Integrated Reservoir Characterization with 2-D Seismic Interpretation, Well Logs Interpretation And Seismic Inversion of Sinjhoro Area, Lower Indus Basin, Pakistan

By

Muhammad Ehsan Rafique

BS Geophysics

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Department of Earth Sciences

Quaid-i-Azam University Islamabad, Pakistan

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INTRODUCTION

1.1 Introduction to Area

Sinjhoro development consists of a number of small fields discovered in proximity of each other with in the Sinjhoro Exploration License (such as Chak-2, Chak-63, Chak-63SE, Chak-66, Chak-66NE, Chak-7, Hakeem Daho, Lala Jamali and Resham) that are producing from the lower Goru formation of the early late cretaceous period (OGDCL,2014). Sinjhoro is part of lower Indus basin. It is extensional regime and normal faults are present there. Geographically it is located in south Eastern part of province Sindh and basin wise it is located in southern Indus basin. Also it is in between Indian basement, Kirther fold and thrust belt. Normal faults are present in the area. The Sinjhoro field is located about 65km NE of Hyderabad city of Sindh province in lower Indus basin and covers area of 102 acres. The main reservoirs are Basal and Massive sand and lower Guru formation in the area. My objective is to interpret the seismic lines of Sinjhoro which is town in Sanghar district, Sindh (Pakistan) about 22.5 km NORT-WEST from Sanghar city, along Sanghar-shah dad purr road. The given dissertation is to interpret the seismic section along the seismic lines **GO-SNJ-01,GO-SNJ-03, GO-SNJ-04 and GO-SNJ-23** located in Sindh province. It is oriented in SW-NE direction. Sinjhoro Gas Field is currently producing with full potential having 3000 BPD oil, 30 MMCFD gas and 155 MTD of LPG (OGDCL,2014).

1.2 Location of the Area

Sinjhoro block is located in the Thar platform of southern Indus basin. The Sinjhoro area is characterized by a series of horst and grabens structure present almost below the base. The extensional tectonics during the cretaceous time created the tilted faults blocks over a wide area of eastern lower Indus sub basin. Satellite image of the location of study area is shown in figure 1.1.

The location of study area is:

- Latitude: 26° 00’ 00N to 26°15’ 00 N
- Longitude: 68° 48’ 00E to 69° 05’ 60 E

Figure 1.1: Satellite image of the Area. (Courtesy Google Images)

1.3 Base map

A 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 geographic reference such as latitude and longitude. Geophysicist typically use shot points maps, which show the orientation of seismic lines and the specific points at which seismic data were required to display interpretation of seismic data.

1.3.1 Base map generation

We generate base map by loading navigation files using software. It have latitudes and longitudes, we use X,Y Coordinates and convert units into meters. This map may become base map showing dip and strike lines orientation, wells and shot points, also called **shot point location map**.

1.3.2 Steps for Base Map Generation

- Loading Data on Kingdom Suit (8.6).
- Navigation Data (X, Y).
- Seismic Data (SEG Y data).
- Base Map

Base map of the Sinjhoro area having all the seismic lines and all wells is shown below in figure 1.2.

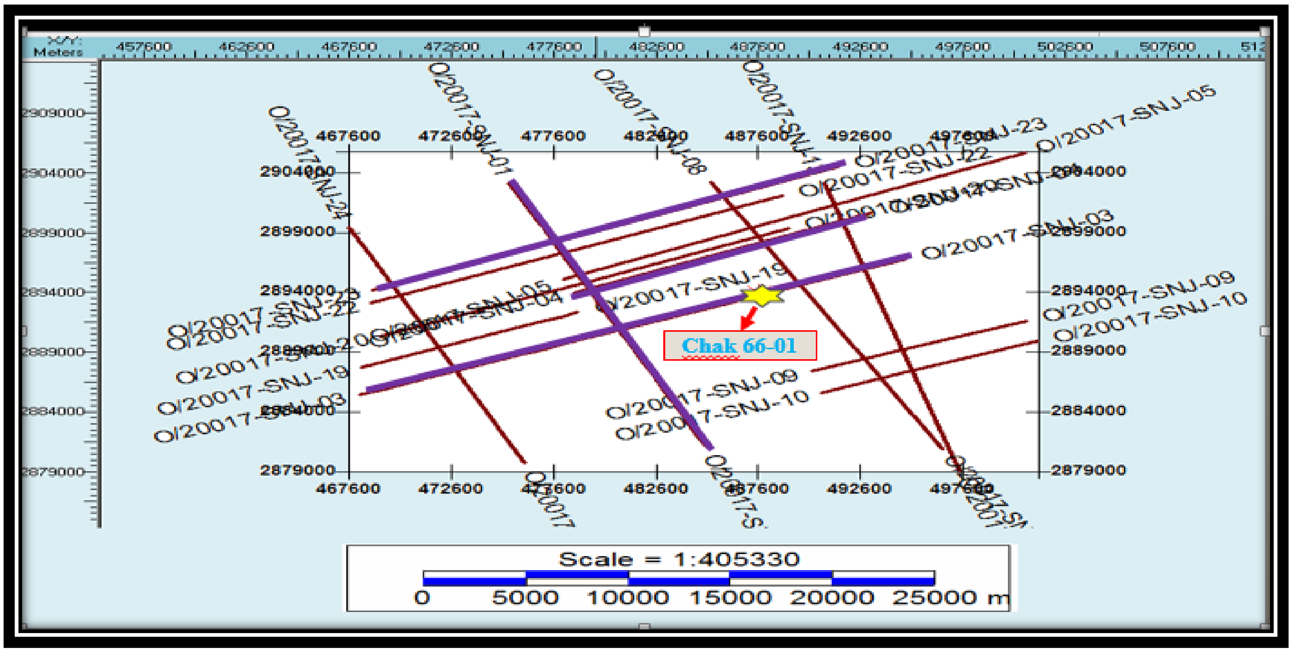

Figure 1.2: Base map of the study Area.

1.4 Seismic Lines

The Data set used in the study area consists of **four** 2D-seismic lines shown below in Table. A Single well is in the study data to understand the subsurface geology. Dip lines are GO-SNJ-03, GO-SNJ-04 and GO-SNJ-23 contain short points while GO-SNJ-01 is the strike line along with well Chak # 66-01. These lines have been processed to get final migrated stacks which have been used for interpretation. Seismic lines show many prominent reflectors which are displayed at different location. The breakage in the reflectors helps in identifying the faults. Basement and other prominent reflectors show high amplitudes, indicating strong reflection coefficients. Table of all the selected seismic line's name, their nature and orientation is given below:

Line name	Nature of line	Orientation of line	Well
GO-SNJ-01	Strike	NW-SE	
GO-SNJ-03	Dip	NE-SW	**Chak#66-01**
GO-SNJ-04	Dip	NE-SW	
GO-SNJ-23	Dip	NE-SW	

1.5 Base map of selected Seismic lines:

There are three dip lines and one strike line in selected four seismic lines. . Dip lines are GO-SNJ-03, GO-SNJ-04 and GO-SNJ-23 contain short points while GO-SNJ-01 is the strike line along with well Chak # 66-01. Base map of the selected seismic lines is shown in figure 1.3.

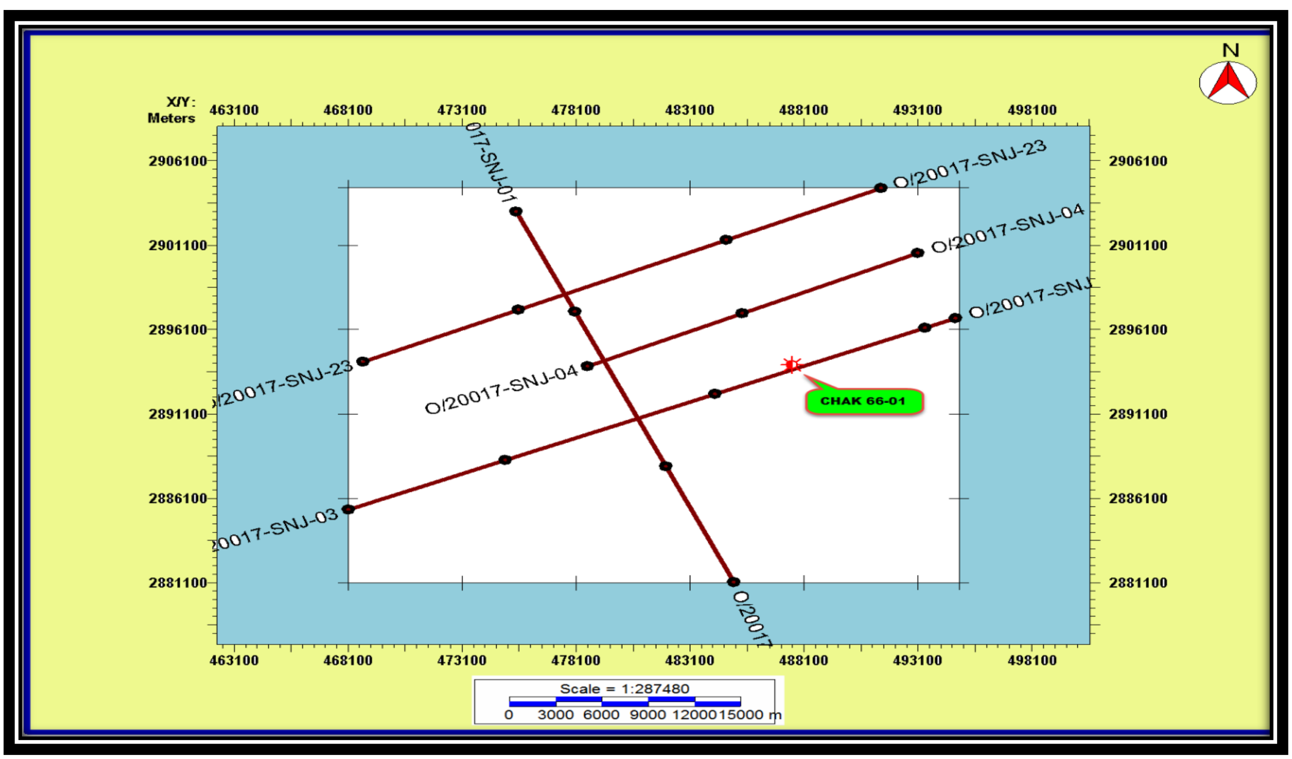

Figure 1.3: Base map of the selected lines.

1.6 Data description

- OGDCL is data constructer.
- Energy source is Dynamite.
- Range of frequency: 7-15 Hz.
- Sampling Interval: 4ms
- Dominant frequency: 30 Hz.
- Hole Depth is 30m.

1.7 Software Tools Used

To complete project and completion of this dissertation course work, following software were used:

- SMT Kingdom 8.6
- Matlab Inc. 2010
- SnagIt 11 (Editor)
- MS office 2010

1.8 Well information

Complete well information with location, its elevation, depth, unique well ID, well type and status of well CHAK 66-01 is given below in the table.

Well name	Latitude	Longitude	Elevation	Total Depth	UWI	Type	Status
Chak 66-01	026.165194	068.876250	31.93 KB	2999 m	001212	Exploratory	Oil & Gas

1.9 Formation Tops & Time

Formation tops are the depths in a well at which formations are found in the subsurface, except for the glacial drift formation. In the case of the glacial drift, the "top" is actually the bottom or base of the drift. This "base of drift" is the depth of the bedrock surface at the well. All the formation names, formation depths and their two way travel time is given below in the table:

Formation Names	Depth (m)	Two way Travel Time (sec)
Alluvium	0000.000	0.000000
Laki	0612.000	0.552241
Ranikot	1161.000	0.918786
Parh	1631.000	1.247427
Upper Goru	1773.000	1.311462
Lower Goru	2023.000	1.519580
Basal Sand	2842.000	1.815000
Talar	2866.000	1.915000

1.10 Objectives

The main objective of this research work is to carry out a comprehensive interpretative study of the available seismic lines. However, a complete and reliable picture of the subsurface could not be obtained on the basis of the four available seismic lines.

Some important objectives are:

- To know the stratigraphy and explore geological structures present in the area.
- To mark faults and horizons to find the tectonics of the area.
- Identification and making of reflectors.
- Preparation of time section and time to depth conversion to know the actual depth of the reflectors.
- To prepare synthetic, time contour and depth contour map to analyze the lithologies.
- To perform petro physical analysis to well identification the properties of petroleum play.

Chapter: 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 Jurassic 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 (Tarbuck et al, 1997).

2.2 Tectonics zone of Pakistan

On the basis of plate tectonic features, geological structure, organic history (age and nature of deformation, magmatic and metamorphism) and lithofacies, Pakistan may be divided into the following broad tectonic zones and these are also shown in Figure 2.1.

- **Indus platform and fore deep.**
- **East Baluchistan folds and thrust belt.**
- **Northwest Himalayan fold and thrust belt.**
- **Kohistan-laddakh magmatic arc.**
- **Karakoram block.**
- **Kakar khorasan flysch basin and makran accretionary zone.**
- **Chagai magmatic arc.**
- **Pakistan offshore.**

Within these broad tectonic zones these are subtle differences in tectonic and change in structure style to merit further subdivision into smaller subdivision. Here we are not concern about those; we are going to discuss the relevant that is the **Indus platform and fore deep** which is our area of interest as from all above mentioned tectonic zones our seismic line belongs to this area. Tectonic zones of Pakistan are also shown in Figure 2.1.

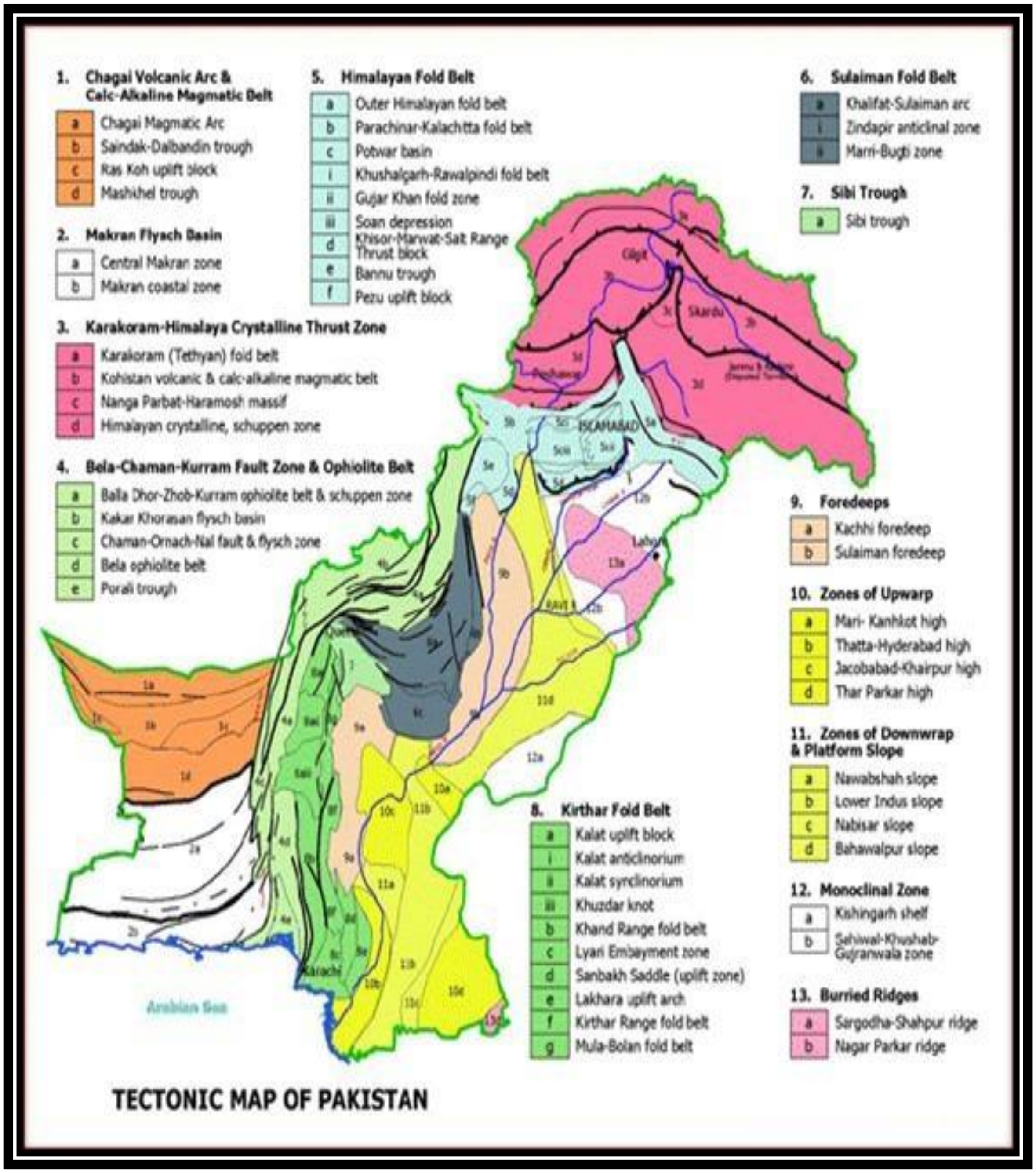

Figure 2.1 Tectonic Map of Pakistan (Ghazanfar,1993)

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 as shown below in Figure 2.2.

