2-DIMENSIONAL SEISMIC MODELLING AND RESERVIOR CHARACTERIZATION USING WELL DATA OF SINJHORO BLOCK, LOWER INDUS BASIN.

By

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CERTIFICATE OF APPROVAL

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DEDICATION

My whole work is dedicated to my Parents, Teachers & My Friends and especially to my **Mother** whose valuable ideas and motivation made me able to touch this Stage.

Acknowledgement

First and foremost, all praises to **Allah Almighty**, the most beneficent and the most merciful. Secondly, my humblest gratitude to the **Holy Prophet Muhammad (Peace Be Upon Him)** whose way of life has been a continuous guidance and knowledge of humanity for me. This thesis appears in its current form due to the assistance and guidance of several people. It gives me great pleasure to express my gratitude to all those who supported me and have contributed in making this thesis possible.

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Abstract.

The present study relates to interpretation of seismic data, petrophysical analysis and colored inversion of Sinjhoro. The area is part of Southern Indus Basin. The work is carried out on 3 seismic lines along with petrophysical logs of Chak 66-01, using software Kingdom 8.8.

The integrated study involves; structural interpretation of seismic data, time to depth conversion, synthetic seismogram, petrophysics, facies analysis and colored inversion.

The seismic section shows Horst and Graben structure bounded by normal faults. The horizons were identified using formation tops from wells and their depth were confirmed through correlation with synthetic seismogram generated from sonic and bulk density logs. Time, depth and horizon contour maps of the horizons of interest have been generated to understand the spatial geometry of the structures.

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Chapter # 01

INTRODUCTION TO THE STUDY AREA.

1.1 Introduction to the Area :

Hydrocarbons are among the earth's most important natural resources and hydrocarbons are the main constituents of petroleum (literally, "rock oil"), also called "oil," and natural oil. They are commonly found in and extracted from the Earth´s subsurface. Petroleum is a mixture of liquid hydrocarbons, while natural gas is mainly constituted of methane gas.

The extraction of liquid hydrocarbon fuel from a number of sedimentary basins has been integral to modern energy development. Hydrocarbons are mined from tar sands and oil shale. These reserves require distillation and upgrading to produce synthetic crude and petroleum. A future source of methane may be methane hydrates found on ocean floors.

The area of research is located in Sindh province of Pakistan. It is located in Lower Indus basin(Southern) bounded by Sargodha high in the north, Indian Shield in the east, Kirthar and Suleiman ranges in the west and Indus Offshore in the south. The basin is separated from Upper Indus Basin by Sargodha High and Pezu uplift in the north.

1.2 Location of the study area:

A seismic survey was carried out in Sinjhoro (Sanghar District, Sindh) by OGDCL Pakitan in 2001. The area is in extensional regime and normal faults are present there.

The geographical coordinates of the area are:

- Latitude of the area 26^{o} 01’00N to 26^{o} 17’00N
- Longitude of the area 68^{o} 35’00E to 69^{o} 05’E

The location of the study area is shown in Figure 1.1

Figure 1.1: The satellite image of the area (Google Earth)

1.3 Seismic Data :

The project is given to interpret the seismic section along 2D seismic lines 20017-SNJ-04 , 20017-SNJ-05 , 20017-SNJ-08 , and 20017-SNJ-23. A single well is in the study area to understand the subsurface geology.

The orientation and direction of seismic lines are shown in Table 1.1

:

Serial no	Line no	Line Orientation
1	20017-SNJ-04	Dip line
2	20017-SNJ-05	Dip line
3	20017-SNJ-08	Strike line
4	20017-SNJ-23	Dip line

Table 1.1 : The line number and orientation.

1.4 Well data:

Well name	Unique well ID	Elevation(m)	Depth Reference	Total depth	Status
Chak66-01	001212	0.00	KB	2999	Oil and gas well.

1.5 Base map :

Base map is the map on which primary data and interpretations can be plotted. A base map typically includes locations of concession boundaries, wells, seismic survey points with a geographic reference such as latitude and longitude or UTM grid information. Base map of the area is given below in Figure 1.2 .

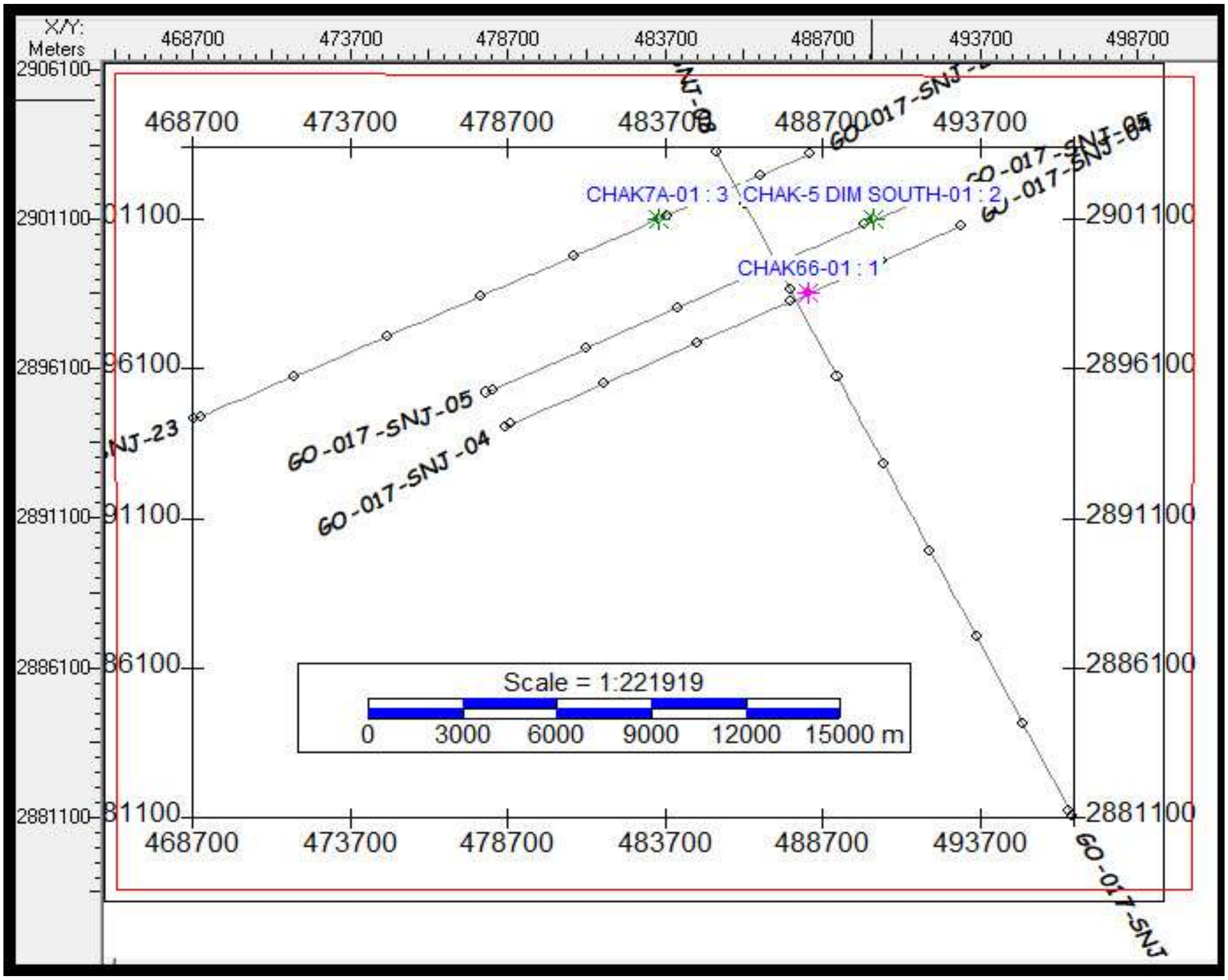

Figure1.2 : Basemap of the area showing location and orientation of seismic lines.

1.6 Objectives:

The main objectives of this dissertation based on interpretation of seismic section are:

- Structural interpretation using 2D seismic reflection data to understand subsurface geologic framework and its relation with surface geology.
- Generate time and depth contour maps on different levels of strata to analyze structural and stratigraphic trend of the area.
- The identification of seismic horizons by using synthetic seismogram.
- Petrophysical interpretation of the area to understand the subsurface rock properties and its contribution to the hydrocarbon generation.

- To find the petrophysical properties of reservoir zone by using statistical analysis.
- Colored Inversion performed for the reservoir characterization of Lower Goru.

Chapter # 02

Geology and Stratigraphy.

2.1 Introduction :

The information about the geology of an area plays an important role for precise interpretation of seismic data. The main reason behind that, in many cases similar signature is obtained from different lithologies and vice versa. In order to deal with such complexities an interpreter must have background knowledge of geology about the area and its stratification, unconformities and major structure of area under study (Kazmi & Jan,1997).

Pakistan is geologically divided into three main basins Indus, Baluchistan and Kakar Khorasan which are further sub-divided into different sub-basins. Our interested basin Indus is divided into Upper and Lower basins. Upper Indus basin is subdivided into Kohat Sub-Basin and Potawar Basin and Lower Indus basin is divided into Central and Southern Indus Basins. Thar Platform, Karachi Trough, Kirther Foredeep, Kirther Fold Belt and Offshore Indus make up Lower Indus Basin (Kadri, 1995).

The study area Sinjhoro lies in Sanghar District (Latitude 26^o 01’00N to 26^o 17’00N : Longitude 68^o 35’00E to 69^o 05’60E) in Sindh province of Pakistan. It is located in Lower Indus basin(Southern) bounded by Sargodha high in the north, Indian Shield in the east, Kirthar and Suleiman ranges in the west and Indus Offshore in the south.

2.2 Tectonic zones of Pakistan:

Two broad geological divisions of this region the Gondwanian and the Tethyan domains are discussed. In this scenario Pakistan is unique as it is located at the junction of these two diverse domains. The southeastern part of the Pakistan belongs to Gondwanian domain and is sustained by the Indo-Pakistan crustal plate. The northern most and western regions Pakistan fall in Tethyan domain and present a complicated geology and complex crustal structure as shown in Figure 2.1. On the basis of plate tectonic features, geological structure, orogenic history (age and nature of deformation, magmatism and metamorphism) and lithofacies, Pakistan may be divided into the following broad tectonic zones.

• Indus Platform and fore deep.

• East Balochistan fold-and-thrust belt.

• Northwest Himalayan fold-and-thrust belt.

• Kohistan-Ladakh magmatic arc.

• Karakoram block

Figure 2.1 shows the tectonic framework of the Pakistan in which Sinjhoro area is highlighted using coordinates.

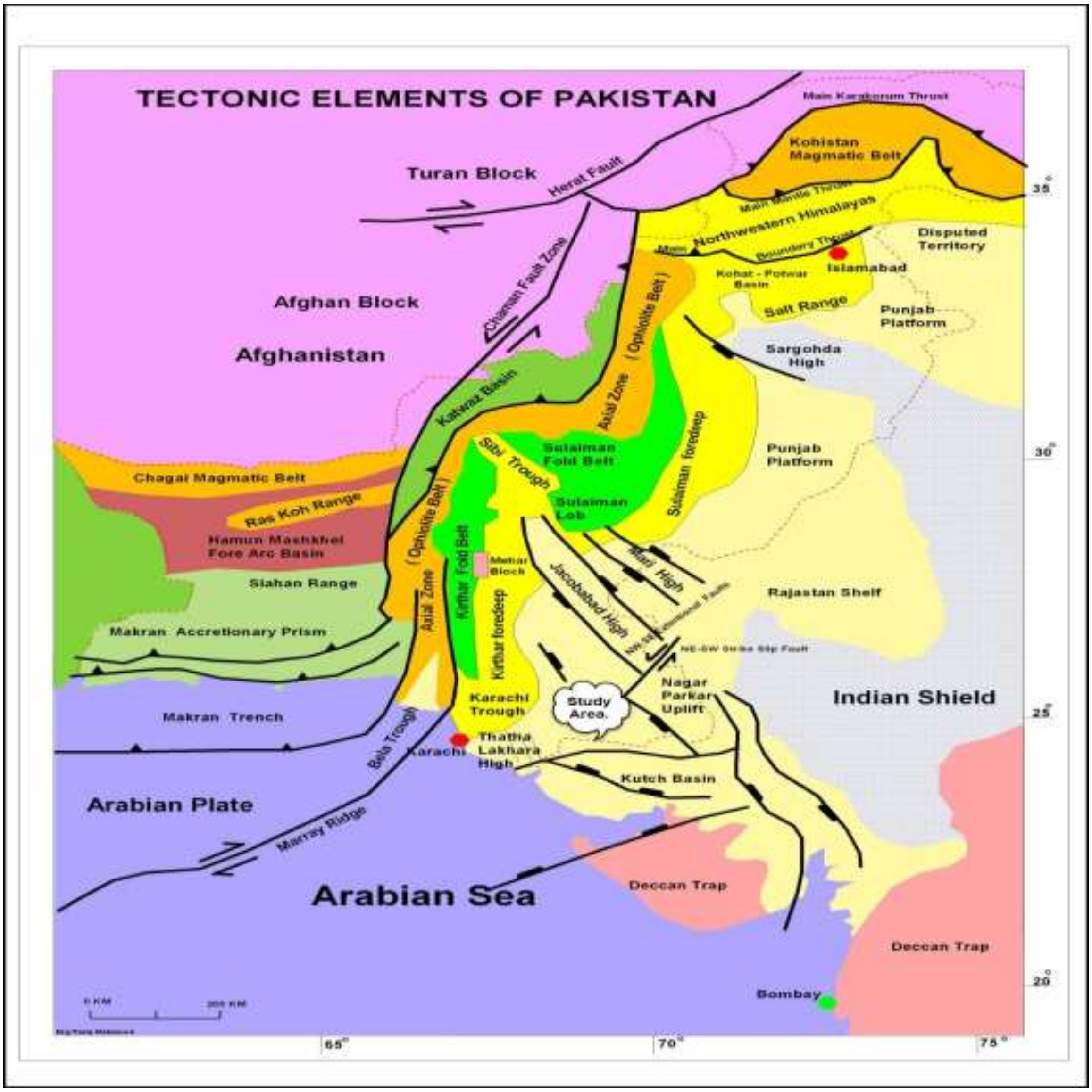

Figure 2.1 : The tectonic and geological setting of the Pakistan including greater Indus Basin and study area in Lower Indus Basin (modified after Kazmi and Snee, 1989)

2.3 Sedimentary Basins:

Basin is an area characterized by regional subsidence and in which sediments are preserved for the longer periods of time. In a basin a receptacle or container, which is basin's substratum is called the Basement. The container fill 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 Depocenter may not correspond to the zone of maximum subsidence (Duval, 1999).Pakistan comprises following three sedimentary basins:

- Indus Basin.
- Balochistan Basin
- Pishin Basin.

