Reservoir Characterization of the Khipro Area, Lower Indus Basin, Pakistan

By

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بسم الله الرحمن الرحيم

CERTIFICATE

This dissertation submitted by FAWAD ABBASI s/o NASEEM AHMED ABBASI 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 merciful and most beneficent. All praises to him who is Almighty, The One, The Everlasting, Who begets none, is be gotten, by no one, and there is none His equal. O' God I am really thankful to you that you make me capable to complete my work. I am nothing without your help. Please keep me always in prostration before you and let me not leave before anyone except you.

I am especially thankful to my dissertation supervisor Dr. Aamir Ali that he always gave me his loving guidance whenever I asked and spared His precious time for me during my work. I would like to thank my friends especially FAUJI GROUP who supported me with constant motivation. I am thankful to my respectable friend and senior Brother Mr. Farhad for his cooperation and guidance in every aspect of life not only in thesis work.

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DEDICATION

I dedicate my work to my beloved and respected parents, my supervisor and whole family who motivated, supported and encouraged me in every field of life. And whatever today i am, it is just because of them.

ABSTRACT

The present study pertains to the structural and interpretation of Khipro block in order to determine the probable zone for the accumulation of hydrocarbon. The data used for this study consists of seismic data and well logs data of Khipro area which is provided by the Department of Earth Sciences Quaid-i-Azam University Islamabad. Khipro area lay in the Lower Indus Basin is known for its hydrocarbon (oil and gas) structural traps.

Surface lithological units' identification is done using Aster LT-1 data. Preprocessing of data is done which removes noise and other atmospheric anomalies. Then image is interpreted using different image processing techniques such as PCA, MNF and Band Ratioing.

For the interpretation of the seismic lines, two reflectors are marked by correlating synthetic seismogram on seismic section. As the area of study lies in the Lower Indus Basin, horst and graben geometry in this region is common which is confirmed by fault polygon, time and depth contours made from time and depth grid respectively.

We use well logs data for this study. Petrophysical analysis is carried out to narrow down the promising zones and presence of potential hydrocarbons in the formations of lower Goru sands.

Seismic attribute analysis using envelope and instantaneous phase is then applied to confirm both structural and stratigraphic interpretation.

Colored inversion is applied to enhance and focus on the layer properties of the marked horizons. Very low acoustic impedance is observed in Lower Goru sands, which could further affirm our results of hydrocarbon presence in the promising zones.

Contents

CHAPTER 01

INTRODUCTION

1.1 Introduction

Hydrocarbons play a vital role in the growth of economy of any country and have wide uses at smaller scales in everyday life as well. Geoscientists are trying since a long time for the exploration of hydrocarbons from subsurface and are applying different methods in this regard. Geophysical methods are the most widely used methods in the exploration of hydrocarbons; especially Seismic Method has a great importance in this regard. Seismic interpretation is the process of determining information about the subsurface of the earth from seismic data (Coffeen, 1986). It may determine general information about an area, locate prospects for drilling exploratory wells, or guide development of an already-discovered field (Coffeen, 1986). Conventional seismic interpretation implies picking and tracking laterally consistent seismic reflectors for the purpose of mapping geologic structures, Stratigraphy and reservoir architecture. To meet the challenges of exploring ever increasingly complex targets, there have been tremendous advancements in data acquisition equipment, computer hardware and seismic processing algorithms in the last three decades (Khan et al., 1986)

Petrophysical interpretation of well logs basically provides us a way to calculate important physical properties like velocity, porosity, volume of shale, water saturation, and hydrocarbon saturation using empirical relations (Akhter et al. 2015, Ali et al. 2015, Asquith et al. 2004.

1.2 Objectives

The main objectives of this dissertation based on interpretation of seismic section are Seismic interpretation to mark the horizons of interest and to identify the probable structures favorable for hydrocarbon accumulations. Generation of synthetic seismogram to mark the seismic horizons accurately. Preparation of time and depth contour maps based on seismic data to confirm the presence of structures in our study area. Different logs such as Gamma Ray, spontaneous potential, resistivity, sonic, porosity, and density were analyzed and interpreted to define reservoir geometry and properties. Colored inversion is done to analyze the variation of the acoustic impedance at reservoir level.

1.3 Data used

The data used for current research includes four seismic lines and Naimat-Basal-01 well. Seismic data is of three different vintages 2000, 2001 and 2003 acquired by Orient Petroleum Inc in which two are dip lines and two are strike lines. The orientation of seismic lines with the location of wells is shown in the base map Fig 1.1. The detail of these seismic lines is given in Table 1.1. Naimat-Basal-01wells is gas condensate and have been drilled up to the Basal Sand unit of Lower Goru. The well data details of these two wells are given in the Table 1.3.

LINE NAME	NATURE	LINE ORIENTATION	WELLS
2000KH-04	Dip line	W-E	
2000KH-08	Dip line	W-E	Naimat-Basal-01
2000KH-35	Strike line	S-N	

Table 1.1: Seismic reflection data used for base map.

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: Well top data used for desertion.

Three lines are provided to us and horizons were marked on three lines. Nature of these three lines and their orientation is given in the Table: 1.1 along with the well name which lies on the survey lines.

1.4 Base Map

The base map is important component of interpretation, as it shows the spatial position of each picket of seismic section. For a geophysicist, a base map is that which shows the orientations of seismic lines and specify points at which seismic data were acquired or simply a map which consist of number of dip and strike lines on which seismic survey is being carried out. A base map typically includes location of lease and concession boundaries, wells, seismic survey points and other cultural data such as buildings and roads with geographic reference such as latitude and longitude. Geophysicist typically use shot points maps, which show the orientation of seismic lines and shot points at which seismic data were required, to display interpretation of seismic data base map of study area shown in Fig 1.1

1.5 Methodology

To achieve the desired objectives of the dissertation work, first the surface geology of Khipro is interpreted using remote sensing. Synthetic seismogram is generated using well log data and seismic data. Based on synthetic seismogram horizon of interest are marked on the seismic sections. Then two-way travel time is noted at a constant interval of distance of each marked horizon and fault. Based on the times and velocities of marked horizons and faults, a time section is prepared in Kingdom suit of Software. A section in time and depth mode is prepared in HIS Kingdom suit of software. Time and depth contouring maps of the reservoir formations are prepared on Kingdom suit of Software. Seismic attribute analysis is carried out in order to confirm the structural interpretation. Petrophysical analysis is done to know about porosity, volume of shale and water saturation. Colored inversion is done to affirm petrophysical results.

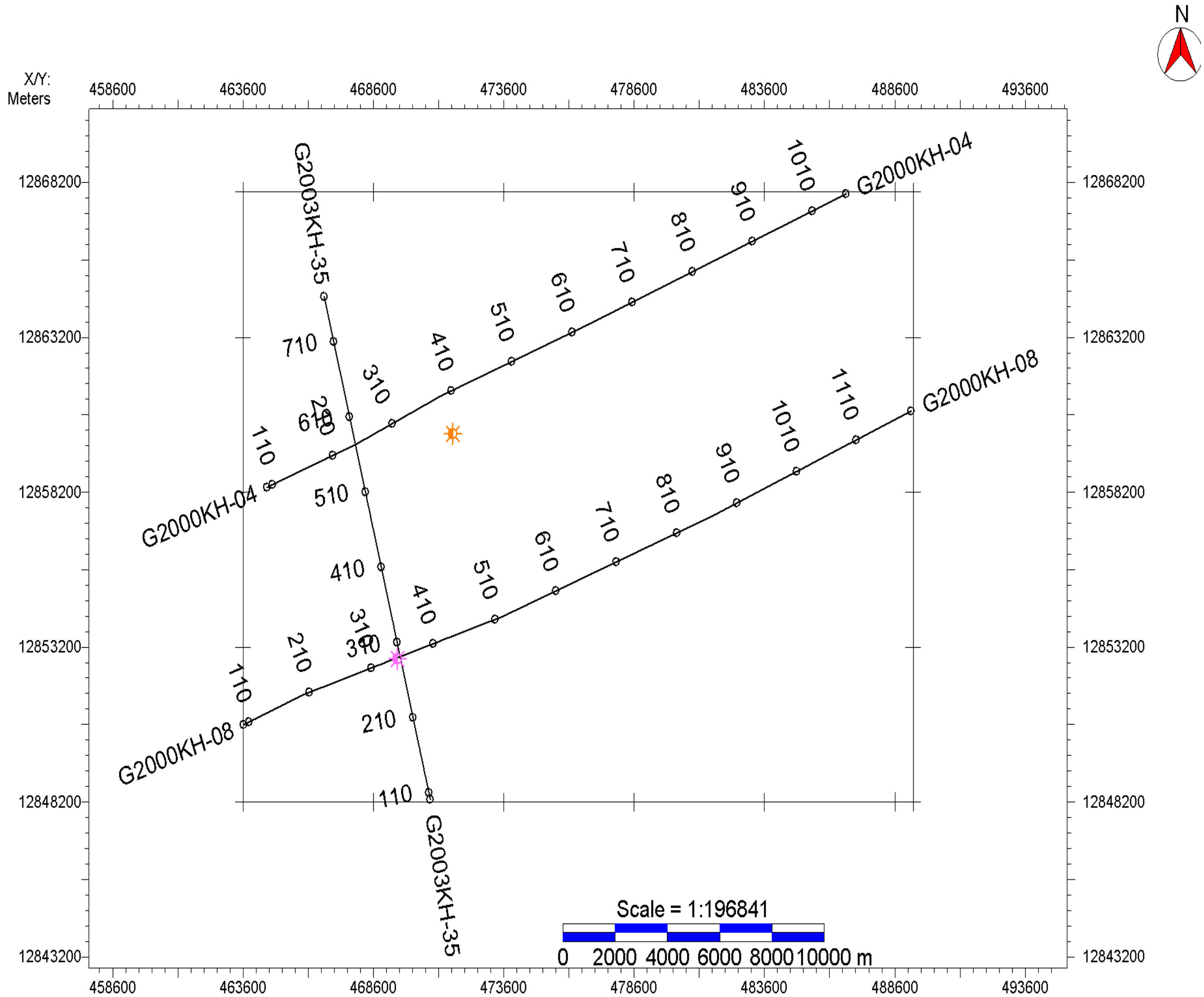

Figure 1.1: Shows the Base map of study area.

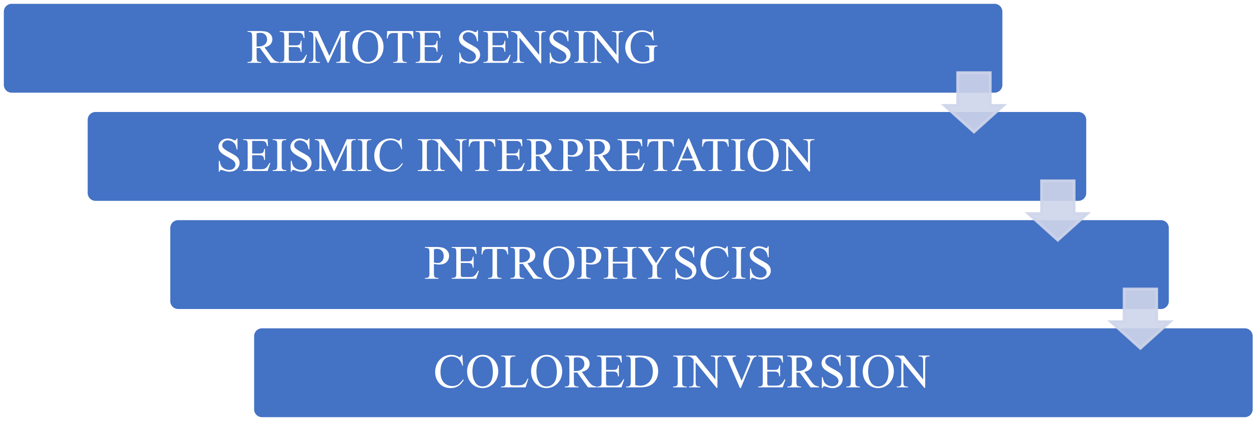

Figure 1.2: Workflow of dissertation.

1.6 Introduction to Study Area

The study area as shown in Fig 1.3 recovering an area of 2376 km is the part of Indus offshore basin of Pakistan. Khipro is part of Thar platform which is west word sloping monocline and is controlled by its basement topography Kadri (1995). Indus offshore basin falls in the type IV (Intermediate Crustal type): An Extra-continental down warp to small ocean basin combined with tertiary delta basins toward oceanic areas. Geographical coordinates of the area is shown in Fig 1.3.

