Characterization of Pab Formation using Rockphysics Analysis and 3D Seismic Inversion in Zamzama Field, Lower Indus Basin, Pakistan

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Dr. Shazia Naseem

DEDICATION

This work is dedecated to my family who always been supportive to me

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First and above all, I praise Allah, the almighty for providing and granting me this opportunity and capability to proceed successfully. This thesis appears in its current form due to the assistance and guidance of several people. I would therefore, like to offer my sincere thanks to all of them.

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Irum Khurshid

ABSTRACT

For hydrocarbon prospecting, seismic reflection is a widely used indirect geophysical method. The main goal is to characterize physical parameters and evaluate hydrocarbon reservoirs. Because the Zamzama gas field is located in the Lower Indus Basin and has a compressional regime, the structural interpretation is a thrusted anticline. The major purpose of this research is to improve reservoir characteristics estimation in the sands of the Pab Sandstone formation in the Zamzama Gas field in the Lower Indus Basin.

Seismic interpretation, petrophysical analysis, seismic inversion, and rock physics techniques are mainly used to achieve the objectives. Acoustic logs were used to create a Synthetic Seismogram at the well location. Horizons of interest are identified after a successful cross correlation of synthetic and seismic traces at the well location. Khadro formation, Pab Sandstone, and Fort Munro Formation are the marked horizons. In the study area, Pab Sandstone acts as a reservoir. To see the depth variations of these reflectors in the study area, Two way time and depth contour maps of selected horizons were created. Subsurface structures are also confirmed with time and depth contour maps.

Petrophysical study of well log data is used to evaluate reservoir parameters. The Pab formation has been identified as a reservoir that satisfies all the criteria for a reservoir at Zamzama-02. The Pab formation has the potential to produce effective porosity greater than 8%, shale volume less than 30%, water saturation 30% to 60% and high hydrocarbon saturation 40% to 70%, according to petrophysical results. Using well Zamzama-02 Cross-plotting of neutron against density porosity and density vs effective porosity confirms the reservoir lithology. These studies are carried out at various reservoir levels, indicating that the reservoir primary lithology is sand.

The seismic inversion technique (Model Based Inversion) resolves the seismic in the acoustic impedance model. Porosity was determined and extrapolated. High impedance value above and below the Pab sandstone indicating the existence of shale or another high impedance rocks Porosity maps were distributed across the study region. Impedance and porosity have an inverse relationship, which means that Pab Sandstone has a low impedance but a high porosity, confirming the petrophysical and rock physics results.

In terms of elastic moduli, rock physics modelling confirms the zone of interest, calculates reservoir parameters to obtain a better knowledge of reservoir properties, and also confirms the result of petrophysical analysis. As the acoustic impedance and VpVs ratio decrease, it indicates the existence of gas sand. As VpVs ratio and acoustic impedance increase indicate presence of brine sand. Decrease in acoustic impedance and increase in VpVs ratio indication of shale.

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CHAPTER: 01

INTRODUCTION OF STUDY AREA

Exploration has a major impact on an economic growth of a country. Seismic exploration techniques were primarily required to survey for hydrocarbons in sedimentary rocks below the surface in the 1920s. Seismic reflection lines reveal details on the internal structure of the earth.

The first 3D seismic surveys were conducted in the 1970s and early 1980s. Geological structures under the surface are 3D in nature. 3D structure reveals the exact results of subsurface geological structure, so seismic interpretation is more reliable due to 3D. Wireline logging is the most important type of data for geoscientists and petro physicists when characterizing a reservoir.

Wireline logging allows for continuous recording of borehole measurements, which are then used for geological research, fluid distribution, and reservoir parameter measurements. But there are various factors, including the type of drilling fluid used, the state of the borehole, and the rock itself, that affect these rocks attributes.

1.1 INTRODUCTION:

Pakistan is located at the intersection of Arabian, Eurasian and Indian plate. Sedimentary basins in Pakistan have developed into a variety of structural patterns. Pakistan is made up of two sedimentary basins, the Indus and the Balochistan Basin, both having different geological histories and different origins. These basins developed over time and were eventually merged together along the Ornach Nal/Chaman strike fault during the Cretaceous/Paleocene.(Kadri 1995).

The Pashin basin, also referred to as the Kakar-Khorasan basin, is a recent discovery. Based on Cretaceous/Paleocene ages, the lower Indus basin was divided into the southern and central indus basins.(Ahmed 1992).

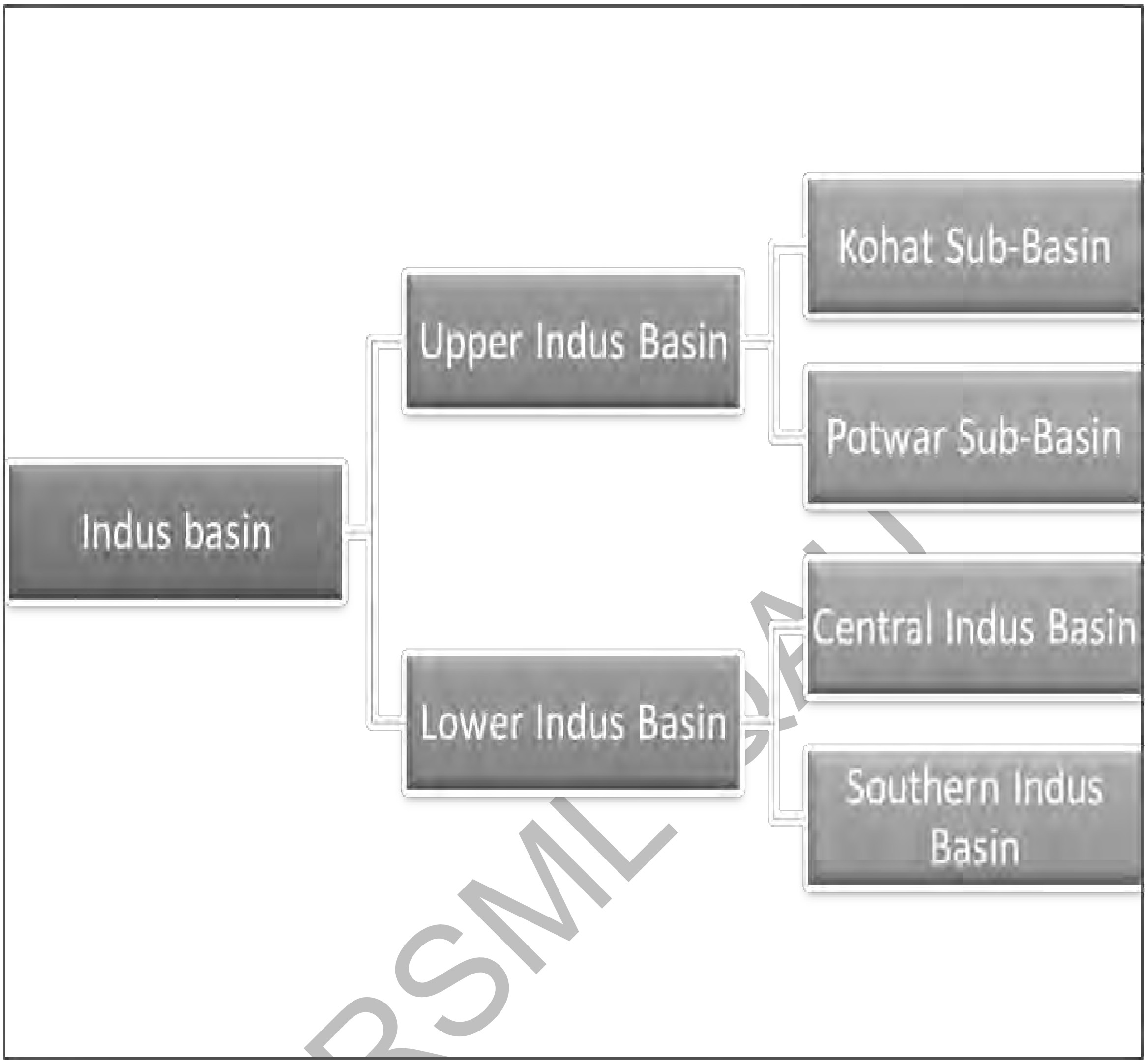

Figure 1.1: Classification of Indus Basin (Ahmad 1992)

By the Pezu uplift and Sarghoda high, the central Indus basin is divided from the upper Indus basin. The Sukkar Rift, formed by the Mari Kandhkot highs and Jacobabad high, divides the Central and Southern Indus basins. Southern and Central Indus basins evolved from the Lower Indus basin. lower Indus basin concists of five units.(Kadri 1995)

- Thar Platform
- Kirther Foredeep
- Kirther Fold Belt
- Karachi Trough
- Offshore Indus

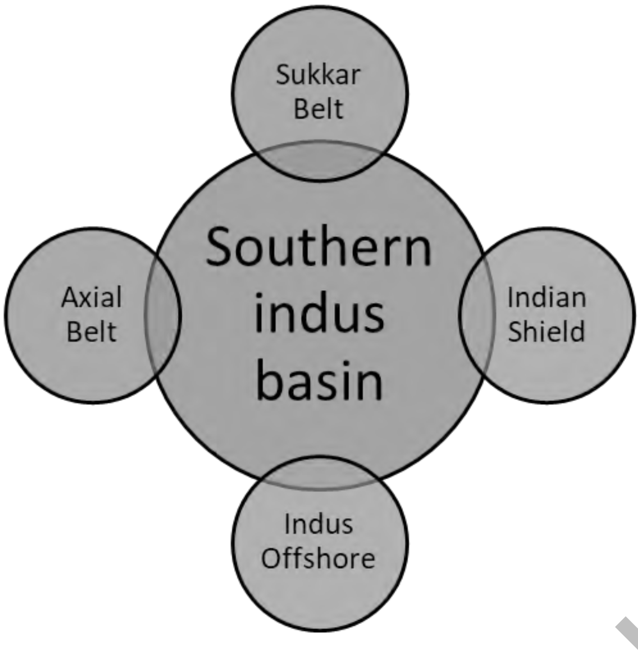

Figure 1.2: Geographical boundaries of Southern Indus Basin (Kadri 1995)

The borders of the Southern Indus Basin are defined by the Indian Shield to the east and the Indian Plate (IP) to the west, with the south extending to the Indus offshore and the northern boundary of the Sukkar belt.(Kadri 1995).

The classification of the southern Indus basin is shown in figure 1.3.

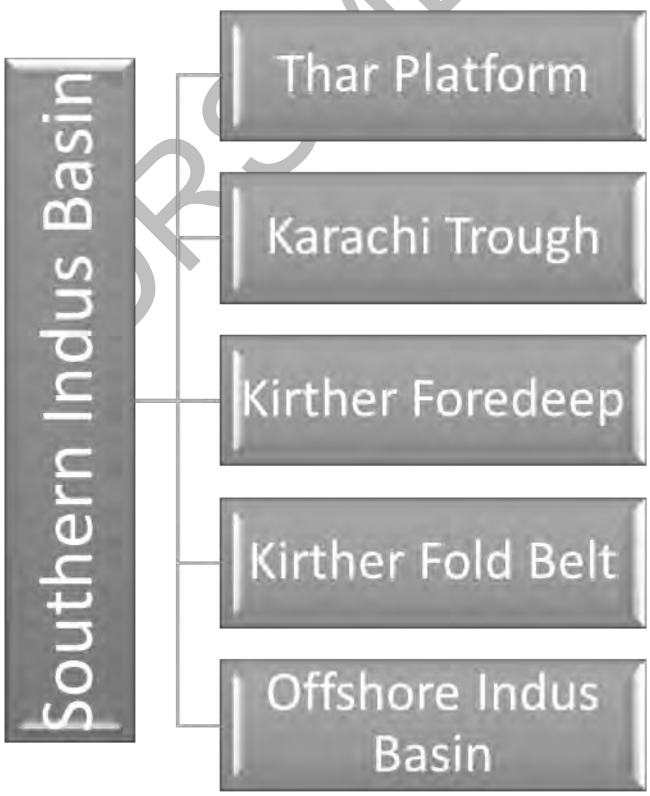

Figure 1.3: Classification of Southern Indus Basin (Kadri 1995)

8 km west of the existing Sui-Karachi pipeline, in the Kirther Fold Belt of Sindh Province, Pakistan, around 200 km north of Karachi, is the Zamzama gas field. In Sindh province, theZamzama gas field, with total area of around 120 km2, was found. Zamzama gas field is a large resrvior of gas.

In terms of gas reserves, Pakistan's Zamzama gas field is ranked fourth. Zamzama gas field provides 15% of Pakistan's daily gas production. Southwest of this gas field, at the junction of the Kadanwari, Sawan, and Miano fields, is the Bhit gas field.

Figure 1.4: Location map of Zamzama gas field in the southern Indus Basin (Kadri 1995)

1.2 PROJECT DESCRIPTION:

First off, the zamzama gas field was found in 1998 with an estimated 2.4 TCF of wet gas already in place.(Zafar,et al. 2018) The Zamzama gas field is located in the Dadu concession block and was once run by BHP Petroleum however, OPL (Ocean Petroleum Pakistan) is currently operating on this block. This field is located in the Dadu District's Kirther area in the Sindh province. Separating the southern indus basin from the central indus basin were Mari kandhkot and Jacobabad Heigh(Qureshi, et al. 2021).

The latitude and longitude of the Zamzama gas field are 26° 42'30.24" to 26° 42'34.32"N and 67° 39'43.2" to 67° 40'9.12"E, respectively. About 10 km to the west of Dadu and 200 km to the north of Karachi are the Zamzama gas fields. The location of the gas field at Zamzama is shown in figures 1.5.

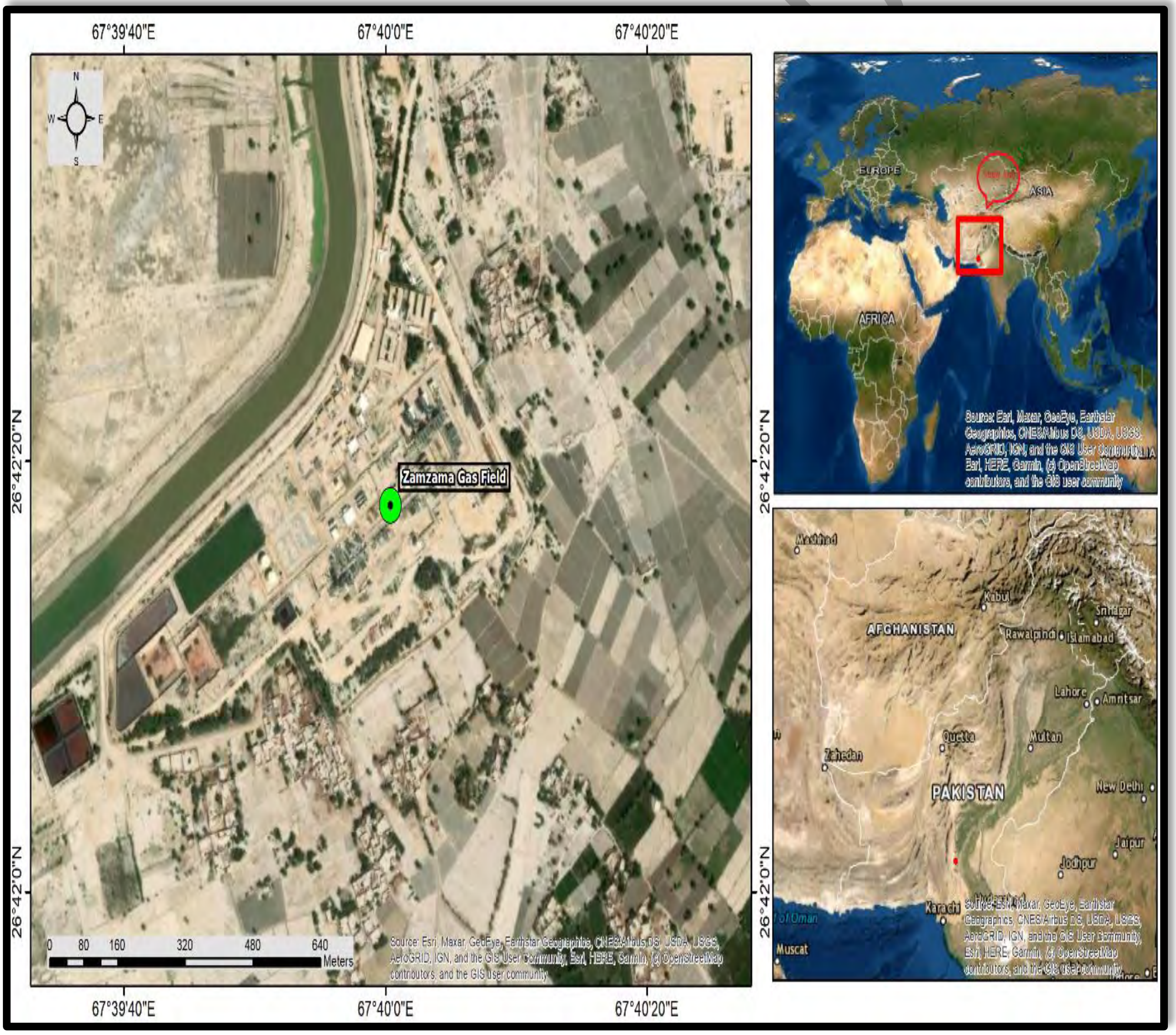

Figure 1.5: Location of study area, Zamzama Gas Filed by its latitude and longitude.(Google earth)

1.3 EXPLORATION HISTORY:

The lower lndus basin, which is discussed in the review of 1993-1994, is the largest suggested basin. When a 2D survey was conducted in the Dadu concession in February 1995, the Zamzama Gas Field identified its structure. (Block 2667-1)(Jackson,et al. 2004) The most productive reservoir in the Zamzama gas field is Pab, which combines sweet and dry gas reservoirs and has a very low condensate ratio of gas of about 6.5(Barrel Per Million Micro Cubic Feet), is located at a depth of 3500 metres. About 1.7TCF (Trillion Cubic Feet) of gas9 (gross) was produced by the Zamzam gas field, and BHP's equity stake is equal to 650BCF. Buildings for the processing plant and control room are included in the Zamzama project.(Jackson, et al. 2004)

First, Zamzama-1/ST1 was the well that was drilled in January 1998 at a depth of 3983 metres. In the Khadro and Pab formation, a gas column indicates a 300m quantity, which is also supported by well data. The Zamzama-02, estimated the presence of hydrocarbons in the Pab and Khadro formations by 3D seismic interpretation and drilling. The acquisition and drilling of 3D seismic indicates a 90MMcf/d gas production rate, and well data up to a total depth of 3933m reveals an estimated 350m gas column. Gas production from the Zamzama gas field averages around 320MMcf/d.(Smewing, et al. 2002)

1.4 DATA USED:

With special permission from the DGPC, data in SEGY format covering more than 10 square kilometres of the 3D Pre-Stack depth migrating Zamzama gas field were obtained from LMKR. The specified 3D grid has 108 crosslines and 135 in-lines (567-701) as

Lines	Start	End
In-lines	567	**701**
Cross-lines	**1356**	**1463**

indicated in table 1.1. (1356-1463).

Table 1.1: Number of Inline and Xlines given in 3D survey.

Three wells' digitalized well data and logs in the same LAS format were obtained from LMKR on the recommendation of the Earth Sciences Department and the DGPC.

WELL DATA			
LOGS	**Zamzama-01/ST-1**	**Zamzama -02**	**Zamzama-04/ST-3**
GR	Present	Present	**Present**
SP	Present	Not Available	**Present**
CALI	Present	Present	**Present**
NPHI	Present	Present	**Present**
RHOB	Present	Present	**Present**
MSFL	Present	Present	**Present**
LLS	Present	Present	**Present**
LLD	**Present**	**Present**	**Present**

Table 1.2: Well logs detail of Wells Zamzama-01/ST-1, Zamzama-02 and Zamzama-04/ST-3.

