2D-SEISMIC REFLECTION DATA INTERPRETATION INTEGRATED WITH PERTOPHYSICAL ANALYSIS SEISMIC ATTRIBUTES AND ROCK PHYSICS MODELLING OF KHIPRO AREA, PAKISTAN

PRESENTED BY

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بسم الله الرحمن الرحيم

CERTIFICATE

This dissertation submitted by JAMAL ABDUL NASIR s/o ISHTIAQ AHMED is accepted in its present form by the Department of Earth Sciences, Quaid-i-Azam University Islamabad as satisfying the requirement for the award of BS degree in Geophysics.

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In the name of Allah, the most Beneficent, the most Merciful. All praises to Almighty Allah, the creator of universe. I bear witness that there is no God but Allah and Holy Prophet Hazrat Muhammad (P.B.U.H) is the last messenger of Allah, whose life is a perfect model for the whole mankind till the Day of Judgment. Allah blessed me with knowledge related to Earth. Without the blessing of Allah, I could not be able to complete my work as well as to be at such a place.

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2016-2020

DEDICATION

I would like to dedicate this thesis work to my sweet parents also my siblings whose love, encouragement, guidance and prays make me able to achieve such success and honor, their love support and prayers are always with me and Allah blessed me with what I wished to achieve in life. May Allah bless my family with honor, dignity, health and respect.

ABSTRACT

The present study pertains to integrated seismic and petrophysical analysis of Khipro area, with special emphasis on seismic attributes and 2D rock physics modelling. The area lies in Lower Indus basin of Pakistan, is very prominent for hydrocarbon accumulation in structural traps. The work is carried out on six seismic line along with the well data (petrophysical logs).

The study includes the structural interpretation of seismic data. Three horizons are marked mainly reservoirs which are identified using formation tops from well along with normal faults indicates extensional regime. Reflectors of three formations namely Middle Sands, Sand above Talhar Shale and Sand below Talhar Shale are marked on seismic section, with the help of synthetic seismogram of Naimat-Basal-01 well. Time and depth contours maps of the three horizons are generated which delineates the horst and graben structures that confirms normal faulting in the study area. Naimat-Basal-01 well is drilled on the horst in Khipro area. To confirm seismic interpretation seismic attribute analysis have been carried out to identify the lithological boundaries, discontinuities in lithologies and structural disturbance. Petrophysical analysis have been carried out for the demarcation of reservoir zone to find the hydrocarbon potential in the area, based on which three zones of interest are marked using different petrophysical logs. Low volume of shale, high effective porosity, low water saturation and high hydrocarbon saturation in zone of interest are the indicator for hydrocarbon presence and the porous reservoir formation, which is suitable for hydrocarbon accumulation, also for quantitative interpretation averages of the different petrophysical logs are calculated. Rock physics cross-sections have generated using velocity windows for formulation of velocities and physical parameters like elastic moduli, porosity and seismic density.

CONTENT

CHAPTER 01

INTRODUCTION

1.1 Introduction

Geophysical investigation of interior of earth and measurement taken at or near the earth surface that are molded by the distribution of the physical properties. And analysis of these measurement can give an insight about how the physical properties of the Earth's interior vary in different directions. Geophysical surveying is used for exploration of hydrocarbons, for metalliferous minerals and environmental applications. Seismic methods are the most important techniques because of their routine and widespread use in the exploration for hydrocarbons, in terms of the amount of money expended annually. Seismic methods are particularly well suited to the investigation of the layered sequences in sedimentary basins that are the primary targets for oil or gas (Kearey et al. 2002).

The study area, Khipro Block shown in figure 1.4 is tectonically situated in Southern Indus Basin and geographically in Sanghar District Sindh province of Pakistan. Southern Indus Basin is very important for hydrocarbon exploration because it is the main producing oil and gas basin of Pakistan. Khipro is in Thar platform area of southern Indus basin. The Khipro area is characterized by a series of horst and graben structures present almost below the base Paleocene unconformity within the cretaceous age (Shuaib, 1981). Oil production has been established in the Lower Goru sandstones, in the bottom layers of Cretaceous age. The formation, along with the shales of the Lower Goru formation, represents the major source of hydrocarbon in the Lower Indus Basin (Kadri, 1995). The Lower Goru hydrocarbon accumulation in the project area is bounded on the east and on the west by regional extension faults dipping to the east and trending NW-SE (Kazmi and Jan,1997).

1.2 Objective

The main objectives of the dissertation are 2D seismic interpretation to mark the horizon of interest and to identify the probable structures favorable for hydrocarbon accumulations. Structural interpretation of the seismic data by generation of synthetic seismogram based on which marking of horizons is done accurately. Also, for identification of different structures in the area, time and depth contour maps are designed based on seismic data. Attribute analysis have been done to improve understanding and mapping reservoir and to resolve structural complexities. Petro-physical interpretation has been carried out for estimation of volume of shale, Porosity, water saturation and hydrocarbon saturation based on which zone of interest is marked within the reservoir formation. Rock physics analysis have been executed for computation of the elastic properties of rock.

1.3 Data Used

Seismic data provide is of three different vintages 2000, 2001 and 2003 acquired from Directorate General of Petroleum Concessions (DGPC). We are provided with 6 lines among which two are strike lines and four are dip lines, two wells have been used for research.

1.3.1 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 typically includes location of wells & seismic survey points as shown in Figure 1.1. Highlighted lines were assigned to me for completion of project.

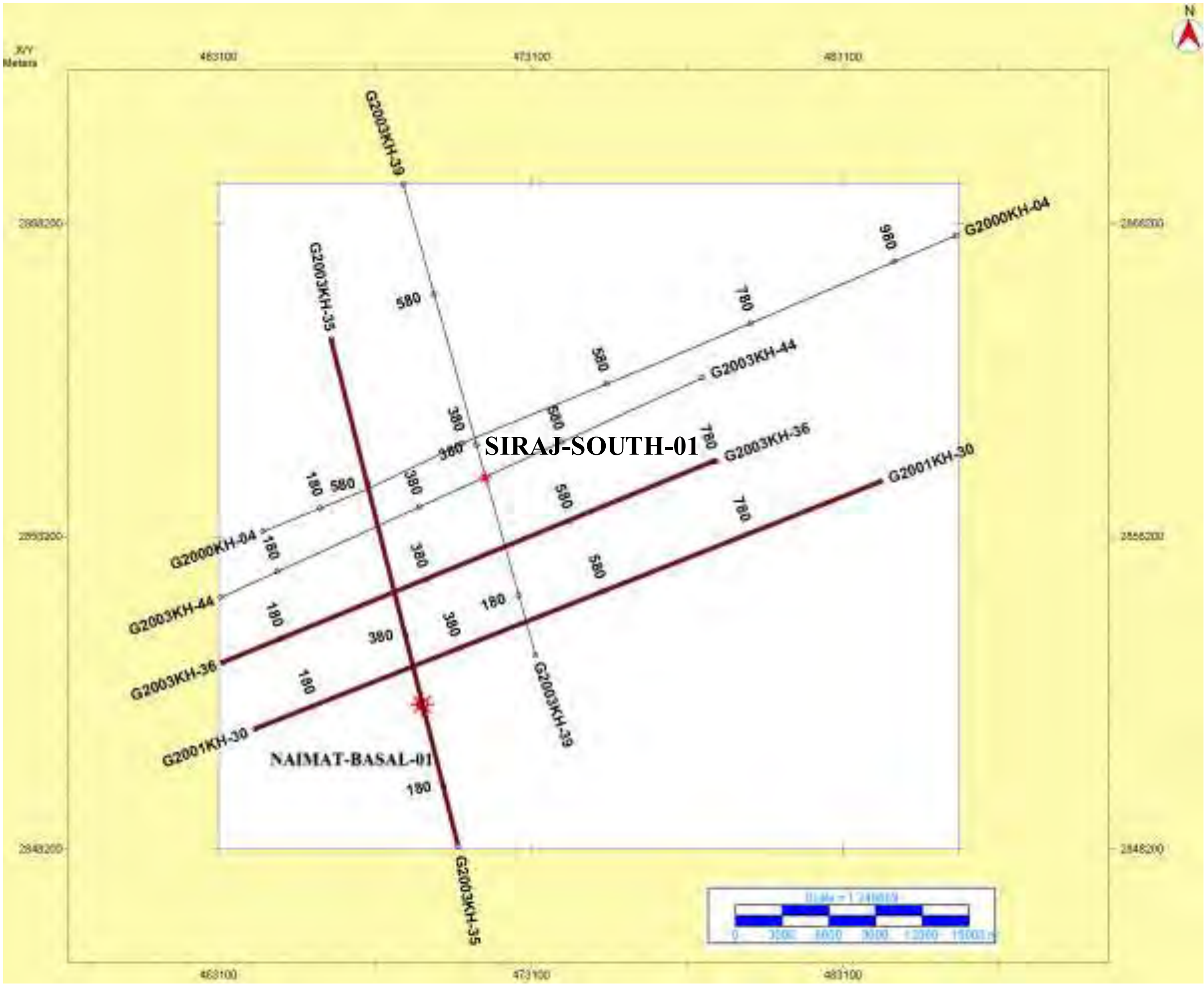

Figure 1.1: Base map of the area showing well and seismic lines.

1.3.2 Well Data

Well data of Naimat-basal-01 well of Khipro area is given in the table 1.1 and 1.2.

Technical Well Data			
Operator	**OPI**	**Province**	**Sindh**
Type	**Exploratory**	**Status**	**Gas/Cond**
Well Bore Name	**Naimat Basal-01**	**Source**	**Dynamite**
Longitude	**068.696482**	**Latitude**	**025.793802**
Depth Reference Elevation(ft.):	**110(m)**	**Total Depth(m)**	**3621.6300 m**
Depth Reference	**KB**		

Table 1.1: Well data used for research work.

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 the detailed information of naimat-basal-01 well.

1.4 Seismic Data Presentation

The digital format of data is utilized for interpretation of the subsurface structure and petrophysical analysis. Seismic lines are in a SEG-Y format chosen for further use of subsurface structural analysis in the Kingdom Software. Navigation file (DAT file) is in text format that is used to load the seismic lines. Information about the well location is available in the header of the LAS file (a text file having some basic information and depth versus wire line logs) of seismic data. Information in the LAS file comprises of the header that gives basic information about the well and the values of different types of logs are present below the header.

1.5 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 seismic attributes analysis is performed by using well log data and seismic data as shown in the figure 1.2 and1.3.

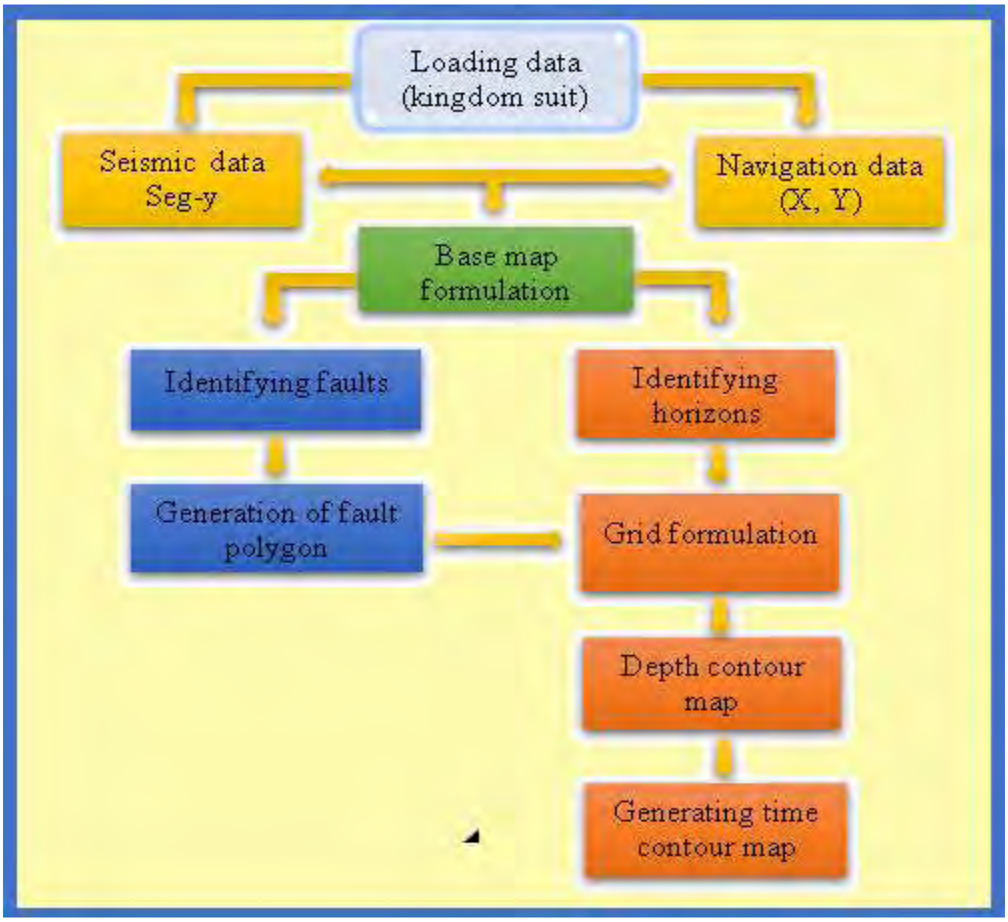

Figure1.2: Seismic interpretation flowchart.

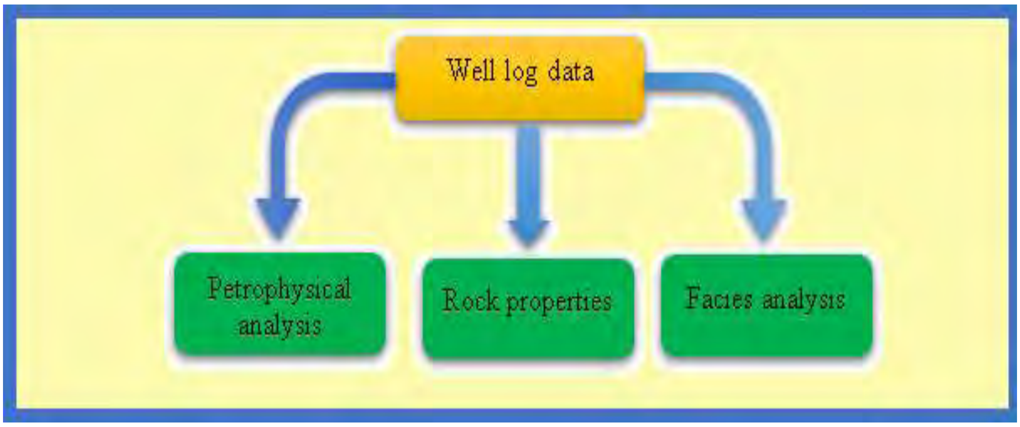

Figure 1.3: Petrophysical interpretation flowchart.

1.5.1 Methodology

It includes the generation of synthetic seismogram using seismic data and well data. Based on synthetic seismogram different horizons are marked on the seismic section. Faults are marked on the seismic section due to the discontinuities in the reflectors. Time and depth contours of the marked horizons are generated. Seismic attribute analysis of the marked horizons done on the seismic line for the confirmation of the seismic interpretation. Rock physics modelling is done for the confirmation of petrophysical interpretation, which is carried out for the indication of zone of interest.

1.5.2 Seismic Method

Types of seismic methods.

- Seismic reflection method
- Seismic refraction method

1.5.3 Types of Seismic Waves

- Body waves
- Surface waves

1.5.4 Seismic Attributes Analysis

- Frequency
- Phase
- Trace Envelop

1.6 Introduction to Study Area

The study area is laying in Southern Indus Basin. Normal faults are more prominent structures in the area (Horst and Graben geometry), which form the structural traps. The identification of these traps is one of the main tasks for the Geoscientists in exploration of hydrocarbon. To observe these structures the seismic lines 2003KH-44, 2000KH-04, 2001KH-30, 2003KH-35 and well Naimat-Basal-01 is provided by the Department of Earth Sciences Quaid-i-Azam University. Geographical location of the area are shown in Figure 1.4.

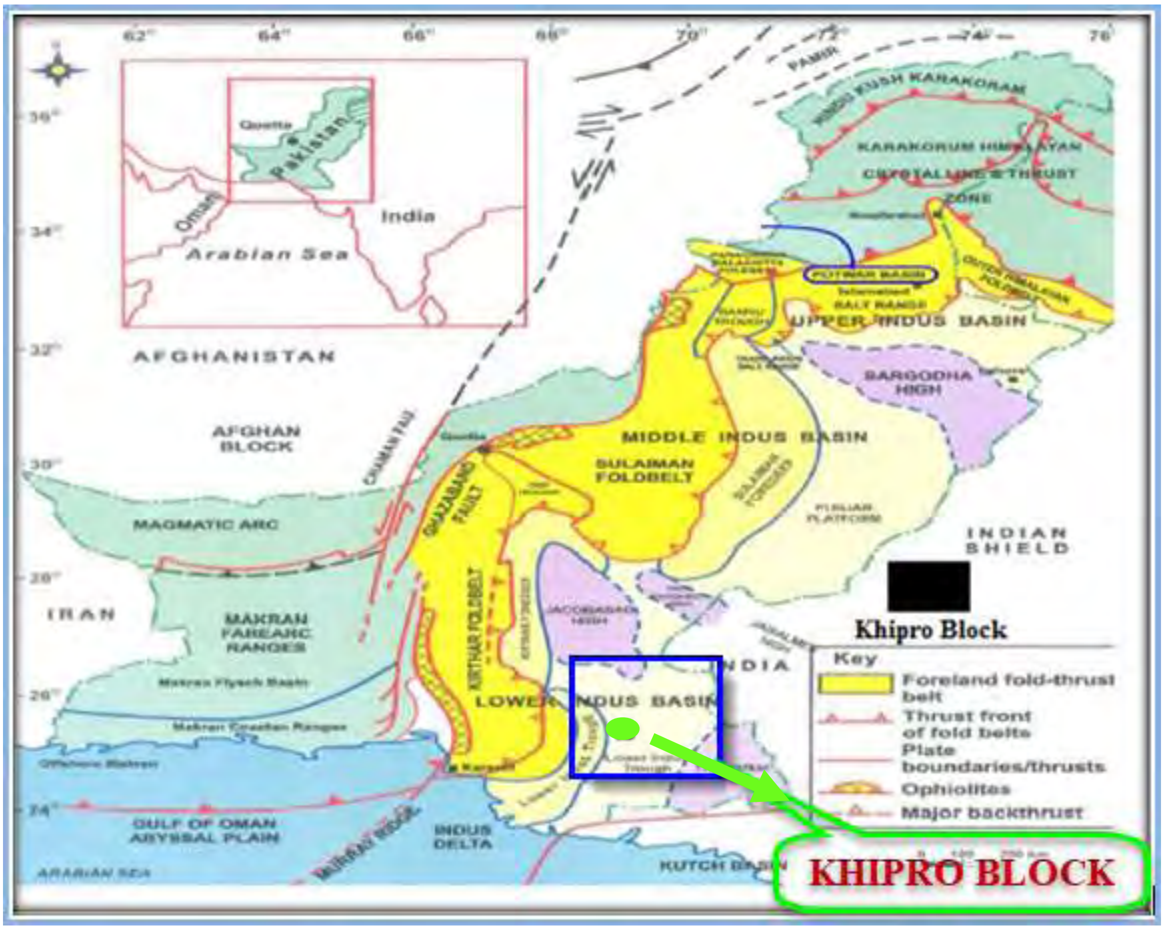

Figure 1.4: Shows the geographical location of the Khipro area Pakistan.

