STRUCTURAL INTERPRETATION AND DETERMINATION OF HYDROCARBON POTENTIAL OF BITRISM FIELD BY USING SEISMIC INVERSION AND ROCK PHYSICS MODELING, LOWER INDUS BASIN OF PAKISTAN

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ABSTRACT

Bitrism gas field is recently developed gas field of the lower Indus basin. Objective of this research was to identify the subsurface structure of the area and to characterize reservoir potential of the Lower Goru Formation which is the main producing reservoir of Bitrism block. First, seismic interpretation of 2D seismic data is done for delineation of subsurface structure which show the presence of a normal faulting and existence of horst and graben structures. Petrophysical analysis is done on Fateh-01 well to know the reservoir properties of Lower Goru Formation..

Seismic inversion is a technique for making a connection between seismic data and interpretative elastic physical characteristics of potential reservoirs. Post-stack seismic inversion is used to estimate reservoir characteristics like as porosity and acoustic impedance in the calculation of reservoir characterization. The reservoir parameters, as well as fundamental variables such as acoustic impedance and porosity of the target zone, are delineated using post-stack time migrated seismic data (POSTM) and log data in this study. Seismic inversion and rock physics modeling were employed to finish this task. The method for inverting seismic data into acoustic impedance is essential to the study's main findings. Furthermore, a good wavelet representative of the given conditions is necessary for a positive outcome. Then, applying rock physics modeling is used to estimate the porosity, Volume of shale and water saturation of Lower Goru Formation.

CHAPTER 1

INTRODUCTION

The study area is located in Khairpur district Sindh Province 26°16′ - 26°29′ N Latitude

and 68°54′ - 69°0′ E Longitude. Sanghar is the main town which is about 40km south of the location. It is located in Central Sindh Province and is bounded on the North by Jacobabad High (Sukkur Ridge), on the East by (Jaisalmir High), on the South by Thar Slope and Nagarparkar Ridge and on the West by Thatha and Hyderabad High. The interpretation of seismic data in geological terms is the objective and end product of a seismic work to investigate the geology of an area.

Since the early 1990s, the area has been actively explored by the "OGDCL" which is discovered this field since May 1990 and began normal production in December, 1994 from the Lower Goru Formation which is cretaceous in age, was discovered to be a gas reservoir. So far, three wells have been drilled, with two of them producing gas or condensate producers (Raza et al., 1989). In this study, an attempt was made to connectthe seismic data results in order to obtain a structural model.

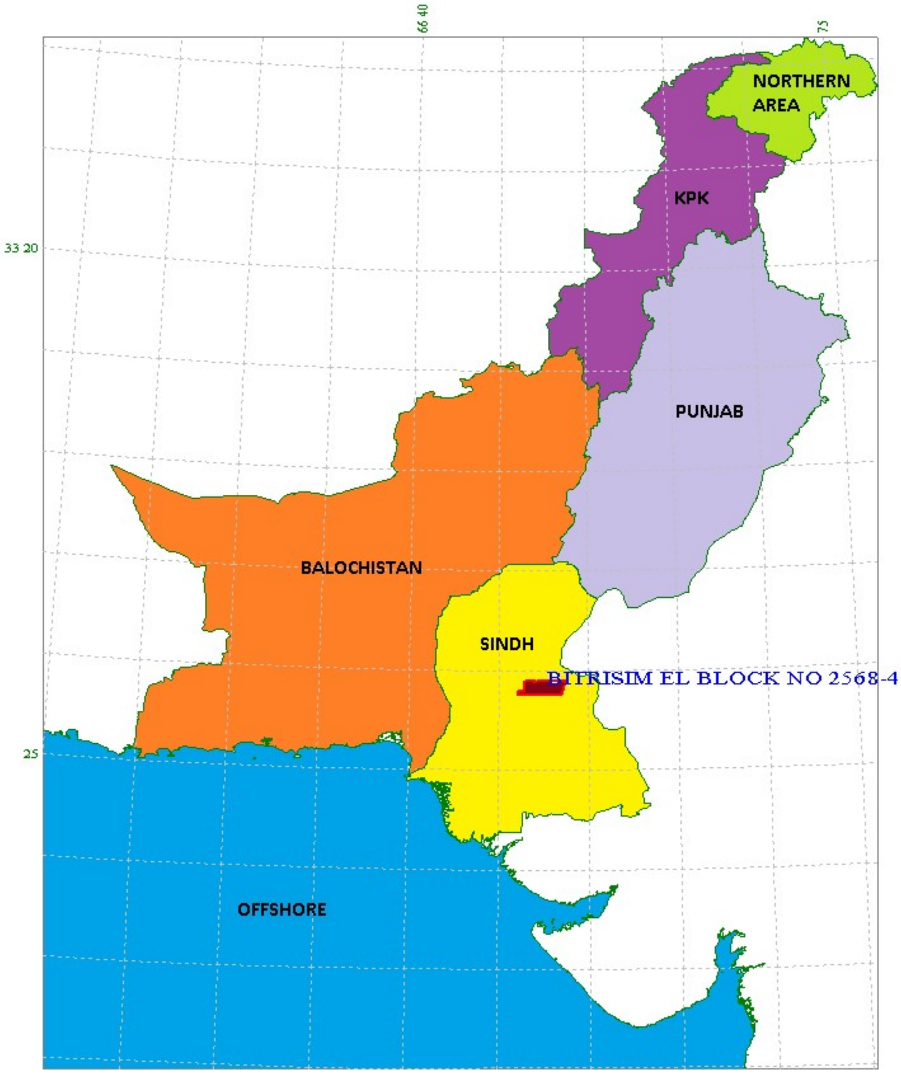

Figure 1.1 Geographical location map of Mehar block

1.1. Reason of research

The reason behind research is to estimate lithology, fluid, and characteristics of reservoir of study area. Different techniques are utilized to examine these characteristics of the reservoir in recent time. According to research conducted by many scientists, it was concluded that most of the scientist focus were on petrophysics and seismic inversion. Our focus is to determine the reservoir properties of study area with help of techniques like seismic inversion and rock physics modeling.

The seismic inversion method can be simply described as a simplified workflow-based procedure. This method converts the seismic data, which is data of reflectivity into impedance, which considered as rock property and uses the values of density and sonic velocity in a multiplicative manner. The traditional assumption associated to the reflection of seismic able to be linked like a boundary association with a large amplitude based on the response of the geological formation. According to previous studies, it is concluded that such extracted data can be precisely utilizes during the structural interpretation process. An inverted data set is the individual of amplitude that facilitates to know the characteristics of the rock, demonstration of fluid type existing in lithology and rock. Reservoir characterization and stratigraphy interpretation can be performed using an inverted data set. (Francis, 2014).

The major application of rock physics is to estimate the elastic parameters of rocks with known mineral composition, porosity and pore geometry etc (Biot, 1941). Machine learning depicts the algorithms which learns and make predictions of data. Its necessary to train the each model multiple times with different hyperparameters to reach maximum accuracy and stability predictions. So, Support Vector Regression(SVR), Random forest(RF) (Druker et al.,1996) (Ali et al., 2008).

1.2. Exploration History

The study area remained under-explored in the past, probably due to the variations of the structural styles and exposure of the potential reservoir of Cretaceous and older sediments in most of the area. Another major reason is the security conditions in Sindh, which slow down E&P companies from acquiring exploration analysis in these regions (Khan., 2017).

The first exploratory well in the study area, Kand-1, was drilled by OGDCL in 1968 to evaluate the hydrocarbon potential of Lower Ranikot sands. The well was abandoned as dry hole. Major part of the study area has no seismic data and exploration activities were mainly confined to the extreme southern and eastern limits of the study area. Only about 1000-line km of seismic data is available within the study area, whereas the seismic data and wells is mainly concentrated in front section (Ali et al., 2008).

The Bitrism gas field in Sindh's Lower Goru Formation has yielded 18 million cubic feet per day (MMCFD) of gas and 1,550 barrels of natural oil, according to OGDCL

1.3. Hydrocarbon Potential

OGDCL, with a 70% stake and GHPL, with a 30% stake, are the other partners in Bitrism Gas field. The Bitrism’s Block's surface facilities include 30 MMSCFD amine softening and dehydration plants, a hydrocarbon dew point control unit (HCDP), a well collection network, HP separators, vending compressors and a storage facility. of condensate. (Rice, 1984).

1.4. Objectives

1. Seismic data interpretation of the study area to identify and map subsurface structure
2. Petrophysical and Rock physics modeling to determine the reservoir properties of the area
3. Seismic Inversion and rock physics modeling to Identify low impedance sand/shale packages

1.5. Available Data

2-D Seismic data of Bitrism gas field with five seismic lines in format of SEG-Y and Fateh-01 well data in the format of Las file was provided by LMKR, after the approval of DGPC.

Table 1- 1Seimic and well data obtained from LMKR

Well Data	Seismic Data
Complete well suits of Fateh-01	0/20017-BTM-02 0/20017-BTM-03 0/20017-BTM-05 0/20017-BTM-06 0/20017-BTM-07

1.6. Literature Review

There is no seismic study and research have been done in Bitrism block because it is a newly development gas field. however small amount of research has been carried by OGDCL, although these studies are private and not published and these repost are not offered for open source. As the Bitrism block is lies near the Jacoabad-Khairpur Hight to obtain a sense of the area's surroundings, we take a look at few latest research completed in the neighboring region of Bitrism block.

Research investigation of the Miano area used petrophysical analysis, seismic characteristics, facies modelling, and seismic inversion techniques. It presents a structure with horst and negative floral structure that illustrates a sloping crack and an irregular graben block located in the southwest and northeast orientation. The B interval of lower Goru shows prominent light spots that tend to offer instantaneous amplitude while still offering the potential of a reservoir. The assessment and modelling of the facies also support the presence of a considerable amount of lithology shale and sand in the Goru B sand interval, which was also identified as the primary reservoir. The results of the selected well's petrophysical examination revealed at least one prospective reservoir in the sandy range of the lower Goru zone, as well as at the Miano well. A model-based inversion was used to assess acoustic impedance, with the results revealing small to large variations in impedance values. The correlation is analyzed using porosity and petrophysical analysis, and then extracted from the seismic inversion, which is then examined for the results' credibility (Zaheer et al., 2018).

There is different type of work done in surrounding field of Bitrism block like Sanghar field. This research is based on, combined study created on result of Seismic Interpretation, Well-logging, seismic inversion and rock physics modeling will be carried out for the Bitrism block, that has not yet been discovered using such techniques, and the consequences and comparison will be used to assess the correctness of these methodologies for study purposes.

1.7. Methodology

The methodology involves the following steps:

1) Generation of Base map.
2) Create the time versus depth chart
3) Identification of the reflectors.
4) Picking the time and velocities of marked reflectors.
5) Preparation of time, velocity and depth contour maps.
6) Petro physical analysis to observe hydrocarbon potential of Dhodak-01 and Dhodak-05 Wells.
7) Rock Physics analysis to predict hydrocarbons by fluid replacement method.
8) Seismic Inversion analysis to confirm results gotten from Seismic interpretation.

CHAPTER 2

REGIONAL GEOLOGY AND TECTONIC OF AREA

The Indus Basin covers roughly 533,500 km2 and is characterized by a recent Precambrian sedimentary fill. Several finds of hydrocarbon have been founded in inner folded portions of mountain region, as well as close-ups of Kithar Suleiman, the Karachi depression, the Kohat Plateau, along with the Indus shelf (Sukkar, Punjab, and Sindh Monocline, respectively). It separated into three different segments based on sedimentation history and structural style, namely the top, central, and lower Indus sub-basins. (Jadoon et al., 1992).

The Lower Indus basin is split into six major tectonic units and exhibits both extensional and compressional tectonics, as well as wrenching.

1. Thar Platform.

2. Karachi Trough.

3. Kirther Foredeep.

4. Kirther Fold belt.

5. Offshore Indus.

2.1. Thar Platform

The subsoil topography controls the Thar platform and the Punjab platform that exist in middle Indus basin. Sediment that covers on Indian Shield is exposed at Nagar Parkar High which pinches out. Thar platform shows the buried structures, this is how it differs from the Punjab platform, where there is extension tectonics due to the rotation of the Indian plate counterclockwise. of a watch (Qadri, 1995).

2.2. Karachi Trough

According to geological history, it is a trough. Karachi trough contains thick strata of Cretaceous sediments of late marine. There are narrow chains of anticlinal structure which contains oil and gas fields like;   Hundi, Sari and Kothar. Interestingly, some of the Cretaceous rocks, which had been deposited continuously along the Cretaceous-Tertiary (K-T) boundary, are very well preserved (Qadri, 1995).

2.3. Kirthar Foredeep

Kirthar Foredeep contains 15,000 m thick sediments trending from north-south. In addition, it contains a faulty boundary (on the east side) with the Thar platform. At this region, a well-developed Paleocene stratum can be seen whereas, the Upper Cretaceous strata is missing. Kirthar Foredeep was discovered with an excessive potential for source rock maturation (Qadri, 1995).

2.4. Kirthar Fold Belt

Tectonically trending north south, the Kirther Fold belt resembles the Sulaiman belt. It is bordered on the west by the Bela-Zhob ophiolites and the thrust belt, on the north by the Sibi trough, and on the west by the Kirthar foredeep and the Indus Platform. Triassic to modern rocks have been deposited here (Qadri, 1995).

2.5. Offshore Indus

It is portion of the continental margin that is not active. Sedimentation on the Indus coast occurred in two different stages of geological time, such as the Cretaceous to Eocene phase and the Oligocene to recent phase (Jadoon et al., 2020).

