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

BY

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بسم الله الرحمن الرحيم

I commence with the Name of Allah – in whom all excellences are combined and who is free from all defects and with the name of his Holy Prophet Hazrat Mohammad(SAWW) for whom He created this universe. He is the Compassionate, one whose blessings are extensive and unlimited. The Merciful One whose blessings are inherent and eternal. He sends down the rain and knows that which is in the wombs. No person knows what he will earn tomorrow, and no person knows in what land he will die. The knower of the unseen is Allah these are the keys of the unseen, whose knowledge Allah alone has kept for himself and no one else knows them unless Allah tells him about them.

CERTIFICATE OF APPROVAL

This dissertation by **Abdul Moiz Ahsan** S/O **Sajjad Hussain** is accepted in its present form by the Department of Earth Sciences, Quaid-i-Azam University Islamabad as satisfying the requirement for the award of degree of BS Geophysics.

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Finally, I would like to acknowledge my mother for her constant support, unceasing prayers, and best wishes. Her motivation uplifted my morale whenever I needed. I also Acknowledge to my Grandfather who always standbys with me through every thick and thin. May Allah(SWT) grants him high ranks in Jannah-ul-Firdous (Ameen). I do thank all those who have helped me directly or indirectly in the successful completion of my thesis.

Abdul Moiz Ahsan Awan

DEDICATION

I dedicate my work to my beloved MOM who is everything to me. Her efforts mean a lot to achieve my goals at every step of life.

Abstract

This dissertation is based on structural and stratigraphic interpretation of seismic data using seismic techniques and well log analysis. The Joya Mair 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. 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 triangular zone in the subsurface. The general trend of the structures is northwest southeast which indicated that the area lies in compressional regime. The reservoirs of Eocene occur 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 66% of hydrocarbon saturation. Rock-physics validates the petrophysical results. Facies modelling marks the dominant lithology.

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Chapter 1:

Introduction

1.1 Introduction to Hydrocarbon exploration:

The exploration of hydrocarbons in Pakistan initiated in 1868 at Kundal near Mianwali 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 is either in on-shore or off-shore areas, is considered quite bright (Sroor, 2010). 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 Upper Indus Potwar sub-basin is in the sub Himalayan land and contains many structural traps created because of Tertiary Himalayan thrusting and folding. It consists of Potwar plateau, the Salt Range, and the Jhelum Plains. The Potwar sub-basin is filled with thick Pre-Cambrian evaporates overlain by relatively thin platform deposits of Cambrian to Eocene age followed by thick Miocene-Pliocene molasses. This whole section has been deformed by intensive Himalayan orogeny in Pliocene to Middle Pleistocene.

Eocene and Paleocene reservoirs are the most productive reservoirs in different areas. The eastern Potwar have one of the most productive zones in this area. The Potwar sub-basin is one of the oldest oil provinces of the world, where the first commercial discovery was made in 1914 at Khaur. In the area, 396+ wells have been drilled.

The Joya Mair Oilfield lies in the south-southeast of the Salt Range-Potwar foreland basin (SRPFB). Joya Mair 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 situated in the upper Indus basin. It lies in the south of Himalayan and Karakoram Mountains in the north of Pakistan. The area lies in UTM (Universal Transverse Mercator) zone 43N in the World Geodetic System. The coordinates in degrees, minutes and seconds are Latitude 32º 59′ 52″ N to 32º 99′ 80″ N and Longitude 72º 49′ 31″ E to 72º 82′ 31″ E.

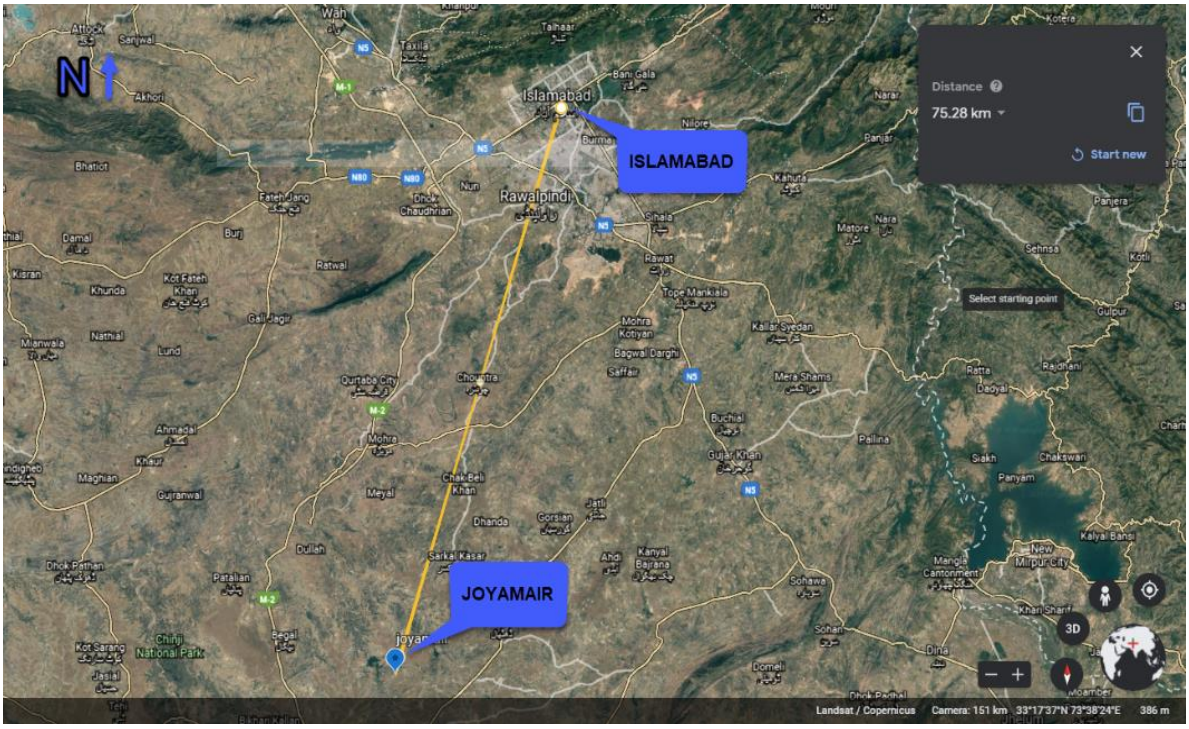


Figure: 1.1 Study area location: google earth.

1.4 Upper Indus Basin Exploration History:

In the Upper Indus basin Petroleum exploration in Pakistan began with drilling of first well in 1866 at Kundal, Mianwali. Petroleum Exploration history of the Potwar Basin starts huge quantities of oil were discovered in 1914 at Khaur, district Attock, Punjab by the predecessor of Attock Oil Company (AOC). As a result of the combined efforts of AOC and Burma Oil Company (BOC), Dhulian (1936), Joya Mair (1944) ,Balkassar (1946) and Toot (1968). During this period Pakistan Oil Limited (POL) discovered oil at Meyal (1968). Oil fields were discovered in the Potwar area establishing the oil potential of Potwar region. Occidental reported the most prolific discovery at Dhurnal-1 in Potwar region in 1984. The discovery of condensate/gas and oil at Dakhni (1983 and Dhurnal 1984) provided new leads to the hydrocarbon potential of Northern Potwar regions. Oxy discovered oil at Bhangali and Pindori during 1989-1990 in their Soan Concession. Pindori-1 during recompletion blows out and the well had to be abandoned but Pindori-2, 3, 4,5A and 6 are producing. OGDC discovered heavy crude at Chak Naurang (1986) and found oil at Missa Keswal-1 (1990). Oil was also discovered by OGDC in Potwar at Sadkal (1991) near Fatehjang, Rajian (1993) and Kal (1995) near Chakwal. Other significant discoveries were made by POL at Pariwali-1 (sidetrack in 1986) and Turkwal-1 (sidetrack in 1997) wells in Central Potwar Concessions. OGDCL make a breakthrough when oil was discovered for the first time in Kohat region at Chanda (former Shakardara Structure) from Datta Formation of Early Jurassic. As a matter of fact, this was first ever hydrocarbon discovery in KPK province which was followed by another discovery namely Manzalai (2002) and Makori (2005) by MOL of Hungary making Kohat plateau, new focus area for exploration. The discovery of Mela oil/gas (2006) by OGDCL, which were reinforced the belief of many Geologist that this region can host large hydrocarbon reserves with upside touching tens of trillion cubic feet of gas.

1.4.1 Work history of Potwar region:

First commercial oil in the Potwar area was produced from the Miocene (Murree Formation) at Khaur in 1914 (Kazmi and Jan 1995) .At the time of independence (1947), Pakistan inherited four productive fields, Khaur, Dhulian, 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).

1.4.2 Previous work history of study area:

Joya Mair field was discovered in 1946 by Attock Oil Company, establishing the potential of fractured Eocene limestone. The Chorgali (Chorgali) 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 MinwalX01) 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 in the northwestern compartment of the field, while POL-1 is 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.

1.5 Geographical Boundaries:

Geographically Joya Mair shares borders with Kalar Kahar 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.

1.5.1 Geological Boundaries of Potwar Basin:

The left lateral fault of Jhelum 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).

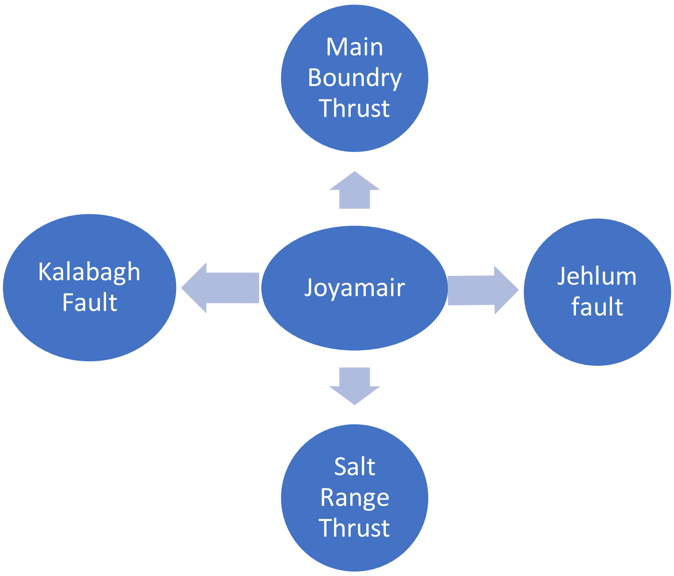


Figure: 1.2 Geological boundaries of study area.

1.6 Prospectively 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 Mair area lies in zone-II which is medium risk - high to medium cost areas.

1.7 Exploration and production Information:

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

Production information of Joya Mair oil field.

Recoverable reserves	Oil=38.3 MMstb, Gas = 234.86MMscfd
PPL working interest	100 percent
Operator	POL
Peak production	3700 BOPD in 1965
License Area	149.13 Sq Km

1.8 Data Formats:

The final migrated seismic section along with supportive data and petrophysical data obtained in following formats:

Types of Data	Format
Petrophysics	LAS format
Seismic	SEG-Y format
Navigation	DAT format
Well	LAS format
DEM	Grid format
Georeferenced satellite image	gif, jpg format

1.9 List of software tools and application:

- Kingdom suit.
- Kingdom used for Rock Physics and Engineering Properties.

1.10 Acquisition Parameters:

Data Record:

Recorded by	POL
Party Number	Seismic party # 7
Data recorded	30 SEP 1996

1.11 Seismic Source Description:

Energy Source	Dynamite
Charge Pattern	1 Hole
Average Charge Size	5 kg
Shot Point Interval	50 Meters

1.12 Data Recording Parameters:

System	SN388
Format	DMU*SEG D
Aliasing Filter	120 Hz
Notch Filter	Out
Field Sampling Interval	2 milliseconds
Record Length	6 seconds
No. of Data Traces	120

1.13 Survey Parameters:

Spread	3075-125-*-125-3075
Group Interval	50 meters
Type of Geophones	SM4
Geophone Code	0312
Group Length	97.30 meters
Geophone Interval	2.78 Eters

1.14 2D Seismic Lines Data set:

The well data used in current study is Minwal X-1 along with the six 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.

LINE NUMBER	LINE TYPE	LINE DIRECTION	WELL
POL93 MN 05	Dip line	NW-SE	
POL93 MN 06	Dip line	NW-SE	
POL93 MN 08	Dip line	NW-SE	Minwal X1
POL93 MN 09	Dip line	NW-SE	
POL93 MN 10	Strike line	NW-SW	
POL93 MN 11	Strike line	NW-SW	

1.15 Well Data Type:

The well data includes the following files:

- LAS 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 Minwal X-01.

1.16 Well Tops Information:

Formation Tops	Formation Tops Age	Formation Tops Values (m)	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

1.17 Base Map:

Base map is the map on which primary data and interpretations can be plotted. The base map displays the spatial position of each picket of a seismic section. It also shows the spatial relationship of all seismic sections under consideration, their tie point locations and provides the framework for contouring. The base map of the area is generated using KINGDOM SUITE as shown in figure 3.2.

1.18 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.

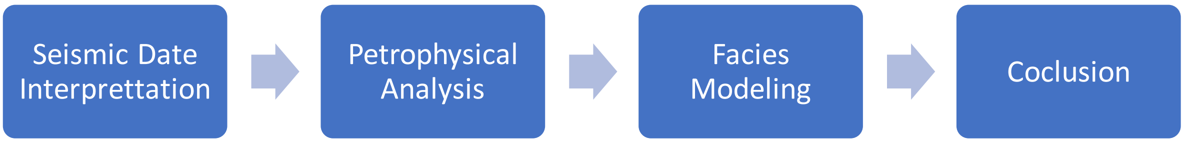
- The main objectives of the current study are the following:
- The Seismic data interpretation to delineate the subsurface structural geometry of the area. The describe of the subsurface structural and stratigraphic traps for hydrocarbon accumulations.
- Seismic Attribute Analysis for the confirmation of the horizon marking.
- Conversion of interpreted time section into depth section to identify the depth of key horizons and to construct depth surface maps of the reservoir rocks.
- Integration of seismic and well data to enhance the precision of the interpretation process.
- Petrophysical analysis of the reservoirs present in the study area.

1.19 Methodology:

According to recent information that is under seismic facts and wells data of Minwal X-01 Base map of the concern area, seismic lines and well locations:

- Identify the exact location of horizons with the help of well data i.e. check shot and synthetic seismogram
- Time horizons are marked on the identified reflectors that form the petroleum play system.
- Time contour maps for the marked horizons are generated.
- Time to depth conversion is done with the help TD chart and velocity relation.
- Depth contour maps for the horizons are generated.
- Petrophysics is performed for the production potential of the reservoir.

1.20 Workflow:



Chapter 2:

REGIONAL TECTONICS AND STRATIGRAPHY

2.1 Introduction

The information about the geology of an area plays an important role for precise interpretation of seismic data. The interpretation of seismic data in geological terms is the objective of seismic project. Therefore, seismic data interpretation is based on the stratigraphy and structural geology of the area. So as if we do not know geological formations in area, we don't recognize the different reflections appearing in the seismic section. This chapter deals with a brief description of the tectonic setting, structural geology, and stratigraphy of the study area (Joya Mair) and adjoining areas of upper Indus Basin.

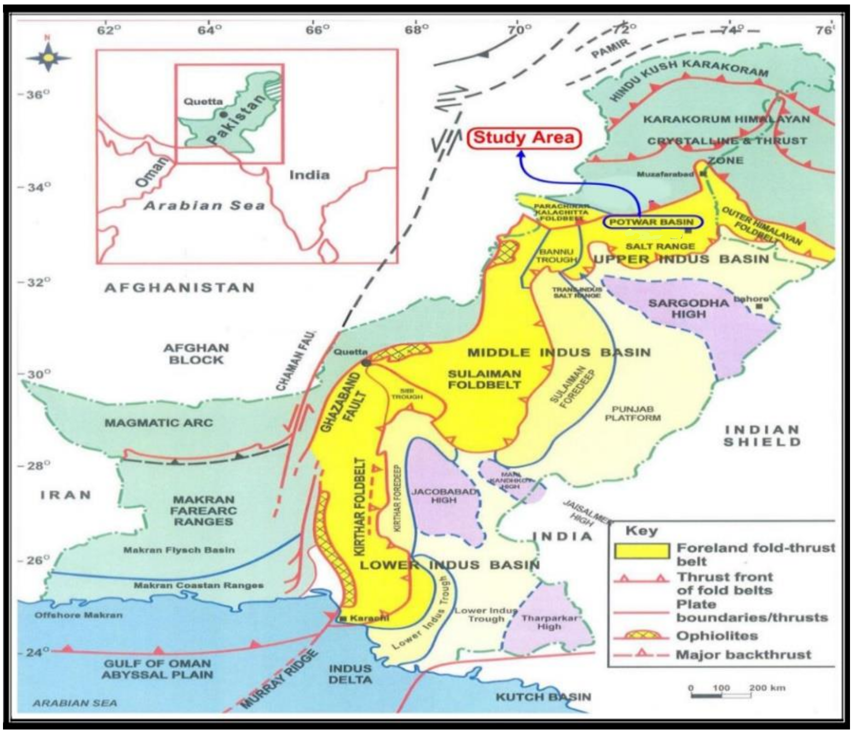


Figure: 2.1 Map Showing study area and geological boundaries.

2.2 Regional Geology and Tectonics setting:

The Himalayan Orogenic belt is the youngest mountain belt in the world which came into existence because of collision between the Indian plate in the south and Eurasian plate in the north. The site of collision is a broader zone and marked by the Himalayan-Karakorum-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 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. 1987). 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. 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 Kashmair 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.

2.3 Sedimentary Basins of Pakistan:

There are the following three basins lies in Pakistan:

- Indus Basin
- Pashin Basin
- Balouchistan Basin

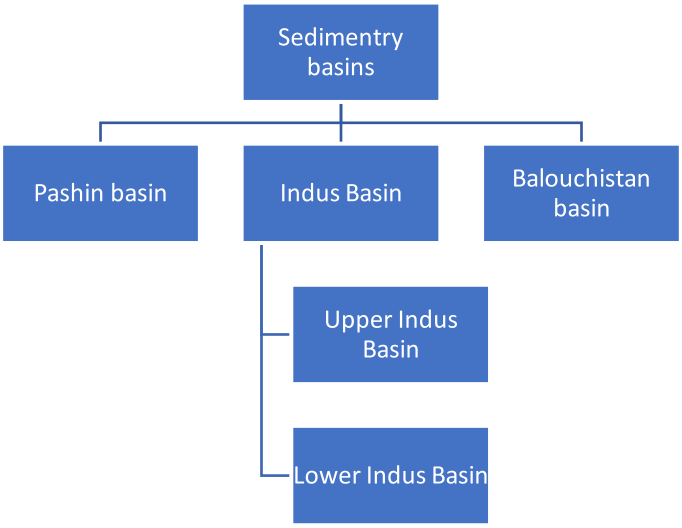


Figure: 2.2 Sedimentary basins of Pakistan.

