SEISMIC INVERSION AND PETROPHYSICAL ANALYSIS OF MUBARAK AREA,CENTRAL INDUS BASIN,PAKISTAN

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ABSTRACT

Mubarak block is present in Ghotki area Sindh,Central Indus basin.Due to extensional tectonic regime normal faults are present in this area.Jurrasic to most recent rocks are present in its stratigraphic sequence.The most promising formation in this area is Lower Goru as it contains thin interbedded sandstone and shale. This study has been carried out in Rehmat gas field (Mubarak block).The provided data was seismic 3D data and well data of Rehmat-02.The purpose of study is to know the potential of Lower Goru formation.Structural and stratigraphic interpretation of 3d seismic data, fault geometry mapping and time and depth contour maps are main methods used to complete task. Three horizons are marked Sui Main Limestone, Upper Goru and Lower Goru Formation. Due to extension normal faults are developed which divide the area into horst and graben structures which play an important role in reservoir compartmentization.For estimation of fluid potential petrophysical logs are applied. Only one reservoiz zone of significant thickness and hydrocarbon saturation was marked.The estimated volume of shale varies between 20%-30%, effective porosity between 10-11% and saturation of water from 20-30%. Estimation of sand channels and detailed reservoir characterization is done by post stack inversion. Model based inversion technique play an important role in understanding lithology and porosity of B-interval reservoir. Model based inversion gives appropriate estimation of acoustic impedance and lithology. North to South impedance value increases and from East to West it decreases.At the encounter of Lower Goru formation, there is sharp increase in acoustic impedance showing low porosity value above and below well location and at well location low impedance value suggest high porosity which show presence of hydrocarbons.   Hence, the study shows Lower Goru formation of Cretaceous has potential to produce hydrocarbon at commercial scale.

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INTRODUCTION

1.1 Research purpose

Pakistan needs advanced techniques for the development of hydrocarbons to meet its current energy requirements. In geophysics seismic exploration techniques are improvised to obtain hydrocarbons. With the help of reflected seismic waves we can gather information about subsurface. The development of hydrocarbon projects need integrated studies and inversion is one of the key steps to evaluate addiotional information from the geophysical data. From seismic data the detailed seismic and rock properties such as acoustic impedance and inversion can be calculated through seismic inversion. It enables us to interpret the petrophysical and geological subsurface boundaries. The results obtained through inversion have higher resolution, more accuracy and better ranking of prospect (Veeken et al., 2004)

The geological structures present in subsurface are mostly 3D in nature. For better interpretation and absolute image of subsurface 3D seismic data is used (Yilmaz, 2001). Worldwide the geoscientist and petrophysicist used wireline logs for reservoir characterization. They give measurement of borehole in the form of ongoing record which is further used to shed light on the parameters calculated in reservoir, geological environment and distribution of fluid. However, rock properties are greatly affected by the type of fluid used during drilling and borehole condition (Glover, 1990).

1.2 Study area

The study area Mubarak block lies in Central Indus basin Pakistan. The area is present about 72 meters above Mean Sea level. It’s bounded towards North by Sulaiman fold belt and South by Khairpur Jacobabad high. Kirthar fold belt and Mari Kandhkot high are present on west and east sides respectively. Structurally normal faulting is exhibited in this area and horst and graben structures act as traps (ogj.com)

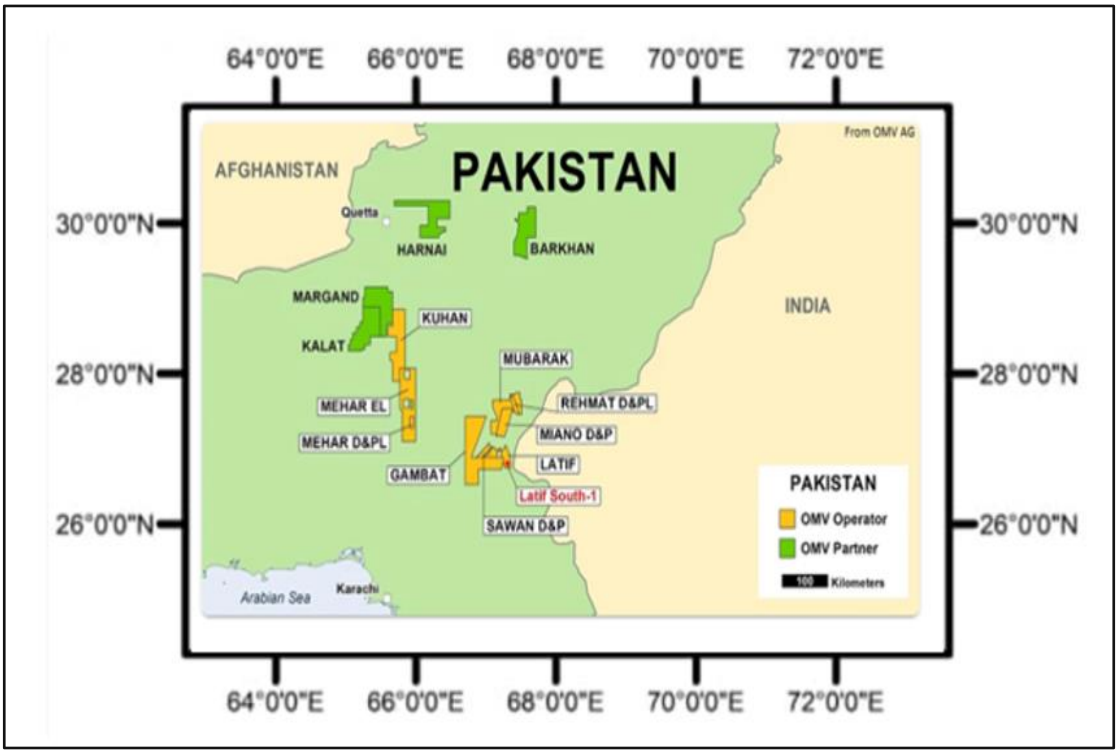


Figure 1. Map of Pakistan showing location of Mubarak Block with surrounding field (Rehman et al., 2013)

1.3 Exploration history

Petronas in 1999 were awarded for the collection of data in Mubarak block. They announced the production of gas from Rehmat field in Block Mubarak. In 2004 Petronas Carigali carried out a 3d seismic survey of about 550km and interpreted as a gas prone area. Currently OMV is operating this field and hold 25 percent share. B sands of Lower Goru formation act as reservoir in Mubarak area (Courtesy by petronas). The petrophysical analysis of the area suggests to drill more wells on the central part of southwestern side of Mubarak area because the southern side of the area is economically viable as compared to northern side which is more water saturated and has shaly content (khan,2018)

1.4 Objectives

The main purpose of research is ranking of reservoir formation by the help of post stack inversion procedures using 3D seismic and well log data.

The identification of prospect and to interpret structures and structural trends in subsurface.

Evaluation of strata particularly B sand interval of Lower Goru formation and wells laying in 3d cube for hydrocarbon promising computation.

Petrophysical analysis helped to differentiate between reservoir and shale zone, also marks zone of interest.

For the identification of lateral and vertical variation in strata, fluid content and rock properties model based seismic inversion is used.

1.5 Data used

For seismic interpretation 3D seismic cube of 10 square km was provided by LMKR after approval from DGPC. well data of Rehmat-01, Rehmat-02, Rehmat-03 was also provided. The data set comprises of

Navigation data (DAT file)

Seismic data (SEG-Y)

Well data

LAS file

Well header

Formation Tops

1.6 General workflow

For reservoir characterization following work flow has been adopted. Seismic interpretation is done to know about structure and stratigraphy of subsurface. Well to seismic correlation is established and series of horizons are marked by using software packages. Complete log suit and 3D seismic data are used as an input for post stack seismic inversion. Initially wavelet would be extracted from seismic data and well correlation is performed as a result of which impedance wavelet is extracted. Then horizontal impedance layers change with with respect to wells. These layers would expand into small cells making grid nodes. Each grid node has its own value of time and impedance. After each iteration the value of grid node would be updated. Final model will be the one with minimum error. Seismic inversion is used to establish lateral variation in rock properties and fluid content which are integrated with well correlation.

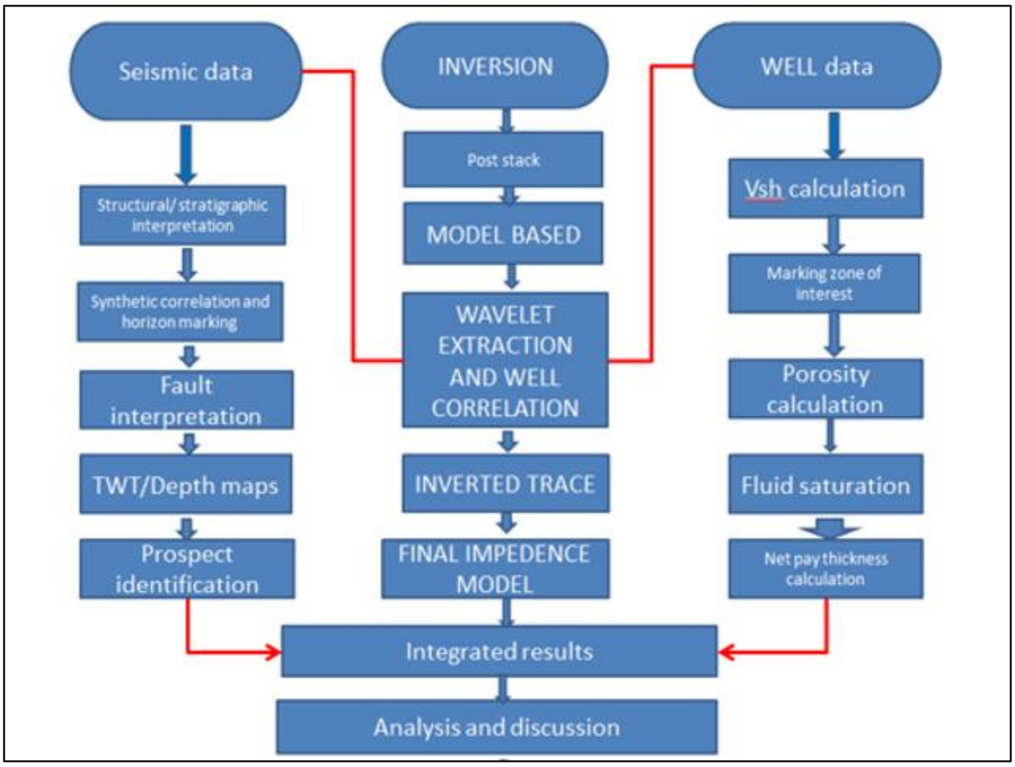


Figure 1.2 Workflow of seismic interpretation, petrophysical analysis and seismic inversion

CHAPTER 2

TECTONICS AND STRATIGRAPHY

For seismic interpretation the knowledge of area is very important. Environment of deposition and basin forming mechanism help in studying history of basin (Kingston et al., 1983). In an integrated manner geology and geophysics are the best ways for inquiry of hydrocarbons. (jocobs, 1991)

Geologically Mubarak area lies in Panu Aqil graben. In the north Mubarak block is bounded by Sulaiman fold belt and south by Khairpur Jacobabad high on east by Kirthar fold belt and west by Mari Kandhkot high. Normal faults are the common geological features, horst and graben act as traps in this area. Mainly basin was formed in Jurassic as a result of rifting of Indian plate from Gondwanaland (Kadri, 1995).

2.1. Regional geology and tectonics of area

According to global tectonics Pakistan is located at the intersection of three plates Indian, Eurasian and Arabian. The Indian plate has drifted from Gondwanaland during early Mesozoic and collided with Eurasian plate during early tertiary. The face-to-face collision resulted in Himalaya orogeny. The presence of normal faulting in Southern Indus basin is the evidence that the major tectonic events have occurred in past. (Ahmad et al., 2010).