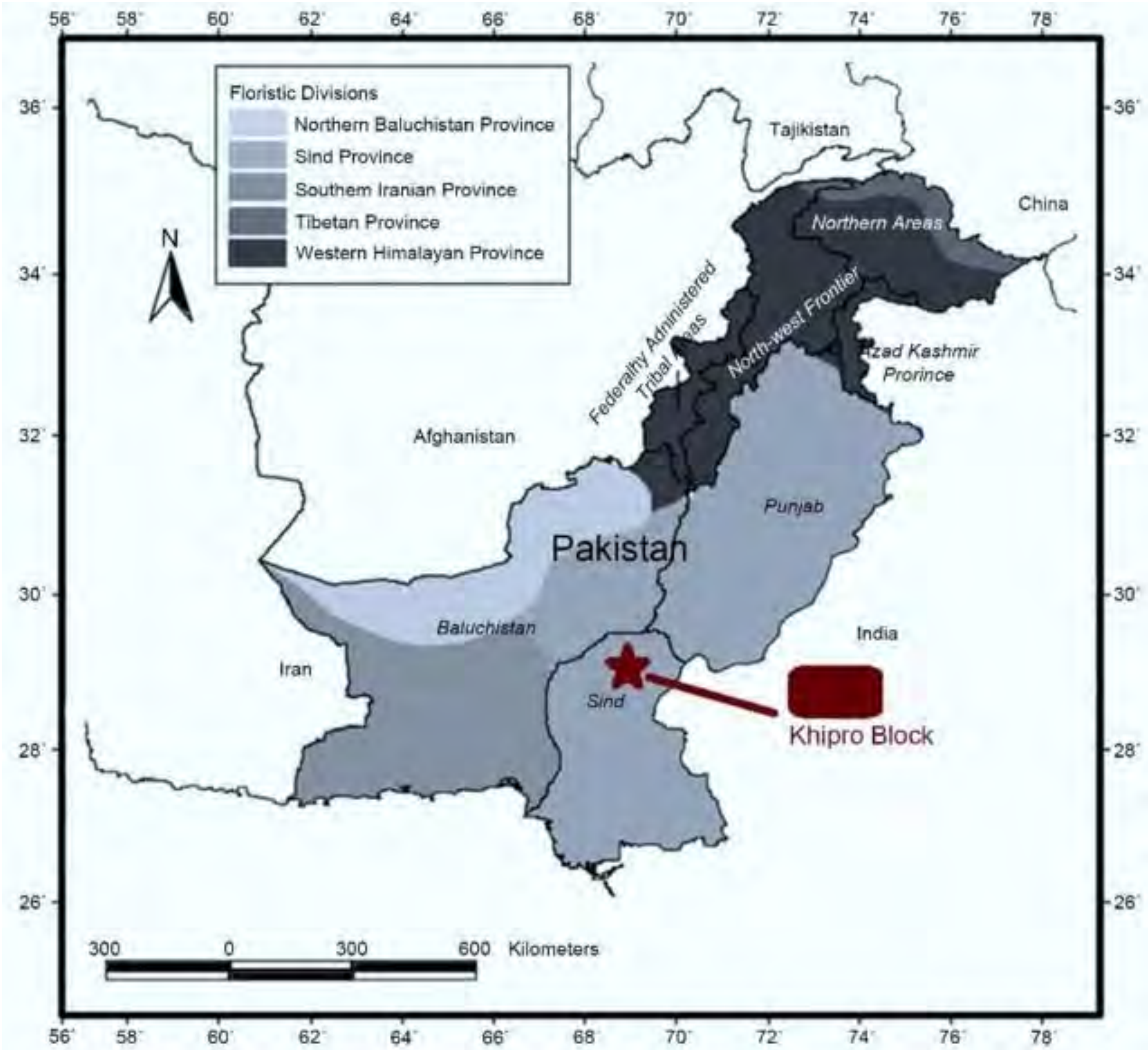

Figure 1.3: Map showing the location of Khipro block in this study (Banks and Warburton, 1986).

CHAPTER 02

GEOLOGY AND STRATIGRAPHY OF STUDY AREA KHIPRO

2.1 General Geology of the Study Area

Information about the geology of an area is very important in seismic survey. As the same velocity effect can be produce from the formations of different lithology and vice versa. The position and penetration of local fault and the presence of the unconformities between the rocks is very necessary for interpretation point of view. So as if we don't know geological information in area, we don't recognize the different reflections appearing in the seismic section. A geological history of basin can be compiled by considering basin forming tectonics and depositional sequence (Kingston et al., 1983).

The basinal history of Khipro block is related to rifting and breaks up of Gondwana plate in Jurassic period. In the Cretaceous, east Gondwana plate (India, Antarctica and Australia) separated from the west Gondwana plate (Africa and South America). The Indian plate separated from east Gondwana in Aptian Time (120 Ma). At the end of Cretaceous, Seychelles and Madagascar separated from India with associated faulting accompanied by Basaltic flows (Deccan Volcanic) in the southern part of lower Indus basin. After Paleocene there were a continuing oblique convergence of Indian plate and Asian plate throughout Tertiary time and the collision causes tilting of the entire region. The presence of Jurassic rocks in area show deposition during rifting. The rifting has resulted in the formation of normal faulting and horst and graben structures. The famous among these structures include "Sukkur Rift". However, this localized rifting phase was unable to continue after the Paleocene-Eocene time (Powell., 1979; Smith et al., 1994).

2.2 Geological Mapping of Khipro Using Aster Lt-1 Data

The geological and mineral maps are essential for advancement and investigation of mineral assets to acquire bona fide geosciences data. The geological maps represent the outcropping pattern on the surface of the ground. This pattern may show bed rocks. The boundaries and the strata of outcropping features are represented in geological maps. The reason for investigating the landmass can be given by these maps in search of its assets.

Common mapping strategies and mineral investigation systems are labor intensive and experimental methods of extrapolation and interpolation utilized for mapping makes these techniques costly, hard and long. To conquer these issues, the satellite data can be utilized for the significant wellspring of data. As a matter of fact, geological highlights which are on the surface of the earth might be distinguished in bedrock outcropping, through air photos (photogeological surveillance) as well as from remote sensing imageries. The information is digital and georeferenced which is present in remote sensing data for geological mapping. Numerous previous researches have suggested that hyper spectral and multispectral remote sensing data sets can be used for surface feature mapping and lithological discrimination (Rencz, 1999).

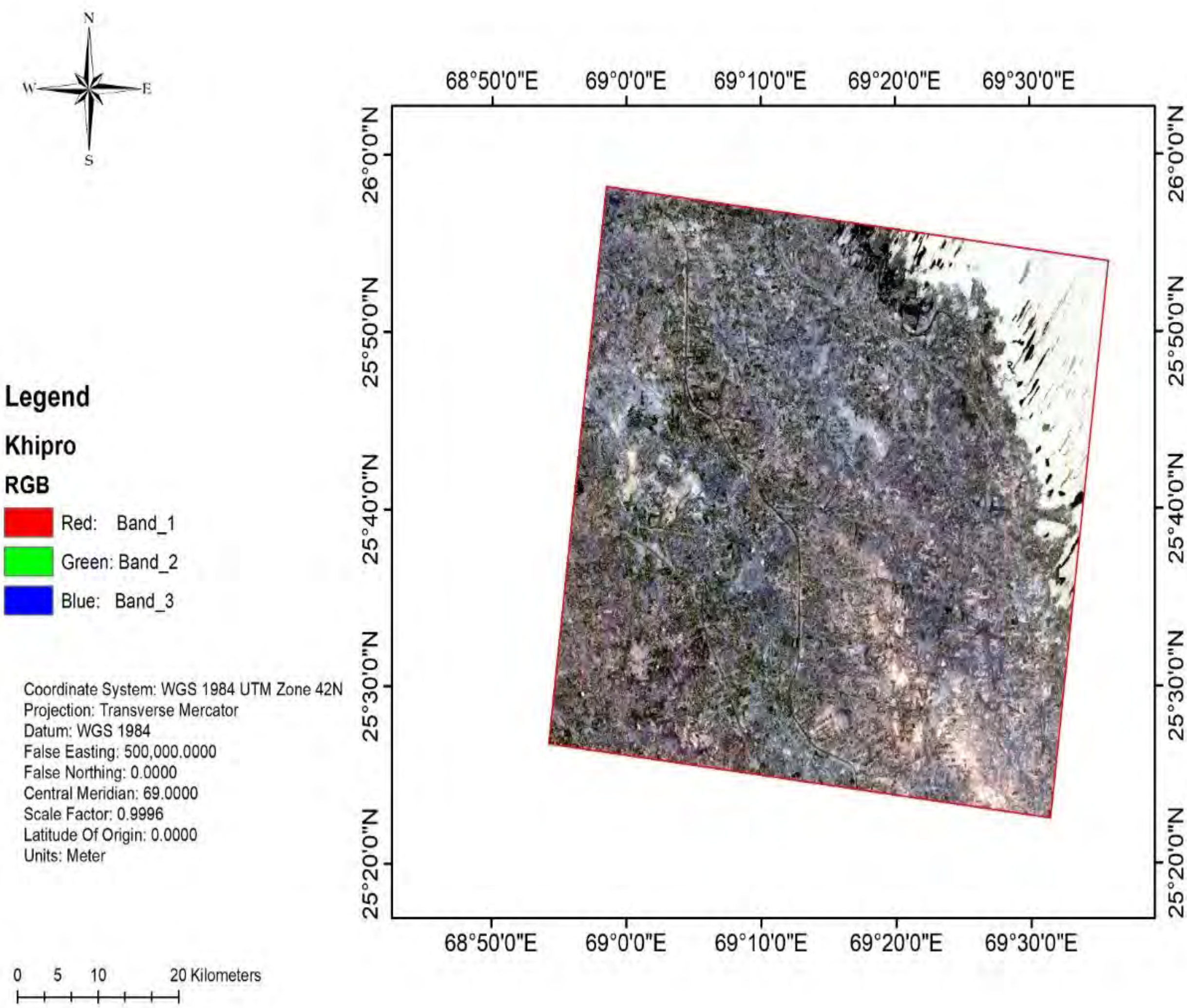

Figure 2.1: Aster LT1 image showing satellite image of Khipro

2.3 Principle Component Analysis

The decorrelation of data and the reduction of the study dimension on the nine ASTER bands have been realized by a principal component analysis (PCA) (Richards and Xiuping 1998). The PCA is a multivariate statistical method which is largely employed for multispectral image interpretation founded on linear algebraic matrix operations. The PCA chooses uncorrelated linear combinations of variables in order that each component successively extracts linear combination and possesses a smaller variance. The principle is to create a new set of orthogonal axes that have their origin at the data mean and that are rotated in order that the data variance is optimized (Pour and Hashim, 2011)

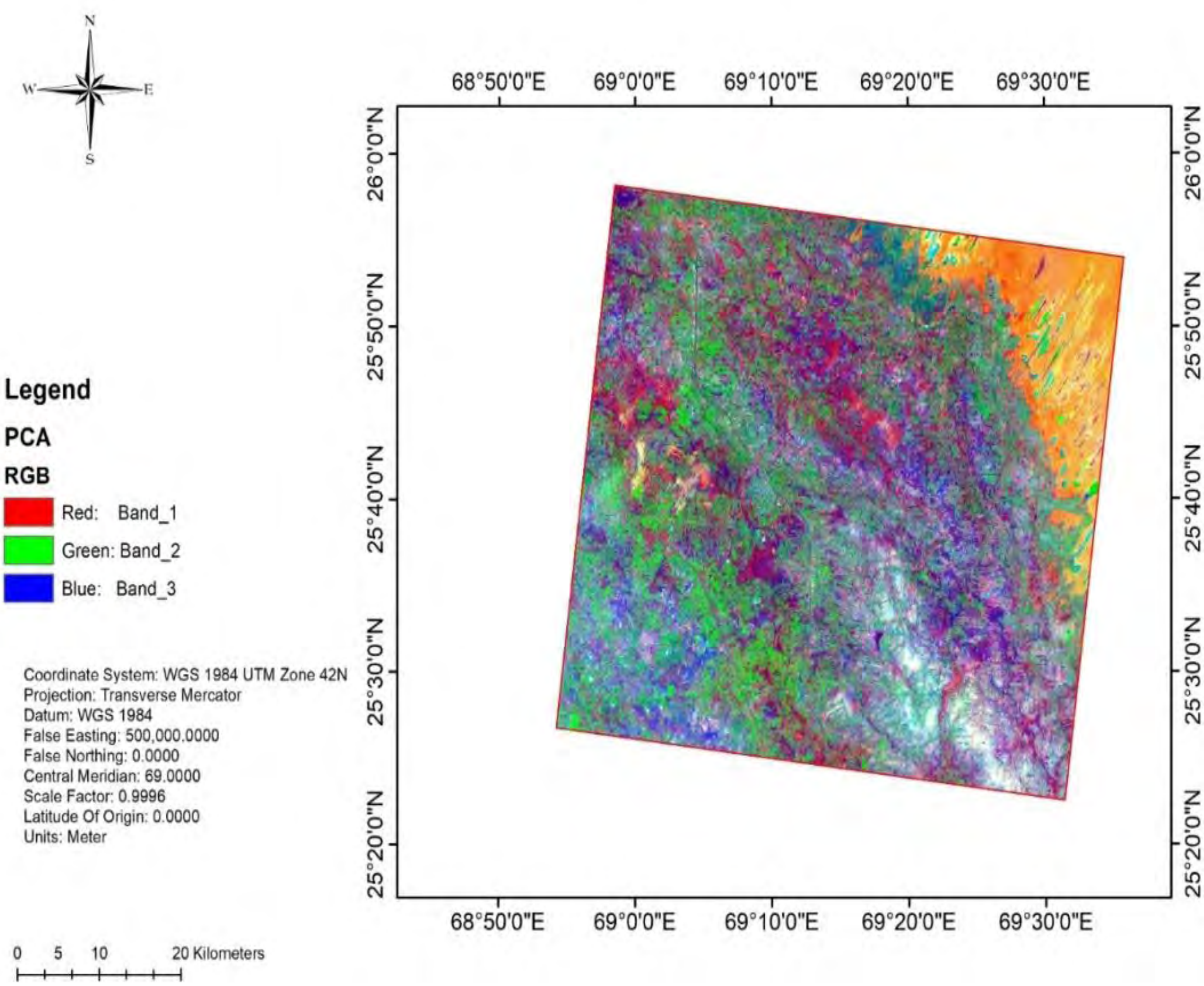

Figure 2.2: Aster LT1 image showing satellite image of Khipro.

