INTEGRATED SEISMIC INTERPETATION, PETROPHYSICAL ANALYSIS ALONG WITH SEISMIC ATTRIBUTE ANALYSIS, INVERSION AND FACIES ANALYSIS OF MISSAKESWAL AREA

By

Falak Sher

BS Geophysics

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Department of Earth Sciences

Quaid-i-Azam University Islamabad Pakistan

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

CERTIFICATE

This dissertation submitted by **FALAK SHER** son of **SAJJAD AHMAD** 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 BS degree in Geophysics.

RECOMMENDED BY:

DR. MATLOOB HUSSAIN ________________________

(Supervisor)

DR. AAMIR ALI ________________________

(Chairman of Earth Sciences Department)

EXTERNAL EXAMINER ________________________

DEDICATION

I would like to dedicate this thesis work to my parents, siblings especially to my mother, sisters and the people who believed in me. Their love, selflessness encouragement, guidance and prayers made me able to achieve such success and honor, their love support and prayers were always with me. May Allah bless my family with honor, dignity, health, happiness, respect and fulfill their dreams and goals. AMEEN

ACKNOWLEDGEMENT

In the name of Allah, the most Beneficent, the most Merciful. All praises to Almighty Allah, the creator of universe. I bear witness that there is no God but Allah and Holy Prophet Hazrat Muhammad (P.B.U.H) is the last messenger of Allah, whose life is a perfect model for the whole mankind till the Day of Judgment. Allah blessed me with knowledge related to Earth. Without the blessing of Allah, I could not be able to complete my work as well as to be at such a place.

I am especially indebted to my dissertation supervisor Dr. Matloob Hussain for giving me an initiative to this study. His inspiring guidance, dynamic supervisor, and constructive criticism helped me to complete this work in time.

I would like to express my appreciation to my whole family, especially my mother and sisters for their support and help without which I was unable to reach at this stage. I also wish to thank the whole faculty of my department for providing me with an academic base, which has enabled me to take up this study.

I would like to thanks my seniors Yawar Khattak , Ehsan Mughal and to my friends **FAUJI GROUP** .

FALAK SHER

BS Geophysics

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ABSTRACT

Missa Keswal area is part of Potwar sub-basin of Upper Indus basin which is known for hydrocarbons and structural traps. Work has been done on three lines GO-994-GNA-09, GO-994-GNA-10, GO-994-GNA-11. For the interpretation of seismic data Kingdom software is used for marking of reflectors depending on prominent wiggles which describes the amplitude and then these reflectors are named as Murree, Chorgali, Sakesar, Khewra Sandstone and based on generalized stratigraphic column encountered in well **MISSA KESWAL-03** lying on the given seismic line GO-994-GNA-11. Faults were also marked to examine the subsurface structure. Pop-up structures can be seen in the marked seismic section.

Prospect evaluation (including gridding, Time and Depth contouring and identification of structural traps) has been carried out using Kingdom suit of Software.

Time sections are converted into the depth sections to view the real picture of the interpreted horizons. Time and depth contour maps of all formations are also prepared at a particular level to analyze the variations based on time and depth. Anticlines acts as a trap in the area, which is best for hydrocarbon accumulation. These structures have been marked at Murree, Chorgali, Sakesar and Khewra Sandstone formations.

Seismic attribute analysis is used for the confirmation of 2D Seismic interpretation and it also highlights the zone of interest.

Petrophysical analysis is done which provided information regarding the zone of interest for the presence of hydrocarbon.

Facies modeling is carried on the well MISSA KESWAL-03 for lithology identification. Based on Facies modeling different lithologies e.g. Clayey Shale and Sand are marked.

Colored inversion is carried on the line GO-994-GNA-09 to acquire indication of the hydrocarbons.

CHAPTER 1: INTRODUCTION

1.1 GEOGRAPHICAL LOCATION OF THE AREA

The study area is geographically located on the upper side of Dina, which is 17.7 kilometers to the north west of the Jhelum city having longitudes 73’58’’E and longitude of 33’2’’N. It is connected to Dina on one side and Rawalpindi on the other side through G.T road and north western railway both running from Peshawar to Lahore.

Hydrocarbons are one of the most essential part of economics of any country. Even on the smaller scale hydrocarbons play a wide role in everyday life. Geophysicists are trying since a long time for the exploration of hydrocarbons and are applying different methods in this regard. Seismic method is one of the most widely used methods in the exploration of hydrocarbon, especially Reflection Seismology (used in the present work) has the great importance in this regard.

Pakistan has high potential of hydrocarbons in its northern (Potwar, Kohat) and southern (Badin, Mari etc.) parts. The Indus basin, including the Kohat-Potwar (study area) depression, belongs to the category of extra-continental downward basins which account for 48% of the world’s known petroleum resources (Hasany & Saleem, 2001).

The Potwar sub-basin is dominated by the structural traps and mostly seismic data is incorporated for the delineation of these structures. On the other hand, the incorporation of seismological data for interpreting the structures has not been done yet by previous workers for the area of Potwar. Although in other parts of the world, the integration of seismic with seismology has been carried out since ages.

In the present work, an attempt has been made to correlate the results obtained by the seismic data to obtain a structural model of the Northern Potwar Deformed Zone (NPDZ). Interpretation of the seismic lines has been carried out to study the subsurface structure of the area.

The climatic conditions of the area suggest that it is hot in summers and cold and dry during winters. The average rainfall in this region is 880mm and the temperature climbs up to approximately 42 degree centigrade and shoots down to 8 degrees in winters (Saqib, et al., 1998). The geographic location of the Missa Keswal is at longitude 73’22’’0 E and latitude of 33’12’’0 N.

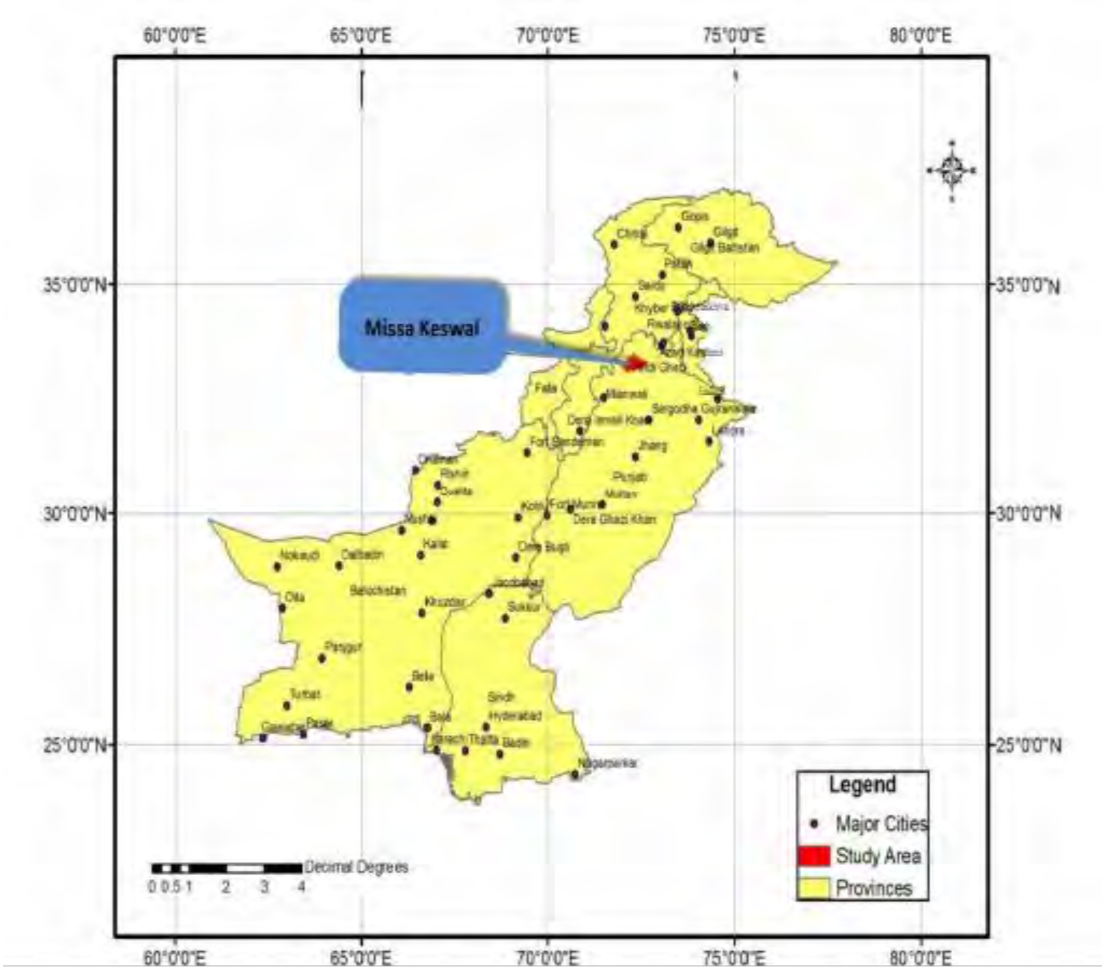

Figure 1.1a: Image of Pakistan along with area marked.

1.2 SURVEY INFORMATION

It includes all the information about the lines, wells and base map of the study area.

1.2.1 SEISMIC REFLECTION DATA

The trend of the seismic dip and strike lines in SE-NW and SW-NE, respectively. Given below in table (1.1)

S.NO.	LINE NO.	NATURE	LINE ORIENTATION
1.	994-GNA-09	DIP	NW-SE
2.	994-GNA-10	DIP	NW-SE
3.	994-GNA-11	STRIKE	NE-SW

Table 1.1: seismic lines

1.2.2 WELL DATA

Well name	**MISSA KESWAL-03**
Well type	**Oil and Gas**
Latitude	**33.1999619304041**
Longitude	**73.341338546945**
Starting depth(m)	**259.22 meters**
Total depth(m)	**2250**
Elevation(m)	**427.12**
Depth Reference	**Kelly Bushing**

1.2.3 DATA FORMATS

Seismic reflection data which consist of

- SEG-Y
- LAS
- Navigation

1.3 BASE MAP OF THE STUDY AREA

The base map shows the spatial position of each picket of seismic section, orientations of seismic lines and specify points at which seismic data were acquired. It is simply a map which consist of number of dip and strike lines on which seismic survey is being carried out. A base map typically includes location of lease and concession boundaries, wells, seismic survey points and other cultural data such as buildings and roads with geographic reference such as latitude and longitude.

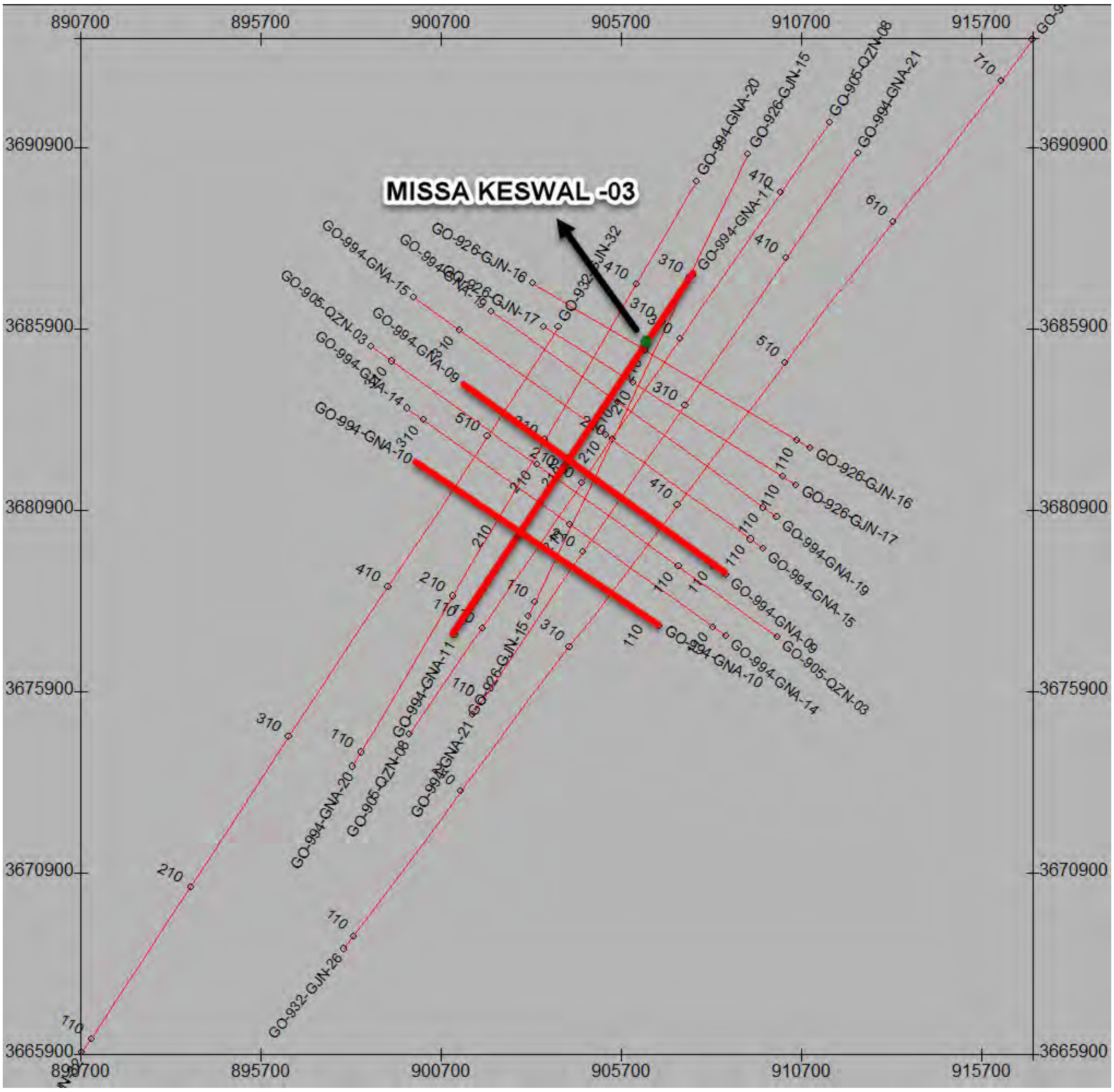

Figure 1.1b: Base map of the study area

1.3.1 SPATIAL LOCATION

The seismic lines with their orientation and well data used for the generation of Basemap are tabulated below in table (1.2)

LINE NAME	NATURE	LINE ORIENTATION	WELL
GNA-09	**Dip Line**	**NW-SE**	
GNA-10	**Dip Line**	**NW-SE**	
GNA-11	**Strike Line**	**NE-SW**	**MISSA KESWAL-03**
GNA-14	Dip Line	NW-SE	

GNA-15	Dip Line	NE-SE	
GNA-19	Dip Line	NW-SE	
GNA-20	Strike Line	NE-SW	
GNA-21	Strike Line	NE-SW	
QZN-03	Dip Line	NW-SE	
QZN-08	Strike Line	NE-SW	
GJN-15	Strike Line	NE-SW	
GJN-16	Dip Line	NW-SE	
GJN-17	Dip Line	NW-SE	
GJN-26	Strike Line	NE-SW	
GJN-32	Strike Line	NE-SW	

Table 1.2 : lines used for making basemap.

1.4 SEIMIC AQUISTION AND PROCESSING PARAMETERS

Our data is in three vintages but my lines fall in one vintage Gulyana that is mentioned in table (1.3)

GENERAL ACQUISTION PARAMETERS

Survey Area	Gulyana
Date processed	May,1999
Datum velocity	2300M/sec
Datum plane	350M
Processing sampling interval	2 Msec
Recorded by	OGDCL
Party Number	Sp-04
Date Recorded	March,1999
Aliasing Filter	125HZ
Source	Dynamite
No of Holes	01
Hole Depth	35m
Charge	18kg
S.P Interval	100 Meters
Instrument	MDS-16

Format	SEGB
Notch Filter	OUT
Record Length	6 seconds
No of data traces	120
Spread	3075-125-X-125-3075
Group interval	50Meters
Geophone Frequency	10HZ
Geophone Interval	1.40

Table 1.3 : Acquisition and processing parameters.

1.5 PROCESSING SEQUENCE

After the data has been acquired, it passes through the whole processing sequence that includes different data processing techniques that are used to enhance the quality of the data. The raw seismic data is processed to enhance the signal to noise ratio and get the final seismic sections. The processing sequence flow chart is given below in (figure 1.2)

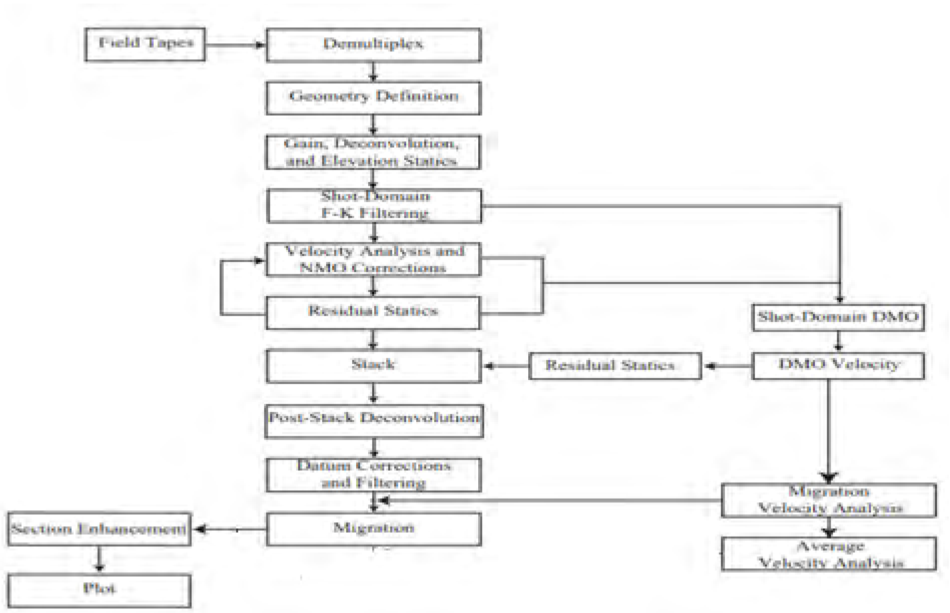

Figure 1.2: Seismic Data Processing flow chart

1.6 LIST OF SOFTWARE TOOLS AND APPLICATIONS

- ➢ IHS Kingdom 8.8
  - Synthetic seismogram generation
  - Interpetation.

- Time to depth conversion.
- Time contour map
- Depth contour map
- Seismic attribute analysis
- Inversion
- Petrophysics
- Facies Modelling

1.7 OBJECTIVES OF STUDY.

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

(a) To carry out different steps for the Seismic interpretation of migrated stacked sections.

(b) Conversion of time section to depth section.

(c) To generate time and depth contour map of the selected reflectors.

(d) To delineate the structural trap, if present, using the data acquired.

(e)Confirmation of depth section by correlation with Synthetic Seismogram & Formation tops of well Missa Keswal-03.

1.8 Workflow

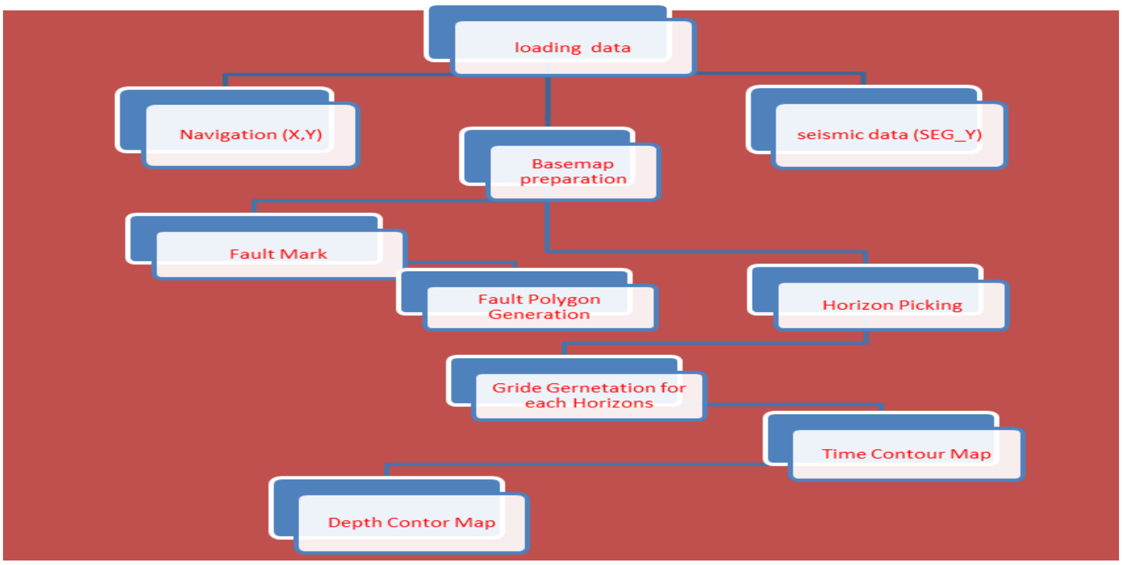

Figure 1.3: Seismic data interpretation flow chart

CHAPTER 2: GEOLOGY AND STRATIGRAPHY

2.1 GENERAL GEOLOGY OF POTWAR PLATEAU

Pakistan possesses the northwestern boundary of the Indian lithospheric plate. The under-thrusting of Indian Plate beneath the Eurasian Plate is producing compressional thick-skinned tectonic features since Eocene time on the northern and northwestern fringes of the Indian Plate. The continued under thrusting of the Indian Plate since Cretaceous produced the spectacular mountain ranges of the Himalaya and a chain of foreland fold-and-thrust belts as thick sheets of sediments thrusted over the Indian craton.

In Northern Pakistan, the Himalayan trend is divided into four major subdivisions.

- Main Karakoram Thrust (MKT)
- Main Mantle Thrust (MMT)
- Main Boundary Thrust (MBT)
- Salt Range Thrust (SRT)

Karakoram ranges and Hindukush lie in the north of the Main Karakoram Thrust (MKT). South of the Main Karakoram Thrust (MKT) and north of Main Mantle Thrust (MMT) lies the Kohistan-Ladakh block. Low ranges of Swat, Hazara, and Kashmir that are analogous to the Lesser Himalayas of India lie between the Main Mantle Thrust (MMT) and the Main Boundary Thrust (MBT).

The outlying Potwar Plateau, bounded on the south by the Salt Range Thrust (SRT), represents the marginal foreland fold-and-thrust belt of Indo-Pakistan Subcontinent, equivalent to the Sub-Himalayas in India (Pennock et al, 1989). Thrusting in the Indian Plate is certainly the main accommodation method of shortening in the Himalayas Fault plane solutions of earthquakes give evidence that these are linked to the thrusts.

However, in the Northwest Himalayas where our study area lies, complications arise as earthquake fault planes do not follow the thrusts which change in orientation, suggesting that other accommodation features besides simple thrusting are occurring in the Northwest Himalayas. Kazmi and Jan, 1997 named the Northwest Himalayas as the Northwestern Himalayan Fold-and-Thrust Belt, in their tectonic division of Pakistan. This belt is described as follows.

2.2 NORTHWEST HIMALAYAN FOLD-AND-THRUST BELT

The Northwest Himalayan fold-and-thrust belt consists of irregularly shaped mountainous region and it covers a wide area i.e. 250x560 km2. It extends from the Afghan border near Parachinar up to the Kashmir Basin. Its eastern boundaries are the Hazara-Kashmir Syntaxis and Nanga Parbat Syntaxes, whereas Main Mantle Thrust (MMT) in the north and the Salt Range Thrust (SRT) in the south are its structural limits. The Nanga Parbat, Hazara, southern Kohistan, Swat, Margalla, Kala Chitta, Kohat, Safed Koh, Salt Range and its western extension are also covered by it. The belt is divisible into two parts i.e. hinterland zone and foreland zone by a major thrust i.e. Panjal-Khairabad Fault. The study area belongs to the foreland zone, which is further comprised of the Hazara-Kashmir Syntaxis, Salt Range and Kohat-Potwar fold belt, and the Kurram-Charat-Margala thrust belt. Below is the tectonic/geological description of the Potwar area only (Kazmi and Jan,1997).

2.2.1 POTWAR PLATEAU

Physiographically, the Plateau is a low relief surface, except where dissected by major rivers. Potwar Plateau is an elevated nearly flat region located about 100km north of the Salt Range. The Kala Chitta and Margalla Hills bound the Potwar Plateau to the north, the Indus River and Kohat Plateau to the west, and the Jhelum River and the Hazara-Kashmir syntaxis to the east. It is largely covered by the Siwalik sequence, though at places upper Eocene shales and limestones crop out locally in folded inliers. The wide and broad Soan syncline divides the Potwar Plateau into Northern Potwar Deformed Zone (NPDZ) and Southern Potwar Platform Zone (SPPZ). The NPDZ is more intensely deformed than the southern part. It is a belt of Neogene deformation, extending southward from the Main Boundary Thrust (MBT) to the Soan syncline.

Formation outcrops and faults are generally east-northeast trending, approximately perpendicular to the tectonic transport direction.

The highly dissected NPDZ is an area of wide synclines, compressed folds and closely spaced imbricate thrusts. The deformation style of NPDZ abruptly changes from east to west (figure 2.1). The eastern NPDZ represents a buried thrust front with the development of foreland syncline on the back of Dhurnal Fault, passive roof duplex (triangle zone) and hinterland dipping imbricate stack farther north while the western NPDZ which is characterized by compressed and faulted anticlines separated by large synclines, representing the emergent thrust.

The horizontal shortening for the zone between the Soan syncline and a point near MBT is calculated as about 55km and the minimum rate of shortening in this zone is estimated to be

18m NPDZ is followed to the south by asymmetrical wide and broad Scan syncline, with a gently northward dipping southern flank along the salt range and a steeply dipping northern limb along NPDZ (Jaswal et al, 1997). The eastern part of the Southern Potwar Platform Zone represents strong deformation as compared to the central and western parts. The thrusts and back thrusts bounded salt cored anticlines represent both foreland and hinterland verging deformation. In the central and western parts of the southern Potwar only minor deformation is present within the over-thrusted Phanerozoic sedimentary section due to effective decoupling within Eocambrian evaporites above the basement (Kazmi and Jan, 1997).

2.3 REGIONAL GEOLOGY

Pakistan comprises of three main geological subdivisions referred to as Laurasian, Tethyan and Gondwanaland domains (Kazmi, et al., 1997). Late Paleozoic is their origin. All the continents had drifted apart to form a super continent known as Pangea. By late Triassic, Laurasia drifted to the north and Gondwanaland to the south separated by Tethys seaway resulting in the split up of Pangea. Pakistan is located at the junction of Gondwanian and Tethyan domain.

2.3.1 TECTONIC FRAMEWORK OF PAKISTAN

Tectonics of Pakistan is characterized by two active convergent boundaries:

(a) In the northeast there is an active continent-island arc-continental collision boundary. The west end of the Himalayan orogen.

(b) In the southwest, there is an active boundary of oceanic lithosphere subducting arc trench gap sediments and continental sediments, the oceanic part of the Arabian plate passing under the Makran arc-trench gap and Afghan microplate.

These two convergent boundaries are connected by a very large displacement north-south left lateral strike slip faults of Chaman-Transform Zone.

2.3.2 TECTONIC ZONES OF PAKISTAN

Based on Plate tectonic features, geological structure, orogenic history (age and nature of deformation, magmatism and metamorphism) and lithofacies, Pakistan may be divided into the following Tectonic zones.

(a) Indus Platform and foredeep, East Baluchistan fold-and-thrust belt.

(b) Northwest Himalayan fold-and-thrust belt.