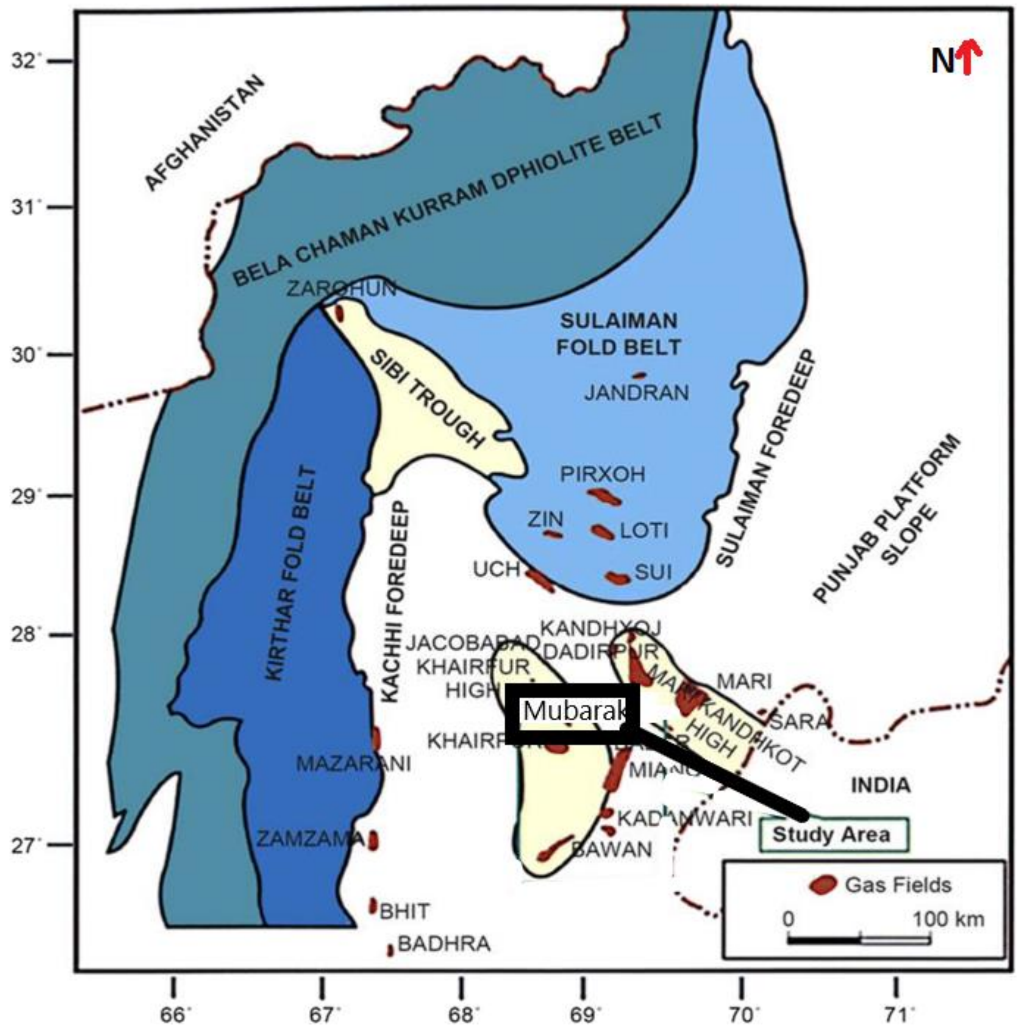


Figure 2.1 Geologic map of central Indus basin with location of Mubarak block (Ahmed et al., 2013)

During early Cretaceous the process of rifting resulted in formation of structures when Indian plate was separating from Medagascar about 90 Ma years ago. The event occurred during the deposition of Lower Goru formation and continued till the upper Goru formation. Jacobabad Khairpur high and Mari Kandhkot high exhibit normal faulting so Mubarak area is a part of extensional regime formed due to separation of Indian plate first from Africa and then from Medagascar (Aziz,2013)

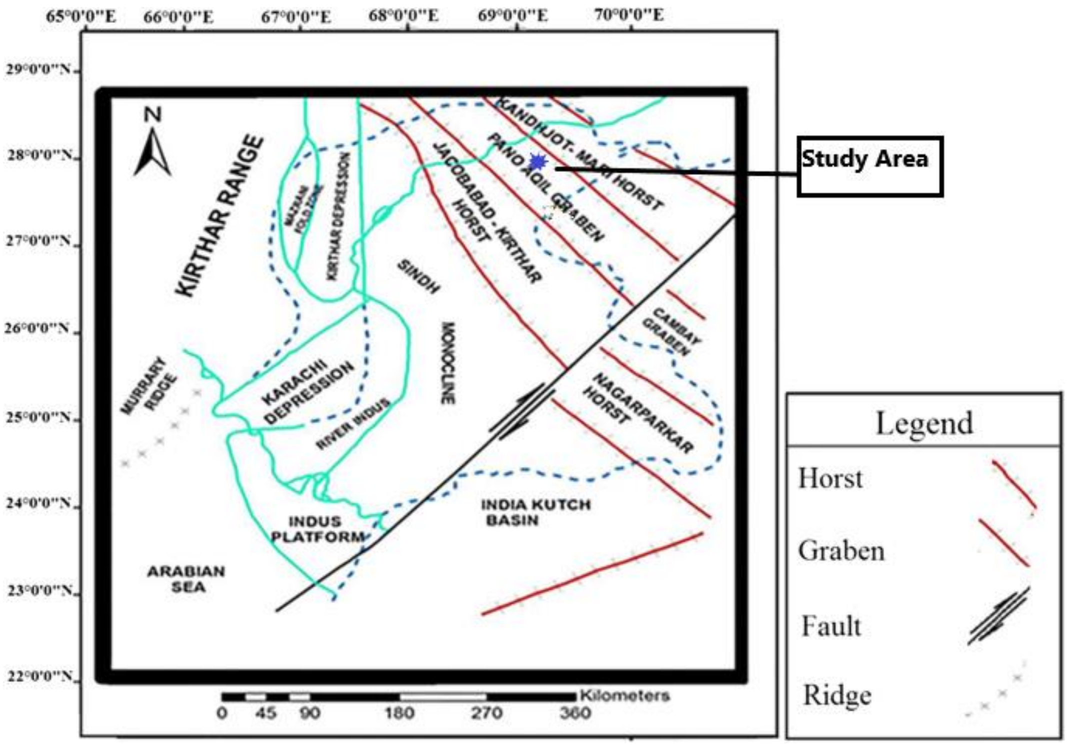


Figure 2.2 Generalized tectonic map of the study area and adjoining regions in the Central Indus Basin. (Jadoon et al., 2016)

2.2. Basins of Pakistan

Pakistan has three main sedimentary basins which are as follows.

1. Indus Basin
2. Balochistan Basin
3. Pishin Basin

Indus basin was formed during Cambrian and is further divided into upper, lower and central Indus basin.

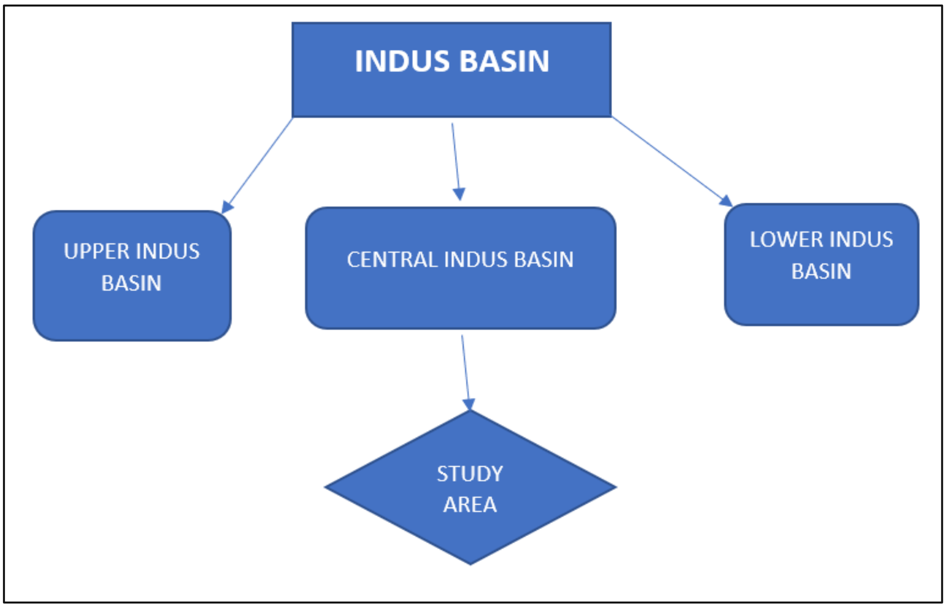


Figure 2.3 shows division of Indus basin

2.3 Strutural styles in central indus basin

Due to the rifting of Pangea Medagascar there is extensional tectonics in southern Indus basin horst and graben structures with normal faulting is most common. Most evident structures in the area are Horst and Grabens which are suitable for the accumulation of hydrocarbons. Some stratigraphic traps with normal faulting is also observed in this area (Naeem at al.,2016)

2.4 Generalized stratigraphy of the area

In central Indus basin the rocks are ranging from Middle jurrasic to paleocene. Triassic age rocks are the oldest in this area. The oldest rocks are of Chiltan formation of middle jurrasic age and oldest are Ranikot formation of paleocene age. Until lower/middle Cretaceous there was no division between central and southern Indus basin. This is evident from the homogenous lithologies of Chiltan limestone of Jurassic age and Sember formation of cretaceous age around the high (Ahmed and Ali, 1991).

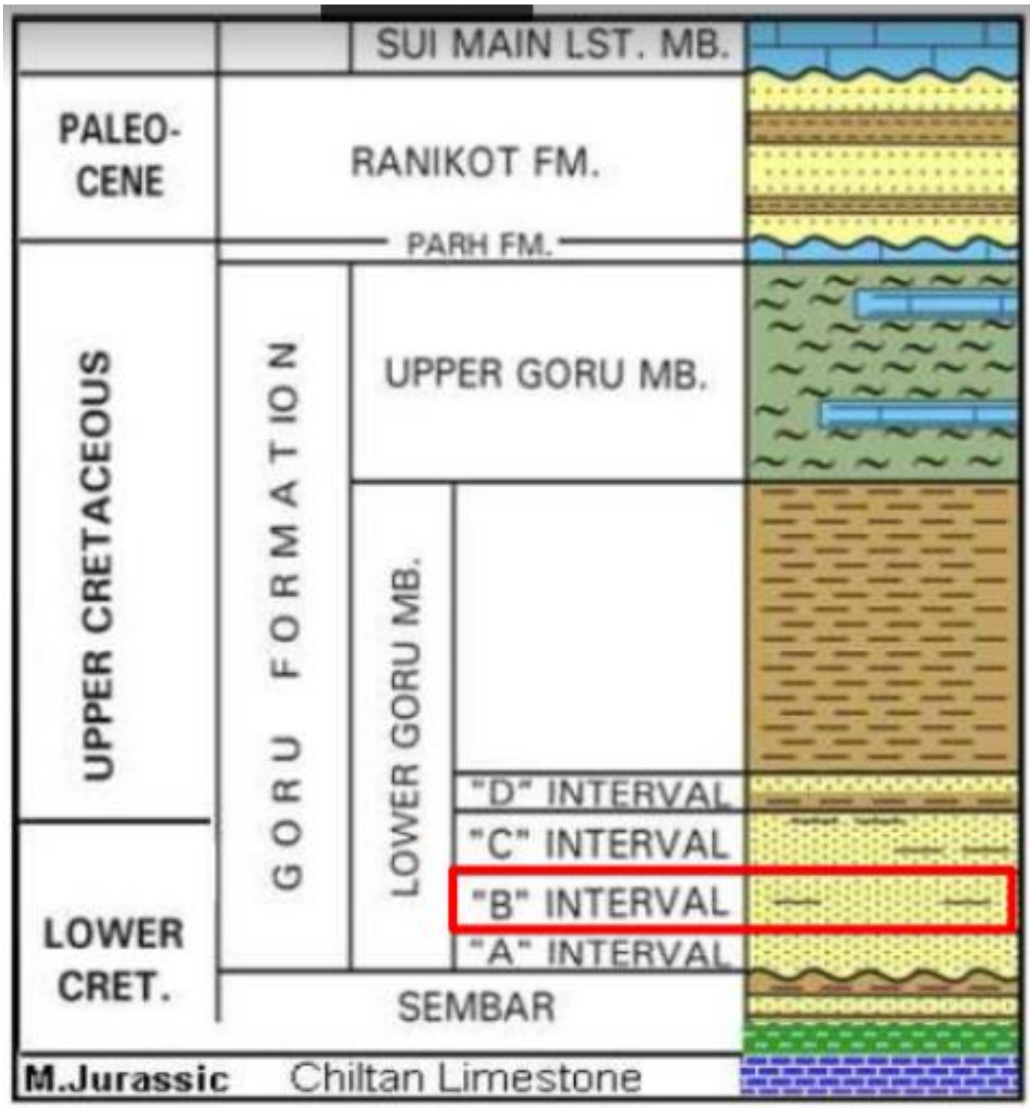


Figure 2.4 Generalized Stratigraphic column of Central Indus Basin. (Ahmed et al, 2016)

2.5. Petroleum play of study area

For petroleum system to occur there is a need for source rock, maturation of organic matter, migration of hydrocarbon, reservoir, seal, trap and accurate timing of formation is required. If any of these is absent in a basin hydrocarbons could not be produced.The shales of Lower cretaceous is a proven source for oil and gas. Mainly sember formation is type 3 kerogen capable of generating gas. Sandstone acts as reservoir in deltaic to shallow marine environment. Lower part of lower Goru formation has shale showing it has a good genetic potential. In this are massive sands of lower Goru formation act as reservoir.Massive sands of the Lower Goru Formation are the main reservoir in the area. Shale and marl of the Upper Goru Formation as well as the shale with in the Lower Goru Formation serves as seal rock for the underlying sandstone reservoir (Shah, 1997).

