2D SEISMIC DATA INTERPRETATION INTEGRATED WELL DATA CHARACTERIZATION OF JOYA MIR, UPPER INDUS BASIN, PAKISTAN

BY

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Abstract

This dissertation is based on structural and stratigraphic interpretation of SEG-Y data format using seismic techniques and well log analysis. The Joya Mir area lies in the upper Indus Basin in south east of Salt Range-Potwar Foreland Basin. It has hydrocarbon potential due to its anticlinal structures. For Seismic structural interpretation three horizons and two reverse faults were marked by using IHS Kingdom 8.8 version and construction of fault polygon, time contours and depth contours takes place. The marked horizons were recognized using formation tops from wells and their depths were confirmed through correlation with synthetic seismogram. The purpose of time and depth contour maps was to understand the spatial geometry of the structures and the nature of geological structures as identified by the seismic section of the area. Seismic interpretation of the 2D data reveals that the study area has undergone severe deformation illustrated by the development of thrusts and back thrusts forming a triangle zone in the subsurface.The general trend of these structures is northwest-southeast which indicated that the area lies in compressional regime. The reservoirs of Eocene occurs at depth of about 2020.48 m from well tops. The interpreted horizons are Chorgali Formation and Sakesar Formation, which has the major petroleum potential in the study area. Petrophysical analysis of Minwal X-1 well indicated the hydrocarbon potential in marked reservoirs and gave approximately 67% of hydrocarbon saturation. Rockphysics validates the petrophysical results.Facies modelling marks the dominant lithology .Colored inversion also validates the hydrocarbon potential in reservoir zone.

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CHAPTER 1
INTRODUCTION

1.1 Introduction to Hydrocarbon exploration

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 Introduction to the Study Area

The Joya Mir Oilfield lies in the south-southeast of the Salt Range-Potwar foreland basin (SRPFB). It is the result of Tertiary Himalayan collision between the Indian Plate and Eurasian plate in late Eocene and characterized by number of Reverse and Thrust Faults which formed the structural hydrocarbon traps. Joya Mir structure is the combination of thrust and back-thrust, forming a triangle zone at subsurface. The triangle zone is the result of two phases of Himalayan thrusting. Stratigraphically it comprises of a petroleum play in which Patala Formation of Paleocene age act as a source rock while Chorgali and Sakesar Formation of Eocene age are two major reservoirs and Murree Formation of Miocene age is acting as a seal in the study area.

1.3 Location of the study area

The study area lies in Chakwal district in the South-west of Capital Islamabad city located 105 km away from Islamabad. It is a small village covering an area 2550 square km. The area lies in UTM (Universal Transverse Mercator) zone 42^o N in the world Geodetic System. The coordinates in degrees, minutes and seconds are **Latitude 32º 59′ 52″ N** and **Longitude 72º 82′ 31″ "E.**

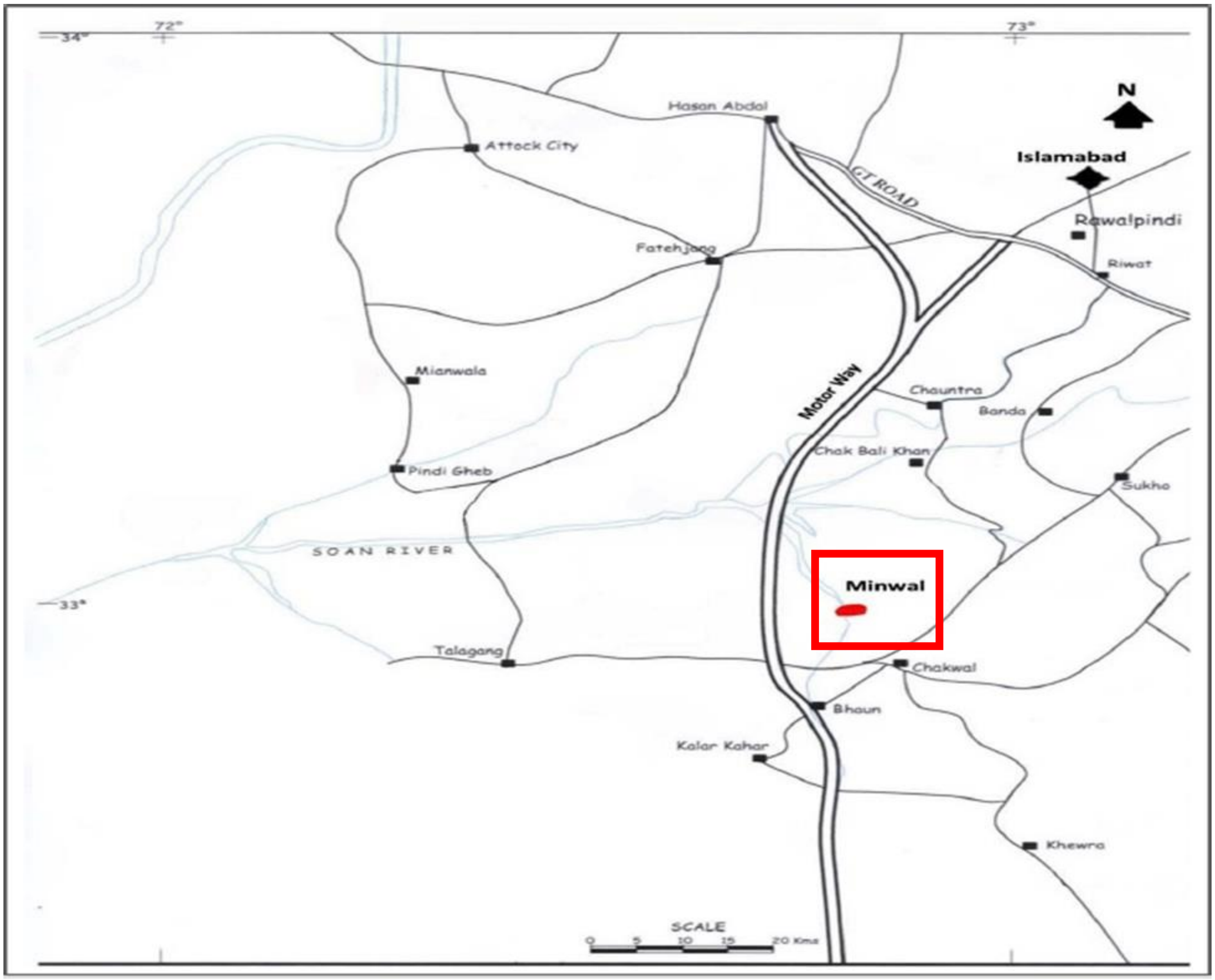


Figure 1.3 Location map of study area (Mehmood, 2008)

1.4 Geographical Boundaries

Geographically Joya Mair 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 extra continental watersheds, which account for 48% of the world's known oil resources (Hasany&Saleem, 2001).The study area is shown in figure 1.3.

1.5 Geological Boundaries of Potwar Basin

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).

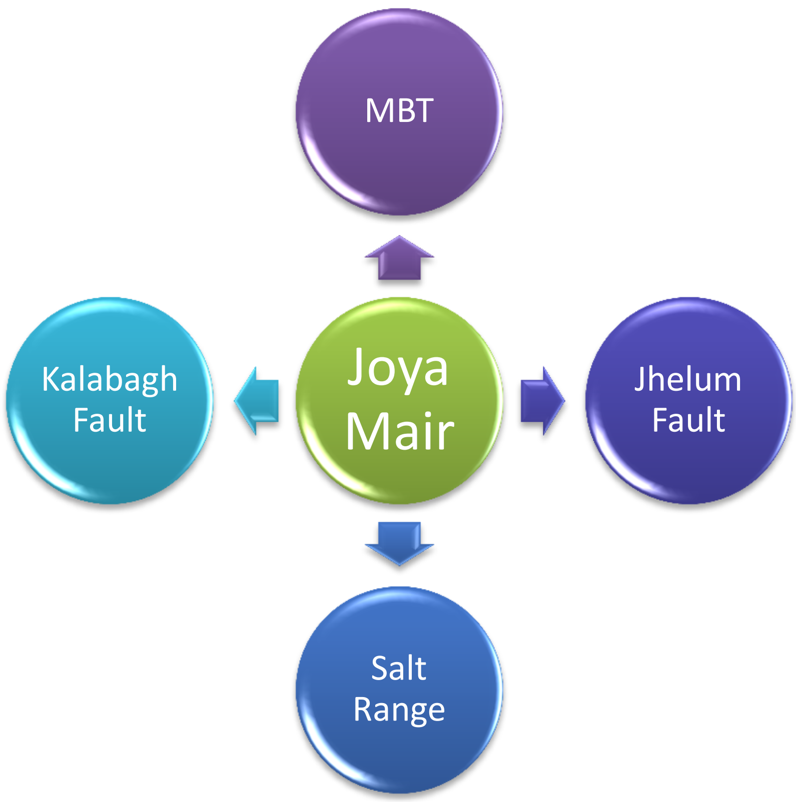


Figure 1.5 Geological Boundaries of Joya Mir Area

1.6 Prospectivity Zonation of Pakistan

The country has been divided into zones based on their relative prospectively 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 Mir area lies in zone-II which is medium risk - high to medium cost areas.

1.7 Previous work history

First commercial oil in the Potwar area was produced from the Miocene (Murree Formation) at Khaur in 1915 (Kazmi and Jan 1995) .At the time of independence (1947), Pakistan inherited four productive fields, Khaur, Dhullian, JoyaMair and Balkassar. Traces of hydrocarbons occur in several other localities, and exploration continues in Punjab, Sindh and Baluchistan by arrangement between various foreign companies and the Oil and Gas Development Corporation (OGDC).

Joya Mair 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 Mir. Minor oil production comes from Paleocene Lockhart Formation.

1.8 Exploration and production Information:

Following is the production and exploration information of Joya Mir oil fields.

Table 1.8 Production information of Joya Mir oil field

Recoverable reserves	Oil=38.37 MMstb , Gas =234.86 MMscfd
PPL working interest	100 percent
Operator	POL
Peak production	3700 BOPD in 1965
License Area	149.13 Sq Km

1.9 Data set used in current study

The well data used in current study is Minwal X-1 along with the five Seismic lines, including three dip lines and two strike lines mentioned below in Table 1.6. The data has been acquired from the Directorate general of petroleum concession (DGPC). The trend of the seismic dip and strike lines in SE-NW and SW-NE respectively.

Table 1.9 Data Set

LINE NUMBER	LINE TYPE	LINE DIRECTION	WELL
POL93 MN 08	Dip Line	NW-SE	Minwal X1

POL93 MN 06	Dip Line	NW-SE	
POL93 MN 05	Dip Line	NW-SE	
POL93 MN 10	Strike Line	NE-SW	
POL93 MN 11	Strike Line	NE-SW	

1.10 Well Data Type

The well data includes the following files:

- LAS files
- Navigation files
- Well tops

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.

1.11 Well Tops Information.

Table 1.11

Formation Top	Formation Top Age	Formation Top Value	Thickness (m)
Nagri	Pliocene	0.0	231.74
Chinji	Miocene	231.74	680.87
Kamlial	Miocene	912.61	87.5
Murree	Miocene	1000.11	1020.37
Chorgali	Eocene	2020.48	33.76
Sakesar	Eocene	2054.24	121.995

1.12 Aims and objectives

The main objective of research was to reveal the structure of the area and hydrocarbon prospect with the help of available 2D seismic data.

The main objectives of the current study are the following

- Detailed seismic interpretation for identification of structures favorable for hydrocarbon accumulation, which mainly includes:
  - To construct the Base map of Study area.
  - To mark the Horizons and Structure on the seismic Section by using well data.
  - To construct the synthetic seismogram.
  - Generation of time and depth contour maps
- Petro physical analysis to infer the reservoir properties.
- Rock physics evaluation for reservoir zone.
- Facies modeling for validation of petro physical analysis.
- Depositional environment from sequence stratigraphy using well log data
- Seismic colored inversion for impedance analysis.

1.13 Work Flow adopted:

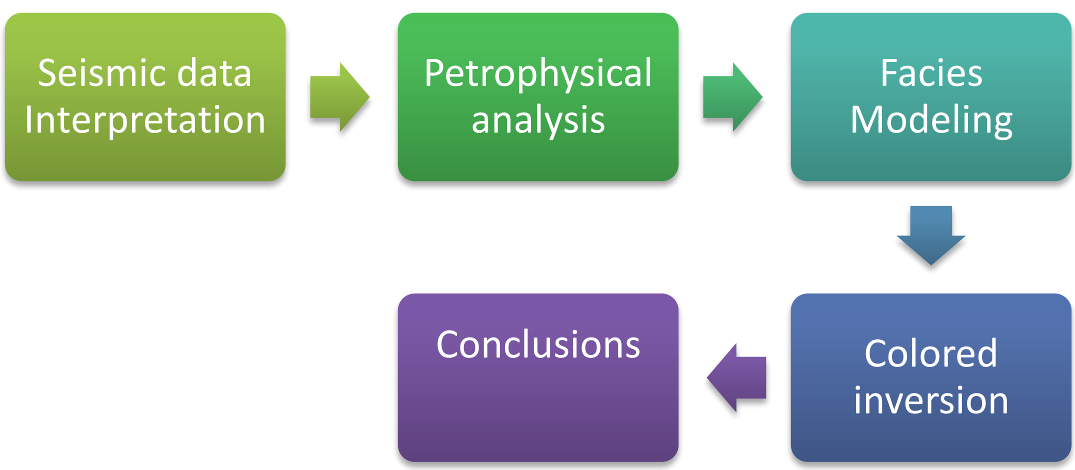


Figure 1.13: Workflow adopted for thesis

CHAPTER 2

REGIONAL TECTONICS AND STRATIGRAPHY

2.1 Regional Tectonics

The Himalayan Orogenic belt is the youngest mountain belt in the world which came into existence as a result of collision between the Indian plate in the south and Eurasian plate in the north. The site of collision is considered to be a broader zone and marked by the Himalayan-Kurrakuram-Hindukush ranges in northwestern Pakistan (McDougal and Hussain, 1991). The Himalayan along with associated mountain chain trend east-west, switching to a more north-south trend in the west. Beginning about 55 Ma ago, collision of the indo-Pak sub-continent with Eurasia plate produced the Himalayan Orogenic belt which is considered to be a broader zone. They include Meta sedimentary and igneous rock of the southern Asian plate emplaced over the rock of Kohistan island arc along main Kurrakuram Thrust (MKT) during late cretaceous (Butler et al. 1985). Kohistan island arc terrain is composed of metamorphic and basic to ultra-basic rocks which are thrusted over northern margin of Indian plate along Main Mantle Thrust (Tahir kheli et al. 1979). The foreland consisting of telescoped igneous, sedimentary and metamorphic rocks of the northern Indian cratonic foreland basin is marked by Main Boundary Thrust (MBT) in the south. The MBT extends westward from the front of main Himalayan range around Hazara Kashmir syntaxes and thrust the hill ranges over the Kohat-Potwar foreland basin. The main boundary thrust system contains highly deformed Pre-Cambrian-Cenozoic sedimentary rocks which progressively become younger southward. The Kohat- Potwar foreland basin contains deformed Paleocene-Pleistocene sedimentary sequence bounded by the Salt Range Thrust (SRT) in Potwar plateau and the southern boundary of Trans Indus Range and the unreformed Bannu basin in Kohat plateau. The un-deformed foreland or indo-gigantic plain lies south of the Salt Range and Trans-Indus ranges and is the present day depocenter for the Himalayan shed.

The northwest Himalayas in Pakistan can be divided into four tectonomorphic terrain which is separated by major fault systems. These four tectonomorphic terrains are from north to south which is as under

- Main Karakoram Thrust (MKT).
- Main Mantle Thrust (MMT).
- Main Boundary Thrust (MBT).
- Salt Range and Trans Indus Ranges Thrust.

2.2 Sedimentary Basins of Pakistan:

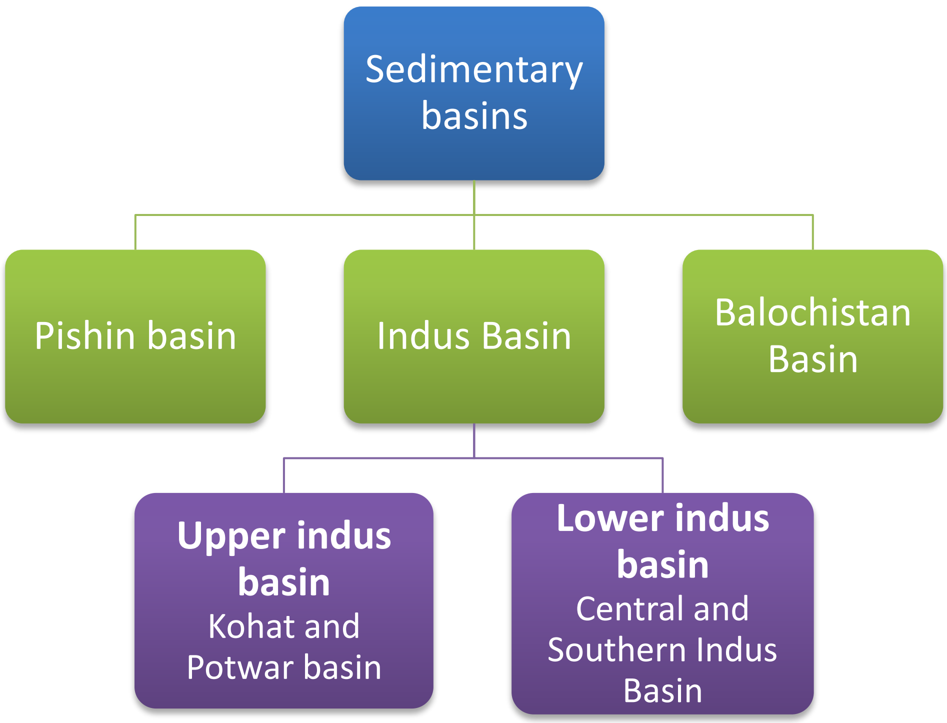


Figure 2.2 : Sedimentary basins of Pakistan.

2.3 Local Tectonic of Study area

The Potwar Plateau is comprises of less internally deformed fold and thrust belt having a width of approximately 150 km in N–S direction. The Potwar Plateau comprises of undulated terrains and topography. The Potwar sub basin is tectonically situated directly below the western foothills of Himalayas and falls in Potwar Plateau. It is bounded in the north by Main Boundary Thrust (MBT) and to the east by Jhelum left lateral strike slip fault and to the south by Salt Range Thrust and to the west it is bounded by Kalabagh right lateral strike slip fault. (Aamir and Siddiqui, 2006).

2.4 Tectonic boundary of Potwar Plateau

The Potwar is bounded by the following two strike-slips and two thrust faults which are as under.

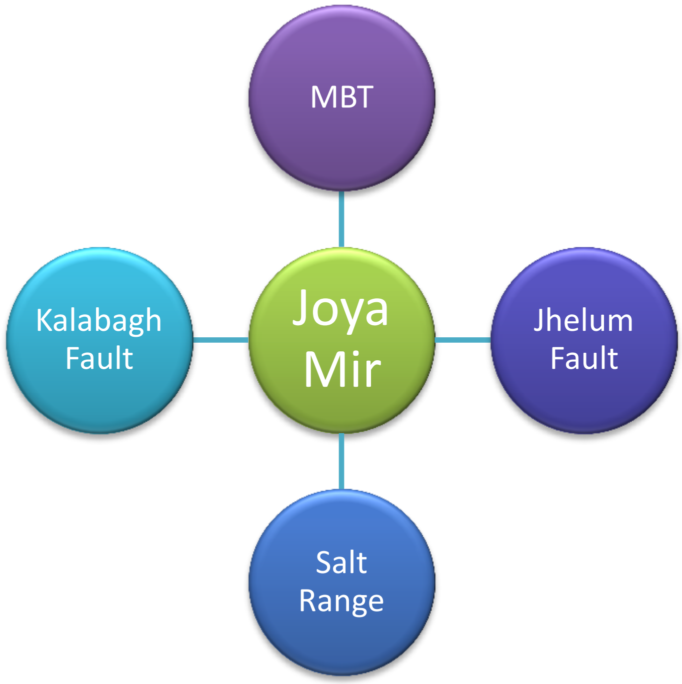


Figure 2.4 Tectonic boundary of potwar plateau

Kalabagh fault

It is right lateral strike-slip fault and its direction is from north to west 150 km which can be seen as faulted block. It lies in the north of the Kalabagh City, Mianwali and is the Trans-Indus extention of Western Salt Range (McDougal & Khan, 1990)

Jhelum Fault

Extending from Kohala to Azad Pattan the Murree is hanging while Kamlial, Chingi and Nagri formations are on the footwall. Starting from the Indus-Kohistan to Ravi it is the active aspect of the Indian Shield. It is seen in the map that MBT, Panjal Thrust and HFT cut shortened by left-lateral reverse Jhelum Fault in west (Baig, Lawrence, 1987).

Salt Range Thrust

It is also known as Himalayan Frontal Thrust. Salt range and Trans-Indus Himalayan ranges are the Foothills.

Main Boundary Thrust

The MBT which lies in the north of the Islamabad is called as Murree fault. The western part of this fault is orienting to north east forming non-striking fault in its western part i.e. Hazara Kashmir-Syntexis (Latif, 1970; Yeats and Lawrence, 1984: Greco, 1991) also this fault strike the in the direction of east moving in the direction of Southern side of Kala chitta Range and North of Kohat plateau (Meissner et at, 1974).

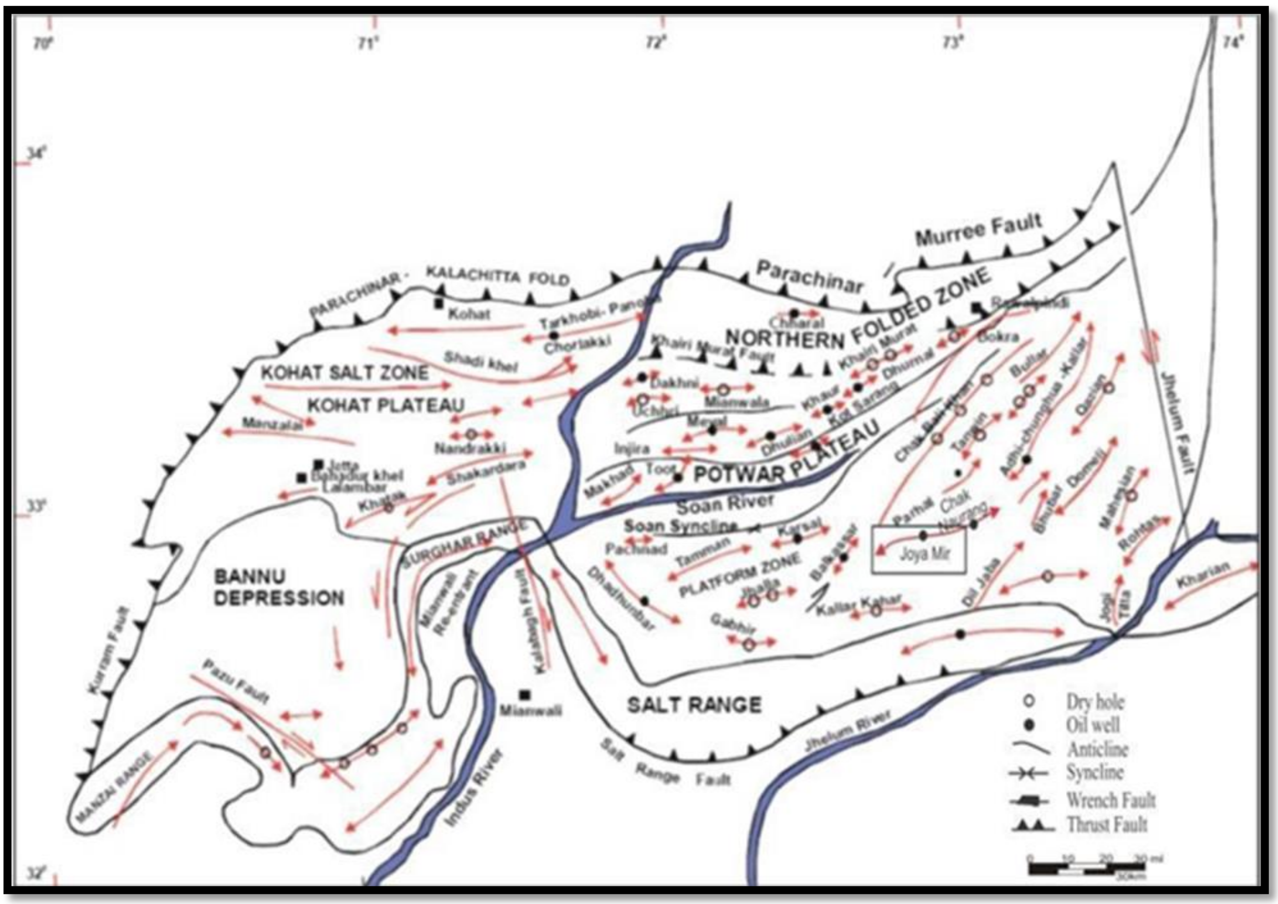


Figure 2.4: Tectonic map of Pakistan (after Shami,1998)

According to the seismic interpretation subsurface geological structures found in Potwar region may be classified into.