1.5 OBJECTIVE:

The major objective of this research work are as follow

- To use 3D seismic interpretation to find the best hydrocarbon concentration zones and subsurface structure.
- Identify and label the most likely zones in the reservoir using a petrophysical analysis.
- Measuring the thickness and lithology of formations in the study region using an overlaying gamma ray curve.
- To analyze the elastic properties of the reservoir and determine lithology, rockphysics analysis were used.
- Porosity cube and statistical porosity estimation.

1.6 METHODOLOGY:

The following methodology was applied to achieve the specified objective:

- Seismogram correlation was connected to Time Seismic to establish horizons.
- To produce the time depth chart, this aids in the conversion of horizons from time to depth.
- Time contour maps in two dimensions were created.
- Depth contour maps were produced after converting time to depth section.
- To determine the best zones of interest within the reservoir, the following metrics were derived from the well log data: effective porosity (PHIE), porosity density (PHID), the volume of shale (VSH), hydrocarbon saturation (Sh), total porosity (PHIT), and permeability (K).
- Rock physics parameters such as fluid content, elastic properties, and reservoir investigation were established.
- Cross plots of the VpVs ratio against the acoustic impedance and the Poisson's ratio were created to learn more about the underlying lithology of the wells.
- A cross plot of Poisson's ratio log and PHIE (effective p) serves as additional confirmation of the findings of the Petrophysical investigation.
- The basic model was built with logs and marked horizons.
- Finally, by include the low frequency model in the inversion result, the resolution was increased. The reservoir's characteristics are used to calibrate the p-impedance cube.

1.7 SIGNIFICANCE:

This research discovered that for hydrocarbon accumulate a subsurface structure in the Zamzama gas field is suitable.

Petrophysics is helpful for the estimation of hydrocarbon saturation.

In impedance domain interpretation of reservoir feature is much easier than seismic domain.

The two outputs of seismic inversion is porosity and acoustic impedance.

With the help of rockphysics analysis determined the presence of lithologies in the subsurface.

By combining all of these geophysical approaches determined the hydrocarbon zones of interest for field development.

CHAPTER 02

GENERAL GEOLOGY OF THE AREA

The geology of a region is important to the interpretation of seismic data. To interpret the horizons of reflections from various lithologies on the seismic section, one needs to be aware of the geological details of the formations from whence the reflections came. Understanding the geological framework is essential to comprehending basin development.

2.1 TECTONIC FRAMEWORK OF SOUTHERN INDUS BASIN:

Three factors must be known in order to determine the basin development under study.

- Tectonic of basin formatting
- Depositional order
- Basin transforming tectonics

Two major sedimentary basins in Pakistan are as follows.

- Balochistan basin
- Indus basin

The Indus Basin is divided into the Lower and Upper Indus Basins. The Central Indus Basin and the Southern Indus Basin each contain one subbasin of the Lower Indus Basin.

Two sub basins the Kohat and Potwar basin make up the Upper Indus basin. Other modern basins exist in addition to this, including the Siwaliks and Peshawar basins. (Kadri 1995).

Triassic-aged rocks are the oldest in the Lower Indus basin. One notable feature is the Khairpur-Jacobabad high, which separates the Central and Southern basins of the Lower Indus.(Kazmi and Jan 1997) Figure 2.1 shows the fundamental divides of the Indus basin and a tectonic map of the Zamzama gas field.

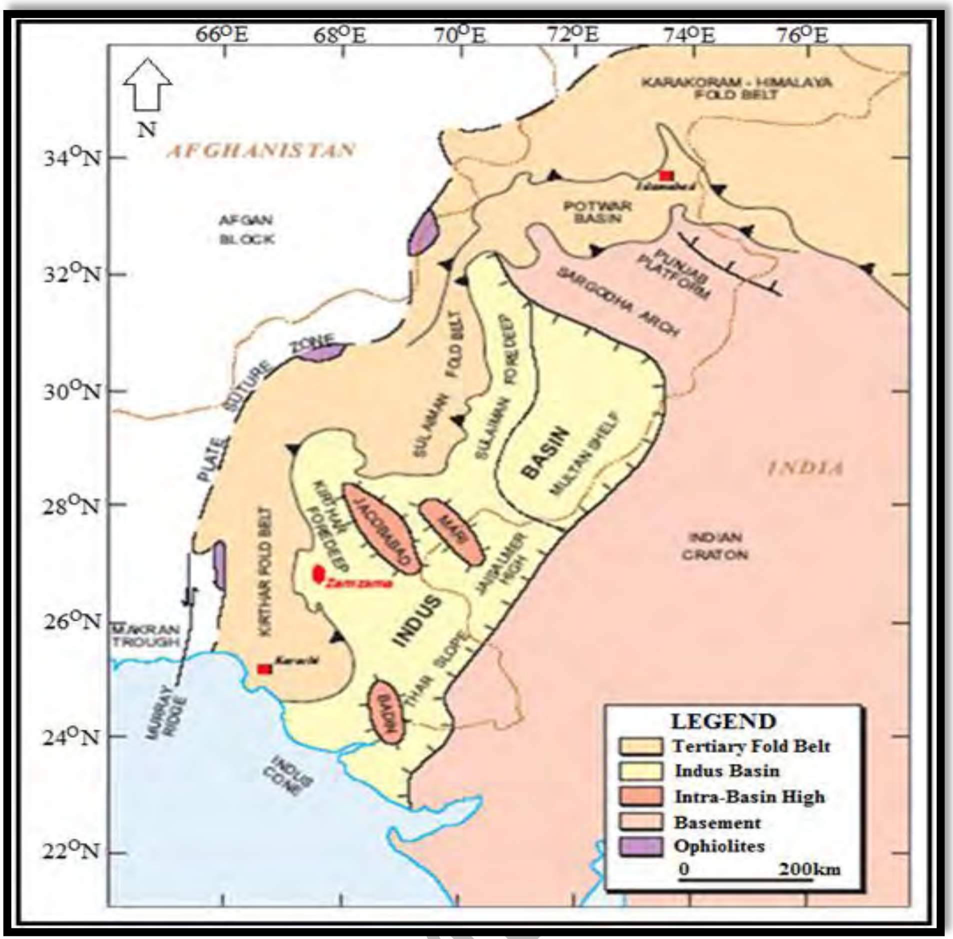

Figure 2.1: Tectonic map of Zamzama Gas Field and surrounding areas (Courtesy: Zamzama development plan by BHP Billiton).

2.1.1 THAR PLATFORM:

Similar to the Punjab platform, it is a sloped monocline controlled by basement topography. Both of the surface manifestations of the Indian shield—the Nagar Parkar High and the sedimentary wedge narrow toward it—include these features. In contrast to the Punjab platform, the Thar platform has buried structures that were created by the Indian plate's current circular rotation.

The Kirther and Karachi trough, the Indian shield, and the Mari-Bughti inner fold zone all encircle the Thar platform on its western, eastern, and northern borders, respectively. The stratigraphic and structural variance between the two sub-basins is clearly visible in the Thar platform, offshore Indus, and Karachi Trough. Early to middle Cretaceous and Goru are the reservoirs for all oil/gas marks with the aid of this platform. (Kazmi and Jan 1997)

2.1.2 KARACHI TROUGH:

A trough called the Karachi trough leads into Arabian Sea. It is recognized for its substantial cretaceous deposits, which mark the conclusion of marine sedimentation. There are many anticlines in the Karachi trough, however there aren't many gas fields. Rocks from the early, middle, and late Cretaceous periods are well preserved here. Throughout the entirety of its geological history, it was a trough. Upper Cretaceous used to mark the westward spread of the marine delta.

2.1.3 KIRTHER FORDEEP:

When Kirther Foredeep trends north-south, sediments accumulating a thickness of more than 15,000 metres are deposited there. The eastern boundary between Kirther Foredeep and that Flatform is faulted. Sedimentation is still happening in this depression.

The Kirther foredeep lacks the upper Cretaceous, according to the relationship between the Mazarani as well as Mari Khairpur wells. High Paleocene is absent in Khairpur-Jacobabad, but it appears to have been quite well established in the depression. The Sulaiman depressions have a lot of potential for the formation of source rock. (Kadri 1995)

2.1.4 KIRTHER FOLD BELT:

The Sulaiman depressions have huge potential for source rock development. The region of the Kirther fold belt has rocks from the Triassic to the present.

The western boundary of the Indus basin is marked by the Balochistan basin, which is situated close to the western end of the Kirther fold belt. Hydrothermal activity on the western side has also been connected to the production of mineral deposits of lead, fluorite, baryte, zinc, and manganese.

2.1.5 OFFSHORE INDUS:

Offshore indus contributes to the formation of passive continental margins. Cretaceous-Eocene and Oligocene-Recent appear to be two distinct time periods that make up the geological features of the offshore Indus. Offshore indus sedimentation began in the Cratecous period, while submarine fan sedimentation began in the middle of the Oligoene period.

The divides of Indus offshore are a platform and a depression at a hinge line. Along longitude 67°E, an offshore indus runs parallel. It is further divided into the Thar and Karachi through platforms.

2.2 STRUCTURAL PATTERN:

The Kirther fold belt is characterised by open, symmetrical folds that are produced by the inversion of Jurassic extensional faults that are embedded in the basement. Thrusts that include the reservoir during deformation and are marked by horst and graben structures can be found in the Eocene mudstone and thrusts that have a deeper detachment can be found in the Lower Cretaceous source rock interval.

These two detachments have also been interpreted as transcurrent faults.(Zaigham and Mallick 2000) On the eastern edge of the Kirther fold belt, plate collision during the Oligocene and Miocene epoch produced a number of anticlinal features.(Ahmed 1992)

The study analyses the Zamzama block's structural characteristics, historical development, and anticipated shortening. The deformation they describe is comparable to fault propagation folds. This implies that there is a decollement beneath the structure, which would make the Zamzama a thin-skinned construction without a basement function in deformation.

2.3 STRATIGRAPHY OF STUDY AREA:

Stratigraphy includes the arrangement and relative positions of strata as well as how they relate to particular geological epochs. Stratified sediments and rocks that are found on or below the earth's surface are also covered, as well as their correlation, interpretation, and description.(Kadri 1995)

Stratigraphic analysis is a powerful tool used by geologists and scientists to learn important details about the age and past of the world. While igneous and metamorphic rocks can also be stratigraphic in character and connected to stratigraphic classification, sedimentary rocks are the most frequently used for stratigraphy. (Shah 1977)

The stratigraphy of the research region is shown in Table 2.1. This table displayed the study area's lithology, formation, ages, and associated groups. The rocks in this research region range in age from Jurassic to modern. The Jurassic carbonates are underlain by the Cretaceous Sembar formation, which is made up of shale that grades to dark siltstone.

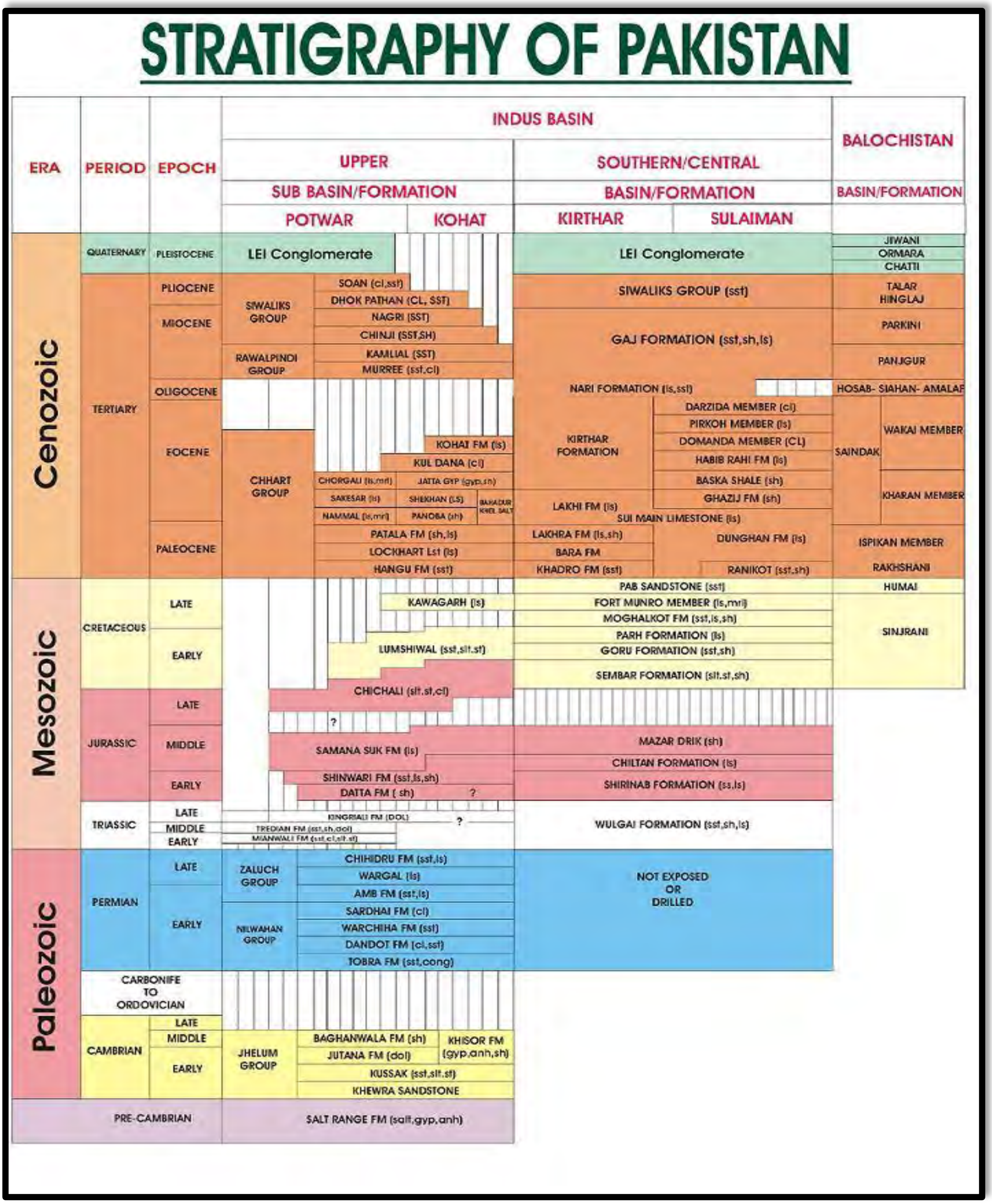

Figure 2.2: Stratigraphy of Pakistan (Kadri 1995)

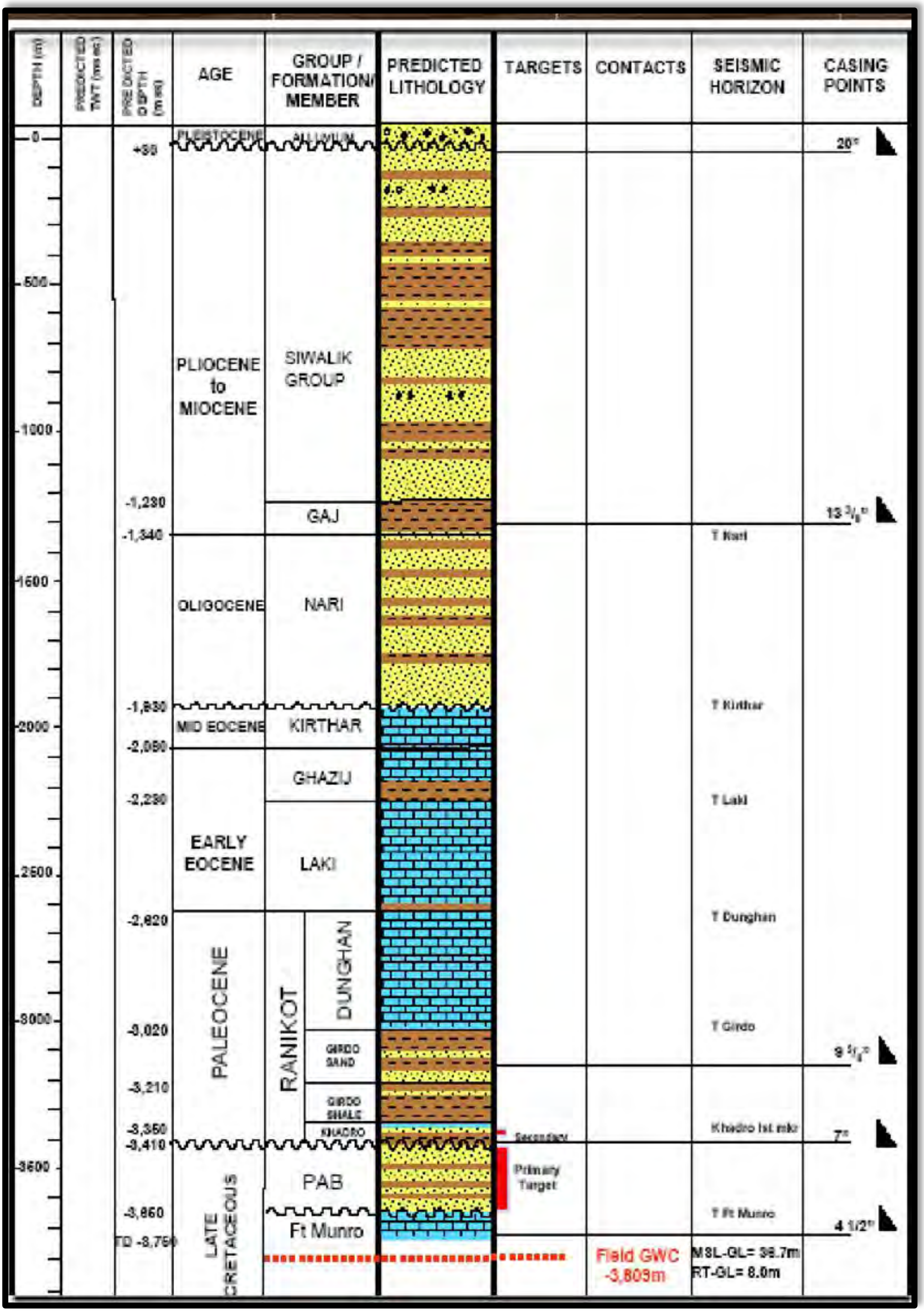

Figure 2.3: Stratigraphic column of Zamzama area (Courtesy: BHP Billiton)

AGE	GROUP	FORMATION	LITHOLOGY
Pleistocene		Lei Conglomerates	Conglomerates
Pliocene	Siwalik	Chingi, Nagri, DhokPathan,Soan.	Cyclic clay and sandstone
Miocene		Gaj	Shale
Oligocene		Nari	Shale, Sandstone
Eocene	Kirthar Group	Kirthar	Limestone, Shale
		Laki	Limestone, Shale
		Sui Main Limestone	Limestone
Paleocene	Ranikot Group	Lakhra	Limestone, Sandstone
		Bara	Sandstone, Shale
		Khadro	Sandstone
Cretaceous		Pab Sandstone	Sandstone
		Fort Munro	Limestone, Shale
		Mughal Kot	Mudstone, Shale
		Parh limestone	Limestone
		Goru	Sandstone, Shale
		Sembar	Shale
Jurassic		Mazar Dirk	Shale
		Chiltan	Limestone
		Shirinab	Shale
Triassic		Wulgai	Shale
NOT EXPOSED			

Table 2.1: Stratigraphy of the Lower Indus Basin (Kadri, 1995).

In the Sembar formation, the deposition environment ranges from deltaic to marginal marine. The Paleocene Rani and Dungan formations are buried beneath the depositional sequence denoted by the Eocene Laki and Kirther formation. (Kadri 1995)

2.4 MAJOR FORMATION:

There are several significant formations in the Zamzama gas field, including the Kirther formation (Eocene), Sembar formation (Cratecous), Dungan formation (Paleocene), Khadro formation (Paleocene), and Pub sandstone (Craterous).

The details of these formations are provided below.