2.4 Tectonic boundary of Potwar Plateau

The Potwar Plateau is comprising 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. (Aamair and Siddiqui, 2006).

The northwest Himalayas in Pakistan can be divided into four tecnomorphic terrain which is separated by major fault systems. The Potwar is bounded by two strike-slips and two thrust faults. These four tecnomorphic terrains are from north to south which is as under:

- Main Karakorum Thrust (MKT)
- Main Mantle Thrust (MMT)

- Main Boundary Thrust (MBT)
- Salt Range and Trans Indus Ranges Thrust

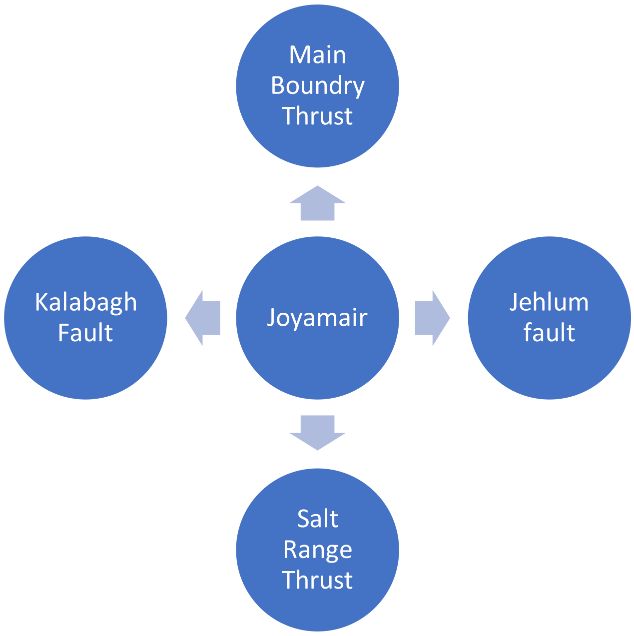


Figure: 2.3 Tectonic boundaries of Potwar Plateau (Shami & Baig, 2003).

2.4.1 Kalabagh fault:

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

2.4.2 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).

2.4.3 Salt Range Thrust:

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

2.4.4 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 Kashmair-Syntaxis also this fault strike the in the direction of east moving in the direction of Southern side of Kala Chita Range and North of Kohat plateau.

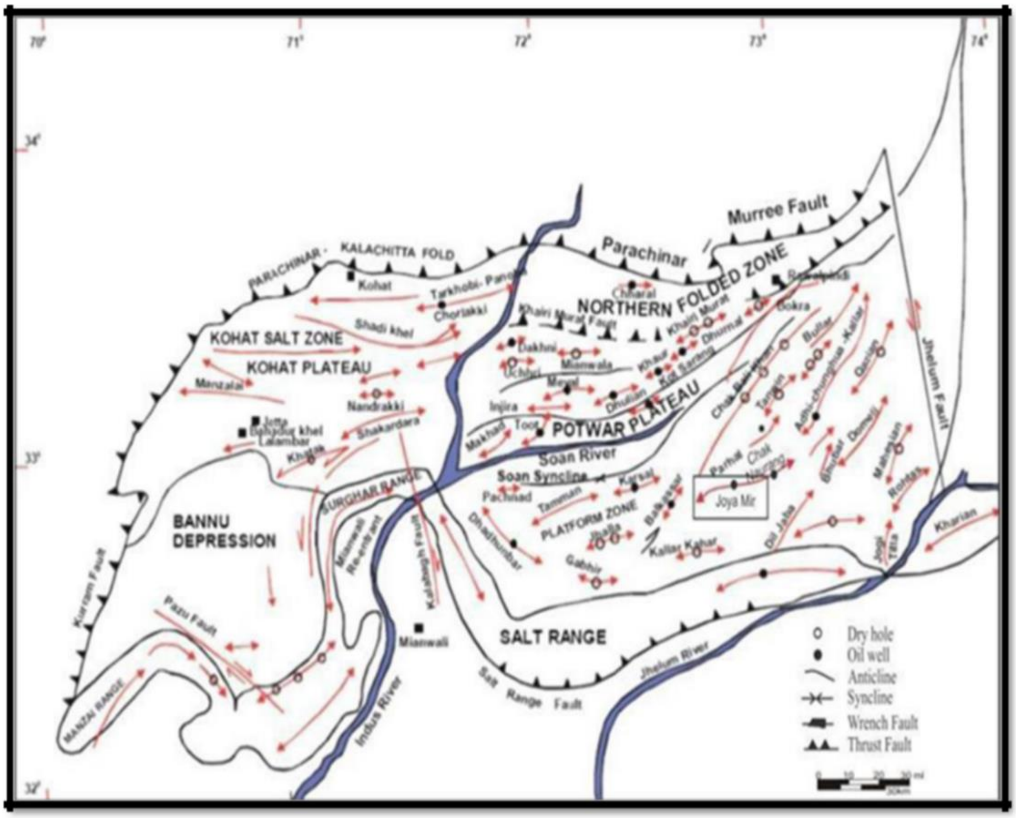


Figure: 2.4 Tectonic divisions of Potwar Basin.

2.5 Structural Style of Potwar Plateau:

The structural style of the central eastern and western parts of Potwar Plateau shows a marked difference. In the central western parts of Potwar Plateau, the deformation appears to have occurred by south-verging thrusting, whereas in the eastern part the deformation is mainly in northeast-southwest direction with tight and occasionally overturned anticlines separated by broad synclines. This difference may be related to lesser amount/thickness of salt in the lntra-Cambrian in the eastern areas and very low dip of the basement (1°-1.5°) as compared to Central Potwar (2^0-3^0). In Central Potwar, structures are mainly fault bounded mostly by thrusts and back thrusts, while at some places, asymmetric anticlines are bound by a single fault.

2.5.1 Local Structural Settings of Study Area

The Joya Mair oil field is in the southeastern part of the Salt Range Potwar Foreland Basin (SRPFB). The study area shows a complicated structural configuration. The Joya Mair area is basically an anticline at the surface and plunges 10° southwest and 4° northeast (Shami et al., 2002). The fold axis of anticline trends northeast-southwest forming northeast-southwest trending Joya Mair Anticline. The formations which are exposed at the surface are Chinji and Nagri. The Chinji Formation is exposed at the core of the anticline and the Nagri Formation is exposed at the limbs and at places they are covered by alluvium. Seismic images of the Joya Mair oil field show that the Joya Mair structure is a triangular zone in the subsurface.

Based on the seismic interpretation, the structures in Potwar area may be divided into: Pop-up anticlines, Salt cored anticlines and Triangle zones.

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

- Pop-up anticlines
- Snake head anticline
- Salt cored anticlines
- Triangle zone

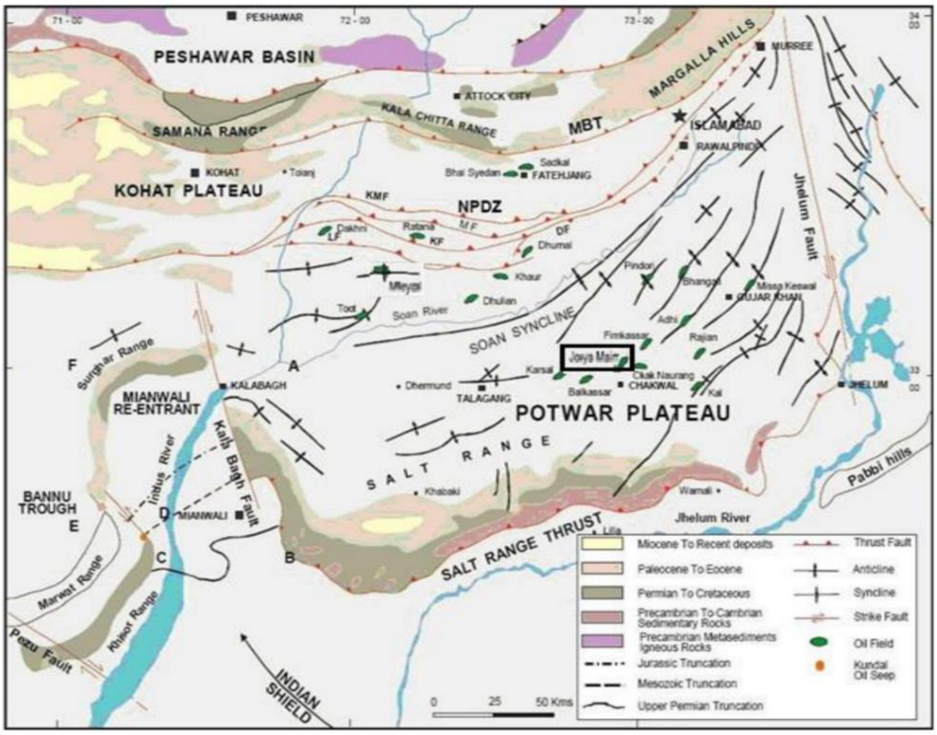


Figure: 2.5 Geological and Structural Map of Potwar Plateau (after Khan and others, 1986; Gee, 1989).

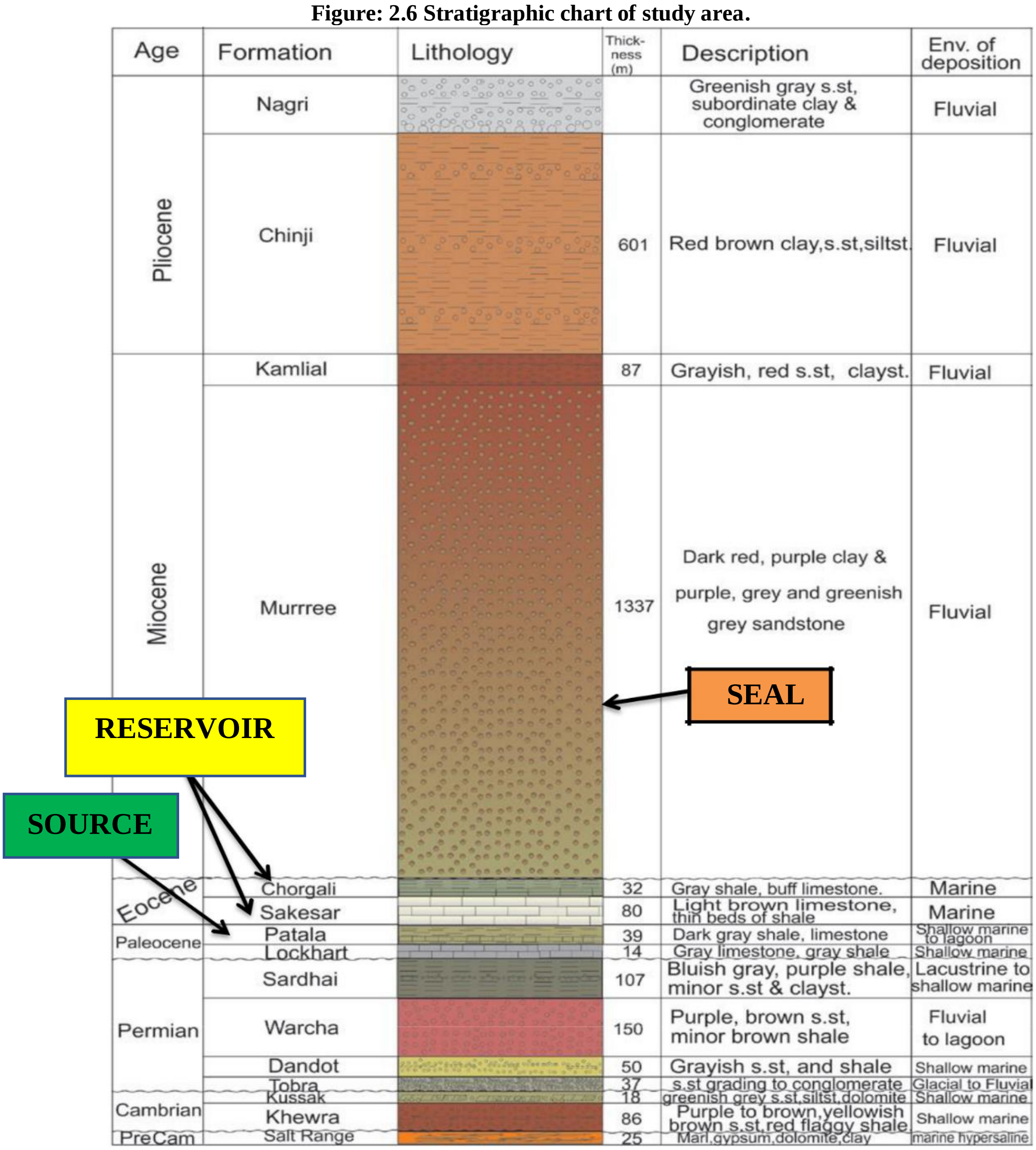
Minwal X-1 lies in near Joya Mair. This region is active area for oil and gas exploration and production. This Well is drilled by POL drill on the Joya Mair in North Eastern limits of the structure. The location of the well was at SP Seismic Line No: 93-MN-08. The Eocene Chorgali and Sakesar formations 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.

2.5.2 Joya Mair triangle zone:

The Joya Mair Triangle Zone is recognized based on seismic survey which is a key structure for the exploration of hydrocarbons in foreland fold and thrust belts. The sedimentary rocks are deformed on the Precambrian evaporates of the Salt Range Formation in SRPFB. Borehole and seismic data show that the Joya Mair structure is not a simple anticline. It is a triangle zone formed by the combination of thrust and back thrust, resulting in the triangular zone geometry in the subsurface and an open anticline at the surface. These thrust and back thrust phases in SRPFB are the result of northwest southeast Himalayan compression. (Aamir et al., 2006)

2.6 Generalized stratigraphy of the area:

Figure: 2.6 Stratigraphic chart of study area.



2.6.1 Paleocene Patala Formation:

The Patala Formation overlies the Lockhart Formation conformably and its type section is in the Patala Nala in the Western Salt Range. 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.

2.6.2 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 forms locality is Namal Gorge Salt Range, Punjab and thickness of this information is 100m at type locality. Its age is early Eocene.

2.6.3 Eocene Sakesar Formation:

With increase in limestone beds, the Namal 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 Mair 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.

2.6.4 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 mollusks, ostracods, and foraminifera. The age of the Chorgali Formation is Early Eocene. It is overlain unconformably by the Neogene sequence.

2.6.5 Miocene Succession Murree Formation:

The type section of Murree Formation is in north of Dhok 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.

2.6.6 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 intraformational conglomerate. Several mammalian fossils have been found (Pascoe, 1963). The age of the Kamlial Formation is middle to late Miocene.

2.6.7 Pliocene Chinji formation:

The type locality of Chinji formation is South of Chinji, Campbellsport, 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.

2.6.8 Pliocene Nagri Formation

Nagri village, Attock 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.

AGE	FORMATION	ENVIRONMENT
Pliocene	Nagri	Fluvial Channel
	Chinji	Fluvial Stream Channel
Miocene	Kamlial	Fluvial
	Murree	Fluvial
Oligocene	Unconformity	
Eocene	Chorgali	Shallow Marine Supratidal Lagoon
	Sakesar	Shallow Marine Supratidal Lagoon
	Nammal	Shallow Marine Restricted Anoxic
Paleocene	Patala	Shallow Marine
	Lockhart	Shallow Marine (Distal to Proximal)
	Hangu	Shallow Marine (Littoral to Proximal)
Cretaceous	Unconformity	
Jurassic		
Triassic Late Permian		
Early Permian	Sardhai	Very Shallow Marine to Estuarine
	Warcha	Fluvial Sub Aerial Paludal, Agonal
	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

2.7 Petroleum geology of the area:

The Salt Range Potwar- Foreland Basin (SRPFB) belongs to the category of extra continental down warp basins, these accounts for 48% of the world known petroleum (Riva, 1983). It has several features suitable for hydrocarbon accumulation including continental margin, thiamine sedimentary sequence, potential source, reservoir, and cap rocks. The thick overburden of 3047m of molasse deposits provides burial depth and optimum geothermal gradient for oil formation. The Salt Range Potwar- Foreland Basin (SRPFB) with an average geothermal gradient of 2 °C/100 m is producing oil from the depth of 2750-5200m (Shami and Baig, 2002). The presence of an optimal combination of source, reservoir and trap within the oil window resulted oil and gas accumulation in Joya Mair, Toot, Meyal and Dhulian oilfields (Kozary et al, 1968).

The Kohat-Potwar depression has several features that make it a favorable site for hydrocarbon accumulations. Located on a continental margin, the depression is filled with thick deposits of sedimentary rocks, including potential source reservoir and cap rock.

Simple and translated fault-propagation folds form important structural traps in fold and thrust belts. These fault traps may be present along back-limb thrusts, between the imbricates in the forelimbs and in upturned beds in the footwall. Secondary traps may also be present within major thrust sheets, particularly at the leading edge of the thrust sheet and above footwall ramps (Mitra, 1990).

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 Mair-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.

2.8 Petroleum system

2.8.1 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. Patala formation is the key source rock of oil production in Potwar sub-basin according to the oil to source correlation.

2.8.2 Reservoir:

The main oil producing reservoirs 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).

2.8.3 Cap Rock:

In Potwar area most of the structures are anticlinal and thrusted anticlinal due to Himalayan orogeny. The Kuldana formation acts as a cap for the reservoirs of Sakesar and Chorgali formations in SRPFB. The clays and shales of Murree formation also provide vertical and lateral seal to Eocene Reservoirs in SRPFB wherever it is in contact.

2.8.4 Traps:

Traps have been developed due to thin-skinned tectonics, which has produced faulted anticlines, pop-up, and positive flower structures above Pre-Cambrian salt. The clays and shales of the Murree Formation provide efficient vertical and lateral seal to Eocene reservoirs wherever it is in contact.

2.8.5 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.

