2D-INTEGRATED SEISMIC INTERPRETATION, ATTRIBUTE ANALYSIS, PETROPHYSICAL ANALYSIS & ROCK PHYSICS BASED FACIES ANALYSIS OF MISSA KESWAL, INDUS BASIN, PAKISTAN

QUAID-I-AZAM UNIVERSITY
ISLAMABAD

By

Asmad Hussain

2016-2020

Department of Earth Sciences

Quaid-i-Azam University Islamabad, Pakistan

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

"In the Name of Allah, the Most Beneficent, the Most Merciful. All the praises and thanks be to Allah, the Lord of the 'Alamin (mankind, jinns and all that exists). The Most Beneficent, the Most Merciful. The Only Owner of the Day of Recompense (i.e., the Day of Resurrection) You (Alone) we worship, and You (Alone) we ask for help. Guide us to the Straight Way, The Way of those on whom You have bestowed Your Grace, not (the way) of those who earned Your Anger, nor of those who went astray.

(The Qur'an- Surah Al-Fatihah)"

CERTIFICATE

It is certified that **Mr. Asmad Hussain (Registration No. 04111613083)** carried out the work contained in this dissertation under my supervision and accepted in its present form by Department of Earth Sciences as satisfying the requirements for the award of **BS Degree in Geophysics.**

RECOMMENDED BY

Dr. Abbas Ali Naseem
Assistant Professor/Supervisor

External Examiner

Dr. Aamir Ali
Chairman

DEPARTMENT OF EARTH SCIENCES
QUAI-I-AZAM UNIVERSITY
ISLAMABAD

DEDICATION

I would like to dedicate this thesis work to my sweet parents, whose love, encouragement, guidance and prays make me able to achieve such success and honor.

ACKNOWLEGMENT

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.

This work would not have been possible without the help I received from the many people involved with this project. I am indebted to my honorable supervisor Dr. Abbas Ali Naseem for giving me an initiative to this study. I express my sincerest appreciation to Dr. Khalid Amin Khan for his guidance in the preparation of this thesis. He helped me in all aspects of work, moral and technical support which was very valuable for my work. I covey my sincere gratitude to Mr. Ajam Abbas, Mr. Noor Asim, Mr. Owais & Mr. Shabir Hussain for their help & support in the completion of this thesis.

I specially acknowledge the prayers and efforts of my whole family, especially my parents, my brothers & sisters for their encouragement, support and sacrifices throughout the study. I sincerely thank to all my friends especially Mr. Ahmed Rafeh, Mr. Farman Ullah, Mr. Muzammil Saleem, Mr. Usama Arshad & Mr. Umer Ghaffar for their endless love, care & moral support during my study. Thanks for the friendship and memories.

ASMAD HUSSAIN

ABSTRACT

Missa Keswal area is part of Potwar sub-basin of Upper Indus basin which is known for hydrocarbons and structural traps. The area is important for its hydrocarbon (oil and gas) structural traps. Missa Keswal oil field is located at the distance of 60 km's in the South East of Islamabad. The field was discovered in June 1991 and came on regular production from December 1992.

The present study has been done on seismic and well log data provided by the Directorate General of Petroleum Concession (DGPC).

For the interpretation of seismic data, the IHS Kingdom software is used. The horizons were identified using formation tops from wells and their depths were confirmed through correlation with synthetic seismogram, four reflectors named as Murree, Chorgali, Sakesar, Lockhart and basement have been marked depending on prominent wiggles & information of Missa Keswal-03. Faults were also marked to examine the subsurface structure. Compressional regime in the area cause faulting and salt of Pre-Cambrian age disturbed the basement creating popup structures. These Pop-up (anticlinal) structures can be seen in the area, they act as a trap and considered best for hydrocarbon accumulation.

Time and depth contour maps of all Formations are also prepared to analyze the variations on the basis of time and depth. Seismic attribute analysis is also performed for the confirmation of 2D Seismic interpretation and it also highlights the zone of interest. Petrophysical analysis is done which shows hydrocarbon and water saturation in Missa Keswal-03. Rock Physics cross-sections have generated to further confirm the interpretation.

Contents

CHAPTER NO. 1

INTRODUCTION

1.1 Study Area

The area under study is Missa Keswal oil field which is located about 9 kilometres from city of Gujar Khan, district Rawalpindi of province Punjab. Geographically the study area lies between 33° 13' 47" North, 73° 21' 44" East. Gujar Khan is located at about 60 kilometres in the south-east of capital city Islamabad. Geologically area lies in the Upper Indus Basin of Pakistan in Potwar Sub-basin part which is structurally very complex as most surface features do not reflect subsurface structures due to presence of decollement at different levels. The Potwar sub-basin is dominated by the structural traps and mostly seismic data is incorporated for the delineation of these structures. The area lies in the compression domain with large numbers of thrust and reverse faults producing asymmetrical structures (anticlines/ synclines). Prospect wise the area is mainly Oil Prone but it is also known for its Gas reserves. Missa Keswal oil field was discovered in June 1991 and its regular production started in December 1992.

Figure 1.1: Satelliet Image showing Missa keswal (Google Earth)

1.2 Climate & Vegetation

The climatic conditions of the study area are quite similar to that of Rawalpindi. 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° C and shoots down to 8° C in winters (Saqib, et al., 1998).

1.3 Objectives

The main purposes of this disquisition are as follows:

- To study the tectonics and structural trends of the area and to understand their nature present in the study area.
- 2-D Structural interpretation to find out the structural traps and horizons of the formation.
- Contour mapping of the formations, to understand the subsurface structural geometry at reservoir level.
- Petrophysical analysis for the identification of the hydrocarbon bearing zones.
- Attribute analysis to improve understanding and mapping reservoir and to resolve structural and stratigraphic complexities.
- Rock Physics analysis for computation of elastic properties and facies modelling.

1.4 Data Formats

The data set used extensively in preparing this dissertation contained data regarding.

- SEG-Y
- LAS
- Navigation

1.5 Data Source

Main emphasis of the present work is the application of 2-D Structural analysis based on Integrated Techniques of Seismic and Well log on Missa Keswal-03, Pakistan.
The data used for current research includes 11 seismic lines in which 6 are dip lines and 5 are strike lines and a well i.e. Missa Keswal-03. The orientation of seismic lines with the location of wells is shown in the base map figure1.2. The detail of these seismic lines is given in Table1.1. Bold lines are assigned to me for the completion of this research work.

1.6 Seismic Lines

Seismic lines display the subsurface image recorded and enhanced by seismic surveying and processing. The data comprises following lines

S No.	Line Name	Type	Orientation
1	926-GJN-15	Strike	SW-NE
2	**926-GJN-16**	Dip	SE-NW
3	926-GJN-20	Dip	SE-NW
4	O/932-GJN-26	Strike	SW-NE
5	994-GNA-10	Dip	SE-NW
6	994-GNA-11	Strike	SW-NE
7	**994-GNA-14**	Dip	SE-NW
8	**994-GNA-16**	Dip	SE-NW
9	994-GNA-19	Dip	SE-NW
10	**994-GNA-20**	Strike	SW-NE
11	994-GNA-21	Strike	SW-NE

Table 1. 1 Seismic lines provided for interpretation

1.7 Well Data

Open hole wireline log data of well Missa Keswal-03 is used to conduct petrophysical study and to generate synthetic seismogram.

Missa Keswal-03 includes following logs data enlisted below in table 1.2.

Lithology Logs	Electrical Logs	Porosity Logs
Gamma Ray Log (GR)	Latero Log Shallow (LLS)	Neutron Log (NPHI)
Spontaneous Potential (SP)	Latero Log Deep (LLD)	Density Log (RHOB)
Caliper Log		Sonic Log (DT)

Table 1. 2: Well logs provided to study.

1.7.1 Information of Missa Keswal-03 Well

Information of the well data which was provided to us for the dissertation is listed in table 1.3.

Well	Missa Keswal-03
Latitude	33.229881
Longitude	73.36245

KB	427.12 m
Total Depth	2250.0 m
Status	Appraisal Oil Well
Company	OGDCL

Formation Tops	**Measured Depth (m)**
CHINJI	0.00
KAMLIAL	935.00
MURREE	1395.00
CHORGALI	1870.00
SAKESAR	1914.00
NAMMAL	1983.00
PATALA	1996.00
LOCKHART	2004.00
HANGU	2017.00
DANDOT-TOBRA	2023.00
BAGHANWALA	2033.00
JUTANA	2039.00
KUSSAK	2057.00
KHEWRA SANDSTONE	2081.00
SALT RANGE	2143.00

Table 1. 3 : Information of Missa Keswal-03 Well.

1.8 Base Map

It is described as a map on which primary data and interpretations can be plotted to produce contour maps of several types. A Base map includes the location of lease or concession boundaries, wells and seismic survey points and other cultural data such as buildings and roads with a geographic reference such as latitude and longitude or Universal Transverse Mercator (UTM) grid information.

The base map is important component of interpretation, as it shows the spatial position of each picket of seismic section, for a geophysicist a base map is that which shows the orientations of seismic lines and specify points at which seismic data were acquired or simply a map which consist of number of dip and strike lines on which seismic survey is being carried out.

Below is the base map of the study area.

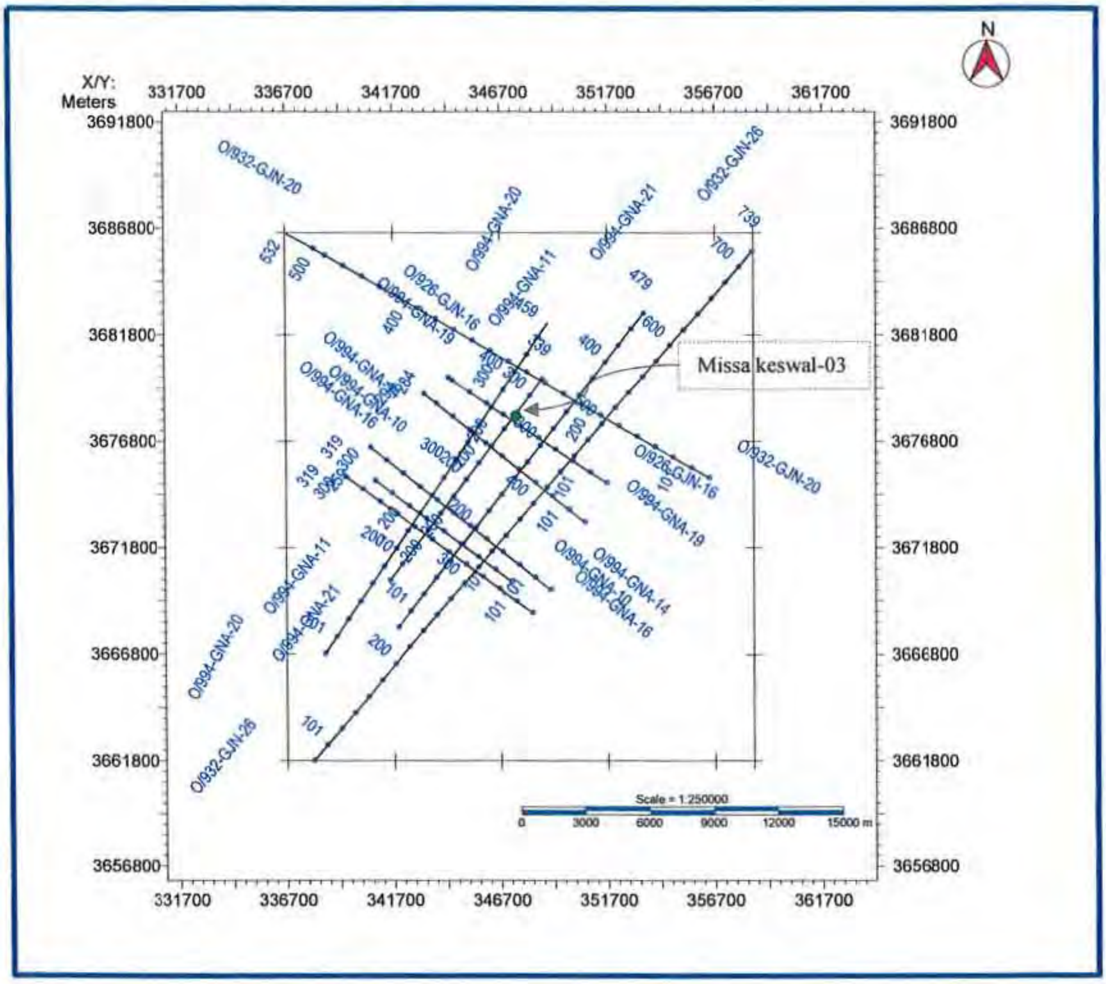


Figure 1.2: Base Map of Study Area

CHAPTER NO. 2

GEOLOGY AND STRATIGRAPHY

2.1 Overview

The Indus Basin is the largest sedimentary basin of Pakistan. The orientation of the basin is in NE-SW direction. Basement is exposed as outcrop at two places, one in NE as Sargodha High and second in SE as Nagger Parker High. It comprises of normal to moderate and some steeply dipping structures. The compression regime of the tectonic plates causes the basin division into Upper, Middle and southern Indus basin.

Indus Basin runs in the dominant trend of north-south and is bounded by the Indian craton (Nagar Parker granite area) to the east, the Kohat-Potwar Plateau to the north, fold and thrust belts of Sulaiman and Kirthar ranges in the west. Upper Indus Basin is further classified into Kohat sub-Basin and Potwar sub-Basin where Lower Indus Basin is further classified as Central Indus Basin and Southern Indus Basin. The geological division between Kohat and Potwar is done naturally by river Indus, the East and West of river represent the Potwar and Kohat Basins respectively. Categorized by the greatest extensive active collision region in the world, it majorly consists of the faulted anticlinal traps ranging in age from Cambrian to Miocene. These traps are the main source for the of hydrocarbons

2.2 Potwar Basin

2.2.1 Introduction

The Potwar Basin is situated in northern Pakistan. It is an onshore basin bounded on the North by Parachinar-Murree fault, on the West by Kurram fault, on the South by Surghar and Salt Ranges and on the East by Jhelum fault. The Potwar Basin is a portion of Indian plate deformed by Indian and Eurasian plate collision and over thrust of Himalayas on the north and northeast. The geological structure of the Potwar Basin is most complex in the world. The Eastern Potwar seems to have more complex geological structures than Western Potwar. The Eastern part of Potwar basin is more affected by intense tectonic activity as compared to Western Potwar. The eastern Potwar contains carbonate reservoir rock of Cambrian to Tertiary ages. The basin infilling started with thick Infra-Cambrian evaporite deposits overlain by relatively thin Cambrian to Eocene age platform deposits followed by thick Miocene-Pliocene molasses deposits. Potwar basin is one of the oldest oil producing basins in this region. Here, mostly the productive reservoirs are Eocene and Paleocene carbonates although more recent exploration are some deeper targets zones of Permian formation.