Latitude: 25 ° 45´ to 25° 57´ North

Longitude: 68° 36´ to 68° 54´ East

CHAPTER 02

GEOLOGY AND TECTONICS OF AREA

2.1 Introduction to Geology

General geology and geological history of an area is very important for exploration of oil and gas. A geological history of basin can be compiled by considering basin forming tectonics and depositional sequence (Kingston et al., 1983)

Rifting and breaks up Gondwana land in Jurassic period is responsible for the formation of Khipro block baisan. 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. Powell (1979) defines in article "A speculative Tectonic history of Pakistan and surroundings" that at the end of Cretaceous, Seychelles and Madagascar separated from India with associated faulting resulting in basaltic flows (Deccan Volcanism) in the southern part of lower Indus basin. 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 (Powell, 1979).

2.2 Geological Boundaries of Area

The study area is situated in southern Indus basin and have following geological boundaries.

- Sukhur rift from north
- Kirthar trough from west
- Indian shield from east
- Sindh monocline from south

2.3 Structural Settings of Study Area

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 Khandkot 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

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 (Kemal, 1991). According to Zaigham and K.A. Mallick,(2000), 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. Kirthar and Karachi depression contain several large anticlines and dome sand some of these contain small gas fields e.g. Sari, Hundi, Mazarani, but in eastern part of it, there are several faults and tilted blocks which form structural traps containing small oil and gas fields e.g. Sinjhoro, Khipro, Sanghar. On the northern side, there is Sukkur Rift zone bearing large anticlimax structures and contains Khandkot and Mari gas fields.

As the Khipro area lies in the foreland side of the Himalayas, so in that region normal faulting is common phenomenon. Faults are generally of low throw. Conjugate faulting is also sometimes present on small scale. As such no great structural variation found in Khipro although bookshelf geometry is present.

The structural style present in the area is due to result of a normal block faulting on west dipping Indus Plain. Kadri (1995) describes as the fault planes act as migrating paths for hydrocarbon from underlying shaly source sequence. Trends of faults and contours are mapped utilizing wells and seismic control for the field. Seismic interpretation creates basis for structural interpretation as no surface outcrops are found over the field. Study area characterized by a series of horst and graben structures present almost below the base Paleocene within the cretaceous age producing reservoir. Basal Sand is bounded on east and west by regional extension faults dipping to west and east and trending NW-SE (Kadri, 1995). Structural boundaries of the Khipro block are shown in the Figure 2.1.

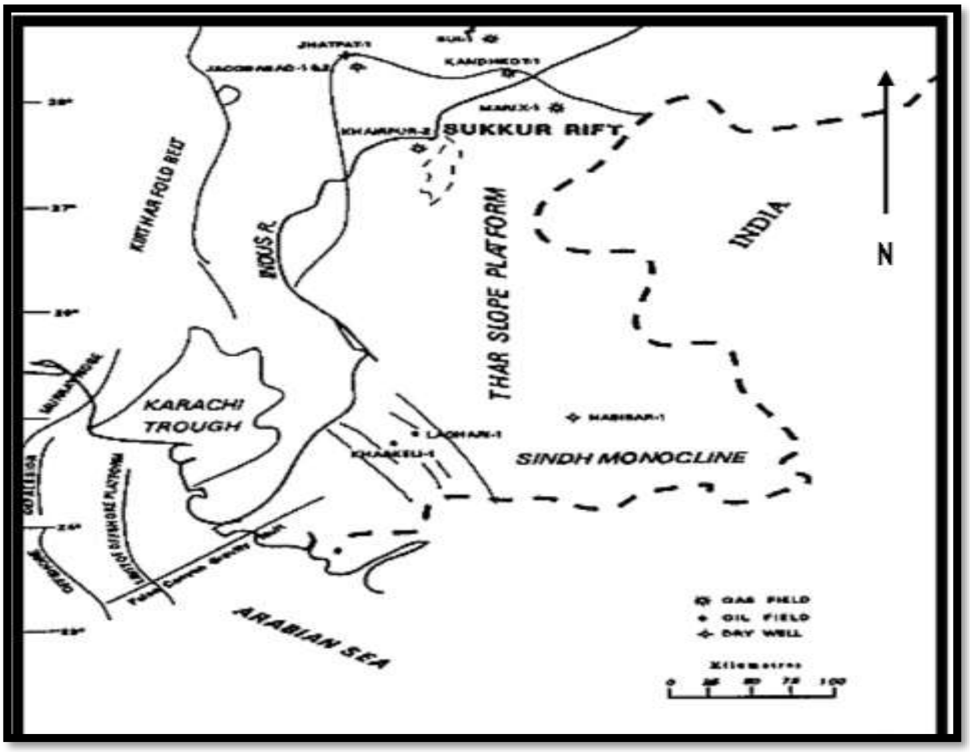

Figure 2.1: Shows the structural boundaries of the Khipro block.

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 and stratigraphic sequence of the study area is given below.

2.4.1 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).

2.4.2 Parh limestone

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

2.4.3 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).

2.4.4 Upper Goru

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

2.4.5 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).

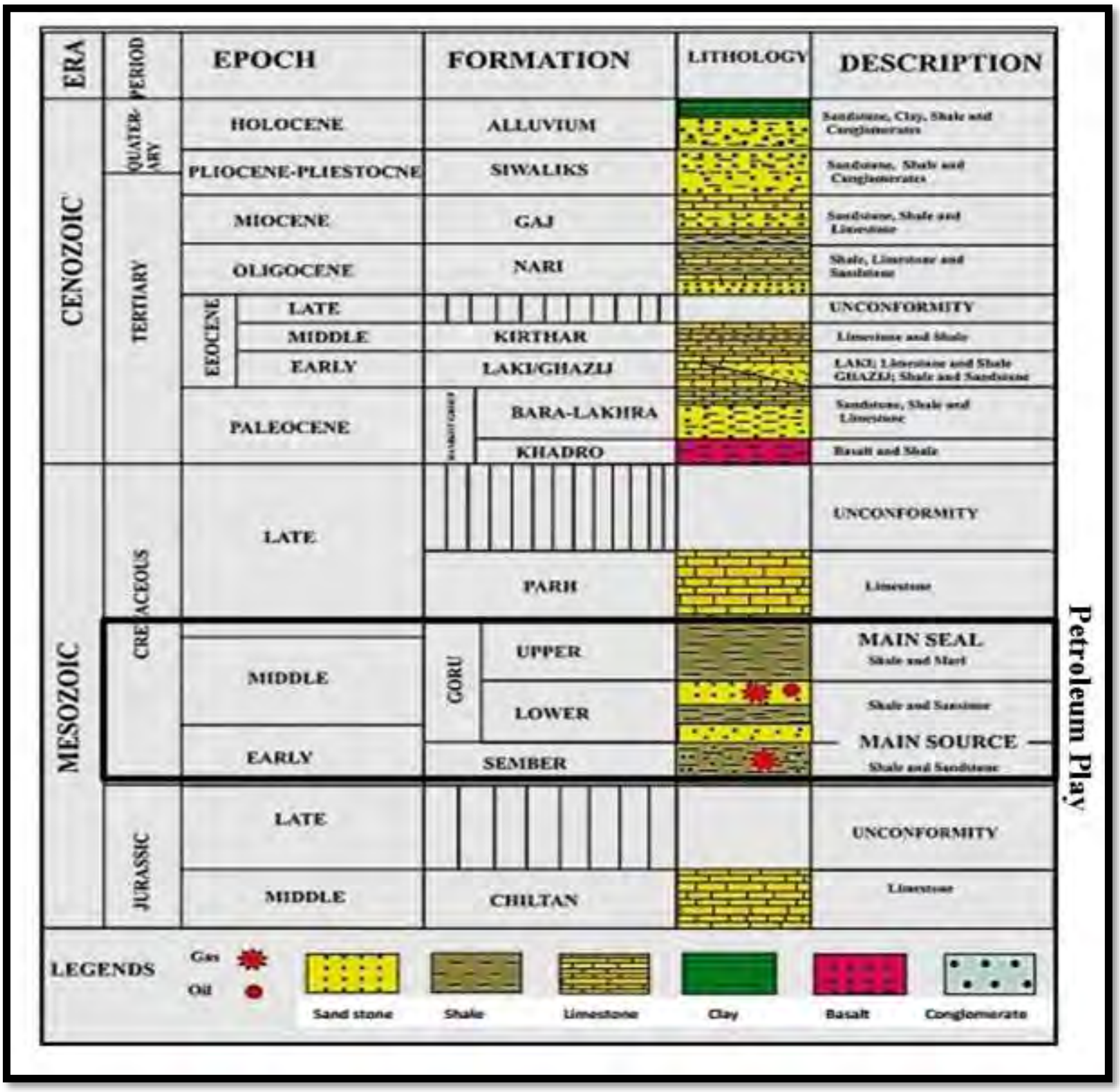

Figure 2.2: Delineates the petroleum play of the area and the stratigraphic information (Zaigham and K.A. Mallick, 2000).

2.5 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 extract from the lower Indus basin (Kadri 1995).

2.5.1 Source Rock

Sembar Formation of Early Cretaceous age is a proven as 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. Shale of Goru is widespread and very thick. They contain abundant organic matter and generally exhibit the good source rock characteristics (Kadri 1995).

2.5.2 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. Ranikot sandstone is also a good reservoir rock. 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. Because of 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).

2.5.3 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).

CHAPTER 03

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 prospects' 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

The Interpretation was carried out using different techniques and steps with each step involve different processes which were performed using the software tools as mentioned above. Simplified workflow used in the dissertation is given in Figure 3.1, which provides the complete picture depicting how the dissertation has been carried out by loading navigation data of seismic lines and SEG-Y in HIS kingdom Software.

Seismic Interpretation workflow includes;

- Provided seismic data was in SEG-Y format and well data in Las format which are used for preparation of base map.
- Synthetic seismogram is generated using well log data and trace from seismic line on which the well is drilled.
- Horizons of interest are marked based on the synthetic seismogram and formation tops.
- Faults are marked on the seismic section after knowing the geology of the area. Faults can also be marked based on the discontinuities within the horizon.
- After fault interpretation generation of fault polygons is carried out on the base map.
- Two-time contour maps are generated for marked horizons. Depth contour maps generated by using the well point velocity.
- Seismic attribute analysis is carried out to confirm the fault and horizon interpretation on the seismic section.

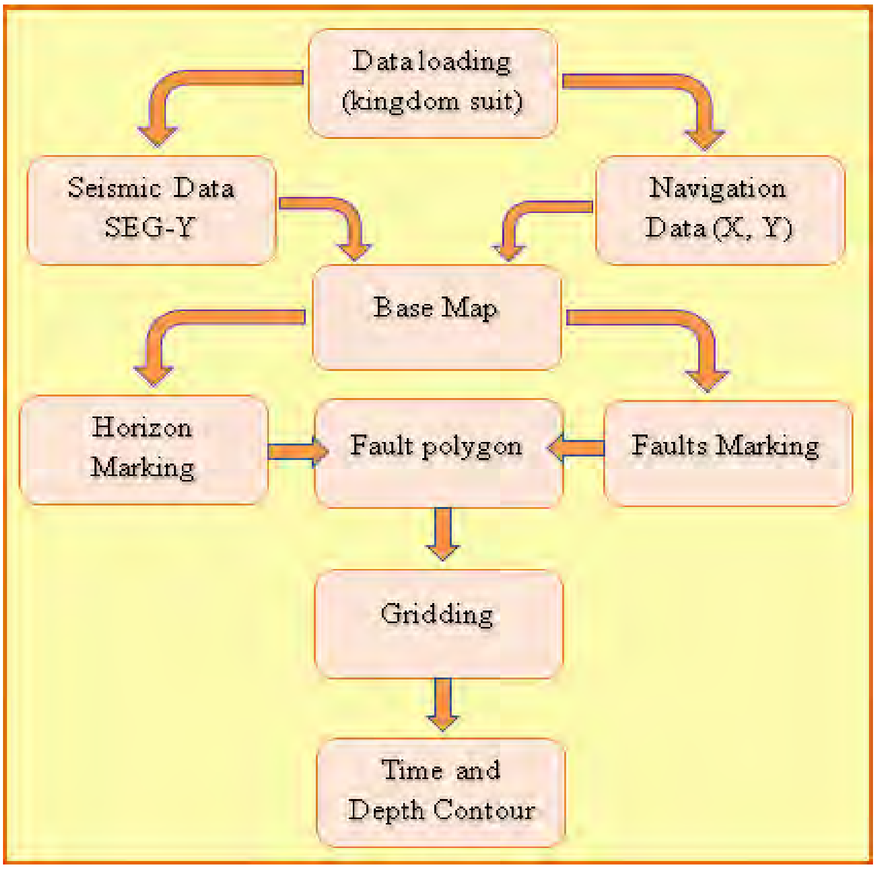

Figure 3.1: Workflow for seismic interpretation.

3.5 Synthetic Seismogram

Synthetic seismogram is an artificial seismic trace that is used to establish for correlations between local stratigraphy and seismic reflections. To produce a synthetic seismogram a sonic log is used. Generally, a density log is used, but sometimes it may not be available. Well data of Naimat-01 well is used to construct the synthetic seismogram, which helps us in identifying the horizons, so that we can mark them easily on seismic section.

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 from well and replacement velocity of the area. By using two-way time against each well top depth time depth chart is prepared. Also, Sonic log (DT) is used itself for the generation of synthetic seismogram as well as Density log (RHOB), gamma ray log (GR) is used as reference log. Wavelet is extracted from the seismic line on which the well is located within frequency range of 50Hz. Seismic trace is also extracted which is used for well to seismic tie, trace is extracted from the seismic line G2003KH-35. And then finally synthetic seismogram is generated by convolving the well data and extracted wavelet having frequency of 50Hz. The synthetic seismogram of Naimat Basal-01 well is shown in figure 3.2 respectively.

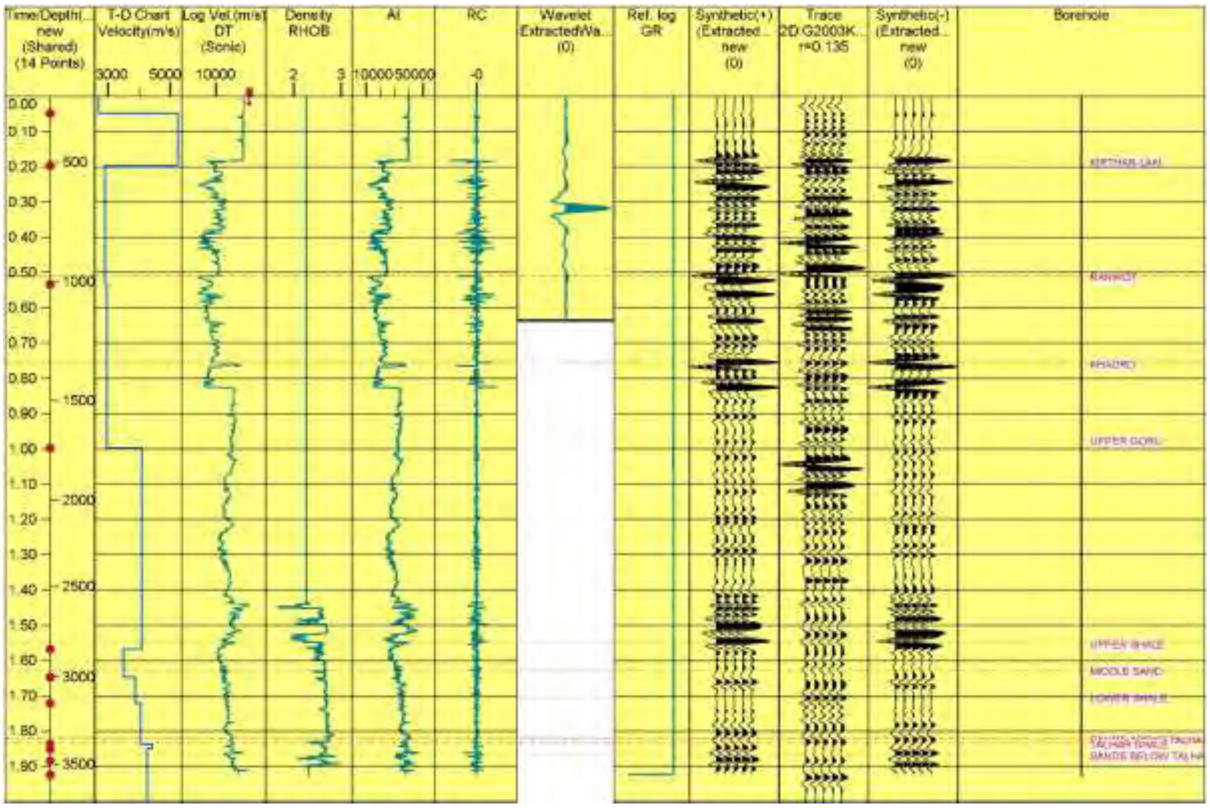

Figure 3.2: Showing synthetic seismogram of Naimat-Basal-01.