1. Pop-up anticlines
2. Snake head anticlines
3. Salt cored anticlines
4. Triangle zone

Minwal X-1 lies in near Joya Mir. This region is active area for oil and gas exploration and production. This Well is drilled by POL drill on the Joya Mir in North Eastern limits of the structure. The location of the well was at SP Seismic Line No: 93-MN-08. The Eocene Bhadrar and Sakesar formations were the primary objective. The well is located in the high fractures reservoir which could contribute in an excellent well productivity. Structurally it is a broad anticline with its axis running SW-NE direction. The limbs of the anticline are in the SW. direction. The Northern limb showing dips which are steeper as compared to the Southern limb, which are slightly gentler.The dips of the Northern limb are in between 50° - 60° while that of Southern limb shows 55° - 75°dips. On the NE side, the anticline is separated by Chak Naurang-Wari fault which is a major fault in the area.

2.5 Stratigraphy of study area

The stratigraphic column is divided into three unconformity-bounded sequences. These unconformities in the study area are Ordovician to Carboniferous, Mesozoic to Late Permian, and Oligocene in age. The Potwar sub-basin is filled with thick infra-Cambrian evaporite deposits overlain by relatively thin Cambrian to Eocene age platform deposits followed by thick Miocene-Pliocene molasses deposits. This whole section has been severely deformed by intense tectonic activity during the Himalayan orogeny in Pliocene to middle Pleistocene time.

2.5.1Paleocene Patala Formation

The Patala Formation overlies the Lockhart Formation conformably and its type section is in the Patala Nala in the Western Salt Range (Davies and Pinfold, 1937). It is acting as a source rock in the study area. It consists largely of shale with sub-ordinate marl, limestone and sandstone. Marcasite nodules are found in the shale. The formation also contains coal, and its thickness ranges from 27m to over 200m (Warwick, 1990). It contains abundant foraminifera mollusks and ostracods (Davies & Pinfold, 1937, Eames, 1952, and Latif,1970). The age of the Patala Formation is Late Paleocene.

2.5.2 Eocene Namal Formation

It comprises grey to olive green shale, light grey to bluish grey marl and argillaceous limestone. In Salt Range, these rocks occur as alteration. In Surghar Range the lower part composed of bluish grey marl with interbedded calcareous shale and minor limestone while upper part consists of bluish grey to dark grey limestone with intercalation of marl and shale. It type locality is Nammal Gorge Salt Range, Punjab and thickness of thisformation is 100m at type locality. Its age is early Eocene.

2.5.3 Eocene Sakesar Formation

With increase in limestone beds, the Nammal Formation transitionally passes into the overlying Sakesar Formation, the type locality of which is the Sakesar Peak (Gee, 1935 and Fatmi, 1973). It is acting as reservoir rock in Joya Mir area. It consists of grey, nodular to massive limestone, which is cherty in the upper part. Near Daudkhel, the Sakesar Formation laterally grades into massive gypsum. Its thickness ranges from 70m to about 450m. Its age is early Eocene.

2.5.4 Eocene Chorgali Formation

The Chorgali Formation rests conformably over the Sakesar Formation (type locality Chorgali Pass) (Pascoe, 1920 and Fatmi, 1973). It consists largely in the lower part, of thin-bedded grey, partly dolomitized and argillaceous limestone with bituminous odor, and in the upper part, of greenish, soft calcareous shale with interbreeds of limestone. Its thickness ranges from 30m to 140m.It contains molluscs, ostracods and foraminifera.The age of the Chorgali Formation is Early Eocene. It is overlain unconformably by the Neogene sequence.

2.5.5 Miocene Succession Murree Formation

The type section of Murree Formation is in north of Dhol Maiki. Murree Formation is composed of thick monotonous sequence of red and purple clay and interbedded greenish sandstone with sub-ordinate intra-formational conglomerate (Wynne, 1873). The thickness of the formation increases from180m to 600m in the Salt Range to 3,030m in the northern Potwar area.

It is poorly fossiliferous though plant remains and some vertebrate bones have been found. This fauna indicates early Miocene age of the Murree Formation.

2.5.6 Miocene Kamlial Formation

The type section of Kamlial Formation is in the southwest of Kamlial, the formation overlies the Murree formation conformably and transitionally at some localities lies unconformably on the Eocene Sakesar Formation (Pinfold, 1918, Lewis, 1937, Fatmi, 1973 and Cheema et al., 1977). The formation consists mainly of grey to brick red, medium to coarse grained sandstone interbedded with purple shale and intraformationalconglomerate. A number of mammalian fossils have been found (Pascoe, 1963). The age of the Kamlial Formation is middle to late Miocene.

2.5.7 Pliocene Succession (Siwalik Group)

Chinji formation

The type locality of Chinji formation is South of Chinji, Campbellpur, Punjab, and its lithology comprises of Clay, sandstone with minor siltstone. According to Shami and Baig thickness of this formation is 750m at type locality. The age of Chinji formation is Late Miocene to early Pliocene.

Nagri Formation

Nagri village, Campbellpur District, Punjab is the type section of the Nagri Formation. Its lithology comprises of salt, conglomerate, clay. Thickness of this Formation ranges from 200m-3000m. Its age is early Pliocene.

Table 2.5 : Generalized stratigraphy of Joya Mir field

AGE	FORMATION	ENVIRONMENT
Pliocene	Nagri	Fluvial Channel
	Chinji	Fluvial Stream Channels
Miocene	Kamlial	Fluvial

	Murree	Fluvial
Oligocene	Unconformity	
Eocene	Chorgali	Shallow Marine Supra tidal Lagoonal
	Sakessar	Shallow Marine Supratidal Lagoonal
	Nammal	Shallow Marine Restricted Anoxic
Paleocene	Patala	Shallow Marine
	Lockhart	Shallow Marine (Distal to Proximal)
	Hangu	Shallow Marine (Littoral to Paludal)
Cretaceous	Unconformity	
Jurassic		
Triassic Late Permian		
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

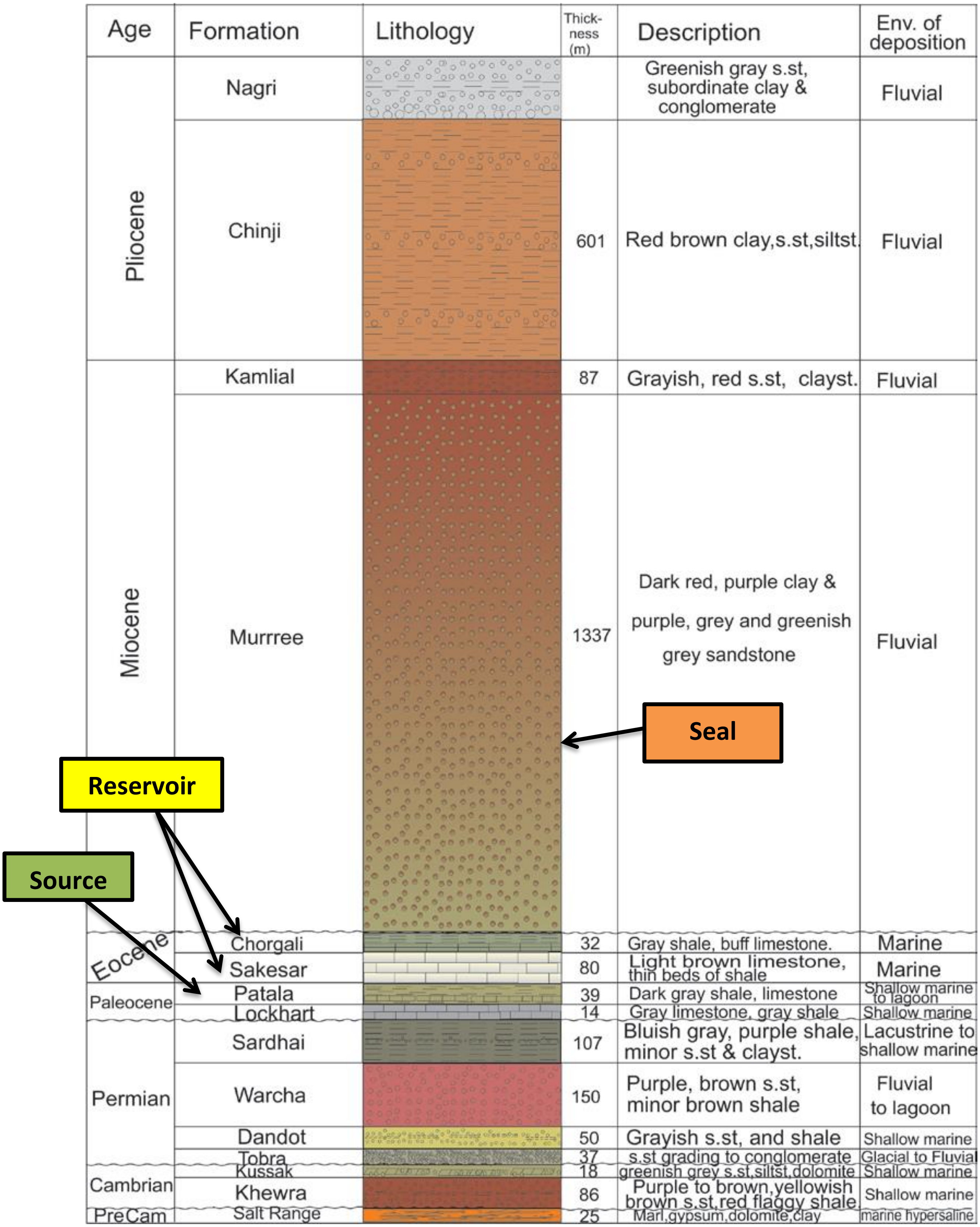


Fig. 3. Stratigraphic column of the Joya Mair area (after Shami, 1998).

2.6 Petroleum geology of the area.

The geological history of this basin begins from Precambrian age. East of Potwar Plateau is salt-cored anticlines which are separated by the wide synclines. Tanwin-Bains-Buttar and Joya Mir-Chak Naurang-Adhi-GungrillaKallar are such major Anticlines of Potwar Plateau. The cores of these salt anticlines are thrusted and originated due to the compression of Himalayan orogeny in Miocene-Pliocene age. The oil and gas in the area has been produced from the fractured carbonates of Paleocene and Eocene age but Mesozoic sandstone and Paleozoic carbonates has produced additional oil (Ahmed, 1995) in the area.

2.6.1 Petroleum system

- **Reservoir**

The main oil producing reserviors in Minwal are the Cambrian, Permian, Jurassic, Paleocene and Eocene age successions. Primary porosity is lower in these reservoirs as compare to the secondary porosity. The main oil producing reservoirs in Minwal area are fractured carbonates which are of Sakesar and Chorgali Formations. The massive light yellow gray and partly dolomitized of Sakesar limestone contain chert. The Chorgali Formation is creamy yellow to yellow gray, silty, partly dolomitic and thin bedded limestone. It was deposited in intratidal conditions dominated environment. (Shami and Baig, 2002).

- **Source Rock**

The potential source rock in Minwal is the grey shales of Mianwali Formation, Datta Formation and Patala Formation. The Eo-cambrian Salt Range Formation contains oil shales with 27%-36% TOC in isolated pocket of shales are the source rock in the Salt Range Potwar Foreland Basin (Shami and Baig, 2002).In Potwar, the TOC 1.57 and hydrogen Index of 2.68 in shales have been observed (Porth and Raza, 1990). Patala formation is the key source rock of oil production in Potwar sub-basin according to the oil to source correlation.

- **Cap Rock**

The thin-skinned tectonics has developed the traps creating the faulted anticlines, pop-up and positive flower structures above Pre-Cambrian salt. The lateral and vertical seal to Eocene reservoir is provided by the Murree Formation's clays and shales (Shami and Baig, 2002).

- **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 Ro range. Dry gas generation begins near at 1.3 percent Ro.

- **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 up dip and vertically into adjacent reservoirs and through faults and fractures associated with plate collision and thrusting.

Table 2.6.1: Generalized Petroleum System

Formation	**Rock type**
Murree	Seal
Chorgali	Reservoir
Sakesar	Reservoir
Patala shales	Source

CHAPTER 3

SIESMIC DATA INTERPRETATION

3.1 Seismic data interpretation

The final step in seismic study of an area is to interpret the processed seismic section so that a geological model of sub-surface can be developed. The objective of seismic reflection interpretation is to study the subsurface structures that help in discovering the hydrocarbon accumulation. As science has not yet discovered the direct method of finding the oil and gas, or of assessing the quantities of hydrocarbons in the subsurface, so the seismic reflection method only indicates the geological situations where the hydrocarbons can accumulate.

Seismic interpretation is the transformation of seismic reflection data into a structural picture, contouring of subsurface horizons and further depth conversion by applying some suitable velocities. The ultimate goal is to detect the accumulations of hydrocarbons delineate their extent, and calculate their volumes.

3.2 Methods for the Interpretation:

The main methods for the interpretation of the seismic section are.

1. Structural Analysis
2. Stratigraphic Analysis

3.2.1 Structural analysis

It is the study of reflector geometry on the basis of reflection time. The key use of the structural analysis of seismic section is in the search for structural traps containing hydrocarbons. Most structural interpretation uses two-way reflection times rather depth. And time structural maps are constructed to display the geometry of selected reflection events. Some seismic sections contain images that can be interpreted without difficulty. Discontinues reflections clearly indicate faults and undulating reflections reveal folded beds.

3.2.2 Stratigraphic analysis:

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

3.3 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 figure 3.3

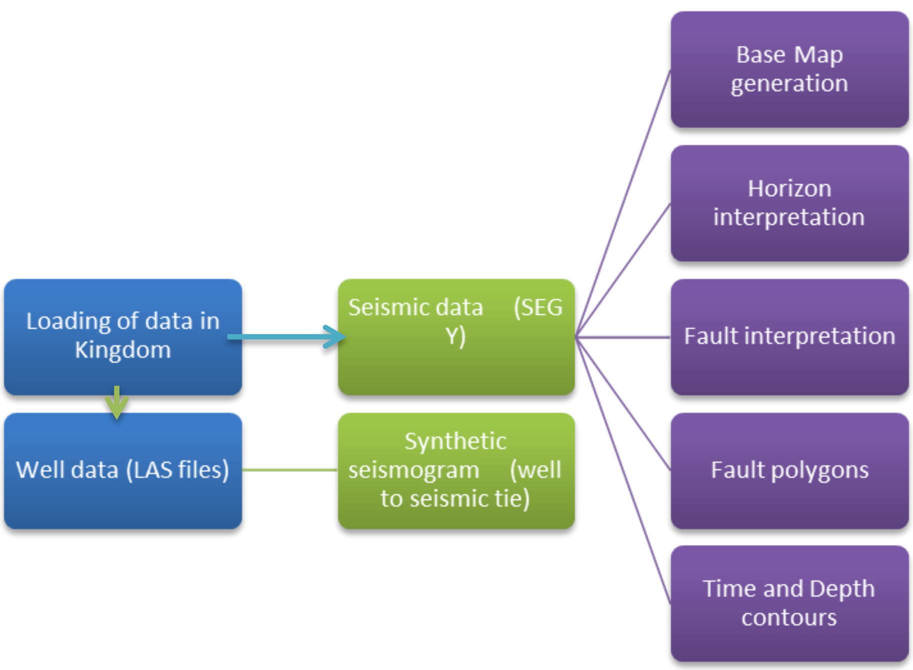


Figure 3.3: Work flow adopted for the seismic data interpretation

3.4 Structural Interpretation of Joya Mair Area

Seismic interpretation of Joya Mir area involves five seismic lines.While interpreting these seismic lines, structural changes is observed.Mainly indicating thrust and reverse faults. These structures are results of compressional forces as it falls in the compressional regime. Mostly the structures present in this area are anticlines folds and thrust faults along with triangular zones and pop-up structures.

3.5 Data assigned for interpretation

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

LINE NUMBER	LINE TYPE	LINE DIRECTION	WELL
POL93 MN 08	Dip Line	NW-SE	Minwal X1
POL93 MN 06	Dip Line	NW-SE	
POL93 MN 05	Dip Line	NW-SE	
POL93 MN 10	Strike Line	NE-SW	
POL93 MN 11	Strike Line	NE-SW	

3.6 Base Map Generation

The base map is an important component of interpretation. For a geophysicist a basemap 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.

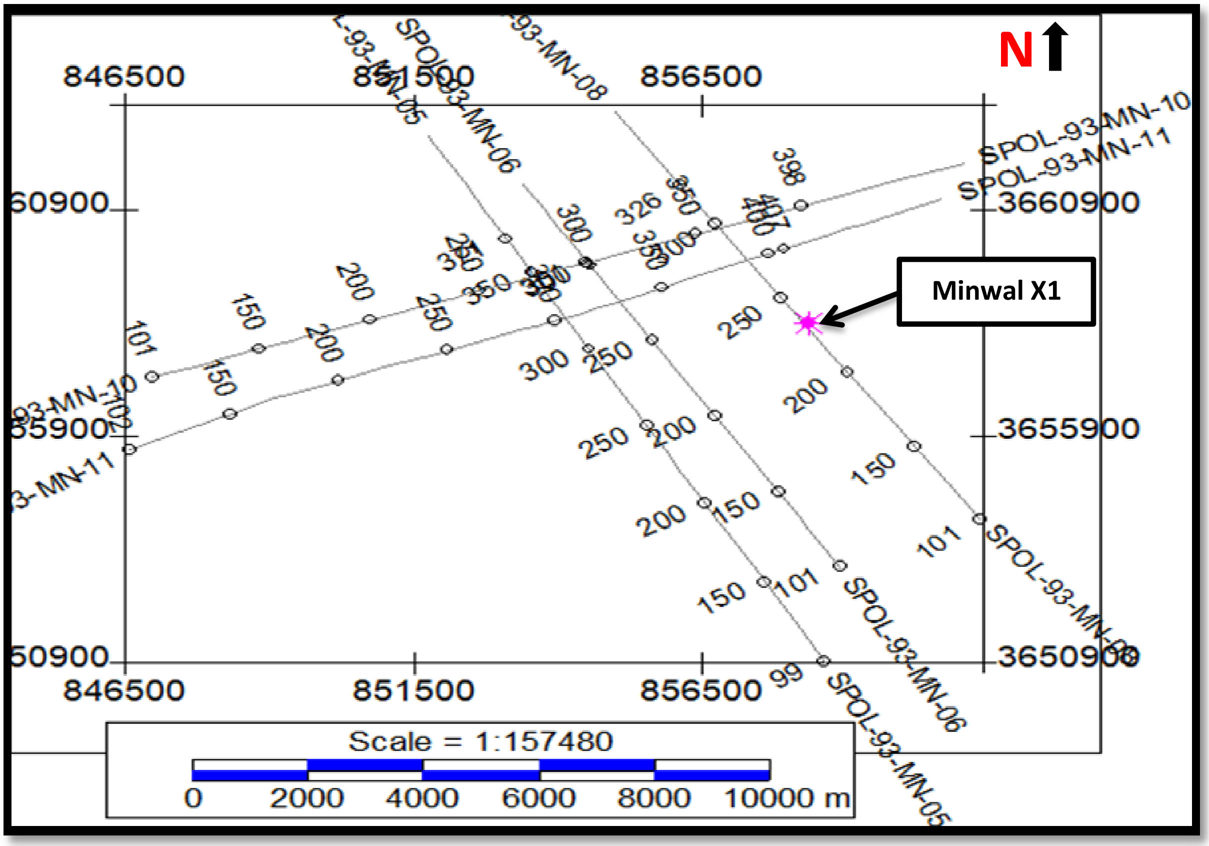


Figure 3.6: Base map of Joya Mir

3.7 Generation of Synthetic Seismogram:

Synthetic seismogram is convolution of reflection coefficient from well data and the source wavelet. The purpose of generating the synthetic is to 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 three horizon were marked on the line. Then by tie marked seismic line with other lines and horizons are marked on these lines. Well to seismic tie is an efficient way to mark the prospect zone. The time section gives the position and configuration of the reflectors in the time domain. However, the objective is to target the rock formations of the reservoir.The synthetic is displayed in figure 3.7.

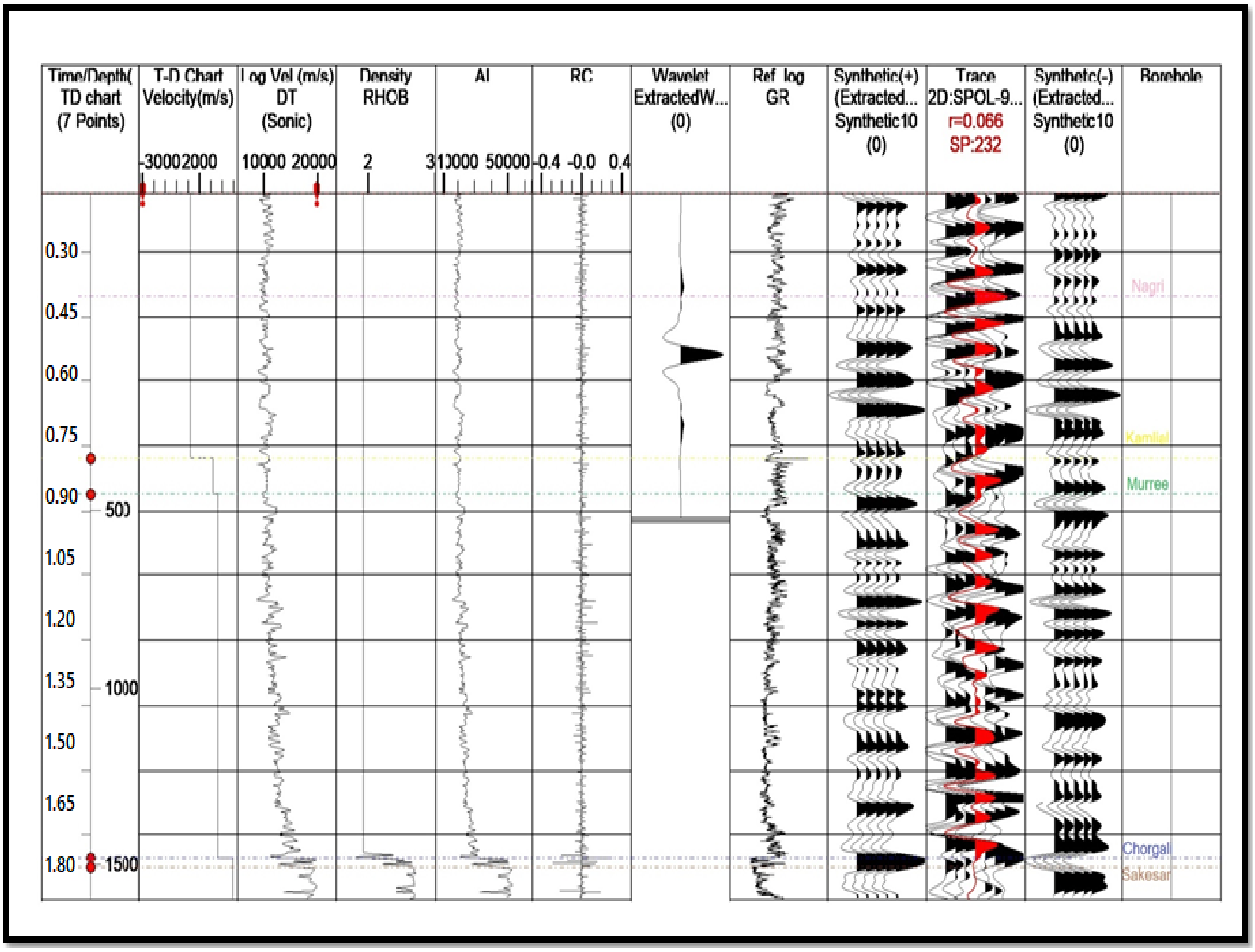


Figure 3.7: Shows the Synthetic Seismogram (Minwal Well X-01)

3.8 Horizon marking and interpretation:

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

Seismic lines POL-MN-93-08, POL-MN-93-06 and POL-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, 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.