2.9 Migration and Accumulation:

The Paleogene reservoirs show favorable properties for migration and accumulation of oil in SRPFB. The Eocene carbonates of Sakesar and Chorgali show very low primary porosity. The limestone is deposited in supratidal to intratidal environments, indicating very low primary porosity, which averages from 1-3% as obtained through the core analysis of Joya Mair, Dhulian and Meyal oilfields. The dominant secondary porosity in these carbonates is the fracture porosity. The fracture trend study indicates that the migration of oil within the structure occurred upward and laterals in northeast-southwest and northwest-southeast directions.

The oil migrated and accumulated in the hanging wall anticlines of the southeastern and northwestern flanks of the triangle zone. The oil is trapped in the hanging wall anticlines because the clays of the Murree formation lie in the footwall and above the Paleogene reservoir. The accumulation of oil in the hanging wall anticline of the southeastern flank is proven by the drilled oil wells in the Joya Mair oilfield. The similar hanging wall anticline occurs along the northwestern flank of the triangle zone.

Formation Name	**Rock Type**
Murree	Seal
Chorgali	Reservoir
Sakesar	Reservoir
Patala Shale	Source

Figure: 2.7 Generalized petroleum system.

Chapter 3:

SEISMIC DATA INTERPRETATION

3.1 Introduction:

The Seismic interpretation is the process of determining information about the subsurface of the earth from seismic data. It may determine general information about an area, locate prospects for drilling exploratory wells, or guide development of an already-discovered Field (Coffeen, 1986). Conventional seismic interpretation implies picking and tracking laterally consistent seismic reflectors for the purpose of mapping geologic structures, stratigraphy, and reservoir architecture. The goal is to detect hydrocarbon accumulations delineate their extent and calculate their volumes. Conventional seismic interpretation is an art that requires skill and thorough experience in geology and geophysics. To meet the challenges of exploring ever increasingly complex targets, there have been tremendous advancements in data acquisition equipment, computer hardware and seismic processing algorithms in the last three decades (Khan, 1995). The seismic method has thus, evolved into a computationally complex science. The computer-based working (Processing & Interpretation) is more accurate, precise, efficient, and satisfactory which provides more time for further analysis of data. This whole work is carried out using by the computer software products, which is SMT Kingdom suit.

3.2 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 analyzing 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 Structural analysis:

It is the analysis of reflector geometry based on 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. Time structural maps are constructed to show the geometry of reflected events. Discontinues reflections clearly indicate faults and undulating reflections reveal folded beds**.**

Seismic is correlated with the formation tops penetrated in the wells using well tops if available. In this study, seismic interpretation is done by picking horizons and marking faults on seismic lines. Mistie are major concern during interpretation, which is resolved by using of bulk shift of different time. Two-way time (TWT) maps are generated using fault polygons to describe the structural inclination at different levels.

3.3.1 Structural Interpretation of Joya Mair Area:

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

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 below in figure:

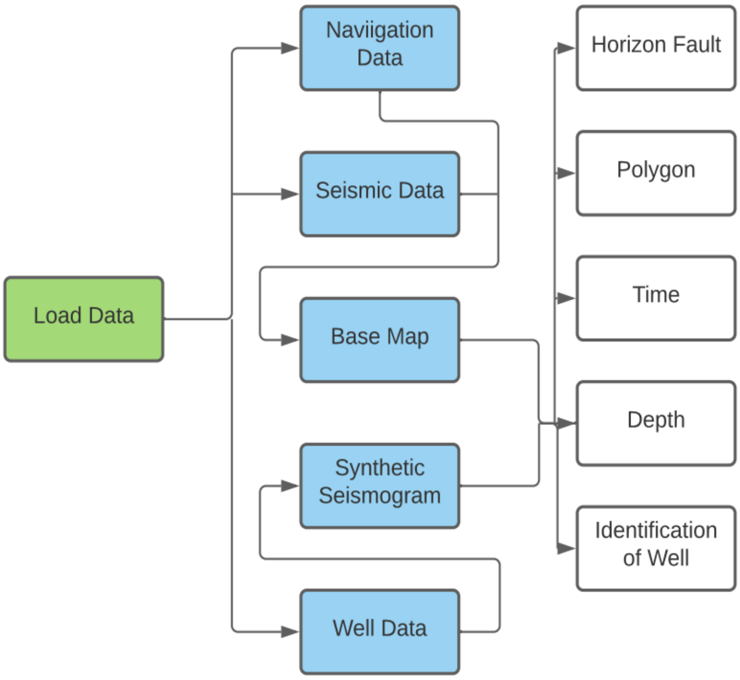


Figure: 3.1 Workflow adopted for the seismic data interpretation.

3.5 Data assigned for interpretation:

I have been assigned with three dip lines and one strike lines as follows:

Line Number	Line Type	Line Direction	Well Name
POL93MN08	Dip line	NW-SE	Minwal-X1
POL93MN06	Dip line	NW-SE	
POL93MN09	Dip line	NW-SE	
POL93MN11	Strike line	NE-SW	

3.6 Seismic section:

Seismic section is the outcome of the seismic reflection survey. The seismic section shows the high values of traces in vertical line which are called recorded peaks in the cross section. Most importantly it points out some the features of a geologic cross-section. These high value traces in seismic section is filled in with black shows the wiggle-variable area. The seismic section displays or plot the data of the seismic line. The vertical scale in the seismic section displays the arrival time (Two-way travel time). Seismic section plots or displays seismic data along a line. The vertical scale is usually arrival time but sometimes depth and the Horizontal axis shows the shot points and CDP.

3.7 Base Map Generation:

The base map is an important part of interpretation. Base map generally includes the location of wells, seismic survey points with geological reference such as latitude and longitude For a geophysicist a base map shows the alignment of the seismic lines and specifies the points where the seismic data were acquired. Base map of the study area is in figure.

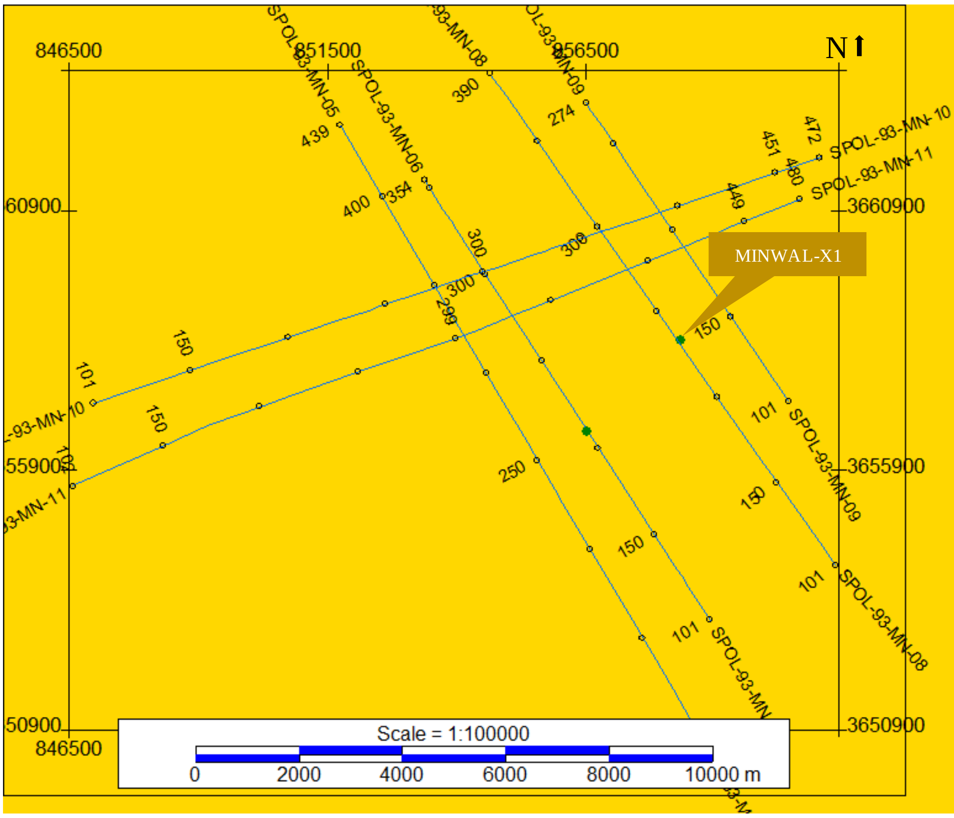


Figure: 3.2 Base map of Joyamair Area.

3.8 Generation of Synthetic Seismogram:

Synthetic seismogram is an artificial seismic reflection record prepared from velocity log data by convolving the reflectivity function derived from digitized acoustic and density logs with the wavelet derived from seismic data. Synthetic seismogram is an artificial model of the Earth that is contracted to mark the different geological horizon on the seismic section. It is direct one-dimensional model of acoustic energy traveling through different layers of Earth.

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). Seismic data is provided in time scale and well tops are given in depth. So, we cannot mark horizons in time form. 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 the well exhibiting seismic line. Then tie is marked with well exhibiting line and rest of other lines. In this way horizons are picked on rest of other 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 reservoir formation. The synthetic seismogram is displayed in figure

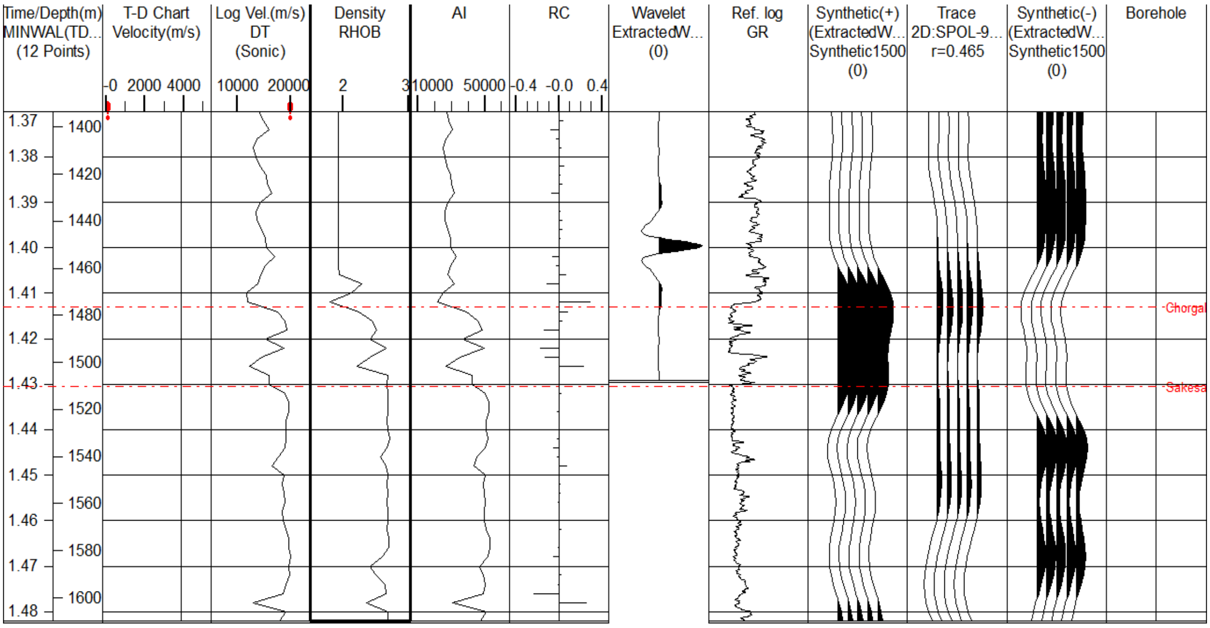


Figure: 3.3 Shows the Synthetic Seismogram (Minwal Well X-01)

3.9 Horizon marking and interpretation:

The reflection that can be traced across a seismic section is called a seismic horizon. 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 (Chorgali, Sakesar, Khewra Sandstone, Salt Range Formation and Basement) terminated by fore-thrust and back-thrust reverse faults structure which is an identification of Triangle zone in this area.

The Joya Mair triangle zone is limited by oppositely dipping 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 diapers of salt.

3.9.1 Marked horizons:

Horizons are interpreted on basis of synthetic seismogram, generated from well MINWAL-X1. In this project, five horizons were being marked.

- Chorgali Formation (Reservoir)
- Sakesar Formation (Reservoir)
- Khewra Sandstone Formation
- Salt Range Formation

- Basement (Rock)

3.9.2 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 forming a triangle zone at subsurface. The triangle zone is the result of two phases of Himalayan thrusting. Therefore, two reverse faults are marked on assigned lines.

- F1 Reverse Fault
- F2 Reverse Fault

3.9.3 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 Minwal X-1 well is drilled on the respective line.

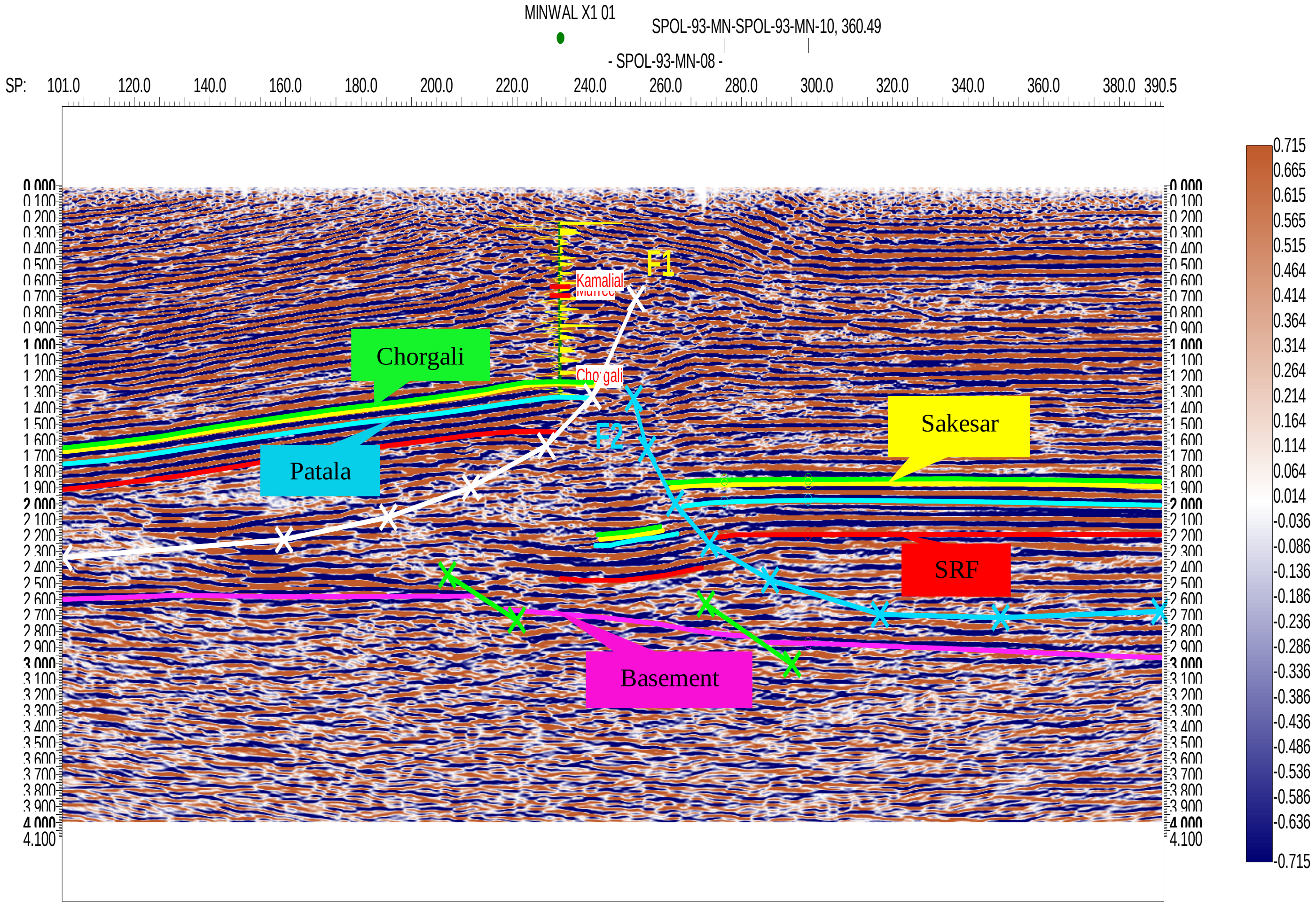


Figure: 3.4 (POL-MN-93-08) Dip line

3.9.4 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 Minwal X-1 wells. The structures portrayed by this seismic line are very similar to those present in the line 93-MN-08 and 93-MN-09 (fig 3.6 & 3.4). The Joya Mair structure is basically a triangle zone consisting of a fore-thrust verging towards southeast and a back thrust verging towards northwest. Both thrusts die out in Siwaliks Group.