3.6 Horizon Marking and Fault Identification

As we know that for interpretation of seismic data we must know about the horizons as an interface between geological formation. For doing this we need to know about the structural and stratigraphic information of the area so for this purpose.

I marked three horizons based on synthetic seismogram of Naimat-basal-01 well. Naimat-basal-01 is drilled on line G2003KH-35. Three horizons are picked on line G2003KH-35 while on remaining five lines horizons are picked by digitize arbitrary line method. Marked horizons are named as Middle Sand, Sand above Talhar Shale and Sand below Talhar Shale.

For the project I have been given with following three lines, G2001KH-30, G2003KH-35, and G2003KH-36. Three seismic horizons (of early cretaceous age) are marked. Along these seismic horizons, different normal faults are marked. The interpreted seismic sections of the assigned lines are shown in figure 3.3, 3.4, 3.5. As we can see from the marked seismic section horsts and grabben structure are clear except on line G2003KH--35 which is a strike line. The horsts and grabben structures are associated with normal faulting which shows the study area lies in extensional regime. Also, bookshelf symmetry can be seen clearly on the seismic section.

Line G2003KH-35

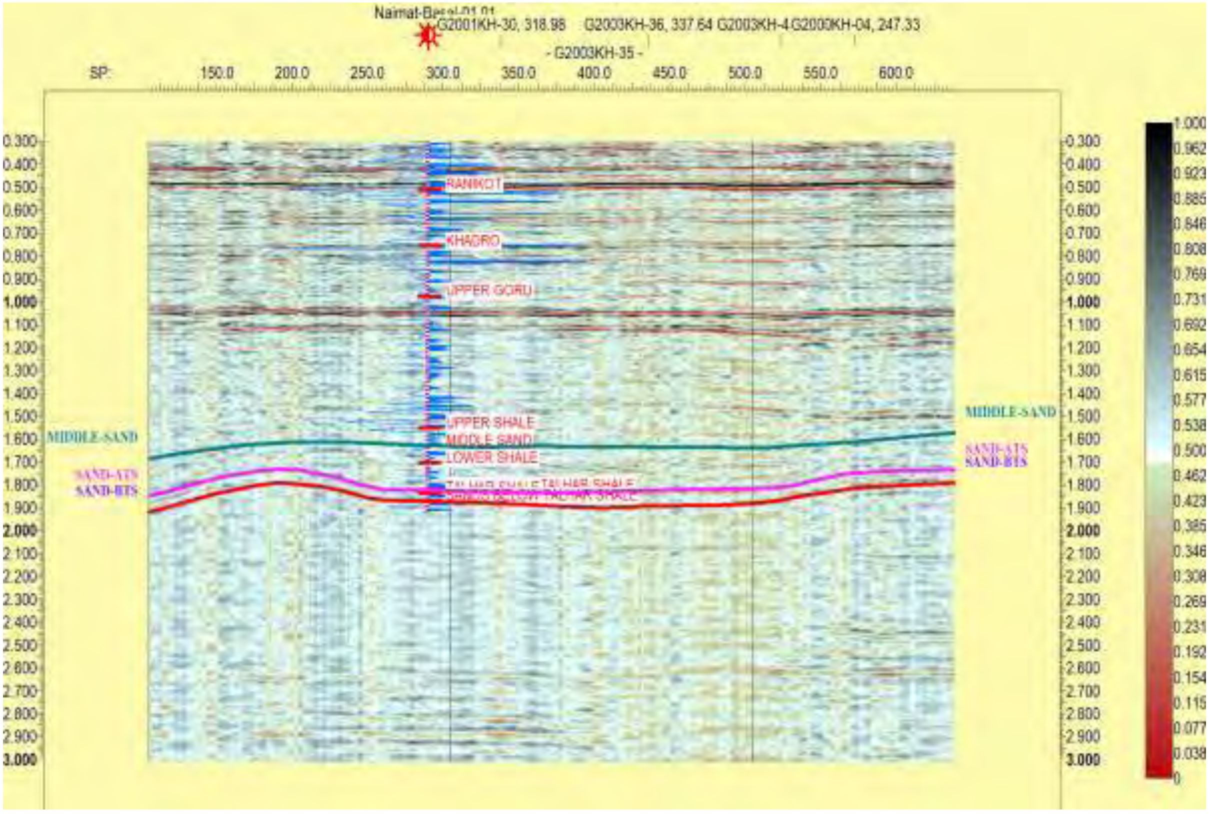

Figure 3.3: Figure shows strike line G2003KH-35, along with well and the marked horizons, line orientation is from NW to SE.

The strike line G2003KH-35 shows Naimat-Basal-01 well on which three horizons are marked among the three Sand above Talhar Shale and Sand below Talhar Shale are main reservoirs, Middle Sand is also a reservoir formation. Faults are not marked on the strike line because structure are form from east to west. Reflectors of three formations are marked with the help of synthetic seismogram of Naimat-Basal-01 well.

Line G2001KH-30

Figure shows dip line G2001KH-30 on which three horizons are marked by using digitizing technique, also there are seven major faults marked on dip line based on the discontinuities along the reflectors and normal faults are marked based on the geology of the area. Delineating horst and graben structure which are formed as a result of normal conjugate faulting. There is no reverse faulting in the area. As Fault F2 is dipping toward east while F3 fault is dipping toward west and hanging wall is moving downward, it shows graben structrue. F4 fault is dipping toward west while F5 is dipping opposite to F4 fault in east and hanging wall is moving downward over the dip of both faults. These area the indicators of horst and graben structure in khipro area of Pakistan. It also confims the horizon interpretation. Figure also shows that book shlef symmetry.

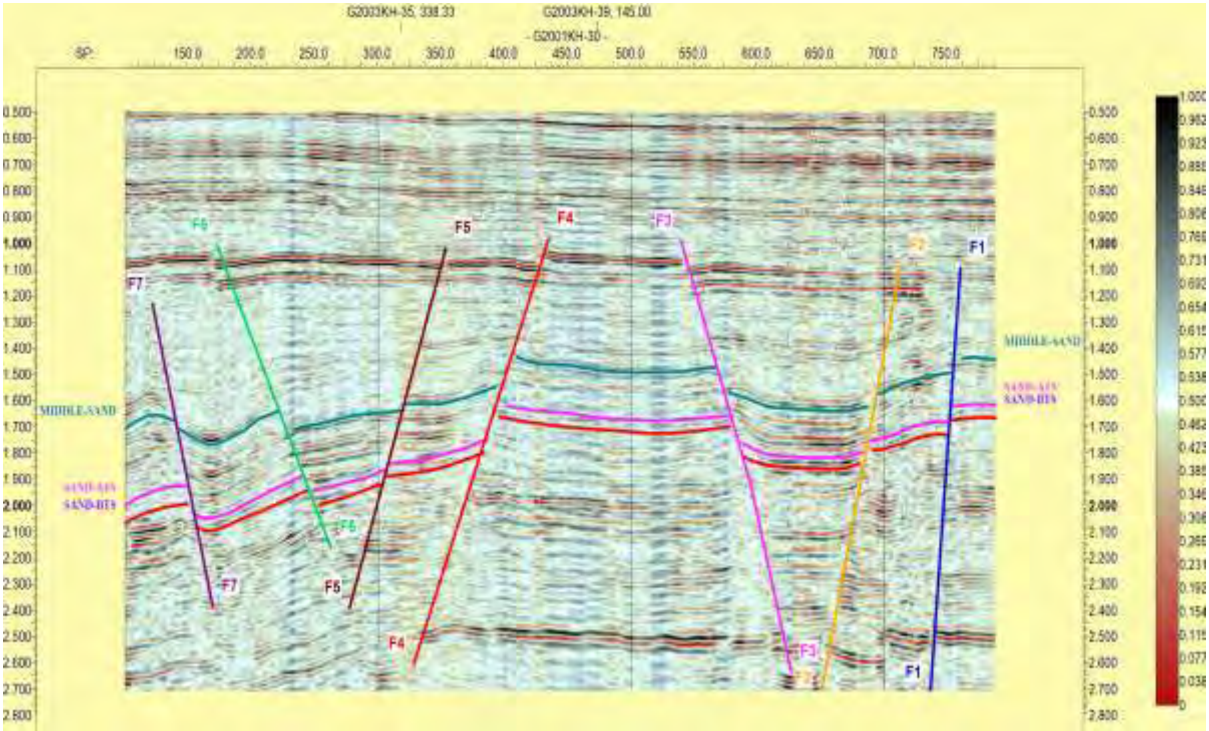

Figure 3.4: Figure shows dip line G2001KH-30, also marked horizons with associated faults are shown, also line orientation is from NE to SW.

Line G2003K-36

Dip line G2003KH-36 is shown in figure 3.5 on which horizons are marked by using digitizing technique, also five major faults are marked by keeping in view the geology of the area. As from the figure 3.5 horst and graben structures can be identified on the dip line. These horsts and grabben structures are the result of normal faulting which delineates that the area lies in extensional regime.

Horst is present between fault F4 and F5 also graben is structure is in between fault F2 and F3. The discontinuity in the reflection can be seen on seismic section which confirms the fault identification.

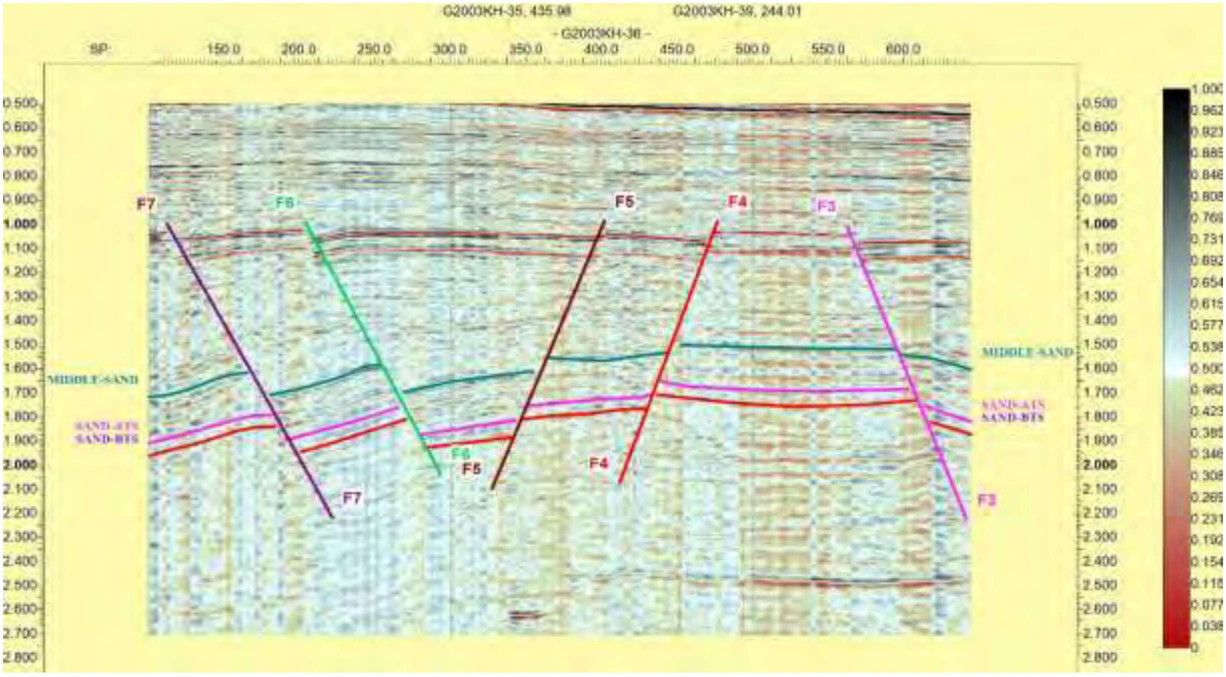

Figure 3.5: Figure shows dip line G2003KH-36, also marked horizons with associated faults are shown, line orientation is from NE to SW.

3.7 Construction of Fault Polygon

As we know that fault polygons are linear data which represent the hanging wall and the foot wall for each horizon. So, in this step we construct fault polygons that is very important as far as time and depth contouring of a horizon is concerned.

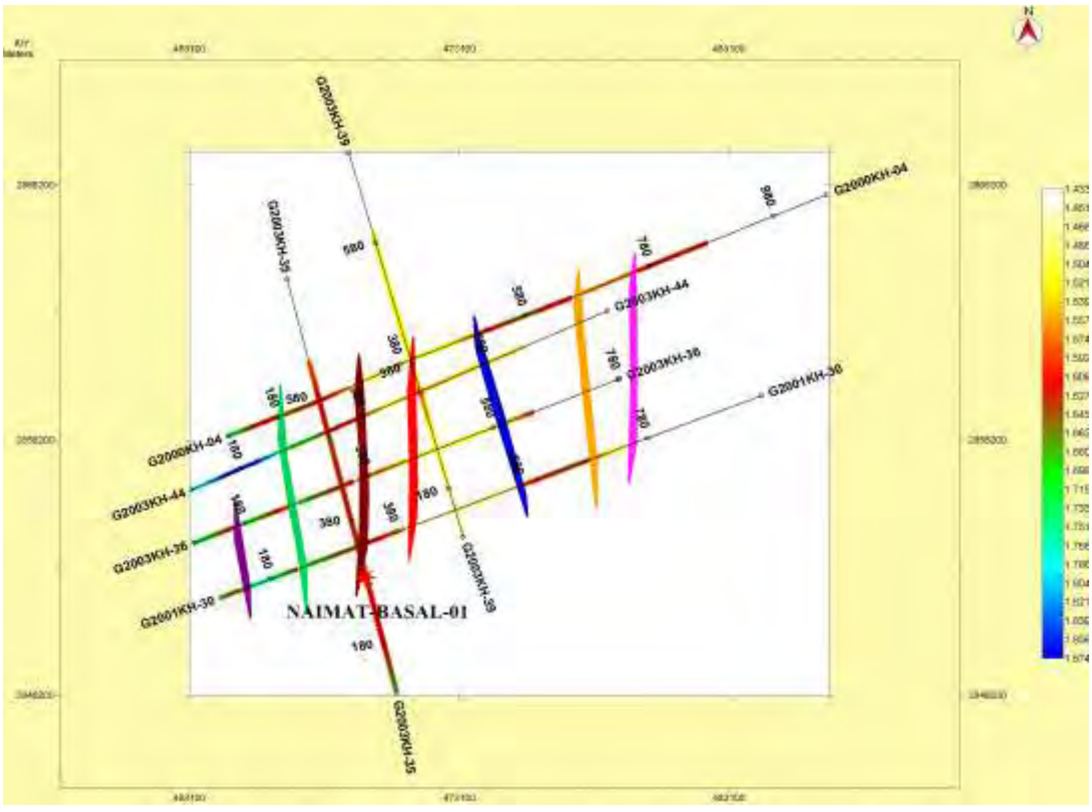

Figure 3.6: Fault polygon of horizon Middle Sand.

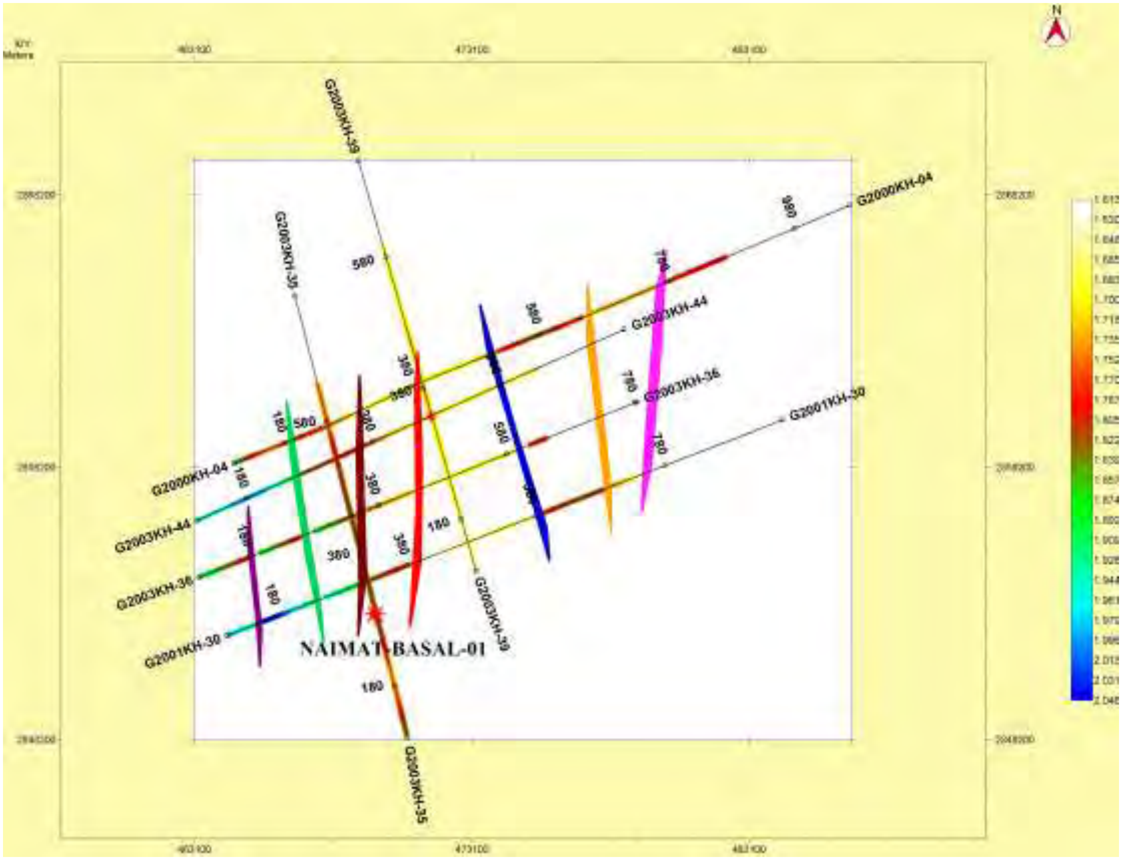

Figure 3.7: Figure fault polygon of Sand above Talhar Shale.