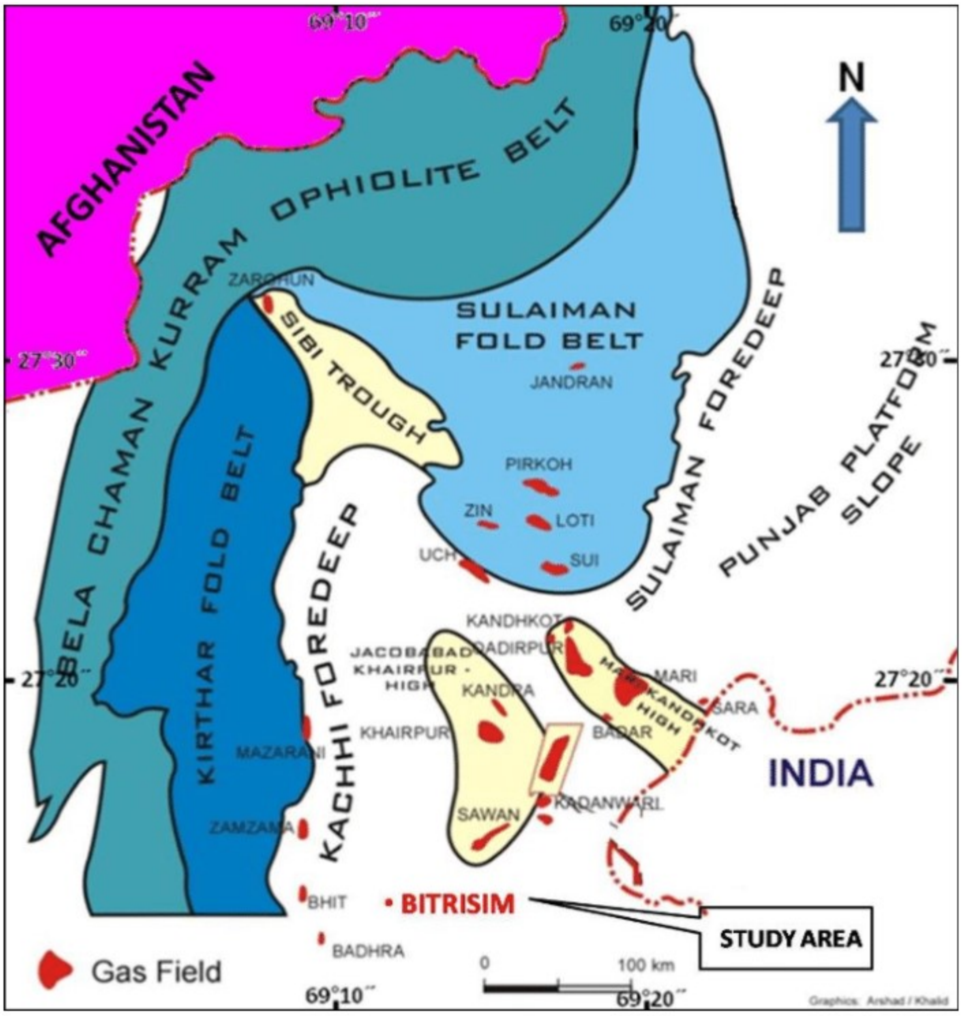

Figure 2.1 General geology map of Pakistan showing the study area and its surrounding geological features (Ali et al., 2021).

2.6. Tectonic of research area

The basinal history of the study area is related mainly to rifting and break up of Gondwana in Jurassic period. The Indian plate separated from East Gondwana in Aptian Time (120 ma). At the end of Cretaceous/early Paleocene, the Seychelles and Madagascar separated from India with associated faulting accompanied by Basaltic flows (Deccan Volcanics) in the southern part of Lower Indus Basin. The regional base Tertiary unconformity is due to thermal doming associated with the separation of the

Seychelles and Madagascar from India. After the Paleocene there was a continuing oblique convergence of India and Asia throughout Tertiary time and the collision of India with Asia caused a westward tilting of the entire region. Domal lifting in during the Early Cretaceous is responsible for the Jacobabad-khairpur high on which the study area is located. Later on along deep seated faults in the Late Cretaceous and Paleocene have been generated (Ahmed and Ali., 1991). On the Jacobabad- Khairpur high, Eocene carbonates (Sui Main Limestone) are widely distributed and form good hydrocarbon reservoirs.

The Indus platform and foredeep comprise the following main structural zones.

I. Zones of upwarp

II. Mari-Kandhkot High

III. Jacobabad-Khairpur High

Jacobabad Khairpur upwarp divides the Indus platform into two segments. The lower segment is comprised of lower Indus trough. It is bounded by Nawabshah and Nabisar slopes which are in turn flanked by Thatta-Hyderabad and Tharparkar highs. The upper segment is traversed by Sargodha Shahpur Ridge splitting into northern Punjab monocline and southern Punjab monocline. Some basement faults straddle major structures such as the Sargodha Shahpur ridge and Kandhkot-Mari and Jacobabad-Khairpur horsts. In Jacobabad Kandhkot zone, some of faults are likely to be post Eocene and post Miocene. South of Sargodha-Shahpur ridge and extending upto Kandhkot-Mari High is a roughly triangular area; the quaternary deposits are underlain by post Eocene, largely fluviatile deposits.

Structurally as a platform of the Indus basin, the Jacobabad-Khairpur horst started becoming a positive area in Late Jurassic. It consists of Mesozoic, Tertiary and Quaternary sediments with the Cretaceous and Jurassic reduced in thickness over horst. Mesozoic and Tertiary plays are significant targets for exploration.

2.7. Structural Setting of research area

Normal faults are generated as a result of entire southern basin exhibiting the extensional tectonics, showing the Horst and Graben structures with former being of great exploratory importance. The extensional tectonics during the Cretaceous time created the tilted fault blocks over a wide area of the Eastern Lower Indus sub-basin (Kemal et al, 1992).

The southern Indus basin is identified as an extension basin resulting from an inferred fossil-rift crustal feature overlain by a thick sedimentary sequence. Extension was a consequence of temporal divergence of the Indo-Pakistan subcontinent from Gondwanaland during the early Paleozoic. Based on magnetic anomaly trends, the Indus basin fossil-rift feature is characterized by horst and graben structures, together with a system of transcurrent faults. The association of seismicity events and basement crustal features suggests that Tertiary reactivation of individual segments of the inferred rift structure has deformed overlying sequences of the Indus basin and also the surrounding areas, particularly the fold and thrust belt of Pakistan on the western side of the basin. (Zaigham and Mallick, 2000)

CHAPTER 3

STRATIGRAPHY AND PETROLEUM PLAY

3.1. Stratigraphy of study area

The Lower Indus Basin was in a passive marginal setting, and sediments were most likely laid down in inner rifts in intermittent interaction with Tethys under partly restricted shallow marine conditions. The Permian sequence overlies the Cambrian deposits. Up until the Late Triassic period, the Central Indus Basin was characterized by shallow marine to paretic conditions. The passive margin thermal subsidence that occurred during the early Jurassic period deposited thick layers of fine-grained clastic deposits. The carbonate platform of the Middle Jurassic was replaced by shallow marine to deltaic shale and sandstone, respectively (Iqbal et al., 1980).

The carbonates platform is replaced by a more clastic-dominated regime through out the Late Cretaceous epoch. The collision of two main tectonic plates, the Indian and Eurasian Plates, during the Middle Miocene epoch resulted in extensive molasses deposits. The Indus Basin, which is part of Gondwanian territory (Southern Earth), is divided from the Baluchistan and Northern portions of Tethyan and Laurasian domains by an axial belt (suture zone) (northern earth). The Indus Basin, which runs through the northwestern section of the Indo-Pakistan peninsula, is divided into three parts: Upper (Kohat and Potwar), Middle (Sulaiman), and Lower (Kirthar).

3.2. Sembar Formation

The Sembar Formation is 133 meters thick on average. The name "Sembar" refers to the type locality of this formation, which is Sembar Pass. The Sembar Formation's lithology contains black-colored shale with inter bedded Siltstone. These Glauconitic- siltstone and Shale are common. This formation forms a gradational contact with the Cretaceous Goru Formation above it, whereas the lower contact is unconformable with Jurassic age formations. Sembar Formation has a geologic date of Early Cretaceous (Iqbal et al., 1980).

3.3. Goru Formation

Goru Formation is 536 meters thick on average. The Goru Formation's main lithology is shale, with inter-bedded limestone and Siltstone. The upper half of the formation is primarily thin bedded Limestone with little Shale, but the lower portion is predominantly Shale with light grey tinted thin beds of Limestone. The Fossils found in this deposit are Foraminifera and Belemnite (Iqbal et al., 1980). The Goru Formation is divided into two members, which are listed below.

3.3.1. Lower Goru Member

The change in lithology from Marl to Claystone characterises the top portion of the Lower Goru component. Lower Goru Shale is dark grey in colour, somewhat hard, sub platy, sub fissile, mildly Calcareous, Silty, and grades to Siltstone locally. Siltstone,on the other hand, is light grey in colour, friable, calcareous (calcium carbonate) and Glauconitic in places, and grades to fine sandstone locally (Iqbal et al., 1980).

3.3.2. Upper Goru Member

Upper Goru is a part of the Upper Cretaceous age. The lithology of the top portion of the Upper Goru varies from Sandstone, Clay-stone, Marl, and Limestone, respectively. In the higher section, Marl grades to Argillaceous Limestone and is light to medium grey in colour, compacted, sub blocky, with Silt and Sand. Limestone is medium to dark grey in colour, slightly hard, sub blocky, Argillaceous (higher clay content), and grading to Marlin some locations. Upper Goru shale is dark grey in color, somewhat hard, sub Fissile, and changes to calcareous Clay stone with time (Iqbal et al., 1980).

3.4. Parh Formation

The average thickness of the Parh Formation is 268 meters. This formation is also called as Parh Limestone as it is dominantly consisting of Limestone while Marl and Shale are also present in this formation. Foraminifera are the index fossil of this formation.Middle Cretaceous is the geologic age of this formation whereas shallow marine marks the environment of deposition. Its top depict K-T (Cretaceous-Tertiary) boundary which indicates break in geologic record therefore this formation makes unconformable upper contact with Ranikot Formation and conformable lower contact with underlying Goru Formation respectively (Iqbal et al., 1980).

3.5. Ranikot Formation

This formation is similar to the Upper Paleocene Dungan Formation and the Paleocene Rakhsani Formation in southern and western Pakistan. It's also linked to the Kohat-Potwar province's Hangu Formation (Late Paleocene) and Patala Formation (Early Paleocene) sequences.The geologic age of this strata is Lower Paleocene (Iqbal et al., 1980).

3.6. Kirthar Formation

The Kirthar Formation (Noetling, 1903) is composed of limestone and shales inter- bedded with some Marl. This formation's Limestone is light grey cream in hue. This formation transitions over the Ghazij Formation of the lower Eocene in most locations. In different sections of the distribution, the formation is very Fossiliferous and represents distinct geologic ages .The geologic age of this deposit is Upper Eocene. (Iqbal et al., 1980).

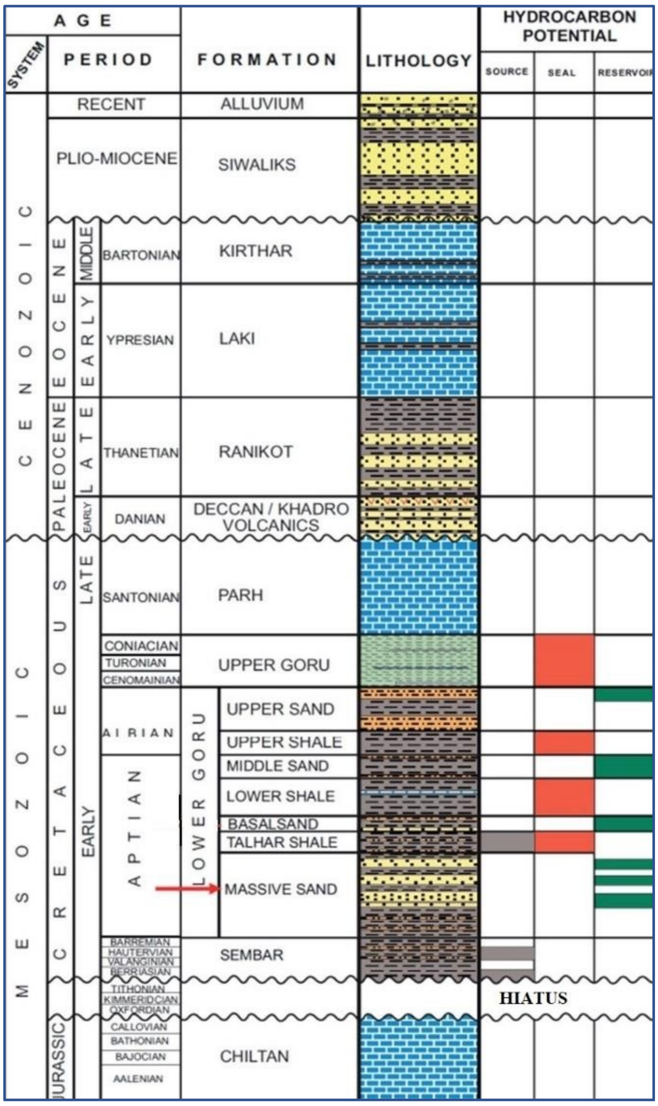

Figure 3.1: Generalized stratigraphy of Kirther fold belt

3.7. Petroleum play of study area

3.7.1. Source Rock

While the Sembar has been identified as the primary source rock for much of the Greater Indus Basin, there are other known and potential source rocks. Rock units containing known or potential source rocks include the Salt Range Formation "Eocambrian" shales, Permian Dandot and Tredian Formations, Triassic Wulgai Formation, Jurassic Datta Formation, Paleocene Patala Formation, Eocene Ghazij formation, and lower Miocene shales. Of all the possible source rocks in the Indus Basin, the Sembar is the most likely source for the largest portion of the produced oil and gas in the Indus foreland. The Lower Cretaceous Sembar Formation consists mainly of shale with subordinate amounts of siltstone and sandstone. The Sembar was deposited over most of the Greater Indus Basin in marine environments and ranges in thickness from 0 to more than 260 m.

As a result, production, movement and accumulation of hydrocarbons must followed in Lower Indus Basin. Broad research show the Sembar Formation of late Cretaceous age is the vital hydrocarbon generating source rock which is organic rich shales deposited in shelf marine environment in this region and other parts of the Indus Basin (Kazmi, A.H., and Jan, M.Q., 1997).

3.7.2. Reservoir Rock

The principal reservoirs are deltaic and shallow-marine sandstones in the lower

part of the Goru in the Lower Indus Basin and the Lumshiwal Formation in the Middle Indus Basin and limestone in the Eocene Ghazij and equivalent stratigraphic units. Potential reservoirs are as thick as 400 m. Sandstone porosities are as high as 30 percent, but more commonly range from about 12 to 16 % and limestone porosities range from 9 to 16 percent. The permeability of these reservoirs ranges from 1 to > 2,000 milli darcies. Reservoir quality generally diminishes in a westward direction but reservoir thickness increases. Because of the progressive eastward erosion and truncation of Cretaceous rocks, the Cretaceous reservoirs all have erosional up dip limits, whereas Tertiary reservoirs extend farther east overlying progressively older rocks.

3.7.3. Seal Rock

The known seals in the system are composed of shales that are interbedded with and overlying the reservoirs. In producing fields, thin shale beds of variable thickness are effective seals. Additional seals that may be effective include impermeable seals above truncation traps, faults, and up dip facies changes. The thick sequence of shale and marl of upper Goru Formation serves as cap rock for underlying Lower Goru reservoir.

3.7.4. Trap

All production in the study area is from structural traps. The tilted fault traps in the Lower Indus Basin are a product of extension related to rifting and the formation of horst and graben structures. The temporal relationships among trap formation and hydrocarbon generation, expulsion, migration, and entrapment are variable- throughout the Indus Basin. These provide the significant trapping system along tilted fault blocks and negative flower structure.

3.7.5. Migration

Oil and gas migrate from source rock to reservoir rock during the migration process. Buoyancy, chemical potential, topography, compression, thermal expansion, maturation (volume increase over time), and gravitational separation of water, hydrocarbon and water are all key factors in migration (Qadri, 1995).