3.9 Marked horizons

Horizon can be interpreted on basis of synthetic seismogram , generated from well.In this project, four horizons were being marked.

- Chorgali Formation (Reservoir)
- Sakesar Formation (Reservoir)
- Salt Range Thrust
- Basement rock

3.10 Fault interpretation and marking

The study area lies in the southern part of the Potwar Plateau which is characterized by northward-dipping strata and local open folds of low structural relief and axes. The area is under compressional regime and having fore thrust and back thrust fault system. Therefore , two reverse faults are marked on assigned lines.

- F1 Reverse Fault
- F2 Reverse Fault

Joya Mir structure is the combination of thrust and back-thrust, forming a triangle zone at subsurface. The triangle zone is the result of two phases of Himalayan thrusting. Stratigraphically it comprises of a petroleum play in which Patala Formation of Paleocene age act as a source rock while Chorgali and Sakesar Formation of Eocene age are two major reservoirs and Murree Formation of Miocene age is acting as a seal in the study area.

The interpreted marked horizons and faults on seismic lines are illustrated in below figures .

3.11 Interpretation of POL-MN-93-08 (dip line)

The line 93-MN-8 is north-west oriented line and is perpendicular to the axis of the structure present in the area and parallel to the dip of the major faults present. Here the reservoir rocks of Cambrian to Eocene are Chorgali and Sakesar present at depth of 2020.48 m and 2054.24 m respectively.Below the depth of 2176.235m the salt range formations start. Basement rock is also marked on the section (Fig.3.11).Minwal X-1 well is drilled on the respective line .

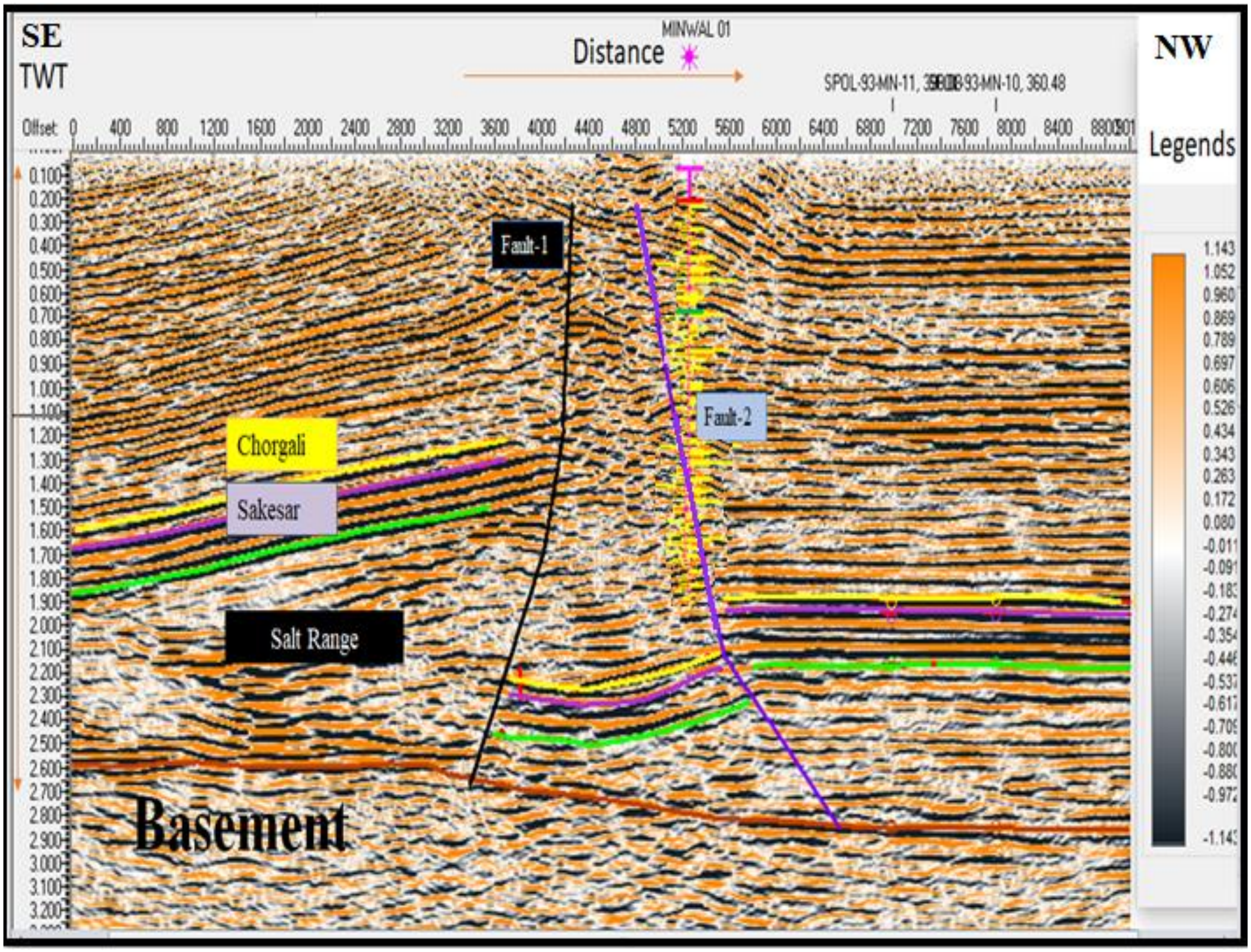


Figure : 3.11 (POL-MN-93-08) Dip line

3.12 Interpretation of POL-MN-93-06 (dip line)

Seismic section 93-MN-6 is north-west oriented line and is to the west of Joya Mair and Mainwal X-1 wells.The structures portrayed by this seismic line are very similar to those present in the line 93-MN-5 and 8 , Figs. 3.11 and 3.13 The Joya Mair structure is basically a triangle zone consisting of a forethrust verging towards southeast and a backthrust verging towards northwest. Both thrusts die out in Siwaliks Group.

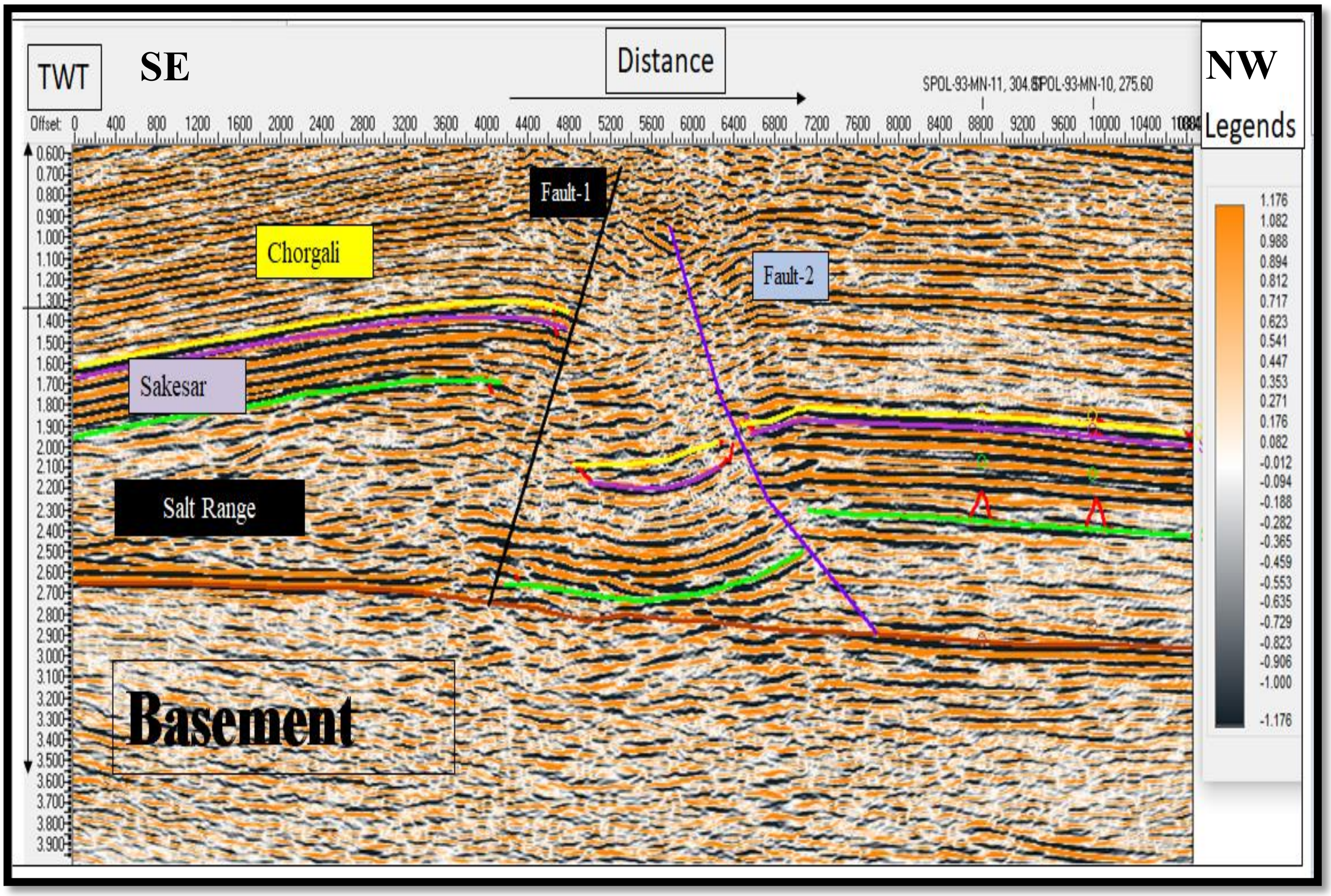


Figure: 3.12 (POL-MN-93-06) Dip line

3.13 Interpretation of POL-MN-93-05 dip line

SE-NW dipping 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. The basement exists at a TWT of 2.6 sec Figure 3.13. The decollement is provided by the Salt Range Formation above the basement. Two major blind thrusts originating from the basal decollement are visible in line 93-MN-5. No well has been drilled on this line. The arrangement of structures show that the forethrust is southeast verging while the backthrust is northwest verging forming a triangle zone.

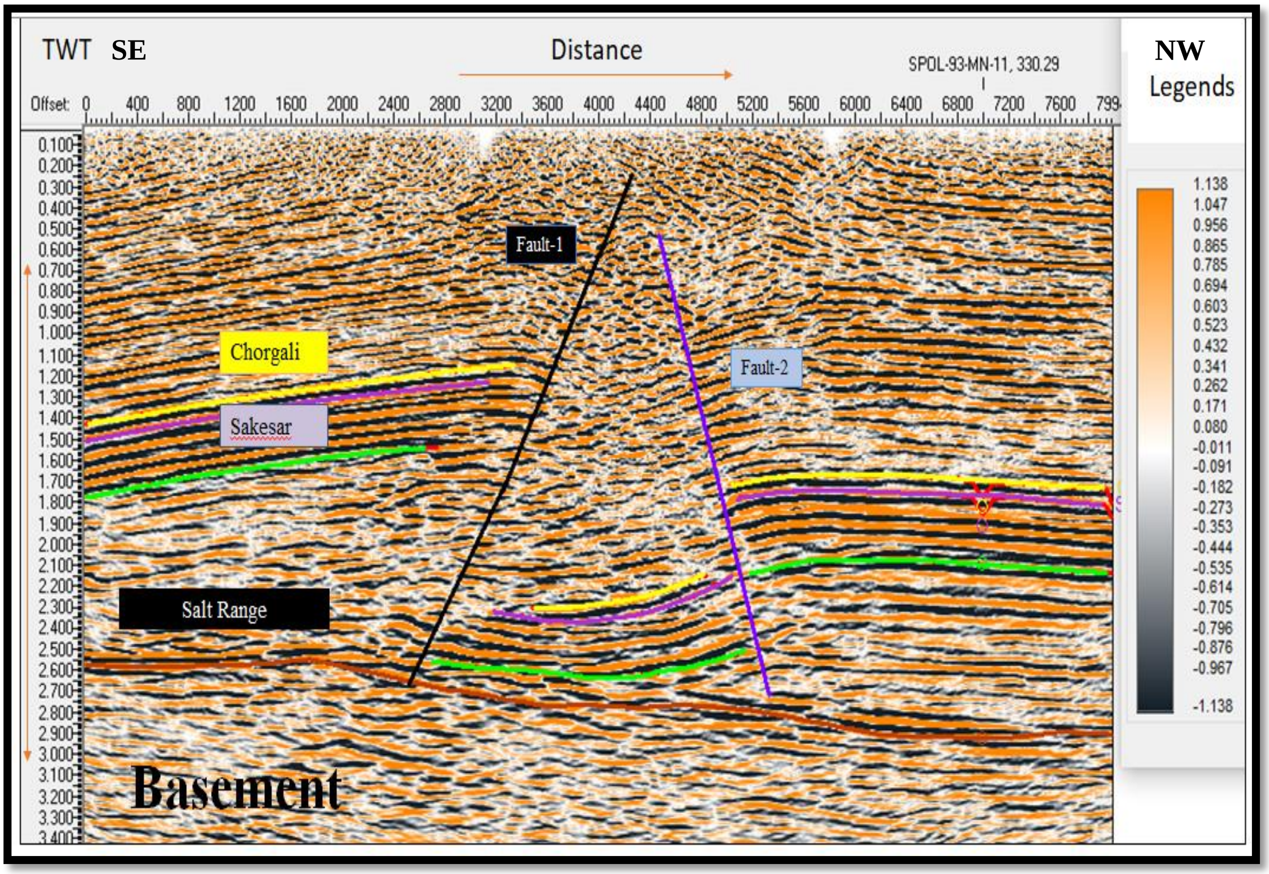


Figure 3.13 (POL-MN-93-05)Dip line

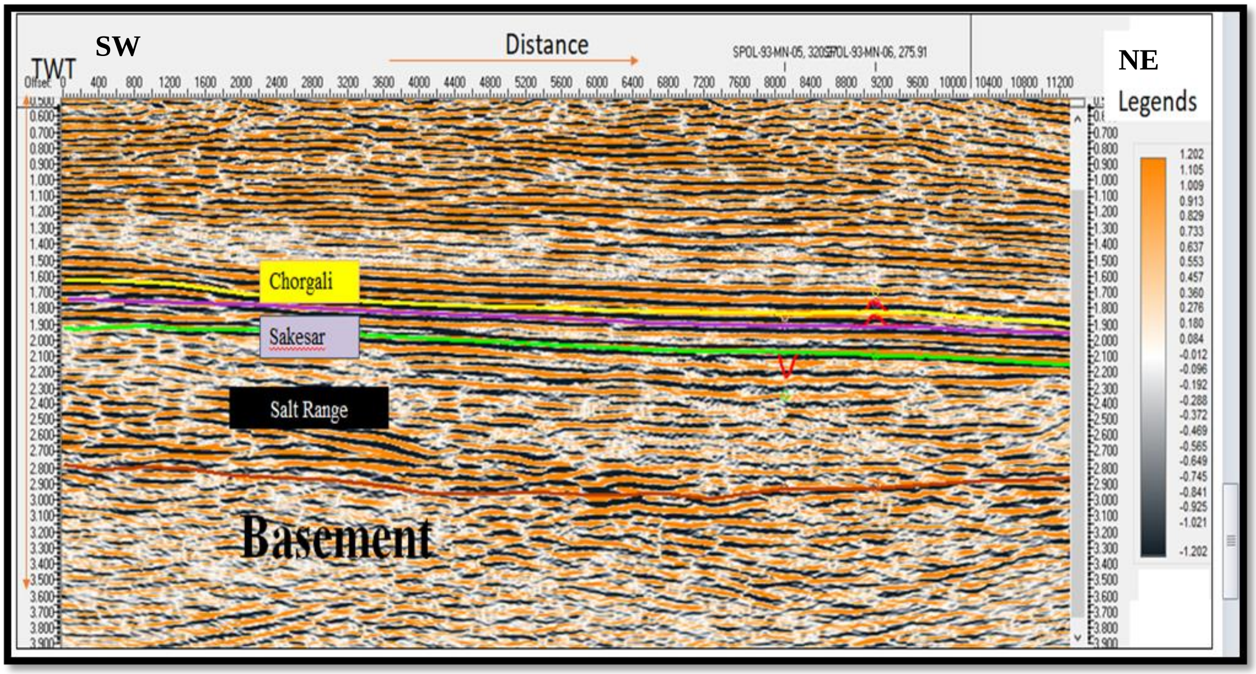


Figure 3.13 a (POL-MN-93-11) Strike line

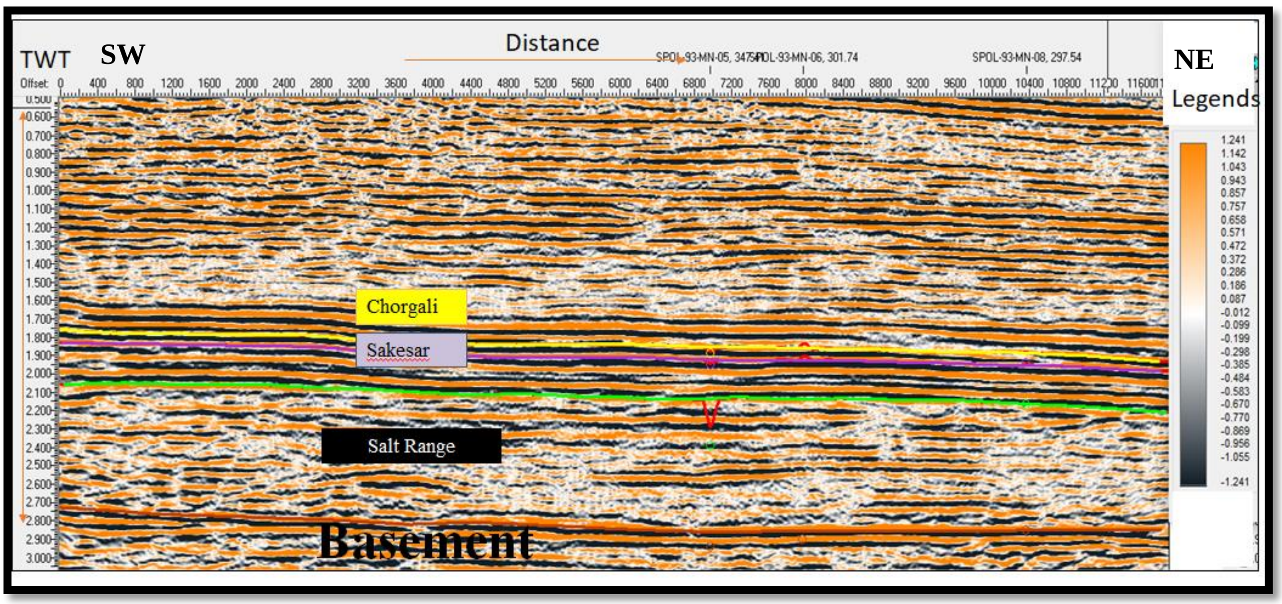


Figure: 3.13 b (POL-MN-93-10) Strike line

3.14 Fault Polygon generation:

Before generation of fault polygons it is necessary to mark and identify the faults by analyzing seismic data. If one finds that the same fault is present on all the dip lines, then all points can be manually joined to make a polygon. Construction of fault polygons are very important as far as time and depth contouring of a particular horizon is concerned. Any mapping software needs all faults to be converted in to polygons prior to contouring. The reason is that if a fault is not converted into a polygon, the software doesn't recognize it as a barrier or discontinuities, thus making any possible closures against faults represent a false picture of the subsurface.So in order to accurately interpret the subsurface , conversion of fault into polygon is must. Figure 3.9 indicates the fault polygon for the sakesar reservoir .The pointed marks on the fault are indicating thrusting.

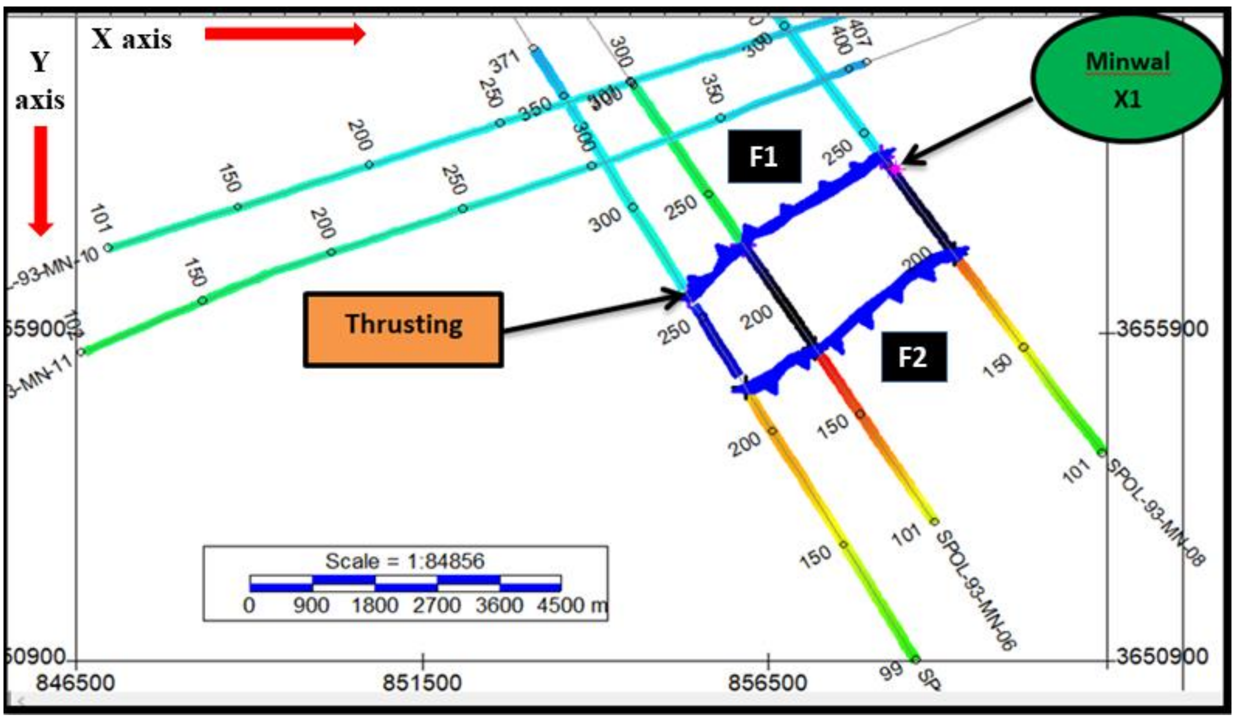


Figure 3.9 : Fault polygon for Sakesar limestone

3.15 Contour Map :

A line that connects the line of equal values is called a contour line. Such maps show us steepness of slopes, elevation top of the subsurface of the sedimentary rock layer and also the two way travel time of the horizon in millisecond (Norman, 2001).