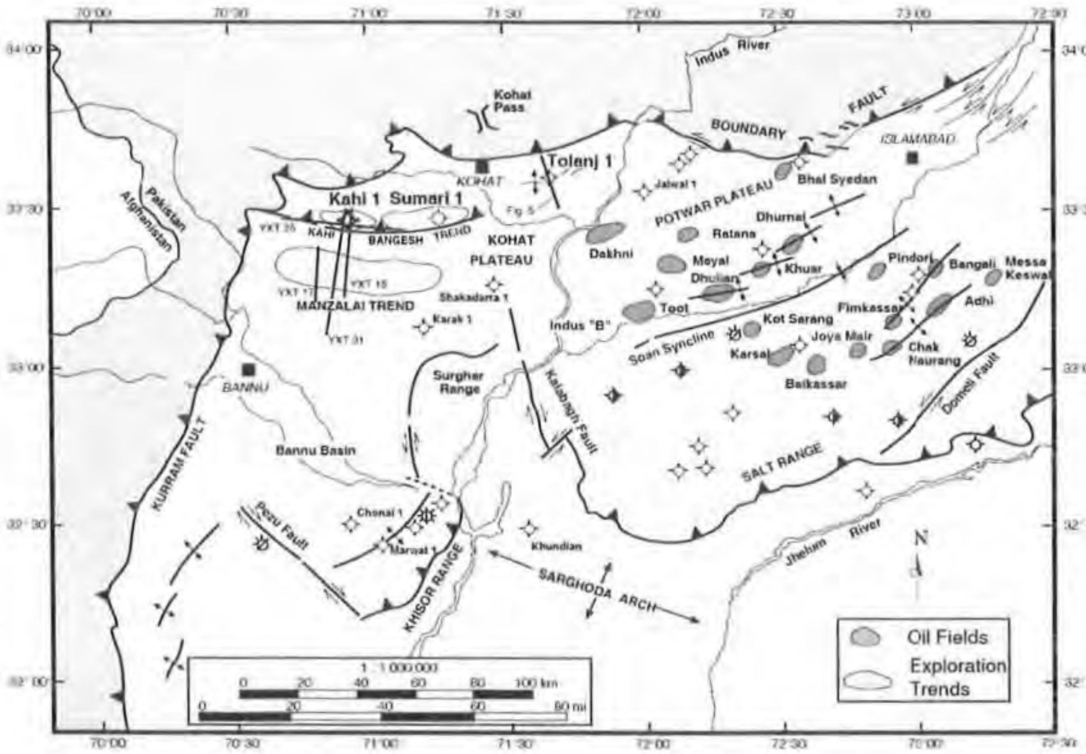


Figure 2.1: Map showing major structural features & oil fields of the Kohat-Potwar plateaus. (William, et al., 1998)

2.2.2 Tectonics & Structure

The Himalayan collision system represents an active collision orogeny between the Indian and Eurasian subcontinents. The collision was active since 55Ma (Jadoon et al., 1999; Powell, 1979) and involves continuous uplifting, erosion and deposition of sediments.

The Potwar Plateau is situated in the lesser Himalayas of Pakistan, a zone of deformed meta-sedimentary and sedimentary rocks originally deposited on the northern Indian continental margin and in the Indo-Gangetic foreland basin. Thrust faults have been traditionally assigned for the fault contacts between zones (Sercombe et al., 1998).

Potwar is in the western foothills of Himalayas in northern Pakistan. It includes the Potwar Plateau, the Salt Range, and the Jhelum Plain. It extends about 130 km from the Main Boundary Thrust (MBT) in the north and is bounded in the east by Jhelum strike-slip fault, in the west by Kalabagh strike-slip fault, in the north by the MBT and in the south by the Salt Range Thrust. The Salt Range and Potwar Plateau is the northernmost feature of Indus Basin, bounded by the MBT and Kalla Chitta Range in the north and Salt Range in the south.

The Potwar sub-basin is one of the oldest oil provinces of the world, where the first commercial discovery was made during early last century in 1914 at Khaur. So far, about 150 exploratory wells have been drilled in the area but many of these were pre-maturely abandoned, as these could not reach their target depths due to drilling problems related to extremely high-pressure water in molasses deposits, which may be related to structural complexities.

2.2.3 Geological Boundary of Potwar Plateau

Potwar Plateau lies below the western foothills of Himalayas. Extending about 130 km from Main Boundary Thrust (MBT), at its north, Jhelum strike-slip fault confines it, in the east and by the Kalabagh strike-slip fault, in the west in addition it is confined in the south, by the Salt Range Thrust (Aamir and Siddiqui, 2006). It consists of less internal folds and thrust belt which is approximately 150km wide extending in NS direction

The Potwar Plateau is confined by four faults which are:

1. Main Boundary Thrust
2. Kalabagh Fault
3. Jhelum Fault
4. Salt Range Thrust

2.2.3.1 Main Boundary Thrust (MBT)

The MBT is one of the major Himalayan thrusts, and is presently amalgamated within the Himalayan thrust wedge displaced above the Indian lithosphere. However, MBT shows recent normal displacement along most of its length. Age is Cenozoic.

2.2.3.2 Kalabagh Fault

Formation of the Kalabagh Fault zone is due to the transgressive right lateral strike slip along the western Salt Range Potwar Plateau. Kalabagh faulting uplifted and displaced Holocene terrace deposits and shifted the course of the Indus River eastward. Seismicity and slip rate associated to Kalabagh fault indicates that the Kalabagh fault zone should be considered active and capable of earthquakes.

2.2.3.3 Jhelum Fault

Jhelum fault is a type of strike slip fault trending in north-south direction. It is an active tectonic feature in the syntaxial zone. It is a young fault which is considered active based on the seismicity. Between Muzaffarabad and Kohala, this fault apparently dislocates MBT and a left-lateral offset of about 30km is indicated on the western limb of the syntaxis.

2.2.3.4 Salt Range Thrust (SRT)

Salt range thrust is also known as Himalayan Frontal Thrust. Salt range and Trans Indus Himalayan ranges mark the foothills of this extensive feature (Kazmi and Jan, 1997).

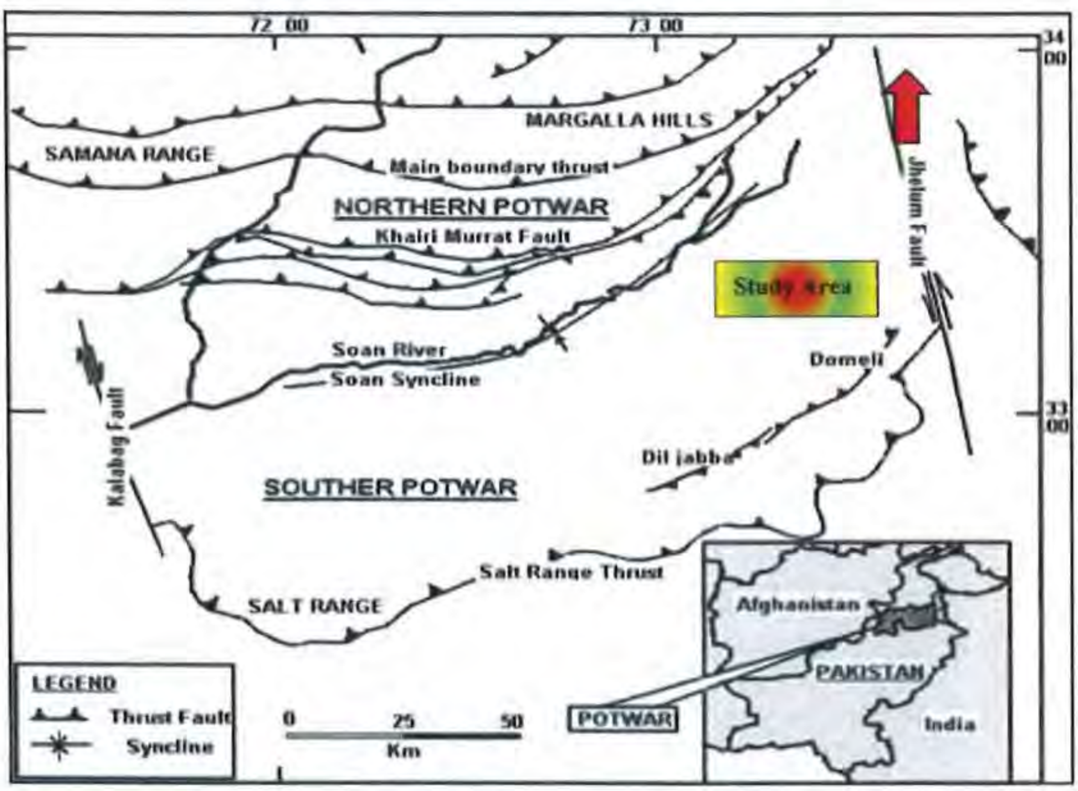


Figure 2. 2: Potwar Basin with sub divisions study area highlighted (Qadri, 1995)

2.3 Stratigraphy of Potwar Basin

Sedimentation in the Kohat-Potwar area began in the Precambrian and lasted until the Pleistocene. Three major unconformities in the area are Ordovician to Carboniferous, Mesozoic to late Permian and Eocene to Oligocene. The basin infilling started with thick infra-Cambrian evaporates with carbonates and oil impregnated shales represented by Salt Range Formation which is overlain metamorphic rocks reported as the oldest sedimentary rocks in the Kohat-Potwar Basin. The salt lies unconformable on the Precambrian basement above the Salt Range, massive sandstone and marine shale of Lower Cambrian Khewra Formation of Jhelum Group are deposited. Cambrian rocks comprised sandstone, siltstone, shale and dolomite represented by Kussak, Jutana, and Baghanwala formations. This whole sequence is marine in origin and terminated by a major unconformity.

Rocks ranging from ages Precambrian to Quaternary are present in the Potwar plateau. These rocks, with a total thickness of more than 26,000feet, were deposited in a variety of environments ranging from marine to fluvial with extensive periods of uplift and erosion, as indicated by several major unconformities.

The Missa keswal area structure is located within the Potwar sedimentary basin, its geology has been broadly studied and stratigraphic units are well recognized. Generalized stratigraphy and petroleum play elements of the Potwar basin is give in table 2.1.

Formation Name	Age	Thickness (m)	Lithology	Petroleum Play Element	
				Source	Reservoir
Siwaliks	Pliocene	400-1500			
Kamlial	Miocene	900-3000	Clay, sandstone, conglomerate		
Murree					
Chorgali	Eocene	50-150	Limestone, marl		
Sakessar			Limestone		
Nammal			Limestone, shale		
Patala	Paleocene	20-60	Shale		
Lockhart			Limestone		
Hangu			Shale, Sandstone		
Amb	Early Permian	10-100	Sandstone, shale,		
Sardai			Clay		
Warcha			Sandstone		
Dandot			Sandstone, Clay		
Tobra			Sandstone, Conglomerate		
Baghanwala	Cambrian	110-270	Shale,		
Jutana			Dolomite		
Khussak			Sandstone, siltstone		
Khewra			Sandstone, Shale		
Salt range	Infra-Cambrian	0-2000	Salt, Gypsum, Anhydrite		
Basement	Pre-Cambrian				

Table 2. 1 :Generalized stratigraphy and petroleum play elements of the Potwar basin.

2.4 Borehole Stratigraphy

Missa Keswal-03 is drilled to the depth of 2250 m. it counts through the formation of Miocene, Eocene, Paleocene, Permian and Cambrian.

Reservoir formations in the borehole

1. Chorgali Formation
2. Sakesar Formation
3. Lockhart Formation
4. Khewra sandstone

2.4.1 Chorgali Formation

The lower part consists of shale and limestone, while the upper part is mainly limestone. The shale of the lower part is greenish grey and calcareous, and the limestone is light grey and argillaceous. The Formation is interpreted to be deposited in an intertidal to supratidal environment during a regressive phase (Jurgan and Abbas, 1991). Chorgali Formation is richly fossiliferous and contains foraminifera, mollusks and ostracods (Latif 1970). Lower contact is with Sakesar formation and this is transitional and conformable. While upper contact is with Kamlial Formation and is unconformable and belongs to early Eocene age group.

2.4.2 Sakesar Formation

Bulk of lithology of this formation is limestone which is cream to light gray in color, nodular, and massive in the upper part and highly fossiliferous. Light gray colored Marl is also found in the top most part and having Chert nodules.

Upper contact with Chorgali formation and lower conformable with Nammal Formation. Fossils found in this Formation are Foraminifera. Due to presence of these fossils, the age assigned to this Formation is Early Eocene.

2.4.3 Lockhart Formation

Grey to dark grey, medium to thick massive bedded, brecciated limestone. The limestone displays very well developed nodularity. The nodularity may be caused by any of the following four reasons.

- Organic activity

- Differential compaction
- Pressure solution
- Stretching

It forms an upper conformable contact with Patala Formation and lower with Hangu Formation and belongs to the mid Paleocene age group.

2.4.4 Khewra Sandstone

This formation mainly consists of sandstone. Sandstone is thin to thick bedded and the color is purple to brown or yellowish brown. Massive sandstone is also present which is of maroon color. The grain size of the sandstone is also varying in this formation. The sandstone is characteristically cross-bedded.

It forms a lower conformable contact with salt range formation and upper contact with Kussak Formation is gradational and conformable. Khewra sandstone has assigned the early Cambrian age.

Formation Name	Age	Formation Top (m)	Thickness (m)	Lithology
Chinji	Miocene	0.00	935.00	Clay, sandstone, intraformational conglomerate
Kamlial	Miocene	935	190	Clay, sandstone, conglomerate
Murree	Miocene	1125	745	Clay, sandstone, intraformational conglomerate
Chorgali	Eocene	1870	44	Limestone, shale
Sakessar	Eocene	1914	69	Limestone
Nammal	Eocene	1983	13	Limestone, marl
Patala	Paleocene	1996	08	Shale, limestone
Lockhart	Paleocene	2004	13	Limestone, shale, marl
Hangu	Paleocene	2017	06	Sandstone
Dandot	Early Permian	2023	10	Sandstone, shale
Tobra	Early Permian	2033	06	Conglomerate
Baghanwala	Middle Cambrian	2039	18	Shale, siltstone.
Jutana	Middle Cambrian	2057	24	Sandy dolomite.
Khussak	Middle Cambrian	2081	62	Shale, dolomite
Khewra Sandstone	Cambrian	2143	102	Sandstone, shale

Table 2. 2: Borehole Stratigraphy

CHAPTER NO. 3

SEISMIC INTERPRETATION

3.1 Introduction

Interpretation is a tool to transform the whole seismic information into structural or stratigraphical model of the earth through the series of different steps. Simply defined, seismic interpretation is the science of inferring the subsurface geology from the processed seismic record. 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.

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.

While modern multichannel data have increased the quantity and quality of interpretable data, proper interpretation still requires that the interpreter draw upon his geological understanding to pick the most likely interpretation from many valid interpretations that the data allow. The word interpretation has been given many different meanings by geophysicists who deal directly with seismic sections and by the geologists who coordinate the geologic information with the seismic information

With respect to basic seismic interpretation, our prime concern is with studies of reflection time, and with the correct representation of geological surfaces. This is of paramount importance to the location of structural traps. Thereafter we may pay more and more attention to reflection character and to its implications for stratigraphic traps

The Seismic reflection interpretation usually consists of calculating the positions, and identifying geologically, concealed interfaces or sharp transition zones from seismic pulses returned to the ground surface by reflection. The influence of varying geological conditions is eliminated along the profile to transform the irregular travel times into acceptable subsurface model. This is very important for confident estimation of depth and geometry of the bedrock or target horizon (Dobrin, et al., 1976).

The major aim of seismic reflection surveying is to reveal as clearly as possible the structure of the subsurface. Geological meaning of seismic reflection is simply an indication of an acoustic boundary where we want to know that whether this boundary makes a fault or a stratigraphic contact with any other boundary. We want to distinguish the features that are not marked by the sharp boundaries. Geologists ordinarily group the sequence of sedimentary rocks into units called "Formations". These formations can be described in term of age, thickness, and lithology of the constituent layer. To distinguish different formations on the basis of seismic reflections is an important question in interpreting seismic data that may be structural, stratigraphic or lithological (Robinson & Coruh, 1988).

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 different softwares, which includes Kingdom Suit, Geographix Discovery, Wavelets and X-Works.

3.2 Analysis & Seismic interpretation

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

- Stratigraphical Analysis
- Structural Analysis

3.2.1 Stratigraphic Analysis

Stratigraphic analysis refers to the analysis mainly covering the seismic expression of genetically related strata. Identification of lithology and their hydrocarbon storage potential is mainly a part of 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-D works is especially important in recognizing the stratigraphic feature with distinct shape. The amplitude, velocity, frequency or the change in wave shape indicates hydrocarbon accumulation. Variation of the amplitude with the offset is also an important hydrocarbon indicator. Unconformities are marked by drainage pattern that help to develop the depositional environment. Reef, lenses, unconformity are example of stratigraphy traps (Sheriff, 1999).

Throughout the history of the reflection method, locating hydrocarbon in stratigraphic traps has been much less favorable than in finding structurally entrapped oil and gas. Stratigraphic oil traps can result from reefs, pitchouts, or other associated erosional truncation, facies, and transition and sand lenses associated with buried channels, lakes or similar sources (Dobrin, et al., 1976).