2.4 Divisions of Indus basin:

- Upper Indus basin

It further has following two partition.

- Kohat Sub Basin
- Potwar Sub Basin

- Lower Indus basin

It further has following partition

- Central Indus Basin
- Southern Indus basin

2.4.1 Southern Indus Basin:

The study area lies in Southern Indus basin so here in this chapter only Southern Indus basin is explained . This basin is located just south of sukkur rift, a divided between central and southern Indus basin. It comprises the following units:

- Thar platform
- Karachi trough
- Kirthar fore deep
- Kirthar fold belt
- Offshore Indus

The platform and trough extend into the offshore Indus. The southern Indus basin is bounded by the Indian shield to the east and the marginal zone of Indian plate to the west. It is southward extension is confined by offshore muray ridge- oven fracture plate boundary Figure 2.1. The oldest rocks encountered in the area are the Triassic age. Central and southern Indus basins were undivided until khairpur- Jacobabad high became a prominent positive feature. This is indicated by homogeneous lithologies of Chilton limestone (Jurassic) and sember formation (lower cretaceous) across the high. Sand facies of Goru formation (lower middle cretaceous) are also extending up to kandhkot and Giandari area. This is further substantiated by khairpur and jhatpat wells located on high. Paleocene facies south of the high are quite different from those in north and are dominant by clastic sediments derived from the positive areas (khair-jacobabad high and nabisar arc).

2.5 Stratigraphy of Area:

Stratigraphy column of Lower Indus Basin is shown in Figure 2.2. This column shows distribution, age and lithologies of the area. In eastern side the southern indus basin is bounded by the Indian shield, kirther range in the west, Jacobad khaipur high in North and in southern side off shore, Murray Plate boundary. The kirther and khairpur depression have huge anticlines, domes and a number of these hold small gas fields e.g. Sari, and Maharani and eastern part of it a number of fault and slanted block of Mesozoic rocks from structural traps having small oil fields. In north Sukkaar Rift zone demeanor large anticlimax structures and have Mari gas fields. The foremost reservoir in Sindh monocline is cretaceous Lower Goru sandstone. Normal fault produce because complete southern basin exhibiting the extensional tectonics, showing the Horst and Graben structures with former begin of great exploratory importance, The extensional tectonic in cretaceous time formed the tilted fault block over a wide area of the Eastern Lower Indus sub-basin. Seismic study shows cretaceous and older layers are broken by a system of faults faults with normal dip separation. . The tilted fault block traps were in continuation at the time hydrocarbon generation. Fault associated structural closures are responsible for trapping oil and gas in Lower Goru sandstone in the sinjhoro block. The under filling of the structures can be attributed to upward leakage across the extensive structures and redistributed the hydrocarbon (Kemal et al., 1991)

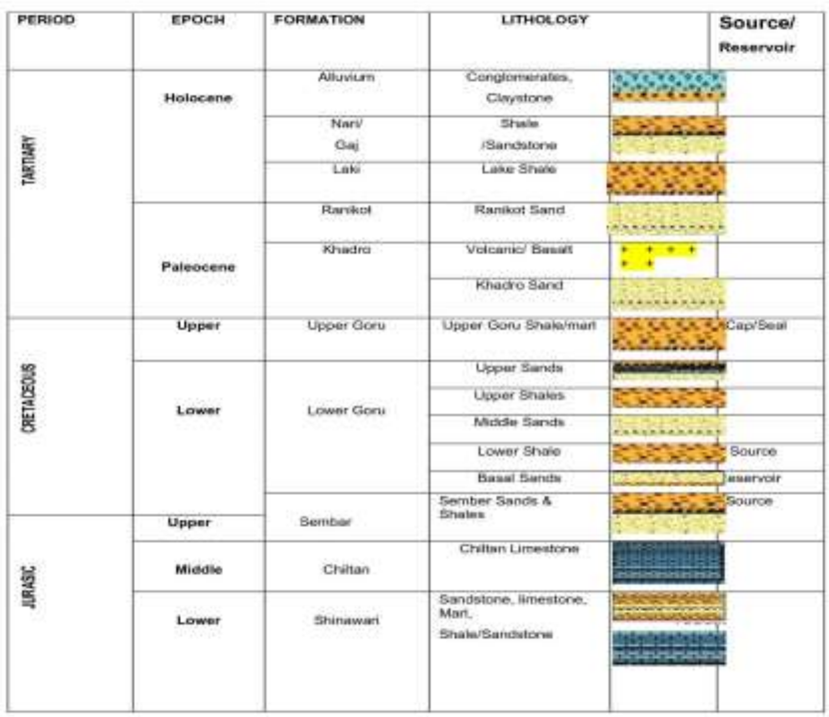

Figure 2.2 : Generalized Stratigraphy of Lower Indus Basin.

2.5.1 Chiltan limestone:

It is massive, thick bedded and dark limestone. It shows variation in color and texture. The color varies from black, dark gray, gray, light gray, bluish gray to white. Pisolitic limestone beds are present locally. Texture varies from fin-grained to oolitic. Veins and nodules of black or rusty weathering chert are present locally, thickness of chiltan limestone varies from place to place the chiltan limestone has not yielded identifiable fossil though poorly preserved fragmentary remains are occasionally. The upper contact of chiltan limestone is gradational with mazar drik formation. It has disconformable contact with overlying sember formation. Chiltan limestone correlates with the samanasuk formation of Upper Indus Basin.

2.5.2 Sember formation:

This name was introduced by Williams, after sember pass in the Mari hills, to include lower part of the "belemnite beds". It consists of black silty shale with interbreeds of black siltstone & nodular rusty weathering, argillaceous limestone beds or concretion. Glauconitic is commonly present. Pyretic & phosphate nodules & sandy shale are developed locally in basal part. Thickness is 133 m to 262 m. Its upper contact with chiltan limestone & shirinab formation is disconformable while upper contact is generally gradational with guru formation. The formation is reported to contain foraminifers, but most common fossils are belemnites. The age of formation is late Jurassic. The sember formation is correlated with chinchilla formation.

2.5.3 Goru formation:

The name goru formation was introduced by Williams for rocks included by Oldham in the upper parts of his "belemnites beds". Goru formation consists of interceded limestone, shale and siltstone. The limestone is fine grained, thin bedded, light to medium gray. Limestone is dominant in the lower and upper part of the formation. It is 536 m thick in type locality, but decreases to 60 m. the lower contact with the sember formation is conformable, though locally an unconformity has been reported, the formation contains, foraminifers and belemnites, the age of formation is assessed mainly as early cretaceous. It may be correlated with lumshiwal formation of the kohat-potwar-province. It is divided in two parts :

- Lower Goru.
- Upper Goru

2.5.4 Lower Goru:

The Lower Goru is main reservoir rock within the area. The lower goru horizon as a general divisions based on predominant lithologies. The basal sand unit, lower shale, middle sand unit (which has a good reservoir potential), upper shale, upper sand.

2.5.5 Upper Goru:

The Upper Goru sequence of the middle to late cretaceous unconformable overlies the lower goru formation, which consist of mainly marl and calcareous clay stone occasionally with inbreeds of silt and limestone. (Gilbert Killing et al).

2.5.6 Parh limestone:

It is very distinct unit. It is hard, light grey, white, cream, thin to medium bedded, argillaceous, occasionally platy to slab limestone. It is widely distributed in lower Indus basin. In the type area the thickness is 268 m but varies from 300 m to 600 m. the formation is rich in foraminifers and is dated as late cretaceous. The formation is correlated with the kawagarh formation of the kohat-potowar-province.

2.5.7 Ranikot Group:

It is considered to comprise three formations, which, in ascending stratigraphic order are, khadro formation (cardita beaumonti beds), Bara formation (lower ranikot) and lakhra formation (upper ranikot)

2.5.8 Laki Formation:

Laki formation also represent the “sui main limestone” to distinct members are identified in the lower part of formation in parts of kirthar province. The formation consist mainly of cream colored to gray limestone but marl, calcareous shale, sandstone and lateritic clay may vary up to 600m. the formation is unconformable underlain by the ranikot group and contact is marked by sohnari member. The formation contains rich fossils assemblages including, bivalves, echinoids and algae. These fossils indicate an early Eocene age. The formation is correlated with Karin formation.

2.6 Petroleum System :

The Petroleum System consists of a mature source rock, pathway, reservoir, trap and seal. Appropriate relative timing of formation of these elements and the processes of generation, migration and accumulation are necessary for hydrocarbons to accumulate and be preserved. Exploration plays and prospects are typically developed in basins or regions in which a complete petroleum system has some likelihood of existing. (Kadri, 1995)

2.6.1 Petroleum Play in Study Area :

In Sinjhoro, complete petroleum system exists. Here :

Source rock → “Sembar Formation”

Reservior rock → “Lower Goru” and “Massive Sand”

Seal rock → “Upper Goru” and “Talar Shale”

CHAPTER # 03.

Seismic Interpretation.

3.1 Introduction:

Seismic interpretation is the process of determining information about the subsurface of the earth from the seismic data.The acquisition and processing of reflection seismic data usually result in a seismic image of acoustic impedance interfaces. If these interfaces are assumed to follow lithological boundaries, then the seismic image is actually an image of subsurface geological units and the structures they form. The goal of seismic interpretation is to recognize geological patterns in the seismic image. The process of determine subsurface structure from seismic data to locate prospects for exploratory wells. Usually stratigraphy and available well log data are encounter for the interpretation of an area (Dobrin1960).

An interpreter of seismic data may have good hold in both geology and geophysics. To extract geologic significance from aggregate of many minor observations. For example, down dip thinning of the reflection might be result from normal increase velocity with depth or thinning of the sediments or flow of the shale or salt may develop illusory structure in the deeper horizon (Sheriff 1991).

In seismic prospecting we require both types of approach, traveltime and waveform studies. The first approach is for the purpose of defining the subsurface anomalous structure and the second is mainly for enhancing the signal-to noise ratio, and for investigating subsurface stratigraphic anomalies (Hamid, 1980). The importance of the seismic methods over other geophysical methods as mentioned by Robinson Coruth (1988) and Kearey & Brooks (1966) is due to its accuracy, resolution and presentation.

Following are the main seismic methods:

- **Seismic Reflection Method.**

- **Seismic Refraction Method.**

3.2 Methods for the Interpretation of Seismic Data:

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

- Stratigraphic Analysis
- Structural Analysis

3.2.1 Stratigraphic Analysis:

Stratigraphy analysis involves the delineating the seismic sequences which present the different depositional units recognizing the seismic facies characteristic with suggest depositional environment and analysis the reflection characteristic variation to locate the stratigraphic change and hydrocarbon depositional environment 3-D works is especially important recognizing the stratigraphic feature with distinct shape. The amplitude velocity and frequency or the change in the wave shape are the indicative of the hydrocarbon accumulation. Variation of the amplitude with the offset is also important hydrocarbon indicator. Unconformities ae mark by the change in the drainage basin but that helps developed the depositional environment. Reef, lenses, unconformities are the example of the stratigraphic (Sheriff, 1999**).**

3.2.2 Structural Analysis :

This type of analysis is very suitable in case of Pakistan, as most of the hydrocarbon are being extracted from the structural traps. It is study of reflector geometry on the basis of reflection time. The main purpose of structural analysis on seismic section is in the search for the structural traps containing hydrocarbon. Most seismic interpretation used two way 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 reveal folded beds (Sheriff, 1973)

Some of the parameters used in seismic stratigraphic interpretation are:

- Reflection Configuration
- Reflection Continuity
- Reflection Amplitude
- Reflection Frequency.

- Interval velocity
- External form.

3.2.3 Working procedure:

The following steps were followed for interpretation purpose.

- Preparation of basemap.
- Generation of synthetic seismogram.
- Fault marking and identification.
- Horizon marking.

All digital maps along with geo-referenced imagery were produced by using Kingdom Suite. The interpretation was done on Kingdom which provides an interactive interface for marking horizons and faults, exporting horizon's time, velocity and depth data for contouring and for further analysis such as Facies analysis and well columns correlation.

