55km and the minimum rate of shortening in this zone is estimated to be 18m NPDZ is followed to the south by asymmetrical wide and broad Soan syncline, with a gently northward dipping southern flank along the salt range and a steeply dipping northern limb along NPDZ (Jaswal et al, 1997).

The eastern part of the Southern Potwar Platform Zone represents strong deformation as compared to the central and western parts. The thrusts and back thrusts bounded salt cored anticlines represent both foreland and hinterland verging deformation.

Moreover, geophysical data along various transects indicate that the structural elements of Potwar sub basin exhibit wide variation from east to west. These structural complications are attributed to a different mechanical behaviour during detachment and propagation between Jhelum and Kala-Bagh strike slip faults in addition to occurrence of salt. In the eastern Potwar sub basin, the structures are left stepping whereas right stepping structures in en-echelon pattern are present in the east of Kala Bagh fault. Due to the combined effect of these faults and associated splays the overall migration of the basin is to the south where along HFT it is thrusting over Punjab Plain (Aamir and Siddiqui, 2006).

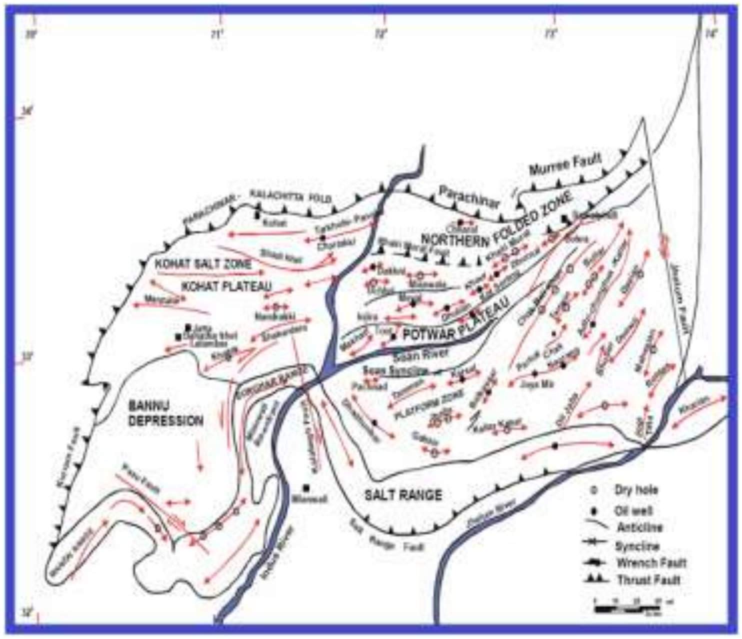



Figure 2.5: Tectonic division of Potwar Basin (Shami and Baig, 1998)

### 2.5: Structure

The two-dimensional seismic reflection data of the zone revealed distinct, tectonically controlled episodes of (1) normal faults in the subsurface followed by (2) thrust faulting in the sedimentary cover sequence.Normal faults in the subsoil indicate Pangea's rifting and Jurassic fractionation.The duplexes and triangle areas, which are common in the northern part of the Potwar Plateau, are not developed in the JoyaMair region due to comparatively less crustal shortening in the region.Borehole data indicate a 4-km-thick succession of Precambrian to Pliocene sedimentary rocks interrupted by four pre-Cambrian-Cambrian-Permian, Permian-Paleocene and Eocene-Miocene unconformities.

The JoyaMairstructure is located in the central Potwar on the southern flank of the Soan Synclinal. Joya Mair is a triangle zone structure with a well-defined axial plunge on both sides. It is a flat top, a salt cored, an anticlinal pop-up whose limbs are steep to the east and west. The orientation of the structure is northeast-southwest and is bounded by inverse faults on each side. A small saddle delimited plunges into the central part of the anticline and results in a compartmentalization of the field. Its northern part, known as the North Potwar Distorted Zone (NPDZ), is more heavily deformed. It is characterized by east-west, tight and complex folds, overturned to the south and sheared by steep-angle faults (Kazmi& Jan, 1997).

The structural style of the eastern and western parts of the Potwar Plateau shows a marked difference. In the central western part of the Potwar Plateau deformation appears to have occurred by a southerly thrust, while in the eastern part the deformation is mainly in the northeast-southwest with tight anticlinals and sometimes turned apart By large synclines. This difference may be related to a lower quantity / thickness of salt in the Cambrian in the eastern regions and to a very low basement depth (1 ° - 1.5 °) compared to the Central Potwar (20-30 °)

In Central Potwar, the structures are essentially delimited mainly by thrusts and backthrusts, while in some places asymmetric anticlines are bound by a single fault. Based on the seismic interpretation, structures in the Potwar region can be divided into: Pop-up anticlines, salt corn anticline and Triangle zones (Mughal et al., 2003).

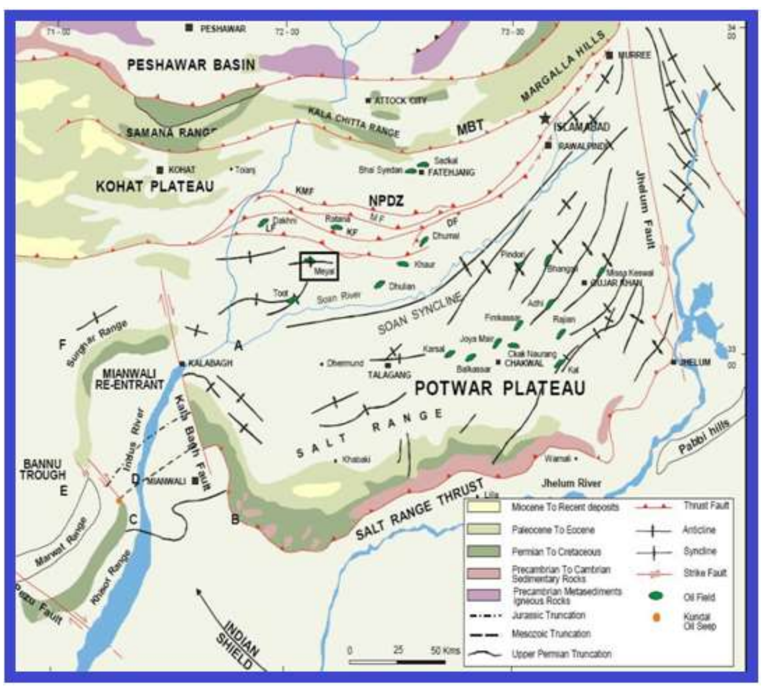



Figure 2.6: Geological and Structural map of Potwar plateau (www.gsp.pk.com)

## 2.6: Composite Oil System

### 2.6.1: Source rocks

Potential rocks in the Salt Range Potwar-Foreland Basin (SRPFB) are the gray shales of the Mianwali (triasic age), Datta (Jurassaic) and Patala (Paleocene) eras (Khan et al., 1986). The oil shale of the Eo-Cambrian Salt formation include between 27% and 36% total organic content (TOC) in isolated schist bags and are considered source rock in SRPFB (Shami and Baig, 2002).There are several potential rock sources in the geological province of Kohat-Potwar. These include the upper-lower Proterozoic interval of the Cambrian; Permian Wargal, Sardhai and Chhidru; Paleocene Lockhart; And Eocene Patala (OGDC, 1996; Quadri and Quadri, 1996). The Chichali and Lumshiwal formations may be the youngest mature rocks with a potential source in most of the Kohat plateau. The oldest source rocks are found in the salt formation, which consists of a lower section, a carbonate-dominated central section and an upper section dominated by evaporites.

The formation of the Paleocene Patala appears to be the main source of hydrocarbons, but other potential sources may contribute to different parts of the basin. The shallow shales of the Eocene Patala formation, 20 to 180 m thick, are probably the main source of oil in the Potwar basin (OGDC, 1996). Patala TOC ranges from 0.5 percent to more than 3.5 percent, with an average of 1.4 percent, and are type II and III kerogens. The exception to this may be the Dhurnal field where Patala samples have low TOC values, while TOC values in the Permian Wargal are 1.0 percent and in the Lockhart they are 1.4 percent (Jaswal et al. , 1997). The oil samples from the Dhurnal field also do not correspond to those known to be obtained by the Patala. The sulfur content of oils is less than 0.65%, except in Joyamair where the sulfur content is greater than 2% (Khan et al., 1986).

### 2.6.2: Reservoir Rocks

The fractured carbonates of the Sakesar and Chorgali formations are the main reservoirs of production in the region of JoyaMair. In MeyalChorgali and Datta Formations are the main productive reservoirs. The limestone of Sakesar is light yellow gray, massive and partially dolomitized and locally contains concretions of chert. The Chorgali formation is creamy yellow to yellow gray, silty, partly dolomitic and limestone to thin bed. The formation of Datta is mainly sandstone. Analysis of Meyal, Dhulian and Balkassar cores shows that the primary porosity is less than 1% in the Chorgali and Sakesarlimestones. The porosity of the fracture is relatively higher in the northwest Potwar wells because the rocks deformed several times during the Himalayan orogeny. Fractures tend towards the east-west, north-east-southwest and north-west-south-east. The fractures develop parallel, obliquely and perpendicularly to the axes of folds of the anticline. Fractures are usually concentrated along the crestal part of the anticline (Shami and Baig, 2002).

### 2.6.3: Traps and Seals

Most of the fields discovered in the Kohat-Potwar geological province to date are overturned faultedanticlines, popup structures, or fault-blocking traps. In this zone, anticline structures generally strike east-northeast to west-southwest and are approximately parallel to the collision-plate area. The last booster traps started at about 5 and 2 Ma (Jaswal et al., 1997Clays and shales of the Murree Formation also provide effective vertical and lateral sealing to the Eocene reservoirs of the Potwar-Foreland Basin (SRPFB), where ever it is in contact.

### 2.6.4: Maturation

The thermal maturities of the Kohat-Potwar rocks range from 0.3 to more than 1.6 percent. A basin profile indicates maturities equivalent to vitrinite reflectance of 0.62 to 1.0 percent for tertiary rocks in the productive part of the Potwar Basin. Fluid inclusion data, with vitrinite reflectance data used for calibration, shows calculated and measured Ro samples between 0.6 and 1.1 percent for Cretaceous, 0.5 to 0.9 percent for Jurassic, and 0.65 to 0.95 percent for Permian rocks .North of the main boundary thrust fault, maturities are higher. In the northern and probably central basin, Cretaceous rocks are in the 1.0 to 1.6 percent $R_o$ range. Dry gas generation begins near at 1.3 percent $R_o$.

### 2.6.5: Generation and Migration

Generation of hydrocarbons most likely began in Late Cretaceous time for Cambrian through Lower Cretaceous source rocks and again from Pliocene time to the present for younger source rocks (OGDC, 1996). Burial-history plots by Law and others (1998) start at about 30 Ma and therefore show only a late or second period of generation beginning 20 to 15 Ma and continuing to the present. The burial-history plots of Law and others (1998) also indicate that maximum burial was reached approximately 2 million years ago. Migration is primarily over short distances updip and vertically into adjacent reservoirs and through faults and fractures associated with plate collision and thrusting.

# CHAPTER03

## STRUCTURAL INTERPRETATION

### 3.1: Introduction

The geophysicist deals with the seismic section. Seismic methods are physical measurements performed at the surface, which are then interpreted in terms of what could be under the surface, position and behavior of the interfaces, resulting in each reflection event being then calculated from their time of arrival. The resulting information is then combined in cross-section, which represents the structure of the geological interfaces responsible for the reflection data are a bidirectional process.

### 3.2: Seismic interpretation

Interpretation is the transformation of seismic reflected data into a structural image through the application of corrections, migration and time-depth conversion (Dobrin and Savit, 1988).

Interpreting seismic data is a very complicated process involving many problems and difficulties because each area is different from the others, so the approach used before would probably not work on the new area. For this purpose, an interpreter has to get really familiar with an area to work it well and trying one thing and then another is an excellent way to really know the area.The importance of seismic work in the exploration of oil is attested by its extensive application. Almost all major oil companies rely on seismic interpretation to select sites for exploratory oil wells (Telford and Geldart, 1999).

