2D-Integrated Seismic Interpretation, Petrophysical and Facies Analysis, Attribute Analysis and Post Stack Colored Inversion of Chak Naurang area, Upper Indus Basin, Pakistan

By

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BS Geophysics

(2016-2020)

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“PAY THANKS TO ALLAH EVERY MOMENT AND GO TO EXPLORE THE HIDDEN TREASURES, ITS ALL FOR YOUR BENEFIT” (AL-QURAN).

CERTIFICATE

This dissertation submitted by Abdul Haseeb Aslam S/o Muhammad Aslam 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.

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Acknowledgement

As a matter of first importance, all gestures of recognition to ***Allah Almighty***, the most helpful and the most benevolent. Also, my humblest appreciation to the ***Holy Prophet Muhammad*** (Peace Be Upon Him) whose lifestyle has been a persistent direction and data of humankind for me. This Thesis shows up in its present structure because of the help and direction of a few people. It gives me incredible delight to offer my thanks to each one of the individuals who bolstered me and have contributed in making this proposal conceivable.

I express my profound sense of reverence to ***Dr. Shahid Iqbal*** *who* gave me the opportunity to work under his supervision. His continuous support, motivation and untiring guidance have made this thesis possible and helped me to complete this work in time. I pay my thanks to whole faculty of department of Earth Sciences especially the teachers and senior students of Department of Earth Sciences.

I am thankful to all my friends especially **FAUJI FRIENDS**, my class fellows and senior students of Department of Earth Sciences, for giving their kind support during my dissertation work.

Last but not least, I would like to acknowledge my **family** for their constant support, unceasing prayers and best wishes. They uplifted my morale whenever I needed.

I do thank all those who have helped me directly or indirectly in the Successful completion of my thesis. Anyone missed in this acknowledgement are thanked.

Abdul Haseeb Aslam

Abstract

The dissertation pertains to investigate the 2D seismic interpretation. Data of Chak-Naurang area situated in Potwar Fold and Thrust Belt was used which consists of seismic lines 881-CW-07, 881-CW-08 and 881-CW-09. The provided data was recorded and process in 1988 by OGDCL. After passing through processing sequence reflectors are marked and time section is made. Four major reflectors are marked on the basics of Synthetic Seismogram made by well data and time sections for each line is made on the basics of two-way arrival times. Chorgali formation and Sakesar Limestone are major productive reservoir rocks in Potwar Fold and Thrust Belt. This area is tectonically very complex and a compressional regime here anticlinal structures are present which may act as trap for hydrocarbon accumulation Nature of faults is majority reverse but also normal at many places. In addition to that Petrophysical analysis of Chorgali formation confirm its reservoir formation properties.

Facies modeling being one of the important tool for the confirmation of lithologies. In this thesis, with the help of facies analysis of Amirpur-01 well, we came to the result revealing limestone as the reservoir lithology.

After that seismic inversion has been studied to confirm the seismic interpretation. Seismic inversion results are also demonstrating that Chorgali and Sakesar are good reservoirs.

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CHAPTER NO:1

INTRODUCTION TO THE STUDY AREA

1.1 Introduction

Hydrocarbon is one of the most essential part of economics of any country. Even on the smaller scale hydrocarbon play a wide role in everyday life. Geoscientists are trying since a long time for the exploration of hydrocarbon and are applying different methods in this regard.

Geophysical methods are the most widely used methods in the exploration of hydrocarbon especially reflection seismology has a great importance in this regard. Seismic method is the leading exploration technique used now days. This dissertation is to interpret seismic section along the migrated seismic lines of Chak naurang area (Fig 1.2). To carry out this exercise seismic reflection data which consists of lines 881-CW-07, 881-CW-08, 881-CW-09 of Chak Naurang area situated in upper lndus Basin. Data was recorded and process in 1978 and 1988 by OGDCL. The data is interpreted by using log data of well Amipur-01, which is located in Chak Naurang area. The impose of interpretation is to understand the structure, tectonics and stratigraphy of the area also to locate the prospective zones by using data of lines and wells

1.2 Objectives

The main objective of dissertation is to present a subsurface model, estimates the reservoir properties and to identify the new well location. All objectives are stated below in points

1. To carry out different steps for the Seismic interpretation of migrated stacked sections.
2. Conversion of time section to depth section.
3. To generate time, depth and velocity contour map of the selected reflectors.
4. To delineate the structural or stratigraphic trap, if present, using the data acquired.

1.3 Geographical Location of Study Area

Chak Naurang Oil Field lies in upper Indus basin, and is bounded between

Latitudes 33° 10' 12"N to 33°55' 37"N

And

Longitudes 72° 40' 09"E to 73° 10' 05"E.

and at a distance of about 90 Kms in the south-west of Islamabad. The field was discovered in March 1952 and came on regular production from April 1953.

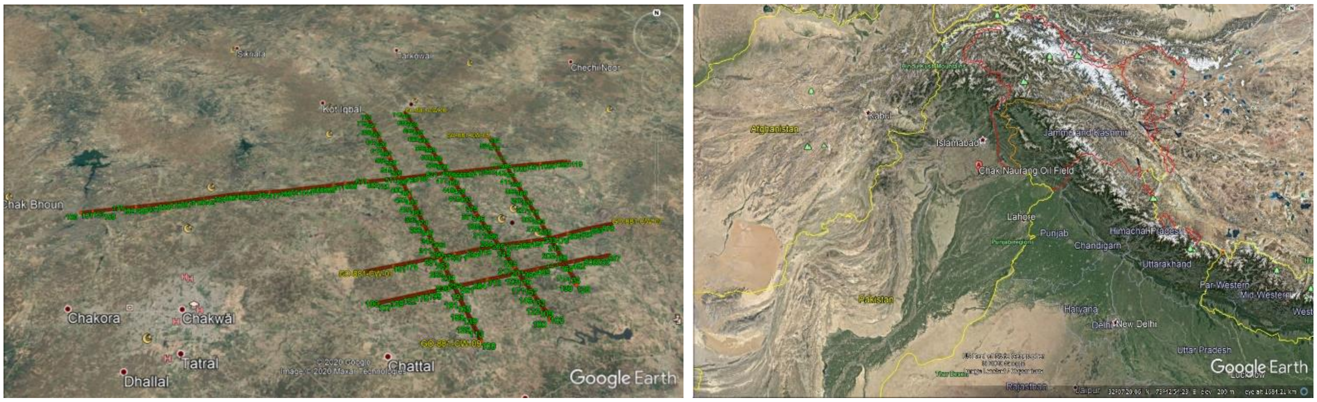


Fig1.1 study area

This area is tectonically very complex, that's why seismic study of area is very tough. There is a high concentration of hydrocarbon in the area. Thrust related structures like popup duplex and anticlinal traps are common in this area.

1.4 Base Map

A base map shows lines and latitude, longitude of area as well as latitude longitude of the lines. The base map is an important component of interpretation, as it displays the spatial position of each picket of a seismic section. It also shows the spatial relationship of all seismic section under consideration, their tie point location and provides the framework for contouring. The base map of the area is generated by plotting data in Universal Transverse Mercator UTM zone 43N geodetic reference system. The base map given in fig (1.2) shows orientation of lines present in Chak Naurang area. The map is generated in Kingdom

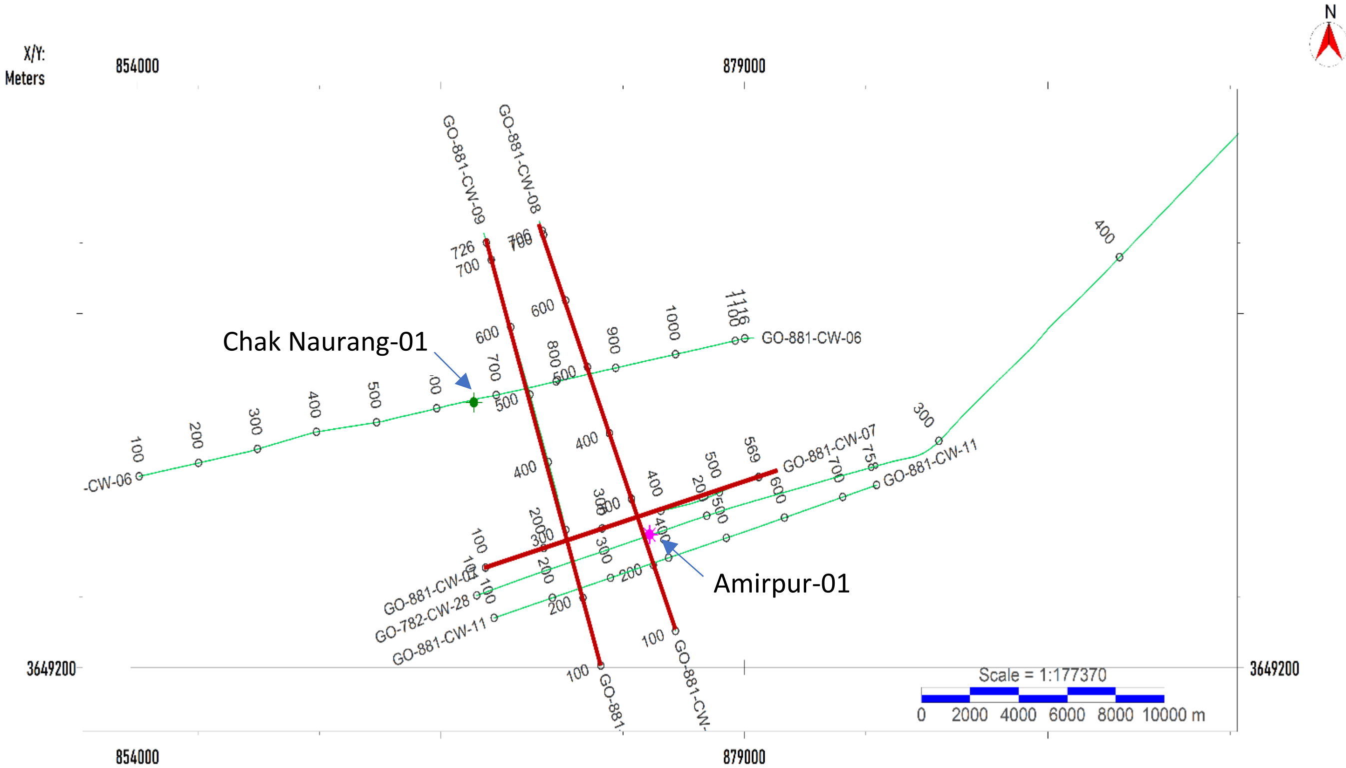
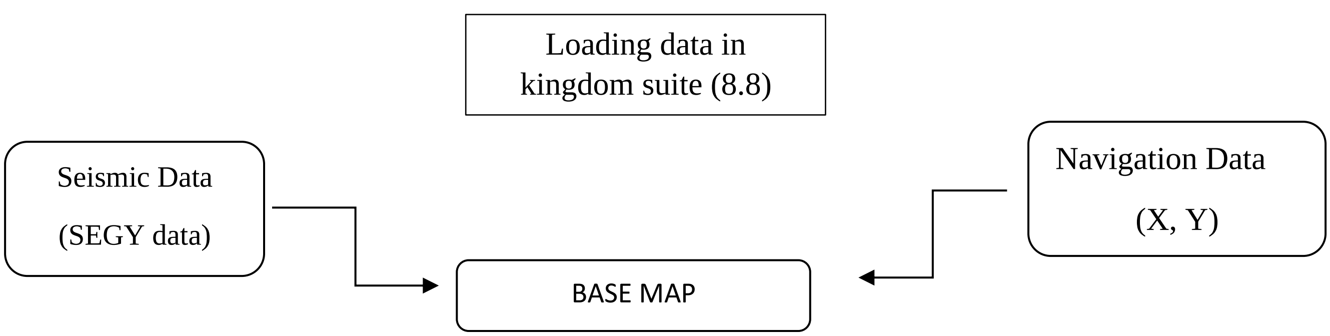


Figure 1.2 Base map

1.4.1 Steps for the construction of base map

The major requirement for the construction of the base map is the Navigation file (DBO format) and SEGY files. Flow chart elaborated steps for the construction of the base map



1.5 Spatial location

The lines their orientation and well used for generation of base map are listed in (table 1.1). the base map is generated by using Kingdom software.

Sr No	Line name	Nature	WELLS
1	782-CW-27	Strike	
2	782-CW-28	Strike	Amirpur-01
3	881-CW-05	Dip	
4	881-CW-06	Strike	Chak naurang-01
5	881-CW-08	Dip	
6	881-CW-09	Dip	
7	881-CW-11	Strike	

Table 1.1

1.6 Data Formats

the data sets were provided by Directorate General Petroleum Concession (DGPC) Pakistan.

- Seismic SEG Y format
- Petrophysics LAS format
- Navigation DBO format

Well name	AMIRPUR-01
Well Type	OIL & GAS
Latitude	32.959547
Longitude	73.012919
Starting depth(m)	290m
Total depth(m)	3030m
Elevation(m)	507m
Depth Reference	Kelly Bushing

1.7 Introduction to Seismic Lines

The migrated seismic sections of lines are provided for analysis and interpretation. These lines have been processed to get the final migrated stacks which have been used for interpretation. Seismic lines show many prominent reflectors. The breakage in reflectors help identifying the faults. Basement and other prominent reflectors show high amplitudes, indicating strong reflection coefficients.

1.8 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 1.3)

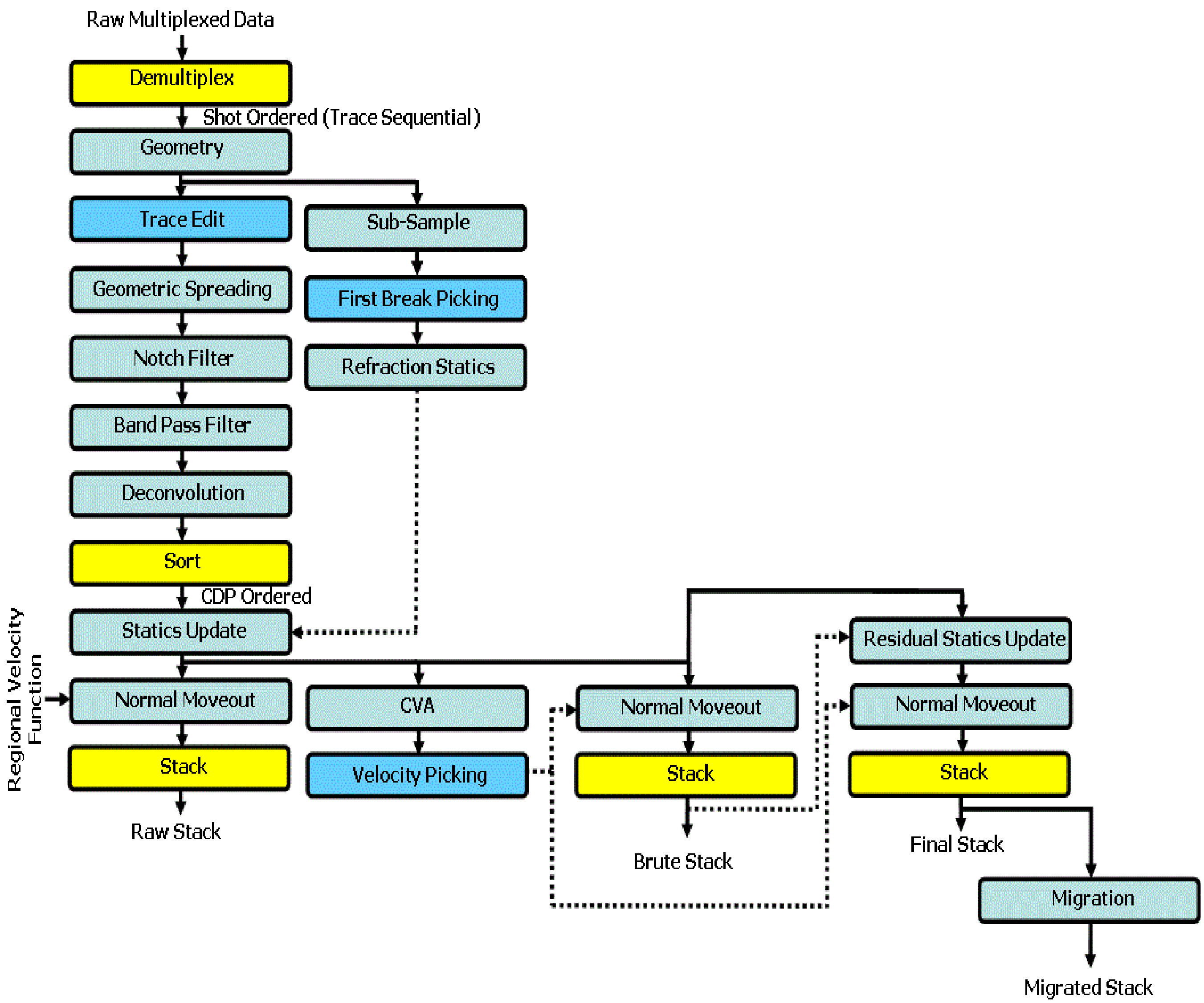


Figure 1.3: Seismic Data Processing flow chart (Khan et al., 2009)

1.9 Software Tool and Applications

- Kingdom Suit
  - Interpretation
  - Time Contouring
  - Depth Contouring
  - Attribute Analysis
  - Petrophysical Analysis
  - Facies Analysis

- Colored Inversion

1.10 Methodology

The dissertation is carried out on the seismic lines 881-CW-07, 881-CW-08 and 881-CW-09. Kingdom software is used through which the horizons of interest are marked on the basics of synthetic seismogram that is made by well data. Major faults are marked. Based on marked horizons time section is prepared through which we can analyze the structures present in the area. In addition to above work Petrophysical analysis is done which give clear information about the properties of hydrocarbon bearing zone.

CHAPTER NO: 02

GEOLOGY, STRATIGRAPHY AND TECTONICS

2.1 Regional Geological Setting:

The planet earth came into being about 4.6 billion years ago, up to the JURAISIC age there was only one land mass on the earth which was called Pangaea, this land mass started breaking about 200 million years ago and was divided into two parts, the northern part was called Laurasia southern part was called Gondwana land. This breakage was initiated by two rifts, one in the northern part, between North America and Africa; it gave to the birth North Atlantic Ocean. Second rift was in the southern part, south America and Africa which gave the birth to the South Atlantic Ocean. Now due the rift that was produced between south America and Africa, a Y shaped crack was produced in the southern part of Gondwana land due to which India was separated from the Gondwana land, it was done about 130 million years ago(Tarbuck et al, 2014)

2.2 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. 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 (the study area is the part of which), 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.

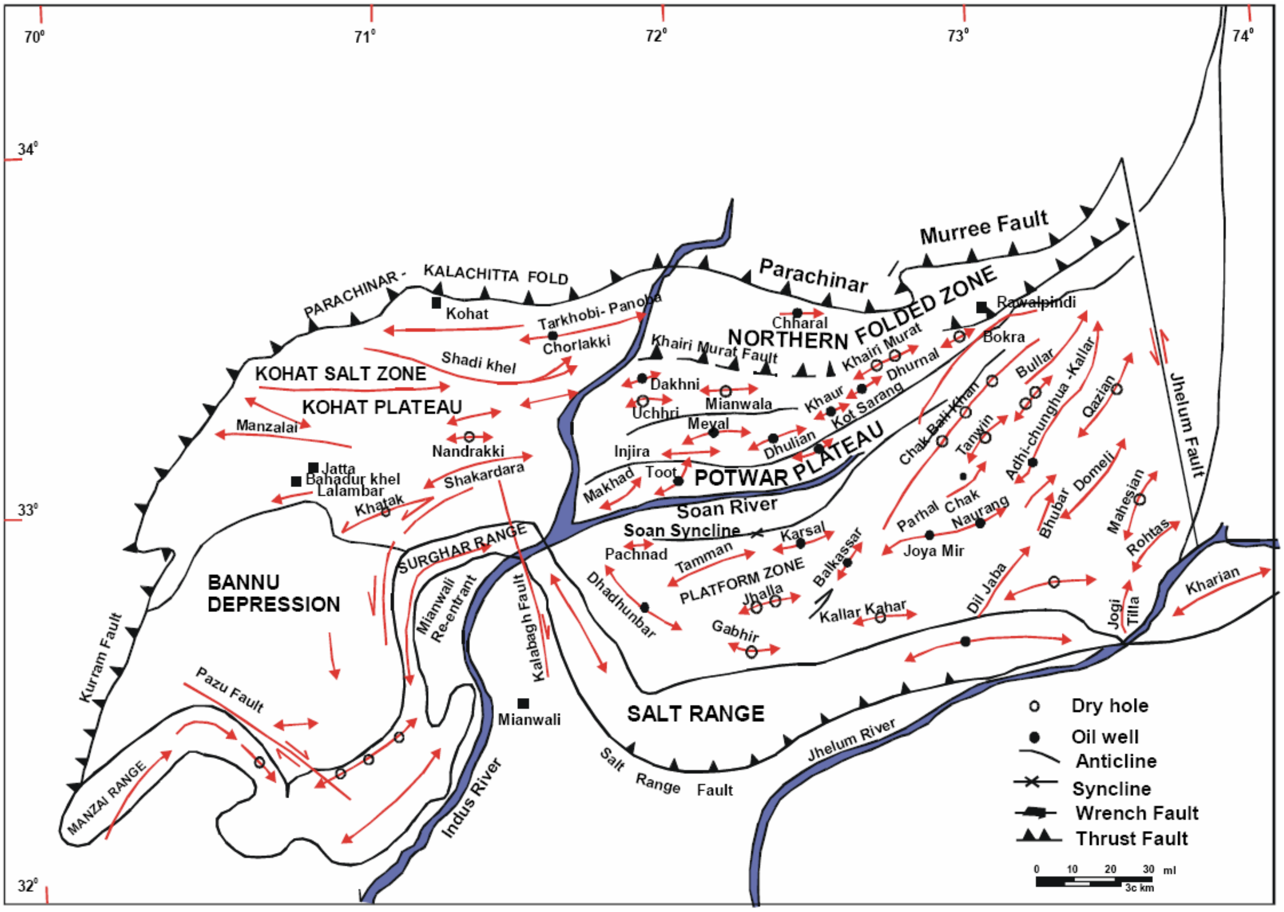


Figure 2.1: Tectonic division of Potwar Basin (Shami and Baig,2003)

2.2.1 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 Khorasaan flysh basin and Makran Accretionary Zone.

