2D SEISMIC REFLECTION DATA INTERPRETATION INTEGRETED WITH PETROPHYSICAL AND FACIES ANALYSIS OF KHIPRO AREA, LOWER INDUS BASIN, PAKISTAN

BY

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بسم الله الرحمن الرحيم

CERTIFICATE OF APPROVAL

This dissertation submitted by **Sardar Muhammad Muzammil Khan** S/O **Sardar Muhammad Khalique Khan** accepted in its present form by the Department of Earth Sciences, Quaid-I-Azam University Islamabad as satisfying the requirement for the award of degree of **BS Geophysics.**

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ABSTRACT

The present study pertains to the structural and Stratigraphy interpretation, facies analysis, petrophysical analysis and estimation of rock physics of Khipro area.. Khipro area is prominent in the Lower Indus Basin for its hydrocarbon (oil and gas) structural traps.

For interpretation of these seismic lines two reflectors and normal faults were marked.The marked horizons were identified using formation tops from wells and their depths were confirmed through correlation with synthetic seismogram. From time and depth grids time and depth contour maps of the horizons that were generated to understand the spatial geometry of the structures and the nature of geological structures as identified by the seismic section of the area.

Normal faulting as identified on seismic sections confirmed that study area lies in extensional tectonic regime. The resulted seismic interpretation of these lines confirmed Horst and Graben structures by normal faulting. A detailed petrophysical analysis was conducted in order to mark the probable zone of interest in the Basal Sand reservoir in the area.

Chapter # 1

Introduction to the Study Area

1.1 Introduction

Seismic methods are the most important and commonly conducted geophysical survey technique used in the oil and gas exploration industry. Seismic measurements can be used to gain knowledge about geological structures in the ground. The oil industry uses seismic measurements to locate oil-and gas reservoirs. Identification of subsurface structure, petro physical analysis and estimation of rock properties are the most important tools to identify hydrocarbons.

The purpose of this dissertation is to interpret the subsurface structures on the basis of seismic reflection data. We try to transform the whole seismic information into structural or stratigraphical model of the earth through the seismic interpretation. As seismic section represents the geological model of earth, we try to find out the final zone of anomaly by interpretation. According to Sheriff (1999) it is very rare that we can make sharp boundary of correct or incorrect interpretation because actual geology is rarely well known. The test of good interpretation is consistency rather than correctness. Good interpretation be consistent with all the seismic data, but it is also important to know all about the area, including gravity and magnetic data, well information, surface geology as well as geologic and physical concept .

The conditioning and analysis of log data for quantitative seismic interpretation is often simply categorized as rock physics. Rock physics represents the link between qualitative geologic parameters and quantitative geophysical measurements. Increasingly over the last decade, rock physics stands out as a key technology in petroleum geophysics, as it has become an integral part of quantitative seismic interpretation. Ultimately, the application of rock physics tools can reduce exploration risk and improve reservoir forecasting in the petroleum industry (Avseth 2005).

Investigation of the earth's interior using geophysical methods, involves taking measurement at or near the surface of the earth for analysis that can expose both vertical and lateral variations of the physical properties of the earth's subsurface, Logs ranging from electrical, nuclear and acoustic have been in use for deriving these parameters (Richardson, 2013).

In order to know the quantity of hydrocarbon accumulation in reservoir rocks (sandstone, limestone or dolomite), some basic petrophysical parameters must be evaluated. These include storage and flow properties (porosity, permeability, fractional flow), fluid identification, fluid phase distribution within gross void space (saturation), interaction of surface forces existing between the rock and contained fluids (capillary pressure), measurements of pressure, stress conditions, electric conductivity of fluid-statured rocks etc. these properties and their relationship are used to recognize and assess hydrocarbon reservoirs, source rock, cap rock, and aquifers.

1.2 Objectives

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

- Structural and stratigraphic interpretation to find out the structural traps and horizons of the formation
- Petrophysical analysis for the identification of fluid in a reservoir.
- Facies analysis to investigate the depositional environment.

1.3 Introduction to study area

The study area is Khipro block which is situated in district sanghar Lower Indus basin (southern part of Indus basin) between latitude 25˚ 20´N to 26˚ 30´N and longitude 68˚ 20´E to 69˚ 14´E. Covering an area of 2376 km, Figure 1.1 shows the location of Khipro block. Khipro block is very important for hydrocarbon exploration because it is the main producing oil and gas area.

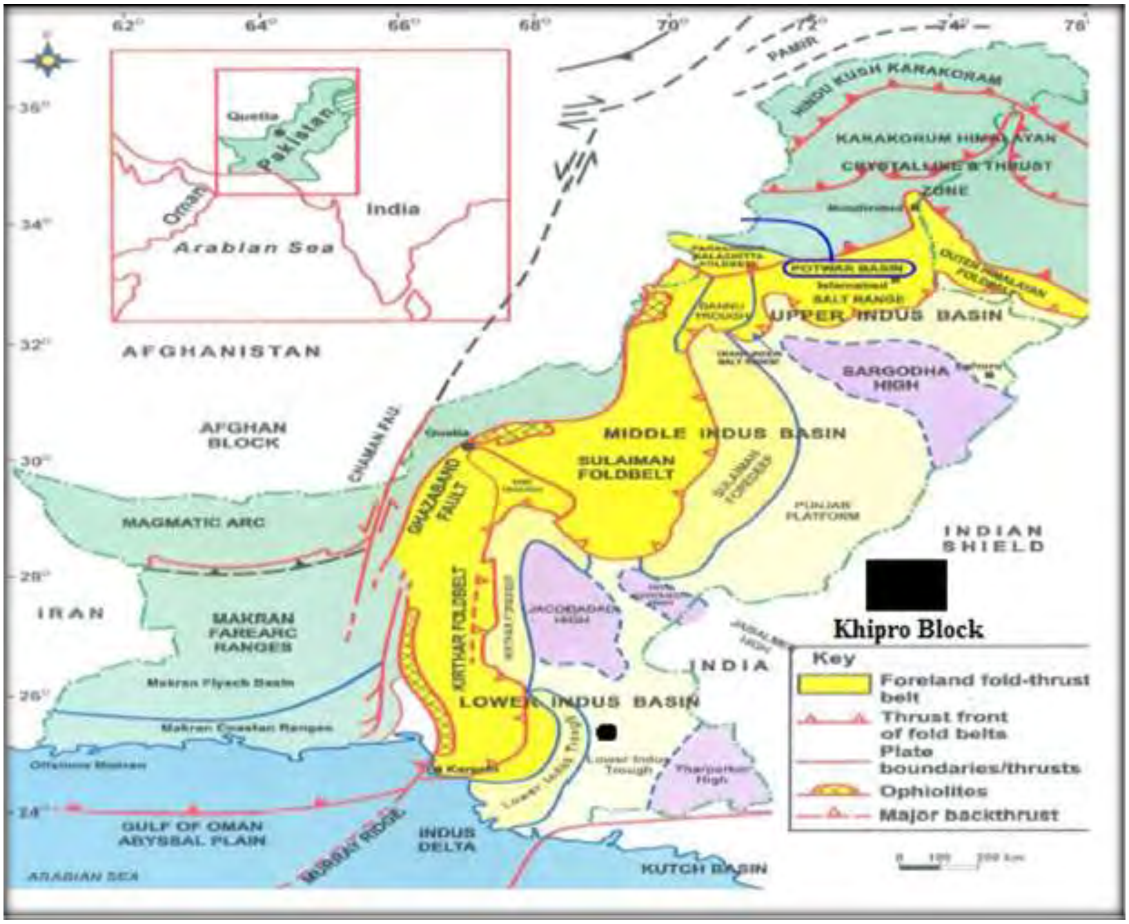

Figure1.1; shows Geographic location of study area (Banks and Warburton, 1986).

1.4 Data used

Seismic reflection, well and navigation data which consist of following formats respectively;

- Seismic data in SEG-Y format
- LAS file (well log data)
- Navigation

1.4.1 Seismic Data

The data used for current research includes 6 seismic lines and one well. The orientation of seismic lines with the location of wells is located on the base map. Bold lines are assigned to me for the completion of this research work.

1.4.2 Base Map

For a geophysicist a base map is that which shows the orientations of seismic lines and specify points at which seismic data were carried out. It is a map on which primary data and interpretation can be plotted. A base map typically includes location of concession boundaries, wells, seismic survey points and length of seismic spread, longitude and latitude of the study area. Following 2-D reflection seismic lines are used to construct the Base map of 2-D seismic survey for given study area..

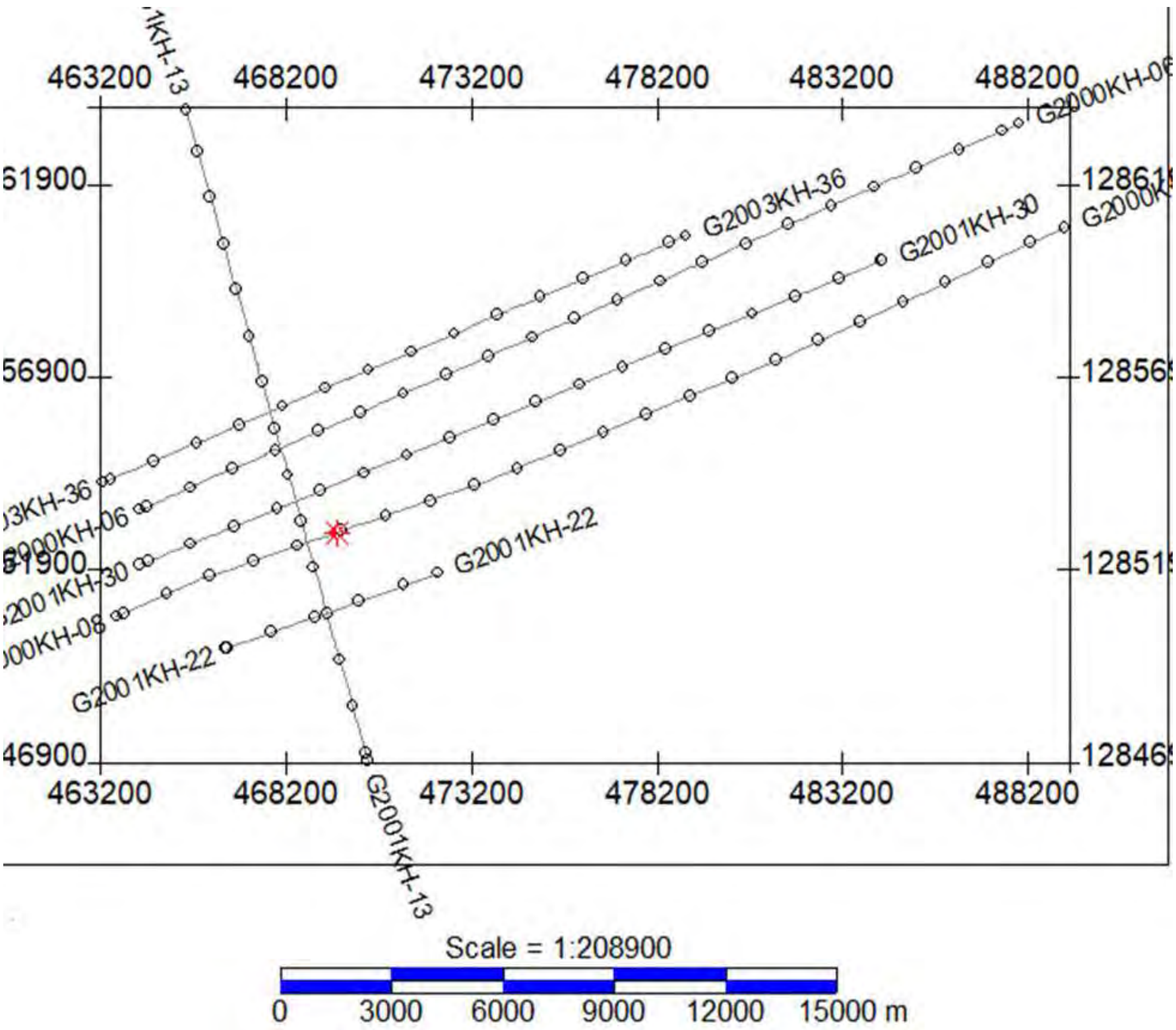

Figure 1.2 Base map of the study area.

1.4.3 Well Data

Information of well data, used in this research, is given in Table 1.2.