### 3.3: Methods of interpretation

Interpretation is a tool for transforming all seismic information into a structural or stratigraphic 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 area of final anomaly. It is rare that the correctness or inaccuracy of an interpretation is so certain, because real geology is rarely well-known. The criterion of correct interpretation is consistency rather than accuracy.Not only is a good interpretation consistent with all seismic data, it is also important to know everything about the area, including magnetic and gravity data, well information, surface geology and the geological and physical conditions (Telford et al., 1999).

Conventional seismic interpretation involves the collection and monitoring of laterally coherent seismic reflectors for the purpose of mapping geological structures, stratigraphy and reservoir architecture. The ultimate goal is to detect the accumulations of hydrocarbons delineate their extent, and calculate their volumes. Conventional seismic interpretation is an art that requires skill and extensive experience in geology and geophysics.To meet the challenges of exploring increasingly complex targets, there has been considerable progress in data acquisition equipment, computer hardware and seismic processing algorithms over the past three decades.

Computer work (Processing & Interpretation) is more precise, accurate,efficient and satisfying, which gives more time for further analysis of the data. All this work is carried out using Kingdom software. Our main objective is to make the reflection as clear as possible of the structure and the stratigraphy of the subsoil. The geological significance of reflection is the indication of the limits of the change in acoustic impedance; to distinguish the different horizons with the seismic data, we will correlate the well information with the seismic data. The structure and estimation of the deposition environment, seismic velocity, seismic stratigraphy and lithology are identified using the best available seismic data (Dobrin&Savit, 1988).

There are two main approaches to the interpretation of seismic sections:

- Structural Interpretation
- Stratigraphic Interpretation

### 3.3.1: Structural Interpretation

This type of analysis is very appropriate in the case of Pakistan, as most hydrocarbons are extracted from structural traps. It is the study of the geometry of the reflector based on the reflection time. The main application of the structural analysis of the seismic section is the search for structural traps containing hydrocarbons. Most structural interpretations use two way reflection 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 reflections reveal folded beds. (Sheriff, 1990).

### 3.3.2: Stratigraphic interpretation

Seismic stratigraphy is used to find out the depositional processes and environmental settings, because genetically related sedimentary sequence normally consists of concordant strata that show discordance with sequence above and below it. It also helps to identify formations, stratigraphic traps and unconformity. This method also facilitate for the identification of the major pro-gradational sedimentary sequences which offer the main potential for hydrocarbon generation and accumulation Stratigraphic analysis therefore greatly enhances the chances of successfully locating hydrocarbon traps in sedimentary basin environment.

## 3.4: Interpretation workflow

This interpretation was performed using different techniques and steps with each step include various processes performed with the use of software tools. Simplified workflow used in the thesis given in Figure4.1.

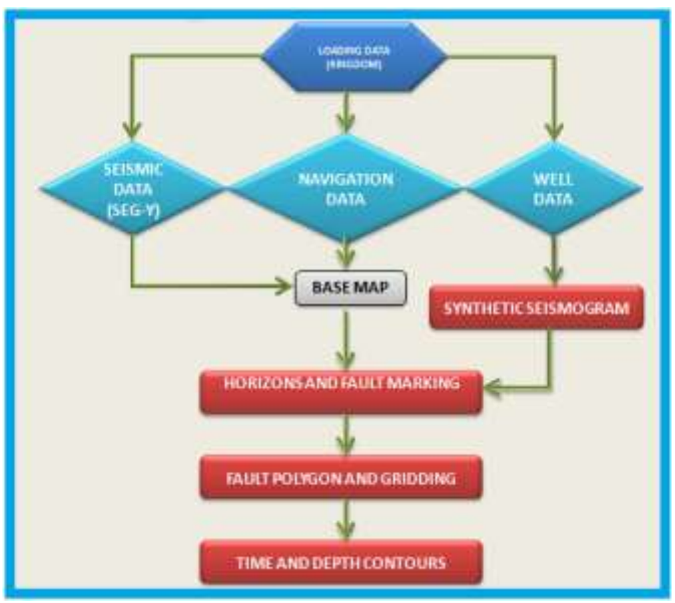



Figure 3.1: Work flow adopted for the seismic data interpretation

## 3.5: Structural Interpretation of Joya Mair Area

Seismic survey is conducted to acquire data for subsurface analysis, to know structural patterns in the subsurface.Seismic interpretation of Joya Mair area involves six seismic lines.While interpreting these seismic lines, it is observed that these seismic lines showing structural changes. These structures are results of compression forces as it falls in the compressional regime. Mostly the structures present in this area are folds and thrust faults along with triangular zones and pop-up structures.

Tie the synthetic seismogram with the Seismic line, on which well is located (Line POL-MN-93-08). 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 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.

I have been assigned with two dip and a strike line which are interpreted in following sections.

## 3.5 Base Map And Generation Of Synthetic Seismogram

Basemap represents the orientation of seismic line along which data is acquired.Following is the basemap of our area.

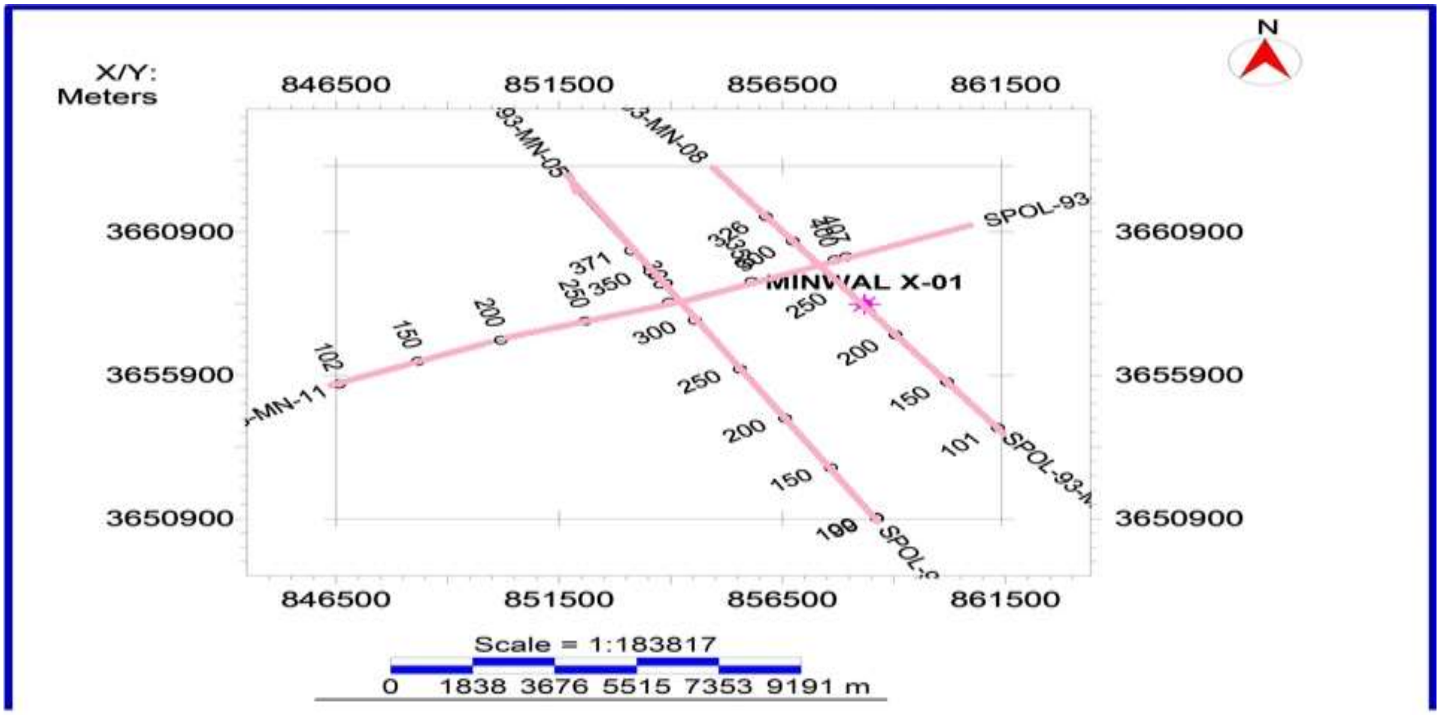



Figure 3.2: Basemap of the area with Minwal well x-01

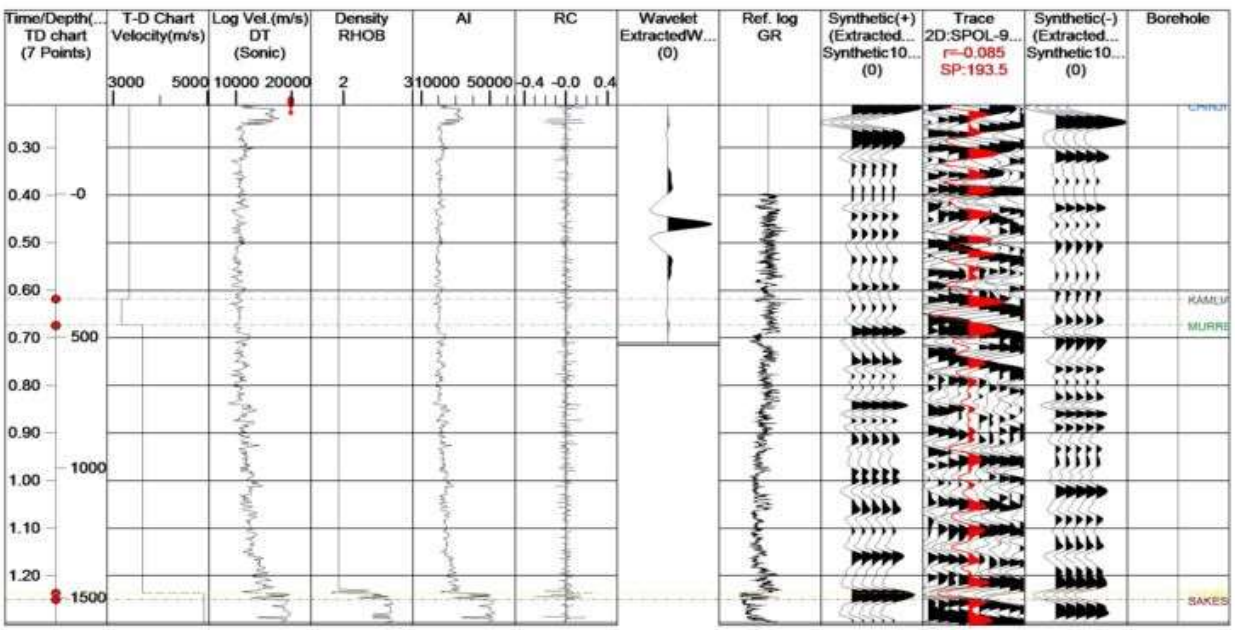


Figure 3.3: Shows the Synthetic Seismogram(Minwal Well X-01)

## 3.6: Time marked Sections

The time section gives the position and configuration of the reflectors in the time domain. Two reflectors are marked on seismic lines. Each reflector is marked with different colors so that they can be easily distinguished. However, the objective is to target the rock formations of the reservoir.

**POL-MN-93-08 and POL-MN-93-05**

Figures (3.4) and (3.5) are seismic linesPOL-MN-93-08 andPOL-MN-93-05 oriented towards NW-SE, showing different horizons (Basement, Sakesar and Chorgali) terminated by forethrust and backthrust reverse faults structure which is an identification of Triangle zone in this area.

The Joya Mair triangle zone is limited by a fore thrust (Fault-1) on the SE side and a back thrust in the NW (Fault-2) side. In Figure 3.2, the pop-up structures form a saddle-type structure, which may be the result of an increased effect of strike slip fault behavior near the Jhelum fault and may be the result of the diapirism of salt.

**POL-MN-93-05**

Figures 3.5is SW-NE strike oriented seismic line 5, showing different horizons (Sakessar and Chorgali). Horizons are forming an asymmetric anticline whose limbs are gentle in the SW side and somewhat steep in the NE side. This triangle structure probably is the result of salt tectonics. Joyamair triangle zone is doubly plunging in the NE and SW.