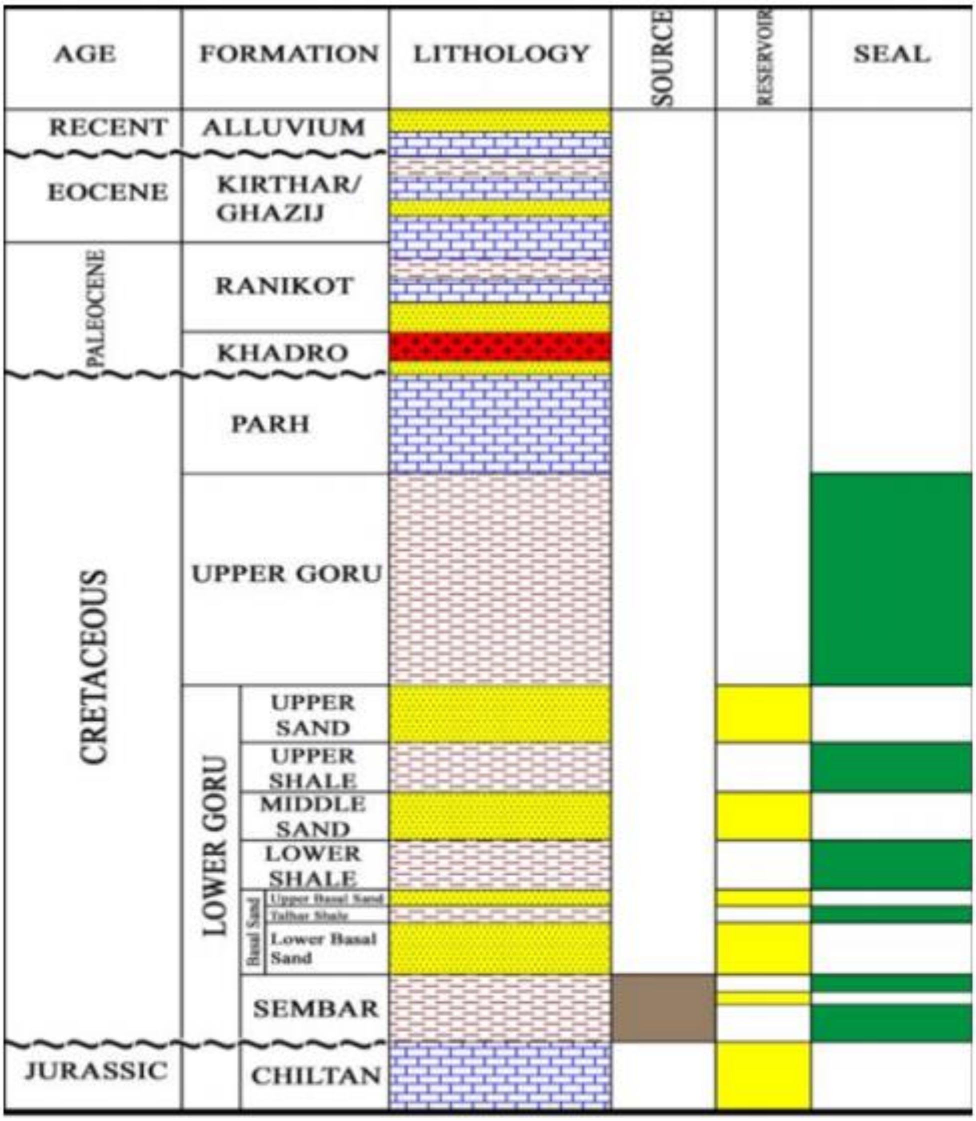


Figure2.5 Generalized stratigraphy and petroleum system of central Indus basin (Mozaffar et al.,2002).

2.5.1 Source rock

The most prominent source rock is Sember formation of early cretaceous age in central Indus basin. Shales of Lower Goru Formation act as source and reservoir especially B-interval shales are transgressive shales according to OGDCL. Convention and other shale intervals are also considered because they have the ability for generation and expulsion of oil and gas. Sember has very good to good Toc value greater than 1.5 wt%. (Sheikh et al., 2017)

2.5.2 Reservoir rocks

In lower Indus basin Chiltan limestone is fractured. Through field studies its evident that the porosity and permeability of lower Goru sands is excellent and sand prone sequences are prospective and consist of interbedded sandstone shale paralic deposited in deltaic marine. It's a proven reservoir with medium to coarse sand-shale deposits in shallow marine setting. In the study area and nearby field it's the most productive reservoir interval. (Naseer et al.,2015).

The sands of Lower Goru formation are divided into different intervals(A,B,C,D) respectively from bottom to top. (Ahmed et al.,2010). B-sand interval of Lower Goru formation act as reservoir for oil and gas production in this study area and the surrounding fields.

2.5.3 Seal rocks

In central Indus basin the shales of upper Indus basin acts as seal for petroleum play of sember Goru. There is also possibility for shales of sember formation of cretaceous age and Ranikot formation of tertiary age acting as seal rock. In lower Goru thin layers of shales also act as seal for better accumulation of hydrocarbons (Naeem et al.,2016)

2.5.4 Traps

There must be structural and stratigraphic traps for the trapping of hydrocarbons. Presence of normal faults are identified and marked on seismic data as well due to presence of extensional tectonic regime since rifting from Pangea. In Jurassic age mostly due to normal faulting horst and graben structures are formed.

CHAPTER 3

SEISMIC INTERPRETATION

Seismic interpretation begins by mapping large scale subsurface structures in area i-e marking faults and horizons. On seismic sections horizons are marked on strong reflectors followed by seismic data. Reservoirs and sequence boundaries are usually marked as they tell us about geological age and stratigraphic traps. Faults are marked if there is discontinuity, distortion or displacement in horizon (Bakker,2002)

Seismic data is subsurface image and its interpretation allow us to understand structures and stratigraphy. The main focus of interpreter is targeting minerals, hydrocarbons, engineering purpose, earthquakes, reservoirs. Structural and stratigraphic analysis can be made based on seismic data. (Coffeen, 1986).

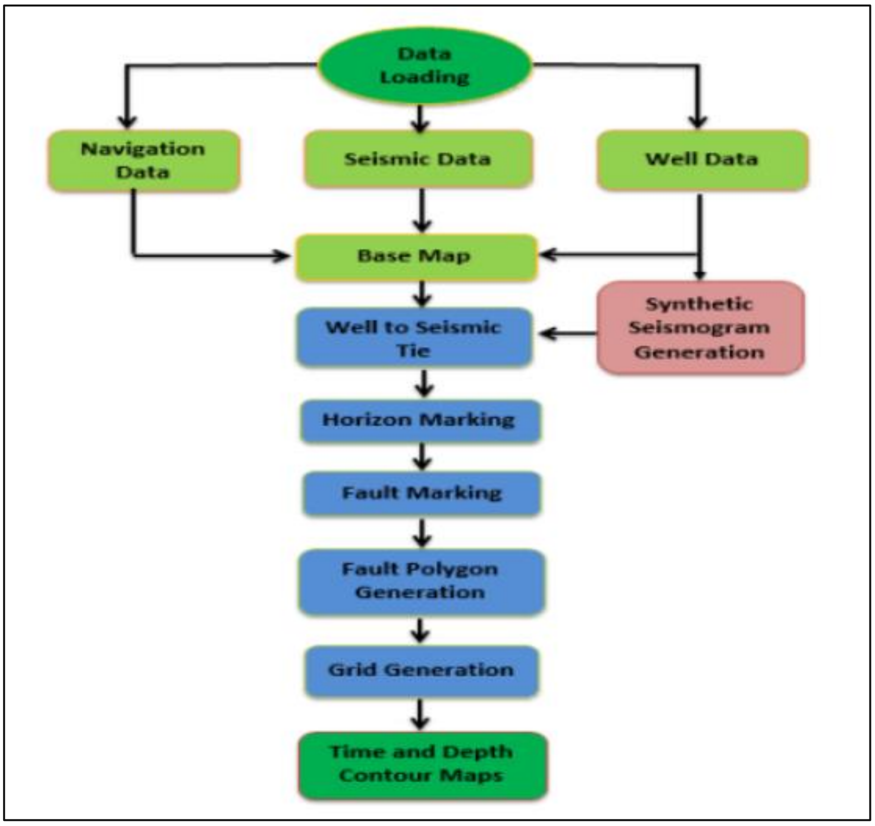


Figure 3.1. Workflow adopted for seismic interpretation

3.1 Structural analysis

In structural analysis our main goal is to mark horizons and faults on seismic data and identify hydrocarbon bearing zone. On the basis of faults, formations, structures and ages potential zones are marked. As seismic data is on time scale, two-way travel time is used for structural interpretation. Time domain data is then converted to depth domain which show the depth of geometric features. Depth is calculated accurately by velocity calculation through check shot or vertical seismic profile. Time versus depth is plotted to calculate velocity.

On seismic section the faults are interpreted. Faults are correlated with each other by making polygons and that show certain structures and then on these time faults, horizons are marked which show bedding. After marking faults and horizons on seismic section we get TWT maps. These faults are then used for identifying structural traps, faults geometries and orientation.

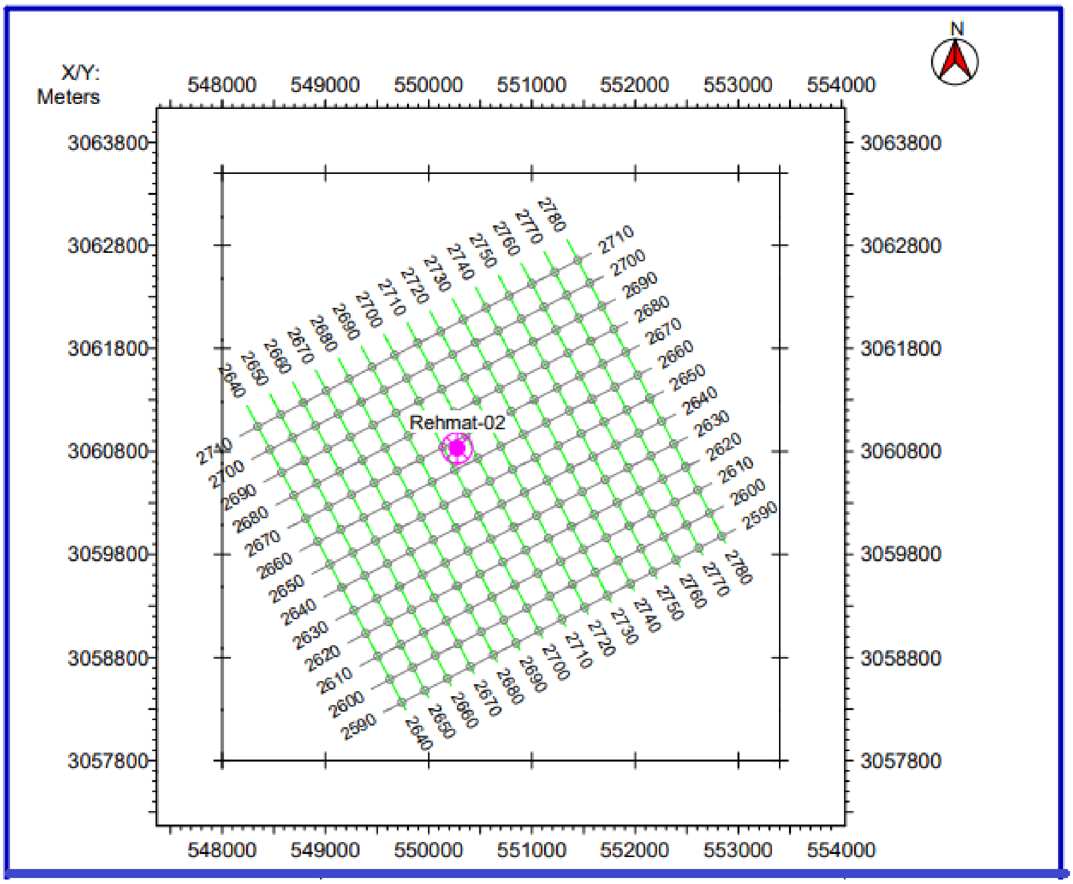


Figure 3.2 Basemap of Study area

3.2 Basic workflow of seismic interpretation

To interpret seismic following steps are to be taken

1. Preparation of base map
2. Marking faults on seismic section
3. Generation of synthetic seismogram
4. Interpretation of horizons
5. Marking fault polygons
6. Preparing contour maps