(f) Chaghai magmatic arc.

(g) Pakistan offshore.

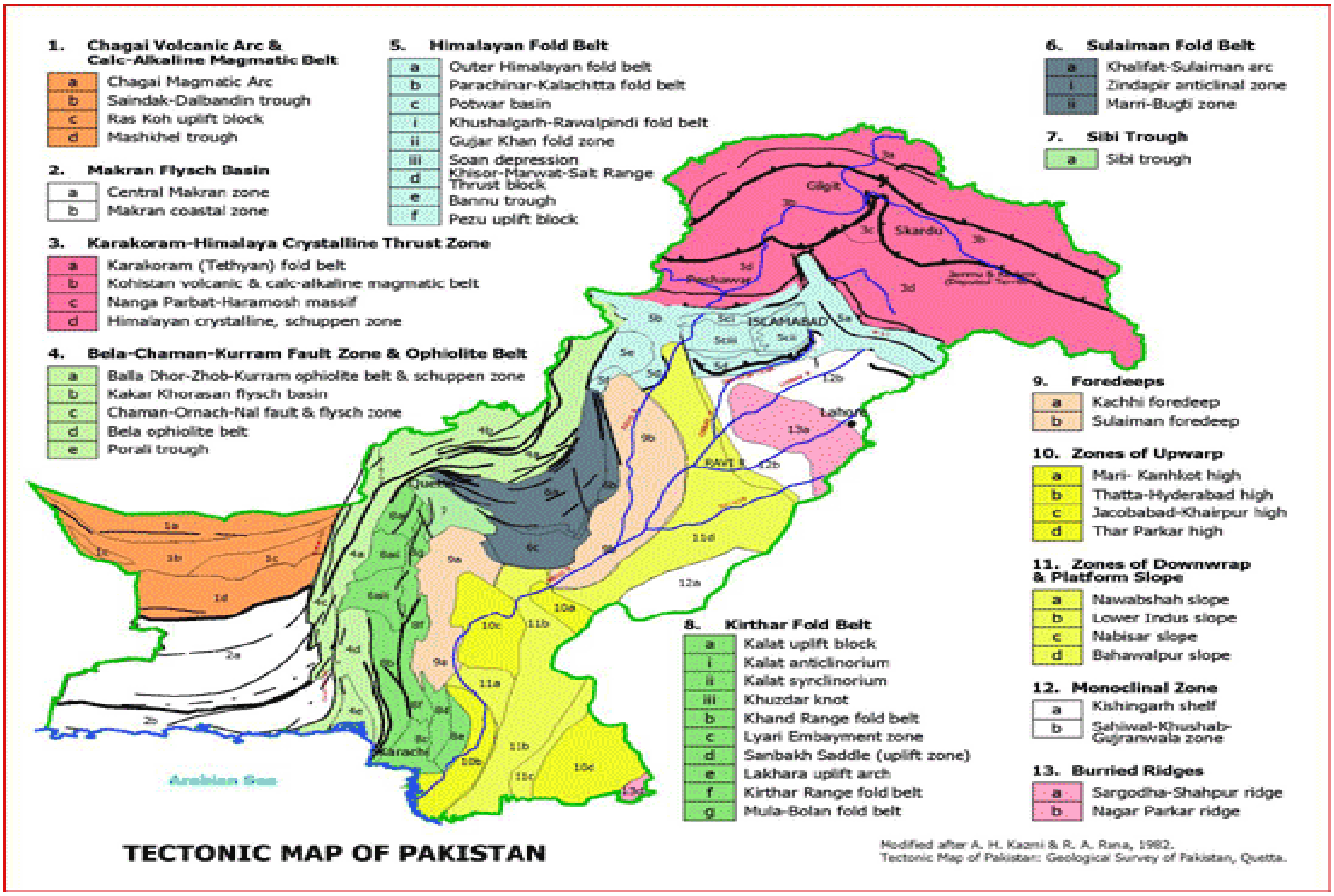


Fig 2.2 Tectonic Map of Pakistan

2.3 Sedimentary Basins:

The basin is an area characterized by regional subsidence and in which sediments are preserved for longer periods of time. In a basin a receptacle or container, which is the basin's substratum is called the Basement**.** The container is filled or content, which is the accumulation of sediments resting on the basement, is called a Sedimentary cover**.** The gradual settling of the basin is called Subsidence**.** The point of maximum sedimentary accumulation is called the Depocenter**.** The datacenter may not correspond to the zone of maximum subsidence. Pakistan comprises following three sedimentary basins Fig 2.2

- Indus basin
- Pashin basin
- Baluchistan basin

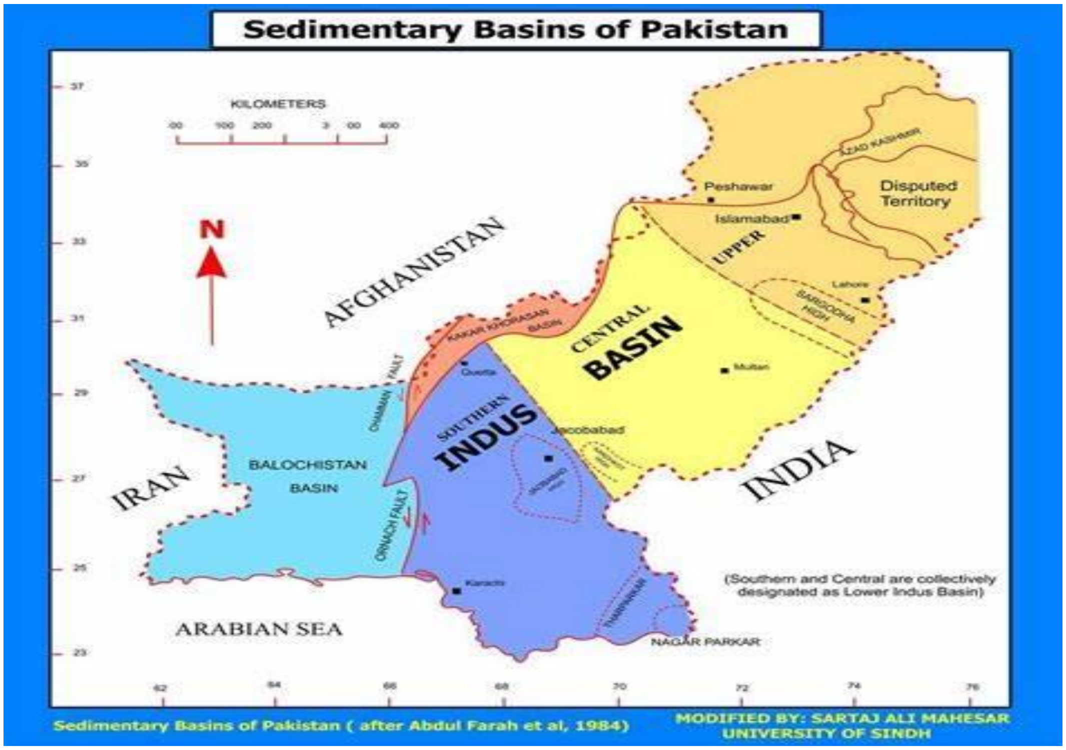


Figure 2.2: Basin Architecture of Pakistan, (Wadood et al, 2020)

2.3.1 Indus basin:

The Indus basin belongs to the class of extra continental trough down warp basins. It is the largest and so far only producing sedimentary basin of Pakistan. The basin is oriented in NE - SW direction. Basement exposed at two places, one in NE (Sargodha high) and second in SE corner (Nagar parker high). The convergence between Indian and Eurasian plate has resulted in partitioning of the basin into three parts. Upper, middle and lower called as northern, central.

Division of Indus basin:

- Upper Indus basin
- Central Indus basin
- Lower Indus basin

2.3.2 Upper Indus Basin

It is located in the northern Pakistan and separated from the lower Indus Basin by the Sargodha High. In its north MBT, while in east and west strike slip faults Jhelum and Kalabagh is located, Upper Indus basin is subdivided into Potwar and Kohat Basins along the Indus River (Kazmi & Jan1997). In the Upper Indus Basin Deposition started From Pre-Cambrian. It is only on basin in Pakistan which receive the deposition from Pre-Cambrian time fig 2.1 (Aamir and Siddique, 2006). The general Stratigraphy of Upper Indus Basin is shown in the stratigraphic column, which shows two main unconformities and some small unconformities.

Potwar plateau lies in Western sub-Himalayan tectonic zone, This east west trending fold belt comprises the low rolling hills and valleys of the uplifted Kohat-Potwar Plateau, The salt range and its westward extension; it is about 85 km wide and extend for 200km. it is diverted structural zone bounded in the north by north dipping Main boundary Thrust (MBT).

Tectonic of the Potwar plateau is controlled by following factors:

- Slope of the basement (steeper in western Potwar Plateau).
- Thickness of Cambrian evaporates beneath the cover.
- Reactivation of basement brittle tectonics (more enhanced in eastern Potwar plateau).

2.4 Geology of Study Area

Chak naurang lies in Potwar Plateau sub basin which is the northern most structural feature of Indus Basin bounded by Main Boundary Thrust and Kala Chitta Range in the north and Salt Range to the south. The rocks of Miocene-Pliocene age known as Nagri Formation and Chingi formation are exposed in the core of the structure and its flanks. A prominent thrust cum tear fault Chak Naurang Wari Fault is passing through the area. There is a general disharmony between the younger molasses sequence and the lower older sequence due to thrust tectonics, which are playing a dominant role in the potwar region. the lithological territories are laying unconformably over Paleozoic and the whole Mesozoic section is absent in and around the area. The Sakesar Limestone and chorgali Formation of Eocene age are the primary reservoir objective while Permian and Cambrian sandstone are secondary objectives. The Eocene, Paleocene and Permian shales to be the potential source and cap rocks (Kann! and Jan 1997).

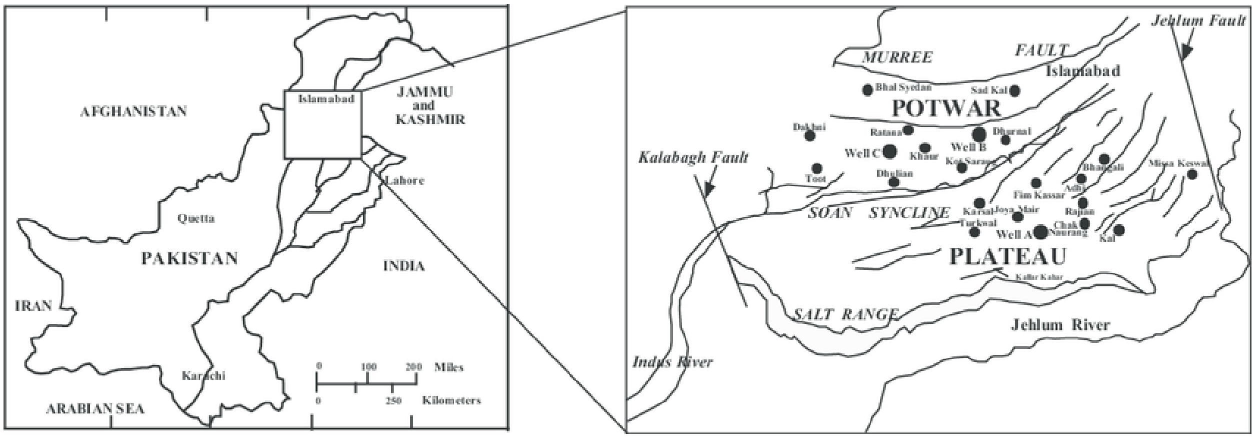
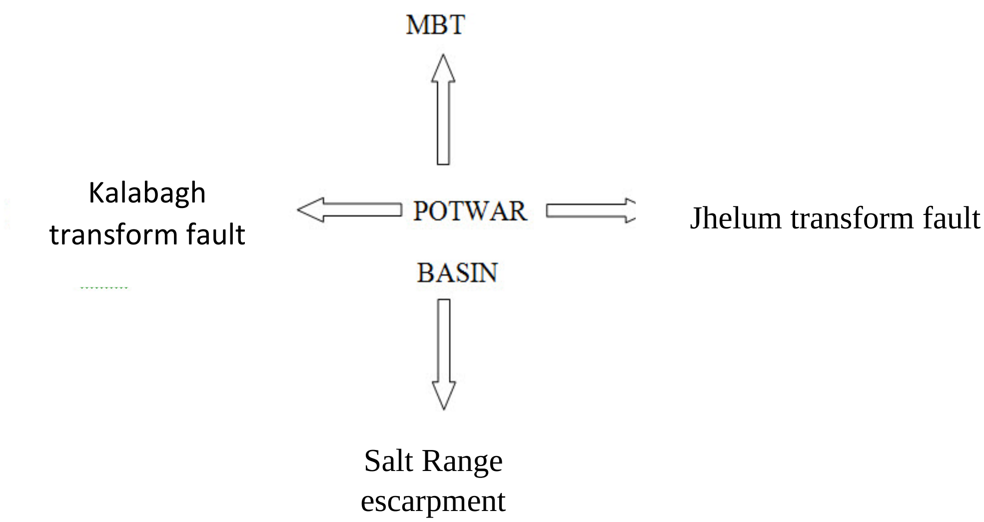


Fig 2.3 potwar plateau

2.5 Geological Boundaries of the Study Area

The Potwar basin is bounded to the south by Salt Range escarpment, to the north by the Main Boundary Thrust, to the east by the Jhelum transform fault, and to the west by Kalabagh transform fault (Aamir and Siddiqui,2006).

The geological boundaries of the study area are shown in following figure.



2.5.1 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)

2.5.2 MAJOR FOLDS IN THE POTWAR SUB BASIN

- Soan syncline
- Chak naurang Anticline
- Mahesian Anticline
- Tanwin-Banis Anticline
- Joya Mair Anticline
- Dhurnal Anticline

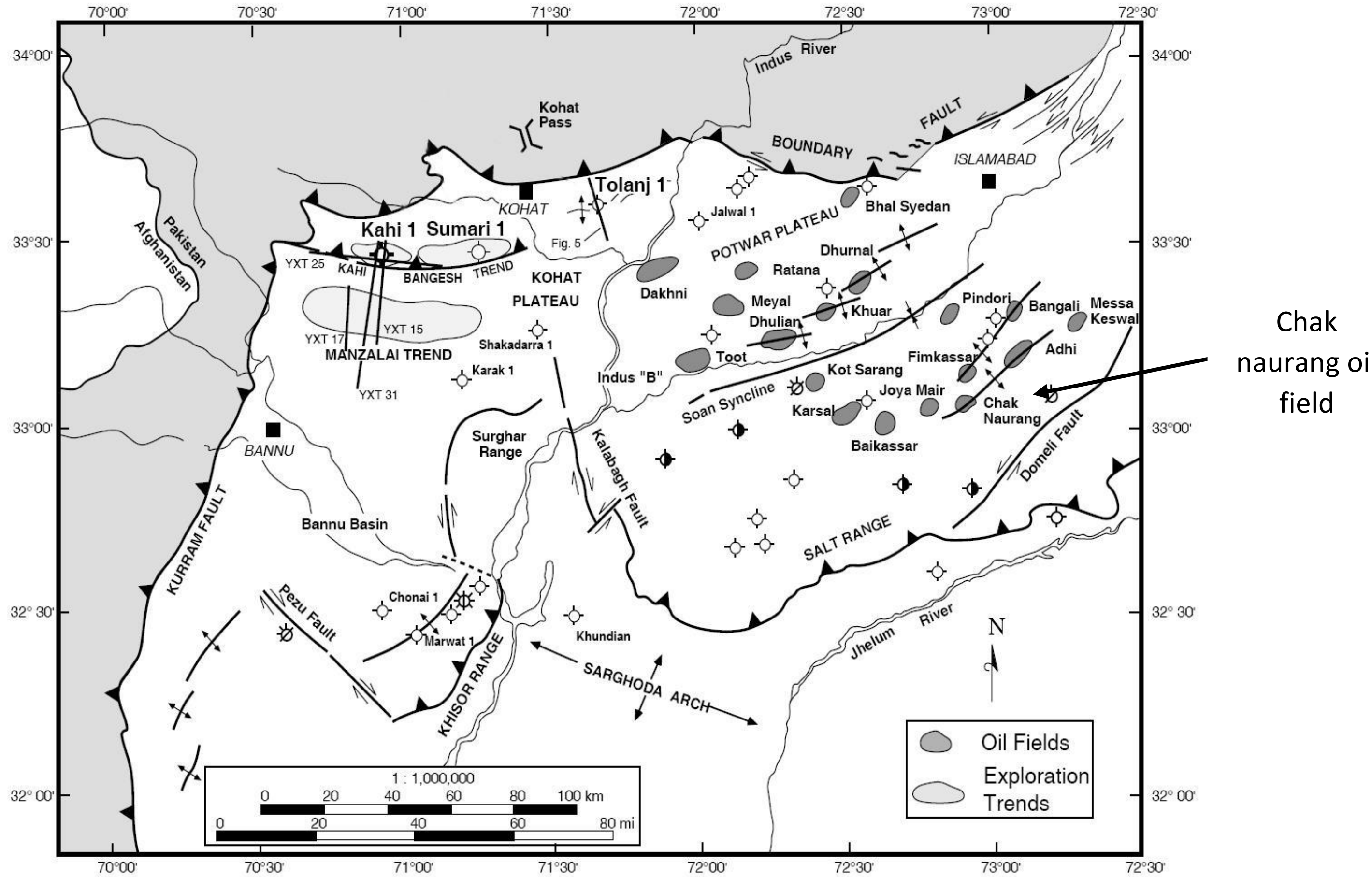


Figure 2.4: Map showing major structural features of the Kohat-Potwar plateaus. Also shown is the Potwar Plateau oil fields and control wells, full seismic coverage not shown. (Shami and Baig,2003)

2.6 STRATIGRAPHY OF AREA

To study the depositional history of that area the stratigraphic study of that area is most important. The sediments varying in age from Precambrian to quaternary are preserved in Potwar sub-basin. (kadri.,1995) The sediments that fill the potwar sub-basin include Cambrian evaporates. These evaporates are overlain by the platform deposits of Cambrian to Eocene age which are relatively thin. Thick Miocene Pliocene molasses further overly these deposits. The Himalayan orogeny during Pliocene to Middle Pleistocene has resulted in the deformation of this whole section(Moghal et al,2007).Various unconformities are responsible for interrupting the whole depositional sequences of Potwar sub-basin out of which, the unconformity between Cambrian and Permian, and between the Eocene and Miocene are considered as the most significant one (khan et al.,1986).The generalized stratigraphy of Potwar sub-basin

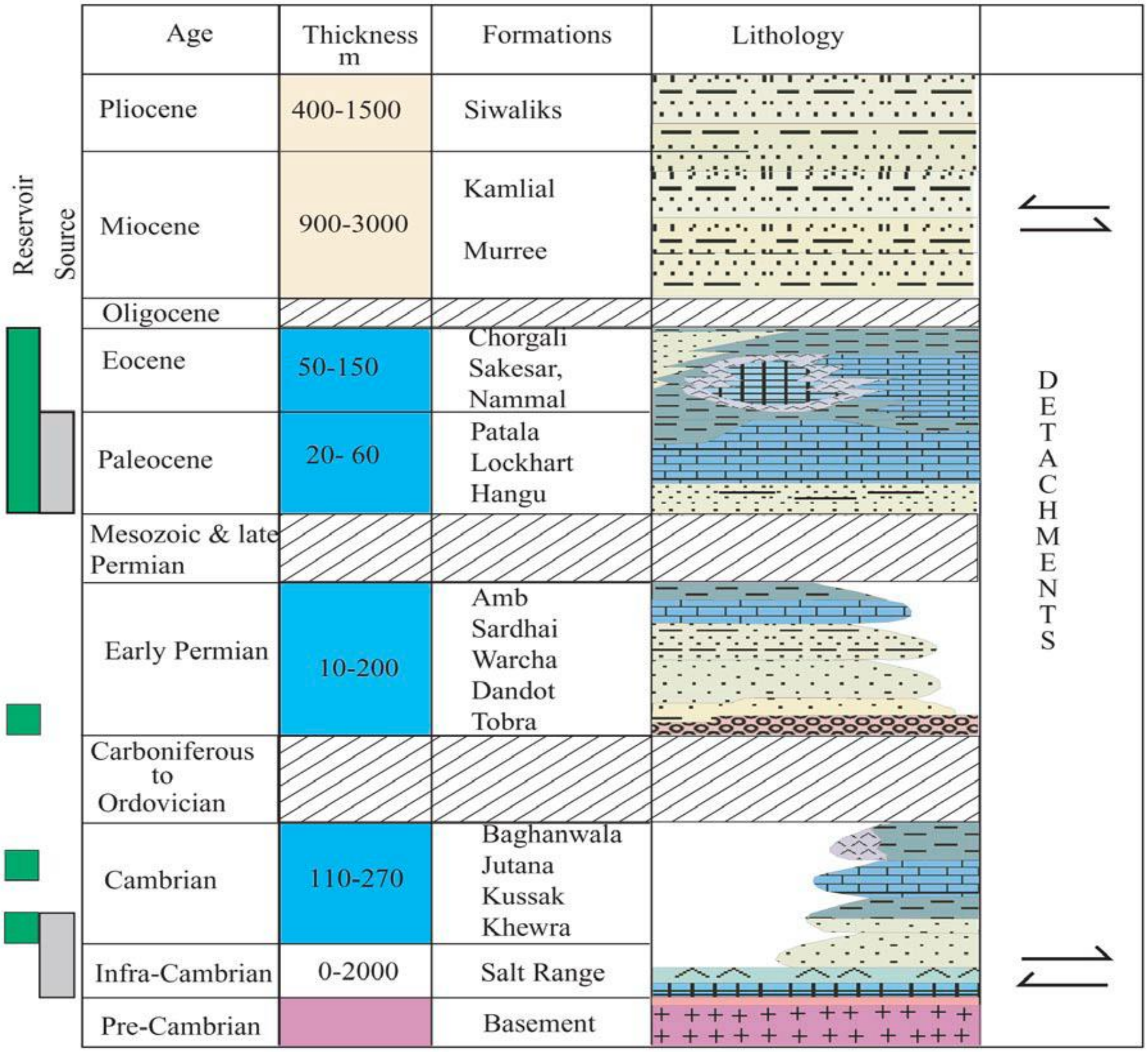


Fig 2.5 stratigraphic chart of the area

2.7 Lithological Description of Formations

Seismic Section shows the different depths interpreted that has been encountered in Amirpur-01. Below explained in tabular form are the lithological description of the section drilled at Amirpur-01which was drilled down to a depth of 3027 meter into formations of post Cambrian age. The Formation tops were initially picked at the well site, which were further refined / confirmed by the electric logs. A list of final formation tops and thickness drilled in Amirpur-01, are presented in the Table 2.1.