3.2.2 Structural Analysis

It is the study of reflector geometry on the basis of reflection time. The main application of the structural analysis of the seismic section is in the search of the structural traps containing hydrocarbons. From our class discussions we have identified many features that can hold hydrocarbons in place and which can be exploited to provide hydrocarbons. In structural analysis main emphases is on the structural traps in which tectonic play an important role. Tectonic setting usually governs which types of the structure are present and how the structural features are correlated with each other, so tectonic of the area is helpful in determining the structural style of the area and to locate the traps. Structural traps include the faults, folds anticline, pop up, duplex, etc. (Sheriff, 1999).

Most structural interpretations uses two way times rather depth. And time structural maps are prepared to display the geometry of selected reflection events. Some seismic sections contain images that can be interpreted without difficulty. Discontinuous reflections clearly indicated faults and undulating reflections reveal folded beds. The most common structural features associated with Oil are anticlines and faults.

3.3 Interpretation Workflow

The Interpretation was carried out using different techniques and steps with each step involve different processes which were performed using the kingdom software. Simplified workflow used in the study is given in figure, which provides the complete picture depicting how the study has been carried out by loading navigation data of seismic lines and SEG-Y in kingdom Software, base map was generated. Then faults and horizons of interest were marked manually. Identification of marked horizons was done with help of synthetic seismogram, generated with help of well data and faults were marked by keen observation on seismic section and knowing geologic history of study area.

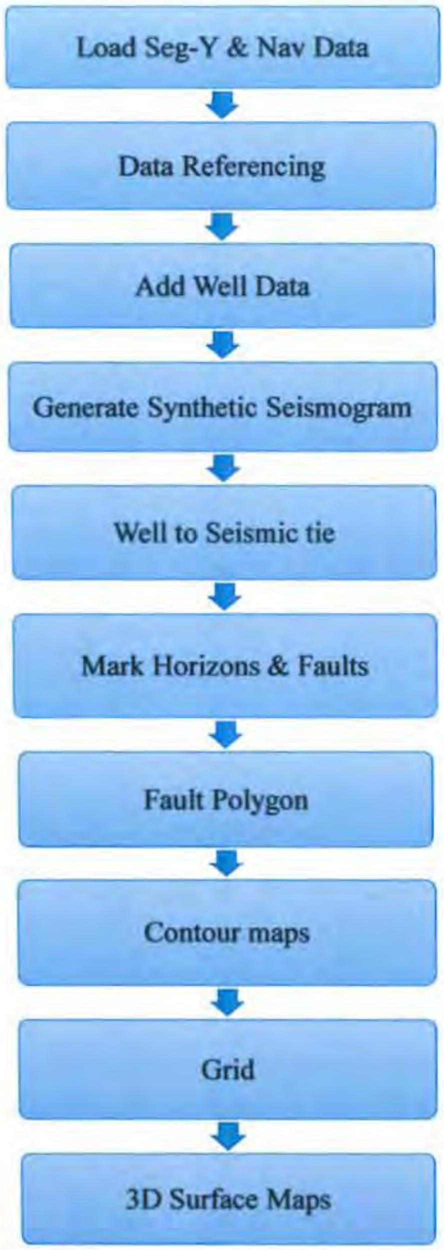


Figure 3. 1: Workflow for seismic data interpretation.

3.4 Interpretation of Seismic Lines

The seismic data provided by DGPC was in digital SEGY format along with Navigation & LAS files, this data was loaded into Kingdom Suit to generate base map.

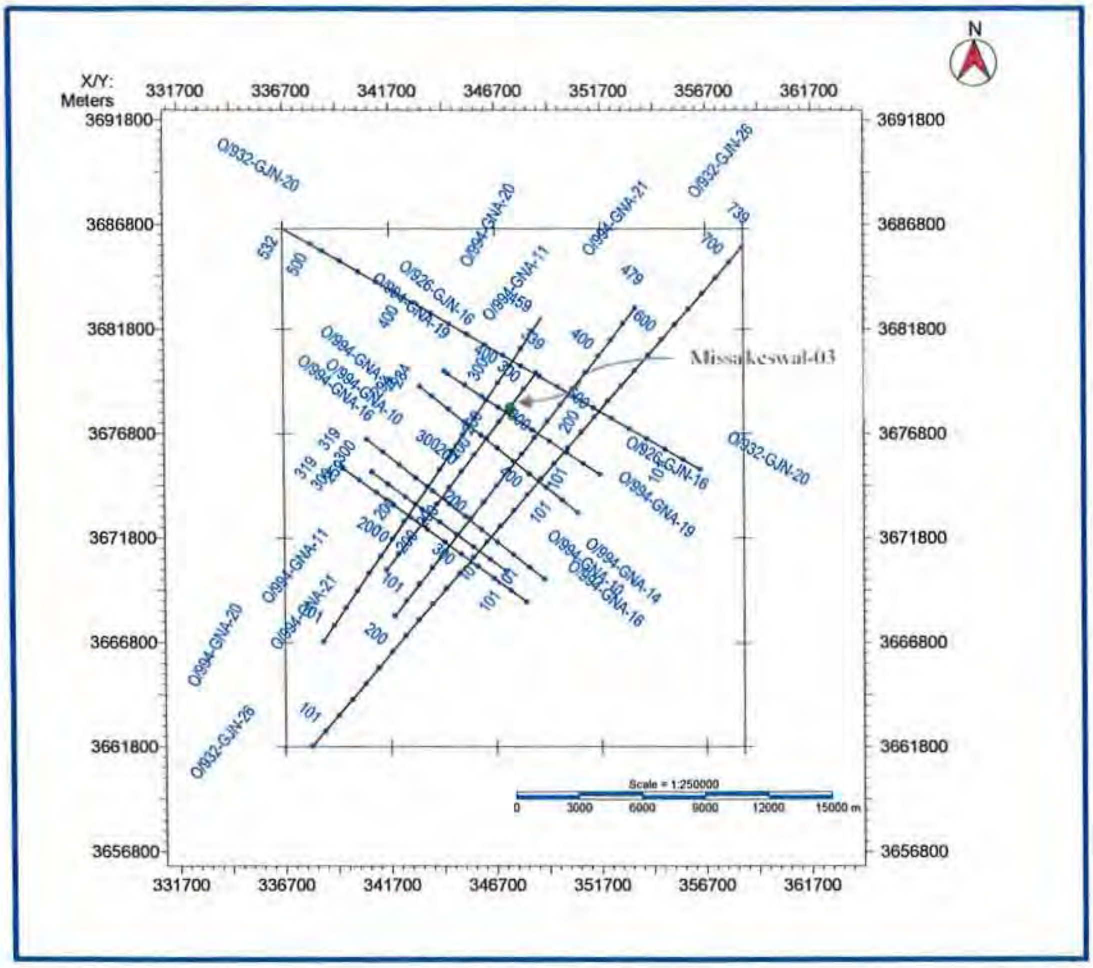


Figure 3. 2: Base Map of Study Area.

In this study seismic data is interpreted in the mode in which the synthetic seismogram generated using well data is first tied to the seismic information, and then the horizons are marked where the synthetic trace tie best with the seismic line then these horizons continue throughout the seismic section. Well tops are used to give names to the horizons.

3.5 Generation of Synthetic Seismogram

Synthetic seismograms are usually generated to compare with the actual seismic data and identify reflectors with layers and formations already known in the wellbore. The synthetic seismogram provides a link between the seismic sections and the core data, which is useful for picking of Reflectors.

Synthetic seismograms are useful tools for linking drill hole geology to seismic sections, because they can provide a direct link between observed lithology's and seismic reflection patterns (Handwerger et al., 2004).

Missa Keswal-03 well data was available which have DT and RHOB logs, which are necessary to generate synthetic seismogram. So with the help of this well data the synthetic seismogram is generated in order to mark the horizons. Sonic and the Density logs have been multiplied point by point to generate an impedance log, which is later convolved with a wavelet to generate a synthetic seismogram trace. For good results, the impedance log is convolved with a zero-phase source wavelet, extracted from the seismic data. The synthetic seismogram is shown in the Figure 3.3.

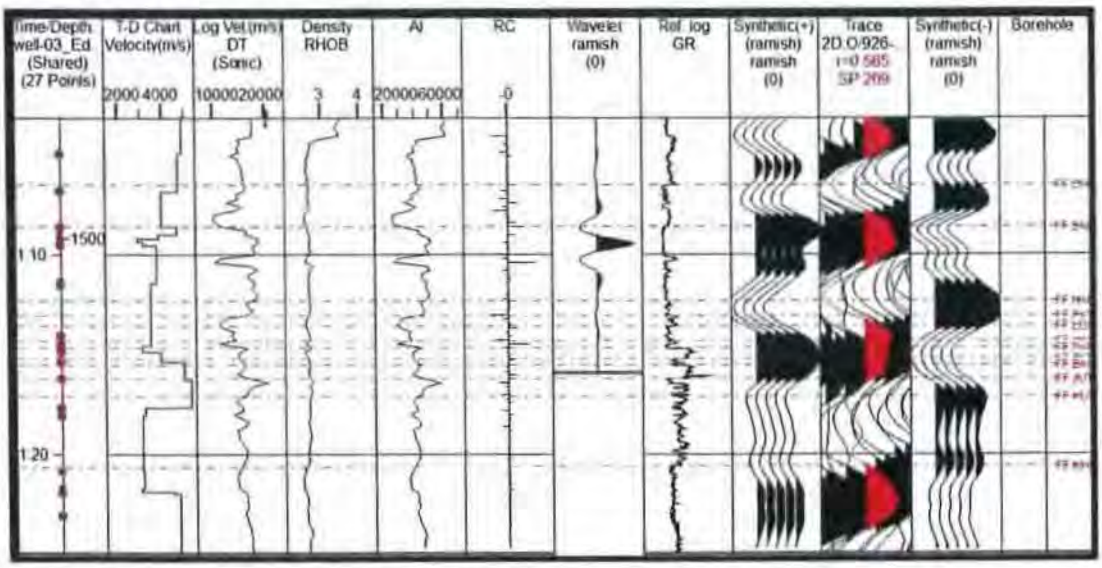


Figure 3. 3: Synthetic Seismogram of well Missa Keswal-03.

3.6 Selection of Control line

Marking the correct horizons requires information about the formation tops. The subsurface information is gained by drilling a well. Formation tops are then determined using well data. The line near which this well lies is called the control line and acts as a reference for marking reflectors on all other lines. In this study the well Missa Keswal-03 is drilled near to the dip line labelled as 994-GJN-16. So this line is used for well to seismic tie and then used as reference to mark horizons on other seismic lines.

3.7 Seismic Horizons

Basic aim in seismic section interpretation is picking a horizon mostly reflections on the section represent a certain geological formation where change in acoustic impedance occurred and this is the seismic way to interpret subsurface stratigraphic features. Thus, main task of interpretation is to identify various reflectors or horizons as interfaces between geological formations. For this good structural and stratigraphic knowledge of the area is required (McQuillin et al., 1984).

Different colors are used to mark different formations. The color of each reflector in the seismic sections and the Formation that they represent is listed below. For all the seismic lines, one color is used for one particular formation.

FORMATION	HORIZON COLOR
MURREE	Cyan
CHORGALI	Pink
SAKESAR	Yellow
LOCKHART	Green
BASEMENT	[illegible]

Figure 3. 4: Formations and their Horizons color.

3.8 Marking Faults

This data belongs to an area with extreme thrusting due to extreme thrusting reverse faults and pop-up structures are formed in this area. So a number of Major & minor faults are observed at the seismic sections. They are recognized on seismic lines where there is displacement or discontinuity in strata. Two major faults F1 and F2 are marked which bound the main popup structure of area, and one minor fault F3 is marked. There are other minor faults but due to presence of salt in this area the reflections are not strong also the data quality is not good so it's difficult to mark those small faults.

3.9 Seismic Line Tie

The identified horizons using synthetic seismogram need to be extended throughout the seismic sections, on all the provided seismic lines. To do this, seismic lines are correlated at intersection points. In line correlation, arbitrary line is generated which combine and display two different intersecting seismic lines side by side. Then using the marked control line as a reference, horizons are marked at the second line. If there is mis-tie between the reflectors of both lines, then bulk shift can be applied to find the best match, where there is a best match horizons are continued from that point.

3.10 Interpreted Seismic Sections

The time section gives the position and configuration of reflectors in time domain. The main reflectors marked on the seismic sections, that are of interest are Chorgali, Sakesar and Lockhart Formations.

The interpreted time sections of line994-GNA-14, 994-GNA-16, 994-GNA-20 and 926-GJN-16 are given below. In these sections, the horizon with cyan color is Murree, pink is Chorgali, yellow is Sakesar, green is Lockhart and blue is basement. 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 Fault F1 with red color is the main thrust fault while the fault F2 with blue color is the back thrust fault and F3 with golden-yellow color is minor fault. Due to compressional regime reverse faulting occurs and a pop up structure is formed between these two major faults. Structurally these pop-up or anticlinal type structures are of great importance and suitable for accumulation of hydrocarbons, Because they form a very good trap for oil and gas accumulation. In this area Khewra and Sakesar are acting as source rock while Chorgali is acting as a seal rock and structural trap is also forming so a complete petroleum system is present is this area. The seismic sections are in time domain, but the real subsurface structures are in depth domain so we have to convert time sections into depth sections using velocities data.

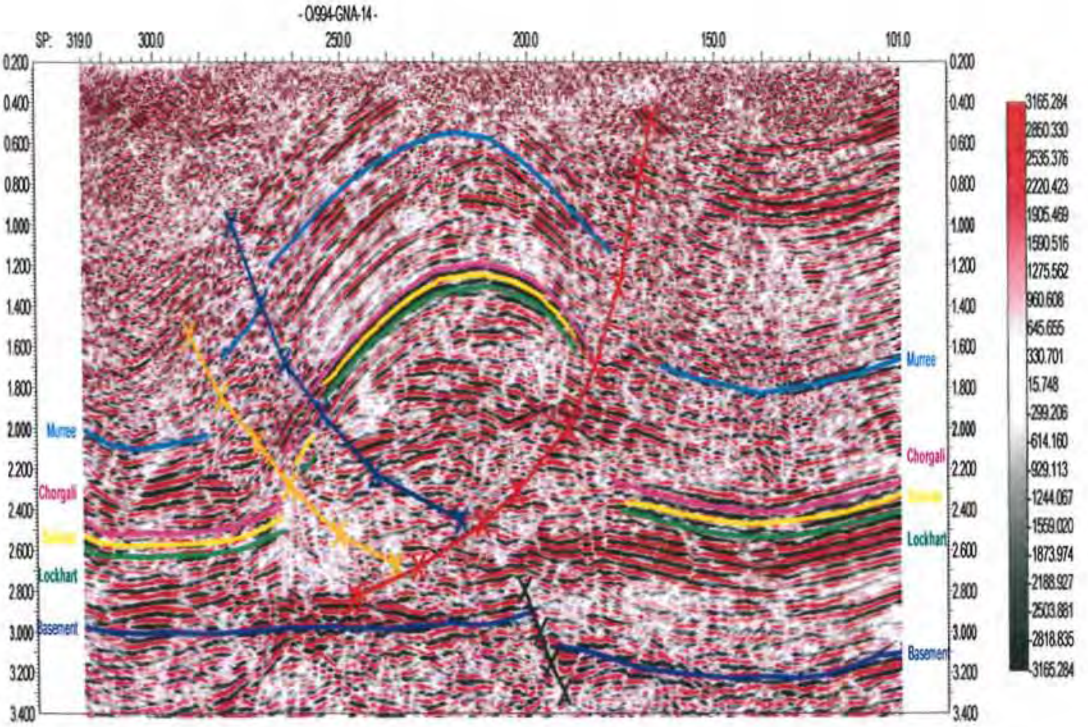


Figure 3. 5: Interpreted seismic line GNA-14. (SE-NW)