- Time Contouring
- Depth Contouring

3.15.1Time contour map

Now the next step is to compute time contour map. For contouring time map, Firstly we have to create grids.The time contour maps of reservoir rocks Chorgali and Sakesar formations are given below in figure 3.10.1 a and 3.10.1 b .The blue color is indicating the deepest parts between the thrusting and red is indicating shallower regions.

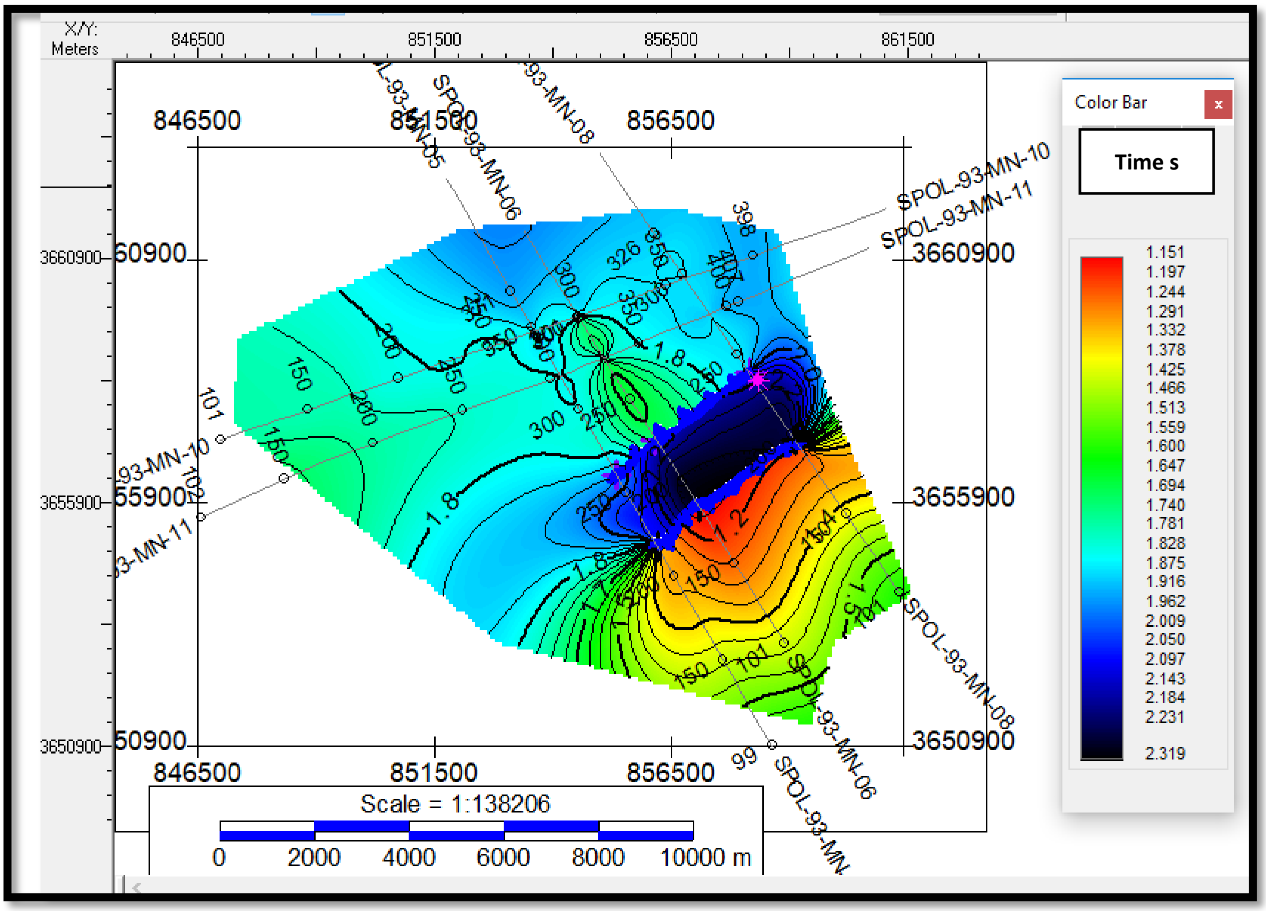


Figure : 3.15.1 a Time contour map for Chorgali

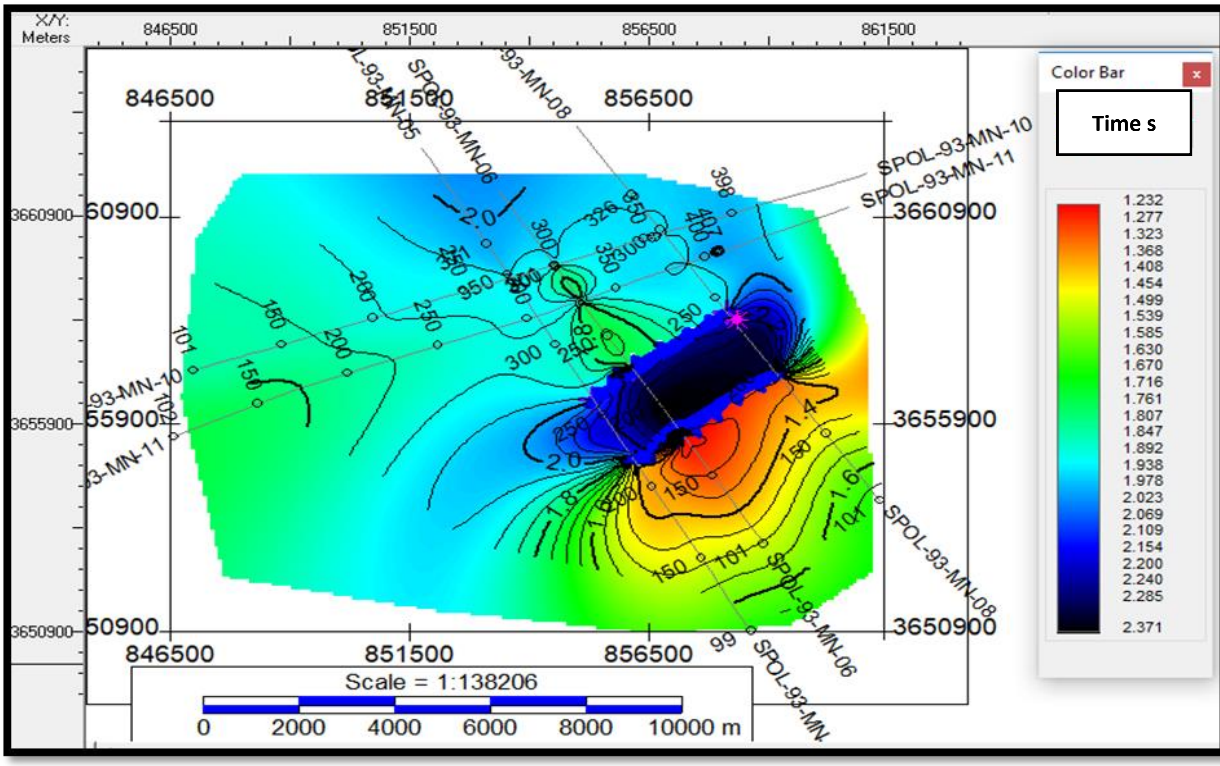


Figure 3.15.1b Time contour map for Sakesar

3.15.2 Depth Contour Map

The depth contour map marks the depth of structure. The depth contour map in the subsurface mainly shows the faults, anticlines and folds. From the scale the central portion between fault polygons is deepest in depth than the surrounding area So after marking the time contour map the depth contour map is being generated in the area of the Eocene top by using the following formula in the software.

$$S=V*T/2$$

Where,

T = Two way reflection time (sec)

V =Average velocity (m/sec)

S=Depth in meters

We have the time and depth of the given formation (Chorgali and Sakesar formations). Firstly calculate velocity of each formation by using the formula.

$$V=2*S/T$$

Then by multiplying the value of velocity with time, we can calculate the depth of each formation and hence we will compute depth contour map. The depth values have assign a color bar which can be used as a guide for interpretation. On basis of color bar orange color shows the deepest point which also give us information about the probable well location while the blue color represents shallowest point as shown in figure 3.15.2 a and figure 3.15.2 b.

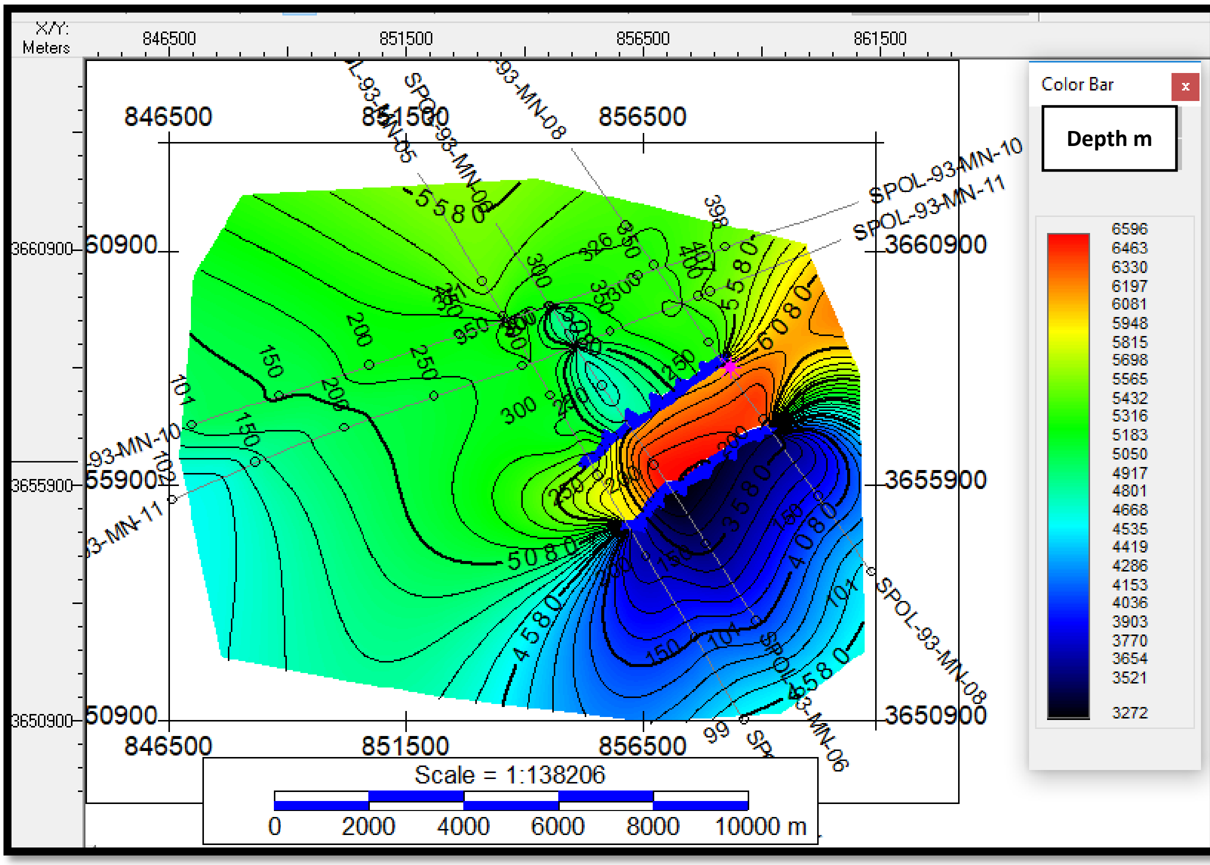


Figure 3.15.2 a Depth contour map of Chorgali

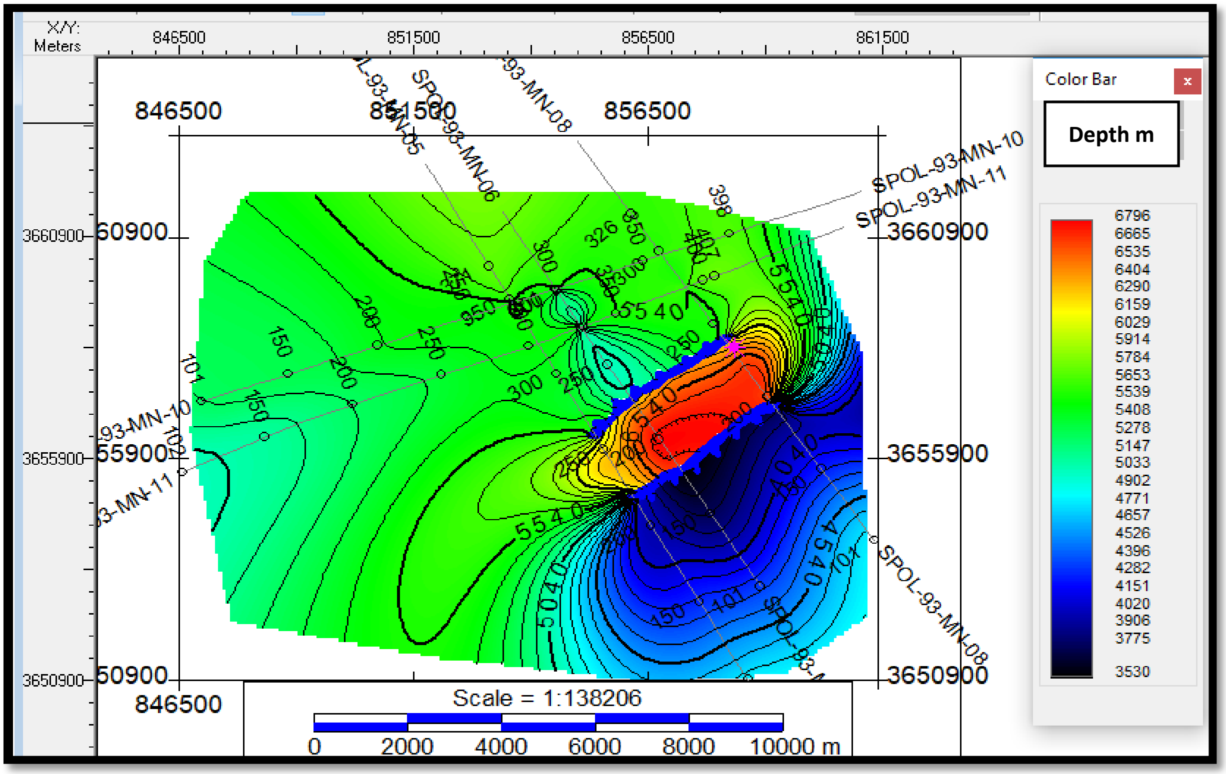


Figure 3.15.2 b Depth contour map of Sakesar.

CHAPTER 4

PETROPHYSICAL ANALYSIS

4.1 Introduction

Petrophysics is a technique used to characterize the reservoir. This study facilitates the identification and quantification of fluid in a reservoir (Aamir et al., 2014)

The petrophysical analysis through wireline logs (Density, Neutron, Self-potential and Resistivity) for the Sakesar Formation of Eocene age in Minwal X-1 well is conducted. The analyses are made to calculate porosity, determine formation water resistivity, water saturation and oil saturation. These findings are very useful in investigating the hydrocarbon potential of the reservoir.This reservoir characterization is the key step in the oil and gas industry as it defines the potential of the well and identify areas of the reservoir that can be recovered.

4.2: Types of logs used

In petrophysics, there are three main tracks. The lithogical track , porosity track and resistivity track. Following are the various type of logs used for petrophysical analysis:

Table 4.2

Lithological Logs	**Porosity logs**	**Fluid Dynamic logs**
Gamma ray Log (Gr)	Sonic Log(DT)	Resistivity Logs (LLD, LLS)
Spontaneous potential Log (SP)	Density log (Rhob)	Induction log
Neutron-density log	Neutron porosity log (NPHi)	
Litho-density log		

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

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

The above mentioned parameters will help in characterization of reservoir rocks i.e Chorgali and Sakesar formation rocks.

Following is the workflow used for petrophysical analysis.

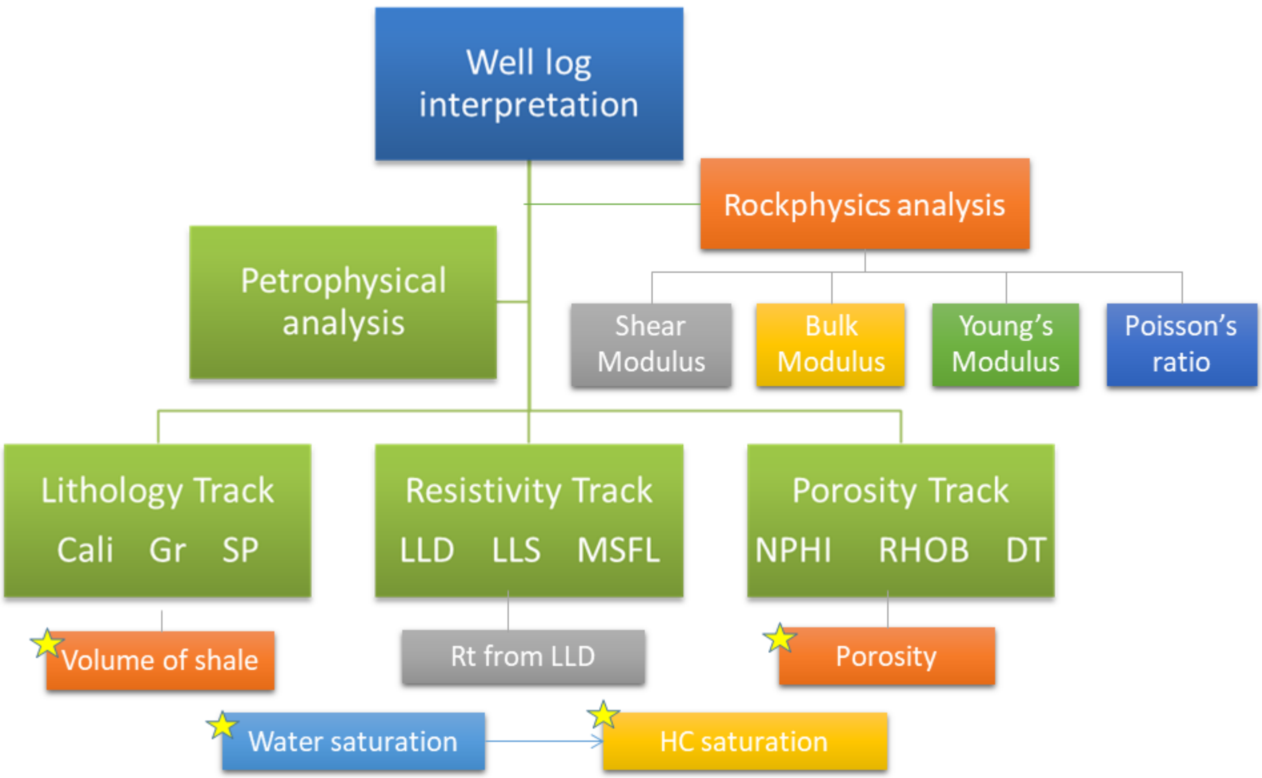


Figure 4.2 Petrophysical analysis workflow

4.3 Interest Zones

The zones of interest are defined on the basis of source, reservoir and seal rock formations given in well tops of Minwal-01 well. The zones of interest which are marked are listed in the Table

Table 4.3

Prospect Zones	Start Depth (m)	End Depth (m)
Chorgali	2020.48	2054.24
Sakesar	2054.24	2176.235

4.4 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.

Table 4.4: Scale used for the different logs

SR NO.	TYPE OF LOG	ACRONYM	SCALE	UNIT
1	Gamma ray Log	GR	0---------150	API
2	SP Log	SP	120-------(-20)	mV
3	Density Log	RHOB	1.50----3.00	gm/cm3
4	Sonic Log	DT	140-------40	µsec/ft
5	Neutron Log	NPHI	0.60---(-0.15)	PU
6	Caliper Log	CALI	6----------16	Inches
7	Laterolog Deep	LLD	1--------2000	Ωm
8	Laterolog Shallow	LLS	1--------2000	Ωm

4.5 Lithological Track:

4.5.1 Gamma ray log (Gr)

Gamma ray logs measure natural radioactivity in formations and because of this measurement, they can be used for the identifying lithologies and correlating zones. Shale-free sandstones and carbonates have low concentration of radioactive material, and give low Gamma ray readings. As shale content increases, the gamma ray log increases because of the radioactive material present in shale.On the other hand gamma ray response for sand and limestone is low.

Sand and shale lines are marked at the minimum and maximum values of Gamma Ray in the selected zone of interest, A cut off line is marked in the middle of the two lines which is used to demarcate sand and shale formations.

4.5.2Calculating Shale Volume

The source formations are commonly shally with higher radioactive content and are therefore indicated by a higher Gamma Ray value. The volume of shale present in subsurface formations can be calculated by using different logs. We use Gamma-ray log for shale calculation. The mathematical calculation from gamma ray log for the volume of shale (Asquith and Gibson, 2004).

Volume of Shale

$$\mathbf{I_{GR} = (GRlog - GRmin) / (GRmax - GRmin)}$$

where

I_{GR} is Gamma ray index

GR log represent Gamma ray log

GR min represents minimum value of GR-log in that formation

GR max represents maximum value of GR-log in that formation.

Firstly take maximum value from the digitized GR log.Then take minimum value from the digitized GR log.

Results:

At the depth of which is start from (2020.48 m to 2176.235 m)

Maximum value = 125.574

Minimum value = 13.109

Average volume of shale is 39%

4.5.3 Caliper Log:

Caliper log is a lithological log use to identify the condition of log.It measues the hole size and shape.The caliper gives a vertical profile of hole diameter.The caliper log help in identifying the increase and decrease in borehole diameter.It indicates washouts, bad hole and tight spots. Straight caliper response indicates, reservoir conditions are good.

4.5.4: Spontaneous potential (SP) log

The spontaneous potential (SP) log was one of the earliest electric logs used in the petroleum industry and has continued to play a significant role in well log interpretation. By far the largest numbers of wells today have this type of log included in their log suits. Primarily the spontaneous potential log is used to identify impermeable zones such as shale and permeable zones such as sand.

The spontaneous potential log is a record of direct current (DC) voltage differences between naturally occurring potential of a movable electrode in the well bore and the potential of a fixed electrode located at the surface (Doll,1948). It is measured in millivolts.

The SP log is recorded on the left hand track of the log in track#1 and is used to:

- Detect direct permeable beds
- Detect boundaries of permeable beds
- Determine formation water reistivity (w_R)
- Determine the volume of shale in permeable beds.

Results

SP min value = 0.01

SP max value= 44.726

SP clean – SP shale = -44.725

4.6 Porosity Track

4.6.1 Sonic log

The sonic log is a porosity log that measures interval transit time (Δt)of a compressional soud waves traveling through one foot of formation. The sonic log device consists of one or more sound transmitters and two or more receivers. Modern sonic logs are borehole compensated devices .These devices greatly reduce the spurious effects of borehole size variations (Kobesh and Blizard,1959), as well as errors due to tilt of the sonic tool(Schlemberger,1972)

Interval transit time(Δt) in microseconds per foot is the reciprocal of the velocity of a compressional sound wave in feet per second.

