2D SEISMIC INTERPRETATION AND PETROPHYSICAL ANALYSIS OF ZAMZAMA BLOCK, LOWER INDUS BASIN, PAKISTAN

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A Thesis submitted to Bahria University Islamabad to fulfill a part of the criteria for a bachelor's degree in geophysics

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ABSTRACT

The study area's structural interpretation and petrophysical investigation utilized the seismic lines and well data of the Zamzama block. The seismic sections showed three separate reflectors. A reverse fault is identified within the dip lines based on the reflectors' trend. The structure has been described as a plunging anticline structure, with the principal reservoir in this region being the Upper Cretaceous Pab Sandstone. In the formation, with average water saturations of 18% is indicated.

ACKNOWLEDGEMENTS

We want to thank everyone who helped us have the courage to finish this study project. We would like to extend a particular thank you to Dr. Said Akbar, Head of the Department of Earth and Environmental Sciences at Bahria University, who gave this study work his valuable time and thoughtful review. We also want to thank Mr. Adil Naseer, Senior Lecturer in the Department of Earth and Environmental Sciences, who is our supervisor, for his direction, regulation, and support. Finally, we would like to express our sincere thanks to DGPC for utilizing seismic and well log data.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 01

INTRODUCTION

1.1. Introduction of the Area

Zamzama field is an important resource, which spreads over an area of about 120 square kilometers based on the gas reserves discovered in Pakistan. The Zamzama field adds nearly 15% to Pakistan's daily gas production, thereby minimizing the need for oil and gas imports.

Sindh is located in the south of Pakistan; it is also known as "Energy Basket" of Pakistan. The Zamzama gas field was discovered in the mid-1990s by BHP Billiton in Sindh province and represented its first commercial production in Pakistan. Several other gas fields include the Bhit gas field, which is located southwest of Zamzama and the Sawan, Kadanwari and Miano fields to the northeast.

Zamzama Gas Field in Zamzama Block is in Dadu District, Sindh (Figure 1.1). The research area is located at the bottom of the Kirthar of the Lower Indus Basin, which in addition to the ZGF has several oil and gas fields. The area is bounded by 26 ° 30'N to 27 ° N and 67 ° E to 67 ° 50'E and is located approximately 200 km north of Karachi and 10 km west of Dadu.

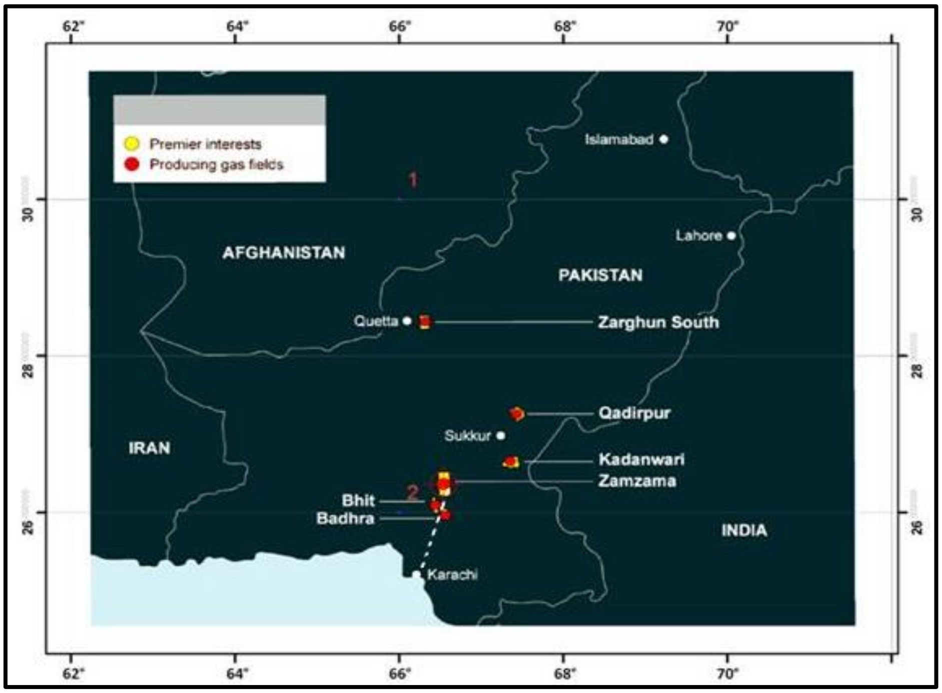

Figure 1.1 Locality of Zamzama gas field along with other fields (Courtesy: OMV, Pakistan).

1.2. Hydrocarbon Potential Of Zamzama Gas Field

Reserves of Zamzama gas field that was proved plus the probable recoverable reserves was proclaimed up to 1.7 trillion cubic feet of gas (gross) and from this total equity shares of BHP Billiton's are nearly 650Bcf.

The plateau production rate of Zamzama field would be nearly 320MMcf/d of gas along with 2,000 (STB/d) of condensates for the time of 10 to 12 years. It is expected, almost 15 to 25 years, economic life of this field.

Pab sandstone formation is the target reservoir in this field which is highly productive reservoir that exist at 3.500 meters depth. The gas explored from Zamzama is sweet and dry, with 6.5 barrels/MMcf, low condensate to gas ratio.

1.3. Objectives

Main objectives of the study are.

1. Identifying the faults associated with subsurface structures to examine the hydrocarbon zones through seismic interpretation.
2. Petrophysical analysis to identify the hydrocarbon bearing zones.

1.4. Data Used

The data was acquired from Directorate General of Petroleum Concession (DGPC). The main theme of this study is to know about the different steps that are carried in seismic inversion and rock physics modeling in order to compare the output obtained by the well logs and seismic data to get a structural representation of the area under study. In this practice, the following seismic and well data was used.

Table 1.1 Seismic data that is utilized in present study

i.	HPK89A-31 (Strike line)
ii.	HPK89A-32 (Dip line)
iii.	HPK89A-33 (Strike line)
iv.	HPK89A-34 (Dip line)
v.	HPK89A-36 (Dip line)

1.5. Methodology

The following steps are involved in methodology.

1. Seismic horizons are picked by tying and correlating the synthetic seismogram of study area with time.
2. Afterwards, time and depth girds are created to compute the time contour maps and depth contour maps are generated by using average velocity.
3. Then, time grids of horizons are converted into depth grid followed by depth contour maps.
4. Petrophysical analysis is carried out to quantify and to better characterize the reservoir. It is done by using various logs i.e., Shale volume (VSH), average-porosity (PHIT), density-porosity (PHID), effective-porosity (PHIE), hydrocarbon saturation (S_h) and water saturation (S_w).

CHAPTER 02

REGIONAL TECTONICS AND STRATIGRAPHIC FRAMEWORK

2.1. Tectonics Framework of The Area

Currently, the tectonic configuration of Pakistan (found in the north-western fringe of the Indian plate) is illustrated by the tertiary convergence between the two plates i.e., Indian and. Eurasian plates. The structures that range from north to south according to the structural position and decreasing age are the main central overlap (TCM), the Indo-Tsango (TS) suture and the main border overlap (Gansser,1981; Seeber et al,.1981). The collision zone originating from the north side of Pakistan is separated as Main Karakoram thrust (MKT), Main Mantle thrust (MMT), Main Boundary Thrust (MBT) and Thrust Salt Range (SRT) (Farah et al,.1984, Yeats and Lawrence, 1984).

According to Shah (2009) "The most significant among these strips is named as the axial belt**,** which divided the geosynclines and initiated the establishment of the two great basins of Pakistan. The belt developed marginal to the western part of the Indian shield and now to its east lies the Indus Basin and to its west the Balochistan Basin and to the north great tectonic zone of the Tectonostratigraphic Basins and Tectonostratigraphic Ranges**,** where each range or chain of mountains and associated depression indicate a unique tectonostratigraphic".