- Indus basin
- Pashin basin
- Baluchistan basin

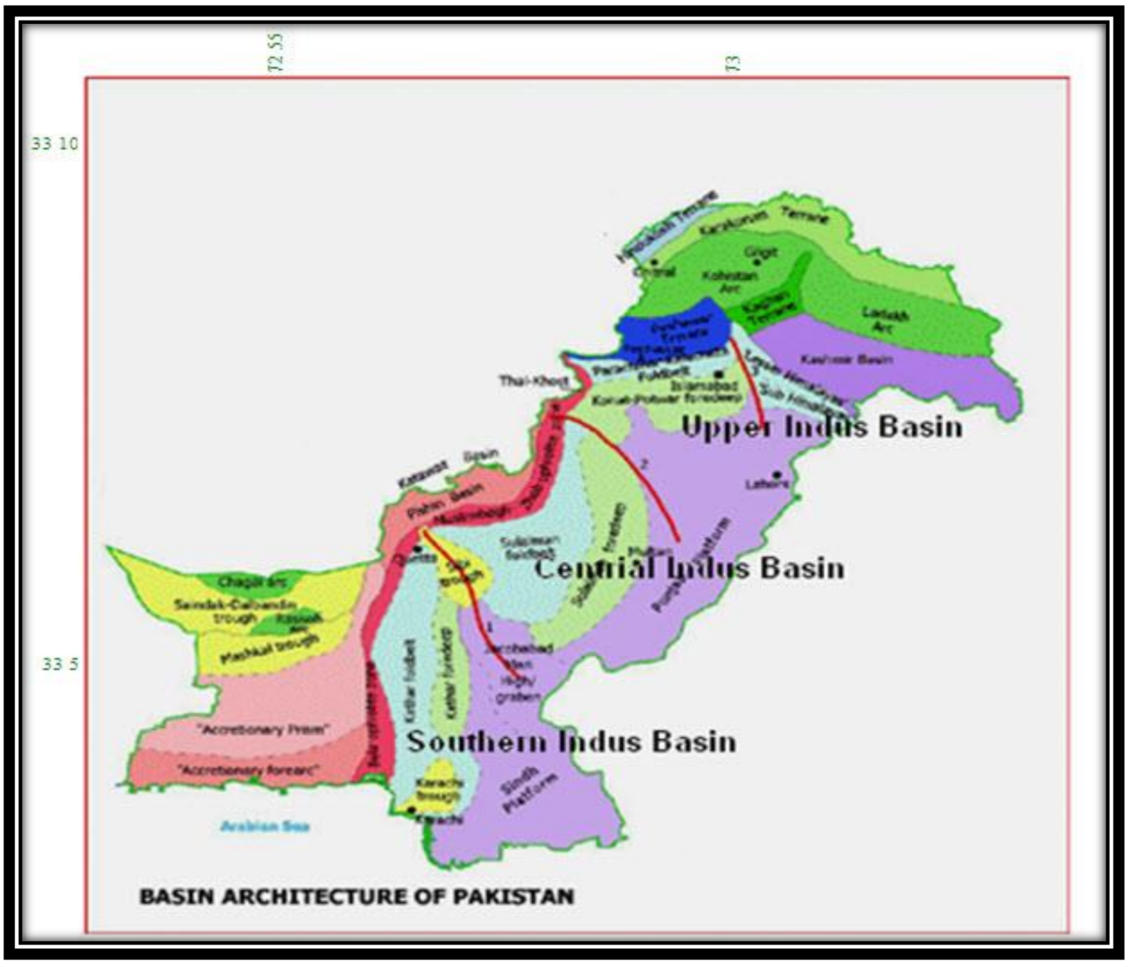

Figure 2.2: Basin Architecture of Pakistan (Kemal 1992)

2.4 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.

Indus basin is following divided into three basins:

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

2.4.1 Lower indus basin classification

This basin is located just south of Sukkur rift, a divided between central and southern Indus basin (Figure 2.1). 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. 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 lithology 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.

2.4.2 Stratigraphy of lower Indus basin

Stratigraphy column of lower Indus basin is shown in Figure 2.3. This column shows distribution, age and lithology of the area. Southern Indus basin is characterized by passive roof complex-type structure and passive back thrust along the Kirthar fold belt, a passive roof thrust forming a frontal culmination wall along the margin of fold belt and the Kirthar depression and out of syncline intermolasses detachment in the Kirthar depression sequence. The generalized Stratigraphy of lower Indus is given by Figure 2.3.

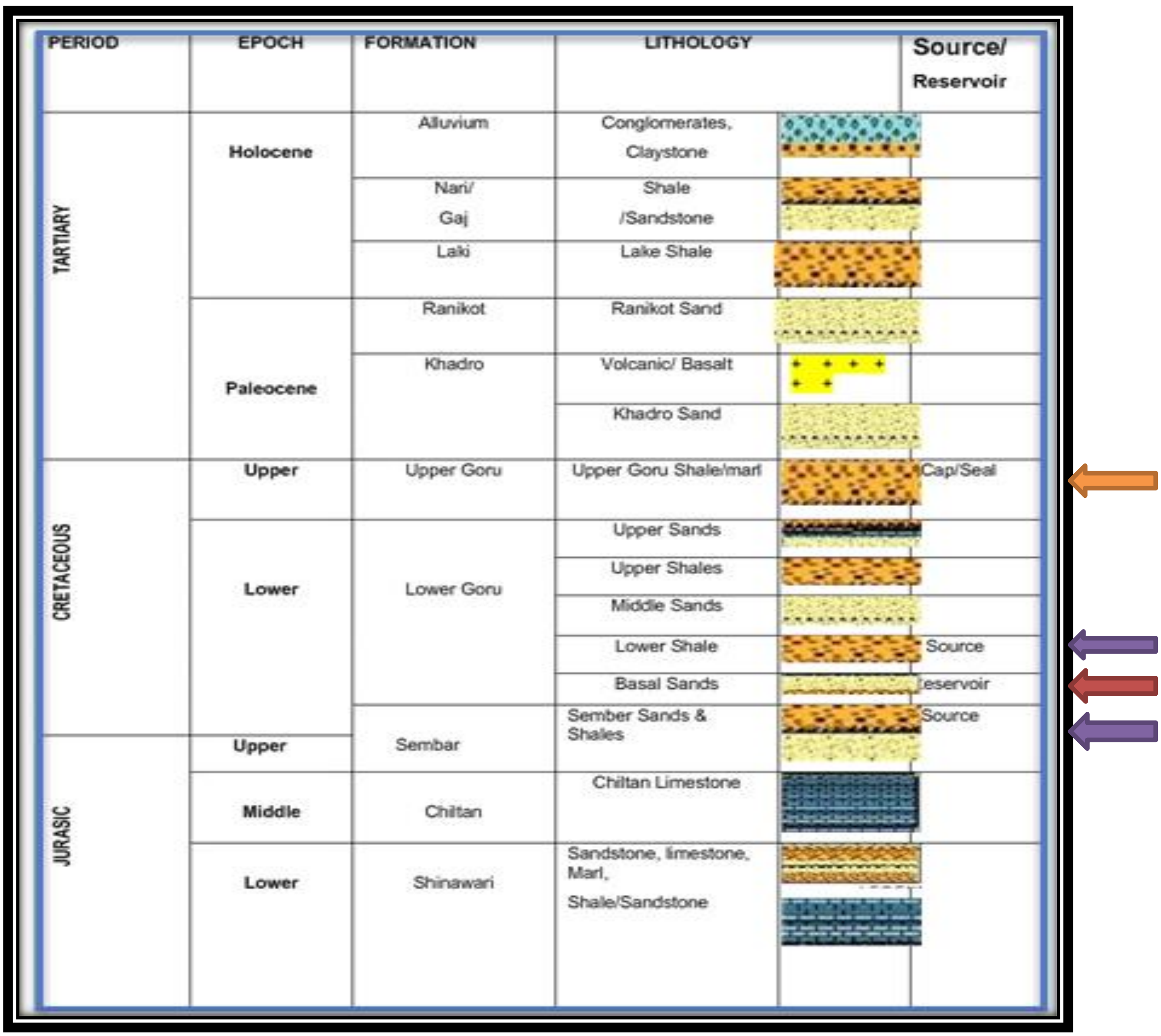

Figure 2.3: Generalized Stratigraphy of lower Indus Basin **(www.gsp.pk.com)**

The Kirthar and Karachi depression contain several large anticlines and dome sandstone of these contains small gas field e.g. sari, Hundi, Mazarani, and Kirthar. But in the eastern part of it there are several faults and tilted the blocks of Mesozoic rocks which form structural traps containing small oil and gas field. On the northern sides of its there is Sukkar rift zone bearing large anticlimax structures and contains the Kandhkot and Mari gas fields. The main reservoir rocks in Sindh monocline are cretaceous lower guru sandstone.

2.5 General Geology of Sinjhoro

As the project area is located in sanghar District, the southern part of the Indus basin. So we can define regional geology of Sinjhoro area. The southern Indus is a strain basins characterized by tectonic faults up on the western edge of the Indo Pakistan sub-continent identifies. Several hypotheses have been proposed, the origin of these crusts explain functions, but Keller chains remain enigmatic. Thar platform gently sloping monoclinic Punjab platform controlled topography of the basement, the sedimentary wedge thins towards the Indian plates whose surface expressions in the form of Nagarparkar high are available, it differs from the Punjab platform that it shows the buried formed by tectonic extension from the from the current counter clockwise movement of the Indian plate resulting structures. It is in the east of the Indian plate limited goes in Kirthar and Karachi trough in the west and in the north by mariBugti inner folded zone.

The platform by Thar, Karachi built trough and offshore Indus stratigraphic structure cross-section clearly shows the stratigraphic and structural differences between the two sub-basins. The platform brands very good development of the early / mid-Cretaceous sand Guru, the reservoir for oil and gas (Kadri, 1995)

Wicky and horst ductile lithology of Upper Guru drapes, possibly along the dip to cut the post slate sand body by a Turonian disconformities forms the common Game Types (ECL,1988).

2.6 Physical features / Topography

The study area is part of lower Indus plain formed by the alluvial deposits of the Indus River. Being a vast alluvial plain its land is very uniform in character and is not diversified by hills or rivers. The southern part of the district is close to the delta of the river Indus and the land surface is, therefore, relatively low as compared to the north half, the general elevation of the district is about 50 meters above sea level. Clay and sand are principal ingredients of the soil and one of the two factors by which the composition of the various soils is differentiated is the extent to which the clay or the sand predominates. The other criterion for the character of a soil is the presence or absence of natural salt.

2.7 Structures of the project area

The structure is the result of a normal faulting on the west dipping Indus plain. The fault planes act as way for the migrating fluids from underlying shaly source sequence. Trends of faults and contour are mapped utilizing all well and seismic control for the field.

Seismic interpretation constitutes the basis for the structural interpretation as no surface outcrops are found over the field. The lower guru hydrocarbon accumulation in project area is bounded on the east and on the west by regional extension faults dipping to the east and trending NW-SE. Generalized cross section showing the structure across the Lower Indus Basin is shown below in the Figure: 2.4.

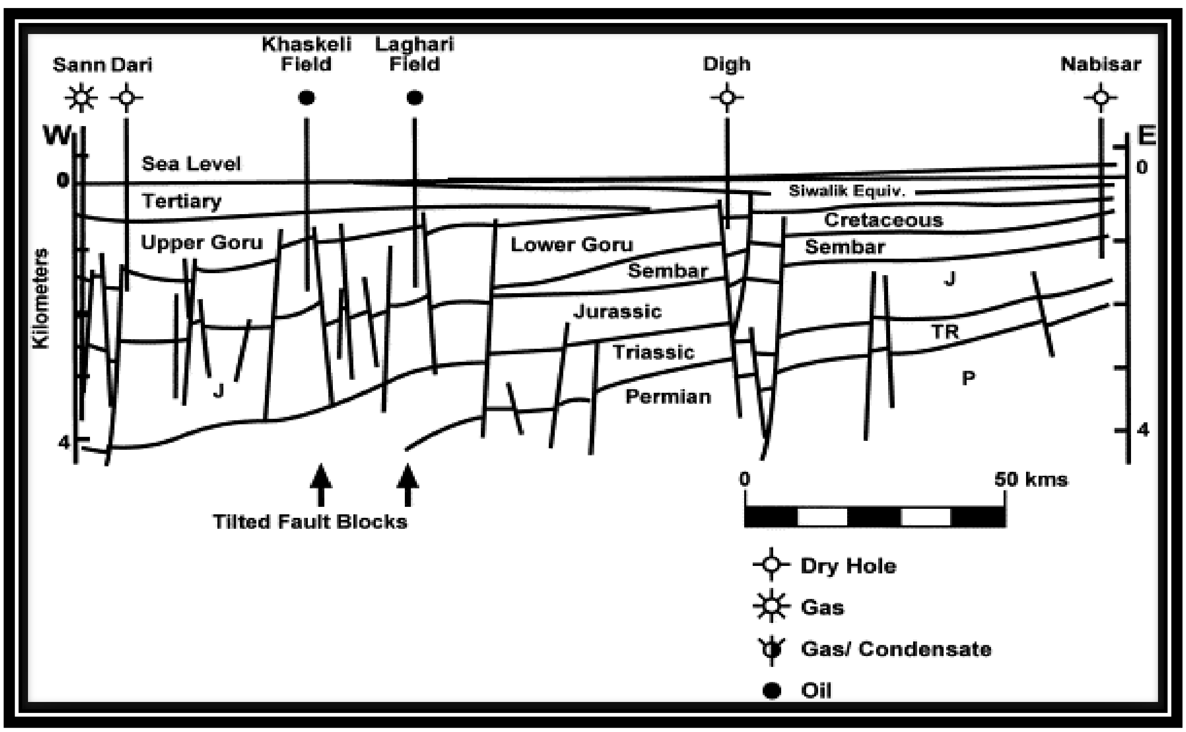

Figure 2.4: Generalized cross section showing the structure across the Lower Indus Basin (OGDCL, 1996)

2.8 Stratigraphy of the Area

The area comprises a full range of formation with oldest rock in the area from Pre-Mesozoic to till most recent formation of Eocene age. But major focus in the area due to petroleum play is on Lower Goru Formation which is of Cretaceous age which is acting as reservoir in the entire basin, Generalized Stratigraphy Column of the area is in Figure 2.5 and Figure 2.6.