2.4.1 SEMBAR FORMATION:

In the Kirther and Sulaiman ranges, the lowermost unit is cretaceous in age and primarily composed of shale interbedded with siltstone, argillaceous limestone, and nodular. The majority of the shale and silt strata of the Sembar Formation are of a glauconitic type. Sembar Formation is 262 metres thick in Mughal Kot and 133 metres thick at the type site. There is a gradational contact as well as an unconformity between the Sembar Formation and the Goru Formation above it. (Williams 1959)

2.4.2 KIRTHER FORMATION:

Kirther is positioned above the Laki formation. The Sulaiman region, as well as some of Waziristan, are all covered by the Kirther formation. It lies on top of the Ghazij group in the region of Sulaiman and Waziristan. The majority of the limestone of the Kirther formation is interbedded with shale and marl. The Kirther formation varies in thickness from 15 to 30 metres in the western Kirther range, and from 1,270 metres in the Gaj river region. Middle Eocene to Early Oligocene is the age of the Kirther formation. (Kadri 1995)

2.4.3 KHADRO FORMATION:

The Khadro formation, which is prevalent in Kirther and the surrounding area, is based on the Moro formation and Late Cratecous Pab sandstone. Oyster and reptile bones can be found in the limestone that makes up this formation. In the type part, the formation is 67 metres thick. It is 170 metres thick in the Rakhi Nala and Sulaiman areas, and 180 metres of it was penetrated by the fossils. (Williams 1959).

2.4.4 DUNGAN FORMATION:

Majority of the Cratecous rocks and the Paleocene sequence make up the Dungan formation in the Sulaiman region (Mughal Kot Formation, Parh Limestone, and Pab Sandstone). The entire Sulaiman range, as well as the Kirther range, contains the Dungan formation. Its thickness ranges from 100 to 600 metres, and it contains an assemblage of fossils and algae. (Williams 1959).

2.4.5 PAB SANDSTONE:

Vredenburg gave the Pab Sandstone its first designation in 1908; it originates in the Pab Ranges and extends into the Kirthar Ranges. This formation has coarse-grained, thick to huge strata of quartzose sandstone that ranges in colour from white to yellow or brown. The cross-layered, yellow-brown weathering argillaceous limestone with subordinate shale. While the shale in the Laki Ranges is sandy and brown with white, green, and maroon in the axial band, it is dark grey and calcareous in the Pab Ranges. (Shah 1977)

The type locality for this Formation is Wirahab Nai.. The type location of this Formation has a thickness of 490 metres. This Formation has a thickness that varies from 240 to 1000 metres.

2.5 PETROLLEUM SYSTEM:

2.5.1 SOURCE ROCK:

The major elements of the petroleum system are seal and reservoir rocks, which are necessary components to store and produce hydrocarbons as well as the migration channels of those substances.

The primary source rock of the Zamzama gas field is the Sembar formation, which is deposited on the continental shelf. Sembar is deposited over the majority of lower indus in a marine environment. The total organic content of the sembar formation in the lower indus basin ranges from 0.4 to 0.6 percent, and type-III kerogen ranges from 1.5 percent, which can produce gas. (Wandrey, et al. 2004)

2.5.2 RESERVIOR ROCK:

In the production phase of the petroleum system, reservoir rocks are important. The Zamzama gas field's primary reservoir is the Pub sandstone. Pab sandstone was deposited in a marine environment with shallow water. It includes systems deposited in coastal plains and sand-rich deltas. (Jackson, et al. 2004).

2.5.3 CAP OR SEAL ROCK:

A piece of rock that prevents the flow of hydrocarbon fluid. To prevent hydrocarbons from escaping the reservoir, these rocks create a seal around it. Rocks that acts as seal or cap rocks are shale and mudstone. The cap rock is composed of Paleocene Lower Ranikot Shales.(Jackson, et al. 2004).

2.5.4 TRAP:

A hydrocarbon-containing rock that sealed the formation to prevent hydrocarbons from escaping. Different types of traps are structural and stratigraphic traps.

The major features of the Zamzama gas field are an eastward trending and an NS thrusted anticline, which serve as a trap. (Jackson, et al. 2004).

2.5.5 MIGRATION PATH:

Fluid hydrocarbon migration began at the source of formations. Rock expulsion at the source is thought to be the primary migration, and hydrocarbon fluid is what causes it. Hydrocarbons are considered to have undergone secondary migration when they travel from their source to reservoir rock. Due to the hydrocarbon's buoyancy impact in relation to its saturation with the nearby rocks, migration takes place from lower to higher areas.

Chapter: 03

SEISMIC DATA INTERPRETATION

3.1 3D SEISMIC DATA INTERPRETATION:

To estimate the saturation of hydrocarbon in the subsurface structure, seismic data interpretation is the primary goal.Due to the lack of direct techniques for the discovery of hydrocarbons, hydrocarbon saturation is a risky task.

Due to its great resolution, seismic reflection is the most significant geophysical technology for exploration. Other techniques, like magnetic and gravity methods, can be used to identify petroleum. All of these techniques are depond on physical laws, in which attributes are measured above or below the surface, interpreted based on what appears below, and the geology is inferred from indirect observations. The interpretation is not unique due to the indirect relationship between the surface and depth readings. There are various phases for 3D data interpretation. Different methods were taken to resolve the seismic section, which comprises many forms of interpretations. Finding and determining the ideal position for trapped hydrocarbon in a particular structure is the main objective of seismic interpretation in the oil and gas sector.

3.2 SEISMIC DATA INTERPRETATION:

Two methods for the analysis of seismic data are briefly discussed.

- Stratigraphic Interpretation
- Structural Interpretation

3.2.1 STRATAGRAPHIC INTERPRETATION:

The seismic segment contains a series of reflections that need to be stratigraphically examined. Seismic sections are interpreted using the seismic expression of roughly adjacent geological sequences. The variety in sedimentary deposition is used to define stratigraphic interpretation.

3.2.2 STRUCTURAL INTERPRETATION:

A structural analysis of the seismic segment is performed to find potential structures that could store and accumulate hydrocarbons. Reflection time is employed in the interpretation of a variety of structures in place of structural traps such as faults, folds, and anticlinal angles. (Kearey, et al. 2002)

The methodology of structural analysis is used in this research to explain the results.

3.3 WORKFLOW OF SEISMIC INTERPRETATION:

The following figure 3.1 is workflow of main interpretation steps needed to understand the 3D seismic data:

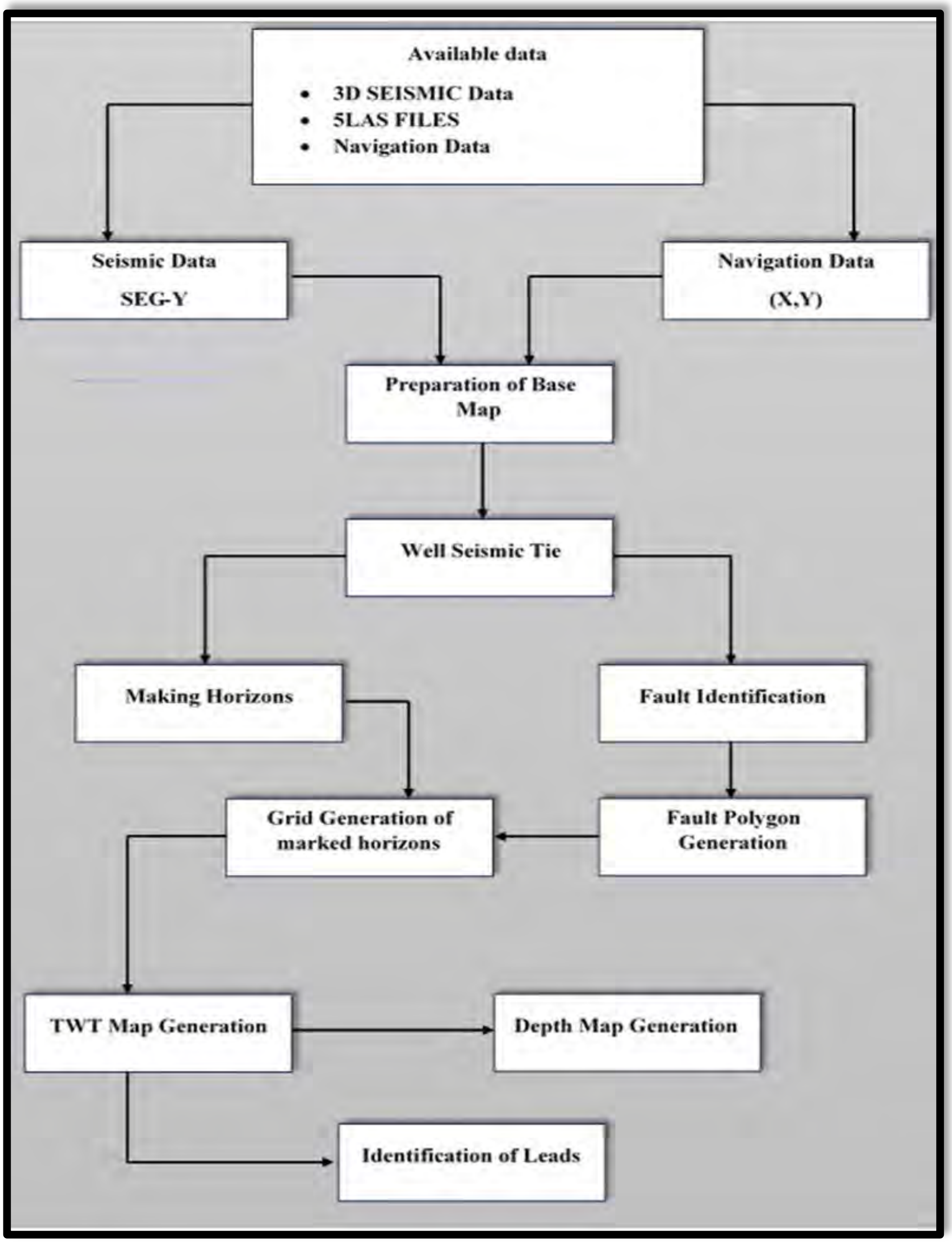

Figure 3.1: Workflow for seismic interpretation

3.3.1 BASE MAP OF STUDY AREA:

3D data in the form of a cube is made up of in-lines and cross-lines that are parallel to the x-axis and y-axis, respectively. In-lines extending northward and cross-lines extending eastward, which are both orthogonal to one another, provide the net geometry. Three wells—Zamzama-01/ST-1, Zamzama-02, and Zamzama-04/ST-3—are also included on the map in their true locations, as shown in figure 3.2.

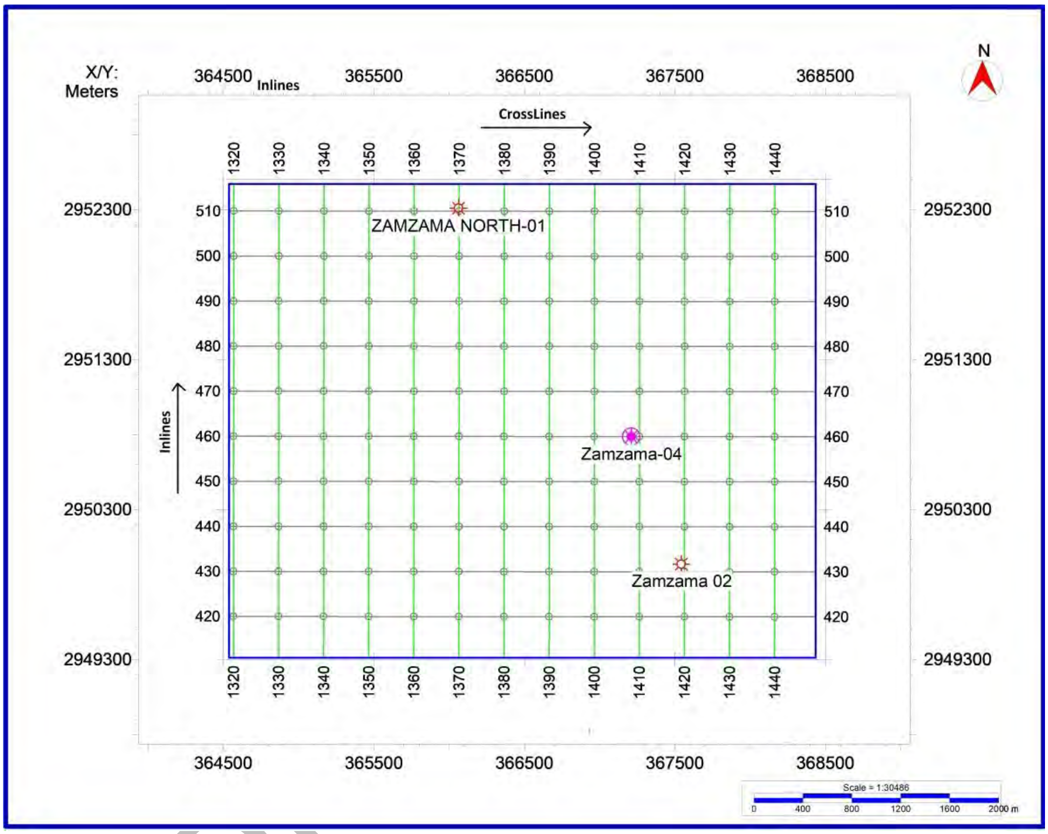

Figure 3.2: Base map of study area

3.3.2 GENERATION OF SYNTHETIC SEISMOGRAM:

Synthetic seismograms were produced by combining density and sonic data, and the acoustic impedance was then calculated. The calculation of the reflection coefficient then involved dividing the total and difference of the acoustic properties of the upper and lower layers by their respective ratios. The final Synthetic Seismogram is created by convolution of the reflection coefficient with a wavelet or trace. Figure 3.4 displays the well Zamzama-02 synthetic seismogram.

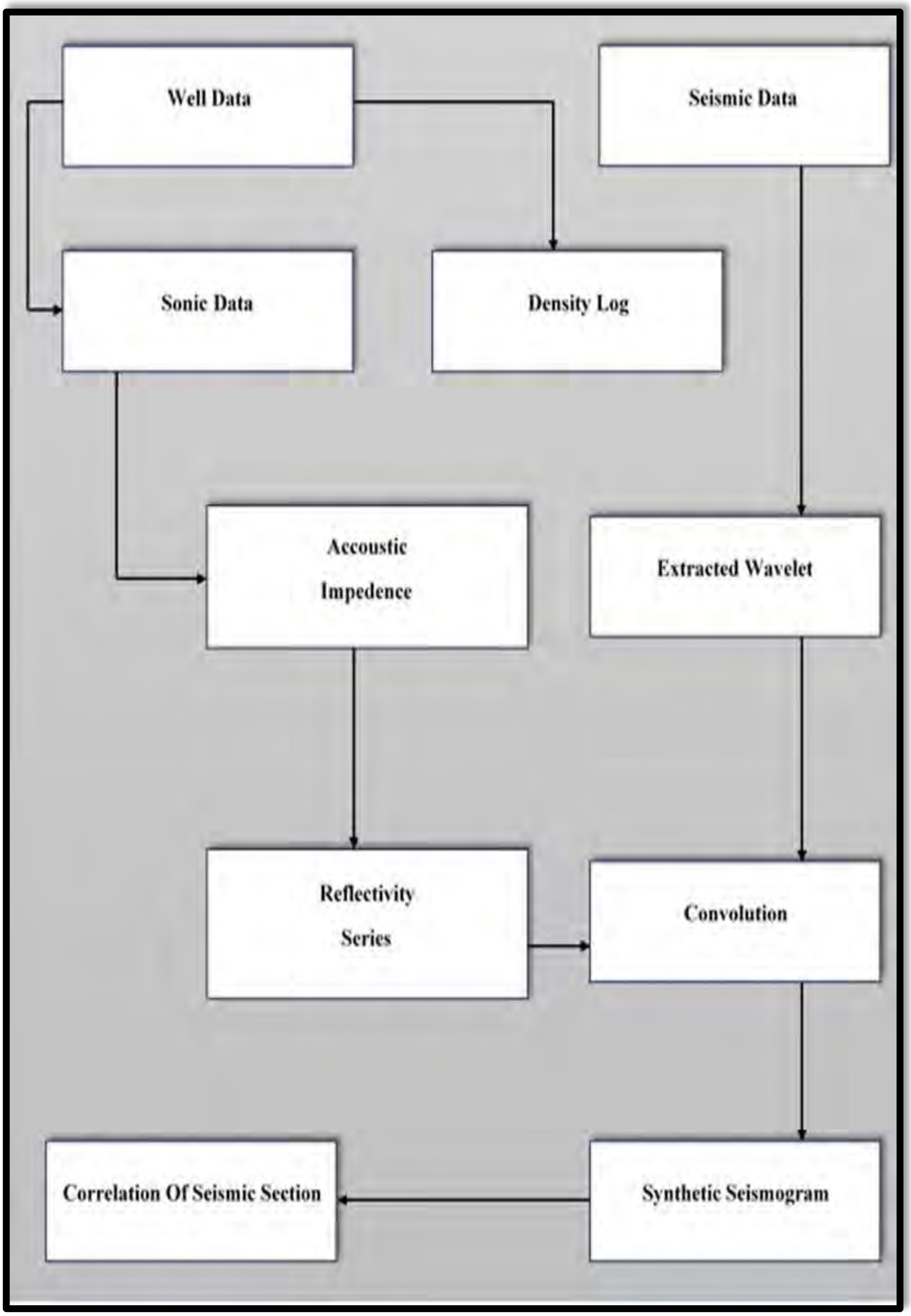

Figure 3.3: Workflow of Synthetic Seismogram

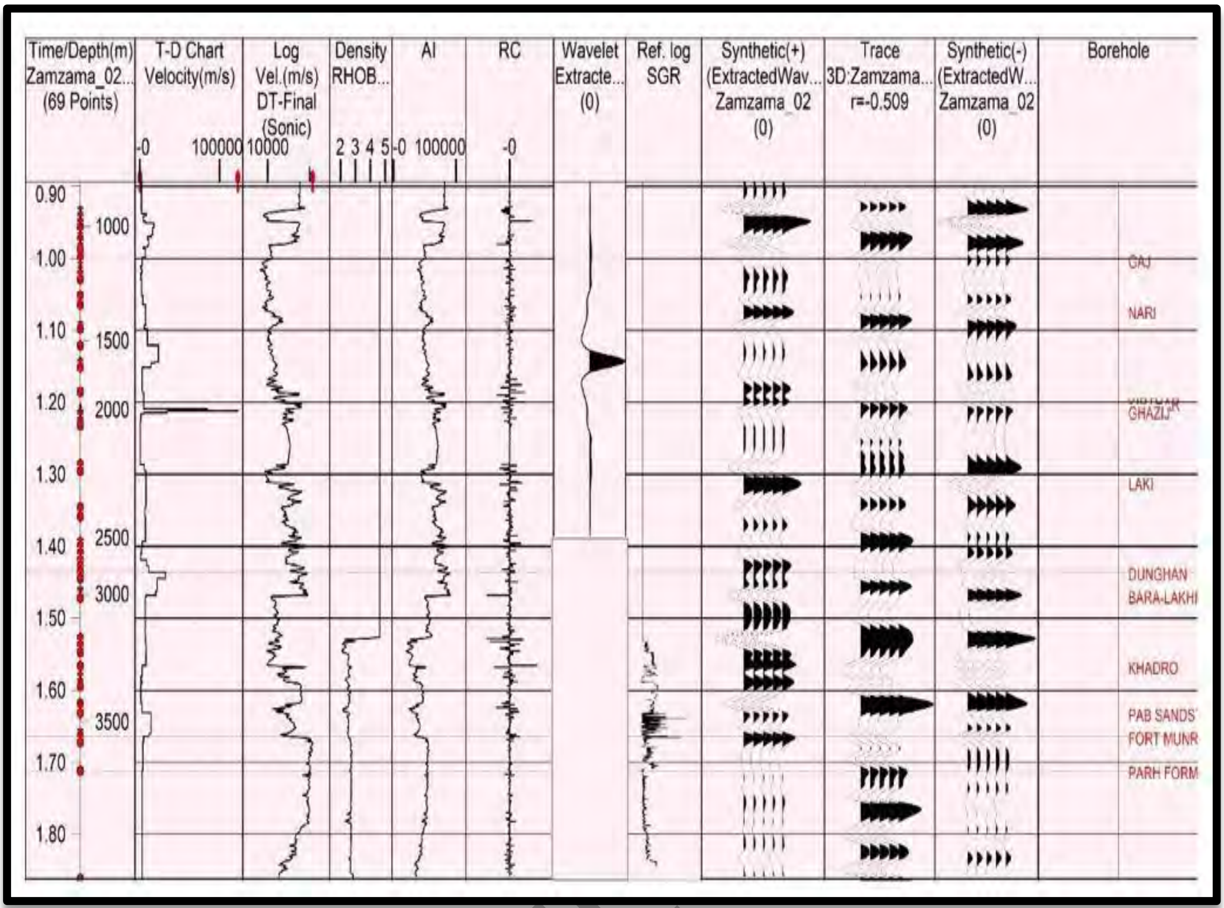

Figure 3.4: Synthetic Seismogram of Well Zamzama-02.