2.2. Generalized Description of Indus Basin

The basin area, of nearly 5,33,500 km^2, has sediments 15,000 m thicker that nearly ages from the Precambrian to the recent age. The oil and gas potential of Indus Basin lies in the inner folded areas of the Kirthar Ranges.

In addition, the Indus basin is parted into three divisions.

1. Upper Indus Basin
2. Central Indus Basin
3. Lower Indus Basin

In this research work, lower Indus basin will be focused as the study area is Zamzama block located in Kirthar fold belt.

2.2.1. Lower Indus Basin

Southern /lower Indus comprises of the following.

1. Thar Platform
2. Karachi trough
3. Kirthar foredeep
4. Kirthar foldbelt
5. Offshore Indus

2.2.1.1. Thar Platform

The subsoil topography controls the Thar platform and the Punjab platform that exist in the Central Indus basin. The sediment cover on the 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 (Kadri.,1995).

2.2.1.2. 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 (Kadri, 1995).

2.2.1.3. 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 (Kadri,.1995).

2.2.1.4. Kirthar Fold Belt

Tectonically trending north south, the Kirthar 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 (Kadri,.1995).

2.2.1.5. Offshore Indus

It is part of the passive continental margin. Sedimentation on the Indus coast occurred in two different phases of geological time, i.e. the Cretaceous-Eocene phase and the Oligocene-Recent phase.

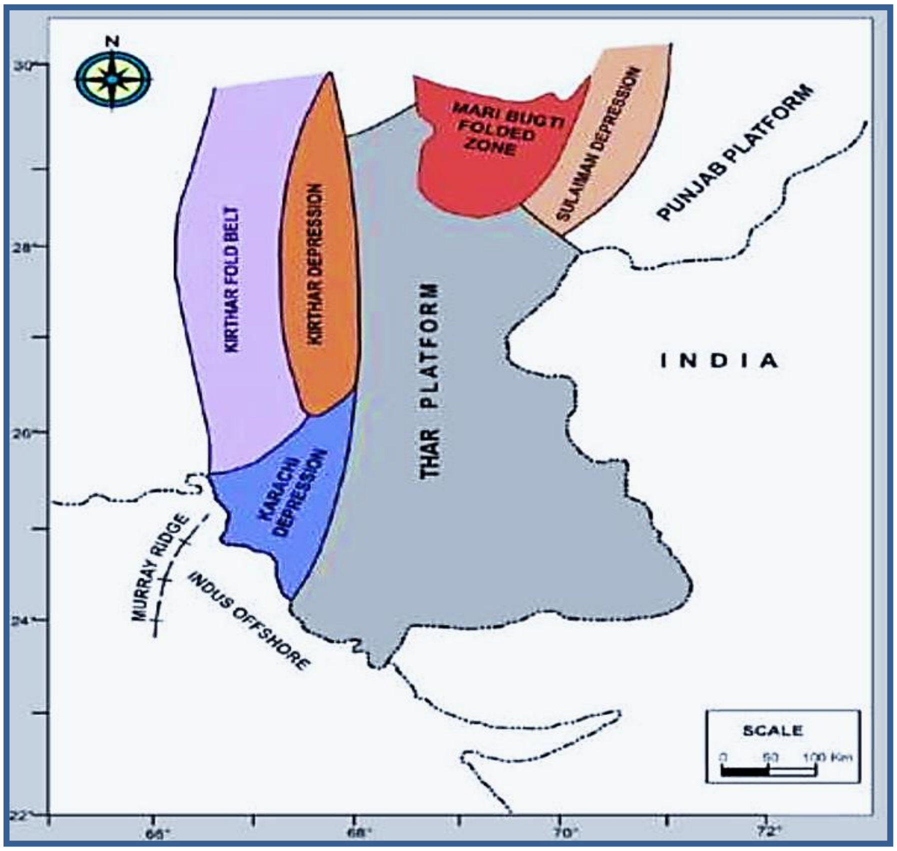

Figure 2.1 Main components of Southern Indus Basin (after Kadri, 1995)

2.3. Geological and Tectonic Setting Of Zamzama Area

Zamzama is basically a thrusted anticlinal structure, with a north-south orientation as given in figure 2.4. The Pab sandstone in the Kirthar Fold belt serves as the primary reservoir, along with Zamzama and neighboring gas Bhit field. Sandstone analysis bordering the Khadro formation shows a gas reservoir in the Zamzama area. The Khadro formation and Pab sandstone formation displays the uniform thickness across the Zamzama structure (Jackson et.al,2004).

The Khadro formation is 54 meters thick on average, while the Pab sandstone is about 300 meters thick. The Pab sandstone formation overlies the Fort Munro formation and forms conformable stratigraphic contact.

Girdo formation acts as a top seal for Pab sandstone and Khadro Formation containing marine shales. Khadro reservoir is a heterogenous formation with poor quality due to the presence of volcanic clasts (Wandrey et. al., 2004).

2.4. Generalized Stratigraphy of Zamzama

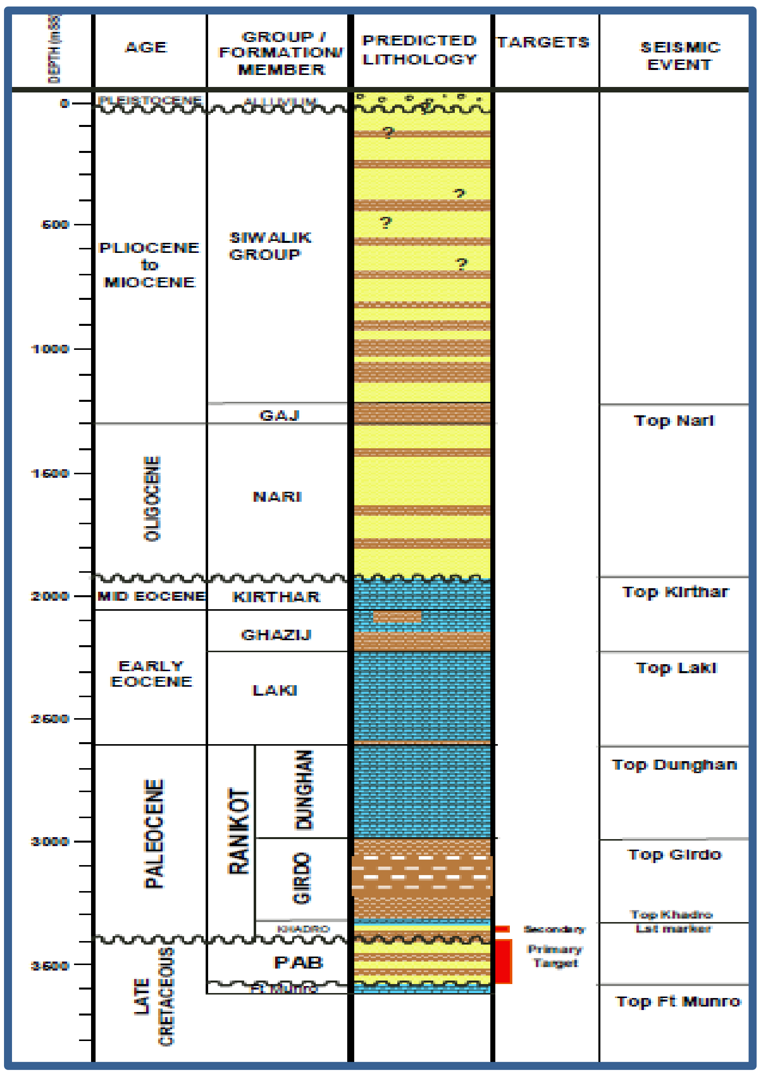

Figure 2.2 Stratigraphy of Zamzama area (Majid et al, 2016)

2.5. Petroleum Play of Zamzama Area

The factors that make up a hydrocarbon trap are source rock maturation, paths for hydrocarbon migration (secondary), reservoir capabilities and seal. Petroleum play is made up of all these elements.