Table 3- 1 Petroleum play of study area

Play Elements	**Formations**	**Age**
Seal	Upper Ranikot	Paleocene
Reservoir	Lower Goru Formation	Late Cretaceous
Source	Sembar Shales	Early Cretaceous

CHAPTER 4

SEISMIC DATA INTERPRETATION

Seismic interpretation is used to identify the subsurface structure of region. It helps to identify the change in structure and fault trend. The research location is in the Bitrism block, which is on eastern side of the Jacoabad Khairpur high. The region is lies in extensional regime whereby horst and graben structures exist in this region that is a major site for hydrocarbon entrapment. The Bitrism block is noted for producing gas condensate from the cretaceous deposit. To understand the discovered structure, fault type, and depth of the primary reservoir in this location, the following steps must be taken. (Jiang et al.,2005).

4.1. Workflow for Seismic Interpretation

Following workflow is adopted for completion of seismic interpretation.

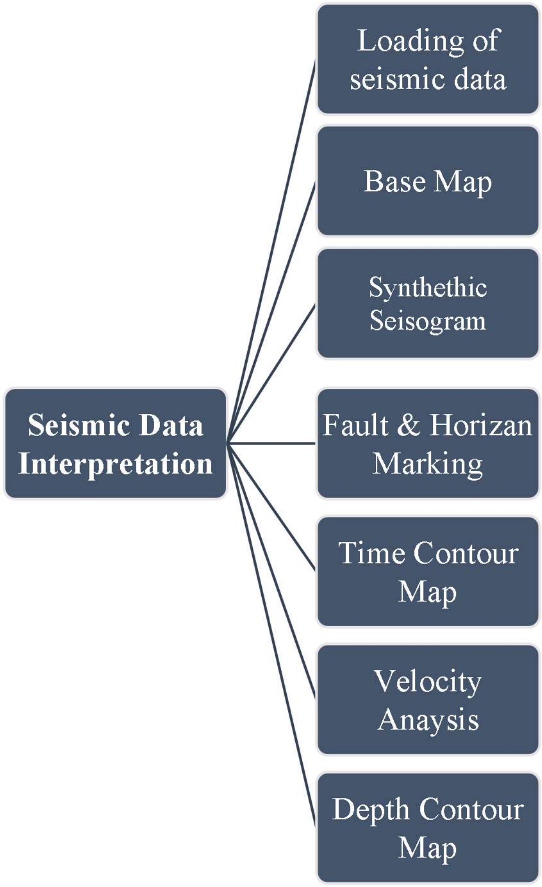

Figure 4.1 Workflow adopted for seismic interpretation

4.1.1. Loading of Seismic Data

A 2D seismic data in SEG Y format for the Bitrism region is provided. The data is loaded into the IHS^{Tm} Kingdom software using SEG Y headers for inline and cross line loading. For this study, 2D seismic data is provided. In addition well data from Fateh-01 well is fed into the software, together with the log curve, to indicate the location on the base map and to generate a synthetic seismogram for the well-to-seismic tie.

4.1.2. Base Map

After seismic data loading is complete, the base map of the given data is generated. The base map shows the orientation of overall dip lines and strike lines. The 2D seismic data is displayed in figure 4.2. The orientation of dip lines is from east to west and for strike line orientation is from north to south direction.

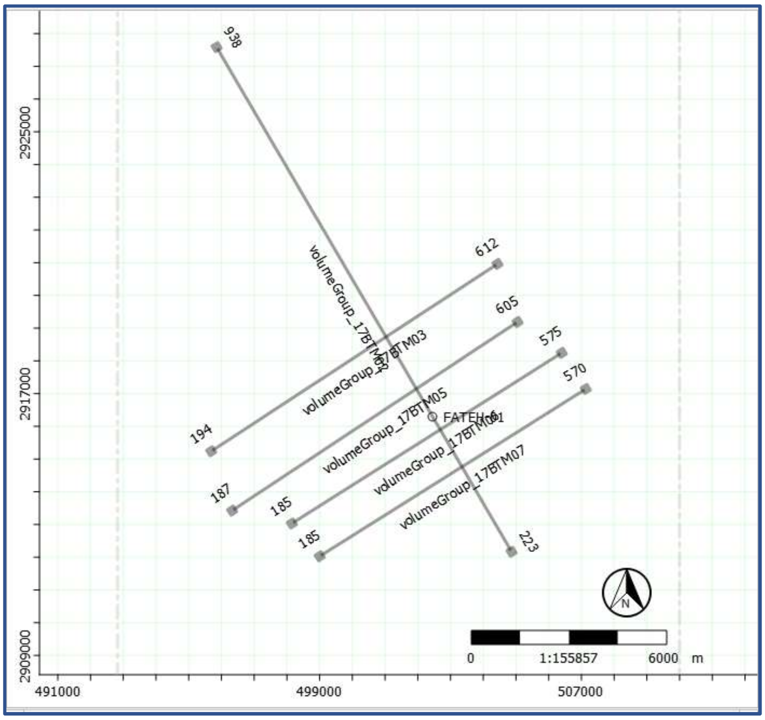

Figure 4.2 Base map of study area

4.1.3. Generating Synthetic Seismogram

Synthetic seismogram is a 1-D forward model of acoustic energy that traveled through the earth horizons having acoustic impedance contrast. This synthetic was created by the merging of earth reflectivity series that was obtained from the sonic and density logs, and the extracted wavelet is used from seismic data. Degree of the correspondence among a seismic section and synthetic seismogram is dependent on the quality of well log data. To produce a synthetic seismogram, sonic (DT) and density (RHOB/ROHZ) are required. Before marking the horizons, synthetic seismogram of given wells is generated (Chopra and Marfurt., 2005).

For a well-to-seismic tie, a seismogram is required. Therefore, we used the sonic log and density log from the Fateh-01, as well as Gamma ray log is also used as a references log. The seismic data traces surrounding the wellbore were used to form a wavelet, which was then convolved with the impedance log generated from the well's sonic and density log to produce a final synthetic seismogram. After that, the synthetic was compared to the seismic data, and changes were performed using shift and stretch. The well to seismic tie was completed once the nature of synthetic and seismic data were matched, and work moved on to the next phase, which was the selection of horizons using the time depth chart correlation produced during the tie.

Synthetic seismogram on the basis of Fateh-01 well are shown in the figures 4.3. The figure 4.3 shows that the time of top Lower Goru Formation is 1.69 sec the time of Basal Sand is 1.75 sec.

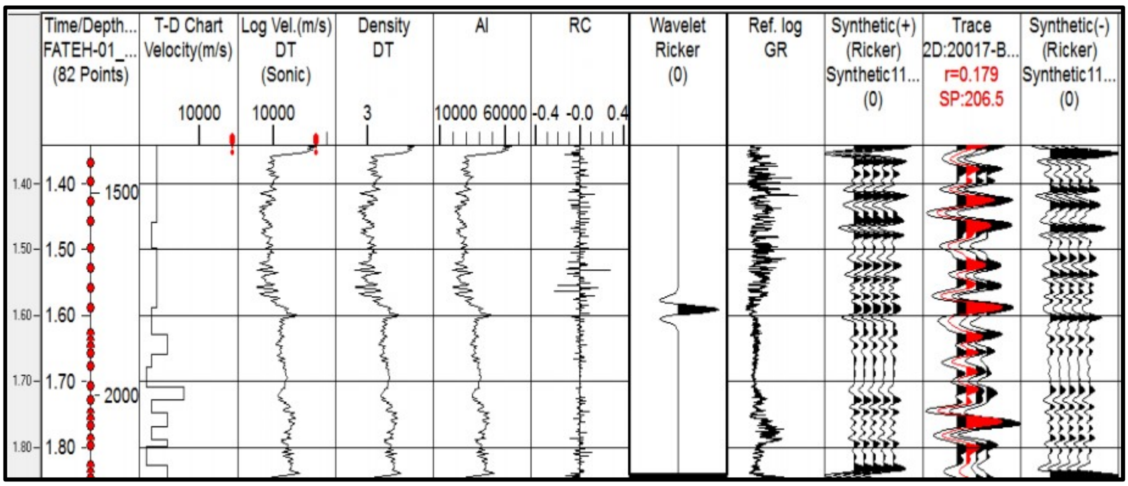

Figure 4.3 Synthetic seismogram on the basis of Fateh-01well

4.1.4. Seismic to Well Tie

After the generation of synthetic seismogram next step is seismic to well tie, the reason behind this tie is to mark the exact reflector of horizon on the seismic section. In the figures given below show the exact location of formation along with synthetic traces on all the provided well. Target formations are marked at their corresponding time. Based on data provided Basal Sands of Lower Goru Formation is marked on the basis of Fateh-01 well

4.1.5. Marking of Fault and Horizons

Following the tie, the next way is choosing concern reflector that have previously been uploaded corresponding on the tops of well in the well data. The Time-Depth graph created through the seismic to well tie will then be used by software to show these horizons of formation on the seismic. Software then displays the reflector for the chosen well formation based on the seismic data.

Primary target of structure interpretation is to mark Basal Sands of Lower Goru Formation Because the major reservoir for the Bitrism block is the Basal Sand of Lower Goru Formation. Now, to fully justify the structure and to achieve the best results from this study, Basal Sands is chosen because its reflector is highly visible and can easily be identified and recognized, thus it aids in data matching, particularly during seismic to well tie.

Reflectors have been approved for concern formations, Horizons and faults have been indicated each seismic line for the given seismic data, because there was so much data disruption near the faults zone due to fractures that it was difficult to mark the concern horizon there. Similarly, normal faults were indicated on every single line throughout the entire area, and then fault surfaces for the entire data were created.

4.1.6. Seismic Interpretation

The entire 2D seismic lines have been interpreted, including the marking, and picking of the Basal Sands, as well as fault marking. Seismic to well tie provides the reflector time that is almost 1.75 sec for Basal Sands at well location of Fateh-01 well. The horizon has been marked over all seismic lines with these picks. There is a significant north-south trending normal fault that was considerably younger and disturbs formations up to cretaceous age.

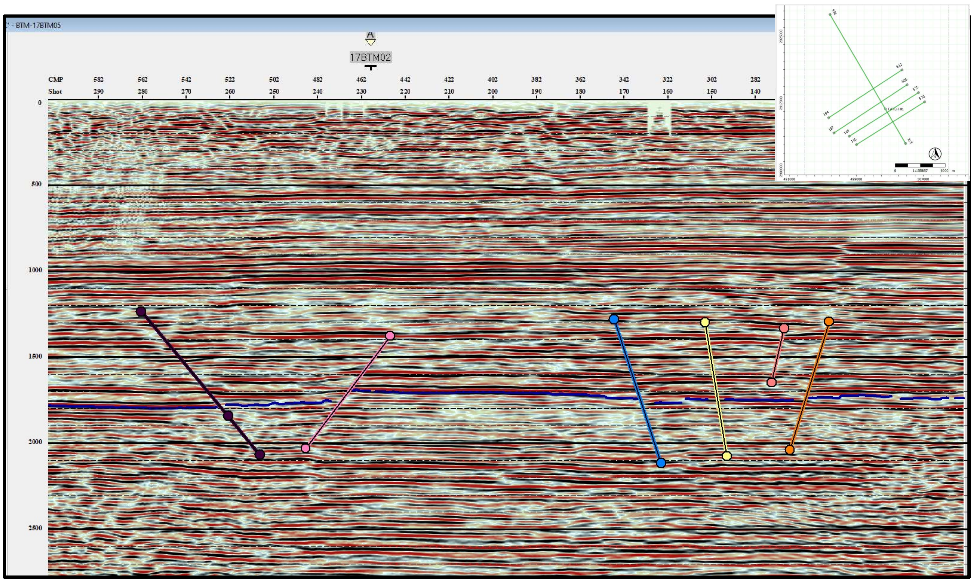

Figure 4.4 Seismic section 20017-BTM-05

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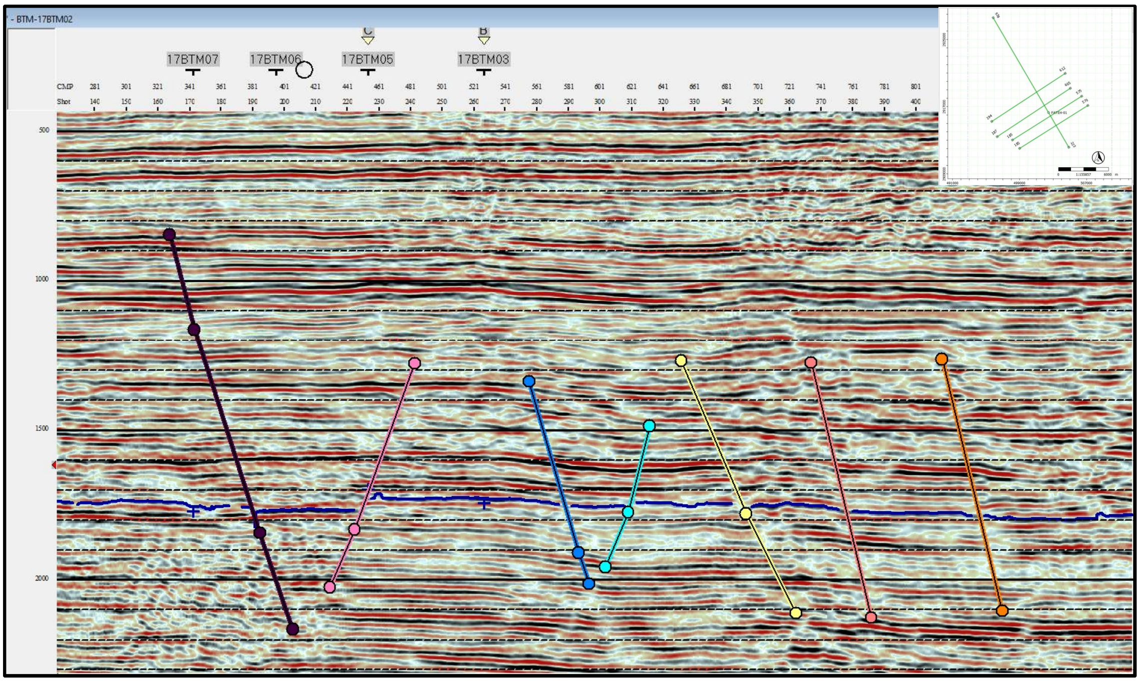