3.2.4 Generation of Synthetic Seismogram:

For the generation of synthetic seismogram two way time for each well top is required. Two way time for each well top or reflector is calculated by using depth, sonic log data of well and replacement velocity of the area. By using two way time against each well top depth time depth chart is prepared. And then finally synthetic seismogram is generated Figure 3.1. Tie this synthetic seismogram with the Seismic line, on which well is located (20017-SNJ-04). Actually seismic data is provided in time scale and well tops are given in depth so we cannot mark horizons in time form. So, the purpose of generation of synthetic is to find two way travel time against each depth for marking of horizons.

With the help of this synthetic seismogram two horizon were marked on this line. Tie marked seismic with other lines and horizons are marked on these lines. During tie lines mistie shift is applied.

Four seismic lines assigned are interpreted and applied in the following sections :

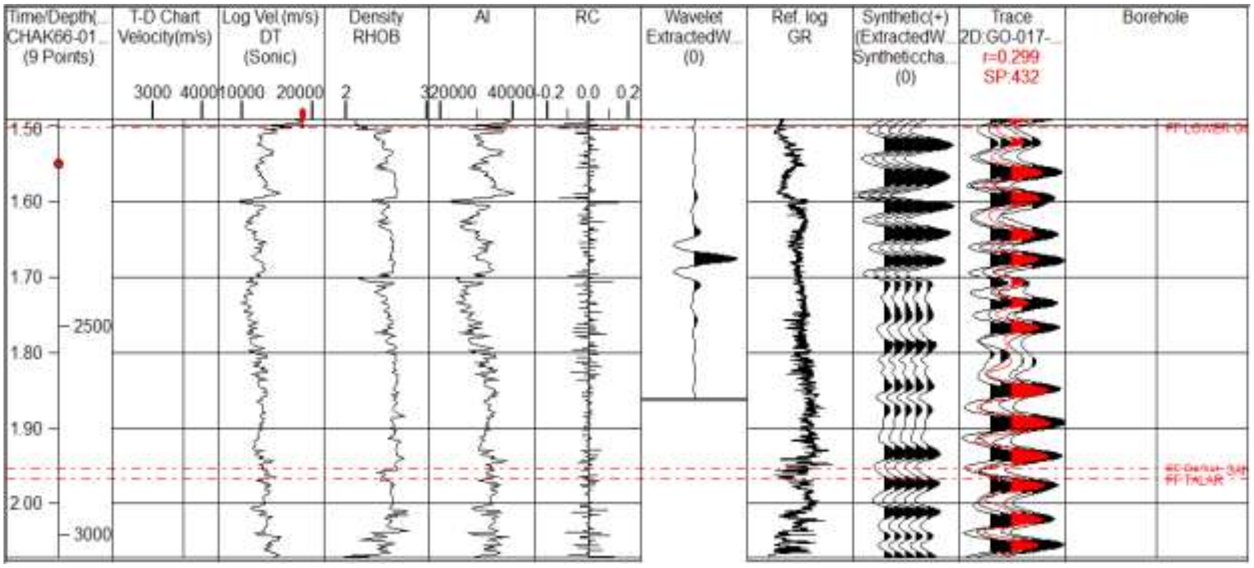

Figure 3.1 : Synthetic Seismogram of Chak66-01.

3.2.5 Marking of Seismic Horizons and Fault identification :

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 two horizons named “Upper Goru” and “Lower Goru” and five faults on the seismic section depicting the ‘horst and graben’structure.

Upper Goru and Lower Goru formations Figure 3.2 which are showing high reflections on seismic section making it easier to be picked.

Fault marking on real time domain seismic section is quite a hard work to do without knowing tectonic history of area (Sroor, 2010). Faults are marked on the basis of breaks in the continuity of reflection. This Discontinuity of the reflector shows that the data is disturbed here due to the passing of the faults. The Sinjhoro area is lying in extensional regime hence we have normal faulting due to which the clear cut horst and Graben are formed.

3.2.6 Interpreted Seismic Sections:

The interpretation shows the alternatively horst and Graben are formed between normal faulting. The fault having almost trend of the N-S. The main purpose was to show the favourable structure for petroleum accumulation. The **horst and graben** structures are considered good structural traps for the petroleum accumulation (Kadri, 1995).

The interpreted seismic section of lines GO-017-SNJ-04 , GO-017-SNJ-23 and GO-017- SNJ-08 is shown in Figure 3.3, Figure 3.4 and Figure 3.5. Total two seismic horizons namely Lower Goru and Upper Goru are marked. Along these seismic horizons, faults are also picked shown in Figure 3.3.

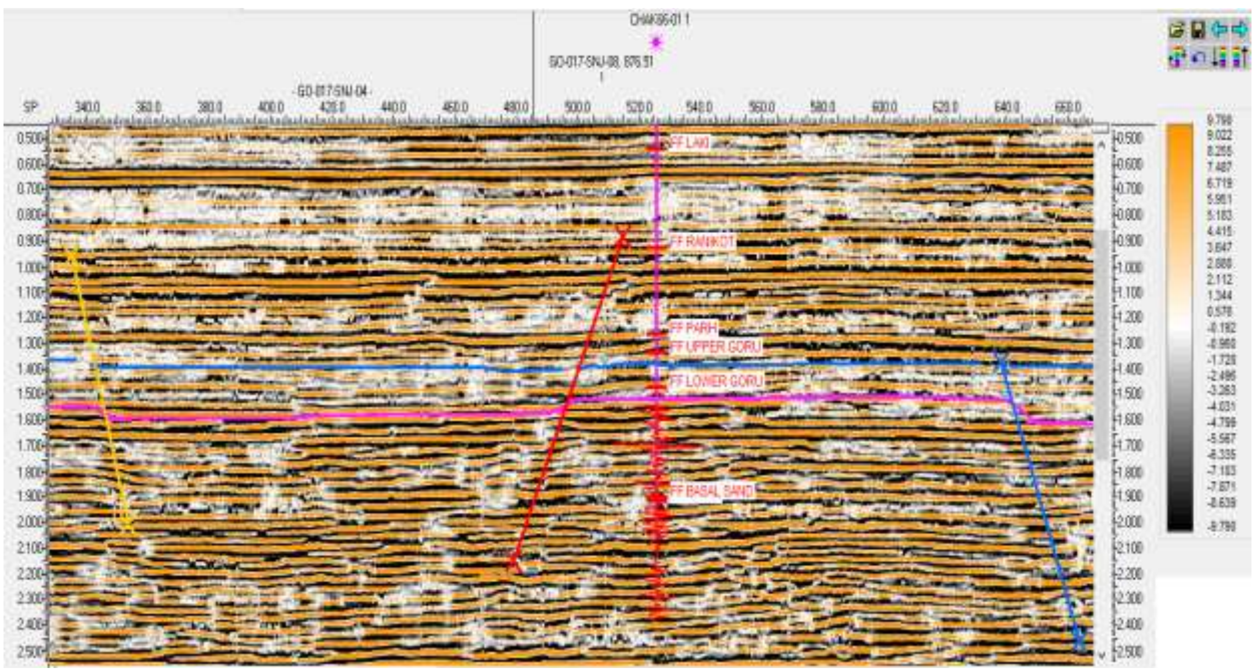

Figure 3.3 : Interpretation of seismic line , GO-017-SNJ-04 (Dip) with synthetic seismogram.

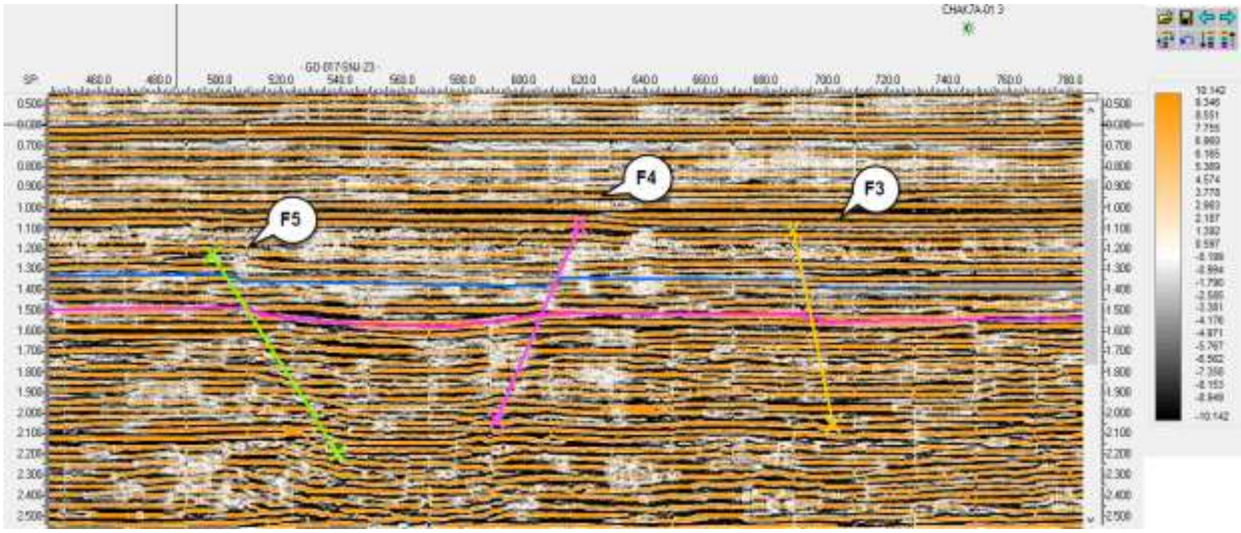

Figure 3.4 : Interpretation of seismic line, 017-SNJ-23 (Dip).

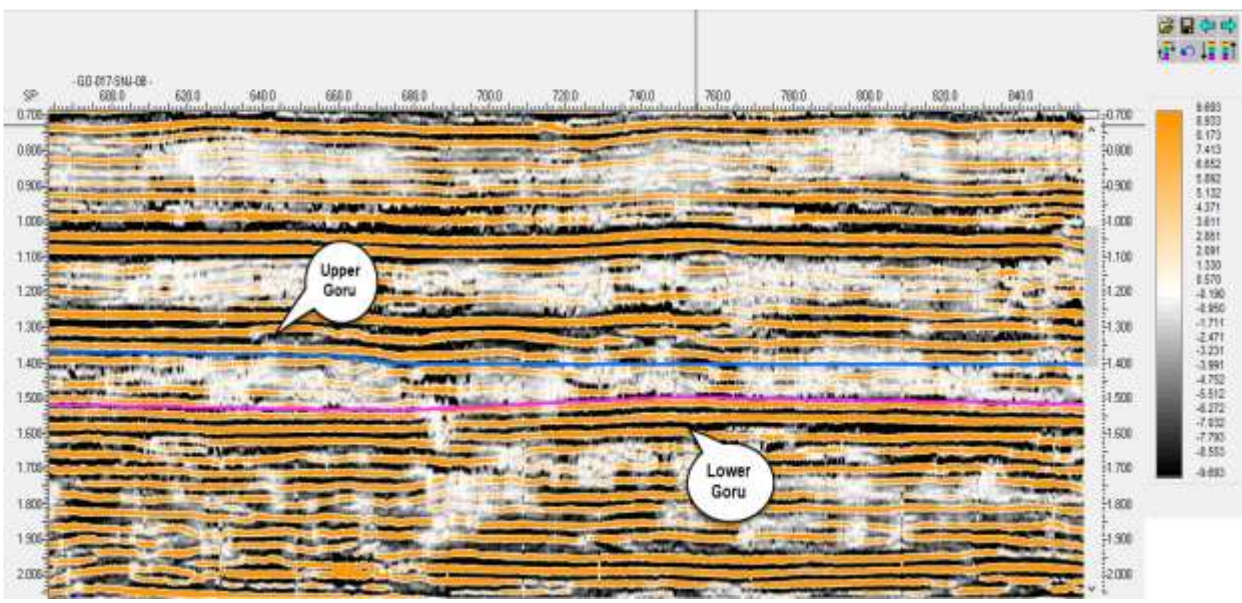

Figure 3.5 : Interpretation of seismic line GO-017-SNJ-23 (Strike)

3.2.7 Fault polygons Generation:

Before generation of fault polygons it is necessary to identify the faults and their lateral extent by looking at the available seismic data. If one finds that the same fault is present on all the dip lines, then all points (represented by a "+" or a "x" sign by Kingdom software) can be manually joined to make a polygon. Construction of fault polygons are very important as far as time and depth contouring of a particular horizon is concerned. Any mapping software needs all faults to be converted in to polygons prior to contouring. The reason is that if a fault is not converted into a polygon, the software doesn't recognize it as a barrier or discontinuities, thus making any possible closures against faults represent a false picture of the subsurface. Figure 3.6 formed at Lower Goru level shows that after construction of fault polygons, the high and low areas on a particular horizon become obvious. Moreover, the associated color bar helps in giving information about the dip directions on a fault polygon if dip symbols are not drawn. Fault polygons are constructed for all marked horizons and these are oriented in NW-SE direction.