(c) Kohistan-Ladakh magmatic arc.

(d) Karakoram block.

(e) Kakar Khorasan flysch basin and Makran Accretionary Zone.

(f) Chagai magmatic arc.

(g) Pakistan offshore.

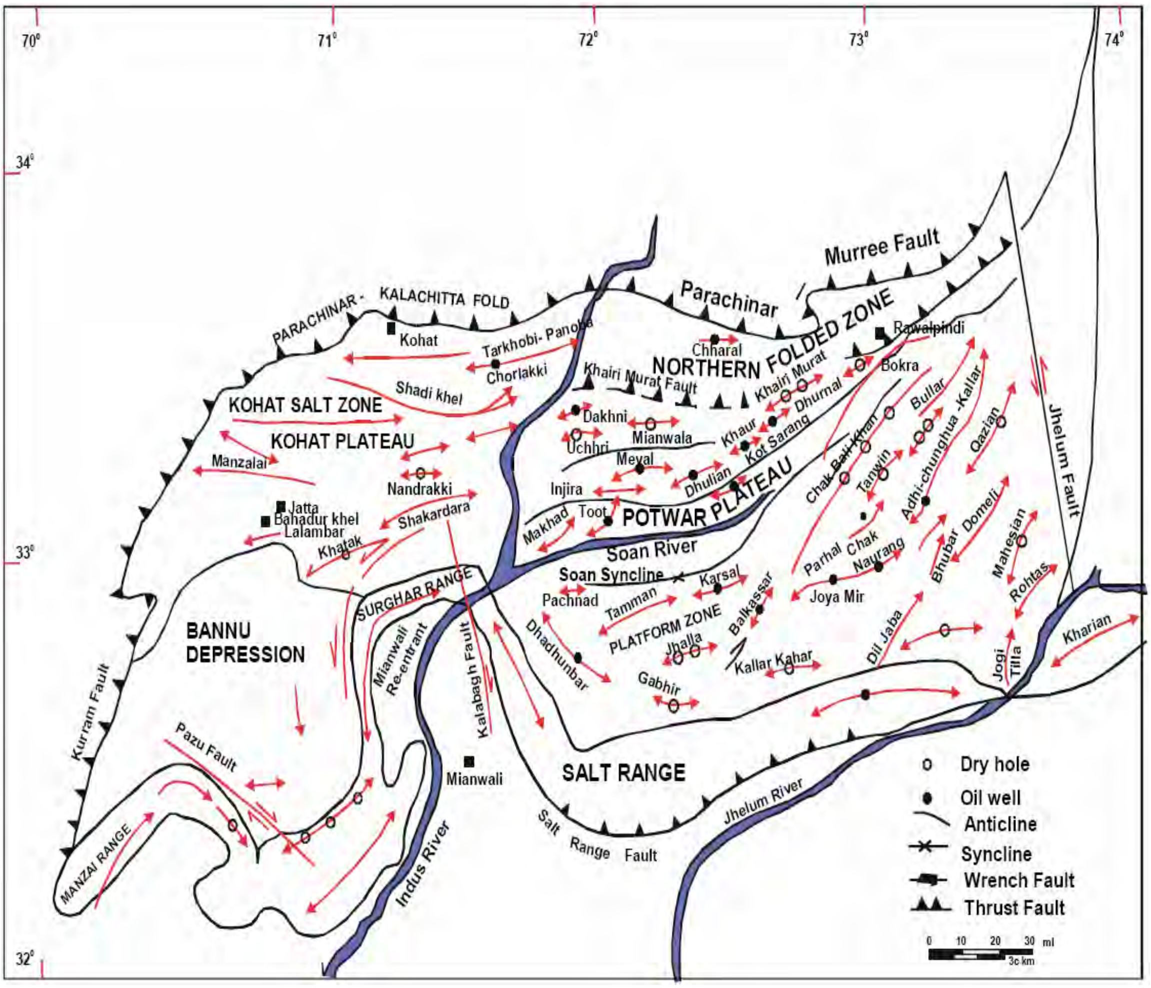

Figure 2.1: Tectonic division of Potwar Basin (Shami and Baig,1998)

2.4 SEDIMENTARY BASINS

Basin is an area characterized by regional subsidence in which sediments are preserved for the longer period. A basin is a depression, or dip, in the Earth's surface. Basins are shaped like bowls or container, with sides higher than the bottom. Basin’s substratum is known as its Basement. The container is filled with sediments accumulated that rest on basement are known as Sedimentary cover. The gradual setting of the basin is called Subsidence. The point of maximum sedimentary accumulation is called the Depocenter.

The depocenter may not correspond to the zone of maximum subsidence. Sediments originate at a certain place. These sediments may be deposited at the same place or may be transported to some other place by transporting agents. The sediments deposited at the same place are called molasses deposits. The transported sediments rest on the basement of a basin and form a sedimentary cover.

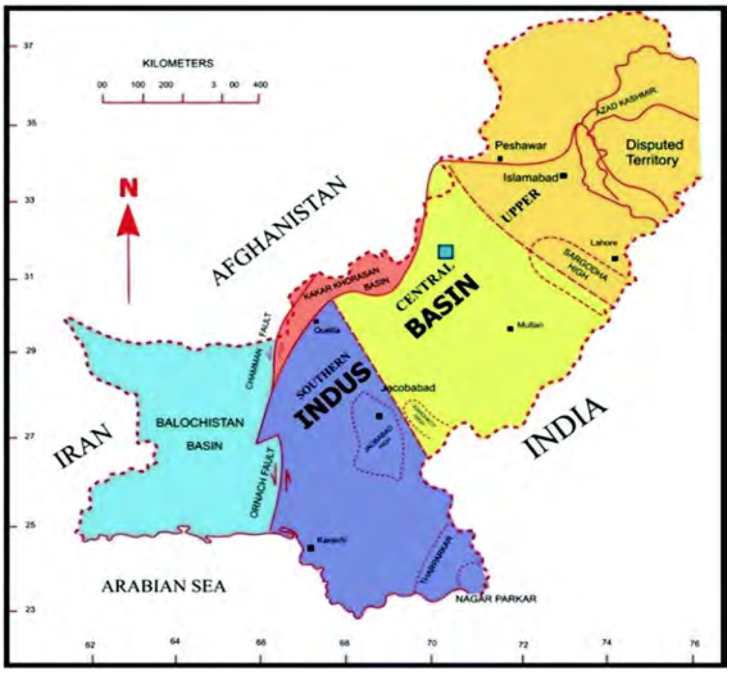

Figure 2.2: Basin architecture of Pakistan (Wadood et al, 2020)

2.4.1 INDUS BASIN

The geological history of Indus basin goes back to Precambrian age. The Paleotopographic features shown on the gravity map influenced to a large extent by the depositional processes throughout the basin development. These features also marked the limit of the basin and its divisions. The ongoing tectonic processes further enhanced and modified the configuration and gave rise to new ones creating an array of modern basis. The first split up of the super continent Pangea which disturbed the equilibrium happened in Jurassic.

Indus Basin is classified as follows:

1. Upper Indus Basin
    i. Kohat sub-basin
    ii. Potwar sub-basin
2. Lower Indus Basin
    i. Central Indus Basin

ii. Southern Indus Basin

<table>
<tr><td rowspan="12">INDUS BASIN</td><td rowspan="2">UPPER INDUS BASIN</td><td colspan="3">KOHAT SUB-BASIN</td></tr>
<tr><td colspan="3">POTWAR SUB-BASIN</td></tr>
<tr><td rowspan="10">LOWER INDUS BASIN</td><td rowspan="5">CENTRAL INDUS BASIN</td><td colspan="2">PUNJAB PLATFORM</td></tr>
<tr><td rowspan="3">SULAIMAN DEPRESSION</td><td>EAST SULAIMAN DEPRESSION</td></tr>
<tr><td>ZINDAPIR INNER FOLDED ZONE</td></tr>
<tr><td>MARI BUGTI INNER FOLDED ZONBE</td></tr>
<tr><td colspan="2">SULAIMAN FOLD BELT</td></tr>
<tr><td rowspan="5">SOUTHERN INDUS BASINN</td><td colspan="2">THAR PLATFORM</td></tr>
<tr><td colspan="2">KARACHI TROUGH</td></tr>
<tr><td colspan="2">KIRTHAR FOREDEEP</td></tr>
<tr><td colspan="2">KIRTHAR FOLD BELT</td></tr>
<tr><td colspan="2">OFFSHORE INDUS</td></tr>
</table>

Table 1.4: Division of Indus Basin

2.4.2 UPPER INDUS BASIN

The basin is in the northern Pakistan and is separated from the Lower Indus basin by Sargodha High. The northern and eastern boundaries coincide with the Main Boundary Thrust (MBT) the southern most of the major Himalaya thrust. The MBT runs through the Margalla Hills, Kala Chitta and Kohat Ranges. Western boundary of the basin is marked by an uplift of Pre-Eocene sediments and eastward directed thrusting to the west of Bannu.

The basin is further subdivided into Potwar, to the east and Kohat, to the west by river Indus. Regardless of the small size of the Potwar and Kohat sub-basin they depict facies variation. Potwar sub-basin preserves the sediments from Precambrian to Quaternary age in the subsurface and all of these are exposed in the Salt Range, a southern most thrust.
The Trans-Indus ranges in south of the Kohat sub-basin expose sediments from Cambria to Pliocene age. Both Kohat and Potwar sub-basin are characterized by an unconformity between Cambrian and Permian.
Mesozoic sediments are also exposed around the basin rim. However, this presence is governed by Pre-Paleocene erosion which progressively cut into older sequence from the Trans-Indus Ranges in the west to east Potwar through Salt Range. In Kohat sub-basin, west of the Potwar sub-basin, Eocene through Siwalik strata are involved in a complex fold and thrust belt in which Eocene Salt occupies the cores of many of anticlines.

2.5 GEOLOGICAL BOUNDARIES

2.5.1 UPPER INDUS BASIN

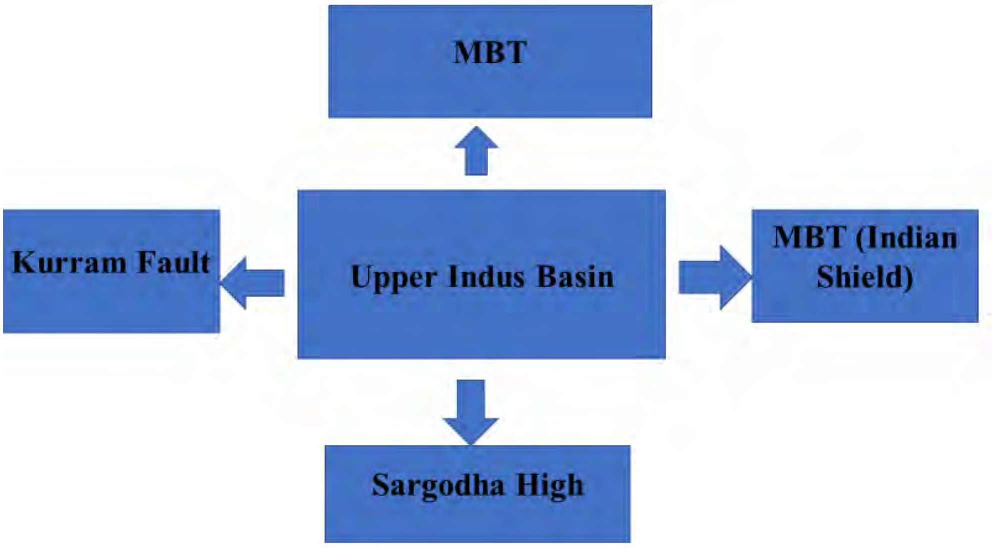

Figure 2.4: Geological boundary of Upper Indus basin

2.5.2 CENTRAL INDUS BASIN

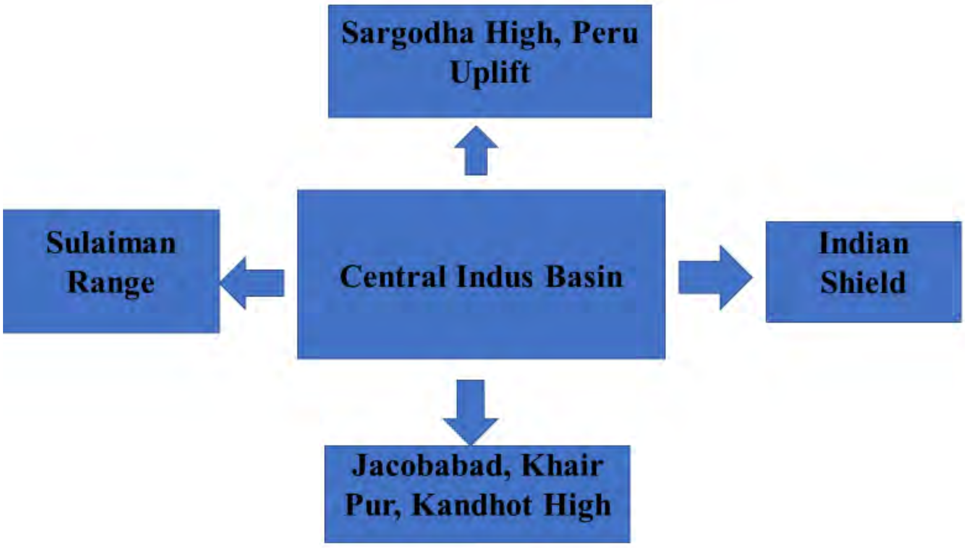

Figure 2.5: Geological boundary of Central Indus basin

2.5.3 LOWER INDUS BASIN

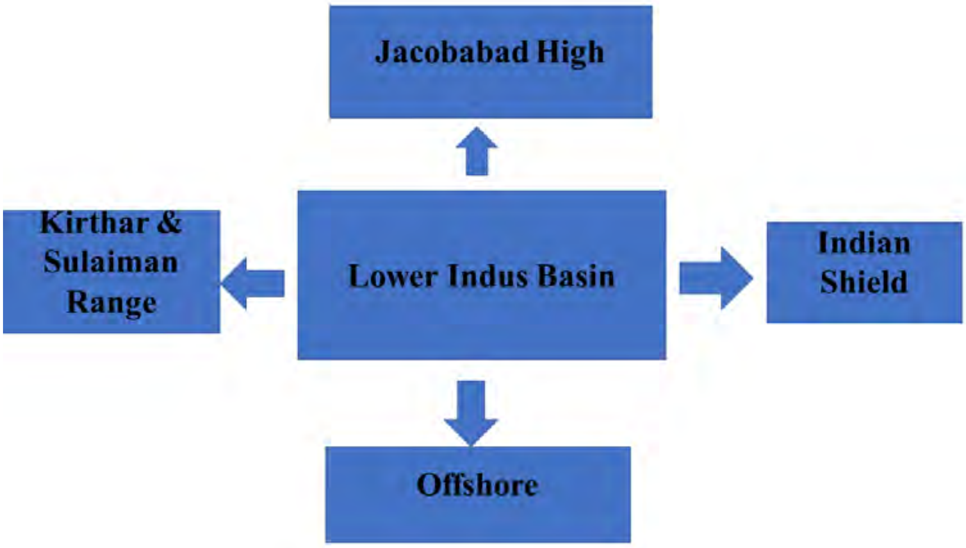

Figure 2.6: Geological boundary of Lower Indus basin

2.6 STRUCTURAL DIVISION

The Missa Keswal structure is bounded by a main thrust fault in the strike direction. Few orthogonal faults exist which may provide lateral barriers to the flow during production. The upward migration of oil from the under thrusted block of the duplex has probably contributed to the occurrence of a multi-reservoir system in the upper block.

The tectonic depression of Potwar sub-basin is formed as result of continent-to-continent collision at the northwest margin of the Indian Plate. Presently two-fold division is envisaged for the Potwar sub-basin based on the deformation style:

(a) Northern Potwar Deformed Zone (NPDZ).

(b) The Platform Zone.

The NPDZ is in the south of Kalla Chitta Margalla Hills. It is structurally complex zone. In these areas Tertiary rocks are exposed along a series of south verging thrust faults. The platform area is mainly covered with thick fluvial sediments of Siwalik group (Chinji, Nagri and Dhok Pathan Formations). These sediments have been folded along with underlying marine sediments of the Indian Plate as the rest of the latest tertiary tectonic movements. The folded structures are generally oriented in sub-latitudinal fashion.

The overall structure of the eastern NPDZ is a duplex structure developed beneath a passive roof thrust. The roof thrust is generated from a tipline in the Miocene Murree Formation, and the sole thrust is initiated from the same Eocambrian evaporite zone that extends 80 km southward beneath the Soan syncline and Salt Range.

The Platform is further divided into three parts:

(a) The eastern Platform Zone.

(b) The central Platform Zone.

(c) The western Platform Zone.

2.6.1 STRUCTURAL STYLE OF POTWAR PLATEAU

Potwar Plateau is largely covered by the Siwalik sequence, though at places upper Eocene shales and limestone crop out locally in folded inliers. Its Northern part, known as the North Potwar Deformed Zone (NPDZ) is more intensely deformed. It is characterized by east-west, tight and complex folds, overturned to the south and sheared by steep-angle faults (Kazmi &Jan, 1997). The structural style of the 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 lnfra-Cambrian in the eastern areas and very low dip of the basement (1°-1.5°) as compared to Central Potwar (20-30). In the central part of the study area, paleomagnetic data indicate that counterclockwise, thrust-related rotation of the Potwar Plateau rocks generally increases from less than 10° in the western part to more than 50° in the eastern part of the plateau.

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. Based on the seismic interpretation, the structures in Potwar area may be divided into: Pop-up anticlines, Salt cored anticlines and Triangle zones (Mughal et al, 2003).

The northern part of the Potwar area is characterized by strong folding and thrust faulting; the major structural trends change from east trending in the western part of the area to northeast trending in the eastern part of the area. The Soan River generally flows through the Soan syncline, which is a major structural downwarp with a sedimentary pile more than 5 km thick in the central part of the study area. Stuructural map of Potwar Plateau is shown in figure 2.1

2.6.2 MAJOR FAULTS IN POTWAR BASIN

As Potwar represents the southern margin of Himalayan collisional zone, a variety of faults and folds can be seen in the area. Some of the major faults in the area are

- Khair-i-Murat Fault (KMF)
- Dhurnal Back-thrust (DBT)
- Kanet Fault (KF)
- Sakhwal Fault (SF)
- Mianwali Fault (MF)
- Riwat Fault (RF)

2.6.3 MAJOR FOLDS IN THE POTWAR SUB BASIN

- Soan syncline
- Chak Naurang Anticline
- Mahesian Anticline
- Tanwin-Bains Anticline

- Joya Mair Anticline
- Dhurnal Anticline

2.7 STRATIGRAPHY

The study of stratified rocks is called stratigraphy. It’s the branch of geology that deals with the description, correlation, and interpretation of stratified sediments and stratified rocks on and in the Earth. Inasmuch as by far the greatest part of the uppermost zone of the earth’s bedrock is sedimentary rock, stratigraphy is an important branch of Earth science**.**

Up until about 1800, thinking about the Earth’s past was largely flood dominated, except for a few who were ahead of their time, like Leonardo da Vinci, who perceived the true significance of fossils in rocks. Nicolaus Steno (born Niels Stensen; 1638–1686), who should be considered the father of stratigraphy, recognized not only the significance of fossils but also the true nature of strata. His thinking has been summarized in the form of Steno’s Laws (although “principles” would be a better choice of word than “laws”) (Nicolai Stenonis, 1669):

- superposition: younger rocks are deposited on older rocks.
- original horizontality: strata were close to being horizontal when they were originally deposited.
- original lateral continuity: strata were originally laterally extensive relative to their thickness when they were deposited

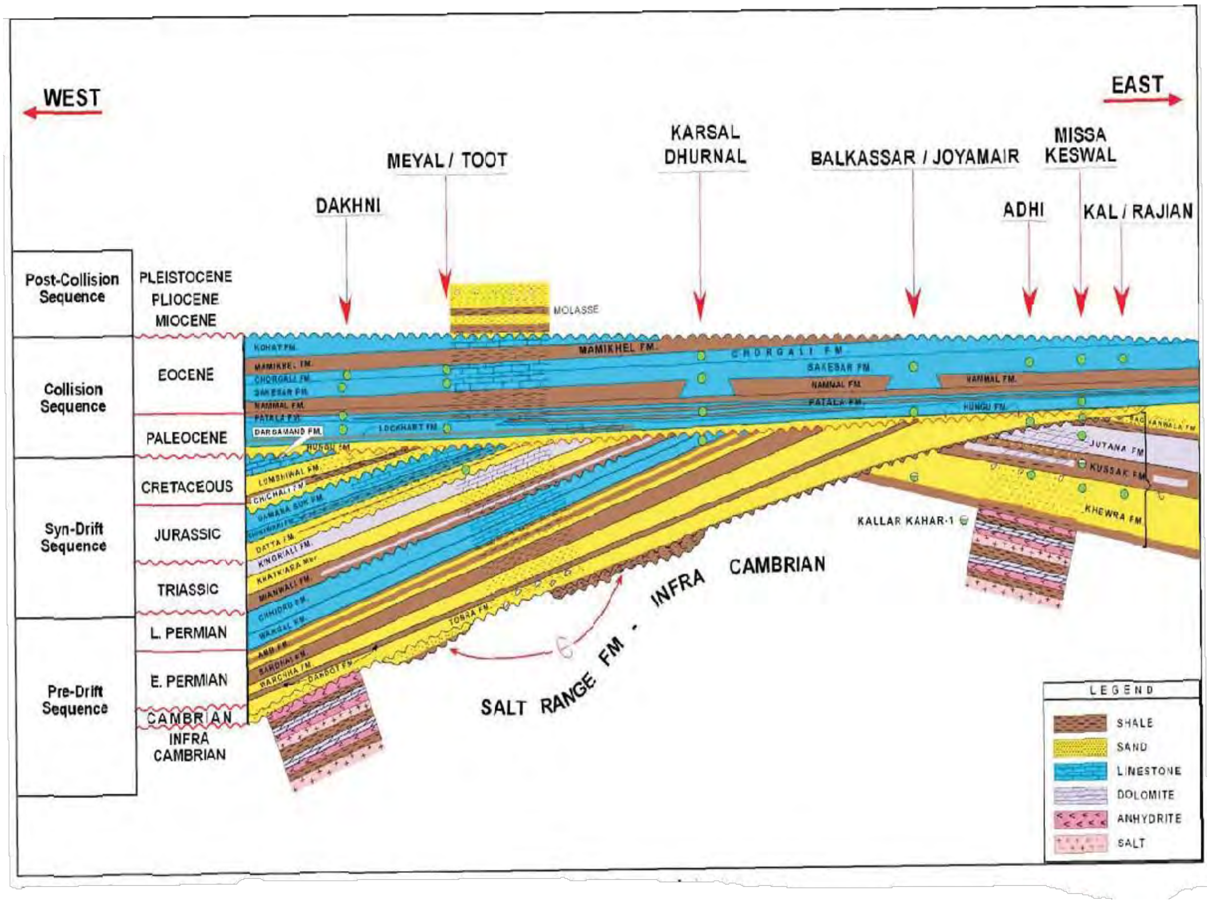

Figure 2.9: Generalized stratigraphy of Potwar sub-basin (Bugti, 2007)

The Stratigraphy the of Salt Range and Potwar Plateau is well established from outcrops in the Salt Range. The stratigraphy in the NPDZ is not that well constrained due to lack of deep drilling. Surface outcrops along the MBT and seismic profile, however, suggest the stratigraphy of NPDZ is like that of the Salt Range and Potwar Plateau. Stratigraphic succession of the Potwar basin is characterized by thick Infra-Cambrian evaporite deposits overlain by relatively thin stratigraphic succession of the Eocene to Cambrian. Thick Miocene-Pliocene molasses deposits are related to severe deformation in Late Pliocene to Middle Pleistocene (During Himalayan orogeny).

The Infra-Cambrian evaporites were deposited in intracratonic setting in a basin that extended from Pakistan to Turkey through Iran and Oman. This deposition occurred over the basement of the Indian Plate. The evaporite sequence is overlain by Cambrian rocks of Jhelum Group which comprises Khewra Sandstone, Kussak, Jutana, and Bhaganwala formations. Deposition of the Jhelum Group was followed by a period of limited deposition and/or erosion from Middle Cambrian to Early Permian. Therefore, the strata belonging to these periods are missing in Potwar sub-basin. The Nilawahan Group of early Permian is restricted to the eastern part of Potwar / Salt Range and is predominantly of continental origin. This group includes Tobra Formation, deposited in predominantly glacial environments, Dandot Formation of olive-green sandstones and claystone, Warcha Formation predominantly red sandstone, and Sardhai Formation's claystone.

The Zaluch Group is restricted to the western and northern/central part of Potwar / Salt Range. It includes marine limestones and claystone of the Amb, the Wargal and the Chhidru formations, deposited during the Late Permian. The Triassic formations are Mianwali and Tredian deposited in deep to shallow marine environment and the Kingriali formation comprising shallow water dolomite. The Jurassic formations include Datta Sandstone, Shinawari (limestone and shale sequence) and the Samana Suk (Limestone) formations.

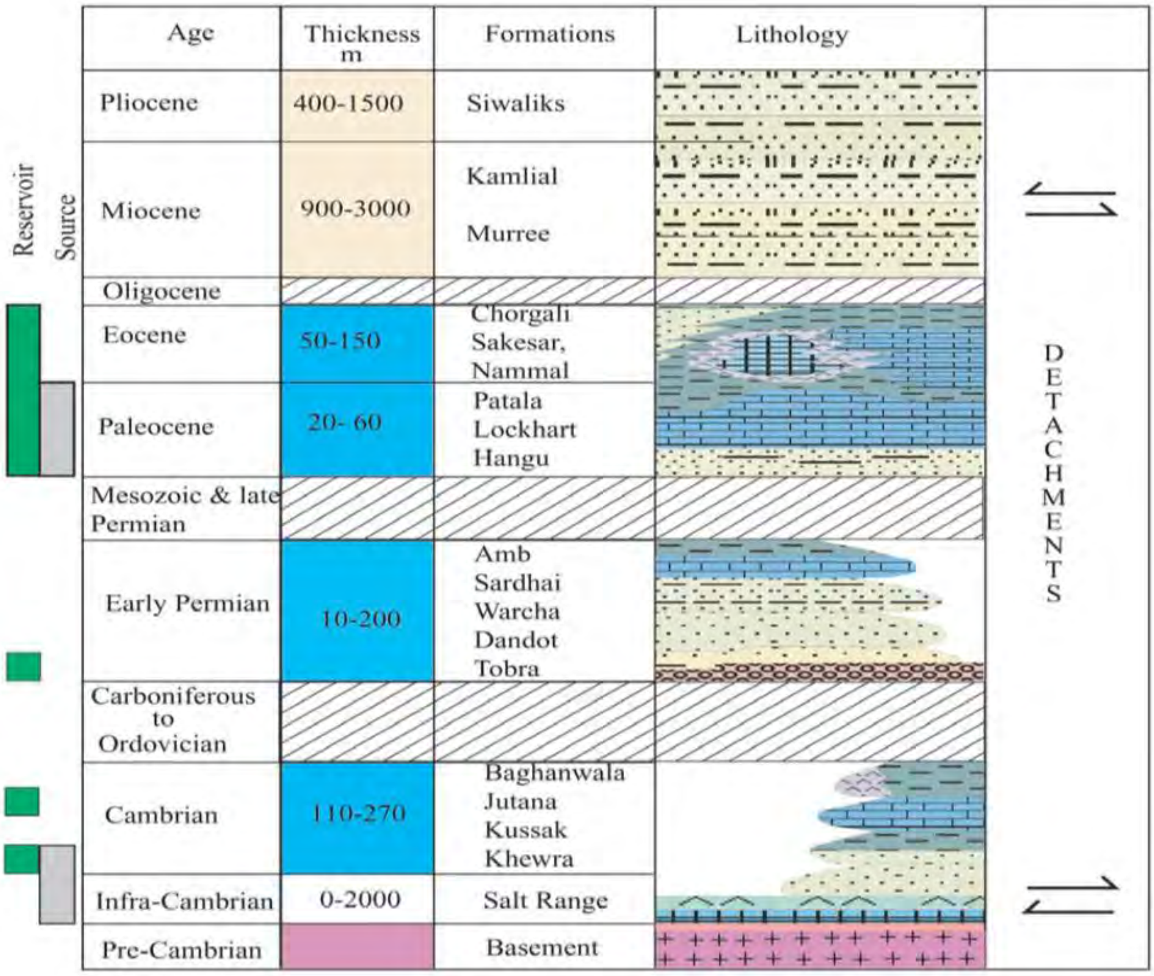

Figure 2.10: stratigraphy of upper Indus basin(Muhammad et al, 2006)

2.8 PETROLEUM PLAY OF POTWAR

Potwar marine facies has great potential of hydrocarbon. Previous drilling was restricted up to Eocene carbonate. Recent discoveries in Potwar result in delineation of deep subsurface crest. (Kadri, 1995).