3.3.3 HORIZON INTERPRETATION:

The horizons were interpreted using Kingdome IHS software.The well tops are correlated with the seismic to identify the precise location of the Horizons on the seismic section.

- Khadro Formation (Sandstone, Paleocene) at 3400 m.
- Pab Sandstone (Sandstone, Late Cretaceous) at 3528 m.
- Fort Munro Formation (Limestone, Shale, Cretaceous) at 3678 m.

Three Horizons were identified by combining these Synthetic Seismograms with the seismic data in time domain. No faults have been identified in the research area. On the basis of amplitude changes and lithological contrast, the horizon is marked. Understanding these objects is essential for this type of interpretation, which is known as structural interpretation.(McQuillin, et al. 1984). Figure 3.5 depicts the interpreted section with marked horizons that is in line with well Zamzama-02.

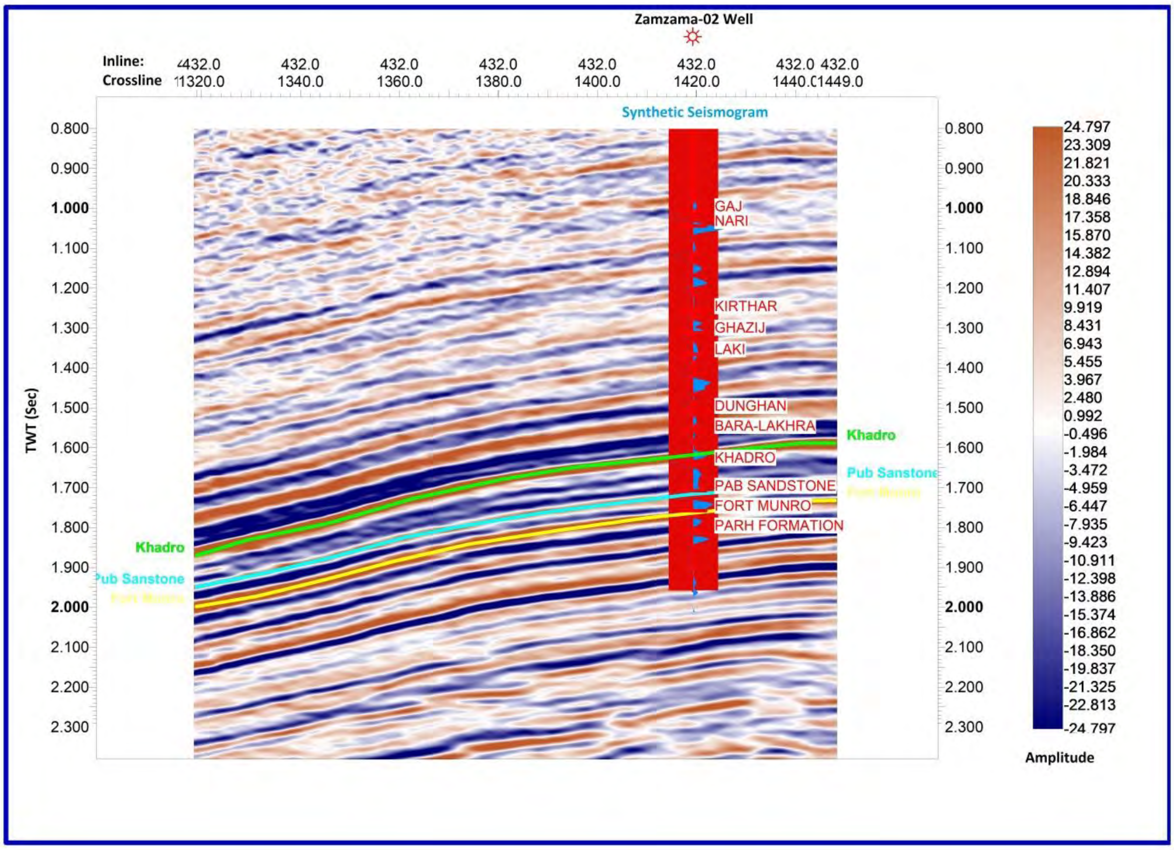

Figure 3.5: Correlation of Synthetic Seismogram of Zamzama-02 with Time Seismic.

3.3.4 DEPTH AND TIME MAP PREPRATION:

Contour maps are the final outcome of seismic interpretation. The faulting, folding, structural relief and formation slope are exposed by contour maps. Through created synthetic, the contours are mapped according to the marked horizon. Later horizons are converted to depth domain using a Time/Depth table, and depth contour maps are generated by converting seismic data from time domain to depth domain.

3.3.4.1 Time Contour Maps:

The position of the horizon in relation to time is shown by time contouring. Figures 3.6, 3.7, and 3.8, respectively, show the time contour maps of the Khadro, Fort Munro, and Pab formations. The generated maps demonstrate the variation and irregularity of the Khadro, Fort Munro, and Pab formation's subsurface pattern. While Khadro formation with time 1.5s acts as a seal for Pab formation, Pab sandstone at time 1.6s acts as a reservoir. The contours will be closed if we cover the entire area. On the basis of structural interpretation rules, we can depict the curvature pattern using the contours. (Jackson et al., 2004). The contour maps of the formations demonstrate that the well was widespread in an area where there was less time, which displays the elevated portion of the structure. Time range of pab sandstone is 1644s to 1959s

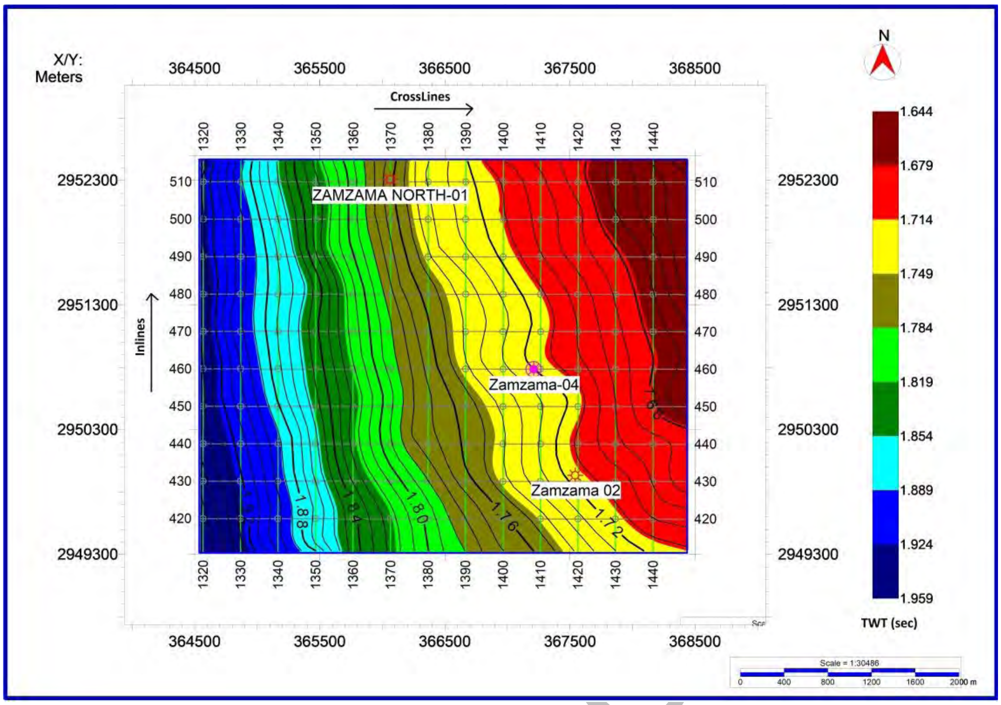

Figure 3.6: Time contour map of Pab Sandstone Formation.

3.3.4.2 Depth Contour Map:

The depth contour map identifies the presence of required structural, traps, and horizon true depths. Using the relationship between velocity, time, and depth, the time contour map of the Pab formation is transformed into a depth contour map. Calculating the depth is as follows:

S= V * T-- (3.1)

S is the depth in metres, V is the speed, and T is the two-way travel time in seconds. Due of its curvature, the depth contour map of the Pab formation depicts the anticlinal form of structure, as seen in figure 3.7. The colour bar clearly shows that Zamzama-01 is located at the top of the structure, while Zamzama-02 is situated at the elevated portion of the anticline. Due to limited 3D seismic data, there is no fault in the provided cube, but according to previous research, a major fault cuts the Zamzama field in a SW-NE direction, with the Hanging wall on the left side of contours and the Footwall on the right side. (Jackson et al., 2004). Pab, which has a thickness of over 217 metres, is the thickest reservoir rock.

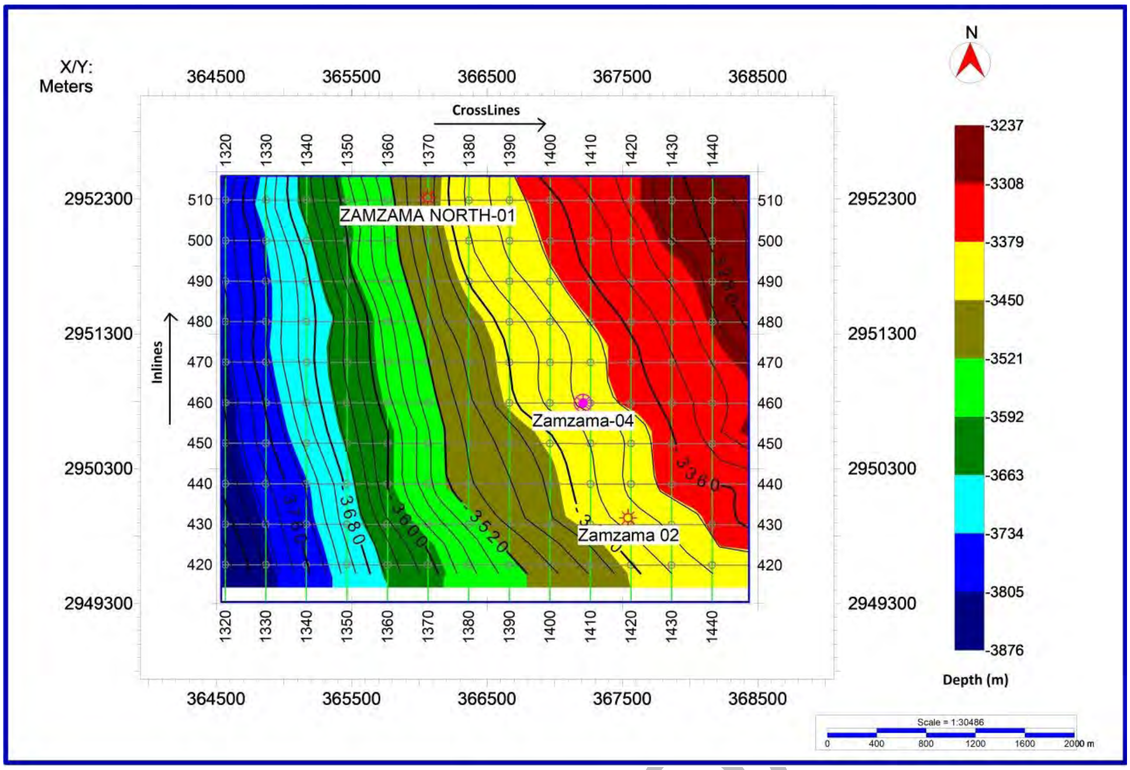

Figure 3.7: Depth map of Pab Sandstone Formation.

CHAPTER 04

PETROPHYSICAL ANALYSIS

4.1 INTRODUCTION:

The study of reservoirs, cap rock properties, and their interactions with aqueous solutions hydrocarbons and gaes is known as petrophysics.Since they are used to evaluate well and field potential as well as identify the zones within the reservoir that contain hydrocarbons and can be trapped, reservoirs are regarded as the key to the oil and gas industry (Bowman 2010)

Petrophysics is one way for figuring out reservoir parameters. This study enables measuring and identifying the liquid in a reservoir. Information on hydrocarbon zones is provided by the physical and characteristic properties of reservoir rock, such as porosity, saturation, and hydrocarbon saturation. Geologists and geophysicists work together with rock physics and petrophysics to identify the hydrocarbon producing zones and hazards in reservoir rock.(Khan, et al. 2010)

For petrophysical analysis, well logs were used to confirm reservoir features and fluid contents. Petrophysical analysis was utilized to interpret wireline well logs. Well logging refers to the precise measurement of geological and geophysical properties along the depth of the well. The "Sonde," well-logging equipment, keeps track of the chemical, physical, and fluid-relationship characteristics of rocks. (Rider 1986)

4.2 WIRELINE LOGS:

The well log is a graph that shows a well's depth and petrophysical features. In order to provide a detailed record of a formation's geological characteristics, wireline logs are utilized in the drilling and exploration industries. "Geophysical analysis and data collection performed as a function of well bore depth, with the capability of linked services" is also another term for wireline logs. There are several different types of wireline logs, which can be characterized according to their technology or purpose. Petro physicists use "open hole logs track" before the well is lined with piping, and "cased hole logs track" once the well is lined with production pipe.

4.3 CLASSIFICATION OF GEOPHYSICAL WELL LOGS:

The several classifications and explanations of geophysical well logs are listed below. The following explanation demonstrates how the logs are explained in terms of the tracks on which they are run.

4.3.1 LITHOLOGY TRACK:

The lithology track shows two logs, which are listed below.

- Calliper log(CALI)
- Gamma Ray Log(GR)

4.3.1.1 CALLIPER LOG (CALI):

The diameter of the borehole was measured using the Caliper log. The information in this record enables us to recognise cavity washouts and break outs. This log is also referred to as the quality check log for other logs as a result. Additional logs are run if this log is failed. Because the porosity and resistivity log will not display the correct values in front of a wash out, if there is wash out somewhere. The calliper log is therefore important to the field of petrophysics.

4.3.1.2 GAMMA RAY LOG (GR):

The high-energy electromagnetic waves from the formation are measured by the GR log. Gamma ray logging is regarded as passive logging since we only measure the formation property without using any sources. The electromagnetic energy that is released by the gamma ray produced by the formation is known as a photon. Compton scattering happens when a photon collides with a formation electron and the energy is transferred to the formation electron. As soon as this released Gamma ray enters the gamma ray detector, it is recorded and displayed as a count per second, hence the name "gamma ray." Identifying shale and non-shale is the primary objective of this log. (Archie 1942)

4.3.2 POROSITY LOG TRACKS:

To calculate the amount of porosity in a specific volume of rock, porosity logs are used. Porosity logs can be used in conjunction with the resistivity log to help differentiate between water, gas, and oil. The porosity logging tracks are listed below.

- Sonic Log(DT)
- Density log(ROHB)

- Neutron Log(NPHI)

4.3.2.1 SONIC LOG:

Sonic log is also referred to as acoustic log or porosity log. The components of a sonic logging system are a transmitter that emits elastic waves (sound waves) and a receiver that captures and records the p waves as they approach it. When they pass through rock, they disperse and weaken. This log contains the depth of time (t), which is also known as interval transient time (t), and which is the reciprocal of the sound wave velocity, needed for a compressional wave to pass through one foot of formation. When compared to sandstone, which has a similar porosity, shale has a lower velocity (a longer transit time). Sometimes, this log is used to measure grain size. For the uses described below,Sonic log can also be used in conjunction with other logs.

- Porosity (using interval transit Time)
- Mechanical properties of formation with (Density).
- Synthetic seismograms (with Density).
- Lithology identification (with Neutron and/or Density).
- Abnormal formation pressures detection.

4.3.2.2 DENSITY LOG (RHOB):

Using this log, the bulk electron density of rocks is determined. A gamma ray strike with an electron in the formation and scattered gamma rays (Compton scattering) picked up on the detector are used to calculate the density of the formation. As the formation's bulk density rises, the count rate falls, and vice versa. Bulk density is computed from the density log as the sum of the fluid density and the matrix density of the formation. On the other hand, density log is used to identify and collaborate with other logs to achieve a variety of goals.

4.3.2.3 NEUTRON LOG (NPHI):

This type of porosity log is used to calculate the amount of hydrogen ions present in a formation. A chemical source continuously emits neutrons in the neutron logging device. Some energy is emitted when these neutrons interact with the nuclei during the creation. Because a hydrogen atom's mass is equal to a neutron's, collisions between electrons and hydrogen atoms result in the greatest energy loss. Energy loss is comparable to the porosity of the formation because hydrogen indicates the presence of fluid in the pores of the formation. The neutron porosity is particularly low when gas 54, rather than water or oil, fills the formation's pores. This is so because gas has less hydrogen than both water and oil do.

The term "gas effect" describes how the presence of a gas causes the neutron PHI to be less porous.

4.3.3 RESISTIVITY LOG TRACKS:

Resistivity logs come in a variety of forms, including MSFL, LLD, and LLS. There are two logs in the data that are described below. These logs measure both the formation fluids' and the subsurface resistivity. They are very helpful in distinguishing between hydrocarbon- and water-saturated deposits. Resitivity logs are as bellow

- Later Long Deep(LLD)
- Later Long Shallow(LLS)

4.3.3.1 LATERLOG DEEP (LLD):

A type of log called a laterlog deep is used to analyse the uninvaded zone in detail (LLD). This log can be used for fresh mud in addition to salty mud. This log is frequently used to calculate a formation's resistivity. It penetrates far deeper than the others when compared to it (LLS log).

4.3.3.2 LATERLOG SHALLOW (LLS):

Laterlog shallow (LLS) is a method for shallowly examining the invaded zone. Mainly because the LLD was more thorough in its investigation.

4.4 WELL DATA:

Landmarked provided the well data in digital form using the LAS (Log ASCII Standard) file format after receiving specific permission from the Directorate General of Petroleum Concession. Additionally, LMKR supplied well tops and headers. The wells and their tops are thoroughly described in the table below. Information regarding the well header is provided in Table 4.1. In Table 4.2, the Well tops of Zamzma-02 are displayed

S#	Common Well Name	Latitude	Longitude	KB(m)	Total Depth(m)
1.	Zamzama-01/ST-1	26.73446° N	67.66197° E	40.0	3950.00
2.	Zamzama-02	26.70466° N	67.66851° E	45.0	4000.00
3.	Zamzama-04/ST-3	26.71381° N	67.66828° E	40.0	3941.00

Table 4.1: Well headers information of wells used in project.

S#	Formation name	Formation Aga	Depth(Meters)
1.	Alluvium	Recent	**7**
2.	Siwalik	Miocene/Pleistocene	**49**
3.	Gaj	Miocene	**1200**
4.	Nari	Oligocene	**1302**
5.	Kirthar	Eocene	**1973**
6.	Ghazij	Eocene	**2128**
7.	Laki	Eocene	**2275**
8.	Dunghan	Paleocene	**2666**
9.	Girdo	Paleocene	**3253**
10.	Khadro	Paleocene	**3400**
11.	Pab Sandstone	Late Cretaceous	**3455**
12.	Fort Munro	Early cretaceous	**3681**

Table 4.2: Well tops of well Zamzama-02.