Formation Name	Tops (m)
FF NAGRI	0
FF CHINJI	543
FF KAMLIAL	1485
FF MURREE	1605
FF CHORGALI	2608
FF SAKESAR	2636.5
FF NAMMAL	2715
FF PATALA	2724
FF LOCKHART	2738
FF HANGU	2747
FF SARDHAI	2752
FF WARCHA	2781
FF DANDOT	2806
FF TOBRA	2833
FF BAGHANWALA	2843
FF JUTANA	2853.5
FF KUSSAK	2878
FF KHEWRA SANDSTONE	2953

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 2^0 C/100 m. Hence the oil window lies between 2750-5200 meters. (Kadri, 1995).

2.8.1 Source Rock

The source rock of Infra- Cambrian to Eocene in the Potwar basin identified by many companies. In Potwar basin the organic-rich shale of Paleocene age (Patala Formation) is the main source of Potwar Oil field. In Potwar Basin, Patala shale of Paleocene have proven as the main source rocks. Due to buckling of basin floor the organic shale of Paleocene age was partly deposited in anoxic conditions. The oil shale intervals contain in Precambrian Salt Range Formation, which show potential of source rock. (Bender, et al, 1995).

2.8.2 Reservoir Rocks

Sandstone of Khewra Formation (Cambrian), Tobra/Dandot (Permian), Lockhart Formation (Paleocene) and carbonates of Sakesar, Chorgali formations (Eocene) are the reservoir rocks in the area. (Bender, et al, 1995)

2.8.3 Seal & Cap Rocks

Most of the fields discovered in the Kohat-Potwar geologic province to date are either overturned faulted anticlines, popup structures, or fault-block traps. In this area, anticlinal features strike generally east-northeast to west-southwest and are approximately parallel to the plate-collision zone. Many of these folded structures are amplified, or they are only present above a detachment zone in Eocambrian salts. The latest trap-forming thrust events began at approximately 5 and 2 Ma. Seals include fault truncations and interbedded shale and the thick shale and clays of the Miocene and Pliocene Siwalik Group. Shale of Chorgali, Patala, Sardhai and Kussak formations serve as cap rocks for underlying carbonates of Chorgali, Sakesar, Lockhart and sandstones of Tobra, Dandot and Khewra formations respectively. (Bender, et al, 1995)

CHAPTER 3:
SEISMIC INTERPRETATION

3.1 Introduction

The Seismic data interpretation is the method of determining information about the subsurface of earth from seismic data. It may determine general information about an area, locate prospects for drilling exploratory wells or guide development of an already discovered field (Coffeen, 1986). Such reflections and unconformities are to be mapped on seismic section, which fully describe the geology and hydrocarbon potential of the area. If the horizon of interest is not prominent and it is difficult in tracing it over the whole area, it is advisable to pick additional horizons above and/or below the target horizon. This helps in understanding the trend and behavior of the target horizon in the zones where its quality is not good enough to be picked with confidence. Final objective of interpretation is conversion of seismic section into a geological section which provides a somewhat realistic subsurface picture of that area, both structurally as well as stratigraphically (Badley, 1985).

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 based on 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 facilitate for the identification of the major pro-gradational sedimentary sequences which offer the main potential for hydrocarbon generation and accumulation Stratigraphic analysis therefore greatly enhances the chances of successfully locating hydrocarbon traps in sedimentary basin environment.

3.2 Interpretation Workflow

First step in the interpretation process is to judge the reflections and faults. If existing on seismic time section. Those reflections are selected which are real, show not good character and even continuity of reflectors was not so good

Base map on Kingdom Software is prepared by loading navigation data and SEG-Y in software Kingdom 8.8. Horizons of interests are marked manually with the help of synthetic seismogram. In this process faults are also marked and identified on seismic section. Faults polygons are generated and horizons are contoured to find out structural high and lows. The interpretation workflow is discussed in Figure 3.1.

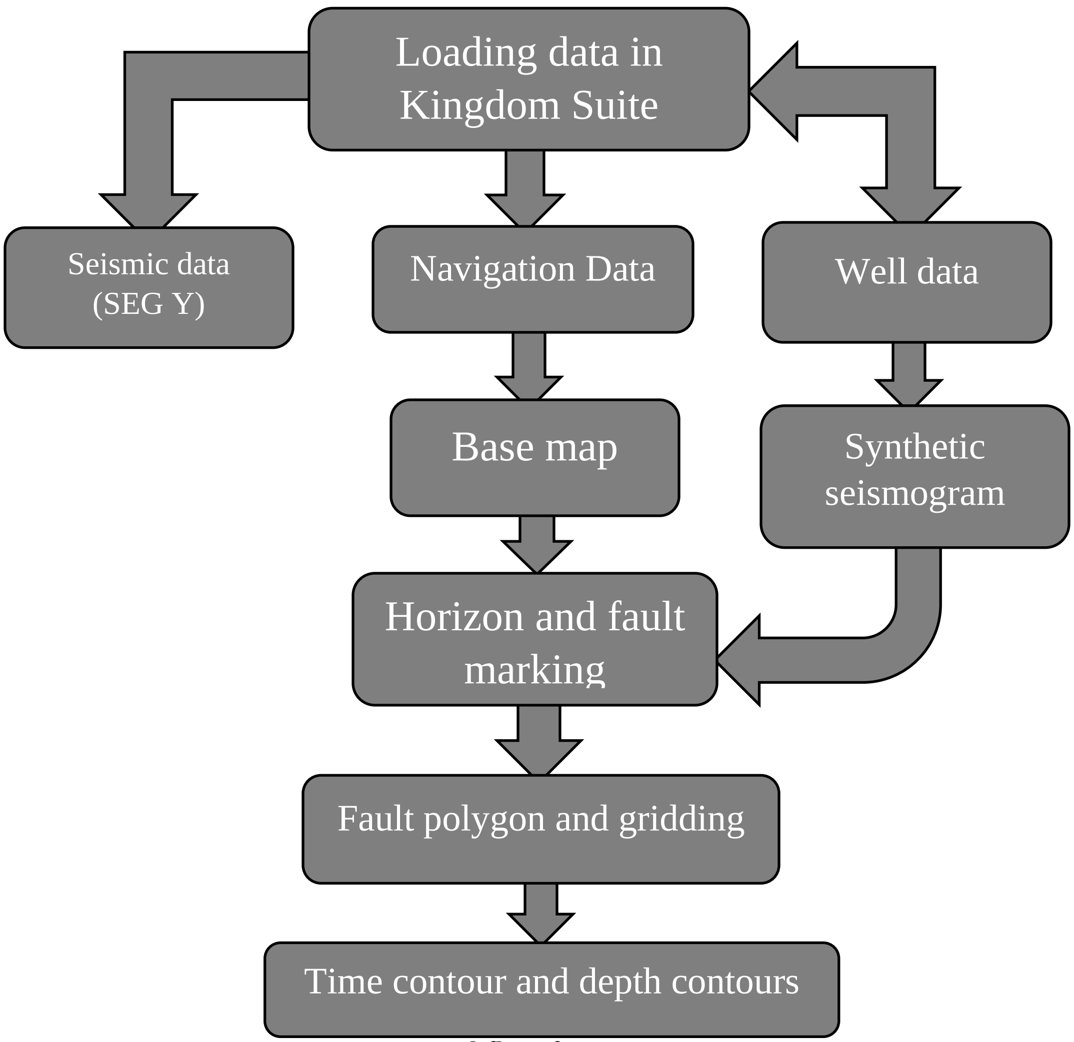


Figure 3.1 Workflow for Seismic Interpretation

3.3 Available Data

Three seismic lines, base map, and well tops of well Amirpur-01 acquired from DGPC for this project. Available seismic lines on which the interpretation was carried out are as follows:

- 782-CW-28
- 881-CW-07
- 881-CW-08
- 881-CW-09

3.4 Synthetic Seismogram

Synthetic seismogram was generated by convolution of Sonic, density curve with the source wavelet of the well Amirpur-01. The source wavelet used was extracted wavelet shown in Figure.3.2.

Basic and most important step of interpretation is generation of synthetic seismogram. It provides a crucial link between lithological variations within a drill hole and reflectors on seismic profiles crossing the site. In essence, they provide a ground truth for the interpretation of seismic data. Synthetic seismogram are useful tools for linking drill hole geology to seismic sections, because they can provide link between observed lithologies and seismic reflection patterns. Reflection profiles are sensitive to changes in sediment impedance, the product of compressional wave velocity and density. Changes in these two physical parameters do not always correspond to observed changes in lithologies. By creating a synthetic seismogram based on sediment petrophysics, it is possible to identify the origin of seismic reflectors and trace them laterally along the seismic data as we use Amirpur-01 data to generate synthetic seismogram for marking the horizons on seismic sections.

Well tops were also imposed on the respective synthetic seismogram showing Chorgali, Sakesar, Hangu, Patalla, Lockhart, Nammal, Tobra, Dandot, Bangawala and Khewra sandstone Formation respectively as shown in Figure.3.2

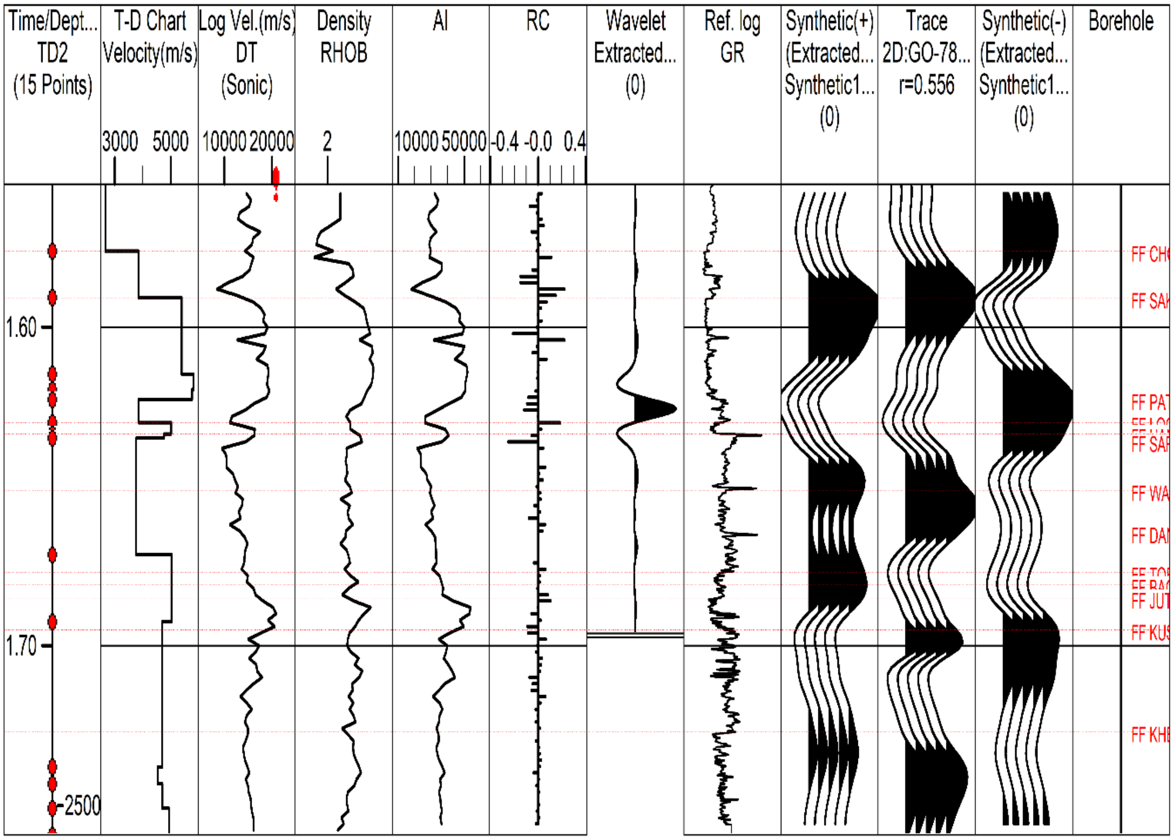


Fig 3.2 synthetic siesmogram

3.5 Marking of Seismic Horizons

Primary task of interpretation is the identification of various horizons as an interface between geological formations. For this purpose, good structural as well as stratigraphic knowledge of the area is required. Thus, during interpretation process, I mark both, the horizons and faults on the seismic section (McQuillin, et al., 1984). Three horizons are picked on the basis of available information (well data and generalized stratigraphic map). The horizons are named on basis of well tops of the well Amirpur-01. The Chorgali, Sakesar and khewra sandstone formations, figure 4.3 which are showing high reflections on a seismic section making it easier to be picked.

3.6 Fault Picking

Faults are picked on the seismic section to delineate the geological structural trend in the study area. This is carried out with the nature of the geology of the basin, that is structural style of the area in mind. Structural styles often provide a broad context for understanding the pattern of faulting that may be expected in a region. Its basic utility lies in identifying certain basic patterns of deformation that are repeated in geologic provinces.

3.7 Seismic Time Section

The time section gives the position and configuration of reflectors in time domain. Four reflectors are marked on seismic lines 782-CW-28, 881-CW-07, 881-CW-08, 881-CW-09 which are named on the basis of stratigraphic column encountered in well Amirpur-01. Each reflector is marked with different color so that they can be easily distinguished. However the aim is to target, the source, reservoir and seal rock formations, the time section of seismic lines782-CW-28, 881-CW-07, 881-CW-08, 881-CW-09 is given in (figure 3.3,3.4,3.5,3.6) respectively. Dip lines orientation is from NW-SE and Strike line is SW-NE.

In each line we see popup structure that is suitable for accumulation of hydrocarbons. As mentioned in (chapter 2) in Potwar Basin there are reserves. we have three reflectors of limestone which is a good reservoir. 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.

We have four prominent reflections marked with different colors so we can easily distinguish them.

- CHORGALI(Cyan)
- SAKESAR(BLUE)
- KHEWRA SANDSTONE(YELLOW)
- BASEMENT(GREEN)