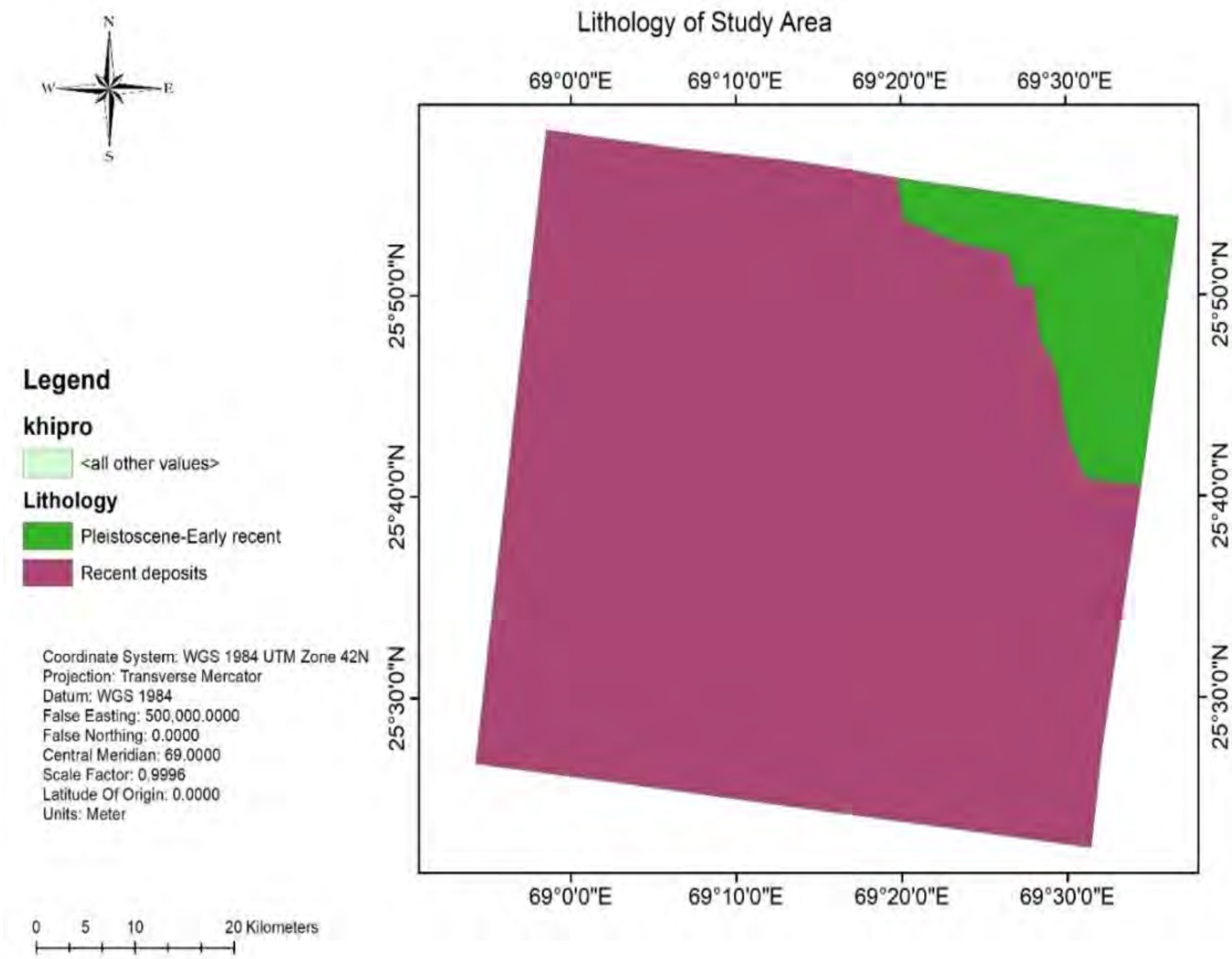

Figure 2.4: Shows interpreted geology of Khipro area showing Pleistocene and Holocene deposits.

2.2 Structural Setting of Khipro Area

The structural setting in the area is due to result of a normal block faulting on west dipping Indus Plain. The fault planes act as migrating paths for hydrocarbons 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).

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. On the northern side, there is Sukkur Rift zone bearing large anticlimax structures and contains Khandkot and Mari gas fields (Zaigham, 2000). Structural boundaries of the Khipro block are shown in the Fig 2.5.

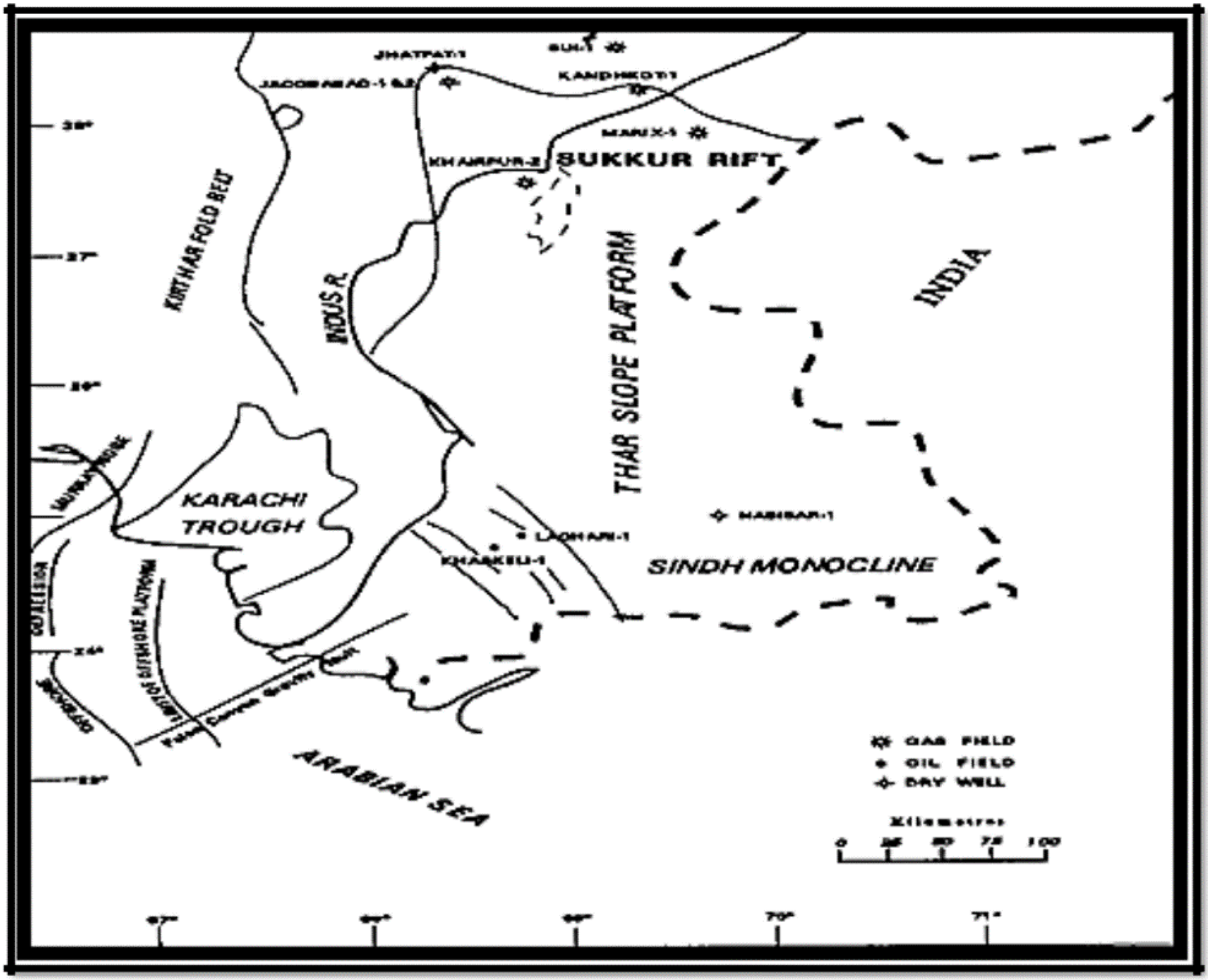

Figure 2.5: Structural setting of the study area. (Kadri, 1995)

2.3 Petroleum play of the Study Area

The below stratigraphic chart shows the generalized Stratigraphy of the Khipro area;

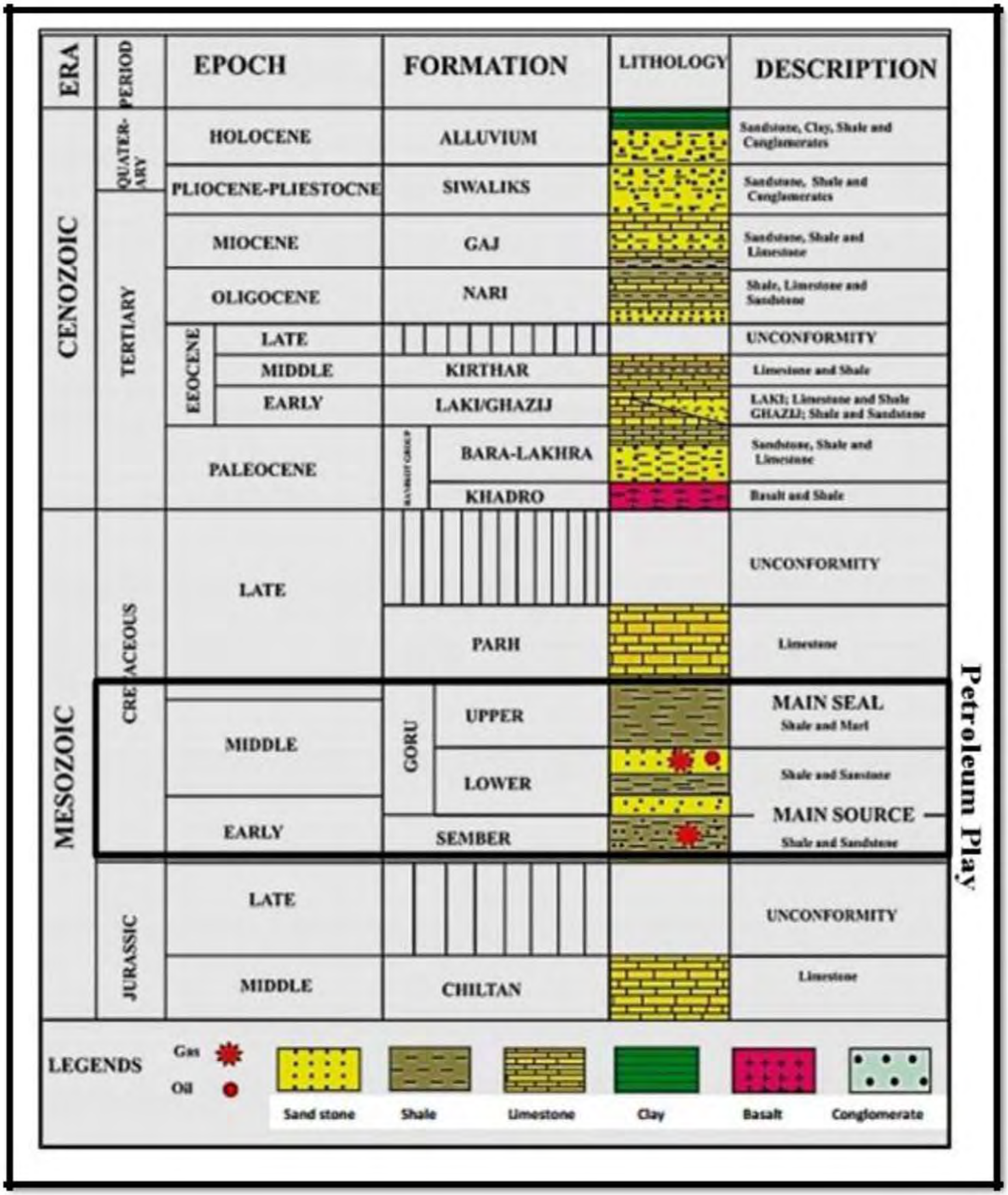

Figure 2.6: General Stratigraphy and petroleum play of the study area. (Zaigham et al., 2000).

Stratigraphy column shown in Fig 2.2 in which 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.

2.3.1 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.

2.3.2 Seal rock

Seal rocks 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 sand.

CHAPTER 03

SEISMIC INTERPRETATION OF STUDY AREA KHIPRO

3.1 Introduction

Interpretation is a technique or tool by which an attempt is made to transform the whole seismic information into structural or stratigraphic model of the earth. Since the seismic section is the representative of the geological model of the earth, by interpretation, one tries to locate the zone of final anomaly (Sheriff, 1999).

Interpretation is the transformation of the seismic reflection data into a structural picture by the application of correction, migration and time depth conversion (Dobrin and Savit, 1988).

3.2 Types of seismic interpretation

Structural interpretation

Stratigraphic interpretation

3.2.1 Structural Interpretation

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, 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, etc. (Sheriff, 1999)

3.3 Interpretation workflow

The Interpretation was carried out using different techniques and steps. Simplified workflow used in the dissertation is given in Figure 3.1. It 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, base map was generated. Faults and Horizons of interest were then marked manually. Identification of marked horizons was done with help of synthetic seismogram, generated with help of well data and faults were marked by keen observation on seismic section and knowing geologic history of study area. Also, time and depth contour maps are generated for further interpretation.

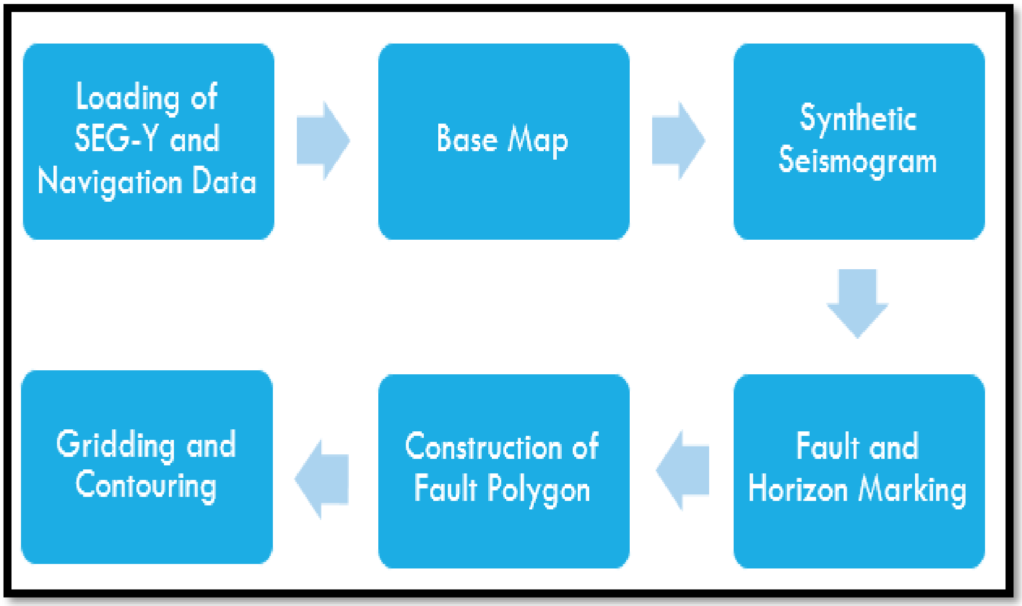

Figure 3.1: Shows the seismic interpretation workflow.

3.4 Synthetic Seismogram

Synthetic seismograms provide a crucial link between lithological variations within a drill hole and reflectors on seismic profiles crossing the site.

Synthetic seismogram is generated using the two-way time for each well top. 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 G2000KH-08. 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.