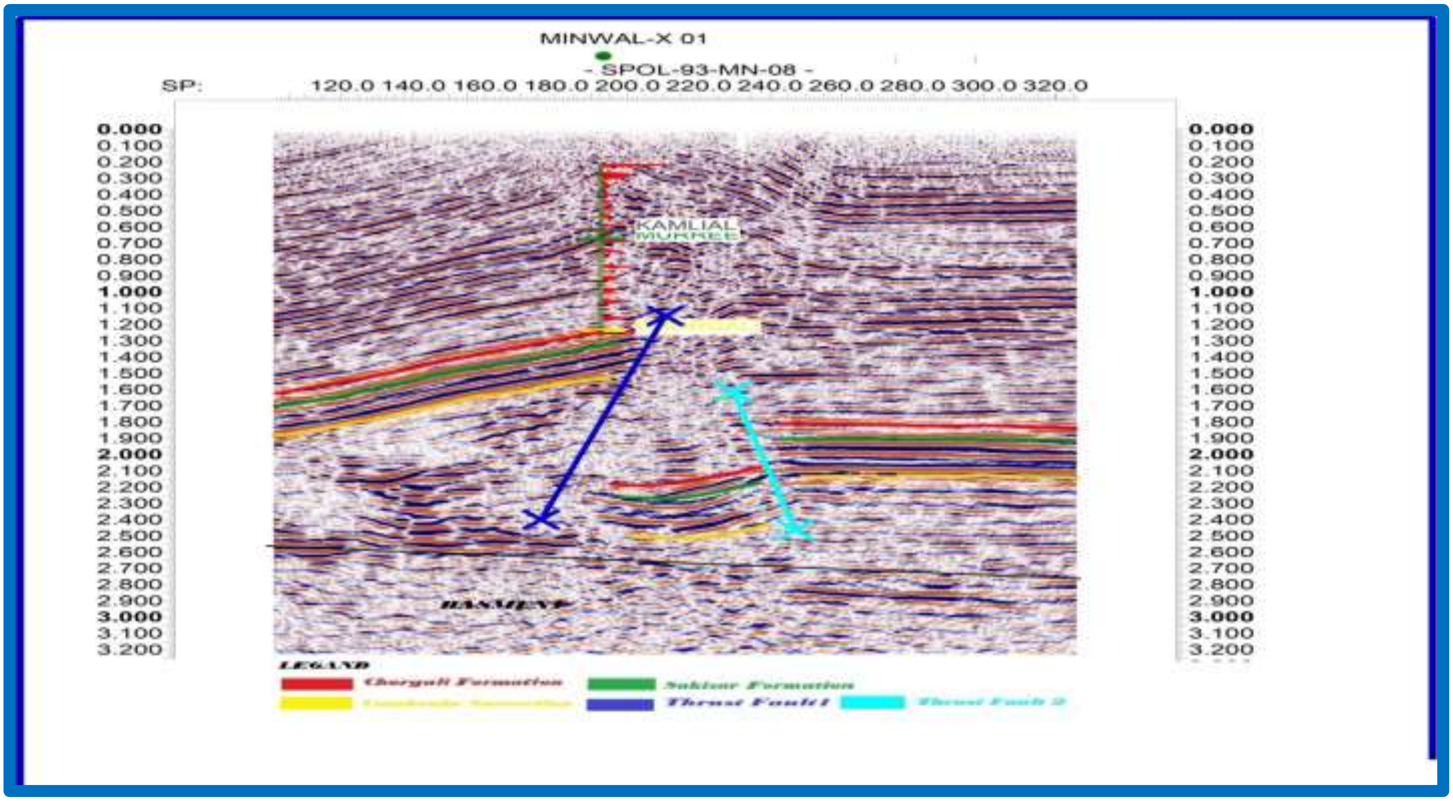



Figure 3.4: Interpreted Time Section of POL-MN-93-08 with well

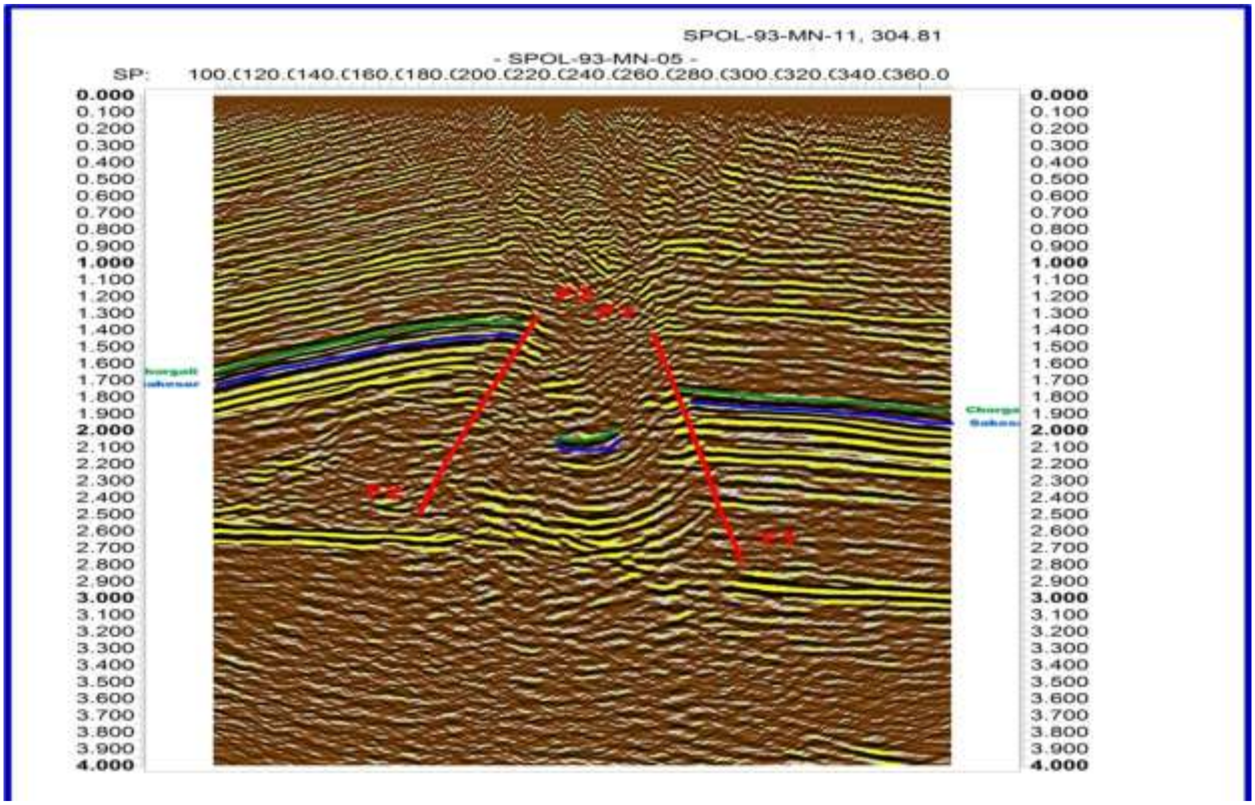



Figure 3.5: Interpreted Time Section of POL-MN-93-05

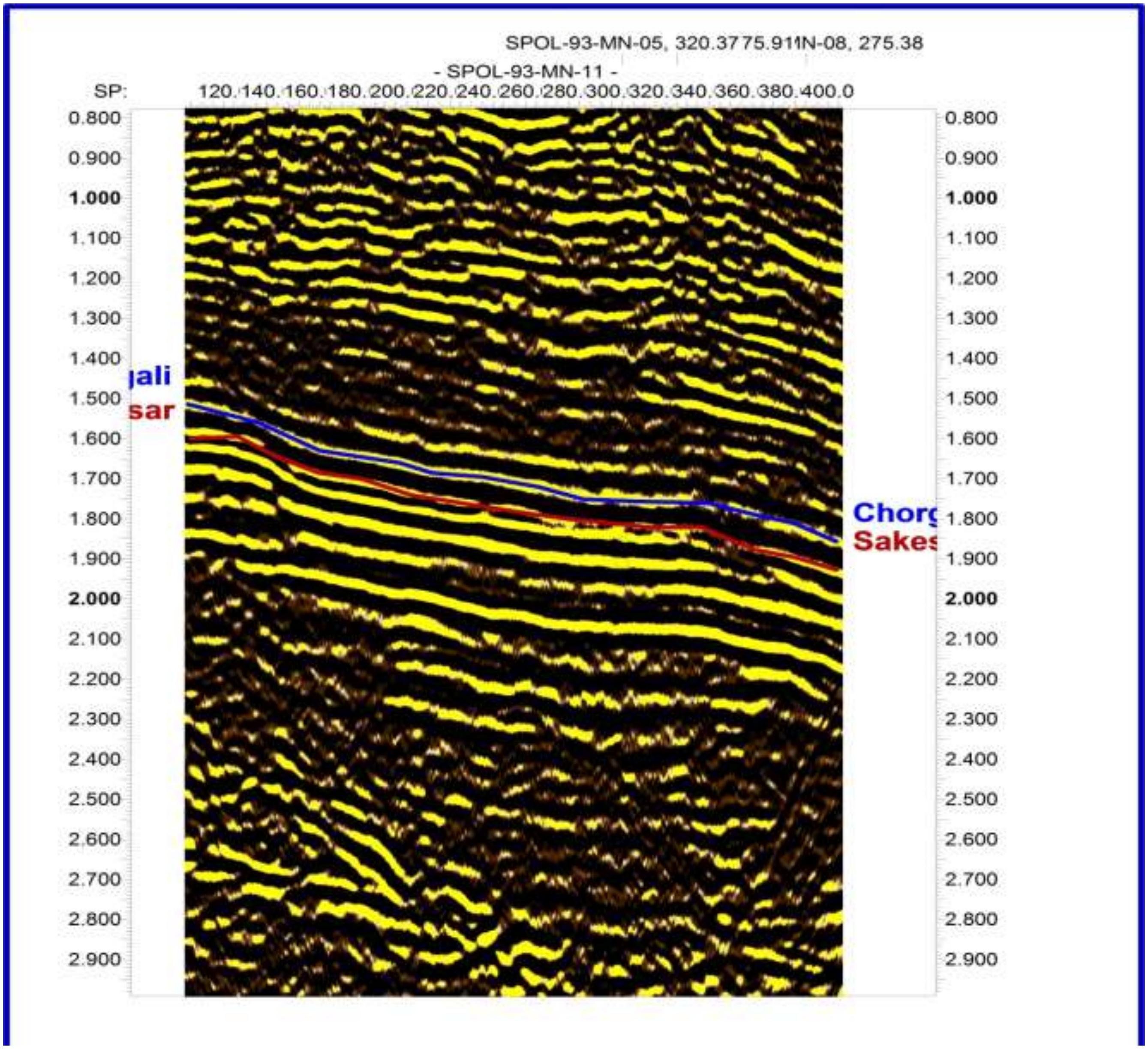



Figure 3.6: Interpreted Time Section of Line POL-MN-93-11(Strike Line)

### 3.7: Contour Maps and Generation of Fault Polygon

The final products of any seismic exploration are contour maps, time or depth. Fault polygon actually represents the area disturbed by a fault and mapping is a part of the interpretation of the data, that on which the whole operation depends for its utility. Contours are lines of equal duration or depth roaming 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, the structural relief of the formation, its dip and any deformation and folding. The interpreted seismic data is contoured to produce seismic maps that provide a three-dimensional image of the different layers within an area that is circumscribed by intersecting shot lines. These time and depth contour maps were generated with the help of Sismic Micro Technology SMT (Kingdom 8.8).

Here are the seismic lines interpreted with the fault polygons showing the regional tendency of the fault.