Potwar region which is traditional oil producing area of Pakistan has the average geo-thermal gradient of the order of 2-degree celsius per 100 meters. Hence the oil window lies between 2750-5200 meters. (Kadri, 1995).

2.8.1 SOURCE AND RESERVIOR ROCKS OF POTWAR BASIN

Noncommercial oil has been encountered in the shale of Precambrian Salt Range Formation (in well drill in Dhariala, Kallar Kahar). In Cambrian, the marine shale of Kussak, Jutana and Khisor formation has source potential for hydrocarbon. Oil is produced from Khewra Sandstone in Adhi field. In Permian, shale of Dandot and Sardhai, Limestone and Black shale of Zaluch group has source potential of oil. Reservoir potential of Permian is also good in Adhi oil filed in Tobra/Dandot/Warcha, Dhurnal oil field in Amb and Wargal while Dhulian Well in Permian sandy Limestone. Triassic unit of Potwar having versatility in the environment of deposition is the reason that it cannot act as a good source rock.

Only the Khatkiara Member of Tredian Formation have good reservoir characteristic. In Jurassic, the black clay and organic content of Data and some part of Shinawari formation are believed to be good source rocks while Data is oil producing reservoir at Meyal, Toot and Dhulian oil field. Similarly, Samana Suk Formation has also good reservoir characteristic. In Cretaceous Chichali Formation has good source potential due to abundant of organic material while Lumshiwal Formation is good reservoir having gas discovered in some area of Punjab Platform.

In Paleocene Patala shale is major source in this region while the Paleocene reservoir is productive in all part of the Indus Basin like in Dhulian, Toot and Meyal. Early Eocene carbonate are good source and reservoir rock, Sakesar and Chorgali having fractured Limestone having hydrocarbon potential in Adhi (PPL), Dhurnal (OXY), Dakhni (OGDCL) etc.

In Dhulian the Permian and Paleocene succession is quite thin. Carbonates of Chorgali and Sakesar Formations are major oil producing unit in this area. Moreover the sandstone of Murree Formation has also good potential. Sakesar is consisted of light gray, massive and partially dolomitized carbonated that locally contains the chert concentration.

Chorgali Formation contains the creamy, yellow to yellowish gray, silty, partially dolomitized and thin bedded limestone. Clay and shale of Murree Formation provides good vertical and lateral seal to these Eocene carbonates. (Geomodelling of Hydrocarbon of Potwar, (Shami & Baig, 1998).

2.8.2 SOURCE ROCKS

The gray shales of the Mianwali (Triassic age), Datta (Jurassaic age) and Patala Formations (Paleocene age) are potential source rocks in Salt Range Potwar- Foreland Basin (SRPFB) (Khan et al, 1986). The oil shales of the Eocambrian Salt Range Formation include 27% to 36% total organic content (TOC) in isolated pockets of shales are considered as the source rock in SRPFB (Shami and Baig, 2003).

i. PATALA FORMATION

The Patala formation is mainly comprised of shale and marl with subordinate limestone and sandstone. The shale is dark greenish gray, carbonaceous and calcareous, selenitic and marcasite nodules bearing. Lithologically the formation shows some variations from place to place. The upper part of Patala formation is characterized by yellowish brown and calcareous sandstone. Its thickness varies from 20-180 m from place to place in Potwar-Kohat sedimentary basins.

Patala formation conformably overlies the Lockhart limestone. It is highly fossiliferous and contains abundant foraminifera, mollusks and ostracods. This formation has been assigned as a Late Paleocene age throughout its extent except for Hazara area where it stretches to Early Eocene.

In Potwar, the TOC of 1.57 and hydrogen index of 2.68 in shales have been observed (Porth and Raza,1990). Patala formation is the key source rock of oil production in Potwar-sub basin according to oil to source correlation.

2.8.3 RESERVOIR ROCKS

The Cambrian, Permian, Jurassic, Paleocene and Eocene reservoirs are producing oil in Salt Range Potwar- Foreland Basin (SRPFB). Petroleum play reservoirs ranging in age from Infra-Cambrian to Miocene are present in the Kohat-Potwar fold belt. The target reservoirs are clastics and carbonates of Infra-Cambrian and Lower Cambrian, Clastics of Permian, clastics of lower to middle Jurassic, clastic of lower Cretaceous, carbonates of upper Paleocene and lower Eocene and clastics of Miocene.

i. CHORGALI FORMATION

The Chorgali formation is named following Chorgali Pass that transects the Khair-e-Murat ridge near the village, Pind Fateh. The formation consists of massive dolostones, marls, nodular, extremely fissile varicolored shales, and evaporite collapse breccia. It is 80 to 90 m thick and is early middle Eocene in age. It contains mollusks, ostracods and foraminifera. There is very slight primary porosity and appears as vugs in certain layers and the process of dolomitization has produced porosities up to 25 % Athar Jamil, Abdul Waheed., (2012)

ii. SAKESAR FORMATION

The Sakesar formation is named following Sakesar town in the Salt Range where it is well exposed. It is major formation, acting as reservoir producing both Oil and Gas in Fimkassar area. It is a fractured reservoir, having negligible porosity (matrix). It is about 70 to 300 m thick and is early to middle Eocene in age. The production from Sakesar commenced in 1980, and this formation is encountered in all the wells, used in research. Fimkassar-01, drilled at the apex, encountered Eocene more than 100 m shallower compared to Turkwal-01 and Turkwal Deep-01, while in Turkwal Deep-X2, it is more than 1,000 m shallower Athar Jamil, Abdul Waheed., (2012)

iii. KHEWRA FORMATION

The Khewra Sandstone is poorly cemented with intergranular porosity but the porosity may be variable and the topmost wave dominated unit probably the better reservoir quality compared with the tide dominated units that contain more fine sand and clay and probably are more heterogeneous in terms of porosity and permeability. Saqab et al. (2009) calculated the porosity of Khewra Sandstone which varies from 4-17 % in which the lower part ranging from 3-7% and topmost part comprises on higher porosity varies from 10 to 17 %. So, it is show that the wave dominated sandstone may have good reservoir potential.

2.8.4 CAP ROCKS

Thick layers of evaporite and shale have good sealing potential for Infra-Cambrian reservoir. Interbedded shale, mudstone and siltstone provide seal to Cambrian reservoirs. Limestones and intraformational shales are the potential seals for the Cenozoic and Mesozoic reservoirs.

Most of the fields discovered in Kohat-Potwar geological province to date are either due to overturned faulted anticlines, popup structures or fault-block traps. The latest trap-forming thrust event began at approximately 5 to 2 Ma (Jaswal, et al., 1997).

CHAPTER 3: SEISMIC INTERPRETATION

3.1 INTERPETATION

Interpretation is a tool to transform the whole seismic information into structural or stratigraphical model of the earth. Since the seismic section is the representative of the geological model of the earth, by interpretation, we try to locate the zone of final anomaly. It is rare that correctness or incorrectness of an interpretation is ascertained, because the actual geology is rarely known in well manner. The test of good interpretation is consistency rather than correctness.

Not only a good interpretation be consistent with all the seismic data, it also important to know all about the area, including gravity and magnetic data, well information, surface geology as well as geologic and physical concept. (Telford et al, 1999). Conventional seismic interpretation implies picking and tracking laterally consistent seismic reflectors for the purpose of mapping geologic structures, stratigraphy and reservoir architecture. The ultimate 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 . 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 a combination of computer software products, which include Kingdom suit.

Our main purpose is to make the reflection as clear as possible the structure and stratigraphy of the subsurface. Geologic meaning of the reflection is the indication of the boundaries where there is change in the acoustic impedance; to distinguish the different horizons with the seismic data we correlate the well information with the seismic data. Seismic data has been interpreted with well control and the well information is used to tie with the seismic data. Structure and estimate of the depositional environment, seismic velocity, seismic stratigraphy and the lithology is identified by using the best available seismic data (Dobrin &Savit, 1988).

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

- **Structural Analysis**

Identification of structural features

- **Stratigraphic Analysis**

Identification of stratigraphic boundaries

3.1.1 STRUCTURAL ANALYSIS

This type of analysis is very suitable in case of Pakistan, as most of the hydrocarbons are being extracted from the structural traps. It is study of reflector geometry on the basis of reflection time. The main application of the structural analysis of seismic section is in the search for structural traps containing hydrocarbons. Most structural interpretation use two way reflection times rather depth and time structural maps are constructed to display the geometry of selected reflections events. Some seismic sections contain images that can be interpreted without difficulty. Discontinue reflections clearly indicate faults and undulating reflections reveal folded beds. (Sheriff, 1990).

3.1.2 STRATIGRAPHIC ANALYSIS

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

3.2 WORK PROCEDURE

The provided Navigation Data was in UTM Zone 43N format. The interpretation was done on Kingdom which provides an interactive interface for marking horizons & faults, exporting horizon's time and depth data for contouring.

- Provided seismic data was in SEG-Y format and well log data in LAS format which are used for preparation of base map.
- Synthetic seismogram is generated using well log data and trace from seismic line on which the well is drilled.
- Horizons of interest are marked based on the synthetic seismogram and formation tops.

- Faults are marked on the seismic section after knowing the geology of the area. Faults can also be marked based on the discontinuities within the horizon.
- After fault interpretation generation of fault polygons is carried out on the base map.
- Two-way time contour maps are generated for marked horizons. Depth contour maps generated by using the well point velocity.

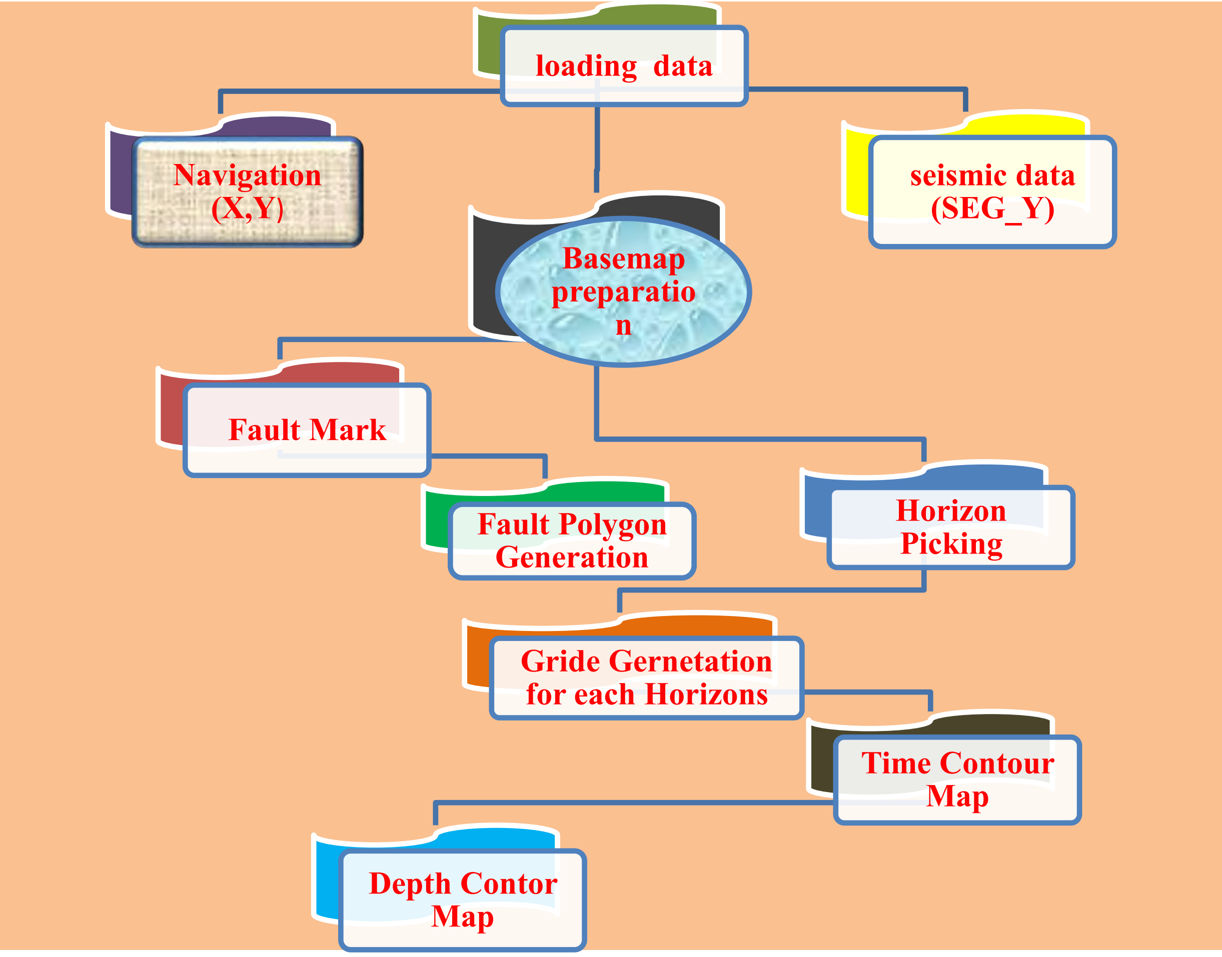

Figure 3.1: Seismic interpretation flowchart

3.3 SYNTHETIC SEISMOGRAM

Synthetic seismogram is an artificial seismic trace that is used to establish for correlations between local stratigraphy and seismic reflections. To produce a synthetic seismogram a sonic log is used. Generally, a density log is used, but sometimes it may not be available. Well data of MISSA KESWAL-03 well is used to construct the synthetic seismogram, which helps us in identifying the horizons, so that we can mark them easily on seismic section.

For the generation of synthetic seismogram two-way time for each well top is required. Two-way time for each well top or reflector is calculated by using depth, sonic log data from well and replacement velocity of the area. By using two-way time against each well top depth time depth chart is prepared. Also, Sonic log (DT) is used itself for the generation of synthetic seismogram as well as Density log (RHOB), gamma ray log (GR) is used as reference log. Wavelet is extracted from the seismic line on which the well is located. Seismic trace is also extracted which is used for well to seismic tie, trace is extracted from the seismic line GO-994-GNA-11. Finally, synthetic seismogram is generated by convolving the well data and extracted wavelet from seismic trace.

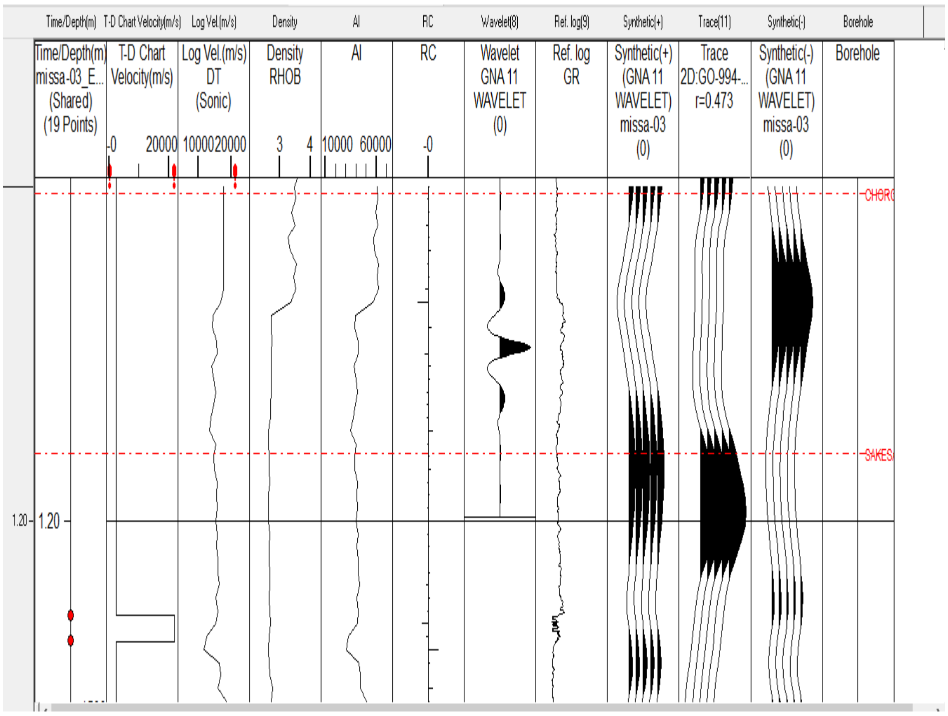

Figure 3.2: Synthetic Seismogram

3.4 SEISMIC HORIZONS

The Prominent reflections that are present on the seismic section are marked, and then selected those that showed good characteristics and continuity and can be traced well over the whole seismic section, are marked. The seismic data was interpreted using IHS Kingdom 8.8 which provides interactive tools for marking horizons and faults.

I marked four horizons based on synthetic seismogram of MISSA KESWAL-03 well. MISSA KESWAL-03 is drilled on line GO-994-GNA-11. Four horizons are picked on line GO-994-GNA-11 while on remaining two lines horizons are picked by digitize arbitrary line method. Marked horizons are named as Murree, Chorgali, Sakesar and Khewra Sandstone.

For the project I have been given with following three lines, GO-994-GNA-09, GO-994-GNA-10, and GO-994-GNA-11. In each line we see popup structure that is suitable for accumulation of hydrocarbon. Reverse faults are seen in upper part of sections and normal faulting in basement. At center depths of reflectors are shallow but as we move away the depth increases. The time section gives the position and configuration of reflectors in time domain. Three reflectors are marked on seismic lines GNA-09, GNA-10, GNA-11 which are named because of stratigraphic column encountered in well MISSA KESWAL-03. Each reflector is marked with different color so that they can be easily distinguished.

- CHORGALI(RED)
- SAKESAR (DARK GREEN)
- KHEWRA SANDSTONE (MAGENTA)
- MURREE(GOLD)
- FAULT
  i. F1(GREEN)
  ii. F2(CYAN)

3.4.1 Line GO-994-GNA-11

The strike line GO-994-GNA-11 is oriented in the direction from NE-SW. Well is located on this line. Horizons on other lines are marked with the reference of synthetic seismogram present on this line. Four horizons are marked using digitizing technique with different colors. Horizons which are marked on this line are Murree(Gold), Chorgali(Red), Sakesar(Green), and Khewra Sandstone(Magenta).

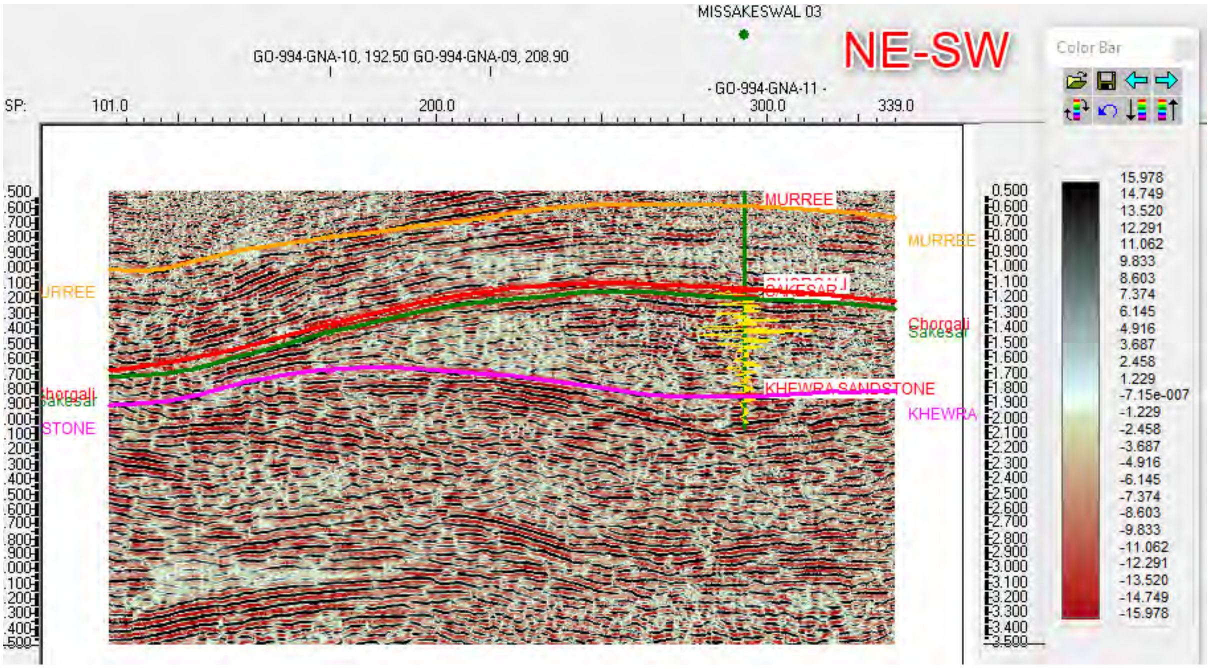

Figure 3.3: Interpreted Time Section of GNA-11 with marked horizons using IHS Kingdom

3.4.2 Line GO-994-GNA-09

Figure shows dip line GO-994-GNA-09 on which four horizons are marked by using digitizing technique, also there are Two faults marked on dip line based on the discontinuities along the reflectors and reverse faults are marked based on the geology of the area. Delineating pop-up structure which is formed as a result of reverse faulting due to its presence in compressional regime. The discontinuity in reflector represents the faults. The main faults F1 and F2 are marked on the seismic sections which are detachment faults.

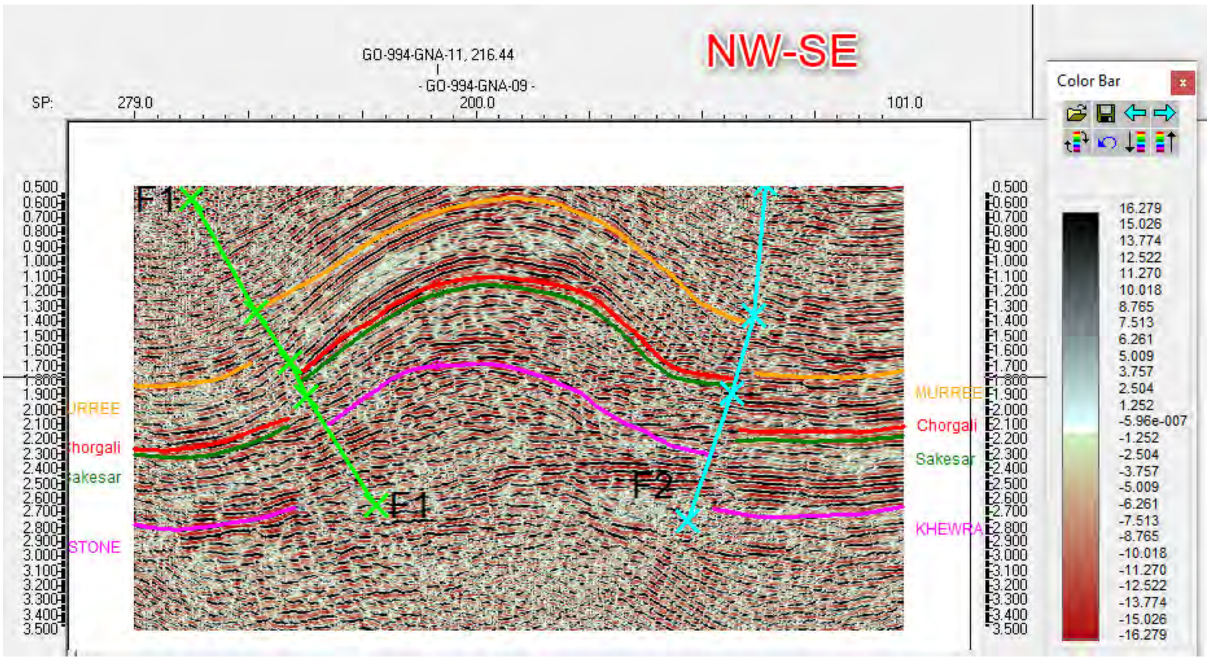

Figure 3.4: Interpreted time section of GNA-09 with marked horizons and faults using IHS Kingdom

3.4.2 Line GO-994-GNA-10

Figure shows dip line GO-994-GNA-10 on which four horizons are marked by using digitizing technique. The interpretation of the map suggests that there is an anticlinal pop-up structure at center and as we move towards periphery, the depth values increase progressively. The anticlinal structure is bounded by two main faults F1 and F2. These are reverse faults that are dipping towards each other from east and west. This dipping of the faults towards each other while bounding the anticlinal structure is the reason why our area of interest is called a 2-way fault bounded Anticlinal pop-up structure.

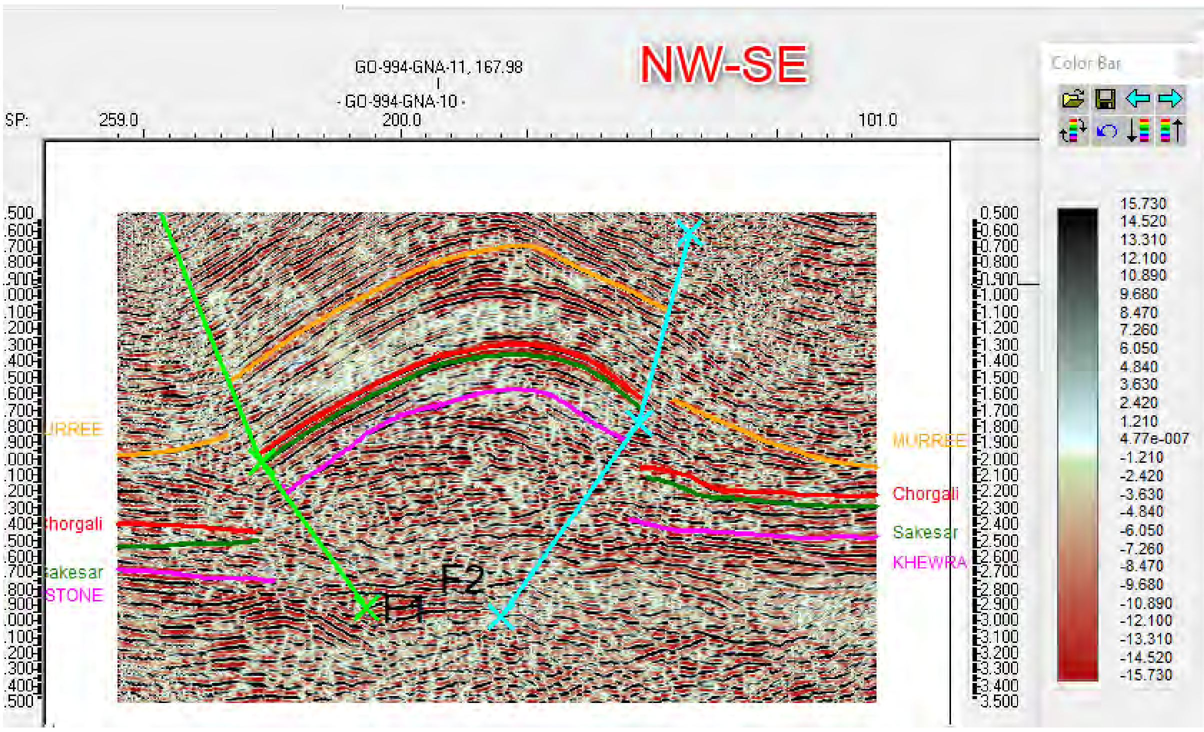

Figure 3.5: Interpreted time section of GNA-10 with marked horizons and faults using IHS Kingdom

3.5 FAULT POLYGONS

Before generation of fault polygons, it is necessary to identify the faults and their lateral extent by looking at the available seismic data. If one finds that the same fault is present on all the dip lines, then all points (represented by a "x" sign by Kingdom software) can be manually joined to make a polygon. Construction of fault polygons are very important as far as time and depth contouring of a particular horizon is concerned. Any mapping software needs all faults to be converted into polygons prior to contouring.