Figure 4.5 Seismic section 20017-BTM-02

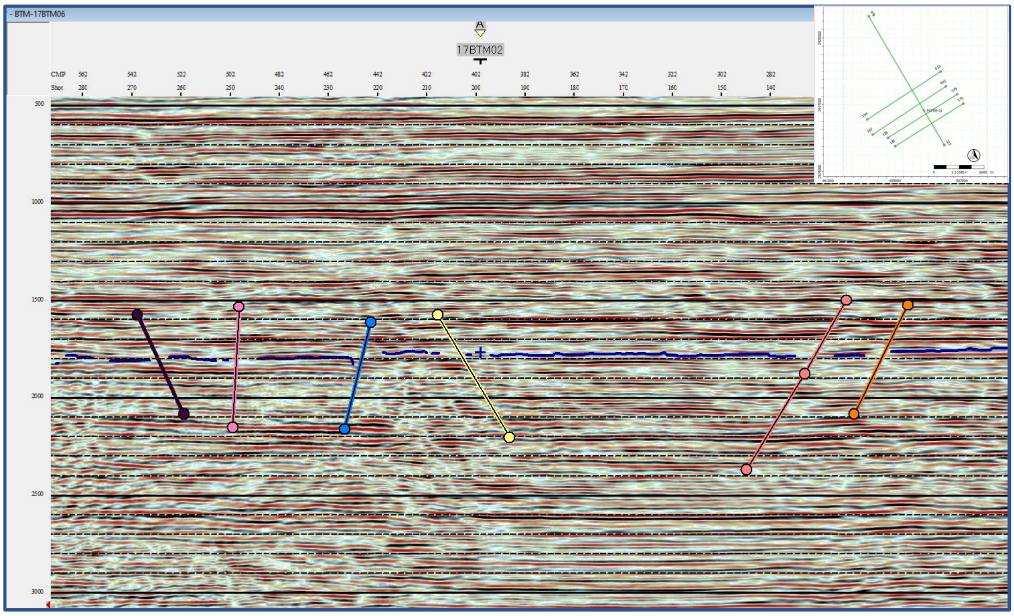

Figure 4.6 Seismic section 20017-BTM-06

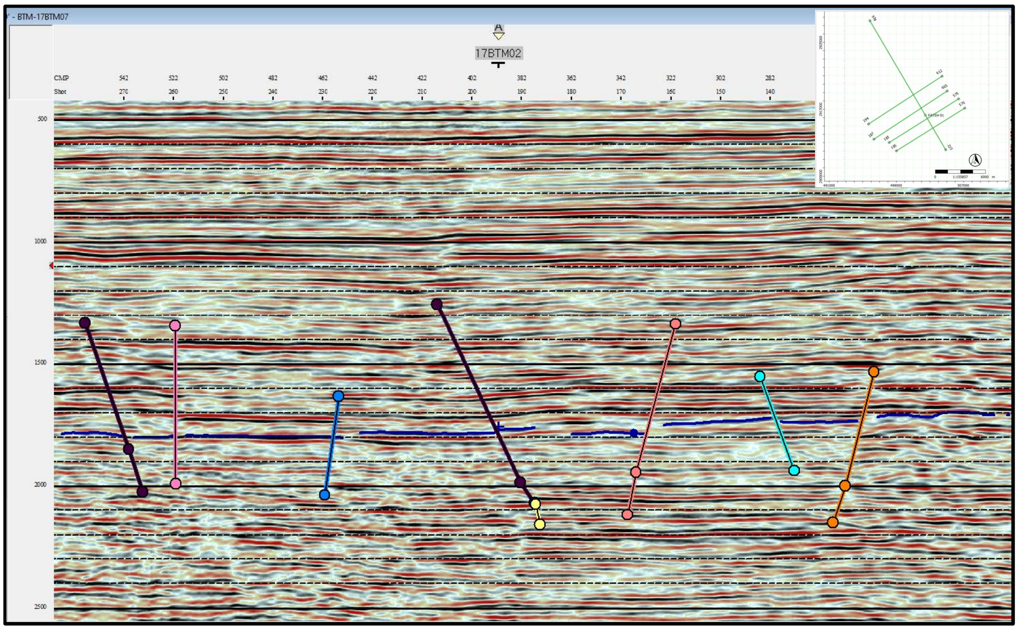

Figure 4.7 Seismic section 20017-BTM-07

The time section gives the position and configuration of reflectors in time domain. Basal sands reflector is marked on seismic lines. The reflector is marked with blue color so that it can be easily distinguished. However the aim is to target, the source, reservoir and seal rock formations. Normal faults are encountered in upper horizons. The time section of seismic line 20017-BTM-05, 20017-BTM-07, 20017-BTM-06 and 20017-BTM-02 is given in Figure 4.4 to Figure 4.7. The seismic sections are in time domain, but the real subsurface structures are in depth domain so we have to convert time sections into depth sections using velocities data. Horizons were marked on all seismic dip line by using the strike line intersecting these dip lines. Faults were marked where there is a break in the continuity of the horizons. Horst and Graben structures can be seen on the seismic section.

4.1.7. Computation of Time Contour Maps

After the marking of faults and horizon of interested formation, next step is to compute the time contour maps . Basically, fault polygons are usually digitized after plotting our interpretation on the base map and then time contour maps are prepared as seismic data is usually in the time domain. The time contour map of Basal Sand is shown in the figure 4.8 . There are four faults shown in blue color that is dipping towards eastern and western side is shown in contour maps. The contour interval is 0.025 sec.

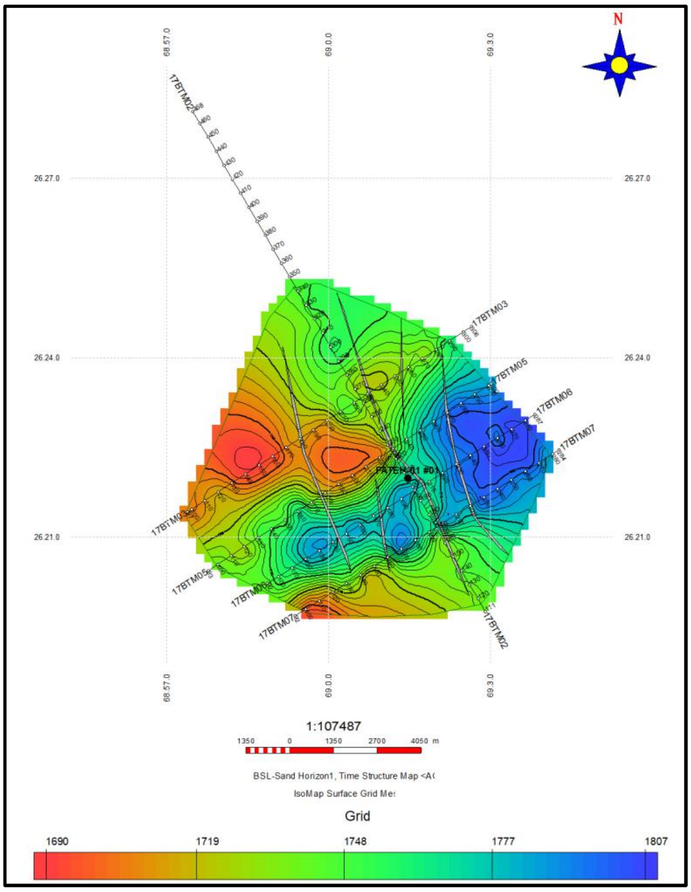

Figure 4.8 Two-way travel time map of Basal Sands of Lower Goru Formation

Time contour map on figure 4.8 shows that near fault surface there is decrease in time of horizons/reflector/ contour value but as move away from the fault the time is increase. The increase in time value is observed in western side of fault. The highest time is observed on east side of fault because at that portion the seismic data quality is bad, so the reflector is marked based on estimation due to which highest time is observed that portion of fault.

4.1.8. Computation of Depth Contour Maps

After making the time contour map the next step is to know the exact velocity of formation. The exact velocity of formation is picked from check shot data. Velocity of interested formation Basal Sands is shown in the table 4.1 along with their time and depth

After knowing the velocity next step is generating depth contouring map. The depth is calculated with the help of simple formula (S = VT/2), where V is the velocity and T is a two-way travel time. The velocity is taken by check shot data then used it to make a depth contour map, figure 4.9 explain the depth contour map of Basal Sands with contour interval of 40 m.

Table 4-1 Demonstration of time, depth and velocity of interested formation with respect to provided well data

Sr.no	Formation	Time (sec)	Velocity (m/sec)	Depth (m)
1	Basal Sands	1.75	2300	2950

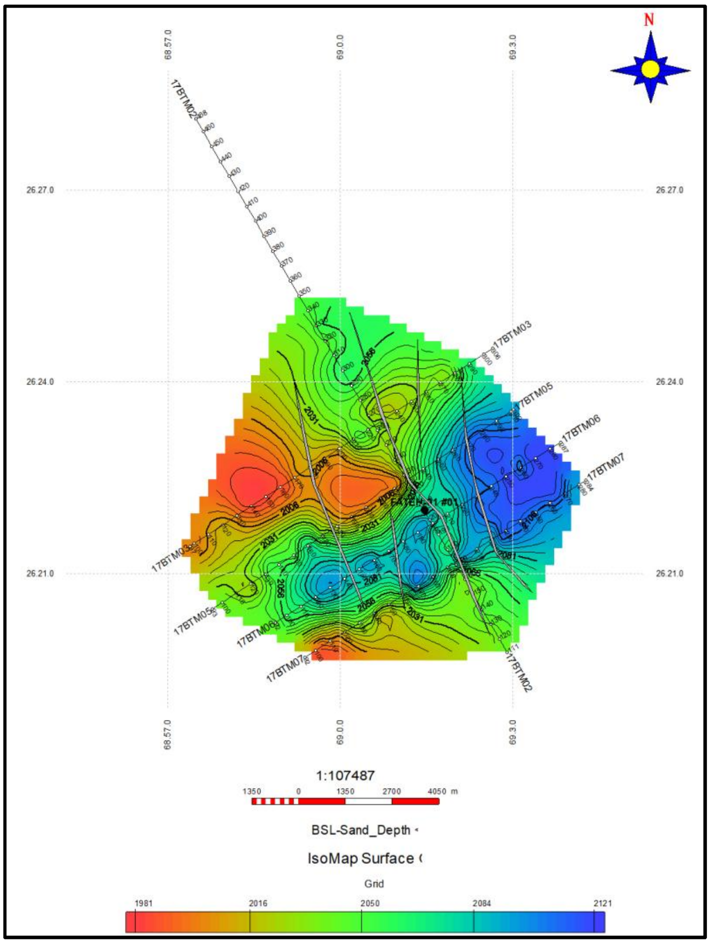

Figure 4.9 Depth map of Basal Sands of Lower Goru Formation

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Depth contour map show the variation of depth in formation. The variation in formation depth is observed in well Fateh-01. The trend of contour shows that near the fault shallow depth is observed as moved away from the fault the depth variation is large as shown in figure4.9 . The variation of depth can easily be seen with color key that is present in contour map.

CHAPTER 5

PETROPHYSICAL ANALYSIS

5.1. Introduction

During petrophysical analysis, the chemical and physical properties of the rock are researched, as well as their behavior and interaction with various types of fluids. Interpretation of the features in producing zone for exploration of hydrocarbon by fluid usually oil and gas firms is main key purposes of such a kind of analysis. This petrophysical research will enable geoscientists to estimate the porosity and how they are interconnected, reservoir lithology and many other regulating and hydrocarbon migration parameters. Some of the significant features of the rock that are analyzed during petrophysical testing include lithology, water and hydrocarbon saturation, rock density, and, most significantly, reservoir rock porosity. Petrophysical study is done by first acquiring the well logs in the borehole as well as by retrieving the cores samples from the borehole. These well logs and core measurements are analyzed, and then merged with other geophysical and geological data to obtain a comprehensive understanding of the reservoir. (Glover.,1990)

5.2. Provided Well Data

Complete log suits for Fateh-01 well respectively is obtainable for petrophysical analysis. Fateh-01 occurs condensate well and drilled in 2002 and the last formation that is present in well is Lower Goru Formation is an appraisal that was similarly drilled in 2002 and is fit for Lower Goru Formation production. The encounter formation in Fateh-01 well is Lower Goru Formation.

5.3. Methodology

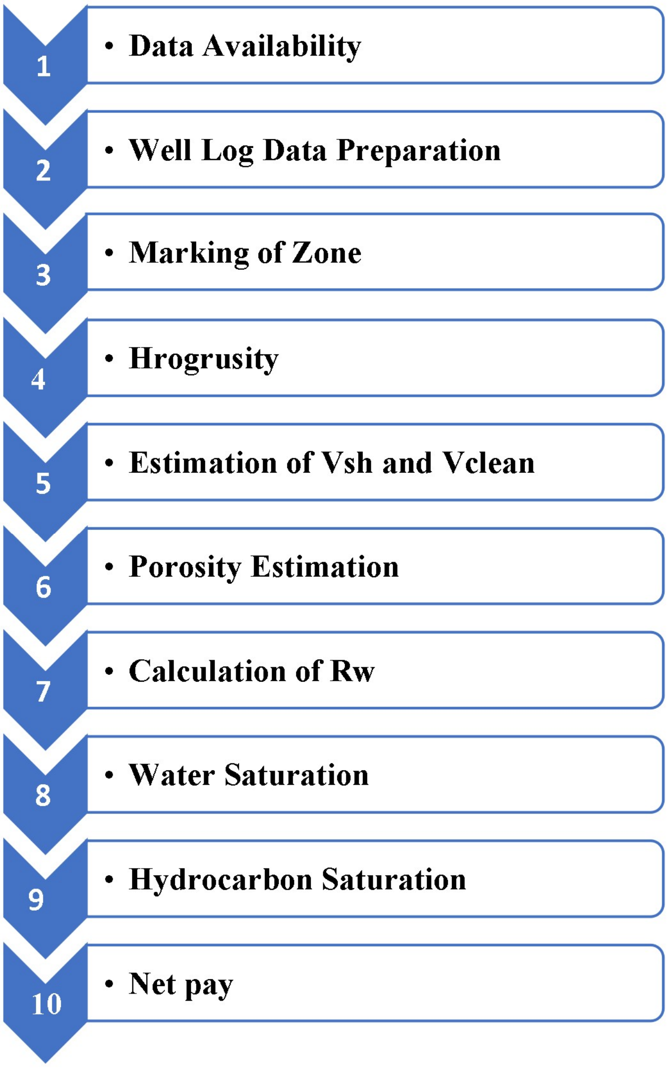

Figure 5.1 Workflow for petrophysical analysis of well

5.4. Marking zone of Interest

Recognizing the zone of interest in a reservoir, there are three important criteria that are demonstrate, which help to identify zone.

First criteria are read the value of gamma ray. It is one of important factor that is used for prediction of area of hydrocarbons. A lower value of the gamma ray shows the presence of clean lithology ,which is the characteristic of the excellent reservoir. If the gamma ray value is high, it cannot be marked as a hydrocarbon zone (Ali et al., 2019).

Second criteria are resistivity log. The resistivity logs are significant because it provides a reservoir hint tha depend on electrical resistivity. There are three valuable logs LLS, LLD and MSFL known as resistivity log. If the MSFL is greater than LLS and LLS is greater than MSFL than it shows the presences of hydrocarbon. In other word there should be a segregation among the LLD and MSFL for existence of hydrocarbon. If there is no separation between them, that area may hold water (Ali et al., 2019).