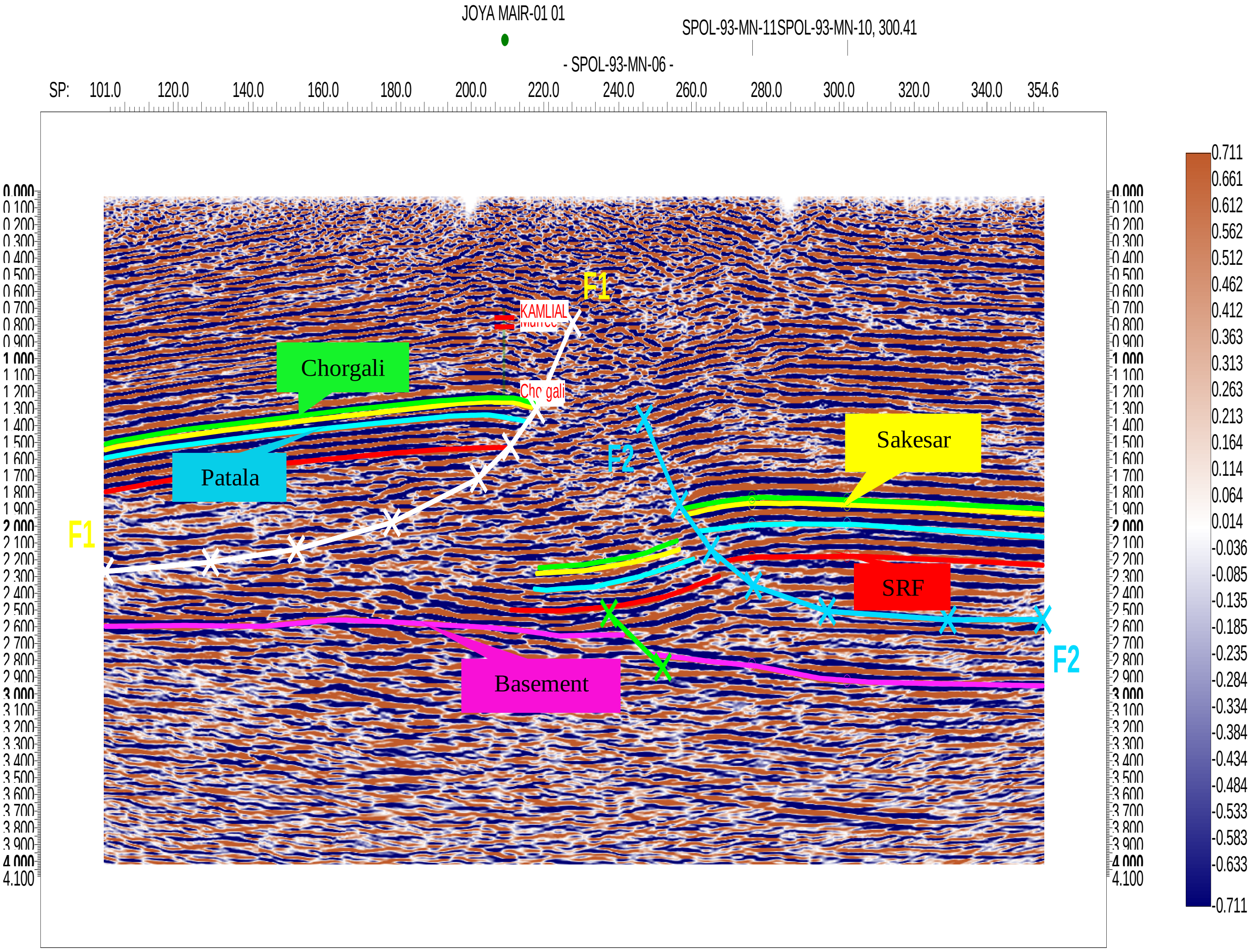


Figure: 3.5 (POL-MN-93-06) Dip line

3.9.5 Interpretation of POL-MN-93-09 dip line

Seismic section 93-MN-9 is SE-NW dipping seismic line 9, showing different horizons (Sakesar 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 2.7sec Figure 3.6. 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-9. No well has been drilled on this line. The arrangement of structures shows that the fore-thrust is southeast verging while the back thrust is northwest verging forming a triangle zone.

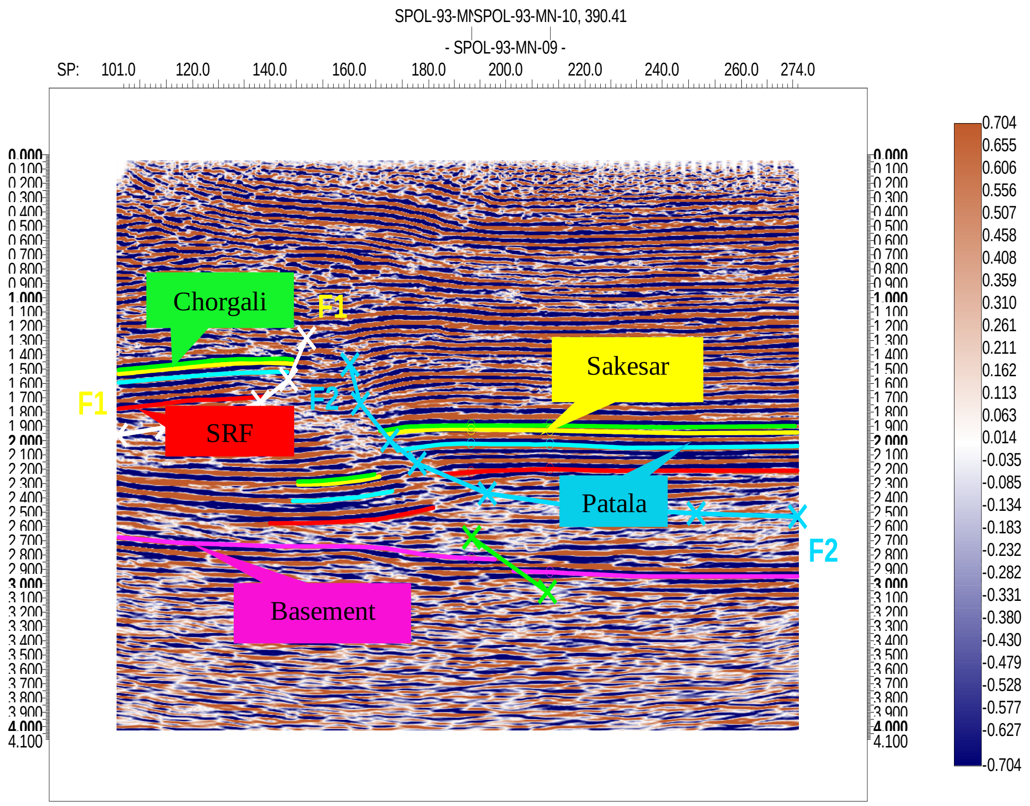


Figure: 3.6 (POL-MN-93-09) Dip line

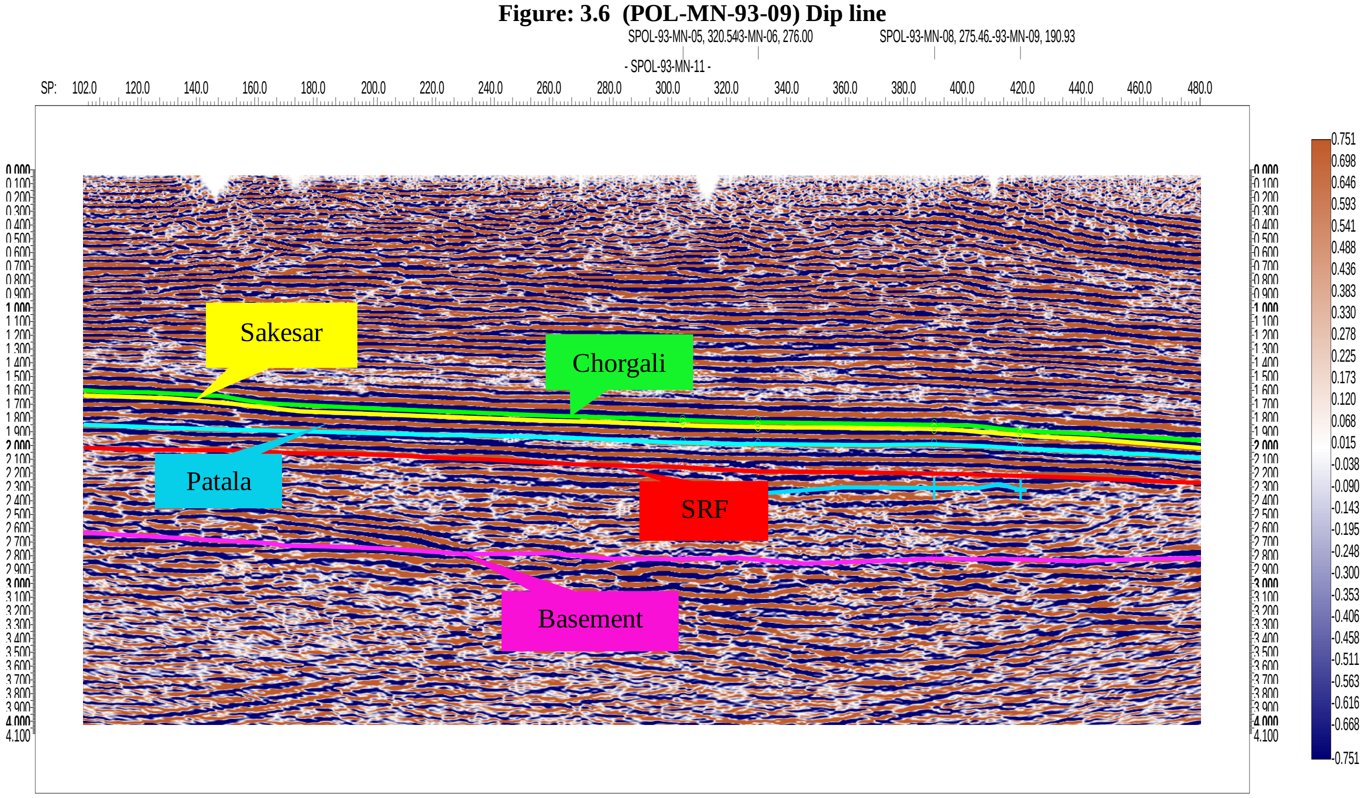


Figure: 3.7 (POL-MN-93-11) Strike line

3.10 Fault Polygon generation:

I construct the fault polygon and grids at Chorgali and Sakesar because the Chorgali and Sakesar acting as reservoir. The fault polygon on both formations is show in fig:3.8 & 3.9.

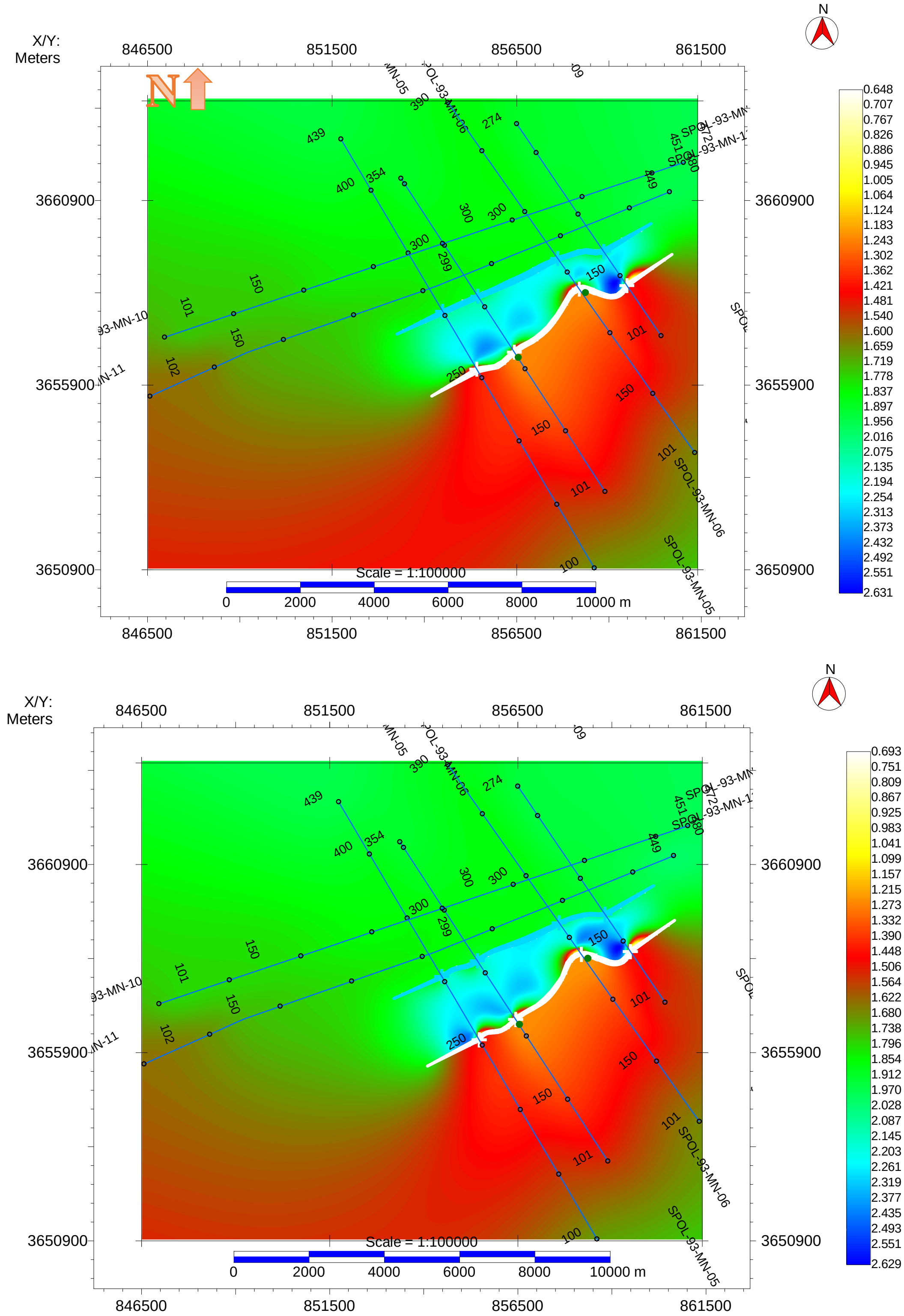


Figure: 3.8 & 3.9 Fault Polygons of Chorgali & Sakesar Formations.

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 into 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.

3.11 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). There are two types of contouring:

- Time contouring
- Depth Contouring

3.11.1 Time contour map:

To compute time contour map, first we must make grids individually for each of the horizon i.e. Chorgali and Sakesar. The blue color is indicating the deepest parts between the thrusting and red is indicating shallower regions.

Time contours for Chorgali and Sakesar formations are shown in figures(3.10 & 3.11)

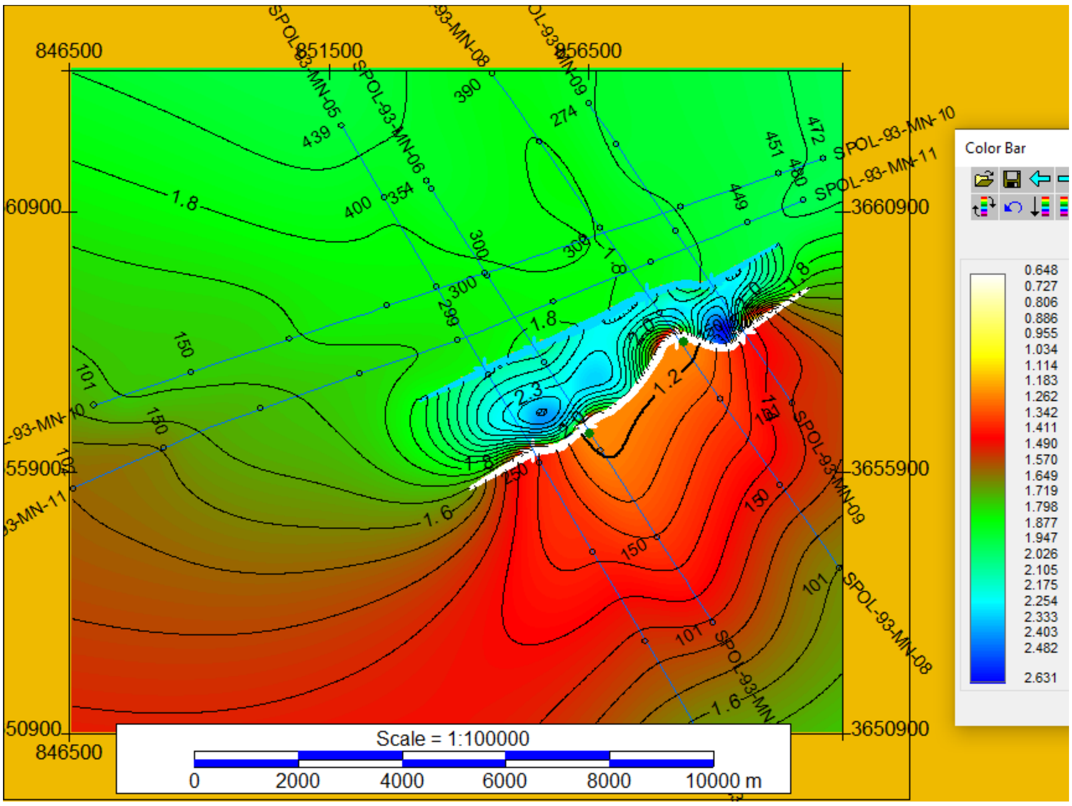


Figure: 3.10 Time contour map for Chorgali Formation.

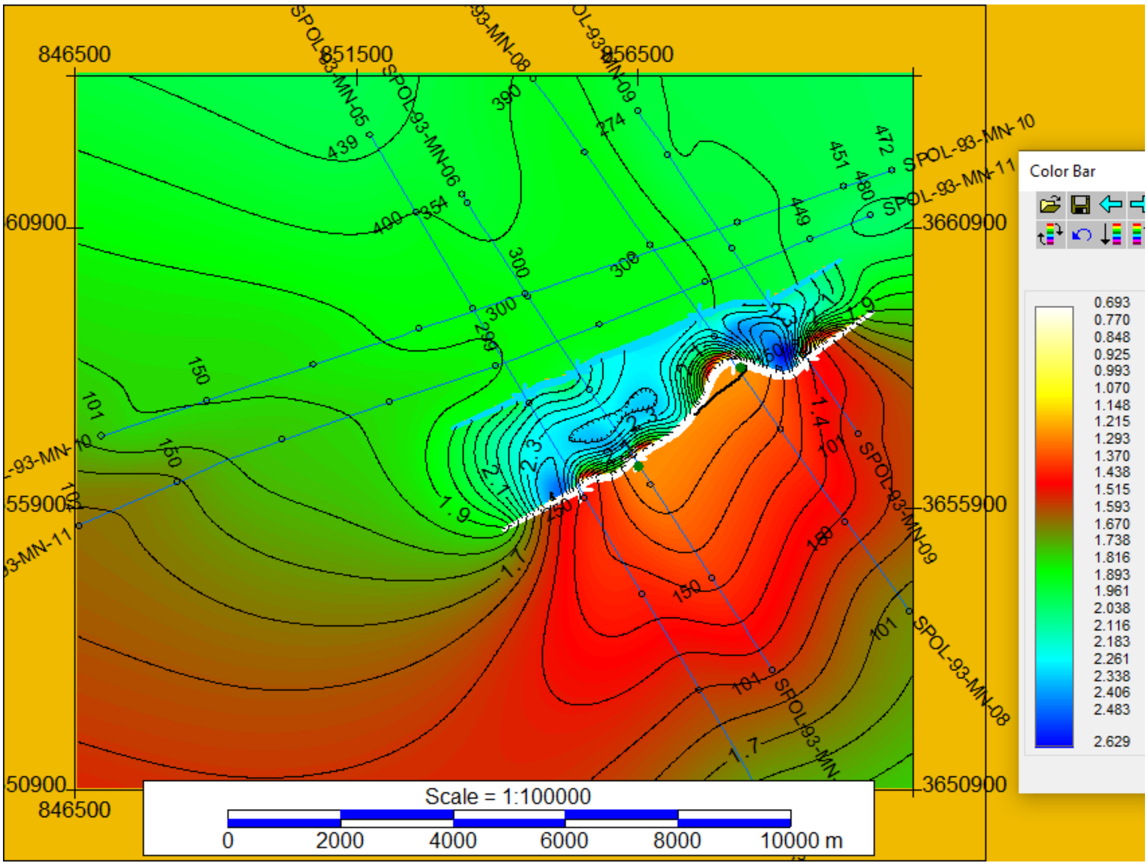


Figure: 3.11 Time contour map for Sakesar formation.