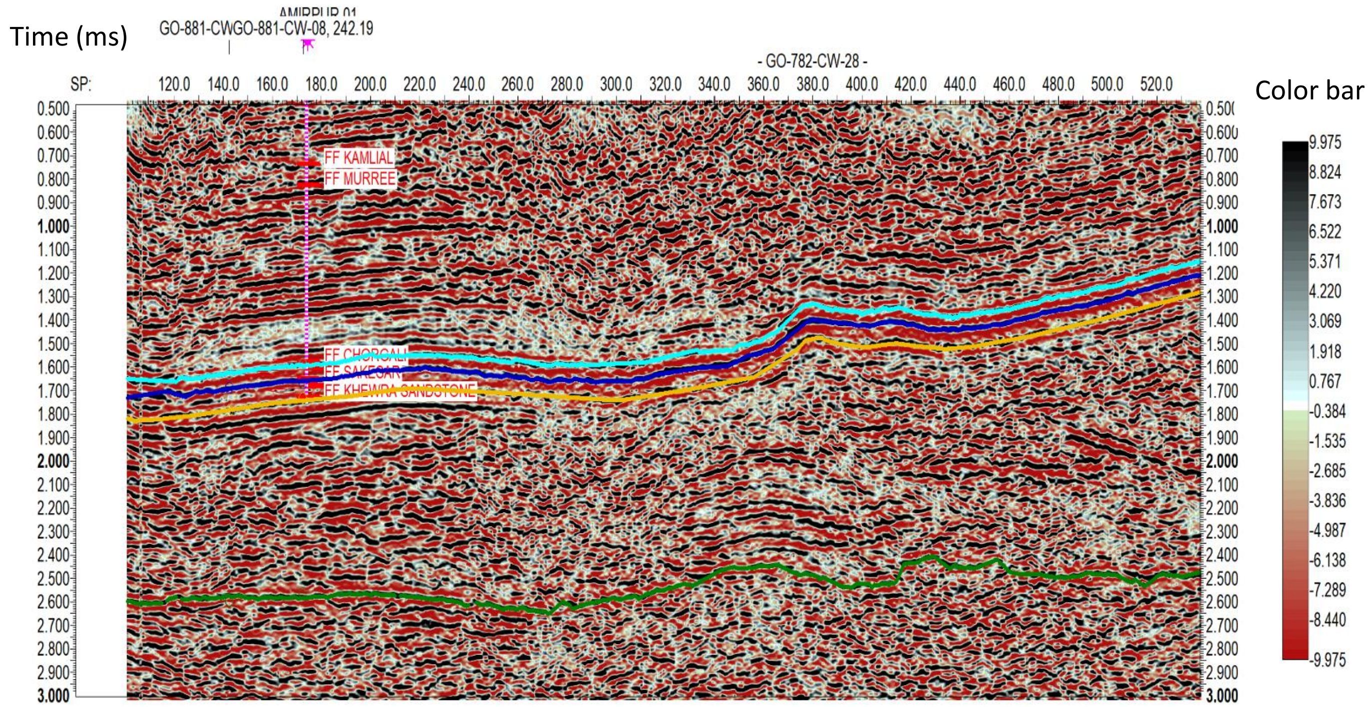


Figure 3.3 Marked section of line 782-CW-28

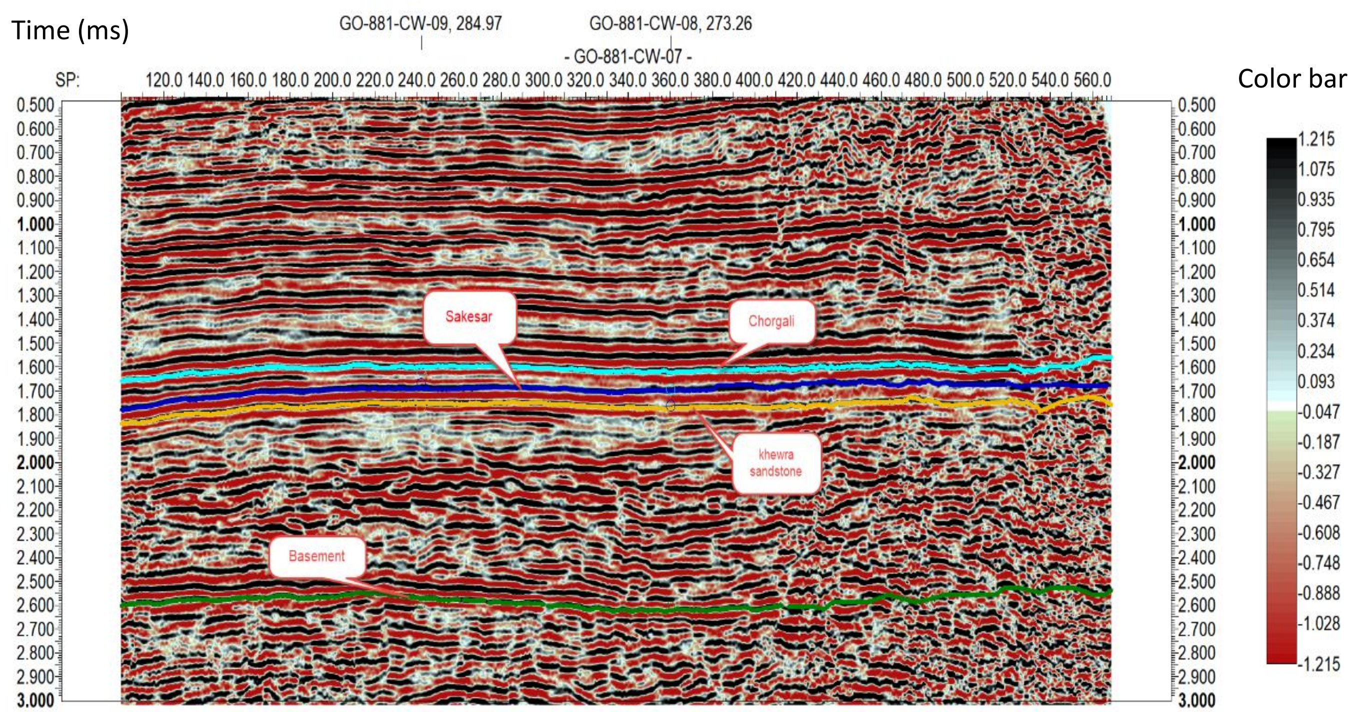


Figure 3.4 Marked section of line 881-CW-07

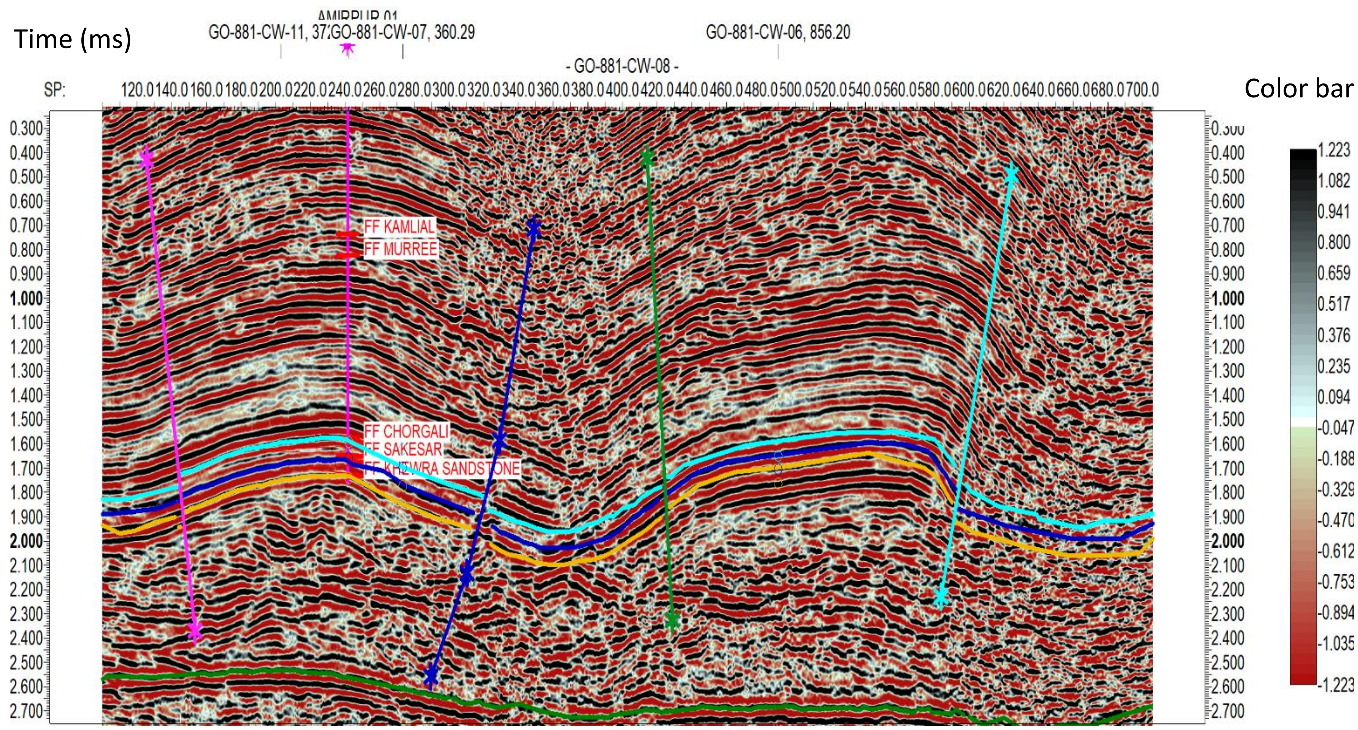


Figure 3.5 Marked section of line 881-CW-08

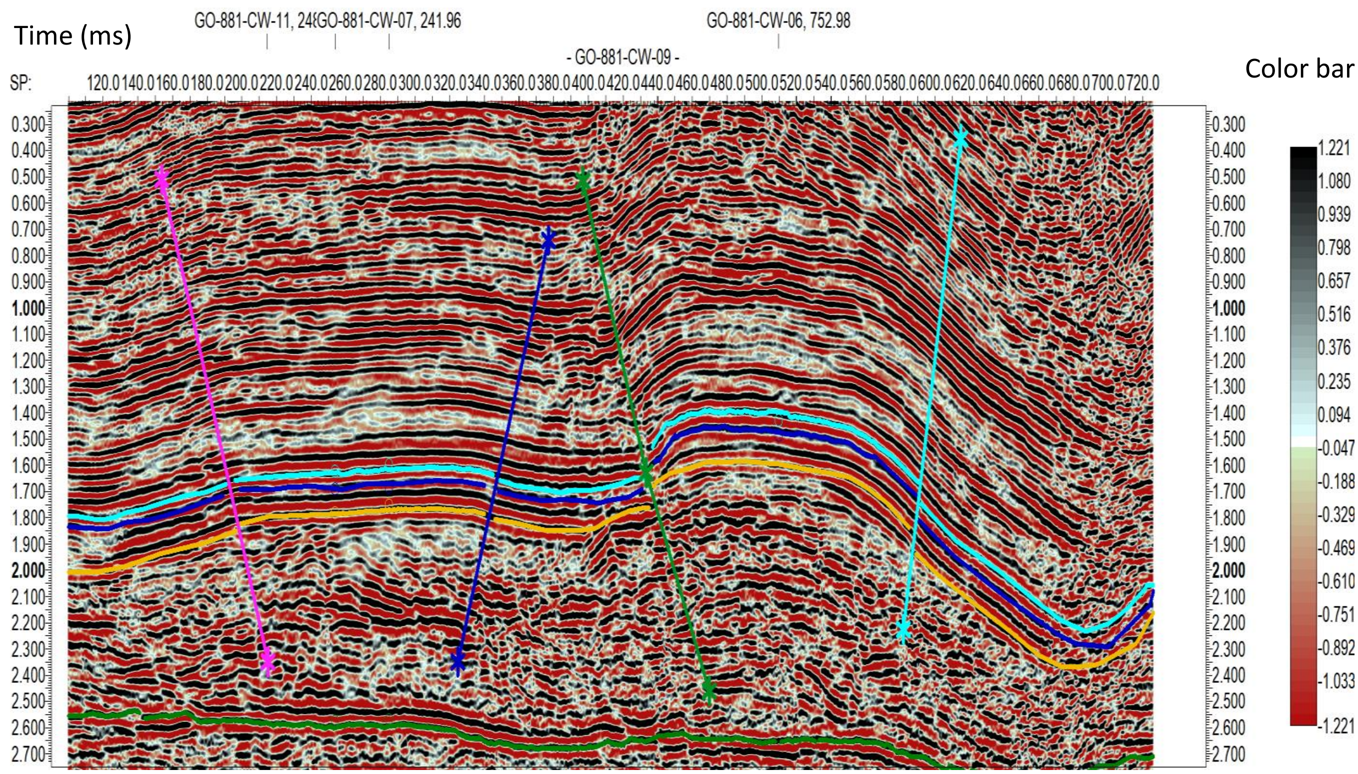


Figure 3.6 Marked section of line 881-CW-09

3.8 Construction of fault Polygon

Before generation of fault polygons, it is necessary to identify the faults and their lateral extent by looking at the available seismic data and assign proper name to all these faults. If one finds that the same fault is present on all the dip lines. Construction of fault polygons are very important as far as time and depth contouring of a particular horizon is concerned. Any mapping software needs all faults to be converted into polygons prior to contouring. The reason is that if a fault is not converted into a polygon, the software doesn't recognize it as a barrier or discontinuities, thus making any possible closures against faults represent a false picture of the subsurface. After construction of fault polygons, the high and low areas on a particular horizon become obvious the fault polygon is shown in figure (3.5)

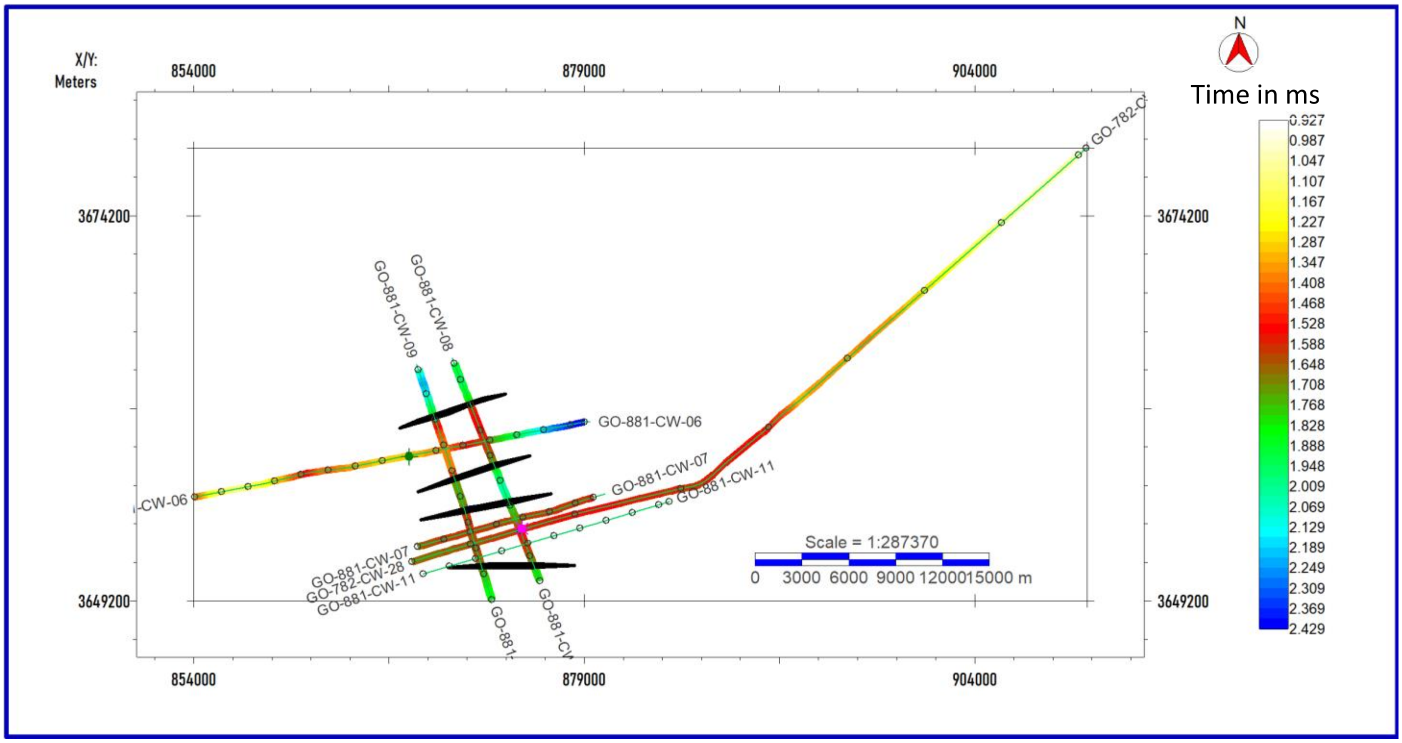


Fig 3.7 fault polygon

3.9 CONTOUR MAPS

The contours are the lines of equal time or depth wandering around the map as dictated by the data, Contouring represents the three-dimensional Earth on a two-dimensional surface. The spacing of the contour lines is a measure of the steepness of the slope; the closer spacing the steeper the slope. A subsurface structural map shows relief on a sub-surface horizon with contour lines that represent equal depth below a reference datum or two-way time from the surface. These contour maps reveal the slope of the formation, structural relief of the formation, its dip and any faulting and folding. 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. 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 all the contour maps.

3.9.1 TIME CONTOUR MAP

Chorgali is main Formation of interest producing oil and gas and composed of limestone. Chorgali Formation have very strong reflections and easy to locate. It is noted from Time contour maps the main structure lies at the center of faulted region and shown by low time on the scale. The map clearly confirms the back thrusting in the area. The closed contours are considered as structural trap, same trend in Sakesar and Khewra sandstone Formation. Structures are getting shallower towards the north east direction as it is showing the minimum time color. Time contour interval is 0.02 second. Well Amirpur-01 is shown with Red colour.

Chorgali time

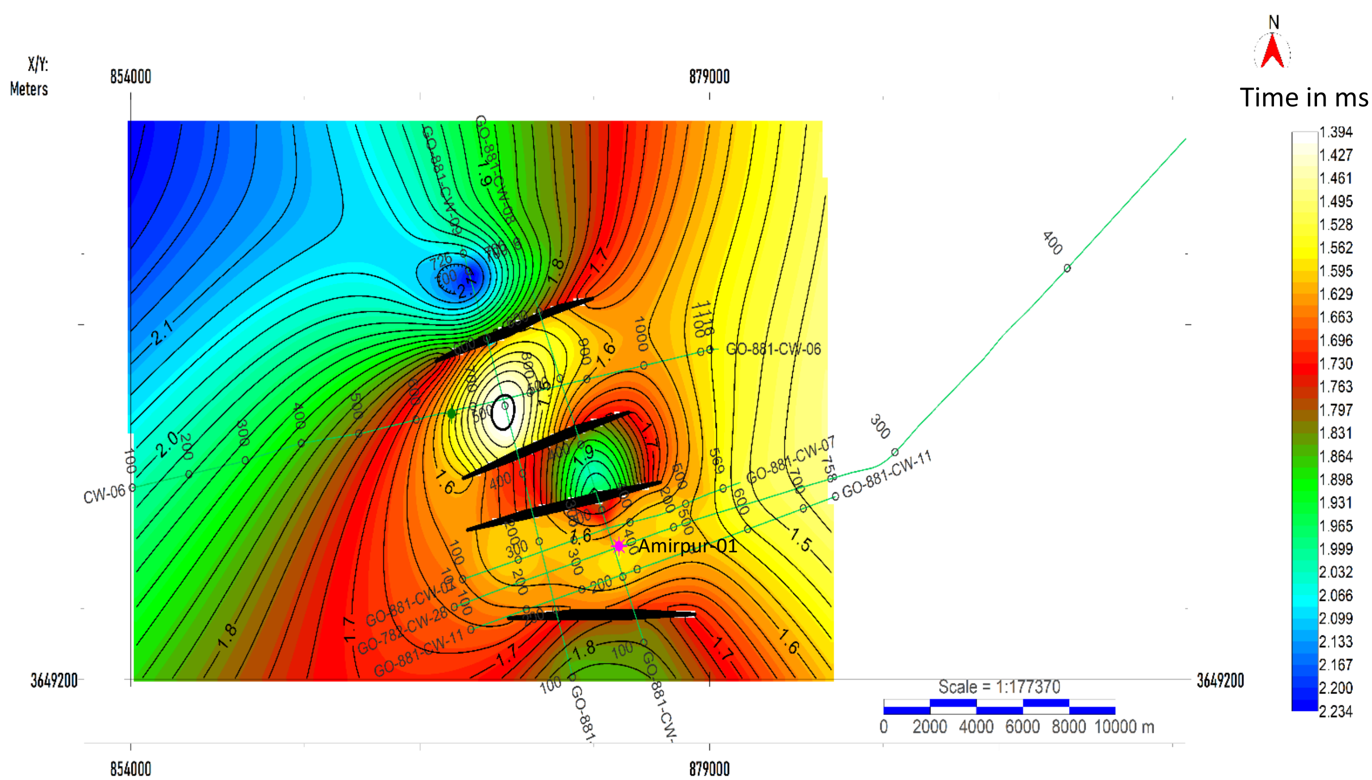


Fig 3.8 Chorgali time contour grid

Sakesar time

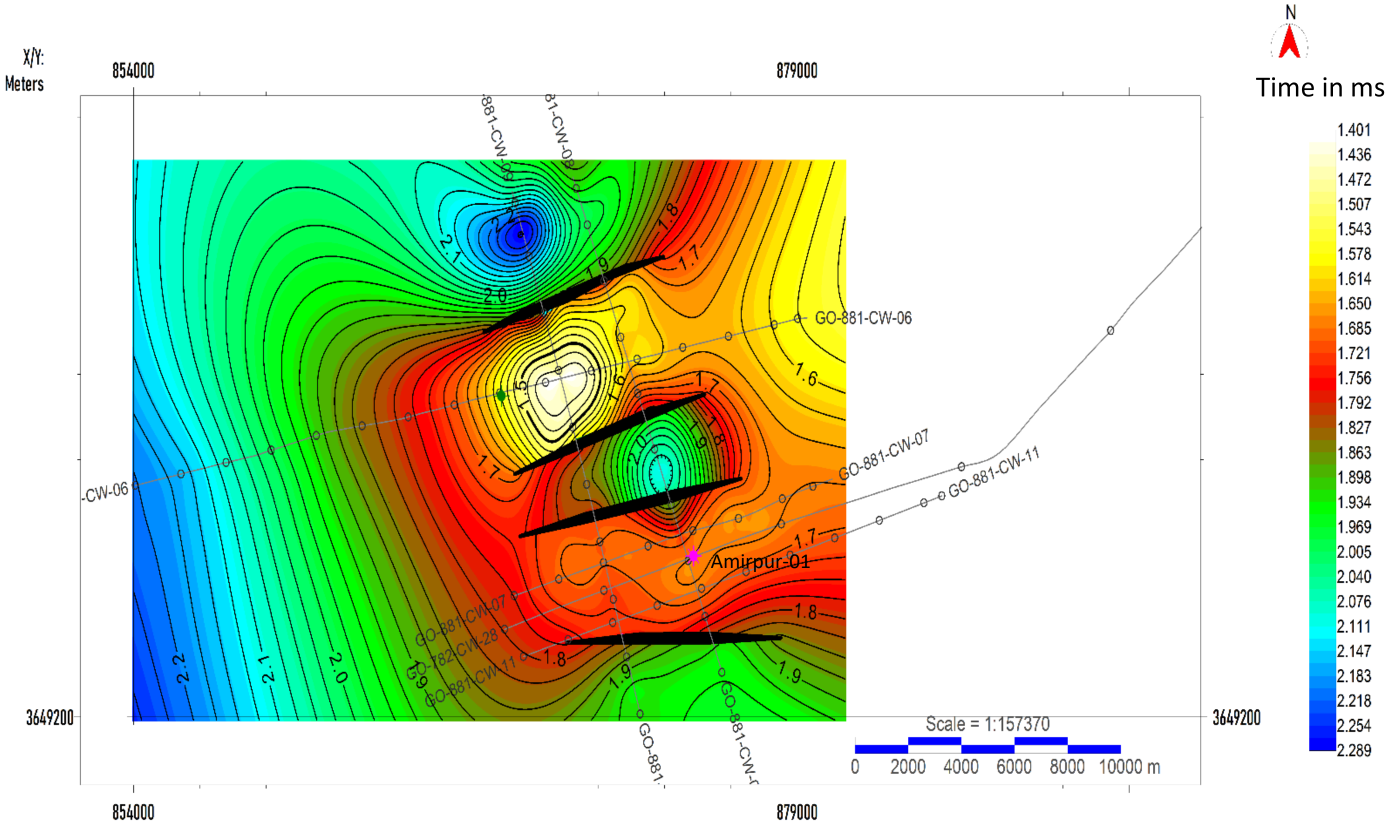


Fig 3.9 Sakesar time contoured grid

3.9.2 DEPTH CONTOUR MAP

Our primary information is the varying time values and by using these values and subsurface velocities depth conversion is done. Depth conversion and depth contour maps are connected to see the horizons in the subsurface at their true positions. Depth must be calculated from time to make a map that is more truly related to the subsurface shapes, because structures is a matter of depth. The idea of converting the times into depths is very reasonable in case of showing the subsurface structures. Depth contour is showing same pattern to the time contour as constant velocity is multiplied with time. Depth contour interval is 25 meters.