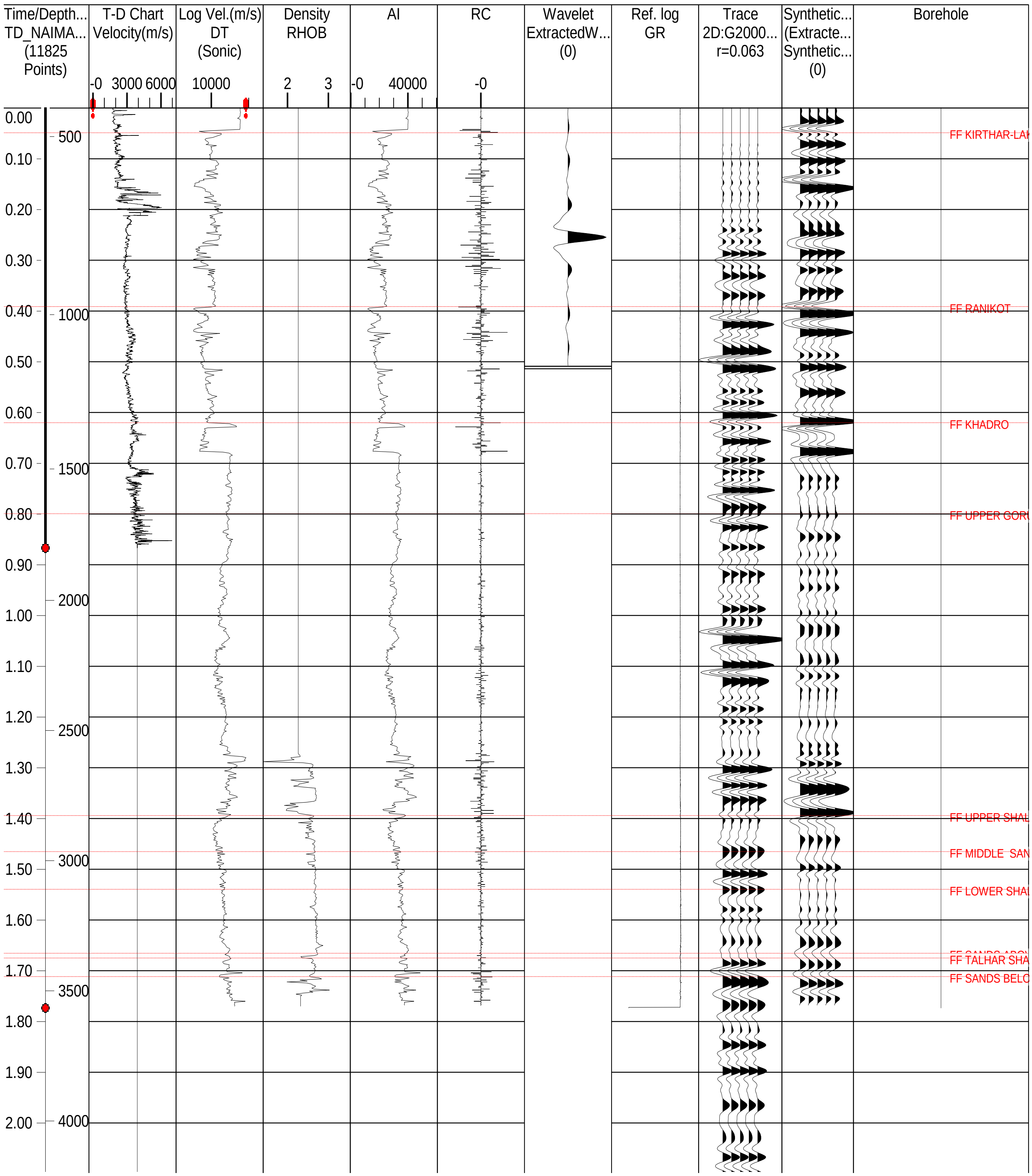

Figure 3.2: Shows the synthetic seismogram of Naimat-Basal-01.

3.5 Horizons and Fault Marking

Fault marking on real time domain seismic section is quite a hard work to do without knowing tectonic history of Area (Sroor, 2010). Faults are marked based on breaks in the continuity of reflection. This discontinuity of the reflector shows that the data is disturbed here due to faults. Naimat Basal-01 is lying in extensional regime hence we have conjugate normal faulting due to which the clear-cut horst and Graben are formed.

Interpreting seismic sections, marking horizons, producing time and depth maps is a task which depends on interpreter's ability to pick and follow reflecting horizons (reflectors) across the area of study (McQuillan et al., 1984). I marked two horizons based on synthetic seismogram of Naimat-Basal-01 well named as Talhar Shale and Sands Below Talhar Shale.

The strike line G2003KH-35 shows Naimat-basal-01 well on which two horizons are marked namely Talhar Shale and Sand below Talhar Shale. Faults are not marked on the strike line because structure are form from east to west. Reflectors of two formations are marked with the help of synthetic seismogram of Naimat-basal-01 well.

3.5.1 Line G2000KH-04

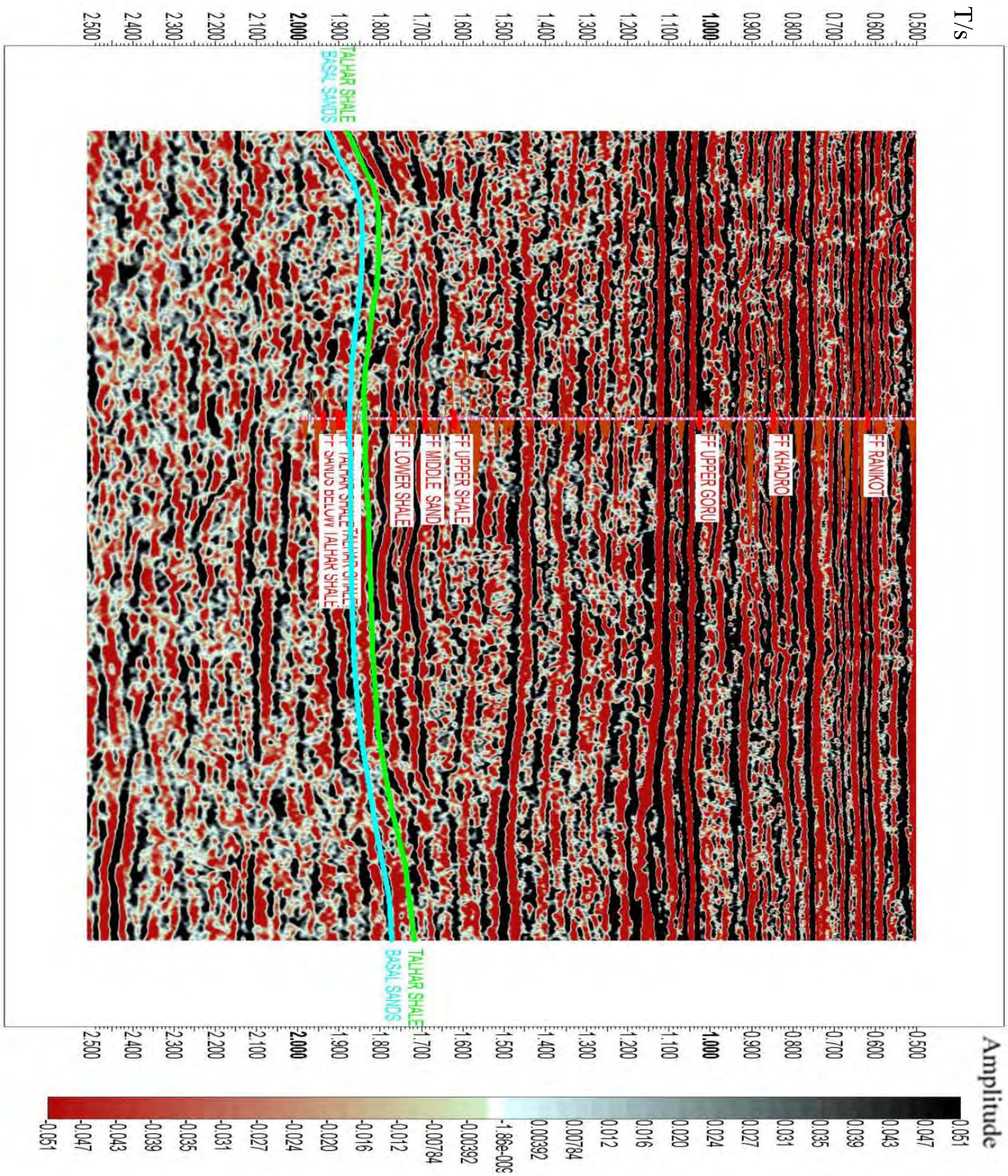

Figure 3.2: Shows the seismic section of line G2000KH-04 with well and marked horizon.

3.5.2 Line G2000KH-08

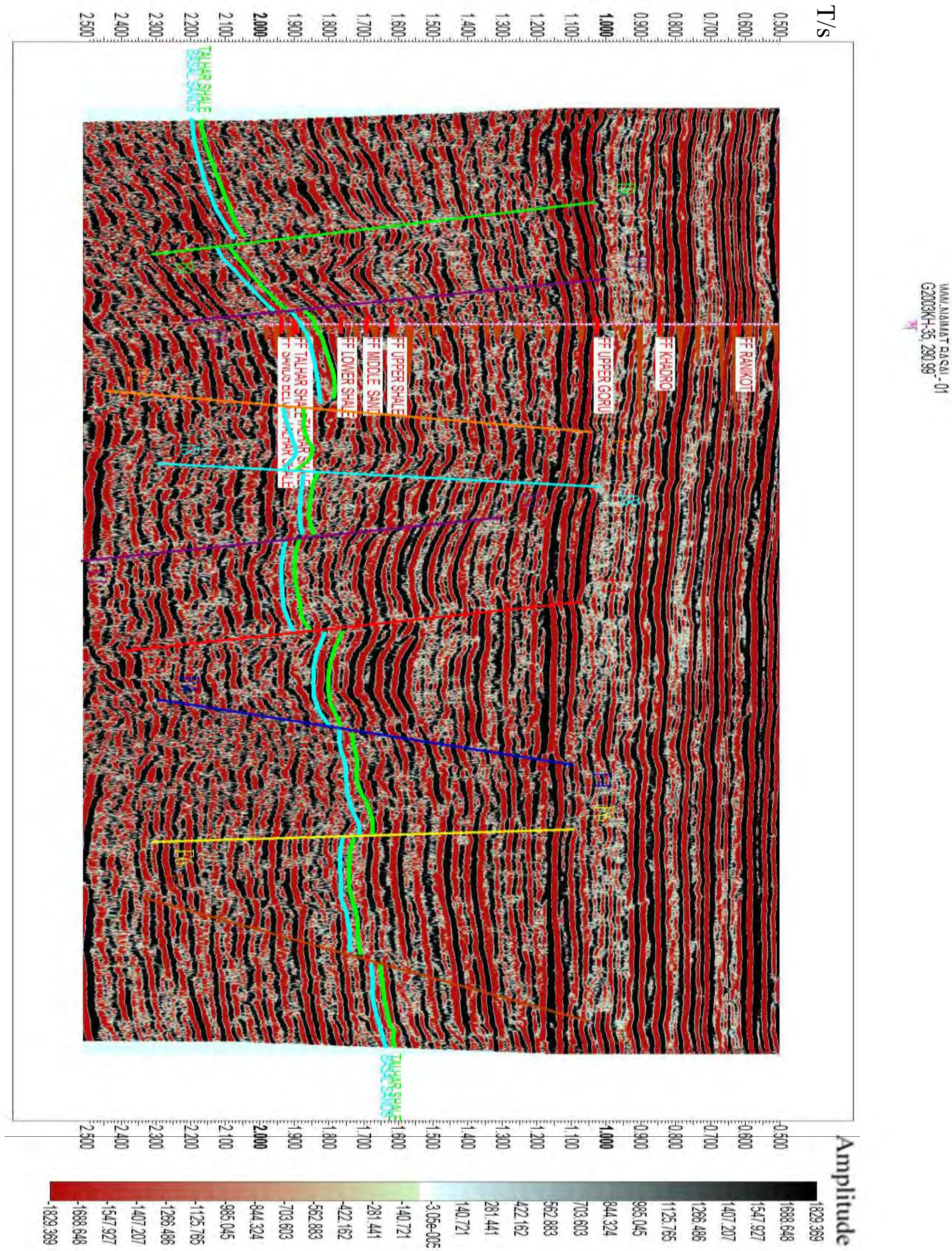

Figure 3.3: Shows the seismic section of line G2000KH-08 with well and marked horizon.

3.5.3 Line G2003KH-35

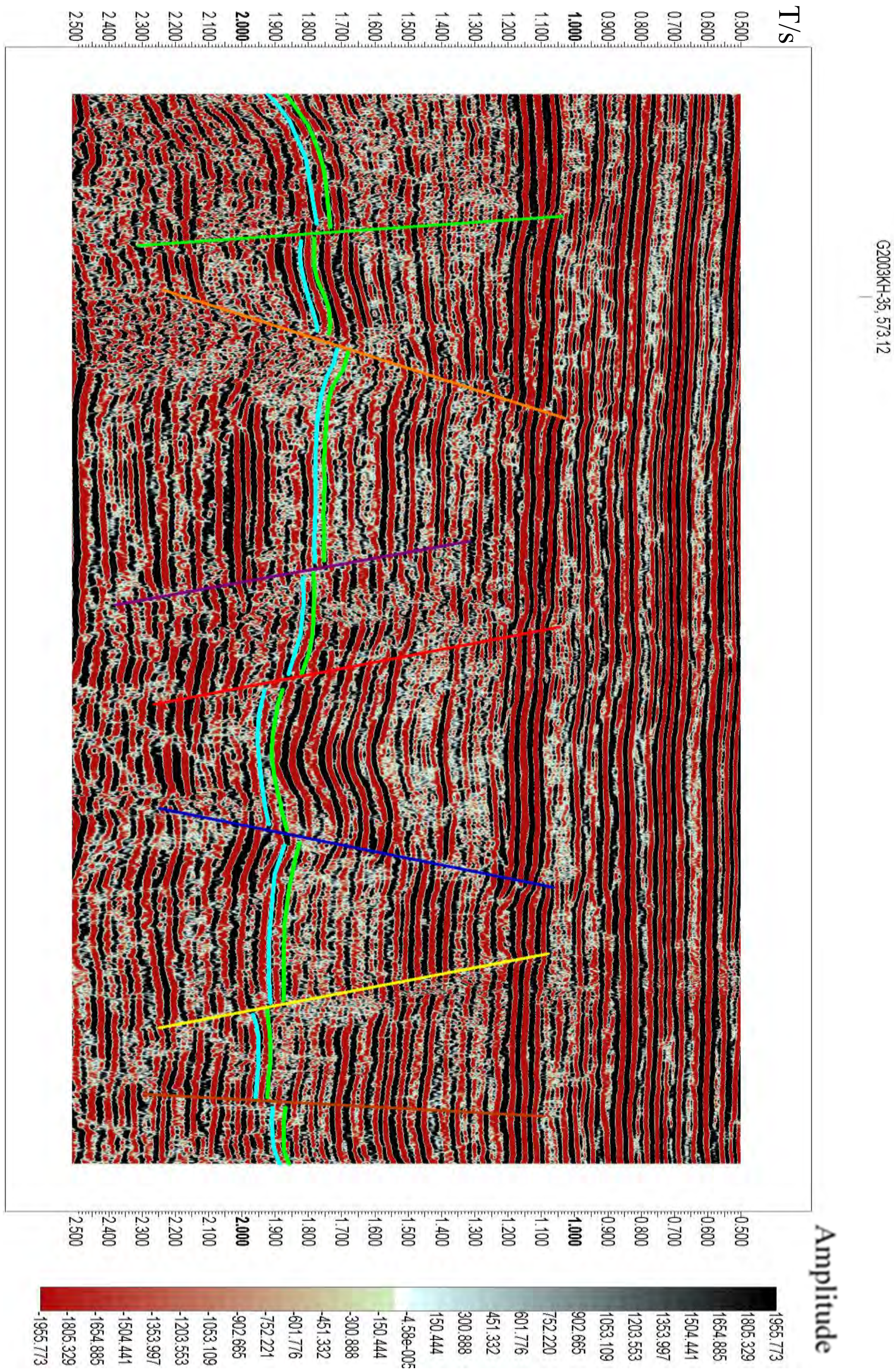

Figure 3.4: Shows the seismic section of line G2003KH-35 with well and marked horizon.