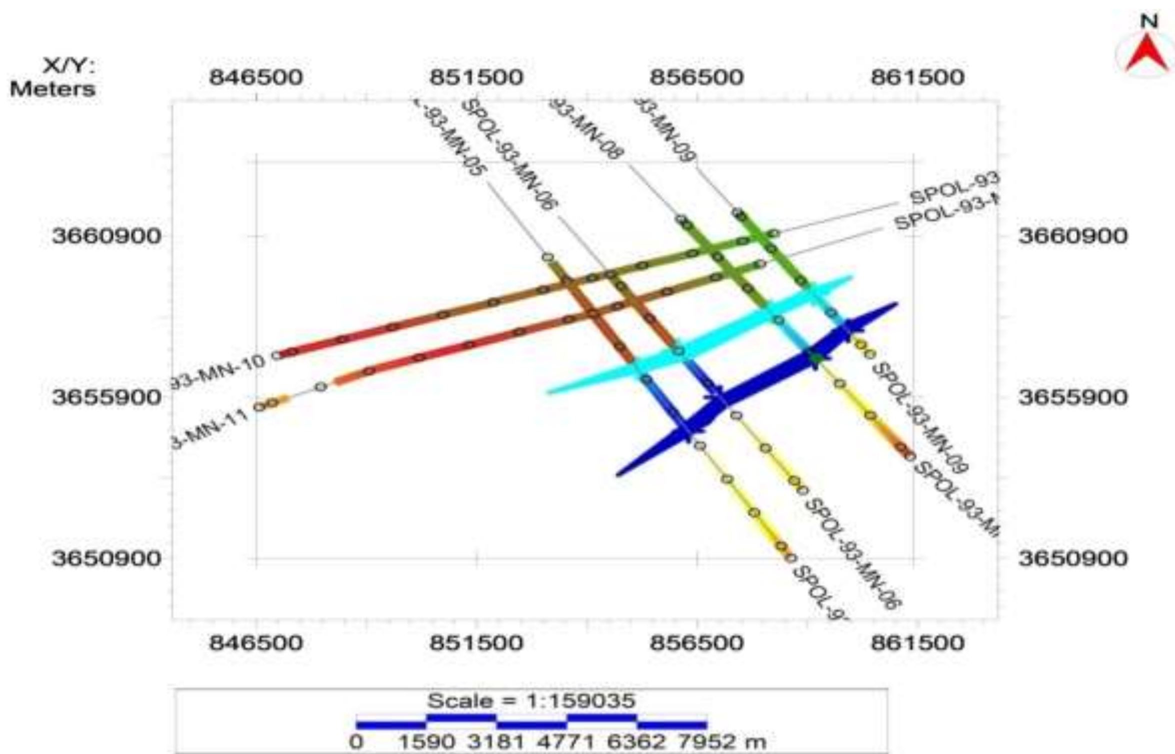



Figure 3.7:Seismic lines with fault polygon showing regional trend of the fault

### 3.7.1: Time maps of marked horizons

In these time contour maps, the central part of the map in the NE-SW direction represented by blue colors, according to the scale, indicates a deeper zone and forms part of the flat shape crustal part of the anticline. Both members are tempered abruptly and terminated by reverse and back thrusts, respectively.

These maps give us clear indications of back thrust in the study area. The closed contour part can be considered as a structural trap.

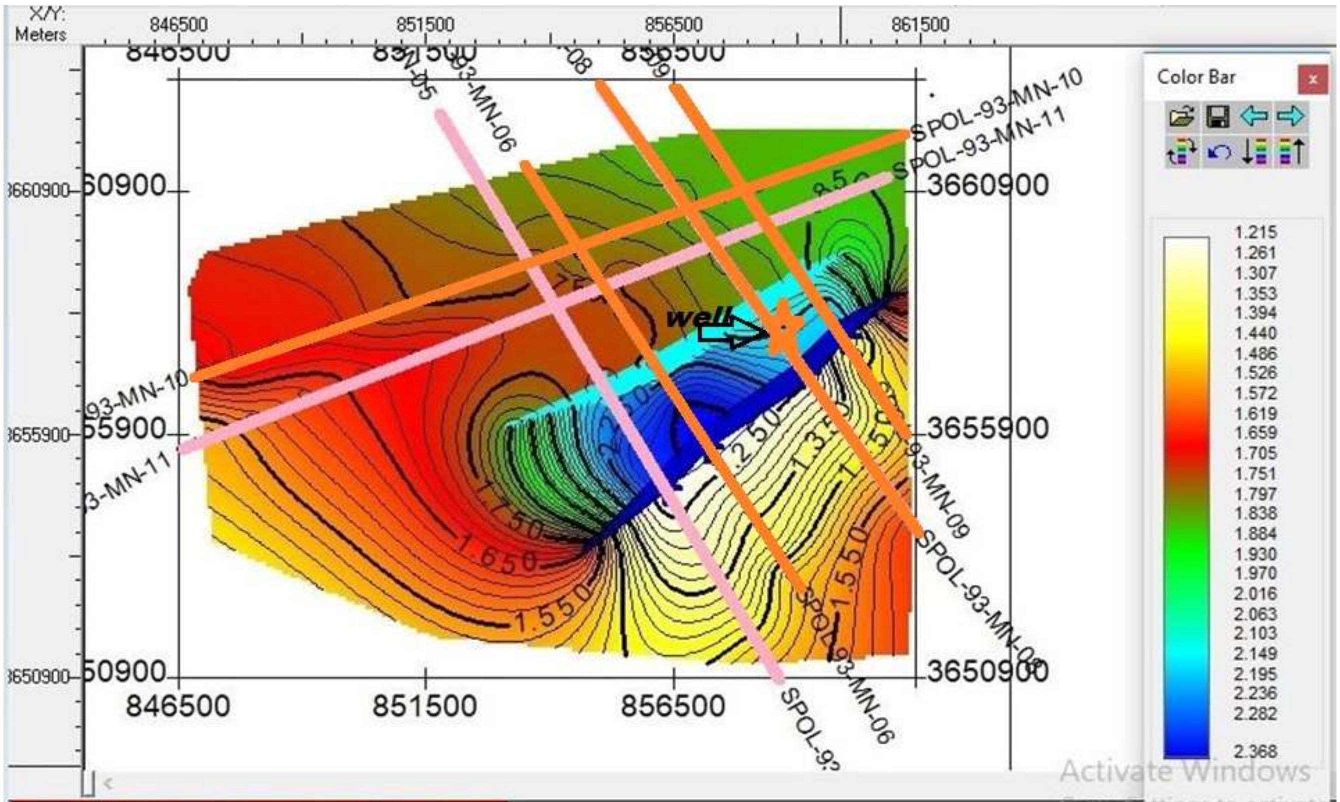


Figure 3.8: Time Contour Map of Chorgalli formation

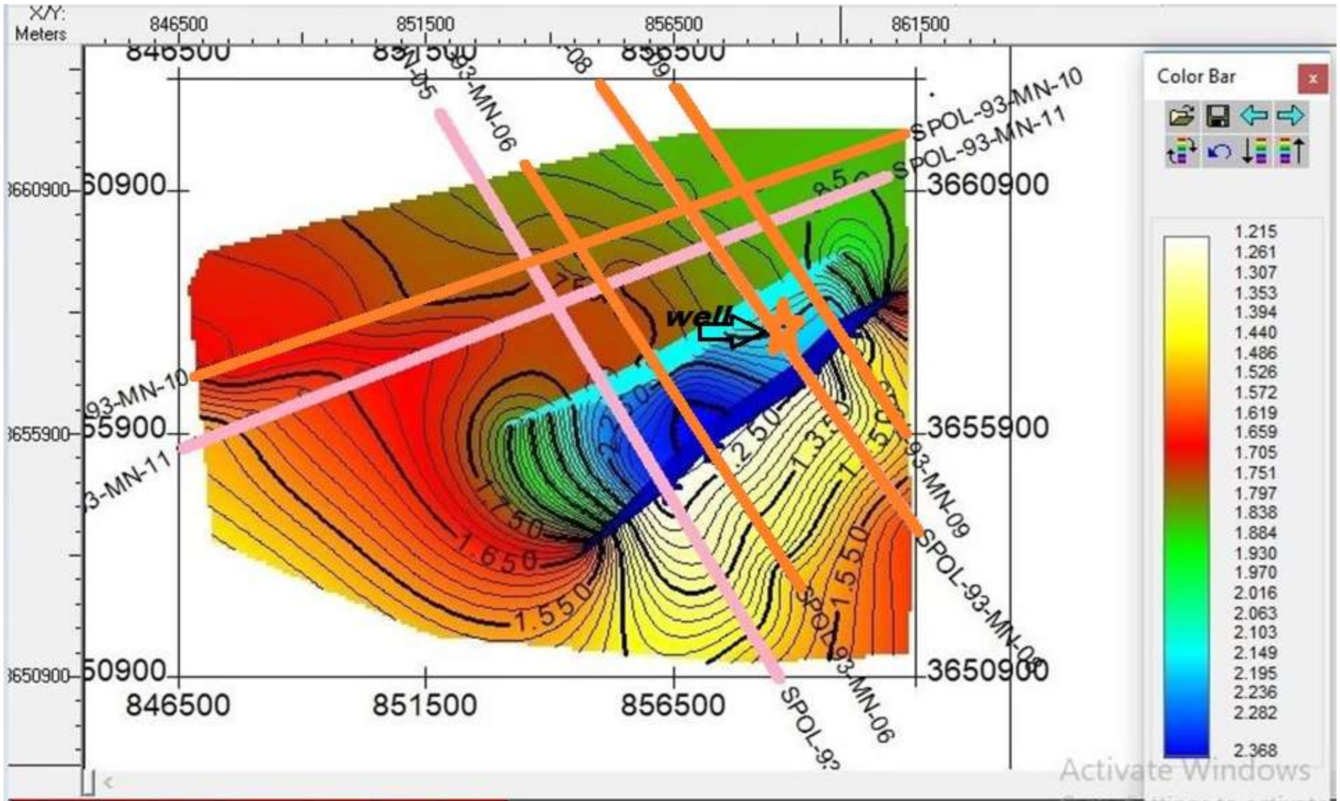



Figure 3.9: Time Contour Map of Sakessar formation

### 3.7.2: Depth contour maps

The time contour map is converted into depth contour map my multiplying the time grid with velocity function for which distance is obtained from well data and time from seismic data by using simple distance time equation.As the seismic data is in Two Way Travel(TWT) time so we divide the time by two to obtain one way travel time.This one way travel time is used to convert time grid into depth contour map.

The depth contour maps show the depth variation of the horizon, from Figs. 3.8 and 3.9, it can easily be interpreted that the horizon forms an triangle zone structure, from the scale the central part between the polygons is deeper than the surrounding area. It should also be noted that there is no change in the profile of the contours of time and depth because the variation is the same either with time or with depth. The shallow part or the upward part is represented by the red color while the lowered blocks of the structure shown by yellow, green and blue color showing more time and depth.