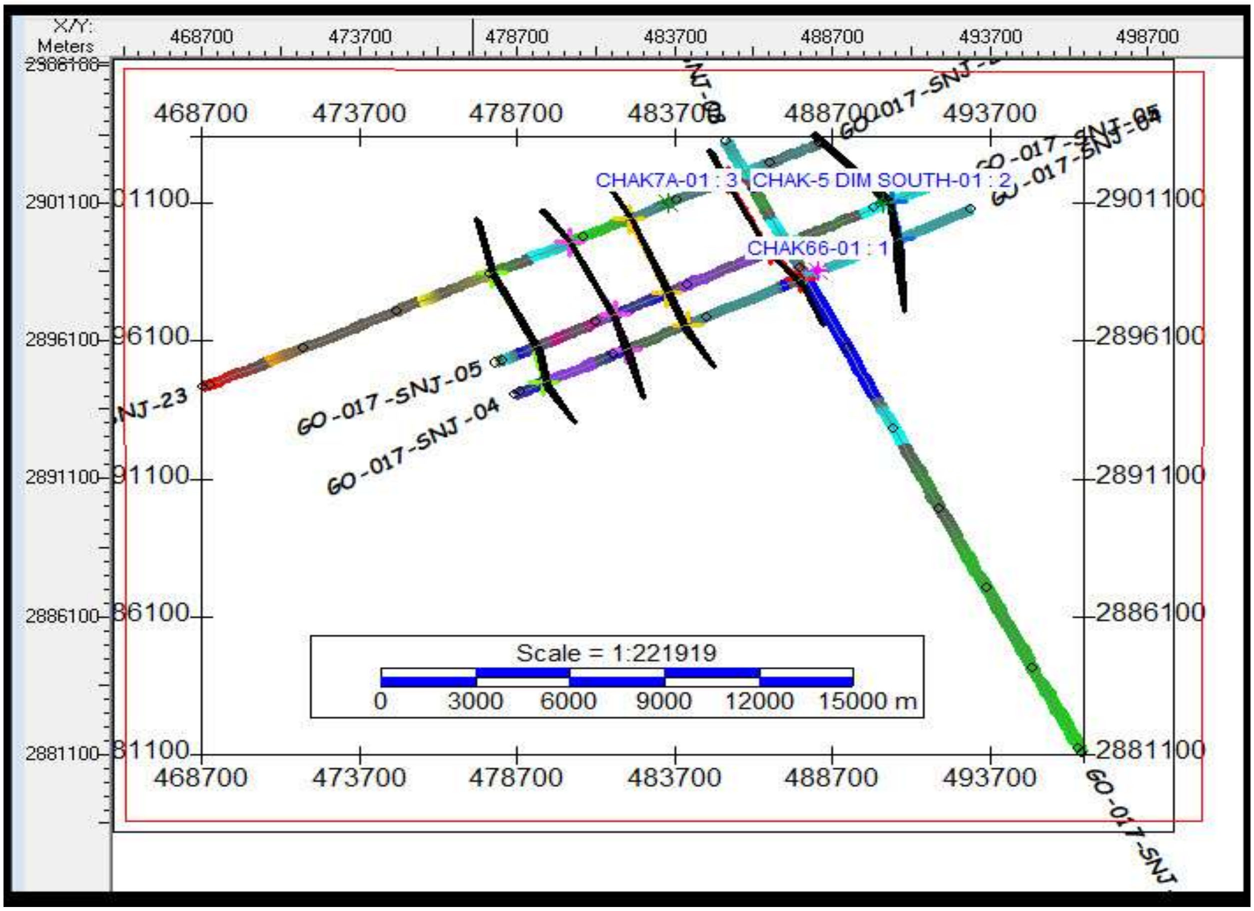

Figure 3.6 : Showing set of fault polygons of Lower Goru horizon marked on seismic section.

3.3 Contour Maps:

The final products of all the seismic exploration are the contour maps, time or depth. Mapping is part of the interpretation of the data, the one on which the entire operation depends for its usefulness. The contours are the lines of equal time or depth wandering around the map as dictated by the data (Coffeen, 1986). Contouring represents the three-dimensional Earth on a two dimensional surface. These contour maps reveal the slope of the formation, structural relief of the formation, its dip and any faulting and folding. 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. These time and depth contour maps have been generated with the help of Kingdom Software.

3.3.1 Time Contour Maps:

Two way time maps are made at different levels which show the position of that formation in time. In this study, time maps are constructed for two formations Upper Goru and Lower Goru. Contour interval is kept to 5 msec. Low values of time are associated with shallow levels which represent horst block and high values of time are associated with deeper levels which represent graben. Figure 3.7 shows the time contour map of Lower Goru.

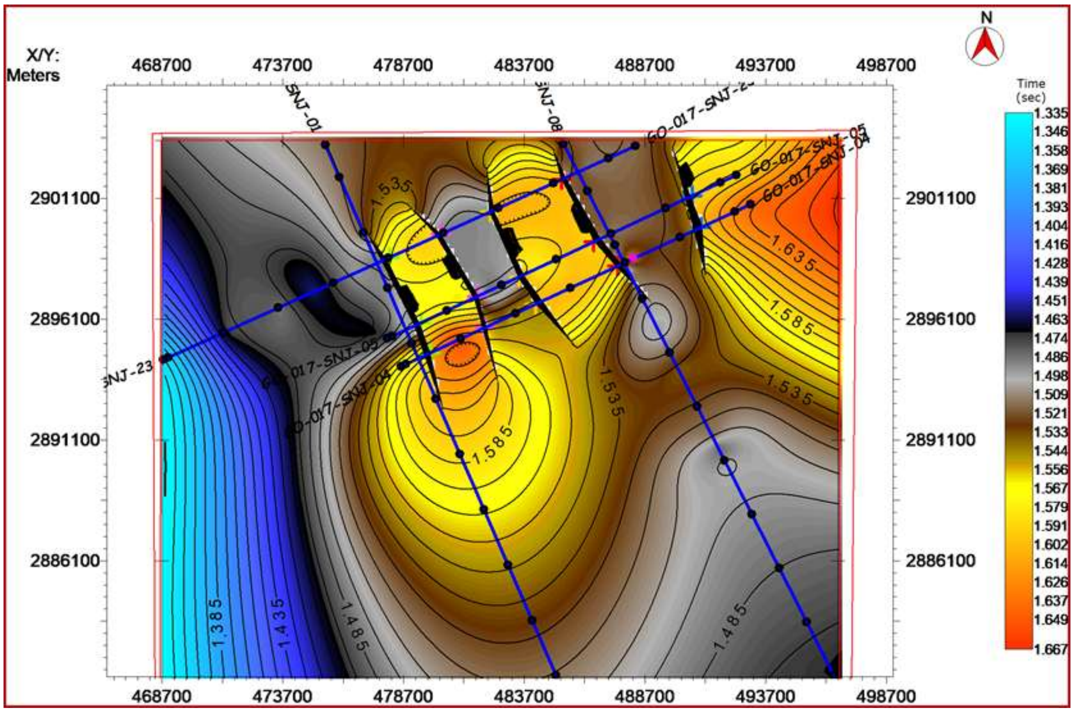

Figure 3.7 : Time contour map of Lower Goru.

Figure 3.8 shows the time contour map of Upper Goru

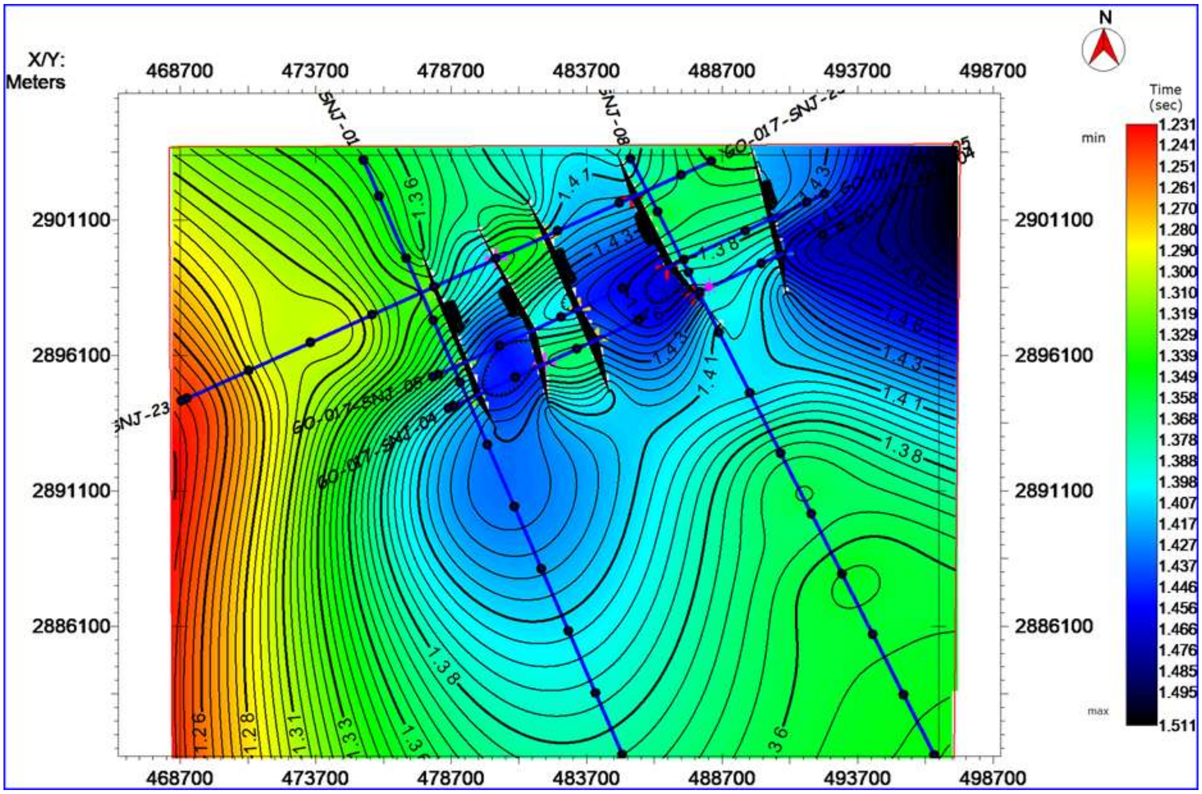

Figure 3.8 : Time contour map of Upper Goru.

3.3.2 Depth contour map of marked horizons.

The depth contour maps show the horizon depth variation. From the Figure 3.8 and figure 3.9 it can easily be interpreted that horizon is forming a horst and graben structures, as from the scale the central portion between fault polygons is deepest in depth than the surrounding area. It also be noted that that there is no change in pattern of time and depth contours because variation is same either with time or with depth.

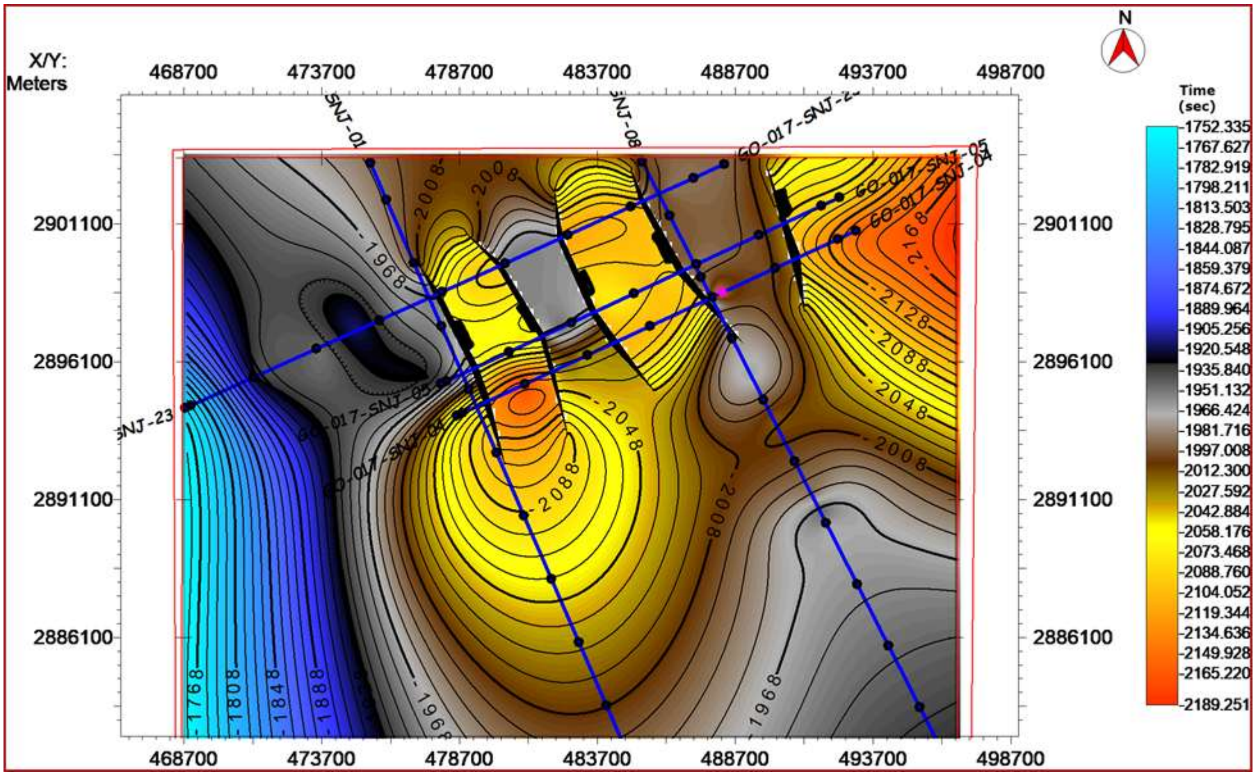

Figure 3.9 : Depth contour map of Lower Goru.