3.11.2 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 assigned a color bar which can be used as a guide for interpretation. On basis of color bar green color shows the deepest point which also give us information about the probable well location while the red color represents shallowest point as shown in figure 3.12 and figure 3.13.

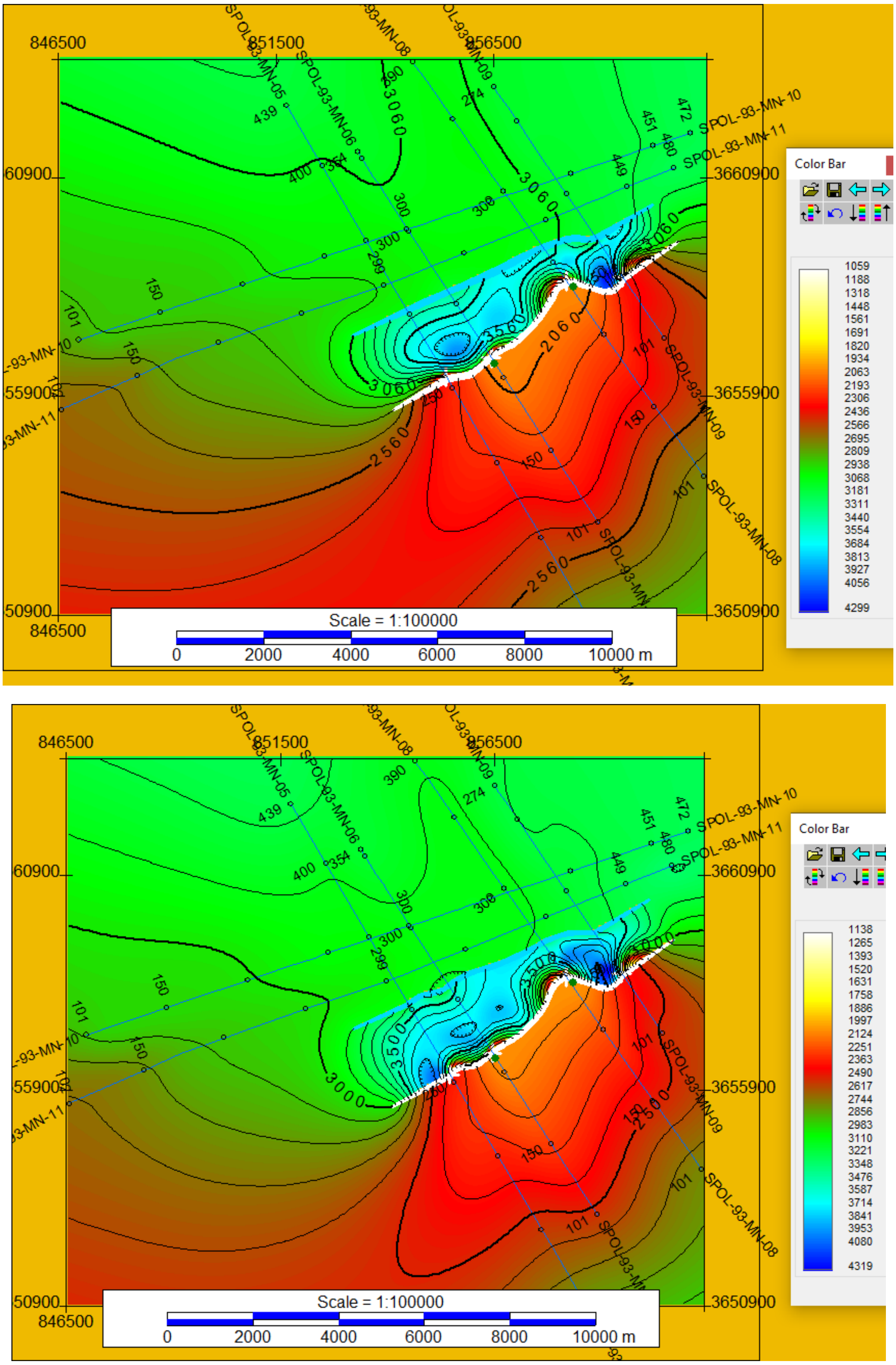


Figure: 3.12 & 3.13 Depth contour map for Chorgali & Sakesar formations.

Chapter 4:

SEISMIC ATTRIBUTES

4.1 Seismic Attributes:

The Components of seismic data which are obtained by calculation are seismic attributes. Seismic attributes are established in 1970s as a part of seismic interpretation. Any information that can be obtained from seismic is seismic attribute.

4.2 Importance:

During the processing sequence we lose lot of information due to AGC (automatic gain control), stacking (changes occur in frequency and amplitude) and deconvolution (trace are reshaped). Attribute are used to regain this information in a meaningful manner.

4.3 Classification of Attributes:

Seismic Attributes are classified into two major categories:

- Physical attributes
- Geometrical attributes

4.3.1 Physical Attributes:

Physical attributes are directly related to lithology, wave propagation parameters. These attributes can be pre stack or post stack. The sub classes of physical attributes are instantaneous and wavelet attributes. Instantaneous attributes are evaluated at every instant of sample while the wavelet attributes show the characteristics of amplitude spectrum and characteristics of wavelet. Post stack attributes are obtained from stacked data.

4.3.2 Geometrical Attributes:

These attributes evaluate geometry of seismic events. It includes discontinuity, dip and azimuth. The dip attribute is related to the dip of seismic events, as the dip makes the event clearer. The amplitude of the data at azimuth attribute show maximum dip direction of the seismic feature.

4.4 Seismic Attributes on study area:

4.4.1 The Trace Envelope:

The trace Envelope is a physical attribute, and it can be used as an effective represents the acoustic impedance contrast, hence reflectivity. It also helps for spotting gas accumulation bright spots. It is also a good discriminator of major for changes in depositional environment. This attribute is applied on POL-MN-93-08 in following figure 4.1.

4.4.2 Average Energy:

Average energy is a post-stack wavelet attribute, in which, within a specified window the square root of the sum of squared amplitudes is calculated and divided by their number of samples. The wavelet attributes are computed at the peak of the envelope, which represent the attributes of the wavelets within a zone defined by the trace envelope minima. These attributes indicate spatial variation of the wavelets and therefore relate to the response of the composite group of individual interfaces below the seismic resolution. The attribute has a blocky response and individually highlights the seal, reservoir and source rocks as shown in Figure 4.2.

4.4.3 Phase attribute:

The argument of the complex function is defined as the phase. The phase component is independent of seismic amplitude therefore can be used as a good indicator of reflector continuity. Instantaneous phase attribute is given by

$$\phi(t)=\arctan|H(t)/T(t)|$$

The seismic trace T(t) and its Hilbert transform H(t) are related to the envelope E(t) and the phase. $\phi(t)$ by the following relation:

$$T(t) = E(t)\cos(\phi(t)) \quad H(t) = E(t)\sin(\phi(t))$$

Instantaneous phase is measured in degrees $(-\pi, \pi)$. It is independent of amplitude and shows continuity and discontinuity of events. It shows bedding very well. Phase along horizon should not change in principle, changes can arise if there is a picking problem, or if the layer changes laterally due to "sink-holes" or other phenomena.

As the variations in the amplitude occurs no change in the real and imaginary part of the seismic trace is observed however the change in the instantaneous phase is observed as it is clear from the figure 4.4.

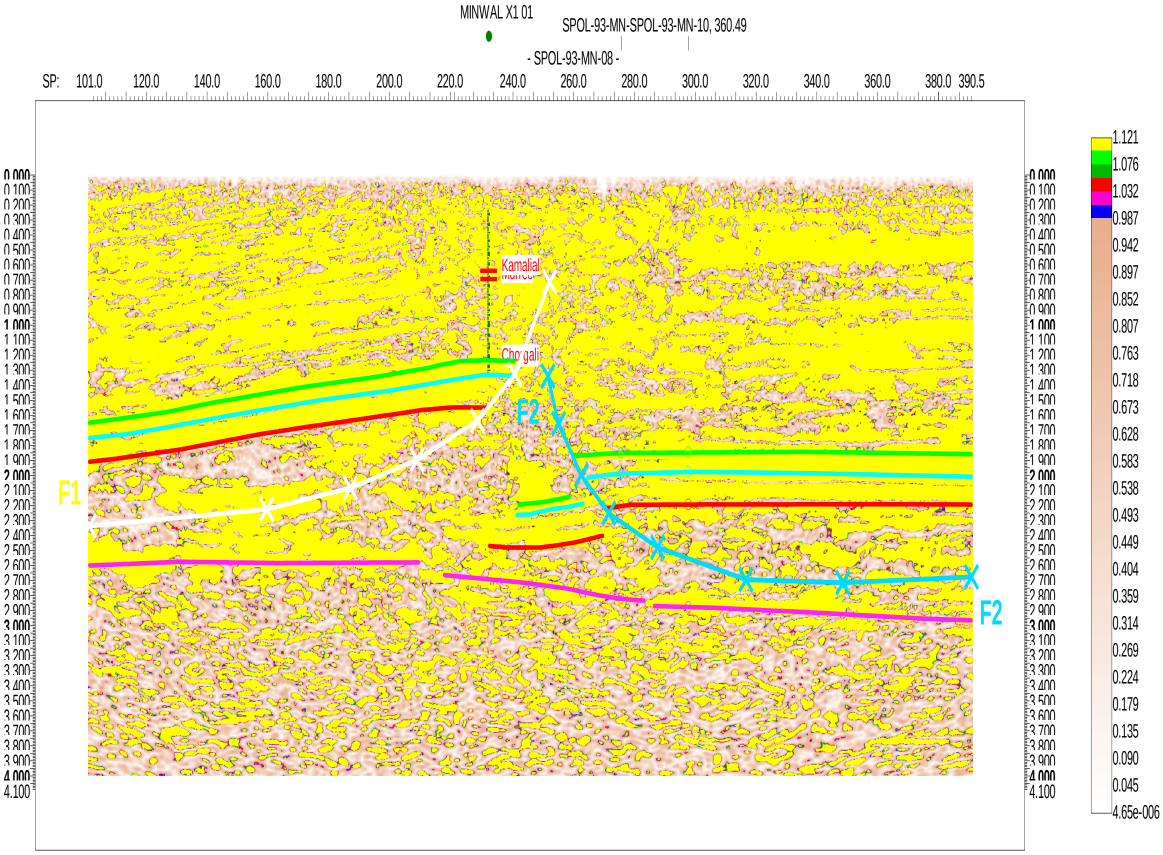


Figure: 4.1 Trace Envelope attribute

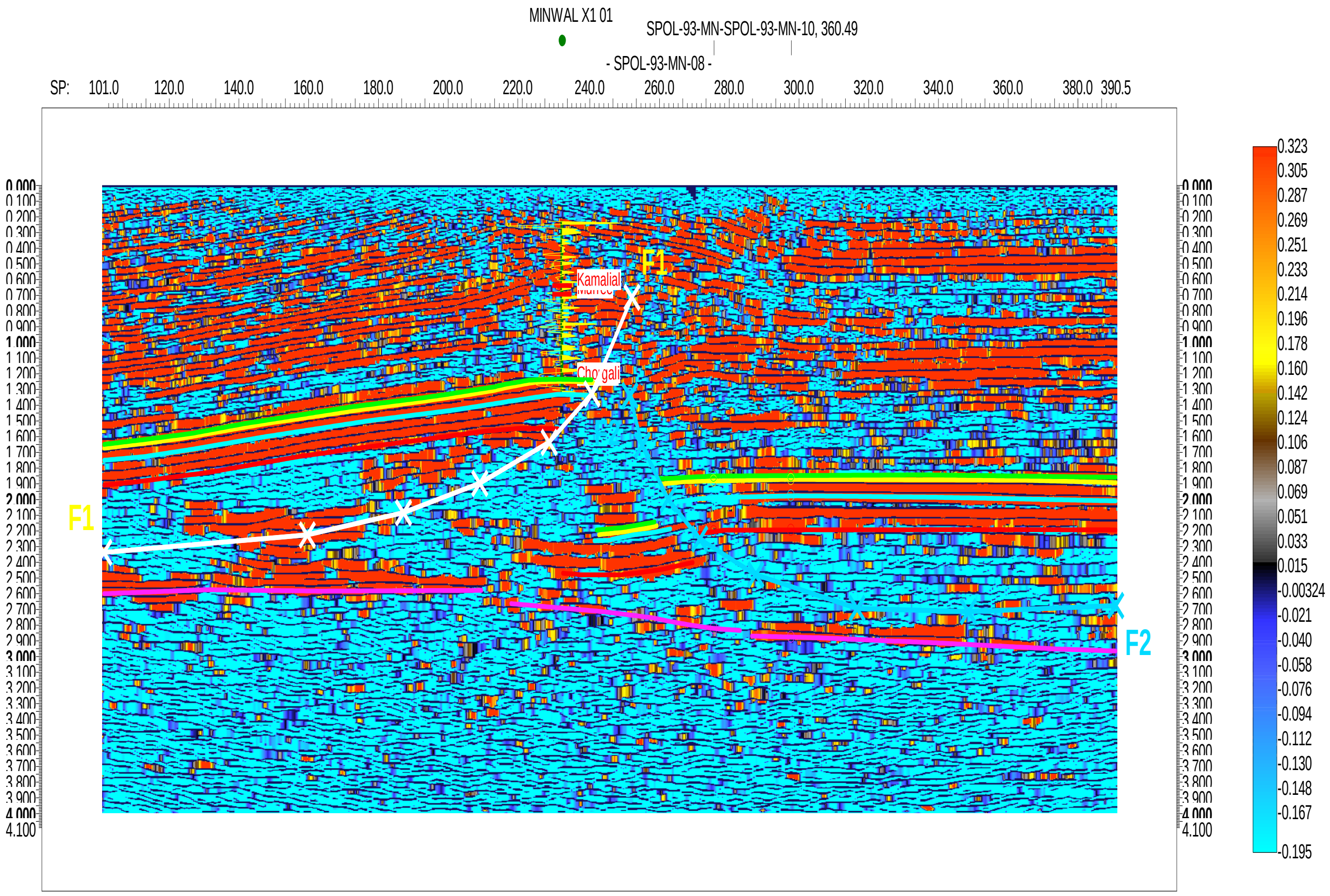


Figure: 4.2 Average Energy attribute

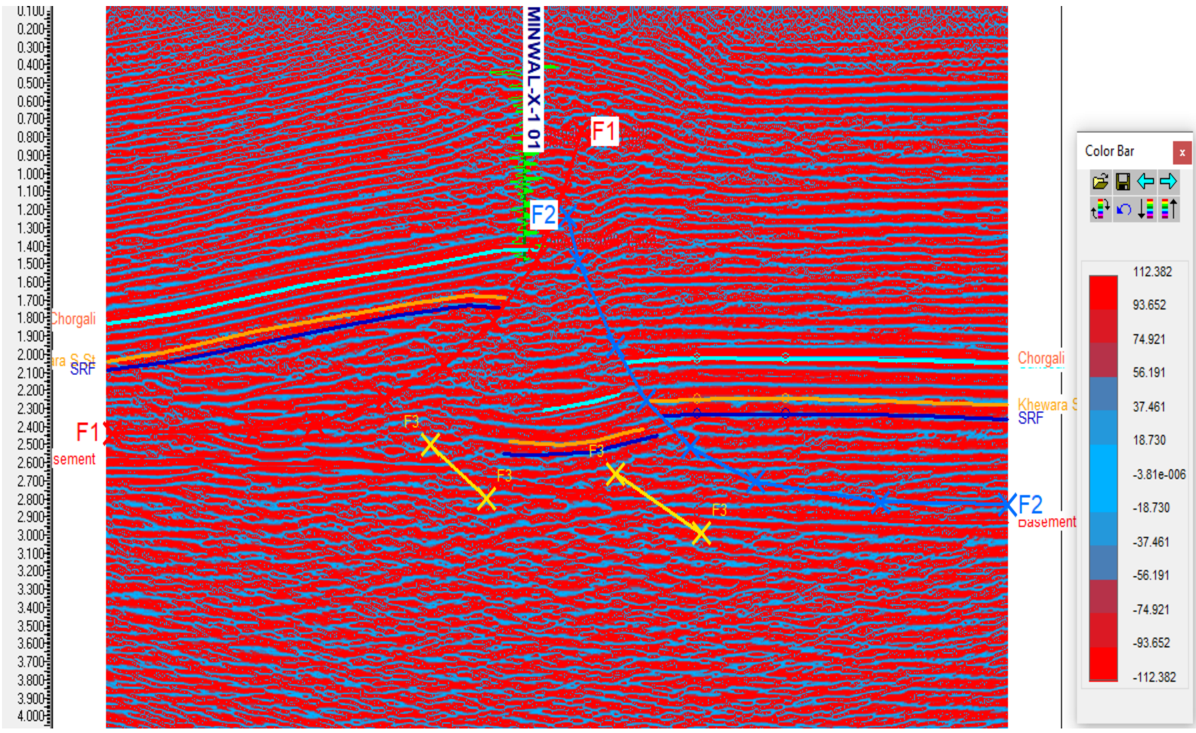


Figure: 4.3 Phase attribute

Chapter 5:

PETRO-PHYSICAL ANALYSIS

5.1 Introduction

Petro physics deals with the study of the physical properties of naturally occurring rocks in relation to fluid movements within these rocks. These properties are porosity, permeability and density etc. It is a technique used to characterize the reservoir. This study facilitates the identification and quantification of fluid in a reservoir (Aamair 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.