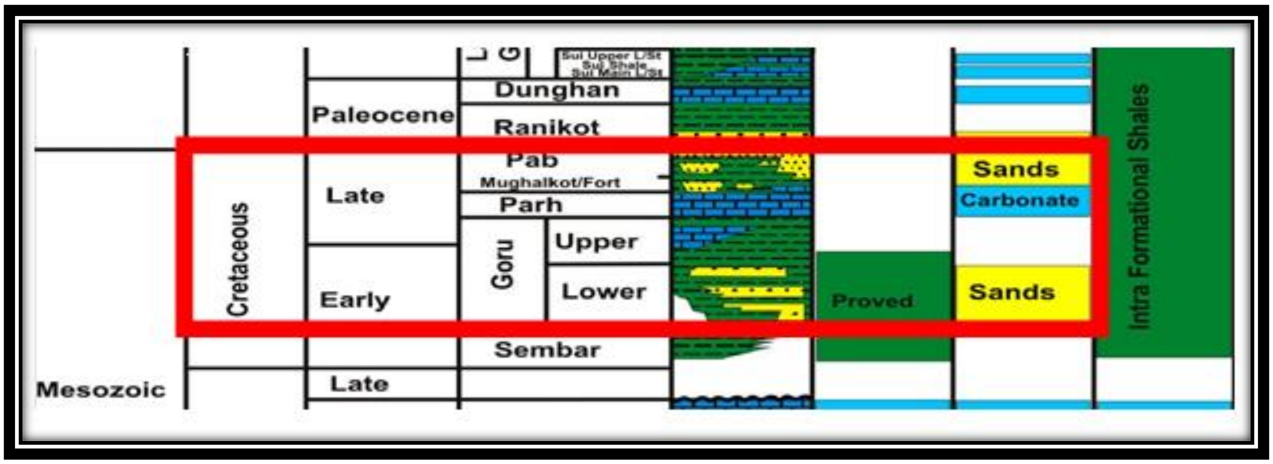

Figure 2.5: generalized stratigraphy of Sinjhoro (www.gsp.pk.com)

2.8.1 Goru formation

Goru arly Cretaceous) consists of interbedded limestone, shale, marls, sandstone and siltstone. The environment of deposition is shelf to shallow marine. Different parts of this thick formation have enough reflectivity indexes to produced very clear reflections. Goru formation is divided into two parts (Kadri, 1995).

- Upper Goru
- Lower Goru

2.8.2 Upper Goru

It is comprised of marl calcareous clay- stone occasionally with inter-beds of silt and limestone (Kadri, 1995).

2.8.3 Lower Goru

The lower Goru is main reservoir rock within the area. It consists of:

- The basal sand unit
- Lower shale
- Middle sand unit (which is a very good reservoir rock)
- Upper shale
- Upper sand

2.8.4 Parh limestone

The Parh limestone is a lithologically very distinct unit. It is a hard, light grey, white, cream, olive green, thin-to-medium-bedded, lithographic and argillaceous limestone, with subordinate calcareous shale and marl intercalations. The formation is widely distributed in parts of the Axial Belt and Lower Indus Basin (Sulaiman and Kirther Province). The lower contact with the Goru formation is transitional and conformable Environment of deposition is shallow marine (Shah ,1997).

2.8.5 Ranikot Formation

One division of Ranikot group suggests that it comprise of three formations which are Khadro formation, consists of olive, yellowish brown sandstone and shale with inter beds of limestone. Keeping ascending Stratigraphy order, Above Khadro formation is Bara formation (Lower Ranikot sandstone) consists of variegated sandstone and shale. And the upper one is the Lakhra formation (Upper Ranikot limestone) consists of grey limestone, grey to brown sandstone and shale. Various authors have given it different divisions. Below are explained the three formations as part of the Ranikot group with details(Shah, 1997). Ranikot formation is considered to be a good source rock for the gas reservoir in the area. It also act as a seal rock (Shah, 1997).

Generalized stratigraphy of study area is shown below in Figure 2.6 showing all the stratigraphy of Lower Indus basin in which area of interest is also marked.

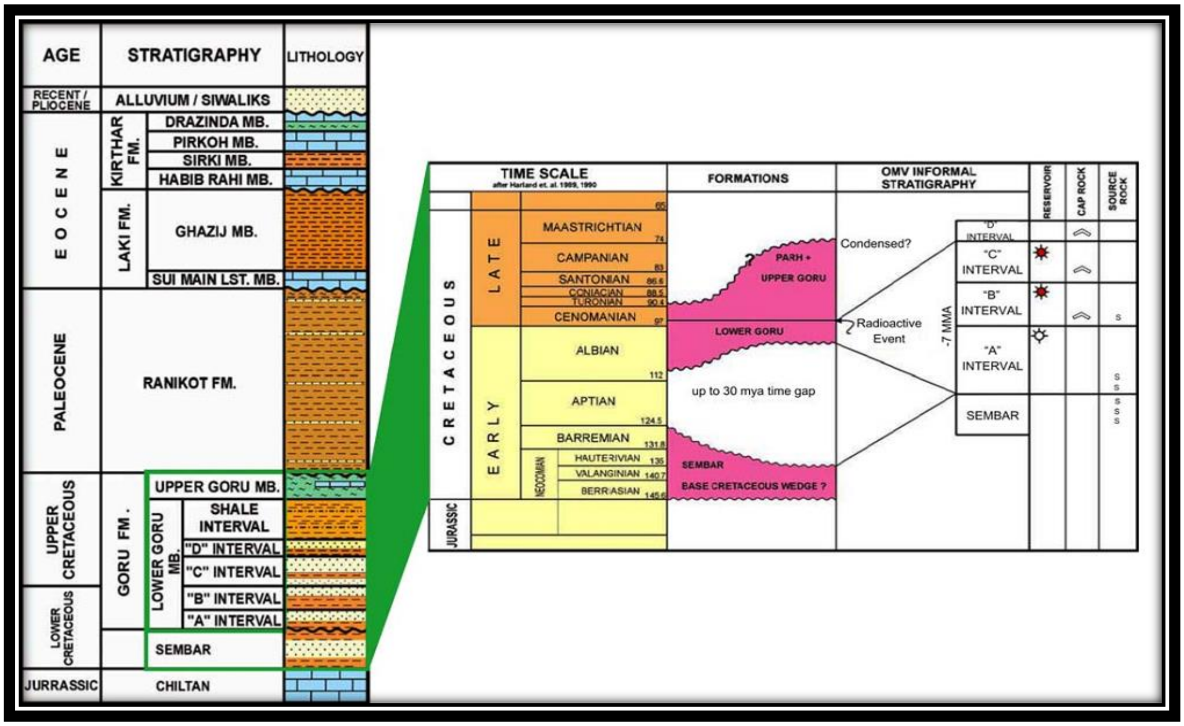

Figure 2.6: Generalized stratigraphy of study area (www.gsp.pk.com)

2.9 Hydrocarbon Potential of the Project Area

The oil production has been established in the **lower guru sandstones**, in layers l, ll and lll of cretaceous age. Progressive rifting of the indo-Madagascar plate commenced, as stretch troughs. Early in the cretaceous period, during the initial phase of the evolution of the rift system the sember formation with significant organic content was deposited under restricted circulation. The formation, along with the basal shale of the lower guru formation, represents the major source of hydrocarbon in the lower Indus basin. With the evolution of the rift system into a more mature half graben stage, the extensional tectonics resulted in tilted fault blocks over the Thar slopes. The lithosphere during the evolution of the rift system underwent readjustment causing subsidence and uplifts.

Coupled with the worldwide Eustatic pulses, the changes in sea level influenced depositional environments, resulting in sequence of delta related sand bodies and marine shelf shale deposits. The tectono-eustatic oscillation also creates a number of minor disconformities and marine transgressions. During mid-cenozonian in one such marine submergence,'' Sinjhoro shale's" were deposited under more open marine environments and characterized by greater carbonate content (marls and thin limestone bands).After subsequent uplift, many reservoirs in the region.

Following a prominent depositional break, Turonian marine transgression created environments for pelagic sedimentation of the upper guru formation. These plastic marls and shale's provide the capping mechanism with a thickness approaching 1,000 meters in the project area. Tilted fault blocks and horst draped by upper guru ductile lithologies; possibly, along the up dip truncation of post-Sinjhoro shale sand bodies by Tournian disconformities form the prevalent play types. (ECL, 1988).

2.10 PETROLEUM PLAY OF THE AREA

Following elements put an important role in making of potential petroleum play:

2.10.1 Source Rocks

The **Lower Cretaceous Shale of Sembar Formation** is proven source for oil and gas discovered in the area because of its organic richness and thermal maturity. The organic matter in the Sembar Formation is mainly type-III kerogen, capable of generating gas. Shale of Sembar and Lower Goru Formations has been established as main source rocks Lower and Middle Indus basin (Raza et al, 1989). Carbonates and shale of deeper horizon may also act as source. The geothermal gradient in the region ranges from 2.0C0/100m to 4.0 C0/100m.The gas window is in the range of 2625m to 5250m, compatible with depth range of Sembar, Lower Goru and deeper horizons source rocks at various structural positions, created due to rifting.

2.10.2 Reservoirs Rocks

Basal sands lower guru (cretaceous) formation is the primary objective in this area. These sands are proven in this area. Average porosities for these sands are around 11% in the prospect area.

2.10.3 Cap Rocks

A thick Stratigraphy sequence of **shale and marl of upper guru** formation serve as cap rock for underlying lower guru sand reservoir. Shale of lower Goru formation has also the same properties.

2.10.4 Migration

Migration provides path for movement of hydrocarbon and its upper limit is trap. Two types of migration occur:

- Primary migration.
- Secondary migration.

Primary migration occurs within the source rock. Secondary migration cause hydrocarbon into specific traps. The tilted normal fault block provides migration path ways for hydrocarbons.

2.10.5 Traps

Trap is necessary for accumulation of hydrocarbon otherwise it leaks to the surface. Traps in Badin are structural and they are as a result of extensional tectonics.

Chapter: 03

SEISMIC SURVEY AND DATA PROCESSIING

3.1 Introduction

The seismic survey is one form of geophysical surveys that aims at measuring the earth's geophysical properties by means of physical principles such as magnetic, electric, gravitational, thermal, and elastic theories. It is based on the theory of elasticity and therefore tries to deduce elastic properties of materials by measuring their response to elastic disturbances called seismic (or elastic) waves.

Seismic surveys are used to locate and estimate the size of underground oil and gas reserves. Seismic images are produced by generating, recording and analysing sound waves that travel through the earth. These sound waves are also called seismic waves. The oil and gas exploration industry has deployed this evolving technology for decades to determine the best places to explore for oil and gas.

3.2 Seismic Methods

Seismic Methods deal with the use of artificially generated elastic waves to locate hydrocarbon deposits, geothermal reservoirs, groundwater, archaeological sites, and to obtain geological information for engineering. It provides data, when used in conjunction with other geophysical, borehole and geological data, and with concepts of physics and geology, can provide information about the structure and distribution of rock types (Kearey et al, 2002).

3.3 Seismic Exploration Method

There are two main sub-methods in seismic method:

- Seismic reflection method

- Seismic refraction method

3.3.1 Seismic Reflection Method:

This method is based on the study of elastic waves, which are reflected from subsurface interface between two geological layers. These layers differ from each other in densities, velocities and product of densities and velocity is called Acoustic impedance. When a seismic wave strikes the interface of two layers having acoustic impedance contrast, it is reflected back. The seismic reflection is very powerful tool being widely used in oil and gas exploration. Depth of reflecting interfaces can be estimated from the record time and velocity information that can be obtained either from reflected signal themselves or from surveys in well (Dobrin & Savit, 1988).

Reflection:

It is the process by which wave came back into the same medium from which it was generated after falling/striking at the boundary between the two mediums, as shown in the Figure 3.1.

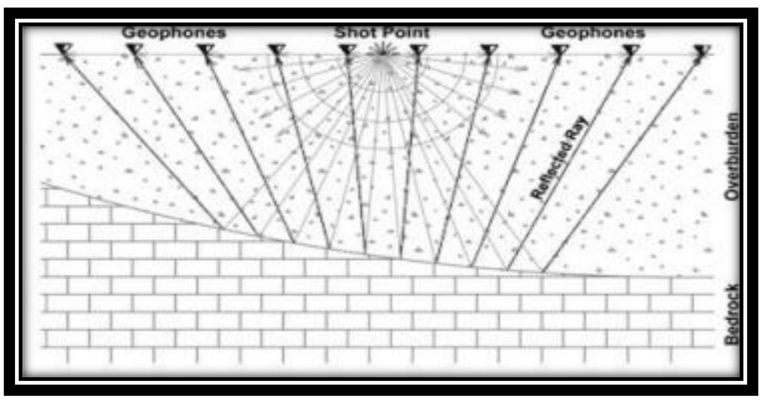

Figure 3.1: seismic reflection survey

3.3.2 Seismic refraction method:

The seismic refraction method utilizes seismic energy that returns to the surface after traveling through the ground along refraction ray paths. This method is normally used to locate refractions from separate layers of different seismic velocities (Kearey et al, 1982).

Refraction:

A Process in which, a wave moves from one medium to other medium, both having different acoustic impedance, then wave changes its path (that is either moves towards or away from the normal to the interface at the point of intercept) as shown in the Figure 3.2.

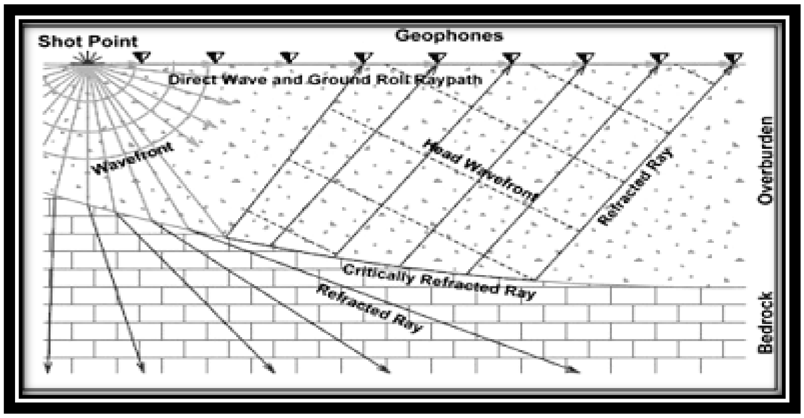

Figure 3.2: Seismic refraction survey

3.4 Seismic Data Acquisition

Seismic investigation starts in the field with the acquisition of data. The purpose of seismic data acquisition is to record the effects produced by mechanical disturbance at the surface of earth, and its effects are observed at number of locations along the surface in a way that its relation with initial disturbance can be interpreted. It includes all those steps which yield final output to be processed and interpreted. The instruments so adopted to acquire seismic data now-a day's differ from those used in past, but essential principle for all instruments is same. The seismic data acquisition starts with, field by few organization divided as if it is land organization or marine organization. Then the whole work starts with field equipment and methods to be adopted for the acquisition of seismic data.

Seismic acquisition system consists of three basic subsystems:

- Energy sources (explosives)
- Energy receiving units (geophones)
- Recording system

Explosives or vibrating plates generate the waves and a line or grid of geophones records them. Density changes between rock or soil layers reflect the waves back to the surface and the speed and strength that the waves are reflected back indicates what geological features lie below.

3.5 Seismic data processing:

The process of data processing includes the sequence of operations. According to predefined program these operations are carried out to convert set of raw data into useful information. Advancement of technology/electronic computers in last two decades brought the digital revolution in seismic prospecting for oil and gas. After the introduction of computers seismic data processing attained new shape. The rationale behind the seismic data processing is to convert the recorded information of field into a form that allows geological interpretation, the reflections presentation with maximum possible resolution on the seismic section and the reduction or elimination of different noises.

The main objectives of the seismic data processing are summarized as below:

- Signal to noise ratio.
- Representation of geology in seismic cross-section.
- Acquire the target provided by client.

Figure 3.3 shows the generalized processing flow chart.