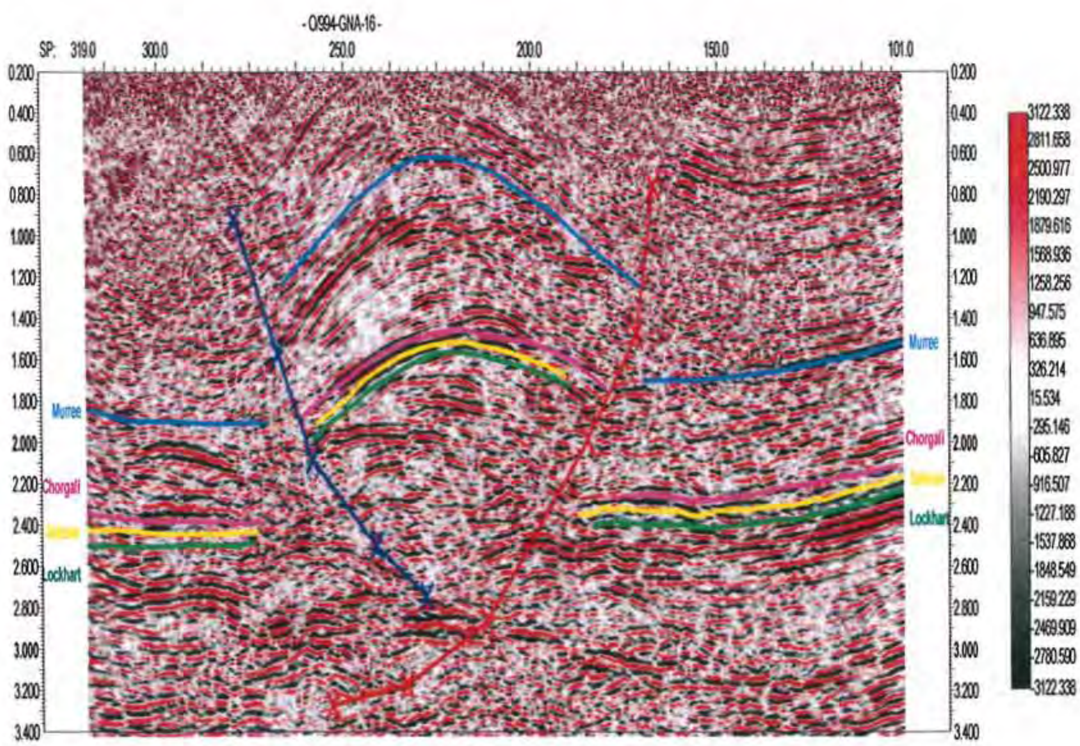


Figure 3. 6: Interpreted seismic line GNA-16. (SE-NW)

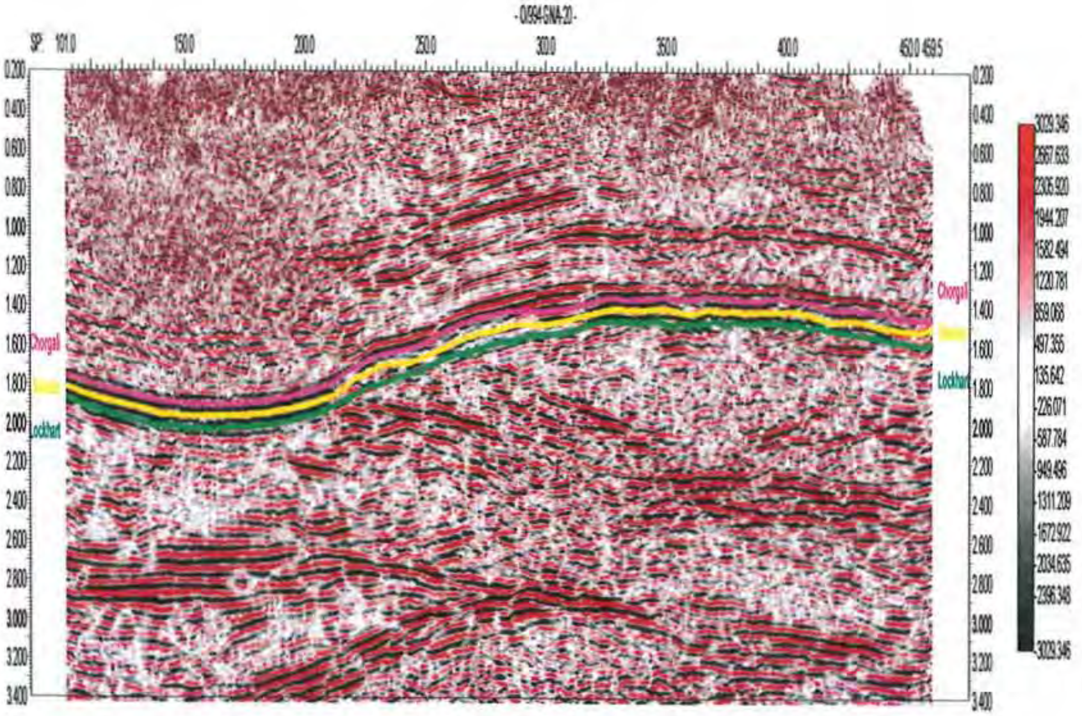


Figure 3. 7: Interpreted seismic line GNA-20. (SW-NE)

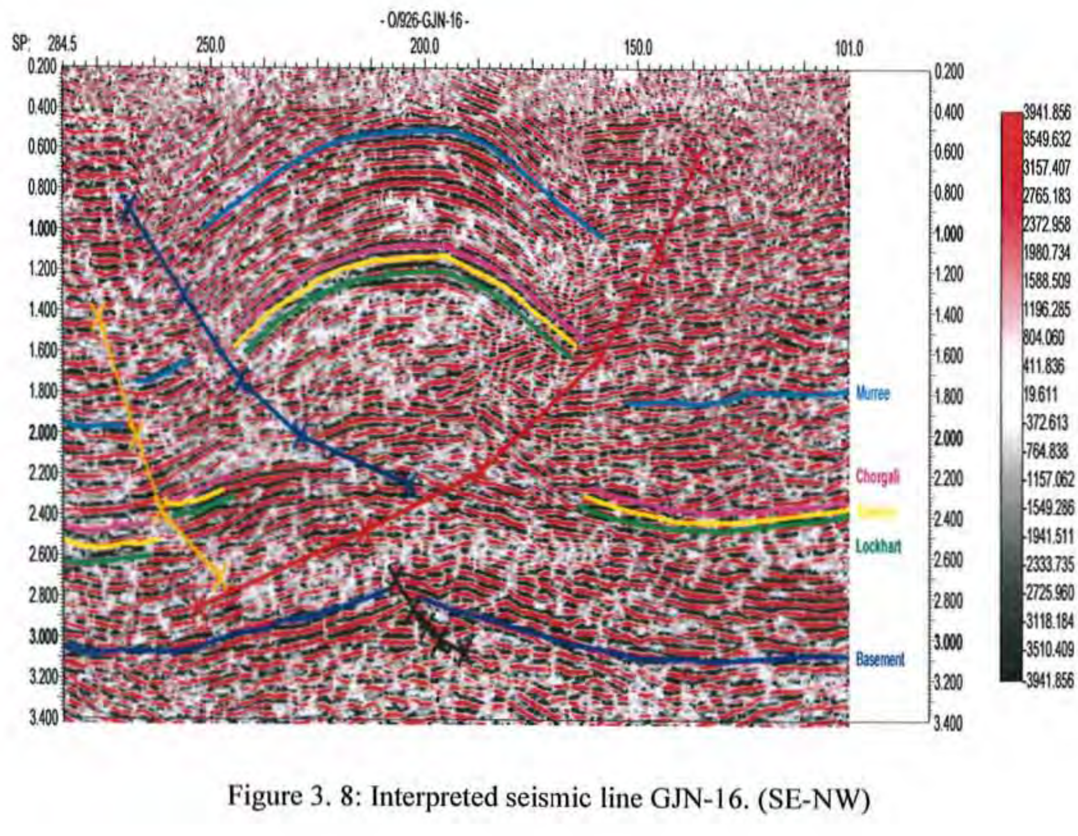


Figure 3. 8: Interpreted seismic line GJN-16. (SE-NW)

3.14 3D Time Surface Maps

The time contour maps, resulting from 2D-seismic lines are displayed as 3D surface to visualize the structural geometry displacements due to faults. Three formations Chorgali Sakessar & lockhart are displayed in cubes given in Figures 3.15.

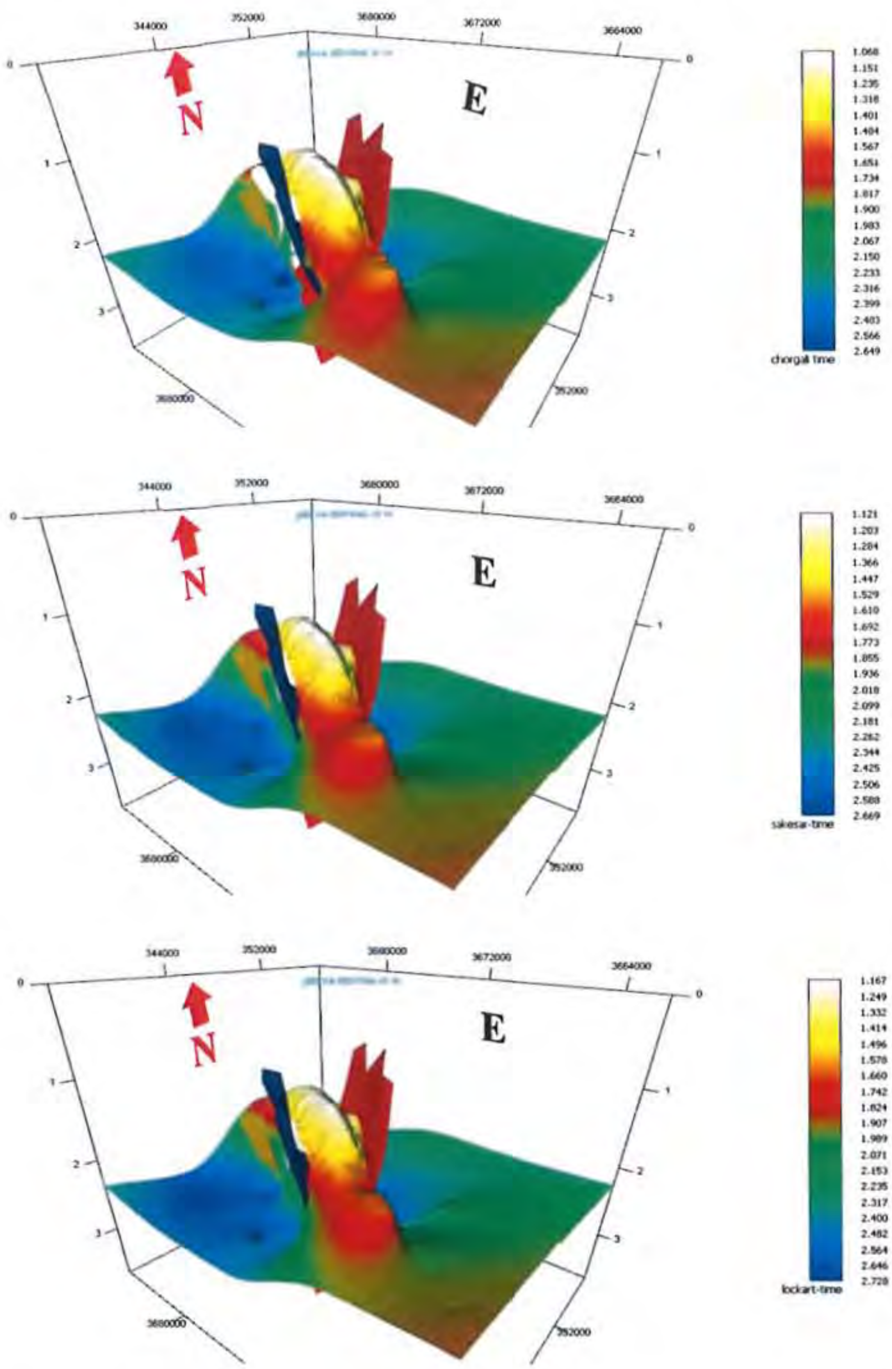


Figure 3.15: 3D time surface maps of Chorgali, Sakkesar & Lockhart.

CHAPTER NO 4

SEISMIC ATTRIBUTES

4.1 Introduction

Seismic Attributes are all the information obtained from seismic data, either by direct measurements or by logical or experience-based reasoning. The increasing reliance on seismic data requires that we gain the most information possible from the seismic reflection data. It empowers interpreters to obtain more information from seismic data. The study and interpretation of seismic attributes provide us with some qualitative information of the geometry and the physical parameters of the subsurface. It has been noted that the amplitude content of seismic data is the principal factor for the determination of physical parameters, such as the acoustic impedance, reflection coefficients, velocities, absorption etc. The phase component is the principal factor in determining the shapes of the reflectors, their geometrical configurations etc. The principal objectives of the attributes are to provide accurate and detailed information to the interpreter on structural, stratigraphic and lithological parameters of the seismic prospect (Taner 1994).

Attribute computations decompose seismic data into constituent attributes. There are no rules governing how attributes are computed. They are applicable in checking seismic data quality identifying artifacts, petroleum prospect identification, hydrocarbon play evaluation and reservoir characterization.

4.2 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. The increasing reliance on seismic data requires that we gain the most information possible from the seismic reflection data. It empowers interpreters to obtain more information from seismic data. Properly chosen seismic attributes highlights specific petrophysical or geological parameters like lithology, fluid content, and degree of fracturing.

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 4. 1: showing attributes and the geological information obtained from attributes

4.3 Types of Seismic Attributes

Attributes can be computed from pre- stack or from post- stack data, before or after time migration. The procedure is same in all these cases. Attributes can be classified in many ways. Several authors have given their own classification. Thus, attributes are of many types: pre-stack, post-stack, inversion, velocity, horizon, multicomponent 4-D.

Here we give a classification based on the domain characteristics of the attributes

4.3.1 Pre-Stack Attributes

Input data are CDP or image gather traces. They will have directional (azimuth) and offset related information. These computations generate huge amounts of data; hence they are not practical for initial studies. However, they contain considerable amounts of information that can be directly related to fluid content and fracture orientation. AVO, velocities and azimuthal variation of all attributes are included in this class (Taner 1994).

4.3.2 Post-Stack Attributes

Post stack attributes are derived from the stacked data. The Attribute is a result of the properties derived from the complex seismic signal. Azimuth related information. Input data could be CDP stacked or migrated. One should note that time migrated data will maintain their time relationships, hence temporal variables, such as frequency, will also retain their physical dimensions. For depth migrated sections, frequency is replaced by wave number, which is a function of propagation velocity and frequency. Post-stack attributes are a more manageable approach for observing large amounts of data in initial reconnaissance investigations (Taner 1994)

These attributes may be sub-classified based on the relationship to the geology.

4.3.3 Physical Attribute

Physical attributes relate to physical qualities and quantities. The magnitude of the trace envelope is proportional to the acoustic impedance contrast; frequencies relate to bed thickness, wave scattering and absorption. Instantaneous and average velocities directly relate to rock properties. Consequently, these attributes are mostly used for lithological classification and reservoir characterization (Taner 1994).

4.3.4 Geometric Attribute

Geometrical attributes describe the spatial and temporal relationship of all other attributes. Lateral continuity measured by semblance is a good indicator of bedding similarity as well as discontinuity. Bedding dips and curvatures give depositional information. Geometrical attributes are also of use for stratigraphic interpretation since they define event characteristics and their spatial relationships and may be used to quantify features that directly assist in the recognition of depositional patterns, and related lithology (Subrahmanyam 2008).

4.4 Attribute Analysis of Line 994-GNA-14

4.4.1 Trace Envelop

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

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

Figure 4.1 shows envelope attribute of line 994-GNA-14. Since this attribute is the square of the real and imaginary components of seismic trace, it always has a positive value. Thus, the vertical resolution of this attribute decreases and it is not able to highlight sand shale intervals. However, it is useful in highlighting the major lithological changes.