Figure 3.2 and 3.3 shows two dip lines G2000KH-04 and G2000KH-08 on which two horizons are marked, 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. Dip lines are oriented from SW-NE and Stike is N-S.

3.6 Faults Polygon

A fault polygon represents the lateral extent of dip faults or strike faults having same trend. Fault polygons show the sub-surface discontinuities by displacing the contours. To generate fault polygons, it is necessary to identify the faults and their lateral extent by looking at the available seismic data. If one finds that the same fault is present on all the dip lines, then all points on base map can be manually joined to make a polygon.

Faults polygons of the two marked horizons are given below in the figure 3.4 and 3.5. 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 NW-SE direction. Well is shown with orange colour.

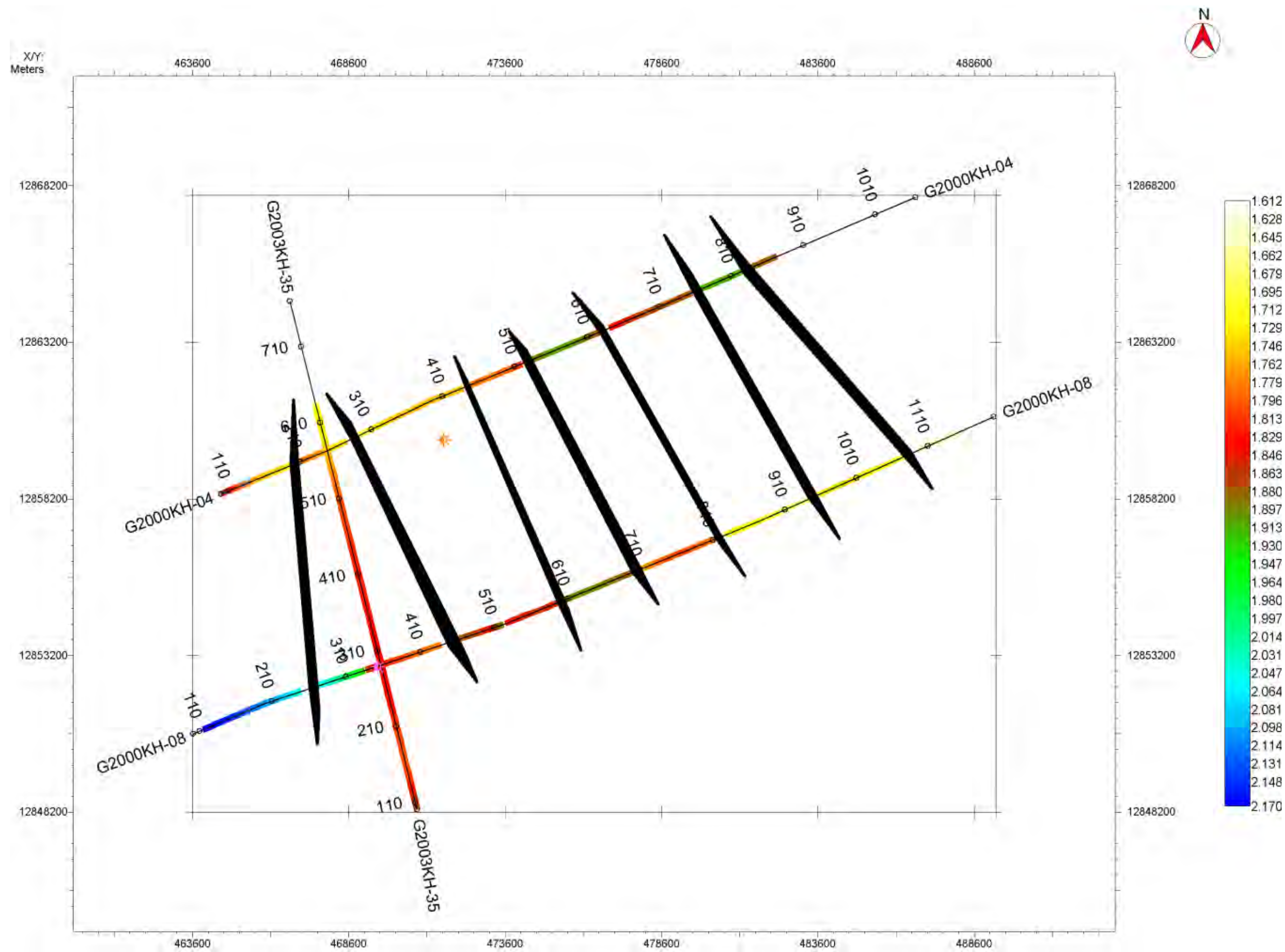

Figure3.4: Figure depict the fault polygon of Talhar shale formation.

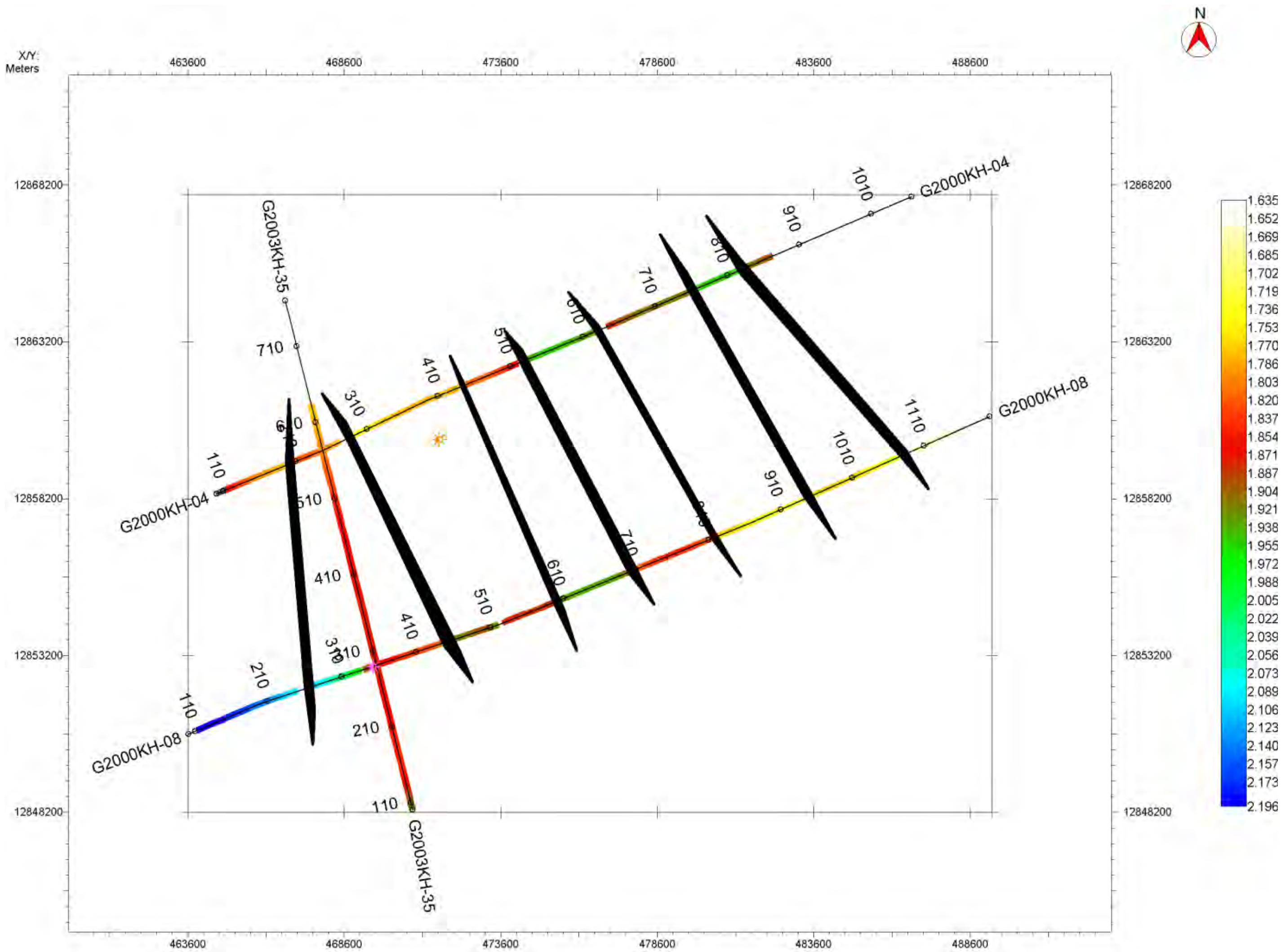

Figure3.5: Figure depicts the fault polygon of Talhar shale formation.

3.6 Contour Map Generation

Contouring is the main tool used in the seismic interpretation. After contouring it becomes obvious that what sort of structure is forming a 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).

3.6.1 Time Contour

Time contour map of the two horizons are generated in order to further confirm the interpretation like fault marking also the bookshelf geometry. The figure 3.6 and 3.7 illustrates time contour of all the horizons like Talhar Shale and Sand below Talhar Shale. As we know that time contour map shows lateral as well as vertical variation. Time contour maps confirm the structural interpretation done on seismic section. Trend of all contour maps is same which shows there is no vertical variation.

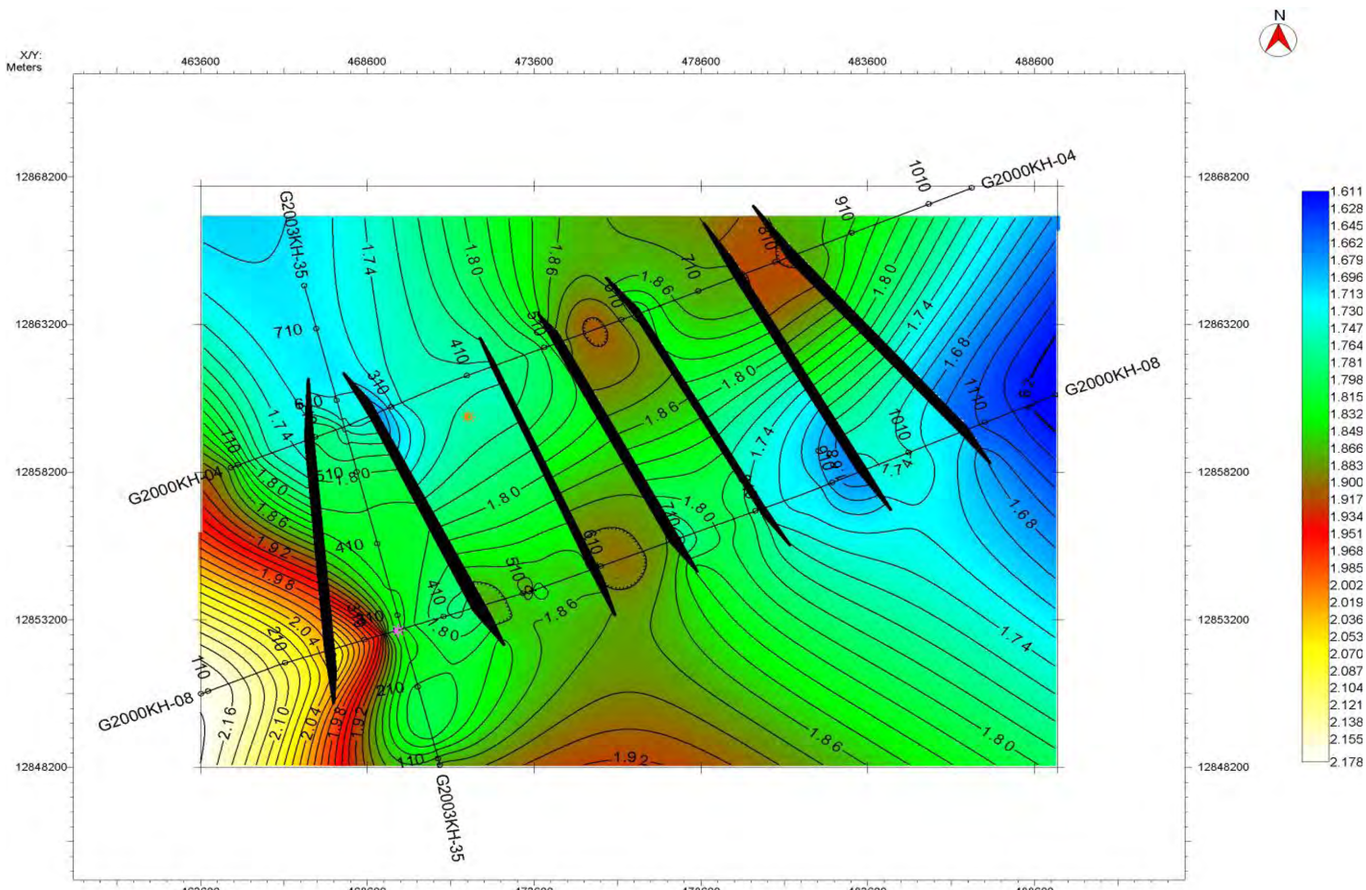

Figure 3.6: Shows the time contour map of the Talhar Shale formation.