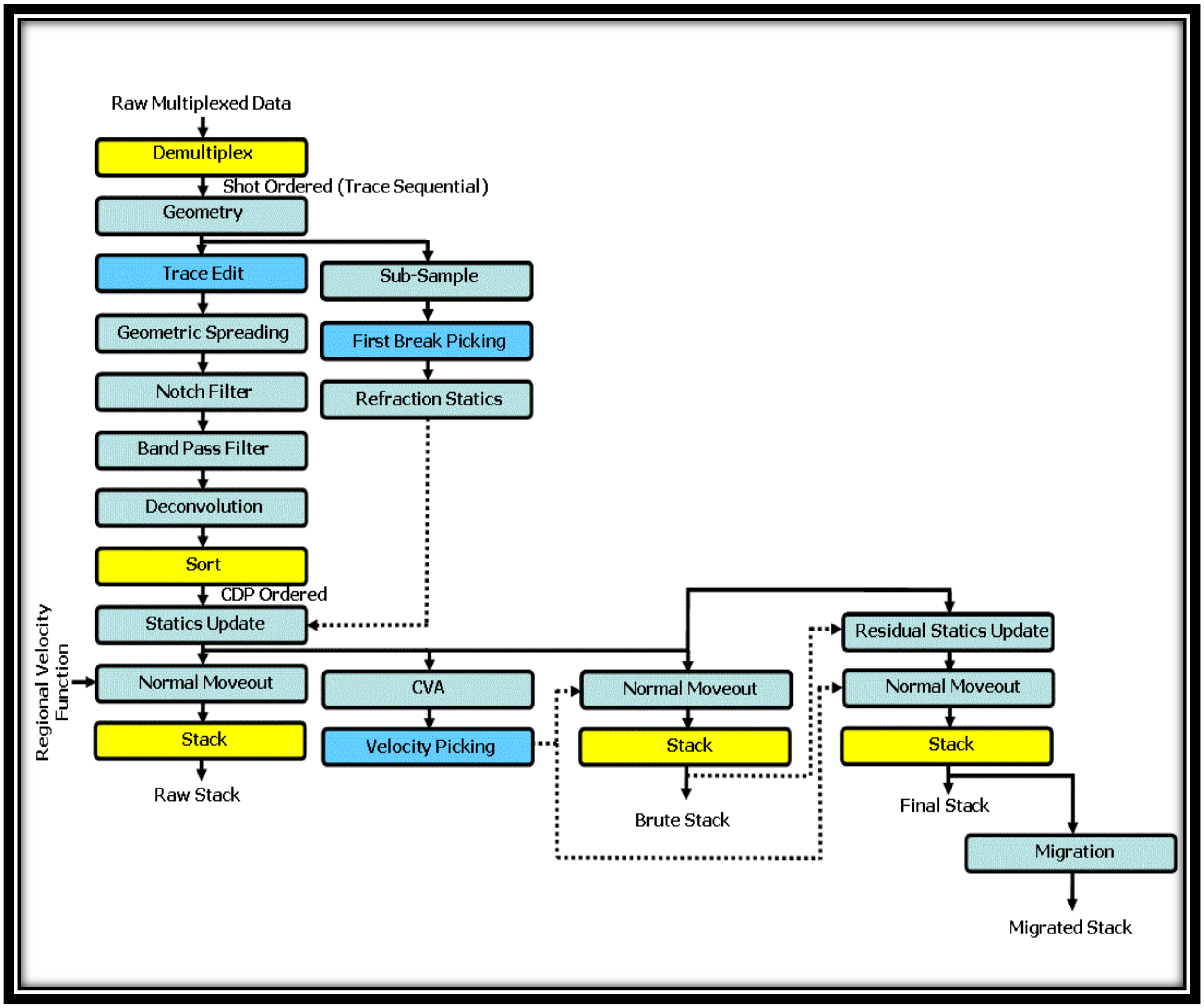

Figure 3.3: Seismic data processing flow chart. (Khan etal, 2009)

3.6 Demultiplexing:

It is the unscrambling of the multiplexed field data to trace sequential form.

3.7 Geometric Correction:

In order to compensate for the geometric effects, we have to apply certain corrections on the recorded data. These corrections are called as geometric corrections (Dobrin, 1988). These corrections are applied on the traces gathered during trace editing and muting. The geometric corrections are:

3.7.1 Static Correction:

Static correction compensates the effect of weathered layer and elevation effect due to disturb surface so static correction is of two types

- Elevation correction
- Weathering correction

For land data, elevation corrections are applied at the stage of development of field geometry to reduce the travel times to a common datum level (Yilmaz, 2001).

3.7.2 Dynamic Correction:

Dynamic correction compensates the effect of offset of receiver from the source .It is also related to the shape of the subsurface interfaces .It is also of two types.

- Normal Move out Correction (NMO)
- Dip Move out Correction

Normal move out correction is related more to the non-dipping interfaces. On the other hand dip move out correction is related to the dipping reflectors. It accounts for the effect of dip of the subsurface interface along with the effect of offset distance of receivers (Robinson and Crouch, 1988).

3.8 Filtering:

Filters are used for enhancement of signal. Thus filtering, "Is a process of spectrum modification which involves suppression of certain frequencies”.

The most common types of filters used are as follows:

- Low pass frequency filter
- High pass frequency filter
- Band Pass frequency filter
- Notch filter

3.9 Deconvolution:

Deconvolution is a filtering process designed to improve resolution and supress multiple reflections (Rehman, 1989).

Data refinement consists of the following two main stages:

3.9.1 Stacking:

In the common depth point (CDP) method ,the geometry is such that the sub surface coverage overlaps .when the data are stacked the traces will be summed together to form one stacked trace .this technique is used for data enhancement (Rehman, 1989).

3.9.2 Migration:

Migration moves dipping reflectors in to their true subsurface positions, and collapse diffractions, thereby shows detailed sub surface features, such as fault planes.

The process of shifting the reflection points to the positions that correctly image the reflector and remove diffraction images, so that we may get an accurate picture of underground layers (Robinson & Coruh, 1988).

3.9.3 Types of Migration:

There are two important types of migration:

Pre-Stack Migration: This type of migration is applied to data before the stacking process.
Post-Stack Migration: This type of migration is applied to data after the stacking process.

Chapter: 04

SEISMIC DATA INTERPRETATION

4.1 Introduction

Seismic interpretation and subsurface modeling are key skills used in oil industry. It is use to generate the reserve able model and predictions about the properties and structure of subsurface. Conventional seismic interpretation implies picking and tracking laterally consistent seismic reflectors for the purpose of mapping geologic structures, stratigraphy and reservoir architecture. The ultimate goal is to delineate hydrocarbon accumulation and their extent and also calculate their volumes.

Seismic interpretation is the process of determining the subsurface information of the earth from seismic data, (coffeen, 1986). It may determine general information about an area, locate prospects for drilling exploratory wells, or guide development of an already-discovered field. Seismic interpretation, sometimes, may not be sufficient to provide enough details about subsurface geology, so along with it other geophysical methods like area knowledge etc should also be considered (Telford, 2004).

In seismic reflection surveys seismic energy pulses are recorded which are reflected back from the subsurface interfaces. The travel times are measured and can be converted into estimates of depths to the interfaces (Kearey & Brooks , 1984).Depth of reflecting interfaces can be estimating from the recorded time and velocity information that can be obtain either from reflected signal themselves or from surveys in well.(Dobrin & Savit, 1976). Velocity may also vary horizontally, due to lateral lithological changes within the individual layers (Kearey & Brooks, 1984).

4.2 Discrimination among different Formation

To distinguish different formations by means of seismic reflection is an important question in interpreting seismic reflection data. For this purpose we correlate the data with the well data and geology of the area under observation. The well data provides links between lithology and seismic reflections. The reflector identification is the next stage by which the actual interpretation starts and it establishes a Stratigraphic frame block for the main interpretation.

Extracting from seismic data the geological structures, such as folding and faulting are referred to as structural interpretation (Dobrin & Savit ,1976). On the other hand, extracting non-structural information from seismic data is called, **"Seismic Facies Analysis".**

4.3 Types of Seismic Interpretation

Seismic interpretation is the transformation of seismic reflection data into a structural picture by the application of correlation of seismic reflectors with geological boundaries and their time-depth conversion. Main approaches for the interpretation of the seismic section are:

- Structural analysis
- Stratigraphic analysis

4.3.1 Structural analysis

In structural interpretation main emphasis is on the structural traps in which tectonics play an important role. Tectonic setting usually governs which types of structures are present and how the structural features are correlated with each other's, so tectonics of the area is helpful in determining the structural style of the area and to locate the traps. Structural traps include the faults, anticlines, duplex etc. (Sheriff, 1999).

Seismic sections can predict the structure that scale up to few tens of kilometers. For large scale interpretation we have to use the grids of seismic lines. Immigrated section is not suitable for structure interpretation, because it creates many problems like synclines becomes narrows and vice versa. Even a migrated section not fully fit for complex area like the area of study.

Some seismic section contains images that can be interpreted without any difficulty. Discontinuous reflectors clearly indicate faults and undulating reflections reveals folded beds. Most interpretation of structural features is directly marked on seismic time sections (Robinson & Coruh, 1988).

4.3.2 Stratigraphic Analysis

Stratigraphic analysis greatly enhances the chances of successfully locating hydrocarbon traps in sedimentary basin environment. 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. We want to distinguish the features that are not marked by the sharp boundaries. Geologists ordinarily group the sequence of sedimentary rocks into units called “formations”. These formations can be described in term of age, thickness, and lithology of the constituent layer. To distinguish different formations on the basis of seismic reflections is an important question in interpreting seismic data that may be structural, stratigraphic or lithological, (Robinson, 1988).

4.4 Workflow for Seismic Data Interpretation

All interpretation projects include a number of tasks which must be completed in order to meet project objectives. The sequence in which these tasks are performed is commonly referred to as an interpretation work flow; in general terms, a work flow is an outline of the steps in a procedure for doing something. Workflow must include in logical sequence all of the essential steps needed to complete the interpretation. Such a work flow is useful for planning and tracking the progress of an interpretation and ultimately for enabling successful and timely achievement of project objectives. For seismic data interpretation, following steps have to follow as shown in Figure 4.1.

Figure 4.1: Workflow for Seismic Data Interpretation

4.5 Synthetic Seismogram Generation

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 time depth chart is prepared and then finally synthetic seismogram is generated. Actually seismic data is provided in time scale and well tops are given in depth so we cannot mark horizons. The purpose of generation of synthetic is to find two way travel time against each depth for marking of horizons. Synthetic seismogram has the information of phase data used and length of wavelet generated the depth scale, reflection coefficient log, sonic log, density logs and the length of source wavelet generated and depth. Seismic Synthetic Seismogram of CHAK 66-01 is shown below in figure 4.2.

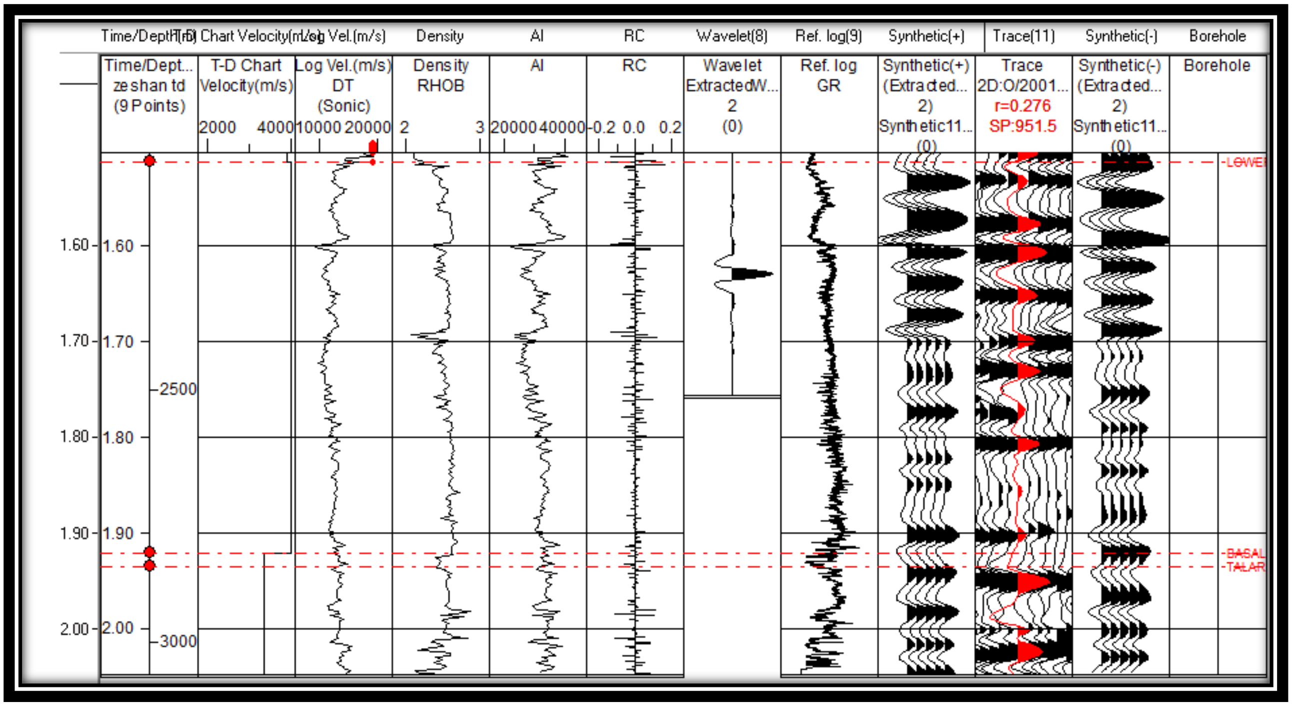

Figure 4.2: Seismic Synthetic Seismogram of CHAK 66-01

4.6 Seismic Interpretation

The main (Prominent) reflections that are present on the seismic sections are marked, and then selected those reflectors that have good characteristics and continuity, and they can also be traced well over the whole seismic section.

There are difficulties in continuing the reflectors at the end of the seismic section and confusions are arrived where reflectors are mixed that may be due to sudden change in lithology, seismic noises and poor data quality in the subsurface at these locations. The seismic data was interpreted using kingdom which is used for interpretation. The SEG -Y format data of seismic lines **SNJ-03, SNJ-04** and **SNJ-23** is loaded by kingdom software for interpretation. After loading data in kingdom software of lines using the interactive tools and applications of Kingdom Software prominent horizons are marked following the trend and continuity of the reflectors. The lines comprise **normal faulting** this shows **horst and graben geometry**.

4.6.1 Line GO-017-SNJ-01

It is a strike line on which I have marked two reflectors starting from Lower Goru formation to Basal sand. Orientation of this line is NW-SE. Interpretation of Line GO-017-SNJ-01 is shown in figure 4.3.

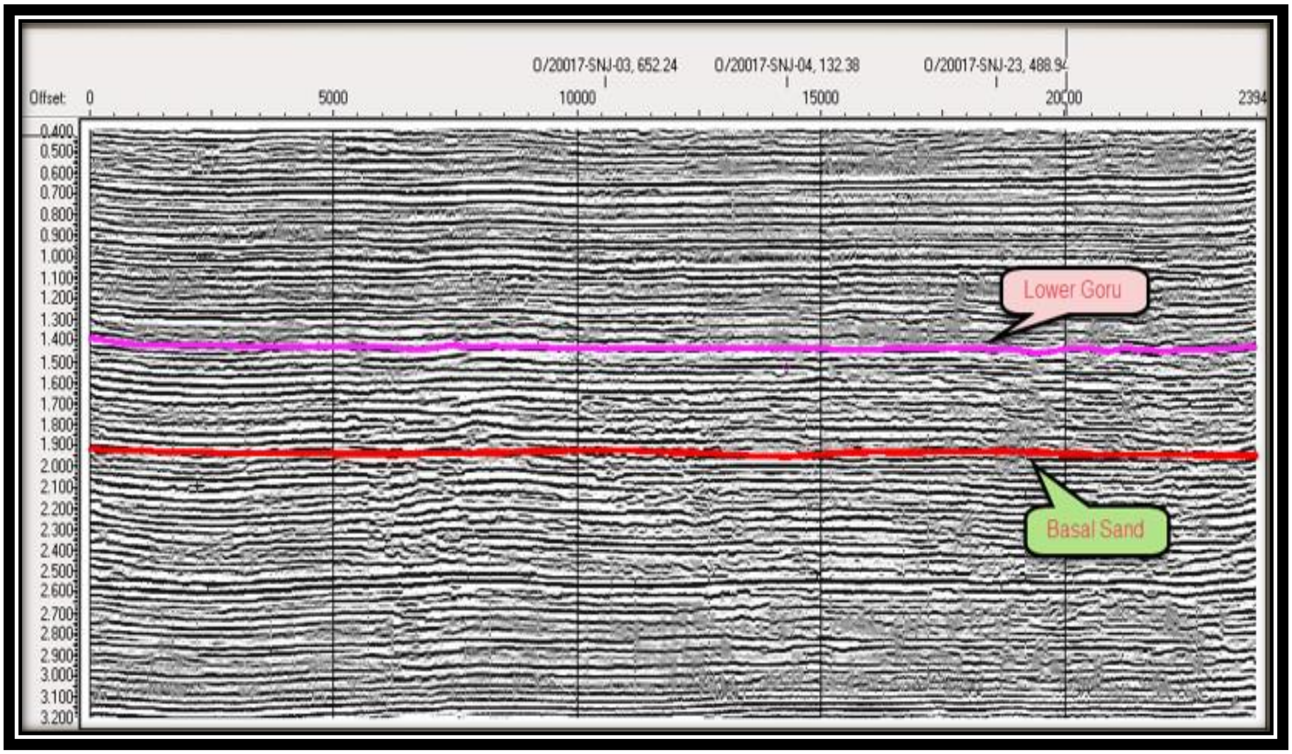

Figure 4.3 Interpretation of Line GO-017-SNJ-01

4.6.2 Line GO-017-SNJ-03

It is a dip line which has series of normal faults and showing series of horst and graben structures. Two reflectors marked on this line starting from Lower Goru formation to Basal sand. All these reflectors marked on the basis of continuous reflection while 6 faults are marked on this line. As discussed CHAK 66-01 well lie on this line and synthetic has generated from this well data and reflectors marked on this section after tying synthetic. All marked faults can be seen in this section. In this section Lower Goru formation is at 1.509 sec, Basal Sand formation is at 1.922 sec. Its orientation is NW-ES. Interpretation of Line GO-017-SNJ-03 show normal faults with horst and graban geometry is shown in figure 4.4.