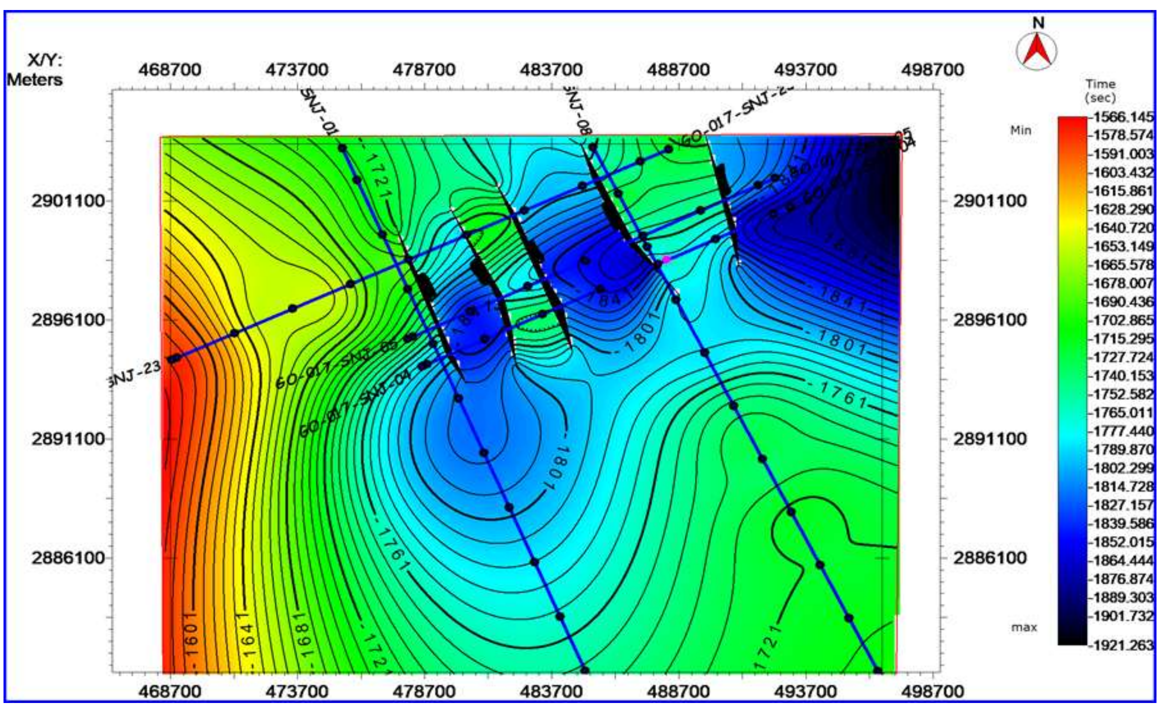

Figure 3.10 : Depth contour map of Upper Goru.

3.4 Conclusion:

After all interpretation it is concluded that in my study area there are horst and graben structures. The Horst and Graben structures are formed in the results of the normal faulting which are also confirmed in the above interpretation. Hence we have favourable structures formed in the result of the normal faulting for accumulation of the hydrocarbon in the Sinjhoro area. This normal faulting is generated in the results of rifting between India and Seychelles during the Late Cretaceous.

All models shown above in 2D showing clear horst and Graben structures which can act a very good structural trap in the petroleum play point of view. From stratigraphic column discussed in previous chapter and Petroleum Plays in study area, the lower Goru formations has potential for hydrocarbons and faults in the area are major migration pathways for hydrocarbon and in most places are acting as traps.

Chapter # 04

Petrophysics.

4.1 Petrophysics:

Petrophysics is study of the physical properties relating the incidences, behavior of the rocks and fluids inside the rocks. Reservoir characterization is the key step in oil and gas industry as it helps in defining the well and field potential so identify the zones within the reservoir which bears the hydrocarbons and can be recovered (Cosgrove et al., 1998). Petrophysics is one technique used for the reservoir characterization. This study facilitates in identification and quantification of fluid in a reservoir (Aamir et al., 2014).

Knowledge of reservoir physical properties like volume of shale, porosity, and water and hydrocarbon saturation is needed to define accurately probable zones of hydrocarbons. The integration of petrophysics along with the rock physics enables the geologists and geophysicists to understand the risks and opportunities in the area. Petrophysics is apprehensive with using well measurements to subsidize reservoir depiction (Daniel, 2003).

Petrophysics uses different geophysical tools (GR, Caliper Log, SP, LLD, and LLS etc.), core data and production data and integrates the results extracted. These geophysical tools are designed to quantify some specific reservoir property such as porosity, shale volume, net pay, effective porosity, saturation of hydrocarbon etc. Pertophysical analysis is often less related to seismic data but more concerned to well log data for reservoir description.

4.2 Petrophysical Analysis:

The petrophysics analysis has been carried out in order to measure the reservoir characterization of the Sinjhoro area using the borehole data of Chak66-01.We used the log curves including caliper log (CALI) ,spontaneous potential log (SP), Gamma ray (GR), Latero log deep (LLD), Latero log shallow (LLS), Neutron log, sonic log, density porosity log, (George, 2012).

4.2.1 Log Curves:

The log data of Chak66-01 was available in Logging ASCII Standard (LAS) format. The log curves along with some parameters given in the LAS file header are used to calculate all basic and advance parameters. The methodology adopted for this work is given in Figure 4.1 and each analysis step is discussed in the proceeding sub-sections.

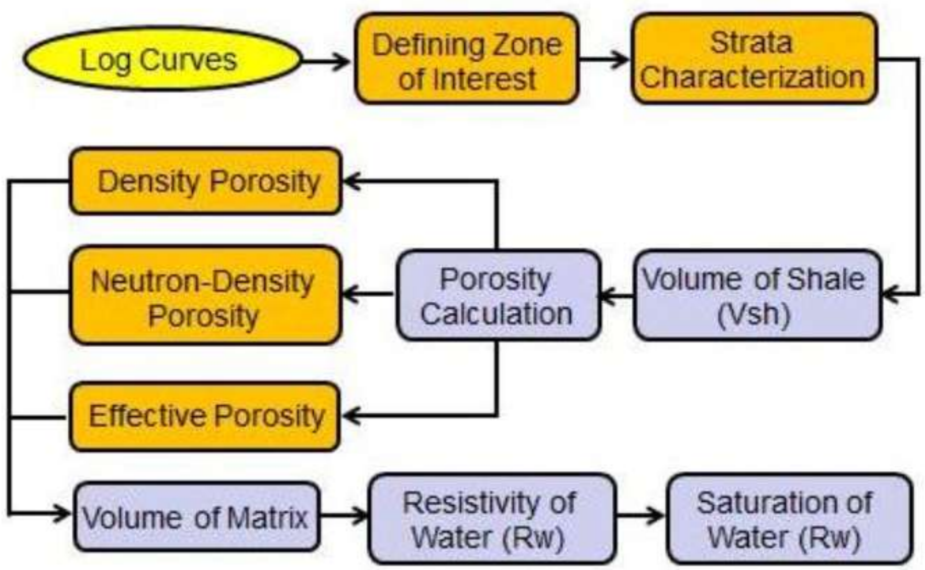

Figure 4.1 : Workflow for petrophysical analysis.

Petrophysics analysis the following parameters are acquired on the basis of the log curves.

- Volume of shale
- Water saturation
- Hydrocarbon saturation

Before going to calculate these properties we must have to know about the different types of the logs and there characteristics which area explained in Figure 4.2.

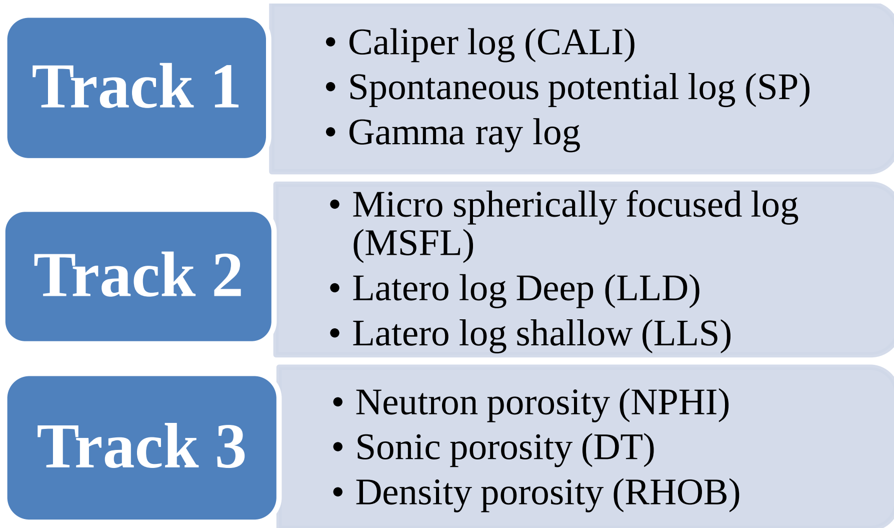

Figure 4.2: Basic three log tracks (George,2012)

4.3 Lithology Track:

In lithology track the following three logs are displayed which are explained as follow.

4.3.1 Gamma Ray Log (GR):

With the help of this log we measure the natural radioactivity of the formation. Basically the gamma ray log is the passive logging because we measure only the formation property without using any source. The gamma ray emits from the formation in the form of the formation in the form of the electromagnetic energy which are called the photon. When photon collide with the formation electron hence they transfer the energy to the formation electron so the phenomenon of the Compton scattering occurs. Now these emitted gamma ray reached to the detector of the gamma ray and counted and displayed as count per second which is termed as the Gamma ray. Basic purpose of this log is to differentiate between the shale and non-shale (Asquith and Gibson, 2004).

4.3.2 Spontaneous Potential log (SP):

The SP log is also passive log which record the naturally occurring potential in the well bore. In this log we used the single moving electrode in the bore hole and reference electrode at the surface, located in the mud pit. Hence the SP log therefore record the potential difference between the reference electrode and the moving electrode in the borehole (Gibson, 2004). This log is used for the following purposes according to the (Danial 2003).

- Identification of the permeable and non-permeable zone.
- Detection of the bed boundaries.
- Determination of the shale volume.
- Determination of the resistivity of the formation.
- Up to some extent the qualitative measure of the permeability.

4.3.3 Caliper Log (CALI) :

Caliper log use to measure the borehole size. This log give us help to identify the cavity washouts and break outs. Hence this log is also called the quality check for other logs. Because if any where there is say wash out then in front of the wash out the porosity and resistivity log will not give the correct reading. Hence caliper log is very important in pertophysical log. (Gibson,2004).

4.4 Electrical Resistivity Logs Track:

These logs measures the resistivity of the subsurface, but actually they measure the resistivity of the formation fluids. They are very helpful in order to differentiate between water filled formation and the hydrocarbon filled formations. Resistivity logs includes the following.

- Latero log Deep(LLD)
- Latero log shallow (LLS)

4.4.1 Latero log Deep (LLD):

Latero log deep is used for the deep investigation of the quietly undisturbed (Uninvaded zone) and it is called Laterolog deep (LLD). This log is also used for saline muds also in case of fresh mud. This log is generally used for measuring the formation resistivity. IT having deep penetration as compared to the (LLS).

4.4.2 Latero log Shallow (LLS):

Latero log shallow (LLS), used for shallow investigation of the transition zone / invaded zone. Because the depth of the investigation is smaller than the LLD (Donaldson, 2011).

4.5 Porosity Logs Track:

Porosity logs measure the porosity in the volume of the rock. Thes logs are also helpful in order to distinguish between the oil, gas and water in combination with the resistivity log (Daniel, 2004).

Porosity log includes:

• Sonic logging (DT)

• Density logging (ROHB).

• Neutron logging (NPHI).

4.5.1 Sonic Log:

Sonic log device consists of a transmitter that emit sound waves and a receiver that picks and record the compressional waves as it reach the receiver. This log is a recording verses depth of time (t) which is required by a compressional wave to go across 1 feet of formation, called interval transient time Δt, while it is the reciprocal of the velocity of sound wave. This time (Δt) is depended upon lithology and porosity of the formation (Asquith and Gibson, 2004).

4.5.2 Density Log:

In the density logging gamma ray collide with the electron in the formation and scattered gamma ray (Compton scattering) received on the detector which indicate the density of the formation. Increse in the bulk density of the formation causing the decrease in the count rate and vice versa. Bulk density which is obtained from the density log is considered the sum of the density of the fluid density and the matrix density of the formation. However density log used separately and also along with the other log to achieve the various goals (Tittman and Wahal, 1965).

4.5.3 Neutron log (NPHI):

This is the type of porosity log which measure concentration of Hydrogen ions in the formation. Neutron is continuously emitted from chemical source in the tool of the neutron logging. When these neutron collide with nuclei in the formation and results in loss of some energy. Hydrogen atom has same mass as that of neutron, maximum loss of energy occurs when electron collides with hydrogen atoms. Hydrogen is an indication of the presence of the fluied in the formation pores, hence loss of energy is releated is releated to the porosity of the formation. The neutron porosity is very low when the pores in the formation are filled with the gas instead of the water and oil, the reason is that gas having les concentration of the hydrogen as compared to water and oil. This less porosity by the neutron NPHI due to the presence of the gas called the Gas effect (Asquith and Gibson, 2004).

4.6 Calculations of Rock Properties:

Many log properties can be derived by geophysical well logs. Below shows that we can calculate the properties by using different equations.

4.6.1 Volume of Shale:

The mathematical formulation used to calculate the Volume of Shale is given below:

$$V_{sh} = \frac{GRlog - GR\,min}{GRmax - GRmin}$$

4.6.2 Porosity Calculation:

❖ **Density Porosity(PHID):**

It is derived from density log using the following equation.

$$\text{PHID} = \frac{\rho m - \rho log}{\rho m - \rho fl}$$

Where;

ρfl is the fluid density
ρm is the matrix density

ρlog is the log density

❖ Neutron Porosity(NPHI):

It is directly obtained from Neutron log values. The Total Porosity is obtained by taking the mean of the above two;

$$\textbf{PHIT} = \frac{(\varphi PHID + \varphi NPHI)}{2}$$

❖ Effective Porosity:

Finally Effective Porosity is given by;

$$\textbf{PHIE} = \frac{(\varphi PHID + \varphi NPHI) * (1 - Vsh)}{2}$$

4.6.3 Calculation of Resistivity of water (R_w):

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

$$R_{mf2} = R_{mf1} * \left(T_1 + \frac{6.77}{T2} - 6.77\right)$$

Where R_{mf1} is Resistivity of mud filtrate at surface temperature, T_1 is surface temperature, T2 is formation temperature and R_{mf2} is resistivity of mud filtrate at formation temperature (zone of interest).