4.6.2 Sonic porosity (ΦS)

Using sonic log porosity can also be easily calculated which is almost near or equal to actual porosity. The interval transit time (ΔT) 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:

$$\Phi S = (\Delta T - \Delta Tmat)/ (\Delta Tf - \Delta Tmat)$$

Where,

ΦS=Sonic porosity μs/ft

ΔT=Log response

ΔTmat= Transit time in matrix

ΔTf= 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 (ΔT) 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)

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

4.6.3: Density porosity (ΦD)

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

$$\Phi D = \rho m - \rho b / \rho m - \rho f$$

Where,

ρm=2.71 gm/cm3 (for Carbonates) (density of matrix)

ρf= 1 gm/cm3 (density of fluids)

ρb= log Response in zone of interest

4.6.4:Total porosity (ΦT)

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

$$\Phi T = (\Phi S + \Phi D) / 2$$

Where,

ΦT=Total Porosity

ΦD=Density Porosity

ΦS=Sonic Porosity

4.6.5:Effective porosity

Effective Porosity is given by;

Effective Porosity = Average Porosity * Vmatrix

Where Vmatrix is Volume of Matrix given by 1- Vshale

4.7: Resistivity Tracks

Resistivity logs are electric logs which are used to:

- Determine hydrocarbon versus water-bearing zones
- Indicate permeable zones

By far the most important use of resistivity logs is the determination of hydrocarbon versus water-bearing zones. Because the rocks matrix or grains are non-conductive . The ability of the rock to transmit a current is almost entirely a function of water in the pores. Hydrocarbon like the rock's matrix are non-conductive , therefore as the hydrocarbon saturation of the pores increases the rocks resistivity also increases.

Table 4.7 Data From well

Borehole Temperature	**152^{o}F = 66.66 ^{o}C**
Surface Temperature	25^{o}C
Formation Depth	2020.48m
Total Depth	2176.235m
Resistivity of mud filtrate	1.016 ohm m

4.7.1: Calculation of Resistivity of mud filtrate (Rmf2)

Formation Temperature can be calculated as:

FT= (BHT-ST/TD)*FD

Where

FT=Formation Temperature

BHT=Borehole Temperature

ST=Surface Temperature

FD= Formation Depth

TD= Total Depth

FT= 38.67^oC

The Resistivity of Mud Filtrate at Zone of Interest (Reservoir Formation) is calculated by the equation given below:

$$Rmf2 = Rmf1 * (ST + 6.77/ FT + 6.77)$$

Where Rmf1 is Resistivity of mud filtrate at surface temperature, ST is surface temperature.FT is formation temperature and Rmf2 is resistivity of mud filtrate at formation temperature (zone of interest/reservoir). These values are obtained from the log header to compute Rmf2 as given below:

Rmf1 = 1.016 ohm m (from given data)

ST=Surface Temperature (25^oC)

FT= 38.67^oC

Rmf2= 0.710

Results:

FT= 38.67^oC

Rmf2= 0.710

4.8 Calculation of Resistivity of water Equivalent (Rweq) and Rw

SSP is difference of maximum and minimum value of SP log. SSP is -60 mv and -18 mv is plotted on Gen-6 (Schlumberger chart)

1. **To calculate True Rweq**

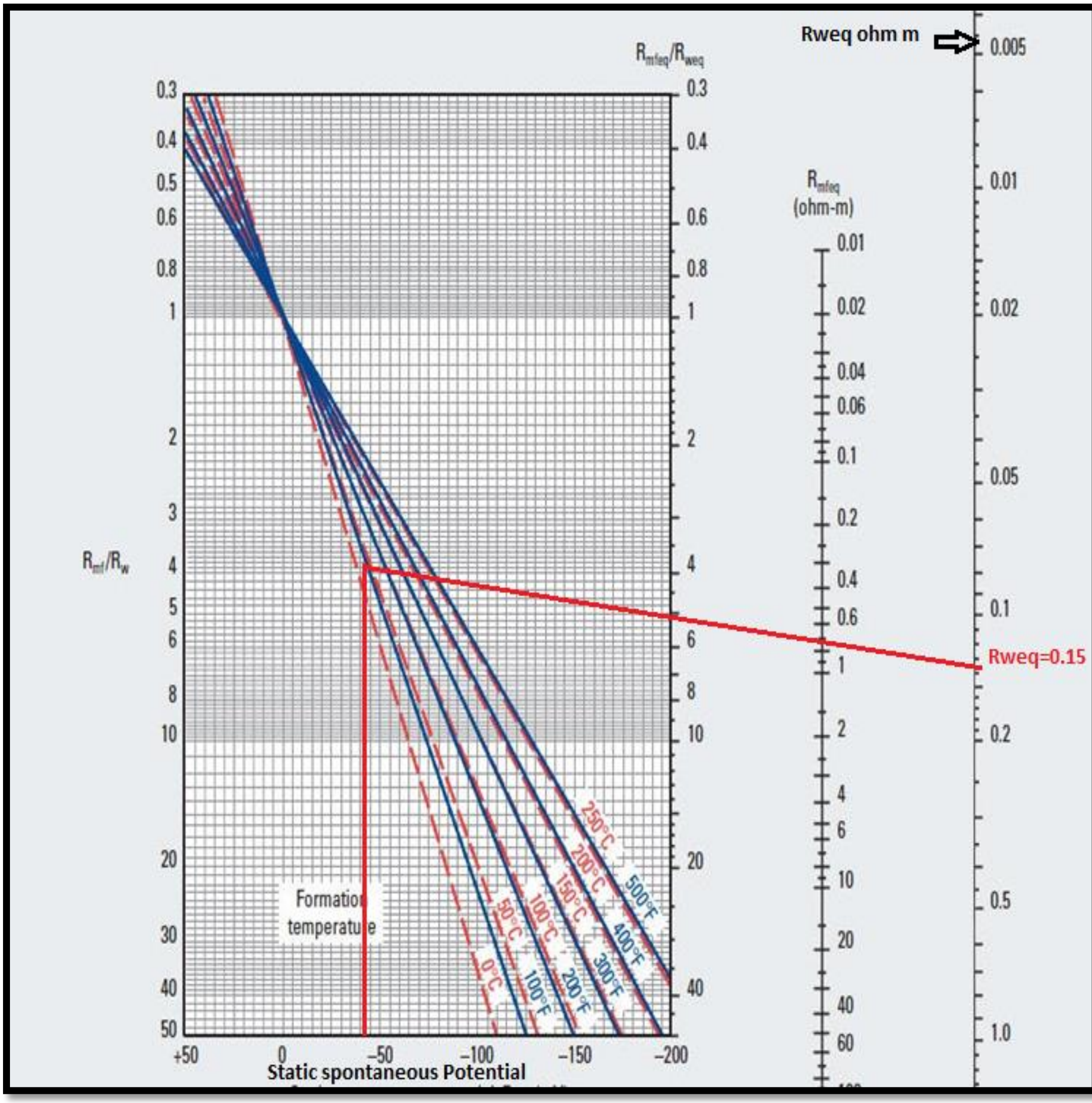


Figure 4.10.1 Schlumberger chart

Rweq = 0.15 ohm m

2. To calculate True Rw

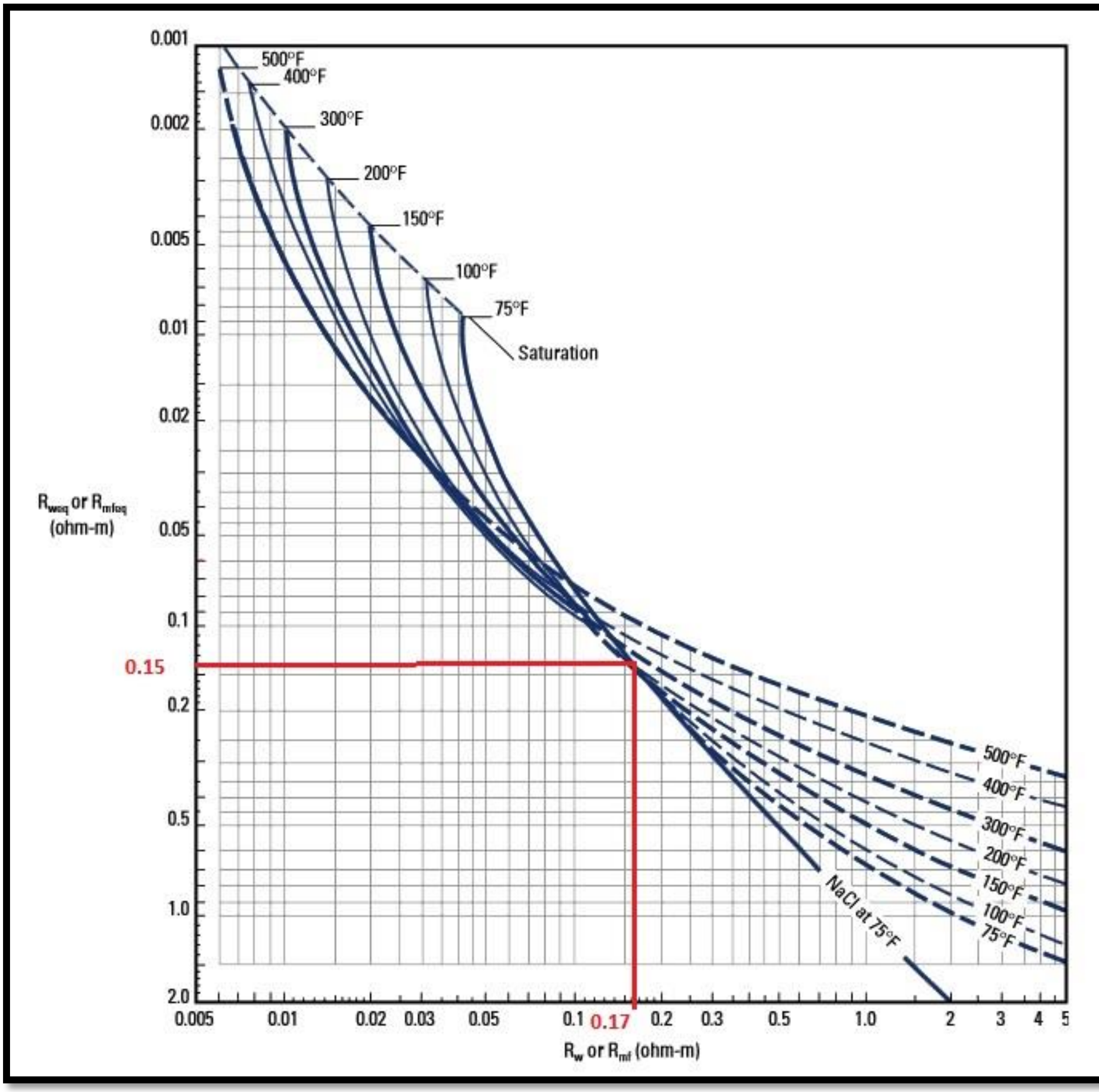


Figure 4.10.2 Schlumberger chart for Rw

Rw= 0.17 ohm m

4.9: Water Saturation (Sw) Determination

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

$$Sw = [((a/\Phi^m) \times Rw)/ Rt]^{1/2}$$

Where,

Sw= water saturation

Rw=water resistivity (formation)

Φ = effective porosity

m(cementation factor) =1.95

a(constant) = 1

Rt= log response (LLD)

Rw has been calculated with help of the following formula:

Rw= 0.17

Φ = porosity in clean zone

Rt =Observed LLD curve in clean zone.

N= saturation exponent and its value varies from 1.8 to 2.5 and it is taken as 2.05

4.10 Calculation of Hydrocarbon Saturation (S_h)

The fraction of pore spaces containing hydrocarbons is known as hydrocarbon saturation and is calculated by relation given in equation (13)

$$\mathbf{S_h = 1 - S_w},$$

where,

S_h= Hydrocarbon saturation,

S_w= Water saturation.

As the S_h is the remaining percentage pore volume other than the percentage of pore volume occupied by water, hence this method is an indirect method which quantitatively estimate hydrocarbon saturation.

4.11 Result of Petrophysical Evaluation

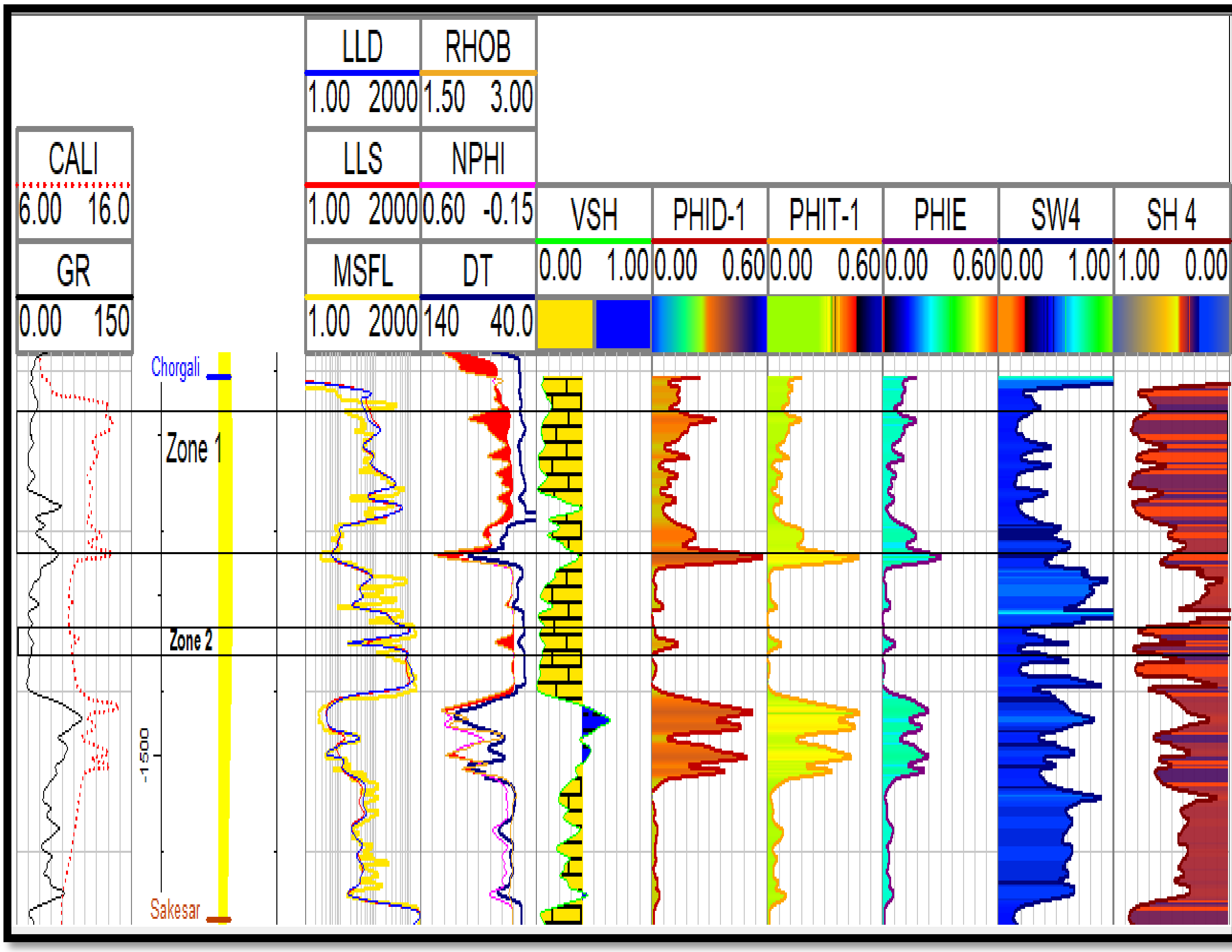


Figure 4.11 a: Petrophysical analysis Chorgali formation.(Minwal well X-01)

Zone 1 and Zone 2:

Zones marked in above image indicates the prospect zone. The zone is marked on basis of log curve responses. In this particular zone, the response of caliper is straight, which indicates favourable prospect condition.The value of Gr log is low indicating non shaly (limestone) lithology, where resisitivity log indicate high responses while MSFL is low. The density and NPHI has a very prominent crossover indicating prospect zone. Whereas the values of porosity are relatively high due to presence of secondary porosity along with primary porosity.Moreover, water saturation percentage is lower than that of hydrocarbon saturation.Thus these zones of chorgali reservoir can be the prospect zones.

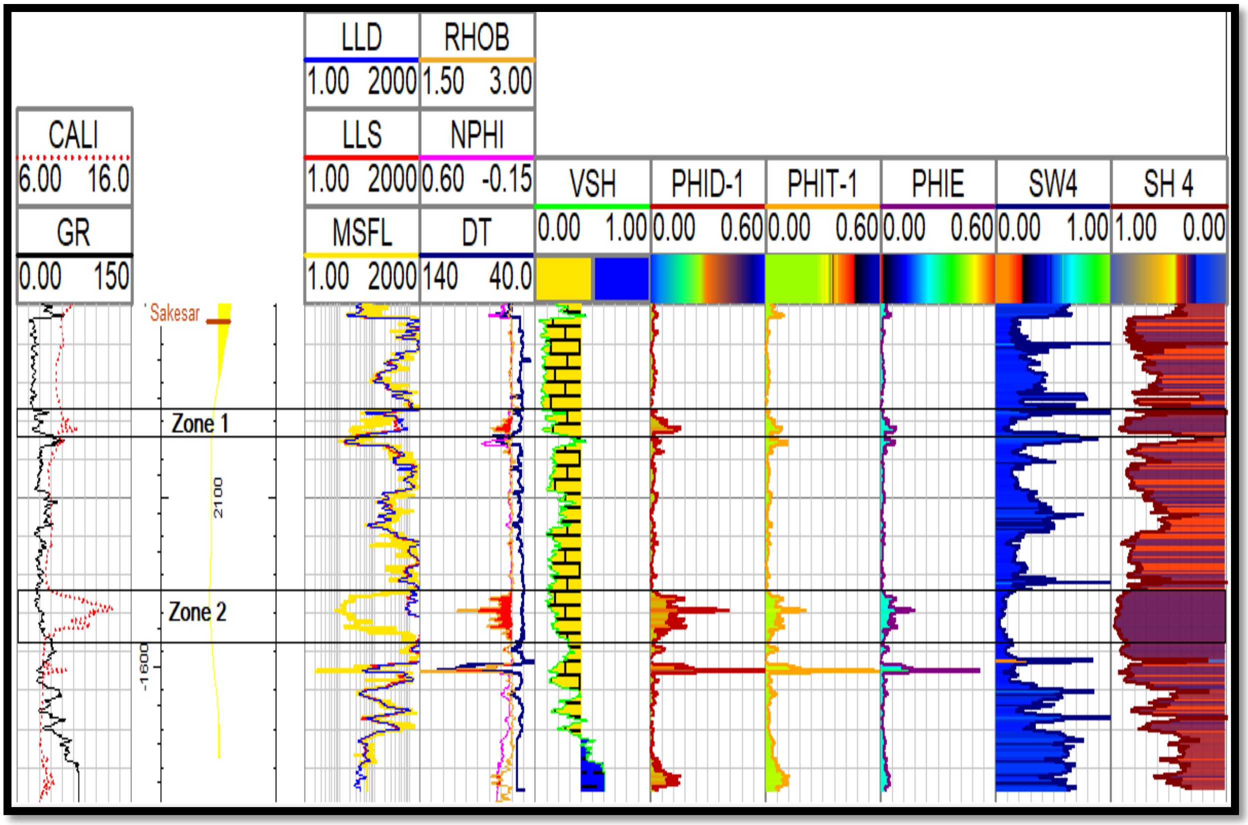


Figure 4.11b : Petrophysical analysis Sakesar formation.(Minwal well X-01)

Zone 1 and Zone 2:

Zones marked in above image indicates the prospect zone. The zone is marked on basis of log curve responses. In this particular zone, the response of caliper s bit disturbed due to presence of fracturing, But the value of Gr log is low indicating non shaly (limestone) lithology, where resisitivity log indicate high responses while MSFL is low. The density and NPHI has a very prominent crossovers indicating prospect zone. Whereas the values of porosity are relatively high due to presence of secondary porosity along with primary porosity.Moreover, water saturation percentage is lower than that of hydrocarbon saturation.Thus these zones of chorgali reservoir can be the prospect zones

Table 4.11 Results of petrophysical analysis.

Petrophysical properties	Overall Net Results%
Water Saturation	33%
Hydrocarbon Saturation	67%
Effective Porosity	19%
Total porosity	25%
Average volume of shale	39%

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 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.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).

Chorgalli formation starts at a depth of 2020.48 m to 2054.24m having a total or gross thickness of 33.76 m .Shale volume for whole depth range is about 39% and the remaining net thickness is is limestone.

Calliper log measure the continuous record of size and shape of borehole.The greater value of caliper log curve in track-1 indicates fracturing due to limestone 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).

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

On basis of the above mentioned figure the logs result is divided into four prospect zones. All the four zones are marked on basis of log response, as value of Gr log reduces and caliper is straightened, it is indicative of favourable hydrocarbon conditions.Similarly the value of resistivity logs are high , porosity is low , dominant lithology of limestone is present. This all is indicative of favourable reservoir conditions in both reservoirs Chorgali and Sakesar formation.

CHAPTER 5

ROCKPHYSICS ANALYSIS

5.1 Rock physics

Rock physics is an essential tool in exploration. Through rock physics we can create a model for each subsurface lithofacies, describing its petrophysical and elastic behavior.

Important aspect of rock physics is fluid replacement which will assess the effect of different fluid fill, such as brine, oil, and gas on the seismic expression.

Rock physics aims to characterize rock properties based on the behavior of seismic waves propagating through them. This requires consideration of how the composition of a rock dictates its stress-strain relationship and thus seismic response.

5.1.1 Shear Modulus

The ratio of shear stress to the shear strain (angle of deformation) is termed as shear modulus. It signifies with the deformation of a solid when it experiences a force parallel to one of its surfaces while its opposite face experiences an opposing force such as friction.It gives information about S waves specifically and values for shear modulus are low in reservoir zone shown in figure 5.1

Mathematically it can be calculated by using relation

$$\mu=\rho*Vs$$

μ = Shear modulus

ρ= Density

Vs= S-wave velocity

5.1.2 Bulk Modulus

The bulk modulus (K) of a rock can be defined as the measures of the resistance of rock to uniform compression. It is the ratio of volumetric stress to volumetric strain. It describes the material's response to uniform pressure.The value of bulk modulus increases with the depth .

It gives information about the P waves and bulk modulus value is showing a decreasing response in reservoir zone shown in figure 5.1

Mathematicaly can be calculated by formula.

$$K = Vp^2 - 4/3\ Vs^2$$

Where

Vp= P-wave velocity

Vs= S-wave velocity

K= Bulk Modulus

5.1.3 Young's Modulus

It is defined as "the ratio of the uni axial stress over the uni axial strain in the range of stress in which Hooke's Law holds". Young's modulus (E) is a measure of stiffness of an isotropic elastic material. As due to presence of fluid in reservoir zone , the value of young's modulus is decreasing in reservoir zone shown in figure 5.1.

Young's modulus, E, can be calculated by dividing the tensile stress by the tensile strain;

$$E=\sigma/\epsilon$$

where

σ= Stress

ϵ= Strain

E= Youngs Modulus

5.1.4 Poisson's Ratio

This constant signifies the elastic properties of solid its value becomes zero in ideal liquid sand gases. Bulk Modulus and Poisson's ratio logs show the opposite character because Poisson ratio can apply only on solids while Bulk Modulus can apply on solids, liquids and gasses.Possions ratio value is increasing in reservoir zone shown in figure 5.1.