Technical Well Data			
Operator	**OPI**	**Province**	**Sindh**
Type	**Exploratory**	**Status**	**Gas/Cond**
Well Bore Name	**Naimat Basal-01**	**Source**	**Vibrosis**
Longitude	**068.696482**	**Latitude**	**025.793802**
Depth Reference Elevation(ft.):	**110**	**Total Depth(m)**	**3621.6300 m**
Depth Reference	**KB**		
List of Well Tops			
Formations	**Formation Age**	**Top(m)**	**Thickness(m)**
ALLUVIUM	**LATE HOLOCENE**	**0**	**524.8**
KIRTHAR-LAKI	**HOLOCENE**	**524.8**	**485.9**
RANIKOT	**LATE PALEOCENE**	**1010.7**	**363.9**
KHADRO	**PALEOCENE**	**1374.6**	**323.1**
UPPER GORU	**LATE CRETACEOUS**	**1697.7**	**1162.7**
UPPER SHALE	**CRETACEOUS**	**2860.4**	**138.7**
MIDDLE SAND	**CRETACEOUS**	**2999.1**	**144.8**
LOWER SHALE	**CRETACEOUS**	**3143.9**	**245.3**
SAND ABOVE TALHAR SHALE	**CRETACEOUS**	**3389.2**	**18.3**
TALHAR SHALE	**CRETACEOUS**	**3407.5**	**71.6**
BASAL SAND	**CRETACEOUS**	**3479.1**	**73.4**

Table 1.2 Shows well data of Naimat Basal well

1.5 Software Tools and Applications

SMT Kingdom 8.8

- Structural Interpretation
- Stratigraphic Interpretation
- Petrophysical Analysis
- Synthetic Seismogram

1.6 Workflow of Dissertation

Base map is prepared by loading seismic data in SEG-Y format and navigation data in (X,Y) horizons and faults identify in seismic section to generate fault polygon and grid of marked horizons then two way time contour map and depth contour map are generated, Petrophysical analysis, Estimation of rock properties of reservoir and facies analysis are performed by using well log data as shown in figure 1.3.

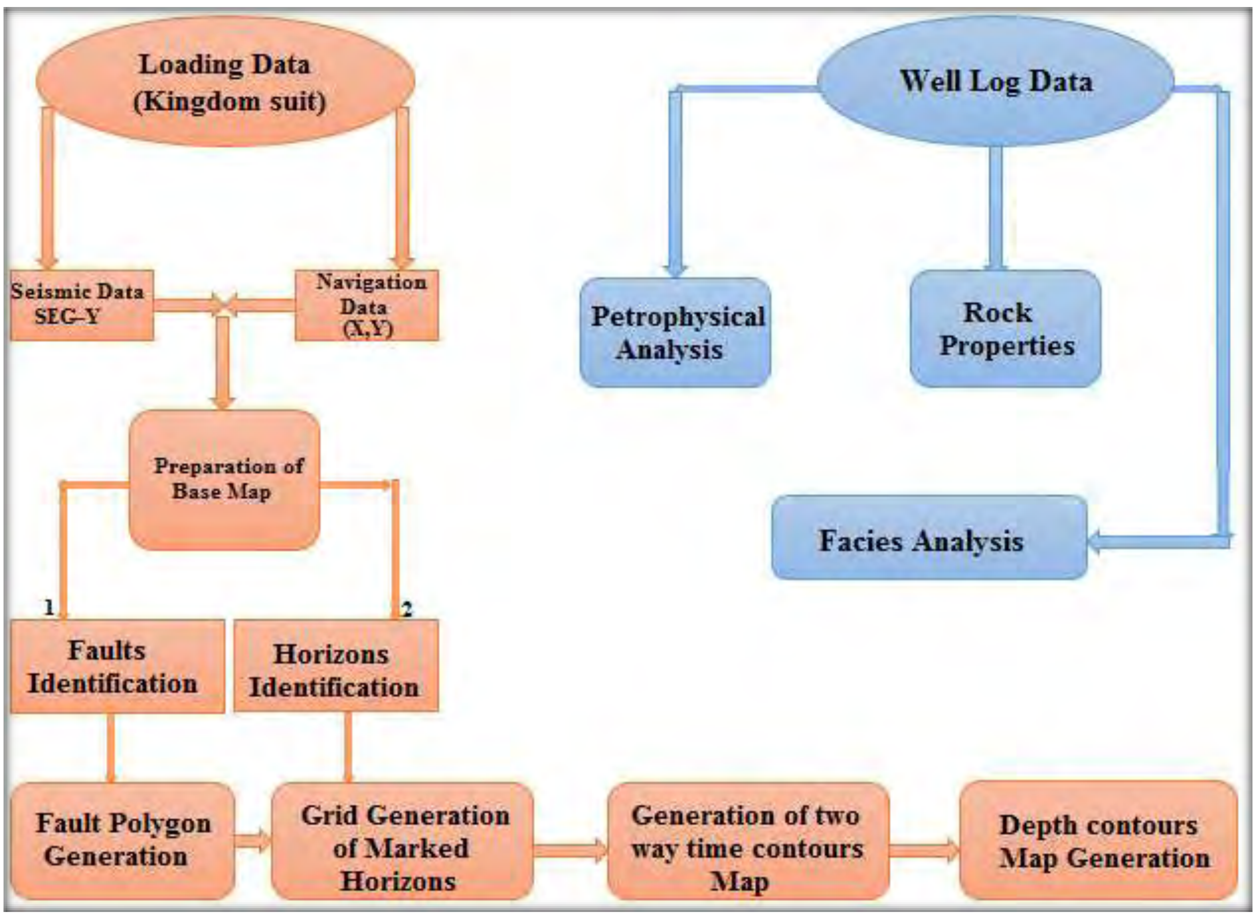

Figure 1.3 Workflow of dissertation

Chapter # 2

Geology and Tectonic of the Area

2.1 Introduction to geology

General geology and geological history of an area is very important for exploration of hydrocarbons. A geological history of basin can be compiled by considering basin forming tectonics and depositional sequence (Kazmi and Jan, 1997). Geology of the area is quite important for the interpretation of the seismic data, without having precise information about the geology of the area we are unable to pick the different horizons in the seismic data. For structural analysis (faulting and folding) in the area is determined by the tectonic history of the area.

The area of study is in lower Indus basin extended approximately between latitude **24° to 28°N** and **66° to 68°E** (eastern boundary of Pakistan).After Paleocene there were continuous oblique convergence of Asian plate and Indian plate throughout Tertiary time and the collision results in tilting of the entire region. Deposition during the rifting shown by the presence of Jurassic rocks in the area. Due to rifting normal faulting and horst and graben structures are formed. The famous among these structures include ―Sukkur Rift". However, this localized rifting phase was unable to continue after the Paleocene-Eocene time. Breaks up Gondwana land in Jurassic period is responsible for the formation of Khipro block basin. East Gondwana plate (India, Antarctica and Australia) separated from the west Gondwana plate (Africa and South America) in the Cretaceous period. In Aptian time (120 Ma), the Indian plate separated from east Gondwana in the cretaceous period.

2.2 Geological boundaries of lower Indus basin

The study area is situated in southern Indus basin and have following geological boundaries as shown in Figure 2.1

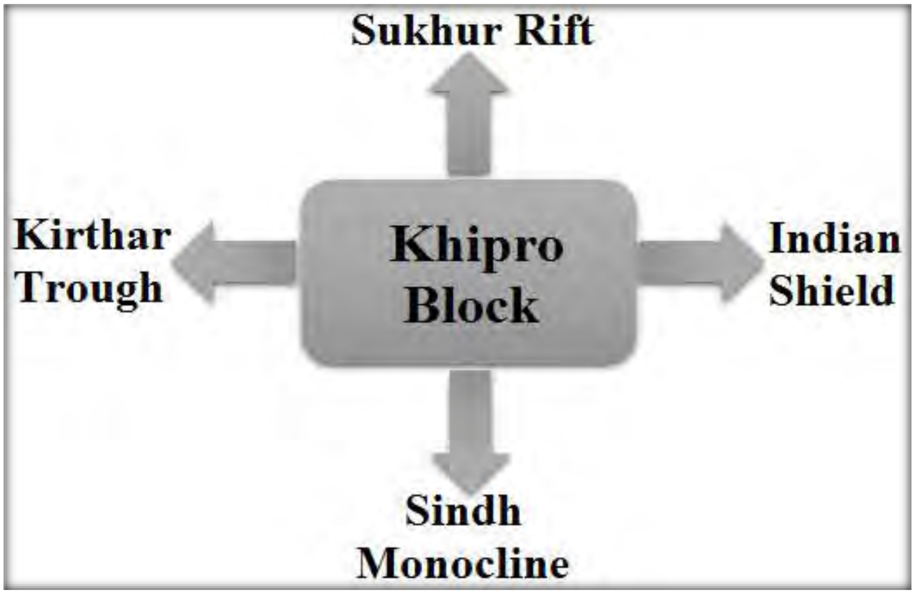

Figure 2.1 Geological boundaries of Khipro block

2.3 Structural Setting of Lower Indus basin

The geological history of Indus basin goes back to the Precambrian age. The Indus basin is mainly classified as upper Indus basin and lower Indus basin (central Indus basin and southern Indus basin). The central and southern Indus basin are separated by Jacobabad and Mari kandkot highs together termed as Sukhur rift (Raza et al., 1990).

The study area is situated in southern Indus basin which is located just south of the Sukhur rift. It comprises the following four main units.

- Thar Platform
- Karachi Trough
- Kirthar Foredeep
- Kirthar Fold Belt

The platform and trough extended into offshore Indus. The southern basin is bounded by Indian shield to the east and the marginal zone of Indian plate to the west, its southward extension is confined by offshore Murray ridge-oven fracture plate boundary (Kadri, 1995).

The oldest rocks encountered in the area are of Triassic age, central and southern Indus basin were undivided until lower/middle cretaceous when Khairpur Jacobabad high became a prominent positive feature. This is indicated by homogeneous lithologies of Chiltan limestone of Jurassic age and Sembar formation of lower Cretaceous age across the high. Sand facies of Goru formation of Lower/Middle Cretaceous are also extended up to Kandhkot and Giandari area (Kadri, 1995).

Normal faults are generated as a result extensional tectonics, forming horst and graben structures with former being of great exploratory importance. The extensional tectonics during the Cretaceous time created tilted fault blocks over a wide area of the Eastern lower Indus basin. Lower Indus basin is characterized by passive roof complex type structure and a passive back thrust along Kirthar fold belt. Passive roof thrust forming a frontal culmination wall along the margin of the fold belt and the Kirthar depression and out of syncline intra-molasses detachment in the Kirthar depression sequence.

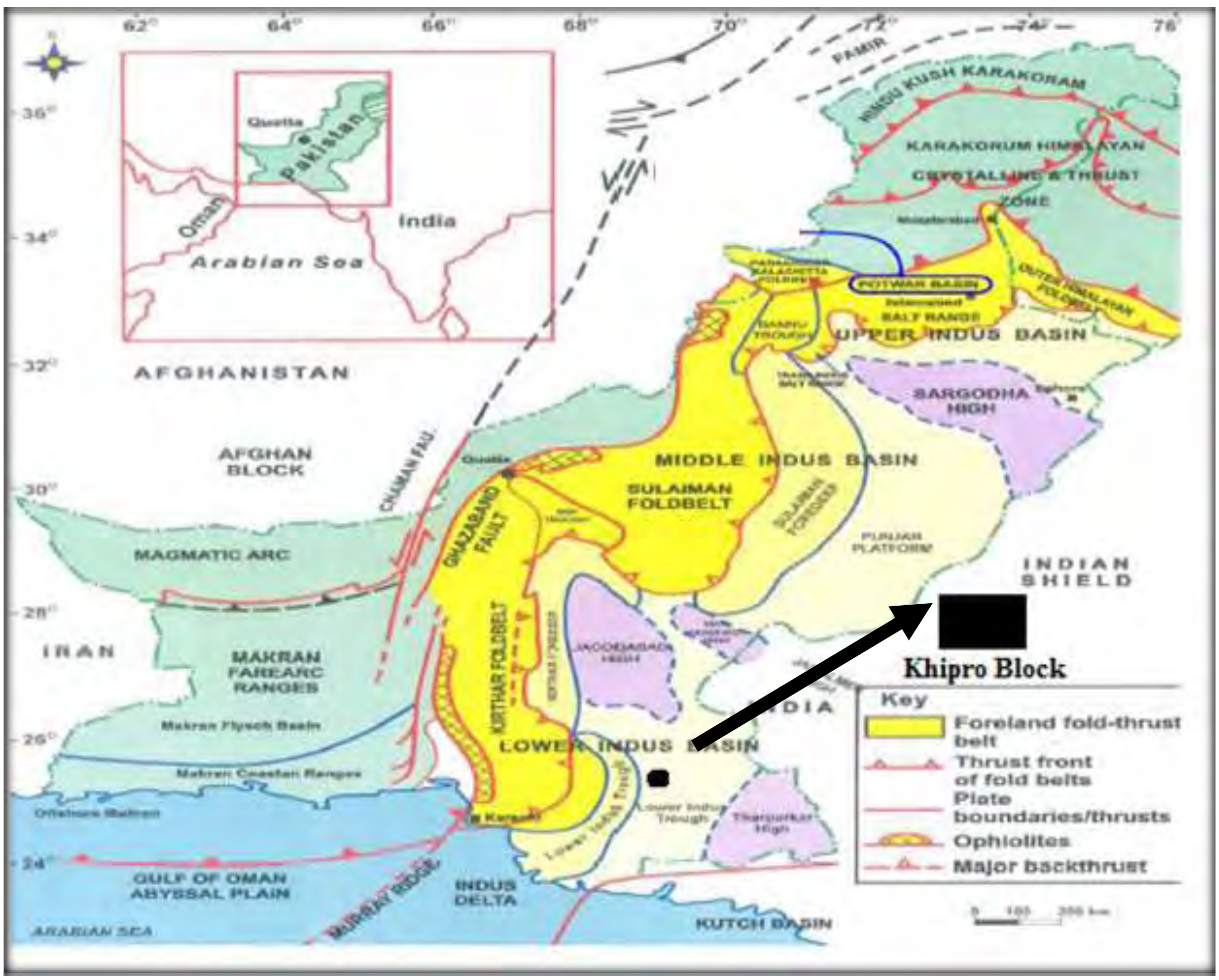

Figure 2.2 Tectonic framework of Pakistan (Banks and Warburton, 1986).