The reason is that if a fault is not converted into a polygon, the software does not recognize it as a barrier or discontinuities, thus making any possible closures against faults represent a false picture of the subsurface. Fault polygons are constructed for all marked horizons and these are oriented in NE-SW direction.

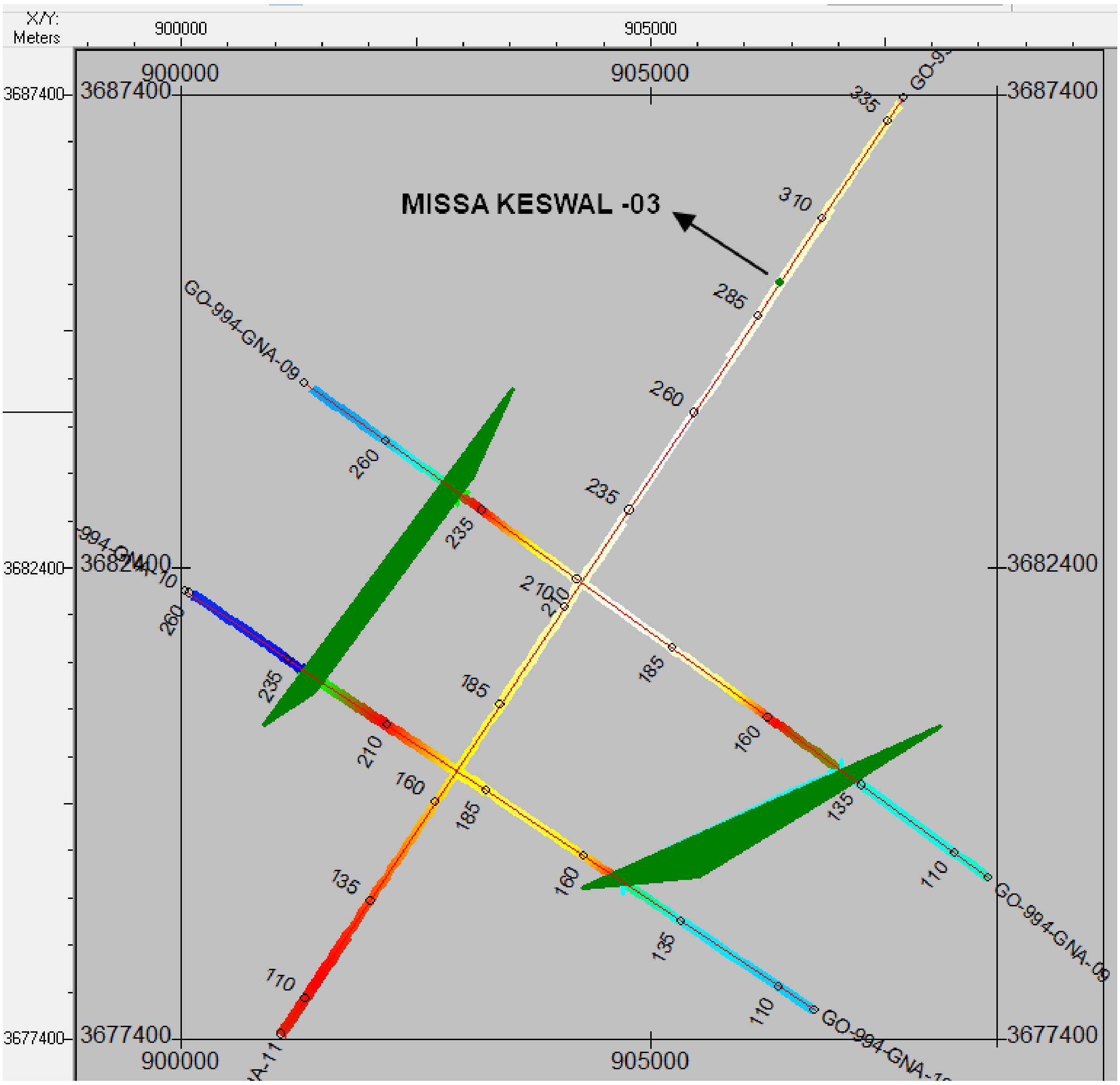

Figure 3.6: Fault Polygon of Chorgali horizon

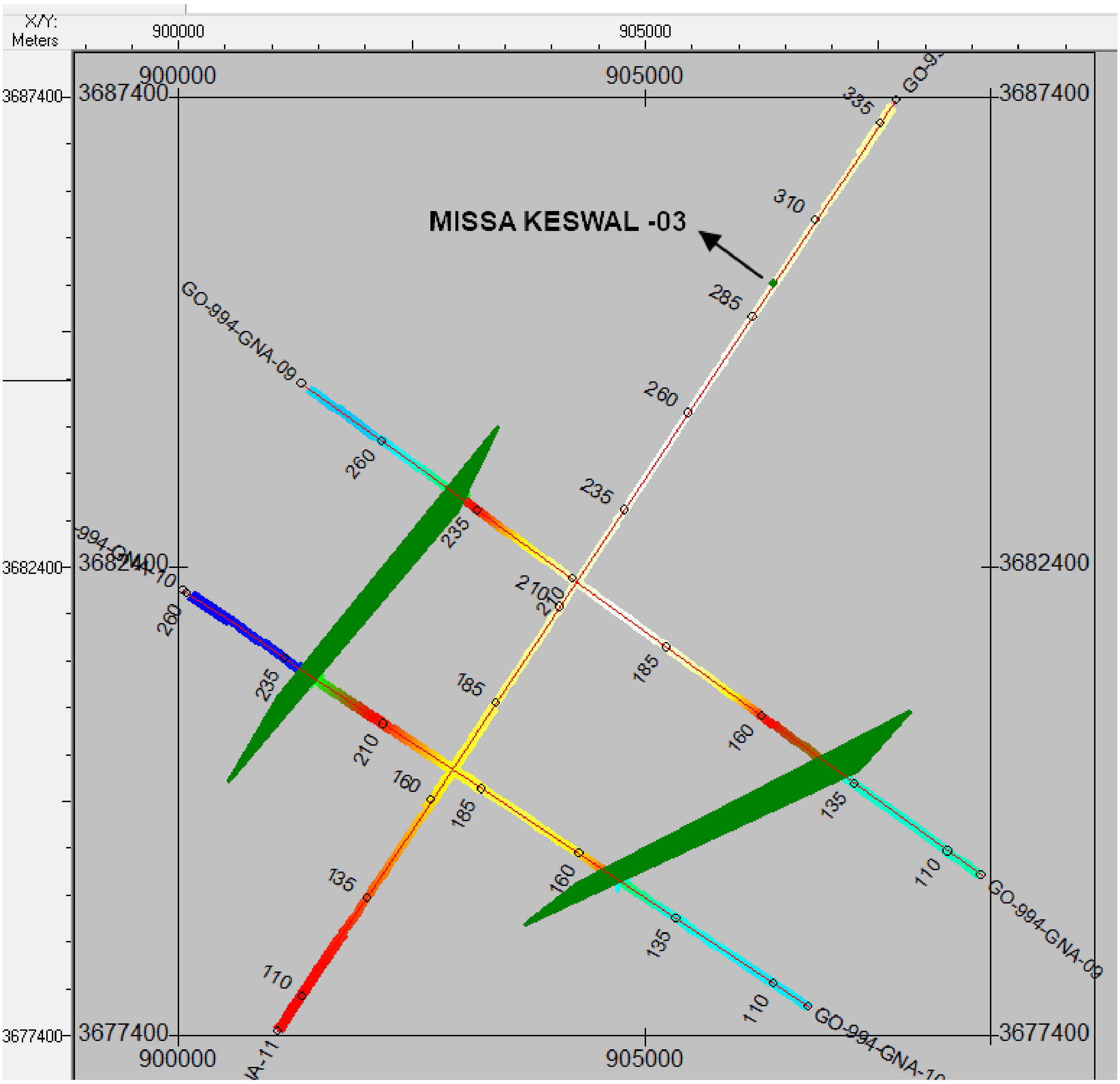

Figure 3.7: Fault Polygon of Sakesar horizon

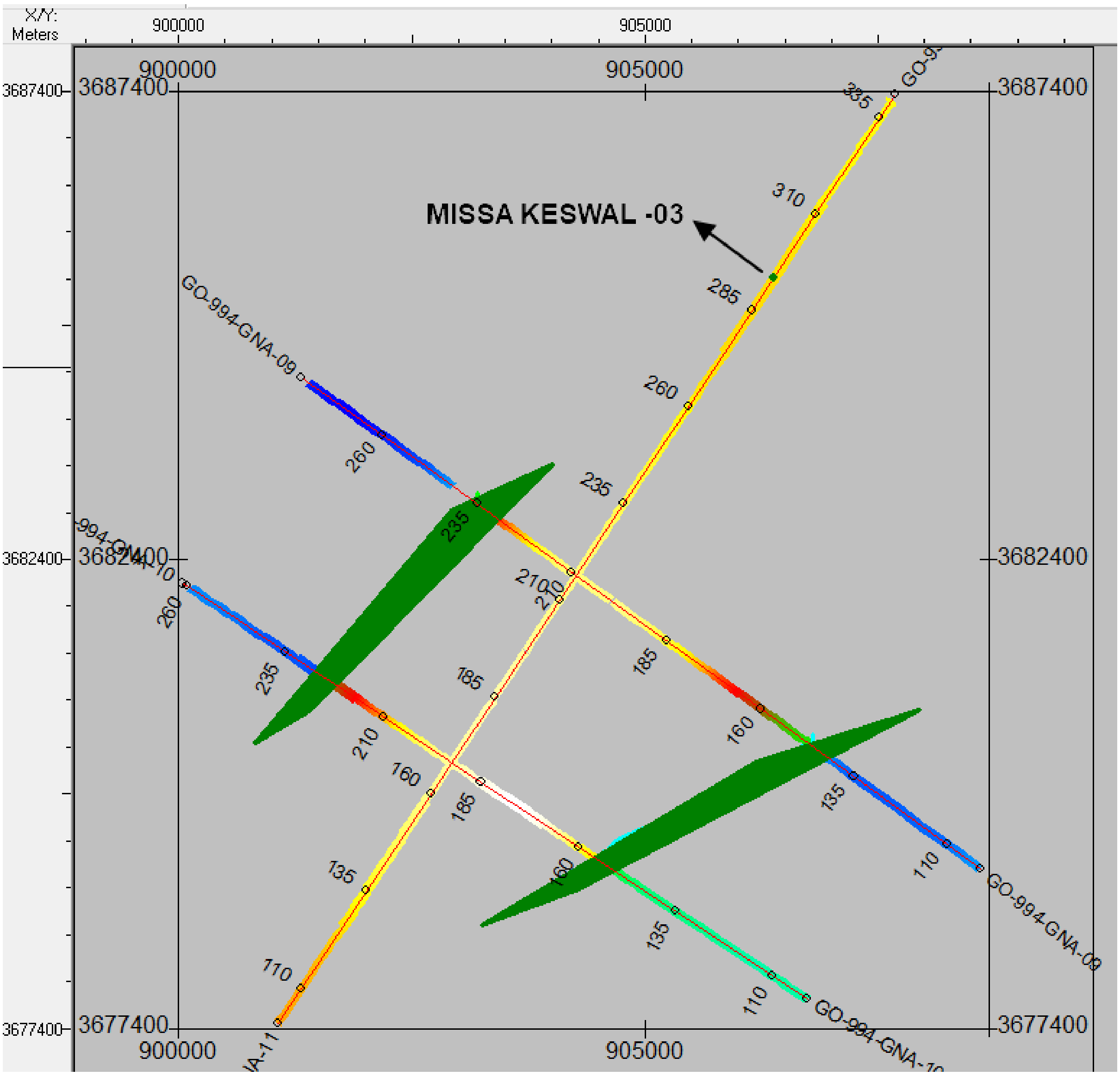

Figure 3.8: Fault Polygon of Khewra Sandstone horizon

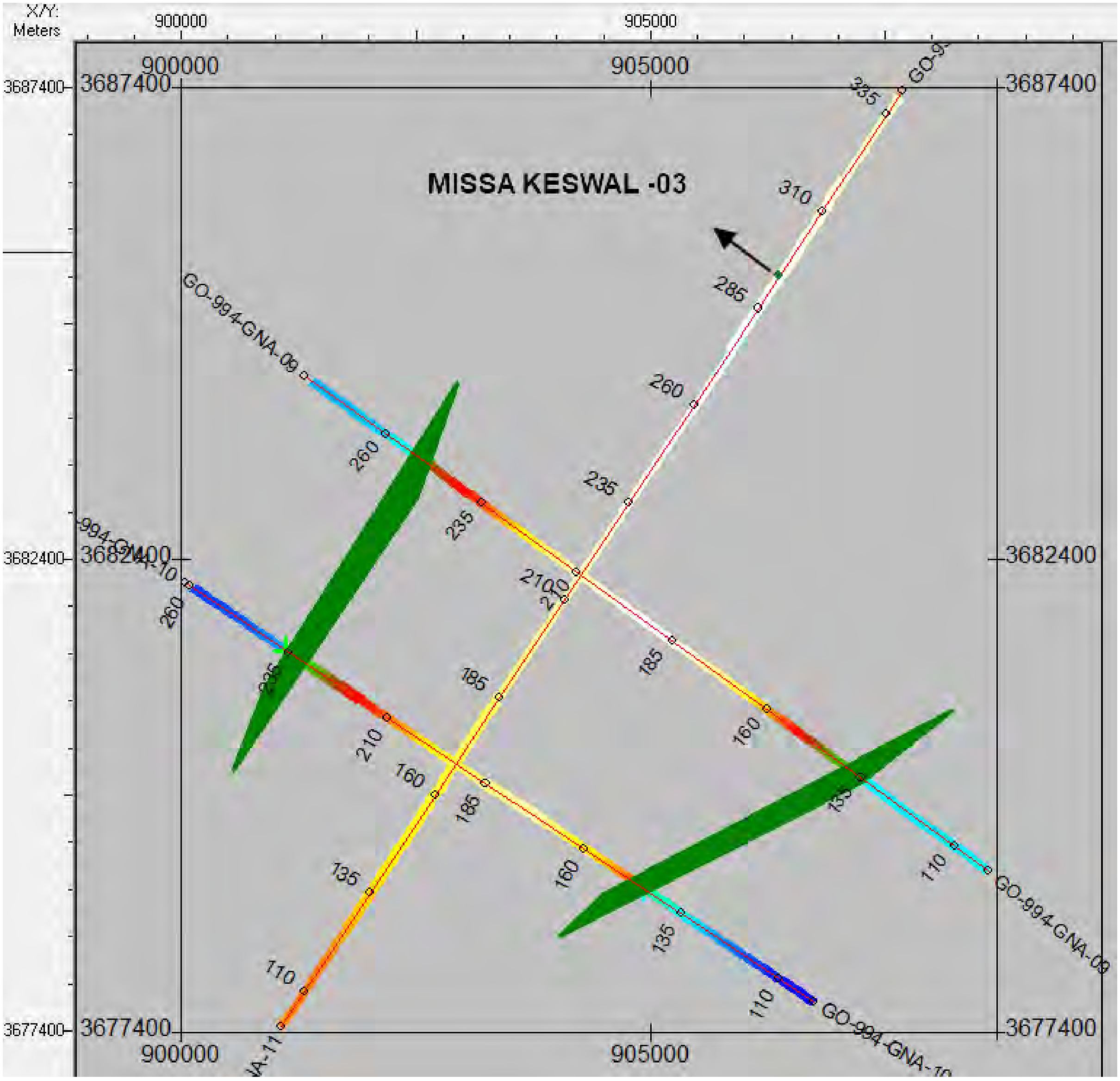

Figure 3.9: Fault Polygon of Murree horizon

3.6 CONTOUR MAPS

Contour maps that are constructed are the results of seismic interpretation. Mapping is part of the interpretation of the data. The contours are the lines of equal time or depth wandering around the map as dictated by the data. In constructing a subsurface map from seismic data, a reference datum must first be selected.

The datum may be sea level or any other depth above or below sea level. Frequently, another datum above sea level is selected in order to image a shallow marker on the seismic cross-section, which may have a great impact on the interpretation of the zone of interest.

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

These contour maps reveal the slope of the formation, structural relief of the formation, its dip, and any faulting or folding. The seismic map is usually the final product of seismic exploration, the one on which the entire operation depends for its usefulness.

The interpreted seismic data is contoured for producing seismic maps which provide a three-dimensional picture of the various layers within an area which is circumscribed by intersecting shooting lines. The picked times for each reflector are exported along with the navigation data in the form of an XYZ file to be used for contouring. The Kingdom software is used to generate the contour maps.

3.6.1 TIME CONTOUR MAPS OF FORMATIONS

The figure 3.9, 3.10 and 3.11 and 3.12 illustrates time contour of all the four horizons Murree, Chorgali, Sakesar and Khewra Sandstone. As we know that time contour map shows lateral as well as vertical variation. Figures show portion between F1 and F2 conjugate fault is deeper. Portion between F1 and F2 conjugate fault is foot wall of both faults and is elevated, we can conclude that horst and graben structures are present.

Time contour maps confirms the structural interpretation done on seismic section for all the four horizons. Trend of all contour maps is same which shows there is no vertical variation. All horizons deform equally by faulting.