4.6.4 Water Saturation (S_w) :

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

$$S_w = \sqrt[n]{\frac{a*Rw}{\varphi*m*Rt}}$$

Where;

S_w = water saturation

R_w =water resistivity (formation)

Φ = effective porosity

m (cementation factor) = 2

a (constant)= 1

Rt = log response (LLD)

Rw has been calculated with help of the following formula:

$$R_{w=} = \varphi^2 * R_t$$

Where, Φ = porosity in clean zone

Rt =Observed LLD curve in clean zone.

4.6.5 Saturation of Hydrocarbon :

It is denoted as Shc. Saturation of hydrocarbon is calculated by given formula below;

$$S_{hc} = 1\text{-}S_w$$

Sw = Saturation of water

Shc= Saturation of hydrocarbon

4.7 Result of Petrophysical Evaluation:

The well log of Chakk66-01 well has been interpreted by using the KINGDOM software Figure 4.3.The petrophysical analysis has been carried out in order to measure the reservior properties of the sinjhoro area using the borehole data of Chak66-01.Determining the porosity and true resistivity of a zone is the first step in converting the raw log data into estimated quantities of oil, gas and water in a formation. These estimated quantities are used to evaluate a zone and to determine whether a well completion attempt is warranted. (Asquith et al,2004)

Lower Goru is our reservior which has different type of sands. Reservior has various zones in the well which have been observed on the basis of logs interpretation. Due to the fact that log data only recorded in depth starting from 2000m to 3000m but we cropped the zone of interest (zone 1) only from 2120m to 2065m. This has done due to the fact that there is no major anomaly or difference identified in other logs and behavior of logs is another reason which restricts us from marking other zones. The results shows that also there are clean sand in the Zone 1 because of low shale value and high matrix value indicated but water saturation increases in this zone and hydrocarbon is less in this zone Figure 4.3, but it has good effective porosity with few amount of hydrocarbons are also present which may be recovered.

The zone of sand by petrophysical evaluation along with depth of lower goru and description of highlighted zone is given below for Chak66-01 as shown in Figure 4.3.

From all this we can conclude that CHAK66-01 may be a hydrocarbon producing well. Zone depth ranges from (2020m-2065m) Lower Goru reservior. Results are shown in Table 4.1.

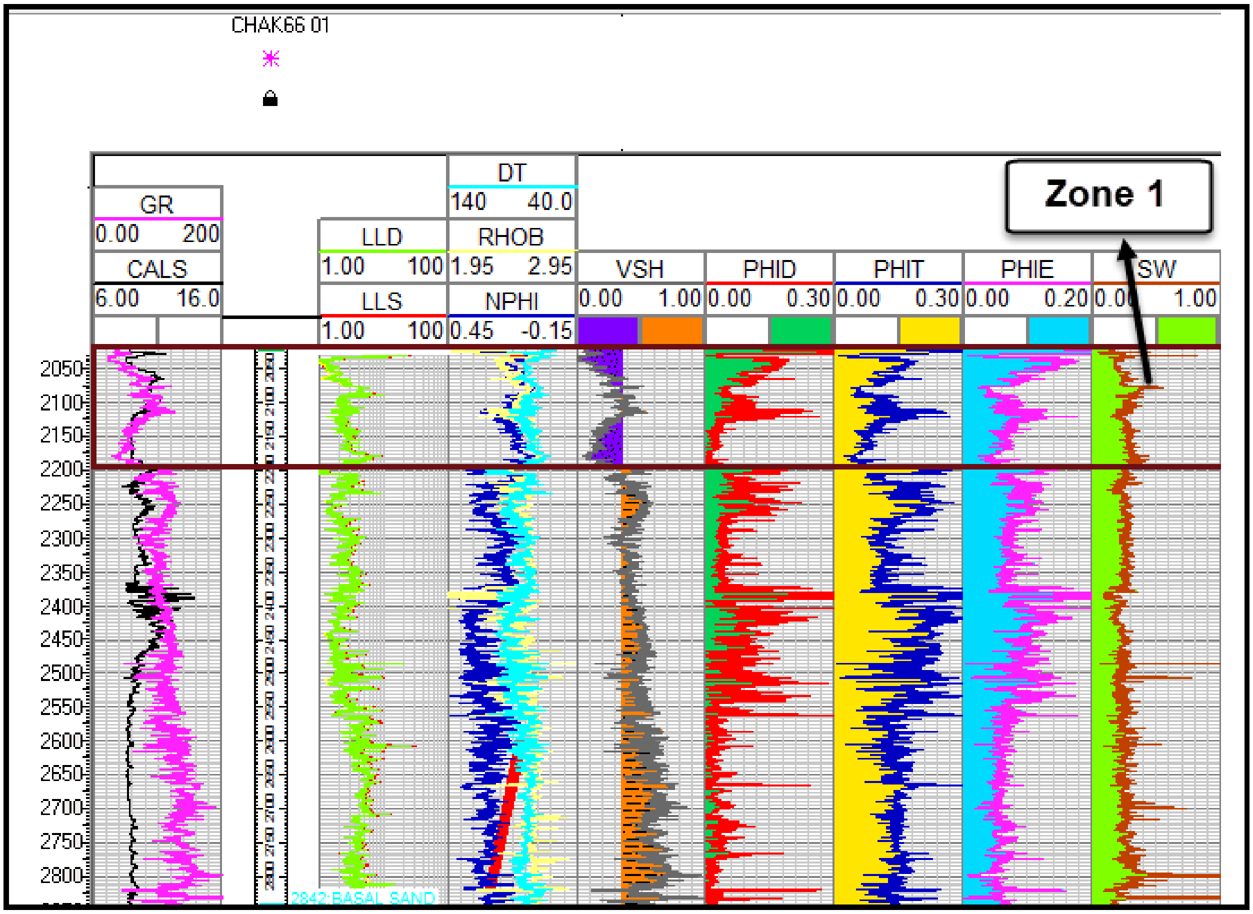

Figure 4.3 : Result of petrophysical analysis of Chak66-01.

Serial No	**Calculation Parameter**	**Percentage % (2020-2065)m**
1	Average Volume of Shale= $\mathbf{Vsh_{avg}}$	**13**
2	Average Porosity obtained from Density Log= $\boldsymbol{\varphi_{davg}}$	**14**
3	Average Porosity in (PHIT) Percentage=$\boldsymbol{\varphi_{avg}}$	**15**
4	Average Effective porosity in percentage=$\boldsymbol{\varphi_{eavg}}$	**13**
5	Average Water Saturation in Percentage=$\mathbf{S_{wavg}}$	**22**
6	Average Hydrocarbon in Percentage= $\mathbf{S_{havg}}$	**78**

Chapter # 05

Colored Inversion of Post Stack Data.

5.1 Wavelet and Acoustic impedance:

For many seismic processing applications, it becomes necessary to derive an estimate of the seismic wavelet. Because the character of wavelet is imprinted on seismic trace, it is important to understand its shape in order to decipher the properties of earth's interior from seismic traces. Inspite 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 the post-stack seismic data for wavelets. A post-stack trace emulates a zero-offset or normal incidence seismogram, which can be simulated using convolution model assuming 1D earth model. Most seismic data contain noise this problem must be compensated.

In frequency domain, the convolution operation is replaced by a multiplication. Three inverse problems are identified:

- Estimation of the wavelet when the reflection coefficient is known.
- Estimation of reflection coefficients or acoustic impedances when the wavelet is known.
- Simultaneous inversion for acoustic impedance of wavelet.

Inversion of seismic data to acoustic impedance is usually seen as a specialist activity, so despite the publicized benefits, inverted data are only used in a minority of cases. To help overcome this obstacle we aimed to develop a new algorithm which would not necessarily be best in class, but would be quick and easy to use and increase the use of inversion products with in BPA. This new technique “Colored Inversion”, performs significantly better than the traditional fast-track routes such as recursive inversion, and benchmarks well against unconstrained sparse-spike inversion.

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’. In this way inversion can be achieved within hours since the volume data donot have to be exported to another package, and no explicit wavelet is required.The inversion is understood simply by the flowchart shown in Figure 5.1.

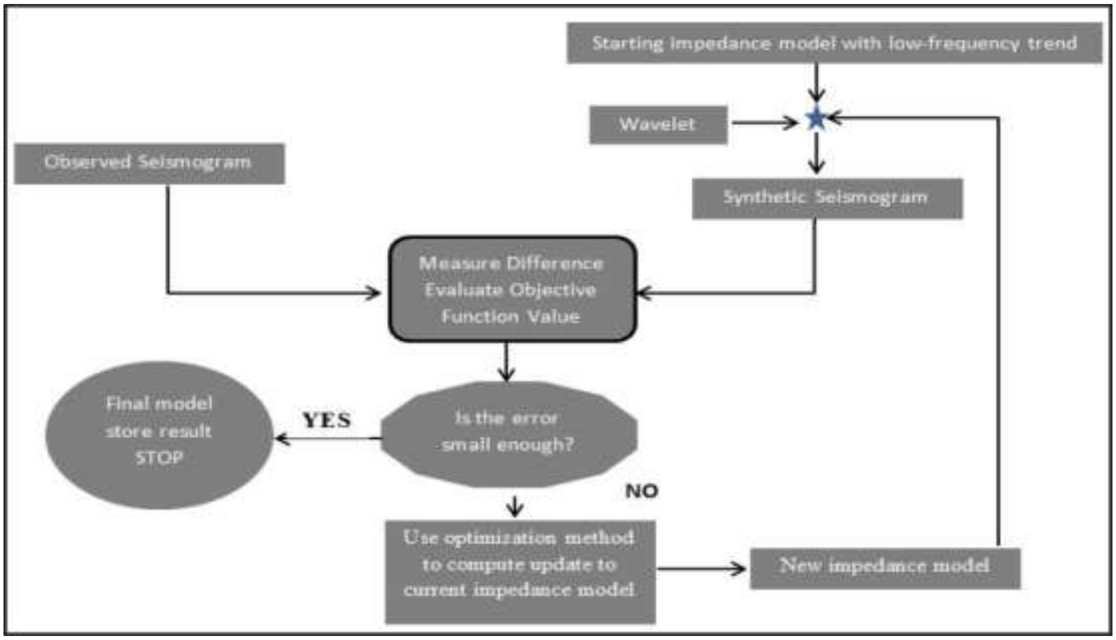

Figure 5.1 : Showing impedance and wavelet extraction scheme.

5.2 Methodology:

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

- The velocity is obtained from sonic log and density is obtained from density log and values of densities are obtained from density log by convolving these values.
- We get acoustic impedance by cross-matching these impedance data with the input reflection data.
- We derive a single optimal matching filter Figure 5.8. Convolving this filter with the input data we see in Figure 5.7 that the result is very much similar, everywhere.
- 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 constant -90^{o} which is in agreement with the simplistic view of inversion being akin to integration, and concept of a zero-phase reflection spike being transformed to a step AI interface, provided the data are zero-phase.

Walden and Hoskins's (1984) empirical observation tells us that earth reflection coefficient series have spectra that exhibit a similar trend that can be simply described as constant function.

The term is a positive constant and is frequency arrives at a similar observation theoretically may vary from one field to another but tends to remain reasonably constant with in any one field (Velzeboer 1981)

It therefore follows that if our seismic data are inverted correctly they too should show the same spectral trend as logs in the same area.

5.3 Non uniqueness and convolution:

The process of convolution for constructing a seismogram using a wavelet and acoustic impedance is performed to generate an operator. Note that wavelet is smoothly varying function, while the reflectivity is a series of delta functions placed at two-way normal time of each reflector (Cooke and Schneider 1983). The spectra of the wavelet and reflectivity series for synthetic are also shown in figure. We observe that wavelet is a band-limited, while reflectivity series is a broad-band. Because the convolution is equivalent to multiplication in frequency domain the spectrum of resulting seismogram is band-limited as well. We can imagine the complexity of the problem further we can take into account the loss of high frequencies of wavelet caused by attenuation. In other words series cannot be assumed to be stationary. Even under stationary conditions the data does not contain all the frequencies. The most common approach to deriving the wavelet is based on well-log data that produce a true reflectivity series.

5.4 Wavelet extraction:

The wavelet is shown in Figure 5.2 is extracted on the basis of the well log data that provides the true reflectivity series (i.e. compressional wave velocity and density computed into acoustic impedance logs, which are mapped into normal incidence reflectivity series). An initial guess of wavelet is convolved with reflectivity series and synthetic normal incidence trace is generated. The difference between the observed and synthetic traced is minimized using a suitable chosen norm with smoothness constraints (Mrinal K. Sen).