From figures below we can clearly interpret the horizon is shallow at well locations and deep at side portions.

Chorgali depth

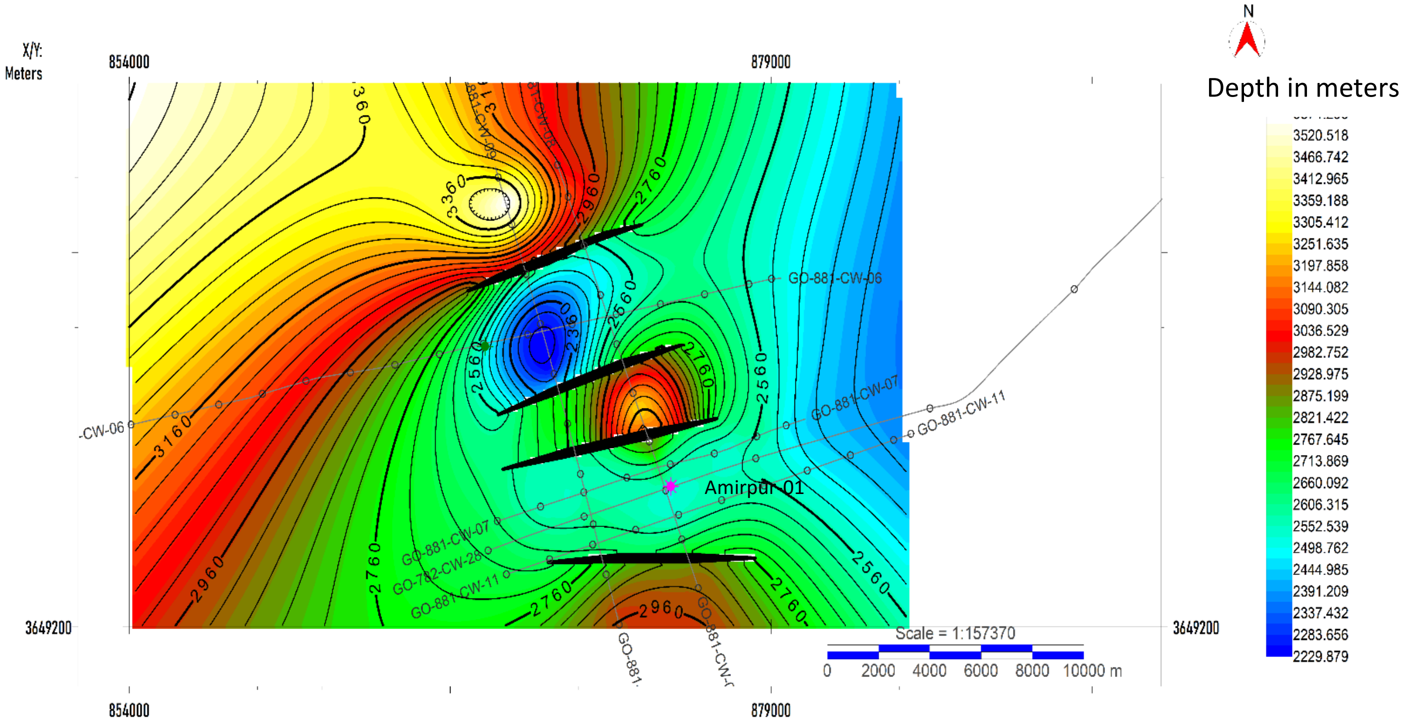


Fig 3.10 chorgali depth countered grid

Sakesar depth

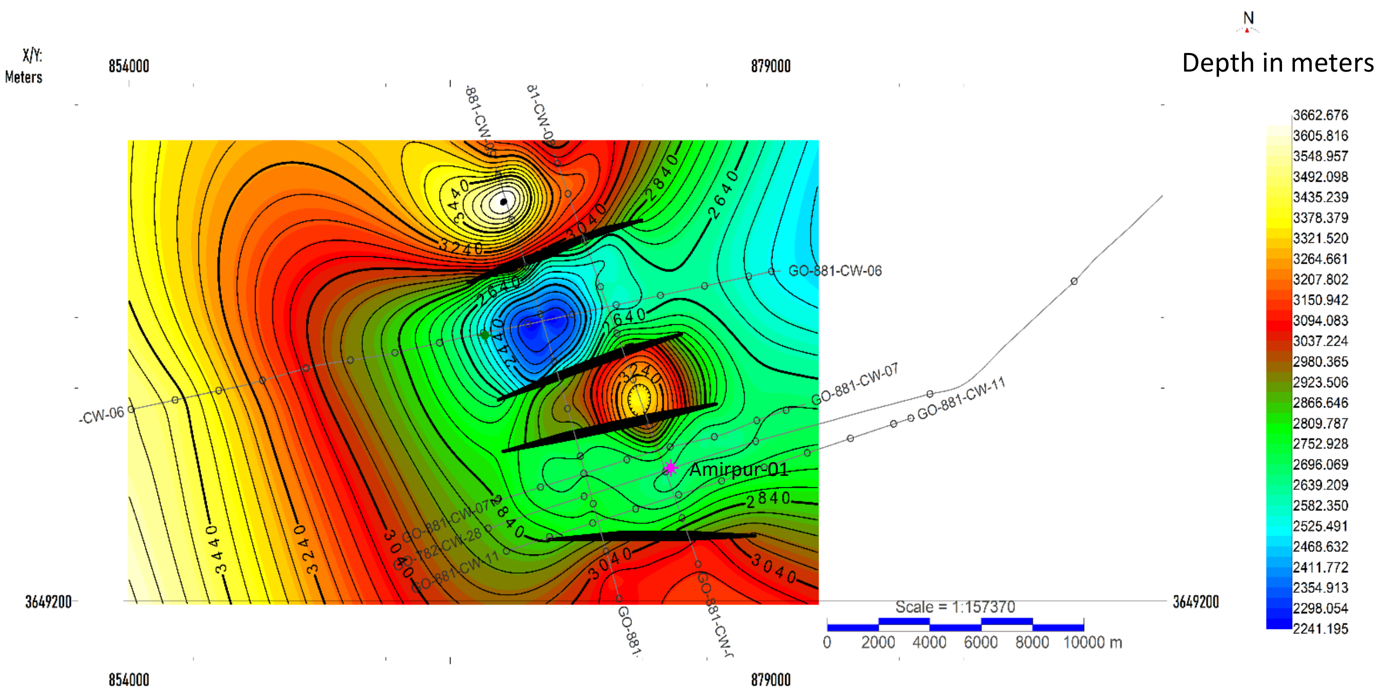


Fig 3.11 Sakesar depth countered grid

CHAPTER 4:
PETROPHYSICAL AND FACIES ANALYSIS

4.1 PETROPHYSICAL ANALYSIS

Well logging is tool to measure the properties of the earth's subsurface. Through this process, various physical, chemical, electrical or other properties of rock and fluid mixtures penetrated by drilling a well into the earth are recorded. Petrophysics is the study of the physical and chemical properties that describe the presence and behavior of rocks, soils and fluids (Rider, 1996). This also defined "Petrophysics is description of that physical properties which relating the occurrence, behavior of rocks and fluids inside the rocks" (Asquith et al, 2004).

Petrophysics uses well logs (caliper, resistivity, GR, DT, RHOB, Neutron logs etc.) and all pertinent information is obtained by use these well logs. Every well log has its own importance and these logs play very important role in quantifying the precise reservoir parameters such as porosity, permeability, net pay zone, fluid content and shale volume. Petrophysical interpretation generally has less concern for seismic while more concerned with using well bore measurements to contribute to reservoir description (Asquithet al,2004)

The petrophysical analysis was carried out by using the following wire-line logs of Amirpur issued by DGPC:

- Density log
- Neutron log
- Resistivity log
- Spontaneous Potential log
- Gamma Ray log
- Sonic log

LOGS USED

- Density log
  (used for calculation of densities)
- Sonic log/porosity log
  (measure interval transient time)
- Gamma ray log
  (calculate volume of shale)

4.2 Classification of geophysical well logs

Geophysical well logs can be classified into three categories

- Lithology logs
- Resistivity logs
- Porosity logs

4.2.1 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)

a) Caliper (CALI)

Caliper logs measure the diameter of the borehole. It records the cavities where the well is caved in, and also 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 (Croizéet al, 2010).

b) 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,

$$\mathrm{Igr} = \frac{\mathrm{GR_{LOG}} - \mathrm{GR_{min}}}{\mathrm{GR_{max}} - \mathrm{GR_{min}}},$$

Where $\mathrm{GR_{min}}$ is minimum value and $\mathrm{GR_{max}}$ is the maximum value of the gamma ray, Igr is the gamma ray index an Gr log represent the gamma ray log. Gamma ray logs are used to identify lithology, the volume of the shale and the correlation between the formations
(Asquith et al, 2004).

4.2.2 Resistivity well logs

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 (0.2 to 2000 ohm) with depth.

Resistivity well logs are

- Deep laterolog (LLD)
- Shallow laterolog (LLS)

a) Deep laterolog (LLD)

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

b) Shallow laterolog (LLS)

Shallow laterolog measure the resistivity of in the invade zone (R_i). In water-bearing zone, the shallow laterolog records a low resistivity because mud filtrate resistivity (R_{mf}) is approximately equal to mud resistivity (R_m), (Asquith et al, 2004).

4.2.3 Porosity well logs

Porosity well logs are providing 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)

a) Sonic/Acoustic (DT)

Sonic logs measure the interval transit time (delta t) 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

(Asquithet 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

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

Where $\emptyset_s$ represent the calculation that derived from the sonic log, Δt_m is the interval transient time of the matrix, Δt_{log} interval transient time of formation, represents the transient time of the fluid (salt mud=185 and fresh mud=189).the interval transient time of the formation depends upon the matrix material, its shape and cementation (Wyllie et al , 1956).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).

b) Neutron Porosity (Φ_n)

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.

c) Density (RHOB)

Density log is the porosity log that measure electron density of the formation, (Asquithet 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.

Relation for the calculation of the porosity from the Density log ($\emptyset_d$)

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 limes tone and shale. By using following mathematical relation, density porosity can be related as

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

where,

- $\emptyset_d$ represent porosity derived from the density log
- $\rho_b$represent bulk density of formation
- $\rho_m$represent matrix density and for limestone it is 2.71
- $\rho_f$represent density of fluid.

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

4.3 Average porosity calculation

Sum of the porosities that are obtained from the different logs divided by number of logs from which porosity is calculated. Here Lower Goru formation is reservoir of cretaceous age 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.

$$\emptyset_{\mathrm{avg}} = \frac{\Phi \mathrm{n} + \emptyset_{\mathrm{d}} + \emptyset_{\mathrm{s}}}{3},$$

where,

- $\emptyset_{\mathrm{avg}}$ is the average porosity calculated from the available porosities
- Φn represents neutron porosity
- $\emptyset_{\mathrm{d}}$ represent the density porosity
- $\emptyset_{\mathrm{s}}$represent the sonic porosity.

4.4 Effective porosity ($\emptyset_{\mathbf{e}}$)

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).

$\emptyset_{\mathrm{e}} = \emptyset_{\mathrm{avg}} \times (1 - \mathrm{Vsh}),$

Where,

- $\emptyset_{\mathrm{e}}$ effective porosity which to be calculated
- $\emptyset_{\mathrm{avg}}$ represent the average porosity
- Vshrepresent volume of the shale.

4.5 Mathematical relation for Water Saturation (S_w)

Water saturation in the formation can be defined as "The percentage of the pore volume filled by water in the formation". The saturation of water in the formation can be calculated by the following Archie equation

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

where,

- F is formation factor which is

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

- R_w represent the resistivity of water
- R_t represent the true formation resistivity
- n represents the saturation exponent
- a is the constant and its value is 1 in case of limestone
- $\emptyset$ represent effective porosity
- m represents the cementation factor and it value is taken 2 for the limestone.

Mathematical relation for Hydrocarbon Saturation (S_h),

$$S_h = 1 - S_w$$

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

Where S_w represent Hydrocarbon saturation, S_h represent hydrocarbon saturation.

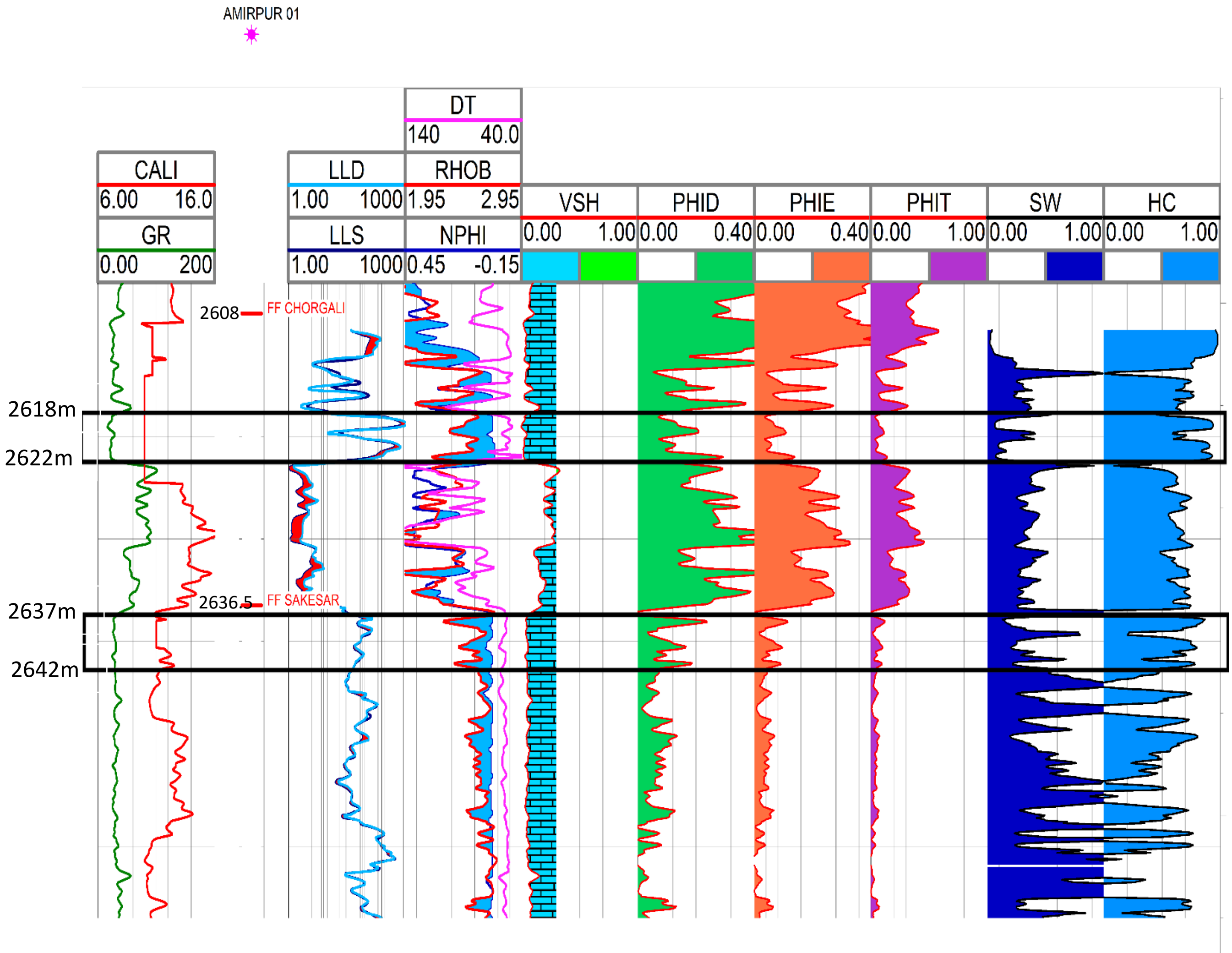


Fig 4.1 Petrophysical analysis of well Amirpur-01

4.6 Interpretation of well log

Kingdom suite software is used for the analysis of well Amirpur 01 within the depth range 2600m to 2700m. GR log, SP log and Caliper log are displayed in track 1. LLD while LLS log are displayed in track 2 in logarithmic scale. DT, NPHI and RHOB are displayed in track 3. The crossover of NPHI and RHOB is important, if depth of NPHI is remain same but value of the RHOB is changed within that depth, it indicates fluid contact (Fi. Volume of shale $V_{(sh)}$is displayed in track 4. Density porosity (PHID) calculated from DT, Average porosity (PHIT) which actually is the sum of NPHI and DT divided by 2 and Effective porosity

(PHIE) are displayed in track-5 after removal of the shale effect. Water saturation (SW) and hydrocarbon saturation (HC) is calculated and displayed in track 6.

Petrophysics is done to depth from 2600 m to 2700 m. The reservoir zones consist of limestone are marked at depth of 2618m to 2622m of thickness 4m and 2637m to 2642m of thickness 5m. Zone 1 lies in chorgali while Zone 2 is in Sakesar based on following signatures of logs. Caliper log should be consistent. In the same track study GR log, it must be decreased. There should be separation between LLD, LLS in next track. In next track there would be crossover between RHOB and NPHI this is indication of Hydrocarbon. In next track Volume of shale should be decreased which is indication of limestone. In next track study Effective porosity, density porosity and total porosity lies between 5-10%. In the last track saturation of water its values lie between 30-40%. The various parameter estimated within reservoir zone is shown in Table.

Calculation Parameter	**Zone 1 % (Chorgali)**	**Zone 2% (Sakesar)**
Average Volume of Shale=V(sh)	5 %	5%
Average Porosity Obtained from Density log= $\emptyset_{davg}$	13 %	10%
Average Porosity in (PHIT) Percentage=$\emptyset_{avg}$	6 %	5%
Average Effective Porosity in Percentage= $\emptyset_{eavg}$	8 %	7%
Average water Saturation in Percentage=S_{wavg}	30%	44%
Average Hydrocarbon in Percentage= S_{havg}	**70%**	**56%**

Facies Analysis

4.7 Introduction to facies analysis:

Per Moore (1949), fade is broken parts of different nature, which belong to any genetically related body of sedimentary deposits. Moore emphasizes that facies are different aspects of stratigraphic units which have mutually space distribution and clarifies the relationship between facies and lithotopes (Mutti and Lucchi, 1978). In geology, the word facies are related to the rock with specific characteristics which are distinguished from the other rocks (Ravia et al., 2010).

Facies are the different rock unit which forms under specific condition, so it represents specific depositional environment. Depositional environment is the specific type of place where the facies are deposited, such as Glacier, Sea bottom, Delta, Glaciers etc. The term facies were introduced by the Swiss geologist Amanz Gressly in 1838. Figure 5.1 shows the different seismic facies with relevant depositional environment, legends are given. Four types of facies are given in Figure 5.1, glacier, narrow channels, broad complex channels and incised valley. One type of sediments can be formed in more than one environments e.g. sand can be found in narrow channels, in complex channels and in incised valley.

Figure 5.1:

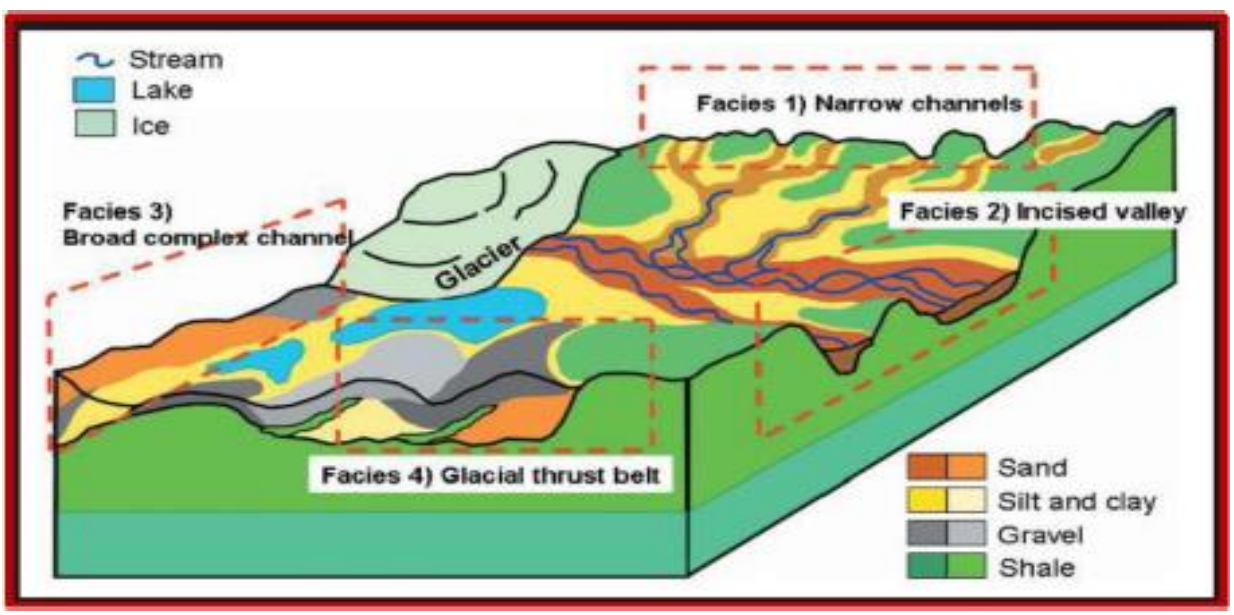


Figure 4.2: Different Environment with different facies

4.8 Facies Analysis:

Depending upon the depositional environment and sedimentary process geologic facies vary in lithology and rock properties and they have different seismic signatures (Nanda, 2016). Development of a facies classification scheme is a challenging interplay between capturing enough information for environmental interpretation yet remaining simple. Particularly important is the characterization of facies such that their recognition criteria relate to critical environmental thresholds such as sea level, normal wave base, and storm wave base. These physical environmental zones regulate sedimentary textures and biotic assemblages. A good understanding of paleoecology always strengthens the interpretation and such studies should be included as part of all depositional facies' studies. Depositional textures in turn affect porosity permeability in carbonates. The vertical and lateral organization of facies is an exercise essential to sequence stratigraphic interpretations (Lucia, 1995).