2.3 Petroleum Play of the Study Area

In geology a petroleum play or simply a play is a group of oil field or prospects in the same region that are controlled by the same set of geological circumstances. The Petroleum System consists of a mature source rock, migration pathway, reservoir rock, 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 (Stoneley, 1995).

Lower Indus Basin is main hydrocarbons producing basin of the Pakistan 37% hydrocarbons of the Pakistan are extracted from the Lower Indus basin (Kadri, 1995).

2.3.1 Source Rock

Sembar Formation of Early Cretaceous age is a proven major source rock in Lower Indus Basin and Intra Lower Goru Shales of Cretaceous age also has source rock potential. Sembar is mainly composed of clastic rocks, primarily shale followed by sandstone and siltstone with minor limestone. Sembar is considered to have been deposited on a broad shelf, gently sloping westward off the Indian Shield. Shales of Goru and Mughal Kot formations both are widespread and thick. They contain abundant organic matter and generally exhibit the good source rock characteristics (Kadri, 1995).

2.3.2 Reservoir Rock

Reservoirs are rocks having hydrocarbon bearing potential. Hydrocarbons are trapped in these rocks after migration. Lower Goru Sands are reservoir rocks in Khipro. The main reservoir rocks are the sand of Cretaceous age (Lower Goru formation). The Goru formation is dominantly shale and mudstone frequently calcareous. Sand is rare in upper part with increasing tendency toward the base where it has developed into a producing reservoir. Based on its lithological content it has been divided into lower Goru and upper Goru, petroleum potential of lower Goru sand is very good as it contains all the hydrocarbons in Sindh monocline (Kadri, 1995).

2.3.3 Seal Rock

Seals act as a barrier for the flow of hydrocarbons. In the Lower Indus Basin Upper Goru and

Intra Lower Goru Shales of Cretaceous age provide seal for the Lower Goru reservoir sands (Kadri, 1995).

Figure 2.4 Petroleum play of Lower Indus basin. Stoneley, (1995)

2.4 Stratigraphy in the Study Area

It is very critical to have knowledge about the stratigraphy of the area for the hydrocarbons prospecting, by this knowledge it is determined that what are the source, reservoirs and seals rocks of the area. The lithological setting (Figure 2.4) and stratigraphic sequence of the study area is given below, with the generalized stratigraphic column of the study area as shown in Figure 2.5

2.4.1 Goru formation

Goru formation (early 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).

2.4.2 Upper Goru

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

2.4.3 Lower Goru

It is consisting of Basal Sand unit, Lower Shale, Middle Sand unit (which is a very good reservoir rock) Upper Shale and Upper Sand (Shah, 1977).

2.4.4 Parh limestone

This formation consists of hard, thin to medium bedded limestone with subordinate calcareous shale and marl intercalations. Environment of deposition is shallow marine (Shah, 1977).

2.4.5 Ranikot Formation

Ranikot formation is a good source rock for the gas reservoir in the area. It also acts as a seal rock (Shah, 1977).

2.4.6 Kirthar formation

Kirthar formation (Middle Eocene) is mainly fossiliferous limestone interbedded with subordinate shale and marl. The limestone is thick bedded to massive and nodular in places. The environment of deposition is shallow marine (Shah, 1977).

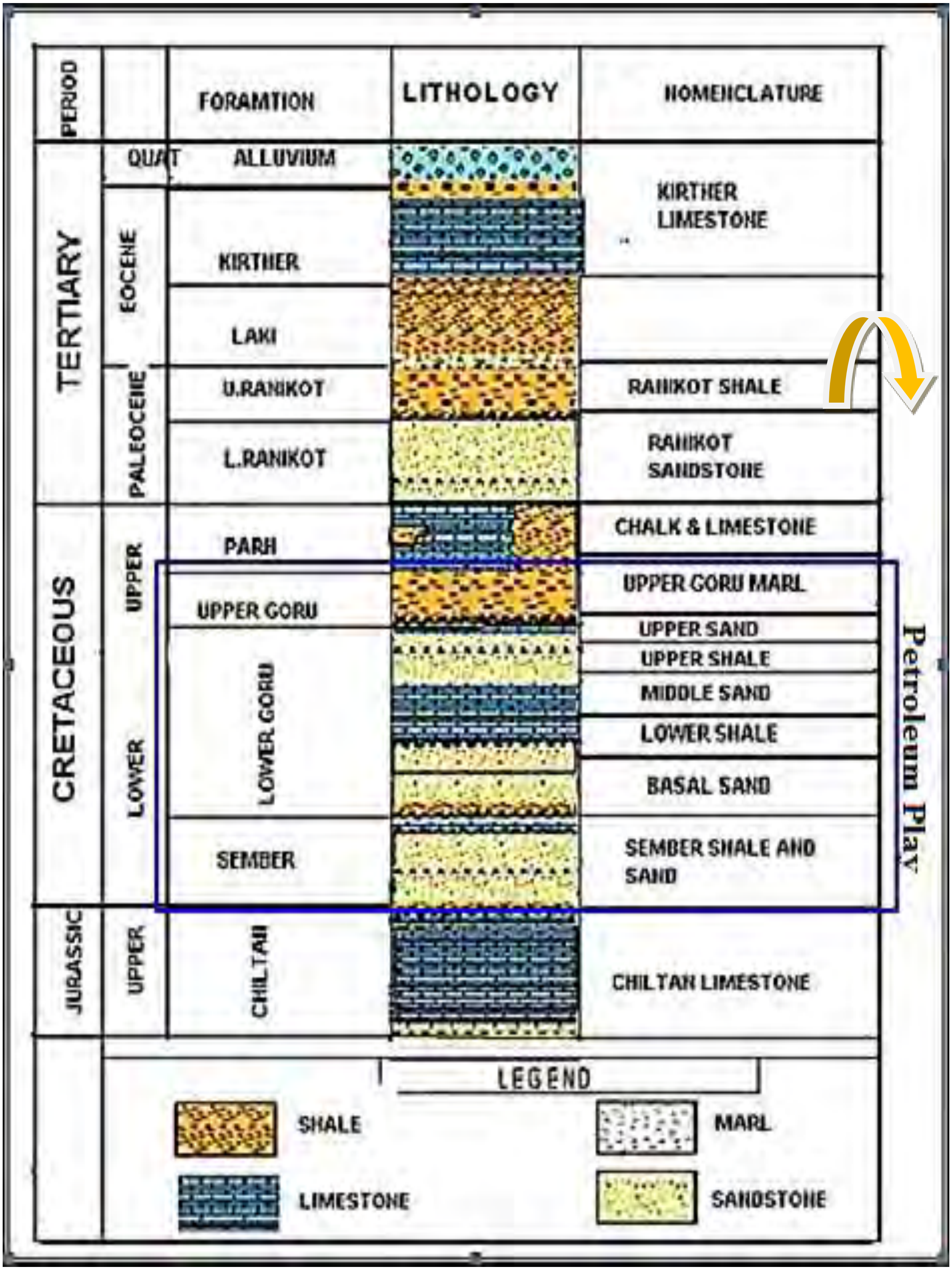

Figure 2.5 Generalized stratigraphic column of the study area.

Chapter # 3

Seismic Data Interpretation

3.1 Introduction

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 an image of subsurface geological units and the structures they form. The goal of seismic interpretation is to recognize possible 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. Basically, there is two type of seismic data interpretation (Dobrin 1960).

An interpreter of seismic data may have good hold in both geology and geophysics. It is the ingenuity and in-depth understanding of an interpreter 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).

3.2 Qualitative interpretation

The primary aim of the qualitative interpretation of the seismic data is to map the subsurface geology. Qualitative interpretation is conventional or traditional seismic technique that include the marking of laterally consistent reflectors and discontinuities characteristics like faults of various types and there mapping on different scales (space and travel time). The geometry on the seismic section is precisely interpreted in view of the geological concept to detect the hydrocarbons accumulation. The structure and stratigraphic architecture of the petroleum is determined and on behalf of the geometric features the location of the well is established. 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 both stratigraphy change and hydrocarbon depositional environment (Bachrach et al, 2004).

In structural analysis main emphases is on the structural traps in which tectonic play an important role. Tectonic setting usually governs which types of the structure are present and how the structural features are correlated with each other‘s, so tectonic of the area is helpful in determining the structural style of the area and to locate the traps. Structural traps include the faults, folds anticline, pop up, duplex, horsts and graben structures etc. (Sheriff 1991).

3.3 Quantitative interpretation

Seismic quantitative interpretation technique as compared to the traditional seismic interpretation technique is more useful. In which the physical variation of the amplitude is considered to predict the hydrocarbons accumulation. Various alterations in these techniques have contributed to the better prospect‘s evaluation and reservoir characterization. Particularly the unconventional seismic interpretation techniques widen the exploration areas. They validate hydrocarbons anomalies and make prospect generation easier. The most important of these techniques include post-stack amplitude analysis (bright-spot and dim-spot analysis), off set-dependent amplitude analysis (AVO analysis), acoustic and elastic impedance inversion, and forward seismic modeling (Bachrach et al, 2004).

3.4 Seismic Interpretation Workflow

Procedure followed for seismic data interpretation is given in figure 3.1. Base map is prepared by loading navigation data and SEG-Y in software SMT kingdom. Horizons of interest are marked manual and by auto-tracking mode. Initially horizons are identified with the help of synthetic seismogram, which is generated by using well data. In this process faults are identified and marked. Faults polygons are generated, and horizons are contoured to find out structural highs and lows. Then time and depth contours are generated. Depth contours are generated by using the well point velocity.

3.5 Identification of seismic horizons

Very basic and the primary task of interpretation of the seismic data is the identification of various horizons as an interface between geological formations. For this purpose, precise information about the structural as well as stratigraphic of the area is required. Thus, to fulfil the first step of the interpretation, I marked the two horizons based on synthetic seismogram of the well data of Naimat Basal-01. Naimat Basal-01 is drilled on shot points 357 and 290 of line 2000KH-08. Two horizons are picked on line 2000KH-08 namely as Talhar Shale and Basal Sand.

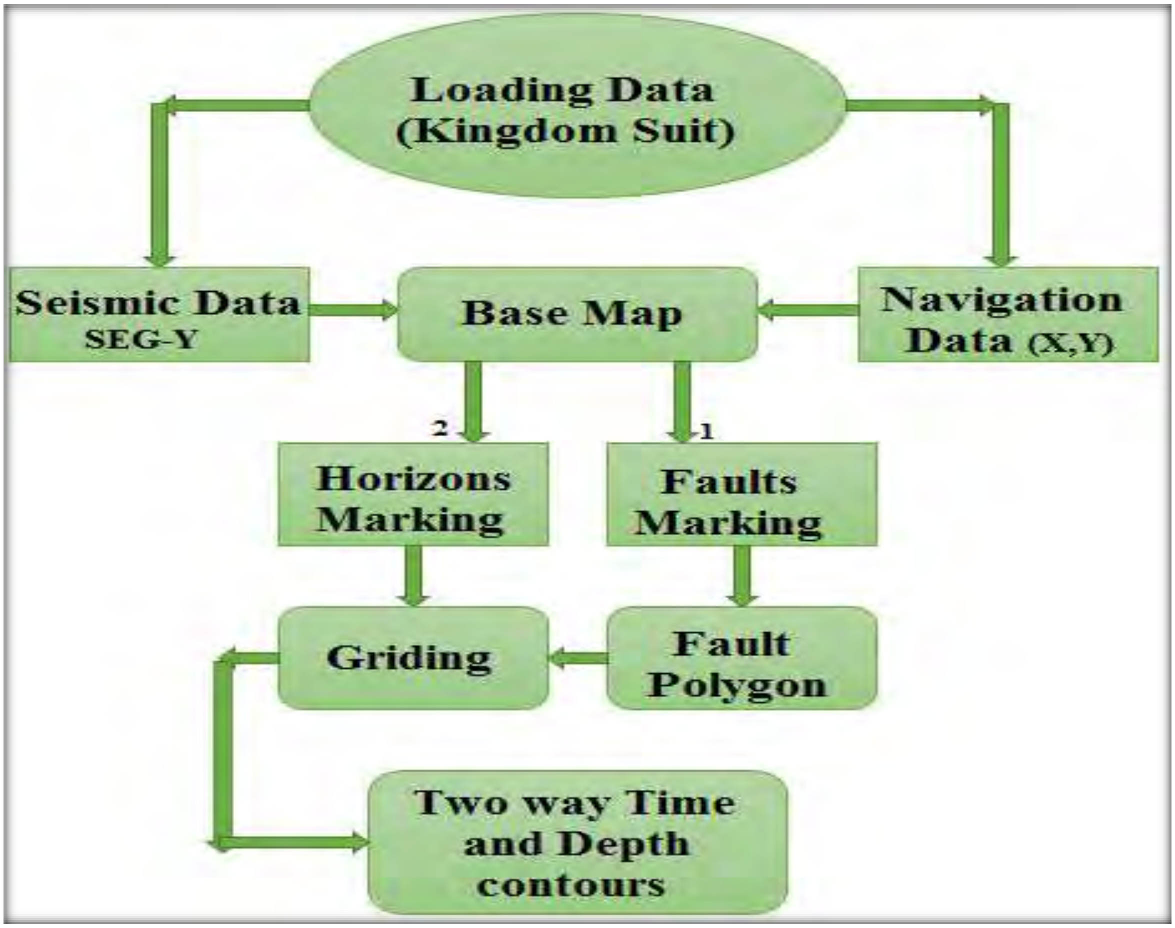

Figure 3.1 Workflow for seismic data interpretation

3.6 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 by convolving the well data and extracted wavelet having frequency of 30Hz, as shown in Figure 3.2.