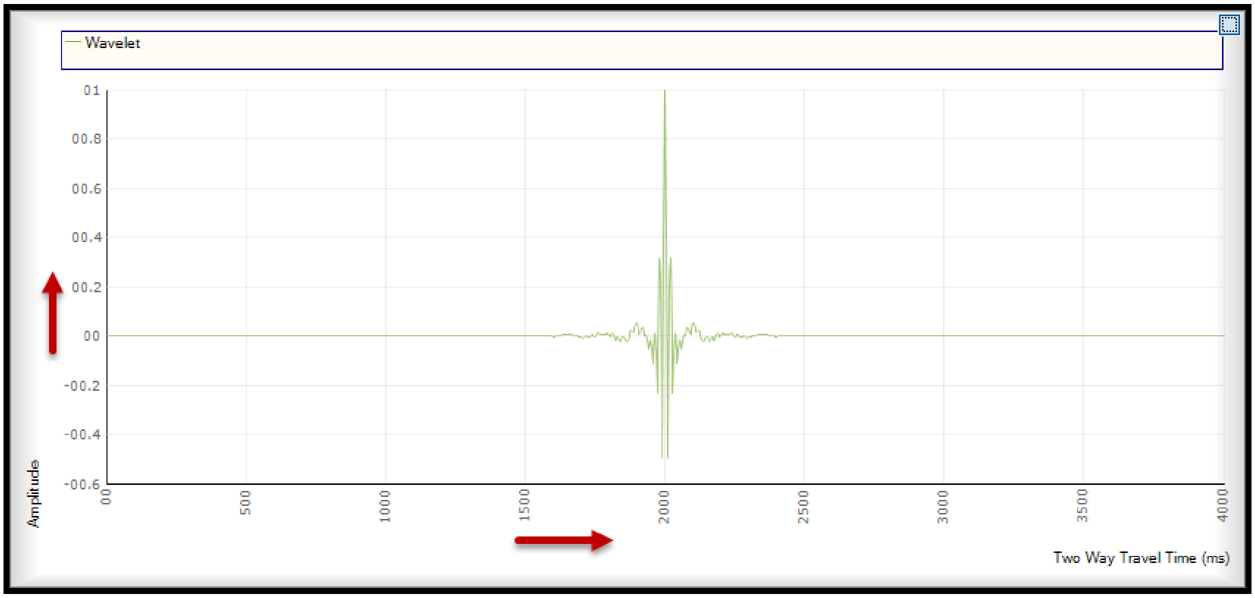

Figure 6.2 : Extracted Wavelet.

5.5 Impedance estimation:

Now our approach is to convolve this wavelet with acoustic impedance (reflectivity series). The acoustic impedance is also computed from well log data as described previously. The impedance spectrum is shown in figure 5.3 is estimated after removing source wavelet; noise must be absent; all multiple reflections must be removed; spherical spreading including all plane reflections (Ghosh 2000)

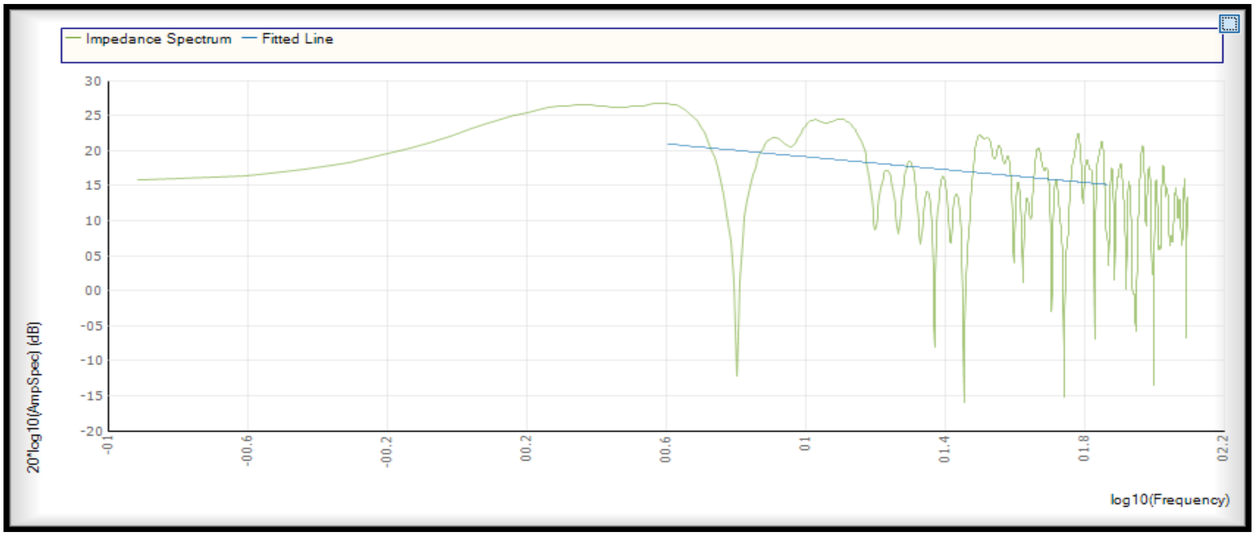

Figure 5.3 : Impedance Spectrum with fitted line.

5.6 Butterworth filter:

The Butterworth filter is a type of signal processing filter designed to have as flat a frequency response as possible in the pass band. It is also referred to as a maximally flat magnitude filter. It was first described in 1930 by the British engineer and physicist Stephen Butterworth in his paper entitled "On the Theory of Filter Amplifiers.
An ideal electrical filter should not only completely reject the unwanted frequencies but should also have uniform sensitivity for the wanted frequencies. This filter is used here for convolution of the wavelet and reflectivity series for for formulation of seismogram. The Butterworth filter is shown in Figure 5.4.

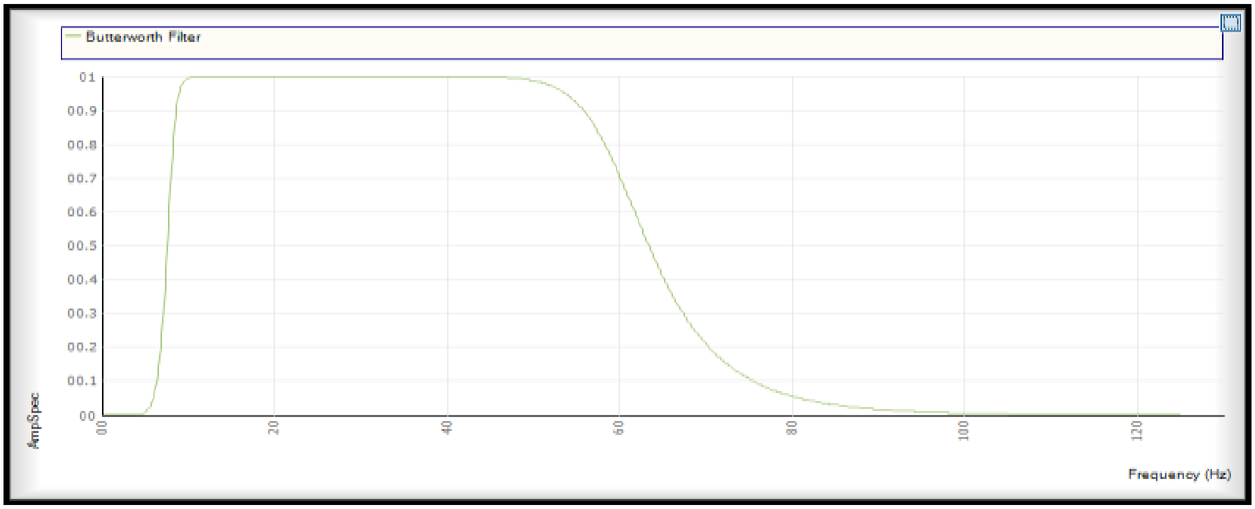

Figure 5.4 : Butterworth Filter.

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

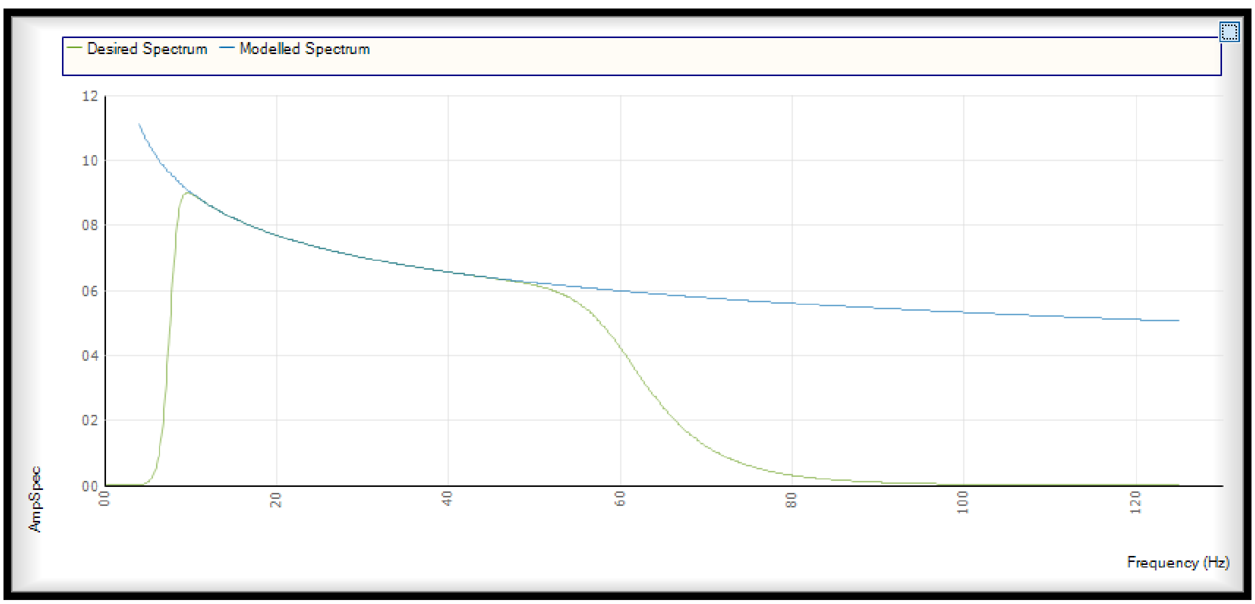

Figure 5.5 : Desired and Modeled Spectrum.

There are two spectrums shown in Figure 5.5 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. Now we need to obtain a spectrum of our desire for this purpose we have to convolve this spectrum with another spectrum known as shaping spectrum which is obtained by applying Fourier transformation on desired spectrum. The Figure 5.6 shows us the shaped seismic spectrum and desired seismic spectrum.

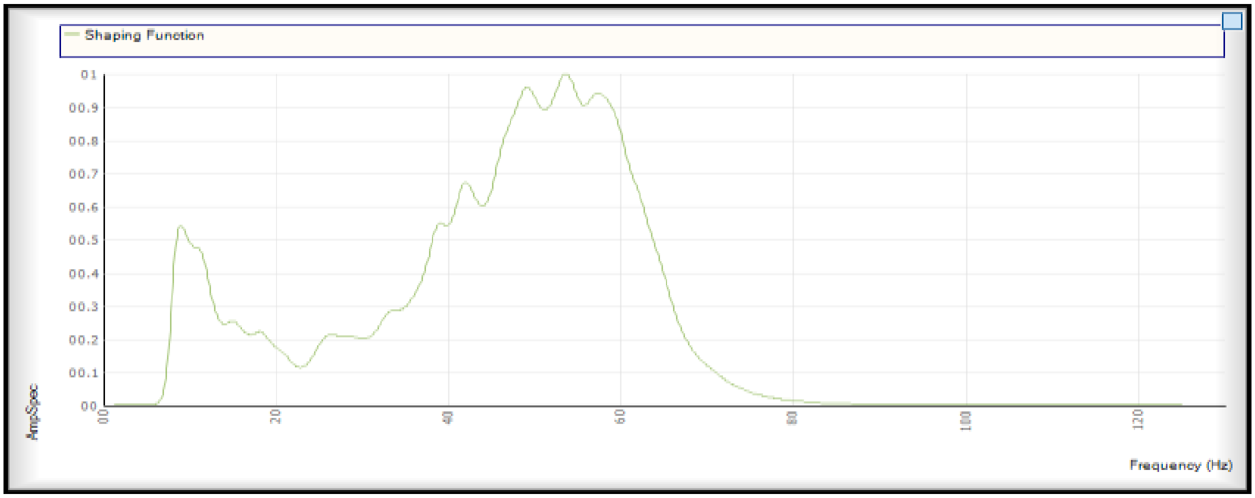

Figure 5.6 : Shaping Function.

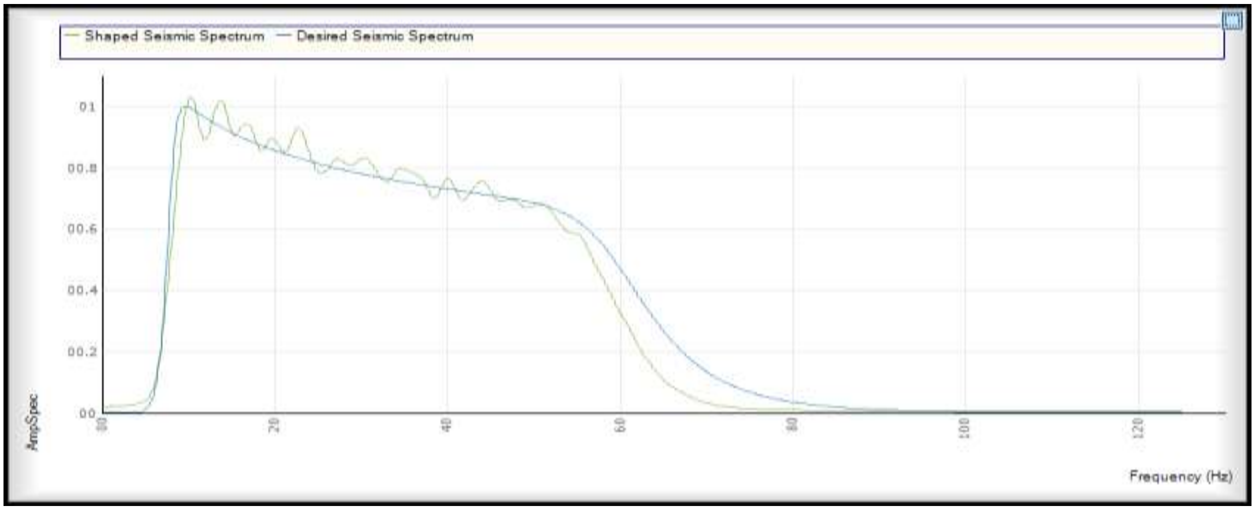

Figure 5.7 : Convolution of shaped seismic spectrum and desired spectrum.