3.2.1 Preparation of base map

For preparing base map latitude and longitude of the area is loaded into interpretational software and then seismic lines are also loaded. 3D seismic data is provided in form of cube with inline and crossline. They are both orthogonal to each other and form net geometry. The wells lying in study area are displayed and loaded on base map. Cubic base map with 3D seismic and three wells are shown in figure below

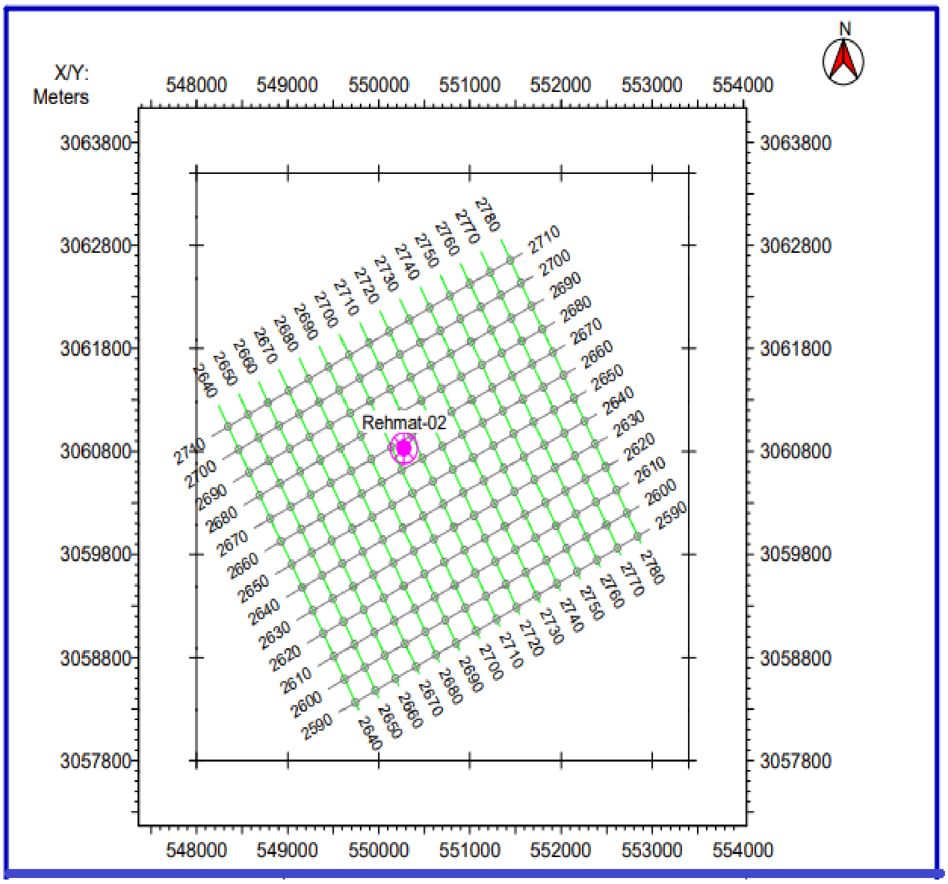


Figure 3.2 shows base map of area

3.2.2 Marking faults on seismic data

On seismic data faults are interpreted when in the bedding plane there is discontinuity or breakage. (Coffeen, 1986)

To identify faults certain steps are necessary in area. The steps are:

1. Geology of area
2. Fault correlation

3.2.2.1 Geology of Area

Literature review of area tell us about the type of stresses applied on area can be tensional or compressional. Mubarak area is present in extensional regime and normal faulting has occurred in this area, previous literature also allows us to understand the age of faults due to which primary and secondary features are easy to understand (Coffeen, 1986).

3.2.2.2 Fault correlation

The extension of faults, heave and throw, dip direction and delineation in study area is known as fault correlation. It’s a network of faults and from which formation it passes.

3.2.3 Synthetic seismogram

It is an artificial trace calculated from well logs data. The product of density and sonic log gives us acoustic impedance and reflection coefficient series is then calculated. It shows seismic response. It is an important tool to generate correlation between geological data from well logs with seismic data. Data obtained through seismic is in time domain so synthetic is developed as it gives both time and depth values.

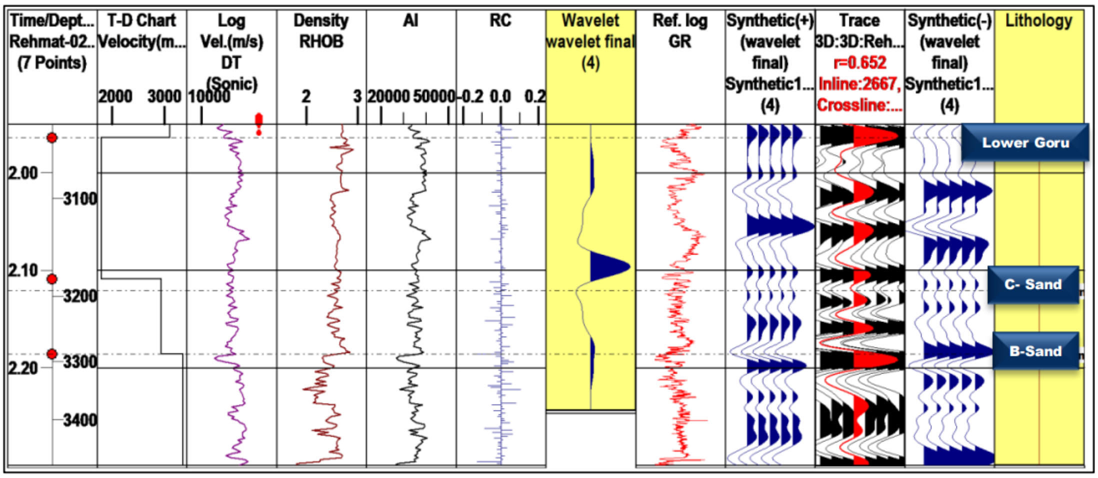


Figure 3.3 shows well to seismic tie

3.2.3.1 Synthetic matching

After generation of synthetic seismogram, it must be correlated with original seismic data. In order to perform this each seismic trace from well is removed. The extracted seismic trace showed the seismic data used for synthetic matching. To get best correlating results synthetic trace should be stretched, squeezed and shifted

3.2.4 Interpretation of horizon

Horizons are the boundaries that discriminate different formations from each other. One should have knowledge about structure and stratigraphy of the area. well tops obtained through well data, must be correlated with seismic in order to mark exact location of horizons. Synthetic trace is generated from well logs various horizons are marked at their respective time and on seismic section normal faults are interpreted. Marking of faults is primary interest for prospect zone. Two faults F1 (black) and F2 (grey) colors are marked. The area lies in extensional regime so normal faults are marked on seismic section. On the basis of well tops of Rehmat-01, Rehmat-02, Rehmat-03 following horizons are marked.

1. Sui Main limestone
2. Upper Goru
3. Lower Goru formation along with B and C sand interval

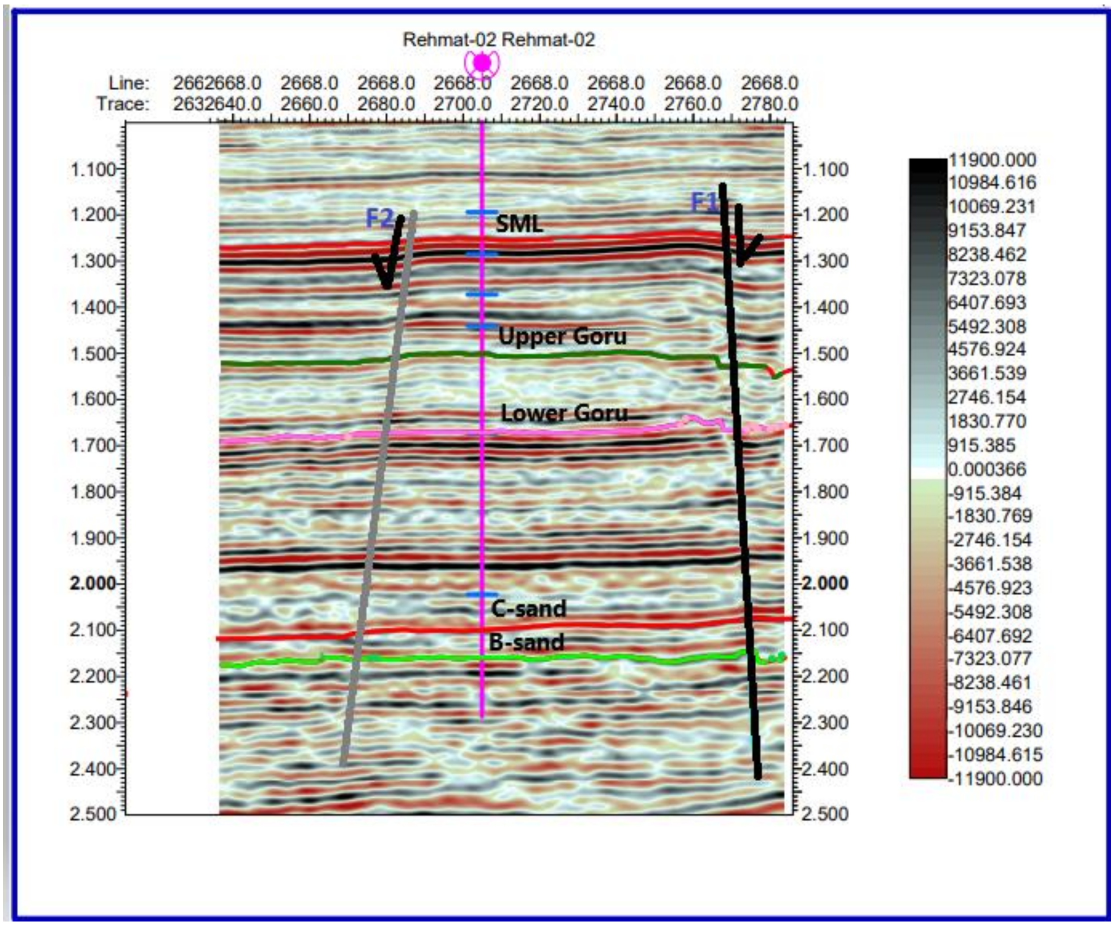


Figure 3.4 shows interpreted horizons on inline 2668 at well location

Inline

On section Rehmat-02 well is located on inline 2668 along with formation tops.

Crossline

Crosslines run parallel to the striking direction, so the section shows no changes in structure along strike line. Five horizons are marked with different colors. Interpreted seismic section of crossline 2705 is shown in figure.

3.2.4.1 Velocity information

In hard session the display of time and velocity at Rehmat-02 panel is given. Interval velocity of each interval is given in panel. Velocity panels are used to calculate depth using formula.

$$S=(V*T)/2$$

Where S= depth, V= velocity, T= two-way travel time

3.2.5 Contour mapping

This is the final stage of seismic interpretation. Contours maps are formed by joining the lines of same physical property in time and space. To generate contour maps generate grid of horizon on grid and contour tool and then first contour maps of TWT and after that depth contour maps are generated on grid. They show the type of structures formed and whether to drill in this area for oil and gas or not.

3.2.5.1 Time-depth contour maps preparation

After that, time and depth contour maps are created, with time contour maps being created first because data is accessible in the time domain, and depth contour maps being created by converting data from the time section to the depth section using the velocity function.

3.2.5.1.1 Interpretation of time and depth maps B-interval

On the seismic data evident in the time and depth maps of the B-interval horizon, two faults, F1 marked with black color and F2 marked with grey are interpreted. Both faults are normal. F1 and F2 faults make horst and graben structure. Due to extension normal faults are developed which divide the strata into horst and graben structure. Well is spudded at shallower depth (horst) for B-interval.

The fluctuations occurring in horizons are shown by time contour maps. Lower Goru B-interval time varies from 2.122 to 2.213 seconds on contour maps. On east side of B-interval time contour values are lowest showing that horizon become shallow on this part. The unit of time contour map is millisecond. Contour interval is 0.003s.

The depth contours of B-interval varies from 3147 to 3320 meters on maps. The contour values are displayed on maps having unit in meters. Like time contour maps depth contour maps also have eastern strata shallower than western strata. Depth contour interval is 5 meters.