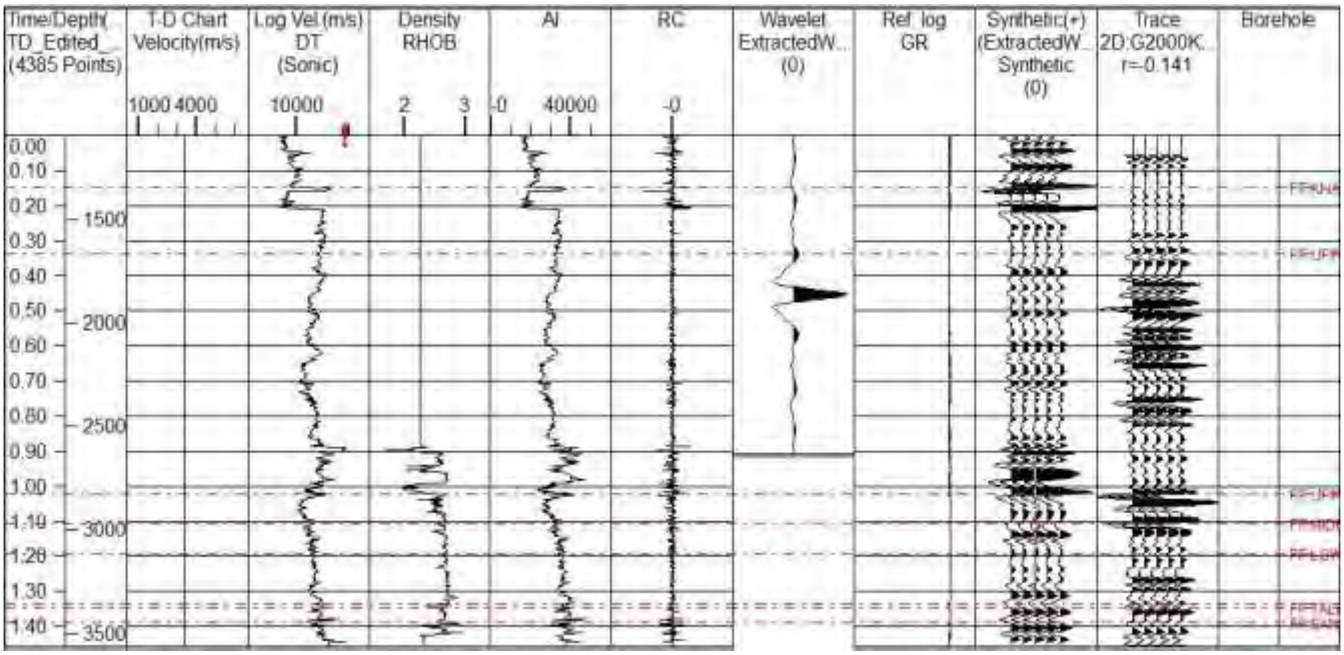

Figure 3.2 Synthetic seismogram obtained using well data from Naimat-Basal-01 well, and seismic data.

3.7 Interpretation of Seismic Sections

For this project I have been assign following four lines, 2000KH-06, 2003KH-36, 2001KH-22, 2001KH-30 and 2000KH-08. Two seismic horizons **BASAL SAND and TALHAR SHALE** (of early cretaceous age) are marked. Along these seismic horizons, eight faults are also picked. The interpreted seismic section of the assigned lines is shown in figure 3.3, 3.4, 3.5, 3.6 and 3.7. These seismic section shows horsts and graben structure except line 2001KH-13, which is a strike line. Structures are not clear in strike line therefore faults are not marked. This horst and graben structures is associated with normal faulting which shows the study area is lies in extensional regime.

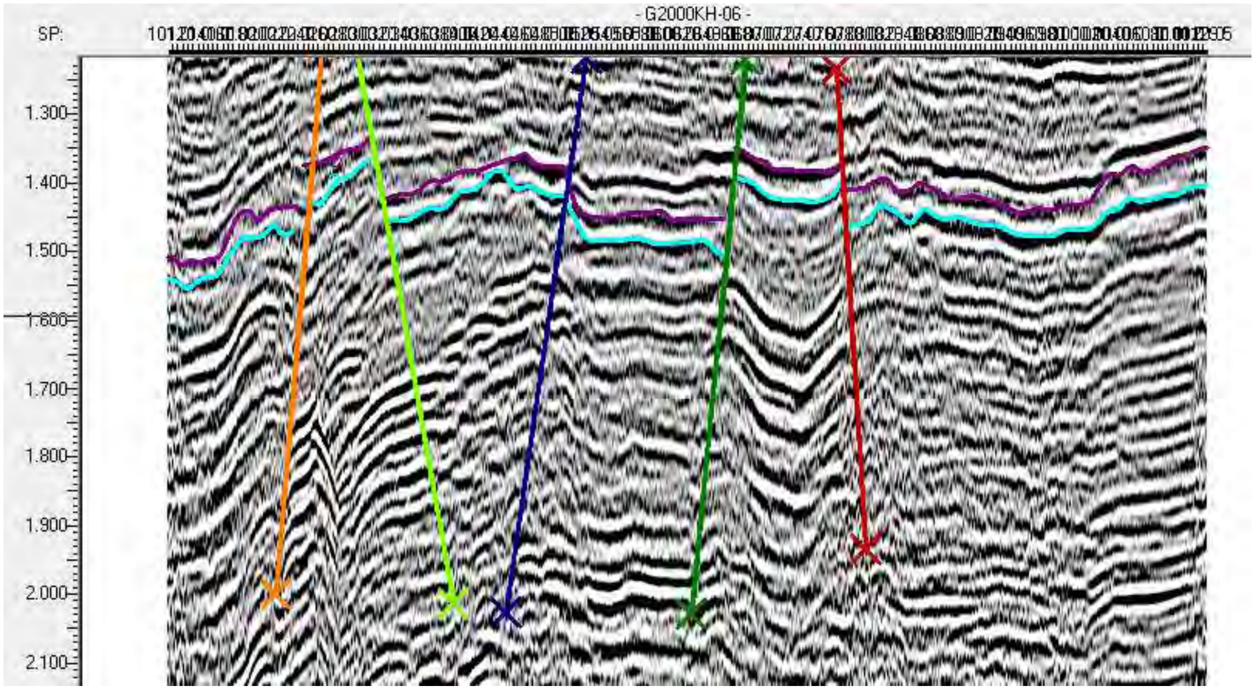

Figure 3.3 Seismic dip line 2000KH-06.

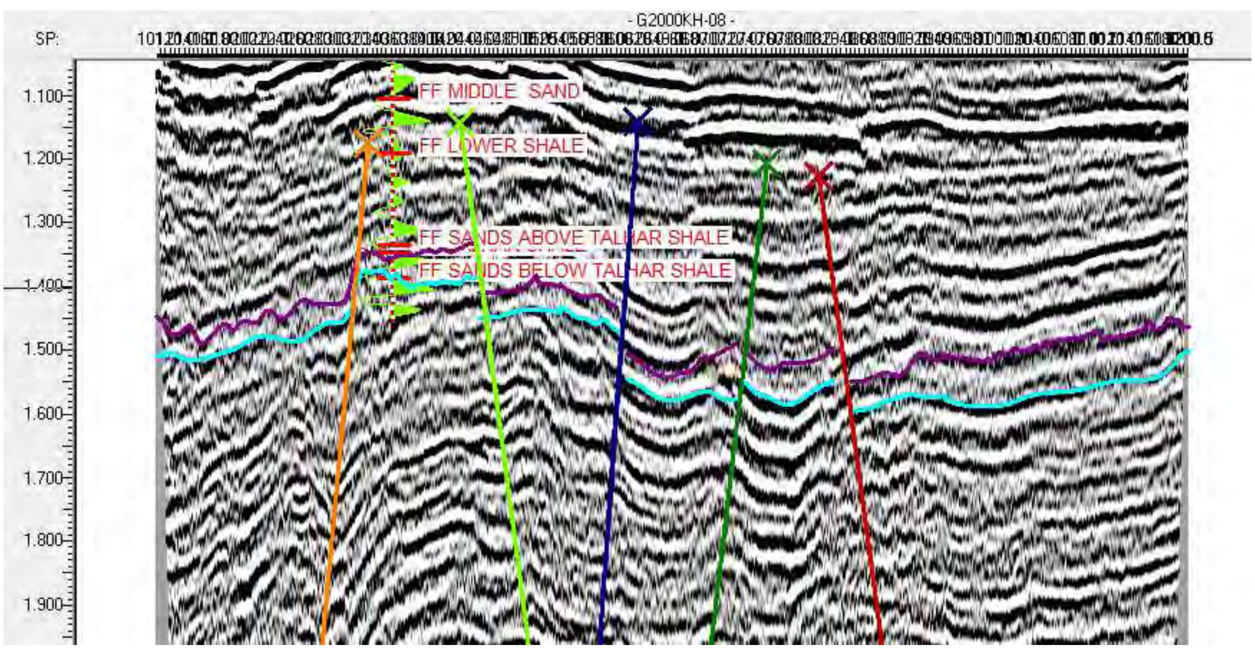

Figure 3.4 Seismic dip line 2000KH-08.

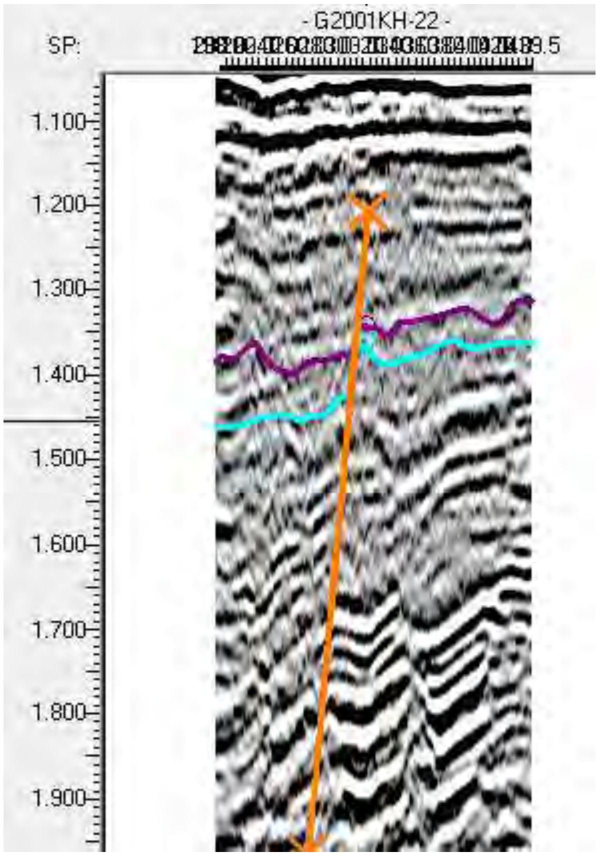

Figure3.5 Seismic dip line 2001KH-22.