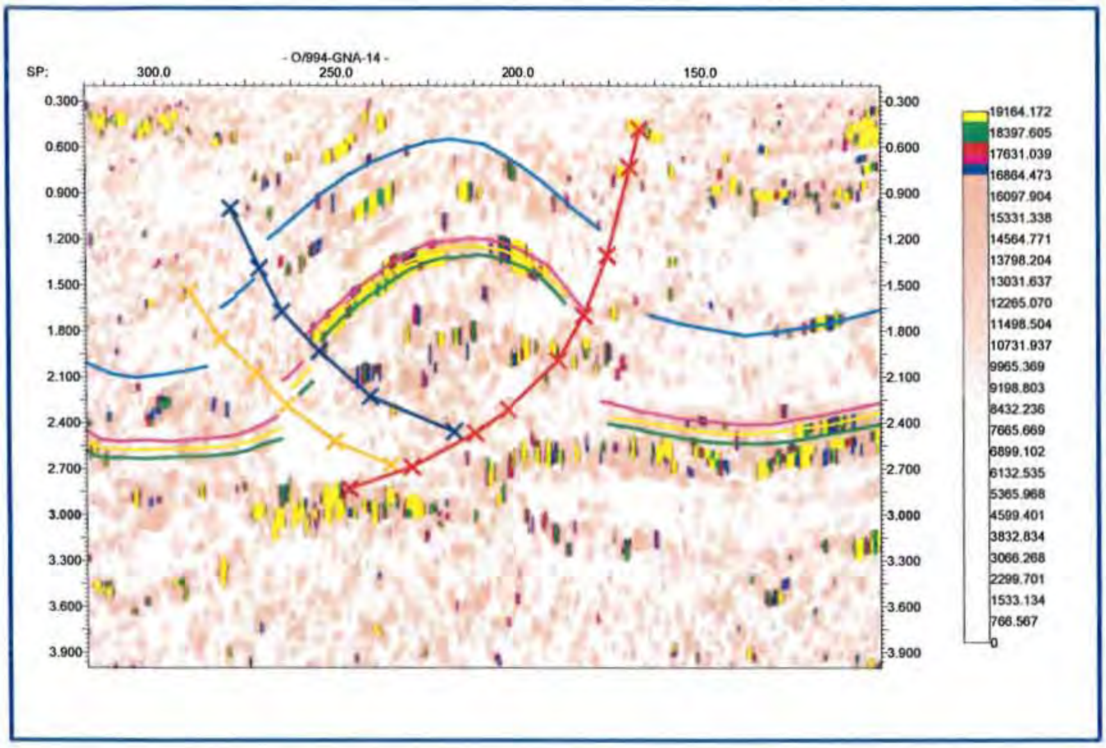


Figure 4. 1: Envelope Attribute Map of Line 994-GNA-14

4.4.2 Instantaneous Phase

Instantaneous Phase attribute is also a physical attribute and can be effectively used as discriminator for geometrical shape classifications. The phase information is independent of trace amplitudes and relates to the propagation of phase of the seismic wave front. It is computed from real and imaginary seismic traces using a mathematical relation as given below;

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

Where h(t) and f(t) are real and imaginary components of the seismic complex trace respectively.

Instantaneous phase used for following purposes:

- Efficient indicator of reflector continuity

- It can be used to highlight interface in sections with high decay of amplitudes and even highlight deeper horizons which are not visible in the normal amplitude sections
- Shows discontinuities
- Detailed visualization of bedding configuration (Subrahmanyam 2008).

Instantaneous phase highlights the continuity of reflectors. Since it is independent of amplitude, therefore it can highlight subsurface imagery in case of low amplitudes. Figure 4.2 shows instantaneous phase attribute of line 994-GNA-14. It is a good attribute to confirm the continuity of marked reflectors.

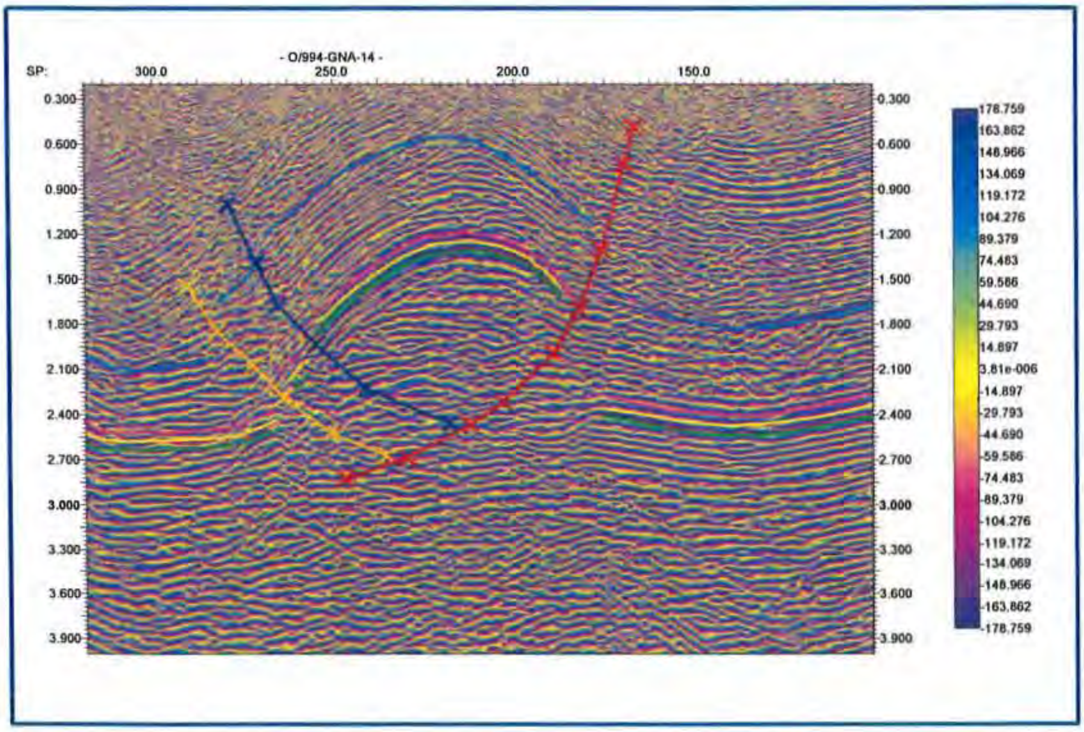


Figure 4. 2: Instantaneous Phase Attribute Calculated for Seismic Line 994-GNA-14

4.4.3 Instantaneous Frequency

Instantaneous Frequency (Hz) is the rate of change of phase over time. The instantaneous frequency attribute responds to both wave propagation effects and depositional characteristics; hence it is a physical attribute and can be used as an effective discriminator (Subrahmanyam 2008).

Its uses include:

- Hydrocarbon indicator by low frequency anomaly. This effect is sometimes accentuated by unconsolidated sands due to the oil content of the pores

- Fracture zone indicator, since fractures may appear as lower frequency zones
- Bed thickness indicator. Higher frequencies indicate sharp interfaces such as exhibited by thinly laminated shale, lower frequencies are indicative of more massive bedding geometries, e.g. sand-prone lithology.

Frequency attribute is used as a geologic indicator in several scenarios. It is most used to highlight the hydrocarbon reservoir with low frequency as the reservoir tends to absorb the higher frequencies. Figure 4.3 shows the frequency attribute of line 994-GNA-14 where the identified reservoirs are highlighted by low frequency.

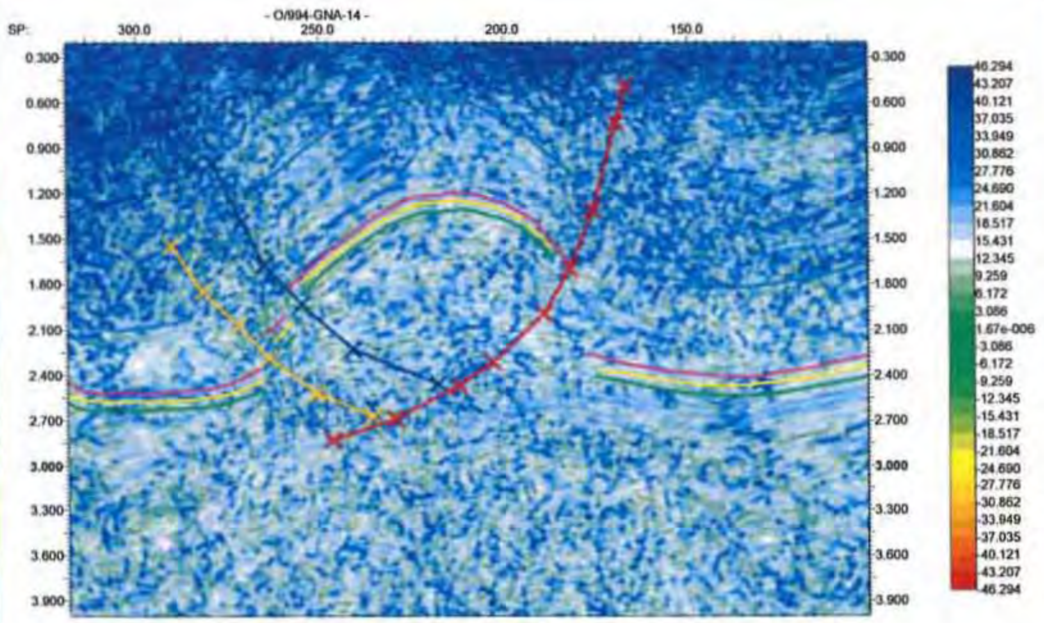


Figure 4. 3: Instantaneous Frequency Attribute Calculated for Seismic Line 994-GNA-14.

4.4.4 Apparent Polarity Attribute

Some of the instantaneous attributes like instantaneous frequency show very sharp and crispy signature therefore are difficult to interpret. Thus, wavelet attributes are computed over each cycle of the seismic trace (Khan, 2010).

Apparent polarity shows the blocky nature as it represents the average value over each cycle in the seismic trace which can be observed in Fig 4.4. Each peak in the reflection indicates the cycle.

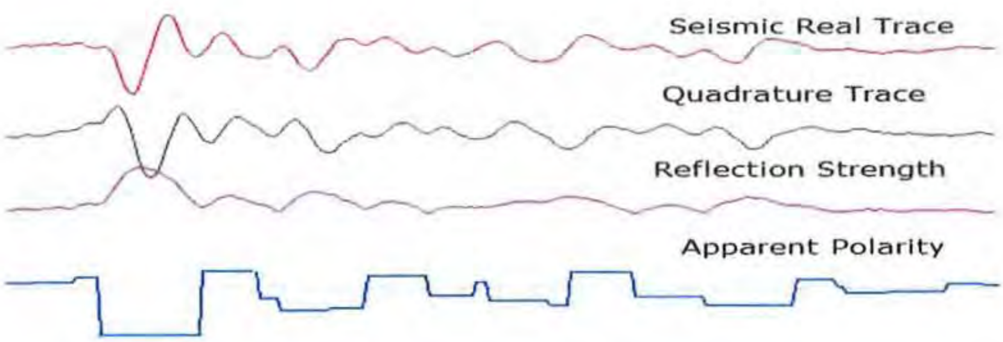


Figure 4. 4: Behaviour of Apparent polarity w.r.t seismic real trace and reflection

The attribute individually highlights the seal, reservoir and source rocks as shown in Figure 4.5. Negative value in the colour bar indicating trough region of the seismic trace.

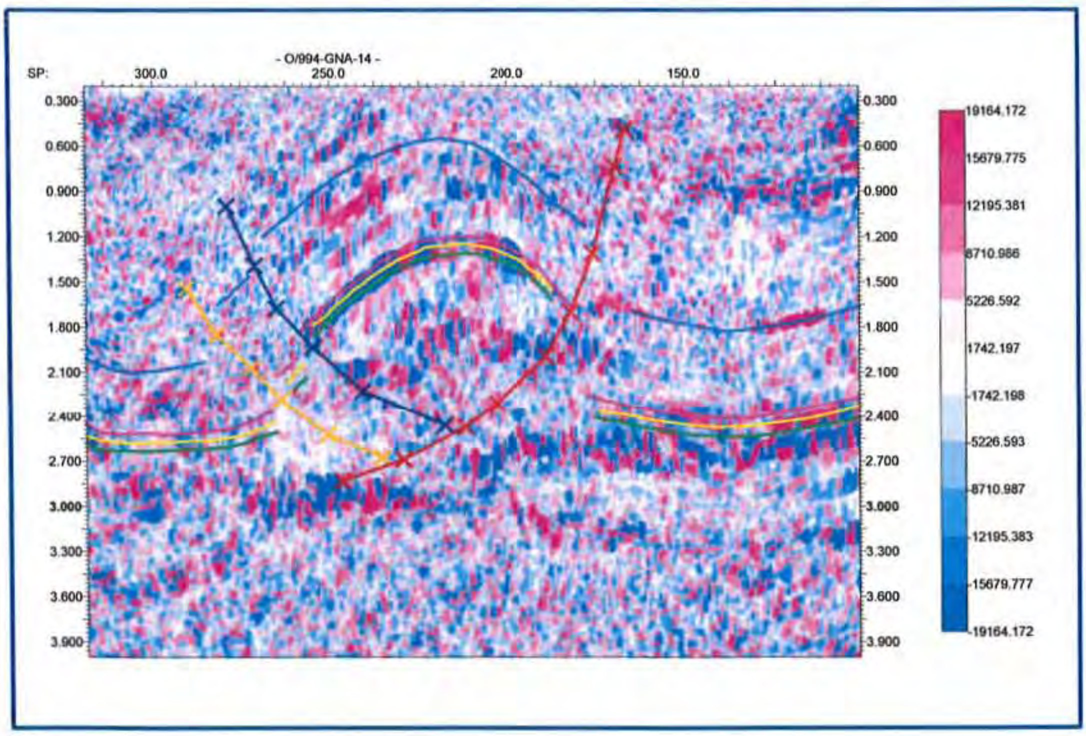


Figure 4. 5: Apparent Polarity Attribute for seismic line 994-GNA-14 showing the reflectors and faults.

4.5 Conclusion

Seismic attribute analysis is done for better structural interpretation and confirmation of results. The three attributes computed for the seismic line GNA-14, clearly confirm the interpretation by highlighting the zones of interest.

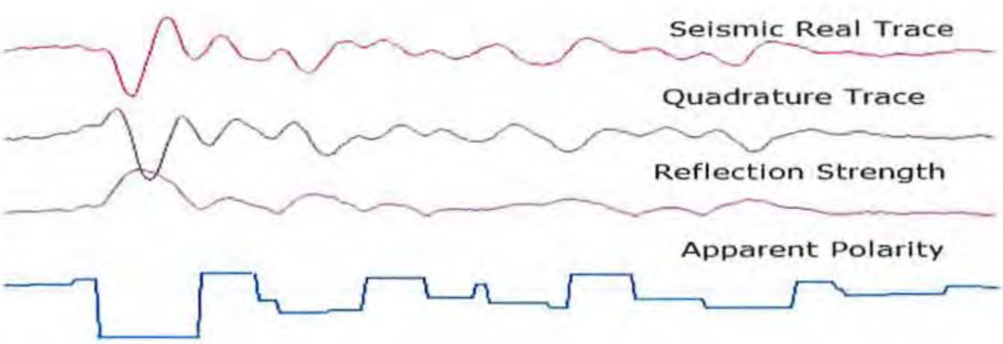


Figure 4. 4: Behaviour of Apparent polarity w.r.t seismic real trace and reflection

The attribute individually highlights the seal, reservoir and source rocks as shown in Figure 4.5. Negative value in the colour bar indicating trough region of the seismic trace.