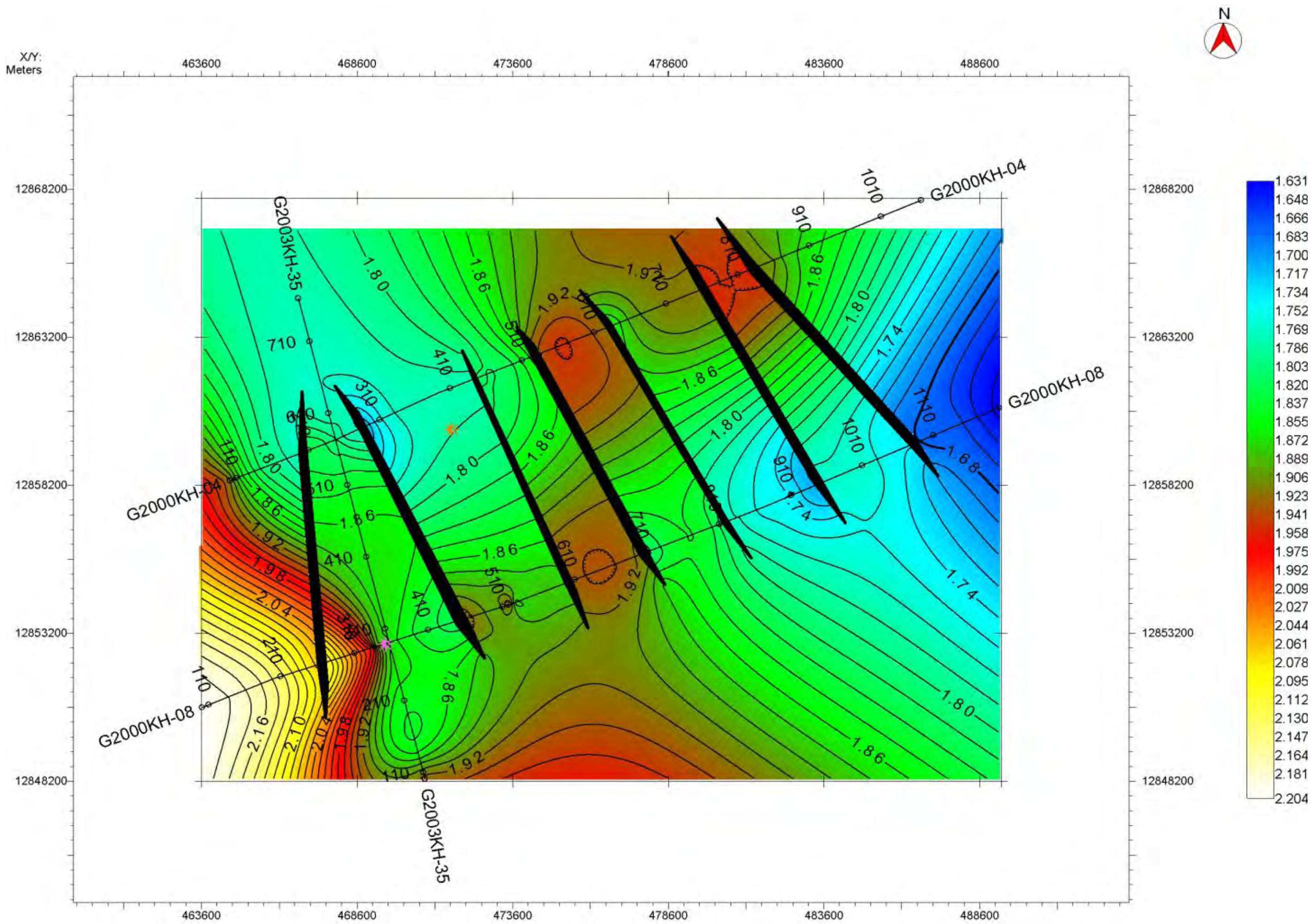

Figure 3.6: Shows the time contour map of the sand below Talhar Shale formation.

3.6.2 Depth Contour Maps

Depth contour maps are not as common as time contour maps. Mostly, the depth estimates are made with the help of time contour maps in the area. However, depth contour maps can give an extra edge when there’s a good velocity control. Contouring can be a challenging job when done over areas of extensive faulting or mapping small features in strati graphically complex regimes. 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.

Depth contour maps of the two horizons Talhar shale and sand below Talhar shale are generated as shown in figure 3.7 and 3.8. Figures depicts the horst and graben structure as shown in seismic section also, the bookshelf geometry can be seen in figures formed due to parallel faulting.

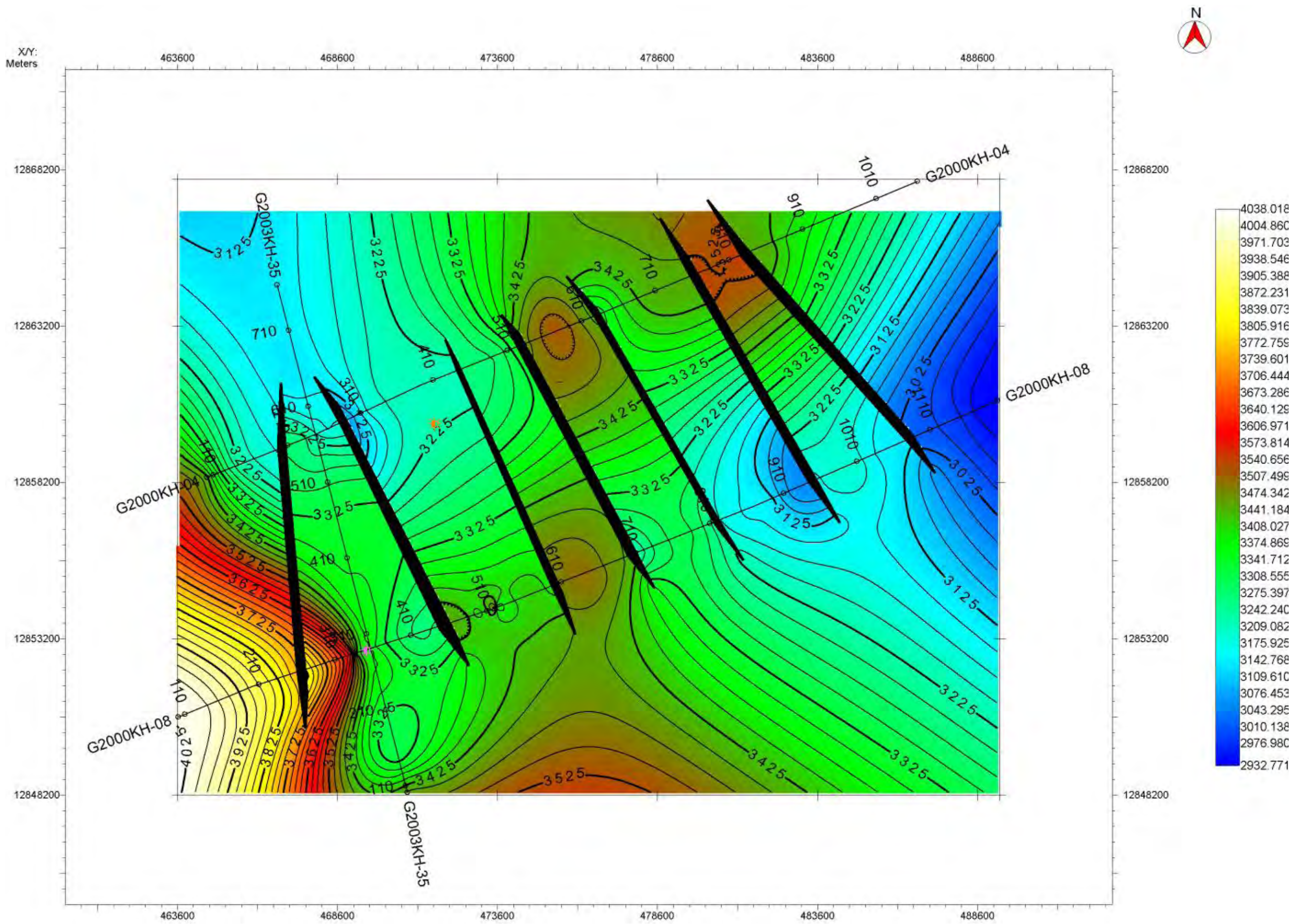

Figure 3.7: Shows the depth contour map of the sand below Talhar shale formation.

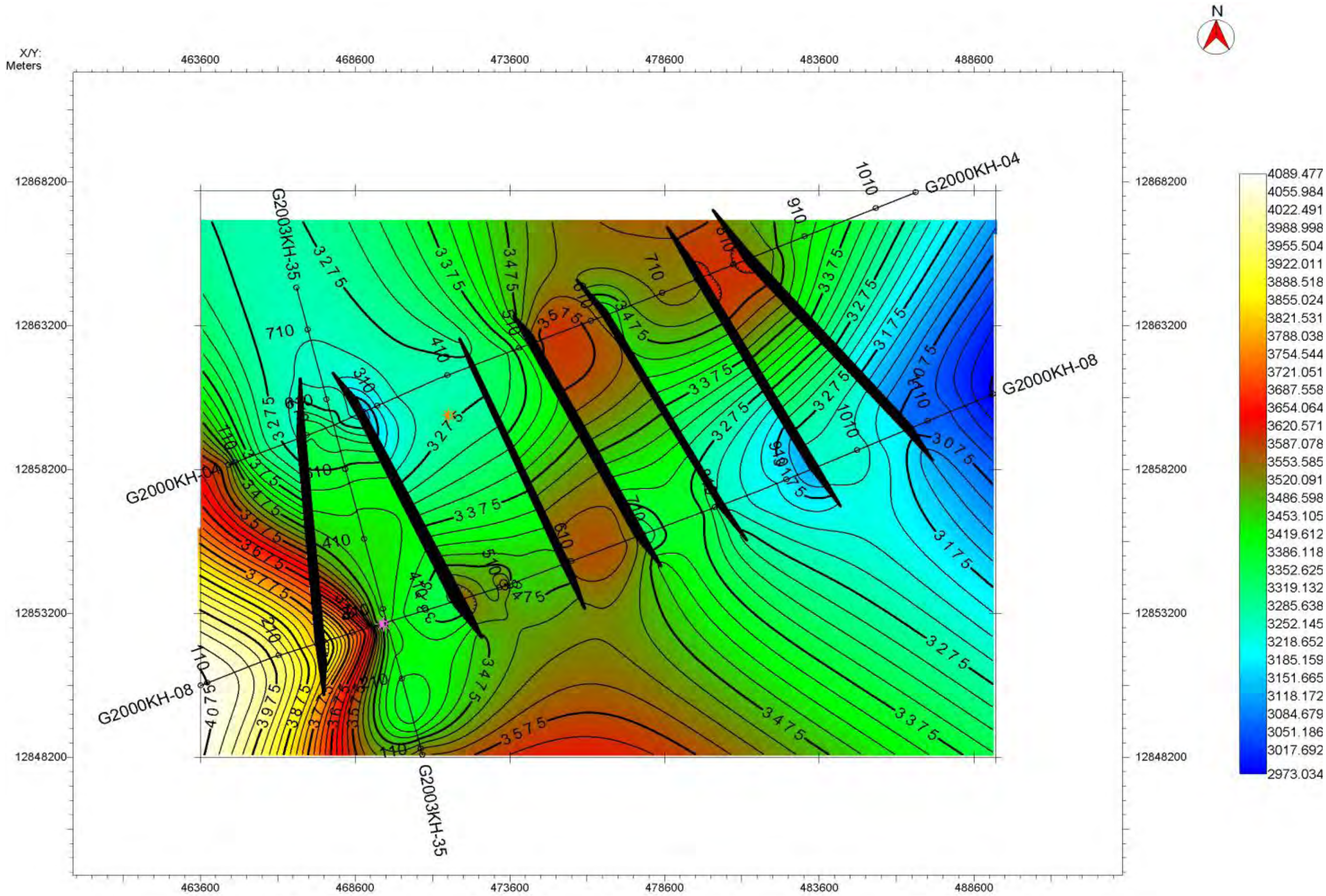

Figure 3.8: Shows the depth contour map of the Talhar shale formation.

CHAPTER 04

PETROPHYSICAL ANALYSIS

4.1 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". 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).

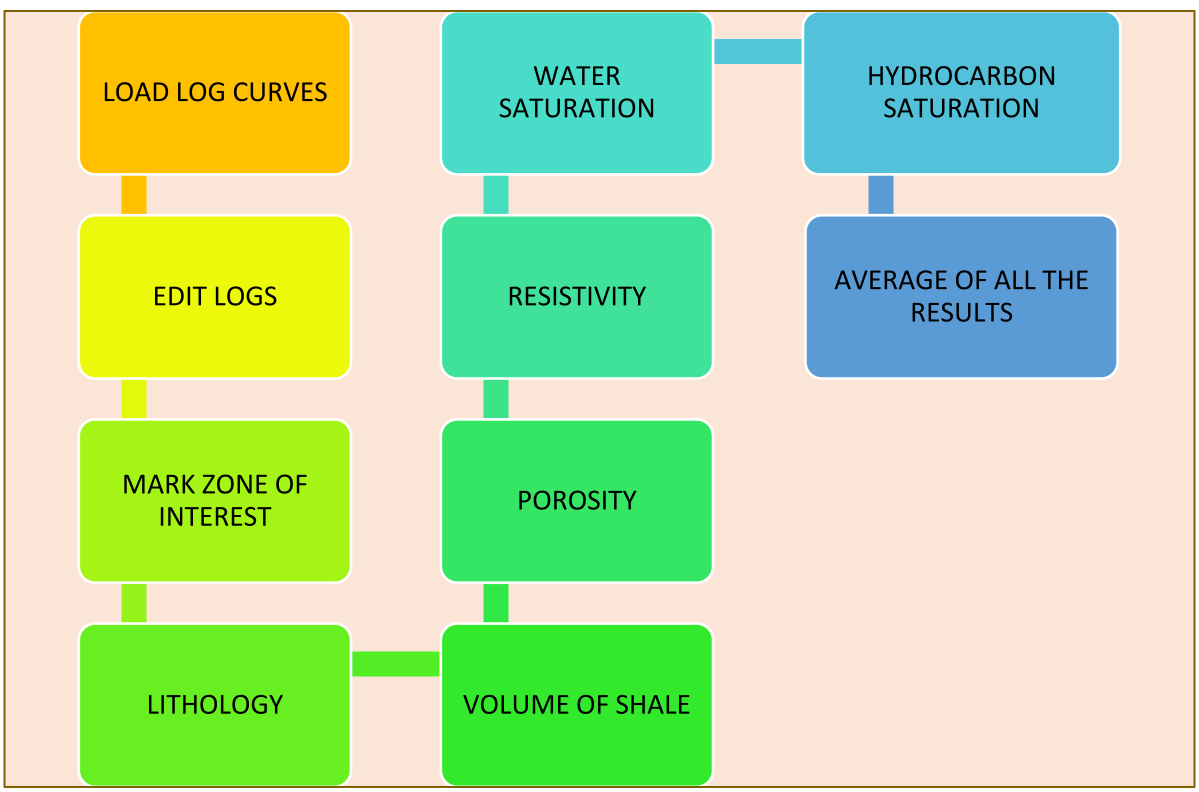

Figure 4.1: Workflow for petrophysical interpretation.