It is calculated by using the following formula

$$\sigma=0.5(Vp2-2Vs2)/Vp2-Vs2$$

where

Vp= P-wave velocity

Vs= S-wave velocity

σ= Poissons Ratio

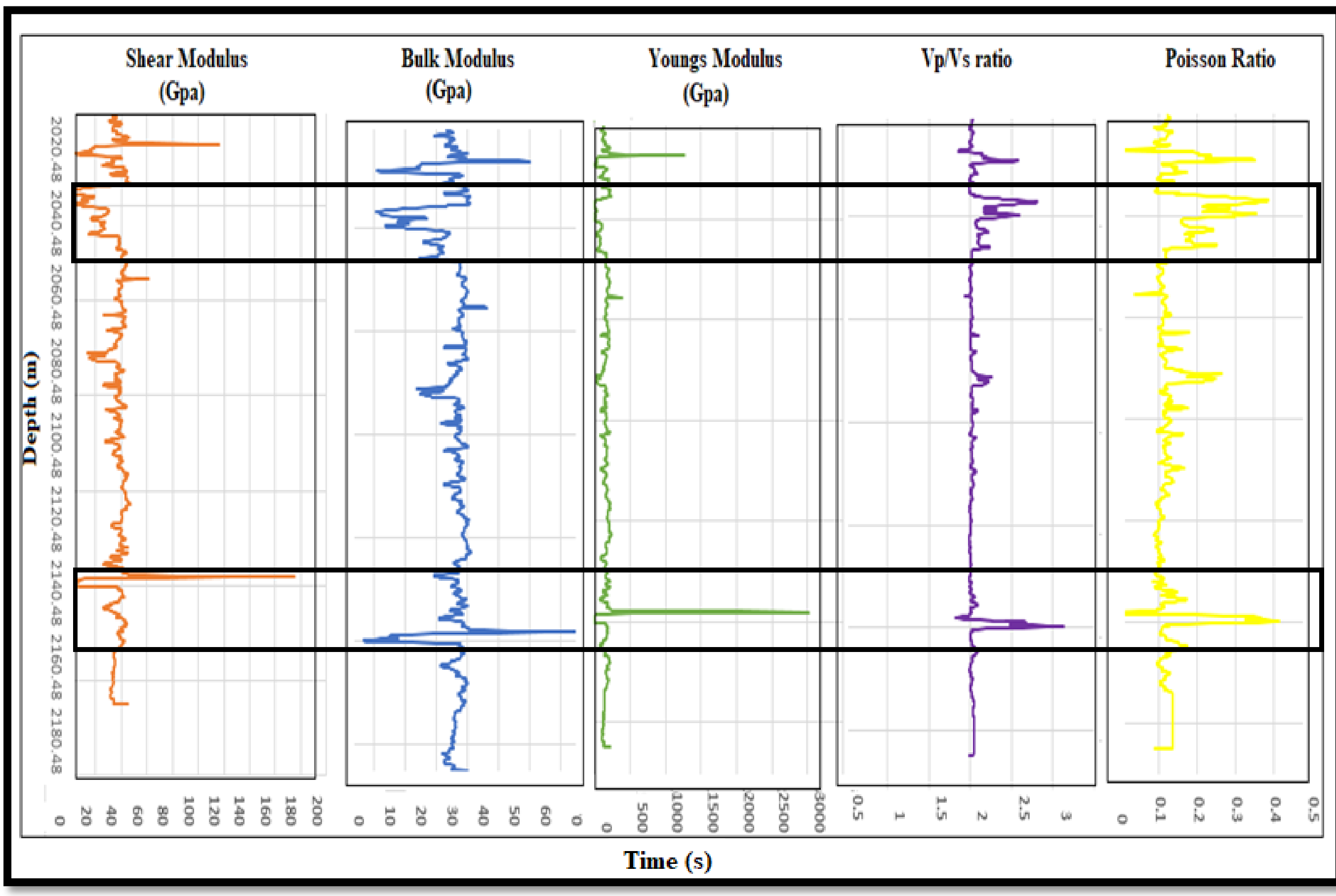


Figure 5.1 Rockphysics interpretation for well Minwal X-01 in reservoir zone

CHAPTER 6

FACIES MODELING AND ANALYSIS

6.1 Introduction

In geology, facies are the observable attributes of a sedimentary rock body that reflect the depositional processes or environments that formed it. These depositional environments are classified as terrestrial, continental slope, slope, and deep marine. The terrestrial environment includes lakes and stream deposits, continental slope environment includes coastal plain to shallowest marine and deep marine environment includes all deposits from shelf, slope and deep ocean.

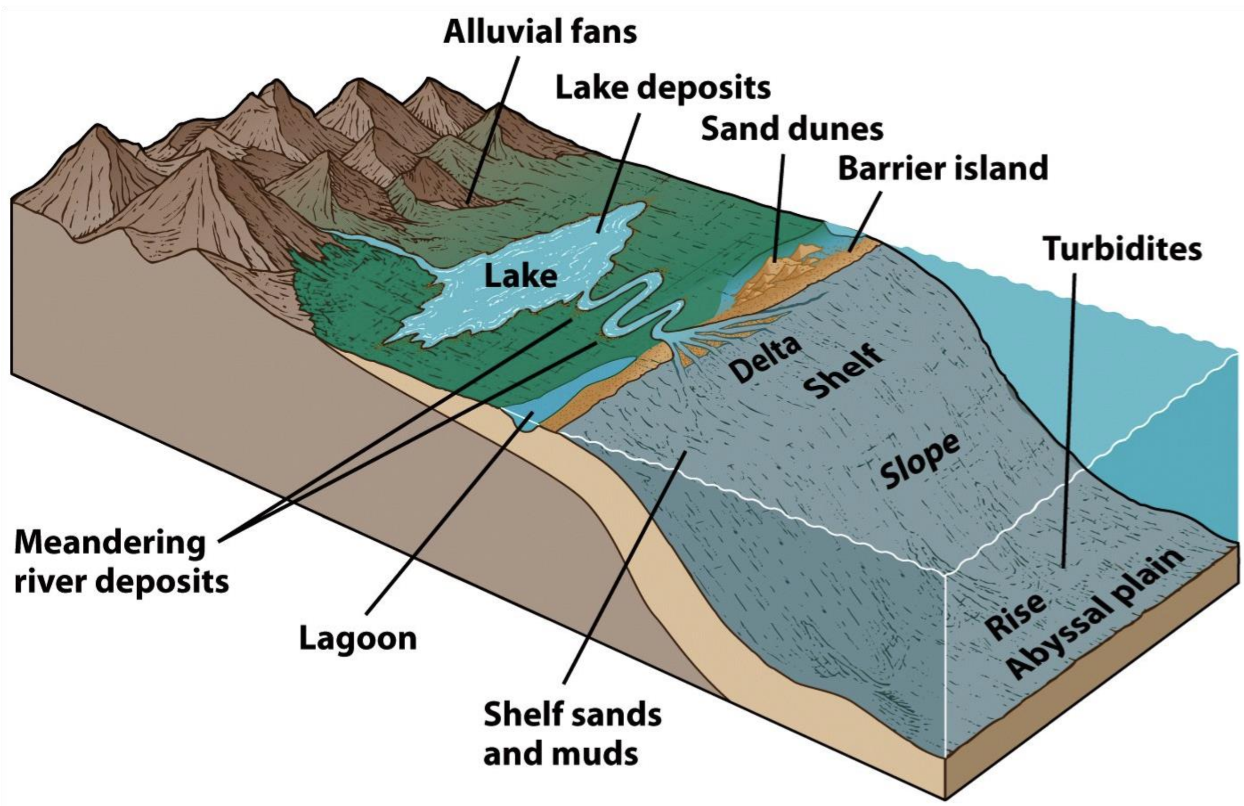


Fig 6.1 Diagram of major depositional environments.

Fluvial a type continental environment formed from influx of sediment in river system. Delta of transitional environment is deposited at mouth of river that caused coastline to swell into standing body of water. As a marine environment deposits, deep water submarine fan is a product of sedimentation of clastic sediments carried by water currents, mainly by density current that flow downslope under ambient sea water (Rais et al, 2012).

6.2 Facies Modeling

Fundamental to all subsurface geologic studies is an analysis of depositional facies. Development of a facies classification scheme is a particular challenging interplay between capturing enough information for environmental interpretation yet remaining simple. Particularly important is the characterization of facies such that their recognition criteria relate to critical environmental thresholds such as sea level, normal wave base, and storm wave base. These physical environmental zones regulate sedimentary textures and biotic assemblages. A good understanding of paleoecology always strengthen the interpretation and such studies should be included as part of all depositional facies studies. Depositional textures in turn affect porosity-permeability in carbonates. The vertical and lateral organization of facies is an exercise essential to sequence stratigraphic interpretations (Lau 1990). The work flow for facies analysis is shown in Fig 6.2.

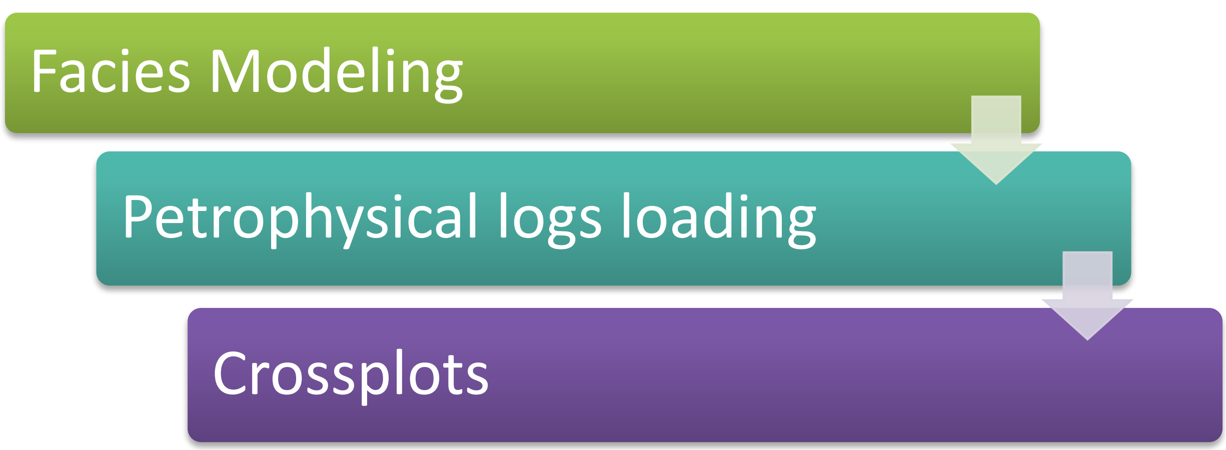
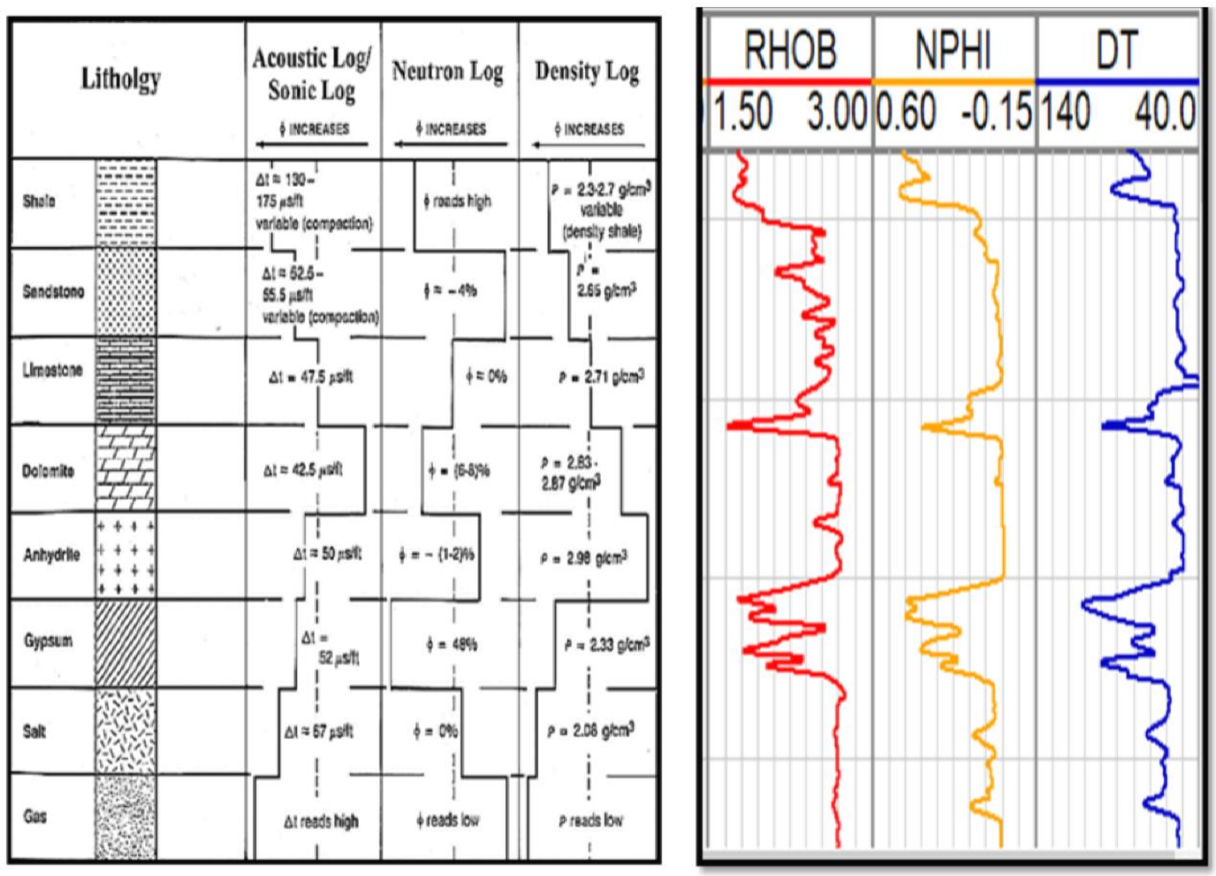


Fig 6.2 Work flow of facies Analysis

6.3: 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 6.3. Comparing this response with that of the logs will show the major lithology of the reservoir zone.



Generalized Pattern of Porosity Logs
Courtesy of Baker Hughes Atlas

Behavior of porosity logs for study well Minwal-X1

Figure 6.3 Generalized comparison of acoustic , neutron and density log responses in common reservoir lithologies versus behavior of porosity logs for well Minwal-X1.

6.4 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 6.4.b.The crossplot is generated with log data from Joya Mair Minwal well X-01, with a gamma ray log as the reference log on the z-axis , Rhob log on y axis and NPHI on x axis. The depth selected for this crossplot is 2020.48 to 2176.235 meters because the reservoir rocks (Chorgali and Sakesar) lie between these depths.

The polygon are drawn and labeled in the crossplot. The group of points is thick in the limestone polygon. It is therefore interpreted that the reservoir is mainly composed of limestone.

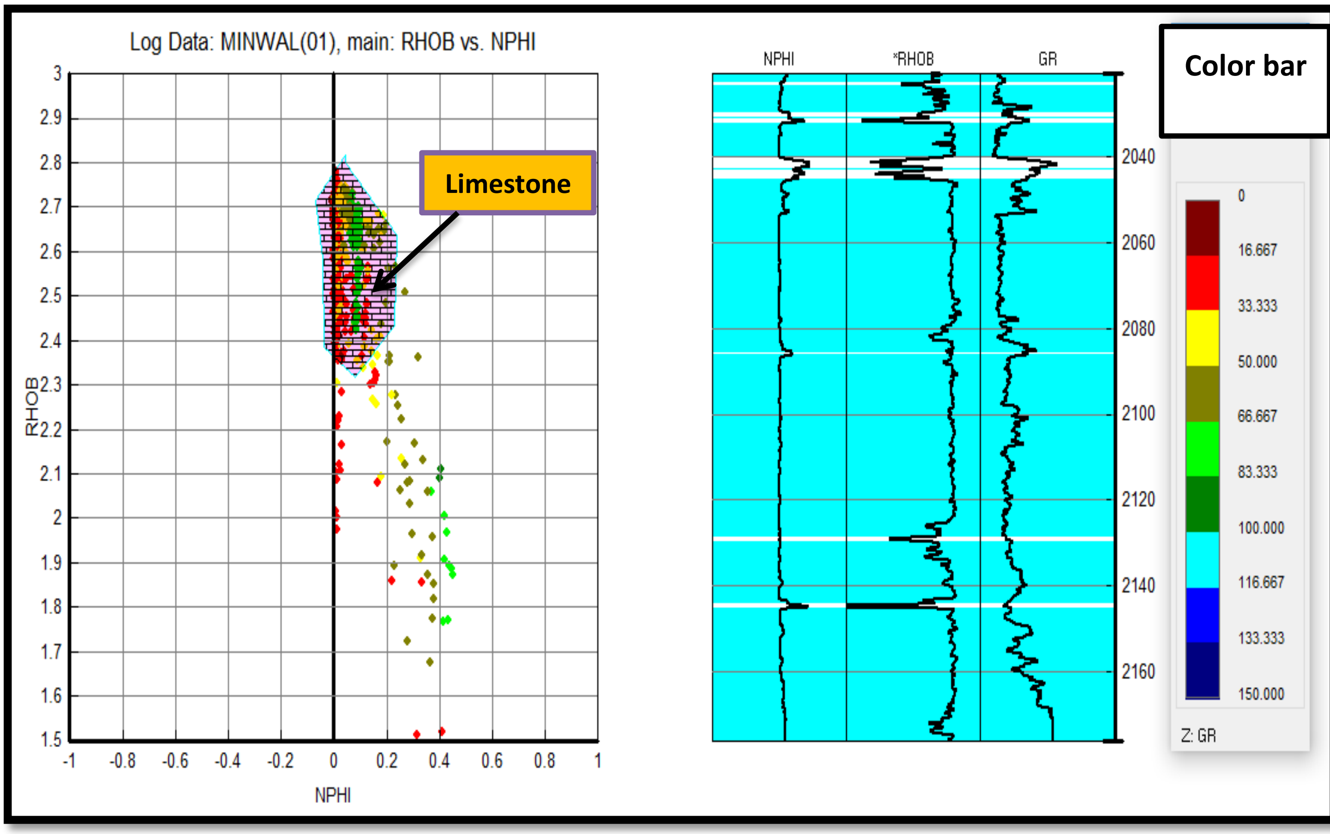


Figure 6.4 a: Minwal X-01 well crossplot between NPHI and RHOB

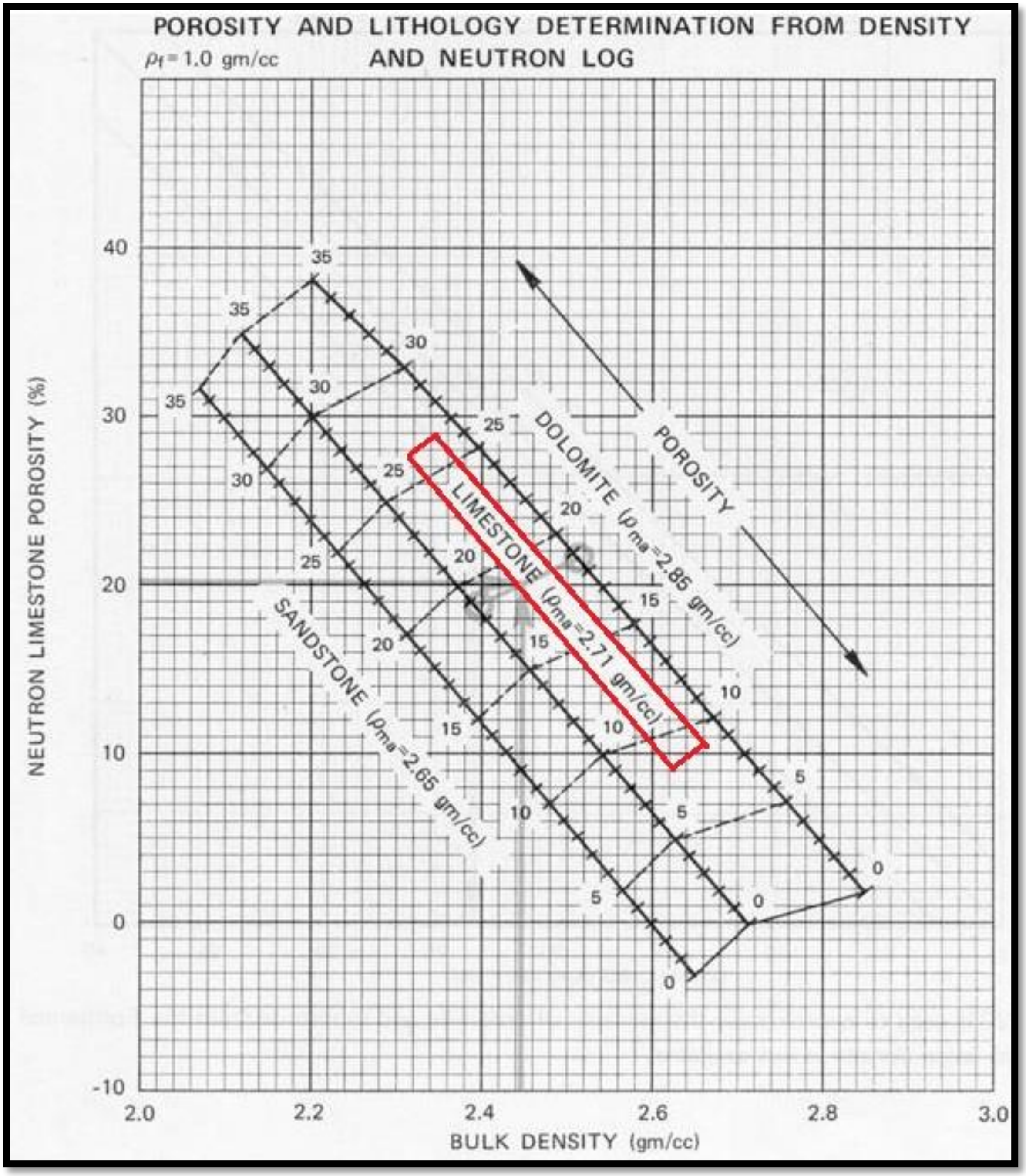


Figure 6.4 b: Standard crossplot between NPHI and RHOB

6.5 : 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 6.5 .In Figure 6.5 , the limestone is in the range of axes marked with blue. In this crossplot Gr is on z axis ,LLD on y axis and Rhob on x axis. By comparing the prepared cross-section, it is clear that the cluster of points is in the same range of axes that is marked in the standard cross-section .Thus, the major lithology in the depth range of the main reservoir is limestone.