Third criteria are there should be a crossover between the neutrons and density log for identifying the area of hydrocarbon. The reservoir's porosity is determined with neutron and density log data. If both the neutron and density values continue to decrease, the crossover with both logs decreasing is obtained, indicating the presence of the hydrocarbon zone (Ali et al., 2019).

5.5. Petrophysical Parameter Calculation

5.5.1. Calculation of Rogusity

The rugosity is computed using a caliper log. Purpose of calculating rogosity is for determine borehole's condition. rogosity is computed using a Bit size and caliper log with the help of formula:

ROGOSITY = CAL – BS

5.5.2. Calculation of Volume of Shale (Vsh)

The shale volume is computed from gamma ray log data. The amount of natural radioactivity in the formation influences the gamma ray log value. Because shale contains many radioactive materials, it has a high value of gamma ray log.

Shale volume can be estimated by using the method (Schlumberger, 1974).

$$Vsh = \frac{(GRlog - GR\ min)}{(GR\ max - GR\ min)}$$

Where,

Vsh = Volume of shale

GR log = Value of Gamma Ray at interested depth

GRmin = Minimum Gamma Ray value

GRmax = Maximum Gamma Ray Value

5.5.3. Estimation of Volume of Clean (Vclean)

The formula used for calculation of clean volume is (Schlumberger, 1974).

$$Vclean = 1\text{-}Vsh$$

5.5.4. Calculation of Density Porosity (DPHI)

Porosity with the help of density can be calculated with the help of density log. Following formulation is used to evaluate DPHI (Schlumberger, 1974)

$$\Phi = \frac{\rho m - \rho b}{\rho m - \rho f}$$

Where,

ρm = Density of matrix

ρb = Formation bulk density

ρf = Fluid Density

Φ = the density porosity of rock

5.5.5. Estimation of Neutron Porosity (NPHI)

The neutron porosity value is brought straight from the neutron log, which goes corresponding to the density log.

5.5.6. Estimation Average Porosity (APHI)

The total number of pores present in a rock is referred to as its porosity. These pores are a critical component of the reservoir for hydrocarbon buildup. The average porosity is calculated using the density and neutron log values. The average porosity of a reservoir is computed applying the formula given below (Schlumberger,1974).

$$\mathrm{APHI} = \frac{\mathrm{NPHI} + \mathrm{DPHI}}{2}$$

5.5.7. Estimation of Sonic Porosity (SPHI)

Sonic log is used for calculation of porosity. Need of sonic porosity can be used when the condition of bore hole is too much bad. So the sonic log is only log that help to know about correct porosity formula of calculation of sonic porosity is given below

$$\mathrm{SPHI} = \frac{\Delta t - \Delta \mathrm{tma}}{\Delta \mathrm{tfld} - \Delta \mathrm{tma}}$$

Where,

Δt = sonic log values (µs/feet)

Δtma = matrix travel time (µs/feet)

$\Delta tfld$ = fluid travel time (µs/feet)

5.5.8. Estimation of Effective Porosity (EPHI)

Fraction of connected pore spaces in relation to the bulk volume is known as effective porosity. The effective porosity is a parameter utilized in computations as it characterizes the interconnected pore spaces that comprise of recoverable hydrocarbon fluids. Effective porosity is computed using the method below. (Hilche, 1978).

If condition of borehole is good

$$EPHI = APHI * Vclean$$

If condition of borehole is bad (Caving),

$$EPHI = SPHI * Vclean$$

As our zones of interest have undergone caving, so effective porosity is calculated using sonic log porosity.

5.5.9. Rw Calculation

Resistivity of water is calculated with help of Picket plot method. Picket plot method represent deep resistivity on X axis and porosity log on Y axis. The Plot is based on the logarithmic of Archie equation. Saturation points (Sw) will be plotted on a straight line with a negative slope of value m. The lowermost line on the plot is defined by water zones. The water resistivity may be estimated from a location on the line because Sw = 1. Other parallel lines with different Sw can be drawn once the water line is formed, assuming a constant n. (usually 2). Then, in terms of Sw, other data can be plotted and evaluated. The Picket plot is used to estimate the resistivity of water for Basal Sands. The Basal Sands resistivity is 0.04 ohm shown in figure 5.2.f

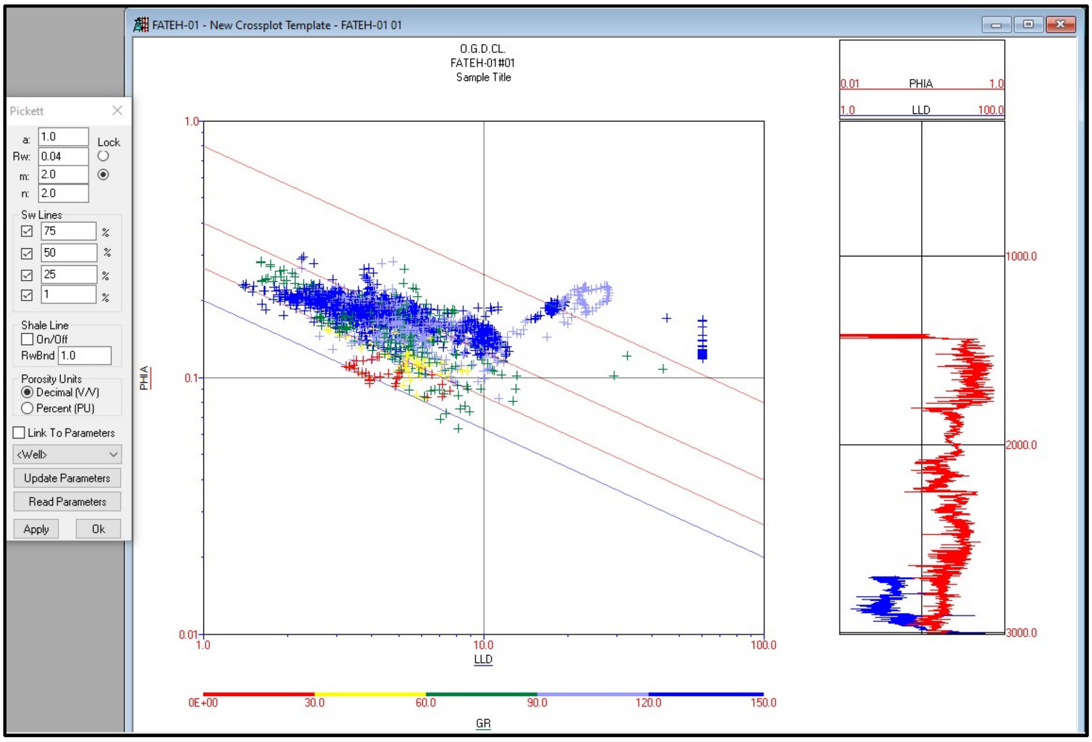

Figure 5.2 Resistivity of water for Basal Sands by Pickett plot method.

5.5.10. Saturation of Water

Water saturation refers to the amount of water in a formation that is not equal to the amount of hydrocarbon present. Sw denotes the saturation of water. It's computed by adding 1 by a Sw. In our case Indonesian equation is used for calculation of saturation of water.

$$SW_{\text{Indonesia}} = \left\{ \frac{\sqrt{\frac{1}{Rt}}}{\left(\frac{Vsh^{(1-0.5Vsh)}}{\sqrt{Rsh}}\right) + \sqrt{\frac{\phi_e^m}{a.Rw}}} \right\}^{(2/n)}$$

Where,

SWI = Saturation off water by Indonesia equation.

Rt = Resistivity of log

Rw = Resistivity of water

Vsh = Volume of Shale

5.6. Petrophysical Analysis of Fateh-01 Well

Complete log suits are available for Fateh-01. Fateh-01 is drilled at the depth of 3000 m, the last formation that is encounter is Lower Goru Formation. The formation tops of Fateh-01 are show in table 5.1. The complete log data is only available till Basal Sands, so petrophysical analysis is only done on Basal Sands in Fateh-01 well, the petrophysical interpretation interval lies between 2650 m to 2950 m.

Table 5- 1 Borehole Stratigraphy of Fateh-01 Well

Formation	**Formation Top (m)**
ALLUVIUM	0
KIRTHAR	654
LAKI	885
SUI MAIN LIMESTONE	1085
UPPER RANIKOT	1196
LOWER RANIKOT	1365
UPPER GORU	1810
LOWER GORU	2083

In Fateh-01 well only Basal Sand is marked as shown in figure 5.3. The overall log data is not reliable because the caliper log is not stable, in all over the Basal Sand, so the condition of borehole is bad, and caving is encounter in well. So due to caving reading of density and neutron log is also not reliable. The petrophysical analysis of log is show in the figure 5.3 , and the table 5.2 show the result of zone that is encounter in Basal Sands.

Table5- 2 Result of reservoir zones marked on Basal Sands based on Fateh-01 well

Thickness(m)	Vshl(%)	PHIA(%)	PHIE (%)	Swl (%)	Sh (%)
15	28	11	6	55	45

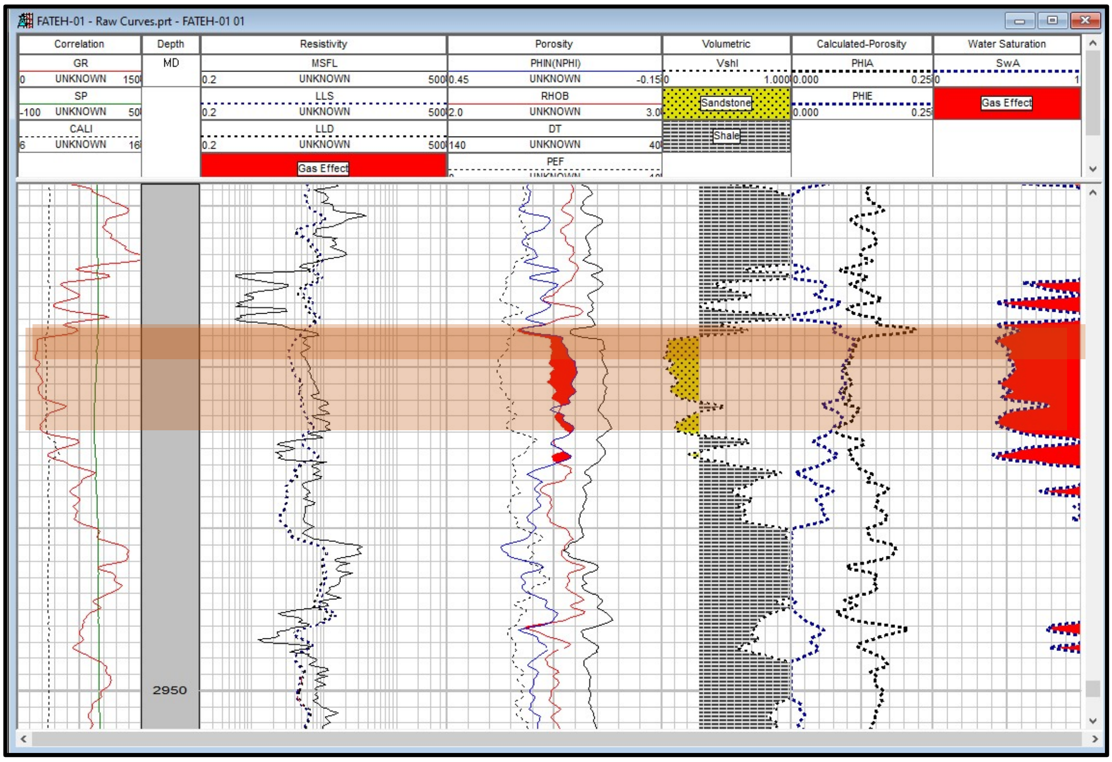

Figure 5.3 Petrophysical analysis of Fateh-01 well on Basal Sands with marked reservoir zone

CHAPTER 6

SEISMIC INVERSION

6.1. Introduction

Seismic inversion is a subsurface geological modelling approach that employs seismic data as an input and a well log as a control (Veeken, P.C.H., and Da Silva, M., 2004).This is performed by converting the amplitude data into acoustic impedance foam.

Forward modelling and inverse modelling are the two basic types of geophysical modelling. Inverse modelling predicts an earth model from a geophysical respond, whereas forward modelling predicts is geophysical respond from the model of earth (Mallick, S., 1995).

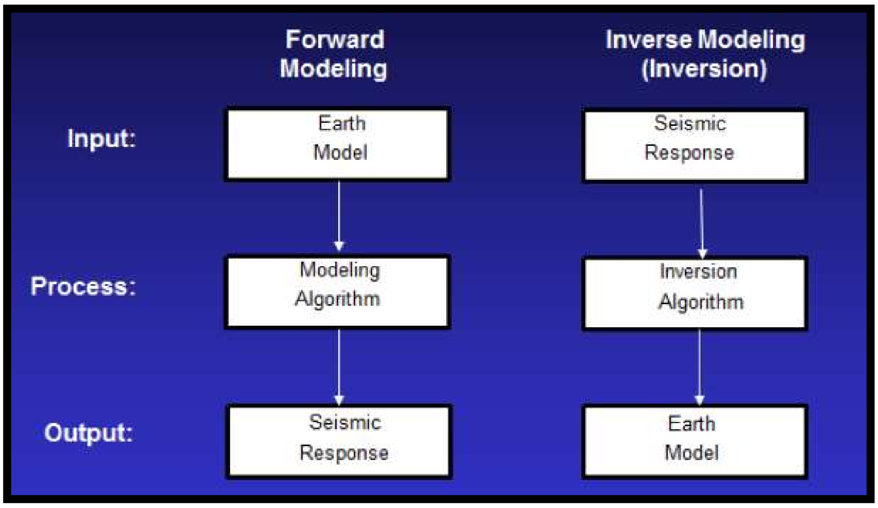

Figure 6.1 Forward and Reverse modelling process (Russel,1999.)

The use of the seismic inversion method aids in the conversion of information about the earth's reflectivity over time into impedance data. The entire procedure appears to be simple, but it is not. The method employs seismic measurements, which are captured from the earth's surface via sound pulses, which then reflect from the layers in the subsurface, revealing the layer's composition. The transmission of pulses causes severe distortion throughout the direction of passage, resulting in very low-quality data. The use of seismic equipment has the advantage of being able to cover a huge area, and the process of digging in offer logs holes provides excellent money against these types of operations. Multiple interactive surveys based on 3D are now retrieved from various seismic reversals and are regarded a significant tool for processing. (Ronghe et al., 2000).