4.2 Classification of Geophysical Well Logs

Geophysical well logs can be classified into three categories

Lithology logs

Resistivity logs

Porosity logs

4.3 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)

4.3.1 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).

4.3.2 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:

$$I_{gr} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \tag{4.1}$$

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).

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

4.3.4 Porosity well logs

Porosity well logs provide the data through which the water saturation can be determine, provide the accurate lithology 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

$$\emptyset_s = \frac{\Delta t_{log} - \Delta t_m}{\Delta t_f - \Delta t_m} \tag{4.2}$$

where $\emptyset_s$ represents 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.

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).

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.

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

By using following mathematical relation, density porosity can be related as:

$$\emptyset_d = \frac{\rho_m - \rho_b}{\rho_m - \rho_f} \tag{4.3}$$

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.

4.4 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.

$$\varphi_{avg} = \frac{\varphi_n + \varphi_d + \varphi_s}{3} \quad (4.4)$$

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.

4.5 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).

$$\emptyset_e = \emptyset_{avg} \times (1 - Vsh) \quad (4.5)$$

where,

$\emptyset_e$ effective porosity which to be calculated

$\emptyset_{avg}$ represent the average porosity

Vsh represent volume of the shale.

4.6 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 in order to find the water saturation.

$$S_{sp} = -\mathrm{K} * \log \frac{R_{mf}}{R_w} \tag{4.6}$$

for K;

$$K = 65 + 0.24 * T°\mathrm{C} \tag{4.7}$$

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;

$$S_w = \sqrt[n]{\frac{F * R_w}{R_t}} \tag{4.8}$$

where,

F is formation factor which is

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.

4.7 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;

$$S_h=1-S_w \tag{4.9}$$

S_w is Hydrocarbon saturation

S_h is hydrocarbon saturation

4.8 Log trend NAIMAT BASAL-01

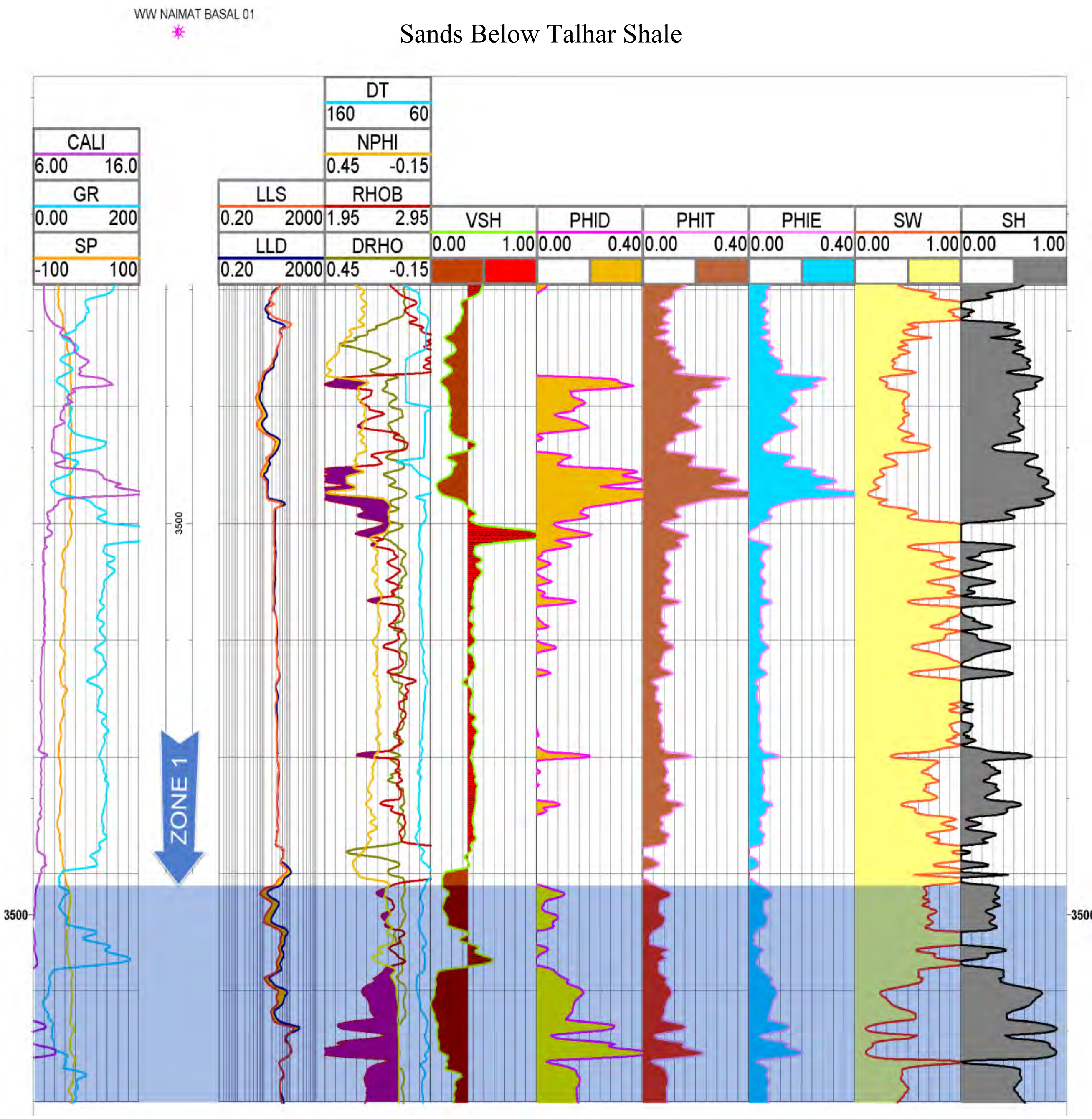

Figure 4.2: Figure shows the Petrophysical interpretation and marked zone of interest in the reservoir formation.

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 4.1: Quantitative interpretation of the zone of interest.

4.8.1 Zone 1 from (3529m to 3550m)

In the zone of interest 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 indication affirms the presence of the hydrocarbon potential in the promising zone.

CHAPTER 05

COLORED INVERSION

5.1 Geophysical Inversion

Geophysical inversion involves mapping the physical structure and properties of the subsurface of the earth using measurement made on the surface of the earth or another way to look inversion is to consider it as the technique for creating a model of the earth using seismic data as input.

Impedance as discussed by Vee ken (2007), is an important tool as it contains essential data from the logs and seismic. Unlike seismic data, which is an interface property, acoustic impedance is a rock property which shows geologic layer and is also closely related to lithology and reservoir characteristics such as porosity and hydrocarbon saturation. Inversion of seismic data to Acoustic Impedance is usually seen as a specialist activity, so despite the publicized benefits, inverted data are only used in a minority of cases. This new technique, colored inversion, performs significantly better than traditional fast-track routes such as recursive inversion, and benchmarks well against unconstrained sparse-spike inversion.

5.2 Color Inversion

The earth's reflectivity can be considered fractal, and the resulting amplitude spectrum favors high frequencies (spectral bluing). If there was no preferred frequency, then you would have a "white spectrum", but as there are some frequencies with more energy, then it is called "colored".

Colored Inversion includes preparation of the well logs, investigating relationships between impedance and reservoir properties and tying the well logs to the seismic. After tying to the seismic, the well log data is used to estimate a seismic wavelet. By application of zero phase deconvolution a broad-band zero-phase dataset is obtained which forms the input to colored inversion (Lancaster and Whitcombe, 2000).

A method was developed by Lancaster and Whitcombe (2000) which called Colored Inversion (CI). The CI method is a simple and fast technique to invert the band-limited seismic data to relative impedance and can be done by generating a single operator to match the average seismic spectrum to the shape of the well log impedance spectrum.

Colored Inversion enhances the seismic signal and adds the auto-picker. Often it can enhance features such as bed resolution, minor faulting, fracture zones and discontinuities due to channels and possibly the presence of hydrocarbon.

5.3 Workflow

The workflow of color inversion is shown below.

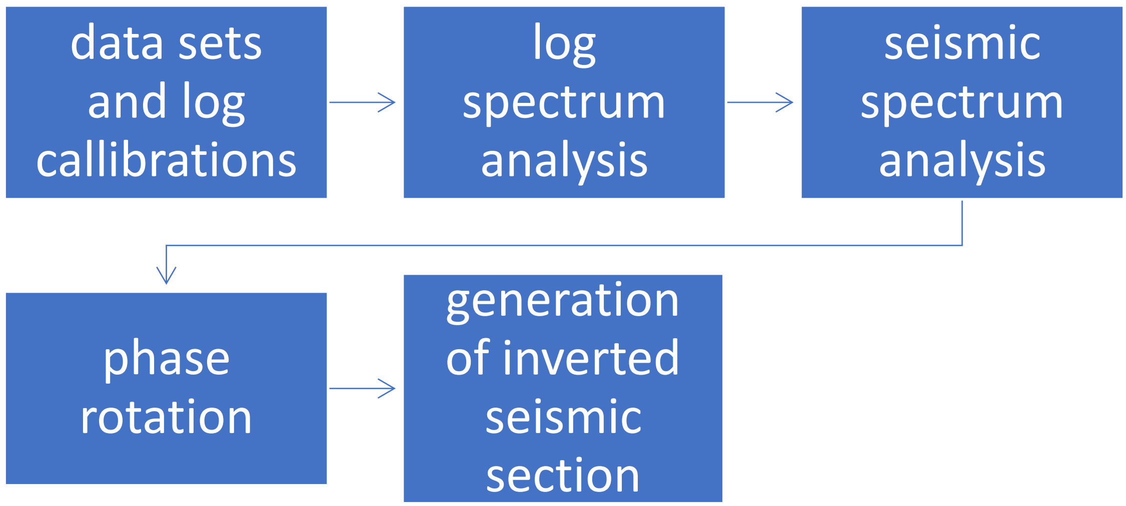

Figure 5.1: Workflow of the colored inversion.

For the Colored inversion we require well data and information of logs. The velocity is obtained from sonic log and density is obtained from density log and by convolving these values. We get acoustic impedance from the log and then we pass a best fit line which is our desired spectrum for seismic. This defines the amplitude spectrum of the required operator. Then we apply phase rotation of the -90^{o} shift which agrees with the simplistic view of inversion to integration, and the concept of a zero-phase reflection spike being transformed to a step AI interface, provided the data are zero-phase. The Colored Inversion operator is converted to the time domain and simply applied to the seismic volume using a convolution algorithm.

5.4 Log Spectrum Analysis

Here the impedance spectrum of the log is generated on the log paper by passing the best fit line in the range of the seismic frequency range. At the beginning the researcher have almost the same impedance but as the amplitude spectrum trend gently rises with frequency the impedance logs tend to decay with frequency having effectively undergone the process of integration relative of the data set figure 5.1

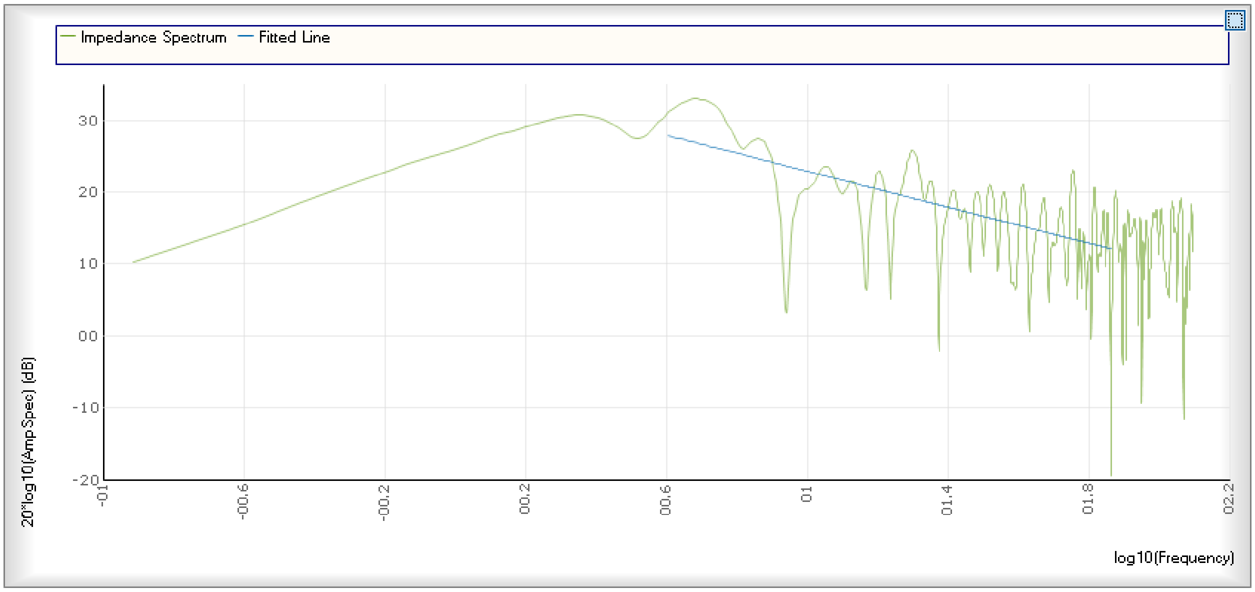

Figure 5.1: Impedance log spectrum with a best fit line.

5.5 Butterworth Filter

Butterworth filter is used to smooth and constrain the impedance log spectrum. The Butter worth filter is a type of signal processing filter designed to have as a flat frequency response as possible in the pass band. It is also referred to as a maximally flat magnitude filter.