5.2 Well Logs Used for Petro-physics:

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

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

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

- Volume of Shale
- Water Saturation
- Hydrocarbon Saturation
- Porosity

5.3 Workflow of Petrophysics:

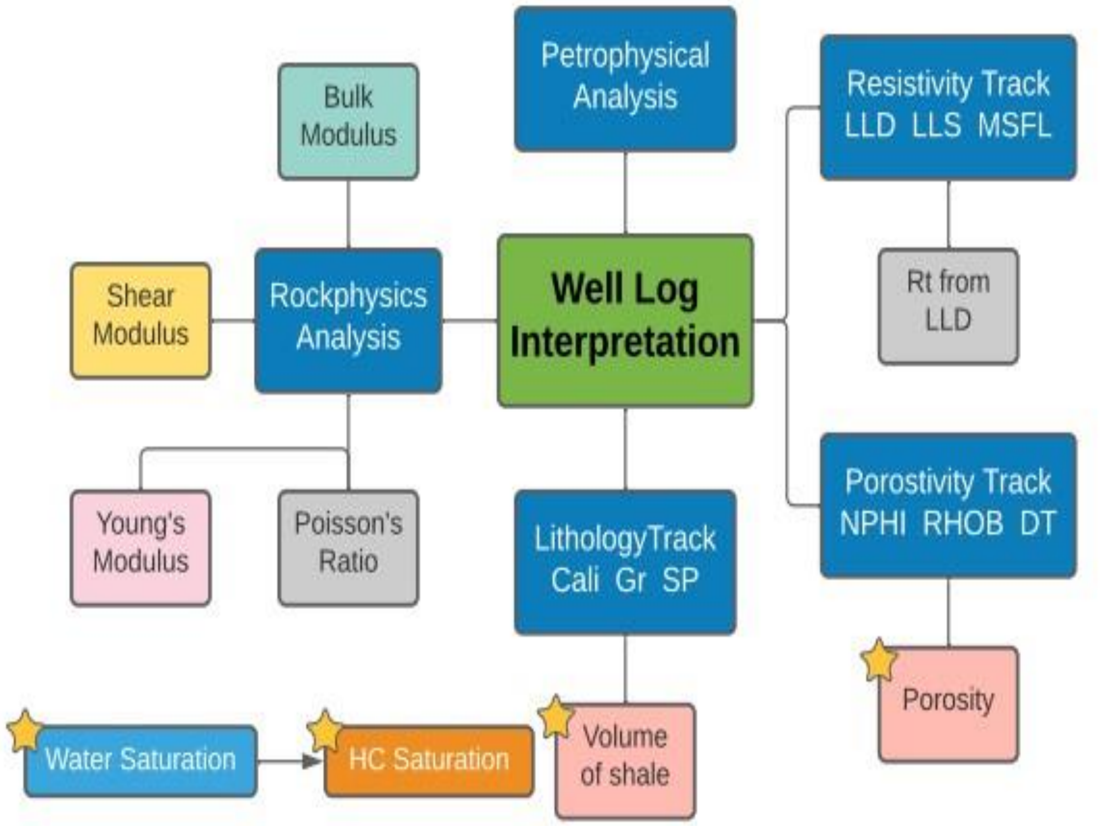


Figure: 5.1 Workflow of Petrophysics.

5.4 Targeted Zone:

The zones of interest are defined based on 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 given below:

Prospect Formations	**Start depth**	**End depth**
Chorgali	2020.48	2054.24
Sakesar	2054.24	2176.235

5.5 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 is given in Figure : 5.2.

SR No.	Type of Log	ACRONYM	SCALE	UNIT
1.	Gamma Ray Log	GR	10---160	API
2.	Spontaneous Potential Log	SP	120---(-20)	Mv
3.	Density Log	RHOB	1.95---2.95	gm/cm^3
4.	Sonic Log	DT	140---40	µsec/ft
5.	Neutron Porosity Log	NPHI	0.45---(-0.15)	PU
6.	Caliper log	CALI	6---16	Inches
7.	Latero log Deep	LLD	1---2000	Ωm
8.	Latero log Shallow	LLS	1---2000	Ωm

Figure : 5.2 Scale used for the different logs.

5.6 Classification of Geophysical Well Logs:

The logs are explained according to the tracks in which they run. shown in figure 5.3.

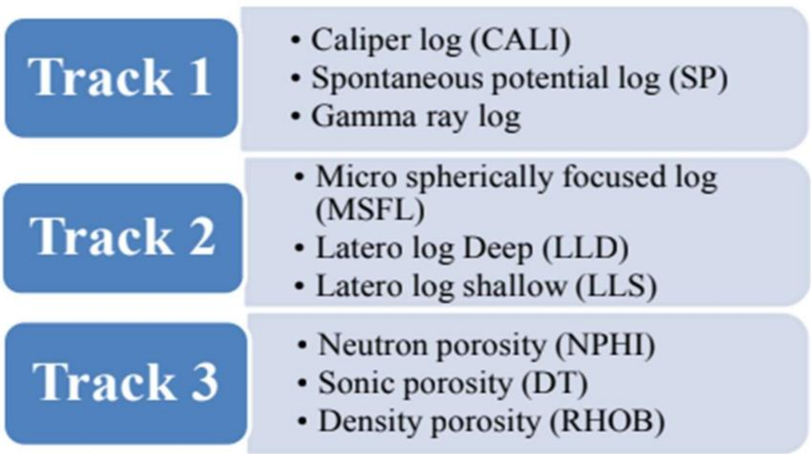


Figure: 5.3 Basic three log tracks

5.7 Lithological Track:

5.7.1 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.

5.7.2 Calculating 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) is as follows:

$$\mathbf{I_{GR} = (GR_{Log} - GR_{Min}) / (GR_{Max} - GR_{Min})}$$

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.

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%

5.7.3 Caliper Log:

Caliper log is a lithological log use to identify the condition of log. It measures the borehole size and shape. The caliper provides 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.

5.7.4 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 resistivity (R_w)

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

5.8 Porosity Track

5.8.1 Sonic log:

The sonic log is a porosity log that measures interval transit time (Δt) of a compressional sound 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.

5.8.2 Sonic porosity (Φ_S):

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:

$$\mathbf{\Phi_S = (\Delta T - \Delta T_{mat}) / (\Delta T_f - \Delta T_{mat})}$$

Where,

Φ_S =Sonic porosity μs/ft

ΔT=Log response

ΔT_{mat} = Transit time in matrix

ΔT_f = Transit time in fluids

The 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). 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)

5.8.3 Density porosity (Φ_D):

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

5.8.4 Total porosity (Φ_T):

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

$$\Phi_T = (\Phi_S + \Phi_D)/2$$

Where,

Φ_T=Total Porosity

Φ_D=Density Porosity

Φ_S=Sonic Porosity

5.8.5 Effective porosity (ΦE):

Effective Porosity is given by:

$$\textbf{Effective Porosity} = \textbf{Average Porosity} * V_{mat}$$

Where V_{mat} is Volume of Matrix given by 1- V_{sh}

5.9 Resistivity Tracks

Resistivity logs are electric logs which are used to determine hydrocarbon versus water-bearing zones and indicate permeable 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.

Borehole Temperature	152^{o}F = 66.6 ^{o}C
Surface Temperature	25^{o}C
Formation Depth	2020.48m
Total Depth	1.016-ohm m
Resistivity of mud filtrate	1.016-ohm m

5.10 Calculation of Resistivity of mud filtrate at formation (Rmf_2):

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^{O}C

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

$$\mathbf{R_{mf2} = R_{mf1} * (ST + 6.77/ FT + 6.77)}$$

Where Rmf_1 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 Rmf_2 as given below:

R_{mf1} = 1.016-ohm m (from given data)

ST=Surface Temperature (25^{O}C)

FT= 38.67^{O}C

R_{mf2}= 0.710

Results:

FT= 38.67^{O}C

R_{mf2}= 0.710

5.11 Resistivity of Water Equivalent (Rweq) and Resistivity of Water (Rw):

The resistivity of water or fluid some other tests may performed in steps these steps are given below Formation water resistivity (Rw) is calculated by knowing certain parameters i.e. static Spontaneous potential(SSP), resistivity of mud (Rmf1) at ground surface temperature (ST), Formation temperature, borehole temperature (BHT) water salinity, resistivity of mud (Rmf2) at formation temperature (FT). Resistivity of water can be calculated by the following formula through different steps and can be find also by Gen-6 (Schlemberger chart).

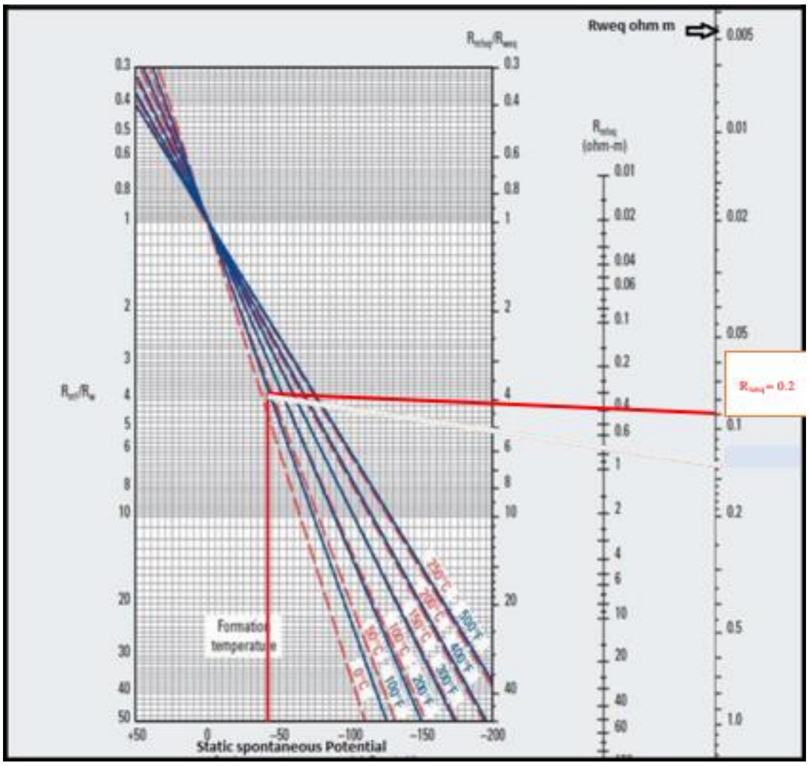


Figure: 5.4 Schlumberger chart

R_{weq} = 0.2-ohm m

5.11.1 Resistivity of Water (R_w):

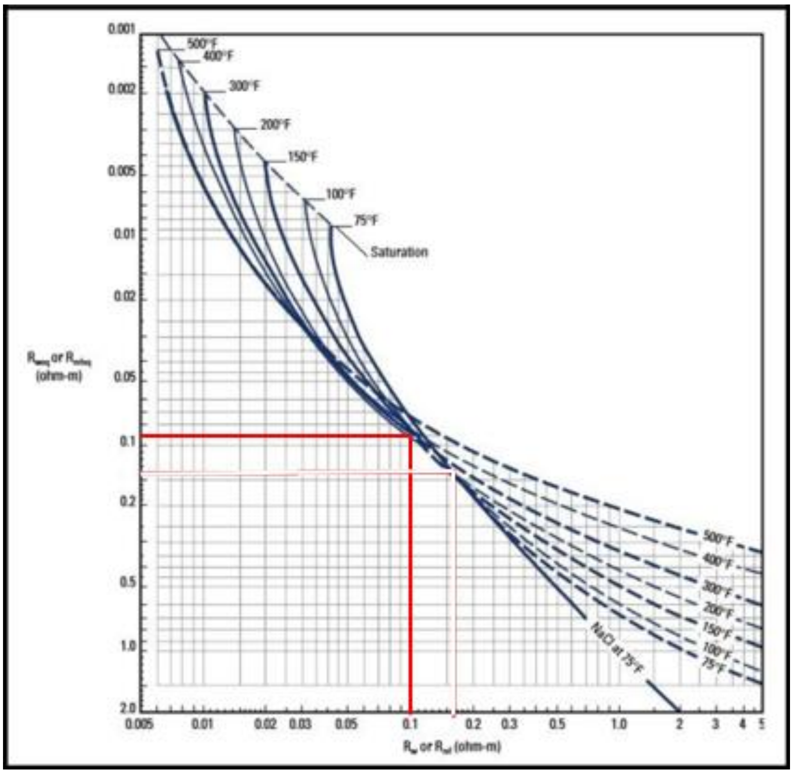


Figure: 5.5 Schlumberger chart for Rw

R_w= 0.1ohm m

5.12 Water Saturation (Sw) Determination:

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

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

where,

S_w= water saturation

R_w=water resistivity (formation)

Φ = effective porosity

m (cementation factor) =1.95

a(constant) = 1

R_t= log response (LLD)

R_w has been calculated with help of the following formula:

R_w= 0.1

Φ = porosity in clean zone

R_t =Observed LLD curve in clean zone.

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

5.13 Calculation of Hydrocarbon Saturation (S_h):

The fraction of pore spaces containing hydrocarbons is known as hydrocarbon saturation and is calculated by relation is given as:

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.

5.14 Petro-physical Report of JOYAMAIR oil field of Minwal X-01 Well:

Different Petro-physical properties for Chorgali and Sakesar Formations obtain from the Logs are as follows:

Petrophysical Properties	Percentage (%)
Average Volume of shale	47%
Average porosity PHIT	24.8%
Effective porosity PHIE	11.5%
Average water saturation SW	34%
Average Hydrocarbon saturation SH	66%

5.15 Prospects of Chorgali Formation:

5.15.1 Zone 1 and Zone 2:

Zones marked in figure indicates the prospect zone. The zone is marked on basis of log curve responses. In this zone, the response of caliper is straight, which indicates favorable prospect condition. The value of Gr log is low indicating non shaly (limestone) lithology, where resistivity log indicates 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.

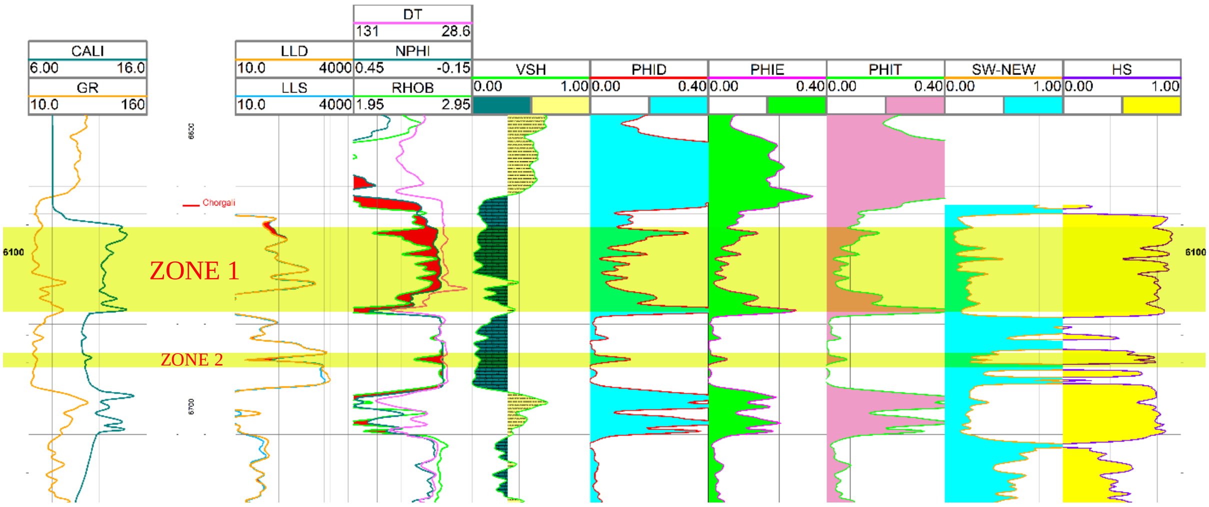


Figure: 5.6 ZONES OF CHORGALI FORMATION

ZONES	V_{SH}%	S_H%	S_W%	PHIT%	PHIE%	PHID%
Zone 1	13.2	80.82	19.17	11.38	9.35	16.29
Zone 2	4.75	5.78	94.21	2.36	2.22	4.78

5.16 Prospects of Sakesar Formation:

5.16.1 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 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 resistivity log indicates 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.

ZONES	VSH%	SH%	SW%	PHIT%	PHIE%	PHID%
Zone 1	12.39	83.36	16.63	4.72	4.17	8.08
Zone 2	16.30	93.70	6.29	6.26	5.29	11.56

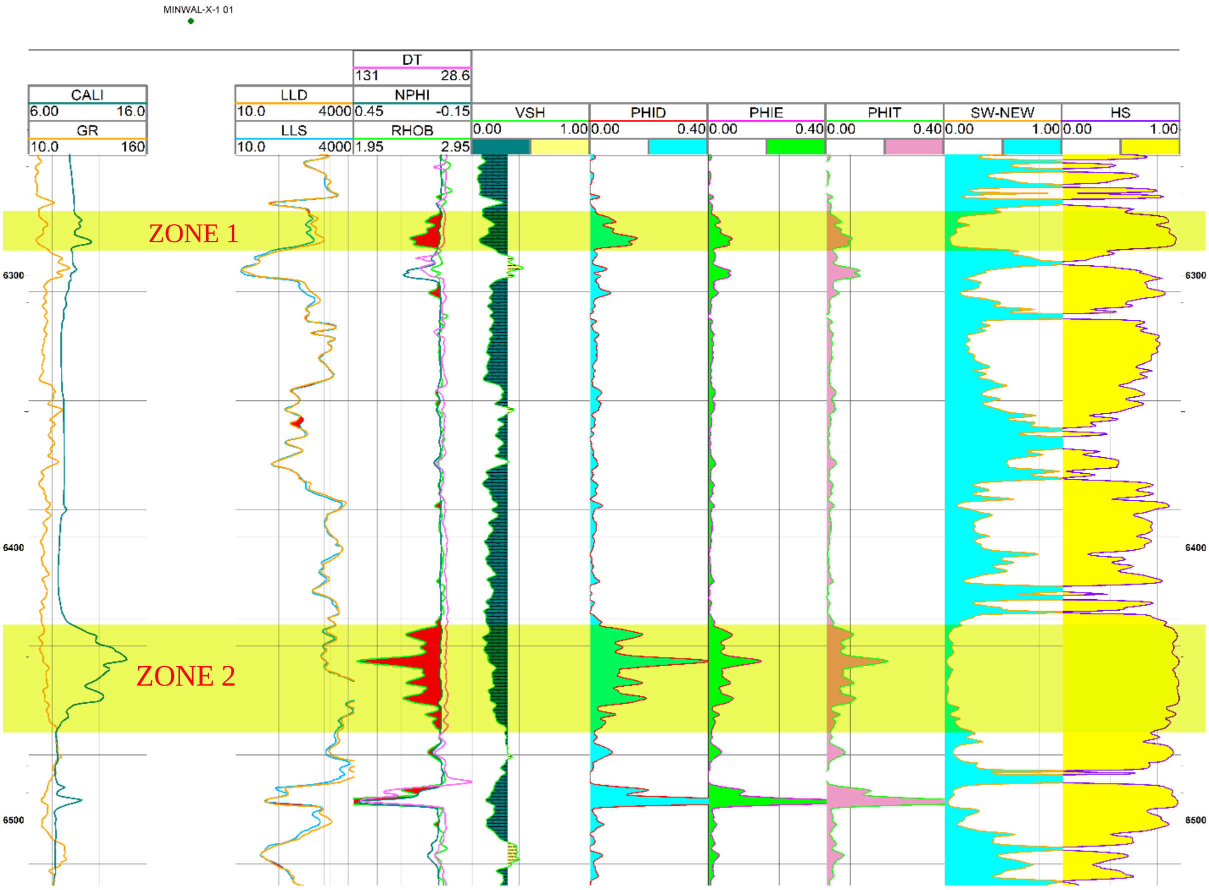


Figure: 5.7 ZONES OF SAKESAR FORMATION

5.17 PETROPHYSICAL ANALYSIS OF STUDY AREA:

Petrophysical analysis of Joya Mair Minwal X-01 is concluded based on 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 S_w 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).