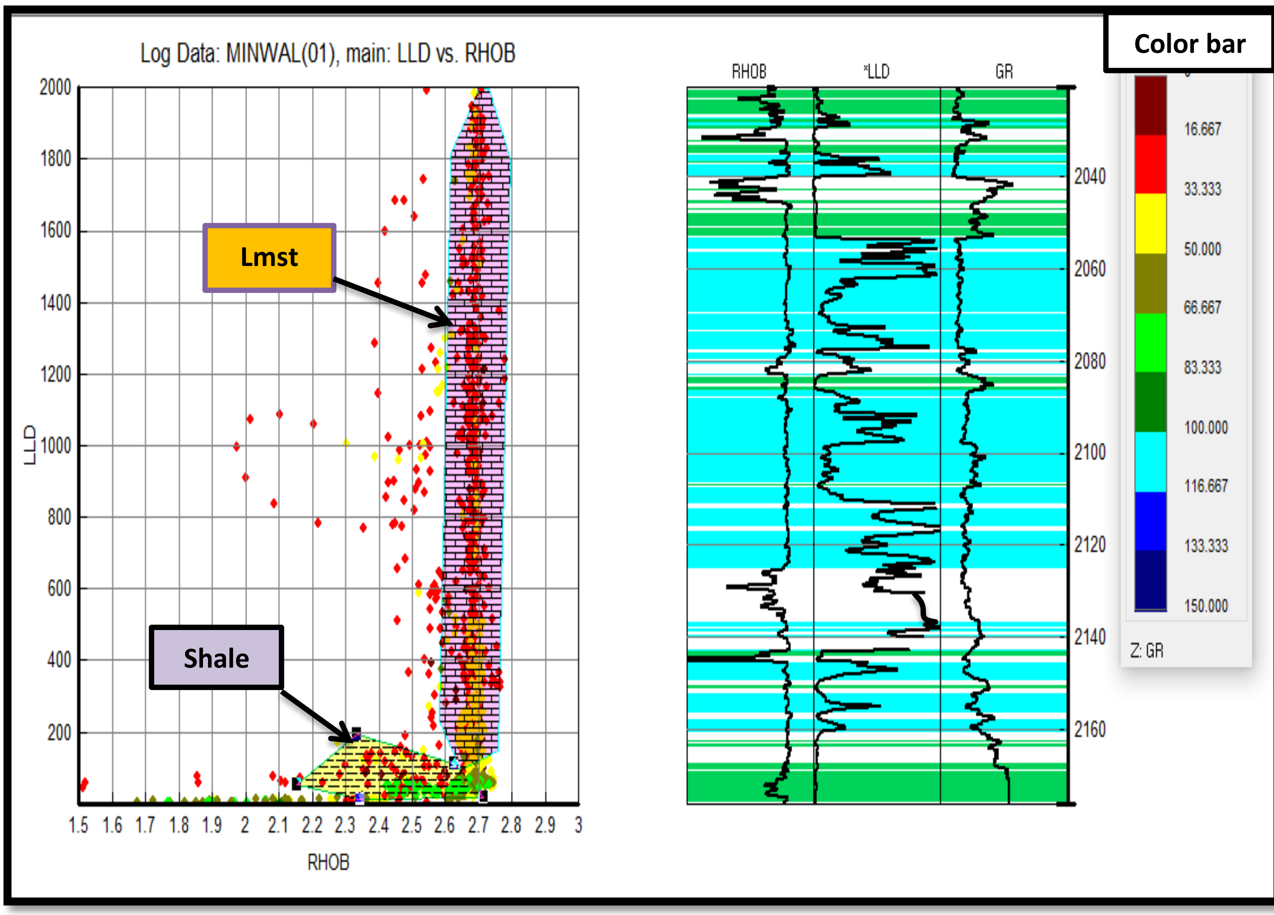


Figure 6.5 a: Cross plot between LLD and Density log of well Minwal X-01

6.6 Crossplot between Sonic log and Density log

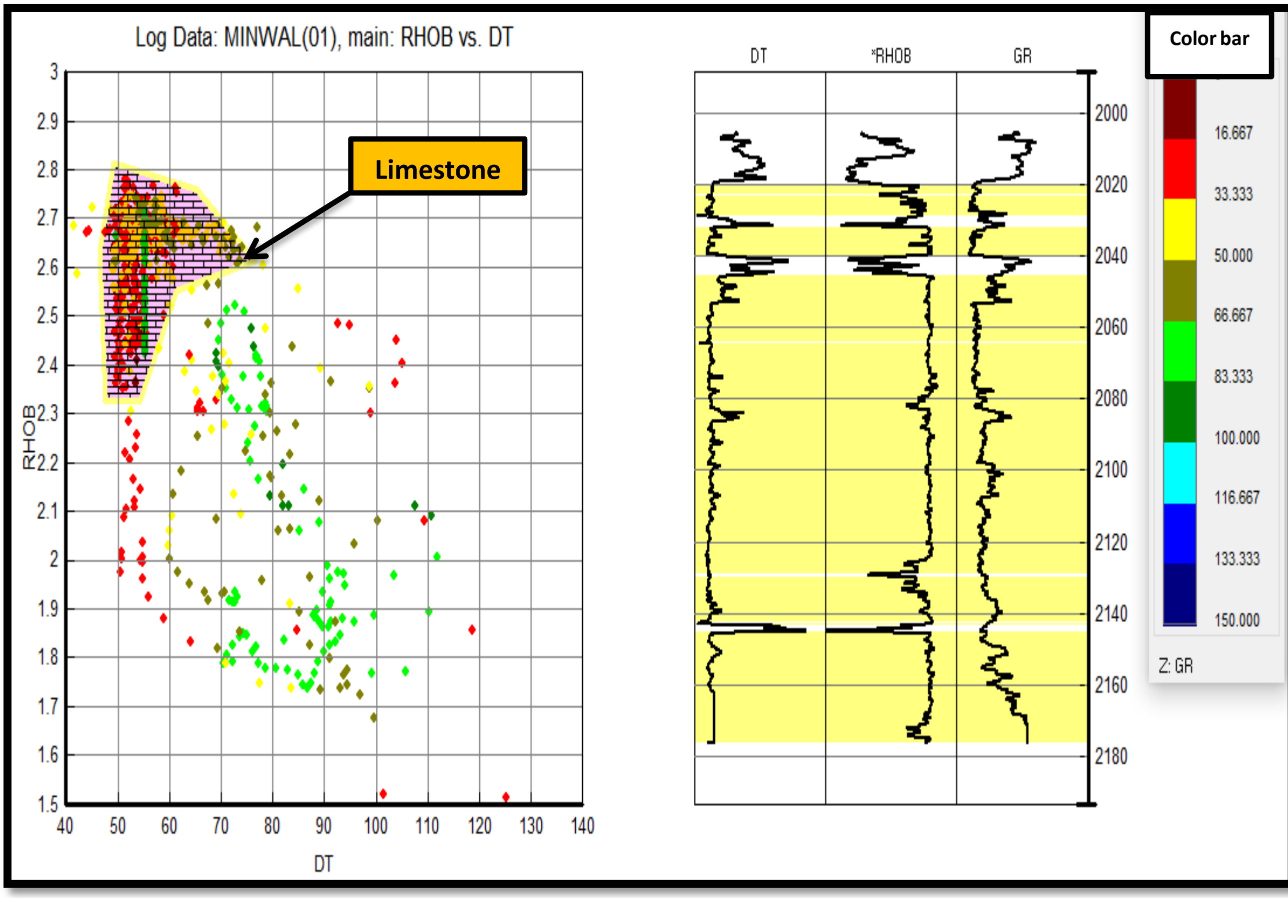


Figure 6.6 :Crossplot between Sonic log and Density log

The crossplot is computed as density log on y ,gamma ray log on z axis and sonic log on x axis. The depth range starts from 2020.28m to 2176.235m for desired prospect zones. Limestone with an average density of 2.71 g/cm3 can be identified in crossplot by density log.

By comparison of the figure , the polygon are drawn and labeled according to the standard crossplots. The group of points is again thick in the limestone polygon. It is therefore interpreted that the reservoir is mainly composed of limestone and can be justified by the value of density.

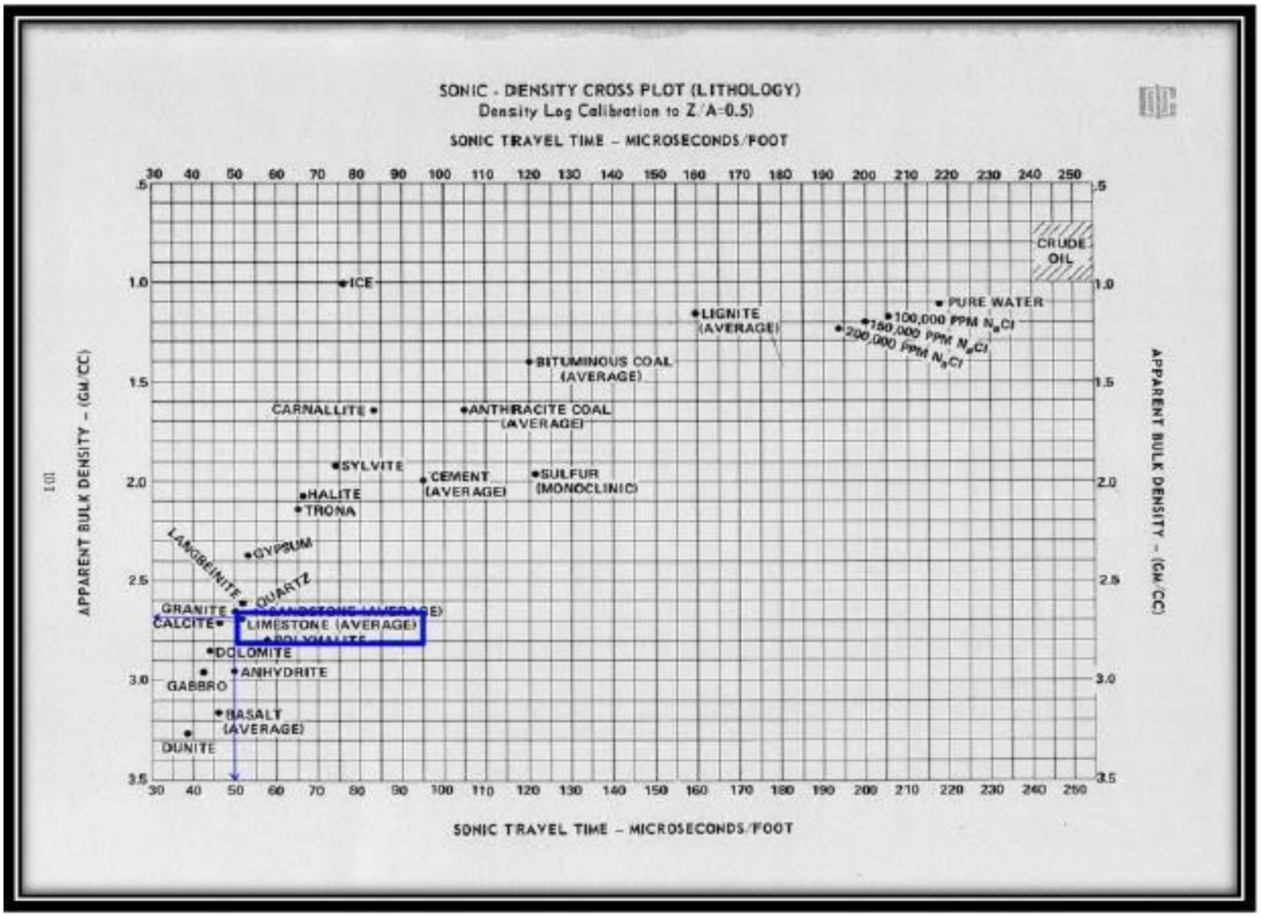


Figure 6.6 .b: Standard Crossplot between Sonic log and Density log

6.7 Depositional Environment Using Well Log Data:

To identify the coarsening and fining of the beds, the gamma and neutron log are considered to be the most useful logs for determining the lithological patterns. For this reason gamma ray log is been used as primary log indicators in well cores. In figure 6.7 the GR log helps us to identify the lithology and depositional environment of the sediments at time of deposition. It also analyzes the transgressive and regressive sequences and indicates the finning and coarsening upward lithology.

Changes in sea level causes the facies to either shift landward or seaward and produces a predictable pattern. These fluctuations can be described as

- **Transgression**
- **Regression**
- **Aggradation**

6.7.1 Transgression:

It is a geological process that occurs when sea level rises, termed as transgression. The facies shift landward and accommodation space will increase.The stratigraphic column exhibits a “fining upward” sequence as the grain sizes decreases moving up the column.

6.7.2 Regression

It is also a geological process that occurs when sea level falls , termed as regression.The facies shift seaward and accommodation space will decrease.The stratigraphic column exhibits a “coarsening upward” sequence.

6.7.3 Aggradation:

A static sea level results in a thick sequence of the same rock type.

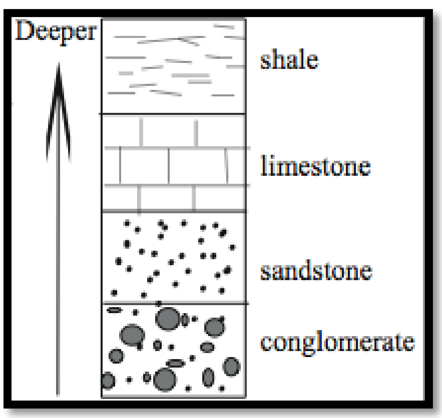


Figure 6.7.1 Transgressive sequence

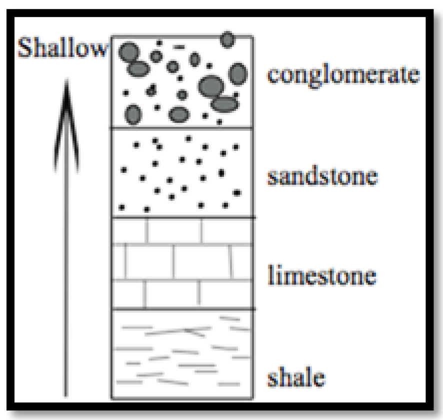


Figure 6.7.2Regressive sequence

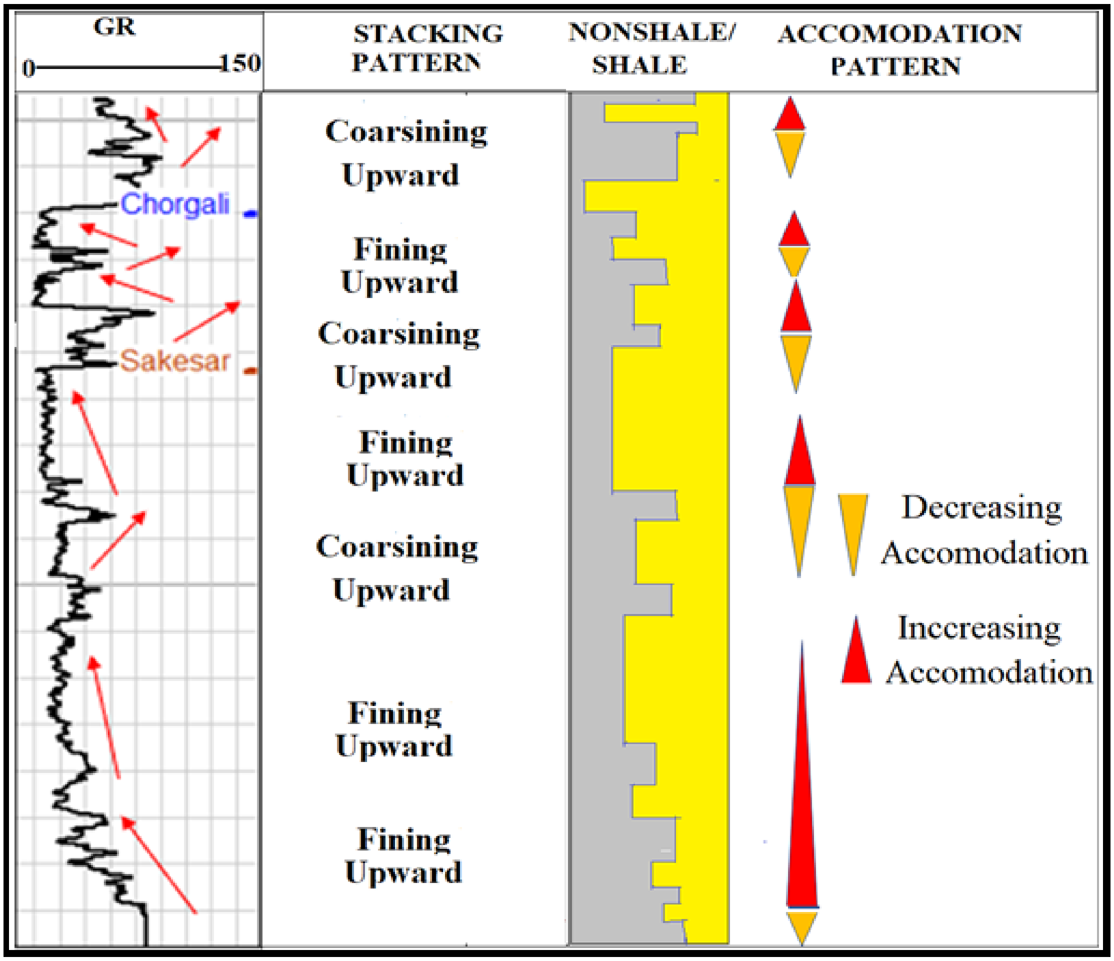


Figure 6.7:GR log response towards different lithological units whereas , arrows represents depositional environment associated with each lithology mainly shale and limestone for high and low values of GR log.Moreover , other charts indicates depositional sequences along with increase and decrease in accommodation spaces.

CHAPTER 7

COLOURED INVERSION

7.1 Introduction

Seismic inversion is an interpretation technique used to extract physical properties of rocks and fluids from seismic data (Krebs et al.,2009). Inversion converts reflectivity data to physical properties of the earth, such as acoustic impedance (AI), the product of seismic velocity and bulk density.

This is crucial because, while reflectivity informs us about boundaries, impedance can be converted to useful earth properties such as porosity and fluid content via known petrophysical relationships.

The basic purpose for applying the colored inversion is to evaluate the response of acoustic impedance in seismic. This new technique, ‘Coloured Inversion’, performs significantly better than traditional fast-track routes such as recursive inversion, and benchmarks well against unconstrained sparse-spike inversion.

Lancaster and Whitcombe (2000) published a fast method for band-limited inversion of seismic data known as colored inversion (CI) that generated widespread interest among interpreters.

Using open-source algorithms, we describe all the steps to go from reflectivity data to inverted cubes:

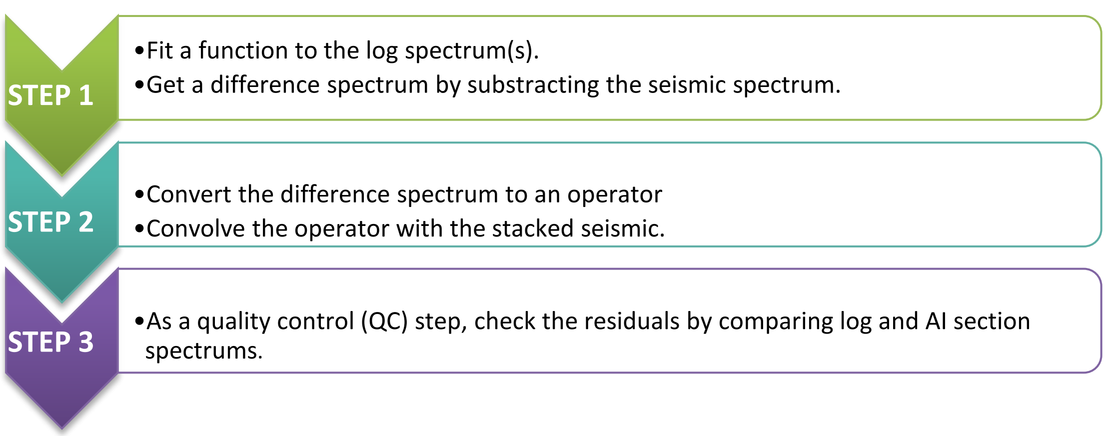


Figure 7.1 Steps for coloured inversion

7.2 Phase Rotation

We have found that the gross spectral form of AI logs from wells in any given field is reasonably constant. This implies that a single convolutional operator can be used to perform inversion. The approach assumes a zero-phase wavelet but does not need an explicit estimate of the wavelet amplitude spectrum. The zero-phase assumption can be compensated for by phase rotation of the inverted data in comparison with the AI logs.

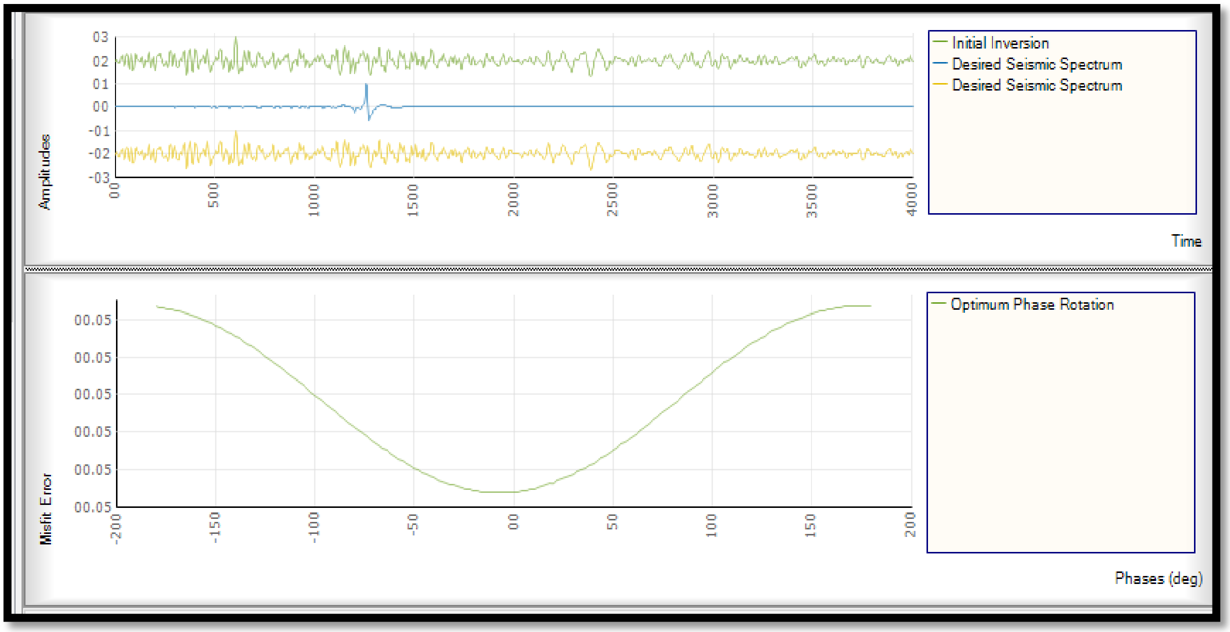


Figure 7.2

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

With Coloured Inversion (CI) we are now able to routinely invert any dataset within hours and establish a base-case against which all subsequently more sophisticated techniques must be judged.

7.3 Logs and Seismic

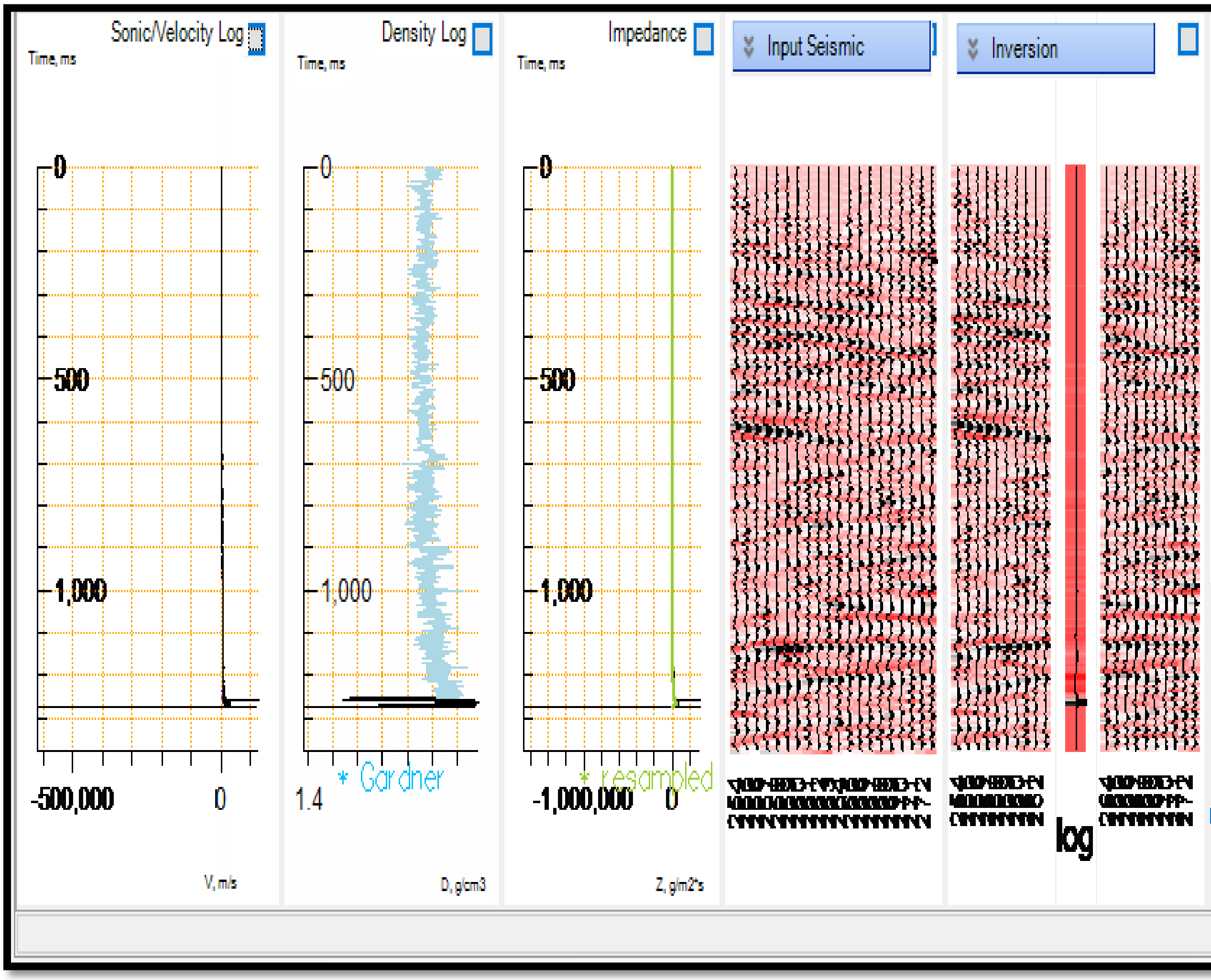


Figure 7.3 Impedance from logs and seismic reflection input data

By cross-matching the impedance data with the input reflection data we derive a single optimal matching filter. Convolving this filter with the input data we see that the result is very similar to the inverted data, everywhere. This empirical observation indicates that inversion can be approximated with a simple filter, and that it may be valid over a sizeable region.