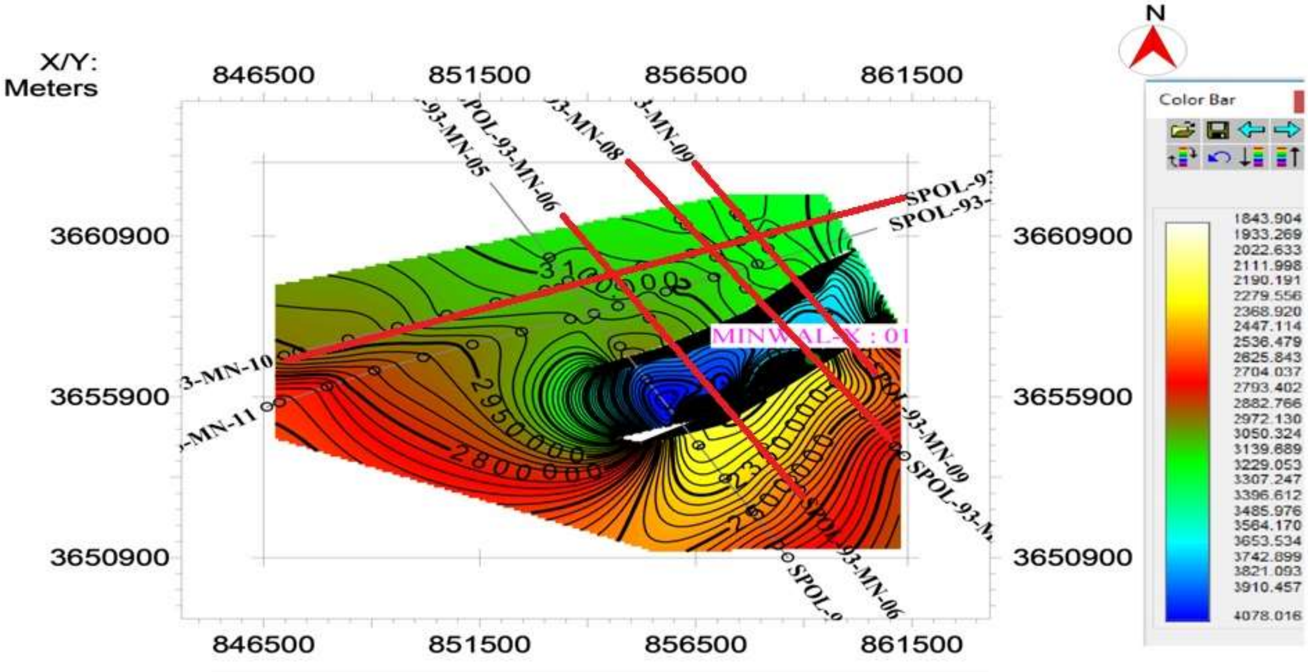



Figure 3.10: Depth Contour Map of Chorgalli formation


Figure 3.11: Depth Contour Map of Sakessar formation

# CHAPTER 04

## PETROPHYSICSAND FACIES ANALYSIS

### 4.1:Well Logging

Petro physics is the study of physical properties concerning the impacts, behavior of rocks and fluids in rocks. Reservoir characterization is the key step in the oil and gas industry as it defines the potential of the well and to identify areas of the reservoir that can be recovered. Petro physics is a technique used to characterize the reservoir. This study facilitates the identification and quantification of fluid in a reservoir (Aamir et al., 2014). Knowledge of the physical properties of the reservoir such as volume of shale, porosity and saturation of water and hydrocarbons is necessary to define areas of hydrocarbons that are likely to be promising. The integration of petro physics with rock physics allows geologists and geophysicists to understand the risks and opportunities in the region. The petro physical analysis was carried out using the wire line log data of BALKASSAR OXY-1 data provided by DGPC:

### 4.2: Types of logs used

Following are the various type of logs used for petrophysical analysis:

- Density log
- Neutron log
- Resistivity Logs
- Spontaneous potential Log
- Gamma Ray Log
- Sonic Log
- Caliper Log

Petrophysics uses different geophysical tools (GR, Caliper Log, SP, LLD and LLS, etc.), core data and production data and integrates the extracted results. These geophysical tools are designed to quantify certain specific properties of the reservoir, such as porosity, shale volume, net pay, effective porosity, hydrocarbon saturation, etc. Pertophysical analysis is often less related to seismic data.

For the analysis of physical activity, the following parameters are determined on the basis of these logarithmic curves.

- Volume of shale
- Water saturation
- Hydrocarbon saturation
- Porosity

Folowing is the petrophysical workflow shown in below figure.

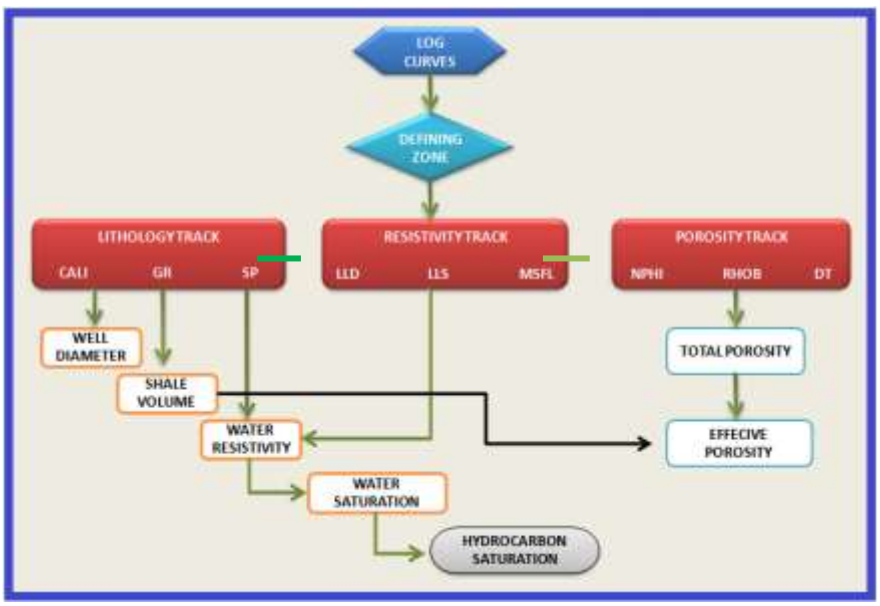



Figure 4.1: Petrophysical workflow

**Log Data:**

The Joya Mair Minwal X-01 log data was available in Log ASCII Standard (LAS) format. The logarithmic curves as well as some parameters given in the header of the LAS file are used to calculate all the basic and advance parameters.

## 4.3: Scale used for the different Logs

The scales used for different logs track area explained in the below table .4.1

Table 4.1: Scale used for the different logs

| SR NO. | TYPE OF LOG | ACRONYM | SCALE | UNIT |
|---|---|---|---|---|
| 1 | Gamma ray Log | GR | 0---------300 | API |
| 2 | SP Log | SP | 120-------(-20) | mV |
| 3 | Density Log | ROHB | 1.95----2.95 | $gm/cm^3$ |
| 4 | Sonic Log | DT | 140-------40 | µsec/ft |
| 5 | Neutron Log | NPHI | 0.45---(-0.15) | PU |
| 6 | Caliper Log | CALI | 6----------16 | Inches |
| 7 | Laterolog Deep | LLD | 1--------1000 | Ωm |
| 8 | Laterolog Shallow | LLS | 1--------1000 | Ωm |

### 4.4: Petrophysical analysis

Following are the petro physical properties calculated for petro physical analysis.

#### 4.4.1: Volume of Shale

Shale is more radioactive than carbonate or sand, gamma ray logs can be used to calculate volume of shale in porous reservoirs. The volume of shale can then be applied for analysis of shally sands. Calculation of the gamma ray index is the first step to determine the shale volume from a gamma ray log (Schlumberger, 1974).

IGR = (GRlog –GRmin)/ (GRmax- GRmin) (1)

IGR= Gamma Ray Index

GRlog= Gamma Ray reading of the formation

GRmax=Maximum gamma Ray (shale)

GRmin= Minimum gamma Ray (clean sand and carbonate)

Then following formula is used to find volume of shale

Consolidated:

Vshale =0.33[2(2*IGR) - 1] (2)

Unconsolidated:

Vshale=0.0883[2(3.7*IGR) -1] (3)

### 4.4.2: Sonic porosity ($\Phi_S$)

Using sonic log porosity can also be easily calculated which is almost near or equal to actual porosity. The interval transit time ($\Delta T$) is dependent upon both lithology and porosity of the medium. Therefore, a formation's matrix velocity given must be known to drive sonic porosity by the following formula given by Wyllie et al in 1958. Sonic porosity has been calculated by using the following the formula:

$\Phi_S = (\Delta T - \Delta Tmat)/ (\Delta Tf - \Delta Tmat)$ (4)

Where,

$\Phi_S$=Sonic porosity µs/ft

$\Delta T$=Log response

$\Delta Tmat$= Transit time in matrix

$\Delta Tf$= Transit time in fluids

Wyllie formula for calculating sonic porosity can be used to determine porosity of consolidated sandstone and carbonates. According to Wyllie interval transit time ($\Delta T$) increased due to the presence of hydrocarbon (i.e. hydrocarbon effect). In order to correct this Wyllie suggested the following empirical correction for hydrocarbon effect.

$\Phi = \Phi s \times 0.7$ (for gas) (5)

$\Phi = \Phi s \times 0.9$ (for oil) (6)

### 4.4.3: Density porosity ($\Phi_D$)

Density porosity has been calculated with the help of following formula.

$\Phi_D$= ρm-ρb/ ρm- ρf (7)

Where,

ρm=2.71 gm/cm3 (for Carbonates)

ρf= 1 gm/cm3

ρb= log Response in zone of interest

### 4.4.4:Total porosity ($\Phi_T$)

Total porosity has been calculated by the help of following formula:

$\Phi_T = (\Phi_S + \Phi_D)$ (8)

Where,

$\Phi_T$=Total Porosity

$\Phi_D$=Density Porosity

$\Phi_S$=Sonic Porosity

### 4.4.5:Effective porosity

Effective Porosity is given by;

Effective Porosity = Average Porosity * $V_{matrix}$ (9)

Where $V_{matrix}$ is Volume of Matrix given by 1- $V_{shale}$

### 4.5: Water Saturation ($S_w$) Determination

Water saturation has been calculated with help of the Archie's Equation:

$S_w = (a/\Phi^m) \times (R_w/Rt)$ (10)

Where,

$S_w$= water saturation

$R_w$=water resistivity (formation)

Φ = effective porosity

m(cementation factor) = 2

a(constant)= 1

$R_t$= log response (LLD)

Rw has been calculated with help of the following formula:

$$R_w = \Phi^2 \times Rt \qquad (11)$$

Where,

Φ = porosity in clean zone

$R_t$ =Observed LLD curve in clean zone.

### 4.6: Saturation of Hydrocarbon

It is denoted as $S_{hc}$. Saturation of hydrocarbon is calculated by given formula below;

$$S_{hc} = 1 - S_w \qquad (12)$$

**$S_w$**= Saturation of water

**$S_{hc}$**= Saturation of hydrocarbon

### 4.7: Calculation of Water Saturation ($S_w$)

To calculate saturation of water in the formation, a mathematical equation was developed by Archie given in equation (10). All the parameters of Archie equation can be calculated from resistivity and spontaneous potential logs.

$$S_w = \sqrt[n]{\frac{F \times R_w}{R_t}}, \qquad (13)$$

where,

$R_w$= Resistivity of water,

$R_t$= True resistivity (LLD)

n= saturation exponent and its value varies from 1.8 to 2.5 and it was taken as 2,

F= Formation factor ($F = \frac{a}{\emptyset^m}$),

a=Constant and its value is assumed as 1,

Ø= Effective porosity,

m= Cementation factor (with a constant value 2).

**Resistivity of Water (□□)**

Formation water resistivity ($R_w$) was calculated with the help of certain parameters like bottom hole temperature, surface temperature, water salinity in ppm and static spontaneous potential.

**Calculation of resistivity of water (□□)**

1. Read the SP value at the depth of maximum deflection, which gives SSP and is calculated by using the equation (14)

$$SSP = SP_{clean} - SP_{shale}, \quad (14)$$

Where,

SSP = Static Spontaneous Potential,

$SP_{clean}$= Spontaneous potential for sand,

$SP_{shale}$= Spontaneous potential for shale.

**2.** Calculate the formation temperature (FT) from relation given in equation (15) at the depth of the SP value. Use Gen-6, (Schlumberger chart) given in appendix-1, with total depth and maximum temperature from the log header.

$$FT = \left[\frac{(BHT-ST)}{TD} \times FD + ST\right] \quad (15)$$

where,

FT = Formation temperature,

BHT = Borehole temperature,

FD = Formation depth (from surface to Fm)

ST = Surface temperature,

TD = Total depth (from surface to end)

**3.** Resistivity of mud filtrate ($R_{mf1}$) at surface temperature (ST= 26℃) is calculated using Gen-6 (Schlumberger chart) .

**4.** Now after calculating the value of $R_{mf2}$, calculate the resistivity of mud filtrate at zone of interest (FT) and it is calculated by equation (16)

$$R_{mf2} = \frac{(ST+6.77)\times R_{mf1}}{(FT+6.77)}, \tag{16}$$

where,

$R_{mf1}$ = Resistivity of mud filtrates at surface temperature (from well header)

ST= Surface temperature,

FT= Formation temperature,

$R_{mf2}$= Resistivity of mud filtrates at formation temperature. .

**5.** Resistivity of mud filtrate equivalent ($R_{mfeq}$) at formation temperature, this is important step and is performed by considering the following, two conditions,

**a.** If $R_{mf2}$ is greater than 0.1 Ωm then correct it to formation temperature using the following relationship given in equation (16)

$$R_{mfeq} = 0.85 \times R_{mf2}, \tag{17}$$

**b.** If $R_{mf2}$ is less than 0.1 (Ωm) then use chart SP-2 (Schlumberger Chart) to derive a value of $R_{mfeq}$ at formation temperature.