Chorgali 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 limestone.

Caliper logs 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 shows low SP response because the interstitial 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.

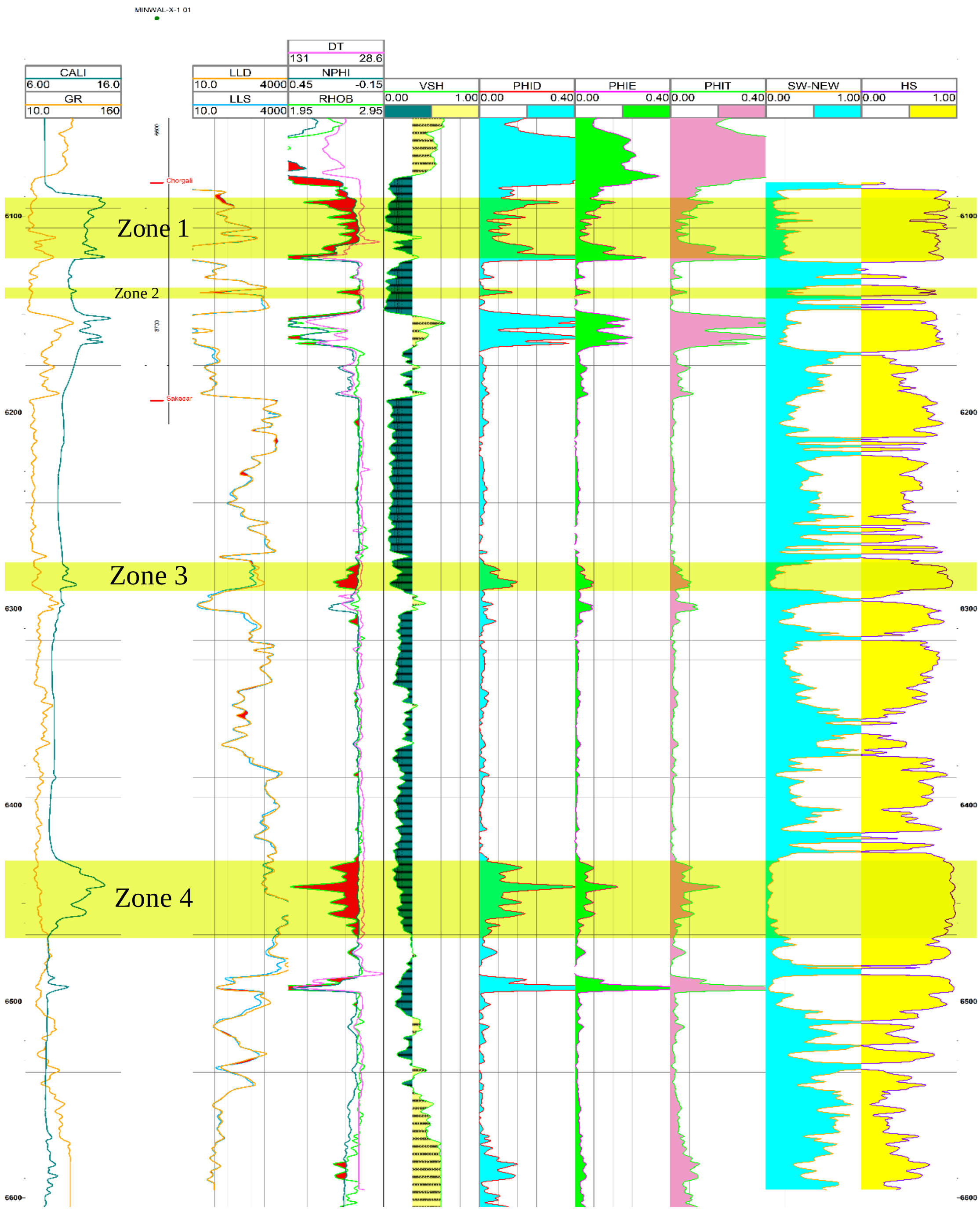


FIGURE: 5.8 Petrophysics of MINWAL-X1

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 favorable hydrocarbon conditions. Similarly, the value of resistivity logs is high, porosity is low, dominant lithology of limestone is present. This all is indicative of favorable reservoir conditions in both reservoirs Chorgali and Sakesar formation.

Chapter 6:

ROCKPHYSICAL ANALYSIS

6.1 Introduction

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. It involves the techniques that relate the geological properties (e.g. porosity, lithology, saturation) of a rock with the corresponding elastic and seismic properties (e.g. elastic modulus, velocity, impedance) at certain physical conditions (e.g. pressure, temperature) termed as Rock Physics. These techniques are used for rock physics modeling, i.e. to estimate geology from seismic observations or rock physics inversion (Dewar & Pickford, 2001).

In Rock physics we usually use Sonic, Density and Dipole logs to establish relationship between P-wave velocity (Vp), S-wave velocity (Vs), Density with Bulk, Rigidity module Porosity, etc.

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.

6.2 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

Mathematically it can be calculated by using relation

$$\mu = \rho * Vs$$

μ = Shear modulus

ρ= Density

Vs= S-wave velocity

6.3 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.

Mathematically can be calculated by formula.

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

Where;

Vp= P-wave velocity

Vs= S-wave velocity

K= Bulk Modulus

6.4 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.

6.5 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. Poisson's ratio value is increasing in reservoir zone.

It is calculated by using the following formula:-

$$\sigma = \frac{0.5(Vp^2 - 2Vs^2)}{Vp^2 - Vs^2}$$

$$V_p = 1.16 * V_s + 1.36 \qquad V_p = \sqrt{\frac{K + \frac{4\mu}{3}}{\rho}} \qquad V_s = \sqrt{\frac{\mu}{\rho}}$$

$$V_s = (V_p - 1.36) / 1.16$$

$$\rho = 0.31 * V_p^{.25} \qquad A = V_p * \rho \qquad VpVs_{Ratio} = \sqrt{\frac{K}{\mu} + \frac{4}{3}}$$

$$\mu = \rho V_s^2 \qquad K = \rho(V_p^2 - \tfrac{4}{3}V_s^2) \qquad E = \frac{9K\mu}{3K + \mu}$$

$$M = K + \frac{4\mu}{3} \qquad \sigma = 0.5(V_p^2 - 2V_s^2) / (V_p^2 - V_s^2) \qquad \lambda = K - \frac{2\mu}{3}$$

Figure: 6.1 Equations for computation of Rock Physical & Engineering Properties (Castanga et al., 1985)

6.6 Rock physics analysis of study area:

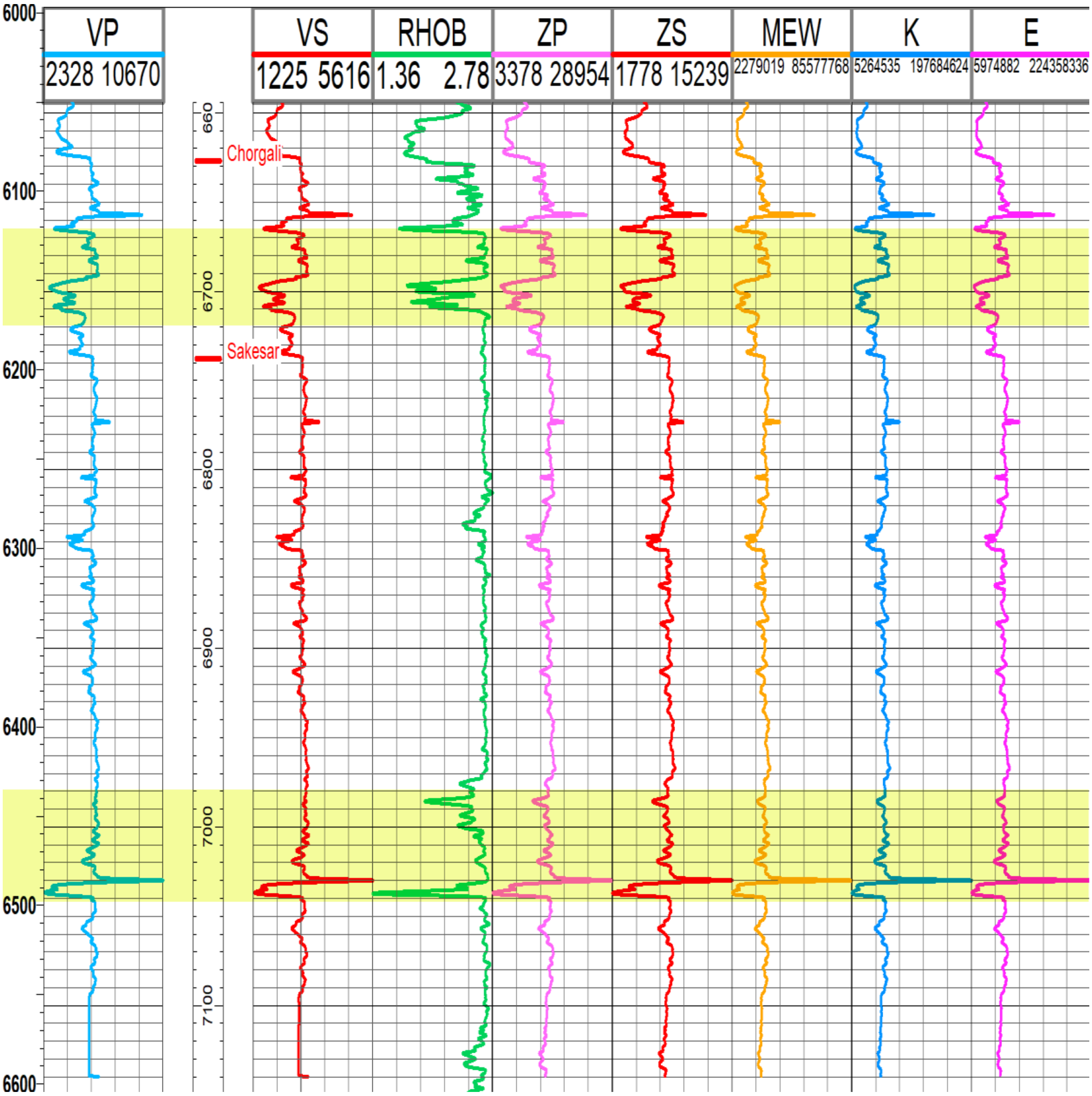


Figure: 6.2 Rock physical analysis of study area

Chapter 7:

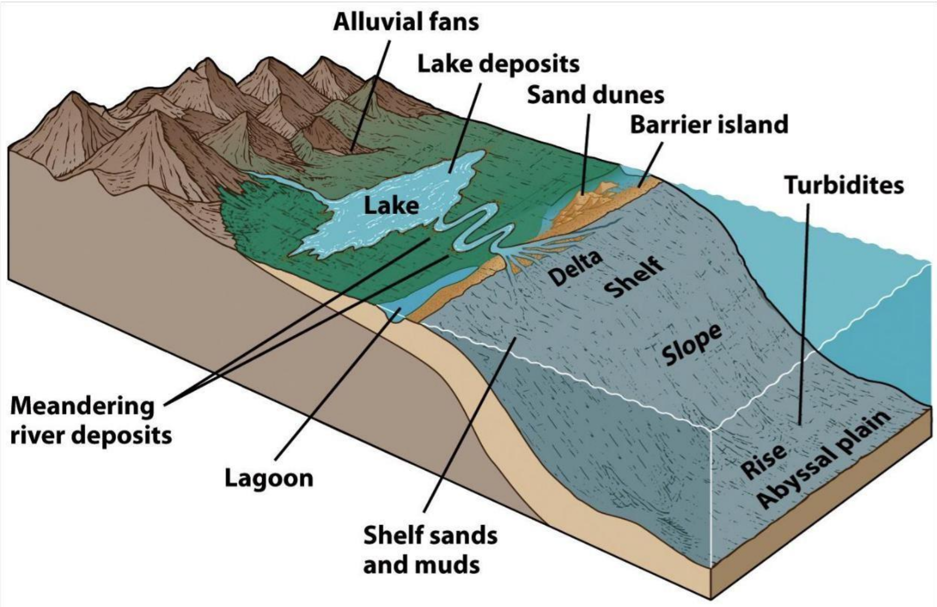
FACIES MODELING

7.1 Introduction

Facies are generally considered as bodies of rocks that show some specific characters but ideally these are rock units that form under certain conditions of sedimentation, displaying a particular process or environment of deposition.

Different types of sedimentary environments are known as Continental sedimentary environment that include glacial, alluvial fan, river channel, flood plain, aeolian, and dunes environments. Transitional (shoreline) environment include delta, beach, barrier island, lagoon and tidal flat environments. Marine environments include coral reefs and submarine facies. Each unit (facies) possesses a distinctive set of characteristics reflecting the conditions in a particular environment. The facies types reflect high-energetic and low-energetic hydrodynamic conditions that are either related to gradually increasing water depths or are produced by superimposed high-energy events, for instance, during storms. The famous law about the deposition of sediments is the Walther‟s law that is briefly explained.

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).



7.2 Importance of Facies Analysis:

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 strengthens 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).

7.3 Walther's law of Facies

Walther's Law of Facies states that the vertical succession of facies displays lateral changes in environment. Conversely, it states that when a depositional environment "migrates" laterally, sediments of one depositional environment come to lie on top of another. A classic example of this law is the vertical stratigraphic succession that typifies marine transgressions and regressions that are briefly explained. However, the law is not applicable where the contact between different lithologies is non-conformable.

7.3.1 Aggradation:

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

7.3.2 Transgression:

A marine transgression is a geologic event during which sea level rises relative to the land and the shoreline moves toward higher ground, resulting in flooding.

7.3.3 Regression:

A marine regression is a geologic event during which sea level falls relative to the land and the shoreline moves toward lower ground and exposes former sea bottom.

Three combinations have been recognized on the basis facies analysis given below:

- Lower energy facies consisting of cross bedded sandstone, thin bedded sandstone and grey shale, massive sandstone, and pelagic limestone.
- Moderate energy facies consisting of laminated sandstone and gravestone.
- High energy facies consisting of interbedded gypsiferous shale and siltstone/sandstone and bio clastic grain stone (Ahmad et., 2002).

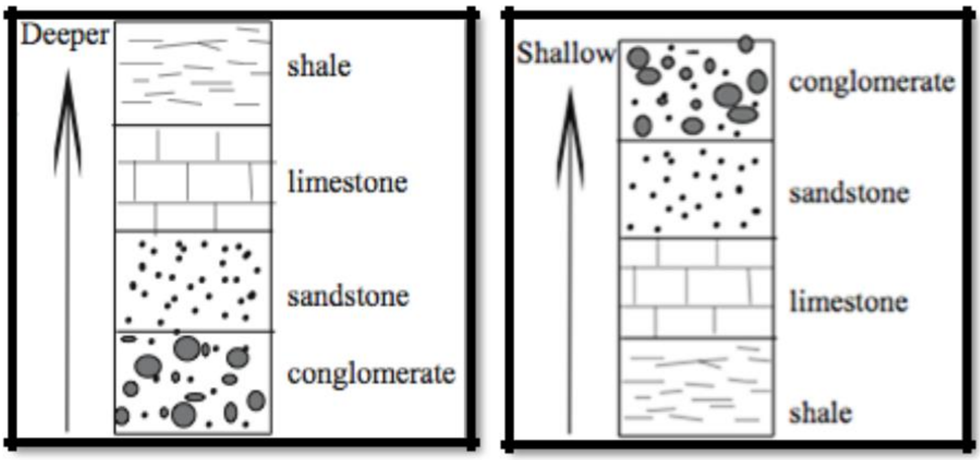


Figure: 7.1 (a) transgressive sequence (b) regressive sequence

7.4 Workflow:

7.5 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 6.1. Comparing this response with that of the logs will show the major lithology of the reservoir zone.