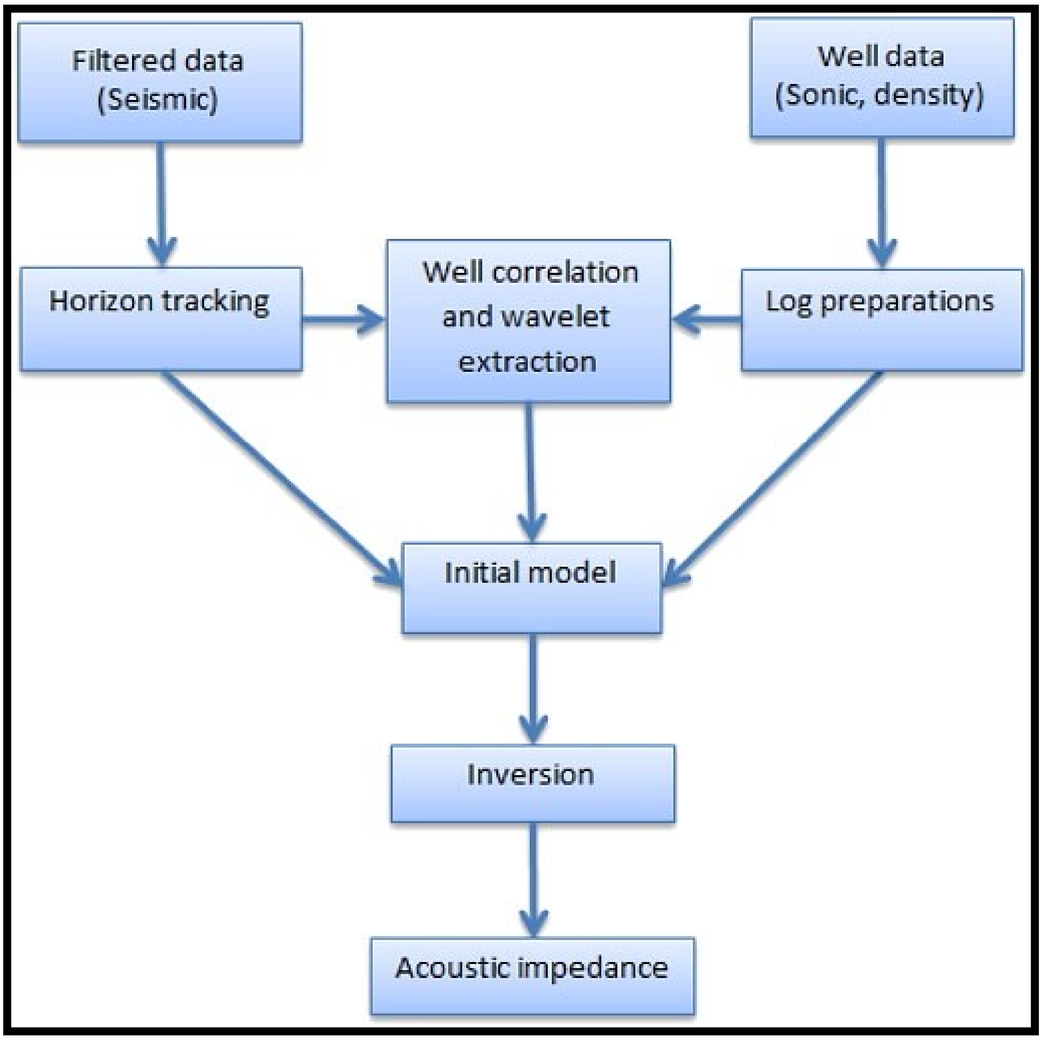

Figure 6.2 Generalized workflow of seismic inversion

We deal with two kinds of seismic data in the seismic inversion method: pre-stack seismic and post-stack seismic data. Because seismic amplitude is only characterized by R(0), post-stack seismic data produces only P impedance, whereas pre-stack seismic data produces both P and S acoustic impedance and its derivatives such as Vp/Vs, Lamda-rho, Mu-rho to estimate fluid and lithology parameters from the subsurface. Seismic inversion is based on a 1-D convolution model, in which seismic traces are a convolution of earth reflectivity and wavelet with noise (Barclay., F. 2008). However, only post-stack inversion is discussed in this research.

6.2. Purpose of seismic inversion

Seismic inversion's main goal is to change seismic reflection information into a quantifiable property of rock that illustrates the reservoir. Acoustic impedance logs are generated for each CMP in their most basic form, which simply implies that if we had drilled and logged wells at the CMPs, what would the impedance logs have looked like? Inversion results demonstrate higher resolution and support more accurate interpretations as compared to dealing with seismic amplitudes. As a result, reservoir parameters like porosity and net pay can be better estimated. Another advantage is that interpretation efficiency is substantially increased, which more than compensates for the time wasted in the inversion process. (Veeken et al., 2004).

6.3. Post Stack Inversion

Stacked Seismic data is given as input for post stack inversion. Stacking reduces the noise effect from the signal by keeping true amplitude preserved (Da Silva et al., 2004). Traces from common-mid-point (CMP) are picked and stacked at zero incidence angle. Resulting seismogram represent reflectivity at normal incidence. So, inversion performed on such seismic data is called post-stack seismic inversion. Seismic post stack inversion is robust technique with its simpler assumptions. It has two approaches band limited and broad band inversion methods respectively (Karim et al., 2016).

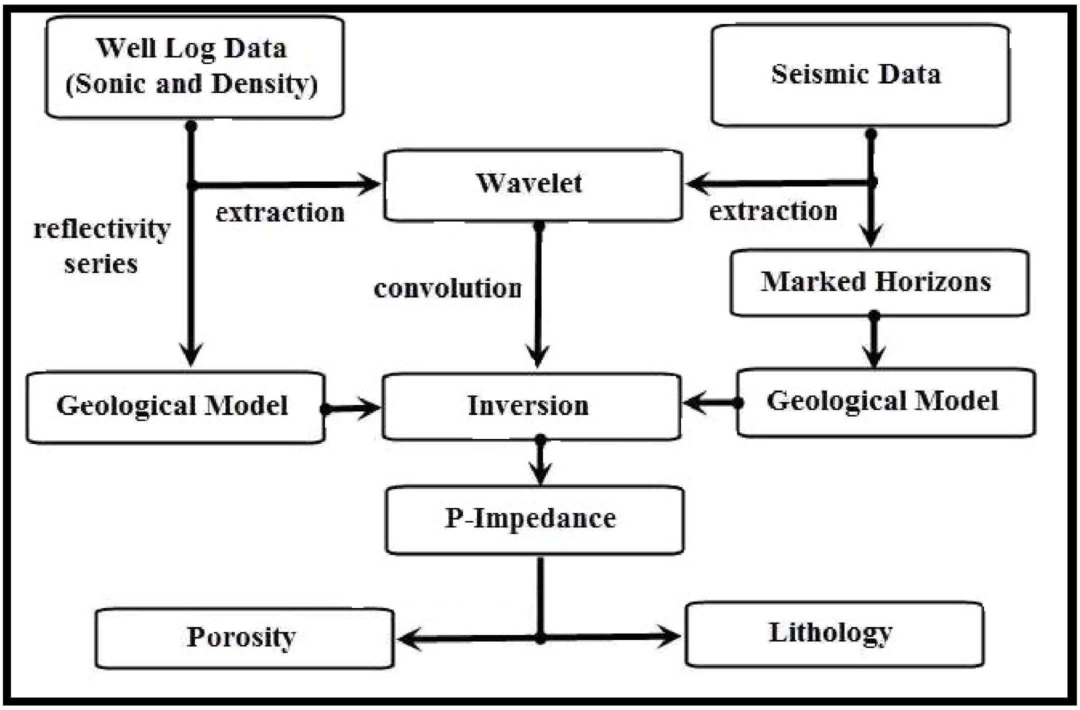

Figure 6.3 Generalized Post stack Inversion process

6.4. Advantages of seismic inversion

Seismic inversion advantages include:

1. Compensation for and decrease of the effects of wavelet tuning
2. Demonstration of output as geologic layers rather than reflection edges,
3. Merging of known low frequency geologic and geophysical information with seismic data, modelling and inclusion of layer stratigraphy,
4. Inclusion of geophysical constraints from known information or analogues,
5. Calibration to well log data, improved interpretability of seismic horizons, and increased ban are all advantages of seismic inversion. (Veeken, 2004).

6.5. Model Based Inversion

Foundation of Model Based inversion is convolution theory. The convolution theory states that normal Incidence seismic trace can be modeled as convolution of source wavelet with earth reflectivity plus addition of noise (Mallick, 1995).

Model based inversion starts with initial geological model and perturbs this model until a good correlation between synthetic seismogram and seismic trace is obtained. It is appealing method because it cannot directly invert seismic data (Francis., A, 2014).

Model based inversion is affective for thin reservoir because seismic data is band limited, the resolution and accuracy of direct inversion methods cannot fulfill the requirement of exploration industry (Russell, B.H., 1988). Model based inversion contains both high frequency and low frequency components so detailed information about stratigraphic and physical properties is obtained.

$$J = \text{weight}_a \times (S\text{-}W * R) + \text{weight}_b \times (M\text{-}H * R) \quad (6.1)$$

In the equation mentioned, seismic trace mentioned by S, W for wavelet extracted form seismic data, reflectivity series by R data, initial created model denoted by M and H integration operator. As it is obvious that in the initial part of equation is modeled with seismic trace and other part modeled the initial model estimated (Russell, B.H., 1988). In above equation first part modeled the seismic trace and second part modeled the initially estimated impedance.

6.6. Methodology for Model Based Inversion

Inversion techniques consist of following steps shown in flow chart given below. Hampson and Russell Software version 10 is used to perform the model-based algorithm of post stack inversion. Following steps are taken place for inversion.

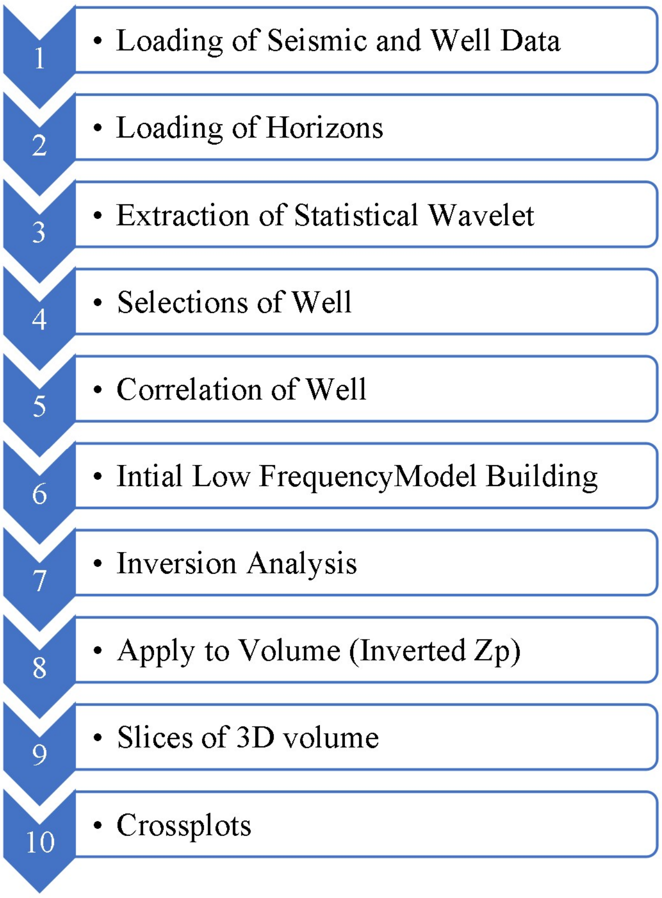

Figure 6.4 Workflow adopted for Model Based Inversion

6.6.1. Loading of Seismic and Well Data

First step in post stack inversion is loading of seismic and well data in Hampson & Russell Software. The seismic data of Bitrism block is loaded in the software along with interpretated well data in LAS format is loading in software. After loading the data, the location of Wells is matched with seismic data to confirm the exact location of well in the seismic cube.

6.6.2. Loading of Horizons

Next step is loading of horizon in seismic section. The interpreted horizon is export from Kingdom software in time amplitude format. Then this horizon is importing in software. The reflector of Basal Sands along with location of Fateh-01 well is loaded on Hampson & Russell Software

6.6.3. Extraction of Statistical Wavelet

Estimation of seismic wavelet from seismic data or the source used is highly important, and it is necessary to be very accurate for various inversion approaches, such as generating the synthetic trace by convolution of wavelet with the reflectivity series. (Jain, C., 2013).

Wavelet change with time and depth because of many subsurface effects, making it more sophisticated (Barclay., 2008). Figure 6.5 shown statistical wavelet that is use in inversion was extracted from a time window spanning 1000-3000ms, with a wavelength of 200ms and a tapper length of 25ms.

In seismic interpretation and inversion methods, wave phase is critical; for best results, wave phase should be zero. The phase shift in the input has a significant impact on the inversion outcomes. The average phase of the statistical wavelet extracted is shown as a dotted line in the figure 6.5 . If the phase shifter is more than the error, the resultant impedance will be higher. (Jain, 2013).

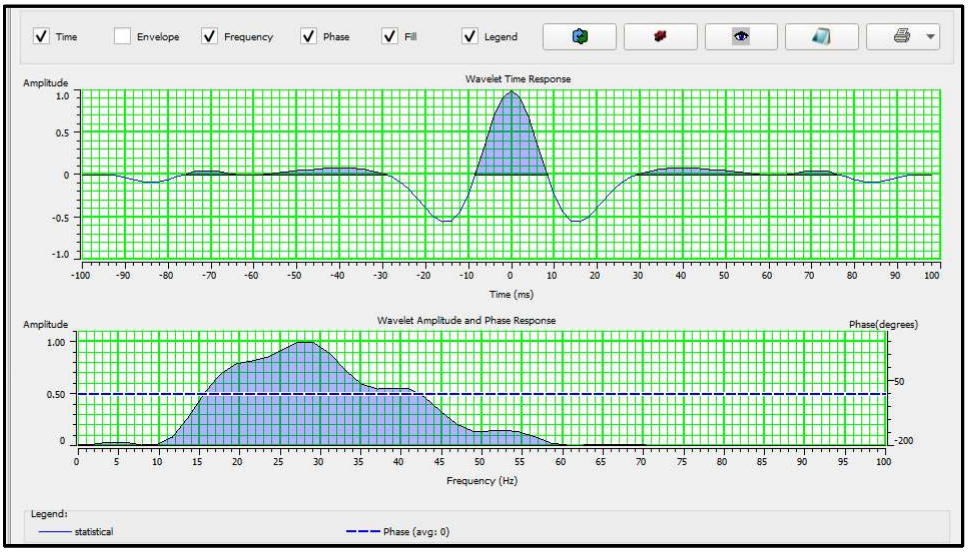

Figure 6.5 Extraction of Statistical wavelet

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6.6.4. Selection of Well

Fateh-01 well is used for correlation of well and seismic data with the synthetic traces which is generated with extracted wavelet.

6.6.5. Correlation of Well

The correlation is very important for seismic interpretation because it provides the tie between the well and seismic data. The maximum coefficient for correlation of Fateh-01 shown in figure 6.6, is comes out to be approximately 90.7% and this coefficient is related to seismic.