Matching operator that optimally converts the input seismic to inversion. Convolving the operator with the seismic gives the inverted data.

7.4 Operator's amplitude spectrum (Impedance log Spectral Analysis)

Walden & Hosken's (1984) empirical observation tells us that all earth reflection coefficient series have spectra that exhibit a similar trend that can be simply described as f, β.

The β term is a positive constant and f is frequency.Velzeboer (1981) arrives at a similar observation theoretically. β may vary from one field to another but tends to remain reasonably constant within any one field.We have observed similar behaviour for AI spectra.

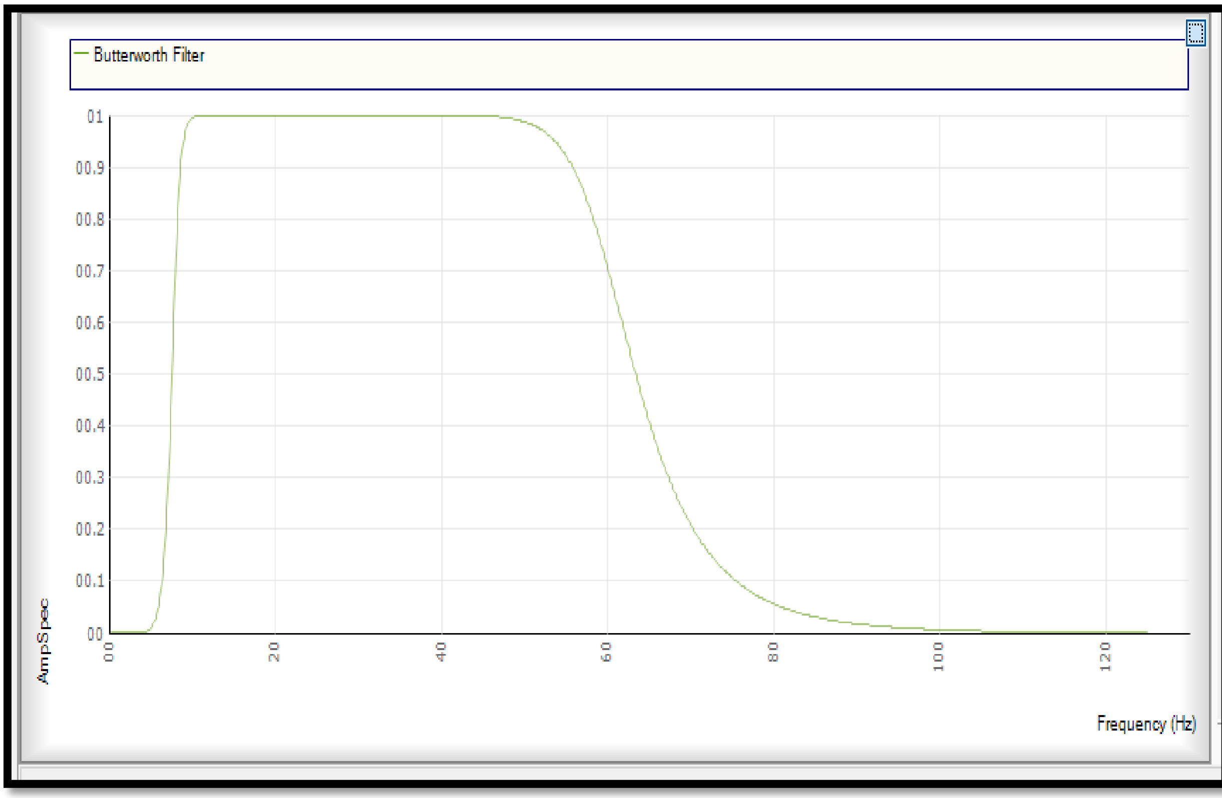


Figure 7.4.1 Butterworth filter

7.5 Butterworth filter

The most distinctive characteristics of butterworth wavelets is that they are minimum phase wavelets .A butterworth wavelet will start at time zero while ricker , ormby and klauder wavelts all have their peaks at time zero.

7.6 Spectral Shaping of seismic data

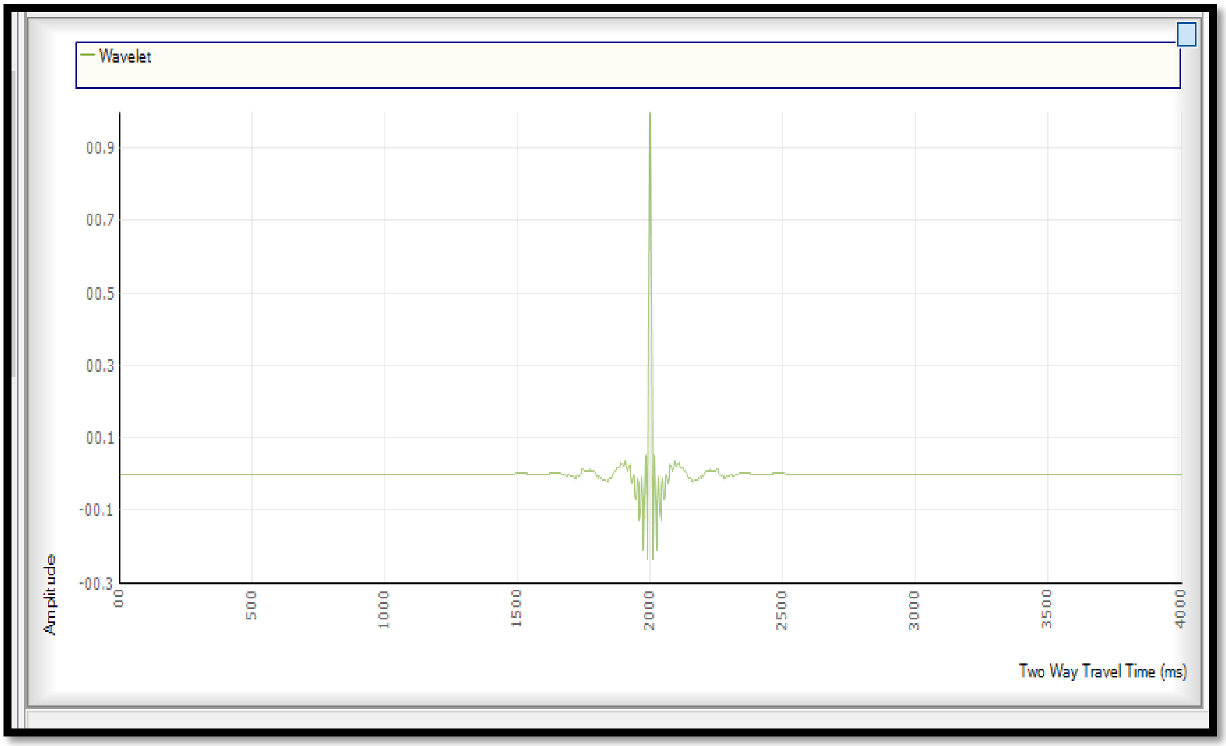


Figure 7.5.1 Wavelet

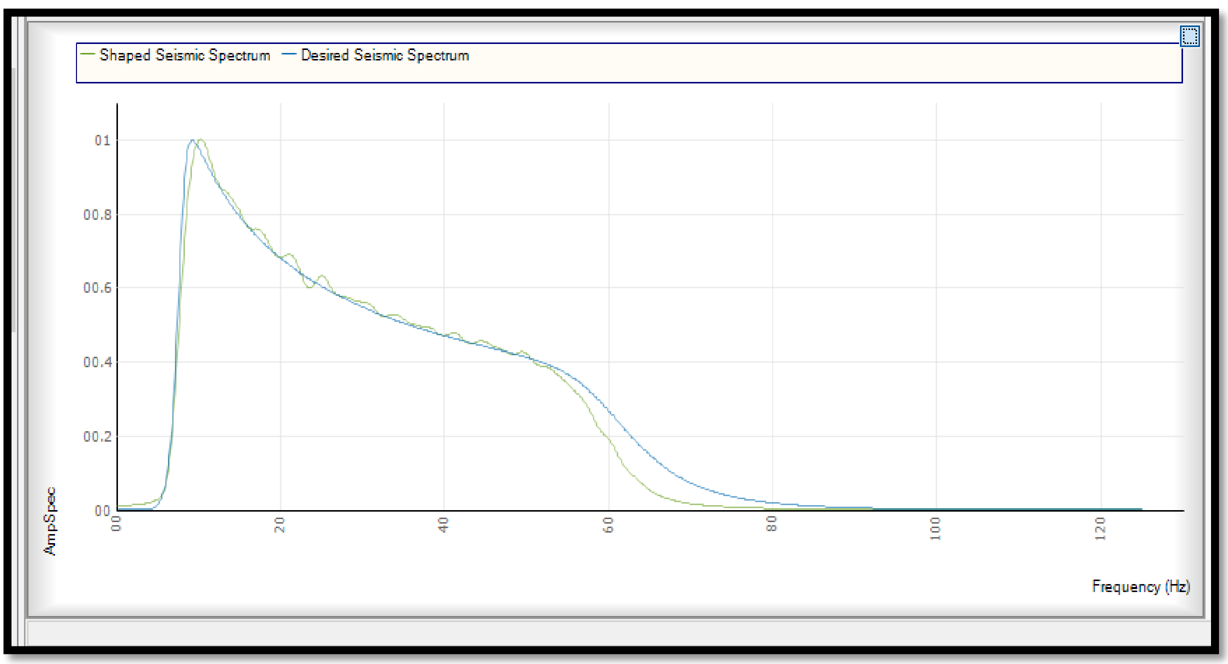


Figure 7.5.2 Desired Seismic Spectrum

7.7 Inverted seismic trace (line POL-MN-93-08)

All that is needed to derive our CI operator are AI logs over the zone of interest and enough seismic traces to form a good estimate of the mean seismic response. Once the CI operator has been derived it can easily be applied using standard interpretation software,

Colored inversion is applied on line POL-MN-93-08 and the resulted trace is given below:

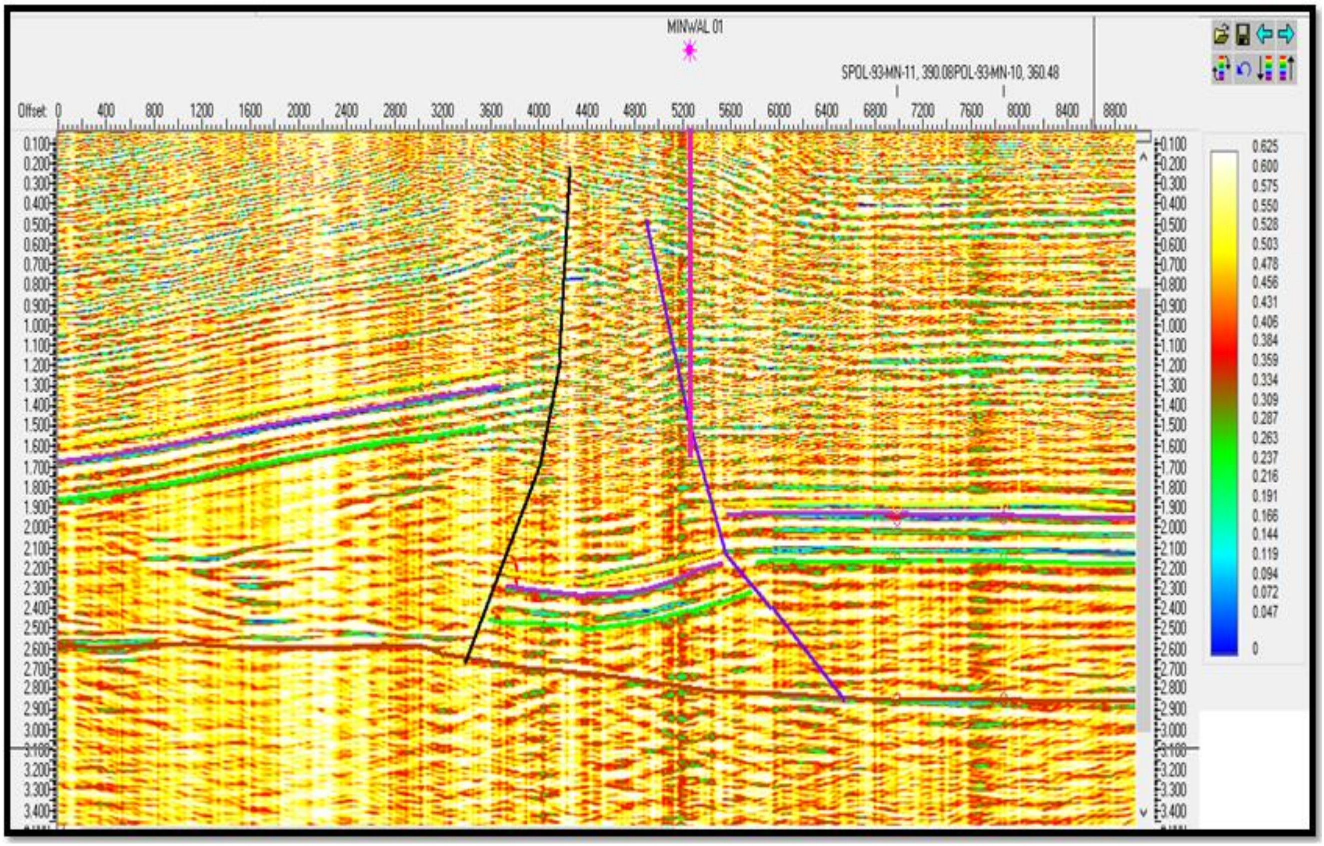


Figure 7.7.1 Colored inversion on line POL-MN-93-08

The process of inversion computes the acoustic impedances and display a contrast of impedances on seismic section.

Lower value of impedances are good indicative of hydrocarbon potential , we will analyze and mark low impedances in prospect zones further.

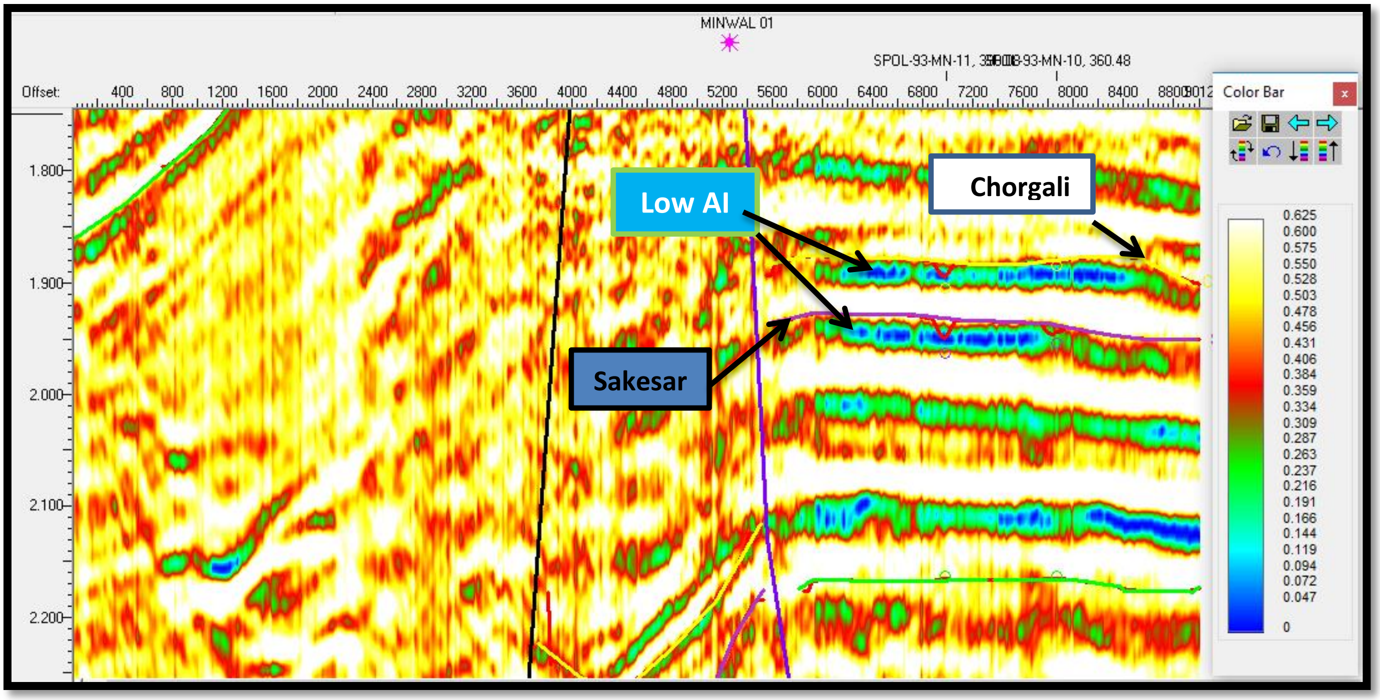


Figure 7.7.2 Low impedance in Zone of interest

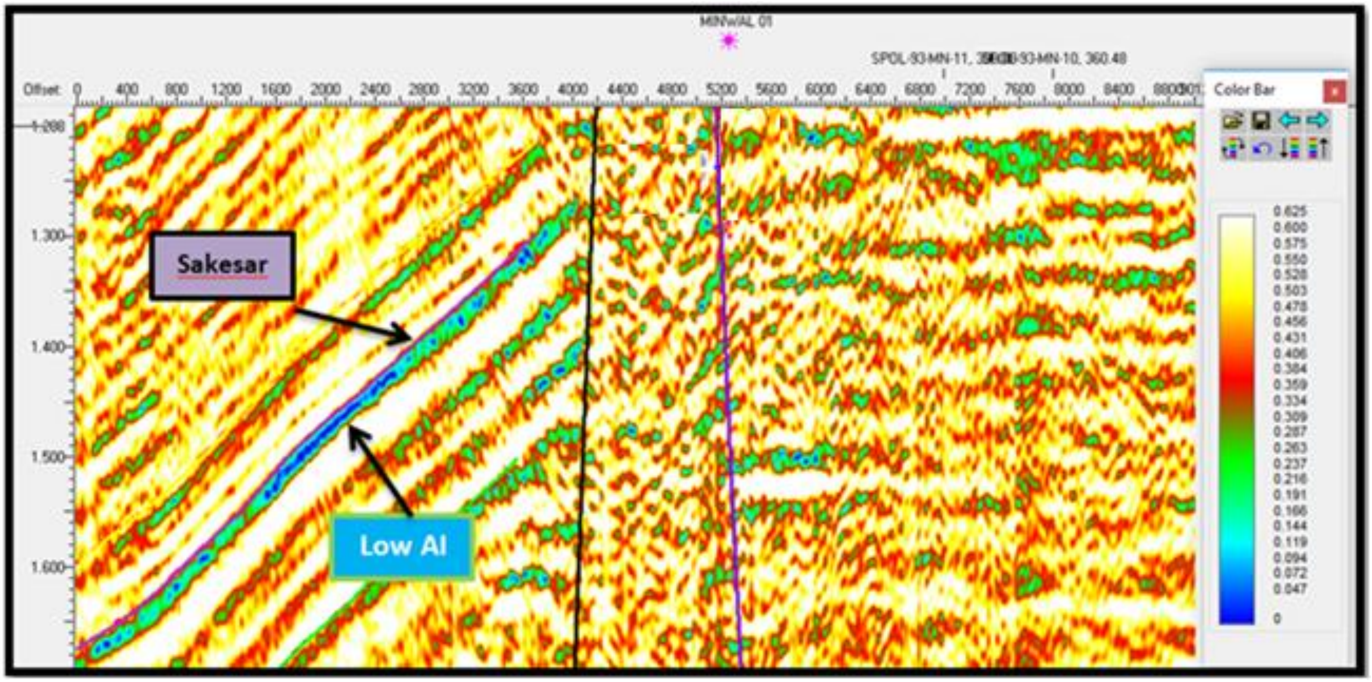


Figure 7.6.3 Low impedances at Sakesar prospect zone

7.8 Results

The Coloured Inversion result are very similar to sparse spike inversion but the Coloured Inversion took far less time and effort to achieve.In above mentioned line , the sakesar and chorgali formation which are prospect zones are good indicative of low impedances at several points. Low impedance validates our zone of interest as potentially rich.

Coloured Inversion enables the rapid inversion of data. A single convolutional inversion operator is derived that optimally inverts the data and honours available well data in a global sense. In this way the process is inherently stable and broadly consistent with known AI behavior in the area.

Construction of the operator is a simple process and implementation can be readily performed on most interpretation workstations. No explicit wavelet is required other than testing for a residual constant phase rotation as the last step. This removes an inherently weak-link that more sophisticated processes rely on. Since only a single convolution is applied, the process is a direct transform of the seismic data, which implies that the result can be viewed as a base-case, showing what information in the AI domain comes directly from the seismic.

Use of subsequent inversion methods, that employ constraints and/or a-priori models, can be compared with the Coloured Inversion to determine what the additional constraints have contributed to our image of the AI domain, over and above that from the seismic.

Coloured Inversion assumes that adequate noise attenuation has been performed, so that the seismic spectrum within the frequency bounds defined for the inversion is dominated by the contributions from the seismic wavelet and earth reflectivity. However, the process can be iterated so that further noise attenuation is performed on an initial inversion, and a correction filter applied to re-shape the spectrum to the measured earth spectrum.

Conclusions:

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

- Correlation of depth converted sections with formation tops and synthetic seismogram indicate Murree formation as seal ,Chorgali and Sakesar limestone as reservoir and Patala shale as source rocks.
- Two reverse faults F1 and F2 were marked on given sections.
- Time and Depth contour maps of Chorgali and Sakesar help us to confirm the presence of anticlinal structure in the given area.Surface contour map of Chorgali and Sakesar gives the real shape of sub-surface structure, which is a Triangle zone bounded by forethrust and back thrust faults.
- Petro physical analysis of the reservoir zone show the hydrocarbon potential of the well by yielding 33% water saturation and 67% hydrocarbon saturation.
- Rock physics also supports the petro physical results.
- Facies modeling with the help of cross plots confirm the presence of limestone as the dominant lithology.
- Depositional environment indicate transgressive sequence
- Colored inversion shows low impedances in desired zone of hydrocarbon potential.

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