2.5.1. Source Rock

The main source rock in Zamzama area is Sember shales, which were deposited on the broad shelf, while evidence fauna (Goru) indicates a pelagic habitat. The Sember is mostly type-III Kerogen, and the TOC (total organic content) values of Sember source rock in the Lower Indus Basin range from 0.5 to 3.5 percent, with an average of about 1.4 percent, indicating a considerable potential for gas production (Wandrey et. al, 2004).

2.5.2. Reservoir Rock

It is a necessary component in the formation of a complete petroleum play of an area. The Pab Sandstone from the late Cretaceous, is the primary reservoir for the Zamzama gas field having Fluvial-tidal depositional environments. It also includes a changeable deposited system, such as the sand-rich delta coastal plain system (Jackson et. al 2004).

2.5.3. Cap/Seal Rock

It's a type of rock that prevents fluid or hydrocarbon movement by acting as a barrier in its path. It usually acts as a barrier around and above the reservoir rock carrying hydrocarbons, trapping hydrocarbons and limiting their movement to reservoir rock. Mudstones and shale normally act as a seal or cap such as, the Lower Ranikot group, which has Paleocene-aged shales (Bara-Lakhra and Girdo formations) acting as a seal/cap in this petroleum play (Jackson et. al 2004).

2.5.4. Trap

Traps are an essential part; without it the hydrocarbon petroleum play would be incomplete. The movement of hydrocarbons is stifled and sealed by impervious rocks. The Zamzama structure, which is north-south trending, is a massive structure (thrusted anticline) that leans east, making it a big trap (Jackson et. al 2004).

2.5.5. 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 (Magoon., 1995).

Table 2.1 Petroleum play of study area.

Play elements	Formations	Age
Seal	Lower Ranikot	Paleocene
Reservoir	Pab Sandstone	Late Cretaceous
Source	Sembar Shales	Early Cretaceous

2.6. Borehole Stratigraphy

Table 2.2 Borehole stratigraphy of Zamzama-01 well

Formations	Formation Top (meters)	Thickness (meters)
SIWALIK	8	1269
GAJ	1277	103
NARI	1380	593
KIRTHAR	1973	150
GHAZIJ	2123	150
LAKI	2273	393
DUNGHAN	2666	396
BARA-LAKHRA	3062	338
KHADRO	3400	54.5
PAB SANDSTONE	3454.5	223.5
FORT MUNRO	3678	86
PARH FORMATION	3764	169

CHAPTER 03

SEISMIC INTERPRETATION

3.1. Introduction

Seismic interpretation is the process of studying and interpreting seismic data in order to understand underlying geological features and formations. Seismic interpretation is a challenging and unique skill that requires training as well as experience. Geologists, geophysicists, and other earth science specialists frequently participate in this process of investigation. The software tools and methodologies used might differ depending on the particular purposes of the interpretation and the available data (Sheriff,1999)

Seismic interpretation's primary purpose is to provide a visual depiction of subsurface characteristics such as rock layers, faults, folds, and other structural components. Seismic interpretation comprises numerous processes, including data collection, data processing to improve the quality of seismic pictures, and actual interpretation, in which geoscientists evaluate the data to develop geological maps and subsurface models. Seismic data visualization and interpretation can often be assisted by advanced software technologies. Overall, seismic interpretation is important in a variety of scientific and industrial applications that need knowledge of the Earth's subsurface structures and features (Dobrin and Savit, 1988).

Seismic interpretation's major goals are to extract useful geological and geophysical knowledge from seismic data in order to properly understand subsurface structures, characteristics, and prospective resources. The key goals of seismic interpretation involve structural analysis, stratigraphic analysis, reservoir characterization, fault and fracture analysis, hydrocarbon exploration, and geological mapping. Geologists, geophysicists, and other earth scientists use seismic interpretation as a key tool for discovering significant information about the subsurface. It supports a variety of applications, such as resource exploration and geological hazard assessment, and it advances the field of science and our knowledge of the complicated geological processes which define the Earth (Dobrin and Savit, 1988).

The interpretation of a seismic section can be divided into two approaches: stratigraphy analysis and structure analysis.

3.1.1. Stratigraphical interpretation

Stratigraphic interpretation is the process of investigating and understanding the sequence, associations, and features among different rock layers (strata) within the Earth's crust. In order to properly understand the geological history of a region and the processes that over time defined its stratigraphy, this interpretation involves looking at the vertical and lateral arrangements of sedimentary, igneous, and metamorphic rock units. Understanding Earth's history, evolution, and the processes that have shaped its surface requires stratigraphic interpretation. The change in wave shape, amplitude, velocity, or frequency can all be used to detect hydrocarbon accumulation. Another crucial hydrocarbon indicator is amplitude variation with offset. Drainage patterns that contribute to the development of the depositional environment serve to identify unconformities. Examples of stratigraphy traps include reefs, lenses, and unconformities (Sheriff, 1999)

3.1.2. Structural interpretation

Structural interpretation is the process of investigating geological features and structures within the Earth's crust using several kinds of geological data, including seismic data, well logs, outcrop observations, and geological maps. Understanding the spatial arrangement, geometry, and deformation history of rock layers, faults, folds, fractures, and other subsurface structures is the main objective of structural interpretation. The structure that measures up to a few hundreds of kilometers can be predicted by seismic section. To interpret data on a large scale, seismic line grids must be used. Unmigrated sections present several kinds of challenges for structure interpretation, such as making synclines narrower and vice versa (Sheriff, 1999).

3.2. Base Map

The most important aspect of seismic interpretation is the basemap. The base map in seismic interpretation gives geophysicists the orientation of the seismic lines and the locations where seismic data was collected. It's just a map that shows the number of seismic dips and strike lines used in the seismic survey. The location of the concession and its limits, as well as wells, seismic survey locations, and other cultural data such as roads, buildings, and bridges, are normally included on a base map, along with geographic references such as latitude and longitude.

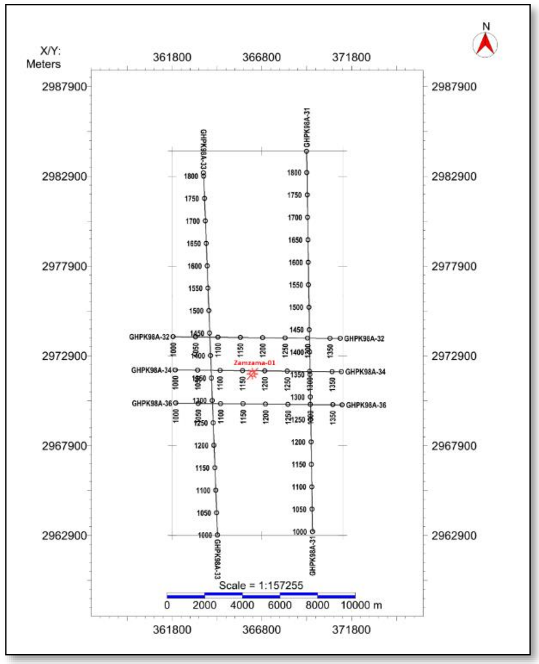

Figure 3.1 Demonstration of base map of the study area.