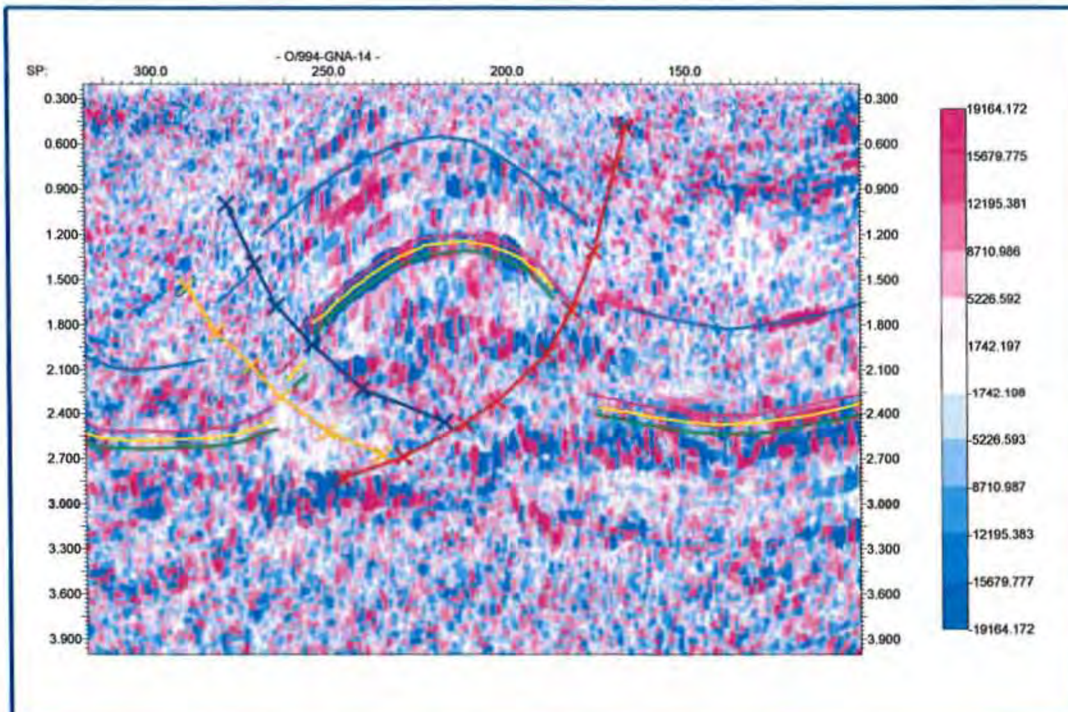


Figure 4. 5: Apparent Polarity Attribute for seismic line 994-GNA-14 showing the reflectors and faults.

4.5 Conclusion

Seismic attribute analysis is done for better structural interpretation and confirmation of results. The three attributes computed for the seismic line GNA-14, clearly confirm the interpretation by highlighting the zones of interest.

CHAPTER NO. 5

PETROPHYSICS

5.1 Introduction

Petrophysics is the study of rocks physical and chemical properties and their interactions with fluids (hydrocarbons, gasses, aqueous solutions). Petrophysical properties of porous and permeable rocks (mostly sandstone, limestone, dolomite, shale, and siltstone) have been measured to delineate hydrocarbon potential and transformability of the medium. Common petrophysical properties measured are lithology, shale/clay content, porosity (average and effective), permeability, resistivity of medium and aqueous solution and fluid saturations. Petrophysics not only deal to delineate reservoir quality of rock but also to determine composition, facies analysis, depositional environments and source rock potential.

5.2 Petrophysical Analysis

To perform petrophysical analysis, Formation data has been obtained by running complete well logging suite in a wellbore, drilled mostly up to targeted reservoir formation. These logs include GR, SP, Calliper, Resistivity, Neutron, Sonic and Density tools which obtain different formation physical and chemical parameters to extract petrophysical properties. These measured parameters have been plotted on specified scales and viewed on software (e.g. Techlog, GeoGraphix) to delineate reservoir zones called zones of interest for further calculation to determine others petrophysical properties.

5.3. Petrophysical Properties

5.3.1. Lithology

Lithology gives us the answer of the question that what type of rock is it. When combined with local geology and core study, geoscientists can use log measurements such as natural gamma ray, neutron, density, photoelectric absorption, resistivity or their combination to determine the lithology down hole.

5.3.2. Porosity

Porosity gives an indication of the rock's ability to store fluids. It is defined as the ratio of the pore volume to the bulk volume of the porous medium. Porosity may be classified as total or effective porosity. Total porosity accounts for all the pores in the rock (interconnected and isolated pores) whereas effective porosity only accounts for the interconnected pores. Therefore, effective porosity will be less than or equal to total porosity depending on the amount of isolated pores in the rock. From a reservoir engineering standpoint, it is the effective porosity that matters, not the total porosity.

Porosity may also be classified as primary or secondary. Primary porosity is that which was formed at the time of deposition of the sediments whereas secondary porosity was developed after deposition and burial of the formation. Sandstone porosity is practically all primary porosity whereas carbonate porosity tends to be secondary porosity. (Beard DC., 1973)

5.3.3 Permeability

Permeability is important because it is a rock property that relates to the rate at which hydrocarbons can be recovered. Values range considerably from less than 0.01 milli darcy (md) to well over 1 Darcy. A permeability of 0.1 md is generally considered minimum for oil production. Highly productive reservoirs commonly have permeability values in the Darcy range. Permeability is expressed by Darcy's Law:

$$Q = A\ (k/\mu)\ (\Delta p/L)$$

Where Q is rate of flow, k is permeability, μ is fluid viscosity, $(\Delta P)/L$ is the potential drop across a horizontal sample, and A is the cross-sectional area of the sample. Permeability is a rock property, viscosity is a fluid property, and $\Delta P/L$ is a measure of flow potential (Beard DC., 1973).

5.3.4 Relative Permeability

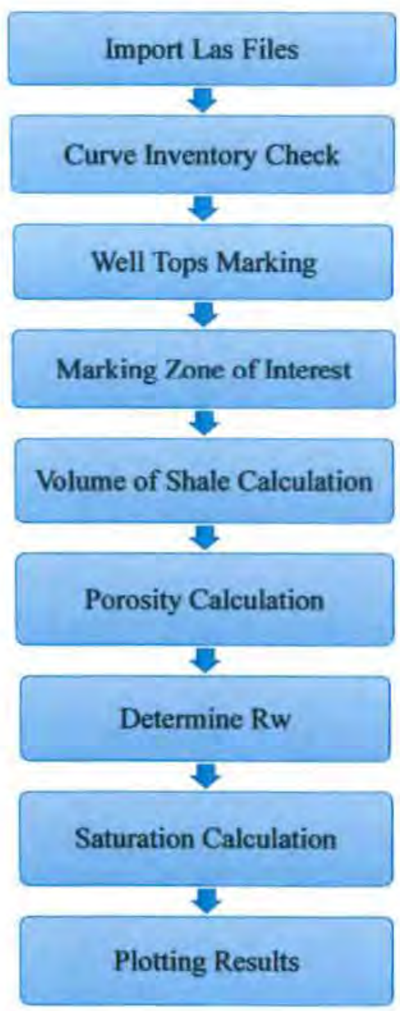
Relative permeability is simply the permeability measured at a specific fluid saturation expressed as a fraction of the total or absolute permeability. Absolute permeability is the permeability of a rock that is 100% saturated with a single fluid. In a water-wet rock only water can totally saturate the pore system, and brine permeability is normally taken as the absolute permeability. (Beard DC., 1973)

5.3.5 Effective Permeability

Effective permeability is the permeability of one fluid in the presence of another fluid measured at a specific saturation state. Effective permeability is always lower than the absolute permeability and will change as the saturation changes. Thus, if a rock 100% saturated with brine has a permeability of 50 md whereas the brine permeability in the presence of 50% oil saturation is 10 md, the relative permeability of brine at 50% oil saturation is said to be 0.2.

5.4 Methodology

Following methodology was adopted to conduct petrophysical analysis of well Missa Keswal-03 using Kingdom software. Petrophysical interpretation was conducted of each possible reservoir Formation.



5.4.1 Importing Las Files

Wireline logging data often stored and provided in las file format which need some software to display this data. In this research work Kingdom suite has been used to display log curves and to perform petrophysical analysis. Its made sure all the curves inventory when importing las files as sometimes default software setting can make error and not show all curves on display window. Log scales are checked as well and then well tops imported.

5.4.2 Mark Zone of Interest

After importing las files and well tops, all logs have been viewed to mark perspective zones where further detail petrophysical study will be carried out. This zone is called zone of interest and often marked on following basics:

- Good hole condition (Gauged hole).
- Low GR or CGR.
- High Deep Resistivity (LLD Value).
- Separation in Resistivity curves (MSFL and LLD).
- Low values of density and neutron logs which make good cross over.
- High Sonic Transit Time value.

Marking Zone of interest is very crucial and important in formation evaluation process and always mark by looking every data set / log available, and not rely on one or two logs to mark zone of interest.

5.4.3 Shale Volume Calculation

One of the major factor which impact reservoir property (porosity & Permeability) of matrix is volume of dirtiness or volume of shale. It doesn't mean we are measuring shale content but dirtiness content of matrix and correspondingly measure volume of clean. Several approaches made to measure volume of shale but here we use total gamma ray "GR" and computed gamma ray "CGR" to measure shale volume. GR represents total effect of potassium "K", thorium "Th" and uranium "U" whereas CGR eliminates the uranium effect and only represent the sum of potassium "K" and thorium "Th". So CGR is better tool to interpret lithologies having high radioactivity. (Paul. Glover)

$$IGR = \frac{(GR\ log - GR\ clean)}{(GR\ shale - GR\ clean)}$$

And

$$IGR = \frac{(CGR\ log - CGR\ clean)}{(CGR\ shale - CGR\ clean)}$$

Whereas

$$Vshale = f * (IGR)$$

In linear relationship, "f" is equal to 1 but several approaches have been made to adjust this "f" factor, here we use Stabier model to correct Vsh values.

5.4.4 Porosity Measurement

The highest important factor regarding reservoir evaluation to explore oil and gas is matrix porosity which refers to void spaces within the rock holding fluid. In reservoir evaluation porosity can be absolute or average porosity which corresponds the bulk pores within the rock body while another name effective porosity which corresponds only those pore spaces from which fluid can be extracted or through which fluid can flow to wellbore. Normally porosity present in clean or sandy lithology refers to effective porosity.

5.4.5 Density Porosity

Density tool measure bulk density of the formation to calculate porosity values. Density tool is padded tool and has less depth of investigation thus making at sensitive to borehole environment, same apply to neutron tool.

$$\emptyset D = \frac{(\rho max - \rho b)}{(\rho max - \rho f)}$$

$\emptyset D$ = Density porosity.

ρmax = Matrix density (2.65 for sandstone, 2.71 for limestone).

ρb = Bulk density of formation measured by log.

ρf = Filtrate density (1 for fresh water mud system, 1.1 for saline mud system).

5.4.6 Sonic Porosity

Sonic tool used sound waves to measure interval transit time of formation to calculate porosity. Sonic tool has advantage that it works well in bad borehole environment where density and neutron tools give wrong readings.

$$\emptyset s = \frac{(\Delta T - \Delta Tmax)}{(\Delta Tf - \Delta Tmax)}$$

Øs = Sonic porosity.

ΔT = Transit time measured by log.

$\Delta Tmax$ = Transit time of matrix. (55.5 for sandstone, 47.6 for limestone).

ΔTf = Transit time in fluid. (182 – 168 or 156).

Whereas neutron porosity (ØN) is direct measurement of neutron log to measure fluid filled porosity of formation.

5.4.7 Average Porosity

Neutron and Density tools both give false porosity readings in presence of hydrocarbon, as hydrocarbon poses low density and hydrogen index. If we plot neutron and density values on same track but in reverse scale direction to each other, then both curves will go opposite to each other and make cross over (also called gas effect) in hydrocarbon bearing zone. Here both tools are reading less porosity but giving good indication of hydrocarbon presence. To correct this porosity error, we take average of neutron and density porosity values.

$$\emptyset avg = \frac{(\emptyset N + \emptyset D)}{2}$$

5.4.8 Effective porosity

Effective porosity corresponds to those pore spaces favorable for fluid to flow through it. Clean rocks with low amount of volume of shale poses good effective porosity rather than shaly rocks. So, to measure effective porosity, product of average porosity and volume clean has been taken.

$$\emptyset e = \emptyset avg * Vclean$$

$$\emptyset e = \emptyset s * Vclean$$

5.4.9 Determination of Rw

One of the most important parameters required to calculate hydrocarbon in place from wireline logs data is resistivity of formation water or connate water uncontaminated from drilling mud or filtrate. The most accurate way to calculate Rw is by measuring resistivity or chemical composition of water produced from formation. If produced formation water is not available then wireline logs measured parameters are utilized to calculate Rw. Here two methods have been used to determine Rw. a) Rwa / Hingle method, b) Pickett plot method.

5.4.9.1 Pickett Plot Method

Another good way to determine formation water resistivity is pickett plot method (named after G.R. Pickett), which is a graphical representation of Archie's equation in terms of resistivity. Archie equation is resolved for resistivity:

$$Rt = \frac{a * Rw}{\emptyset^m * Sw^n}$$

Taking algorithm:

$$\log Rt = \log(a * Rw) - m.\log(\emptyset) - n.\log(Sw)$$

If zone is 100% water bearing then Sw = 1 and log(Sw) = 0, and above equation will reduce to:

$$\log Rt = \log(a * Rw) - m.\log(\emptyset)$$

Equation in this form $(y = b + mx)$ shows that if resistivity 'Rt' plotted on y-sclae and porosity '$\emptyset$' on x-axis and both on logarithmic scale, one can determine the product of (a*Rw) from intercept of the line 'b' and cementation exponent 'm' from slope of the line 'm'.

In practice formation resistivity 'Rt' is normally plotted on x-axis and porosity '$\emptyset$' on y-axis. In this convention equation will be:

$$\log(\emptyset) = \log(a * Rw) - \frac{1}{m}\log(Rt) - nlog(Sw)$$

resistivity in Kadanwari-10. Rw calculated by Hingle method is 0.124 ohm.m.

5.4.10 Calculation of Saturation

Most important and somehow ultimate objective of any Petrophysicist is to determine water saturation, which is the fraction of pore volume occupied by a certain fluid. (Flevry, Efnik et al, 2004). Different saturation model is used to determine fluid content dependent upon either the reservoir is clean or shaly. Most common approach is Archie model to calculate water saturation which relates saturation of water to formation water resistivity, porosity, and resistivity of saturated zone. (Alfosail and Alkaabi 1997).

5.4.10.1 Archie's Model

$$Sw^n = a * Rw \,/\, \emptyset e^m * Rt$$

Where

a = Tortuosity factor

m = cementation exponent

n = Saturation exponent

$\emptyset e$ = Effective porosity

Sw = Saturation of water

Rw = Resistivity of Formation water

Rt = Formation resistivity

Archie took rock matrix as an insulator to electric current and model was established for clean rocks, so it doesn't consider the clayey rocks. Clean formations tend to exhibit as electric insulator, so only fluid in pore spaces contribute to conductivity of electric current. (Worthington 1985).

5.5 Chorgali

Choargali Formation ranges from 1870 to 1914 meters, having gross thickness of 44 meters is shown in figure 5.1. Upper portion of Chorgali Formation has low borehole rugosity and volume of shale ranges from 20 to 30%. Average effective porosity in upper portion of Chorgali Formation is about 6% whereas average saturation of water is above 90%. Lower porion of Chorgali Formation has high borehole rugosity with volume of shale ranges from 55 to 60%. Average effective porosity in lower portion is about 10% whereas average saturation of water is about 70%. Overall, no prominent hydrocarbon bearing zone has encountered in Chorgali Formation.