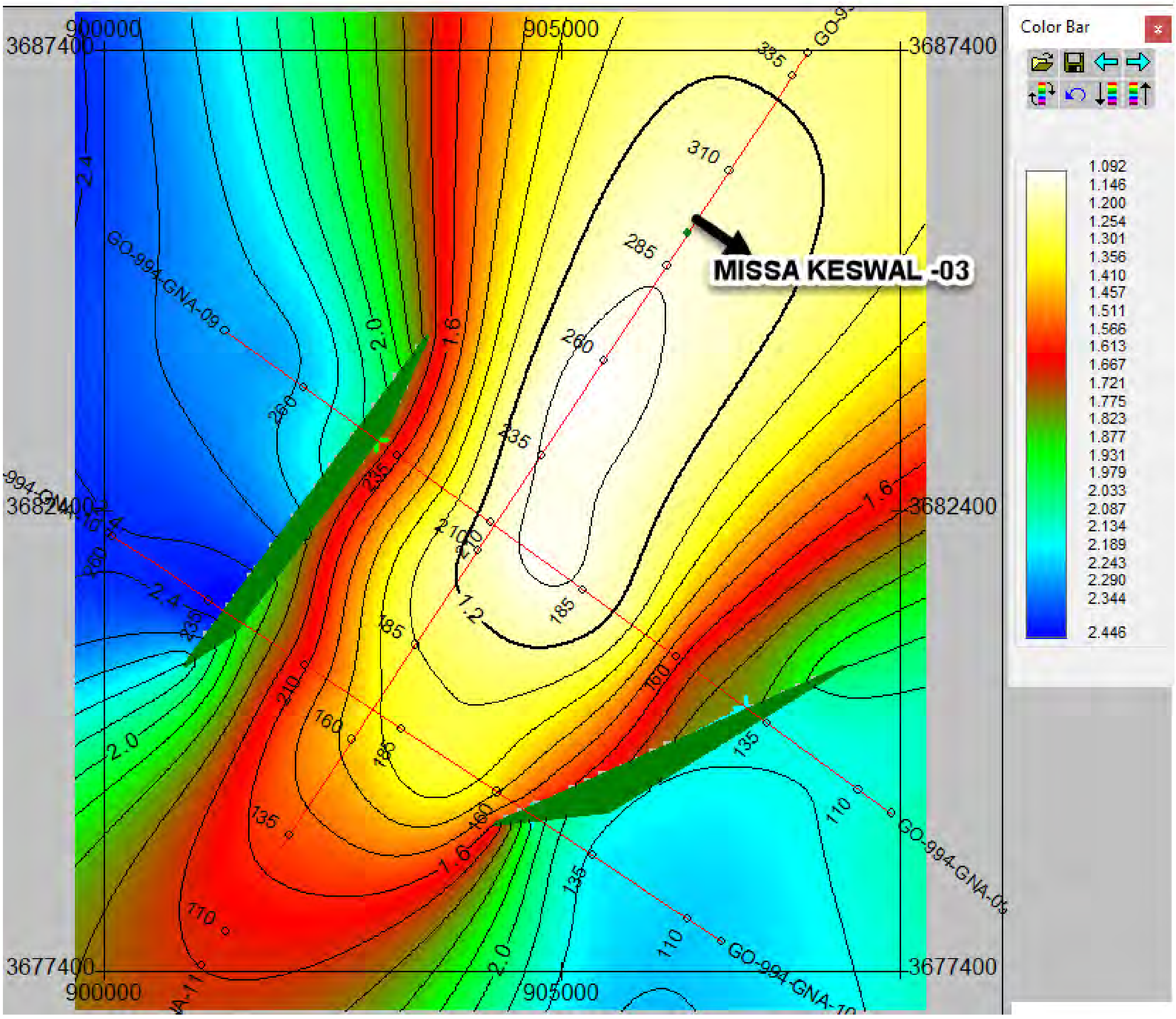

Figure 3.10: Time Grid and Time contour map of Chorgali horizon

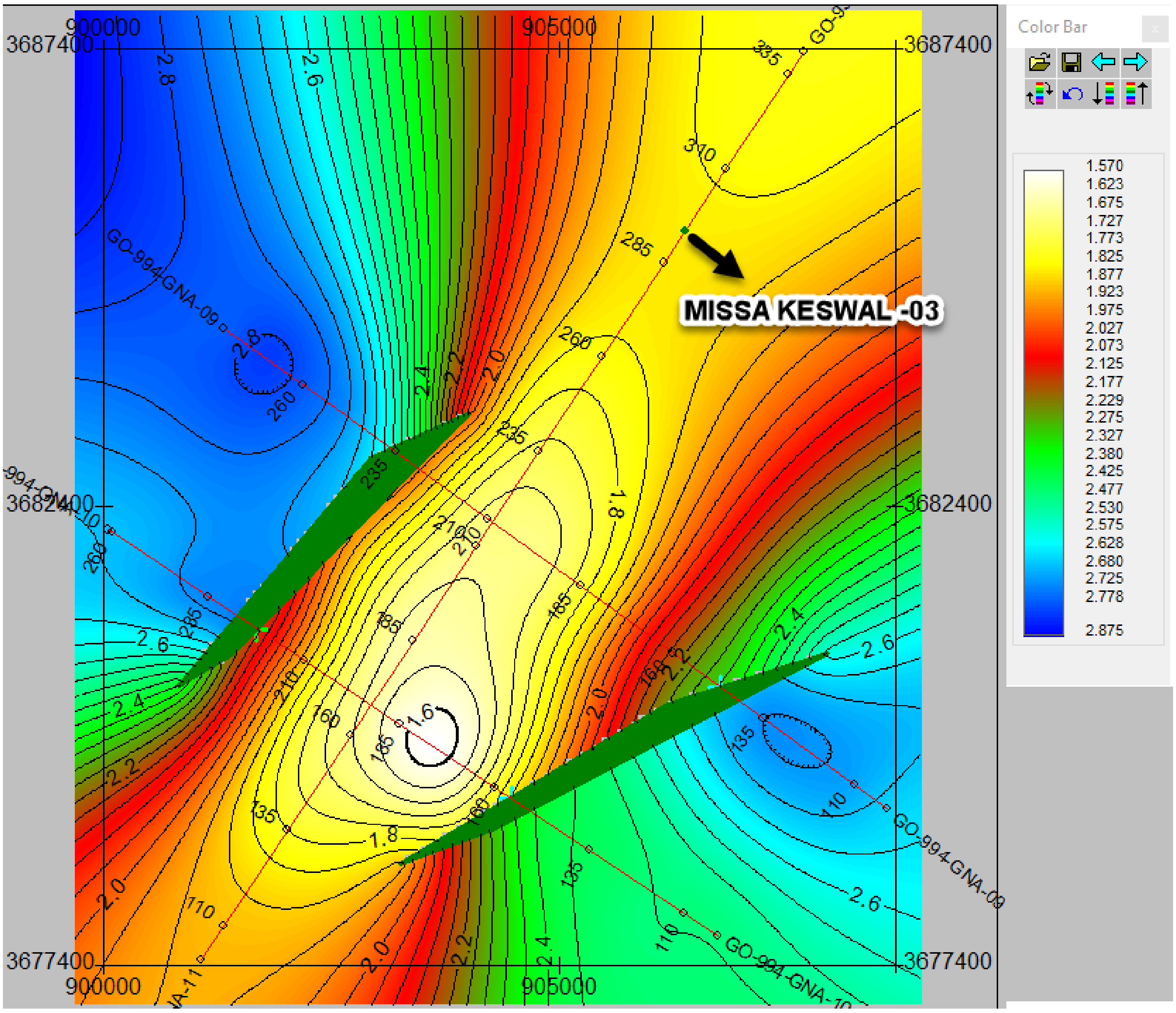

Figure 3.11: Time Grid and Time contour map of Khewra Sandstone Horizon

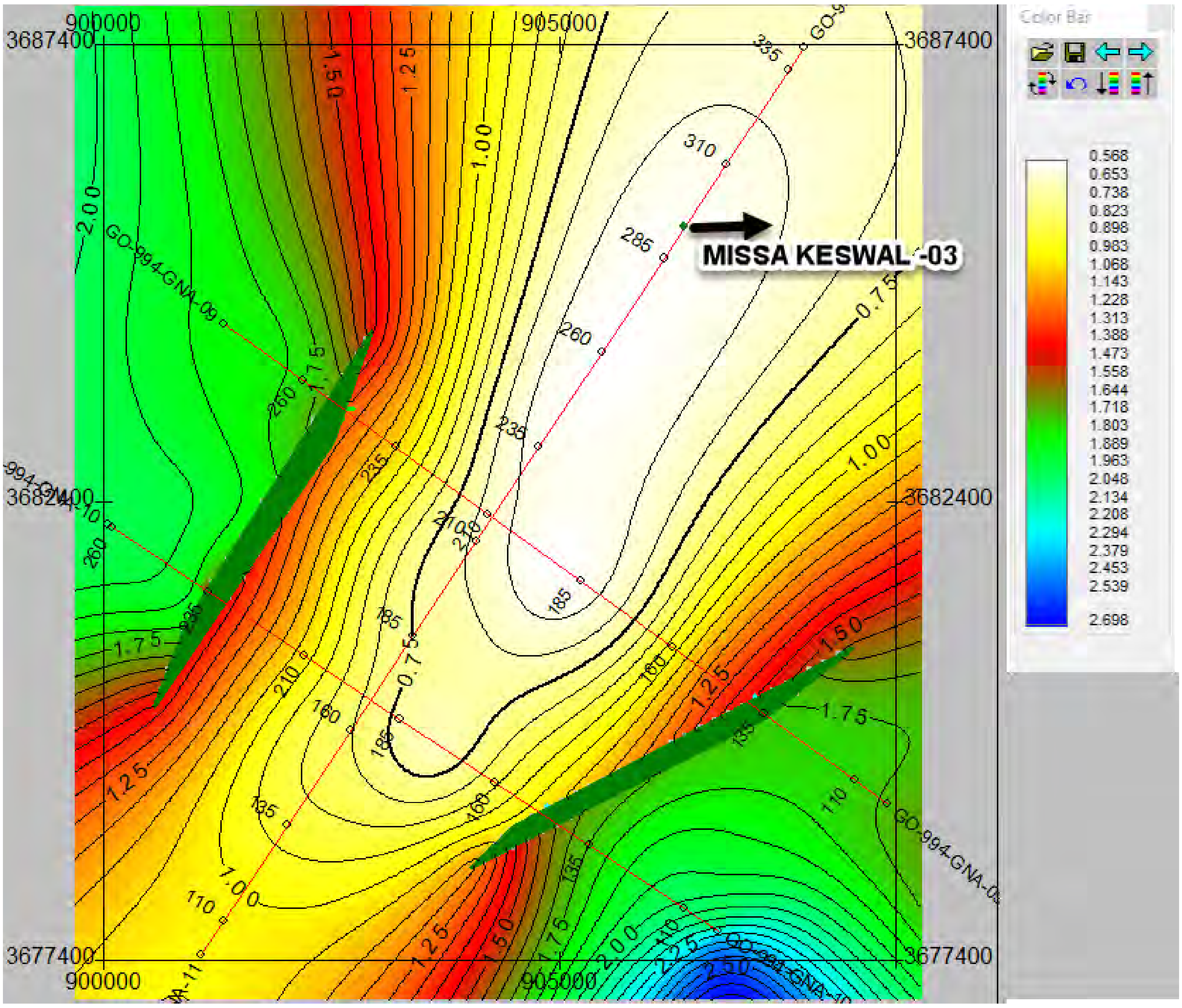

Figure 3.12: Time Grid and Time contour map of Murree Horizon

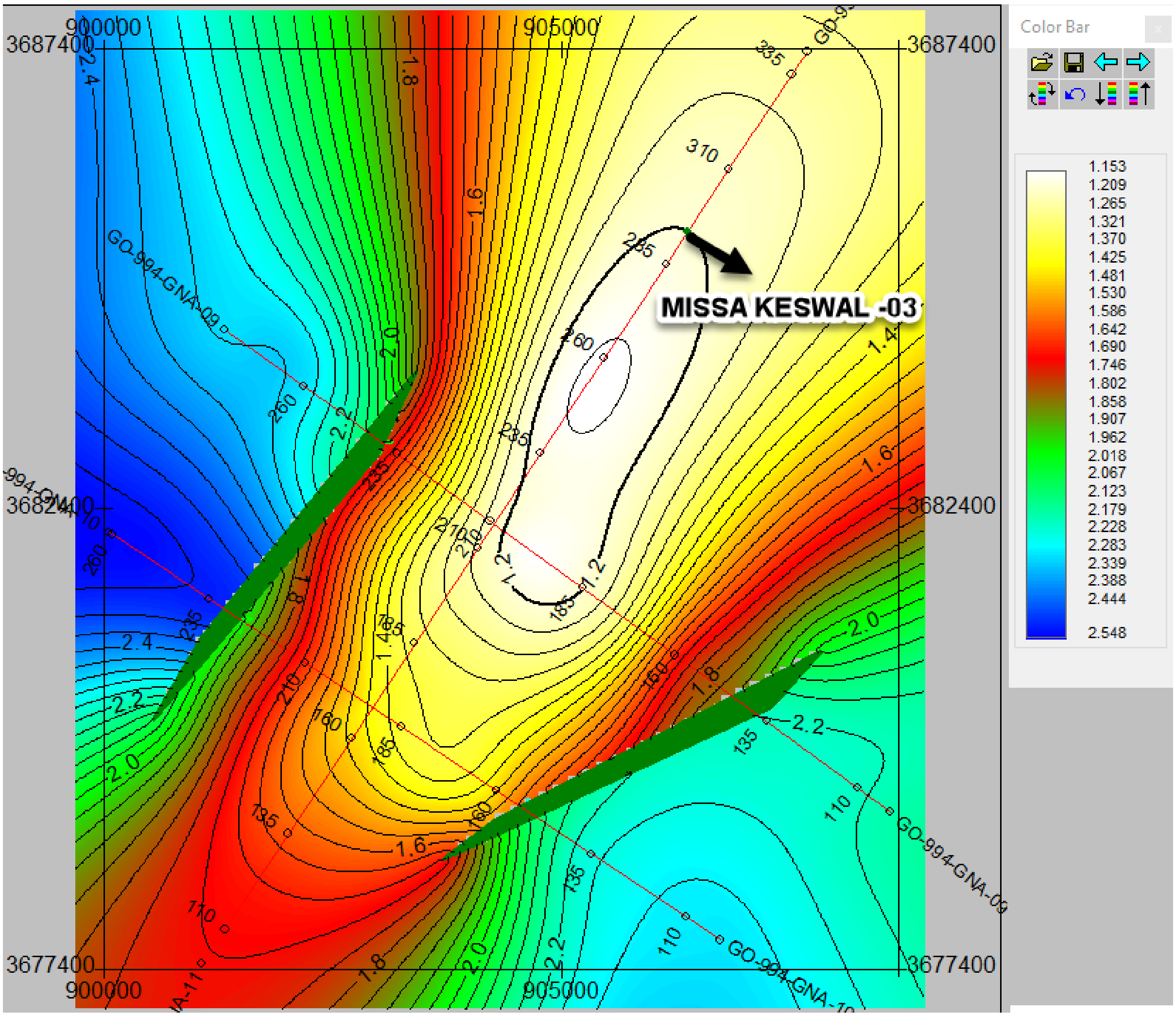

Figure 3.13: Time Grid and Time contour map of Sakesar horizon

3.6.2 DEPTH CONTOUR MAP OF FORMATIONS

For depth contouring we need depth horizons which can be formed by using average velocity. This velocity can be found from well point and it will be very accurate if correlation is good. As we know that depth contour map shows lateral variation with respect to depth. The trend of depth contour maps is same as of time contour maps because there are same lateral variations with time as well as depth.

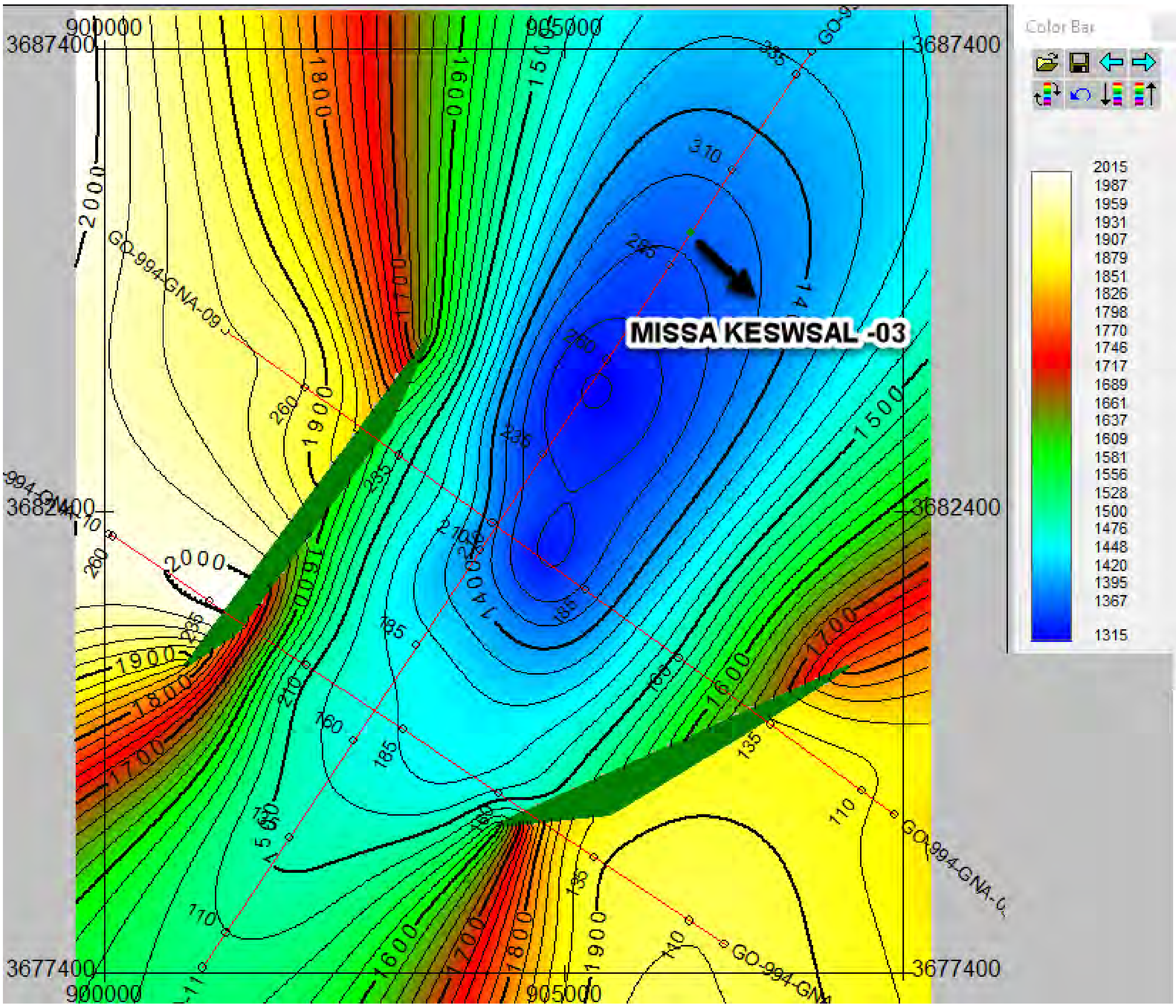

Figure 3.14: Depth Grid and Depth contour map of Chorgali hoizon

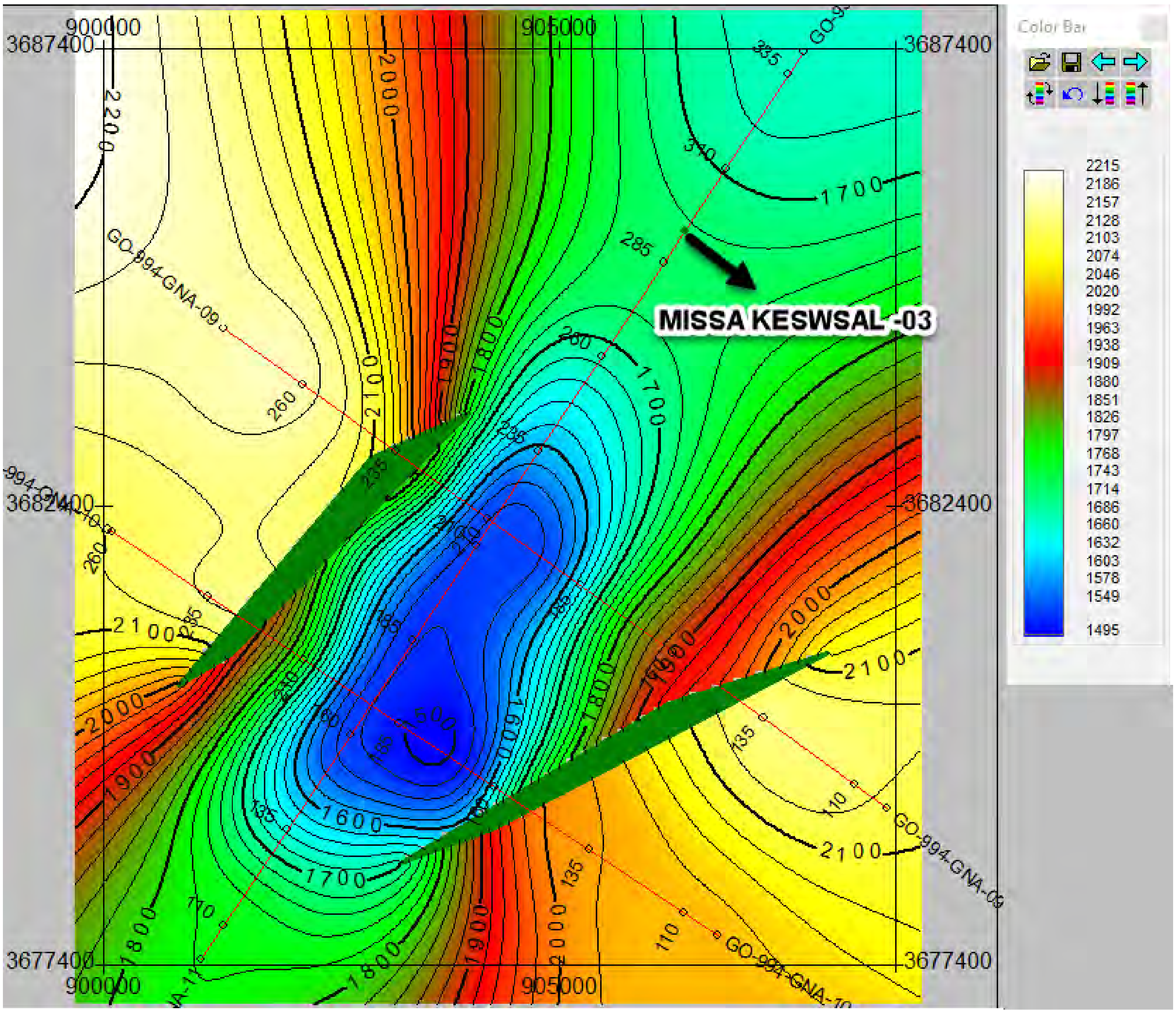

Figure 3.15: Depth Grid and Depth contour map of Khewra Sandstone hoizon

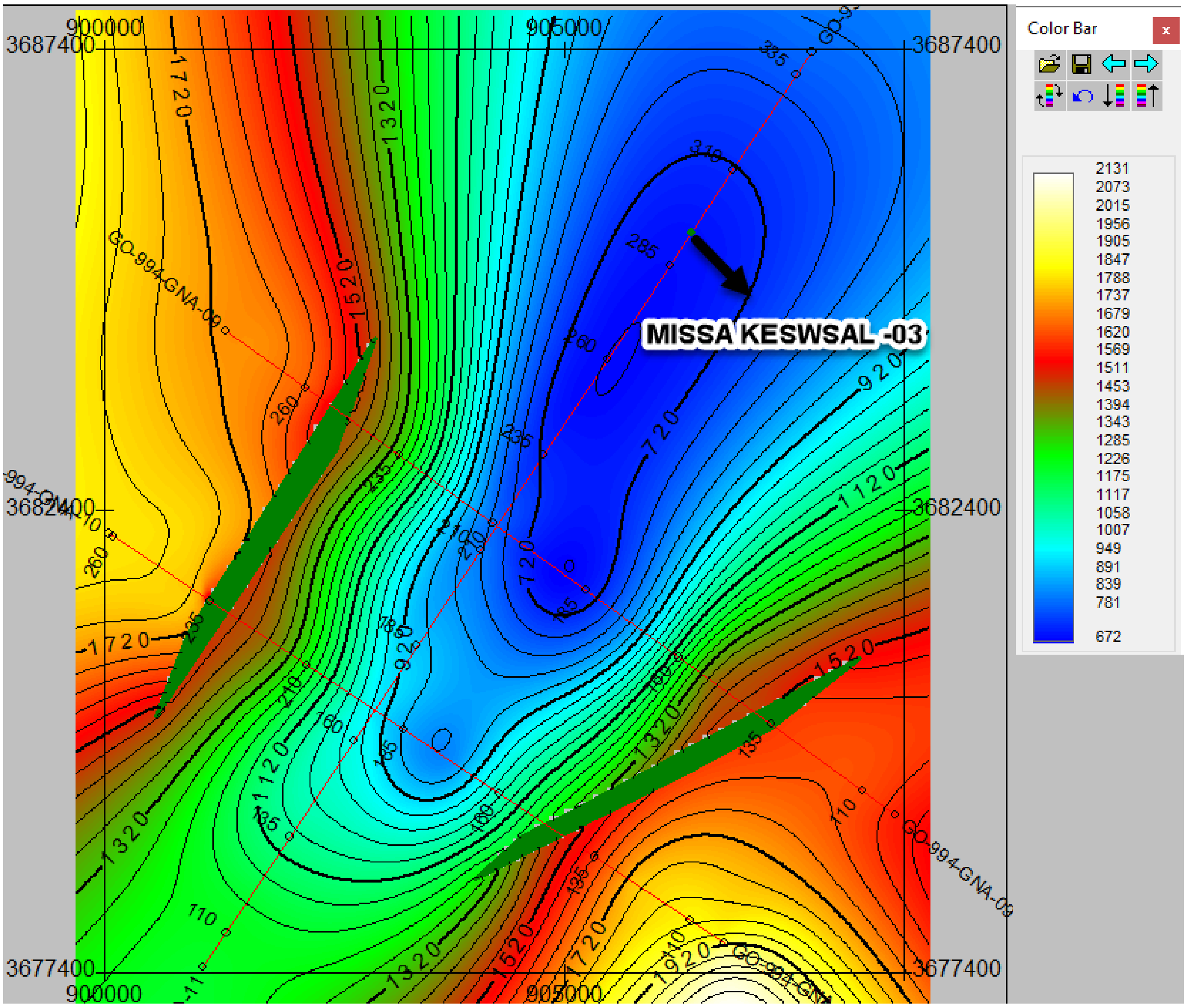

Figure 3.16: Depth Grid and Depth contour map of Muree hoizon

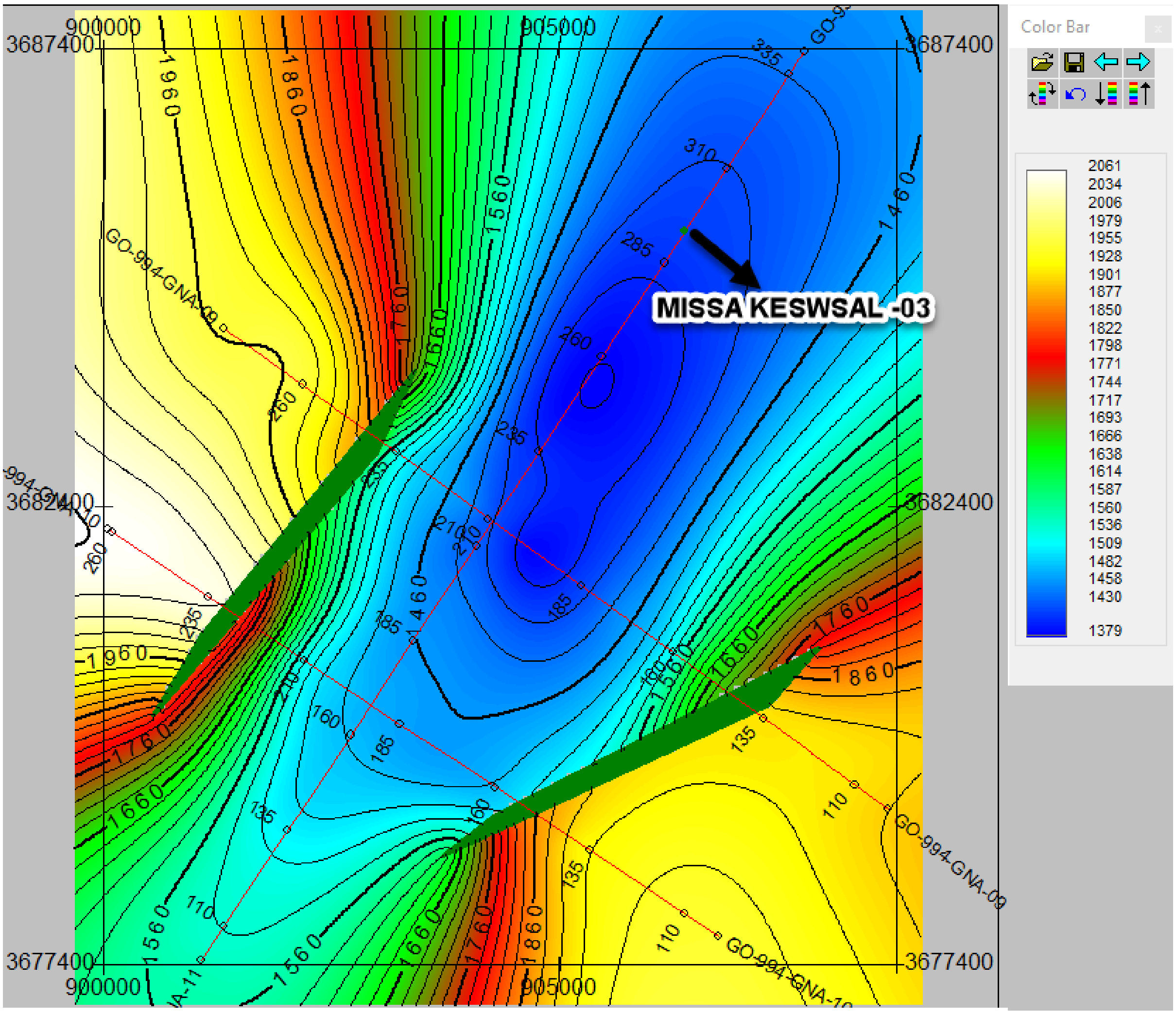

Figure 3.17: Depth Grid and Depth contour map of Sakesar hoizon

3.6.3 CONCLUSION

The seismic sections show the displaced (thrust faulted) and popup anticlinal structure where the marked reflectors are named based on well formation tops. The time and depth contour maps of formations help us to confirm the presence of anticlinal structure in the Missa keswal area. The surface maps of formations give the shape of sub-surface structure which is anticline. The hydrocarbons accumulate in anticlinal structure is bounded by faults planes.

CHAPTER 4: PETROPHYSICAL ANALYSIS

4.1 INTRODUCTION

The word logging means recording of any information with respect to depth or time. The term 'well-logging' had a wider meaning and application in borehole geophysics, ever since its adaptation. Well-logging is a wireline study of different formations encountered in a well.

In oil exploration, the interest lies mainly in identification of porous and permeable formation, their thickness and extent, and geometry of the reservoir. Well logging is exactly such a device which aims at acquiring this information, by measuring various physical, chemical and lithologically properties of the formations This information when supplemented with other information available from core analysis, seeks to give depth, formation, its nature, fluid type, extent of fluid contact, porosity, permeability, mobility of hydrocarbon the flow rate, formation pressure and a score of other details with a high degree of precision.

The advancement in electronics and instrumentation and the advent of computers have found their wide applicability in well-logging. Thereby the well-logging has entered the field of high technology and modernization. The transmission of down hole data through wireline cable has opened a new era in well logging offering the scope of recording vast amount of information in the sense of real time data acquisition. Thus, presently the data acquisition and data interpretation through application of computers in well-logging has made new vistas for hydrocarbon exploration and exploitation.

Geophysical well logging, for more than a century has played a central role in the discovery and development of petroleum and natural gas resources. It tells the nature of rock formation penetrated by a drill. The drill itself does not provide unambiguous information about the formations. Rock cuttings tell us what lithologies are present but are unclear about exactly where they occur. Even core drilling, which can be prohibitively expensive, yields incomplete information about formation fluids, and 100 percent core recovery is seldom possible.

Hence the needs of an assortment of well logs for more complete evaluation of the formations. The productivity of wells in a hydrocarbon-bearing (oil/gas) reservoir depends on Petrophysical properties. Hydrocarbon bearing reservoir rock consists of two components: the rock matrix and an interconnected pore network. The pores can have dimensions varying from sub-microns for tight sandstones to centimeter for vuggy carbonate rock

The main Petrophysical properties are porosity, permeability, saturation and capillarity.

Porosity determines the storage capacity for hydrocarbons and permeability determines the fluid flow capacity of the rock. Saturation is the fraction of the porosity that is occupied, by hydrocarbons or by water.

Finally, capillarity determines how much of the available hydrocarbons can be produced.

Accurate determinations of these Petrophysical properties are essential to assess the economic viability of the development of reservoirs.

Lately, the geophysical well-logging technology has led to enormous developments in downhole data acquisition and interpretation techniques due to advances in science and technology particularly in the field of electronics and computerization. In the west, the logging companies are equipped with diversified advanced logging systems.

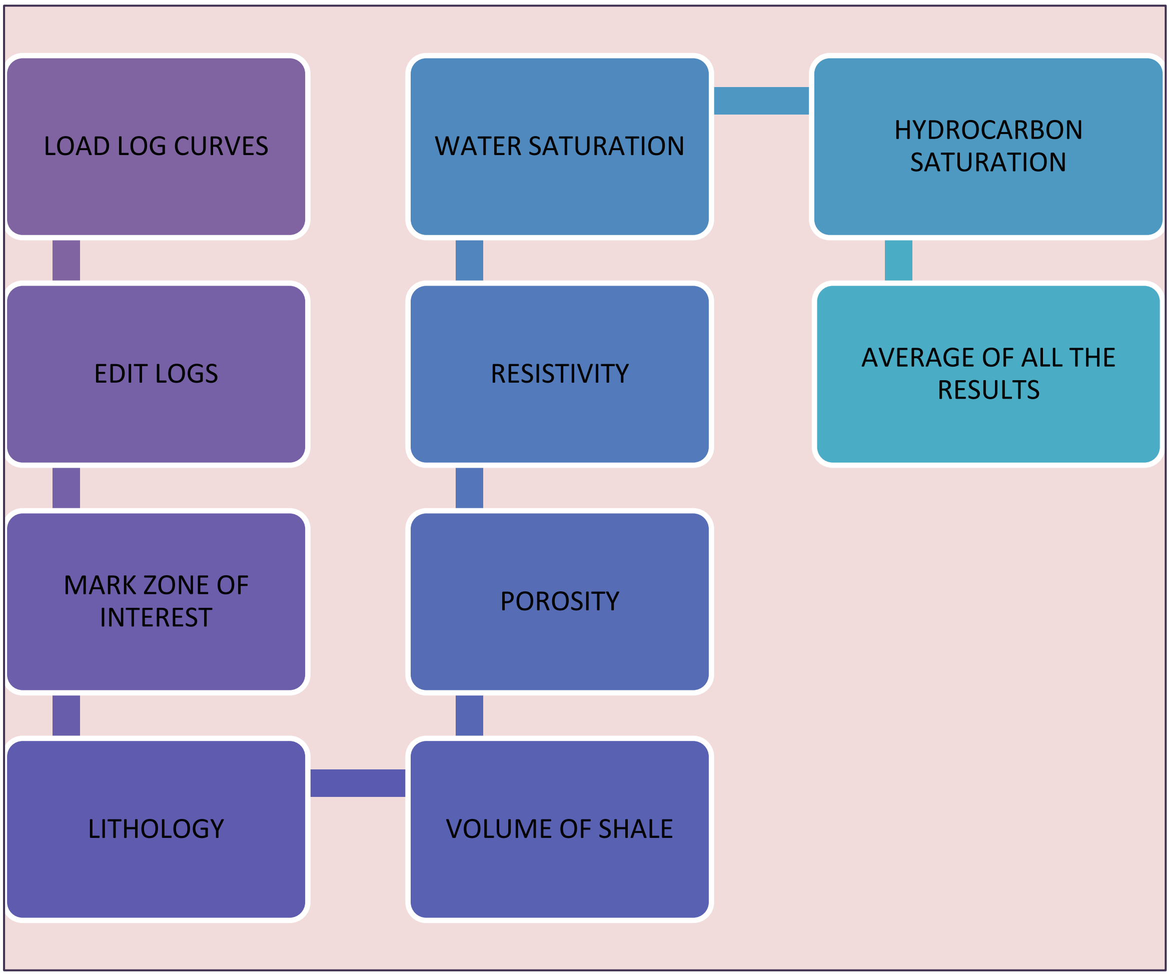

Figure 4.1: Workflow for petrophysical interpretation

4.2 CLASSIFICATION OF GEOPHYSICAL WELL LOGS

Geophysical well logs can be classified into three categories

- Lithology logs
- Resistivity logs
- Porosity logs

4.3 LITHOLOGY LOGS

Lithology log are mostly used to identify the boundaries between the permeable and non-permeable formation, information about the permeable formations provide lithology data for the correlation with other well logs.