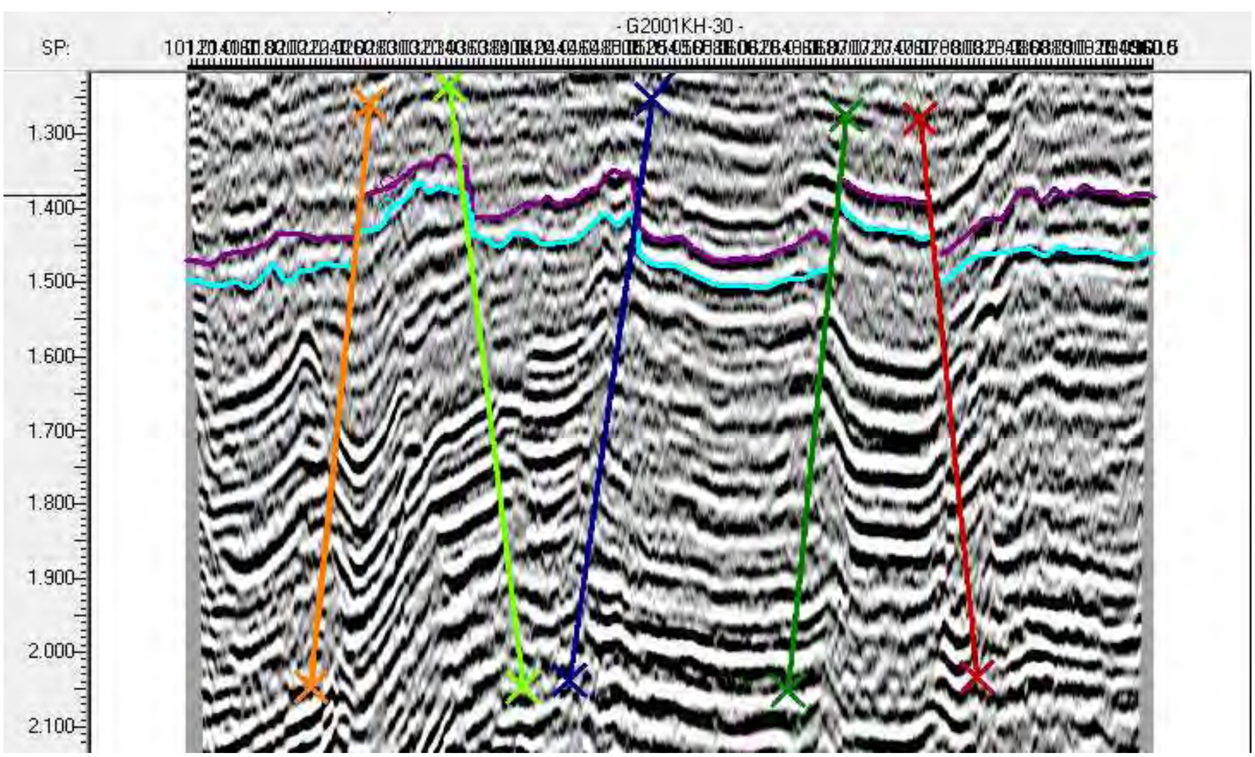

Figure 3.6 Seismic dip line 2001KH-30.

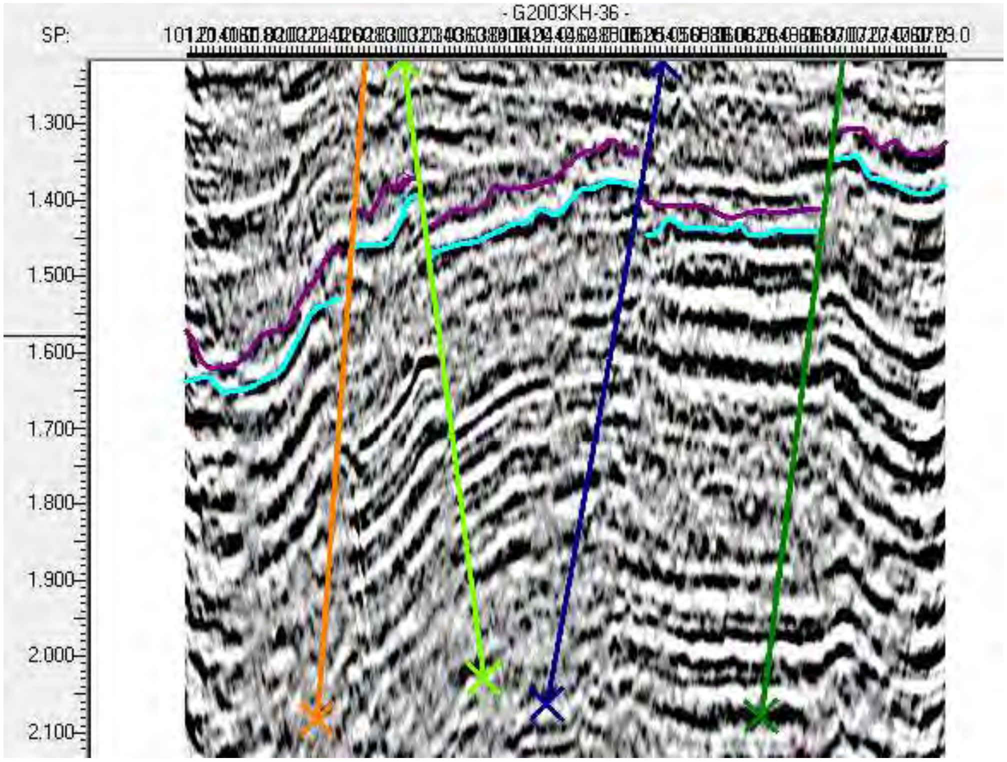

Figure 3.7 Seismic dip line, 2003KH-36.

3.8 Construction of Fault Polygon

Construction of fault polygons are very important as far as time and depth contouring of a 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. Fig 3.8 and figure 3.9 are formed at Talhar Shale and Sand below talhar shale level shows that after construction of fault polygons, the high and low areas on a 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 NE-SE direction.

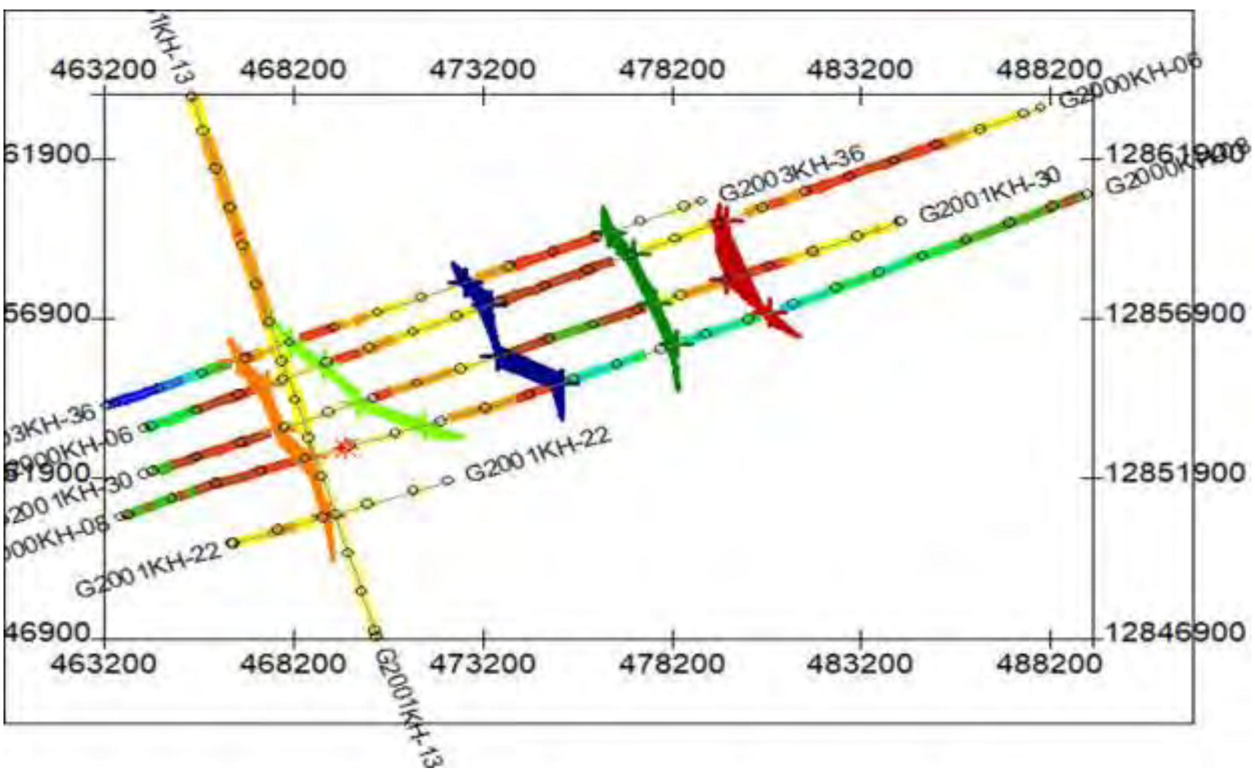

Figure 3.8 Fault polygon constructed on Talhar shale

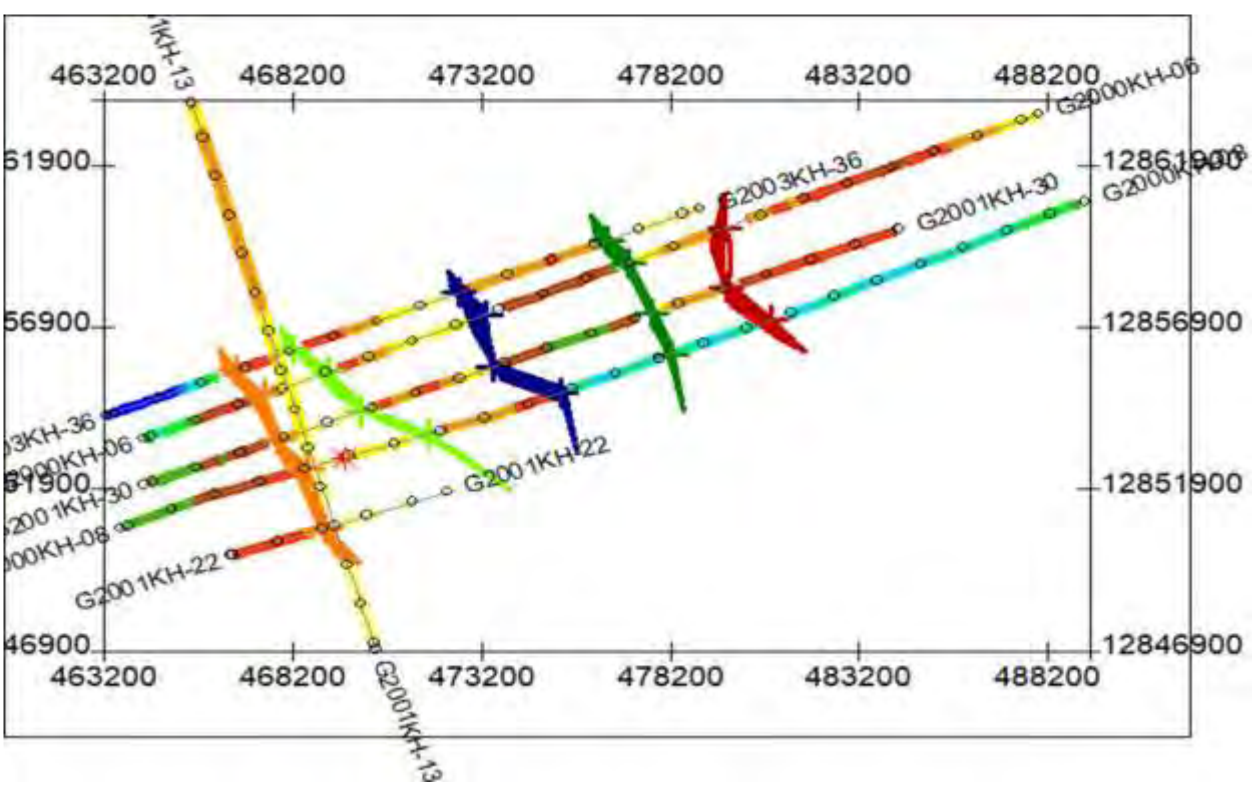

Figure 3.9 Fault polygon constructed on Basal Sands.

3.9 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. Formation is selected for the purpose of constructing contour maps. In constructing a subsurface map from seismic data, a reference datum must first be selected. The datum may be sea level or any other depth above or below sea level. Frequently, another datum above sea level is selected in order to image a shallow marker on the seismic cross-section, which may have a great impact on the interpretation of the zone of interest (Gadallah & Fisher 2009).

3.9.1 Time Contour Maps

Time contour maps shows lateral as well as vertical variations with respect to time at the level of horizons. Time contour maps are constructed on Talhar shale and Sand below Talhar shale horizons, figure 3.10 and 3.11 respectively. Color variations clearly showing the horsts and graben structure. Lighter color shows relatively shallower part while darker color shows relatively deeper portion. Trend of both contour maps is same which shows there is no vertical variation. Both horizons deform equally by faulting.