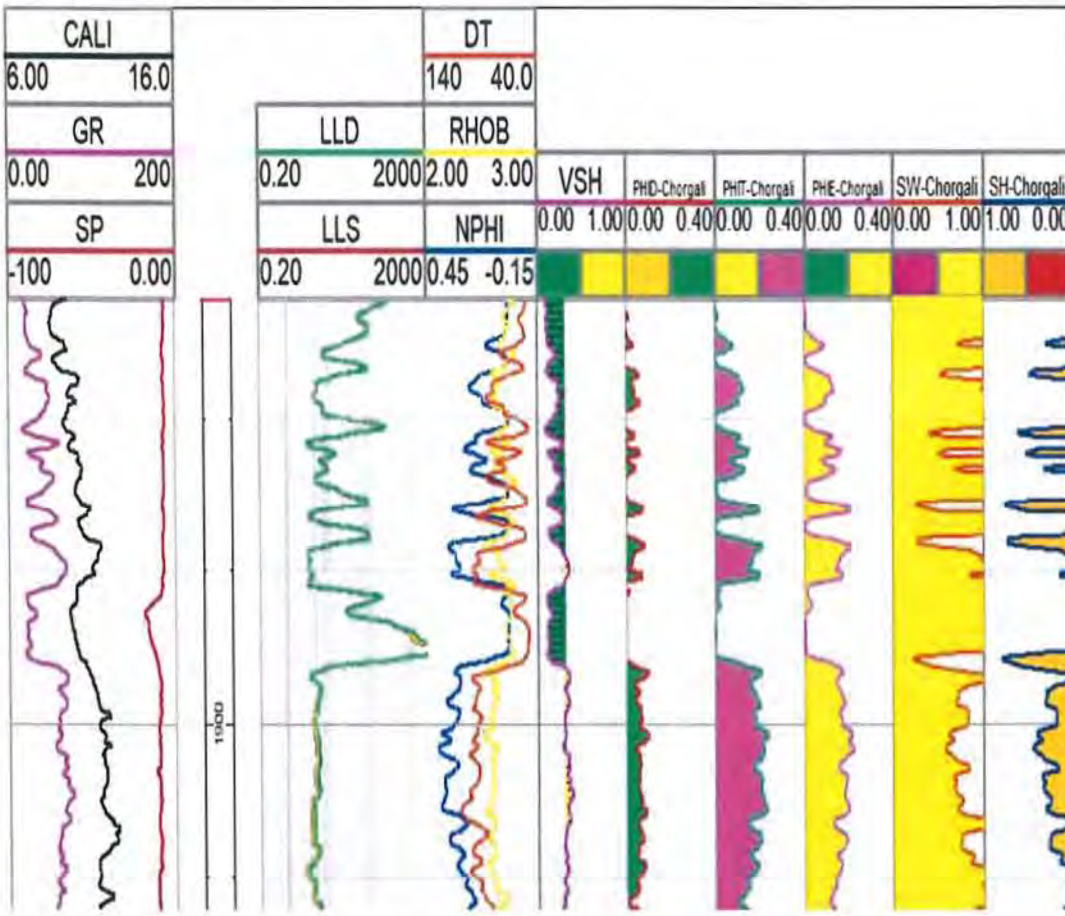


Figure 5. 1: Petrophysical analysis of Chorgali.

5.6 Sakessar

Sakessar Formation ranges from 1914 to 1983 meters, having gross thickness of 69 meters, shown in figure 5.2. Sakessar Formation exhibit good, gauged hole as borehole rugosity is very low. Upper portion of Sakessar formation is clean with more than 90%

volume of clean while lower portion has some volume of shale which ranges from 15 to 20%. Both average and Effective porosities are extremely low throughout the Sakessar Formation in Missa Keswal well-03. There is no significant Hydrocarbon bearing portion throughout the Sakessar Formation as all the formation has water saturation more than 85%.

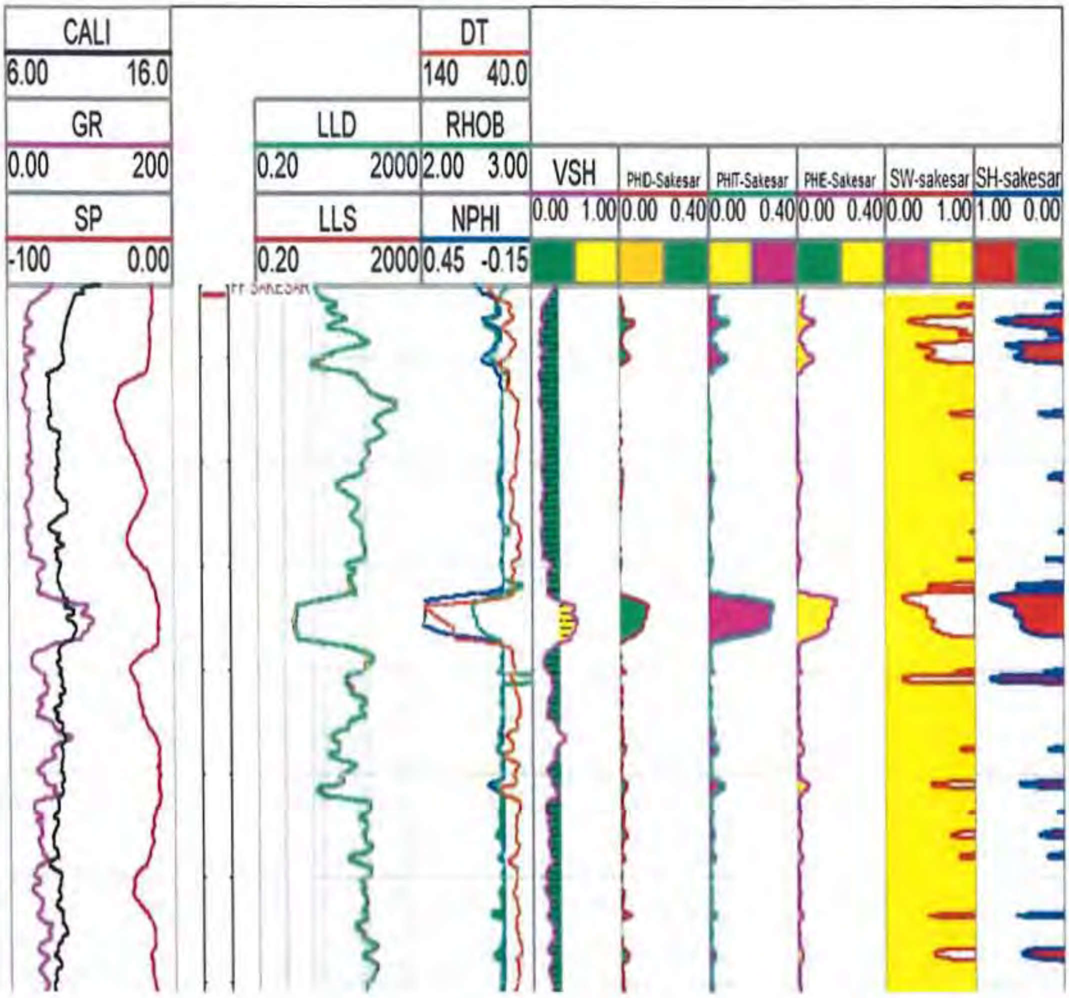


Figure 5. 2:Petrophysical analysis of Sakesssar.

5.7 Lockhart

Lockhart Formation ranges from 2004 to 2017 meters with gross thickness of 13 meters is shown in figure 5.4. Borehole rugosity is very low which marks a good, gauged borehole. Average volume of clean in Lockhart is 70% but average effective porosity is only 5% which makes it unfavorable to consider as prominent reservoir formation. Moreover, Neutron-density crossover is absent and resistivity values are also lower side. Though there is about 70% average saturation of hydrocarbon but due to low porosity and higher shaliness, Lockhart Formation in Missa Keswal Well-03 cannot be considered as prominent reservoir.

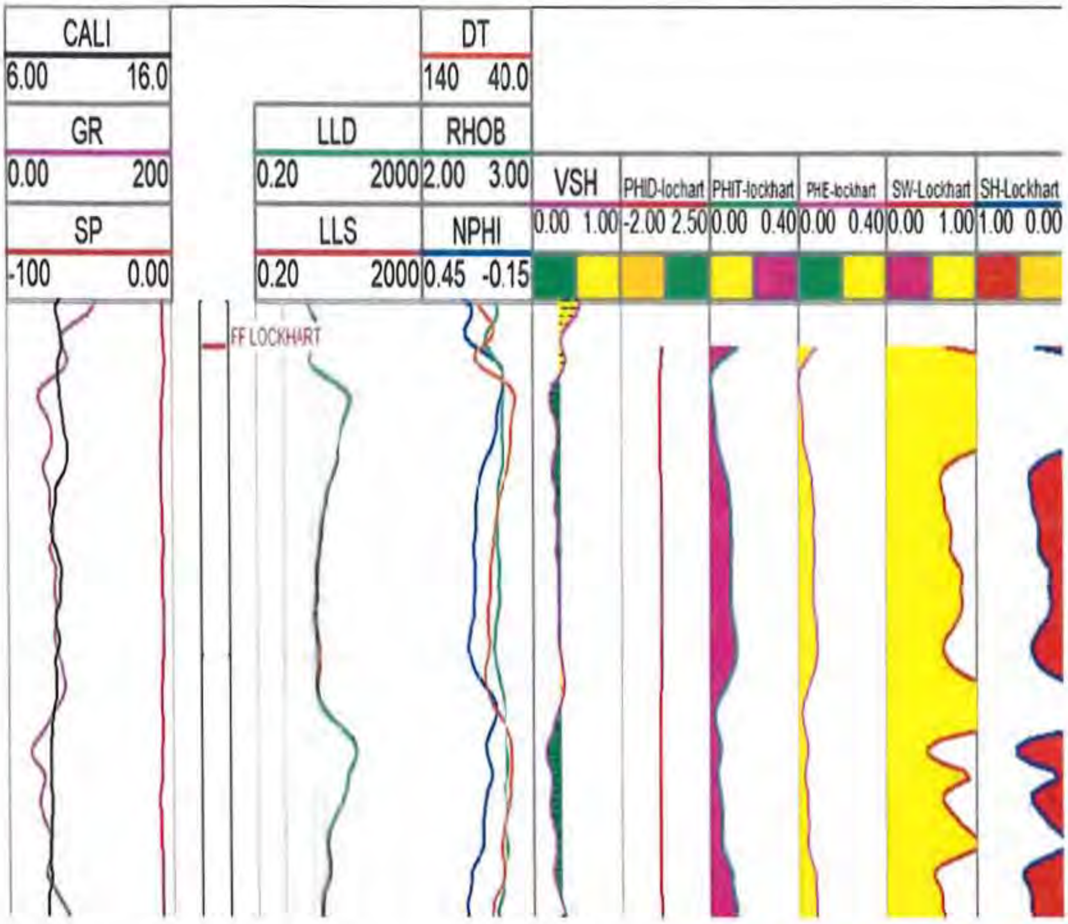


Figure 5. 3:Petrophysical analysis of Lockhart.

5.8 Khewra Sandstone

Khewra Sandstone Formation ranges from 2143 to 2245 meters with gross thickness of 102 meters is shown in figure 5.3. Borehole rugosity is absent throughput the formation which marks it a good, gauged borehole. Average volume of clean in Khewra Sandstone is 30% and average effective porosity is below 5% which makes it unfavorable to consider as prominent reservoir formation. Moreover, no prominent Neutron-density crossover is seen and resistivity values are also on lower side. Saturation of water is above 90% throughout the formation except upper most portion where saturation of water is about 60%. No prominent hydrocarbon reservoir feature is seen in Khewra Sanstone Formation in Missa Keswal well-03.

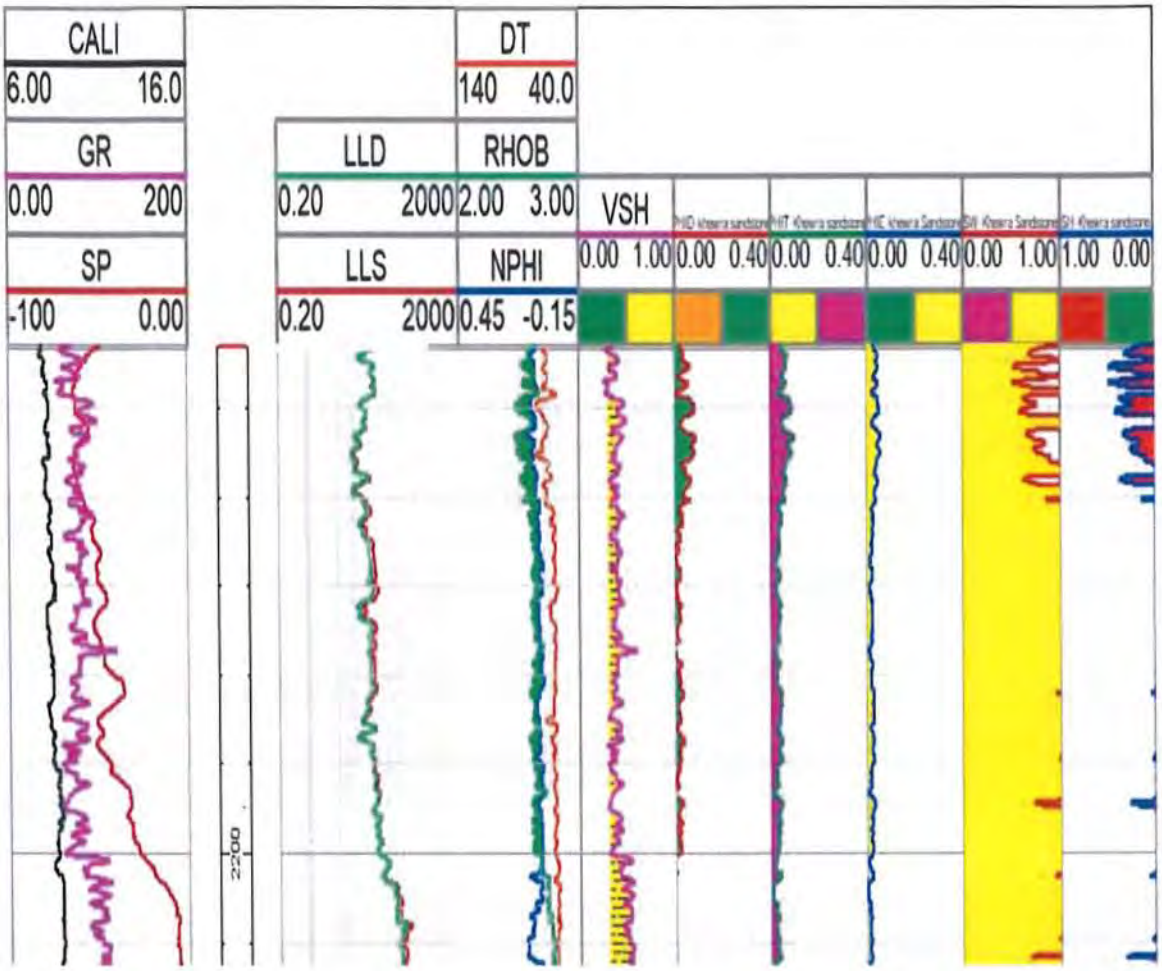


Figure 5. 4: Petrophysical analysis of Khewra Sandstone.

5.9 Summary

Formation	Vcl.	PHIA	PHIE	Rw	Sw
Chorgali	73%	13%	07%	0.075	75%
Sakessar	82%	03%	02%	0.09	87%
Lockhart	70%	08%	05%	0.016	35%
Khewra Sandstone	76%	06%	04%	0.015	75%

Table 5. 1: Summary of petrophysics analysis.

CHAPTER NO. 6

ROCK PHYSICS & FACIES MODELLING

6.1 Introduction

Rock Physics is an integration science linking seismic data, its derived attributes, Petrophysical data, computed as well as lab measured elastic parameters and core data. Rock Physics describes a reservoir rock by physical properties such as porosity, rigidity, compressibility, properties that affect how seismic waves physically travel through the rocks. It consists of a wide range of empirical relations that have been established through best-fit least square regression. Correlations can be established between any two or more rock properties that can be used to compute one rock parameter with another.

Rock physics templates have been developed to visualize lithological and mineralogical variations in terms of Petrophysical logs; derived rock physics derived seismic attributes and can be applied for the quantitative interpretation of well log and seismic data. Figure 6.1 shows the Petrophysical logs of well Missa Keswal-03 for the depth range 2227 to 2627 meter. To compute the elastic logs we need sonic, shear sonic and density logs. Since shear log is not available for this well. Thus, the Castagna et al., (1993) empirical relationship is used to compute the shear velocity from the P-wave velocity (sonic) log.

The Petrophysical logs along with the computed Acoustic Impedance and Elastic Logs are used in various types of cross plot for classification or facies modeling.

Brief description of each elastic parameter is given below.

6.1.1 Acoustic Impedance (AI)

Acoustic impedance is a layer property of a rock and is equal to the product of compressional velocity and density. The density log and the compressional wave velocity log generated from the DT log are used to compute the acoustic impedance log by using equation:

$$AI = V_P \times \rho_b$$

Where, ρb is the density of the formation and Vp is he compressional wave velocity.

6.1.2 Shear Impedance (SI)

Shear impedance is a layer property of a rock and is equal to the product of shear velocity and density also known as elastic impedance. Similarly, as acoustic impedance the density log and the shear wave velocity derived from the Castagna et al., (1993) empirical relation was used to generate the shear impedance log using equation:

$$SI = V_S \times \rho_b$$

Where, ρb is the density of the formation and Vs is the shear wave velocity.