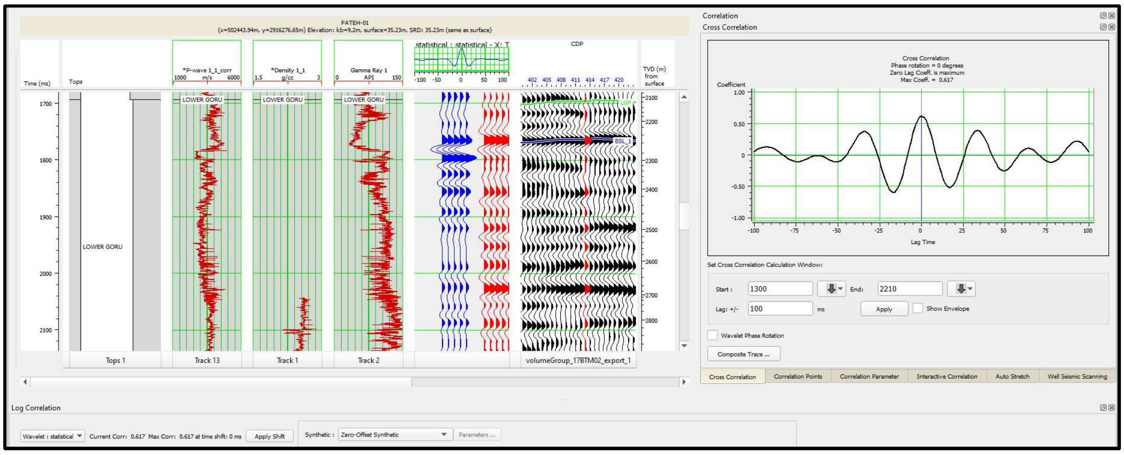

Figure 6.6 Correlation of seismic data with Fateh-01 well

6.6.6. Initial Low Frequency Model

Acoustic impedance is used to estimate the initial model of low frequency, as acoustic impedance can be separated into two types: Relative Acoustic Impedance and Absolute Acoustic Impedance. The computation of relative acoustic impedance does not require the creation of a low frequency model. It is beneficial for qualitative interpretation of seismic sections because of the relative qualities of strata. (Lee, K. et al., 2013).

Because absolute acoustic impedance is an absolute property of strata, it is employed for both quantitative and qualitative interpretation of seismic data (Chopra, S., & Marfurt, K. 2005). For inverting the given seismic amplitude data, an initial lower frequency model (about 0–15Hz) was necessary. Adding the required lower frequency model to inversion methods ensures that the results are more significant in interpretation. (Lee, K. et al., 2013).

In the inversion algorithm of Model-based inversion it is a requirement to add an initial low frequency model. Initial obtained low frequency model is generated by using density and sonic log in vicinity of well. Figures 6.7 show estimated initial model of low frequency with well Fateh-01.

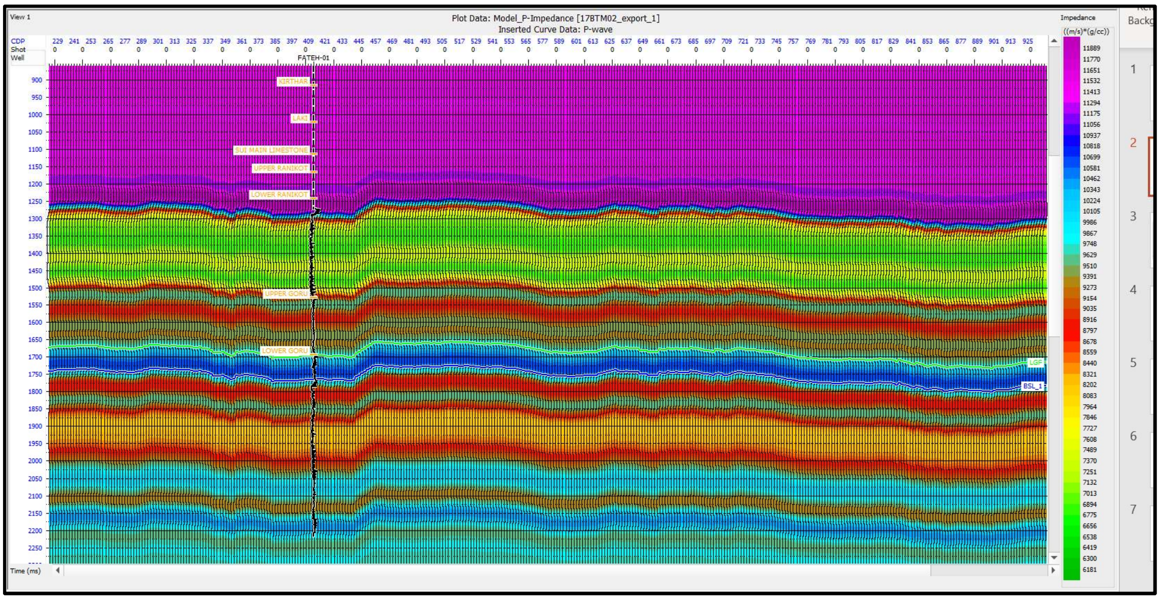

Figure 6.7 Low frequency model with well Fateh-01

6.6.7. Inversion Analysis

The provided seismic data was analyzed for model base inversion at the well site, Fateh-01. The wavelet extracted from the time window of 1000 to 3000ms. Wavelet extracted seismically, was adjusted by the comparison of synthetic trace and inverted trace at the well location. From the figure 6.8 shown, correlation between seismic. Black color show traces and red color show synthetic traces, Fateh-01 well is having good correlation coefficients of 90.7% with the root means square error between the seismic trace and synthetic is 0.234. The high percentage of correlation will be led to generation of good impedance model.

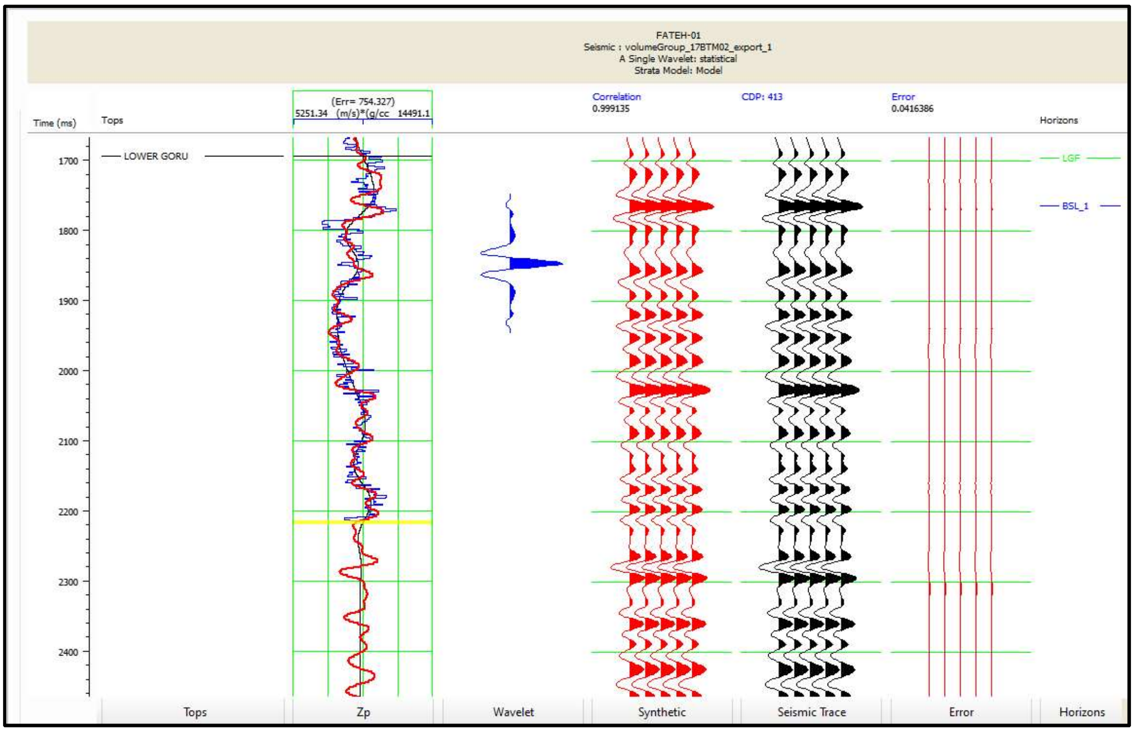

Figure 6.8 Model based inversion analysis of Fateh-01 Well

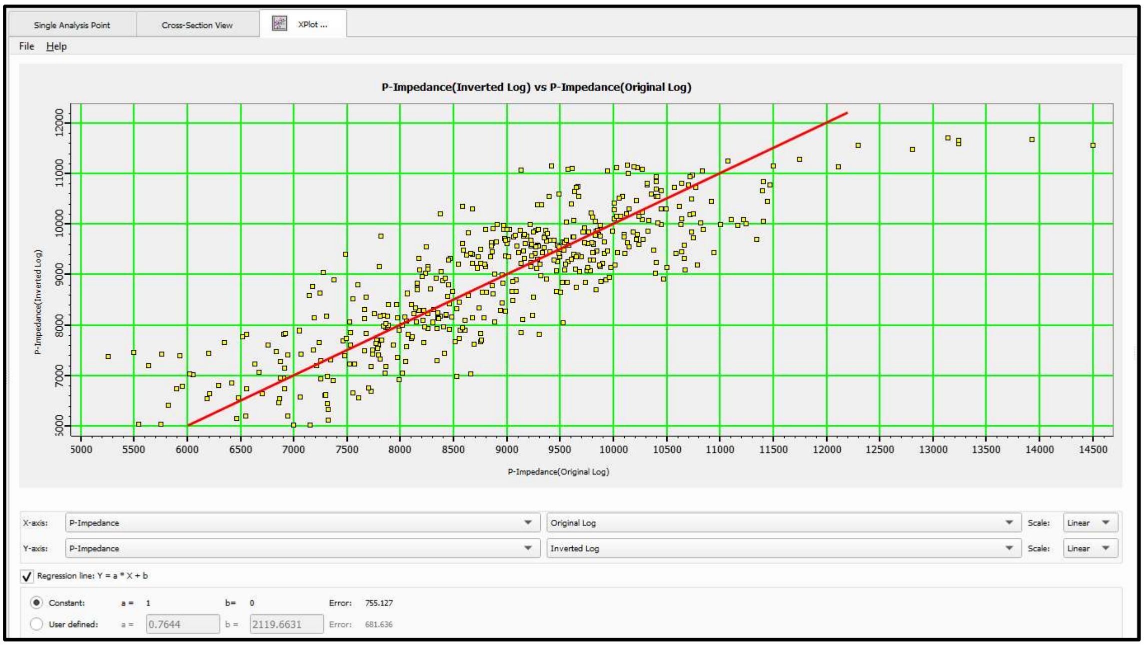

Figure 6.8 P-Impedance Correlation of Fateh-01 Well

6.6.8. Apply to Seismic Data (Model Based Inversion Result)

The wavelet that is extracted, for the model-based inversion, of zero phase is showed in figure 6.5. Moreover, coefficient shown in figures 6.8 between well log impedance and seismically derived acoustic impedance for Fateh-01 well. From the analysis of model-based inversion it can be observed that seismically derived inverted impedance better match and picks the trend of well log impedance furthermore, it is concluded that the coefficient of correlation between derived synthetic (black) and seismic trace(red) is almost 90.7% for Fateh-01 well and error found is 0.234. Model-based inversion is effective and very useful when we are interested in lateral as well as vertical variation in acoustic impedance applied inversion of model-based technique is shown in figure 6.9. As we are interested in Basal Sands of Lower Goru Formation, which is the major reservoir of Bitrism field are marked by very low impedance of 6181 & 11889 ((m/s)*(g/cc)), that can be observed with the impedance color bar. The low impedance observed at the main reservoir is clear indication of gas saturation in the

Basal Sands of Lower Goru Formation. The higher impedance indicates the top of Lower Goru Formation. Inverted colorful section of impedance shows that model-based inversion has very good lateral resolution along with picking the variation in impedance within reservoir.

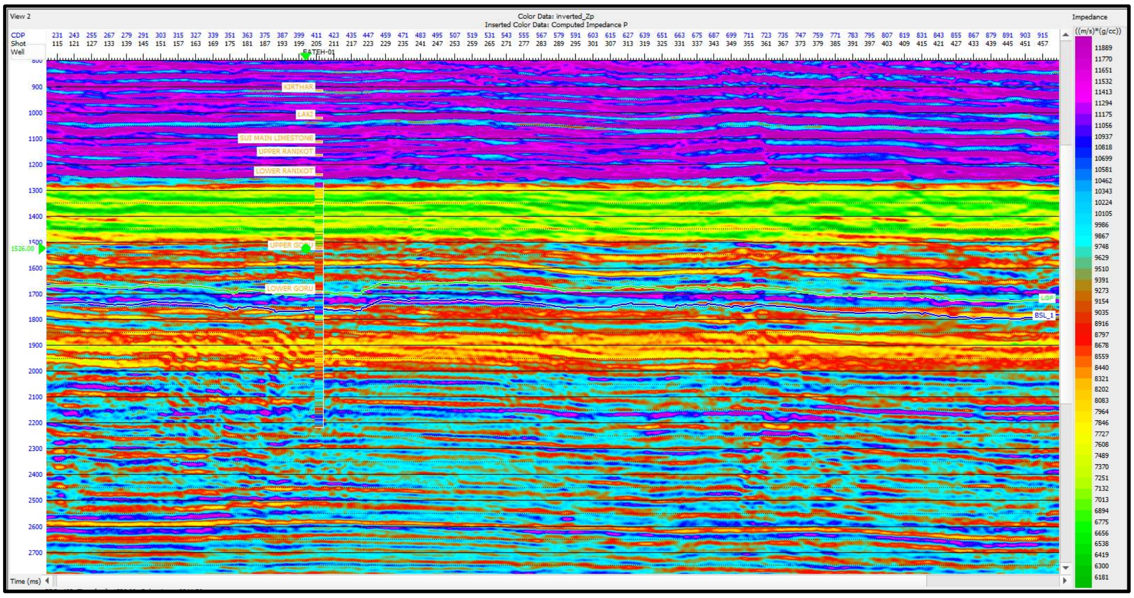

Figure 6.9 Final Computed impedance model showing with Fateh-01 Well

CHAPTER 7

ROCK PHYSICS MODELING

The task of extracting the maximum amount of hydrocarbon from a well is always difficult. One of the most common causes of well failure is rising water saturation. Seismic data can only tell you how likely it is that hydrocarbons are present in the structure. The fluid substitution, which is an important aspect of rock physics modelling, provides data on the fluid and quantity in the reservoir (Akhter et al., 2014; Kumar, 2006). The effects of various fluid saturation levels on seismic velocities and densities are examined in this research. For a successful well, the reservoir properties must be understood completely. So, up to the extent of available data, good quality seismic data aids in understanding such features. For the exploration of hydrocarbon, it is important to characterize reservoir in term of fluid and lithology. LMR (Lambda-Mu-Rho) cross plot are generated for inversion feasibility and to discriminate fluid and lithology within reservoir. Reservoir properties and its fluid heterogeneities are not sufficiently observed by only seismic data but with integrated well log data. Reservoir properties are estimated by petrophysical analysis. It shows Basal Sands has sufficient hydrocarbon bearing zone in study area. The data used in this study include seismic and well data of Fateh-01well that was provided by DGPC. These cross plots are generated using Hampson Russell Software (HRS). In exploration and petroleum industry application of seismic inversion techniques have become effective tool for the detection of hydrocarbon and detailed reservoir characterization, Seismic data carry information about interface and applied inversion transforms this property into layer property which can directly correlate with well log data, in this way inversion help for enhanced characterization of reservoir (Ming Li, 2014). Feasibility analysis is carried out, to predict the sensitivity of reservoir rock properties, to determine the best inversion algorithm applied for the characterization of reservoir.