4.8.1 DT, RHOB and GR cross plot:

The standard cross plot between DT on y-axis and RHOB on x-axis with logarithmic data from well-28, with GR as reference on z-axis is given in the figure below. For facies analysis, I selected depth between (2600-2700).

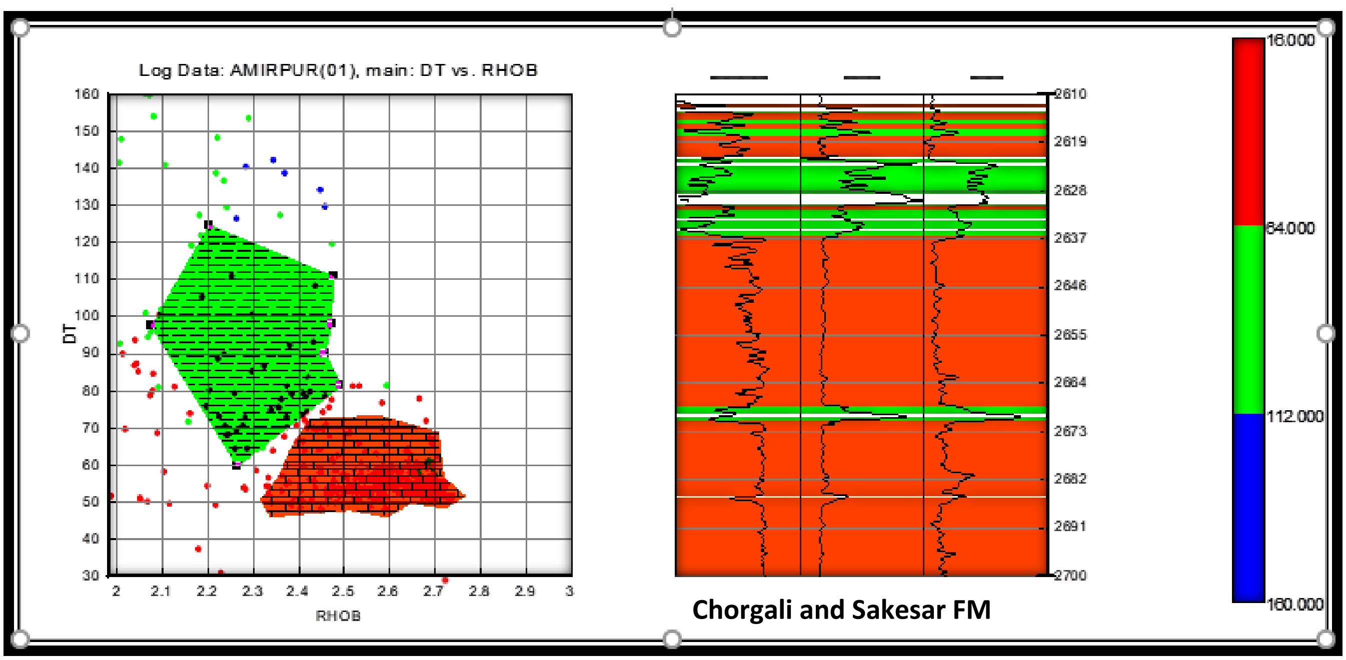


Figure 4.3

In the Figure 4.3 it can be clearly seen that there is an inverse relation between sonic and neutron logs. Limestone having low DT and high RHOB comparatively to shale and have low GR value. In the Figure 4.3 above, green color showing the shale, orange is for limestone. This Figure 4.3 shows that our reservoir may lie between 2618 to 2624 and 2637 to 2842m.

4.8.2 GR, LLD and RHOB cross plot:

There is direct relationship between LLD and RHOB for limestone reservoir i.e. due to the presence of limestone the density (RHOB) increases, while due to oil/gas resistivity (LLD) increases. Cross plot between LLD and RHOB is shown in the Figure 4.4 below. For this plot, we select logarithmic scale for LLD and linear for RHOB. Units of LLD is ohm-m and for RHOB its g/cc. depth selected for this cross plot was 2600 to 2700m. RHOB is selected on X-axis and LLD on Y-axis, as a reference GR with unit's API is selected on Z-axis. Limestone is colored in pink while shale is in green.

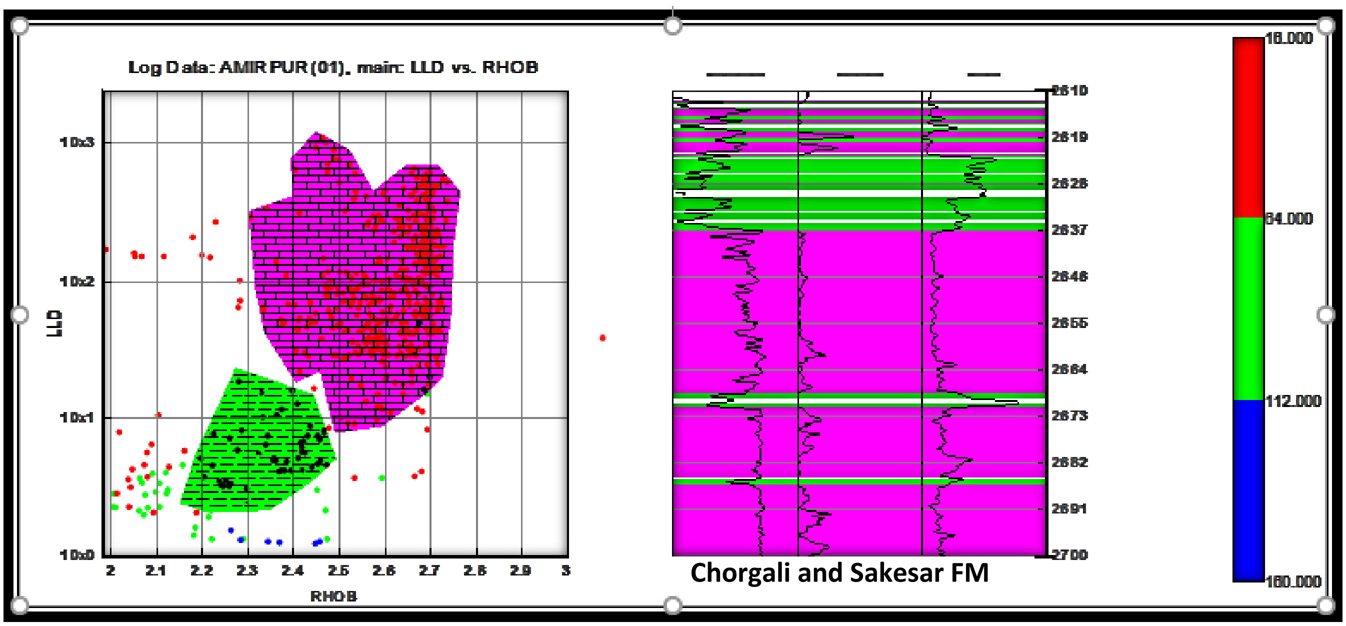


Figure 4.4

Chapter no 5
Seismic Attributes Analysis

5.1 Introduction

What are Seismic Attributes?

"Seismic Attributes are all the information obtained from seismic data, either by direct measurements or by logical or experience-based reasoning." (Taner, 2001)

Seismic attributes typically provide information relating to the amplitude, shape, and/or position of the seismic waveform.

5.2 Families of Attributes (based on method of generation)

5.2.1 Complex Trace Attributes

The seismic data is treated as an analytic trace, which contains both real and imaginary parts. Various amplitude, phase, and frequency attributes can be calculated.

Complex trace attributes Includes:

• Instantaneous Attributes--associated with a point in time

• Response Attributes--related to a lobe of the energy envelope A(t); corresponds to an
event, rather than a single time sample

Figure 1. Complex Trace Attributes.

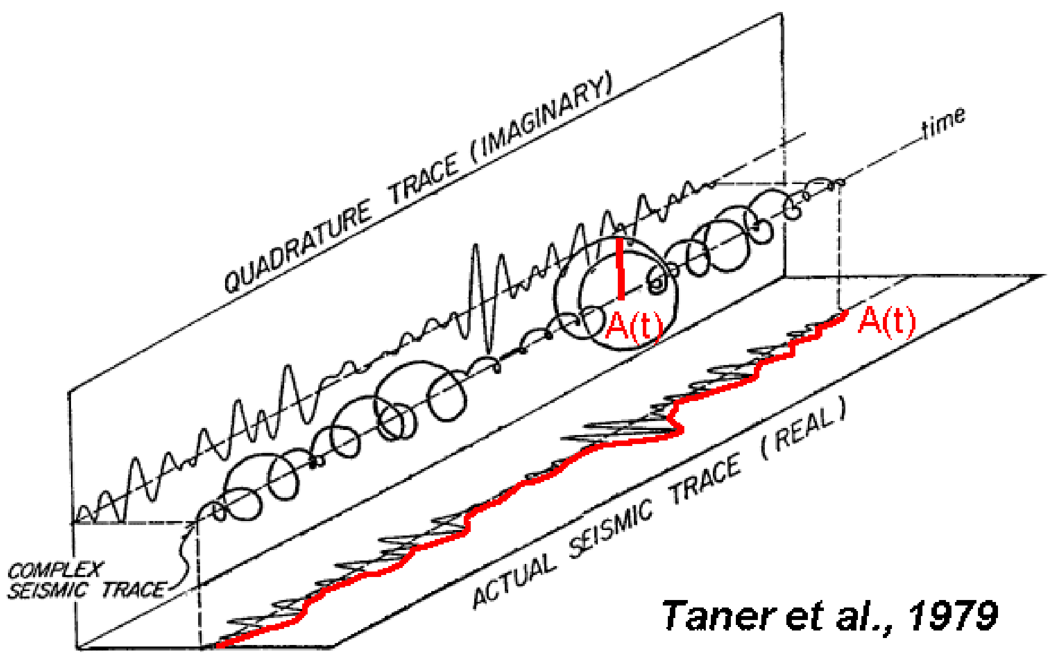


Fig 5.1 complex trace attribute

5.2.2 Fourier Attributes

frequency domain attributes obtained through Fourier analysis (e.g., amplitude variation with bandwidth in frequency (avbf), spectral decomposition)

Figure 2. Fourier Attributes.

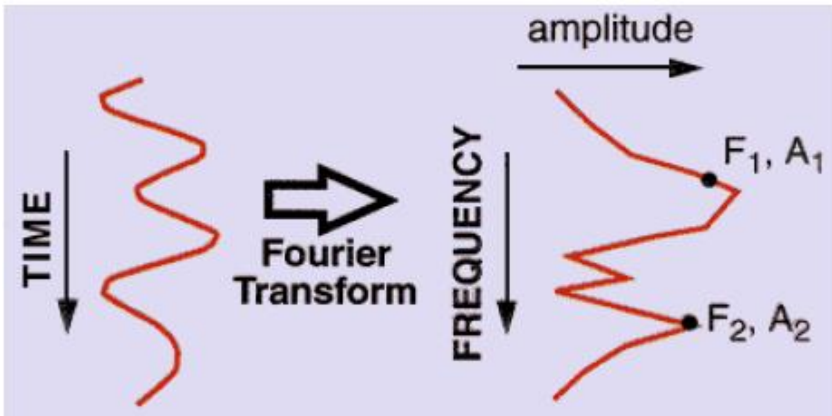


Fig 5.2 Fourier Attribute

5.2.3 Time Attributes

Related to the vertical position of the waveform in the seismic section (e.g., horizon time picks, isochrons)

5.2.4 Window Attributes

Attributes which summarize information from a vertical window of data.

5.2.5 Multi-trace Attributes

Attributes calculated using more than one input seismic trace, which provide quantitative information about lateral variations in the seismic data e.g. (coherence, dip/azimuth).

5.3 Instantaneous Attributes

- Envelope
- Instantaneous Phase
- Instantaneous Frequency
- Weighted Average Frequency
- Apparent Polarity

5.4 Signal Envelope (E) or Reflection Strength

The Signal Envelope (E) is calculated from the complex trace by the formula:

$$E(t) = \sqrt{T^2(t) + H^2(t)}$$

Where:

T(t) = seismic trace

H(t) =Hilbert's transform

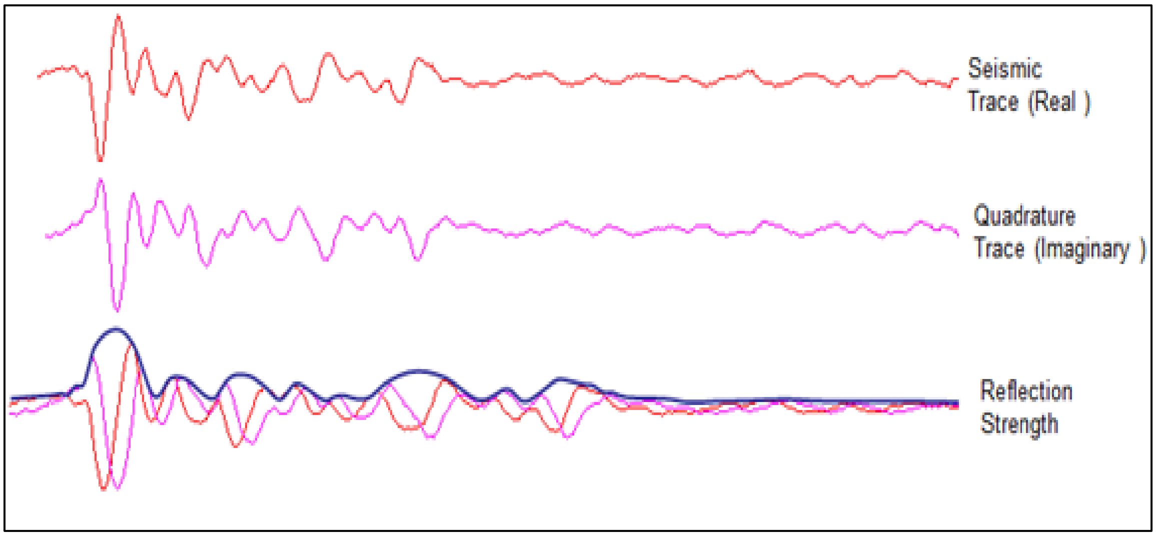


Figure 5.3: Envelope traces attribute for real seismic trace

The Hilbert Transform of the real seismic trace is generates an imaginary trace and using both these traces the envelope trace is computed. Fig 5.3 shows the real, imaginary and envelope trace. The envelope is the envelope of the seismic signal. It has a low frequency appearance and only positive amplitudes. It often highlights main seismic features. The envelope represents the instantaneous energy of the signal and is proportional in its magnitude to the reflection coefficient (Subrahmanyam & Rao, 2008).

Envelop (Amplitude) section of line 881-CW-08

Envelop attribute is computed for seismic line 881-CW-08 Fig 5.4, which shows major changes in lithologies . yellow packages indicate the maximum reflection strength corresponding to the reservoir and seal rocks. Due to limestone present in the area showing strong reflection for most of the area. Also along faults the reflection strength is not prominent, it shows a discontinous reflection. It justified the major part of interpretation, tops of horizons and the fault surfaces.

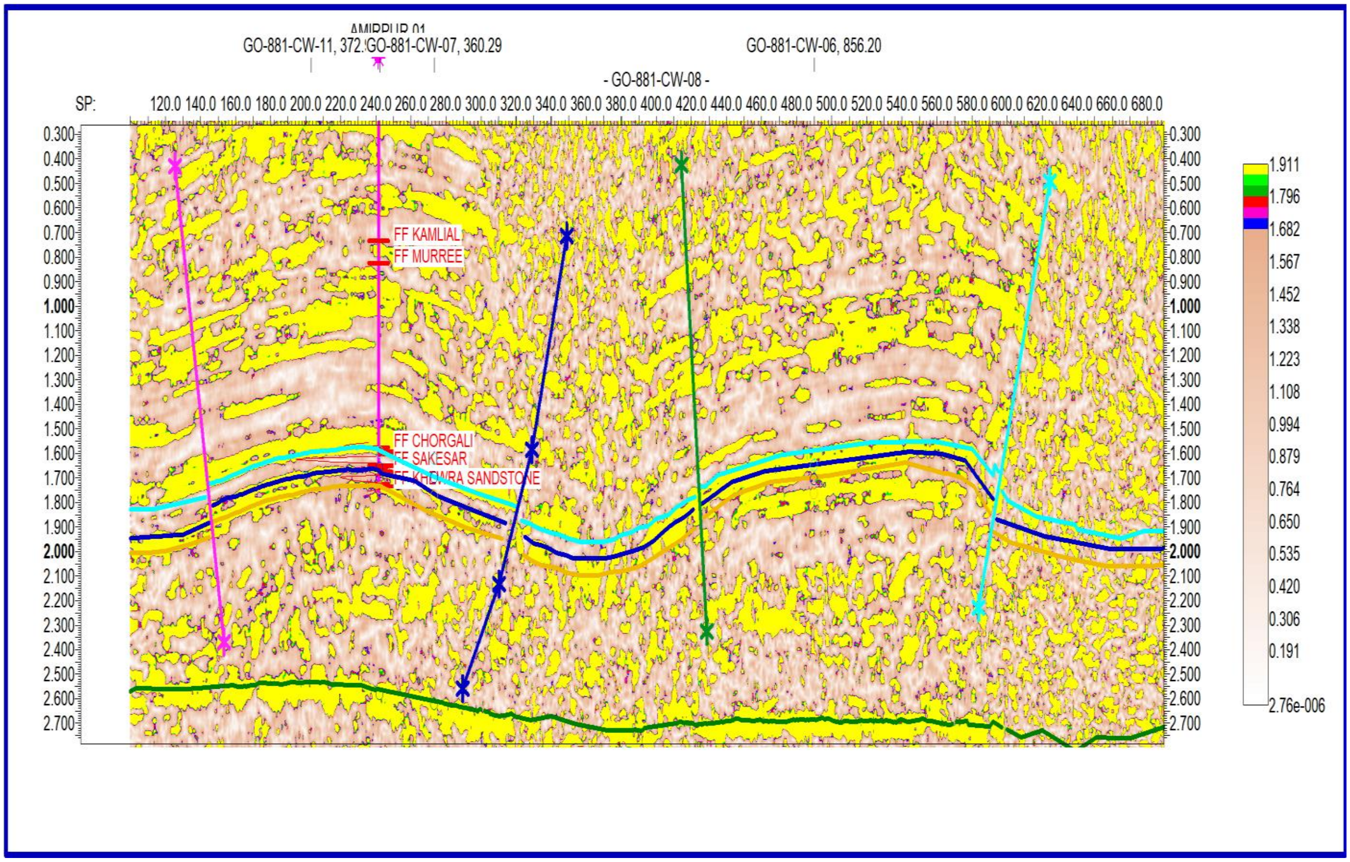


Fig 5.4 Envelop (Amplitude) section of line 881-CW-08

5.5 Instantaneous Phase

Instantaneous phase attribute is given by

$$\emptyset(t) = \tan^{-1}\left|{H(t)}/{T(t)}\right|$$

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

$$T(t) = E(t)\cos(\emptyset(t))$$
$$H(t) = E(t)\sin(\emptyset(t))$$

Instantaneous phase is measured in degrees (-π, π). It is independent of amplitude and shows continuity and discontinuity of events. It shows bedding very well. Phase along horizon should not change in principle, changes can arise if there is a picking problem, or if the layer changes laterally due to “sink-holes” or other phenomena (Subrahmanyam & Rao, 2008).