Caliper (CALI)

Spontaneous potential (SP)

Gamma Ray (GR)

4.3.1 CALIPER LOG

Caliper logs measure the diameter of the borehole. It records the cavities where the well is caved in, and the hardness of the rock cut during drilling. Where there is the porous material, mud cake will be formed that cause the hole diameter to become smaller. Variation in the diameter of the borehole influence the record of the different logs. Therefore, it is important to consult with the caliper logs any artifacts (Croizé et al, 2010).

4.3.2 GAMMA RAY LOG

Gamma ray logs are lithology logs that are used to measure the natural radioactivity of a formation. The radioactive material's concentrations are present in shale, as shale has high gamma ray reading. Therefore, shale free sand and the carbonates have low gamma ray reading. Volume of shall can be calculated by the following formula:

$$I_{gr} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$

Whereas,

GRmin= minimum value of GR

GRmax= maximum value of GR

Igr= gamma ray index

Gamma ray logs are used to identify lithology, the volume of the shale and the correlation between the formations (Asquith et al, 2004).

4.4 RESISTIVITY LOG

Resistivity well logs give the thickness of the formation, accurate value for the true formation resistivity and information for the correlation purposes. All these logs are plotted on the logarithmic scale due to more variation in resistivity (0.1 to 1000 ohm) with depth. Resistivity logs are:

Deep laterolog (LLD)

Shallow laterolog (LLS)

Deep laterolog is the electrode logs and are designed to measure formation resistivity in the borehole filled with saltwater muds (Rmf). The effective depth of the laterolog investigation is controlled by the extent to which the surveying current is focused (Asquith et al, 2004).

Shallow laterolog measure the resistivity of in the invade zone (Ri). In water-bearing zone, the shallow laterolog records a low resistivity because mud filtrate resistivity (Rmf) is approximately equal to mud resistivity (Rm), (Asquith et al, 2004).

4.5 POROSITY LOG

Porosity well logs provide the data through which the water saturation can be determine, provide the accurate lithologic and porosity determination and provide data to distinguish between oil and gas. Porosity well logs are:

Sonic/Acoustic (DT)

Neutron Porosity (NPHI)

Density (RHOB)

Sonic logs measure the interval transit time (Δt) of the compressional sound wave through the formation. The interval transit time is related to the porosity of the formation. The unit of measure is the microseconds per foot or microseconds per meter (Asquith et al,2004).

Relation for the calculation of the porosity from the sonic log, porosity of the formation can be calculated by using the following formula:

$$\emptyset_s = \frac{\Delta t_{log} - \Delta t_m}{\Delta t_f - \Delta t_m}$$

Whereas

Øs= calculation that derived from the sonic log

Δtm = interval transient time of the matrix

Δtlog= interval transient time of formation

The interval transient time of the formation depends upon the matrix material, its shape and cementation. If fluid (hydrocarbon or water) is present in the formation, transient interval time is increases and this behavior shows increase in porosity which can be calculated by using sonic log (Asquith et al, 2004).

Neutron log is the porosity log that measure hydrogen ion (HI) concentration in a formation (Asquith et al , 2004).In the shale free formations where the porosity is filled with the water, the neutron log is related to the water filled porosity (NPHI).In gas reservoir, porosity measured by the neutron log is low then the formation true porosity as the hydrogen ions concentration are less in gas reservoir then that of oil and water (Asquith et al, 2004).It is the one limitation of neutron log that is known as the Gas effect.

Density log is the porosity log that measure electron density of the formation, (Asquith et al, 2004). Formation electron density is related to bulks density of formation. It is the sum of fluid density multiplies its relative volume plus matrix density time relative volume. Density log can be used to find out the correct porosity of the formation, if the matrix densities in the formation or rock type are known (Asquith et al, 2004). The rock type in my research work is sandstone and shale. By using following mathematical relation, density porosity can be related as:

$$\emptyset_d = \frac{\rho_m - \rho_b}{\rho_m - \rho_f}$$

Whereas,

∅d= porosity derived from the density log

ρb= bulk density of formation

ρm= matrix density

ρf= density of fluid

The main purpose of present petrophysics is to obtain calculation about porosity, saturation of water and hydrocarbon.

4.6 AVERAGE POROSTIY CALCULATION

Sum of the porosities that are obtained from the different logs divided by number of logs from which porosity is calculated. Here Khewra Sandstonne formation is reservoir for which the average porosity is calculated, to zone of interest reservoir, all the logs are interpreted. The relation is given below through which average porosity is calculated.

$$\varphi_{avg} = \frac{\varphi_n + \varphi_d + \varphi_s}{3}$$

Whereas,

Øavg is the average porosity calculated from the available porosities

Φn is the neutron porosity

Ød is the density porosity

Øs is the sonic porosity.

4.7 EFFECTIVE POROSITY (Øe)

This will define as “the ratio of the volume of interconnected pore spaces in a rock unit to the total volume of the rock by removing shale effect that rock unit”. The zone which rich in the shale, effective porosity will be zero. Effective porosity is used to mark the saturated zone. The effective porosity can be calculated by the following formula (Asquith et al, 2004).

$$\emptyset_e = \emptyset_{avg} \times (\mathbf{1 - Vsh})$$

Whereas,

Øe= effective porosity

Øavg= average porosity

Vsh= volume of the shale

4.8 WATER SATURATION

Water saturation in the formation can be defined as “The percentage of the pore volume filled by water in the formation”. For water saturation we must have borehole temperature and resistivity of mud filtrate. So first we need to find resistivity of water to find the water saturation.

$$S_{sp} = -\mathrm{K} * \log \frac{R_{mf}}{R_w}$$

for K:

$$K = 65 + 0.24 * T°\mathrm{C}$$

We can find value of SSP from Sp log curve as SSP is the maximum deflection towards negative side, and Rmf is given resistivity of mud filtrate.

So then saturation of water in the formation can be calculated by the following Archie equation:

$$S_w = \sqrt[n]{\frac{F * R_w}{R_t}}$$

Whereas,

F= formation factor

$$F = \frac{a}{\emptyset^m}$$

Rw= Resistivity of water

Rt= true formation resistivity

N= Saturation exponent

A= constant, represent effective porosity

m= Cementation factor

4.9 HYDROCARBON SATURATION (Sh)

Hydrocarbon saturation can be defined as "the pore in formation is filled with hydrocarbon". It can be calculated by using the following mathematical relation:

$$Sh=1-Sw$$

Whereas,

Sw = Water saturation

Sh= Hydrocarbon saturation

4.10 WELL LOG INTERPRETATION

IHS Kingdom software is used for the analysis of well Missa Keswal-03. Due to collapsing of wellbore Rugosity effect will be occur. Therefore, in the depth ranges, if there is Rugosity the value of the other log is not consistent. As we know that we are looking for reservoir zone where hydrocarbon saturation is very important so for this, we need to interpret all logs in addition with other logs like porosity, water saturation, hydrocarbon saturation.

- First of all, the crossover between NPHI and RHOB is important, but the crossover should be on the lower side for both log curves, as we know that hydrocarbon has less density but for hydrocarbon accumulation porosity is necessary so porosity should be little higher in case of hydrocarbon but overall the crossover should be on lower side.
- Secondly, separation between LLD and LLS is very important for petrophysical interpretation, as the separation of LLD and LLS shows the accumulation of hydrocarbon. In resistivity we have 3 zones flushed, transition and uninvaded zone. So, in flushed and transition we have brine mud and in uninvaded zone its hydrocarbon that is why we get separation in LLD and LLS.

- In the third step we interpret Vsh which is calculated by linear method, Shale and sand is being separated by applying 40% cut-off value. Below this cut-off value, there is sand and above this cut-off, there is shale.
- Then after that interpretation of porosity logs are done whereas in reservoir zone porosity should be higher such that accumulation of hydrocarbon could possible, for this density porosity log, effective porosity, and total porosity logs are made.
- Now the last step is the water saturation and hydrocarbon saturation, as the separation of LLD and LLS is an indicator of hydrocarbon but we can't conclude any result by interpreting one log so we need to correlate two or more logs that is why water saturation log is incorporated and interpreted. As we know that hydrocarbon saturation is difference of water saturation by unity.

4.11 ZONE OF INTEREST

Zone (2145m to 2193m) as GR log is on lower side also caliper log is stable, Sp logs shows deflection in track first, in track two there is a separation between resistivity logs (LLD and LLS), third track shows crossover between RHOB and NPHI, also volume of shale in track five shows lower values which indicates clean sand, as in porosities track values of porosities are higher which is very important for reservoir characterization, in water saturation track log shows low water saturation also in hydrocarbon saturation track log shows high values, all of these are the indicator of presence of hydrocarbon in the respected zone.

S. No	Properties of rock	Averages
1	Volume of shale	21.08%
2	Density porosity	6.13%
3	Effective porosity	4.06%
4	Total porosity	5.09%
5	Water saturation	53.2%
6	Hydrocarbon saturation	46.7%

Table 5.1: Table contain average values of different logs of zone of interest.

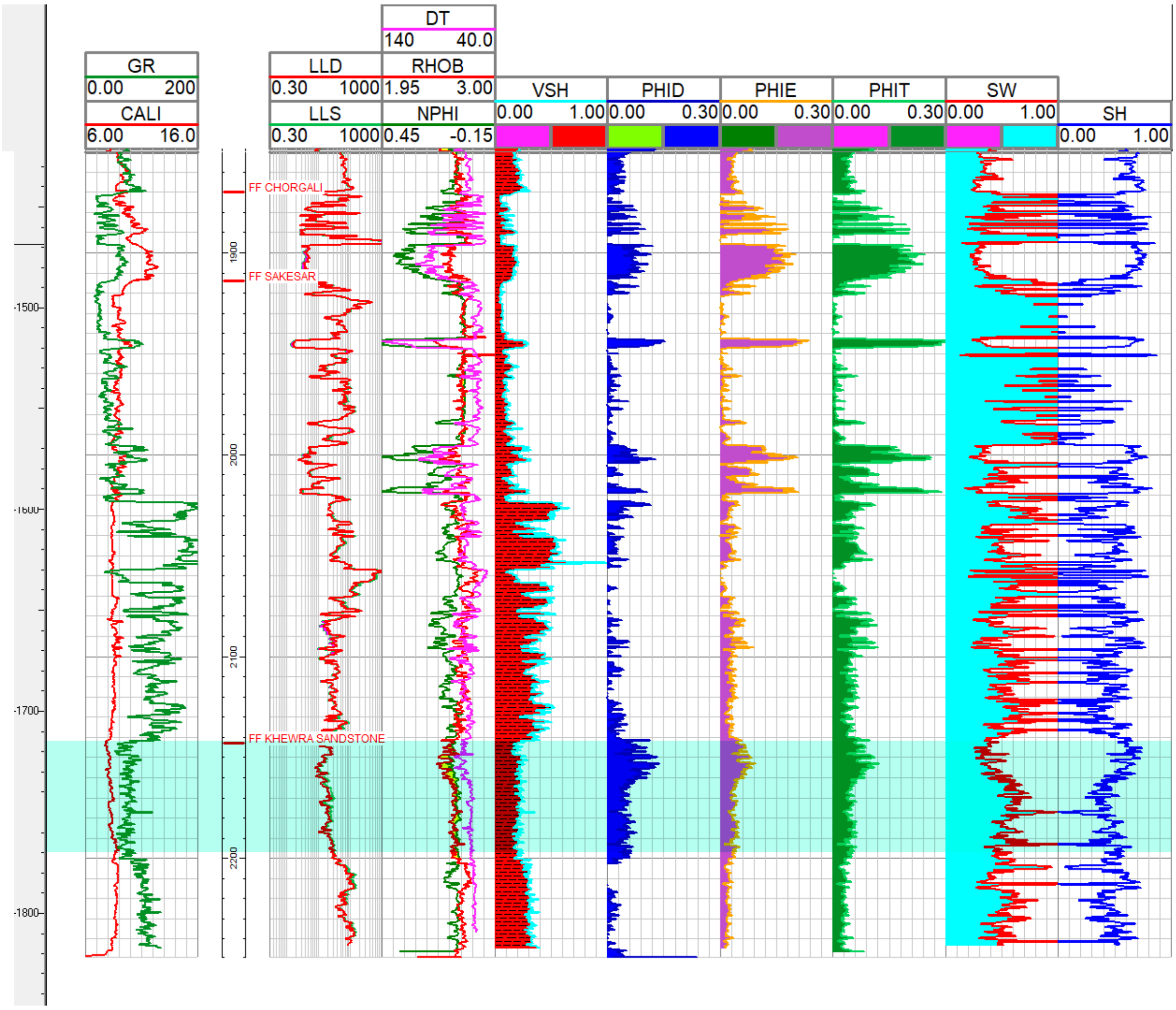

Figure: Shows petrophysical logs and marked zone of interest of well MISSA-Keswal-03

CHAPTER 5: SEISMIC ATTRIBUTE ANALYSIS

5.1 SEISMIC ATTRIBUTE

Attribute is a quality ascribed to anything. Seismic attribute is all information obtained from seismic data, either by direct measurement or by logical or experienced based reasoning (Taner, 2001). Seismic attributes have come a long way since their introduction in the early 1970s and have become an integral part of seismic interpretation projects. Today, they are being used widely for lithological and petrophysical prediction of reservoirs. Various methodologies have been developed for their application to broader hydrocarbon exploration and development decision making (Chopra and Marfurt, 2006).

5.1.1 WHAT ARE SEISMIC ATTRIBUTES

The default attribute of Seismic data is Amplitude. From the early days of seismic prospecting, Explorationists used to draw conclusions about subsurface geology and drilling locations primarily from this single seismic data attribute. Attribute computations decompose seismic data into constituent attributes. There are no rules governing how attributes are computed. A quantity calculated from seismic data can be considered an attribute, thus attributes are of many types: pre-stack, post-stack, inversion, velocity, horizon.

5.2 CLASSIFICATION OF SEISMIC ATTRIBUTE

5.2.1 DATA BASED

- Pre-stack attribute
- Post-stack attribute

Pre-stack attribute

These attributes are calculated from CDP ordered data during seismic data processing. They contain directional(azimuth) and offset related information. Their computation generates huge amounts of data; hence they are not practical for initial studies. They are directly related to fluid content and fracture orientation.

Pro-stack attribute

These attributes are calculated from stacked data before and after time/depth migration. They are usually computed during seismic interpretation . It must be noted that stacking eliminates offset and azimuth related information. In time migrated data time relationships are maintained, hence temporal variables, such as frequency is retained. In depth migrated data, frequency is replaced by wave number, which is a function of propagation velocity and frequency. They are more manageable approach for observing large amounts of data in initial reconnaissance investigation.

5.2.2 Computational characteristic based

- Instantaneous attribute
  (computed sample by sample in trace and represent instantaneous variation)
- Interval attribute
  (computed over time window in a trace)
- Trace to trace attribute
  (computed by trace to trace correlation, represent lateral continuity)

5.2.3 Information characteristic based

- Time derived
  (provide structural information)
- Amplitude derived
  (provide stratigraphic and reservoir information)
- Frequency derived
  (not yet well understood but they will provide additional useful stratigraphic and reservoir information)
- Attenuation

5.3 ENVELOPE OF TRACE (REFLECTION STRENGTH /INSTANTANEOUS AMPLITUDE)

Envelop of a trace, also called as reflection strength, represents the total instantaneous energy of the complex trace which is independent of the phase and is computed as the modulus of the complex trace as given below:

$$A(t)= \{f^2(t) + h^2(t)\}^{1/2} = |F(t)|$$

The envelope relates directly to the acoustic impedance contrasts. It may represent the individual interface contrast or, more likely, the combined response of several interfaces, depending on the seismic bandwidth. The Hilbert Transform of the real seismic trace is generates an imaginary trace and using both these traces the envelope trace is computed. shows the real, imaginary and envelope trace. It can be observed that the envelope trace always remains positive. This attribute is computed for seismic line GNA-09 to see the major changes in lithologies. Even negative reflection coefficients such as limestone formation overlaid on clayey formation would generate a positive response in this attribute.

The thick (yellow) package indicates maximum reflection strength corresponding to the source, reservoir, and seal rocks. It also shows spatial patterns representing changes in the limestone thickness and breakage due to the faults.

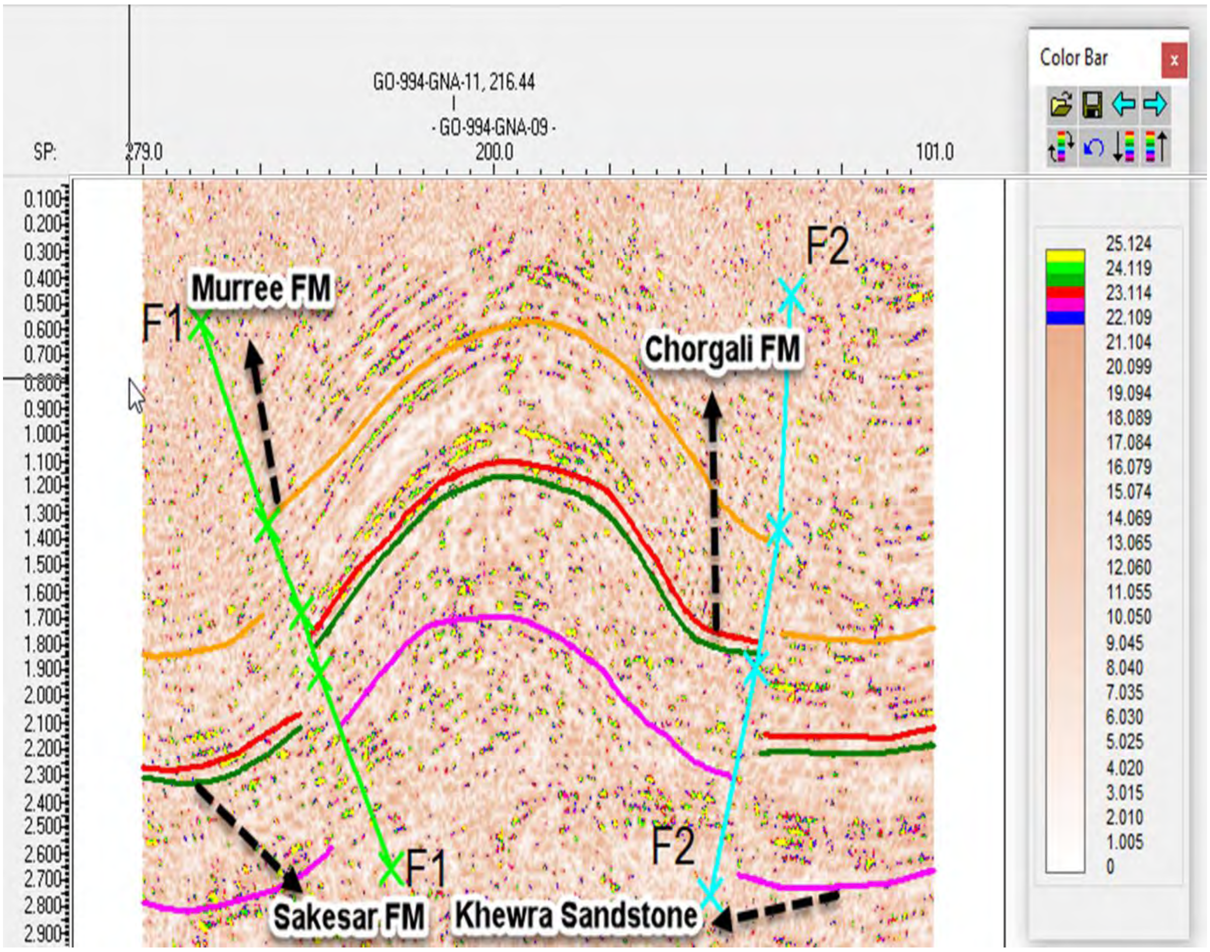

Figure 5.2: An Envelope attribute map of seismic line GNA-09

5.4 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 5.3)

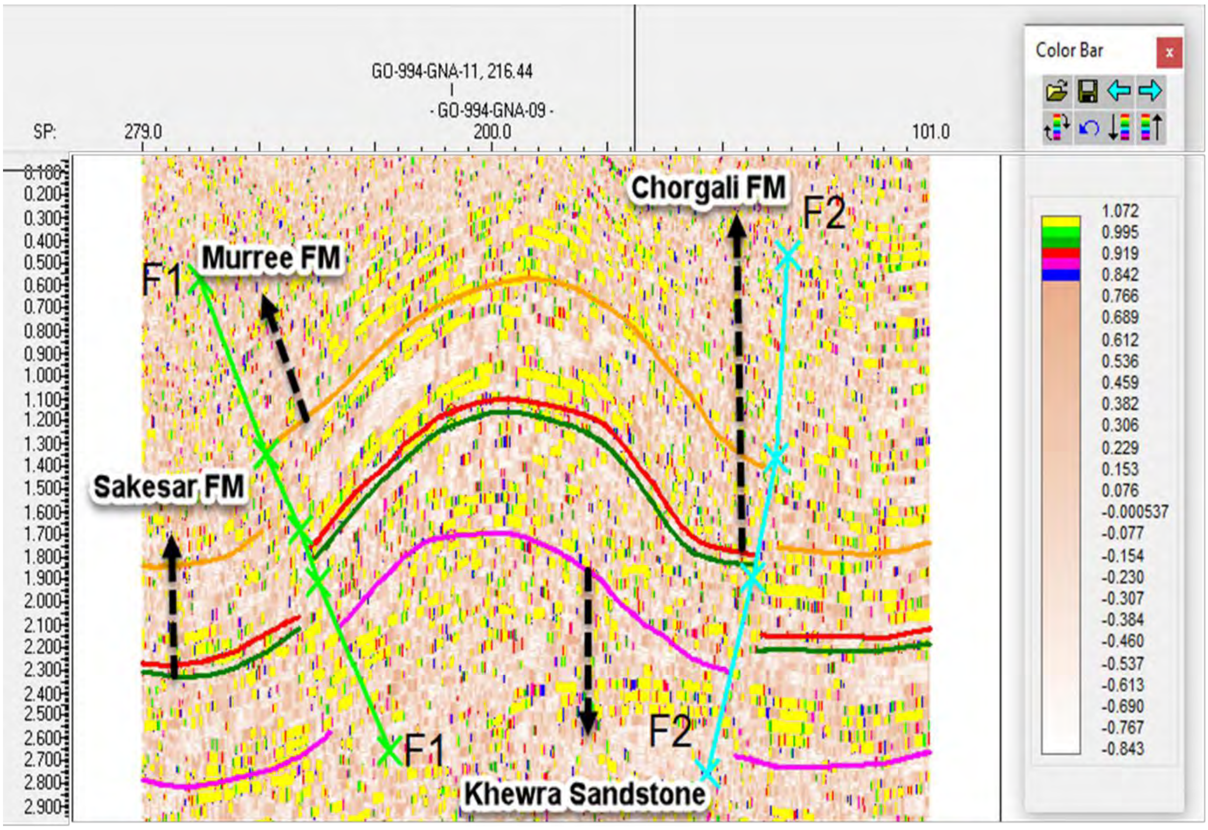

Figure 5.3: Average energy attribute calculated for seismic line GNA-09 confirming the interpreted horizon.

5.5 INSTANTANEOUS PHASE

The phase information is independent of trace amplitudes and relates to the propagation of phase of the seismic wave front. Since, most of the time, wave fronts are defined as lines of constant phase, the phase attribute is also a physical attribute and can be effectively used as a discriminator for geometrical shape classifications. It is computed from real and imaginary traces as given below:

$$\Theta (t) = \tan^{-1} [h (t) / f (t)]$$

Instantaneous phase is the best indicator of lateral continuity, relates to the phase component of the wave propagation and has no amplitude information, hence all events are represented. It can be used to highlight interface in sections with high decay of amplitudes and even highlight deeper horizons which are not visible in the normal amplitude sections. Figure 5.4 shows the instantaneous phase attribute which changes from -180^0 to $+180^0$. The interpreted horizons lie over the minimum phase regions indicated by orange color. This attribute further confirms the interpretation as the input data is zero phase. It can be observed in comparison to amplitude-based sections that the instantaneous phase shows much deeper horizons.

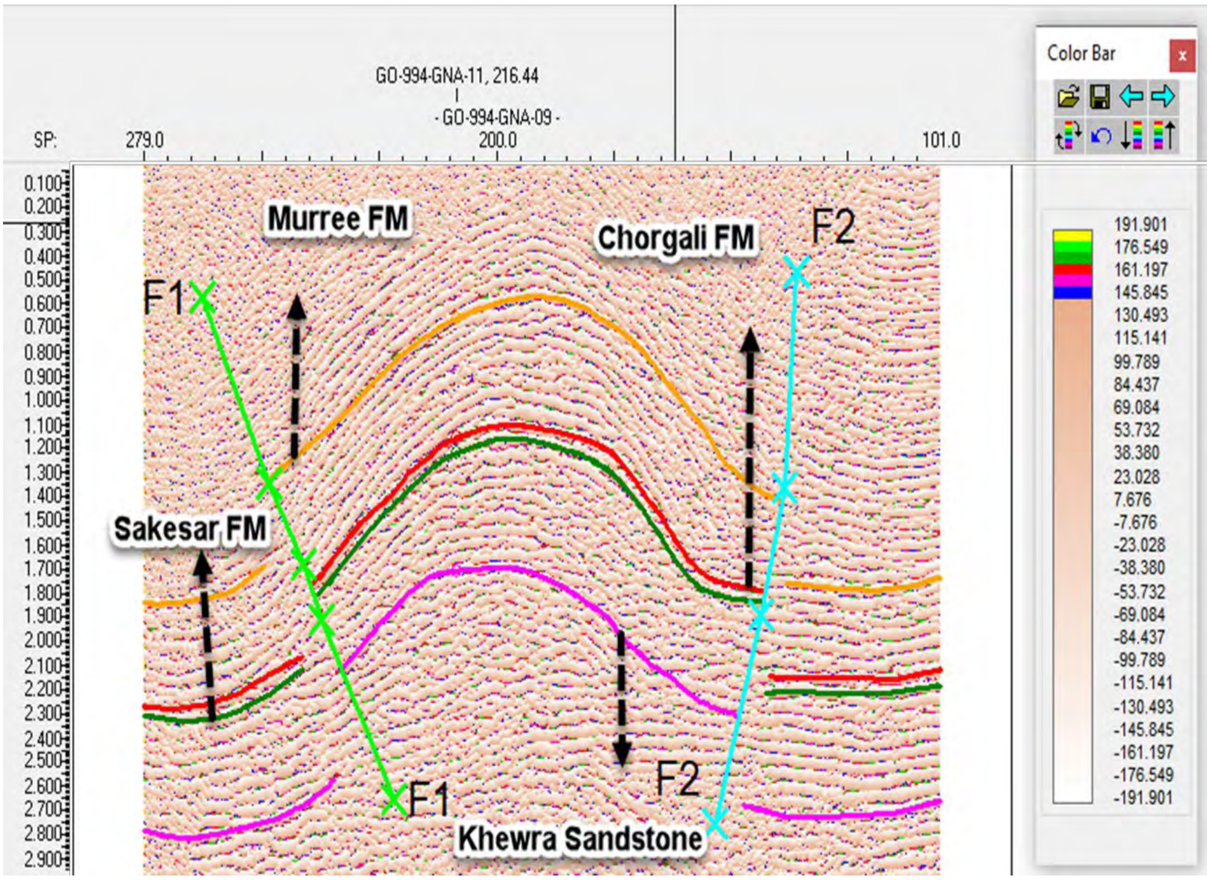

Figure 5.4: Average energy attribute calculated for seismic line GNA-09

5.6 GEOLOGICAL IMPORTANCE OF SEISMIC ATTRIBUTES

Seismic attributes are quantities derived from pre-stack and post-stack seismic data. In many cases they are more closely related to physical rock properties rather than conventional seismic amplitudes. Properly chosen seismic attributes highlights specific petrophysical or geological parameters like lithology, fluid, content and degree of fracturing. Attribute analysis of 3D seismic data with several types of seismic attribute may reveal geologic factors that control spatial distribution of subsurface energy reserves. Table 5.1 shows some seismic attributes and the geologic information they provide.