A seismogram for specific window (as values of acoustic impedance is obtained from well data) is developed now we develop a seismogram to invert whole section. For this purpose we convolve desired spectrum with seismic mean spectrum. After convolving seismogram with seismic mean spectrum we are able to apply it on whole seismic section. The figure 5.8 shows seismic mean spectrum and desired spectrum.

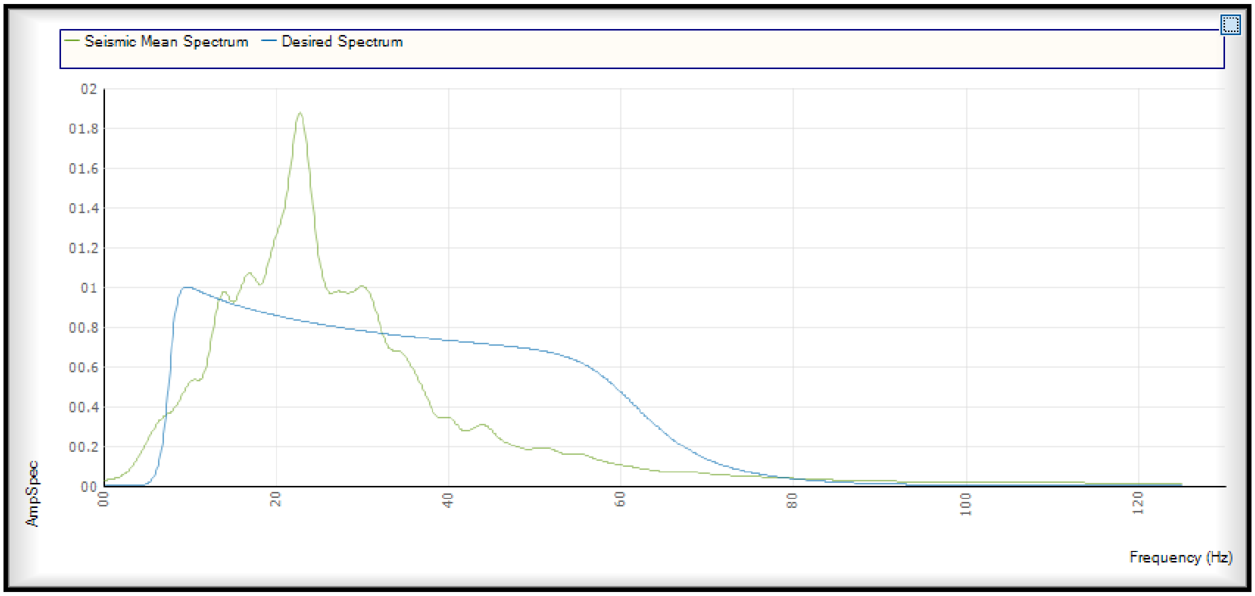

Figure 5.8 : Convolution of seismic mean spectrum and desired spectrum.

After completion of the process of generating synthetic seismogram, the section is inverted an acoustic impedance is shown on section instead of amplitude as shown in Figure 5.9.

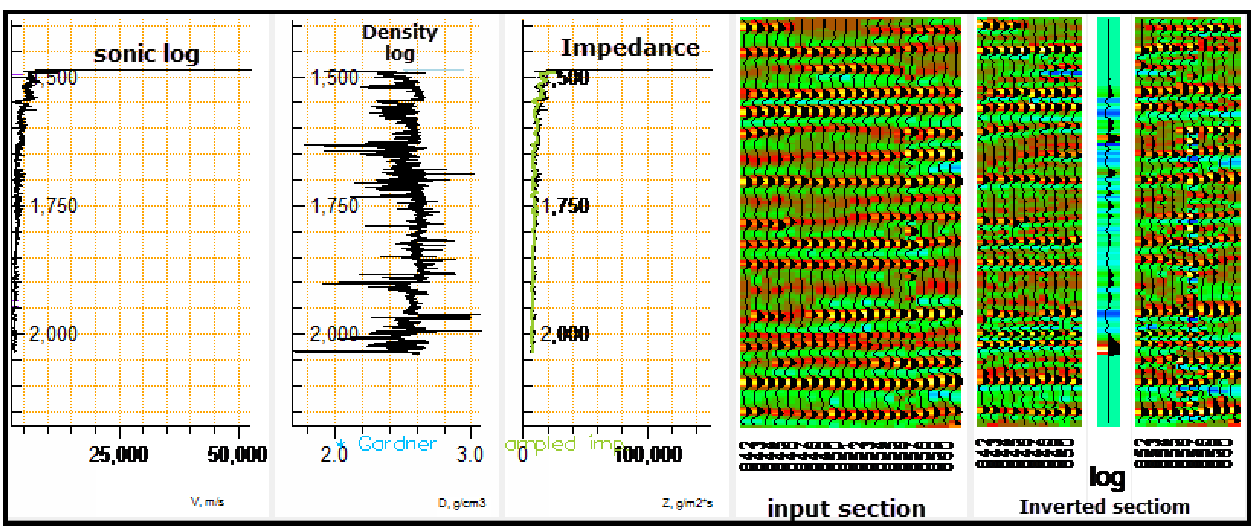

Figure 5.9 : Input seismic section and inverted section along with logs.

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

The zoomed picture of inverted section is shown in Figure 5.10 given below.

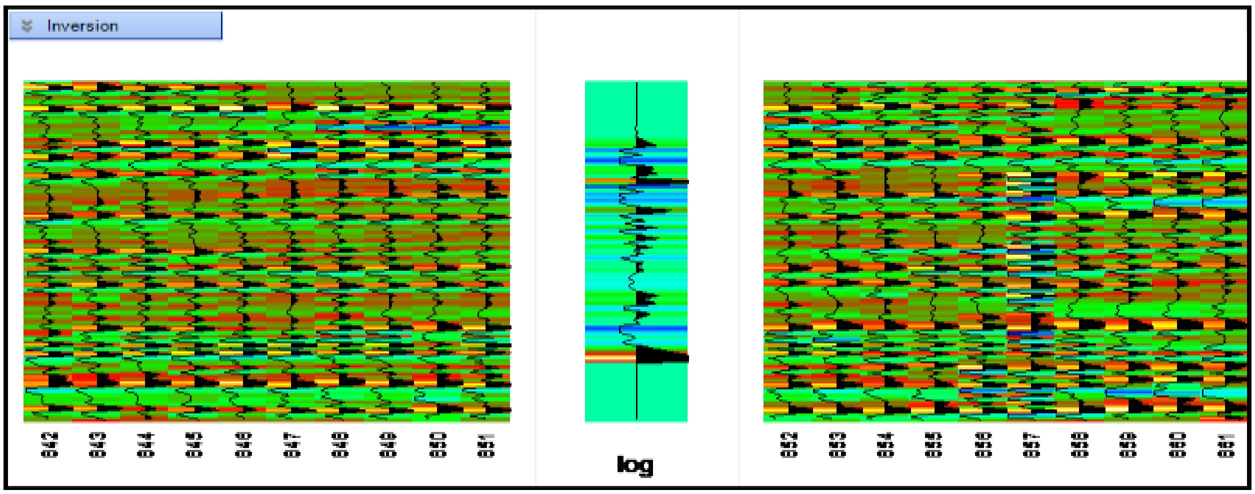

Figure 5.10 : Inverted Section with inverted logs.

Now inversion is applied to the whole section shown in Figure 5.11.

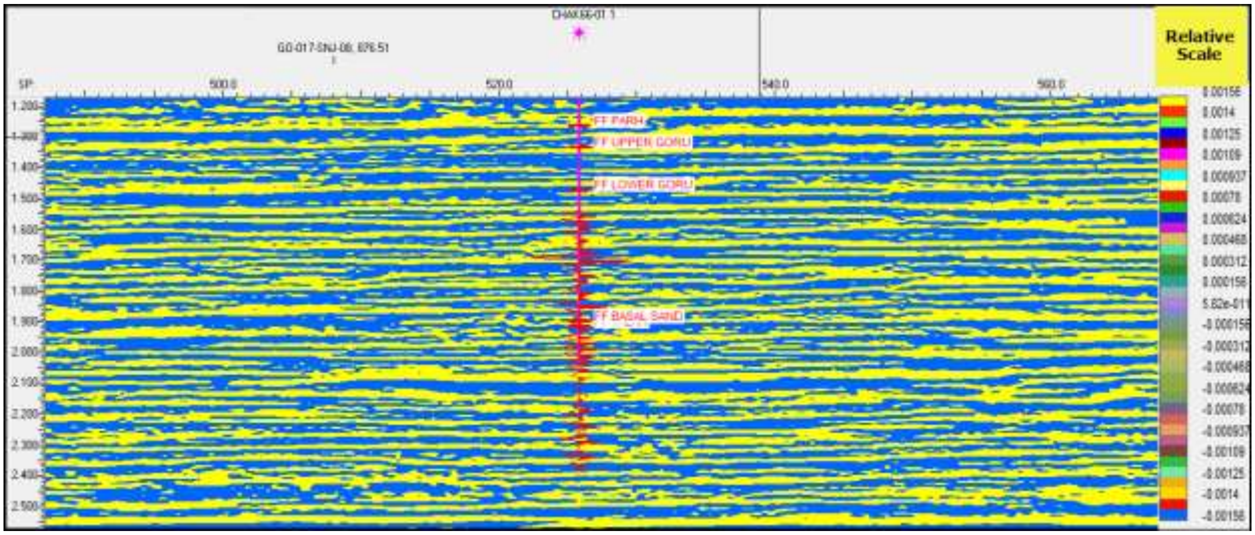

Figure 5.11 : Inverted Seismic Section.

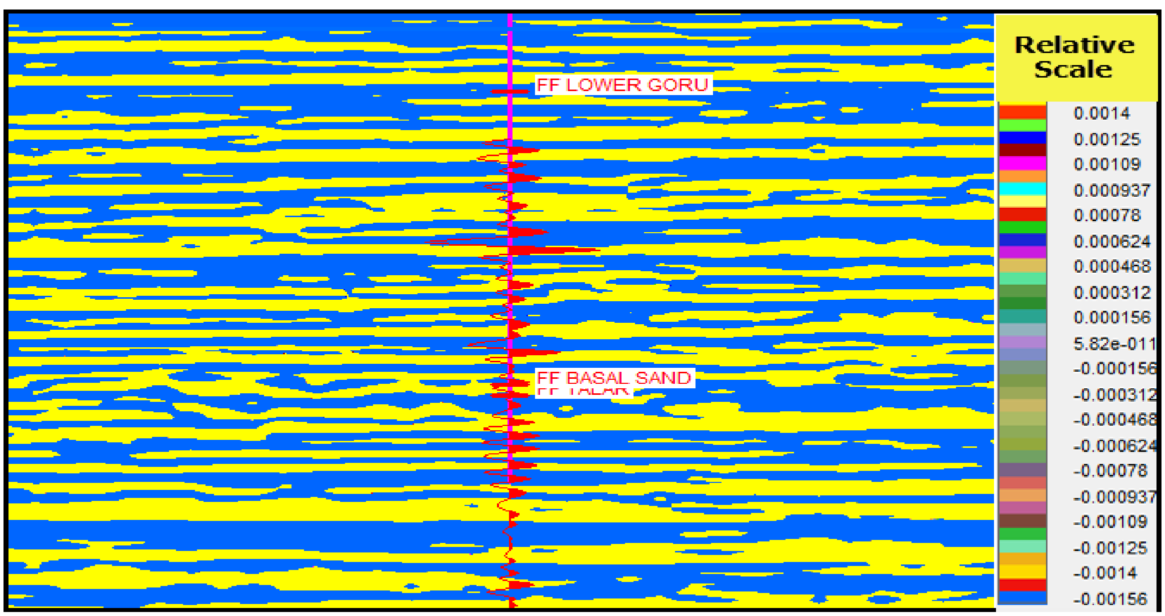

Figure 5.12 : Zoomed picture of inverted seismic section.

***Conclusion*:**

- 2D Seismic data used to interpret the structure present in study area.
- Confirmation of horst and graben structure present in study area.
- Petrophysical analysis of the well CHAK66-01 indicate the 78% hydrocarbons present in the study area with good range of 13% effective porosity.
- For the reservior characterization of area, Seismic Colored Inversion performed to find the low acoustic impedance zone. On the basis of colored inversion, the Lower Goru formation indicate low acoustic impedance zone, which confirms the interpretation and presence of effective porosity at the mark horizon, because porosity is inversely related with acoustic impedance.
- Measuring favorable zone on the basis of colored inversion indicate low impedance zone in the reservior. The range of Accoustic Impedance at the marked horizon, Lower Goru is 0.000937(m/s)(g/cc) .

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