Phase Section of line 881-CW-08

This attribute shows continuity and discontinuity of the reflection event. A general interpreted phase section is shown in the Fig 5.5, which justifies the marked horizons and faults surfaces. Every horizon responds a continuous reflection while along fault there is discontinuous reflection as highlighted in the Fig 5.5

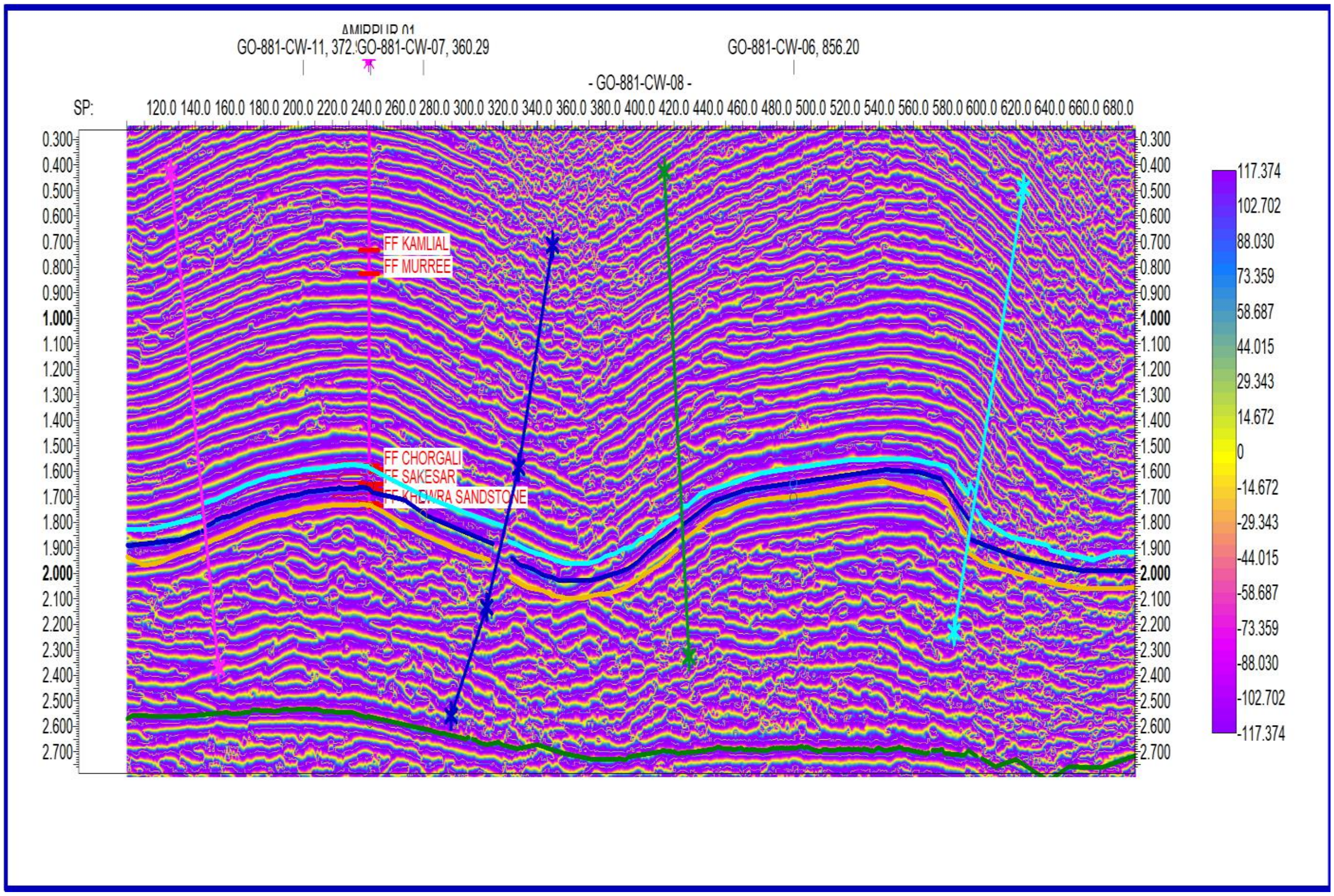


Fig 5.5 Phase Section of line 881-CW-08

5.6 Instantaneous Frequency

Instantaneous frequency is the time derivative of the phase, i.e., the rate of change of the phase:

$$F(t) = \frac{d(\emptyset(t))}{dt}$$

Instantaneous frequency represents the mean amplitude of the wavelet (Subrahmanyam & Rao, 2008).

Frequency Section of line 881-CW-08

Frequency Attribute 881-CW-08 is shown in Fig 5.6, which shows frequency changes along different lithologies. At shallow level in the section low frequency values, even negative values which indicates low impedance and thin beds same behavior also observed along the fault surfaces. The continuity of both the interpreted horizons and discontinuous layering along fault surfaces are to some extent justified by the calculated frequency attribute.

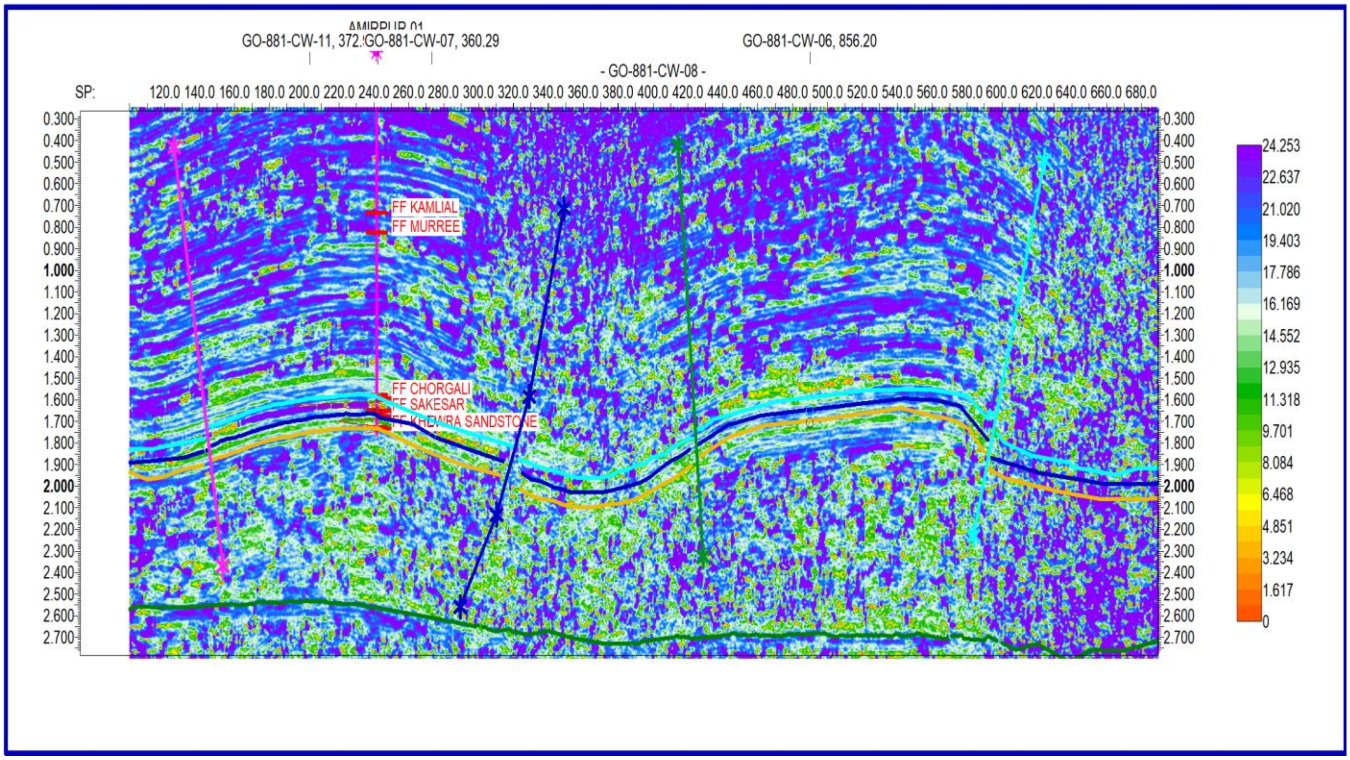


Fig 5.6 Frequency Section of line 881-CW-08

5.7 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 5.7)

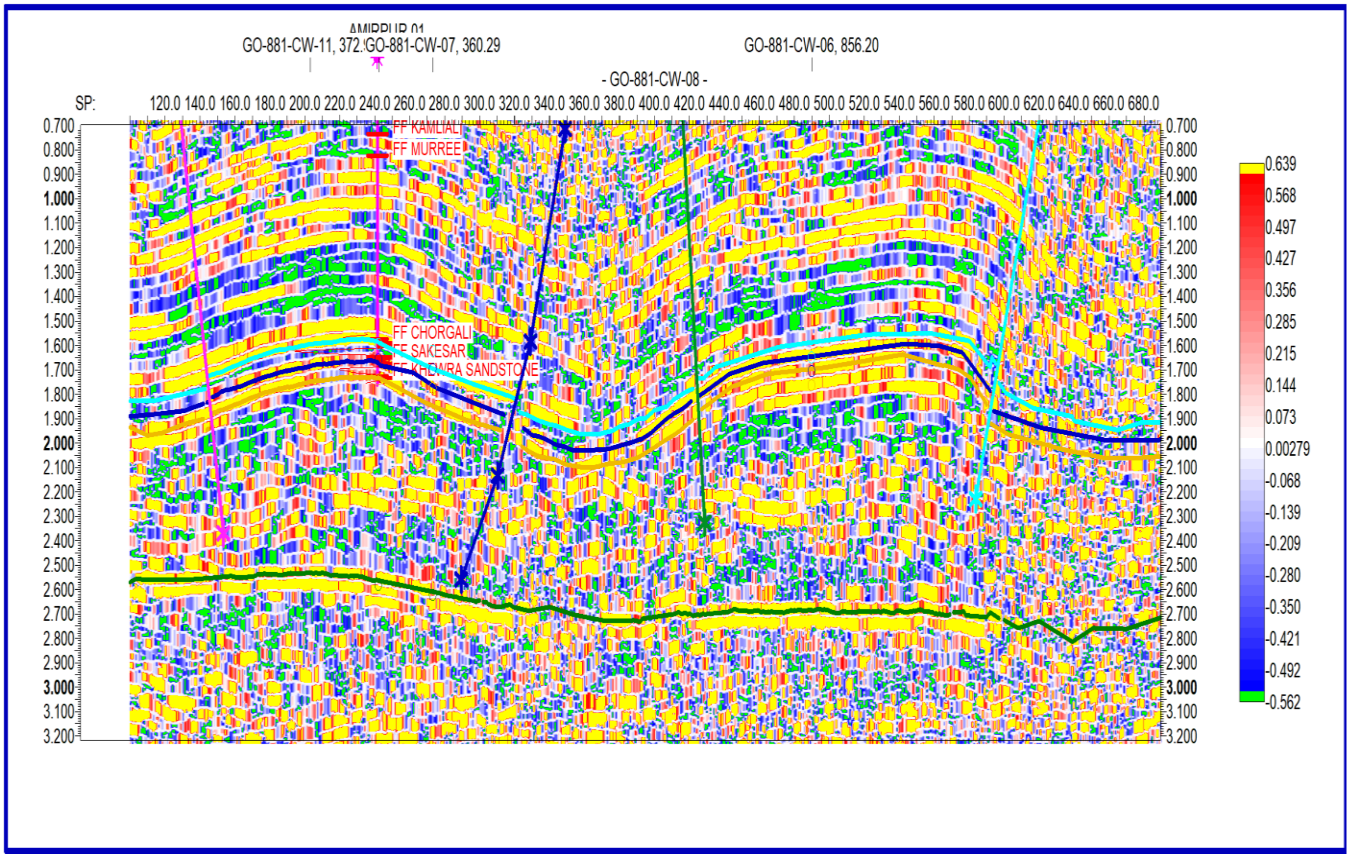


Fig 5.7 Average Energy of line 881-CW-08

CHAPTER NO 6

POST- STACK COLORED INVERSION

6.1. Colored inversion

Seismic colored inversion is a post stack inversion technique which transform seismic data into layered rock properties. Seismic colored inversion performs significantly better than traditional inversion methods like model-based inversion, band-limited inversion methods (Lancaster et al., 2000).

Colored inversion was introduced by Lancaster et al. (2000). In this method, the inversion can approximately be represented as a convolutional (filtering) process. It simply uses an operator (O) in the frequency domain to transform seismic traces (S) directly into impedance (Z) (Z = O* S). This operator maps the seismic amplitude spectrum into the earth impedance spectrum. The phase of this operator is 90° (Neep, 2007), so that it integrates the reflectivity series into impedance. Various seismic and well log spectra are analyzed to define colored inversion Operator that transforms the seismic trace to average acoustic impedance log (Pendrel, 2006). The assumption is that the input seismic data should zero phase. The Colored Inversion operator is converted to the time domain and applied to the seismic volume using a convolution algorithm. Once the Colored Inversion operator has been estimated, it can be used to the seismic data on the interpretation as a user-defined filter. In this way inversion can be achieved within hours since the volume data need not be exported to software and no explicit wavelet is required .

6.2. Wavelet and acoustic impedance

Wavelets are filters that keep us from seeing what we set out to see in seismic data: the earth's reflectivity. Through deconvolution, we try to remove the wavelet from the data. In tying wells, we make a wavelet interact with well-log measurements to create a synthetic representation of the seismic according to the borehole.

There are several ways to estimate seismic wavelets. The following approaches are used to estimate a wavelet when we only have seismic data (RL Brown, W McElhattan, and DJ Santiago, 1988): fitting a band- pass filter to the frequency content of the data doing an autocorrelation. In spite of the fact the wavelet is time varying and is expected to be spatially varying, an overall knowledge of wavelet is crucial to enhancing resolution for better imaging of structure and predicting lithology and fluid content. The most common practice is to invert post-stack seismic data for wavelets. To delineate subsurface lithology to estimate petrophysical properties of a reservoir, it is possible to use acoustic impedance (AI) which is the result of seismic inversion. It is important to remove the wavelet effects from the seismic signal in order to get a reflection series, and then transforming those reflections to AI. Once the Colored Inversion operator has been derived it can be simply applied to the data on the interpretation workstation as a user-defined filter. The inversion is understood simply by this flow chart.

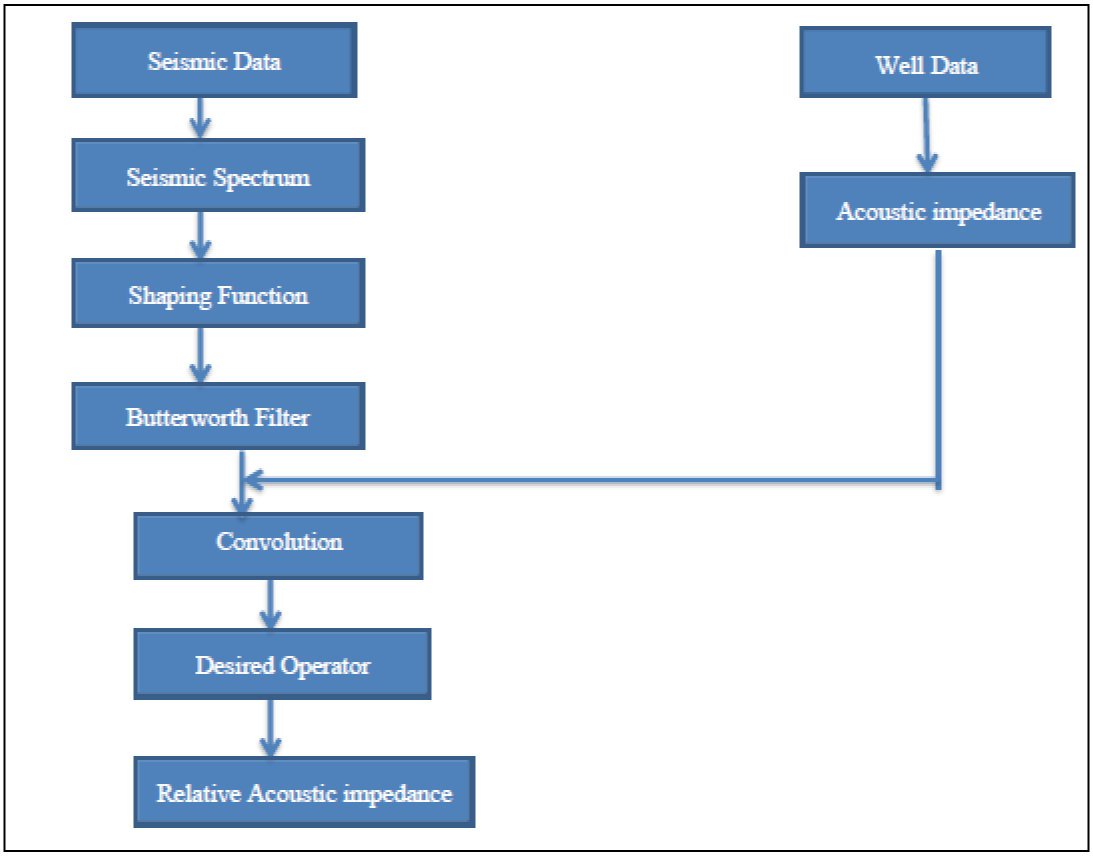


Figure 6.1: Flow chart of colored inversion (Ali et al.,2019)

6.3 Procedure:

Following well logs and information are required for colored inversion in Kingdom Software.

- The velocity and density are obtained from the sonic (DT) and density (RHOB) logs respectively. By convolving we develop acoustic impedance.
- Generated acoustic impedance is cross matched with the input reflection data.
- We derive a single optimal matching filter, convolution of this filter with the input data.
- This Empirical observation indicates that inversion can be approximated with a simple filter and that it may be valid over a sizeable region.

The phase of the operator is a constant $-90o$which agrees 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.

6.4 Wavelet Extraction:

The wavelet is shown in Figure 6.2 is extracted based on 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 by applying different limitations. (Sen).

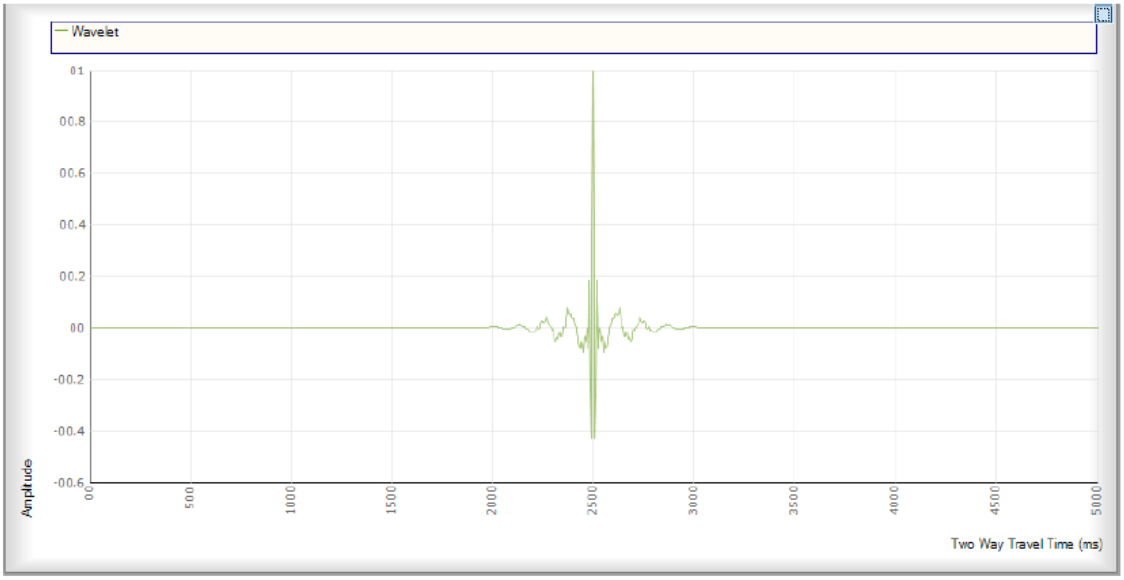


Figure 6.2: Extracted Wavelet

After obtaining a wavelet estimate, the wavelet is used to design an inverse operator to zero phase deconvolve the seismic. The deconvolution may be a de-phase only or a full-inverse procedure to correct both the phase and the amplitude spectra.