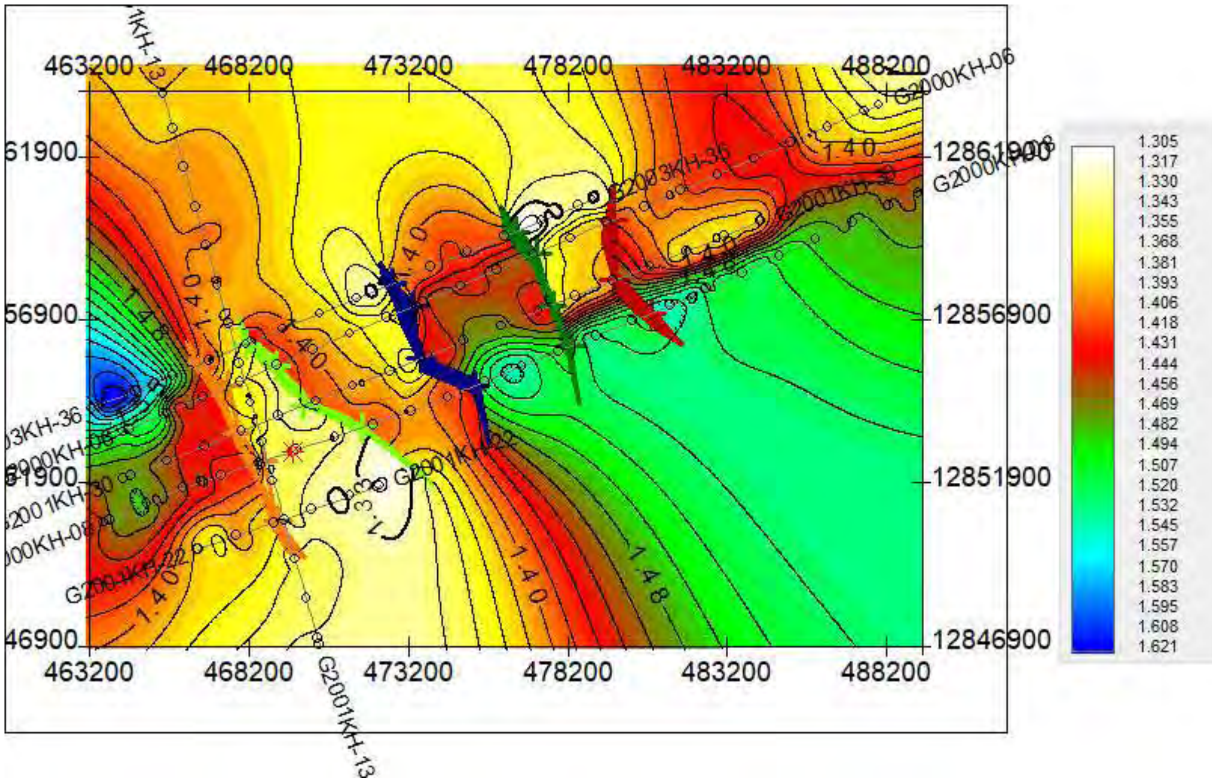

Figure 3.10 Time contour map of Talhar Shale

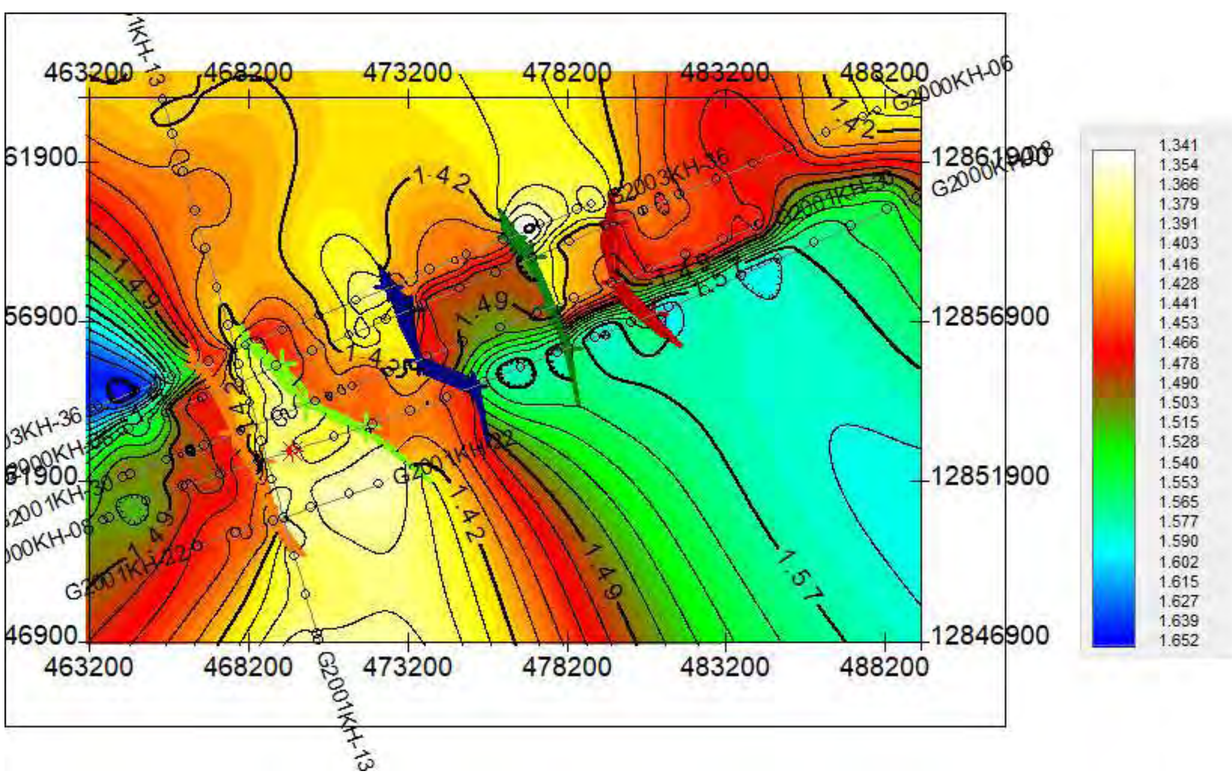

Figure 3.11 Time contour map of Basal Sands.

3.9.2 Depth Contour Maps

Depth contour are generated by using the well point velocity. Depth contour maps also shows lateral variation with respect to depth. The trend of depth contour maps is same as of time contour maps because there are same lateral variations with time as well as depth. Depth contour maps of Talhar Shale and Sand below Talhar Shale are shown in figure 3.12 and 3.12 respectively. From the figures, horsts and graben structures are formed which is also formed in time contour maps, the blue region in the contour maps shows the region where the shallower region is present and is clearly identifiable.

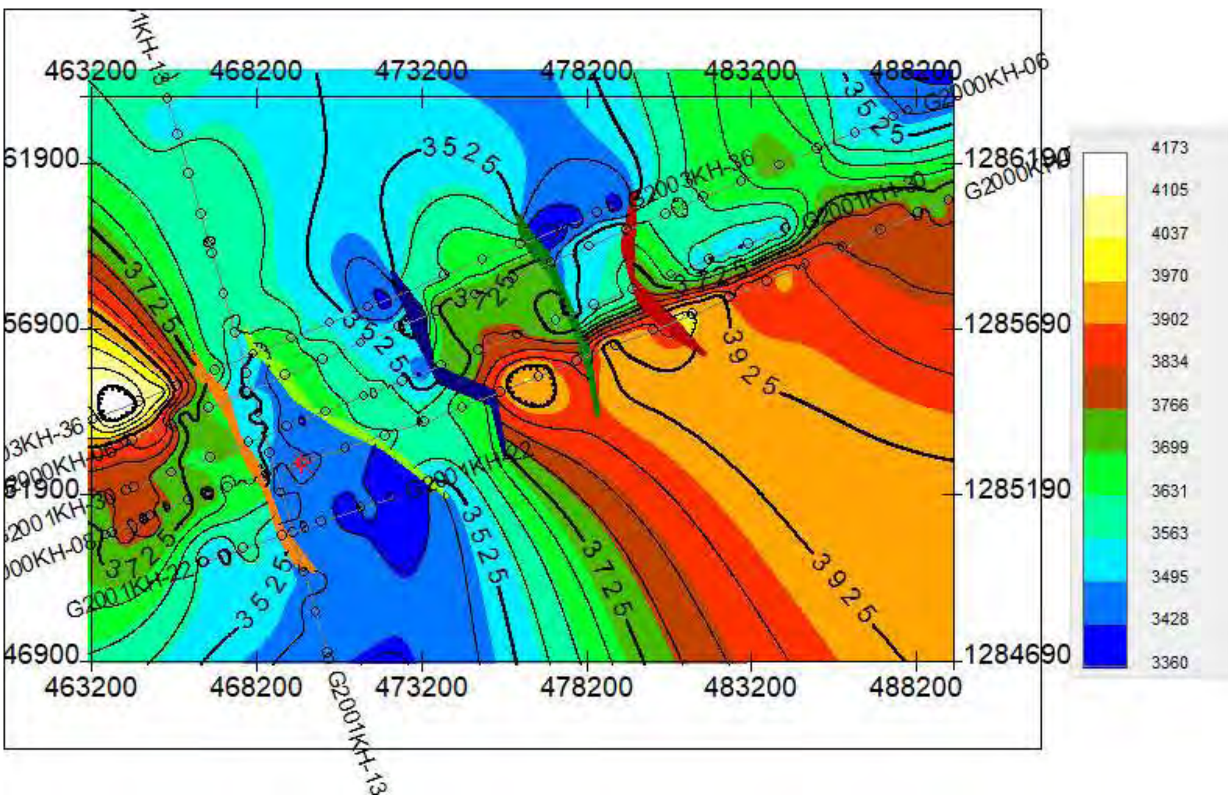

Figure 3.12 Depth contour maps of Talhar Shale.

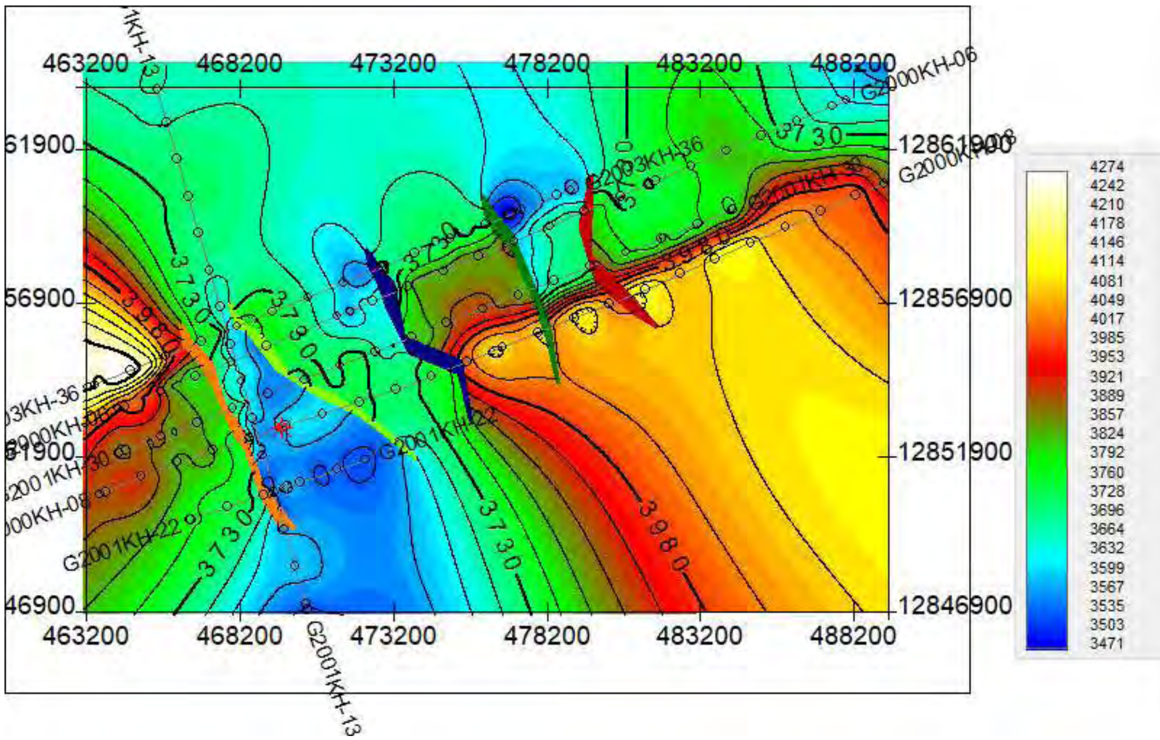

Figure 3.13 Depth Contour Map of Basal Sand.

Chapter 04

PETROPHYSICAL ANALYSIS

4.1 Introduction

This study facilitates in identification and quantification of fluid in a reservoir.Knowledge of reservoir physical properties like volume of shale, porosity, and water and hydrocarbon saturation is needed to characterize precisely probable zones of hydrocarbons. The physical property like volume of shale, porosity, saturation of water and saturation of hydrocarbon is needed to identify the probable zones of hydrocarbons accurately. Petrophysics is apprehensive with using well measurements to subsidize reservoir depiction (Daniel, 2003). . To precisely characterize oil or gas in a reservoir, measurements such as resistivity, porosity and density are made, from which volume of shale, average porosity water saturation and hydrocarbon saturation can be quantified.

4.2 Data Set

Key parameters in the calculation of petrophysics are given below.

- Volume of Shale
- Porosity Calculation
- Water Saturation
- Hydrocarbon Saturation

Before going to calculate these properties, we must have to know about different types of logs and their characteristics which are mentioned below.

4.3 Classification of Geophysical Well Logs

Different classification and short explanations of geophysical well logs is given below. These are explained according to the tracks in which they are run.

4.3.1 Lithology Track

In lithology track, following three logs are displayed.

- **Gamma Ray Log:** It is the measurement of a formation‘s radioactive contents. Since radioactive contents are present in shale thus it deflects owing to the presence of radioactive content. This is why it has been considered as best log for lithology identification. It is also called the ‗shale log‘.