This filter is used here for convolution of the wavelet and reflectivity series for formulation of seismogram. The Butterworth filter is shown in figure 5.2

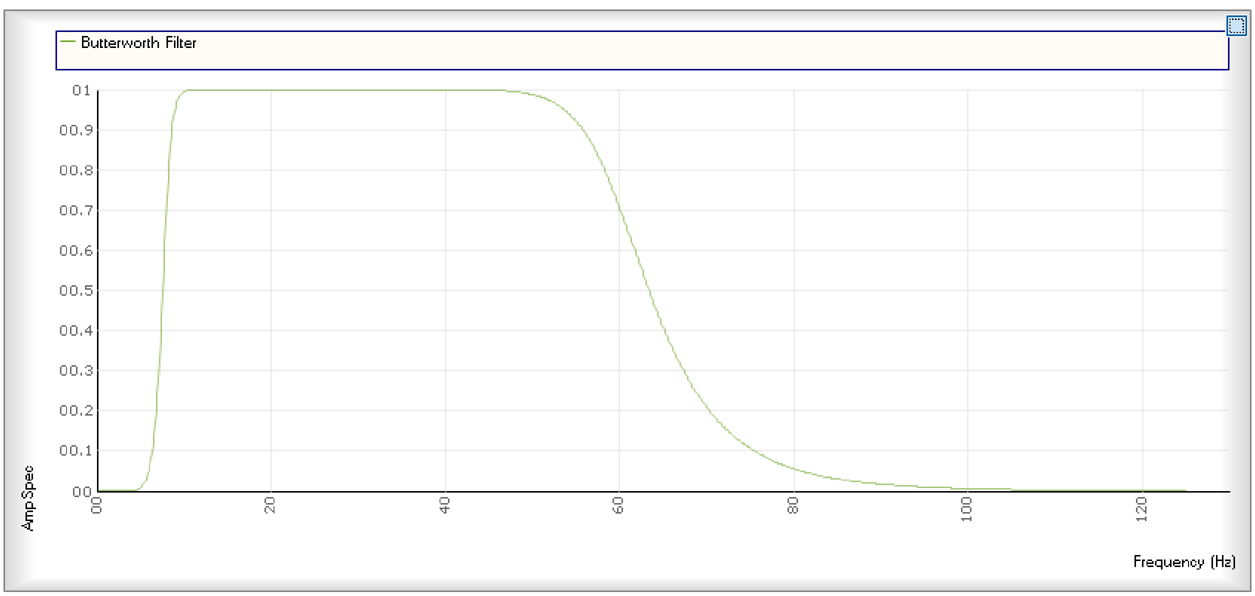

Figure 5.2: Shows Butterworth filter.

5.6 Seismic Spectrum Analysis

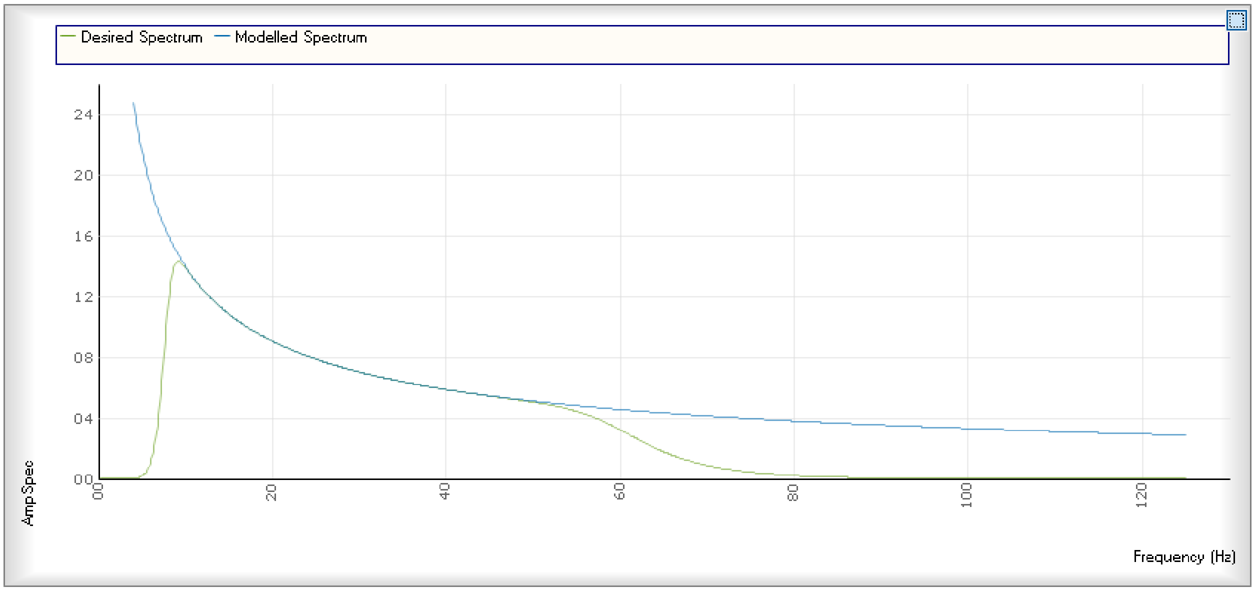

Figure 5.3: Seismic spectrum compared with desired impedance log spectrum.

In the above figure 5.4 the researcher has an average spectrum of seismic data which is superimposed with the desired impedance log spectrum and researcher can clearly see that there is a vast difference between these two spectrums. That's why researcher pass regression line through impedance from which spectrum is generated, the spectrum we generate compare with seismic spectrum and then researcher move for best matching.

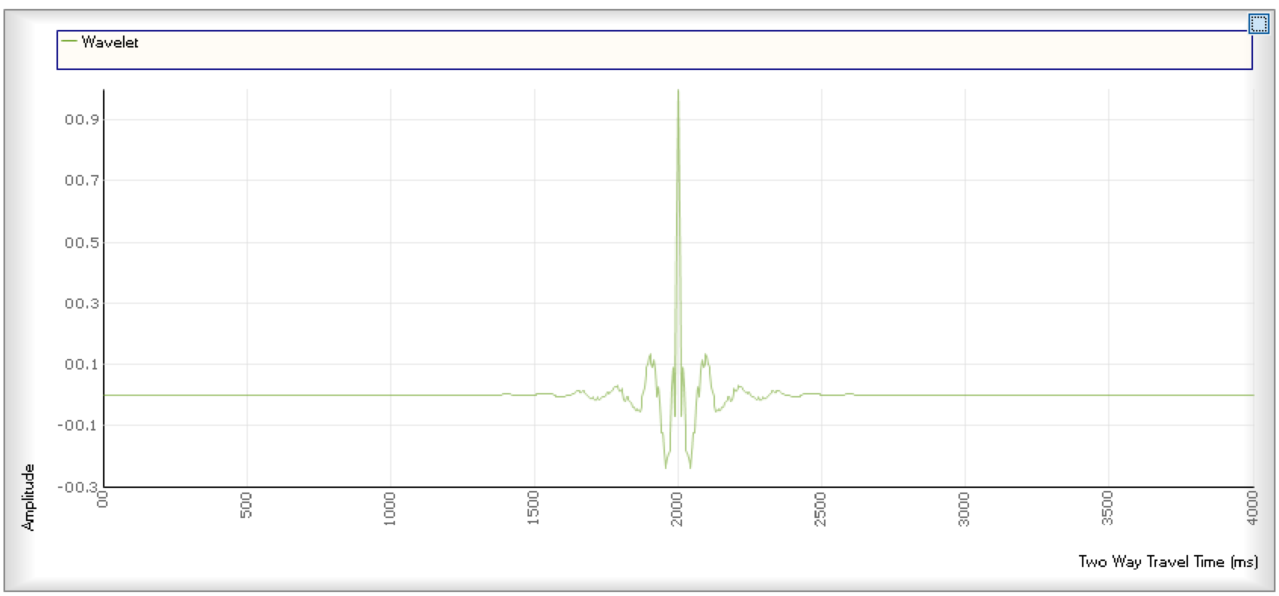

Figure 5.4: Extracted wavelet (operator in time domain).

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

5.7 Generation of Inverted Section

The researcher had a single well data available that is why researcher used one well to derive operator i.e. Naimat-01. When researcher applied operator then the inverted section that has been produced is shown in figure 5.5. The inverted log is applied on the whole section. At the well location researcher have optimum results as researcher go far away from the well the control will be lost because software does interpolation and researcher do not get good result. The seismic section is displayed w.r.t relative acoustic impedance having high (yellow) and low (blue) acoustic impedance. The inverted section is shown in figure 5.5.

5.8 Interpretation of inverted section

The inverted seismic section is generated shown in figure 5.5. The inverted section can be interpreted by using color bar. The white to yellow color shows high values of acoustic impedance and blue to green color shows low impedance. The hydrocarbon accumulation is associated with low acoustic impedance. The given inverted section is shown with T-D chart and it shows Formations as well. The Formation having low acoustic impedance is Lower Goru. Because results obtained from seismic inversion shows low values of impedance and structure formed is horst and graben both conditions give indication of possible hydrocarbon potential zone.

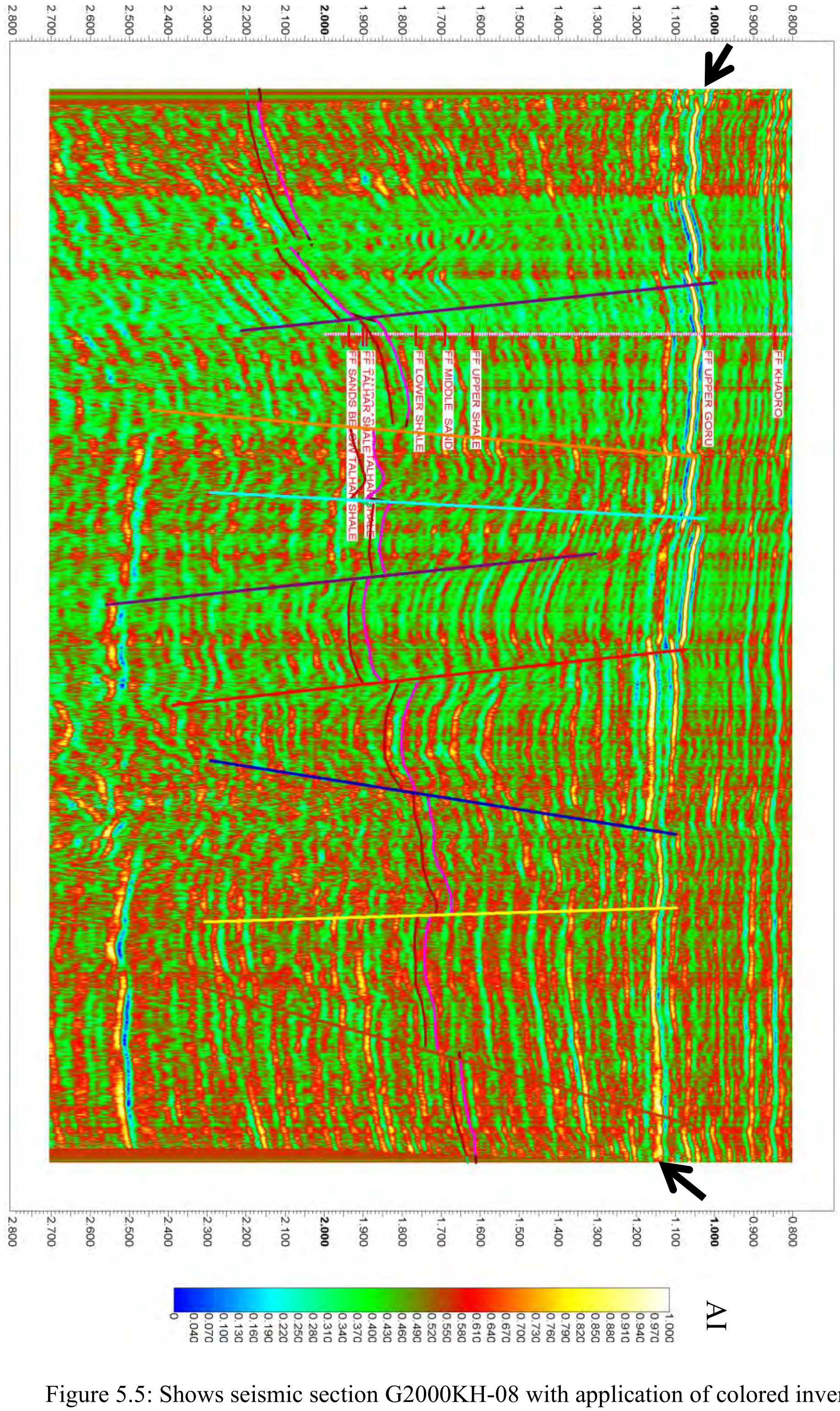

Figure 5.5: Shows seismic section G2000KH-08 with application of colored inversion.

DISCUSSIONS AND CONCLUSIONS

Remote sensing is carried out using ASTER LT1 data to delineate surface lithostratigraphy of the Khipro area. Then image is interpreted using different image processing techniques such as PCA, MNF and Band Rationing.

Structural interpretation involves horizon marking and fault marking on seismic section, two horizons and faults are marked on the seismic section which delineates the presence of horst and graben structures in the area. It also shows the bookshelf geometry due to parallel faulting in the area.

Furthermore, time and depth contour maps of the marked horizons are generated. 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.

Petrophysical interpretation is done by using different geophysical logs and determination of other logs including porosity logs, volume of shale, water saturation and hydrocarbon saturation helped in determining zone of interest in the reservoir zone within different sand packages. It also differentiates the reservoir zone within the area by determining the geophysical logs. The qualitative and quantitative results show that the area is very effective for hydrocarbon potential in the reservoir zone.

Colored inversion is carried out in order to confirm the petrophysical results also show the presence of hydrocarbon in the reservoir zone. Colored Inversion is used for developing the relationship between seismic data and well logs, to improve resolution and to calculate accurately rock properties. Very clear low impedance map of has been achieved by inversion which proved presence of hydrocarbons in marked horizons.

- Remote Sensing is done to identify surface rock units using Aster LT-1 data.
- Structural interpretation is carried out using seismic data which identifies horst and grabens in the area of khipro.
- Markinjg promising zones using well logs data.
- Seismic colored inversion is carried out to mark low impedence areas and promising zones.

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