4.5 WORKFLOW OF PETROPHYSICAL ANALYSIS:

A petrophysical analysis of the wells Zamzama-01/ST-1, Zamzama-02, and Zamzama-04/ST-3 was done using the log curve data. The following geological log curves were produced using known log data.

- Shale volume(VSH)
- Density Porosity(PHiD)
- Total Porosity(PHiT)
- Effective Porosity(PHiE)
- Saturation of water(Sw)
- Saturation of hydrocarbon(Sh)

The entire process of a petrophysical analysis is shown in Figure 4.1.

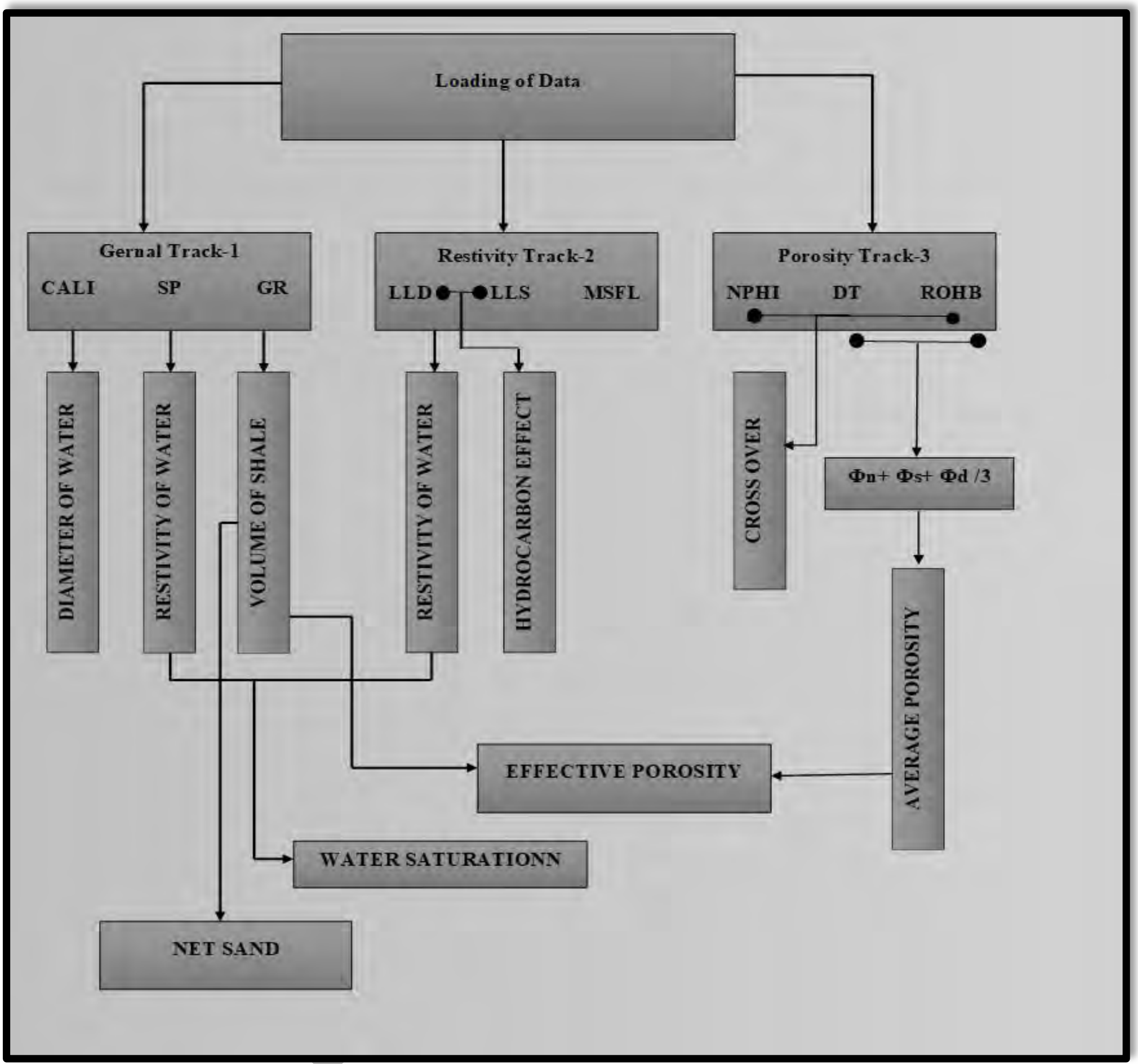

Figure 4.1: Work flow of Petrophysical analysis.

4.5.1 ZONE OF INTEREST:

Using neutron porosity and density logs based on the Gas effect, the target hydrocarbon zone was found. The gas effect, which shows the presence of hydrocarbons and helps in the identification of reservoir zones, is the crossover of the density log and the neutron porosity log. We used a gamma ray log character to confirm the lithology, which shows the occurrence of sandstone and shale. (Rider 1986)

4.5.2 CALCULATION OF VOLUME OF SHALE:

A little amount of radioactivity can be found in most rocks, however metamorphic and igneous rocks have a higher radioactivity level than sedimentary rocks. A simple Gamma ray log is occasionally referred to as a "Shale log" because the greatest radiations are found in alluvial rocks. A quantitative gamma ray (GR) log is used to determine the volume of the shale. The shale base line indicates the largest average log value as being 100% pure shale, whereas the sand base line indicates the lowest average gamma ray log value as being sand. Using a linear scale, the Gamma Ray (GR) log from equation 4.1 can be used to calculate the volume of shale.

$$\boldsymbol{Volume\ of\ Shale\ (Vsh) = I_{GR} = \frac{GRlog - GRmin}{GRmax - GRmin}} \text{..} \mathbf{4.1}$$

Vsh = Volume of shale

GR = Gamma Ray Reading Information

GRmin = Minimum Gamma Ray Value

GRmax = Maximum Gamma Ray Value

The estimated amount of shale in wells is displayed in Table 4.2.

4.5.3 CALCULATION OF POROSITY:

Because reservoir rocks naturally contain oil and gas, the amount of liquids trapped within their empty spaces depends on this. The porosity of a rock is its proportion of void spaces to its total volume, and its permeability is its capacity to allow fluids to pass through specific void spaces.(Tiab and Donaldson 1996)

4.5.4 CALCULATION OF DENSITY POROSITY:

The density porosity may be determined using the density log. To accurately measure porosity, the density log can be utilised if the matrix densities are known. (Asquith, Krygowski et al. 2004)

Sandstone comprises up the rocks in this research area. Equation 4.2 allows us to calculate density and porosity. (Rider 1986).

Density Porosity = (Density Matrix - Density Log) / (Density Matrix- Density Fluid)….4.2

The obtained density porosity values are displayed in Table 4.2.

4.5.5 CALCULATION OF AVERAGE POROSITY:

Average porosity is calculated using the density porosity log and the neutron porosity log. The average porosity can be calculated using equation 4.3 below. (Rider 1986)

Average Porosity = (Density Porosity + Neutron Porosity)/2……………………………4.3

In a petrophysical investigation, the effective porosity or permeability is estimated using the average porosity.

The computed average well porosity values are displayed in Table 4.2.

4.5.6 CALCULATION OF EFFECTIVE POROSITY:

Effective porosity of rock is defined as the volume of interconnected void space divided by the total volume of the rock when the shale effect is zero. The formula 4.4 is used to calculate the effective porosity of the shale rich zone, which is zero (Asquith, Krygowski et al. 2004)

Effective Porosity = Average Porosity * V matrix………………………………4.4

Vmatrix=1-Vshale…………………………………………………………………4.5

The effective porosity value of wells is displayed in Table 4.2.

4.5.7 CALCULATION OF WATER SATURATION:

It can be described as the proportion of effective pores in a formation that are filled with water. To determine water saturation Sw, use the Archie equation below. (Rider 1986)

$$S_w = \{R_w/(R_t * \phi m)\}1/n$$

Where as

Sw= Water Saturation

m= Cementation Factor (constant)

n= Saturation exponent

Rw,Rt= Restivity Of Water And Formation Restivity

PhiT= Average Porosity

Rt =resistivity log (LLD).

Using the parameters a=1, m=n=2, Table 4.2 displays the computed water saturation (SW) for three wells.

4.5.8 ESTIMATION OF HYDROCARBON SATURATION:

The quantity of hydrocarbons present in the pore spaces is referred to as "hydrocarbon saturation." The equation is used to calculate it (4.6).

$$S_h = 100 - S_w \quad (4.6)$$

Sh= Hydrocarbon Saturation

Sw= Water Saturation

This is an indirect method of determining hydrocarbon saturation using well logs. The wells' hydrocarbon saturation is displayed in Table 4.3.

S#	Petrophysical Properties	Petrophysical values
1.	Volume Of Shale	45.0
2.	Density Porosity	55.0
3.	Average Porosity	04.0
4.	Effective Porosity	05.0
5.	Water Saturation	04.0
6.	Hydrocarbon Saturation	45.0

Table 4.3: Values used in the petrophysical analysis.

4.6 PETROPHYSICAL ANALYSIS OF WELLL:

The complete collection of logs is presented in three fundamental tracks, known as the triple combination. The results of the petrophysiological analysis of the Zamzama-02 well are outlined below.

The following three tracks on three genialized well logs

- Lithology Track
- Porosity Track
- Resistivity Track

4.6.1 PETROPHYSICAL INTERPRETATION OF ZAMZAMA-02:

The Pab Sandstone contains a considerable amount of hydrocarbon, according to the petrophysical interpretation of Zamzama-02, and the well is currently producing a significant amount of gas. As shown in Figure 4.2, petrophysics is carried between 3470-3500 metres.

4.6.1.1 ZONE-01:

The Zone-01 range of 3475-3485 is where the Pab sandstone in the Zamzama-02 well is located. The small deflection of the Caliper log indicates that there is some shale in the sand. There is a clear crossover between LLD and LLS, and cross-over response between Neutron porosity and Density log, indicate the presence of hydrocarbon saturation in zone_01. Zone_01 of zamzam-02 is shown in figure 4.2

4.6.1.2 ZONE_02:

The Zone-02 range of 3487 to 3492 is where the Pab sandstone in the Zamzama-02 well is defined. Low gamma ray log values and high resistivity log values, as shown in Zone-02, suggest good hydrocarbon accumulation.

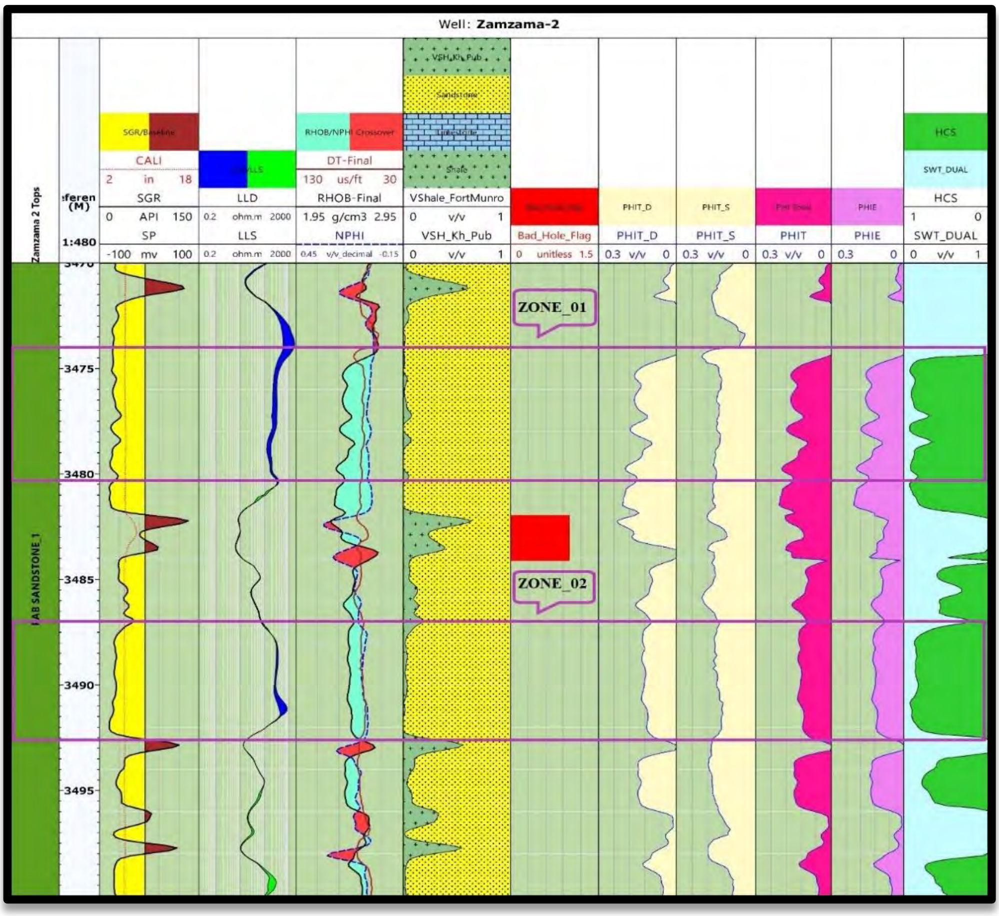

Figure 4.2: Petrophysical interpretation of the Zamzama-02

Well Name	ZONE	Top	Base	VSH	PHID	PHIS	PHIE	SW	SH
Zamzama-02	01	3475	3480	15%	10%	9%	8%	39%	61%
Zamzama-02	02	3487	3492	7%	8%	6%	6%	17%	83%

Table 4.4: Petrophysical results for Zamzama-02

4.7 CROSSPLOT OF NEUTRON AND DENSITY POROSITY:

To assess porosity, the lithology of the rock must be identified. Predicting lithology requires knowledge of both density and porosity. Cross plots of Zamzamza-02's density and porosity logs are shown in Figure 4.3. It was noted that the majority of the data points in these cross plots are in the Sandstone density range of 2.2 to 2.65 g/cc and porosity range of 0.5 to 5%. A gamma ray is captured on the z-axis and used to display the colour points (Mendoza, et al. 2006)

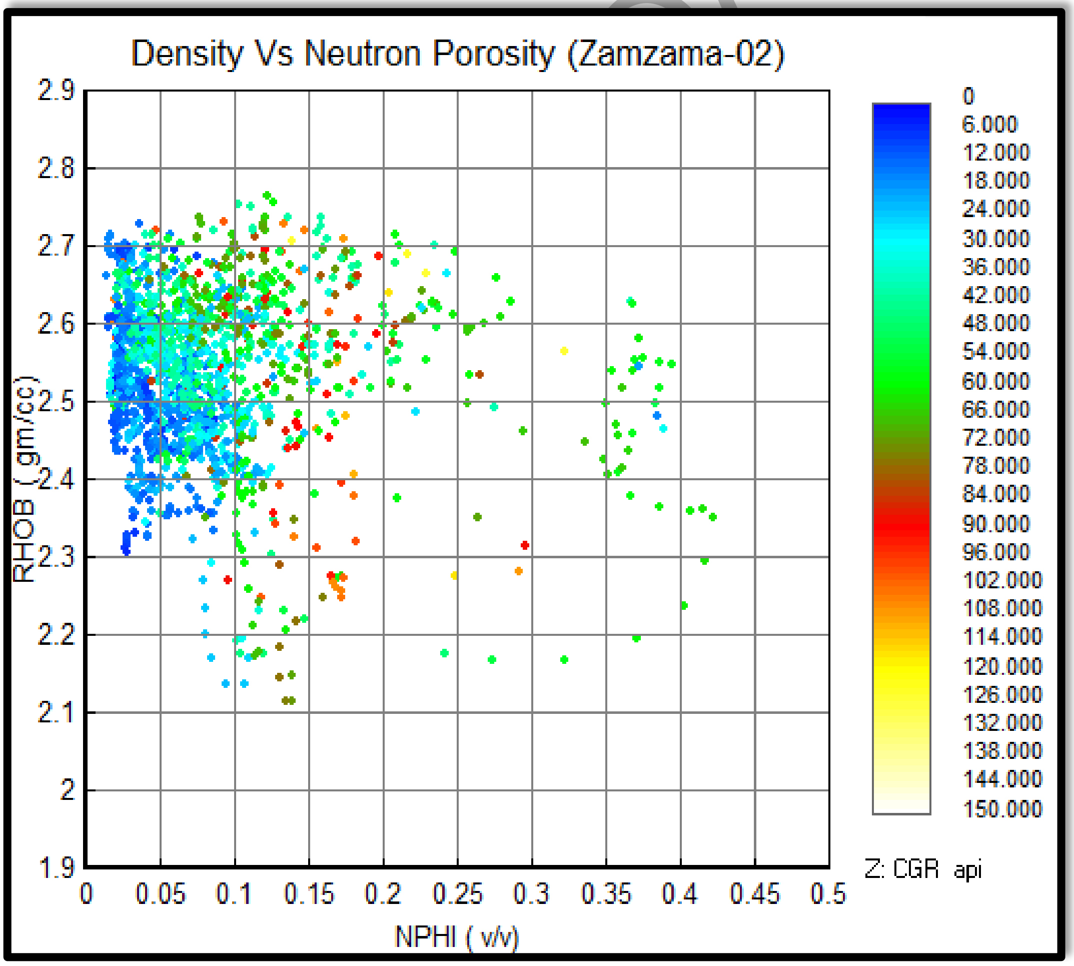

Figure 4.3: Cross plot of Neutron Porosity versus Density of Zamzama-02.

4.8 CROSSPLOT OF DENSITY AND EFFECTIVE POROSITY:

On the basis of density contrast, the Shale and Sand facies of the Zamzam-02 well are recognized in figure 4.4 cross plot between density and porosity. Sand, which is also porous, gets incorporated into this well in significant amount. Hydrocarbon saturation overlying for

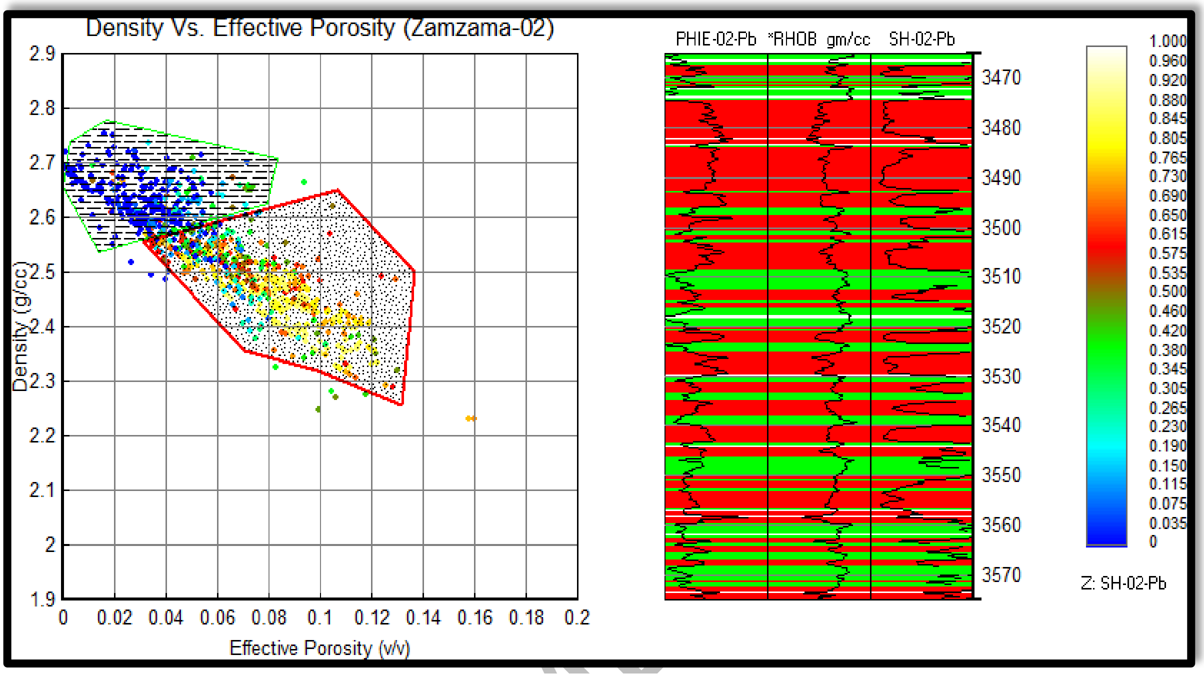

Figure 4.4: Cross plot of Density and Porosity of Well Zamzama-02.(Mendoza, Torres-Verdin et al. 2006)

color coding.