3.3. Time-Depth Chart

Time-Depth (T-D) chart is used for seismic to well tie. The horizons are marked on basis of formations top by calculating the formation depth.

Formation Depth = Formation tops + seismic reference datum – Kelly bushing.

Whereas: S.R.D = 0.0 m (MSL), K.B = 45.2m and formation tops are given below:

Formations	Depth (meters)
Dungan Formation	2666.2
Khadro Formation	3401.0
Pab-Sandstone	3453.5

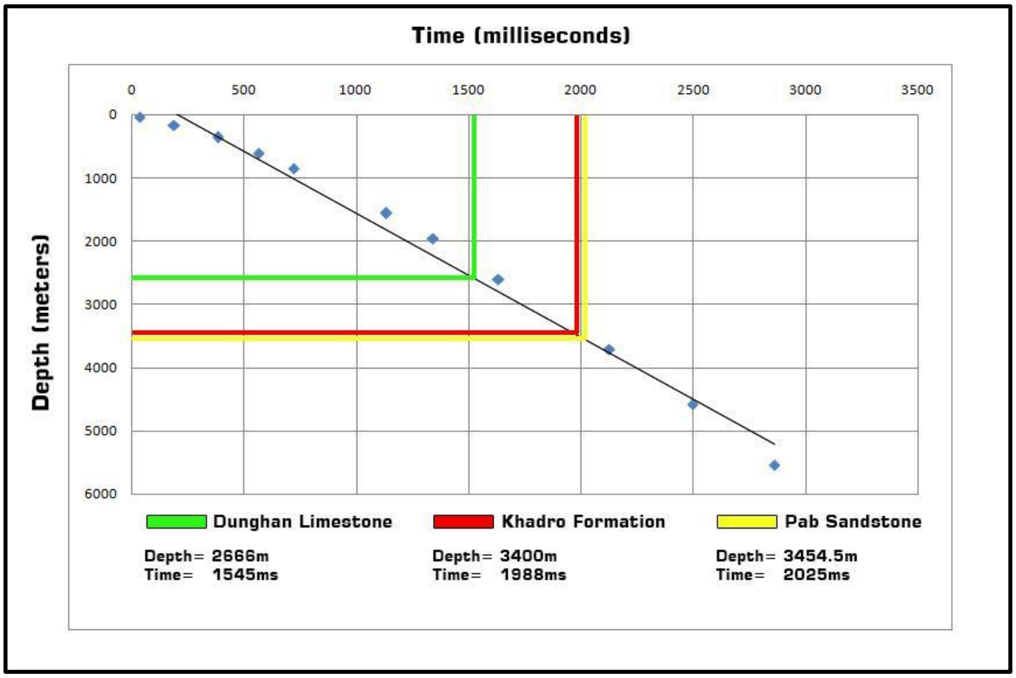

Figure 3.2 Time depth chart of the interested formations.

3.4. Fault Marking

The faults were marked in the seismic window by using kingdom software. These faults are typically picked on basis of any break in our reflector's continuity. The seismic record clearly shows the prominent faults.

3.5. Marking of horizons

The horizon where the best reflectors were selected is marked as the first step in the interpretation process. Reflectors are identified based on significant symmetry of reflections from the subsurface interface that can be observed on the seismic section. Dado area lines revealed three horizons. Dungan, Khadro and Pub shapes comprise the horizon. The depth of each reflector is obtained from the well data available to mark the horizon, and Vavg is then calculated by solving the seismic section velocity window. The time value for each reflector is then calculated using the formula T=S/V, and the resulting horizon is identified.

3.6. Velocity Analysis

The velocity over a specific reflecting surface below the seismic reference datum is the simplest definition of the average velocity (Dobrin, 1976).

Where,

$$V=Z/T$$

Z is the distance from the source to the reflecting surface, and t is the transit time in one direction from the reference to the reflector.

3.7. Interpreted Seismic Section

All of the traces that were recorded on a single line are combined to form a seismic section. The term "horizons" refers to a collection of wiggles that extend laterally. The main goal here is to pick the horizon.

Three horizons, the Dungan Formation, Khadro Formation, and Pab Sandstone, were used to identify the seismic sections. On the seismic section, a fault with the designation F1 was also identified. A massive north-south directed and eastward trending thrusted anticline known as the Zamzama thrust fault was created by the fault, which is a reversal fault in which the hanging wall slides up along the fault plane under the influence of eastward oriented force.

3.8. Interpreted Seismic Sections

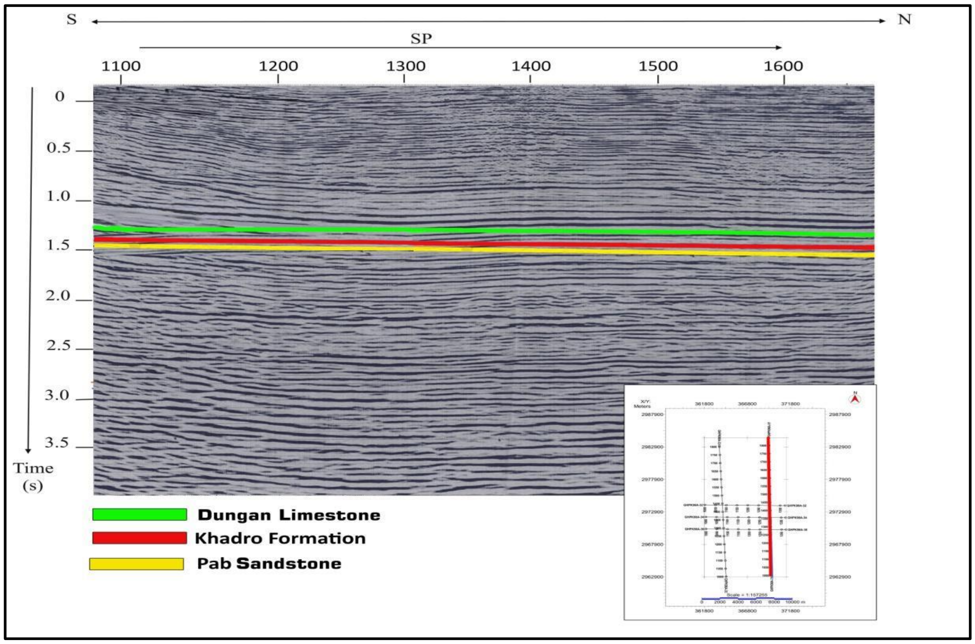

Figure 3.3 Interpreted strike line HPK 98A-31 with orientation north to south and marked horizon of Dungun, Khadro, and Pab Sandstone shown in green, red and yellow color respectively