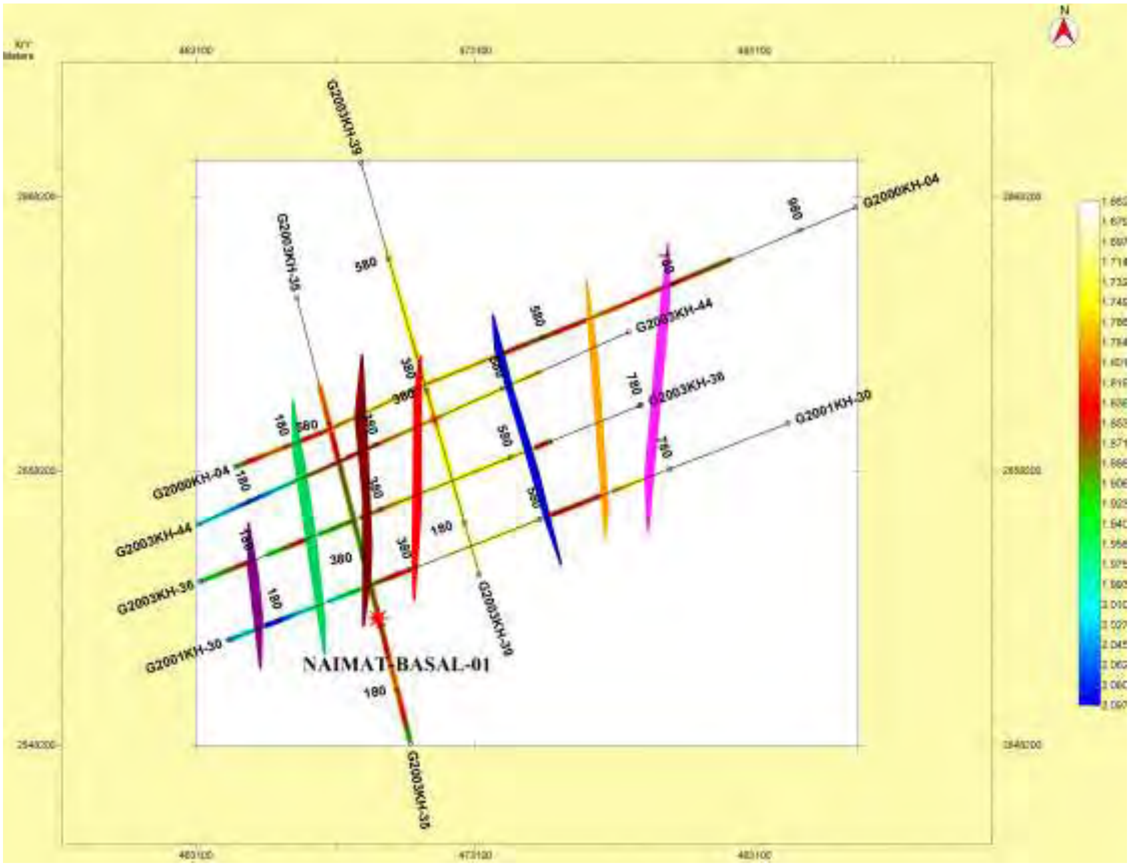

Figure 3.8: Fault polygon of Sand below Talhar Shale.

There are seven polygons as shown in the figures above. Polygons are oriented in NE to SW direction.

3.8 Formation of Grids and Contour Maps

An area has been selected for further detailed exploration based on preliminary geological investigation and economic criteria, the definition of the grid for sub subsequent geochemical and geophysical exploration represents the first step into exploration statistics. Now the last step in structural interpretation is contouring. Contour line is defined as, a line on map representing an imaginary line on the land surface, all points of which are at the same elevation above a datum plane usually mean sea level. Contouring is the main tool used in the seismic interpretation. Through contouring we can conclude that what type of structures are present over a horizon. Horizon 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).Here we will discuss two types of contours one is time contour and other one is depth contour.

3.8.1 Time Contour

The figure 3.9, 3.10 and 3.11 illustrates time contour of all the three horizons Middle Sand, Sand below Talhar Shale and Sand above Talhar Shale. As we know that time contour map shows lateral as well as vertical variation. Figures shows horst and graben structures are present. Bookshelf symmetry can also be seen on the west of F4 fault. Time contour maps confirms the structural interpretation done on seismic section for all the three. Trend of all contour maps is same which shows there is no vertical variation. All horizons deform equally by faulting.

3.8.2 Depth Contour Maps

For depth contouring we need depth horizons which can be formed by using average velocity. This velocity can be found from well point and it will be very accurate if correlation is good. As we know that depth contour map 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.

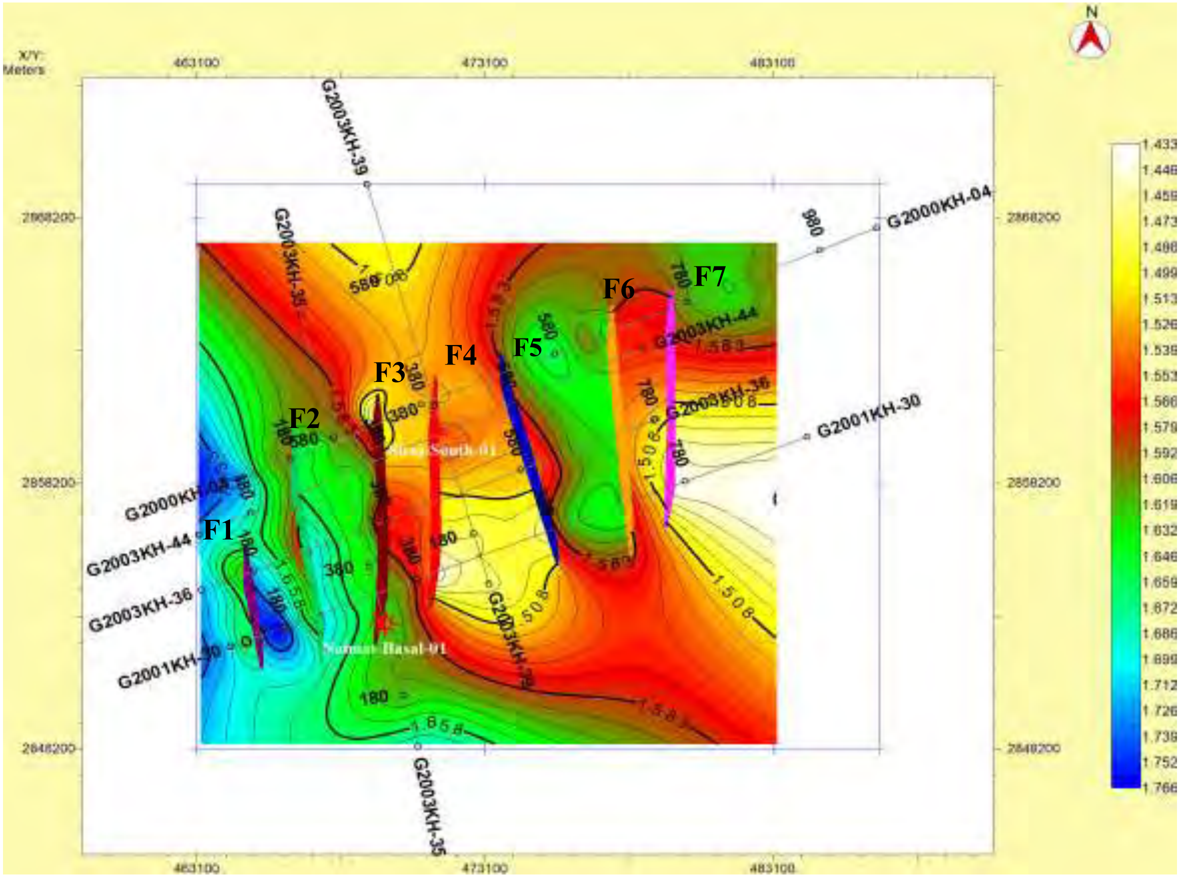

Figure 3.9: Time Grid and Time contour map of Middle Sand horizon.

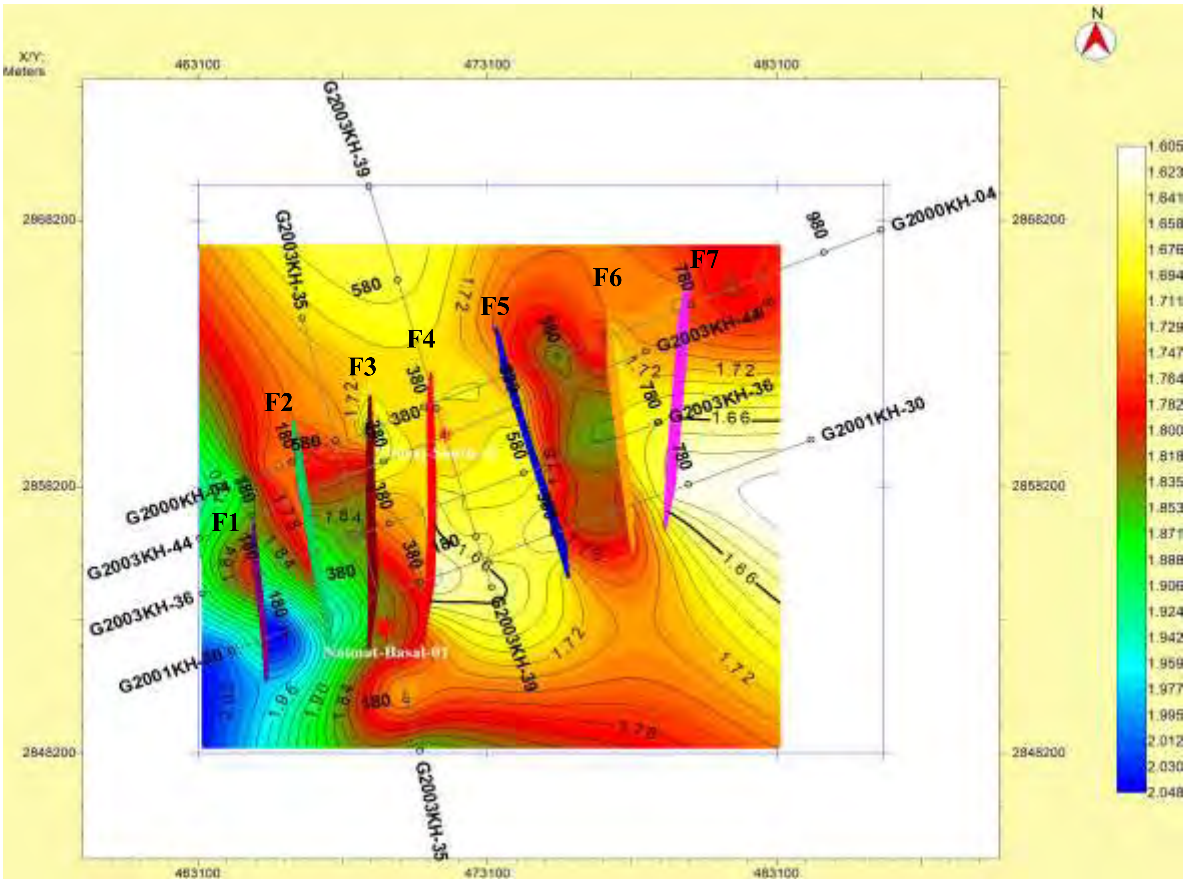

Figure 3.10: Time Grid and Time contour map of Sand above Talhar Shale.

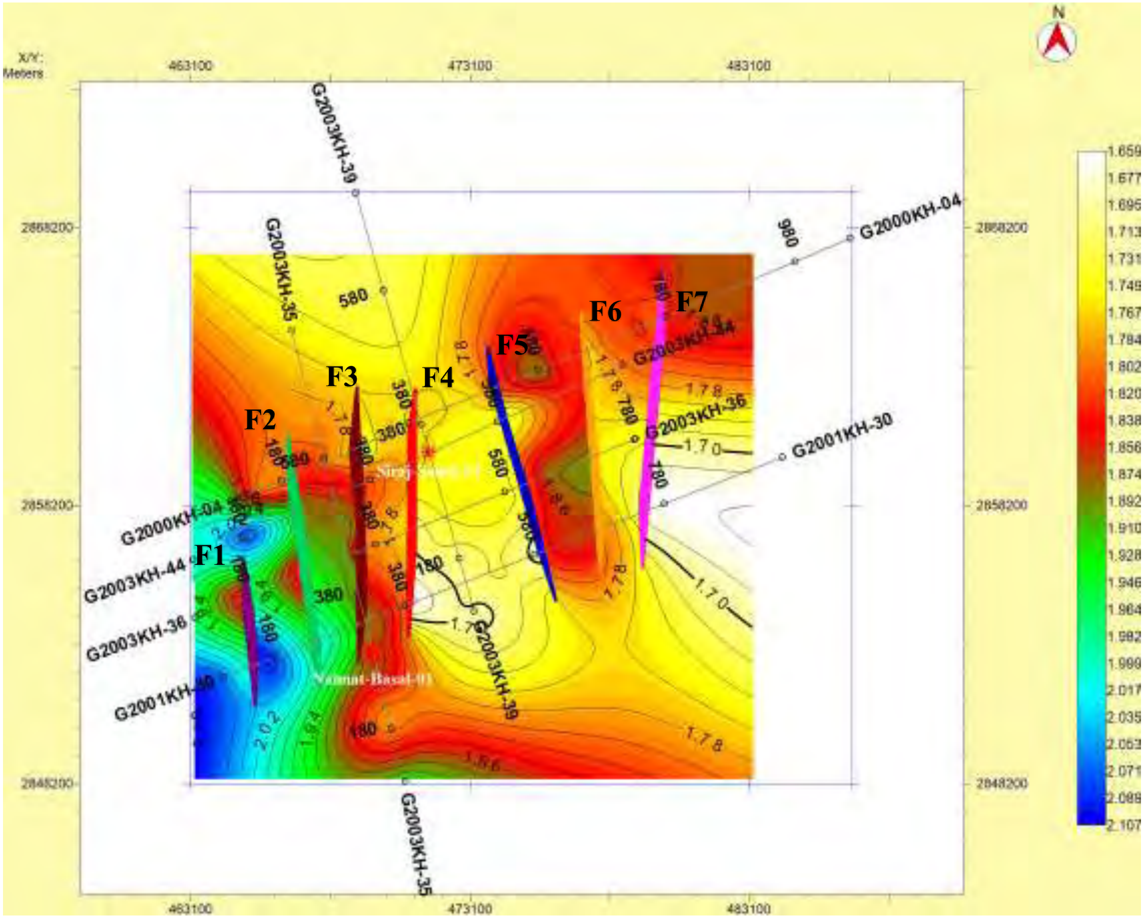

Figure 3.11: Time Grid and time contour map of Sand below Talhar Shale.

From the figures 3.12, 3.13 and 3.14, shows the depth contour map of three horizons Middle Sand, Sand below Talhar Shale and Sand above Talhar Shale. Horsts and grabben structures are clear which can also be seen on time contour maps.

As F4 fault is dipping towards west while F5 fault is dipping toward east, depth has low values between conjugate faults F4 and F5 which shows shallower region while depth has high values between conjugate faults F5 and F6 which delineate deeper region, it indicates horst and graben structure in the area also identify the extensional regime.

As fault F1, F2, F3 and F4 are parallel and are dipping in the same direction towards west as a result bookshelf symmetry is formed, which the result of normal is faulting as a result of extension in the area. It also confirms the horizon interpretation and fault interpretation done on the seismic sections in figures 3.4 and 3.5.

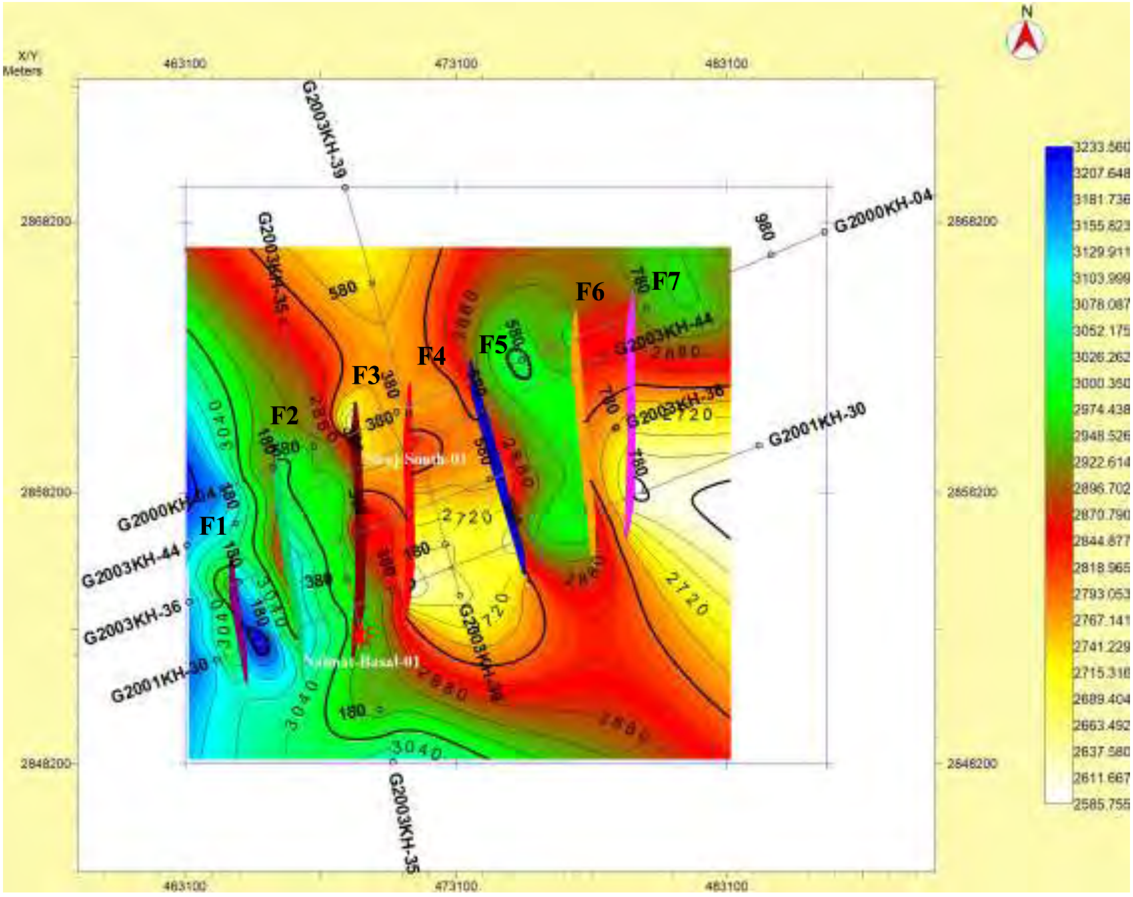

Figure 3.12: Illustrates the depth grid and depth contour map of Middle Sand.