4.9 PETROPHYSICAL RESULTS:

- Petrophysical studies were carried out using well log data to establish the rock parameters. A petrophysical analysis of well Zamzama-02 confirms that the reservoir zone contains significant levels of hydrocarbons (gas).
- Less than 31% of the volume of each well is made up of clean sand.
- Pab Sandstone has an effective porosity of more than 8%. Hydrocarbon saturation ranges from 40 to 70%, whereas water saturation is between 30 and 60%.
- Petrophysical research shows that the Pab sandstone reservoir is 60% saturated with hydrocarbons.

CHAPTER 05

SEISMIC INVERSION

5.1 INTRODUCTION:

Using data collected on the surface, geophysical inversion is the process of calculating earth subsurface properties and mapping the physical structure of the earth. All seismic interpretation and analysis are included by this broad concept.

Our main area of interest is seismic inversion, which mostly relates to impedance results. One of the best methods for finding probable hydrocarbon locations is 3D seismic surveys. Seismic inversion can be used to examine spikes response at geological interfaces where lithology varies underground. It's possible because seismic waves' paths shift at interfaces due to differences in lithology and density. The acoustic impedance is calculated using the product of velocity and density. The layer property is derived from the acoustic impedance, whereas the interface property is derived from the seismic amplitude. We can infer that the interface's acoustic impedance response varies by comparing values of acoustic impedance obtained through inversion. The porosity measured from boreholes can be used to extrapolate the results and determine the nature of the entire reservoir, which can be used for the best possible field development. (Barclay, et al. 2008)

In addition to enhancing seismic resolution, it also makes analysis simple. The seismic cube can be inverted using well log data to determine subsurface characteristics like porosity and lithology. (Veeken and Da Silva 2004)

In seismic inversion, extrapolation from actual collected data is frequently carried out by guessing, comparison, and computation. According to its definition, seismic inversion is "a range of scientific frameworks for lowering information to acquire meaningful facts about the physical environment based on extrapolations resulting from understandings"(Sen 2006)

To rearrange the acoustic impedance, for example, we use porosity in seismic inversion to compute the properties. Seismic inversion helps with the well planning, reservoir characterisation, and monitoring of changes in rock properties when fluids are injected. (Gavotti 2014)

According to Russell and Hampson (1991). There are three different types of inversion (post stack inversion)

- Model Based Inversion
- Pre stack Inversion
- Classical limited or Band Limited inversion

Model-based and sparse-spike inversion includes in this research project. Both model-based and sparse spike inversion techniques provide equivalent and relevant results. Model Based Inversion produces better results over Sparse Spike Inversion when these two approaches are connected to real information. (Russell and Hampson 1991)

5.2 MODEL BASED INVERSION:

A sort of post-stack inversion that is frequently used in industry is model-based inversion (absolute acoustic impedance). With respect to Post-Stack inversion, input data is easily accessible. (Kneller, et al. 2013)

The Model Based Inversion calculation algorithm is shown in the simplified form below. This program aims to change the underlying speculative model until the real wavelet matches the synthetic wavelet, assuming that wavelet (W) and seismic (S) data are available. (Gavotti 2014)

It must be optimized till the error is at its lowest. Until and unless the function minimizes the error between the synthetic and actual seismic trace, we can say that the model (geological) has been transformed into a level equation (6.1) that is reasonable. (Kneller et al. 2013)

$J = weight1 \times (S - W * R) + weight2 \times (M - H * R)$ 6.1

Where as

S= Real Seismic Trace

W= Extracted Wavelet

R= Reflectivity Series Coefficient

M= Interpreted Horizon Data

H= Operated convolved with the reflection coefficient for impedance

Equation 6.1 is divided into two components, the first of which resolves the seismic trace and the second of which models the initial computed impedance. The well data use to reduce modelling error and a little amount of noise. Hard constraints are preferable for inversion analysis, whereas soft constraints (variogram model) can be used to incorporate additional information such as a low frequency model. (Gavotti 2014).

The technique of model-based inversion is shown in Figure 5.1.

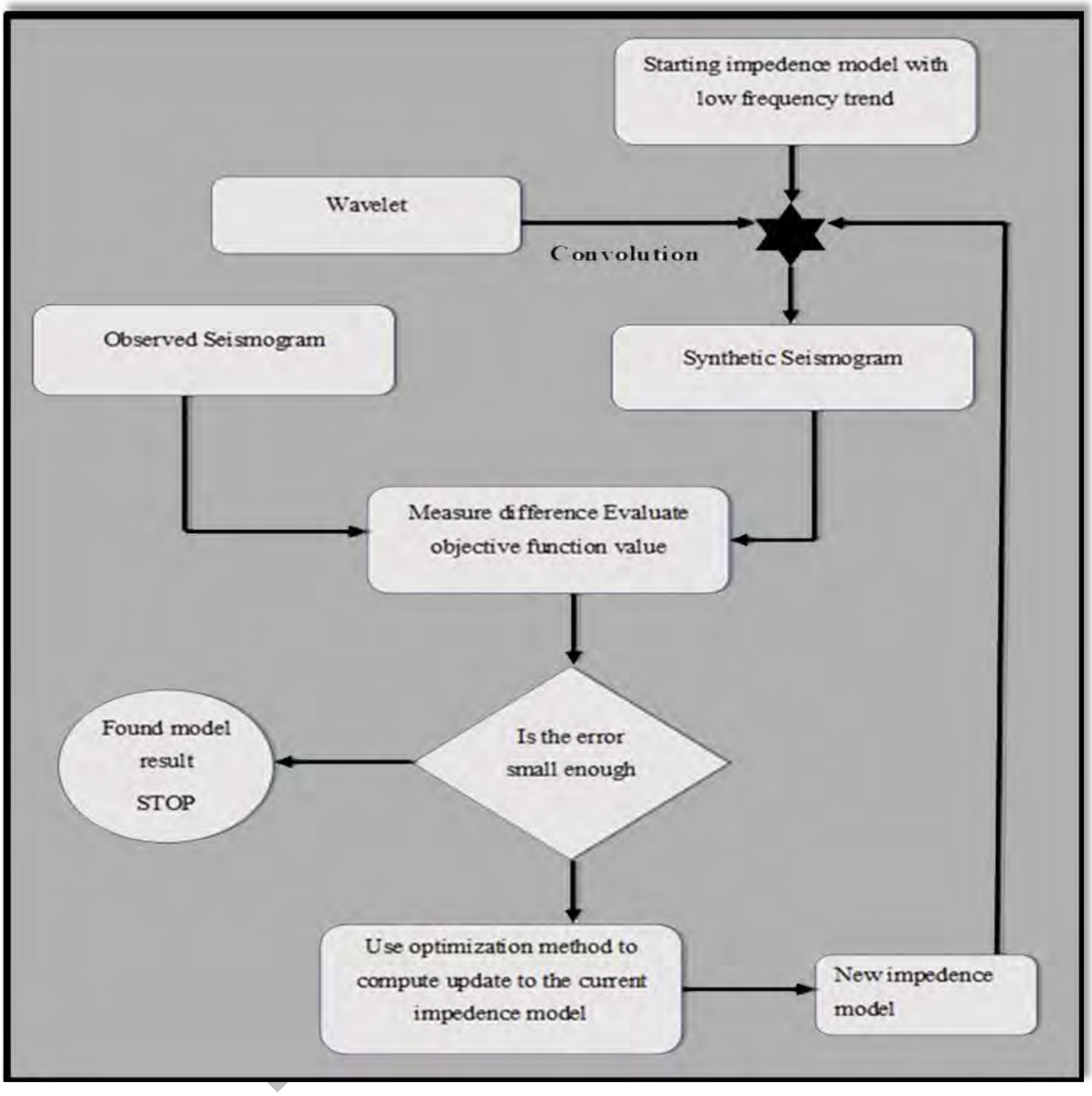

Figure 5.1: Model based inversion scheme for P-impedance estimation (Sen 2006)

5.3 WAVELET EXTRACTION:

All current seismic inversion techniques require seismic data and a wavelet derived from the data. A reflection coefficient series from a well inside the boundaries of the seismic survey is typically used to estimate the wavelet phase and frequency. Accurate wavelet estimation is essential for any seismic inversion to be successful. The results of the seismic inversion, and subsequently the estimates of the reservoir quality, may be strongly affected by the assumed form of the seismic wavelet. (Sen 2006)

After identification of wavelet synthetic logs are generated by seismic inversion for all seismic traces. For quality assurance, the generated synthetic seismic traces are compared to the actual seismic and the inversion result is convolved with the wavelet. (Sen 2006)

Convolution determines inversion, such as when a wavelet and a reflectivity series are convolved to produce synthetic data. (Cooke and Cant 2010)Use of a zero-phase technique will produce more acceptable results for seismic inversion and wavelet interpretation. The worst results of wavelet inversion are caused by phase shift. The acoustic impedance error and the phase shift in a wavelet are proportional.

In order to evaluate the relationship between inverted reflectivity series and recovered reflectivity from seismic at the well site, a zero-phase geostatistical wavelet is shown in Figure 5.2. A 66% correlation exists between true trace and synthetic. Wavelet extraction covered a time range of 1900 to 2300 ms and had a 100 ms wavelength.

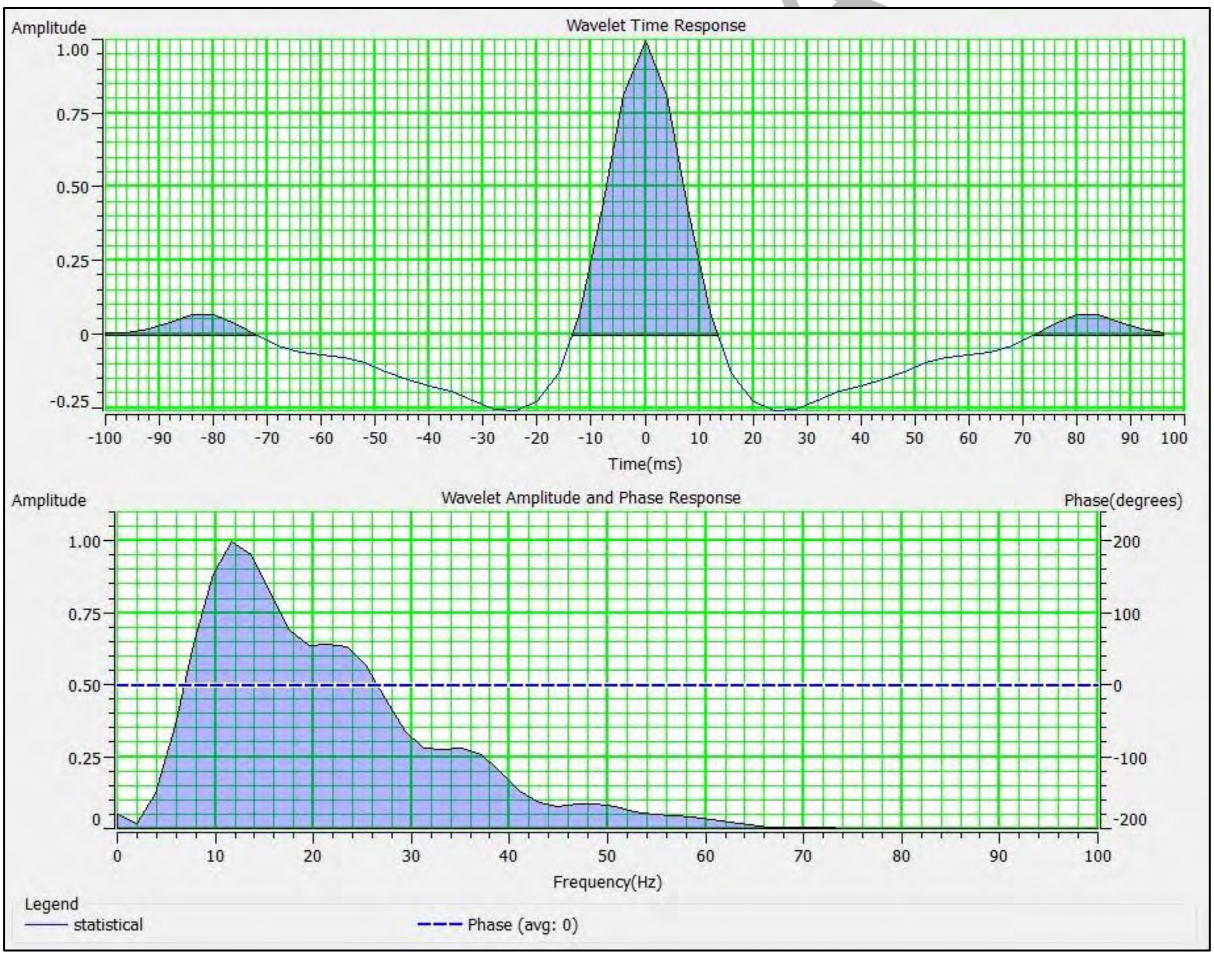

Figure 5.2: Extracted Geostatistical wavelet (top) along with phase spectrum and amplitude (bottom) from the seismic data. Average phase is represented by blue dotted line.

5.4 LOW FREQUENCY MODEL:

Absolute P-impedance (Model based inversion) and relative P-impedance are the only two types of acoustic impedance models. Low frequency model is not involved in sparse spike inversion. For quantitative interpretation, absolute acoustic impedance is used, but relative P-impedance is used for qualitative interpretation. Absolute acoustic impedance is not calculated using the low frequency model itself; rather, the algorithm of the model-based inversion technique included in it. (Cooke and Schneider 1983)

The density and sonic logs, which are the two hard restrictions, can be used with a low frequency model to derive the absolute acoustic impedance from inversion. The results will be more accurate when a low frequency model is used. (Lindseth 1979)A model-based low frequency inversion model is shown in Figure 5.3.

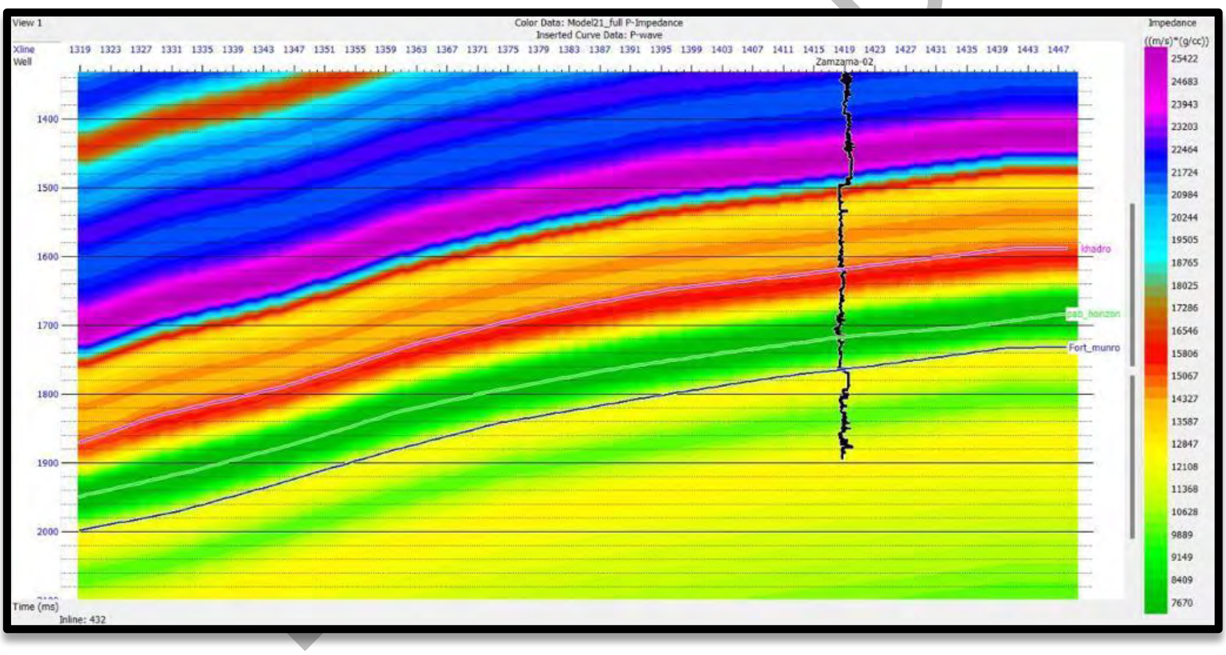

Figure 5.3: Low frequency model for the application Model based inversion.

To develop a precise starting model, some authors recommended using the autoregressive approach with linear programming estimation(Oldenburg, Scheuer et al. 1983) as well as to the development of linear seismic inversion(Cooke and Schneider, 1983), Each of these approaches has a non-uniqueness problem because the seismic reaction can be explained by multiple models. (Gavotti 2014).

5.5 INVERSION ANALYSIS:

The study of well data was followed by model-based inversion on the seismic cube. The acoustic impedance at the well location was inverted from a single trace. The reflection series was convolved with the extracted zero phase wavelet to produce the synthetic. The synthetic trace was correlated with the actual seismic trace.

The inversion result is shown in red. In the left track of the model in figure 5.4, the initial model is illustrated in black, and the filtered impedance is shown in blue. The recovered wavelet from seismic data is shown on the third track in black, while the synthetic trace from inversion is shown on the second track in red. On the fourth track, the RMS error between the seismic and synthetic data is highlighted in red.

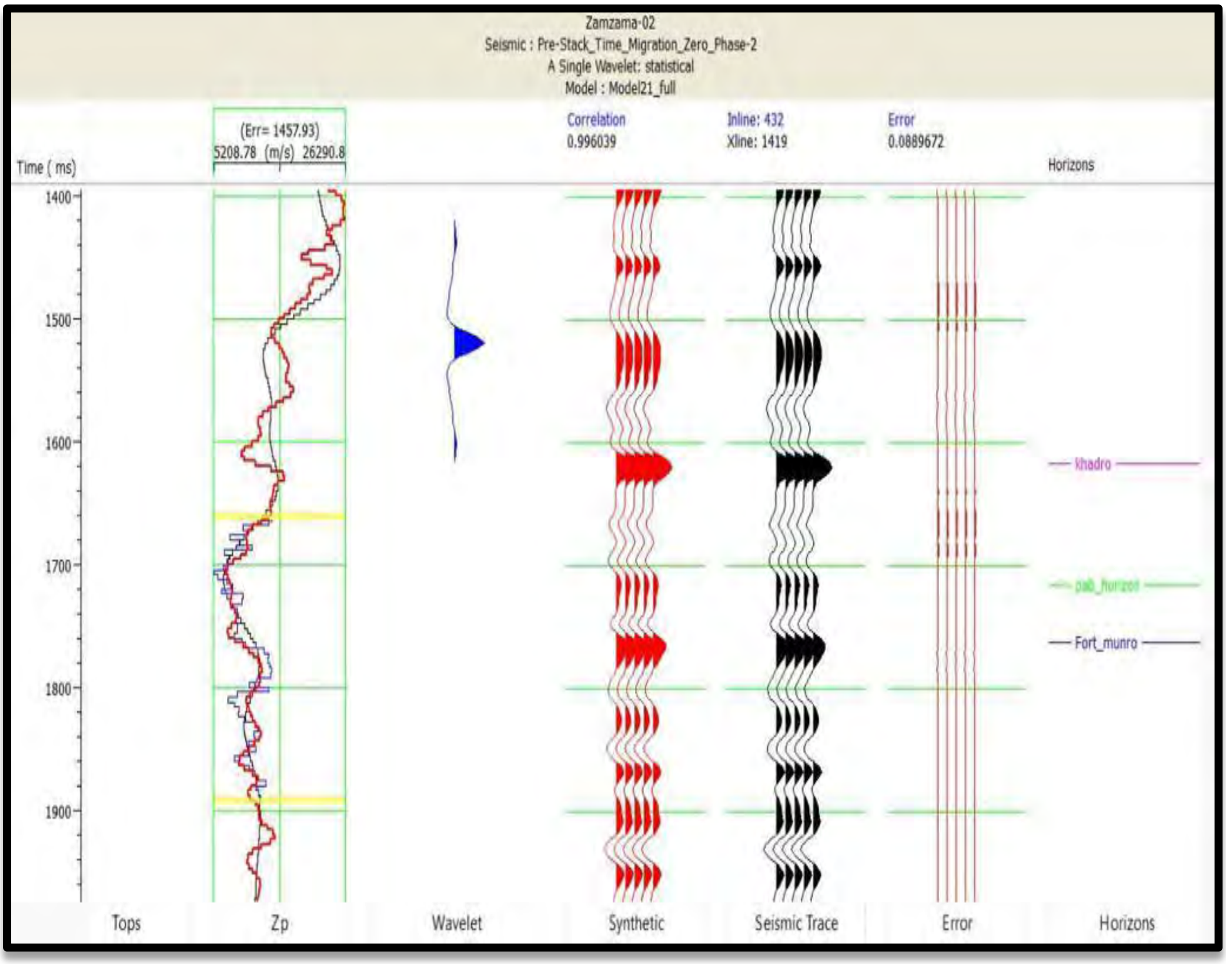

Figure 5.4: Zamzma-02 Model based inversion with initial model.