ATTRIBUTES	GEOLOGIC INFORMATION
Instantaneous frequency	Lithological contrasts, bed thickness, fluid content
Reflection strength	Lithological contrasts, bedding continuity, bed spacing, gross porosity
Amplitude	Lithological contrast, bedding continuity, Bed spacing, gross porosity, fluid content

Instantaneous phase	Bedding continuity
Polarity	Polarity of seismic, lithological contrasts

Table 5.1: showing attributes and the geological information obtained from attributes

5.7 CONCLUSION

Seismic attribute analysis is done for better structural interpretation and confirmation of results. The three attributes computed for the seismic line GNA-09, clearly confirm the interpretation by highlighting the zones of interest.

CHAPTER 6: SEISMIC INVERSION

6.1. INTRODUCTION

Subsurface physical properties can be evaluated by using observed geophysical data in a system known as Geophysical Inversion. The process is known as Seismic Inversion if seismic data is utilized for this purpose. Seismic data is utilized as an input for evaluating earth's Physical properties and generally Sonic and density logs, seismic data volume and the set of interpreted seismic horizons are used as input data for carrying out the post stack inversions. This inversion is classified as post stack inversion if applied after the stacking of the seismic data volume and is regarded as pre stack inversion if applied prior to the stacking process.

The seismic inversion study is used for derivation of acoustic impedance (AI) attribute from surface seismic data (Chambers and Yarus2002). An inversion is an integrated approach utilizing the well data together with seismic data for prediction of the spatial distribution of AI for subsurface lithologies. Seismic data inversion and its output (AI) take the leading edge over the conventional seismic data through following advantages:

- As a lithology property rather than an interface property (like seismic data), AI can be used directly by geoscientist for seismic sequence stratigraphic exploration.
- AI is obtained by integration of various data sets from numerous diverse sources and is strongly related to the subsurface rock properties and is consequently, containing more reliable information than traditional seismic data.
- Seismic impedance inversion is a broadband dataset that contains higher resolution than the band limited seismic data.

6.2 COLORED INVERSION

The colored inversion technique is a process where the spectra of the Acoustic impedance derived from log data are used to compute the spectrum of the operator. The operator is derived in the following steps:

- First, the acoustic impedance is calculated and plotted against frequency for all wells in the area.

- Second, a regression line is fit to the amplitude spectrum of the acoustic impedance to represent the impedance spectrum in the subsurface in the log-log scale.
- Third, the seismic spectrum is calculated from the seismic traces near the wells. These two spectra are used to calculate the operator spectrum which transforms the seismic spectrum into the average impedance spectrum.
- Fourth, the final spectrum is combined with a -90 phase shift to create the desired operator in time domain. The operator in frequency domain can be represented. Colored inversion is fast and suitable for application to 3-D datasets

6.3 METHODOLOGY

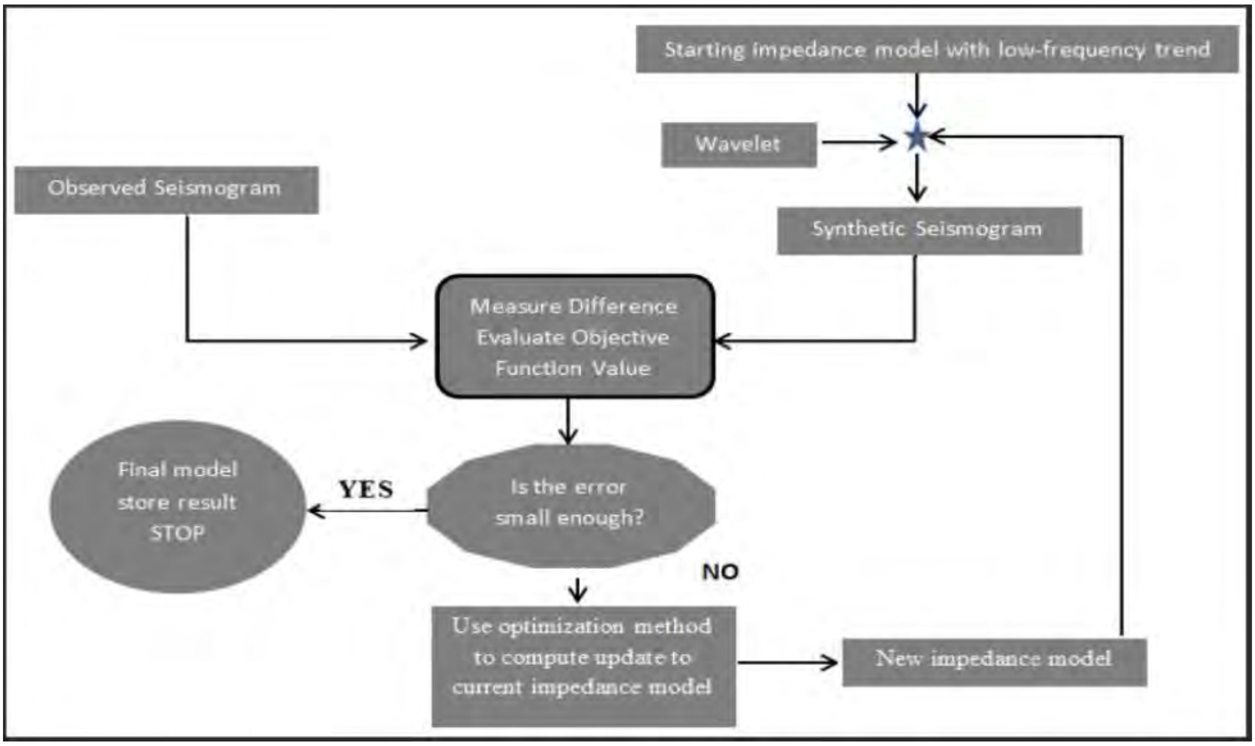

Figure 6.1: Flow chart showing impedance and wavelet extraction scheme

The well data and information of logs is required for the performing the colored inversion in Kingdom Software.

1. The velocity is obtained from sonic log and density is obtained from density log and values of densities are obtained from density log by convolving these values.

2. We get acoustic impedance by cross matching these impedance data with the input reflection data.

3. We derive a single optimal matching filter. Convolving this filter with the input data. that the result is very much similar, everywhere.

4. This Empirical observation indicates that inversion can be approximated with a simple filter and that it may be valid over a sizeable region.

5. The phase of the operator is a constant -90 which is in agreement with the simplistic view of inversion being akin to integration, and the concept of a zero-phase reflection spike being transformed to a step AI interface, provided the data are zero-phase. Empirical observation tells us that earth reflection coefficient series have spectra that exhibit a similar trend that can be simply described as constant function. The term is a positive constant and is frequency arrives at a similar observation theoretically may vary from one field to another but tends to remain reasonably constant with in any one field. It therefore follows that if our seismic data are inverted correctly, they too should show the same spectral trend as logs in the same area.

6.4 NON-UNIQUENESS OF SOLUTION

The process of convolution for constructing a seismogram using a wavelet and acoustic impedance is performed to generate an operator. Note that wavelet is smoothly varying function, while the reflectivity is a series of delta functions placed at two-way normal time of each reflector (Cooke and Schneider 1983).

We observe that wavelet is a band-limited, while reflectivity series is a broadband. Because the convolution is equivalent to multiplication in frequency domain the spectrum of resulting seismogram is band-limited as well.

We can imagine the complexity of the problem further we can consider the loss of high frequencies of wavelet caused by attenuation. In other words, series cannot be assumed to be stationary. Even under stationary conditions the data does not contain all the frequencies. The most common approach to deriving the wavelet is based on welllog data that produce a true reflectivity series.

6.5 WAVELET EXTRACTION

The wavelet is shown in Figure. is extracted on the basis of the well log data that provides the true reflectivity series (i.e. compressional wave velocity and density computed into acoustic impedance logs, which are mapped into normal incidence reflectivity series). An initial guess of wavelet is convolved with reflectivity series and synthetic normal incidence trace is generated. The difference between the observed and synthetic traced is minimized using a suitable chosen norm with smoothness constraints.

6.6 IMPEDANCE ESTIMATION

Now our approach is to convolve this wavelet with acoustic impedance (reflectivity series). The acoustic impedance is also computed from well log data as described previously. The impedance spectrum is shown in Figure is estimated after removing source wavelet; noise must be absent; all multiple reflections must be removed; spherical spreading including all plane reflections

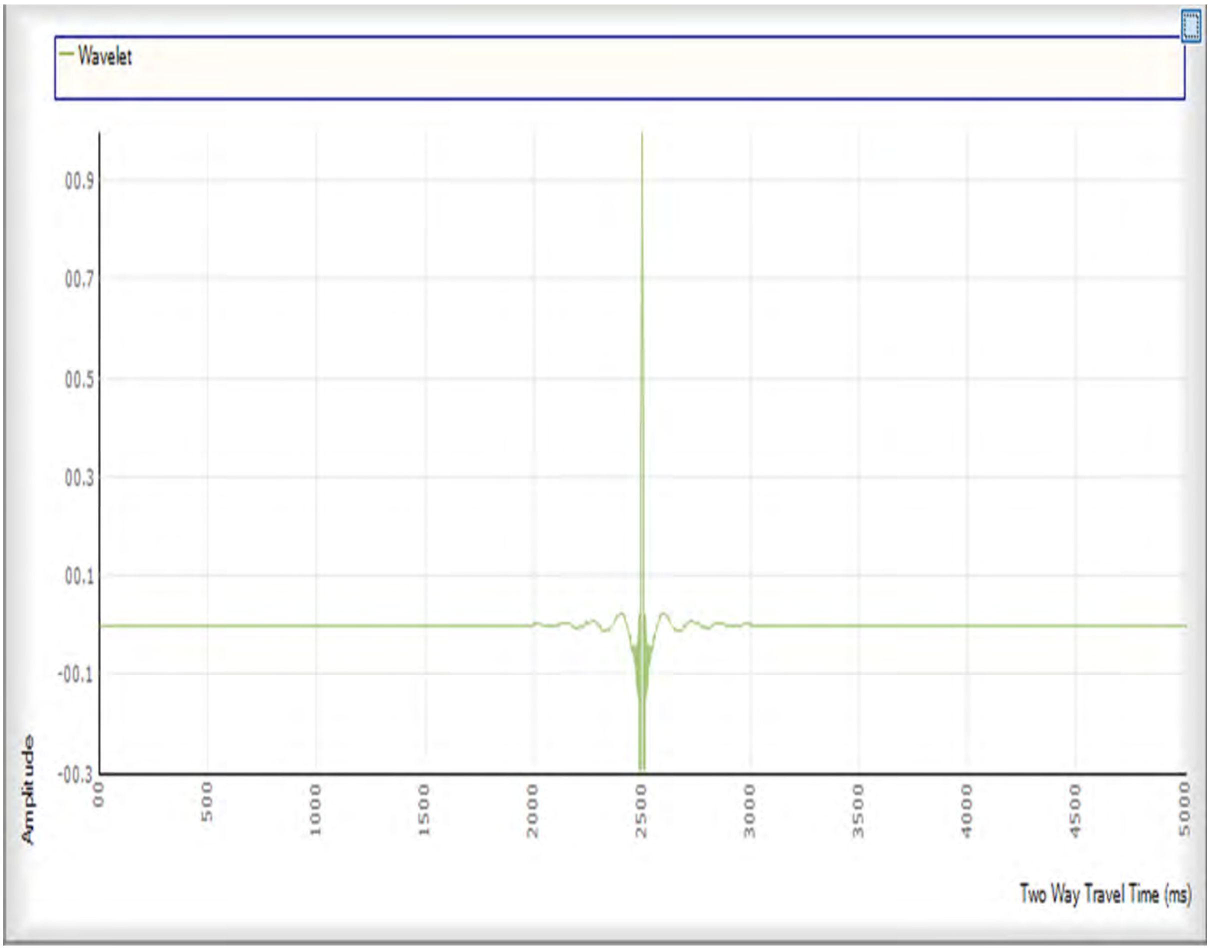

Figure 6.2: Extracted Wavelet

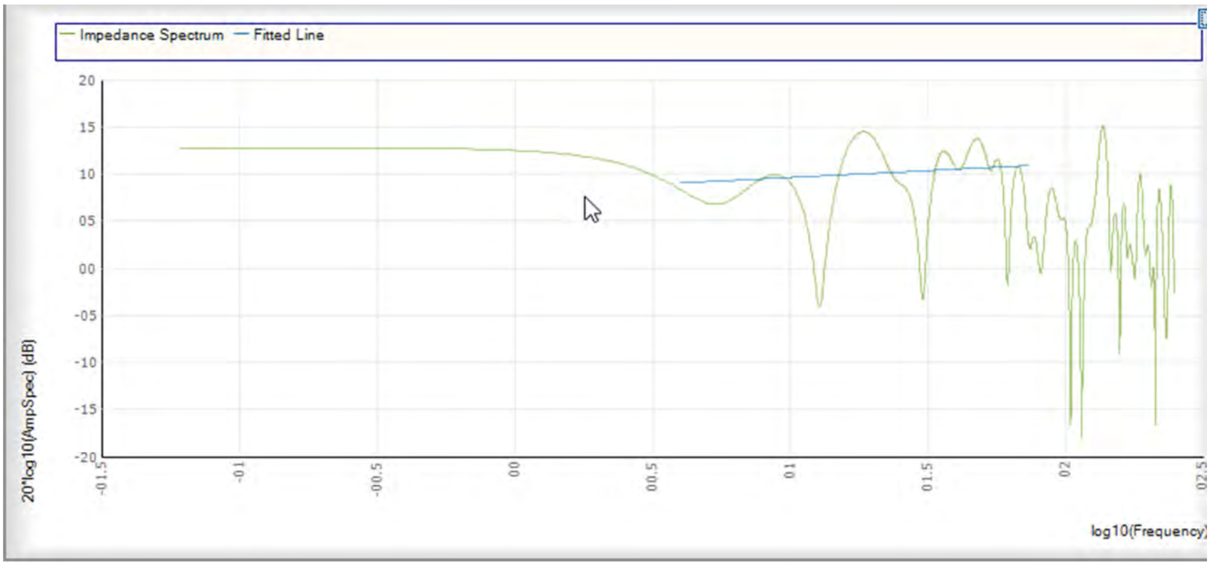

Figure 6.3: Impedance spectrum with fitted line

6.7 Butterworth filter

The Butterworth filter is a type of signal processing filter designed to have as flat frequency response as possible in the pass band. It is also referred to as a maximally flat magnitude filter. It was first described in 1930 by the British engineer and physicist Stephen Butterworth in his paper entitled "On the Theory of Filter Amplifiers. An ideal electrical filter should not only completely reject the unwanted frequencies but should also have uniform sensitivity for the wanted frequencies. This filter is used here for convolution of the wavelet and reflectivity series for formulation of seismogram. The Butterworth filter is shown in Figure 6.4

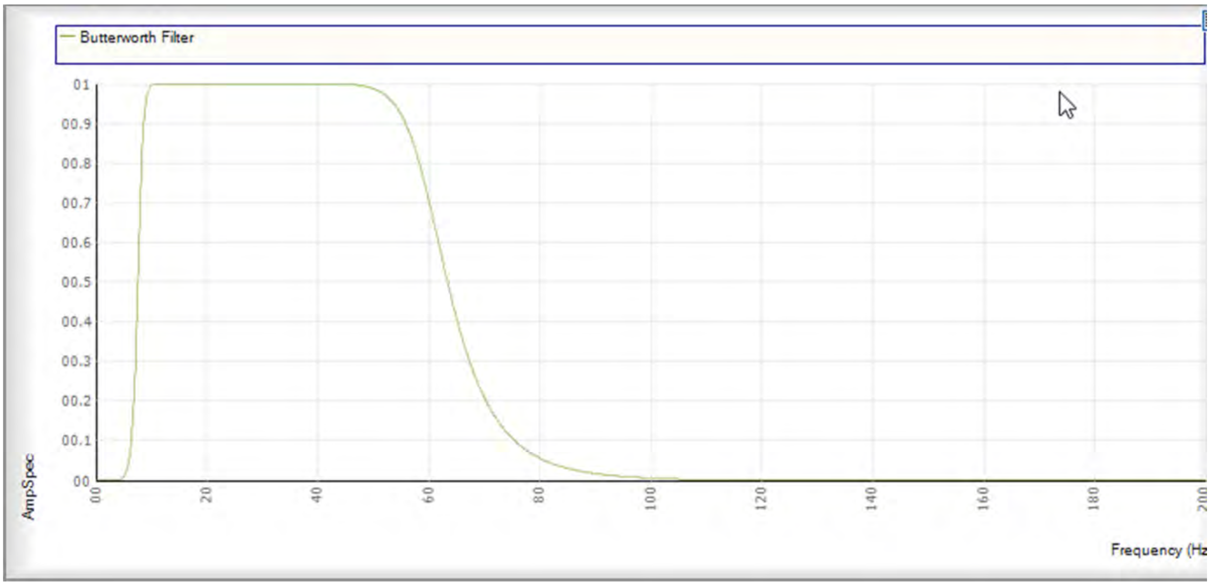

Figure 6.4: Butterworth filter

After the process of convolution is performed, we get the seismogram (operator). There is a vast difference between the seismogram of our desire and the seismogram we obtained from the convolution.

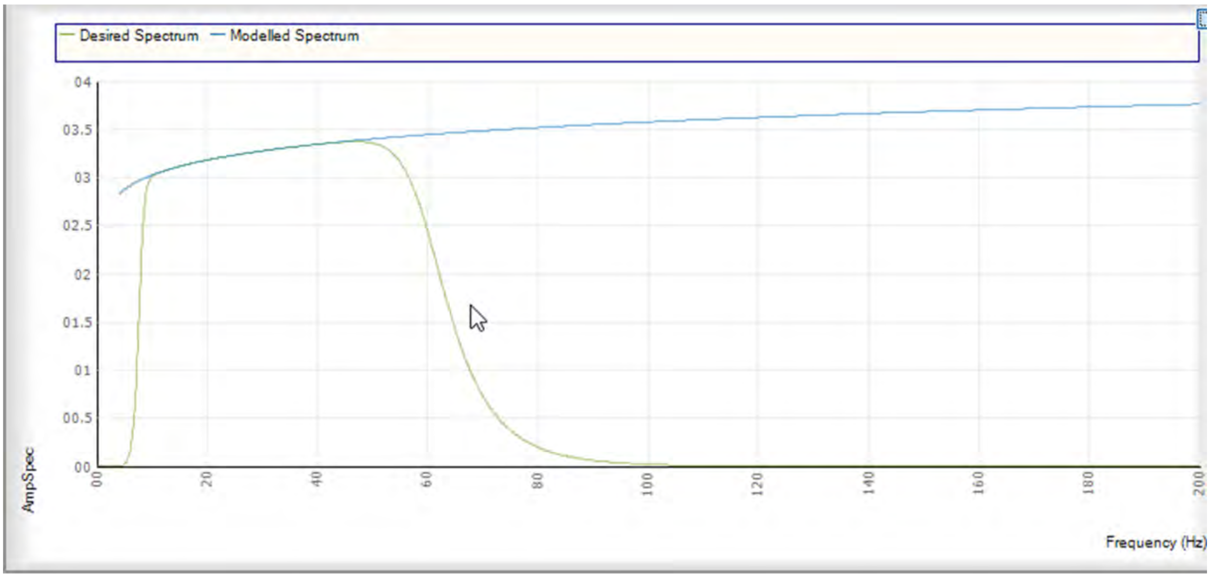

Figure 6.5: Desired and modelled spectrum.

There are two spectrums shown in Figure 6.5 both are of different colours. The blue colour shows the spectrum obtained from convolution of wavelet and acoustic impedance and the spectrum in blue colour shows a desired spectrum. Now we need to obtain a spectrum of our desire for this purpose we have to convolve this spectrum with another spectrum known as shaping spectrum which is obtained by applying Fourier transformation on desired spectrum. The shaping spectrum is shown in Figure 6.6.

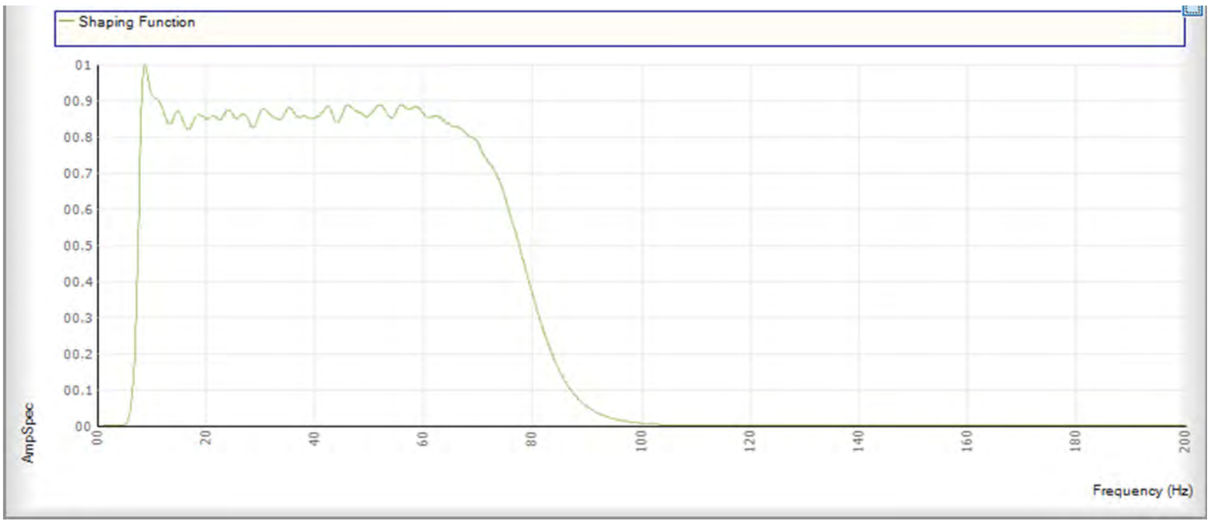

Figure 6.6 Shaping spectrum

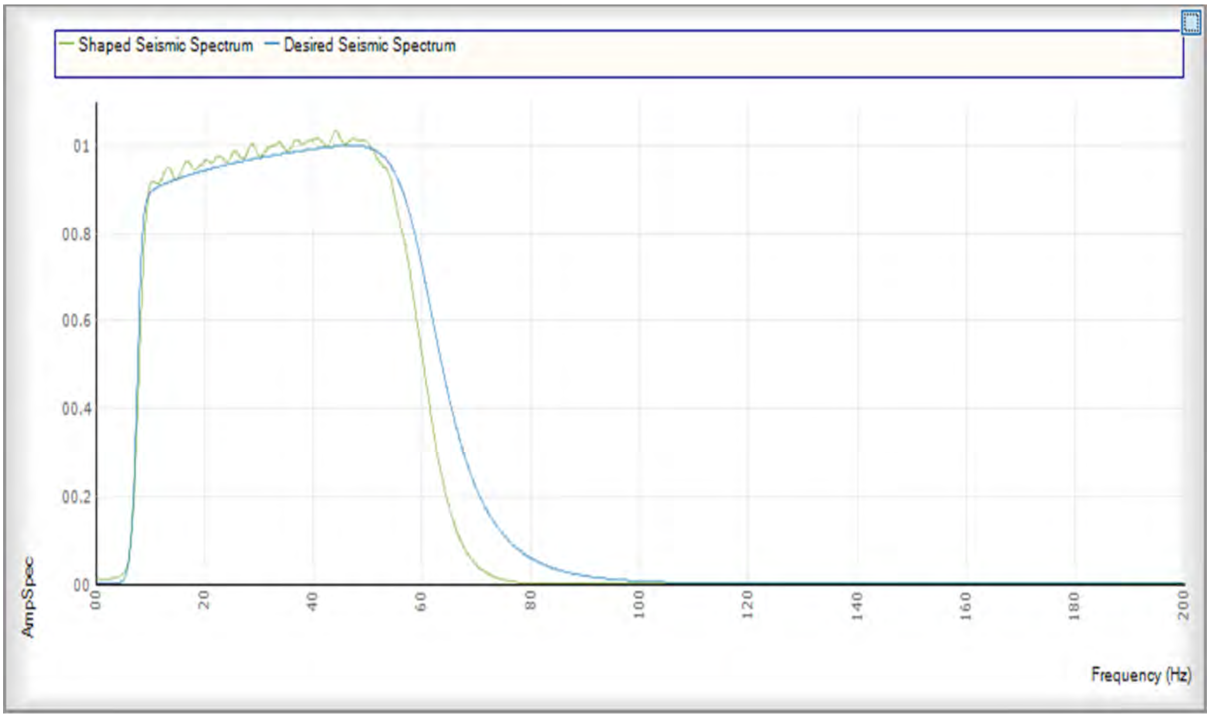

Figure 6.7 Convolution of shaped seismic spectrum and desired spectrum.

At the right corner of the window input seismic section is shown on left side and inverted section is shown on the right-hand side. The inverted section is shown on both sides of logs sides of the well the log is inverted to invert the seismic section.