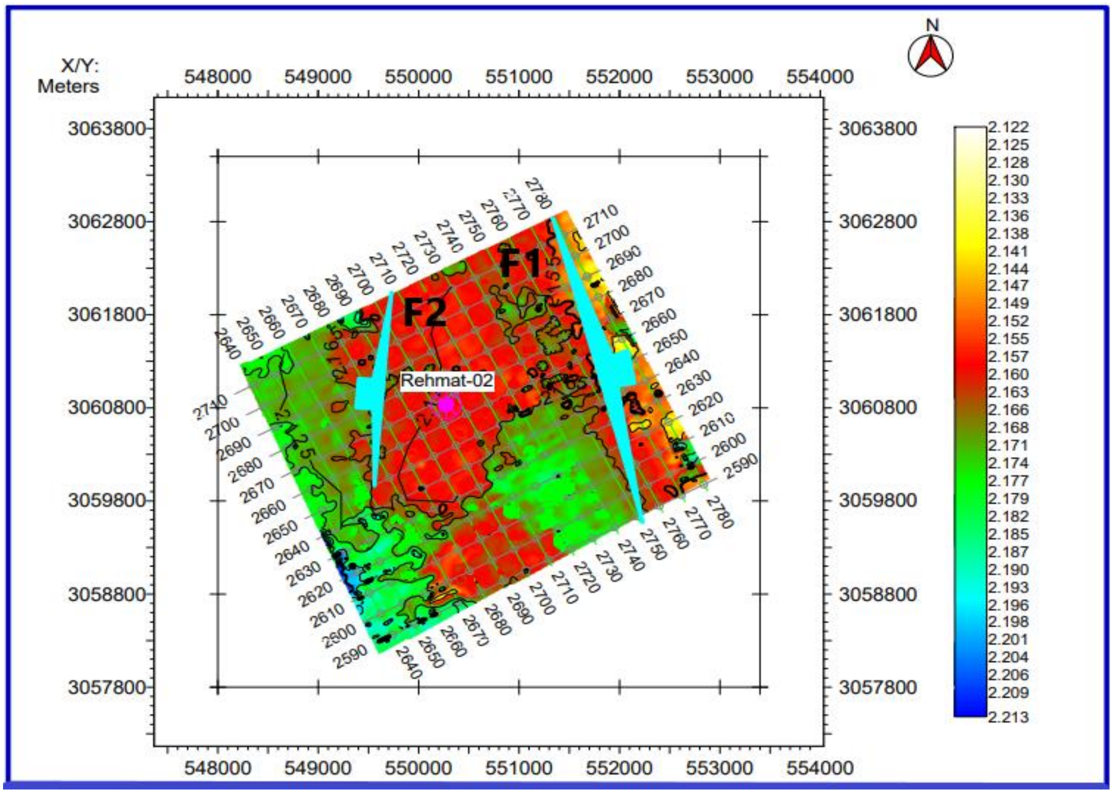


Figure 3.5 Time contour map of B-interval

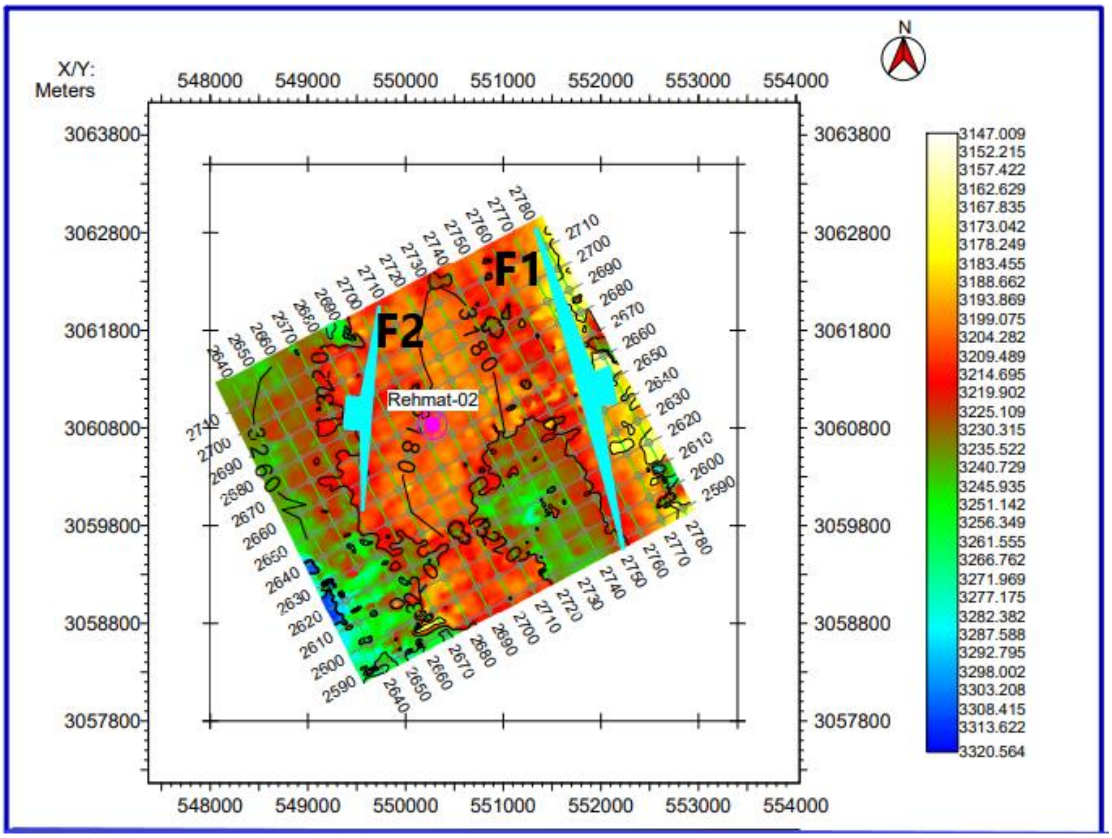


Figure 3.6 Depth contour map of B-interval

CHAPTER 4

PETROPHYSICAL ANALYSIS

4.1. Introduction

In exploration industry for reservoir characterization physical properties of rocks such as fluid and matrix is determined through petrophysics. Petrophysical interpretation helps in calculating saturation of water, volume of shale, resistivity of water, lithology formation, hydrocarbon saturation and net play (Ashraf et al.,2019).

The logs used in petrophysical interpretation are as follows

Lithological log
Porosity log
Resistivity log

First track is of lithology log run, it includes caliper, SP and GR logs. Second track is of resistivity log which includes LLS, MSFL and LLD logs. Third track porosity logs are run which include NPHI or neutron, RHOB or density DT or sonic. For quantification of pay zone petrophysical analysis is carried out. For quantification of net pay zone petrophysical analysis is carried out in Rehmat-02 well.

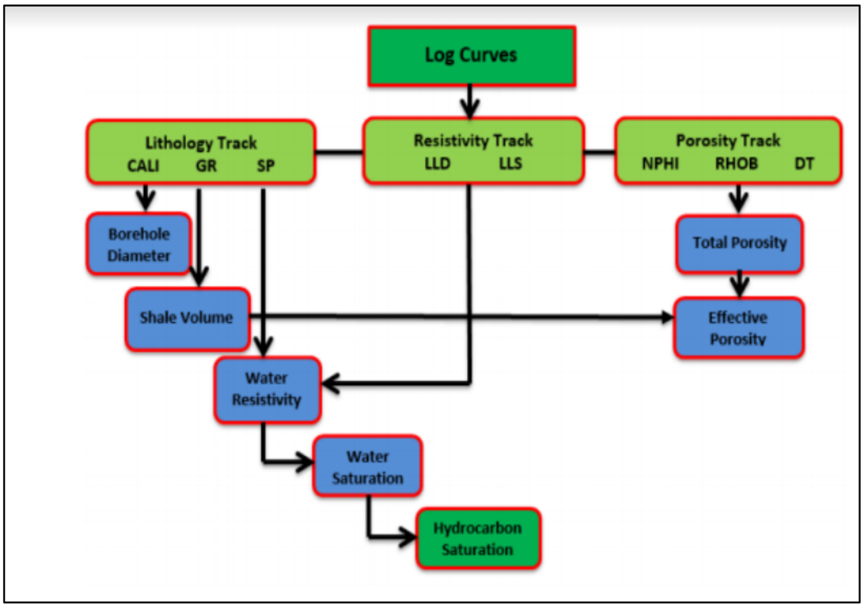


Figure 4.1 workflow adopted for petrophysical study

In petrophysical interpretation first step is to mark zone of interest in raw log. Petrophysical parameters like porosity (φ), fluid saturation (oil and water), resistivity of water (Rw), volume of shale (Vsh) etc are calculated from well logs. This thesis represents petrophysical analysis of Lower Goru B interval of Rehmat-02 well.

4.2. Methodology

4.2.1. Well Data

For petrophysical analysis complete log suit was only available for Rehmat-02 well.It is an appraisal well which was drilled in 2001 and set for production from B-sand of lower Goru formation.For main reservoir Formation petrophysical analysis is done which in this case is lower goru sandstone.

4.2.2. Marking of zone of interest

There are some important criteria's which are important for marking or identifying the zone of interest in a reservoir. Clean zone having less shale volume is first to be identified by using gamma ray log. Another important parameter for identifying the area of hydrocarbons is the crossover in between the neutrons and density logs. Neutron and density recordings provide information about the porosity of the reservoir. If the value of the neutron and density both remain decreasing, then the crossover with both logs decreasing is obtained, which is a clear indication of the hydrocarbon zone.

The resistivity log set is also important because it provides a reservoir image based on electrical resistivity. Three important resistivity logs are MSFL, LLS and LLD. If there is a significant separation between the MSFL curve and the LLD, it shows the presence of hydrocarbons. If no separation is observed between them, then that area may contain water.

4.3 Calculation of log derived properties

4.3.1 Determination of Volume of Shale (Vsh)

Gamma ray log is used to calculate volume of shale because its sensitive to gamma radiations that comes from shale.If volume of shale in a reservoir is less it means lithology is clean, indicating good reservoir characteristics.Estimating gamma ray index and volume of shale is necessary and is first step of petrophysical analysis.(schlumberger, 1974)

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \qquad \textit{Eq.4.1}$$

$$I_{GR} = V_{sh} \ \textit{Eq. 4.2}$$

I_{GR} = Gamma ray index

GR_{log} = Gamma ray reading of formation

GR_{min} = Minimum gamma ray (carbonate or clean sand)

GR_{max} = Maximum gamma ray (shale)

4.3.2 Average neutron density porosity

Total number of pores present in a formation is known as porosity. For reservoir accumulation of hydrocabons these pores are important. Neutron log is used to calculate hydrogen index. Hydrogen ions are present due to hydrocarbon saturation or water. Average neutron density porosity is calculated by using neutron and density log using following formula. (Schlumberger, 1974).

$$PHIA = \left(\frac{PHID + PHIN}{2} \right) \qquad Eq.\ 4.3$$

Where:

NPHI= Neutron porosity, PHIA = Average porosity, *D*PHI = Density porosity

4.3.4 Effective Porosity

Total porosity is the ratio of total pore volume to the total bulk volume, but effective porosity is the total pore space in porous material that is able to pass fluid (Ali et al.,2019). Fluids can only pass-through pores which are interconnected. Following formula (Eq. 4.4) is used for the calculation of effective porosity for the reservoir (Hilchie, 1978).

$$PHIE = PHIA * (1 - V_{sh}) \qquad Eq.\ 4.4$$

Where:

PHIE = Effective porosity, PHIA = Average porosity, V_{sh} = Volume of shale

4.3.5 Water Saturation (Sw) Determination

Archie's Equation is used to calculate saturation of water (Archie, 1942):

$$S_w = \left(\frac{a * R_w}{PHIE^m * R_t}\right)^{\frac{1}{n}} \ Eq.\ 4.$$

Where:

Sw = Water Saturation, PHIE= Effective porosity

a = Lithological Coefficient (taken as 1), m = Cementation factor (taken as 2)

n = Saturation Exponent (taken as 2), Rw = Resistivity of water

Rt = True Resistivity (log respond LLD)

4.3.6 R_W calculation

We used the Pickett plot approach to determine the resistivity of water for the reservoir because comprehensive log header information indicating temperature at surface and borehole, as well as other depth information, was unavailable for the

Rehmat-02 well.By the help of Archie Equation taking factors as a=2,m=1, and n=2. The resistivity index I and water saturation Sw are determined using a log–log plot of deep resistivity (LLD) vs porosity (eff) in this method.True resistivity is a function of porosity, water saturation, and cementation factor, according to the Pickett plot approach (Ali et a.,2019). Rw for Rehmat-02 well is calculatd as 0.03ohm-m