5.6 INVERTED IMPEDENCE SECTIONS:

Figure 5.5 depicts the well Zamzama-02 and P-wave are the inverted acoustic impedance section of inline 432. Pab is a good reservoir rock, as shown in figure 5.5, since it has low impedance surrounded by two layers of high impedance. Model-based inversion was only carried out in the time window of 1900 to 2300 ms, which included the tops/horizons of interest.

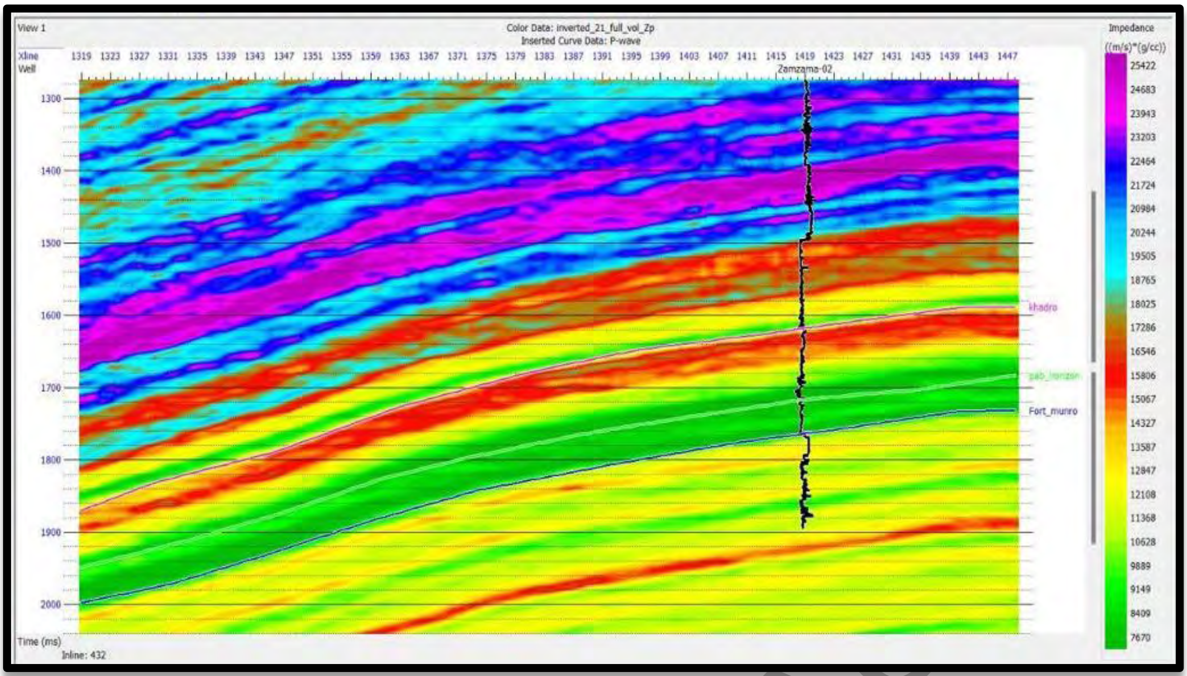

Figure 5.5: Inverted impedance cube of Inline 432 with P-wave curve displayed.

For strata with different lithologies, the model-based inversion results showed patches and varied acoustic impedance values. The Pab sandstone, which has a depth of 3460 metres and is located at a height of 1950 metres, is the reservoir zone. The petrophysical studies described in the previous chapter allows for the simultaneous identification of the Pab and high potential zone at the same depth. The Pab sandstone represented by the green colour patches indicates that the data at this area is in the form of patches. The Khadro and Fort Munro shale can be distinguished by their greater impedance values, which are located below and above the green colour layer, respectively. A shale unit usually has a high impedance. (Gavotti 2014). These layers act as the seal rock for the Pab Sandstone. According to production and current status, the well Zamzama-02 is the top gas-producing well.

5.7 POROSITY CALCULATION:

Petrophysical properties (porosity and permeability), which are difficult to accurately define, and these properties are the most important factor for reservoir characterization. Permeability and porosity measurements are problematic since they are only accurate at the well site and vary significantly between reservoir zones. The abovementioned issue needs the integration of petrophysics, rock physics, seismic inversion, and surface seismic data in order to produce more accurate results. (Leite and Vidal 2011)

Quantitatively calculating the reservoir of Pab sandstone's porosity is a tough but important task. Because discrete shale shows a range of porosities, it makes it difficult to estimate porosity when it is present in reservoir rock. (Adekanle and Enikanselu 2013)

Calculating porosity can be done in a number of ways. Some of these techniques make use of exact models and well-logged data. Well interpretations offer the best vertical resolution and a good estimation of porosity in sparse regions.

The spatial variation of porosity is made more widespread when inversion findings and petrophysics are coupled. Seismic inversion's main goal is to produce models for reservoir parameters like water saturation and effective porosity for all well locations.(Rijks and Jauffred 1991)

Due to the fact that porosity rises as acoustic impedance decreases, we have an inverse relationship between the two. Porosity and acoustic impedance are cross-plotted in Figure 5.6 Porosity and acoustic impedance are equated using the best fit line between the estimated values. Using their approximate value at the well site, below is a diagram of the impedance-based porosity equation.

$Porosity = -0.0016 * AI + 30.151$……………………………...5.2

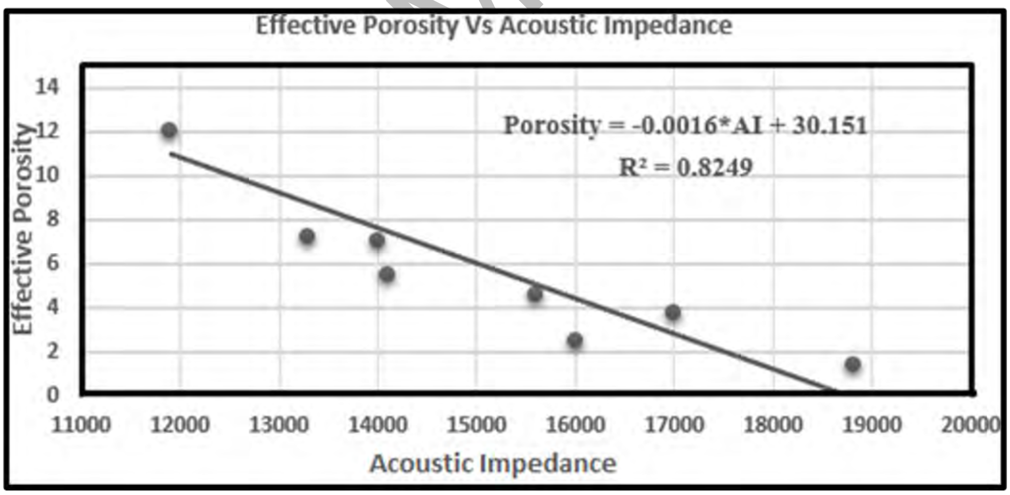

Figure 5.6: Porosity versus Acoustic impedance.

The Pab sandstone's inverted impedance surface is P-impedance according to the relationship mentioned above. The zones indicated in the previous sections can be associated because impedance is inversely proportional to effective porosity. In figure 5.7, 5.8 and 5.9 shown the acoustic impedence map of pab sandstone, fort munro and khadro. The colour bar of these figure clearly shown that the zone of zamzama-02 have low impedence zone than the surrounding zone. Zamzama-02, in the middle of the map, has a lower acoustic impedence than the other regions. When exploring for further hydrocarbons in high-potential zones in the future, this research may be helpful.

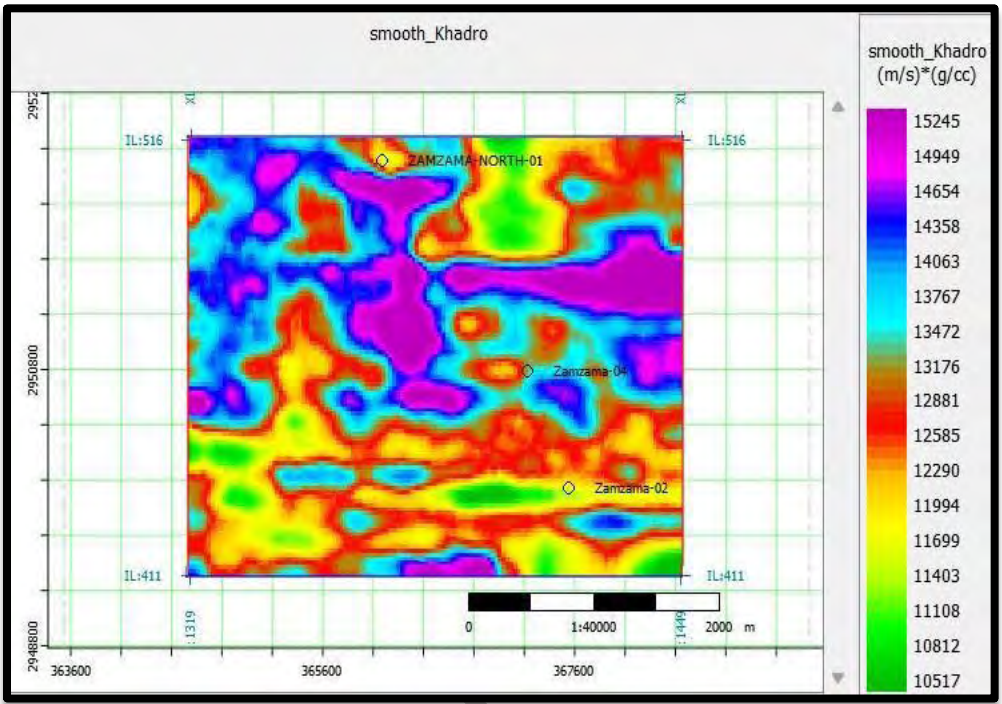

Figure 5.7: The acoustic impedance map of Khadro.

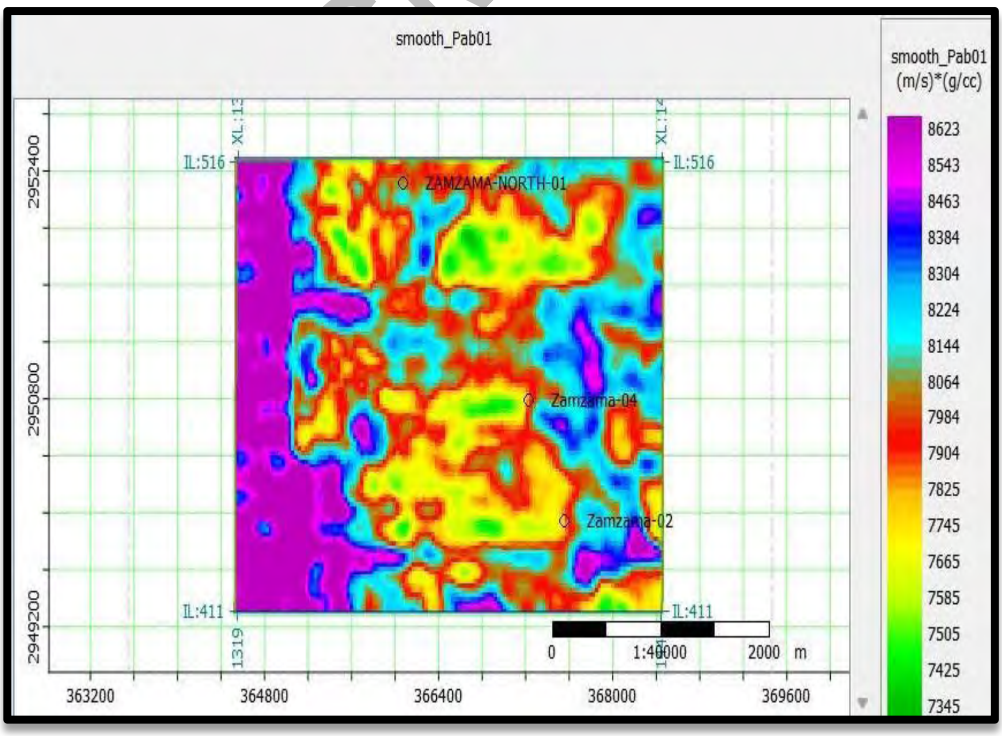

Figure 5.8: The acoustic impedance map of Pab sandstone.

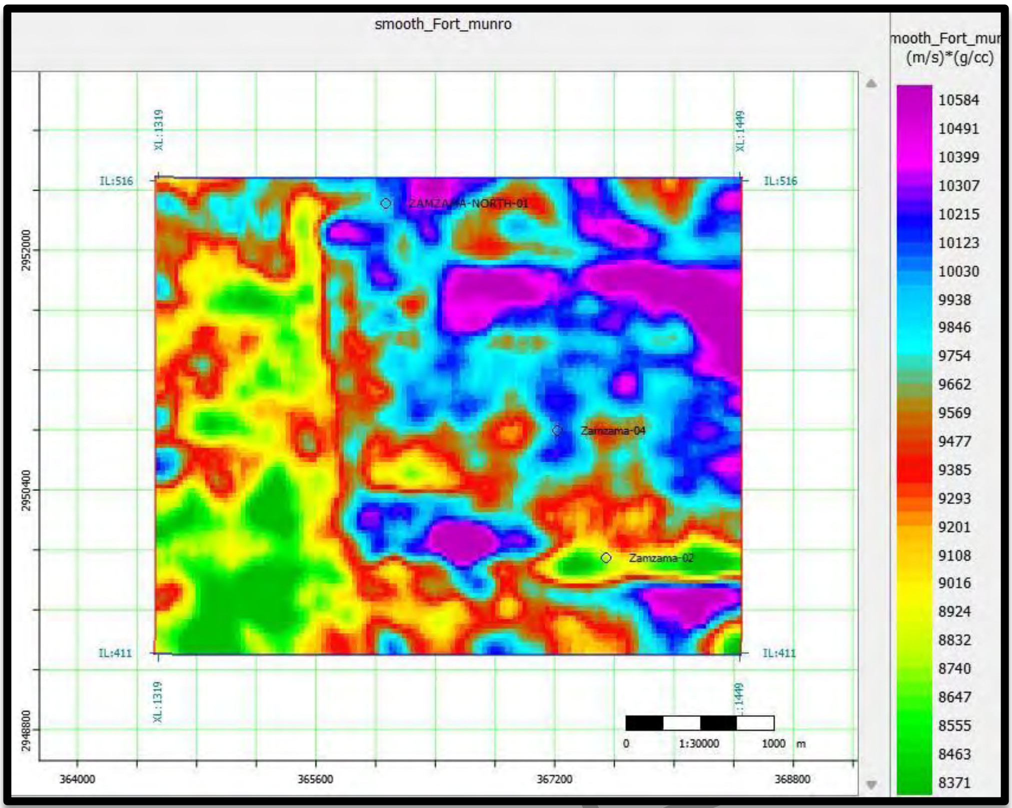

Figure 5.9: The acoustic impedance map of Fort Munro.

CHAPTER 06

ROCKPHYSICS MODELLING

6.1 ROCK PHYSICS MODELLING:

Rock physics modelling fundamentally provides the link between seismic and rock characteristics. Seismic waves are able to travel to tremendous depths in the earth because of their large amplitude and low frequency. We utilize rock physics modelling to connect seismic to rock properties and quantitatively interpret the rock because seismic cannot resolve the underlying characteristics of rock and even thin beds are not detected by seismic.

6.1.1 BULK DENSITY AND COMPRESSIONAL AND SHEAR WAVE VELOCITIES:

Velocities and densities used in seismic modeling for exploration are typically derived from mostly wireline log data. Particle mobility in the P-wave-characterized wave transmission trend. Although moving half as quickly as a compressional wave, the S-wave travels along the same path as the P-wave, but its particle motion is in opposition to the direction of wave propagation. The mean value of the densities of the components is used to create the very straightforward variable known as bulk density.

6.1.2 CALCULATION OF ELASTIC MODULI:

Because we concentrated solely on porosity and densities in Petrophysics, comprehension of the isotropic and elasticity context of velocity and density is also necessary in order to comprehend the rock physics instruments of seismic methods. (Simm, et al. 2014).

The elastic and isotropic behavior of rocks can be explained by a number of different elastic variables. Any other elastic parameter can be calculated from any two independent measurements.

In this study, shear and compression wave velocities are used to measure other elastic moduli. Elastic moduli explain how different stresses affect how rocks respond.

Equation 6.1, which shows that sonic is in microseconds per foot and Vp is in metres per second, is used to compute Vp log by Compressional Sonic log of wells Zamazam-02

$$*\mathbf{Vp} = \left(\frac{\mathbf{10^{\circ}}}{\mathbf{3.28 * DT}}\right) \text{.......................................} \mathbf{6.1}$$

In order to compute the Vs, well Zamazam-01/ST-1 provides both shear and the compressional logs. However, only compressional logs are offered in Zamzama-02 and Zamzama-04/ST-3; as a result, Vp and Vs can be approximated using Castagna's (1985) empirical relation in Table 6.1, below. We utilise the Castagna empirical relation to compute the Vs for both wells, Zamzama-02 and Zamzama-04/ST-3, because Zamzama is a sandstone reservoir and the Castagna empirical relation only applies to sandstone reservoirs.

6.1.3 BULK MODULUS:

It is the ratio of volumetric strain to stress. The response of a substance to uniform compression and uniform pressure is measured by the bulk modulus of the substance.

6.1.4 YOUNG'S MODULUS:

The Young modulus is the proportion of linear stress to linear strain within the elastic limits where Hook's law is applicable. Young's modulus is used to gauge the stiffness of isotropic elastic materials.

6.1.5 POISSON'S RATIO:

The Poisson's ratio is the proportion of longitudinal to transverse strain. A material sample contracts the opposite direction while it stretches in one direction, and vice versa. This tendency is measured by the Poisson's ratio. The Poisson ratio determines how two wave velocities relate to one another (PR). From 0 to 0.5 is the range of the Poisson ratio. Using the elastic moduli formulae, we were able to determine Poisson's ratio using Vp and Vs logs.

The impedance is expressed in units of (m/s*g/cc), whereas the modulus is expressed in (MPA) units.

$$AI = Vp * \rho \qquad 6.2$$

6.2 VpVs RATIO VS. ACOUSTIC IMPEDANCE CROSS PLOTS:

For lithology determination, sonic time is a porosity tool that is usually utilized. Rock properties can also be determined using S-wave time travel. Compressional waves are strongly affected by the fluid.