- **Spontaneous Potential Log:** SP log measures naturally occurring potential of geological formations where no artificial currents are injected. It gives deflection opposite to the permeable beds since shale is impermeable, so it gives straight line opposite to shale known as ‗shale base line'. It is used to indicate permeable zones, calculate volume of shale, and to calculate resistivity of formation of water.
- **Caliper Log:** Used to measure the borehole size. It helps to identify the cavities and washouts and breakouts. Hence this log is also called the quality check for other logs because if there is any washout then in front of the wash out, porosity and resistivity log will not give correct readings. Thus, this log is quite vital in petrophysical analysis.

4.3.2 Porosity Track

Sonic Log (DT), Density log (RHOB) and Neutron porosity logs (NPHI) are porosity logs that are used to calculate pore volume of formations. With the combination of resistivity logs, they are used to calculate water saturation in different formations.

- **Sonic Log:** Sonic log produce compressional waves and measure the transient travel time of waves. Where travel time is higher it is indication of porous media because wave is name of progressive disturbance of media.
- **Density Log:** Gamma rays are bombarded on formation these are scattered from formation's electrons higher the scattering higher the electron density and this electron density is related to bulk density of rocks. Lower the density higher the porosity of medium.
- **Neutron Log:** Neutron log tool emit high energy neutron and the only resistive substance to neutron are hydrogen ions. If value of this log is high, it means high hydrogen ions concentration is present. Since hydrogen ions are present in pore space so neutron log measures porosity. If gas is present than value of log is low because concentration of hydrogen ion is low.

4.3.3 Resistivity Track

Basically, there are different types of electrical Resistivity Logs. Logs of LLS and LLD can separate only when (oil) high resistive fluid is present in the formation. It includes:

- **Laterelog Deep:** Laterelog is used for deep investigation of the undisturbed zone (Uninvaded zone) and it is called Laterelog 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).

- **Laterelog Shallow:** Laterelog shallow (LLS), used for shallow investigation of the transition zone / invaded zone. Because the depth of the investigation is smaller than the LLD.

4.4 Petrophysical Analysis

The major purpose of performing petrophysical analysis is to confirm the presence of hydrocarbons and determine how much, hydrocarbons are present in the formation of interest. This is done with the help of logs to determine different properties of the reservoir formation. The geophysical well data including the logging data of gamma ray, resistivity, caliper, sonic, spontaneous potential, neutron and density is used to identify hydrocarbons in the reservoir formation. We use Archie‘s equation to estimate the Petrophysical parameters including porosity, volume of shale, saturation of water, permeability etc.

The petrophysics analysis has been carried out in order to measure the reservoir characterization of Khipro area using the borehole data of Naimat Basal-01.

The following figure shows the workflow for Petrophysical analysis. Different logs are used in different tracks to evaluate the reservoir properties. Petrophysical interpretation is performed using SMT kingdom software. The workflow followed can be seen in Figure 4.1.

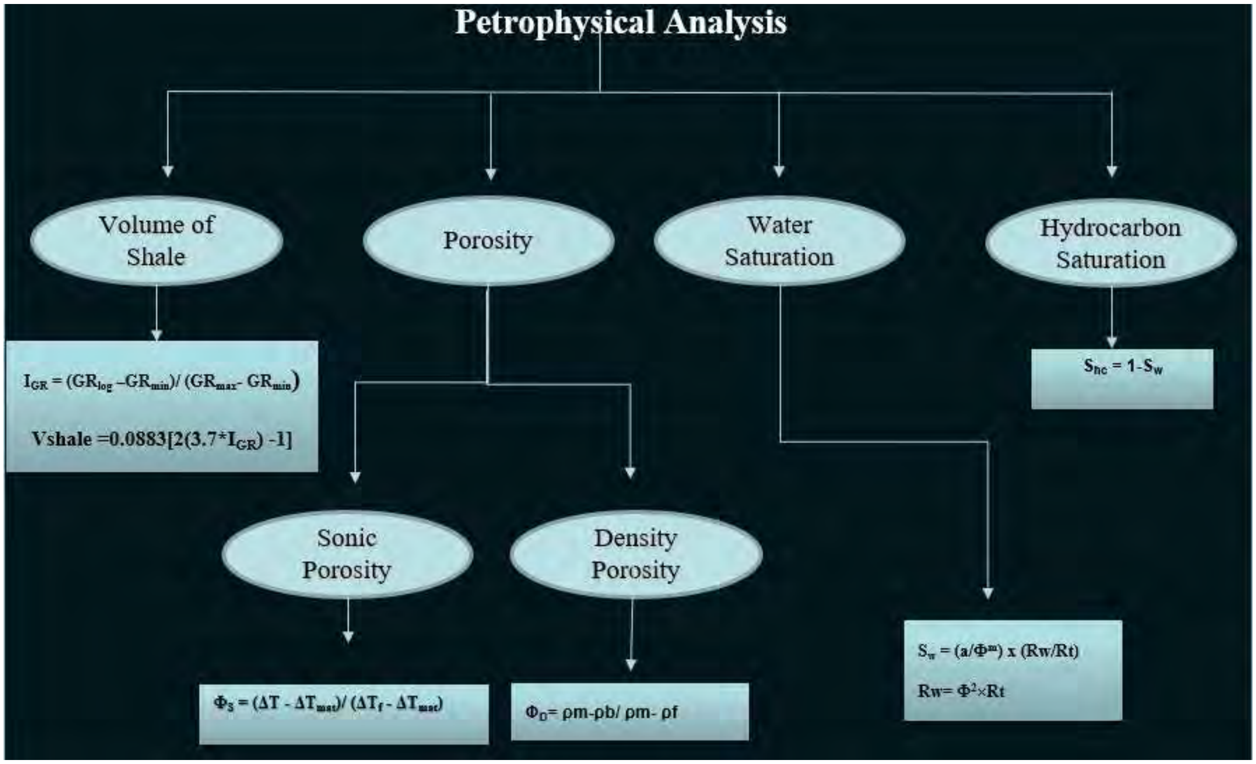

Figure 4.1 General workflow followed during the petrophysical analysis.

4.4.1 Estimation of Volume of Shale

It is defined as the presence of shale or clay in formation. Not only the Shale formations contain the clay minerals, carbonates and sand formations also contain it. Volume of shale ranges from 0 to 1i.e. it is in fractions. It is 0 for clean carbonate or sand and is 1 for clean shale. Shale content determination is necessary of reservoir characterization because volume of shale affect the porosity of reservoir formation.

The volume of shale can be estimated from the response of Gamma ray log. The response of Gamma ray must be known through different lithologies. The gamma ray log is the passive logging because we measure the Formation properties without using any source. Actually, it measures the Formation _s radioactivity. The gamma ray emits from the Formation in the form of electromagnetic energy which are called the photons. When a photon collides 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 rays reached to the detector of the gamma ray and counted and displayed as count per second which is termed as the Gamma ray.

Volume of shale is calculated using the following equation.

$$V_{sh} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$

The Gamma ray log shows maximum value when shale is encountered and shows a minimum value when clean lithology like sand is encountered. These values are calculated from given log response and then volume of shale is estimated by using above equation.

The average volume of shale in lower Goru formation of Naimat Basal-01 well is about 28.41% that has been calculated from the given data.

4.4.2 Porosity Estimation

Porosity is defined as the ratio of volume of voids to total volume of rock. Porosity is calculated for different zones of interest by using the following logs.

- **From Sonic Log:** Sonic log device consists of a transmitter that emits sound waves and a receiver that picks and record the compressional waves as it reaches 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). Sonic log can also be used for the following purposes in combination of other logs as given by (Daniel, 2004).

$$\Phi sonic = \frac{\Delta t_{log} - \Delta t_{matrix}}{\Delta t_{fluid} - \Delta t_{matrix}}$$

- **From 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 increase 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.

- **From Neutron Log:** 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 neutrons 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 fluid in the Formation pores; hence loss of energy is related 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 PHI due to the presence of the gas called the gas effect.

- **Total Porosity:** It is simply the average of porosities measured by DT, RHOB and NPHI.

- **Effective Porosity:** It is the measurement of interconnected pores of formation. Since shale is impermeable so it is calculated after removing the effect of shale from total porosity.

  $\boldsymbol{PHIE} = (\Phi_{\boldsymbol{total}}) * (\mathbf{1} - \boldsymbol{v_{shale}})$

  Its average value is 6.91%.

4.4.3 Saturation of Water

Water saturation is the percentage of pore volume in rock that is occupied by water of Formation. If it is not confirmed that pores in the Formation are filled by hydrocarbons, it is assumed that these are filled with water.

For the Naimat Basal-01 well, water saturation was found by using Archie Equation

$$(S_{water})^n = \frac{a}{(\Phi)^\wedge m} * \frac{R_{water}}{R_t}$$

Where;

S water = Water saturation

n = Saturation Exponent = 2

a = Lithological Coefficient = 1

m = cementation factor = 2

R water = Resistivity of water = 0.05

R t = True Resistivity

The values of the factors a, m, and n come from the core analysis of the data. We assume these three values to be constants and their values are mentioned against them.

By putting values of these parameters and simplifying the above equation, we calculate the water saturation and it is multiplied by 100 to get the results in percentage. Archie equation is used because it gives direct relationship between resistivity of water and true resistivity with water saturation. It is more realistic than any other equation. Finally, this water saturation is subtracted from 100% to give hydrocarbon saturation.

The average value of saturation of water is 65.76%.

4.4.4 Hydrocarbon Saturation

Water saturation is used to find out the hydrocarbon saturation. As we know that the sum of the water saturation and hydrocarbon saturation is always equal to 1 because both are fraction of the water or hydrocarbon in the total volume of the pore spaces. So, Hydrocarbon saturation can be calculated from this by using following relation.

$$HC = 1 - s_{water}$$

Average value of hydrocarbon saturation is 35.24% in the Basal Sand formation.

4.5Well Log Interpretation of Naimat Basal-01

Petrophysical analysis of area is performed by using the well data. Once well is drilled we run different log to evaluate reservoir properties. Different logs have different working principal and depending upon this they show their effectiveness to calculate the reservoir properties.

The interpretation of Naimat Basal is shown in figure 4.2 below. The Basal sands is encountered at the depth ranges from (3479.1m – 3550.35m). It is confirmed as a reservoir by different results obtained from well log. The other logs like Gamma ray log shows low value of Gamma ray readings and resistivity logs shows high values. The volume of shale is far less than 50%. The neutron log shows good porosity values and density and sonic logs shows low values as well. These results are satisfactory thus we can interpret that Lower Goru act as a reservoir. There are two possible hydrocarbon zones in this well. They are named as zone A and zone B.

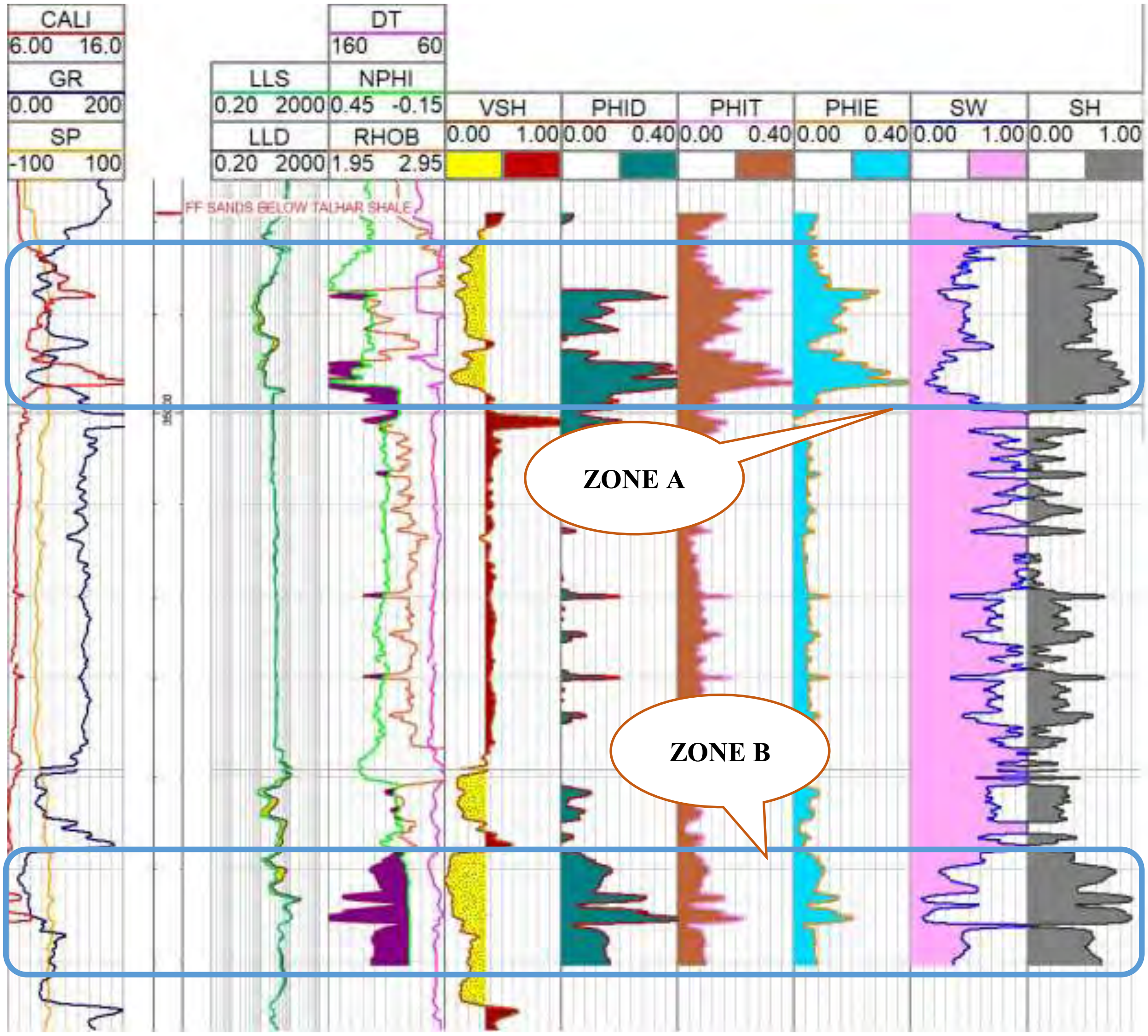

Fig 4.2 Petrophysics analysis for Naimat-Basal 01, with zone of interests marked.