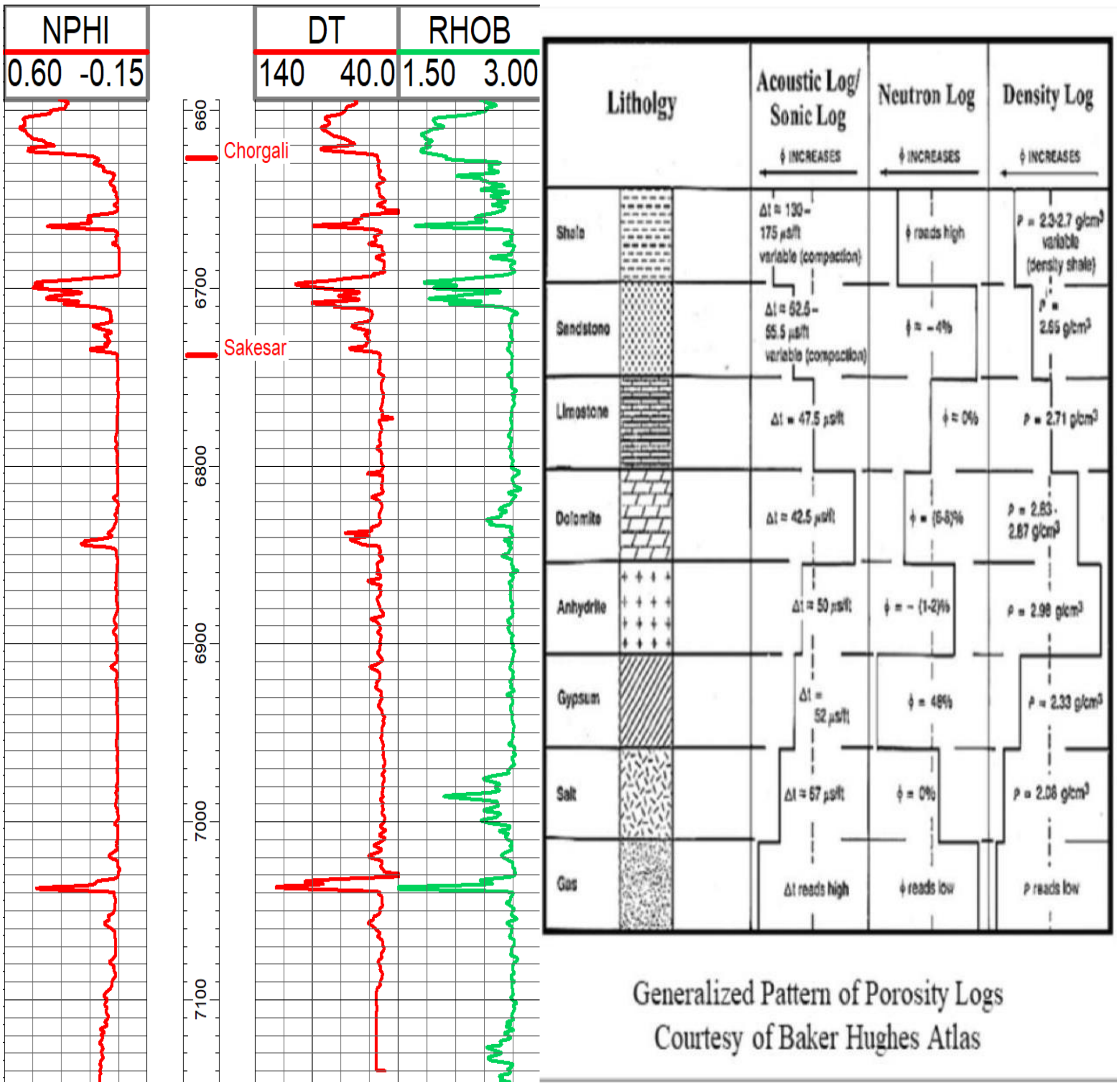


Figure: 7.2 Generalized comparison of acoustic , neutron and density log responses in common reservoir lithologies versus behavior of porosity logs for well Minwal-X1.

7.6 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 7.3 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.

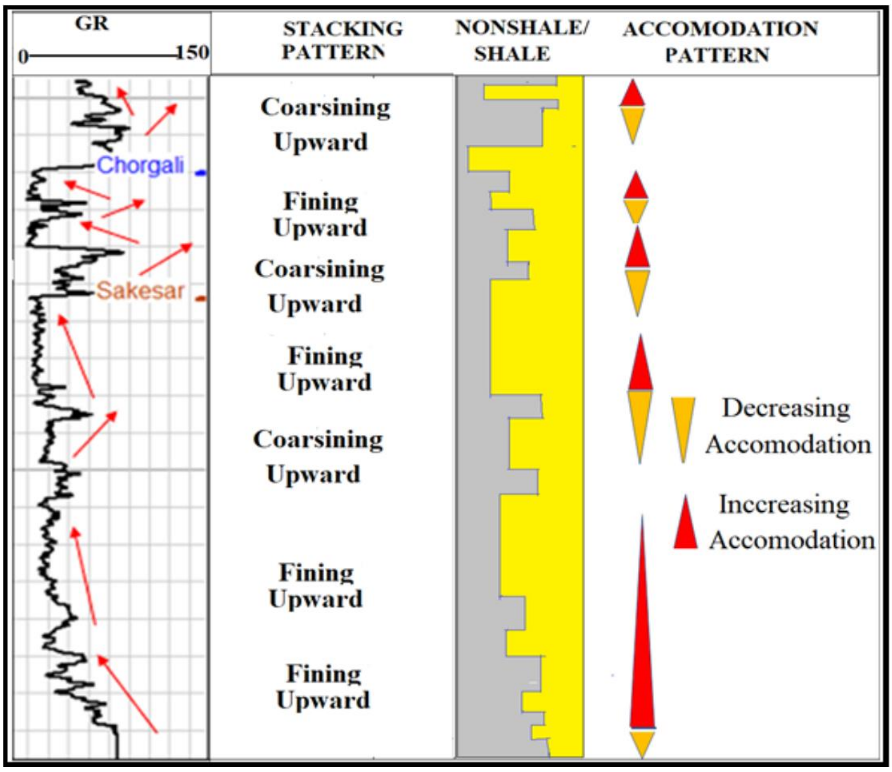


Figure: 7.3 GR log response towards different lithological units whereas , arrows represents depositional environment associated with each lithology mainly shale and limestone for high and low values of GR log. Moreover, other charts indicate depositional sequences along with increase and decrease in accommodation spaces.

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

7.7 Cross plot between Sonic log and Density log:

The cross plot 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 cross plot by density log.

By comparison of the figure , the polygon are drawn and labeled according to the standard cross plots. 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.

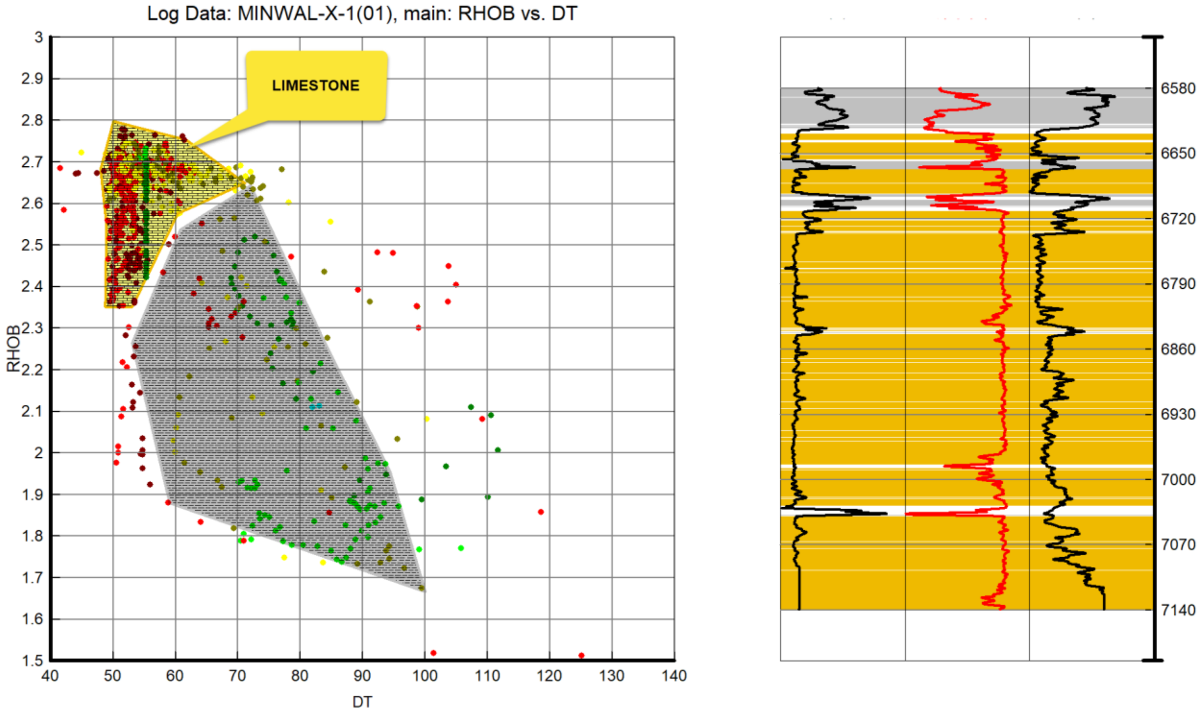


Figure: 7.4 Crossplot of Density Log vs Sonic Log.

Above Crossplot clearly distinguish that reservoir is composed of limestone with interbedded shale.

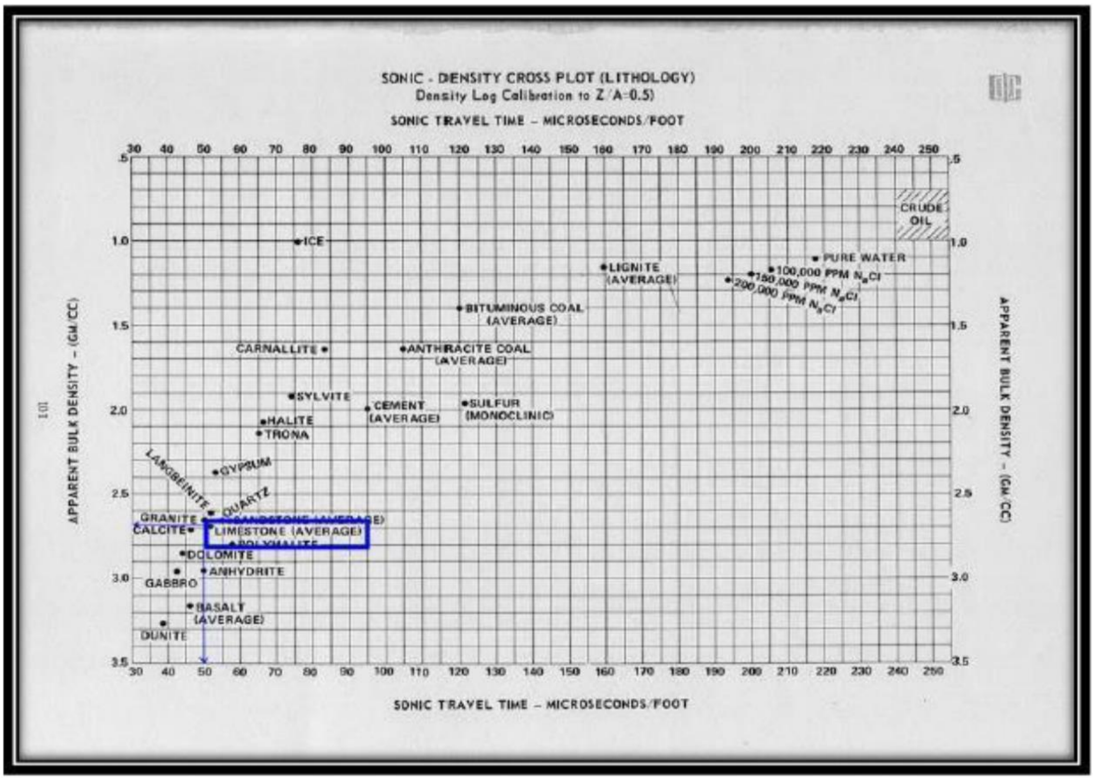


Figure: 7.5 Standard Crossplot between Sonic log and Density log.

7.8 Cross plot between Latero Log Deep and 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 cross plot 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.

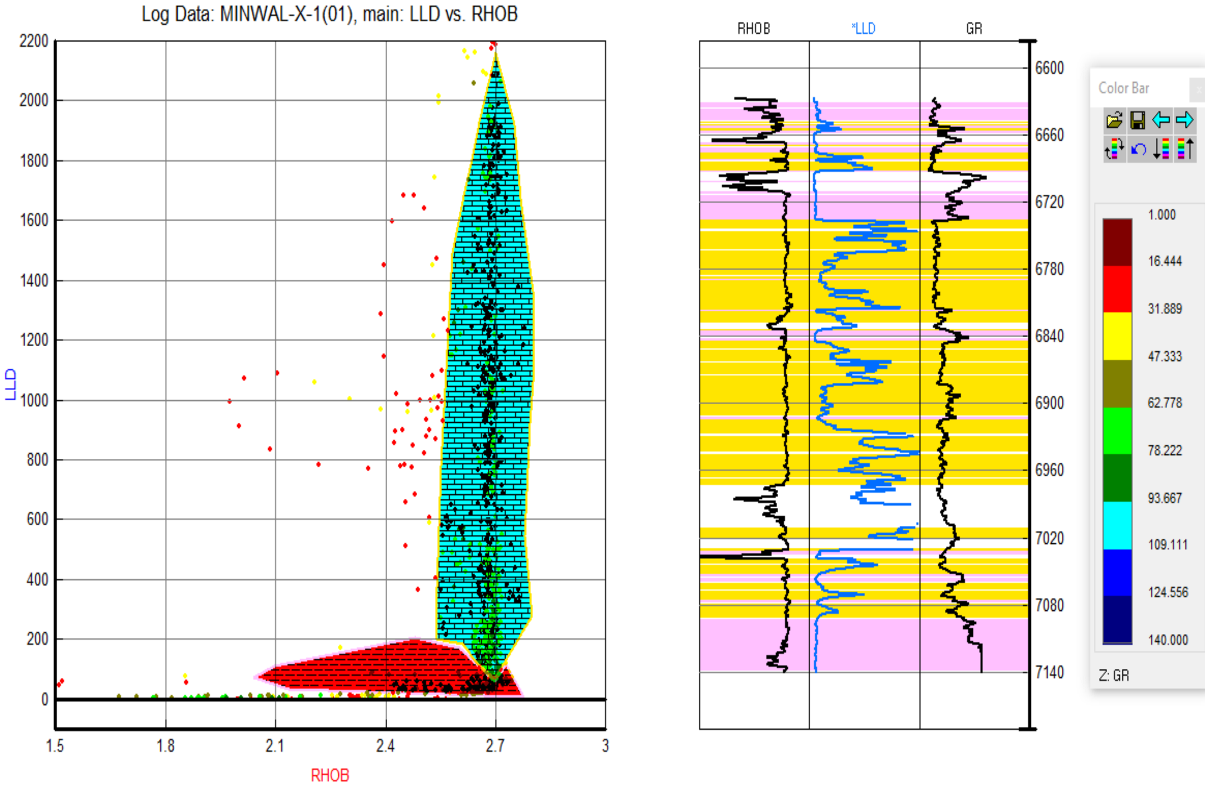


Figure: 7.6 Crossplot of Latero log Deep(LLD) vs Density Log(RHOB).

7.9 Cross plot between Neutron Porosity Log and Density log:

This cross plot is computed as density log on y ,gamma ray log on z axis and Neutron Porosity 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 cross plot by density log.

By comparison of the figure , the polygon is drawn and labeled according to the standard cross plots. 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.

This cross plot is also resembling with above cross plot. Hence it also confirmed the limestone abundance in in zone.

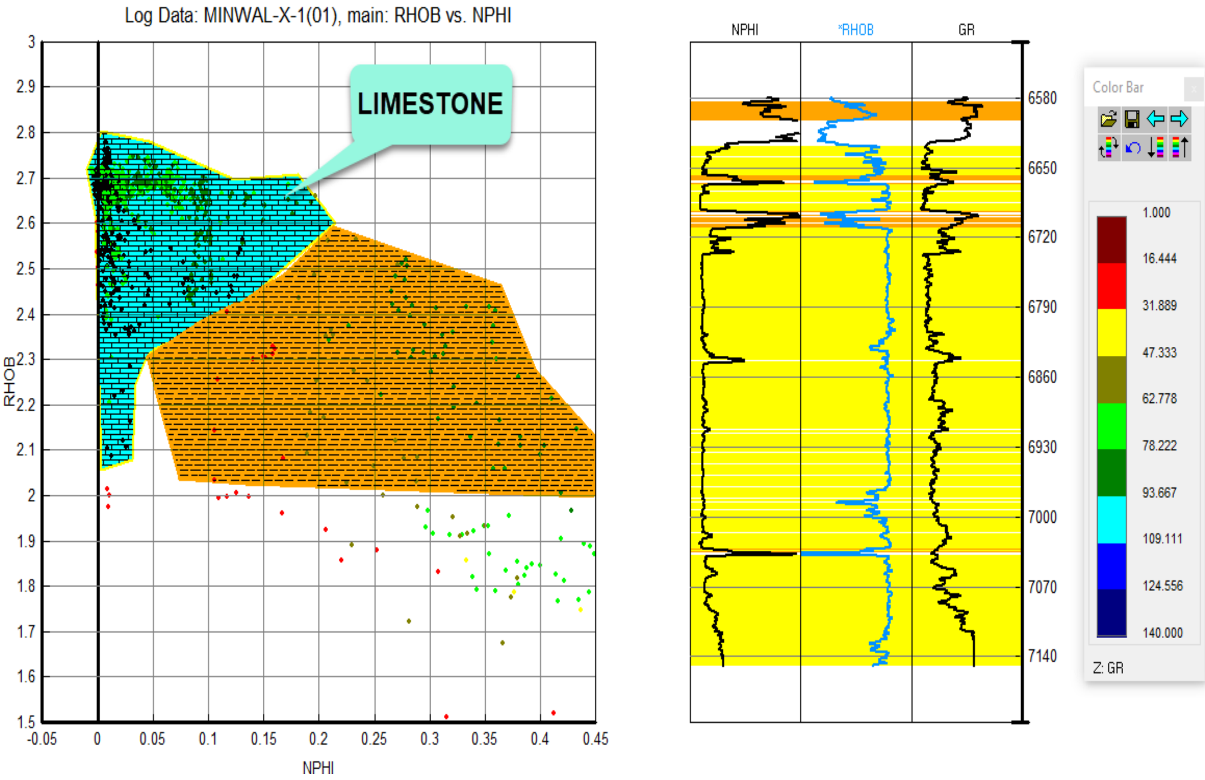


Figure: 7.7 Crossplot of Density Log(RHOB) vs Neutron Porosity(NPHI).

Above Crossplot clearly distinguish that reservoir is composed of limestone with interbedded shale.

Results:

All cross plots directed towards abundance of limestone in reservoir zone.

Hence the major facie of reservoir is limestone.

Chapter 8:

RESULTS & CONCLUSION

RESULTS & CONCLUSION:

- The following conclusions can be drawn from the work carried out in this dissertation.
- The structure of the Joya Mair oil field is recognized as triangle zone in the subsurface and an open anticline at the surface. The triangle zone is formed by the opposite combination of fore-thrust and backthrust. The fore-thrust and backthrust phases are the result of northwest and southeast successive Himalayan compression.
- The forethrust and backthrust of the triangle zone are found to be sealing on either side of the structure. The clays of the Rawalpindi Group act as a seal along these faults.
- 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.
- The reservoir rock is Sakesar Limestone that occurs at the depth of 2023 m interpreted from seismic data.
- 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 34% water saturation and 66% 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 environments indicate transgressive sequence.
- The southeastern flank of the Joya Mair Triangle Zone has been exploited where the northwestern flank is untapped. It is therefore suggested that the northwestern flank of the triangle zone be drilled for further recovery of oil from the Eocene reservoir.

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