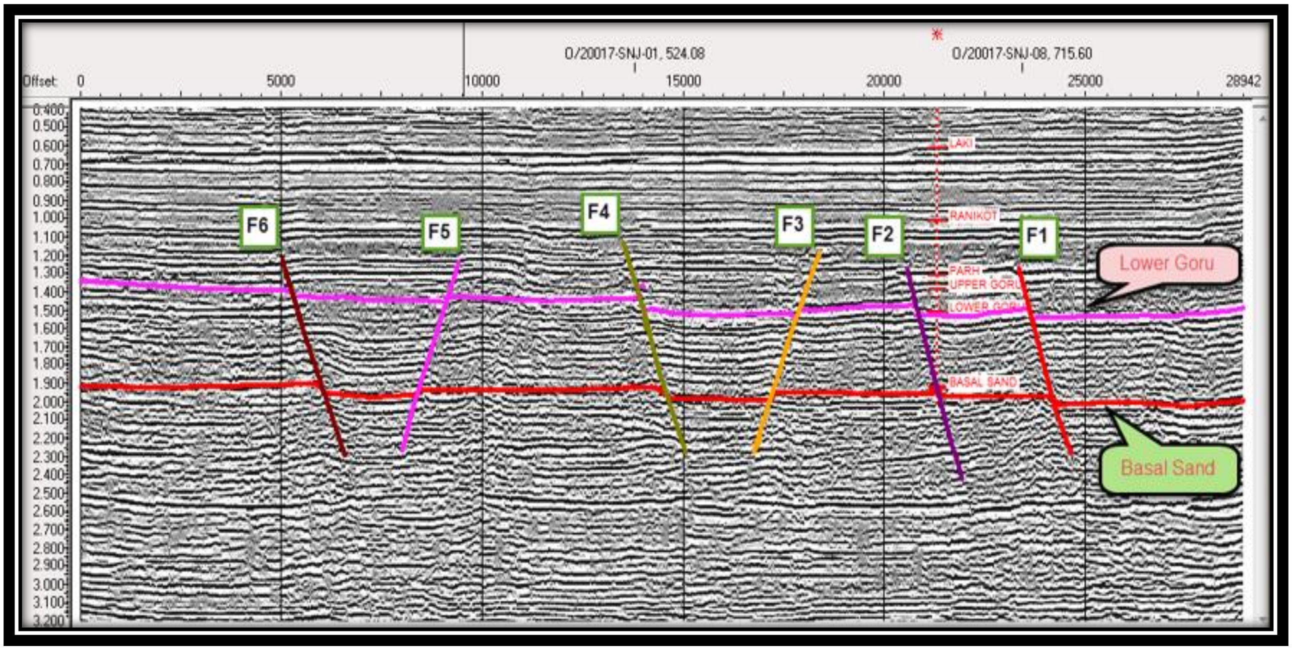

Figure 4.4 Interpretation of Line GO-017-SNJ-03 show normal faults with horst and graban geometry

4.6.3 Line GO-017-SNJ-04

It’s a dip line and has 4 faults and two reflectors are marked. On the basis of discontinuity in Horizons, many Normal faults have been marked on the seismic sections forming the Horst and Graben features. The lines comprise normal faulting this shows horst and graben Geometry. We will mark seismic section of the line. Its orientation is NW-ES. Interpretation of Line GO-017-SNJ-04 show normal faults with horst and graban geometry is shown in figure 4.5.

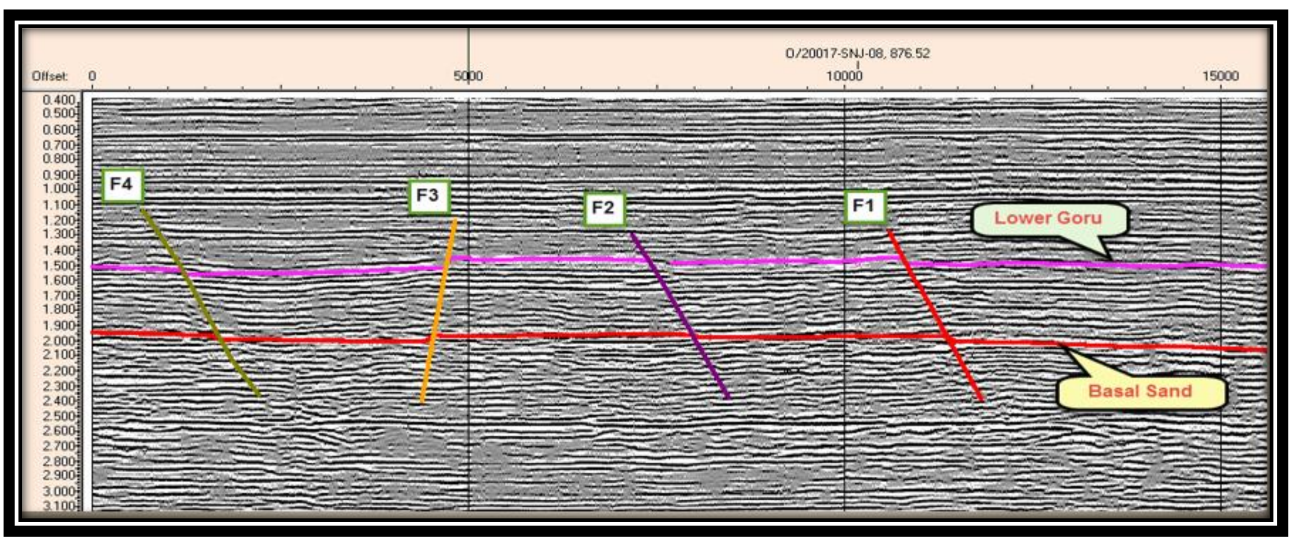

Figure 4.5 Interpretation of Line GO-017-SNJ-04 show normal faults with horst and graban geometry

4.6.4 Line GO-017-SNJ-23

It's a dip line and has 6 extending faults (Figure 3.4b). This line is same as GO-017-SNJ-03. In this section Lower Goru formation is at 1.508 sec, Basal Sand is at 1.861 sec. Its orientation is NW-ES. Interpretation of Line GO-017-SNJ-23 show normal faults with horst and graban geometry is shown in figure 4.6.

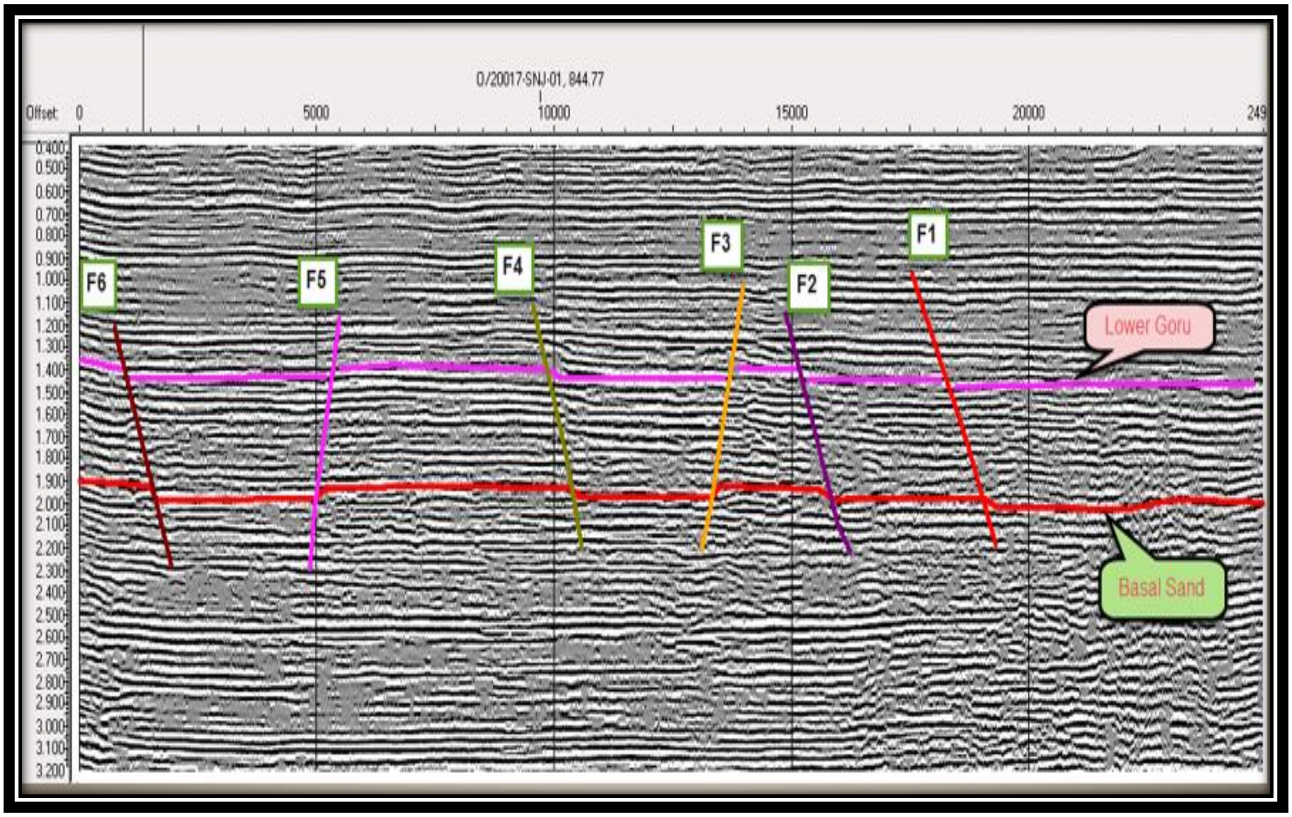

Figure 4.6 Interpretation of Line GO-017-SNJ-23 show normal faults with horst and graban geometry

4.7 Base Map with Fault Polygon

Faults polygons represent the structure geometry of the area. In Study area (Sinjhoro) mostly fault forming structural traps for hydrocarbon accumulation in the form of horst blocks. Six fault polygons are marked in these maps showing faults orientation from NW to SE. Polygon map consist of fault polygon maps, dip direction of faults and selected seismic lines. Base map with polygons is shown below in figure 4.7.

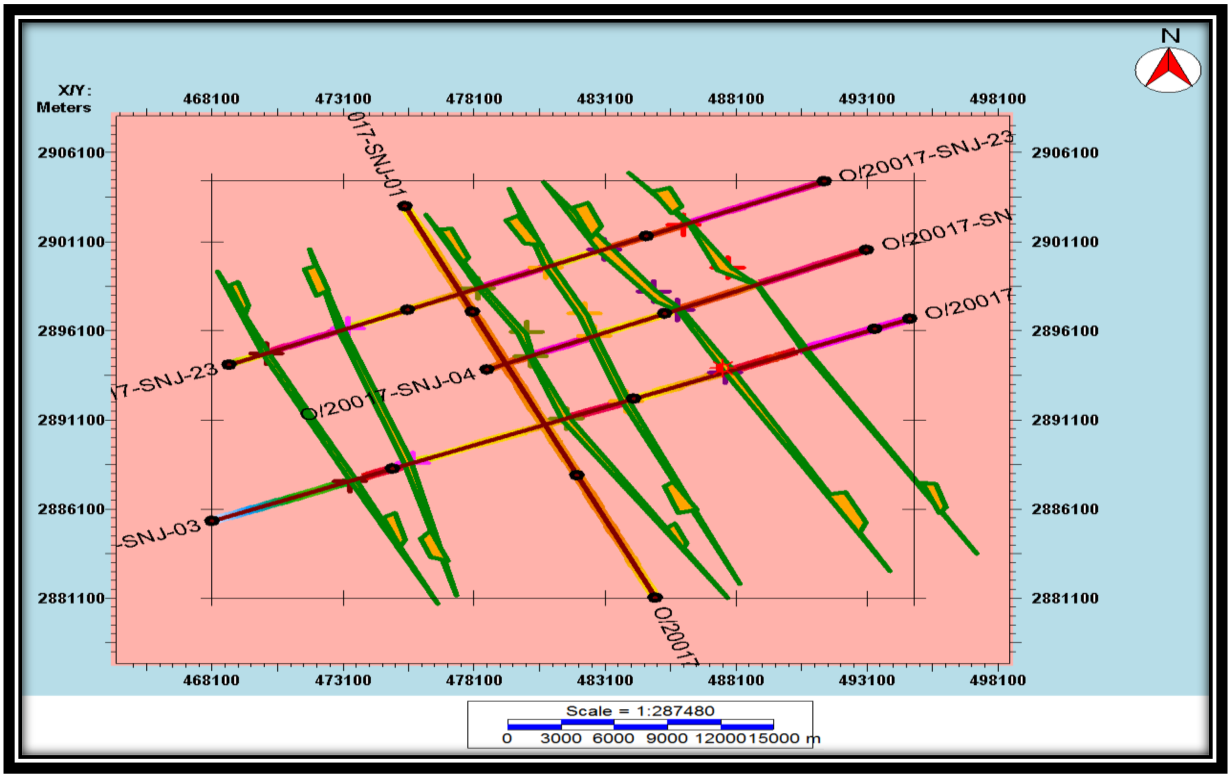

Figure 4.7: Base map with polygons

4.8 Contour Maps

Contouring is the main tool used in the seismic interpretation. After contouring it becomes obvious that what sort of structure is forming a particular horizon. The contour map of reflector is prepared. The main objective of the time contouring is to get information about undulation in the time horizon due to folding and faulting. Contouring represents 3D model on 2D surface. We have generated contour map by using grid.

4.8.1 Time Contour Map

Two way time maps are made at different levels which show the position of that formation in time. In this study, time map is constructed for Basal Sand and Lower Goru. Time contour maps show the different closures on which already wells have drilled and these are gas condensate. Low The contours are the lines of equal elevation (time or depth). Mapping is usually final product of exploration, the one on which whole operations depends for its effectiveness (Coffeen, 1986). Contouring represents 3D model on 2D surface. We have generated contour map by using grid. Time Contour Map For Basal Sand is shown below in figure 4.8.