High hydrocarbon saturation (Sh) causes Vs to increase and Vp to decrease. Compressional wave travel time records can be used to evaluate the porosity and lithology of a rock. S-wave velocity can also be used to identify rock crystals and calculate porosity. S-wave travel duration is favorable to fluid. Combining S-wave and P-wave data makes it easier to identify fluid properties, especially in gas reservoirs (Simm et al. 2014).

The final result of modelling is a rockphysics template that shows how seismic characteristics, lithology, and saturation interact to one another. The rock physics template is a set of tools for interpreting well lithology and pore fluid. These templates are frequently interpreted using cross plots of the acoustic impedance and the vp/vs ratio. It is usual practise to interpret these templates using cross plots of the acoustic impedance and VpVs ratio(Avseth and Odegaard 2004).The following are the effects of basin constraints on a point in the Rock physics template:

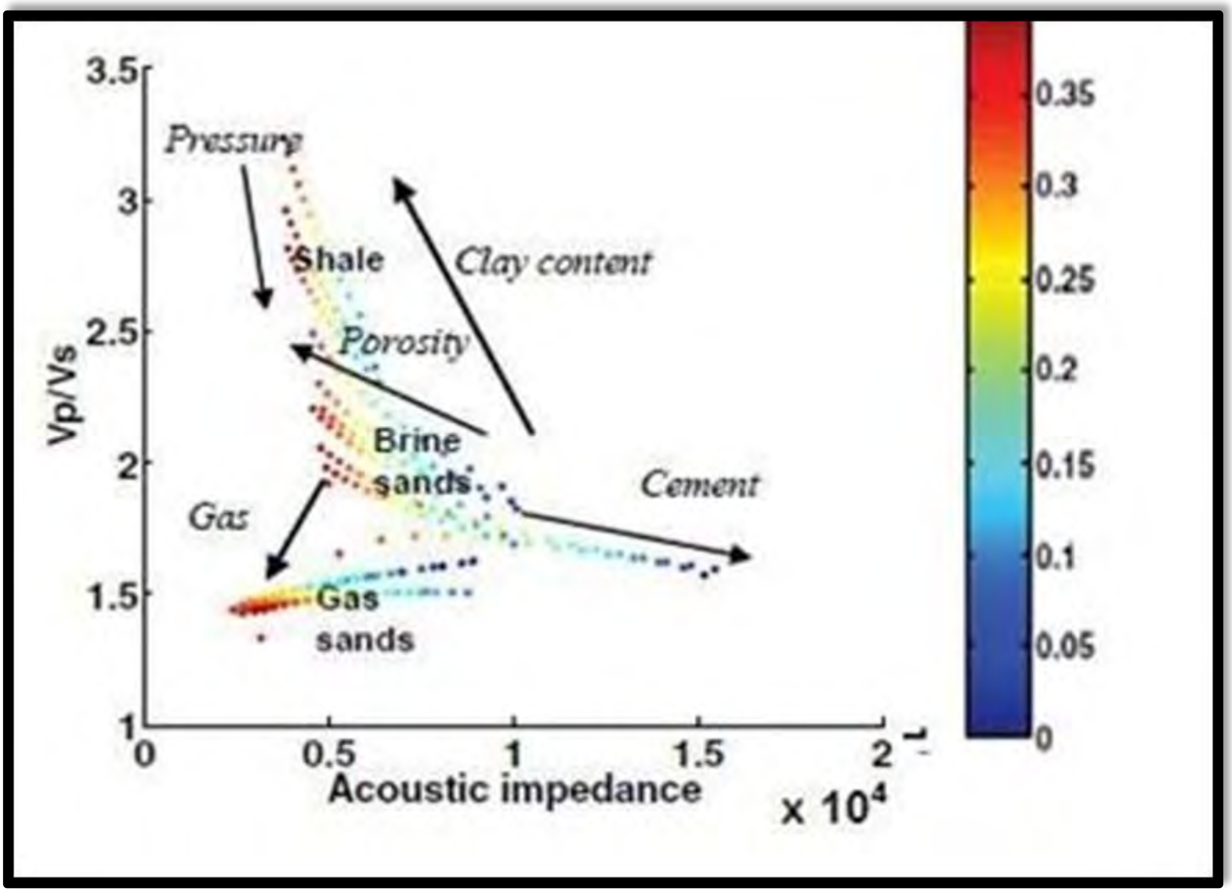

Figure 6.1: Rock physics template (Avseth and Odegaard 2004).

- As gas saturation rises, the P-Impedance and VpVs ratio will decrease.
- Cement rate increases, acoustic impedance increases, and the VpVs ratio decreases.
- As porosity rises, the P-Impedance decreases but the VpVs ratio increases.
- As the amount of shale increases, the Acoustic Impedance will fall as the VpVs ratio rises.

6.2.1 CROSSPLOT OF VpVs RATIO VERSES ACCOUSTIC IMPEDENCE OF ZAMZAMA-02:

A crossplot of the Vp Vs and the acoustic impedence relationship is shown in Figure 6.2. Gamma ray values determines by colour coding, and a polygon is marked for high values of VpVs ratio ranges of 1.7 to 2.06 and low impedence values ranges from 7500 to 10000.

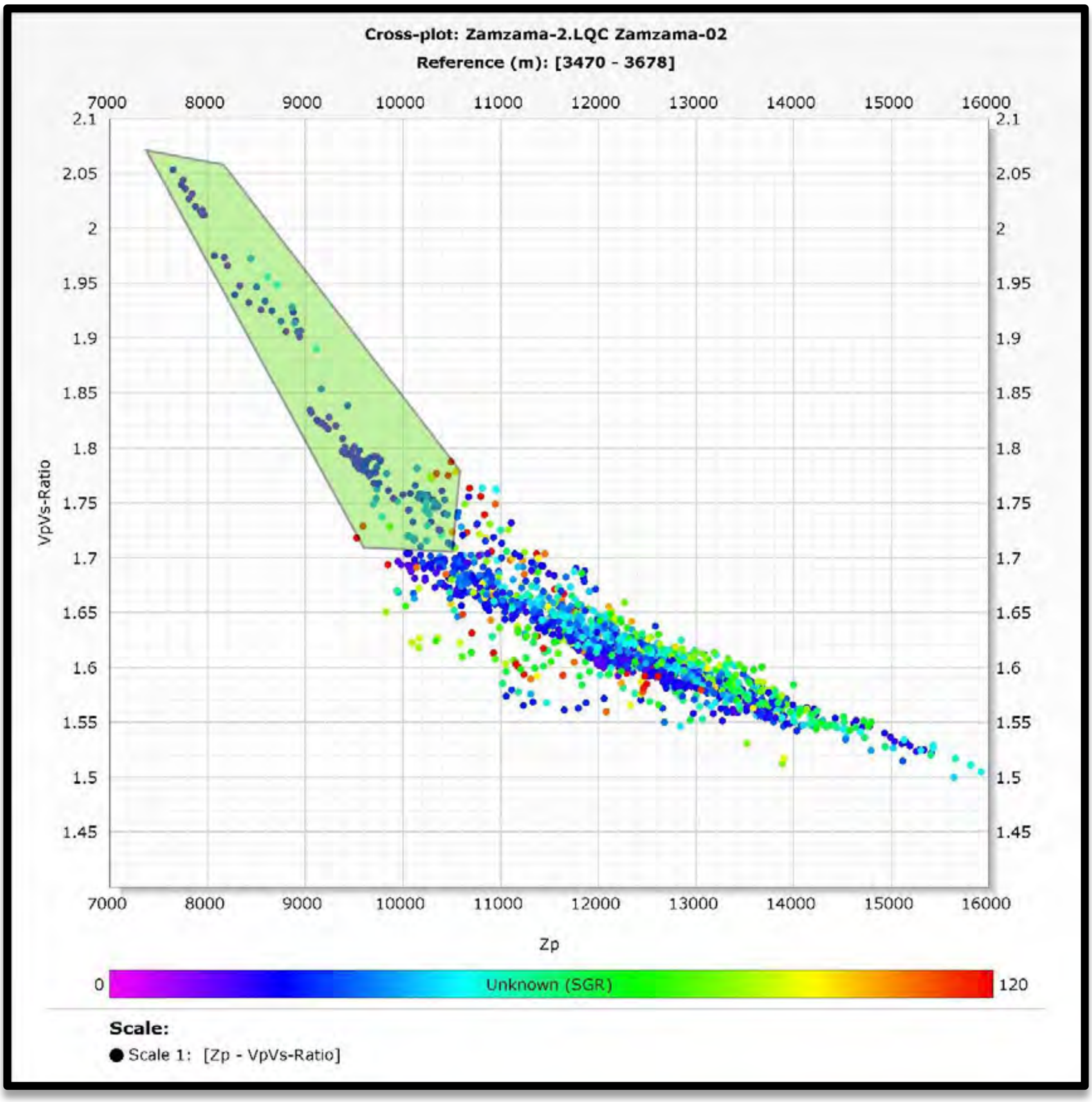

Figure 6.2: Crossplot of VpVS ratio verses acoustic impedence crossplot.

6.3 CROSSPLOT OF SIGMA (POISSON'S RATION) AND PHIE (EFFECTIVE POROSITY):

A crossplot of the Sigma (Poisson's Ratio) and the effective porosity relationship is shown in Figure 6.3. A polygon is marked for poisson's ratio ranges of 0.18 to 0.25 and high effective porosity values. A polygon is used to identify the values with the highest hydrocarbon saturation. In picture 6.1, colour coding is done by using gamma rays.

Figure 6.1 polygon shows that low GR values, high effective porosity and high to moderate values of poisson's ratio indicate hydrocarbon saturation that are filled with sands.

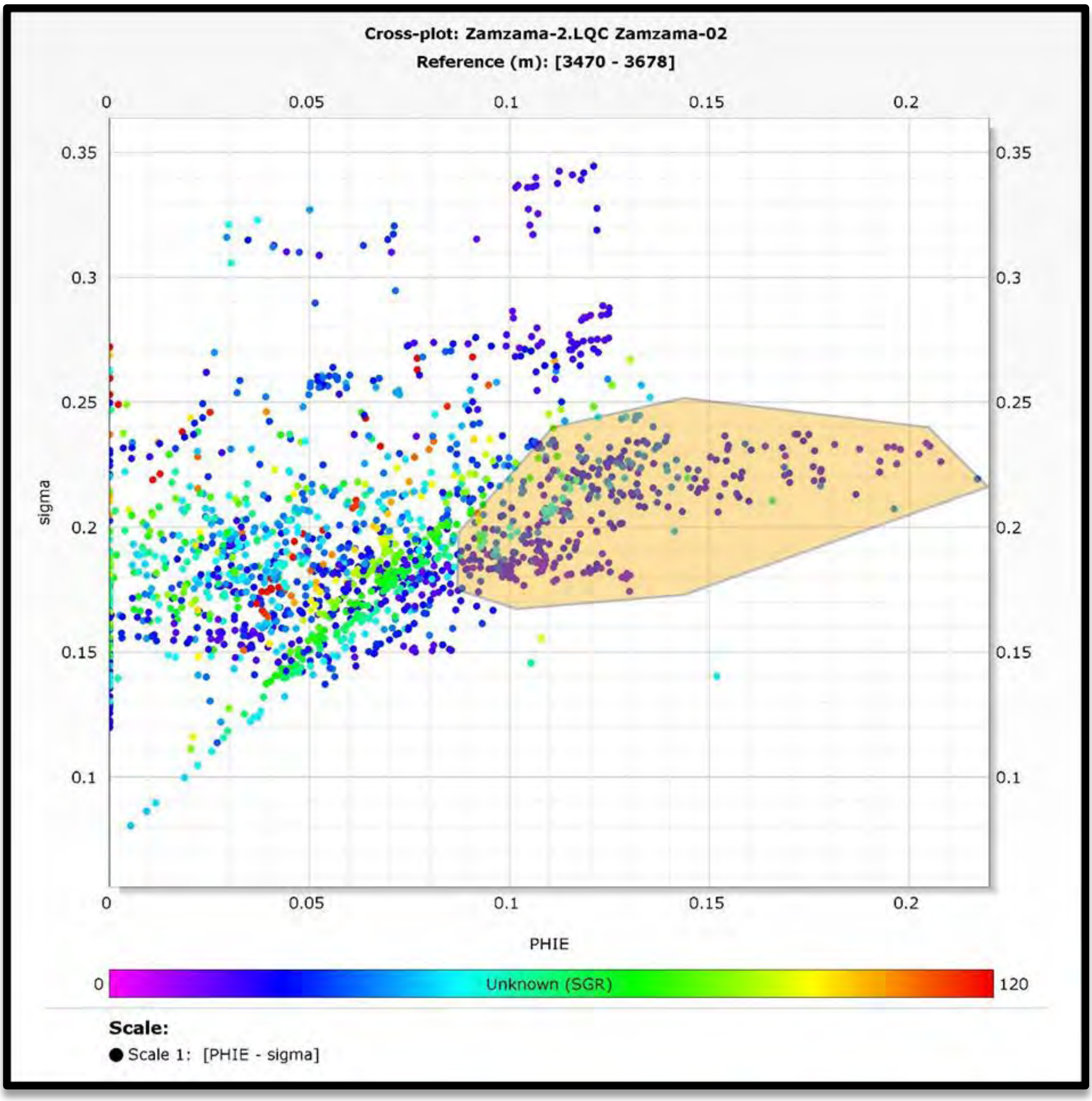

Figure 6.3: Crossplot of SIGMA (Poisson's ratio) verses PHIE (effective porosity).

6.4 CROSSPLOTS OF PHIE (EFFECIVE POROSITY) AND VP:

Figure 6. 2 displays the crossplot between the poisson's ration and Vp. Figure 6.4 polygon shows the low GR value indicate the presence of sand. High effective porosity and low value of Vp indicate the presence of hydrocarbon saturation.

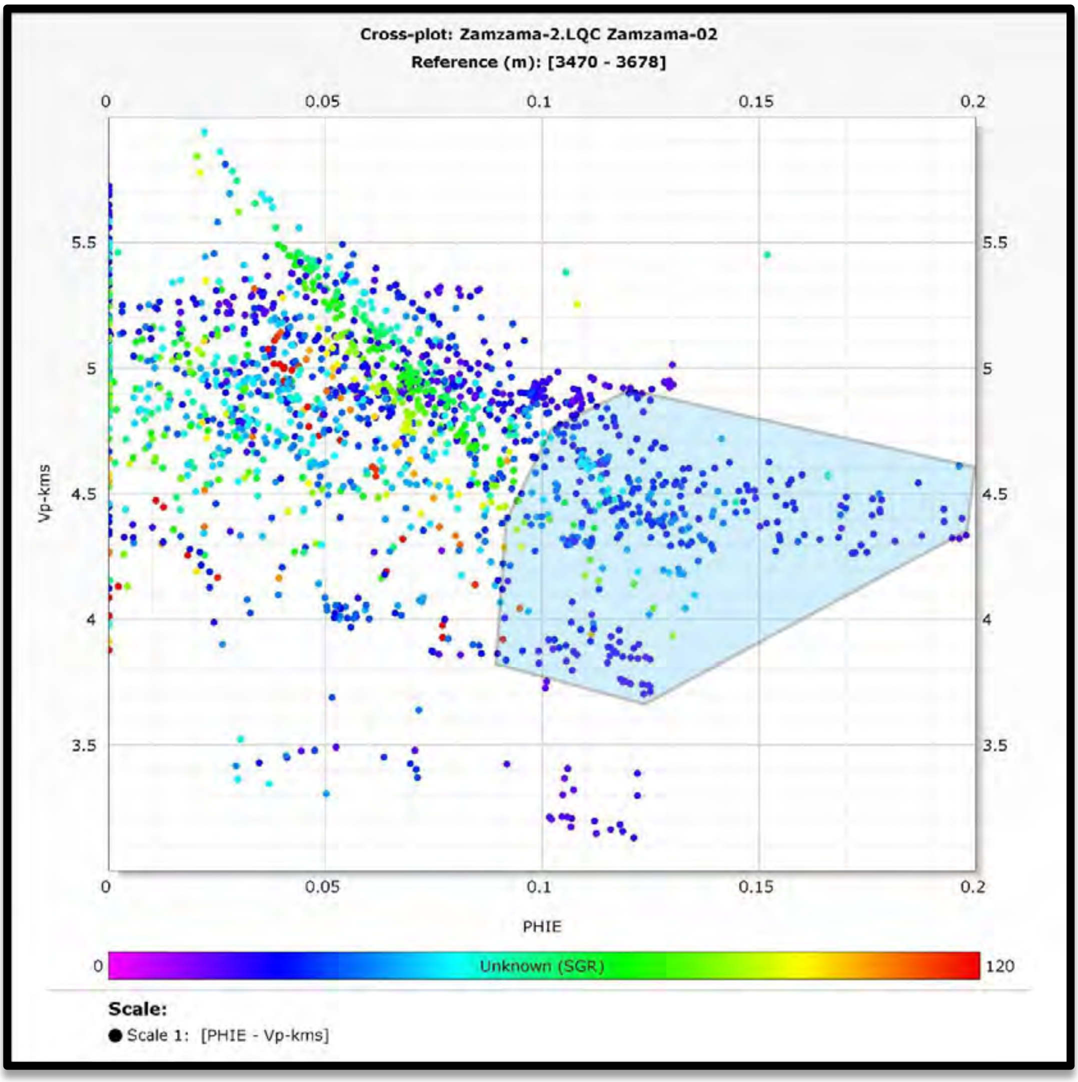

Figure 6.4: Crossplot of PHIE (effective porosity) and Vp.

6.5 DISCUSSION:

In order to obtain a thorough understanding of reservoir characteristics for the well Zamzama-02, rock physics develops reservoir rock physics parameters and confirms the results of the petrophysical investigation.

The presence of gas sand is indicated by a decrease in the acoustic impedance and VpVs ratio. The cross plots of Acoustic Impedance and VpVs ratio allow us to deduce that there is a lot of gas sand present when P-impedance and VpVs ratio decrease.

Due to its high VpVs ratio and acoustic impedance, brine sand is seen as a second type of sand in the cross plots.

Shale can be found in cross plots where the P-impedance is low but the VpVs ratio is large. However, these values differ from the earlier condition for both sand types.

CONCLUSIONS

The southern Indus basin has a faulting regime of extension due to tectonic activity. Three horizons were interpreted together with two-dimensional and cubic time and depth contour maps.

Petrophysical studies were carried out using well log data to identify rock characteristics. The Zamzama-02 wells' high hydrocarbon content has been confirmed by a petrophysical analysis of three of the wells (gas).Shale volume in Zamzama-02 is less than 30%. A perfect sand formation can be seen in the Zamzama region. Pab Sandstone has an effective porosity of more than 8%. Hydrocarbon saturation ranges from 40 to 70%, while water saturation falls between 30 and 60%. Petrophysical tests reveal that the reservoir is saturated with hydrocarbon to varying degrees (greater than 70%).

Rock Physics analyses reservoir rock physics parameters to gain a better understanding of reservoir attributes for wells and confirms the findings of a petrophysical investigation. Acoustic impedance and VpVs ratio declines, indicating the presence of gas sand.

A drop in Acoustic Impedance and VpVs ratio, according to cross plots of these two variables, showed a significant amount of gas sand. Sand (Brine) typically appears in the area of the cross plot where Acoustic Impedance and VpVs ratio are both likely to have slightly higher values. Although the trend of values in both Sand types was different from earlier prevailing conditions, shale deposits were nevertheless found. Shale is found in regions with a high VpVs ratio but low acoustic impedance.

By comparing Young Modulus and Poisson's ratio, it is further demonstrated that hydrocarbon saturation exists in the highlighted zones. The inversion results revealed high impedance values above and below the Pab sand stone, indicating the presence of Shale or another high impedance rock. Shale may serve as a seal rock at the top of the reservoir zone, as is known from stratigraphy to be the source rock for our petroleum play. Shale is located beneath the reservoir zone. Finally, we created a link between acoustic impedance and porosity in order to obtain porosity values throughout the entire study region.

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