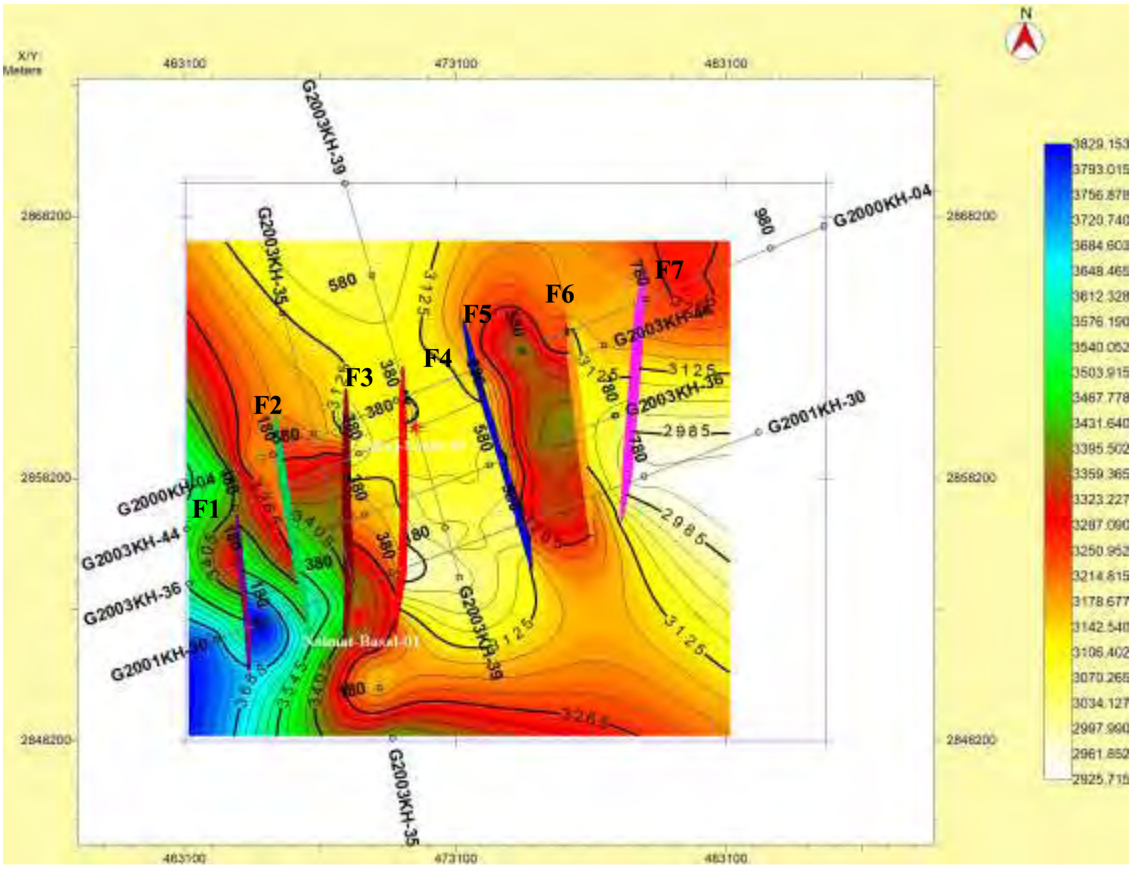

Figure 3.13: Illustrates the depth grid and depth contour map of Sand above Talhar Shale.

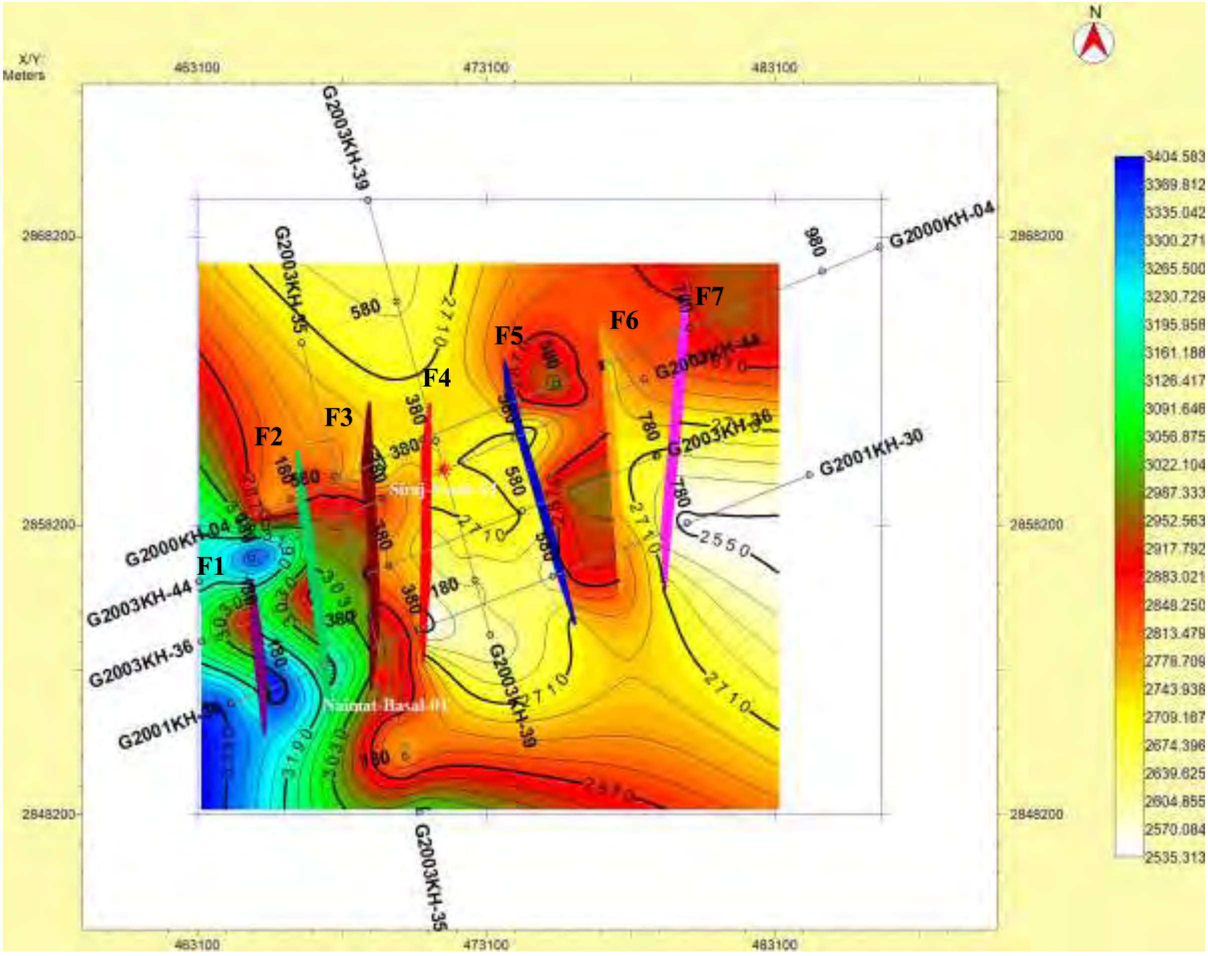

Figure 3.14: Illustrates the depth grid and depth contour map of Sand below Talhar Shale.

CHAPTER 04

SEISMIC ATTRIBUTE ANALYSIS

4.1 Introduction

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

4.2 Types of Seismic Attributes

Attributes can be computed from pre- stack or from post- stack data, before or after time migration. The procedure is the same in all these cases. Attributes can be classified in many ways. Several authors have given their own classification. Here we give a classification based on the domain characteristics of the attributes (Taner 1994).

4.2.1 Post-Stack Attributes

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

4.2.2 Physical Attribute

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

4.2.3 Geometric Attribute

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

4.3 Attribute Analysis of Line G2003KH-36

4.3.1 Envelope of Trace

Envelop trace also called reflection strength is a physical attribute is used to indicate impedance contrast, total instantaneous energy of the trace, it may represent the individual interface contrast or, more likely, the combined response of several interfaces, depending on the seismic bandwidth, also represent bright spots, unconformities, thin bed tuning, major changes in depositional environment, major changes of lithology, spatial correlation to porosity and other lithological variations, indicates the group, rather than phase component of the seismic wave propagation (Subrahmanyam and Rao, 2008).

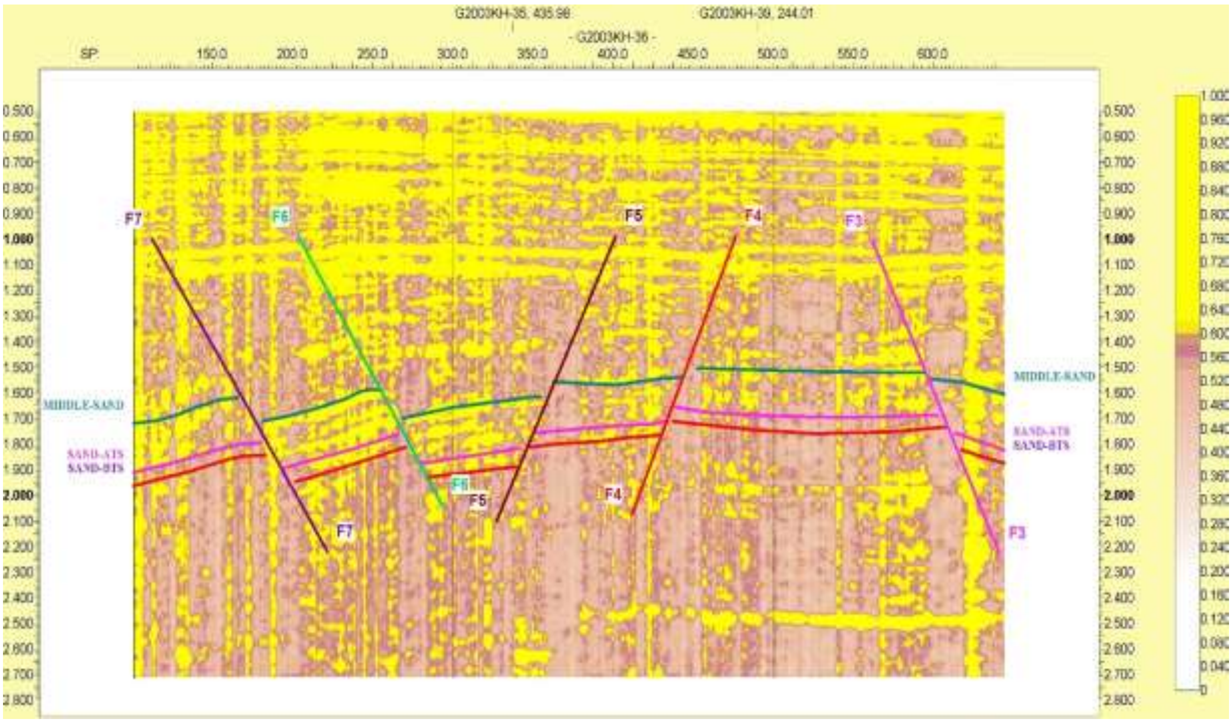

Figure 4.1: Envelop attribute applied on seismic section G2003KH-36, orientation is NE to SW.

As we can see from the figure above shows thick reflection package is indicative of strong positive reflection strength as compared to source and seal rock. It also shows spatial patterns representing changes in the limestone thickness and breakage due to the faults. From the figure 4.1 we can conclude that reflection strength weakens at the fault location. Also, discontinuity in the reflection strength is an indicative of confirmation of faults. Envelop attribute also confirms the horizon and fault interpretation done on seismic section G2003KH-36 as shown in figure 3.5.

4.3.2 Average Energy

Energy and the seismic attribute have the direct relation. Average energy attribute shows the lateral continuity and the reflection strength. The attribute has a blocky response and individually highlights the seal, reservoir and source rocks.

These attributes indicate spatial variation of the wavelets and therefore relate to the response of the composite group of individual interfaces below the seismic resolution. Figure 4.2 shows the discontinuity in the average energy which confirms the presence of faults, it clearly shows the faults displacement and discontinuity. Also, the portion in between faults F4 and F5 is elevated shows horst structure while portion in between F2 and F3 faults is depressed shows graben structure. Average energy attribute also confirms the interpretation of fault marking on seismic line G2003KH-36.

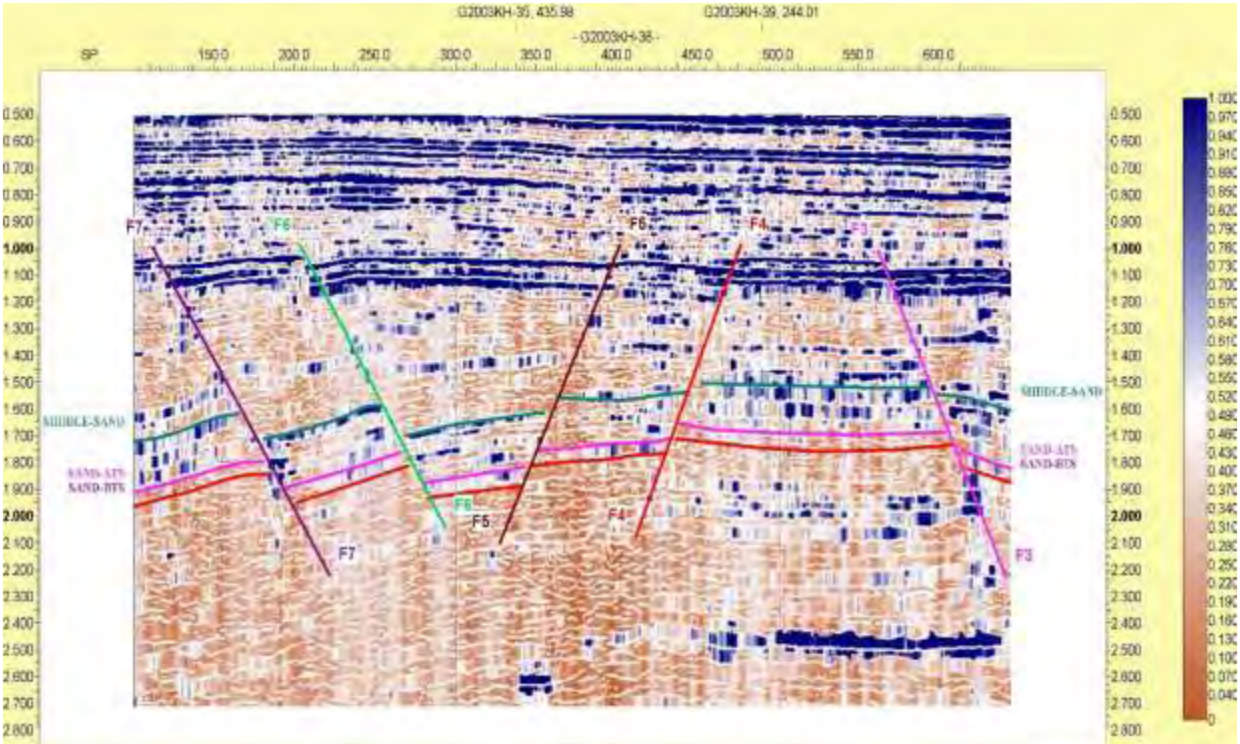

Figure 4.2: Average energy attribute applied on seismic section G2003KH-36, orientation is NE to SW.

4.3.3 Phase Attribute

Phase is a physical attribute and used for the geometrical shape classification. It is independent of amplitude and depend on the propagation of the seismic wave front. 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. It can be used to highlight interface in sections with high decay of amplitudes and even highlight deeper horizons which are not visible in the normal amplitude sections (Subrahmanyam and Rao, 2008).

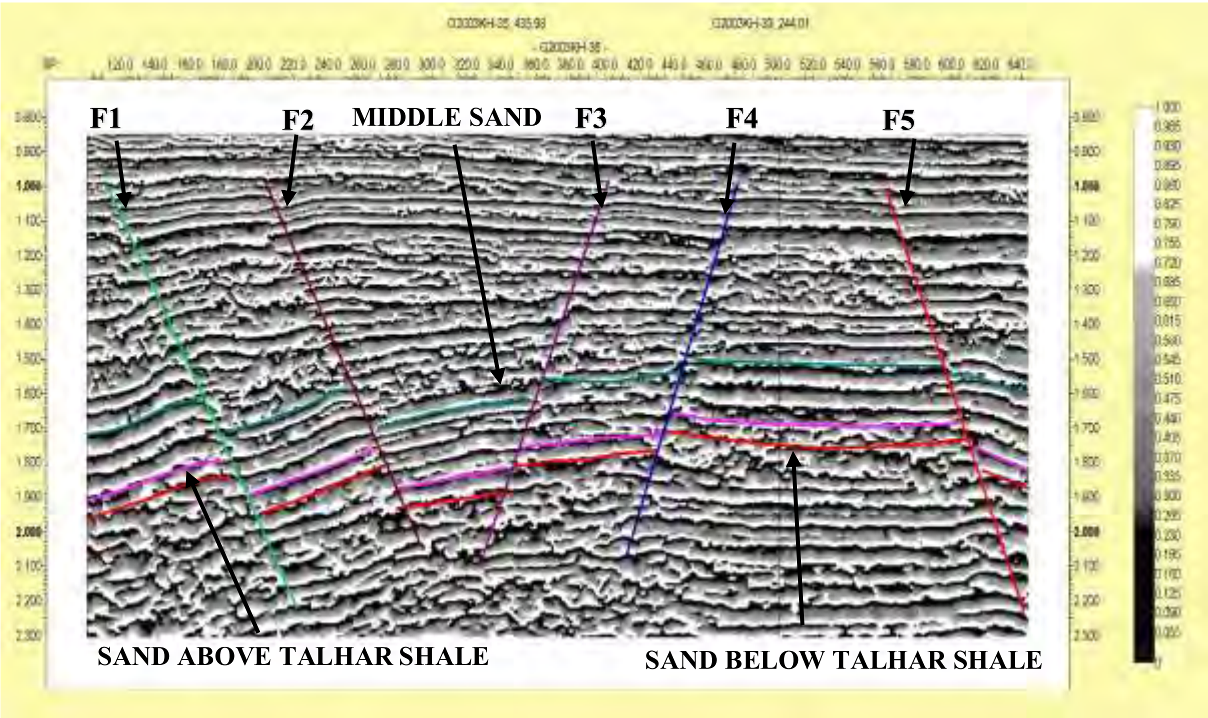

Figure 4.3: Phase attribute applied on seismic section G2003KH-36, orientation is NE to SW.