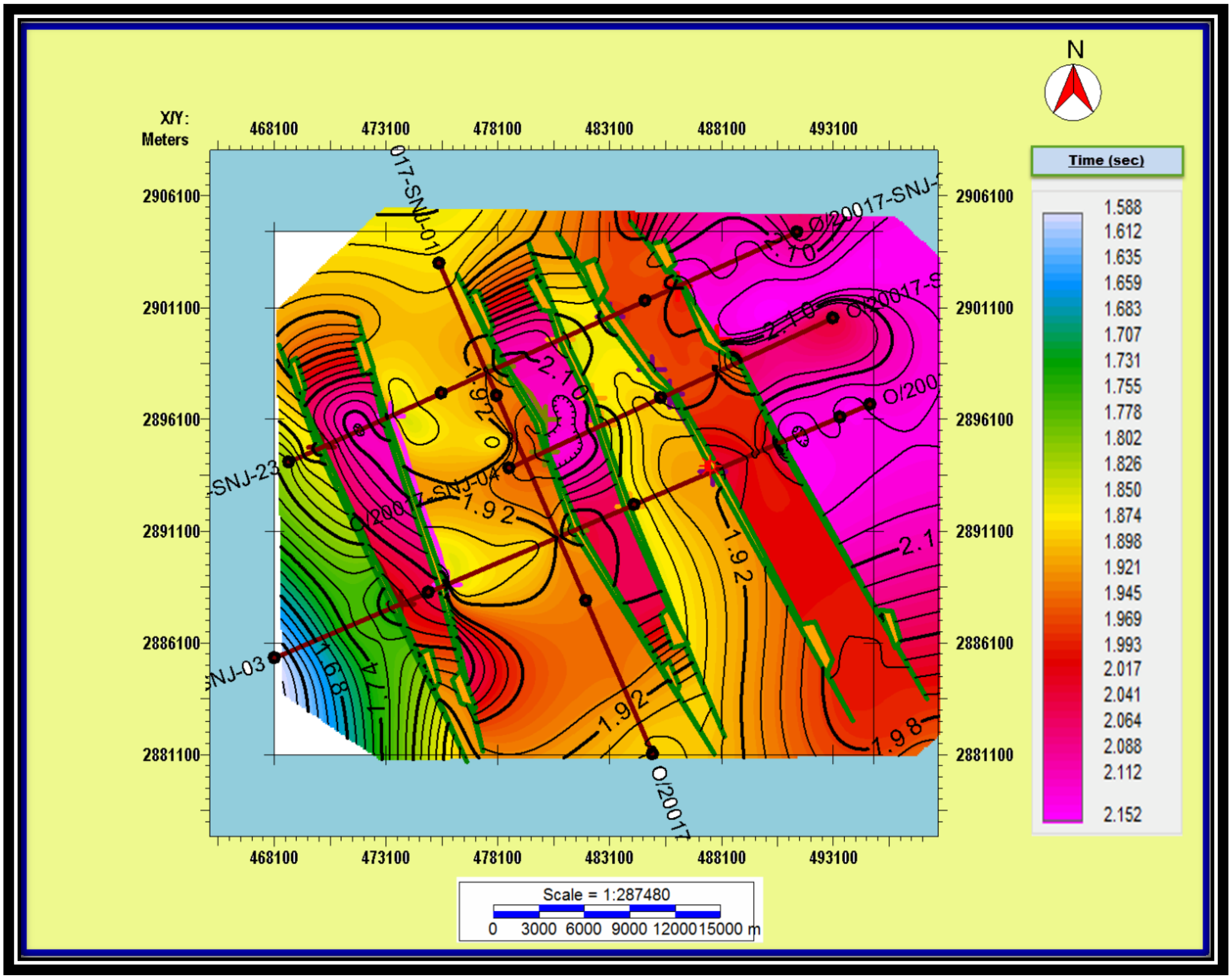

Figure 4.8 Time Contour Map For Basal Sand

4.8.2 Depth Contour Map

Two way time maps are made at different levels which show the position of that formation in time. In this study, depth maps are constructed for Basal sand and Lower Goru. Depth contour maps show the different closures on which already wells have drilled and these are gas condensate. Low values of depth are associated with shallow levels which represent horst blocks. High values of depth are associated with deeper levels which represent graben. Depth Contour Map for Basal Sand is shown below in figure 4.9.

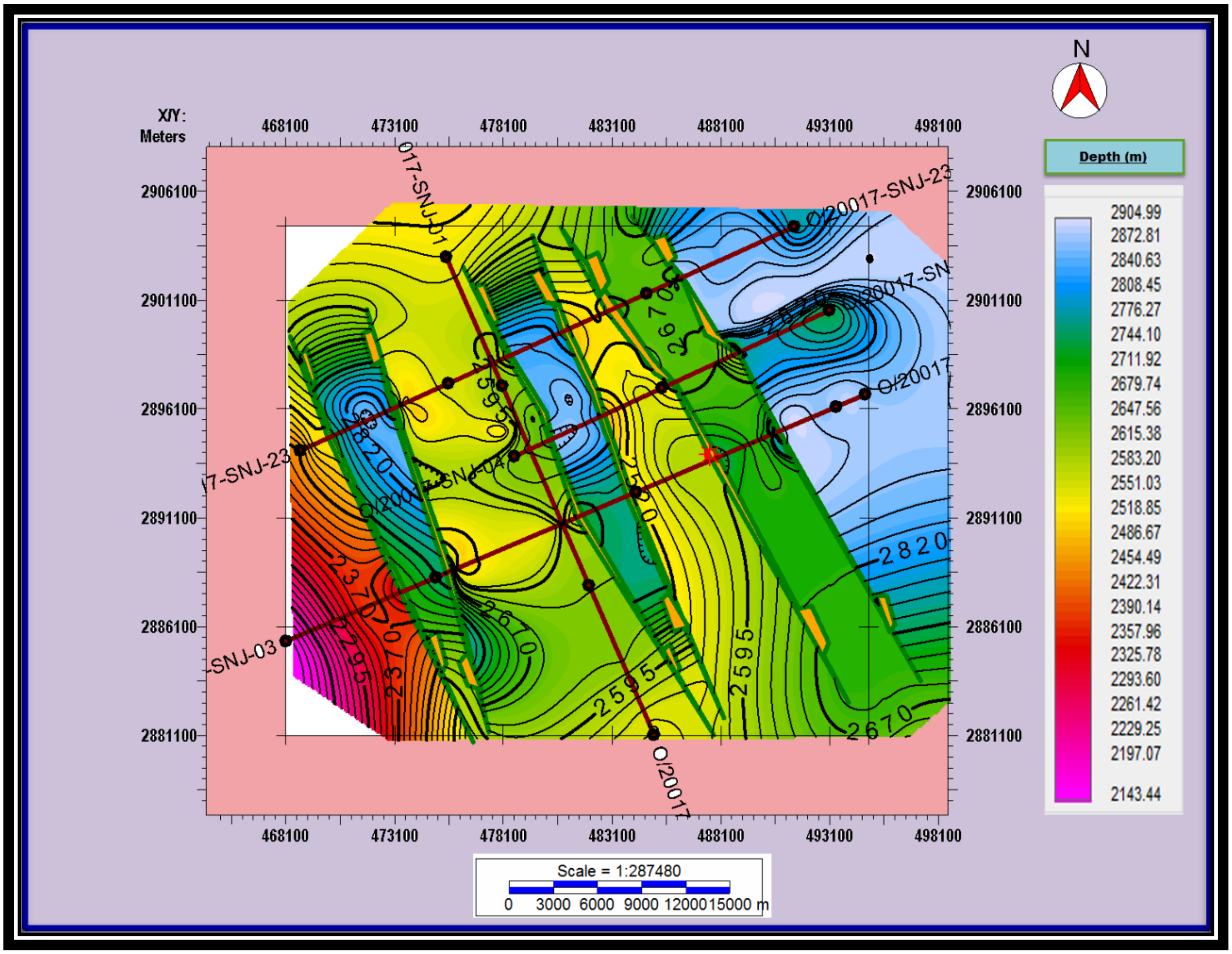

Figure 4.9 Depth Contour Map for Basal Sand

Both time and depth contour maps shows variation on both sides of fault polygons and tells the changes in time and depth across faults. In graben structures value of time and depth is increases but on horst both time and depth decreases relative to the graben structures.

Chapter: 05

WELL LOGGING INTERPRETATION

5.1 Introduction

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 obtain 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. Petophysical interpretation generally has less concern for seismic while more concerned with using well bore measurements to contribute to reservoir description (Asquith et al, 2004).

Propose of well logging is to determine various properties of different lithology and also to determine the actual depth, thickness, two way travel time and interval velocities of these lithology. In well logging the cutting of different lithology which come up with mud filtrate give information about type of material, type of fossil in it and also give us the information about depositional history of that material. In well logging different types of logs recorded in the well with the help of a sond. In early ages different sond are used to do different type of logging in the well but now a day only one sond is used which all type of logging has done both cased and uncased logging. These logs are then interpreted for the petrophysical study.

Petrophysics is the study of the physical and chemical properties that describes the occurrence and behavior of the rocks, soils and fluids. To accurately characterize an oil or gas reservoirs, measurements such as resistivity and density are made, from which effective porosity, saturations and permeability can be quantified.

Work flow of well log interpretation is shown in Fig 5.1.

Figure 5.1: Workflow of Petrophysical Analysis

5.2 Classification of geophysical well logs

Geophysical well logs can be classified into three categories

- Lithology logs
- Resistivity logs
- Porosity logs

5.2.1 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)

5.2.1.1 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 (Croizé et al, 2010).

5.2.1.2 Gamma Ray Log

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

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

Where GR_{min} is minimum value and GR_{max} is the maximum value of the gamma ray, Igr is the gamma ray index and 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).

5.2.2 Resistivity well log

Resistivity well logs give the thickness of the formation, accurate value for the true formation resistivity and information for the correlation purposes. All these logs are plotted on the logarithmic scale due to more variation in resistivity (0.2 to 2000 ohm) with depth.

Resistivity well logs are:

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

5.2.2.1 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 (Asquith et al, 2004).

5.2.2.2 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).

5.2.3 Porosity well logs

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

Porosity well logs are:

- Sonic/Acoustic (DT)
- Neutron Porosity (NPHI)
- Density (RHOB)

5.2.3.1 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 (Asquith et al,2004).

Relation for the calculation of the porosity from the sonic log:

Porosity of the formation can be calculated by using the following formula:

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

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).

5.2.3.2 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.

5.2.3.3 Density (RHOB)

Density log is the porosity log that measure electron density of the formation, (Asquith et al, 2004). Formation electron density is actually related to bulks density of formation. It is actually the sum of fluid density multiplies its relative volume plus matrix density time relative volume.

Density log can be used to find out the correct porosity of the formation, if the matrix densities in the formation or rock type are known (Asquith et al, 2004). The rock type in my research work is sandstone and shale.

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

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
- ρ_b represent bulk density of formation
- ρ_m represent matrix density and for sandstone it is 2.65
- ρ_f represent density of fluid.

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

5.4 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.

$$\emptyset_{avg} = \frac{\Phi n + \emptyset_d + \emptyset_s}{3}$$

Where,

- $\emptyset_{avg}$ is the average porosity calculated from the available porosities
- Φn represents neutron porosity
- $\emptyset_d$ represent the density porosity

- $\emptyset_s$ represent the sonic porosity.

5.5 Effective porosity ($\emptyset_e$)

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).

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

Where,

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

5.6 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 0.62 in case of sand
- Ø represent effective porosity
- m represents the cementation factor and it value is taken 2.15 for the sandstone.

5.7 Mathematical relation for Hydrocarbon Saturation (S_h)

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

$$\mathbf{S_h = 1 - S_w}$$

Where S_w represent Hydrocarbon saturation, S_h represent hydrocarbon saturation.

5.8 Interpretation of well log

IHS Kingdom software is used for the analysis of well Chack66-01; within the depth range 2020 m to 2842 m. Due to collapsing of wellbore Ruguosity effect will be occur. Therefore in the depth ranges, if there is Ruguosity, the value of the other log is not consistent GR log, Caliper log are displayed in **track-1**. LLD while LLS log are displayed in **track 2.** 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 indicate fluid contact. Volume of shale $V(_{sh)}$ is displayed in **track-5**. Shale and sand can be separated by applying **40% cut-off value**. Below this cut-off value, there is sand and above this cut-off, there is shale. Density porosity is displayed in **track-6**, calculated from DT4P.Average porosity (PHIT) is displayed in **track-7** and actually is the sum of NPHI and DT4P divided by 2. Effective porosity is displayed in **track-8** after removal of the shale effect. Water saturation (SW) is displayed in **track-9**. Hydrocarbon saturation (HC) is displayed in **track-10.**

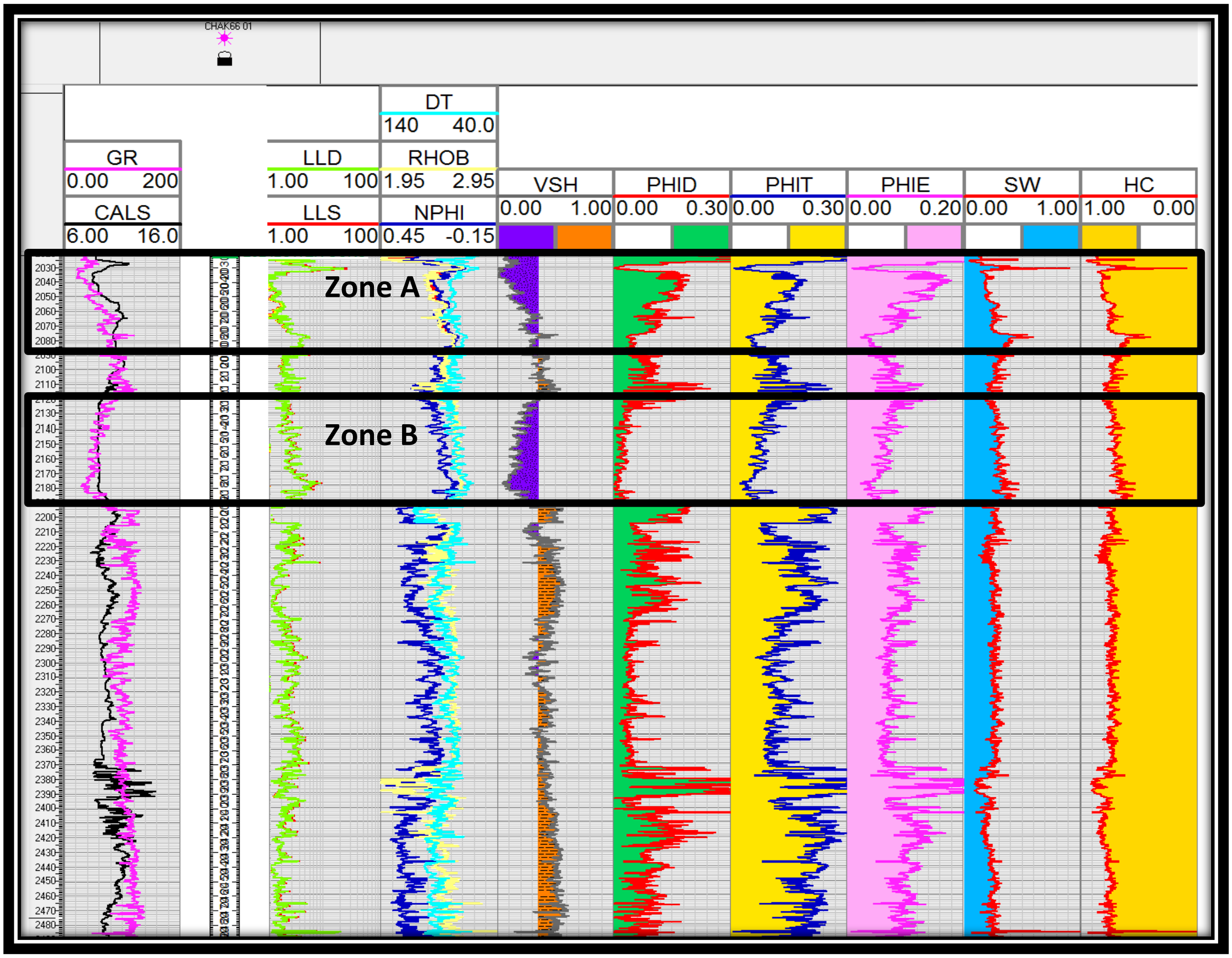

Figure 5.2: Petrophysical Analysis of study Area

Petrophysics is done to depth from 2020 m to 2842 m. The reservoir zone consists of sandstone is marked at depth of 2020m-2095m and 2115m-2190m on the basis of 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 and 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 sand. In next track study Effective porosity, density porosity and total porosity lies between 10-15%.In the last track saturation of water its values lies between 20-30%.The various parameter estimated within reservoir zone is shown in Table:

Serial Number	Calculation Parameter	Percentage
1	Average Volume of Shale=**V(sh)**	13 %
2	Average Porosity Obtained From Density log= $\emptyset_{davg}$	14 %
3	Average Porosity in(PHIT) Percentage=$\emptyset_{avg}$	15 %
4	Average Effective Porosity in Percentage= $\emptyset_{eavg}$	13 %
5	Average water Saturation in Percentage=S_{wavg}	22 %
6	Average Hydrocarbon in Percentage= S_{havg}	78 %

Chapter: 06

SEISMIC ATTRIBUTES

6.1 Introduction

The quantities that are measured computed or implied from the seismic data. From the time of their introduction in early 1970's seismic attributes gone a long way and they became an aid for geoscientists for reservoir characterization and also as a tool for quality control. Development of a wide variety of seismic attributes warrants a systematic classification. Also a systematic approach is needed to understand the use of each of these attributes and also their limitations under different circumstances (Subrahmanyam & Rao, 2008).