7.1 Significance of LMR Cross Plotting

1. For Pre stacked and Post stacked Seismic inversion feasibility.

2. Lambda-Rho inversion slices better server for delineating gas sands and to validate seismic attributes response of sand bodies.

3. Lambda-Rho and Mu-Rho is effective as lithology and fluid discriminator.

4. To map hydrocarbon bearing sands.

5. To check the well logs data quality condition.

7.2 Cross Plot Analysis

Cross plots are well log attribute, in which two or more variables that are visually represented. In order to identify or discriminate anomalies that could be interpreted as indication of lithology and occurrence of hydrocarbon or other fluids. Well log attributes are used to determine rock properties accompanied with better identification of fluids and lithology within reservoir (Omudu et al, 2007). Figure 7.1 shows the workflow adopted for cross plotting LMR parameters. These attributes usually include shear wave velocity log but if it is not present, it is recommended to establish an equation developed from regression analysis from surrounding well. As Vp and Vs are both present in Fateh-01 well of same field, to establish a relation by making cross plot of P-wave and S-wave, the regression analysis is done for estimating shear wave for other well in which shear wave log is absent. So, an equation is developed for this study as given in equation 7.1.

$$Vs = -0.996091153 + 0.835122793 * Vp$$

7.3 Cross Plot Mu-Rho against Lambda-Rho

Cross plot of lambda-rho and mu-rho is robust tool for the lithology identification and to observe fluid presence. Lambda-rho and mu-rho are cross plotted with color coded density. Cross plot is generated in the depth ranges of Basal Sands. Low values of lambdarho ($\lambda\rho$) associated with moderate to high values of mu-rho ($\mu\rho$) indicate the presence of hydrocarbon within the sand reservoirs. Cross plot show separation where the gas zone is present, showing lowest possible values of density. As it can be visualized lambda-rho is more robust for analysis of fluid and the values of mu-rho for reservoir lithology. Cross plot response of mu-rho against lambda-rho shown in figure 7.4

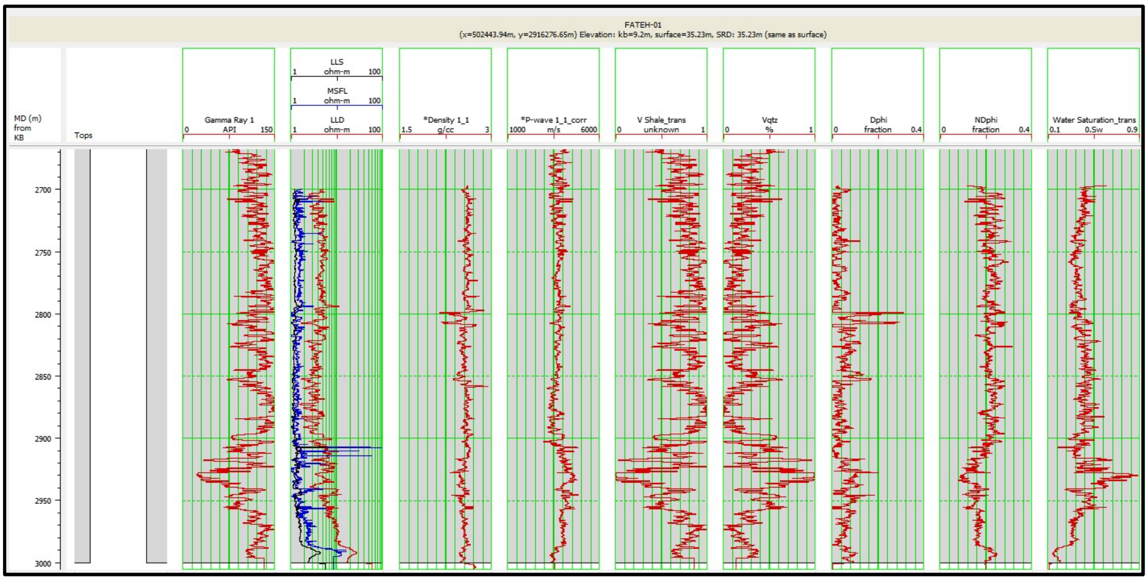

Figure 7.1 Figure showing the curves with the calculated rock physics parameters

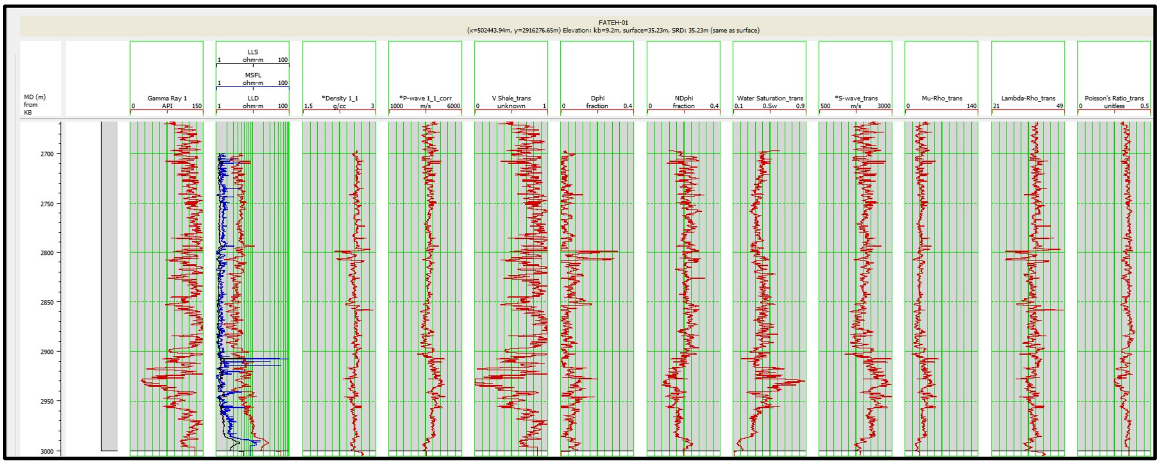

Figure 7.2 Figure showing the curves with the calculated rock physics parameters

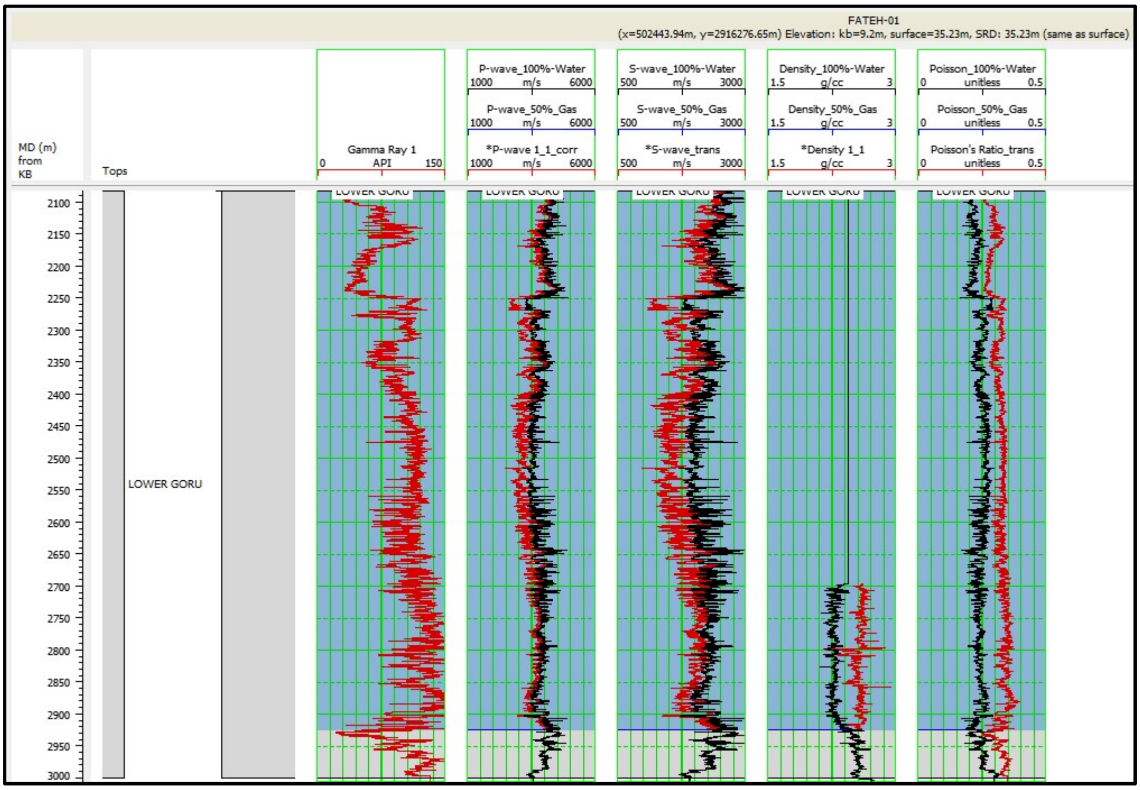

Figure 7.3 Figure showing the curves with the calculated rock physics parameters

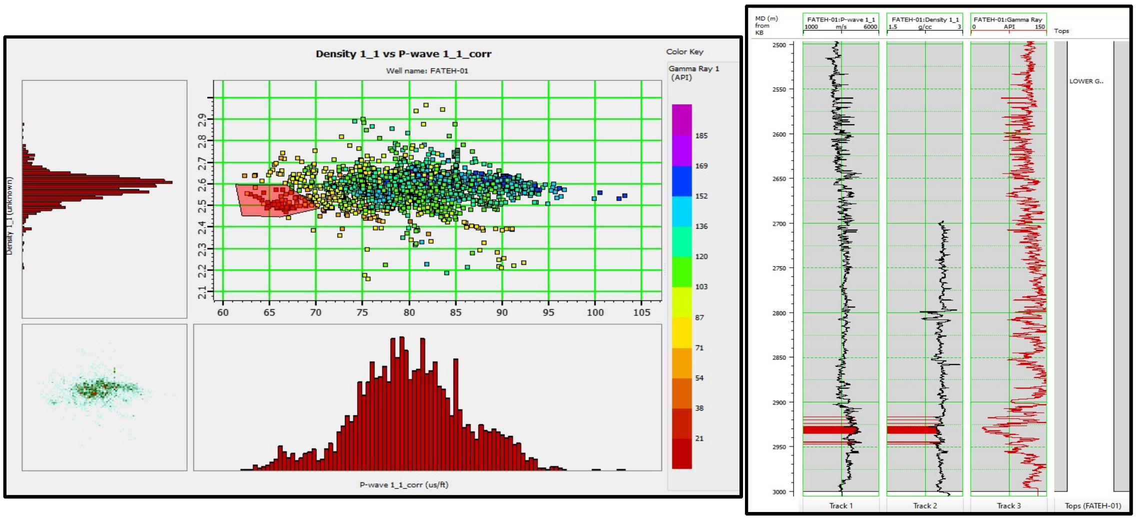

Figure 7.4 Figure showing the cross plot between P-wave velocity and density. The low values of density showing gas bearing sands

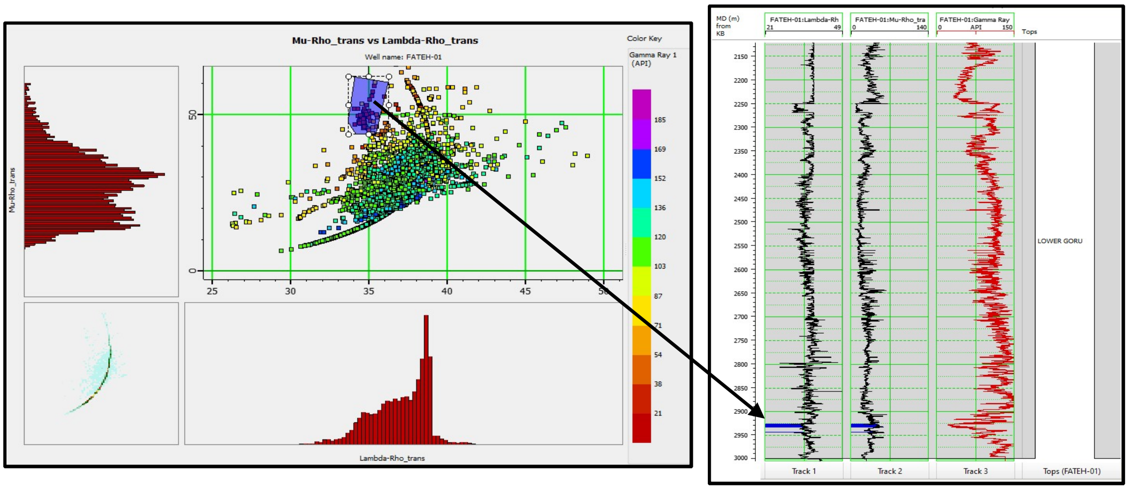

Figure 7.5 Figure showing the cross plot between Mu-rho and Lamda-rho. The high values of Mu-rho and low values of Lamda-rho showing gas bearing sands

To characterize Basal sands reservoir in term of fluid and lithology, LMR cross plots are generated. From the cross plots analysis, P-impedance, Lambda-rho, and Mu-rho attributes were found to be most robust in lithology and fluid discrimination within the reservoir. The LMR technique was able to identify gas sands, because of the separation in responses of both λρ and μρ sections to gas sands versus shale.

CONCLUSIONS

Following are the conclusions drawn from research work which include seismic interpretation, Petrophysical analysis, seismic inversion and Rock Physics modelling of Basal Sands

1. Basal Sands has been marked on the seismic data. Interpretation identified a normal faulting zone and present of horst and graben structures in the subsurface

2. The petrophysical analysis of Fateh-01 well calculated the reservoir properties of the well and proved that Basal Sands of Late Cretaceous age is the main reservoir with respect to hydrocarbon potential.

3. The model-based inversion applied the seismic data along with the Fateh-01 well logs demonstrated the change in the variation of acoustic impedance in the overall structure

4. The inverted impedance volume was used for rock physics model, which help to identify the gas bearing zone of Basal sands

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