### 4.8: Calculation of Resistivity of water Equivalent (□ □□□) and □ □

SSP is difference of maximum and minimum value of SP log. SSP is -60 mv is plotted on Gen-6 (Schlumberger chart)

#### 4.8.1: To calculateTrue Rweq

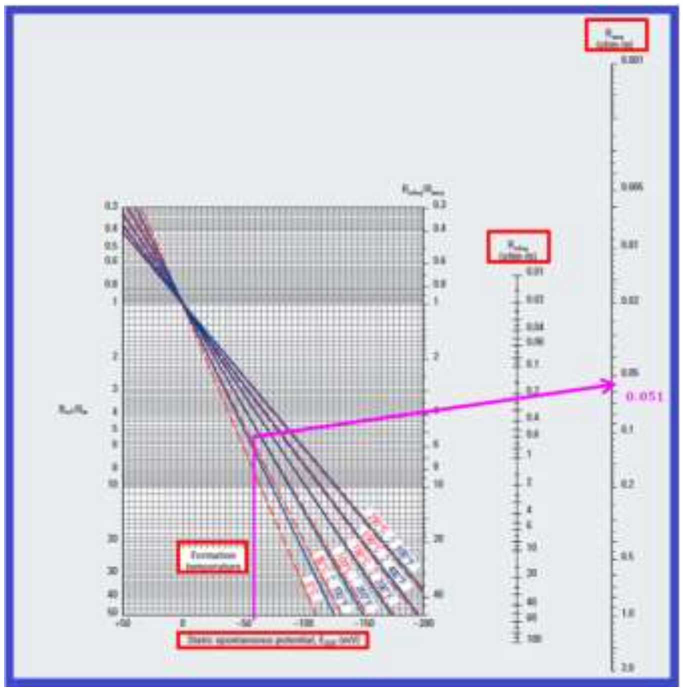



Figure 4.2: Determination of Rweq from SP chart (Schlumberger, 1989)

#### 4.8.2: To calculate True Rw

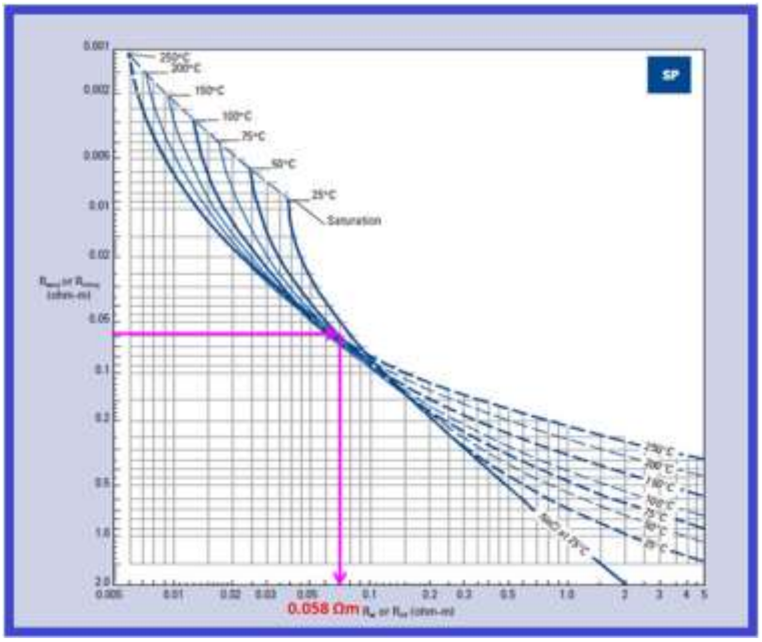



Figure 4.3: Determination of Rw from SP chart (Schlumberger, 1989)

### 4.9: Petrophysical Interpretation of Joya Mair

Petrophysical analysis of Joya Mair Minwal X-01 is concluded on the basis of behavior of different log curves. As a first indicator of lithology, GR log is very useful as it suggests where shale may be predictable. For the higher values of GR, higher will be the percentage of shale. So due to this reason, clean zone or shale free zone is defined easily.

Where there is low value of the shale we can say that this is the zone in the reservoir where the hydrocarbon can be present, but not confirm. Basically to confirm the types and amount of hydrocarbon we go towards the integrative results of other logs that give a comprehensive report about the hydrocarbon and water present in that zone.

The principal use of resistivity logs is to detect and quantify hydrocarbon. That is, resistivity logs are used to give the volume of oil/gas in a particular reservoir, or, in petrophysical terms, to define the water saturation (Sw). When Sw is not 100%, then hydrocarbons are present there. Higher values of resistivity usually indicate the presence of hydrocarbons or fresh water. If separation between LLD and LLS is reported, that is quite possibly a hydrocarbon zone as value of LLD is much higher in case of oil or gas. Density in the study field mainly varies from 2.55 to 2.99 g/cm3. But somewhere at the reservoir level, very high density corresponding to low resistivity is noted. It may be due to the Presence of some heavy minerals like gluconate, Chlorite, Chamosite Siderite etc. (Farid et al 1993).

### 4.10.1: PetrophysicalInterpretation of Chorgalli Formation

Chorgalli formation starts at a depth of 2421.5m to 2467.2m having a total or gross thickness of 45m .Shale volume for whole depth range is about 24% and the remaining net thickness is about 30m which is limestone. Out of 30m there is about 15m having payable porosity and permeabilities ranges in which only upto 9m zone is net payable zone.Net pay is determined through placing cut offs on properties like permeability, porosity, water saturation or volume of shale. Average total porosity is upto 10-15 % whereas effective porosity is upto 7%.Water saturation is upto70%and hydrocarbon saturation is upto 30% on average.

Calliper log measure the continuous record of size and shape of borehole.Thegreater value of caliper log curve in track-1 show the shale wash out portion where the borehole diameter is increased then the normal diameter.

Also the low value of SP log is observed in case of carbonates because of low permeability and low ions exchange in carbonates. The hydrocarbon zone also show low SP response because the interstacial water contact with the borehole fluid is reduced. The SP curve is flat opposite Shale formation because of low permeability and porosity .This creates a straight line known as shale base line.The maximum deflection in clean formations i-e Sand is called SSP (Static Spontaneous Potential).

Gr log is mostly used for lithology identification and it is run from surface to all depth with all other logs because of its application in depth matching. It measures the amount of radioactive materials in subsurface such that shale have high values of GR log where is a shale free formation have low values. There is no source used in GR log so it is Passive logging because it measures the radioactivity of subsurface materials such as Uranium, Thorium and Pattasium.GR log can be used in open as well as cased hole for which correction is to be applied.Asquith and Gibsson relation is used for calculating GR value from logs.

The resistivity log such as LLD and LLS are run in track 2. LLD measure the resistivity of deeper uninvaded zone where hydrocarbons are present whereas the LLS measure the resistivity of shallow invaded zone adjacent to the borehole.The resistivity logs measure same value in this case because of the high saturation of water in the abandoned well.

Density log is used for porosity calculation and it is run in track-3 which measures the formation bulk density along with neutron porosity log. Both the logs measure the porosity of the formation and forming a crossover at the reservoir formation. Attenuation of the gamma rays bombarded on the formation between source and receiver is observed. Much higher value is observed in case of reservoir where hydrocarbons are present while in dense formation Compton scattering occurs and few detectable gamma rays are observed.Sonic log provide the formation interval transit time which is the inverse of Vp (Compressional wave velocity) which is used for porosity quantitatively. By using Wyllie's mathematical relation we can relate porosity with formation velocity.Wyllie et al. (1963)

$$1/V=\phi/V_f+ (1- \phi)/V_{mat} \quad (19)$$

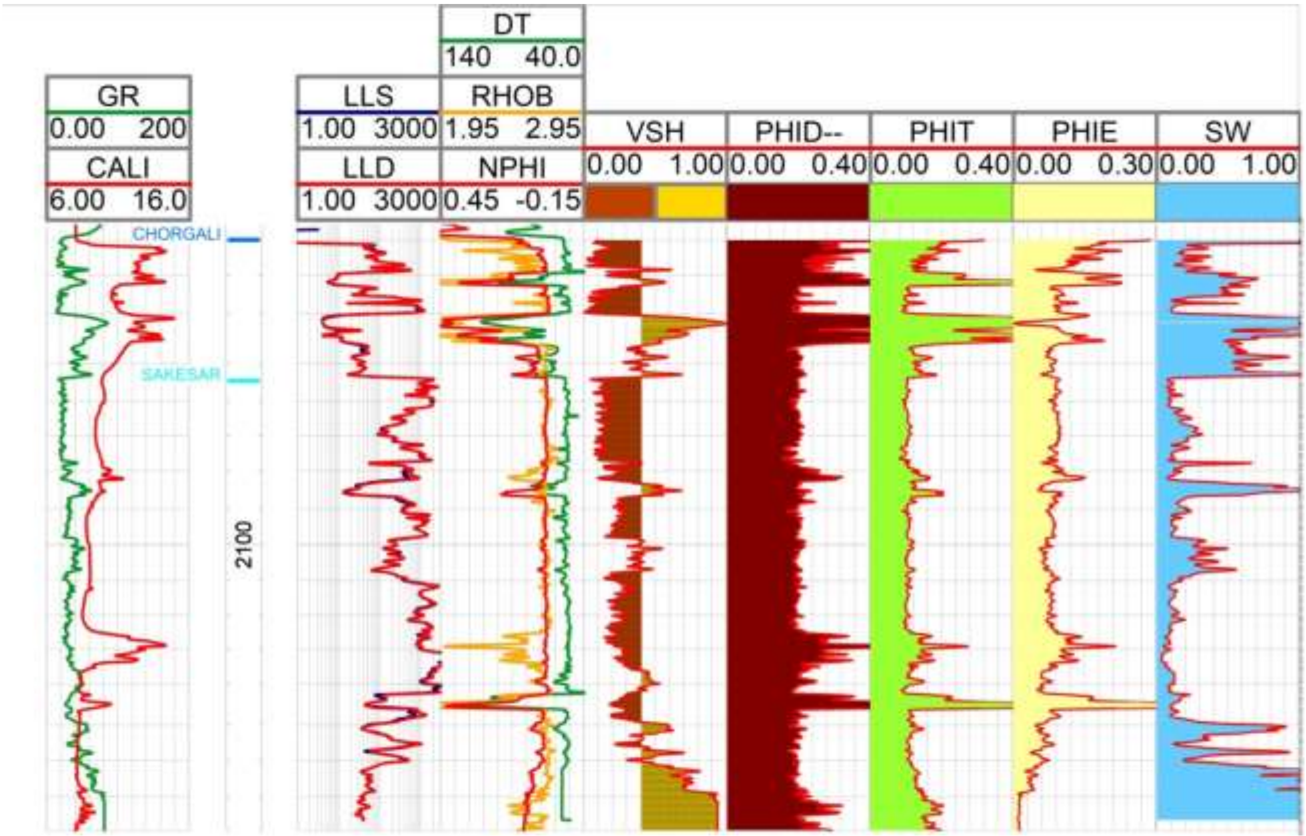



Figure 4.4: Petrophysics of Chorgalli formation(Minwal well X-01)

Table 4.2: Results of Petro physical analysis of Chorgalli Formation

| tro-physical Properties | rcentage(%) |
|---|---|
| erage Volume of shale | 3% |
| erage porosity PHIT | % |
| ective porosity PHIE | % |
| erage water saturation (SW) | % |

| | |
|---|---|
| | |
| erage Hydrocarbon saturation( SH ) | % |

## 4.11: Facies Analysis

In geology, a facies is a body of rock with specified characteristics which can be any observable attribute of rocks such as their overall appearance, composition, or condition of formation, and the changes that may occur in those attributes over a geographic area.The term facies was introduced by the Swiss geologist Amanz Grossly in 1838 and was part of his significant contribution to the foundations of modern stratigraphy.