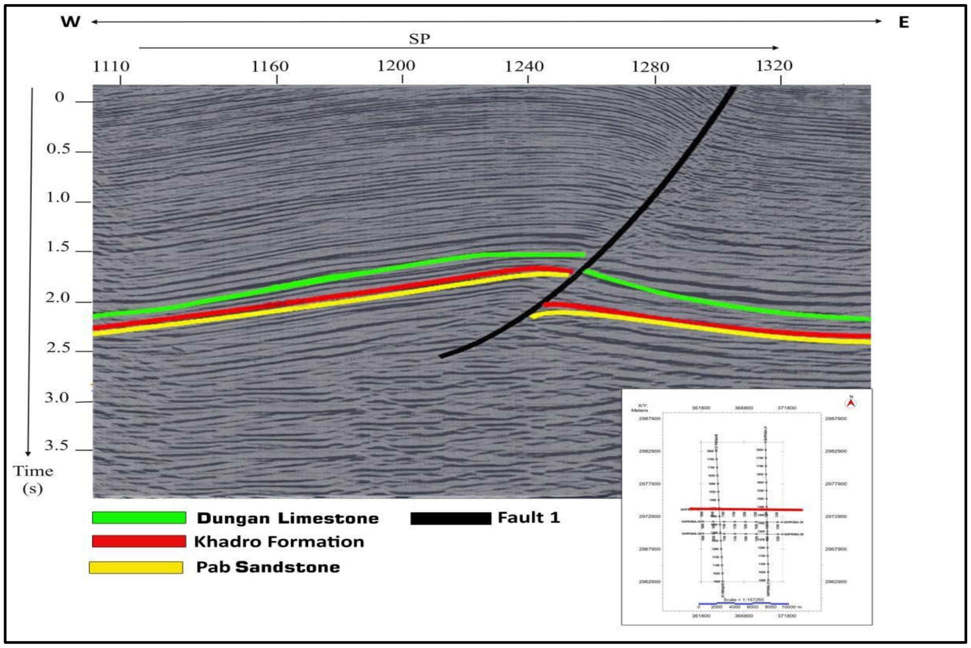

Figure 3.4 Interpreted dip line HPK 98A-32 with orientation north to south and marked horizon of Dungun, Khadro, and Pab Sandstone shown in green, red and yellow color respectively.

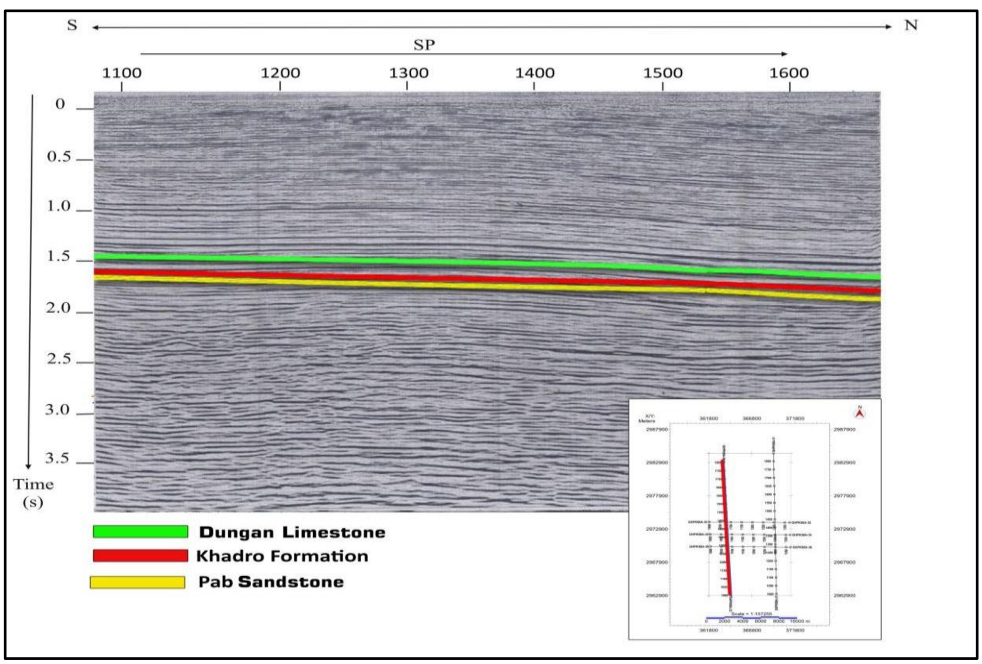

Figure 3.5 Interpreted dip line HPK 98A-33 with orientation north to south and marked horizon of Dungun, Khadro, and Pab Sandstone shown in green, red and yellow color respectively

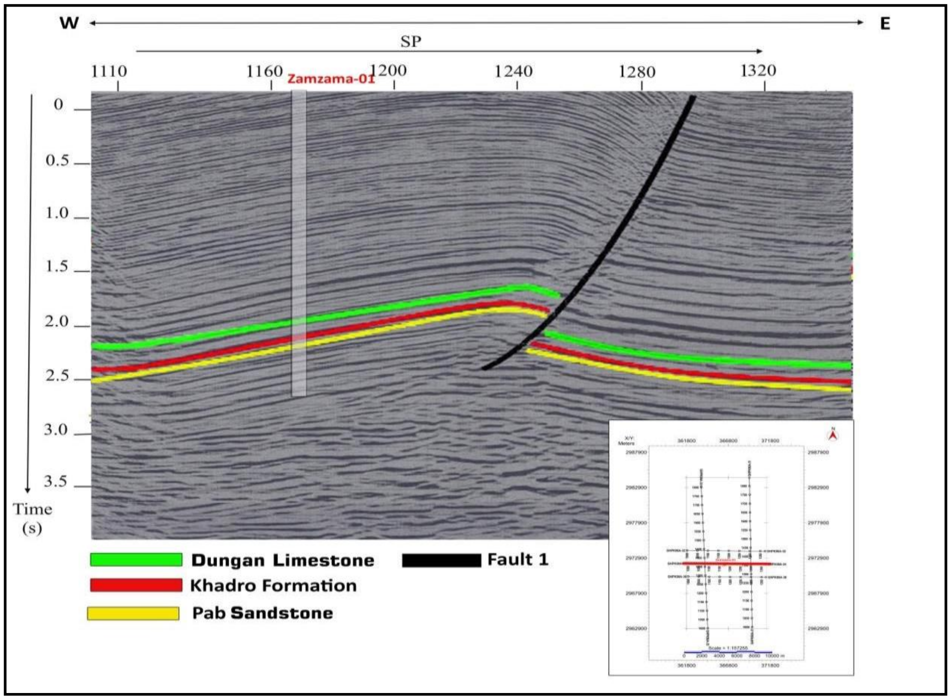

Figure 3.6 Interpreted dip line HPK 98A-34 with orientation north to south and marked horizon of Dungun, Khadro, and Pab Sandstone shown in green, red and yellow color respectively.

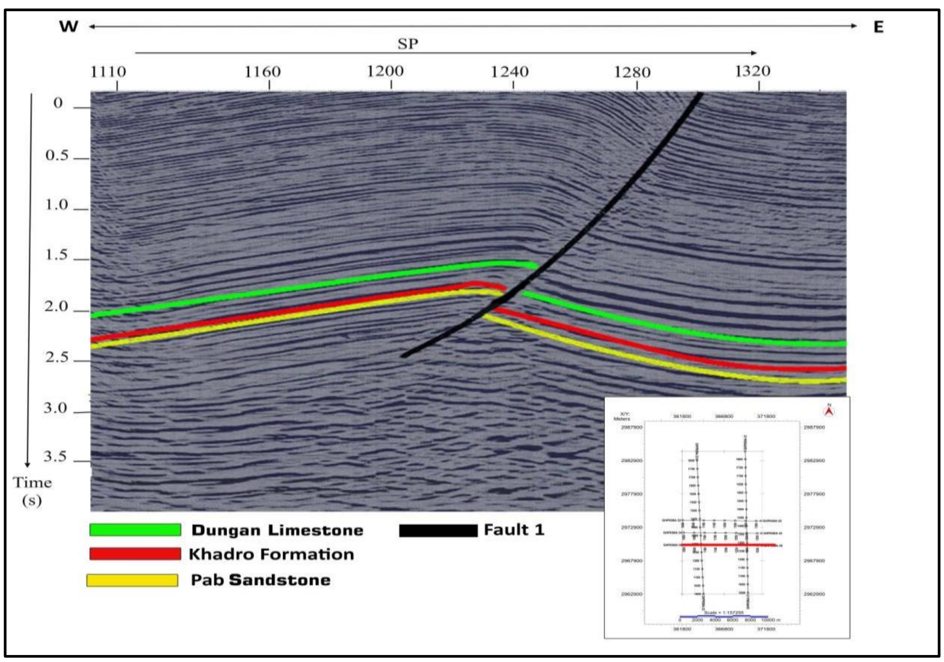

Figure 3.7 Interpreted dip line HPK 98A-36 with orientation north to south and marked horizon of Dungun, Khadro, and Pab Sandstone shown in green, red and yellow color respectively.