6.5 Estimation of Impedance:

The colored inversion method is based on a special filtering technique. In the inversion amplitude spectrum of well log is compared with seismic data. Figure 6.3 showing the impedance spectrum with fitted line estimated after removing source wavelet, noise and multiples should be removed (Ghosh 2000). To remove the mismatch between well spectrum and seismic spectrum we develop an operator. This operator is then applied to the whole seismic data (Lancaster and Whitcombe 2000). To compute the operator a cross plot between amplitude and logarithm of frequency is made. A linear fit is shown in the Figure 6.3, is performed to calculate an exponential function which serves as a shaping filter (Walden and Hosken 1985, Velzeboer 1981). This filter transforms the seismic trace into an assumed equivalent acoustic impedance. We also assume that the seismic input cube is zero-phase, which is hardly ever the case. Now our approach is to convolve the extracted wavelet with acoustic impedance (reflectivity series). The acoustic impedance is also computed from well log data as described early**.**

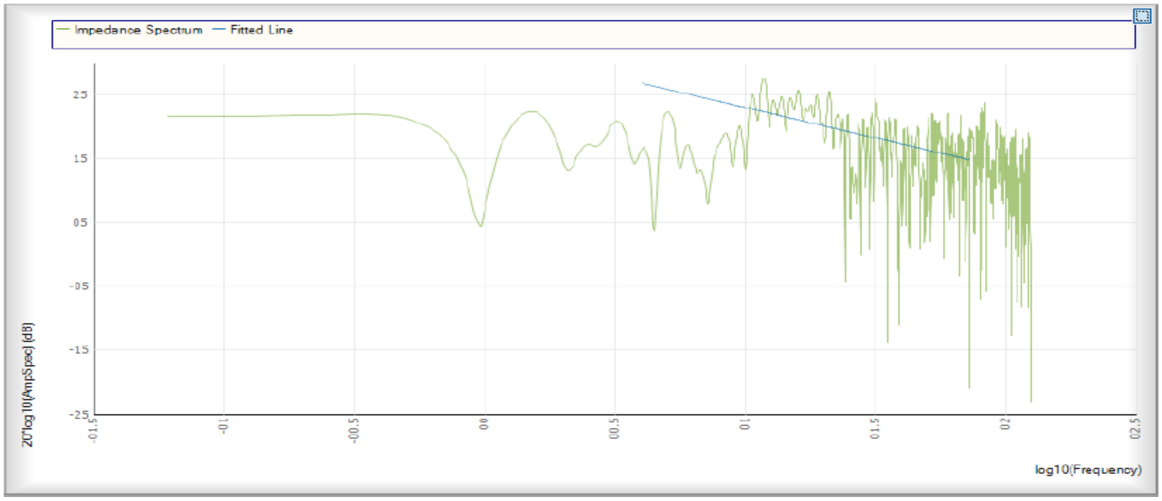


Figure 6.3: Impedance Spectrum with Fitted Line

6.6. Butterworth filter

The Butterworth filter **is** a type of signal processing filter designed to have as flat frequency response as possible (no ripples) in the passband and zero roll off response in the stop-band. Butterworth filters are one of the most commonly used digital filters in motion analysis and in audio circuits. 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).

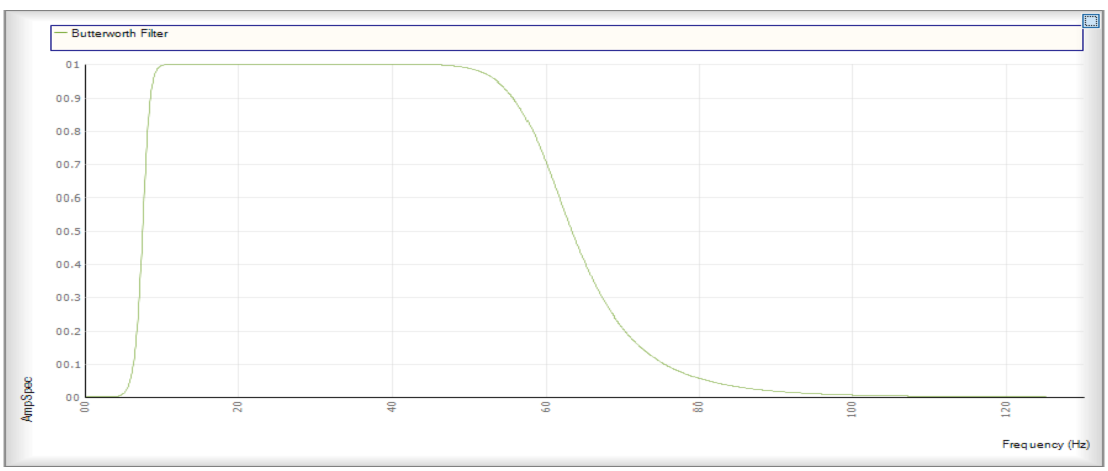


Figure 6.4: Butterworth Filter

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

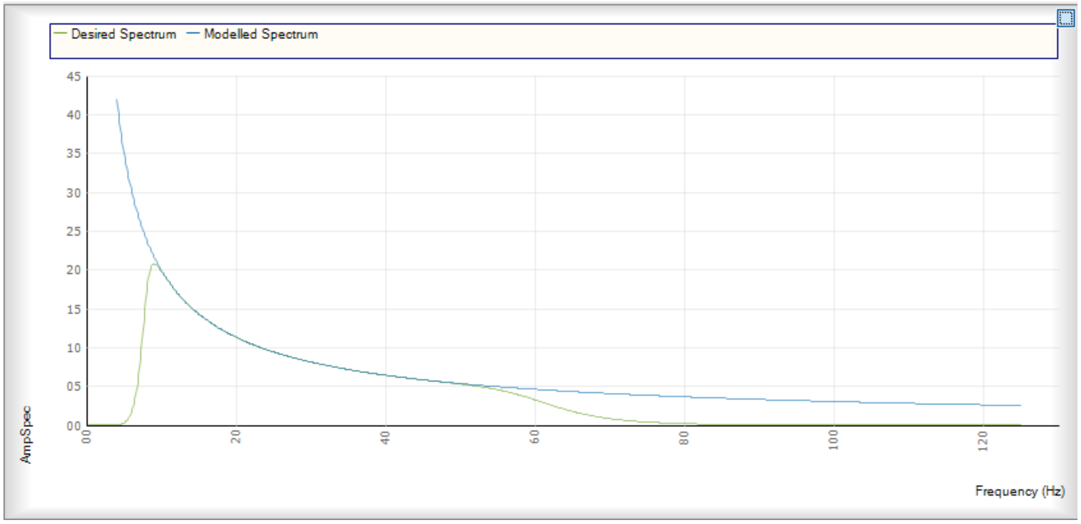


Figure 6.5: Desired and modeled spectrum.

There are two spectrums shown in figure (6.5) both are of different colors. The blue color shows the spectrum obtained from convolution of wavelet and acoustic impedance and the spectrum in blue color shows a desired spectrum. To obtain a spectrum of our desire for this purpose I 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). The figure (6.7) shows us the shaped seismic spectrum and desired seismic spectrum.

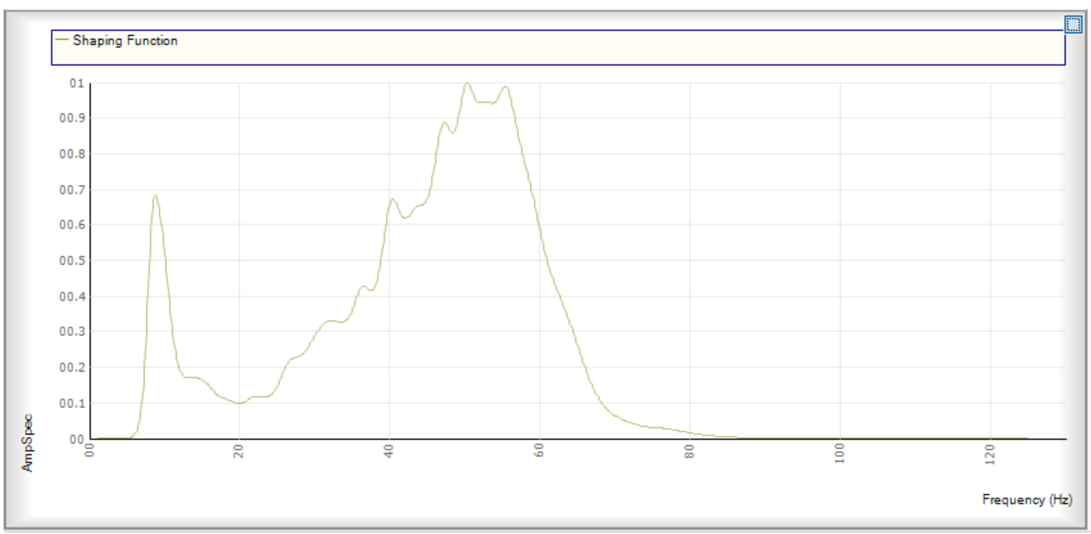


Figure 6.6: Shaping spectrum

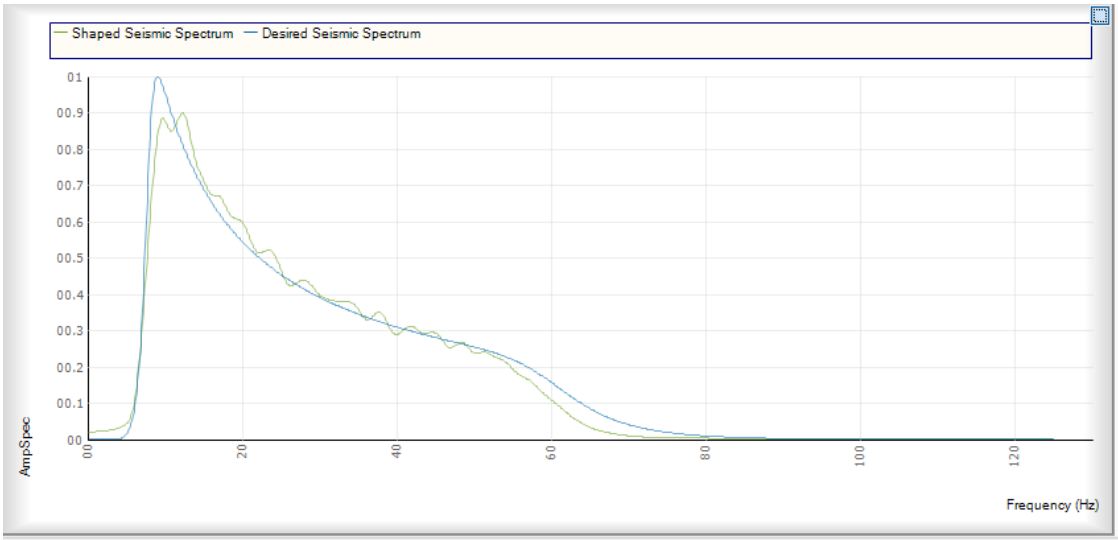


Figure 6.7: Convolution of shaped seismic spectrum and desired spectrum

A seismogram for specific window (as values of acoustic impedance is obtained from well data) is developed then I develop a seismogram to invert whole section. For this purpose, I convolved desired spectrum with seismic mean spectrum. After convolving seismogram with seismic mean spectrum. I am able to apply it on whole seismic section. The figure 6.8 shows seismic mean spectrum and desired spectrum**.**

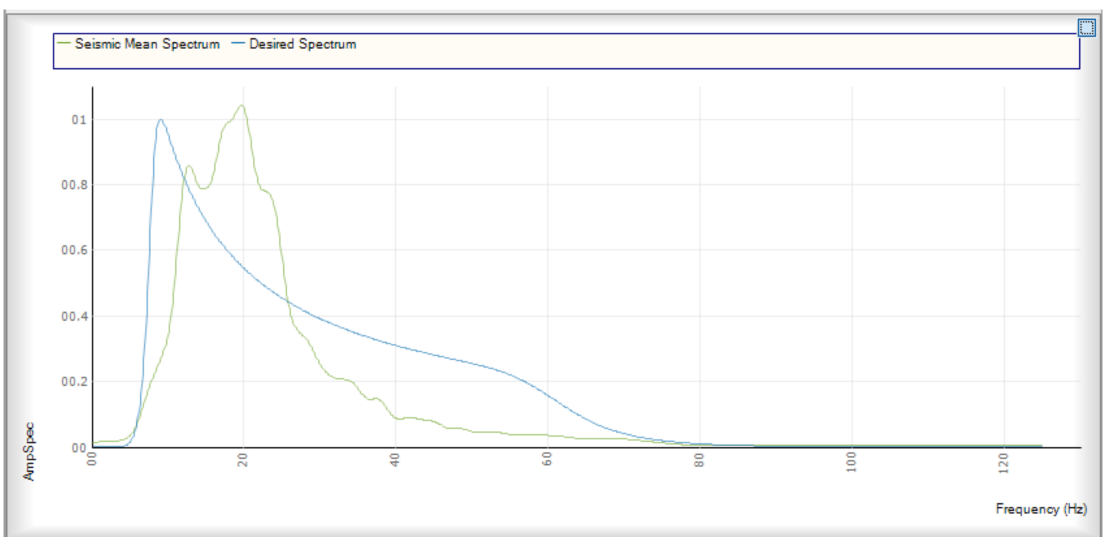


Figure 6.8: Convolution of seismic mean spectrum and desired spectrum.

After completion of the process of generating synthetic seismogram, the section is inverted an acoustic impedance is shown on section as shown in figure (6.9).

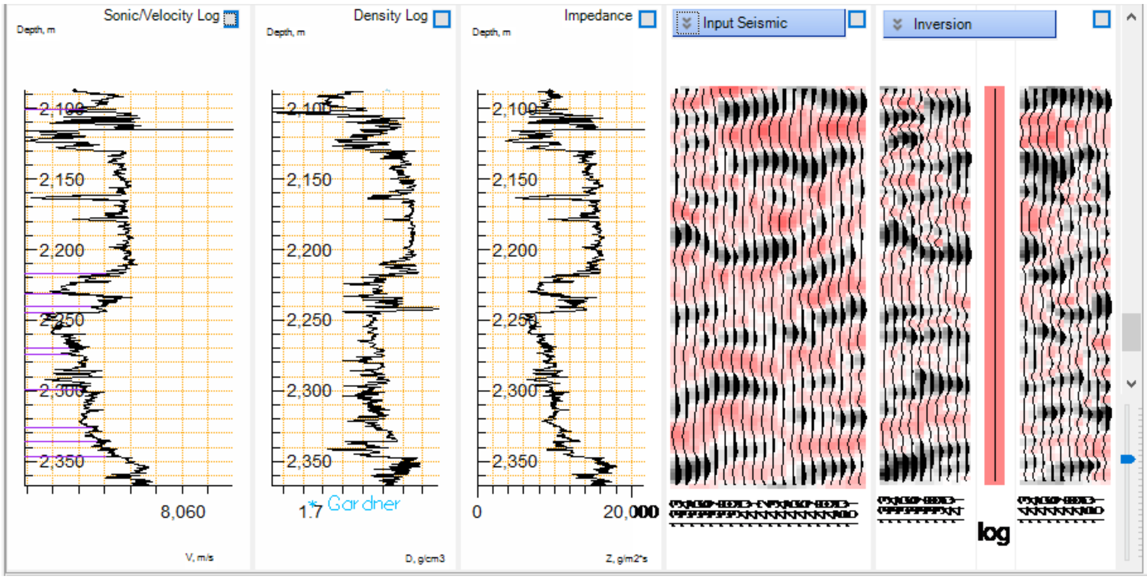


Figure 6.9: Input seismic section and inverted section along with logs

Fig 6.9 displays sonic log and density logs. These logs are used to compute the acoustic impedance. If values of density log are missing, then Gardner equation is used to estimate these densities. This equation is very popular in petroleum exploration because it can provide information about the lithology from interval velocities obtained from data these values are calibrated from sonic and density well log information but in the absence of these, Gardner's constants are a good approximation for density. Then inversion is applied to the whole section shown in figure 6.10.

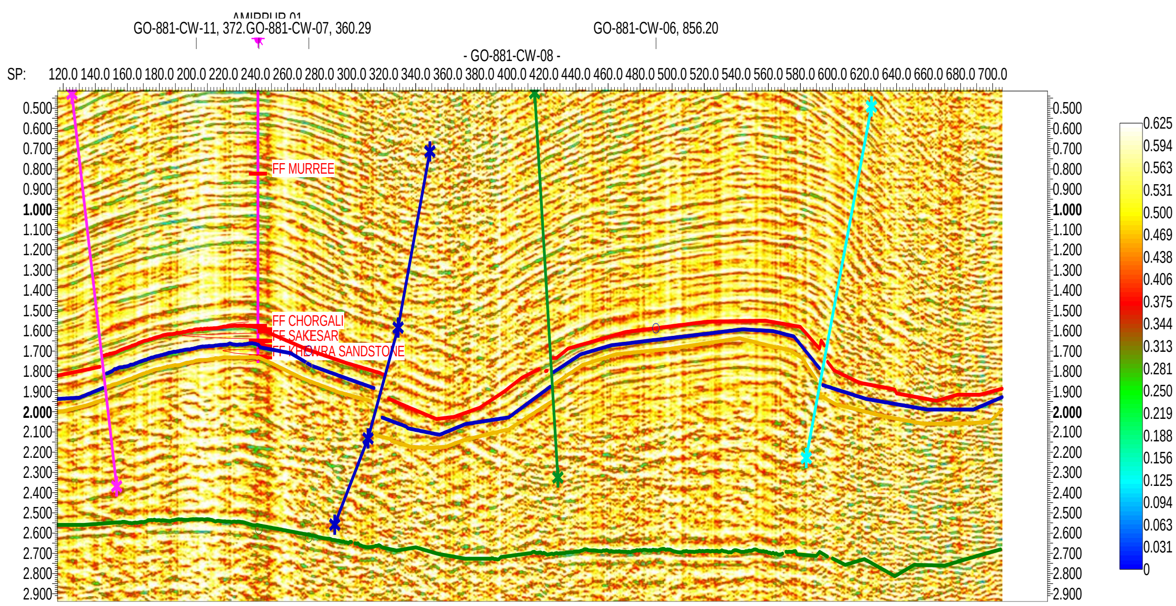


Figure 6.10: Inverted seismic section

6.7. Interpretation of inverted section

After convolution of seismogram with mean spectrum an inverted seismic section is generated as shown in above figures (6.10). The inverted section can be interpreted by using color bar. The white to yellow color shows high values of acoustic impedance and blue to green color shows low impedance. The hydrocarbons accumulation is associated with low acoustic impedance. In the given inverted section in figure (6.10), Formations displayed are chorgali and Sakesar and it yields a response of low acoustic impedance which is related to presence of hydrocarbon accumulation. It is also confirmed from Petrophysical results.

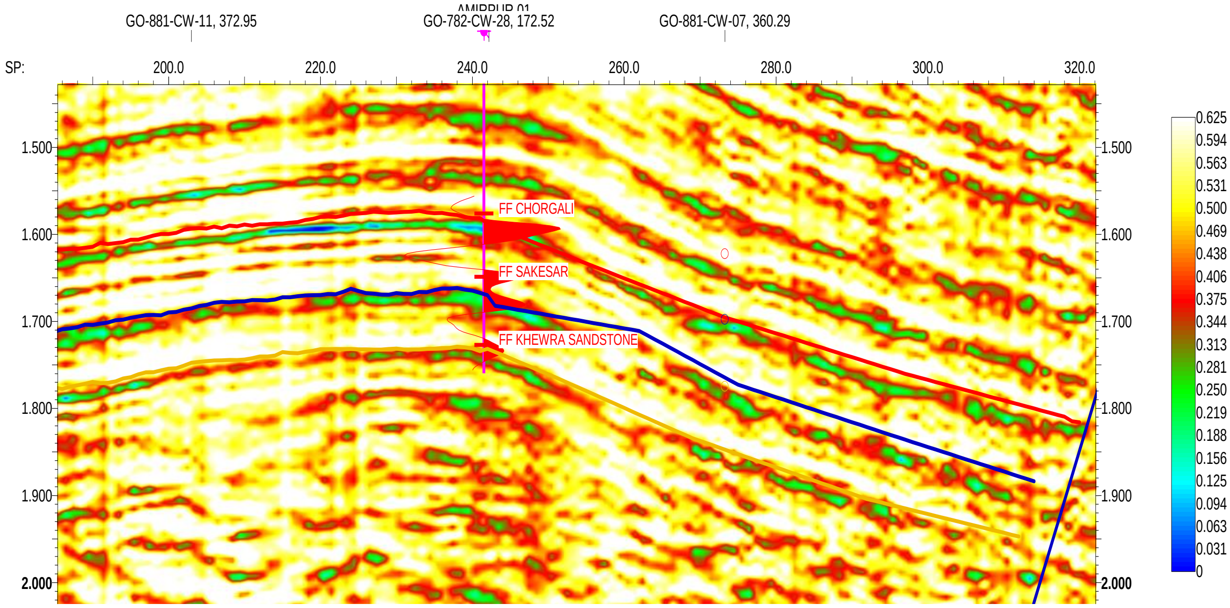


Figure 6.11: Zoomed view of inverted section

Conclusions

- On the basis of general stratigraphic column present in the area and the formation tops of the Amirpur-01 well, three reflectors are marked on seismic sections.
- The marked horizons are named as Chorgali, Sakesar and Khewra sandstone. Horizons are marked with the help of synthetic seismogram of well Amirpur-01 which is generated from well log data by using density log and sonic log.
- Several major faults along with few minor faults were marked on seismic section depend on the geology and tectonics of the study area. Reverse faulting results Anticlinal structures which shows the area of dissertation lies in compressional tectonic regime.
- 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 and Sakesar 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 petrophysical interpretation of well Amirpur-01 leads us to probable zones for hydrocarbon extraction in chorgali and Sakesar formations which show the 70% of hydrocarbon in zone of interest.
- Seismic attributes analysis of line 881-CW-08 having well Amirpur-01 help us to find the zones and Formations of interest.
- Petrophysical logs have been used to compute cross plots have been generated for facies analysis which can effectively discriminate between Limestone and Shale sequences in reservoir zone.
- Seismic inversion shows low acoustic impedance values which are associated with presence of hydrocarbons. It means that Chorgali and Sakesar Formation are producing in study area.

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