**Types of facies:**

Sedimentary facies

Ideally, a sedimentary facies is a distinctive rock unit that forms under certain conditions of sedimentation, reflecting a particular process or environment. Sedimentary facies are bodies of sediment that are recognizably distinct from adjacent sediments that resulted from different depositional environments. Generally, geologists distinguish facies by the aspect of the rock or sediment being studied.Facies based on petrological characters (such as grain size and mineralogy) are called lithofacies, whereas facies based on fossil content are called biofacies.

The characteristics of the rock unit come from the depositional environment and from the original composition. Sedimentary facies reflect their depositional environment, each facies being a distinct kind of sediment for that area or environment.The sedimentary environment of reservoir formations of Chorgalli and sakessar are shallow Marine lagoon environment.

The only Tobra formation in Potwar area has glacial environment except that all other have shallow marine lagoon environment. The different types of sedimentary depositional environment are shown in below Figure 4.5.

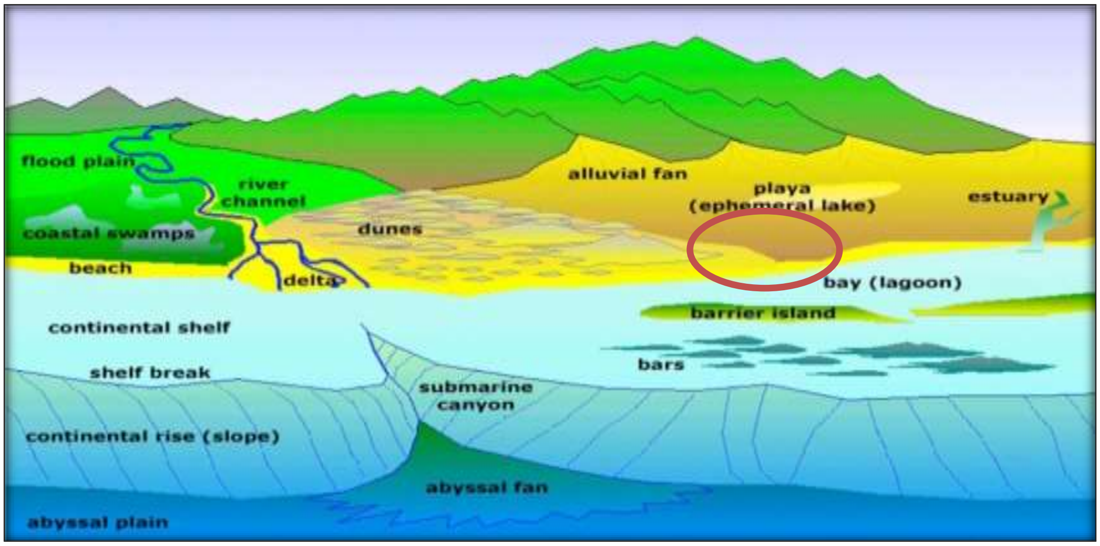



Figure 4.5: Different types of sedimentary environment (http:hkss.cedd.gov.hk)

**Use of Acoustic Logs:**

The acoustic velocity is mainly a function of the rock matrix and can be used to identify different lithologies and 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 designed to aid in lithologic identification (Bruke et al., 1969).

## 4.12: Behavior of Acoustic and Porosity Logs

The behavior of the acoustic log and the log of porosity with respect to the depth is illustrated in Figure 4.9. Comparing this response with that of the logs in Figure 4.8. This comparison shows that the major lithology of the reservoir zone is limestone.

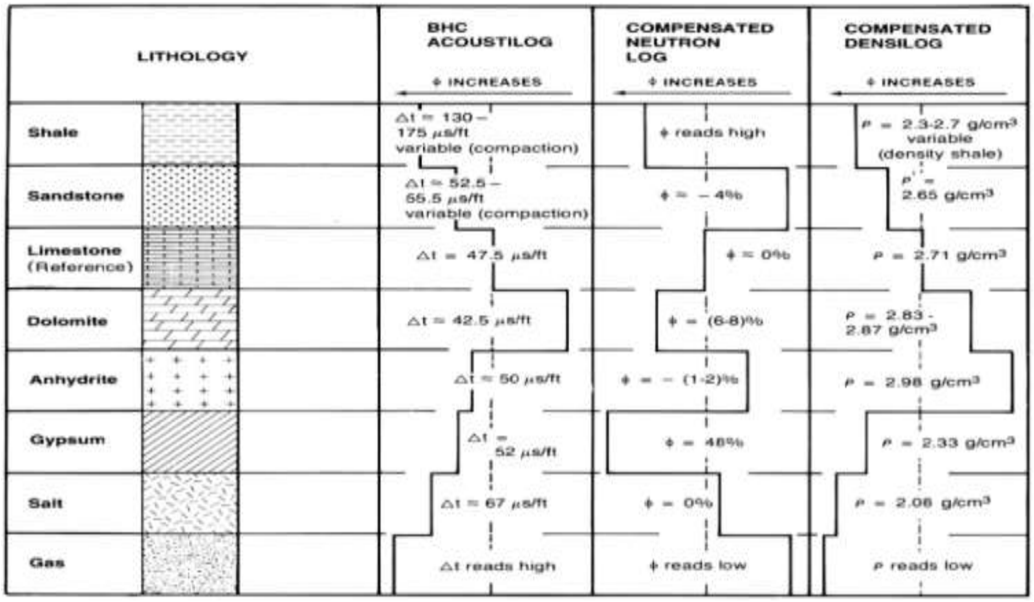



Figure 4.6: Generalized comparison of acoustic-, neutron-, and density-log responses in common reservoir lithologies (courtesy of Baker Atlas)

### 4.12.1: Crossplot between the Neutron Log and the Density Log

A standard cross diagram between the neutron log (NPHI) and the density log (RHOB) is given in Figure 4.8.The same crossplot is prepared with logarithmic data fromJoya Mair Minwal well x-01, with a gamma ray log as the reference log on the z-axis,figure 4.9. The depth selected for this crossplot is 2420 to 2620 meters because the reservoir rocks (Chorgali and Sakesser) lie between these depths.

By comparison of the figure the two figures the polygon are drawn and labeled according to the standard crossplots. The group of points is thick in the limestone polygon. It is therefore interpreted that the reservoir is mainly composed of limestone (www.wellog.com).

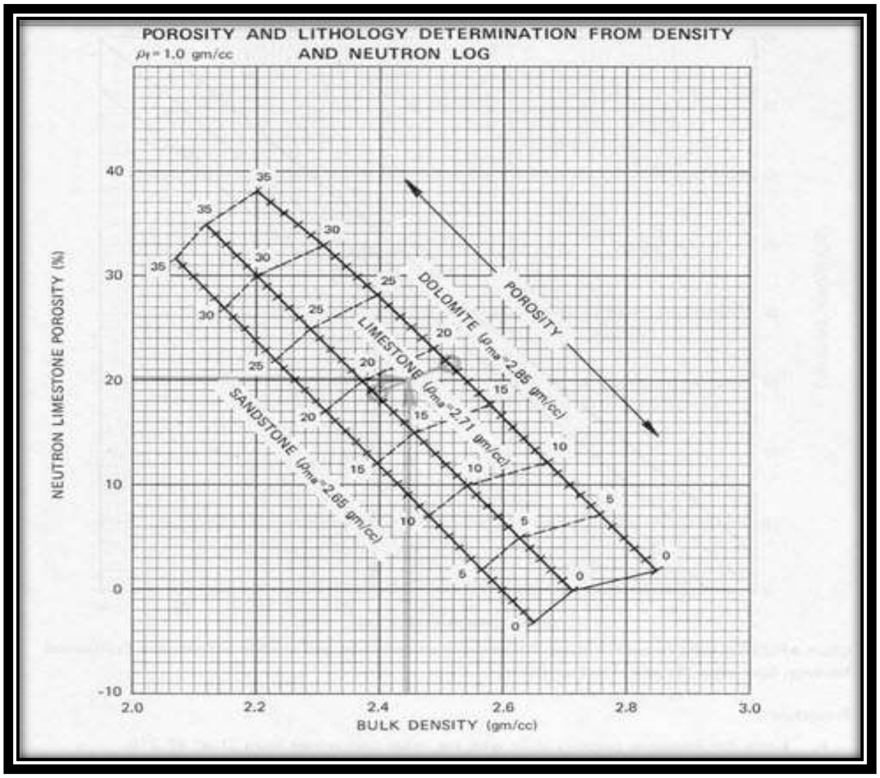



Figure 4.7: Standard crossplot between NPHI and RHOB (www.welllog.com)

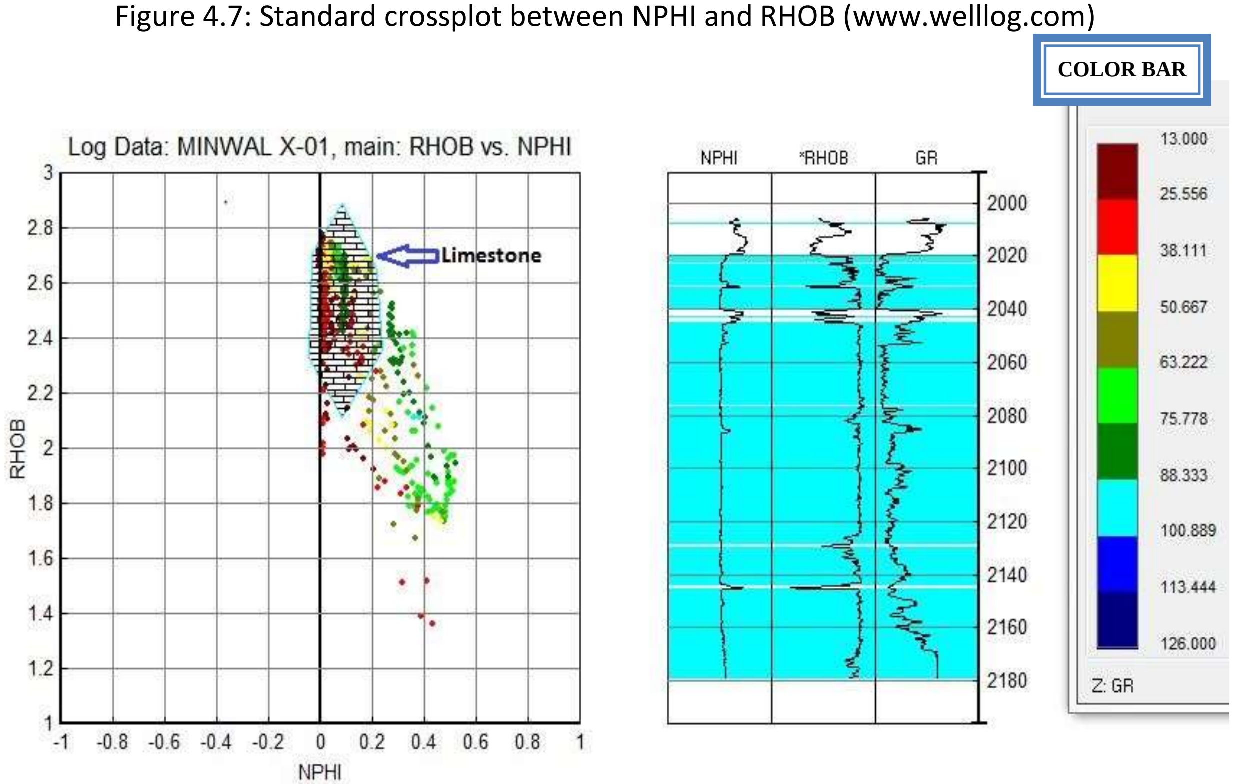



Figure 4.8: Minwal X-01 well crossplot between NHPI and RHOB

### 4.12.2: Crossplot between the LLD and the Density Log

The crossplot, in the depth range of the reservoir rocks, between the LLD and the density log is prepared using software kingdom 8.8. A standard cross diagram between these two logs is shown in Figure 4.10 (www.welllog.com).In Figure 4.10, the limestone is in the range of axes marked with blue. By comparing the prepared cross-section (Figure 4.11), it is clear that the cluster of points is in the same range of axes that is marked in the standard cross-section Figure 4.10. Thus, the major lithology in the depth range of the main reservoir is limestone.