3.9. Contour Maps

Kingdom Suite has been utilized to analyze seismic data in the current investigation. Basically, the oil sector uses this software. Time and depth contour maps, together with faults, have all been created using the Kingdom suite.

3.9.1. Pab Sandstone Time Contour Map

Time contour map is providing the information of what type of structure is there with respect to time. The Kingdom Suite Software is used to calculate and contour the two-way travel time. The time is measured in milliseconds.

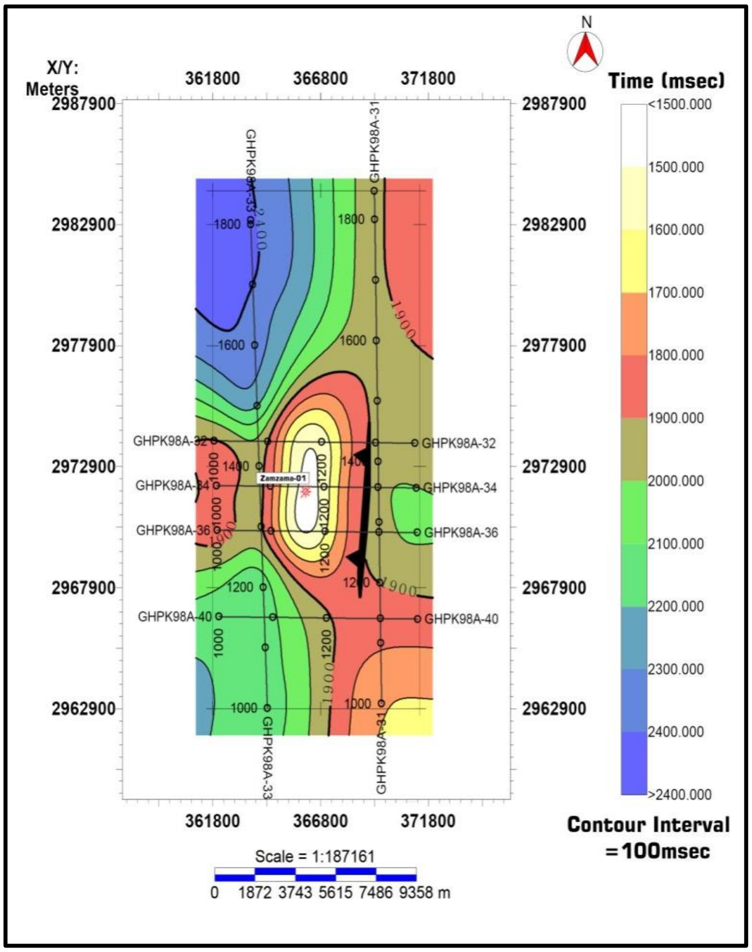

Figure 3.8 TWT map of Pab Sandstone with marked fault in black color

Given that the values of the contours decrease and increase toward the center, respectively, the above-mentioned image shows that the Pab Sandstone has an anticline and syncline pattern. Small values of travel time, which are a representation of a bulge area or an anticline structure, are shown by the closed contours.

3.9.2. Velocity Contour Map of Pab Sandstone

Due to the pressure of the overburden and the increase in density, the seismic velocities rise as depth increases. The velocity contour map indicates that elevated areas can be identified by the closing of the contours and the velocity decreases over those areas. The increase in depth is indicated by the increase in velocity.

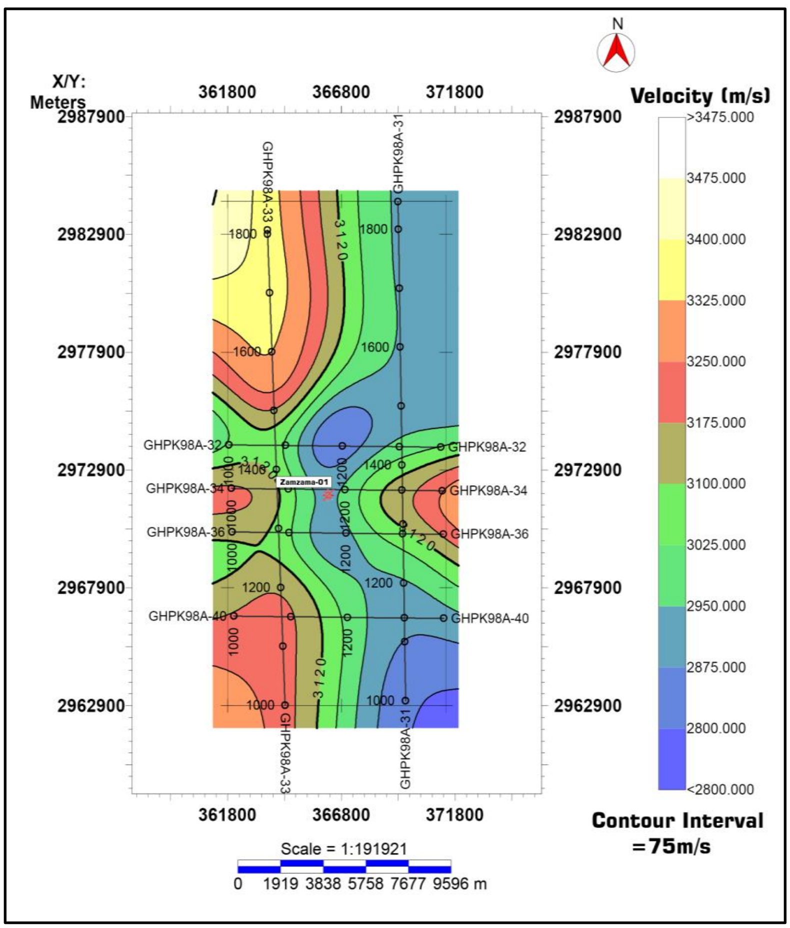

Figure 3.9 Velocity contour map of Pab Sandstone.

3.9.3. Pab Sandstone Depth Contour Map

The formation's depth is identified and contoured, with the closer spacing between contours indicating less variation and the closer spacing indicating immediate variation in either time or depth. Additionally, a thrusted fault that dips northeast can be seen.