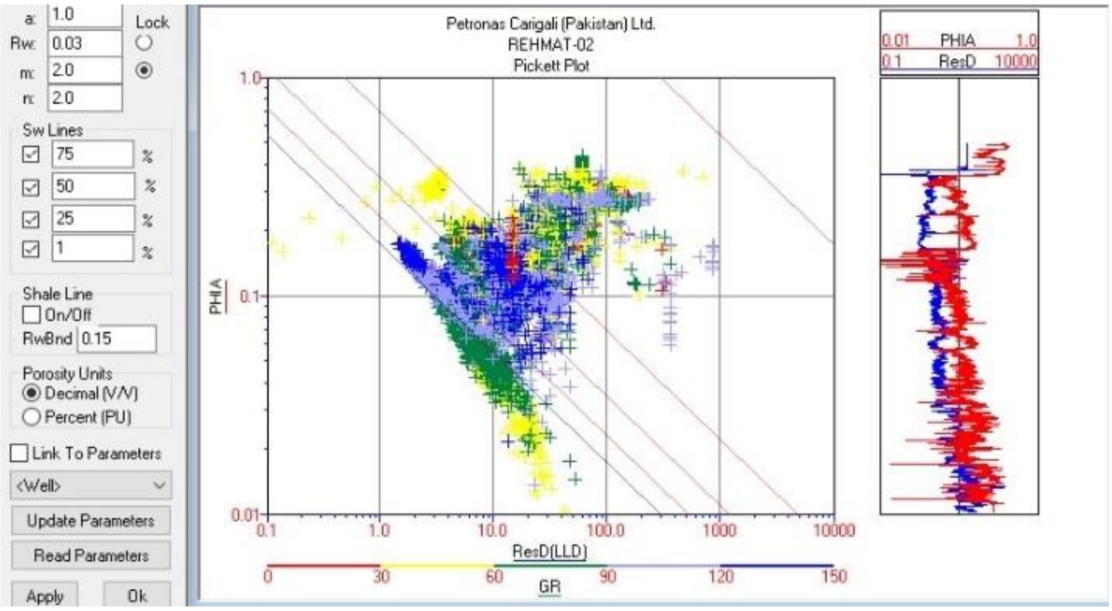


Figure 4.2 Picket plot for estimation of Rw

4.3.7 Saturation of hydrocarbon

The amount hydrocarbon present in a formation other than amount water present is called saturartion of hydrocarbon. Its represented by Sh. Its estimated by subtracting Sw from 1(total saturation of formation) by using following formula. (Eq.4.6)(Schlumberger, 1974):

$$S_h = 1 - S_w \quad \textit{Eq. 4.6}$$

4.4 Identified zone analysis

4.4.1 Zone 1

Only one zone was found to have considerable amount of hydrocarbons and good reservoir properties. The zone lies near lower Goru B-interval and is of 26 meters. MSFL and LLD values are high for this zone. Average porosity is calculated as 22% and effective is calculated as 15% for this zone. Hydrocarbon saturation is calculated as 61% and the remaining 38% is volume of water calculated.This zone appears to be a pay zone for this well based on all of these calculations.

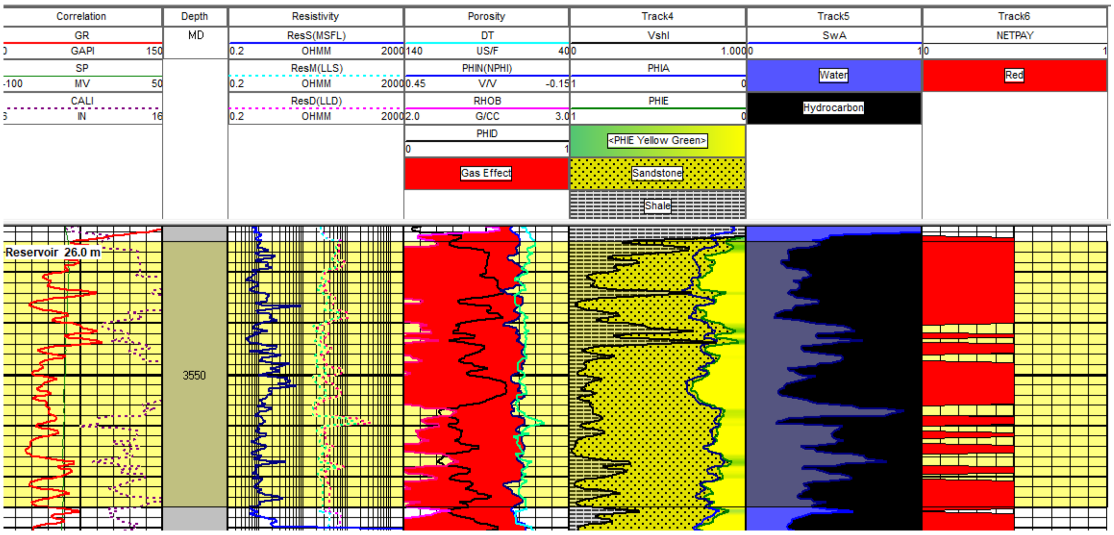


Figure 4.3 Zone 1 (Identified for Rehmat-02 well)

Table 4.1 Zone 1 calculation of petrophysics

Depth(m)	Vsh	PHIA	PHIE	Sw	Sh
3536	0.36	0.14	0.07	0.38	0.62
3538	0.293	0.18	0.12	0.24	0.76
3540	0.13	0.3	0.12	0.32	0.68
3542	0.66	0.3	0.11	0.25	0.75
3544	0.28	0.21	0.2	0.17	0.83
3546	0.35	0.21	0.1	0.4	0.6
3548	0.2	0.17	0.11	0.5	0.5
3550	0.05	0.17	0.1	0.32	0.68
3552	0.06	0.2	0.12	0.24	0.76
3554	0.18	0.12	0.13	0.42	0.58
3556	0.09	0.13	0.14	0.5	0.5
3558	0.08	0.08	0.1	0.68	0.32
3560	0.16	0.14	0.1	0.61	0.39
3562	0.14	0.22	0.12	0.31	0.69
Average	0.216643	0.183571	0.117143	0.381429	0.618571
Average%	21.66429	18.35714	11.71429	38.14286	61.85714

CHAPTER 5

SEISMIC INVERSION

5.1 Introduction

Seismic inversion has become an efficient tool in petroleum industry for the identification of prospects. The physical properties of rocks and fluid can be identified through seismic inversion. Seismic data carries information about the subsurface and applying inversion will transform it into layer property. The most important physical property is acoustic impedance which is a product of density and velocity in the subsurface. Seismologists use inverted impedance models to calculate P-S waves, densities, elastic properties.it also helps in the identification of geological boundaries and identification of sweet spots (Barclay et al.,2007).

The main purpose of seismic inversion is to transform seismic data into different rock properties such as shear impedance, velocity, density, porosity, and other petrophysical parameters water saturation, the volume of shale by establishing good relation between impedance and these properties for extracting petrophysical properties for whole seismic volume.

5.2 Types of seismic inversion

Seismic inversion is basically of two types: 1) prestack inversion can be applied on AVO in which seismic amplitude varies with offset. 2)In post-stack inversion the amplitudes shown by seismic data are converted into acoustic impedance contrast at zero offset using seismic geological and log data.

It’s an ambiguous process that involves the integration of seismic and log data. it starts with the generation of the initial geological model that matches with original seismic data. the model is updated until the generated model matches best with the original. It will help to bring out the hidden information and predicting the physical properties of reservoirs (Veeken Da Silva.,2004). Different techniques are used to perform seismic inversion. Another name of post stack seismic inversion is acoustic impedance inversion. its separated into two main types deterministic and probabilistic. Model based, sparse spike, band limited and colored are types of post stack inversion.

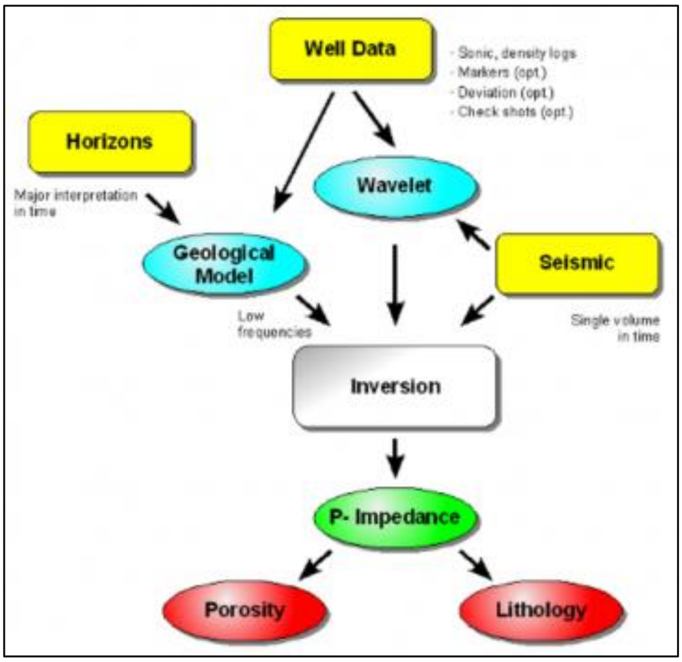


Figure 5.1 post stack inversion workflow(Sen and Stoffa, 1995)

5.2.1 Model based inversion

In model based inversion wavelet is calculated and initial impedance model is generated. By using wavelet Synthetic trace is generated which is matched with the real seismic trace and the model is updated till there is least difference between synthetic and original trace. Final model would the one with least error. Impedance model depends on time picked from horizon and well log data.

Model based inversion uses acoustic impedance which is an accurate property of layer. low frequencies (0-15HZ) from data of wells are added as a component of inversion. They are added to get accurate acoustic impedance in model-based inversion. (Ali et al., 2018)

5.3 Methodology for Model Based Inversion

In post stack seismic inversion 'STRATA' module is used in Hampson Russel software. It takes post stack seismic volume and log data as input and outputs acoustic impedance volume. Following is the workflow for model based inversion.

5.3.1 Wavelet extraction

Extraction of wavelet is the most important step in conversion from reflectivity data to acoustic impedance. The best way is to extract source wavelet from actual data rather than theoretical one. At well location statistical wavelet is extracted from seismic data. To get best results from inversion and seismic interpretation the wavelet should be at minimum zero phase. The size of shift of phase in input wavelet largely influences the outcome of inversion.Wavelet is convolved with reflectivity series of seismic data to get impedance layers.

$$S(t) = W(t) * R + N$$

Where W (t)= wavelet that is extracted

R= reflection coefficient ; N= Noise

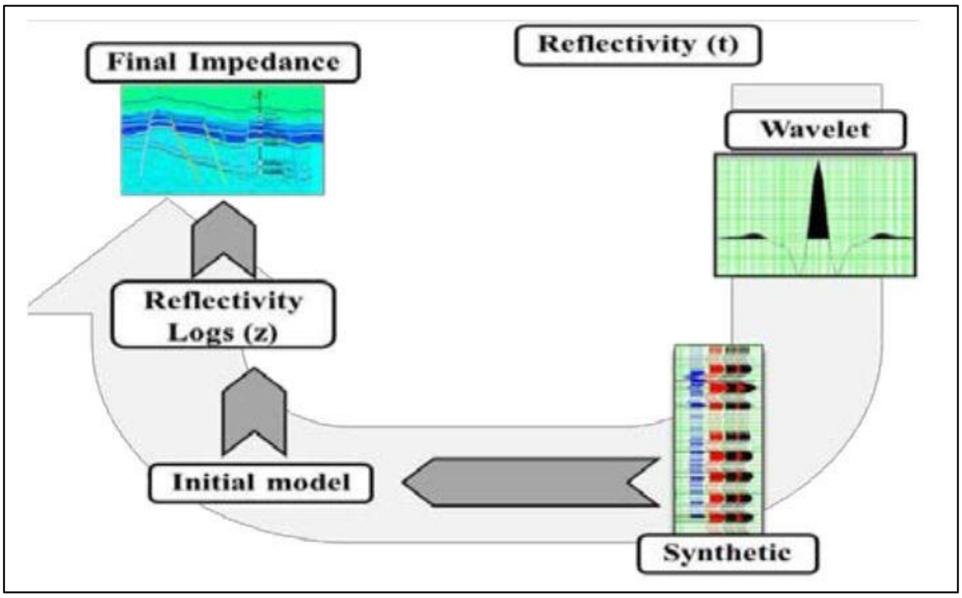


Figure 5.3 workflow of Hampson Russell software for model based inversion.

Figure5.4 shows the statistically generated wavelet showing both time and frequency domain by using seismic data input near well location.