6.2 Classification of Seismic Attributes

Attributes can be classified in many different ways. Seismic attributes can be classified on the following basis:

Seismic Data Domain based Classification:

- Pre-Stack Attributes
- Post-Stack Attributes

Computational Characteristics based Classification:

- Instantaneous Phase Attributes
- Average Energy Attribute
- Trace Envelope Attributes

For current work, seismic attributes are formed using seismic data domain based classification.

6.2.1 Pre-Stack Attributes

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

6.2.2 Post-Stack Attributes

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

Seismic data attributes provide the seismic interpreter with new images that enhance the physical and geometric descriptions of the subsurface. Geometric attributes facilitate the definition of both the structural and stratigraphic framework of the seismic interpretation, while physical attributes may be used as direct hydrocarbon or lithology indicators. When the seismic response is more complex, attributes may be used to drive advanced interpretation and analysis processes (Subrahmanyam & Rao, 2008).

6.3 Instantaneous Phase Attribute

Such type of the attribute is measured in degrees known to be the Instantaneous phase attribute. This attribute gives information about the continuity and discontinuity, relates to the phase component of the wave propagation and can be used to compute the phase velocity, (Subrahmanyam and Rao, 2008). The

Instantaneous phase attribute that is applied on GO-SNJ-03 is shown in Figure 6.1.

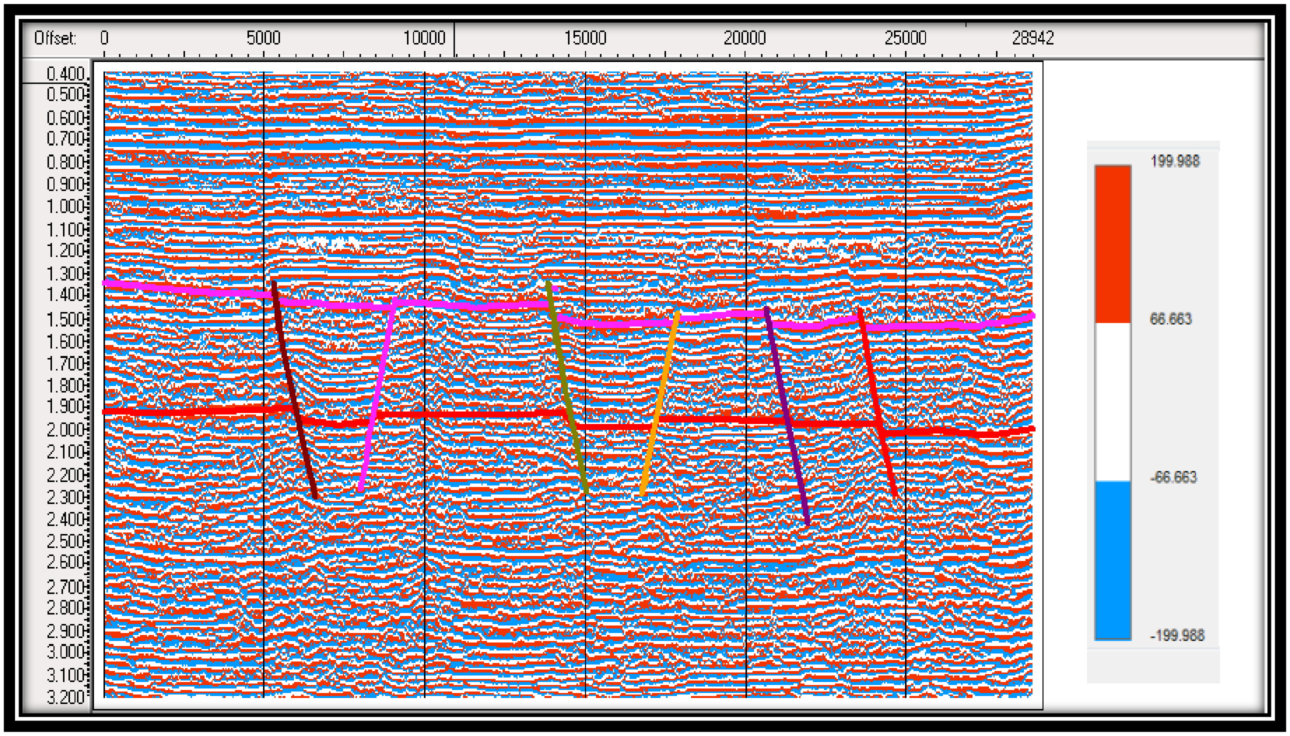

Figure 6.1: Instantaneous Phase Attribute of GO-SNJ-03

6.4 Average Energy Attribute

Energy and the seismic attribute have the direct relation. Average energy attribute show the lateral continuity and the reflection strength. This attribute is applied on the 2D seismic line GO-SNJ-03.Discontinuity represent that there is a fault that is present.

6.5 Amplitude Attributes

Amplitude attributes (e.g., absolute amplitude, average amplitude) are the easiest to understand. They quantify how reflection amplitudes vary within the seismic data volume and intuitively can be related to properties such as porosity, lithology, fluid contact, and bed thickness.

6.6 Trace Envelope Attribute

Trace Envelope can be used as an effectively describe the acoustic impedance contrast, hence reflectivity, Gas accumulation, Bright spots, Major variations in depositional environment, Sequence boundaries, Spatial relationship to porosity and other lithological variations. It is helpful in reflector marking. It justified the major part of interpretation, tops of horizons and the fault surfaces. At some places like edges of the line we are unable to see prominent reflectivity that is due to the limitation of the data. Attribute is applied on seismic line GO-SNJ-03 that clearly shows the reflectivity and also local and the major change in the lithology. Trace Envelop Attribute of GO-SNJ-03 is shown below in figure 6.2.

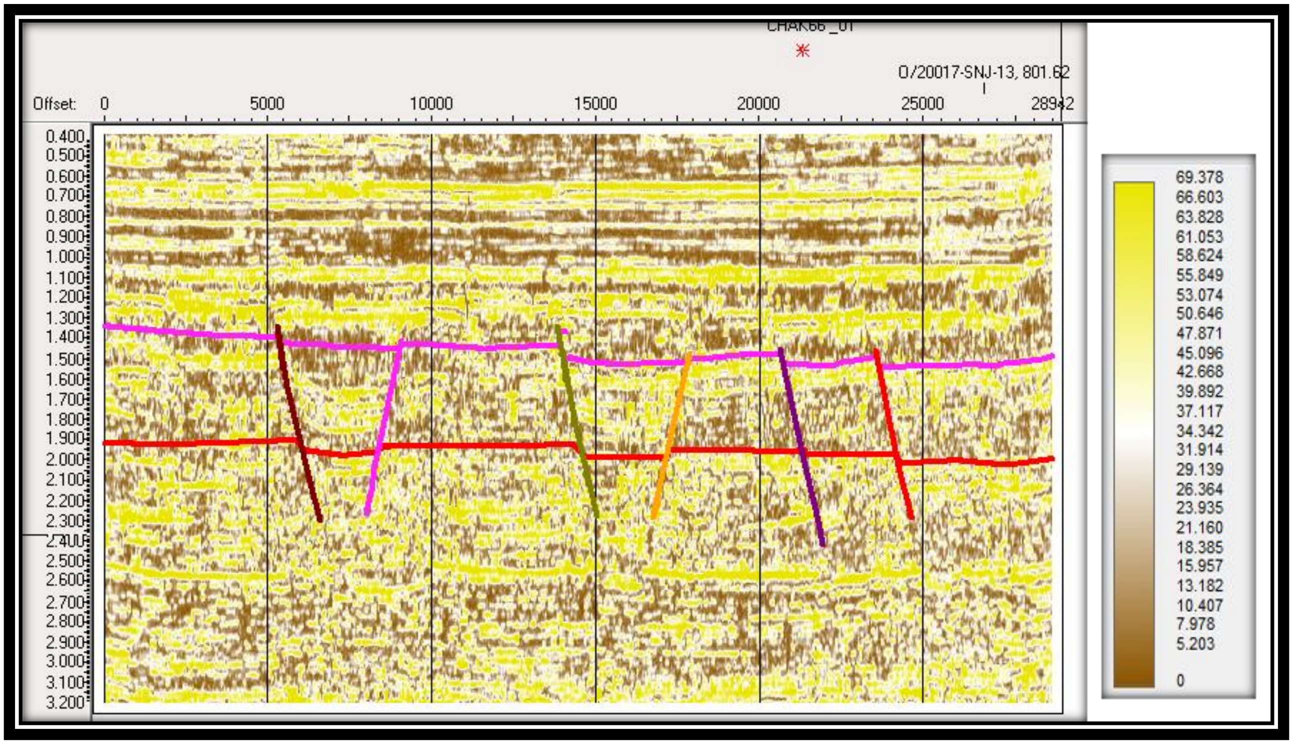

Figure 6.2: Trace Envelop Attribute of GO-SNJ-03

Seismic attribute studies can play an important role in the development of reservoir management strategies.

Chapter: 07

SEISMIC INVERSION

7.1 Introduction

Seismic inversion attempts to extract spatially variable physical parameters from measured seismic data. These physical parameters may be representative of the Earth's subsurface media, and have physical and geological meanings, and thus seismic inversion is a quantitative interpretation of seismic measurement. The inversion procedure is generally nonlinear, as the entire inversion engine to solve the inverse problem, at least partly, depends upon the solution. Seismic inversion uses forward modeling to generate synthetic seismic data that will match the observed seismic data. Data fitting is a principal part of the objective function. The distance can be measured in different ways, such as a weighted quadratic distance, frequently employed in seismic inversion. Regularization considers the properties of the mapping operator G from the mathematical viewpoint: Whether the numerical instability comes from the singularity, and whether the singular operator can be modified to stabilize the computation.

7.2 Purpose of Seismic Inversion

The purpose of seismic inversion is to estimate reservoir properties i.e. porosity by using the inverted impedance. Seismic inversion helps in well planning, characterizing reservoir and to monitor changes in the rock properties resulted from fluid injection or production (Gavotti et al, 2014).

7.3 Categories of Post Stack Inversion

Russell and Hampson (1991) categorized the post stack inversion in to three following methods:

- Classical recursive or Band limited inversion
- Sparse Spike Inversion

- Model Based Inversion

7.4 Model Based Inversion

3D seismic surveys are one of the best tools for identifying potential exploration targets. These seismic data volumes are used to identify the geometry of reflectors and ascertain their depths. This is possible because seismic waves reflect at interface due to contrast in acoustic properties of the material (Barclay et al., 2008).

Seismic reflection data contain more information than reflector position. The amplitude of reflection is controlled by the impedance which is the product of velocity and density.

Seismic amplitude data can be used to invert for the impedance using seismic inversion procedure. Acoustic impedance is a layer property and amplitude of seismic trace is an interface property. By correlating these seismically derived impedances with values measured in borehole (i.e. porosity, water saturation), interpreters may extend well information throughout the reservoir scale. The process is called seismic inversion for reservoir characterization that is used in optimum field development (Barclay et al., 2008). Workflow for post stack inversion is shown below in figure 7.1.

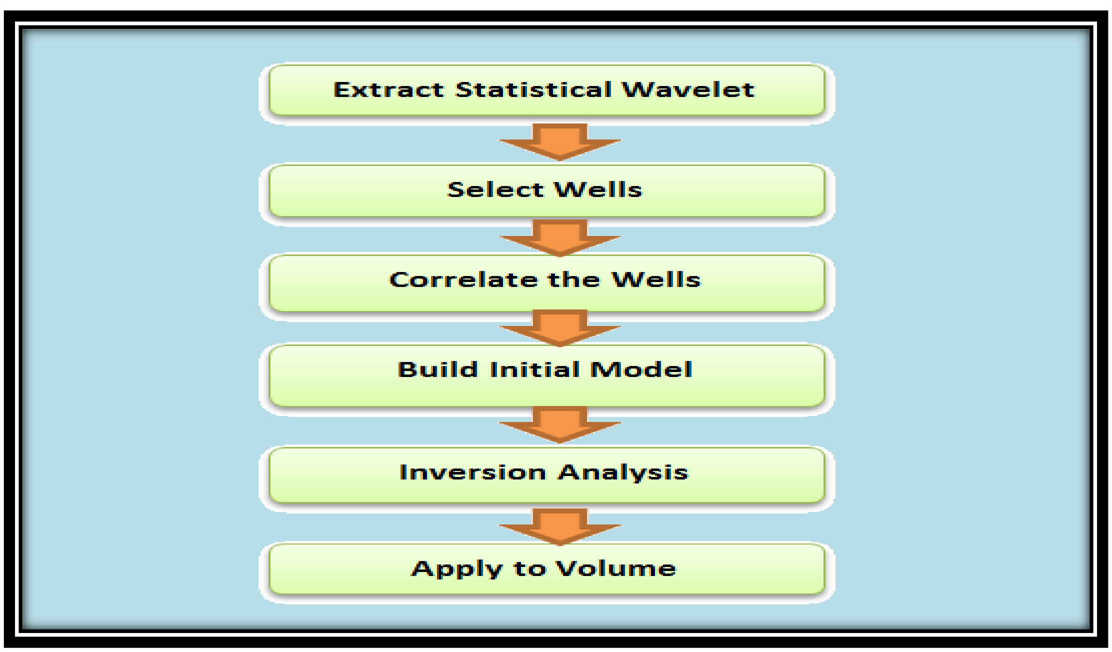

Figure 7.1: Workflow for post stack inversion

7.5 Extraction of wavelet

A constant phase wavelet shown in Figure 7.2 was estimated to perform the correlation of extracted reflectivity and inverted reflectivity from seismic at well location. The correlation found between synthetic and real trace was 0.442451. The window length set for extraction of wavelet was from 1500-2000ms with wavelength of 100ms.

To get desirable results for seismic interpretation and inversion the wavelet should be zero or minimum phase. The amount of phase shift in input wavelet greatly affects the inversion results. The greater the phase shift, the higher will be the error in resultant impedance (Jain, 2013). Extracted Wavelet is shown below in figure 7.2.

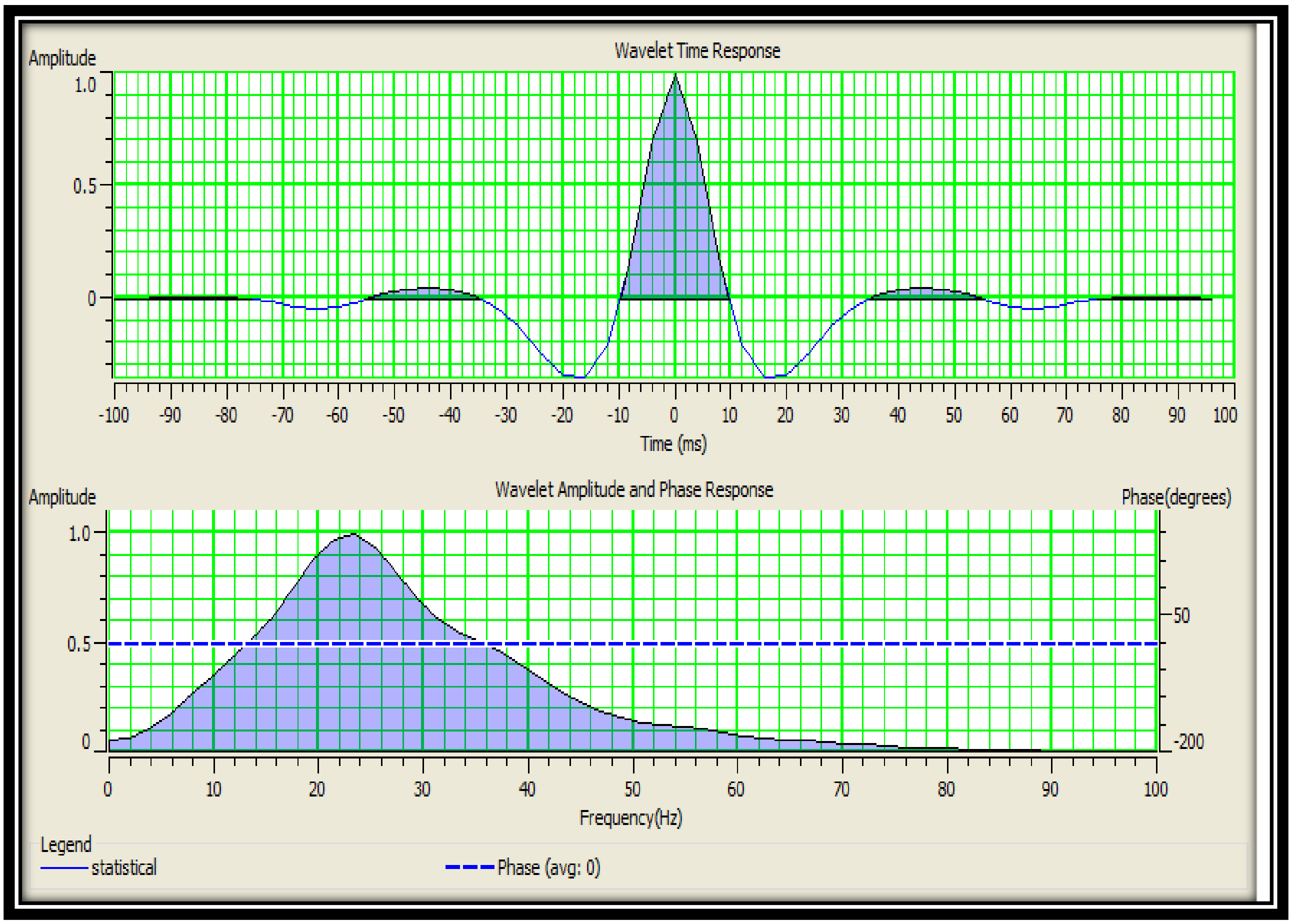

Figure 7.2: (wavelet time, amplitude and phase response).