4.5.1 Zone A

The first possible hydrocarbon zone in Lower Goru formation is marked as zone A ranging from 3482.6m to 3499.975m in depth. Here the GR log shows a decrease indicating sand and porosities are on the increase suggesting the presence of a porous sub surface reservoir. Water saturation is lower than hydrocarbon saturation which is good enough to call it a pay zone.

4.5.2 Zone B

Second possible hydrocarbon zone is at a depth range of 3537.85m to 3545.975m. This is a small pay zone where the log curves show an increase in porosity and an increase in resistivity values. There is a cross over between NPHI and RHOB and hydrocarbon saturation is also fair enough to consider it as a pay zone.

Table 4.1 Petrophysical parameters for Basal Sands

Serial Number	**Calculation Parameters**	**Percentage % Basal Sands**
1	Average Volume of Shale = Vsh_{avg}	28.41
2	Average Porosity Obtained from Density Log = ϕ_{davg}	5.12
3	Average Porosity Obtained in (PHIT) Percentage = ϕ_{tavg}	10.94
4	Average Effective Porosity in Percentage = ϕ_{eavg}	6.91
5	Average Water Saturation in Percentage = S_{wavg}	65.76
6	Average Hydrocarbon Saturation in Percentage = S_{havg}	35.24

Table 4.2 Petrophysical parameters for Zone A

Serial Number	**Calculation Parameters**	**Percentage % (3482.6 to 3499.975) m**
1	Average Volume of Shale = Vsh_{avg}	21.92
2	Average Porosity Obtained from Density Log = ϕ_{davg}	9.43
3	Average Porosity Obtained in (PHIT) Percentage = ϕ_{tavg}	17.57
4	Average Effective Porosity in Percentage = ϕ_{eavg}	16.16
5	Average Water Saturation in Percentage = S_{wavg}	42.14
6	Average Hydrocarbon Saturation in Percentage = S_{havg}	57.86

Table 4.3 Petrophysical Parameters for Zone B

Serial Number	**Calculation Parameters**	**Percentage % Basal Sands (3537.85 to 3545.975) m**
1	Average Volume of Shale = Vsh_{avg}	5.98
2	Average Porosity Obtained from Density Log = ϕ_{davg}	15.11
3	Average Porosity Obtained in (PHIT) Percentage = ϕ_{tavg}	9.71
4	Average Effective Porosity in Percentage = ϕ_{eavg}	8.94
5	Average Water Saturation in Percentage = S_{wavg}	38.97
6	Average Hydrocarbon Saturation in Percentage = S_{havg}	61.02

Chapter 5
Facies Analysis

5.1Introduction
A rock or stratified body distinguished from others by its appearance or composition.

OR

It can be defined as:

The characteristics of a rock or series of rocks reflecting their appearance, composition, and cond itions of formation.

5.2Facies Types
5.2.1Sedimentary Facies
Sedimentary facies are bodies of sediment recognizably different from adjacent sediment deposited in a different depositional environment

5.2.3Metamorphic Facies
The sequences of minerals that develop during progressive metamorphism define a facies series.

5.3 Walther’s Law of Facies

Walther's Law of Facies, or simply Walther's Law, states that the vertical succession of facies reflects lateral changes in environment. Conversely, it states that when a depositional environment "migrates" laterally, sediments of one depositional environment come to lie on top of another. A classic example of this law is the vertical stratigraphic succession that typifies marine transgressions and regressions. However, the law is not applicable where the contact between different lithologies is non-conformable (Lucia 1995).

5.4 Facies Analysis
Fundamental to all subsurface geologic studies is an analysis of depositional facies. Development of a facies classification scheme is a particular challenging interplay between capturing enough information for environmental interpretation yet remaining simple. Particularly important is the characterization of facies such that their recognition criteria relate to critical environmental thresholds such as sea level, normal wave base, and storm wave base. These

physical environmental zones regulate sedimentary textures and biotic assemblages. A good understanding of paleoecology always strengthen the interpretation and such studies should be included as part of all depositional facies studies. Depositional textures in turn affect porosity-permeability in carbonates. The vertical and lateral organization of facies is an exercise essential to sequence stratigraphic interpretations. (Lucia 1995).

5.5 Facies Analysis Procedure

From the KINGDOM software main window menu bar, choose Tools > Cross plot > New to open the Select Data dialog box. Window will appear shown in Figure 5.1.

Data for each axis

X =Rho b

Y= LLD

Z =G

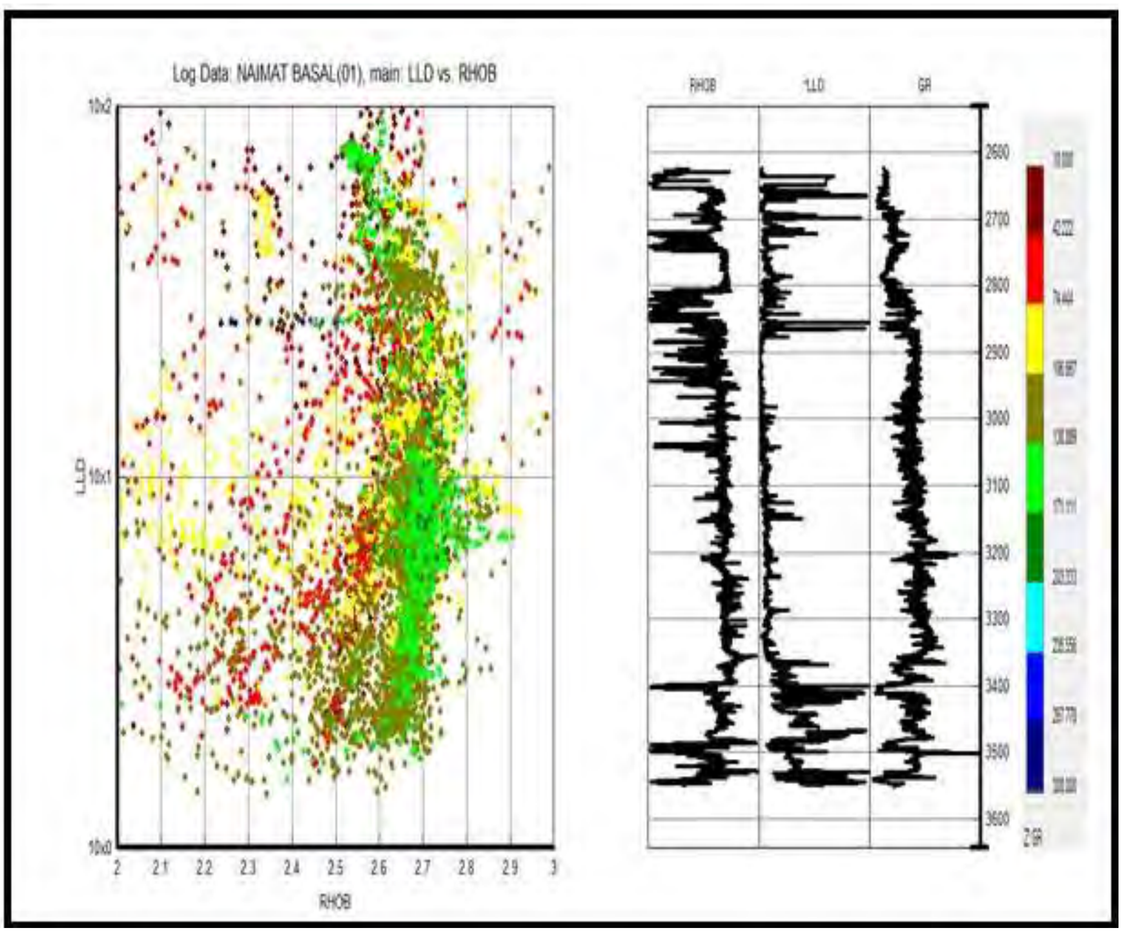

Figure 5.1: Facies models showing different cluster points of lithologies

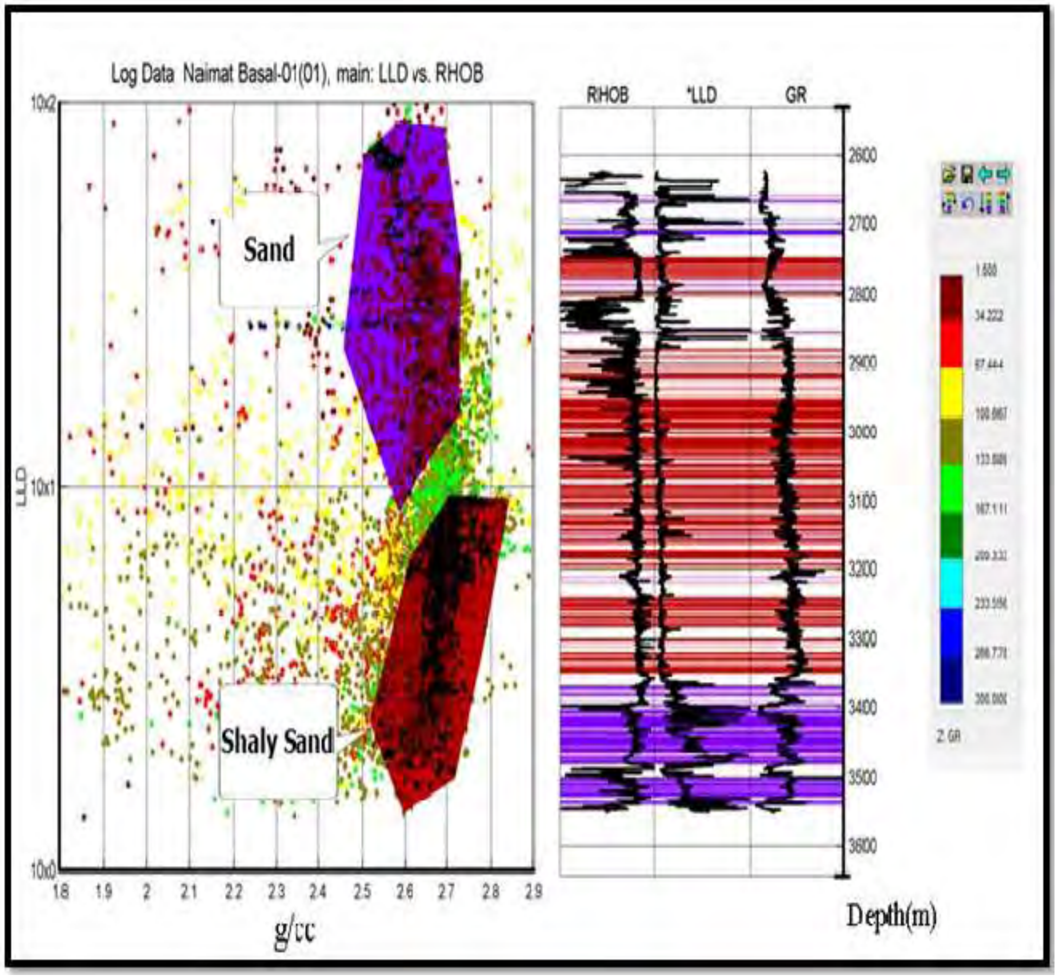

Figure 5.2: Facies model showing the Sand and Shaly Sand in Naimat Basal-01 well

5.6 Results of Facies Analysis

There are two clusters of data points in the Figure 5.2. The high resistivity values and corresponding low Gamma Ray values indicate clean sands. High gamma ray values associated with low resistivity values indicate shale.

CONCLUSIONS

From our work done and interpretation of the work done on kingdom the following can be concluded:

- The subsurface structure as marked on the dip lines shows extensive normal faulting.
- Horst and graben structures can be seen bounded from the contour maps generated.
- The formation of interest Basal sands marked is placed at a shallower depth, while the seal rock Talhar shale formation is also marked and it can also be seen at a shallower depth.
- From our petrophysical analysis of the Basal Sands two zone of interests were marked Zone A and B which were our possible zone of interests.
- The petrophysical parameters of Zone B showed a higher hydrocarbon percentage, and this can be concluded as our productive zone of interest, along with Zone A but Zone A is a massive bed so it is our productive zone.

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