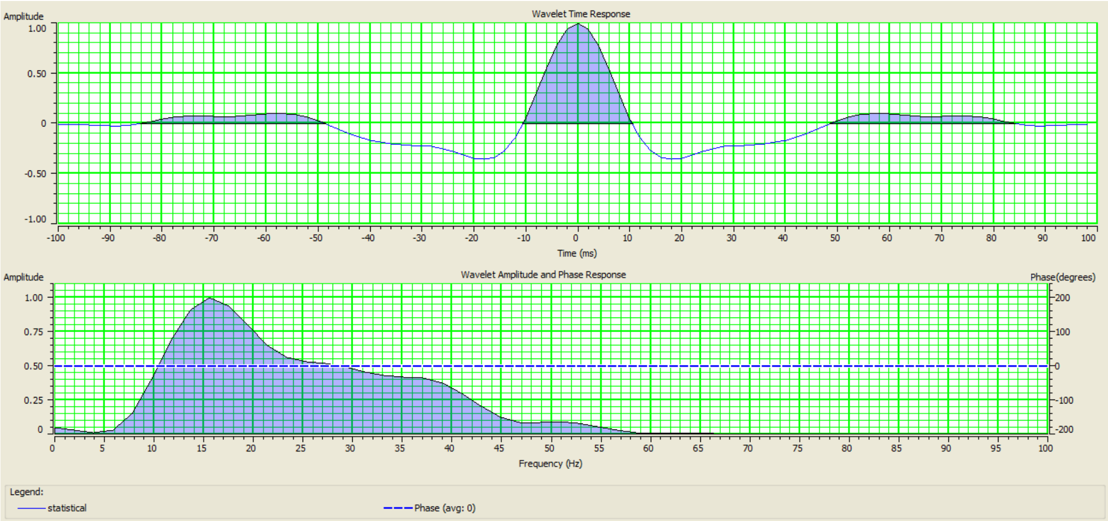


Figure 5.4 showing frequency and time domain of statistically extracted wavelet

5.3.2 Well to seismic tie

To perform well to seismic tie White and Sim have discussed basic steps. Precautions to be taken depend on well data, there must be no spikes on log data otherwise it will affect inversion results. We use Caliper log as a reference to correct log data and predict washout zones. After extraction of wavelet following steps are taken.

- With the help of well data synthetic trace is produced and at well location it is compared with seismic.
- Well and seismic correlation is performed by squeezing and stretching of time window.
- By real seismic trace and manually adjusted synthetic well correlation coefficient and RMS error are calculated.

The acceptable match between seismic and synthetic is shown. The value of correlation coefficient for Rehmat-02 well is 0.683 which is very good.

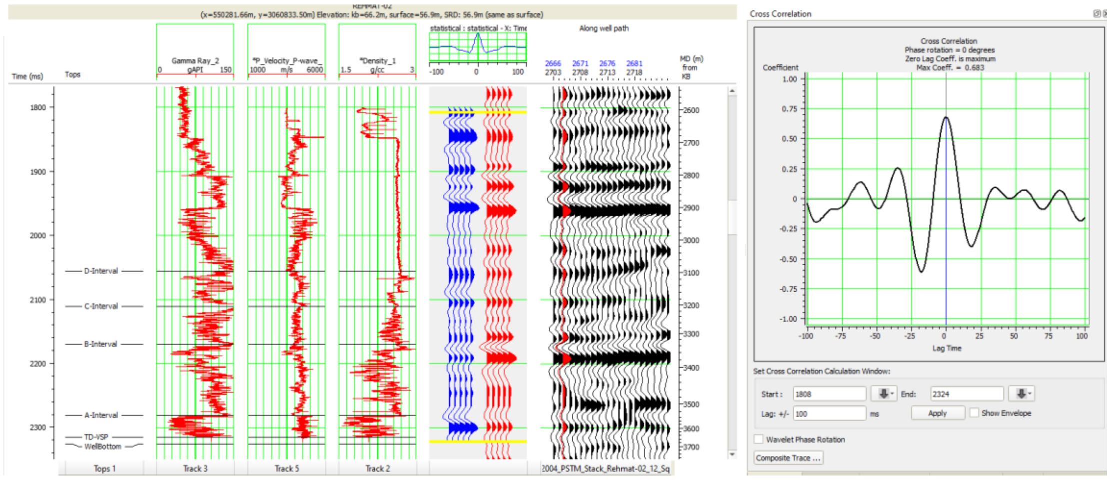


Figure 5.5Well correlation with seismic data.

5.3.3 Low frequency model

In order to calculate absolute impedance, we need absolute properties of layers. In inversion algorithms low frequencies (0-16Hz) are added to find absolute impedance. Initial model is generated in which our formation of interest B-sand lower Goru lie. These low frequencies act as a part of algorithm in model based inversion. The data lost during stacking and processing is regained with the help of initial model parameter. Sonic log is used for generation of low frequency model.

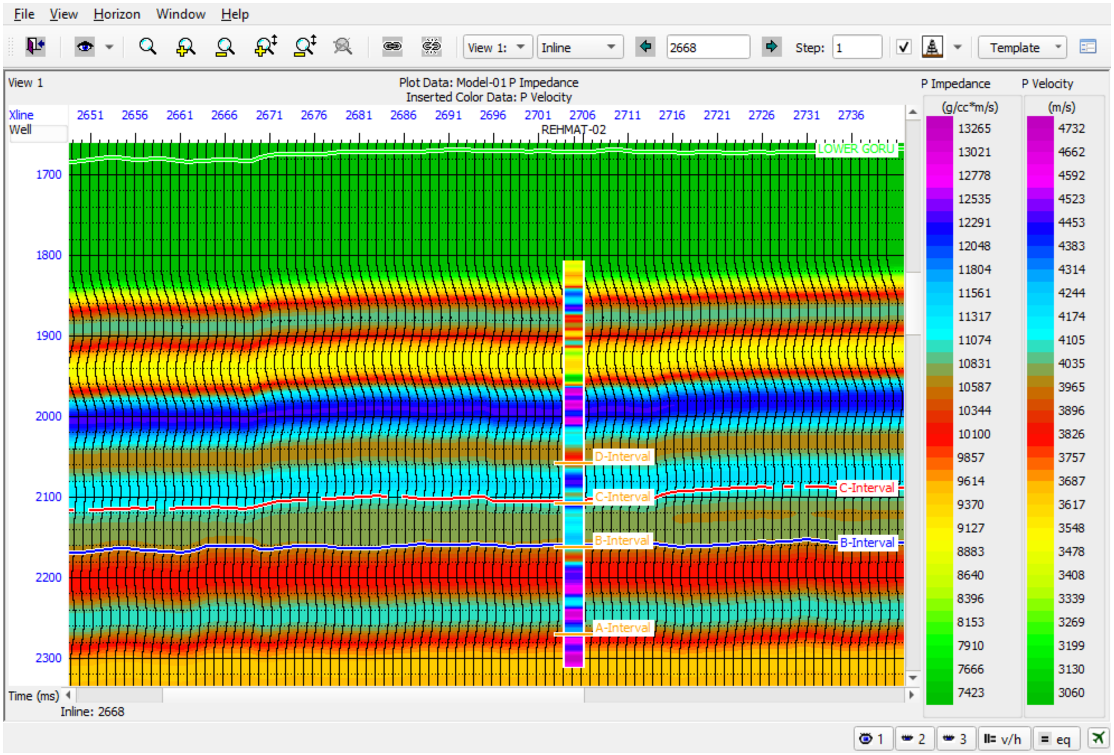


Figure 5.6 low frequency model over inline 2668

5.3.4 Results of model based inversion

A quality control analysis (QC) was performed prior to completing the inversion, as shown in Figure 5.7, to confirm that the inversion results were accurate and that the work was not in vain. Blue curve represent original log and red curve represent inverted result. The window shows matching between them with an error = 869.327 which is negligible. The correlation between seismic in (black) and synthetic in (red) is 0.99% with an error of 0.068

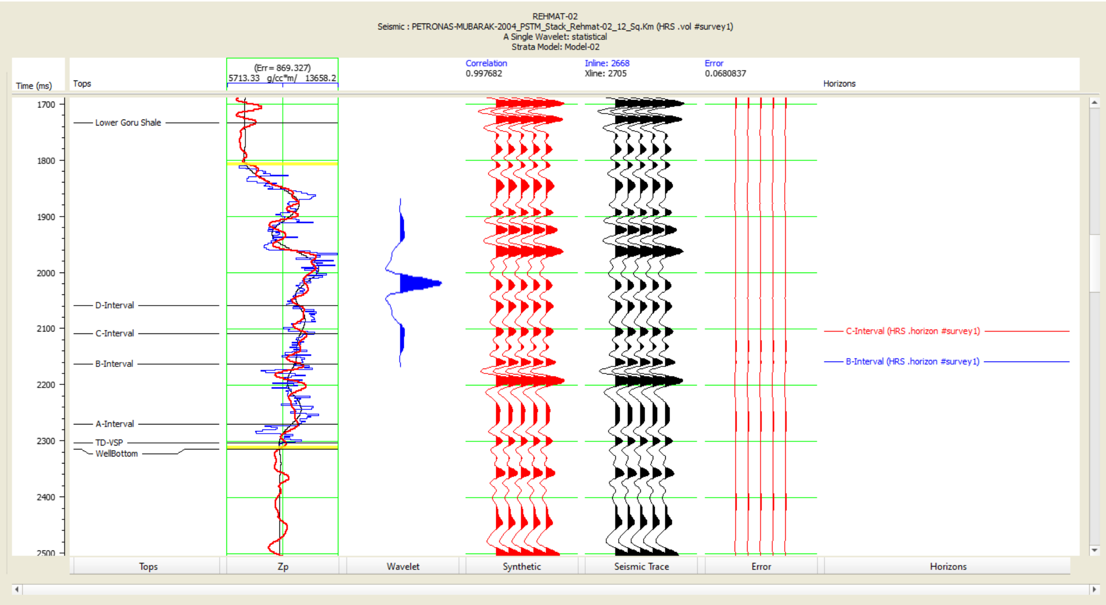


Figure 5.7 shows model based inversion analysis

Below figure 5.8 shows final impedence model for well for inline 2668 on which Rehmat-02 well is located.B-sands of lower goru formation is the main producing reservoir of Rehmat gas field.So the results of final impedance model suggest moderate impedance values across entire reservoir and enhanced porosity and well location which depends on fluid content and lithology present in it. At the encounter of Lower Goru B interval, there is a sharp increase in relative acoustic impedance value. In east west direction suggests high porosity whereas, this impedance increase in north south direction with decreased porosity. Red color may indicate the inception of incompetent lithology with low impedance values. The sky blue layer above the low impedance layer shows high impedance which is believed to reflect the seal unit above the Lower Goru B interval.

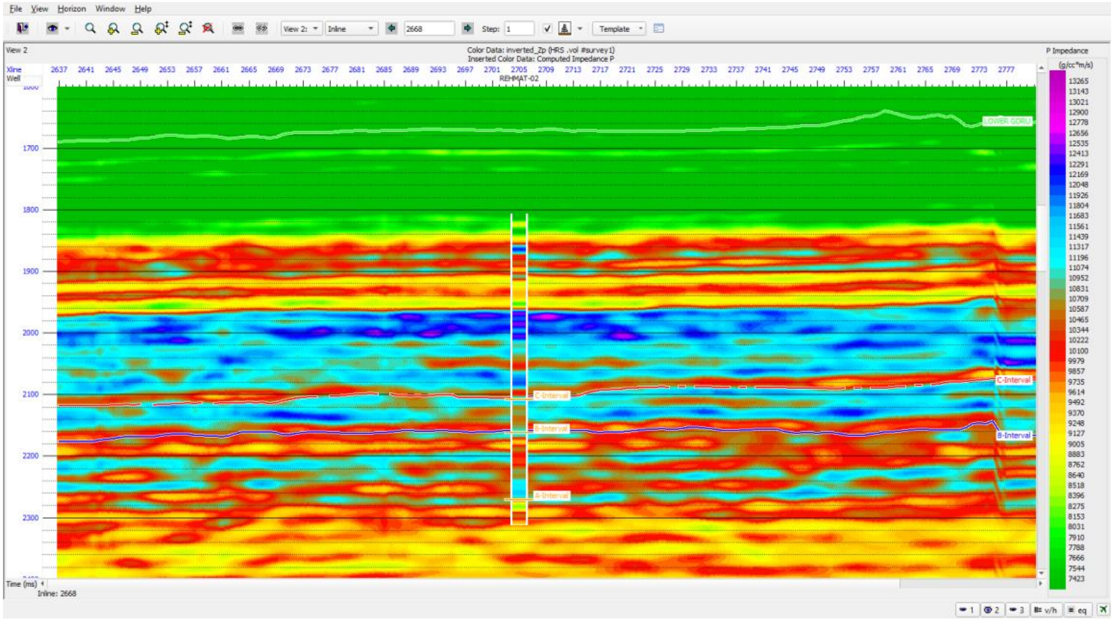


Figure 5.8 shows final impedance model

The figure below represent complete 3D cube of Rehmat block used during analysis showing the impedance variation along the horizon b-sand of lower goru in rehmat block. High values of impedance can be observed on north east side of seismic cube and these values gently decrease as we move towards well location.