The dotted line show the average phase of the wavelet. Seismic inversion is based on the convolution model i.e. convolution of reflectivity series with extracted wavelet to get synthetic trace (Cooke and Cant, 2010).

7.6 Initial Model/Low frequency Model

Two terms are used for acoustic impedance that are relative acoustic impedance and absolute acoustic impedance. Relative acoustic impedance does not involve the generation of low frequency model for its calculation. It is the relative layer property and is used for qualitative interpretation. The absolute acoustic impedance is obtained when a proper low frequency component (approximately 0-15 Hz) is given to inversion algorithm to invert the given amplitude data (Cooke and Cant, 2010). In Model Based inversion low frequencies are added as a part of inversion algorithm rather than generating a separate low frequency model while in Sparse Spike inversion low frequency model is added separately (Cooke and Schneider, 1983). Absolute acoustic impedance is an absolute layer property and is used for both qualitative and quantitative interpretation (Cooke and Cant, 2010).

To get absolute acoustic impedance from inversion results a low frequency model must be added from hard constraints such as sonic and density logs. Adding a low frequency model assure more realistic results (Lindsith, 1979). Several authors suggested the solutions for building an accurate low frequency model such as Linear Programming algorithm and autoregressive process (Oldenburg et.al., 1983) and Generalized Linear inversion (Cooke and Schneider, 1983). All these approaches face the issue of non-uniqueness because there is more than one model compatible to seismic response (Gavoti, 2013). A low impedance model by applying a lower and upper impedance limit is shown below in figure 7.3.

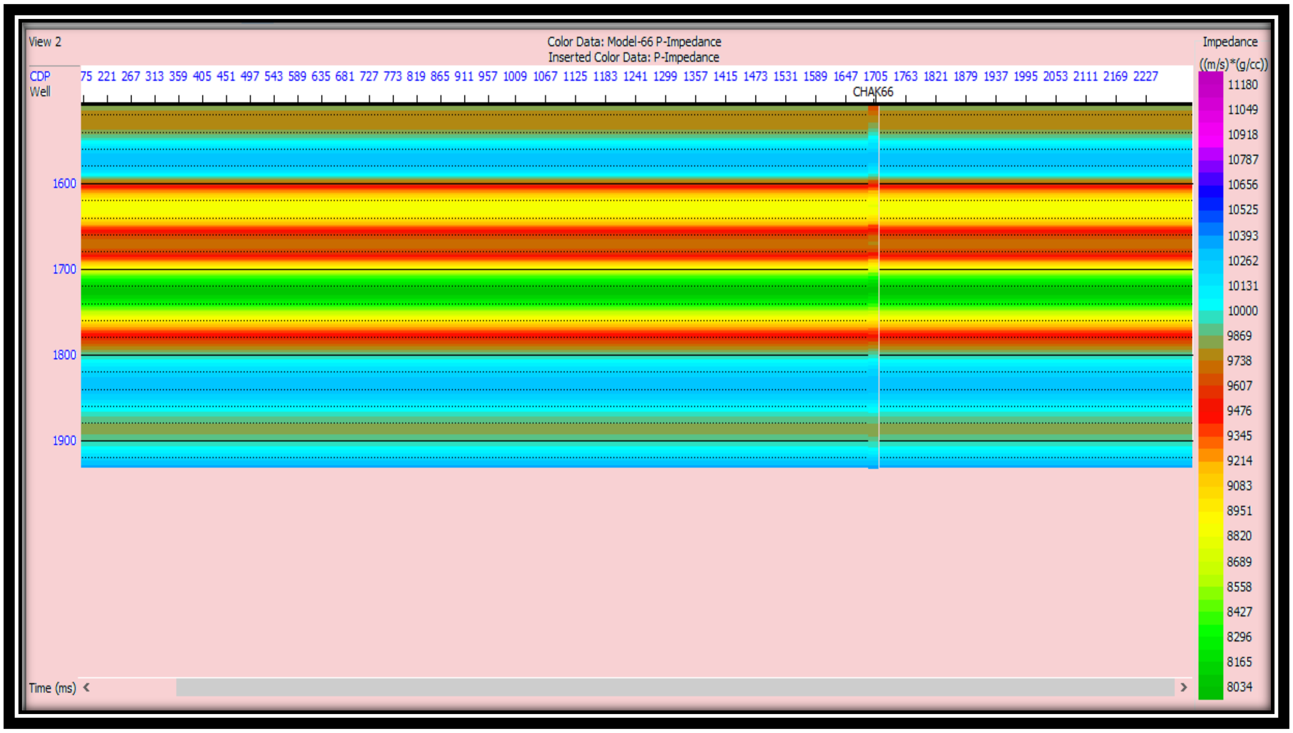

Figure 7.3: A low impedance model by applying a lower and upper impedance limit.

7.7 Inversion Analysis

Following the analysis at the well location the model based inversion was performed on the given 3D seismic cube. A statistical wavelet was extracted in time window from 1500-2000 ms. Frequency range of extracted wavelet was adjusted by comparing inverted trace at well location and the synthetic trace.

Here, **original Log curve is blue curve; initial model is black curve, inverted in red curve**. The estimated RMS error between the synthetic and seismic trace is 0.09. The estimated RMS error between the inverted trace and the impedance log was 7129.69 (m/s)*(g/cc). Analysis of the post stack inversion at well CHAK 66-01 is shown below in figure 7.4.

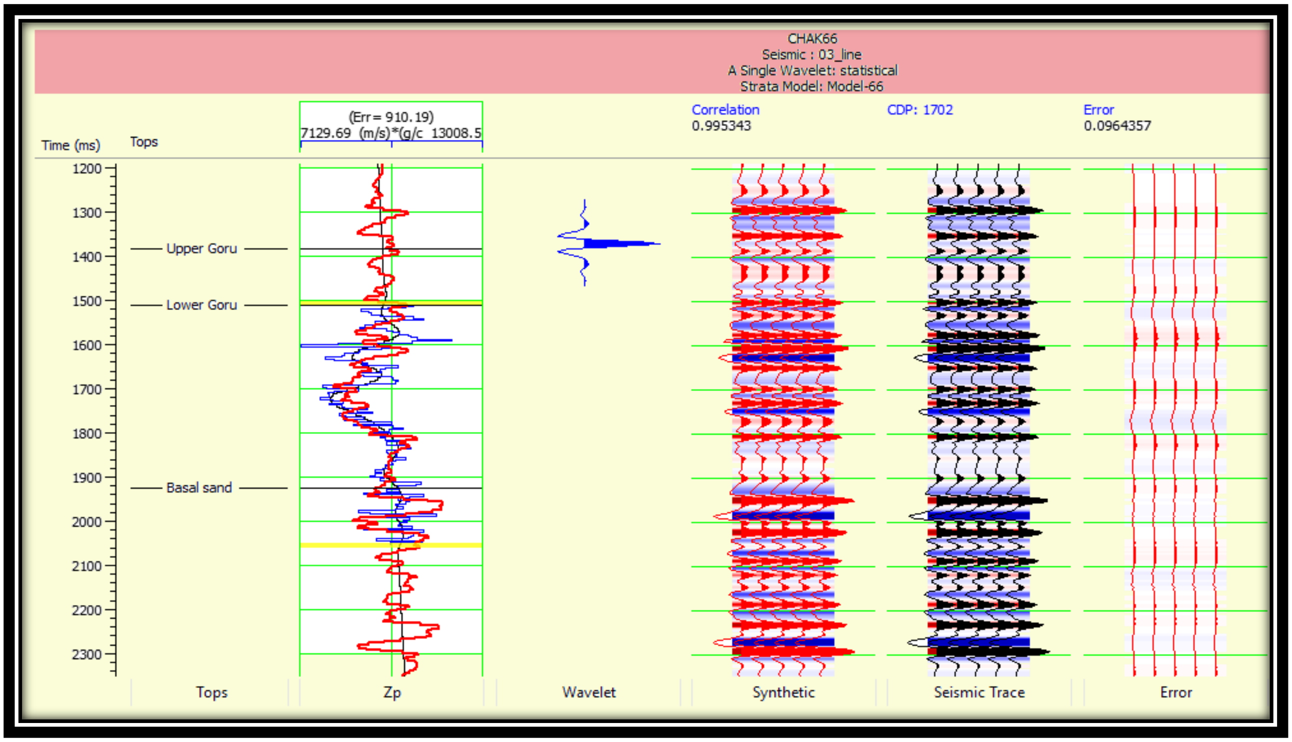

Figure 7.4: Analysis of the post stack inversion at well CHAK 66-01

The inversion was performed only on the selected time window 1500-2000ms in which the horizons of interest lie. The inversion results show colored layers displaying different values of acoustic impedance for each layer. Our zone of interest which is B-sand member of Lower Goru lies at 2020 m depth known from check shot data. Petrophysics results discussed in previous chapter also highlight a favorable zone at the same depth. The purple color layer above the low impedance layer show higher impedance value. The model based inversion results show a good lateral variations in acoustic impedance which can be used for depicting shelling out sequence while in sparse spike inversion. Cross section of line estimated from model based inversion is shown below in figure 7.5.

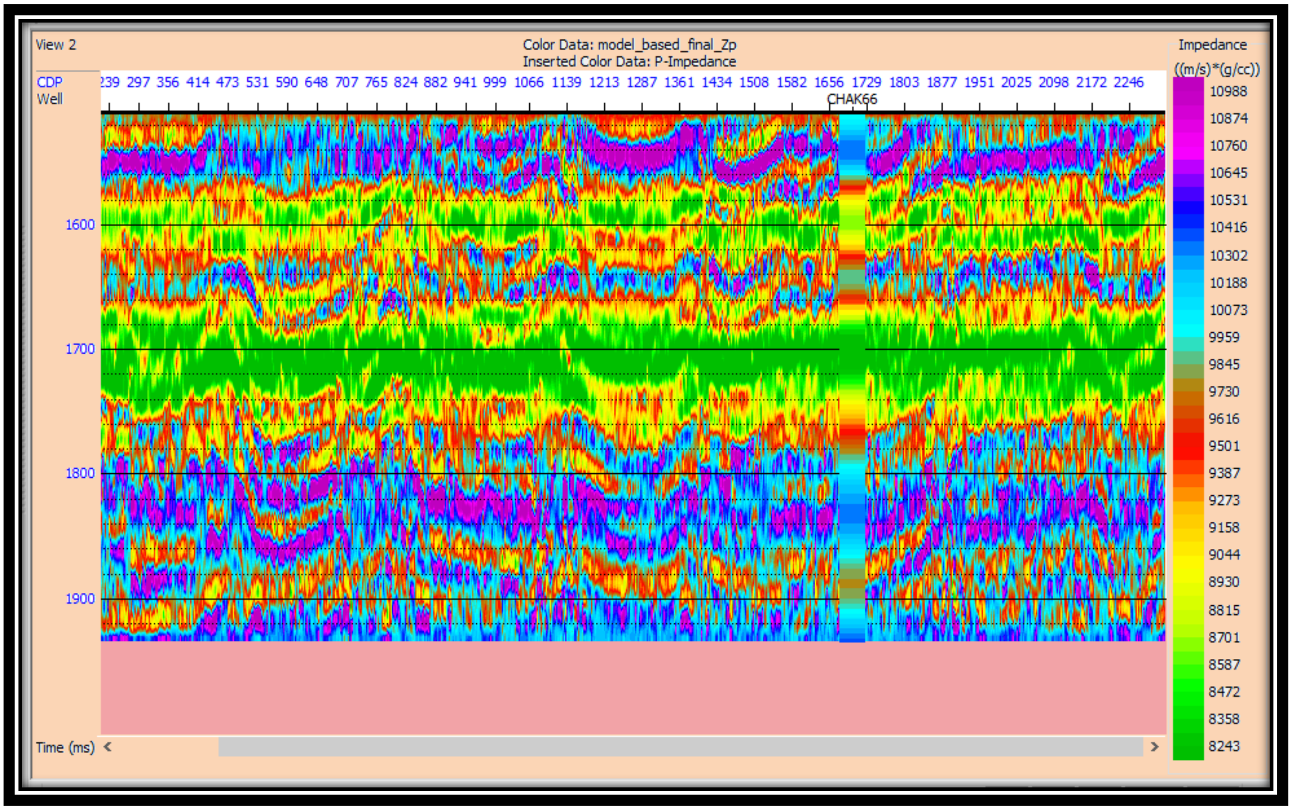

Figure 7.5: Cross section of line estimated from model based inversion.

7.8 Results

From the above cross section, it is clear that low acoustic impedence is in green color which is surrounded by high acoustic impedence value. Low acoustic impedence value is the indication of hydrocarbons. So in this section, a thin and thick bed of hydrocarbons are shown. Basic section is in time range of 1.67-1.74 sec. Sand of Lower Goru is our hydrocarbon potential formation in Sinjhoro.

CONCLUSIONS

This dissertation contains the study and interpretation of 2D seismic reflection data of four selected seismic lines of Sinjhoro area, Lower Indus Basin, Pakistan. It is not sufficient data to accurately approve a zone as potential zone for hydrocarbon. The main purpose of this research was to find the structural trap and zones of the reservoir of Sinjhoro field i.e. Lower Goru by using seismic and well log data and to propose a new well location on the basis of seismic data interpretation. The Sinjhoro concession is prolific **gas-producing block** situated on the eastern limb of the Lower Indus Basin in Pakistan. It contains several developments and production (D & P) leases, which are producing gas from Cretaceous rocks.

After applying seismic and well data on the study area and using different software tools, following conclusions have been deduced:

- On the basis of seismic as well as well data, six faults were marked and also two prominent reflectors were marked on the basis of the synthetic seismogram.
- Seismic interpretation results have identified favorable structures for the accumulation of hydrocarbons that are horst and graben structures.
- Synthetic seismogram was matched with the marked horizons and it has confirmed the structural interpretation.
- Time and depth contour maps were prepared to analyze the overall behavior of the structure. There are small anticlinal structures bounded by normal faults, which is clue towards either horst and graben structures to some extent. These structures are extended from NW to SE and are favorable for accumulation of hydrocarbons in the study area.
- Zone of interest is marked with the help of petrophysics which indicates hydrocarbon potential zone where hydrocarbon saturation is 78 % and water saturation is 22%.
- Seismic attribute analysis confirmed about all the interpreted horizons and faults on different seismic sections.
- Model Based Inversion also supports the results of Petrophysical analysis by showing low impedance value in Basal Sand which is the character of reservoir potential.

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