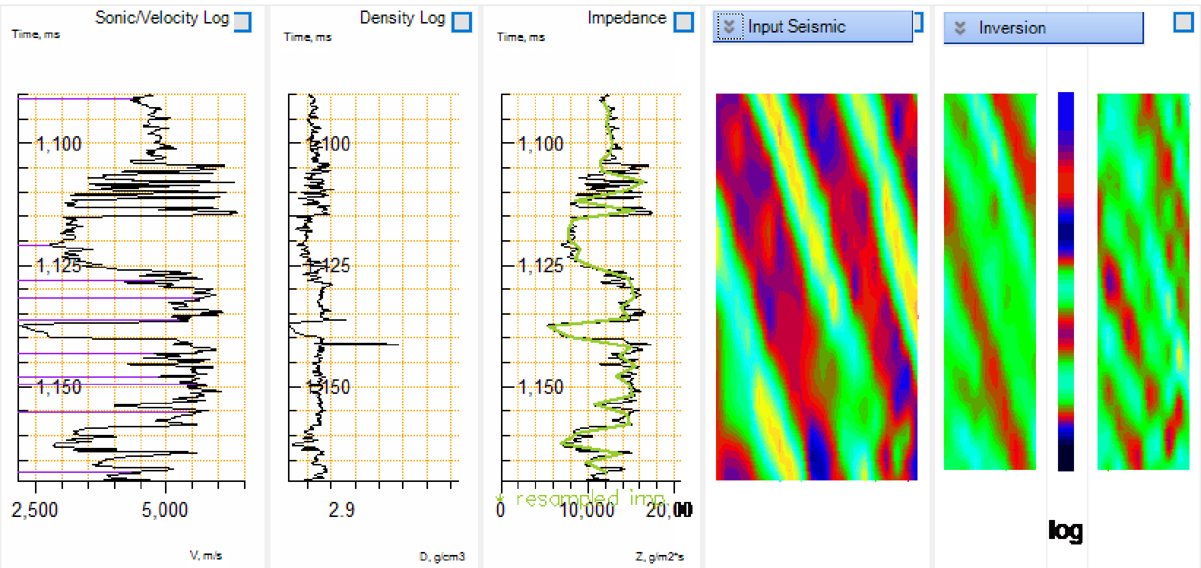

Figure 6.8: **Input seismic section and inverted section along with logs.**

Now inversion is applied to the whole section.

6.8 Interpretation of inverted section

After convolution of seismogram with mean spectrum an inverted seismic section is generated as shown in Figure 6.8. The inverted section can be interpreted by using colour bar. The white to yellow colour shows high values of acoustic impedance and blue to green colour shows low impedance.

The hydrocarbons accumulation is associated with low acoustic impedance. The given inverted section is shown. The Formation in Figure 6.8 is Khewra Sandstone it yields a response of low acoustic impedance which is related to presence of hydrocarbon accumulation. Value of hydrocarbon saturation calculated using petrophysical analysis is 46.7 percent and the reservoir thickness is 40m, there is presence of hydrocarbon in the marked reservoir because of presence of low impedance marks.

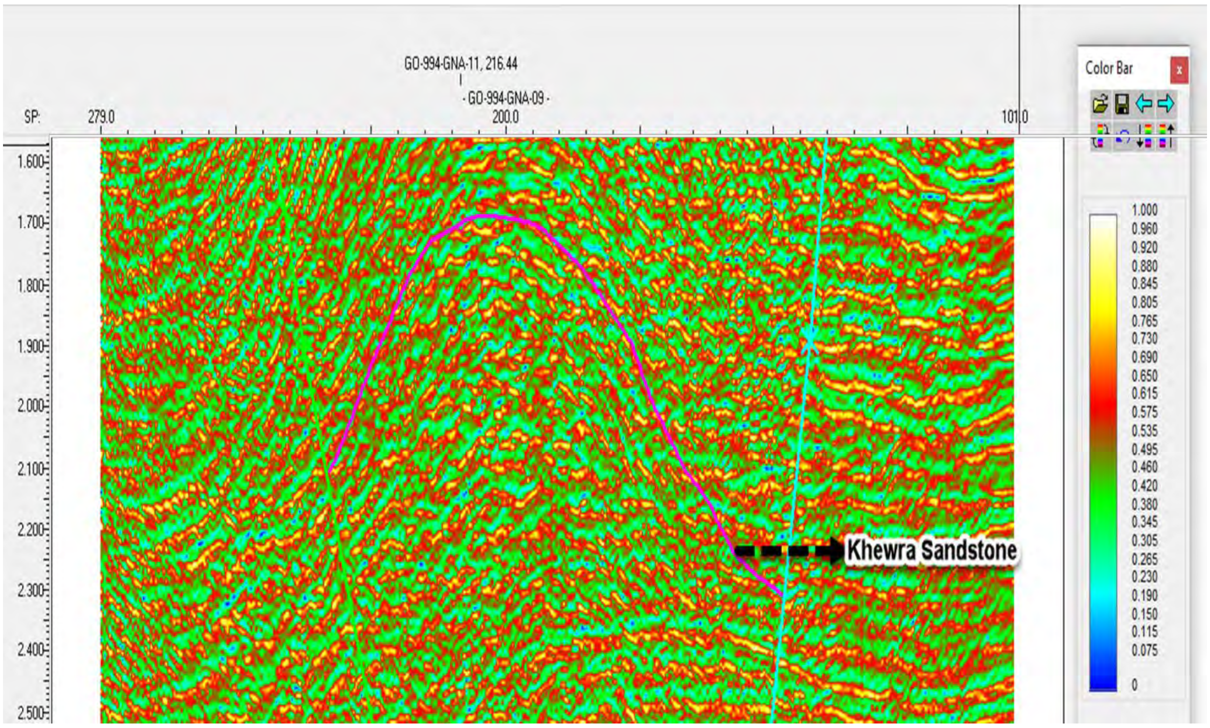

Figure 5.10: Zoomed view of inverted section

CHAPTER 7: FACIES MODELLING

7.1 INTRODUCTION

Geologically facies are a rock body which having some specific characteristics which differentiate it from the other (Riva, J. P., 1983). Generally, facies are rock unit that form under certain condition of the sedimentation that pass through the environmental process. The differentiation between the shale and sand has been constantly challenged for the geoscientist. In this process the key challenge is identifying the facies, from logging and core data, and degree to which the shale content affects the reservoir properties.

This gives the main indication about the productive zone in the reservoir. These Facies are related to the certain depositional environment. Basically, the depositional environment is specific type of place where the Facies are deposited. Such as the Glaciers, Lakes, Abyssal plain, Sea bottom, Stream, Delta etc. The different types of the sedimentary environment are shown in the below figure 7.1

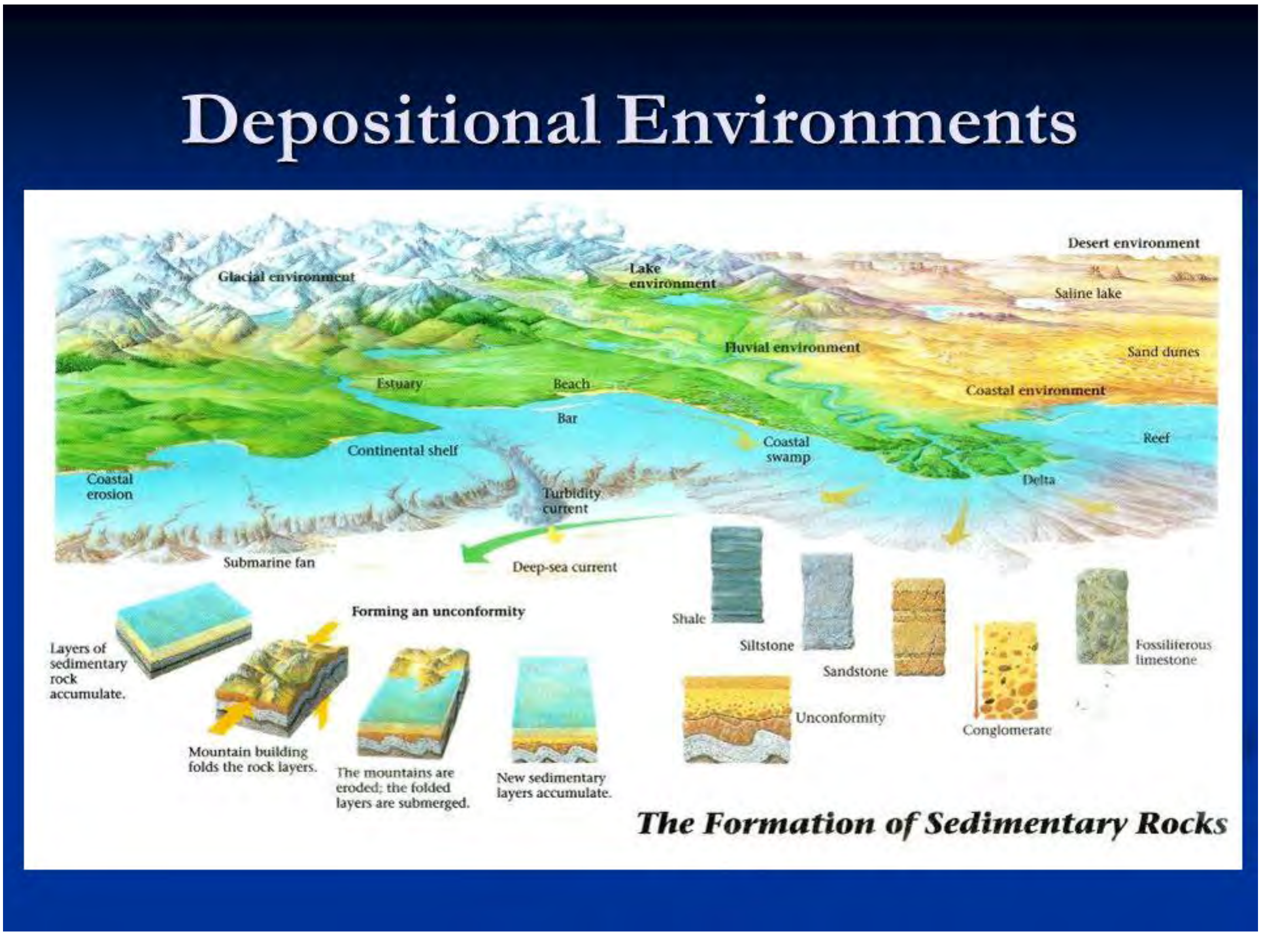

Figure 7.1 sedimentary depositional environments

7.2 TYPES OF FACIES

7.2.1 SEDIMENTARY FACIES

The sedimentary Facies can be distinct from each other on the basics of the change in the depositional environment The observation of sedimentary Facies in outcrops scale is often enough to constrain the location of sequence-bounding unconformities, where such contacts juxtapose contrasting Facies that are genetically unrelated. The sedimentary facies can be differentiated from each other on the basics of the change in the depositional environment.

Sedimentary facies are bodies of sediment recognizably different from adjacent sediment deposited in a different depositional environment, as shown in figure given below. The sedimentary environment is the specific depositional setting of a particular sedimentary rock and is unique in terms of physical, chemical, and biological characteristics. The physical features of a sedimentary environment include water depth and the velocity and persistence of currents

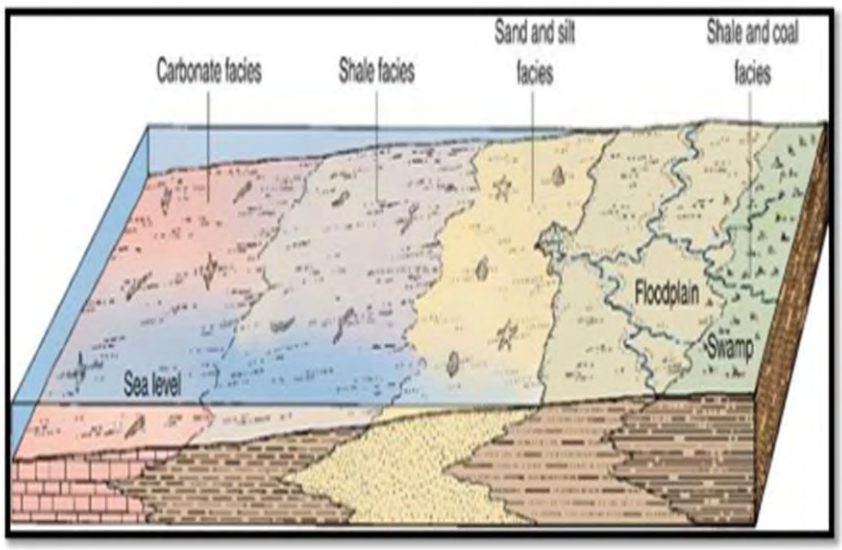

Figure 7.2: Deposition of sedimentary facies

7.2.2 METAMORPHIC FACIES

Metamorphic facies are a set of mineral assemblages in metamorphic rocks formed under similar pressures and temperatures. The assemblage is typical of what is formed in conditions corresponding to an area on the two-dimensional graph of temperature vs. pressure. Rocks which contain certain minerals can therefore be linked to certain tectonic settings, times and places in the geological history of the area. The boundaries between facies (and corresponding areas on the temperature vs pressure graph) are wide because they are gradational and approximate. The area on the graph corresponding to rock formation at the lowest values of temperature and pressure is the range of formation of sedimentary rocks, as opposed to metamorphic rocks, in a process called diagenesis.

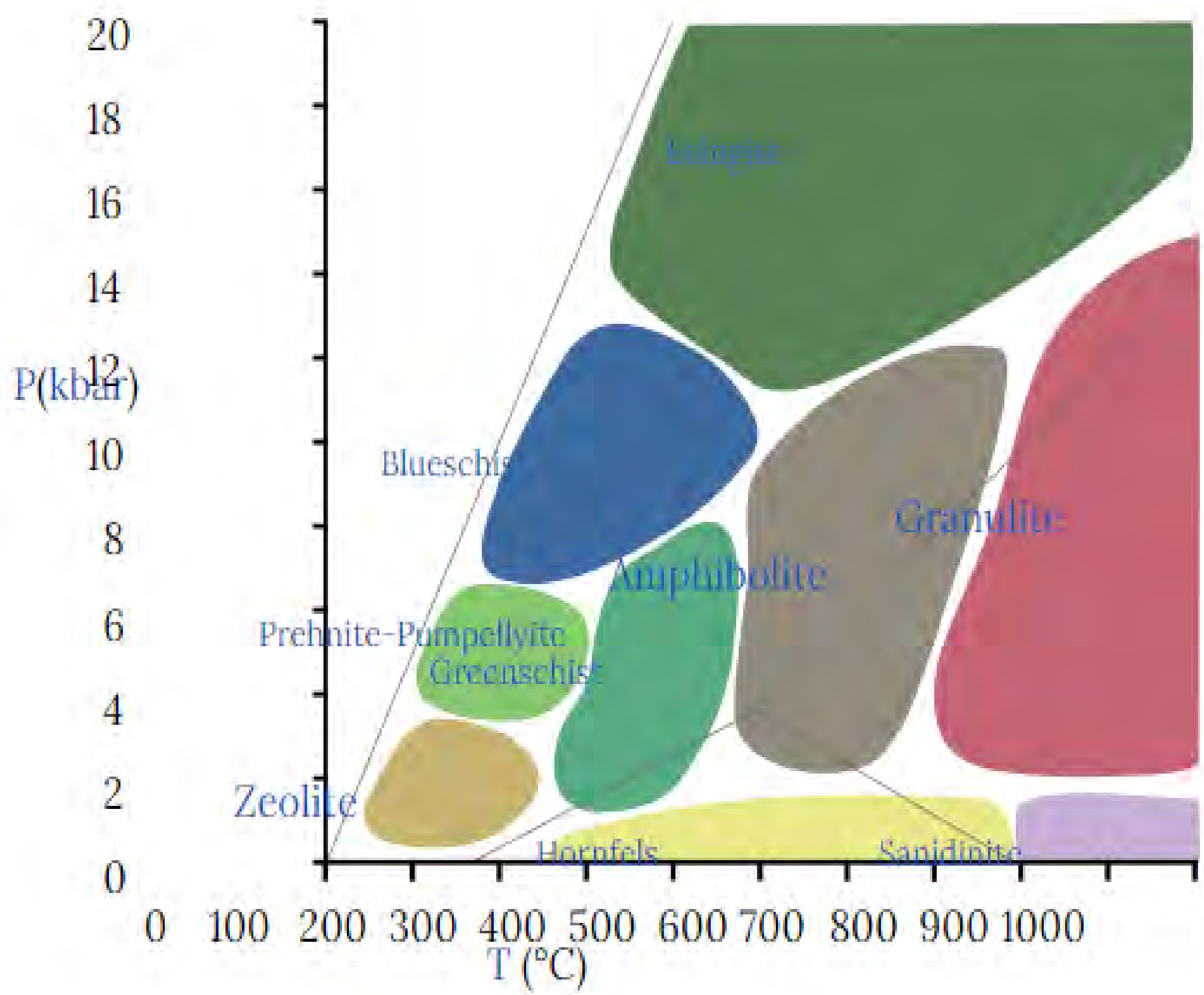

Figure 7.3: Diagram showing metamorphic facies in pressure-temperature space. The domain of the graph corresponds to circumstances within the Earth's crust and upper mantle

7.3 FACIES ANALYSIS OF KHEWRA SANDSTONE

The facies modeling is performed by plotting different logs. The log which is to be run depend upon objectives of facies modeling.

7.3.1 CROSS PLOT OF LDD, RHOB AND GR

The well MISSA KESWAL-03 is an oil well but gas is also present. The figure shows the Cross plot of LLD and RHOB. Since resistivity and density of shale is higher than sandstone, so shale facies are marked at higher values as shown in figure. Since density of shale is highly variable in the case of concentration of organic content. The density of limestone and shale can overlap so Gamma ray log is used as reference log for further separation of facies. The blue color polygon shows the shale while the red color polygon shows the sandstone.

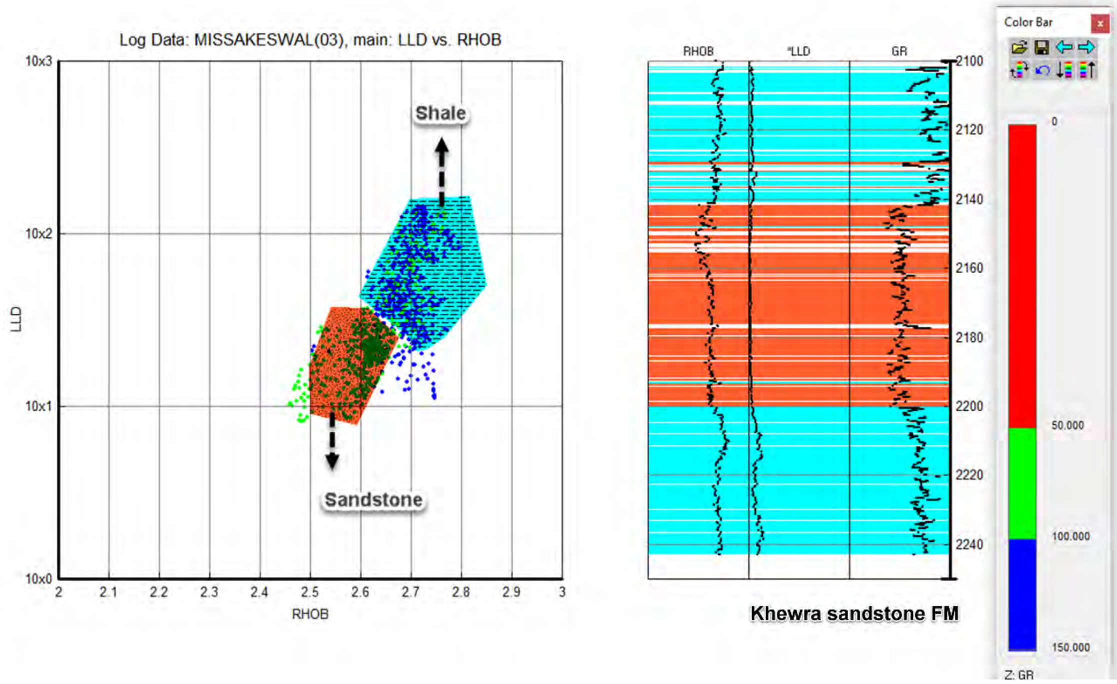

Figure 7.4 Cross plot of LLD, RHOB and GR

7.3.2 CROSS PLOT OF NPHI, RHOB AND GR

There is an inverse relation between NPHI and shale. Greater value of shale and low value of NPHI while on the other hand sandstone has good effective porosity but less neutron porosity. shale is clayey Shale which indicates the presence of water content due to which value of neutron porosity is high in shale as compared to sandstone. NPHI is plotted along y-axis and RHOB is plotted along x-axis. Green points on the cross-plot indicates the high value of GR. So, the presence of green points indicates the presence of Shale. The blue color polygon shows the shale while the red color polygon shows the sandstone.

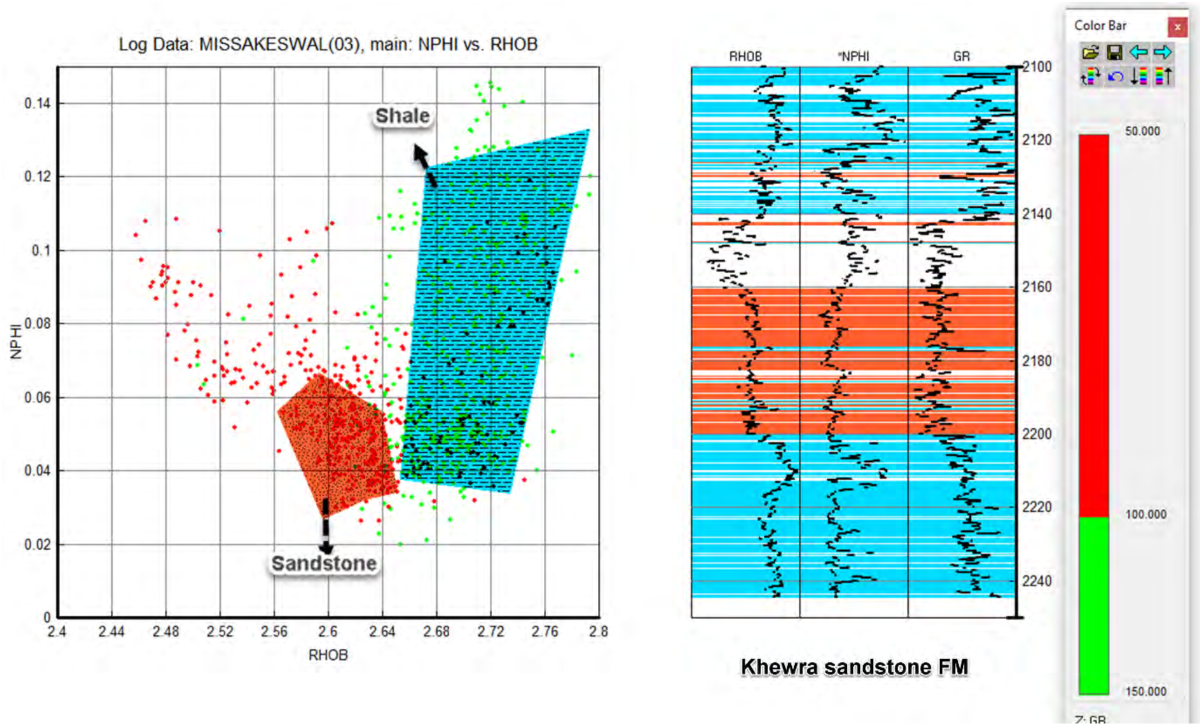

Figure 7.5: Cross plot of NPHI, RHOB and GR

7.3.3 CROSS PLOT OF DT, RHOB AND GR

Shale has low velocity as compared to Sandstone but on the other hand Shale has high value value of RHOB as compared to Sandstone. As we see in our cross-plot the red points have low value of GR which are present at high DT values which indicates that there is presence of Sandstone. Green points on the cross-plot indicates the high value of GR. As we know that GR value increases with the increase of radioactive elements so high value of GR on our cross-plot shows that there is presence of radioactive elements and we also know that Shale gives the high value of GR. So, the presence of green points indicates the presence of Shale.

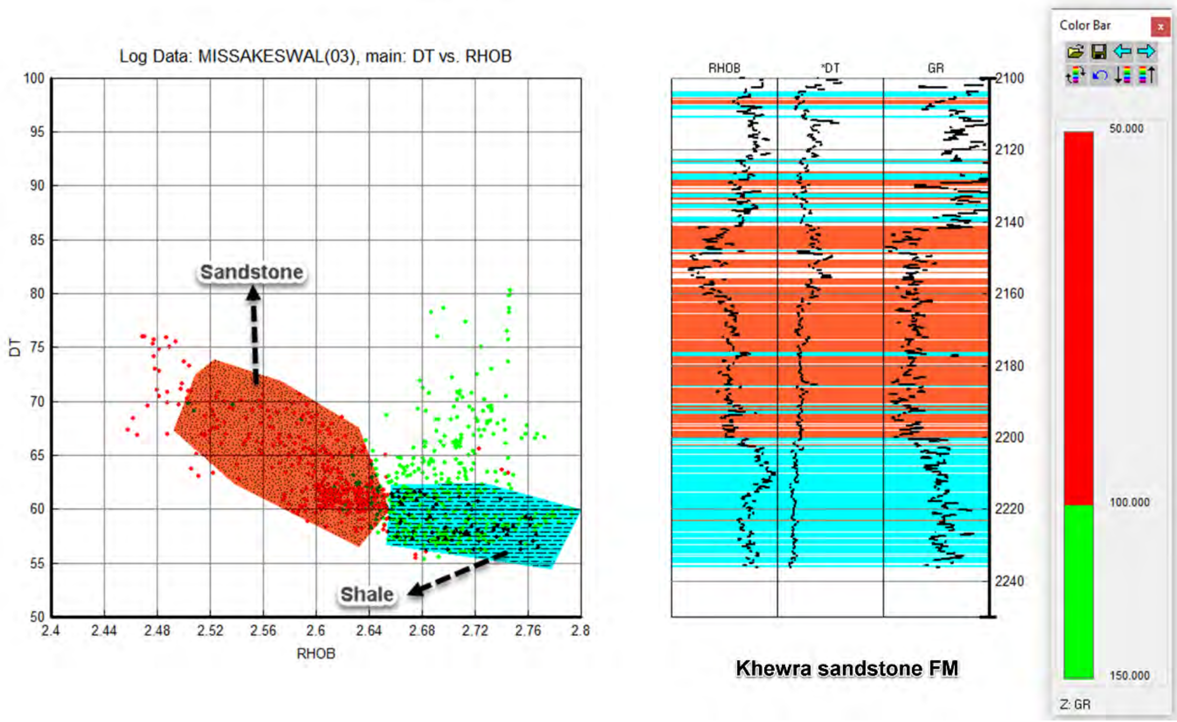

Figure 7.6: Cross plot of DT, RHOB and GR

CONCLUSIONS

The thesis work ends with following conclusions

- The seismic interpretation indicates popup anticlinal structure in the area.
- Time to depth conversion of seismic section gives us the true picture of sub-surface structure.
- Time and depth contour maps of Chorgali help us to confirm the presence of anticlinal structure in the given area. Surface contour map of Chorgali gives the real shape of sub-surface structure, which is anticlinal. This anticlinal structure acts as a trap in the area, which is best for hydrocarbon accumulation.
- The concentration of shale is high at the depths ranging from 2030 to 2140 meters, which indicates the presence of radioactive material.
- Petrophysical analysis of the well logs show a high hydrocarbon potential.
- Synthetic seismogram matches with marked reflectors which confirms the presence of stratigraphic interpretation.
- The structural and lithologic interpretation is further confirmed through seismic attributes maps and rock physics.
- The overall results indicate the economic viability of Khewra Sandstone as a reservoir.

- Seismic attributes analysis of line, GO-994-GNA-09 helped us to find the zone and Formations of interest.
- Inversion of seismic line, GO-994-GNA-09 shows the low amplitude marks in the reservoir zone on the section which leads to the indication of hydrocarbons in the Khewra sandstone formation.
- Facies analysis of different logs provided the lithology information of the reservoir area. The dominant lithology is sandstone, but clayey Shale is also present.

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