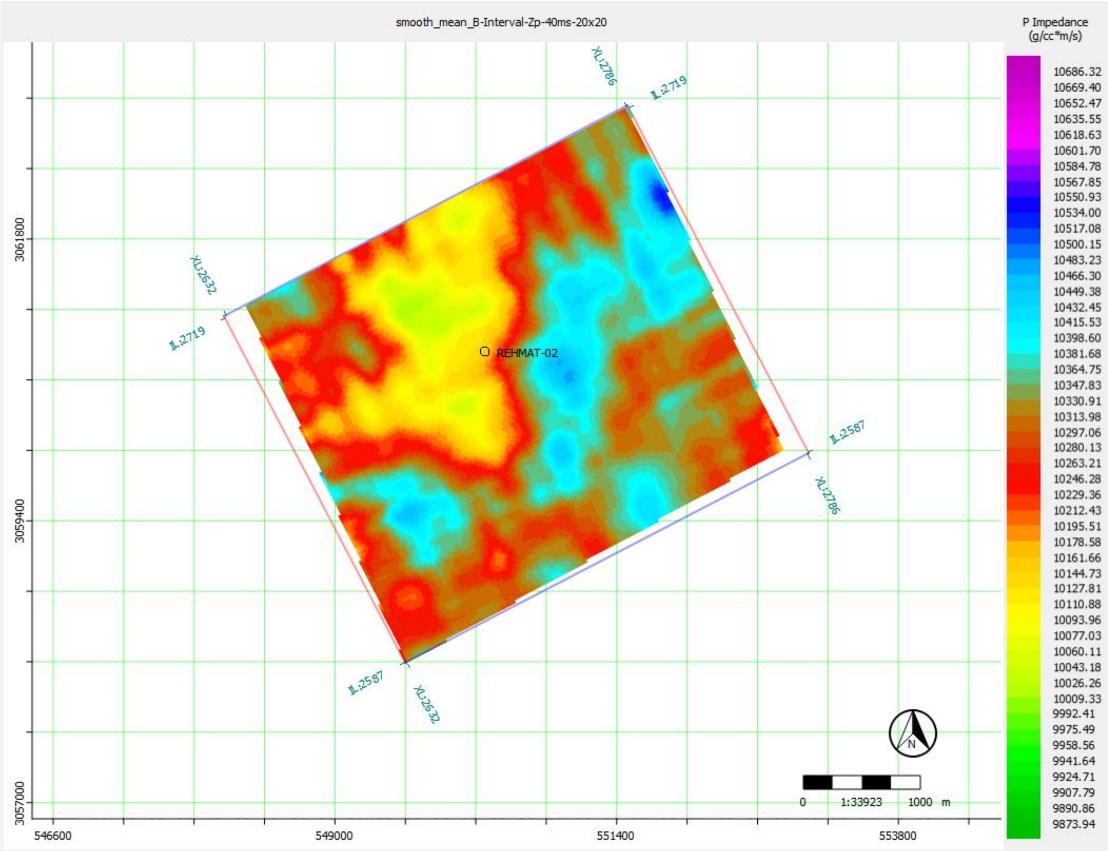


Figure 5.9 shows 3D cube of Rehmat block

After getting the estimate for impedance for concern area, an estimation for porosity was done by using above impedance model. For this, a porosity log from well generated during petrophysical analysis of Rehmat-02 well and an impedance log generated during model-based inversion was corelated by a cross plot method. A window of 100 ms below targeted formation was selected for this analysis. The log values which lies in between this window range was plotted and are corelated with the volume of shale in this zone. Then a best fit line was passed through all plotted points to get the estimated equation of line for whole zone with maximum correlation between logs. The correlation for plotted values comes out to be 0.86 or we can say that 86 % as showns in figure 5.10.

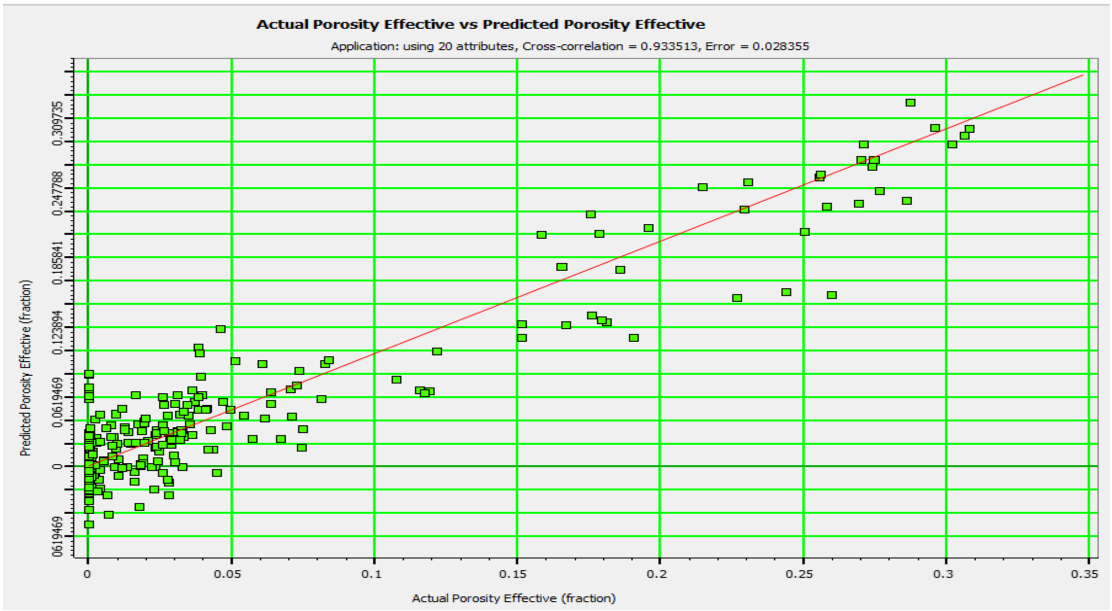
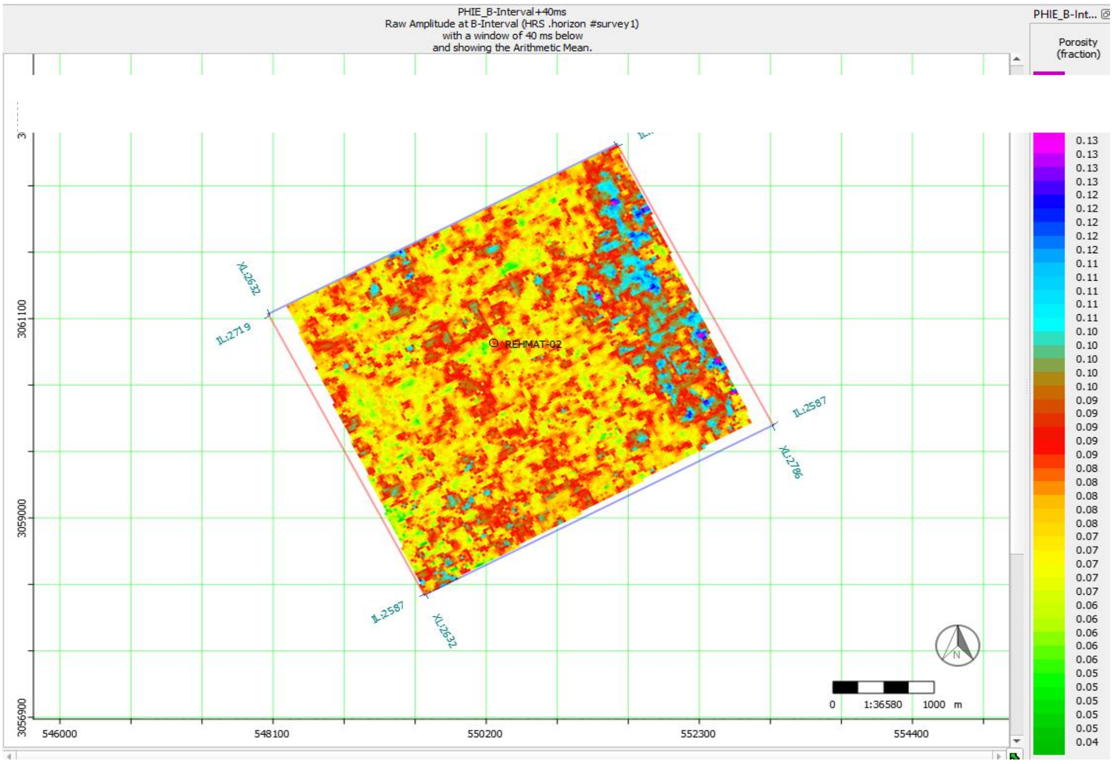


Figure 5.10 Logs cross plot for computation of porosity

Now by using the above-mentioned generated equation, Estimation of porosity for lower Goru Sandstone was done and applied to the whole 3D cube to get an overall porosity distribution. Results were computed at well location and was distributed over hole cube on the basis of already generated impedance values.The porosity value ranges from 8-9% for the Lower Goru Sandstone calculated for the window of 100 ms below targeted horizon. Reason to pick such huge window is to just incorporate both potential zones marked during petrophysical analysis. Figure 5.11 shows the overall distribution of porosity for given seismic cube. The color variation shows the inverse relation of porosity as compared to impedance values for this cube as porosity is slightly low in the west and increases gradually as we move toward the east. These results for porosity through inversion was further calibirated with the petrophysical analysis results which provide us with the reliability of this inversion technique.



PHIE_B-Interval+40ms
Raw Amplitude at B-Interval (HRS .horizon #survey1)
with a window of 40 ms below
and showing the Arithmetic Mean.
PHIE_B-Int...
Porosity
(fraction)
REHMAT-02
IL:2719
XL:2632
IL:2587
XL:2786
IL:2587
XL:2632
546000
548100
550200
552300
554400
3061100
3059000
3056900
0
1:36580
1000 m

RESULTS AND DISCUSSION

In this study, inversion algorithms based on a 3D seismic cube are used to calculate acoustic impedance, which can be linked to lithological changes and used to identify hydrocarbon-bearing zones.Geophysical techniques like seismic inversion, petrophysical analysis and seismic interpretation were done on Mubarak gas field and following discussion can be made after examining the results of these geophysical techniques. The presence of extensional tectonics has been established by seismic interpretation. On the seismic data, two faults, F1 and F2, are interpreted in the B-interval horizon. Both the visible and unmarked flaws are normal faults, formed as a result of extension and sliding, dividing the area into horst and graben.Petrophysical analysis have shown there is only one reservoir zone of considerable thickness at B interval confirming B interval as proven hydrocarbon reservoir in Mubarak block. The reservoir zone in Rehmat-02 well shows 61% saturation of hydrocarbon.

Model-based inversion techniques have been successful in providing a good knowledge of porosity and lithological composition, particularly in B interval reservoirs. Changes in acoustic impedance with colour variations demonstrate changes in acoustic impedance,lithological content at various horizon levels.Final impedance model shows enhanced porosity at well location and moderate porosity across entire reservoir. Because porosity is high at the well location, the colour variation in the cube demonstrates an inverse relationship between porosity and impedance values. Both lithological and hydrodynamic parameters were estimated using the model-based inversion. Additionally, the lateral and vertical changes in acoustic impedance correspond excellent data.

CONCLUSION

For detailed reservoir characterization of lower Goru sand seismic structural interpretation, petrophysical analysis and seismic inversion all play an important role. The reservoir potential of Lower Goru is confirmed by all these studies.

Following conclusions are drawn from these studies.

Seismic interpretation confirmed the presence of extensional tectonics. Seismic section and contour maps showed presence of normal faulting with horst and graben structure.Two faults F1 and F2 are interpreted in B-interval horizon such as horst bounded by F2 fault acts as graben for F1.

Petrophysical analysis showed there is only one reservoir zone of significant thickness and hydrocarbon saturation in Rehmat-02 well. Volume of shale 21%, average porosity is calculated as 18% and effective is calculated as 11% for this zone. Hydrocarbon saturation is calculated as 61% and the remaining 38% is volume of water calculated

For better understanding of porosity and lithology content seismic inversion technique is used. There are two types of inversion of which model based technique is used.MBI uses post stack inversion. Lowr Goru B-sand is the main producing reservoir in Rehmat gas field. MBI showed 99% correlation between inverted impedance and well based p-impedance.

RECOMMENDATION

Following recommendations are suggested for future studies.

I. For better understanding of horizon structure and depth VSP(vertical seismc profiling) data should be provided in order to compare surface seismic with borehole seismic.

II. To improve qualitative interpretation advanced amplitude preserving algorithms should be provided.

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Inversion of Mubarak Area

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