Instantaneous phase is the best indicator of lateral continuity, relates to the phase component of the wave propagation and has no amplitude information, hence all events are represented. It can be used to highlight interface in sections with high decay of amplitudes and even highlight deeper horizons which are not visible in the normal amplitude sections. It can be observed in comparison to amplitude base sections that the instantaneous phase shows much deeper horizons. The phase attribute in Figure shows the lateral continuity. Based on this horizon interpretation done on seismic section is confirmed.

CHAPTER 05

PETROPHYSICS OR WELL LOG ANALYSIS

5.1 Introduction

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 obtained by use these well logs. Every well log has its own importance and these logs play very important role in quantifying the precise reservoir parameters such as porosity, permeability, net pay zone, fluid content and shale volume. Petrophysical interpretation generally has less concern for seismic while more concerned with using well bore measurements to contribute to reservoir description (Asquith et al, 2004).

Propose of well logging is to determine various properties of different lithology and 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 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.

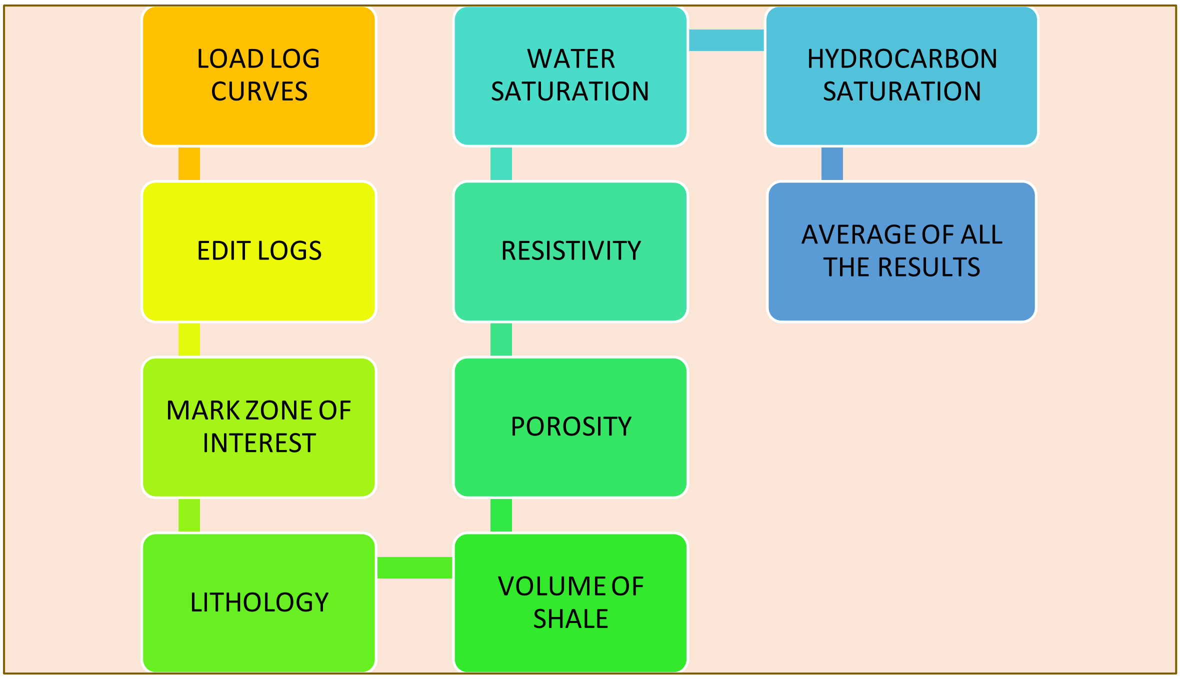

Figure 4.1: Workflow for petrophysical interpretation.

5.2 Classification of Geophysical Well Logs

Geophysical well logs can be classified into three categories

- Lithology logs
- Resistivity logs
- Porosity logs

5.3 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)

5.3.1 Caliper (CALI)

Caliper logs measure the diameter of the borehole. It records the cavities where the well is caved in, and 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).

5.3.2 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:

$$I_{gr} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$

Where GR_{min} is minimum value (17.7399) and GR_{max} is the maximum value (2.8857) 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).

5.3.3 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 1000 ohm) with depth. Resistivity logs are:

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

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).

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).

5.3.4 Porosity well logs

Porosity well logs 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)

Sonic logs measure the interval transit time (Δt) 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. 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).

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.

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

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.

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,

- $\emptyset_d$ is the porosity derived from the density log
- ρ_b is the bulk density of formation
- ρ_m is the matrix density and for sandstone it is 2.65
- ρ_f is the density of fluid (0.3 for Gas).

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.

$$\varphi_{avg} = \frac{\varphi_n + \varphi_d + \varphi_s}{3}$$

Where,

- $\emptyset_{avg}$ is the average porosity calculated from the available porosities
- Φn is the neutron porosity
- $\emptyset_d$ is the density porosity
- $\emptyset_s$ is 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 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". For water saturation we must have borehole temperature and resistivity of mud filtrate. So first we need to find resistivity of water to find the water saturation.

$$S_{sp} = -\text{K} * \log \frac{R_{mf}}{R_w}$$

for K,

$$K = 65 + 0.24 * T\text{°C}$$

We can find value of SSP from Sp log curve as SSP is the maximum deflection towards negative side, and Rmf is given resistivity of mud filtrate.

So then saturation of water in the formation can be calculated by the following Archie equation.

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

Where,

- F is formation factor which is

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

- R_w is the resistivity of water calculated from above formulation (0.03).
- R_t is the true formation resistivity

- n is the saturation exponent (2)
- a is the constant and its value is 0.62 in case of sand
- $\emptyset$ represents effective porosity
- m is the cementation factor and it value is taken 2.15 for the sandstone.

5.7 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.

$$S_h=1-S_w$$

Where,

- S_w is Hydrocarbon saturation
- S_h is hydrocarbon saturation

5.8 Well log interpretation

IHS Kingdom software is used for the analysis of well Naimat-basal-01. Due to collapsing of wellbore Rugosity effect will be occur. Therefore, in the depth ranges, if there is Rugosity the value of the other log is not consistent.

1. As we know that we are looking for reservoir zone where hydrocarbon saturation is very important so for this, we need to interpret all logs in addition with other logs like porosity, water saturation, hydrocarbon saturation.
2. First of all, the crossover between NPHI and RHOB is important, but the crossover should be on the lower side for both log curves, as we know that hydrocarbon has less density but for hydrocarbon accumulation porosity is necessary so porosity should be little higher in case of hydrocarbon but overall the crossover should be on lower side.
3. Secondly, separation between LLD and LLS is very important for petrophysical interpretation, as the separation of LLD and LLS shows the accumulation of hydrocarbon. In resistivity we have 3 zones flushed, transition and uninvaded zone. So, in flushed and transition we have brine mud and in uninvaded zone its hydrocarbon that's why we get separation in LLD and LLS.
4. In the third step we interpret Vsh which is calculated by linear method, Shale and sand is being separated by applying 40% cut-off value. Below this cut-off value, there is sand and above this cut-off, there is shale.

5. Then after that interpretation of porosity logs are done whereas in reservoir zone porosity should be higher such that accumulation of hydrocarbon could possible, for this density porosity log, effective porosity, and total porosity logs are made.
6. Now the last step is the water saturation and hydrocarbon saturation, as the separation of LLD and LLS is an indicator of hydrocarbon but we can't conclude any result by interpreting one log so we need to correlate two or more logs that is why water saturation log is incorporated and interpreted. As we know that hydrocarbon saturation is difference of water saturation by unity.

5.9 Zone of interest

Zone 1 (3399m to 3411m) as GR log is on lower side also caliper log is stable, Sp logs shows deflection in track first, in track two there is a separation between resistivity logs (LLD and LLS), third track shows crossover between RHOB and NPHI, also volume of shale in track five shows lower values which indicates clean sand, as in porosities track values of porosities are higher which is very important for reservoir characterization, in water saturation track log shows low water saturation also in hydrocarbon saturation track log shows high values, all of these are the indicator of presence of hydrocarbon in the respected zone.

S. No	Properties of rock	Averages
1	Volume of shale	9.48%
2	Density porosity	17.6%
3	Effective porosity	13.3%
4	Total porosity	15.06%
5	Water saturation	24.2%
6	Hydrocarbon saturation	75.8%

Table 5.1: Table contain average values of different logs of zone 1.

Zone 2 (3487m to 3500m) as in first track GR log is on lower side, Caliper log is stable, Sp logs shows deflection, in track two there is a separation between resistivity logs (LLD and LLS), third track shows crossover between RHOB and NPHI, also volume of shale in track five shows lower values which indicates clean sand, as in porosities track values of porosities are higher which is very important for reservoir characterization, in water saturation track log shows low water saturation also in hydrocarbon saturation track log shows high values, all of these are the indicator of presence of hydrocarbon in the respected zone.

S. No	Properties of rock	Averages
1	Volume of shale	18.45%
2	Density porosity	13.97%
3	Effective porosity	18.95%
4	Total porosity	22.70%
5	Water saturation	25.157%
6	Hydrocarbon saturation	74.843%

Table 5.2: Table contain average values of different logs of zone 2.

Zone 3 (3529m to 3550m) As in first track GR log is on lower side, Caliper log is stable, Sp logs shows deflection, in track two there is a separation between resistivity logs (LLD and LLS), third track shows crossover between RHOB and NPHI, also volume of shale in track five shows lower values which indicates clean sand, as in porosities track values of porosities are higher which is very important for reservoir characterization, in water saturation track log shows low water saturation also in hydrocarbon saturation track log shows high values, all of these are the indicator of presence of hydrocarbon in the respected zone.

S. No	Properties of rock	Averages
1	Volume of shale	17.15%
2	Density porosity	9.30%
3	Effective porosity	9.81%
4	Total porosity	8.25%
5	Water saturation	37.43%
6	Hydrocarbon saturation	62.57%

Table 5.3: Table contain average values of different logs of zone 3.

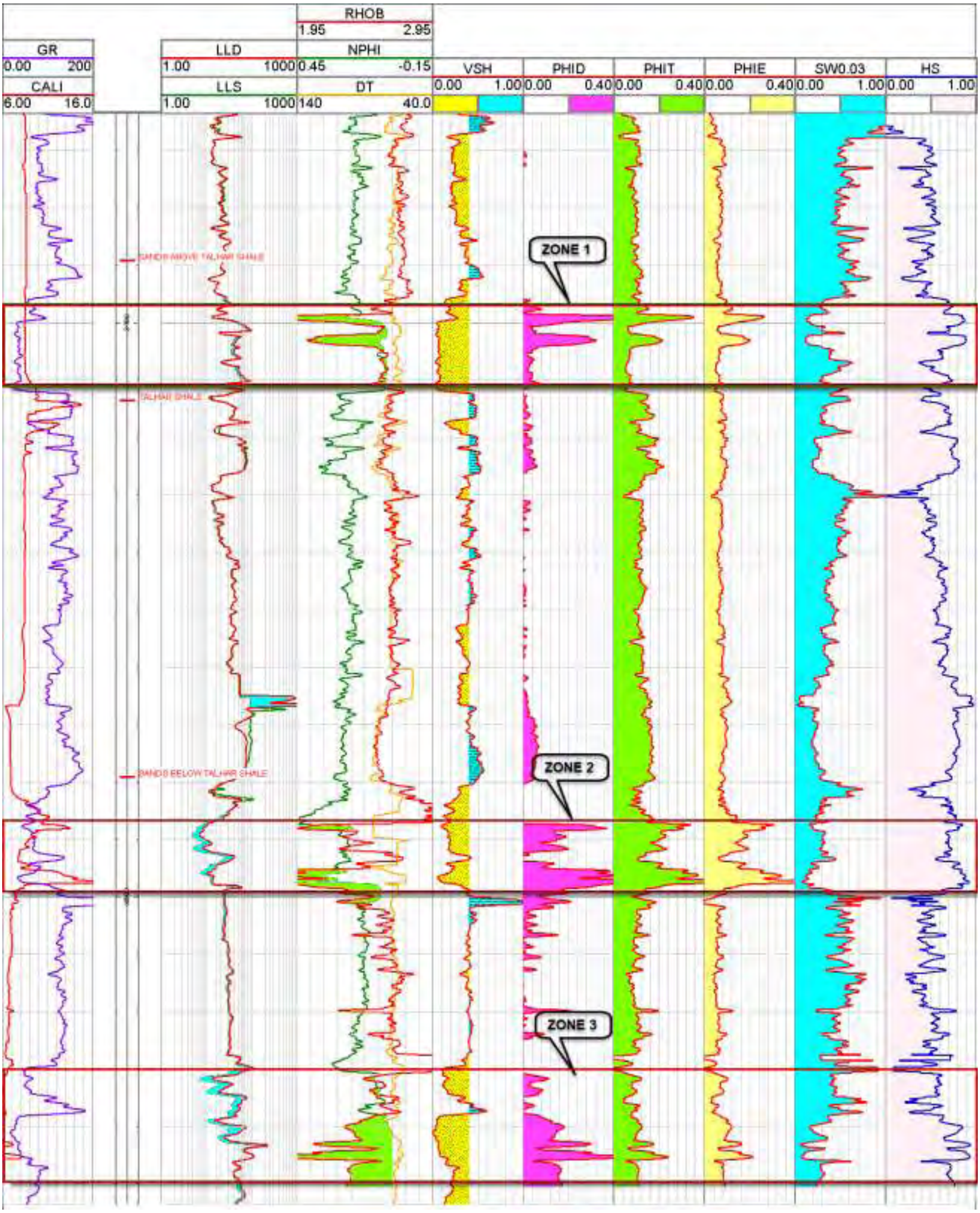

Figure 5.2: Shows petrophysical logs and marked zone of interest of well Naimat-Basal-01.

CHAPTER 06

ROCK PHYSICS MODELLING

6.1 Introduction

Rock Physics describes a reservoir rock by physical properties such as porosity, rigidity, compressibility; properties that will affect how seismic waves physically travel through the rocks. The Rock Physicist seeks to establish relations between these material properties and the observed seismic response and develops a predictive theory so that these properties may be detected seismically.

Accurate relations between rock properties and seismic attributes can help the interpreter to put "rock properties together with seismic horizons" (Peeters, 2001). Rock Physics and Engineering Properties can be computed from more precise borehole log. In addition, they can also be computed from seismic velocities. In the real earth velocity varies laterally as well as vertically, therefore boreholes provide rock properties within a depth range which covers the reservoir while the seismic velocities provide a generalized view of rock properties across the seismic section.

6.2 Seismic velocities

6.2.1 Average Seismic Velocity

The average seismic velocity is the distance travelled by a seismic wave from the source to a reflector in the sub-surface and back to the surface. That is, average seismic velocity is two-way distance divided by travel time and is given as (Onajite, 2014);

$$Va = \frac{2z}{2t}$$

6.2.2 Instantaneous velocity

Instantaneous velocity is the velocity at which a seismic wave propagates at a point within the sub-surface. The closest to instantaneous velocity measurement is the sonic log (Onajite et al., 2014).

6.2.3 Root Mean Square Velocity

RMS Velocity The root-mean square (RMS) velocity is the value of the square root of the sum of the squares of the stacking velocity values divided by the number of values. The RMS velocity is that of a wave through sub-surface layers of different interval velocities along a specific ray path. RMS velocity is higher than the average velocity (Onajite et al., 2014). RMS velocity is calculated;

$$v_{rms} = \sqrt{\frac{\sum_{i=1}^{n} v_i{}^2 \, \Delta t_i}{\sum_{i=1}^{n} \Delta t_i}}$$

6.2.4 Interval velocity (Vp)

Interval velocity is defined as the thickness of a stratigraphic layer divided by the time it takes to travel from the top of the layer to its base;

$$Vi = \frac{2\Delta z}{2\Delta t}$$

As velocities represent individual rock units therefore, they are used for the computation of rock physics properties. The seismic velocities are horizon interpolated along the interpreted horizon (Reservoir) and then converted from RMS velocities to Interval velocities using Velocity Analysis System (VAS) (Khan,2000).

Dix formula is an equation used to calculate the interval velocity between any two points

$$v_i = \sqrt{\frac{v_2^2 T_2 - v_1^2 T_1}{T_1 - T_2}}$$

where V1 and V2 are the velocities at times T1 and T2, respectively, and Vi is the interval velocity (Onajite et al., 2014).

Interval velocity values of horizon (Basal Sand/ Sand below Talhar Shale) are computed from velocity window provided by DGPC. Contour and grid map of Vp values of basal sand is generated by using (kingdom software) as shown in the figure below.

Interval velocity of the horizon Basal Sand is computed. Contours of Vp as shown in the figure 6.1, illustrates that velocity in the reservoir zone is increasing from east to west which shows that compaction rate is increasing from east to west and the range of velocities in the reservoir zone is from 3000m/sec to 5000m/sec.