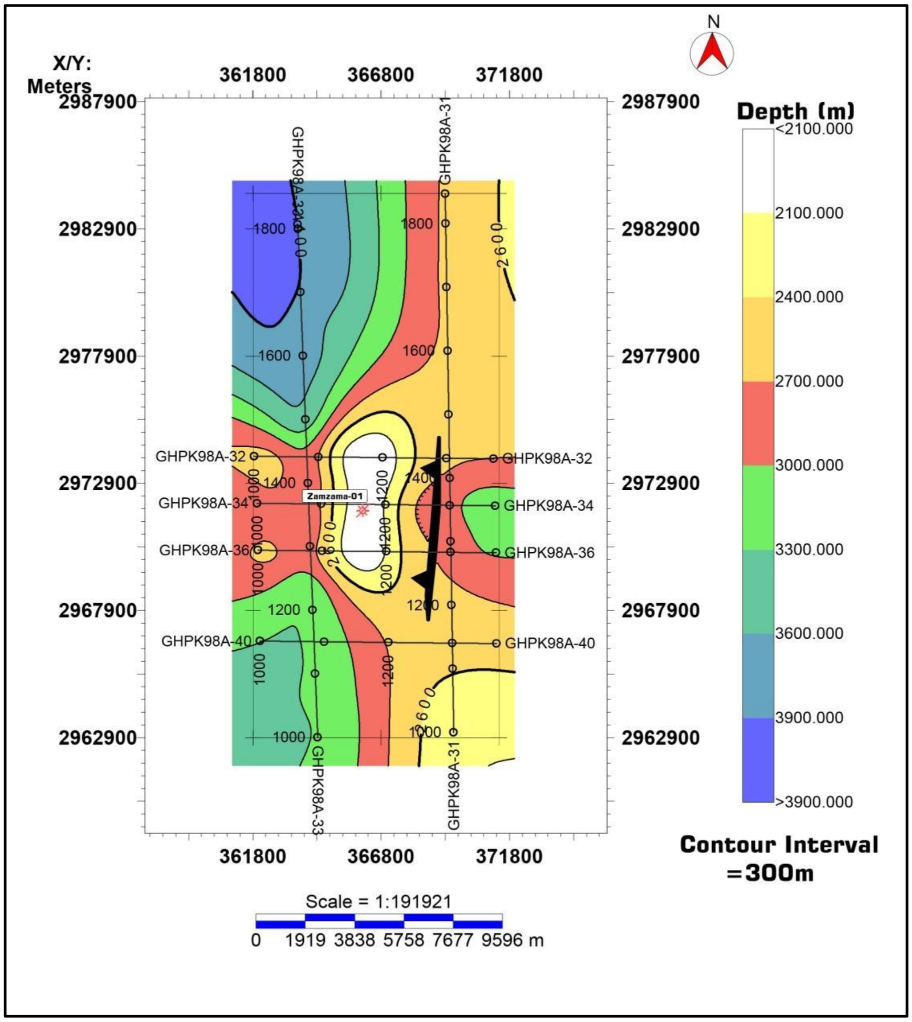

Figure 3.10 Depth map of Pab Sandstone

CHAPTER 04

PETROPHYSICAL ANALYSIS

4.1. Introduction

Petrophysics is a method that is use to illustrate the reservoir. It helps in the identification and quantification of a fluid in a reservoir. By using wireline logs (Density, Neutron, Self-potential and Resistivity logs), Petrophysical analysis of Sakesar Limestone of Eocene age in Missa Keswal-01. The analysis was done to calculate porosity, determine formation water resistivity, water saturation and oil saturation. These findings play an important role in the investigation of hydrocarbon potential of the reservoir (Jaswal et at., 1997).

4.2. Types of Logs Used

There are three main tracks used in Petrophysics. The lithological track, porosity track and resistivity track. Following are the various logs used in petrophysical analysis:

Table 4.1 Types of logs

LITHOLOGICAL LOGS	POROSITY LOGS	FLUID DYNAMIC LOGS
Gamma ray log (GR)	Sonic log (DT)	Resistivity logs (LLD)
Self-Potential log (SP)	Density log (RHOB)	Induction logs
	Neutron log (NPHI)	

For the analysis of Petrophysical activities, the following parameters are identified on the basis of log curves:

1. Volume of shale.
2. Porosity.
3. Water saturation.
4. Hydrocarbon saturation.
5. Resistivity of water.

Following workflow is used in Petrophysical analysis:

Table 4.2 Workflow of Petrophysical analysis.

STEP 1	• Marking zone of interest on the basis of character of log curve
STEP 2	• Calculation of Volume of shale (V_{sh})
STEP 3	• Calculation of V_{clean}
STEP 4	• Calculation of Density Porosity (DPHI)
STEP 5	• Calculation of Neutron Porosity (NPHI)
STEP 6	• Caclulation of Average porosity (APHI) and Effective porosity (EPHI)
STEP 7	• Calculation of Resistivity of Water (R_w) for a particular zone
STEP 8	• Calculation of Saturation of Water (S_w) and Saturation of Hydrocarbon (S_h)

4.3. Formation of Interest

In our log data, only Sakesar formation is present and its upper part is only available in the log data. Starting from 1839m and end at 1907m. The zone marked is

Table 4.3 Marked Formation (Pab Sandstone)

PAB SANDSTONE	
Starting Depth (m)	3764
Ending Depth (m)	3928
Thickness (m)	164

4.3.1. Calculation of Volume of Shale (V_{sh})

To find out the numerical value of volume of shale, the gamma ray index (IGR) is calculated from gamma ray log data. The gamma ray log value is affected by the amount of natural radioactivity of the formation. Shales give high value for gamma ray because large amount of radioactive minerals are present in shale.

Volume of shale (V_{sh}) can be found using the following formula (Schlumberger, 1974).

$$IGR = \frac{(GRlog - GR_{min})}{(GR_{max} - GR_{min})}$$

Where,

IGR = Gamma Ray Index.

GR log = Gamma Ray reading at the depth of interest.

GR_{min} = The Minimum Gamma Ray reading (Usually a mean minimum through a clean sandstone or carbonate formation).

GR_{max} = The Maximum Gamma Ray reading (Usually a mean maximum through a shale or clay formation).

4.3.2. Calculation of Volume of Clean (V_{clean})

The volume of clean is determined by the following formula (Schlumberger, 1974).

$$V_{clean} = 1 - V_{sh}$$

V_{sh} = Volume of shale (IGR)

4.4. Calculation of Density Porosity (DPHI)

Density porosity can be determined by using values from density log. The following formula is used to calculate DPHI (Schlumberger, 1989).

$$\Phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

Where,

ρ_{ma} = Density of matrix (for limestone =2.71 g/cm^3)

ρ_b = Bulk density of the formation

ρ_f = Density of fluid (For saline water = 1.1 g/cm^3)

Φ = the density porosity of rock

4.4.1. Calculation for Neutron Porosity (NPHI)

The values for neutron porosity are directly taken from the neutron log that runs parallel to density log (RHOB).

4.4.2. Calculation for Average Porosity (APHI) and Effective Porosity (EPHI)

Average porosity is calculated by using the following formula (Serra, 1984).

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

Effective porosity shows the total amount of interconnected pore spaces. The following formula is used to calculate EPHI (Serra, 1984).

If there is no caving,

$$EPHI = APHI * V_{clean}$$

If there is caving,

$$EPHI = SPHI * V_{clean}$$

Where, SHPI is a sonic porosity and is calculated as (Serra, 1984).

$$SPHI = \frac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}$$

Where,

Δt = value of time from sonic log (µs/feet)

Δt_{ma} = travel time through matrix (µs/feet) (for limestone= 47.6 µs/feet)

Δt_f = travel time through fluid (µs/feet) (for saline water= 185 µs/feet)

As our zones of interest have not undergone caving, effective porosity is calculated using average porosity.