6.1.3 Young's Modulus (E)

This modulus is obtained to measure the stiffness of the material. The relation between the density, compressional wave velocity, young's modulus, and shear wave velocity is given in equation (Mavko et al., 2009).

$$E = \frac{\rho V_s^2 (3V_P^2 - 4V_S^2)}{V_P^2 - V_P^2}$$

Where, ρ is the density that is obtained from the density (RHOB) log, Vs and Vp are the shear wave and compressional wave velocity that is obtained from the sonic log (DT).

6.1.4 Poisson's Ratio (σ)

The Poisson's ratio is used to indicate the maturity of the shale oil/gas zone. The low value of poisson's ratio will indicate the mature oil/gas shale zone. The relation between the poisson's ratio, compressional wave velocity, and shear wave velocity is given in equation (Mavko et al., 2009).

$$\sigma = \frac{\left(\frac{V_P}{V_S}\right)^2 - 2}{2\left(\frac{V_P}{V_S}\right)^2 - 2}$$

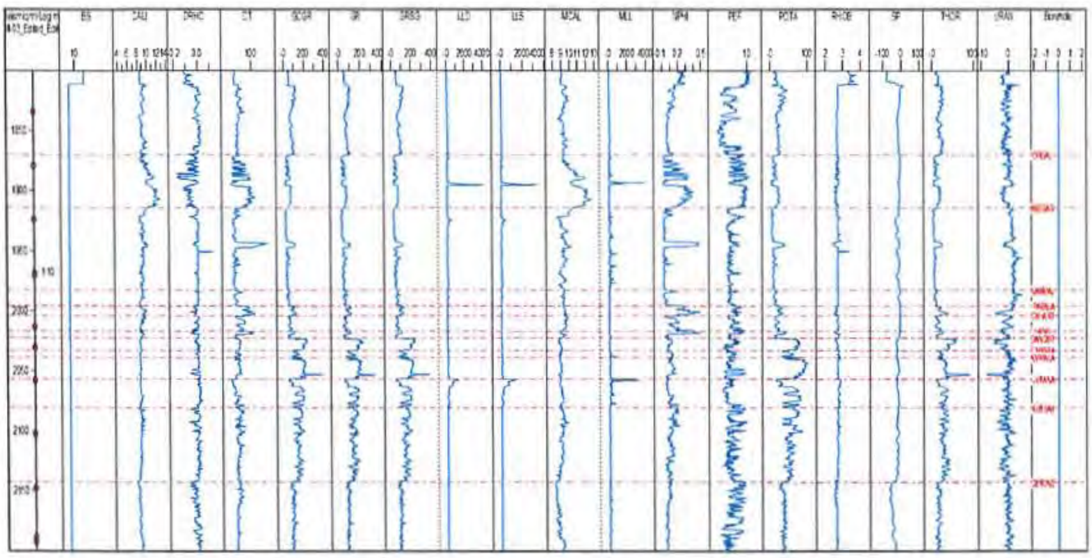


Figure 6. 1: Petrophysical logs of Missa Keswal-03.

6.2 Computation of Elastic Logs

The P-wave velocity (sonic) log, S-wave velocity (computed shear sonic) log and density log are used to compute the elastic logs of various moduli along with acoustic impedance and shear acoustic impedance logs as shown in Figure 6.2.

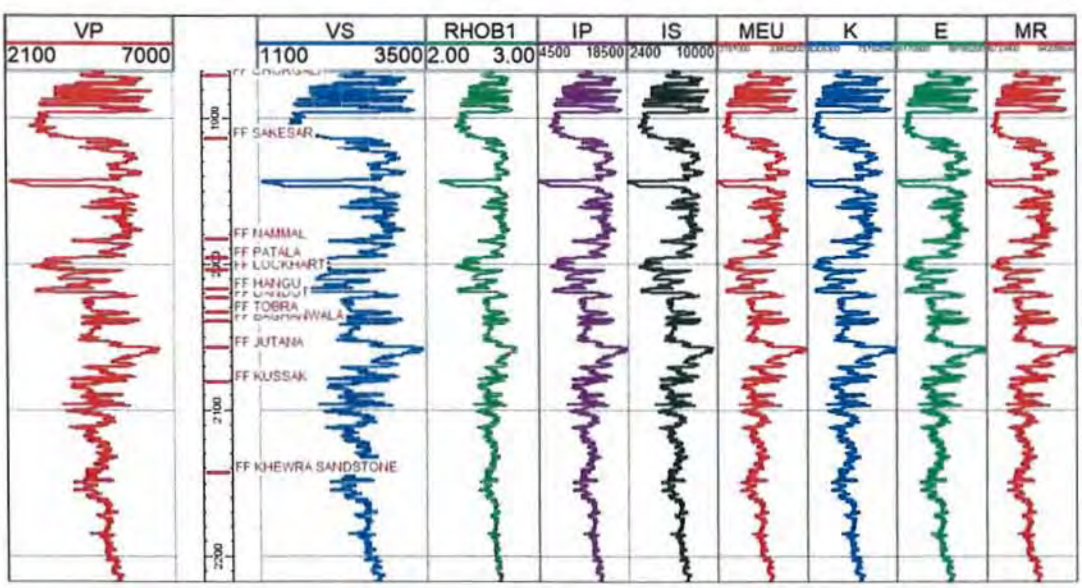


Figure 6.2: AI and Elastic Logs computed from Petrophysical logs of Missa Keswal-03

6.3 Facies Modeling

Cross plot based facies analysis is an important methodology accepted worldwide to properly characterize a hydrocarbon reservoir and exploit the remaining volumes in development phase. Common methods for cross plot based facies modeling are polygon bounds and cluster analysis. In this study the polygon method is used for facies modeling. With the help of Log data different cross plots which are compared with the standard cross plots to identify the lithologies, and the prospect zone to be marked.

6.3.1 Porosity Vs Density

Porosity versus density is a standard cross plot template for classification of facies as shown in Figure 6.3. The GR log is used for lithology classification. It can be observed that the facies modeling results of this log are comparable with the interpretation of previous cross plots.

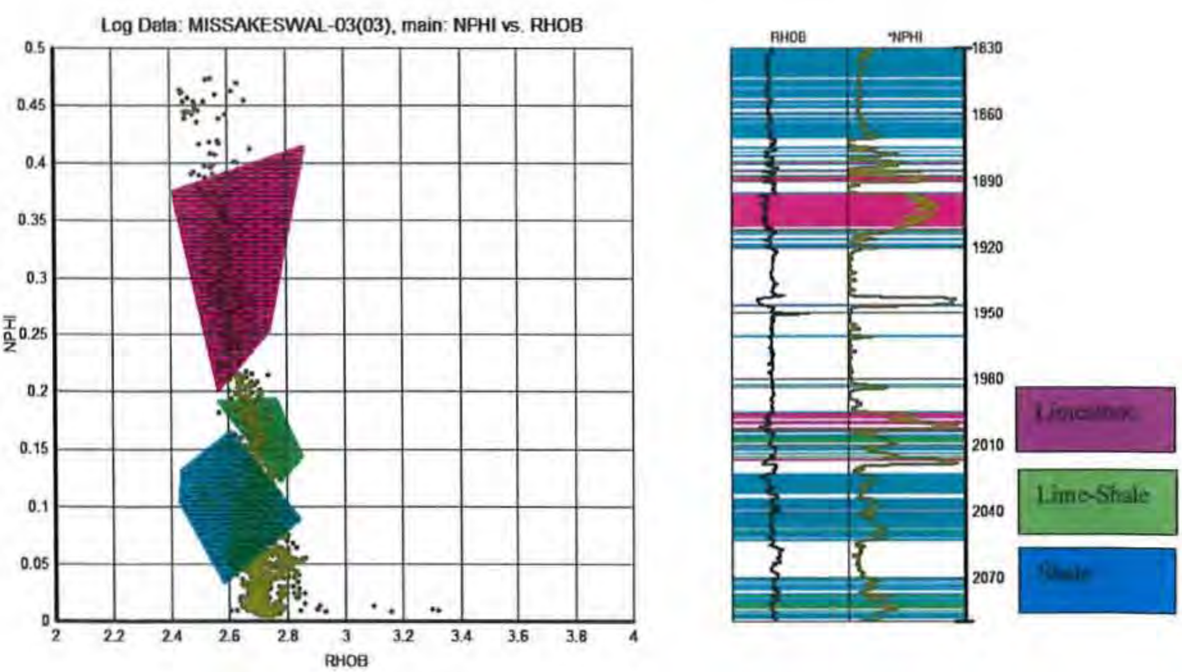


Figure 6.3: Porosity Vs Density Cross-plot

6.3.2 Vp Vs NPHI

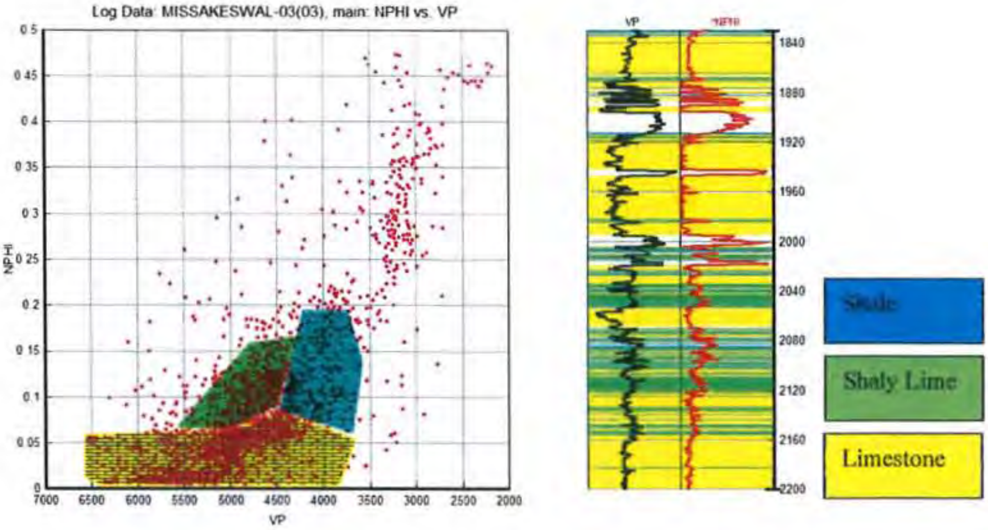


Figure 6.4: Vp Vs NPHI crossplot

6.3.2 RHOB Vs MeuRoh

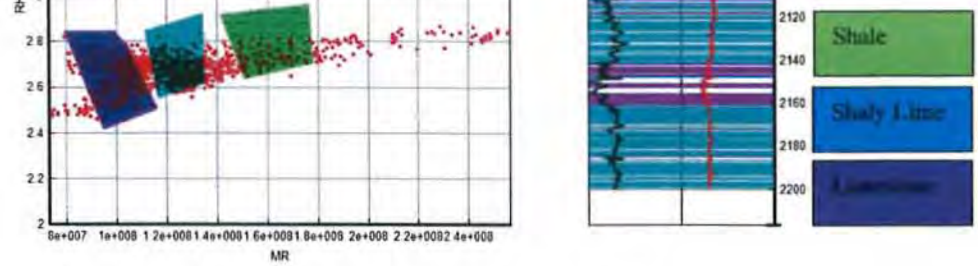


Figure 6.5: RHOB Vs MeuRoh Crossplot

6.4 Conclusion

The different cross plots are generated using the petrophysical logs and elastic logs computed from P wave velocity. On the basis of bulk density range, neutron porosity, p wave velocity, and elastic moduli different lithologies(limestone, sandstone and shales) are marked crossponding to their ranges.

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 subsurface structure.
- Time and Depth contour maps of formations help us to confirm the presence of anticlinal structure in the given area. Surface contour map of formation 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 of 2030 to 2140 meters, which indicate shaleness in the deeper horizons.
- Petrophysical analysis of the reservoir show no hydrocarbon potential.
- The overall results indicate no economic viability of Chorgali, Sakesar, Lockhart & Khewra as a reservoir in Missa Keswal-03.
- Facies Analysis confirms the lithologies limestone, sandstone and shales in different intervals.

REFERENCES

1. Alfosail, K. A., & Alkaabi, A. U. (1997, January). Water saturation in shaly formation. In Middle East oil show and conference. Society of Petroleum Engineers.

2. Amir, M., and Siddiqui, M.M., 2006. Interpretation and visualization of thrust sheets in triangular zone in eastern Potwar, OGDCL, Islamabad, Pakistan.

3. Beard, D. C., & Weyl, P. K. (1973). Influence of texture on porosity and permeability of unconsolidated sand. AAPG bulletin, 57(2), 349-369.

4. Coffeen, J. A. (1986). Seismic exploration fundamentals: Tulsa, OK, PennWell Pub.

5. D.Subrahmanyam, P.H.Rao, (2008), Seiesmic attributes – a Review, 7th International conference ans exposition of Geo physics, Hyderabad, India

6. Dobrin M.B. and C.H. Savit Introduction to Geophysical Prospecting [Book]. - [s.l.]: McGraw Hill Company, 1976.

7. Fleury, M., Efnik, M., & Kalam, M. Z. (2004, October). Evaluation of water saturation from resistivity in a carbonate field. From laboratory to logs. In Proceedings of International Symposium of the Society of Core Analysts, Abu Dhabi, UAE (pp. 5-9).

8. Glover, P. W. (2010). A generalized Archie's law for n phases. Geophysics, 75(6), E247-E265.

9. Jurgan, H., & Abbas, G. (1991). On the Chorgali Formation at the type locality. Pakistan Journal of Hydrocarbon Research, 3(1), 35-45.

10. Kazmi [et al.] Geology and Tectonics of Pakistan [Book]. - Karachi: Graphic Publishers, 1997

11. Khan, K.A., Akhter, G., and Ahmad, Z., 2010, OIL - Output Input Language for Data Connectivity between Geoscientific Software Applications, Computers & Geosciences, Vol 36, pp. 687-697

12. Latif, M. A. (1970). Micropalaeontology of the Chanali Limestone, Upper Cretaceous, of Hazara, West Pakistan. Jahrb. Geol. BA, Bundesanst, 15, 25-61.

13. Mavko, G., & Bandyopadhyay, K. (2009). Approximate fluid substitution for vertical velocities in weakly anisotropic VTI rocks. Geophysics, 74(1), D1-D6.

14. McQuillin, R., Bacon, M., and Barcaly, W., 1984 An introduction to seismic interpretation, Graham & Trotman Limited Sterling House, 66 Wilton Road London SW1V 1DE

15. Robinson, E. S., & Coruh, C. (1988). Basic Exploration Geophysics John Wiley & Sons. New York.

16. Robinson, E.S., and Coruh, C., 1988, Basic Exploration Geophysics, John Wiley & Sons, Inc Newyork.

17. Saqib,R., Rehman,S., and Ajmal, N.,(1998).Identification of Potential Oil Sites Using Remote Sensing & GIS Technology; a case study of Missa Keswal area District Jhelum, Punjab Province [Journal].

18. Sercombe, W. J., Pivnik, D. A., Wilson, W. P., Albertin, M. L., Beck, R. A., & Stratton, M. A. (1998). Wrench faulting in the northern Pakistan foreland. AAPG bulletin, 82(11), 2003-2030.

19. Sheriff, R.E., 1999. Encyclopedic dictionary of exploration geophysics, S.E.G., Tulsa, Oklahoma.

20. Subrahmanyam. (2008). Seismic Attributes- A Review. 7th International Conference and Exposition on Petroleum Geophysics, (pages 398-404). Hyderabad, India.

21. Taner, M. T. (1994). Seismic attributes revisited M. Turhan Taner*, Seismic Research Corporation, James S. Schuelke, Mobil Oil Corporation, Ronen O'Doherty, Seismic Research Corporation, and Edip Baysal.

22. Worthington, P. F. (1985). The evolution of shaly-sand concepts in reservoir evaluation. The Log Analyst, 26(01).

23. Yilmaz, Ö. (2001). Seismic data analysis: Processing, inversion, and interpretation of seismic data. Society of exploration geophysicists.