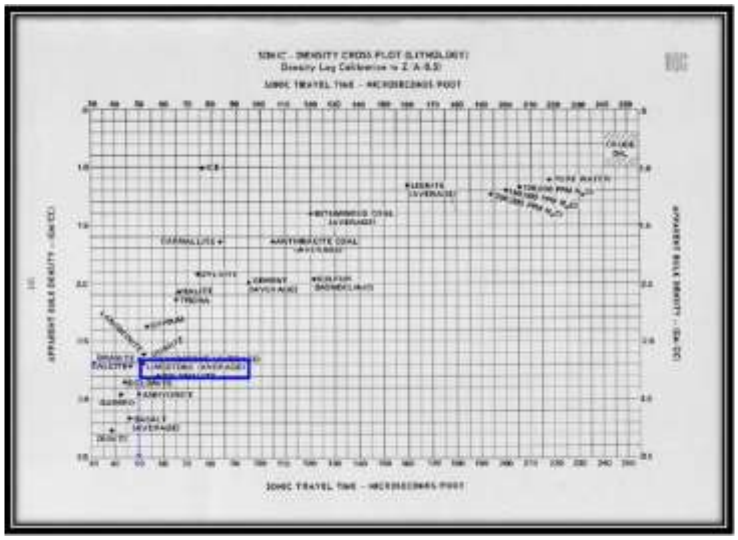


Figure 4.9: Crossplot between Sonic log and Density log (www.welllog.com)

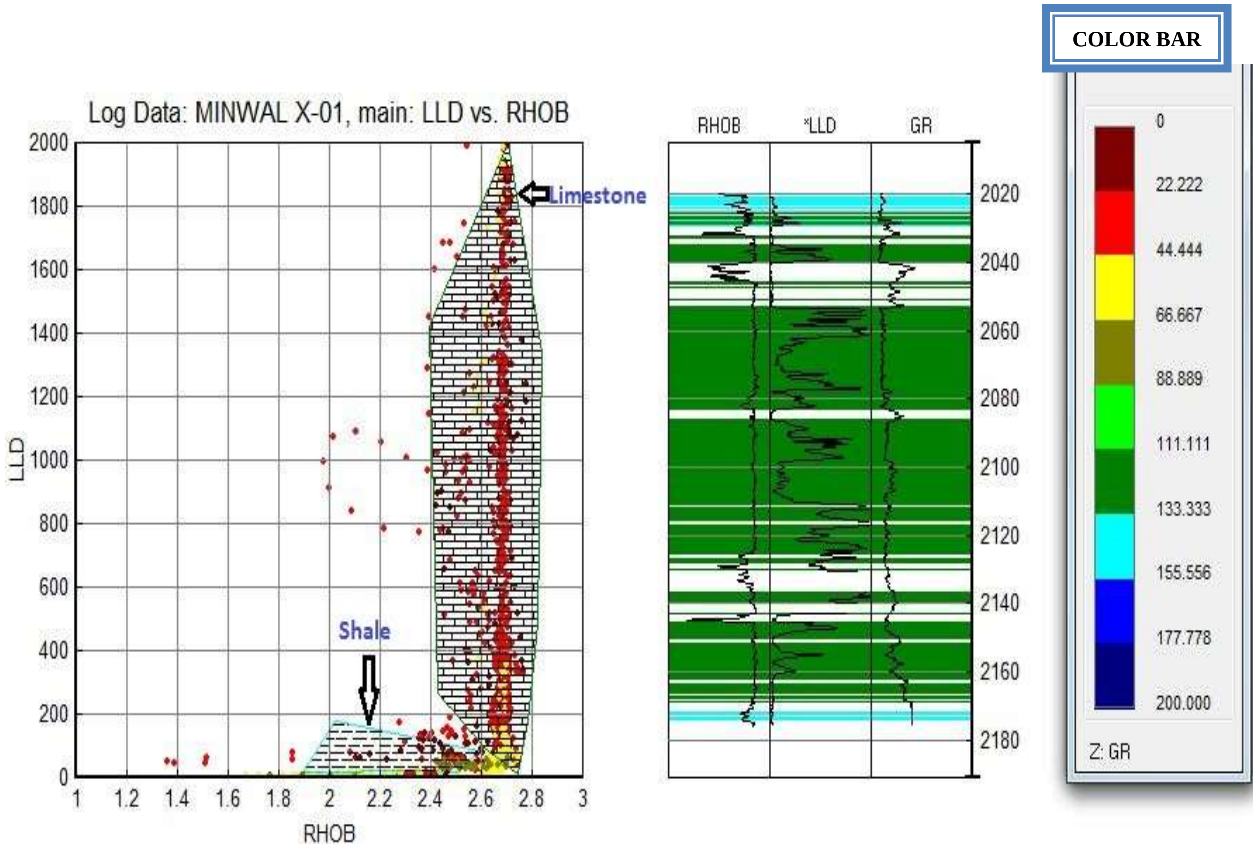



Figure 4.10: Cross plot between LLD and Density log of well Minwal X-01

## Summary and Conclusions

The following conclusions can be drawn from the work carried out in this dissertation.

- Time and Depth contour maps of Chorgali help us to confirm the presence of anticlinal structure in the given area. Surface contour map of Chorgali gives the real shape of sub-surface structure, which isa Triangle zone bounded by forethrust and back thrust faults.
- This anticlinal structure acts as a trap in the area, which is best for hydrocarbon accumulation. This shows that the study area is dominated by compressional tectonic forces.
- The pseudo-synthetic trace is generated via well data that confirms the marking of right seismic sections.
- The Depth Section is further confirmed by correlation with Synthetic Seismogram Generated from Sonic Log & Formation Tops of well Minwal x-01.
- Correlation of depth converted sections with formation tops and synthetic seismogram indicate that Chorgali limestone is the reservoir and Patala shale are the source rocks.
- The structure is closed on two sides by bounded faults and on the remaining two sides closed by providing contours of same time and depth values.
- Petrophysical analyses of the reservoir show the hydrocarbon potential of the well by calculating the various physical properties.
- Faciesanalysis confirm the presence of limestone as the dominant reservoir in the area.
- Study of attribute analysis confirm our 2D seismic interpretation and give us an idea about the promising zone of interest.

## Refrences


- Aamir, M., and M., M., Siddiqui, 2006. Interpretation and visualization of thrust sheets in a triangle zone in eastern Potwar,Pakistan. The Leading Edge, p. 24-37.
- Al-SadiH.N. (1980), "Seismic Exploration Technique and Processing", BirkhauserVerlag, Boston.
- Bust, V. K., Majid, A. A., Oletu, J. U., & Worthington, P. F. (2013). The petrophysics of shale gas reservoirs: Technical challenges and pragmatic solutions. Petroleum Geoscience, 19(2), 91-103.
- Bodine, J.H., 1984, *Waveform analysis with seismic attributes:* Presented at the 54th Annual International Meeting of the S.E.G. in Atlanta, Georgia.
- 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
- Barnes, A.E., 1992, *Instantaneous spectral bandwidth and dominant frequency with applications to seismic reflection data:* Geophysics.
- B. Farid, V. Heine, G. E. Engel, I. J. Robertson, Phys. Rev. B48, 11602 (1993).
- Castagna, J.P., Batzle, M.L., and Eastwood, R.L., 1985, Relationships between compressional-wave and shear-wave velocities in clastic silicate rocks. Geophysics, V.50, pp.571-581.
- Chopra, S., and Marfurt, K., 2006. Seismic attributes – a promising aid for geologic prediction, CSEG Recorder, p.110-121.
- Cohen, L. 1995, *Time-Frequency Analysis,* Prentice-Hall Signal Processing Seies.
- Clavier, C. and Rust, D.H. 1976. MID Plot: A New Lithology Technique. The Log Analyst **17** (6): 16–24.
- DobrinM.B&SavitC.H. (1988), "Introduction To Geophysical Prospecting", 4th Edition, McGraw-Hill Book Company,  London, 49-50.
- Exploration", Pakistan journal of hydrocarbon research, vol. 14 , June 2004, P. 49-59, Pakistan.
- Fatmi, A.N., Akhtar, M., Alam, G.S and Hussain, I., 1984. Guide book to Geology of Salt Range. First Pakistan geological congress, Lahore, Geol. Surv. Pak. 14.

- Geographic Information Systems In Petroleum Exploration And Development, AAPG Book on Computers and Geology, p.215-226.
- Gadallah, J., and Fisher, I., 2009. Exploration Geophysics, Springer-Verlag Berlin Heidelberg. DOI: 10.1007/978-540-85160-8.
- Gee ER (1989) Overview of the geology and structure of the Salt Range, with observations on related areas of northern Pakistan.In: Malinconico LL, Jr. Lillie RJ, (eds.) Tectonics of the western.Himalayas. GeolSoc Am Spec Pap. 232: 95–111.
- Ghazanfar, M., 1993.Petrotectonic elements and tectonic framework of northewestHimalaya.Ph. D. thesis,University of the Punjab, 1 and 2, p. 1-380.
- Hasany, S.T., and Saleem, U., (2001), An Integrated Subsurface, Geological and Engineering Study of Meyal Field, Potwar Plateau, Pakistan.
- Jaume, S.C. and Lillie, R.J., 1988. Mechanics of the Salt Range-Potwar plateau, Pakistan. M.S. Thesis, Oregon State University, Corvallis, Oregon, USA, p. 63.
- Jadoon, W.A.K., B.A. Shami, and I.A. Abbasi., 2003, Fracture analysis of Khaur anticline and its implications on subsurface fracture system. PAPG-SPE Annual Technical Conference and Oil Show 3-5 October, 2003,Islamabad, Pakistan, p. 235-250.
- Jaswal, T., R.J. Lillie and R.D. Lawrence, 1997. Structure and evolution of northern Potwar deformed zone, Pakistan.Am.Assoc. Geol. Bull., v.81, p. 308-318.
- Jaswal,T.M., Robert ,J. Lillie., and Robert ,D. Lawrence., 1997, Structure and Evolution of the Northern Potwar Deformed Zone, Pakistan. AAPG Bu lletin, Volume 81.
- Jadoon, I. A. K., Frisch, W., and Jadoon, M. S. K., 2008, Structural Traps and Hydrocarbon Exploration in The Salt Range / Potwar Plateau, North Pakistan, in SPE – Annual Technical Conference and Oil show 2008-Islamabad, Pakistan.
- Khan, K.A., 2000, Integrated Geo Systems - A Computational Environment For Integrated Management, Analysis And Presentation Of Petroleum Industry Data, In: T. C. Coburn And J. M Yarus (Eds.).
- Khan, K.A., Akhter, G., and Ahmad, Z., 2010, OIL - Output Input Language for Data Connectivity between Geoscientific Software Applications, Computers & Geosciences, Vol 36, p. 687-697 .

- Khan, K. A., Akhter, G., Ahmed, Z., Khan, M.A., and Naveed, A., 2006, Wavelets - A Computer Based Training Tool for Seismic Signal Processing, Pakistan Journal of Hydrocarbon Research, Vol. 16, p.37-43.
- Geophysical well logging,SchlumbergerLimited,Log interpretation, Volume 1, Schlumberger, 1974.
- Sroor, M. (2010). Geology & Geophysics in Oil Exploration (p. 33).
- Sheriff, R.E., 1999. Encyclopedic dictionary of exploration geophysics, S.E.G., Tulsa, Oklahoma.
- Sheriff R.E., (1999), "Exploration Seismology", ($2^{nd}$ edition), Cambriage University Press, USA.
- Telford, W.M., Geldart, L.P., Sheriff, R.E., and Keys, D.A., 1999, Applied Geophysics, Cambridge University Press, London.
- Wyllie, M. R. J., Gardner, G. H. F., and Gregory, A. R., 1963, Addendum to studies of elastic wave attenuation in porous media: Geophysics, 28, 1074. doi:10.1190/1.1439306.

**Internet search:**

- www.gps.com.pk
- www.glossary.oilfield.slb.com
- www.googlearth.com
- www.article.sapub.org
- www.hkss.cedd.gov.hk
- www.welllog.com
- www.wiki.aapg.org/Reserves_estimation
- www.gsp.pk.com.