6.2.5 S-wave velocity

S wave, also called shear waves, is the second type of body wave. S wave is formed when energy is applied in a direction parallel to the surface of a medium. S wave does not propagate through fluids. Shear wave exploration cannot be done with conventional marine seismic acquisition technology (Onajite et al., 2014). S-Wave velocities are computed using Castagna et al. empirical relation (1985) given below;

$$V_s = \frac{(v_p - 1.36)}{1.16}$$

Vs derived by using Castagna formula (for sandstone) written above through which we finally compute any required rock physical parameters.

S-wave velocity of the basal sand horizon is computed. Figure 6.2 shows the contour map of the S-wave velocity illustrates that velocity variation in the reservoir zone. Contour map shows that velocity is increasing from east to west which describes the compaction of the reservoir zone that it is gradually increasing from east to west. Also, the S-velocity is lower than P-wave velocity and is ranges from 3750 m/sec to 2400 m/sec. at the center of the contour map velocity is very high and is gradually decreasing toward east.

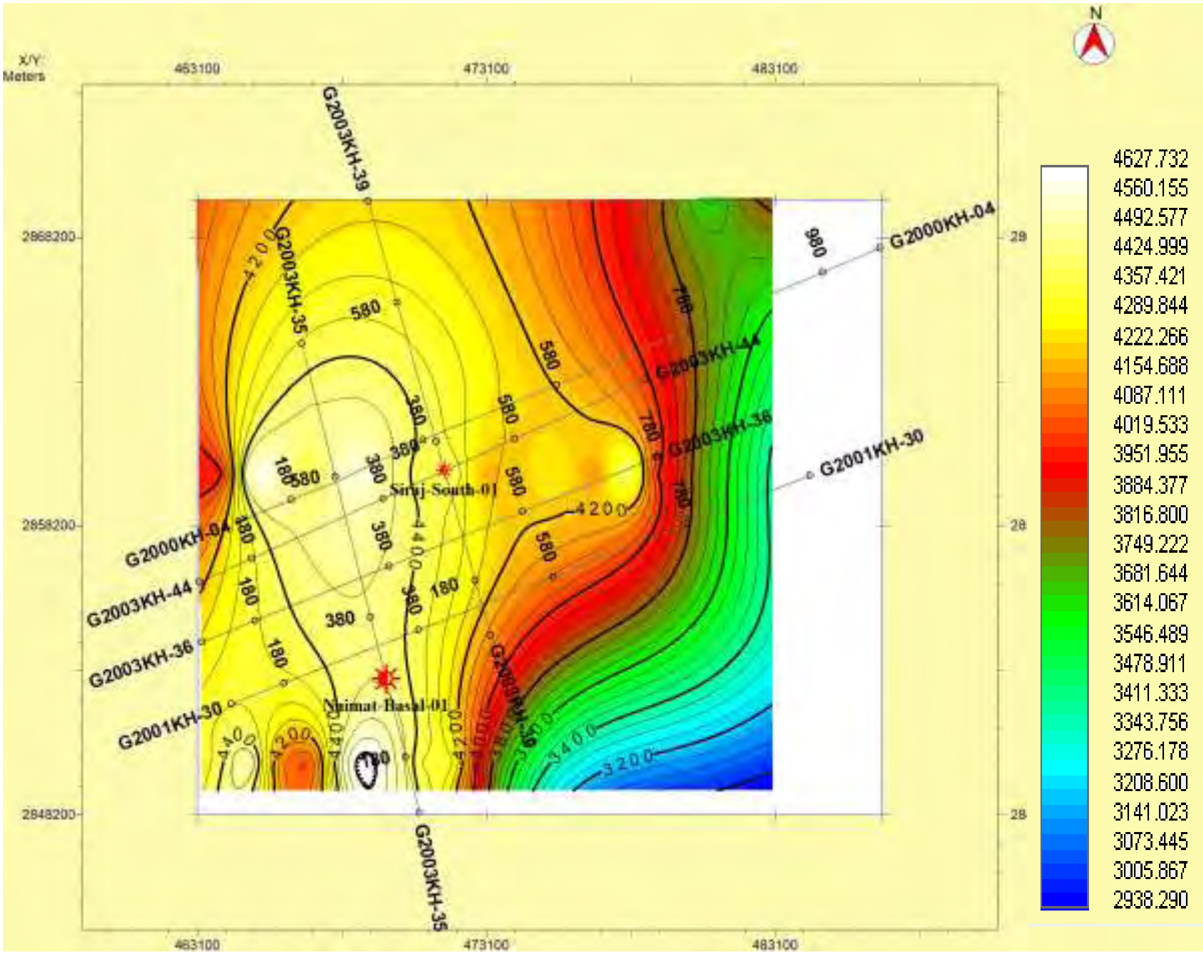

Figure 2.1: Shows the contour map of P-wave velocity.

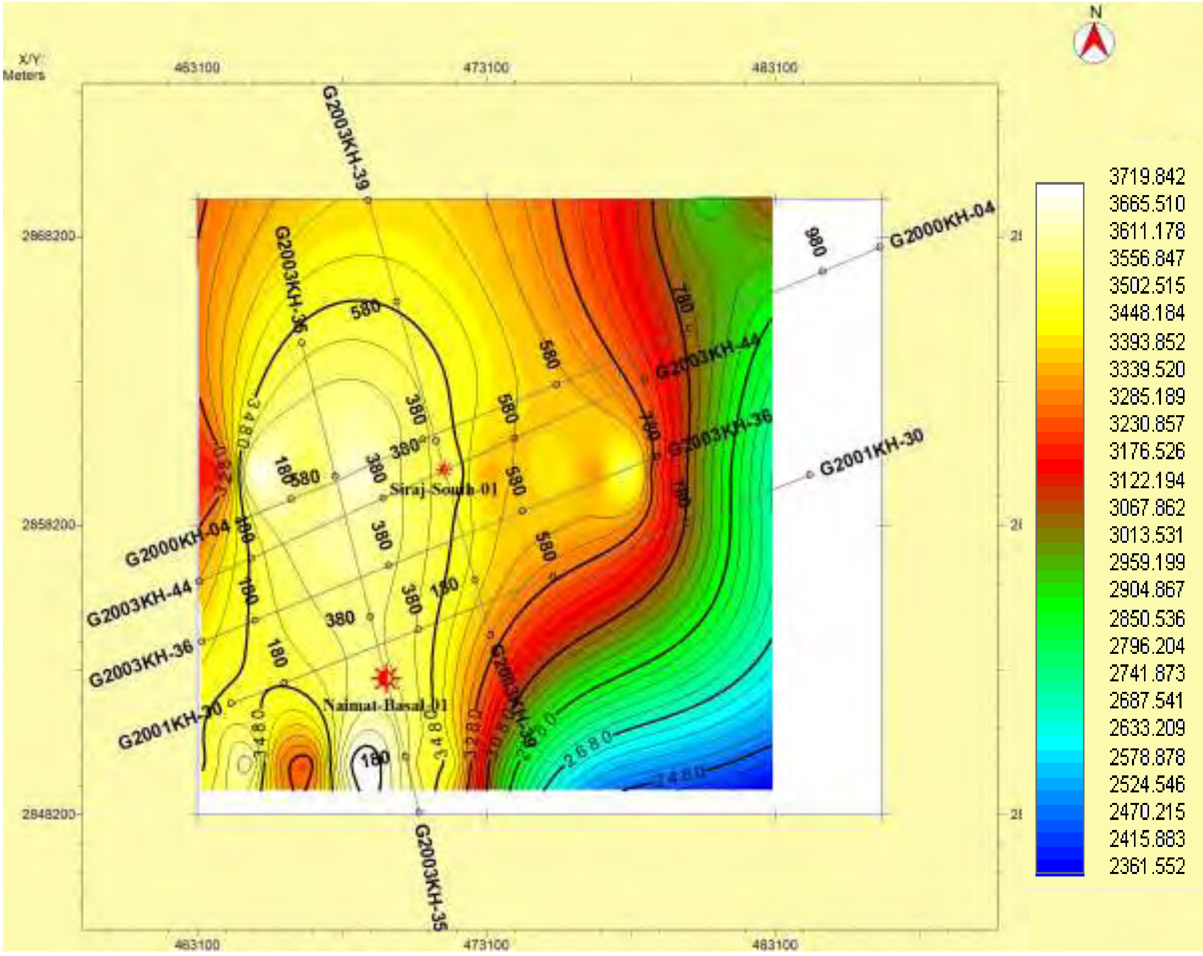

Figure 6.2: shows the contour map of S-wave velocity.

6.3 Physical parameters

6.3.1 Acoustic Impedance (AI)

Acoustic impedance is a layer property of a rock and is equal to the product of compressional velocity and density (Onajite et al., 2014). Acoustic impedance is computed by multiplying the density of the horizon with the P-wave velocity of the respected horizon. Density of the horizon is computed firstly by using P-wave velocity.

$$\rho = 0.31 * V_p^{0.25}$$

Where Vp is P-wave velocity and ρ is the density.

$$AI = V_P \times \rho_b$$

Where, ρ_b is the density of the formation and V_p is he compressional wave velocity.

6.3.2 Shear Impedance (SI)

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

$$SI = V_S \times \rho_b$$

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

6.3.3 Shear modulus (μ)

Shear modulus is the ratio of shear stress to shear strain. Shear modulus is calculated for the respected horizon (basal sand) by multiplying the density of the horizon with S-wave velocity of the horizon.

$$\mu = \rho * V_s^2$$

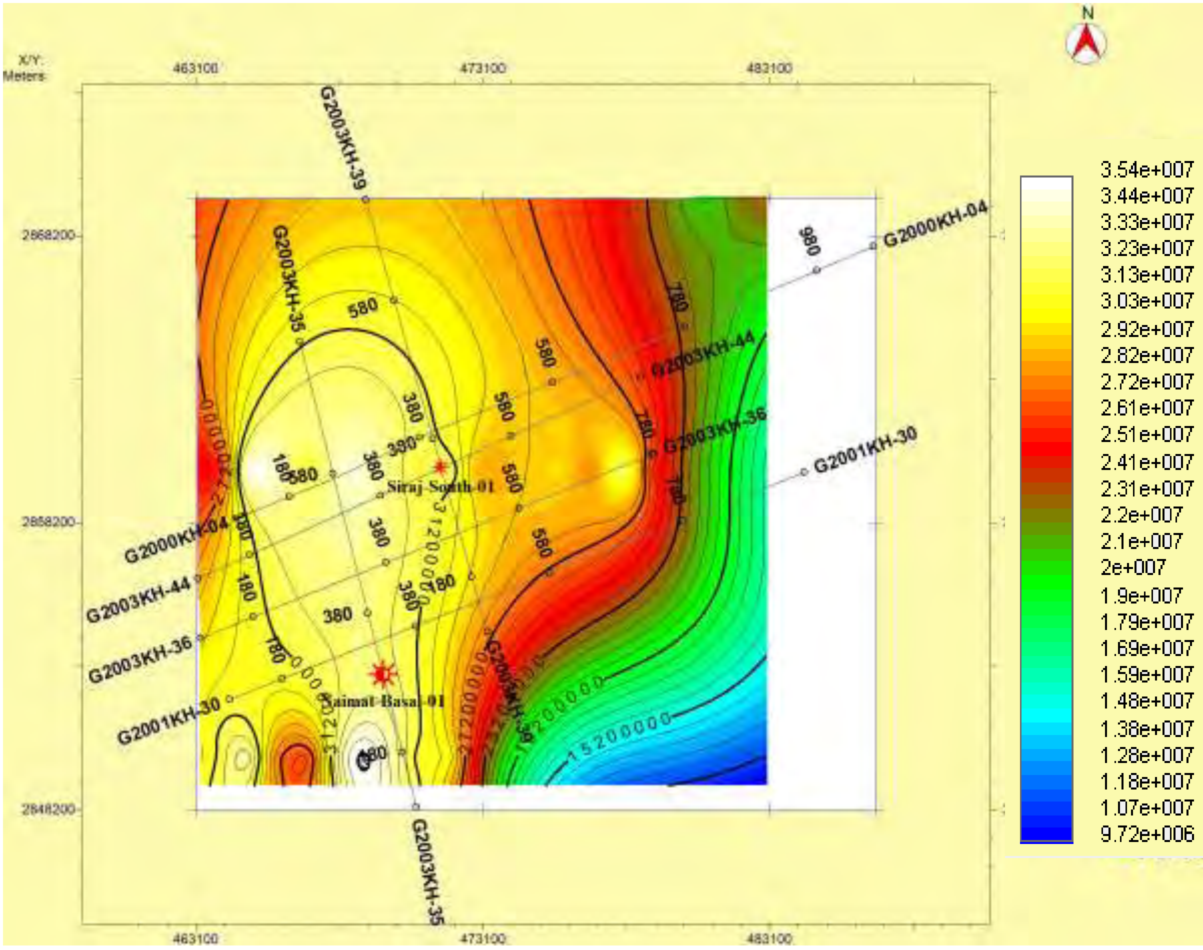

Figure 6.3: Shows the contour map of the Shear modulus.

Shear modulus of basal sand horizon and contour map is shown in figure 6.3. Color bar is showing the variation of shear modulus in the reservoir zone. It ranges from 15200000Pa to 31200000Pa and has high values at the center of the contour map. Shear modulus has high values which describes the compaction of the reservoir and is increasing from east to west.

6.3.4 Bulk modulus K

It is the ratio of volumetric stress to volumetric strain is called bulk modulus. Bulk modulus is computed for basal sand horizon by using formula;

$$K = \rho(V_p^2 - \frac{4}{3}V_s^2)$$

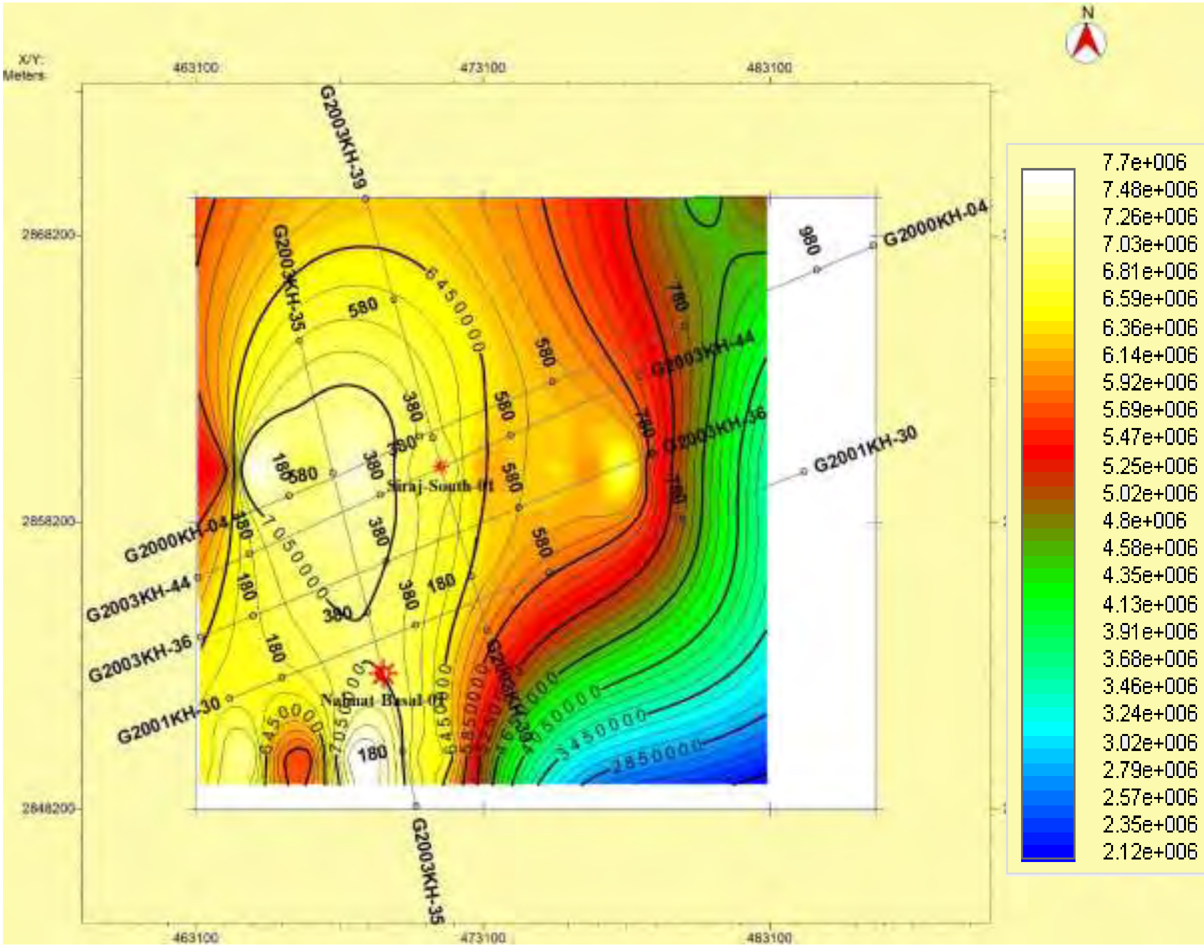

Figure 6.4: Shows the contour map of the Bulk modulus.

Figure 6.4 illustrates the contour map of the bulk modulus of the Basal Sand reservoir. Color variation shows the variation of the bulk modulus, it ranges from 2850000 to 7050000 and has high values at well location. Bulk modulus has high values at which confirms the presence of the reservoir zone.