4.4.3. Calculation of Resistivity of Water (R_w) for the Particular Formation

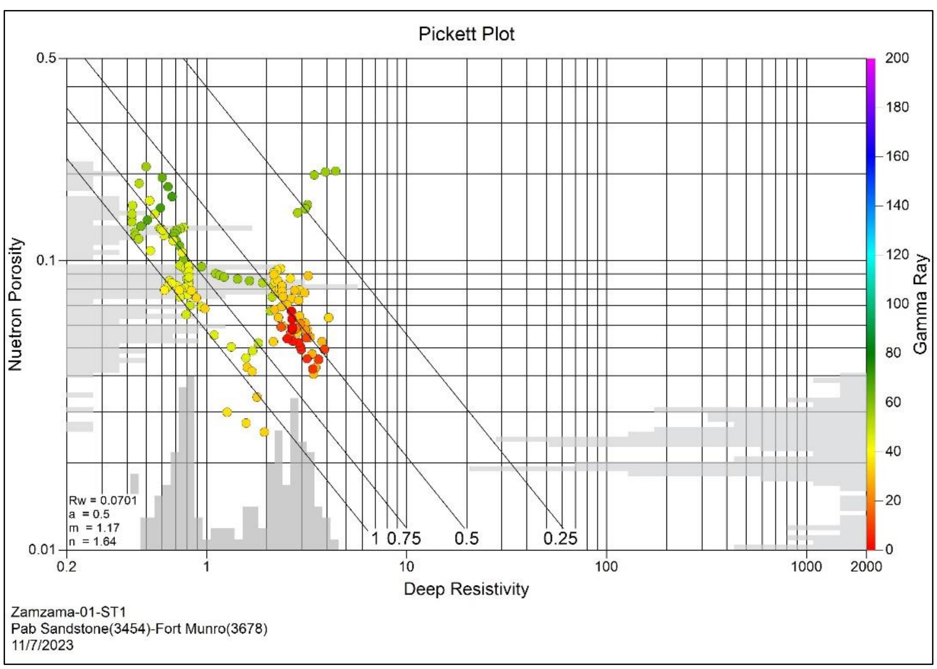

Figure 4.1 Pickett Plot

4.4.4. Calculation for Saturation of Water (S_w) and Saturation of Hydrocarbon (S_h)

The fraction of pore spaces holding water is known as saturation of water. The residual fraction saturated with oil or gas is known as saturation of hydrocarbon.

Saturation of water can be found using Archie's formula

$$S_w = [(a/ \Phi m) * (R_w / R_t)]^{1/n}$$

Where,

R_w = Resistivity of water

R_t = True resistivity of formation

Φ = porosity

a= Tortuosity factor (1.0 for carbonates, 0.81 for consolidated sandstone, 0.62 for unconsolidated sandstone)

m= Cementation exponent (2.0 for carbonates and 2.15 for sandstone)

n= Saturation exponent (normally equal to 2.0)

Hydrocarbon saturation can be found as:

$$S_h = 1 - S_w$$

Figure 4.2 demonstrate the petrophysical analysis of Zamzama-01 0n Pab sandstone formation. The thickness of formation zone is 164 meters. The result of interested formation is show in the table 4.4 below. The density and neutron log is only available at the depth of 3530m due to which porosities and saturation are calculated from that specific depth. Overall formation is water saturated with containing 82% of water in it and remaining 18 % is hydrocarbon. Water saturation is demonstrated with blue color and hydrocarbon is shown with red color. The porosities range is lies between 10 to 15 % along with 54% of shale volume and 46% clean volume.

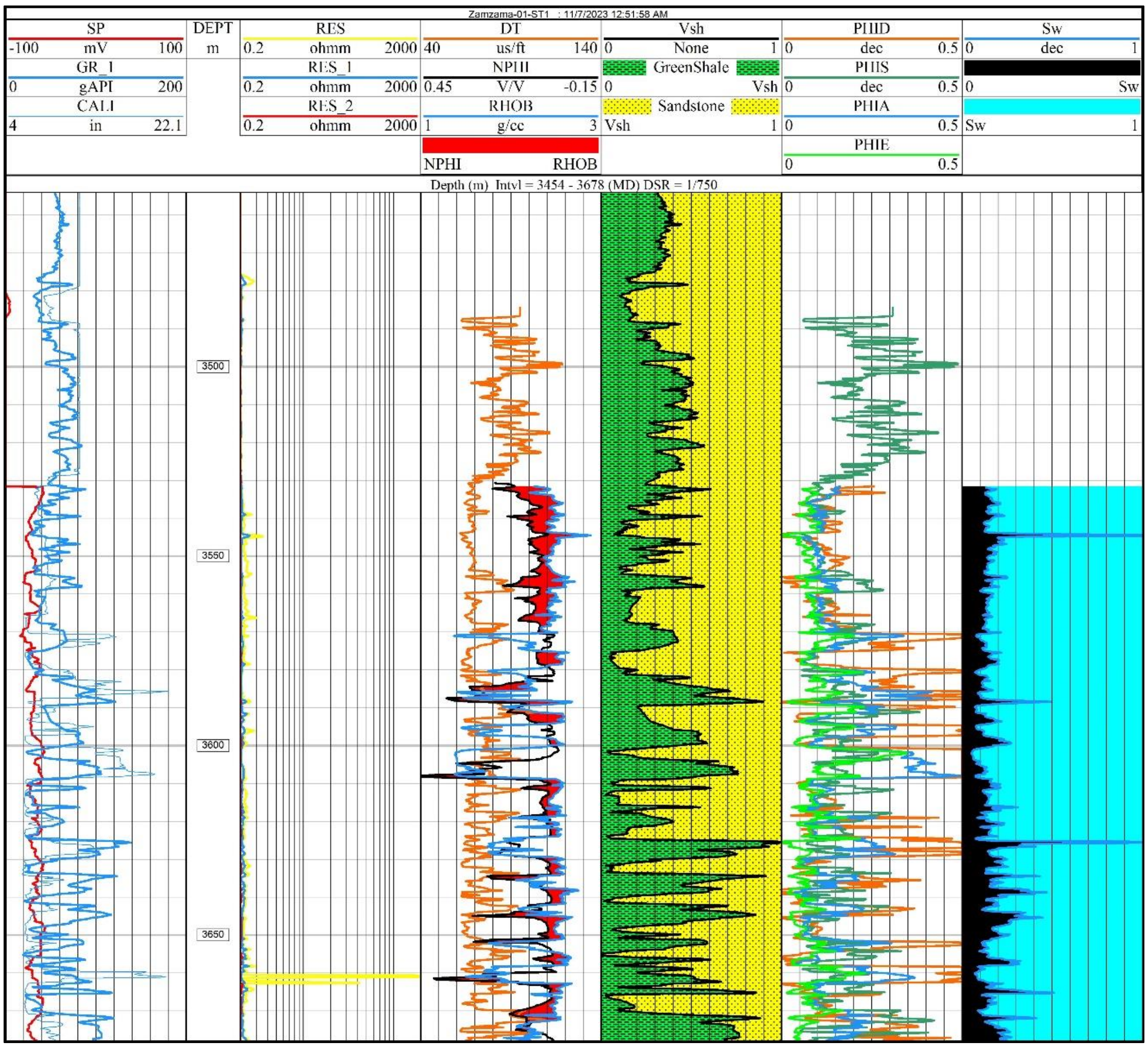

Figure 4.2 Interpreted well log of Zamzama 01

Table 4.4 Final petrophysical results of Zamzama 01 well.

PAB SANDSTONE	
Depth (m)	3764
Thickness (m)	164
Average V_{sh} (%)	54
Average V_{clean} (%)	45
Average Density Porosity (DPHI) (%)	12
Average Neutron Porosity (NPHI) (%)	13
Average Porosity (APHI) (%)	12.5
Average Effective Porosity (EPHI) (%)	10
Average Sonic porosity (SPHI) (%)	15
Average Saturation of water (S_w) (%)	82
Average Hydrocarbon Saturation (S_h) (%)	18

CONCLUSIONS

1. The Zamzama structure is a plunging anticline feature with a north-south orientation and an eastward trending, according to the interpretation of seismic data. Along the Zamzama thrust fault, Zamzama play forms.
2. The effective porosity is 10% and the average porosity in the Pab formation is 12.5%. In the Pab Sandstone, the average water saturation is 82% and the average hydrocarbon saturation is 18%. The Pab Sandstone consequently serves in this location as a reservoir formation.