6.3.5 Young's Modulus (E)

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

$$E = \frac{9K\mu}{3K + \mu}$$

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

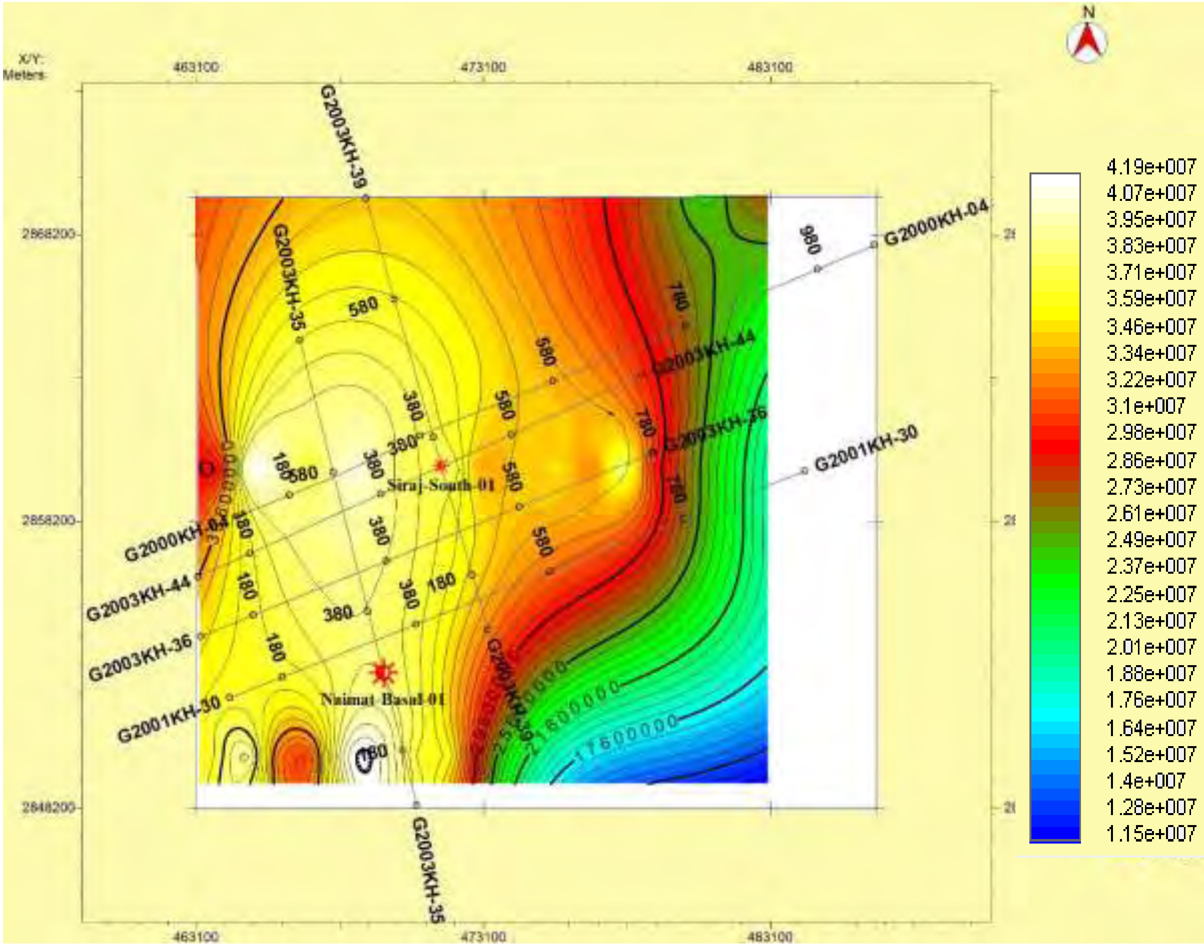

Figure 6.5: Shows the contour map of the Young modulus.

Figure 6.5 illustrates the young modulus of the Basal Sand reservoir, it ranges from 17600000Pa to 37600000Pa and has high value at well location. Young modulus has high values which is the confirmation of a reservoir zone.

6.3.6 Poisson's Ratio (σ)

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

$$\sigma = \frac{0.5(V_p^2 - 2V_s^2)}{(V_p^2 - V_s^2)}$$

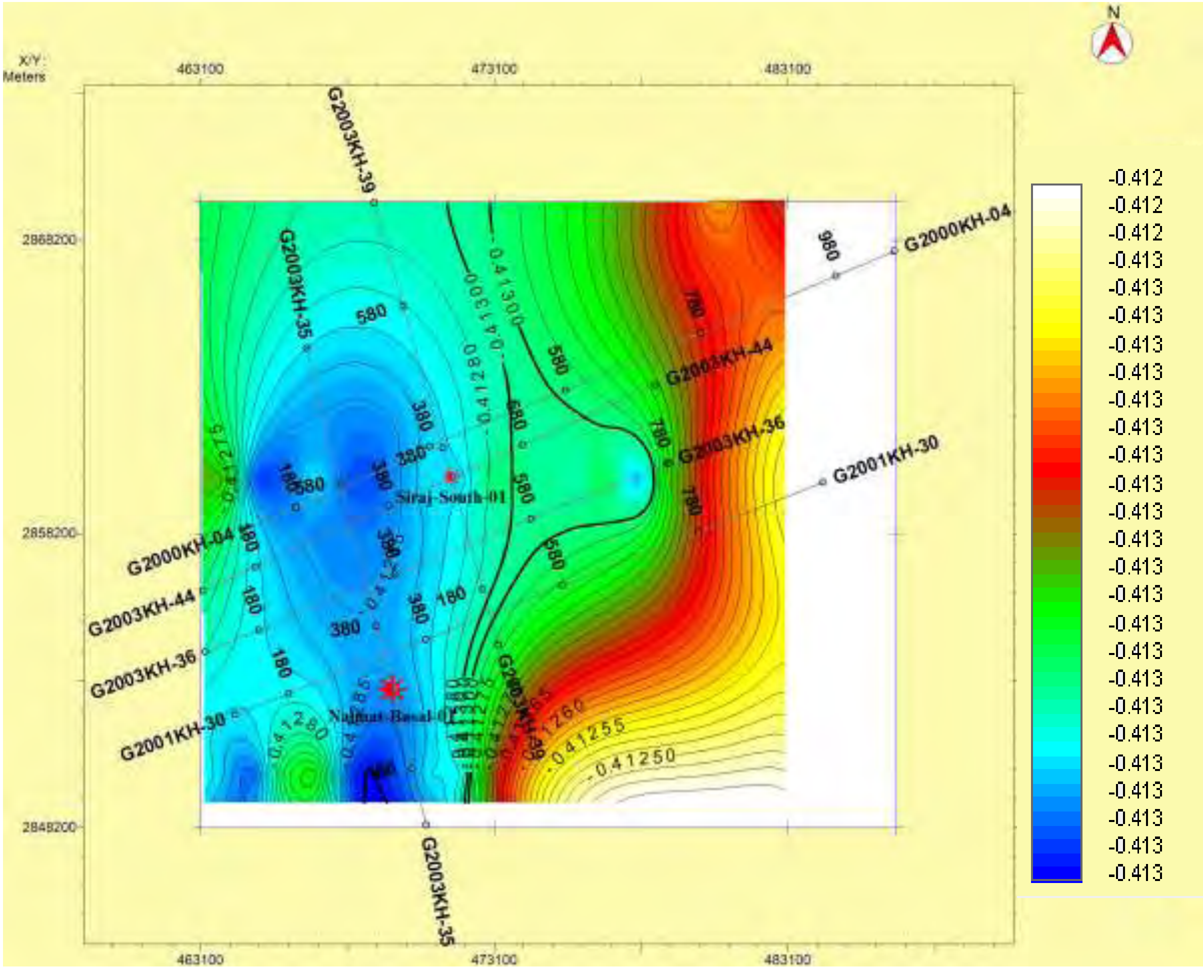

Figure 6.6: Shows the contour map of the poison ratio.

6.3.7 V_p/V_s ratio

V_p/V_s versus Acoustic Impedance is considered as an import cross plot for classification of sand and shale facies. The V_p/V_s ratio can be expressed in terms of represents poisson's ratio (σ) by the following equation (Mavko et al., 2009);

$$\frac{V_p}{V_S} = \sqrt{\frac{K}{\mu} + \frac{4}{3}}$$

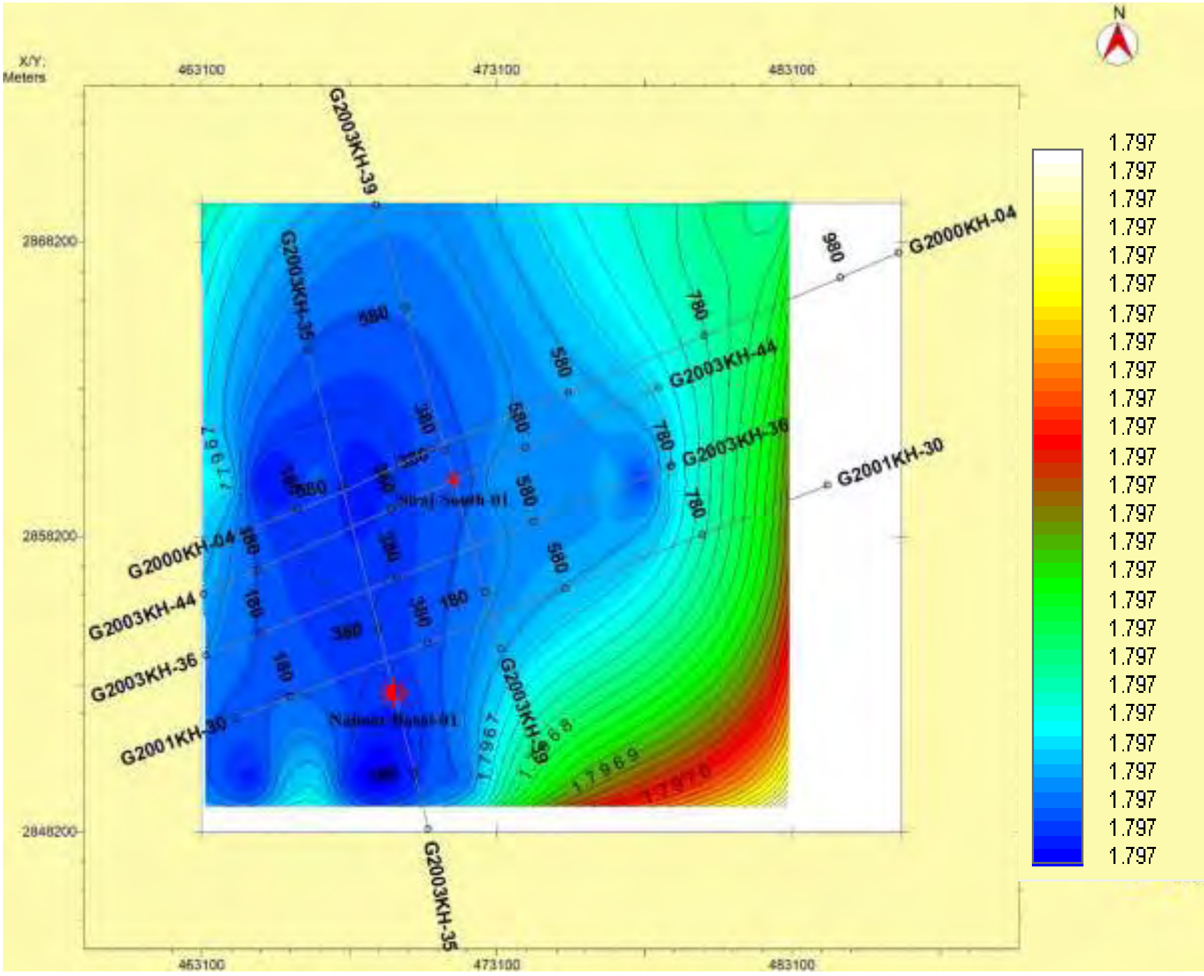

Figure 6.7: Shows the contour map of the Vp/Vs ratio.

Figure 6.7 shows the contour map of the Vp/Vs. Color variation in the figure shows the variation of the ratio between Vp and Vs, it ranges from 1.7971 to 1.7966. Vp/Vs has low values at the reservoir zone which is the confirmation of the presence of a reservoir zone.

6.3.8 Porosity

Porosity is defined as the ratio the volume of void spaces to the total volume of the rock. Velocities have inverse relation with the porosity, so for the small values of velocities the porosity is high.

$$Porosity = \frac{\rho_m - seismic\ density}{\rho_m - 1}$$

Where,

- ρ_m is matrix density and its value being 2.65.
- Seismic density is computed from V_p.

The porosity variation along the CDPs and vertical time is shown in Figure 6.8. The porosity cross-section is very similar to velocity cross-section as the S-Wave velocities are computed from P-Wave velocities. Ideally the S-Wave information must be obtained from a 3C survey to accurately determine the porosity.

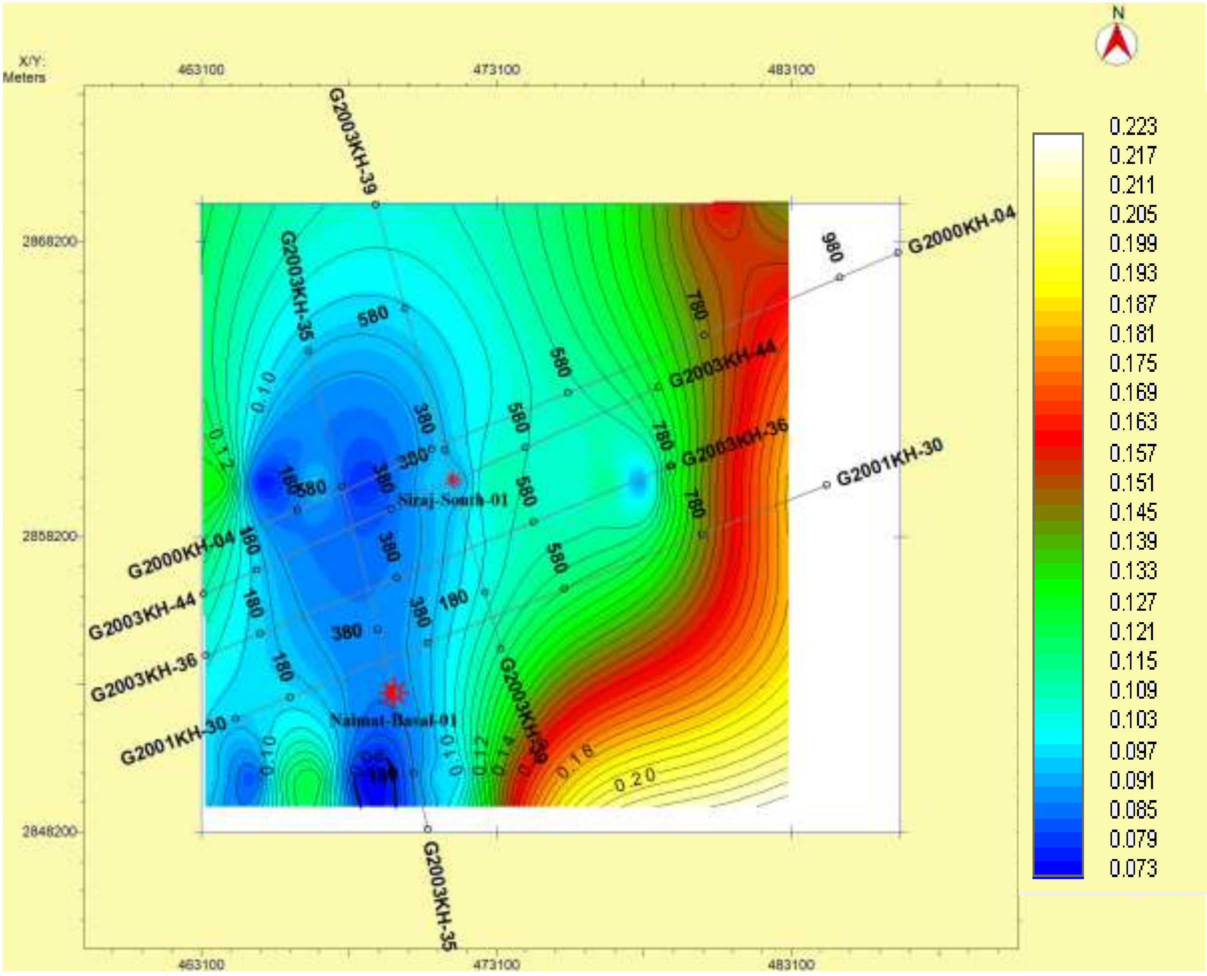

Figure 6.8: Shows the contour map of the porosity.

Porosity of the Basal Sand is computed using the seismic density, matrix density of the respected sandstone reservoir. Figure 6.8 describes the variation of the porosity in the reservoir zone, porosity ranges from 7% to 22%, near the well porosity values are ranges from 8% to 9% which suitable for sandstone reservoir to hold hydrocarbons. It also confirms the quantitative interpretation of petrophysical logs. Also, porosity contour map is same as velocity contour map because all parameters are computed by using Castagna formula.

CONCLUSION

- Seismic interpretation includes horizon marking and fault marking which is done on basis of geology of the area. Horizons are marked with the help of synthetic seismogram of well Niamat-basal-01.
- 7 major faults are marked in the geological section depend on the geology and tectonic of the study area. Presence of normal faults result in horst and graben structures, which illustrates that the area lies in the extensional regime.
- Furthermore, time and depth contour maps of the marked horizons are constructed. Interpretation of the contour maps shows structure high and low, which can be seen on time and depth contour maps of the marked horizon. Also, wells are drilled on elevated portion, which are horsts location and as it is known from the literature that wells are drilled on the elevated part of the horizon.
- Seismic interpretation shows horst and graben structures form as a result of conjugate faults as well as bookshelf geometry in the area formed due to parallel faulting.
- Seismic attributes applied on geological section G2003KH-36, such as Trace envelop confirm the major lithological changes and the instantaneous phase confirm the continuity of marked horizons on seismic section and the average energy attribute increases the reflection strength of the horizons on the seismic sections.
- Petrophysical interpretation is done by using different geophysical logs and determination of other logs including porosity logs, volume of shale, water saturation, hydrocarbon saturation helped in determining zone of interest in the reservoir zone within different sand packages. Quantitative results show that the area is very effective for hydrocarbon saturation.
- Rock physics modelling differentiate non-reservoir and reservoir rock in the area. Seismic velocities and physical parameters along with porosity are used for the confirmation of the reservoir zone. Interval velocity is derived by using seismic velocity windows through which S-wave velocity is derived using Castagna equation, as both sonic log velocity and the seismic derived velocity both are same which confirms the presence of reservoir zone. As porosity derived from seismic data and well log data is similar so that the reservoir would be effective for the accumulation of the hydrocarbon.

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